Pacific Gas and Electric Company®

James R. Becker
Site Vice President

Diablo Canyon Power Plant
Mail Code 104/5/601
P. O. Box 56
Avila Beach, CA 93424

805.545.3462
Internal: 691.3462
Fax: 805.545.6445

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PG&E Letter DCL-10-124

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20852

Docket No. 50-275, OL-DPR-80
Docket No. 50-323, OL-DPR-82
Diablo Canyon Units 1 and 2
Information to Support NRC Review of DCPP License Renewal Application (LRA) Environmental Report – Operating License Renewal Stage

Dear Commissioners and Staff:

By letter dated November 23, 2009, Pacific Gas and Electric Company (PG&E) submitted an application to the U.S. Nuclear Regulatory Commission (NRC) for the renewal of Facility Operating Licenses DPR-80 and DPR-82, for Diablo Canyon Power Plant (DCPP) Units 1 and 2, respectively. The application included the license renewal application (LRA), and Applicant's Environmental Report (ER) – Operating License Renewal Stage.

PG&E is providing the following documents to facilitate NRC review of the DCPP LRA.

Enclosure 1 provides ER Reference 4.10, "Diablo Canyon License Renewal Feasibility Study Environmental Report: Entrainment of Fish and Shellfish Technical Data Report. Pacific Gas and Electric Company, 2009."

Enclosure 2 provides ER Reference 4.13, "Diablo Canyon Power Plant Cooling Water Intake Structure 316(b) Demonstration. Tenera Inc. 1988." PG&E conducted a second study from 1996 to 1999 focusing on entrainment assessment. Please refer to PG&E letter DCL-2000-515 dated March 1, 2000, for the most updated information on Diablo Canyon 316(b) Demonstration Report. As described in Enclosure 1, the power plant entrainment evaluation incorporated in the 1988 dated report was set aside and has been superseded in entirety by the entrainment evaluation incorporated in the 2000 report. Only the impingement related data and associated evaluation incorporated in the 1988 report remains current and valid.

Enclosure 3 provides "Seasonal Distribution of Plankton in the Nearshore Marine Environment of Diablo Canyon Nuclear Power Plant, 1977."

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PG&E makes no regulatory commitments (as defined in NEI 99-04) in this letter.

If you have any questions regarding this response, please contact
Mr. Terence L. Grebel, License Renewal Project Manager, at (805) 545-4160.

Sincerely,

James R. Becker

TLG/5454160
Enclosures
cc: Diablo Distribution
cc/enc: Elmo E. Collins, NRC Region IV Regional Administrator
Michael S. Peck, NRC Senior Resident Inspector
Andrew L. Stuyvenberg, NRC Environmental Project Manager, License Renewal
Fred Lyon, NRC Project Manager, Office of Nuclear Reactor Regulation
Alan B. Wang, NRC Project Manager, License Renewal

Enclosure 1

Diablo Canyon License Renewal Feasibility Study Environmental Report: Entrainment of Fish and Shellfish Technical Data Report. Pacific Gas and Electric Company, 2009

Diablo Canyon License Renewal Feasibility Study
Environmental Report

Technical Data Report

ENTRAINMENT OF FISH AND SHELLFISH IN EARLY LIFE STAGES

Revision 1
2009

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1. Background

NRC made impacts on fish and shellfish resources resulting from entrainment a Category 2 issue, because it could not assign a single significance level (small, moderate, or large) to the issue. The impacts of entrainment are small at many facilities, but may be moderate or large at other others (NRC 1996). Also, ongoing restoration efforts may increase the number of fish susceptible to intake effects during the period of extended operation. Information that needs to be ascertained includes (1) type of cooling system (whether once through or cooling pond) and (2) current Clean Water Act 316(b) determination or equivalent state documentation.

Diablo Canyon Power Plant has a once-through heat dissipation system that withdraws from and discharges to the Pacific Ocean. The general design and operational parameters of the cooling system are provided in License Renewal Environmental Report Section 3.1.2. This technical data report provides further detail of cooling system operations with regard to the impacts on marine fish and shellfish resulting from entrainment. Entrainment is defined as the larvae and eggs of aquatic organisms drawn into the intake system which pass unhindered through debris screening equipment and subsequently are transported through the cooling system.

Marine ecological resources in the vicinity of Diablo Canyon have been studied since the mid-1960s when the area was first considered as a power plant site. The early studies were conducted to provide baseline inventories of marine resources, and to evaluate the potential effects of the planned thermal discharge from the once-through cooling system. Predictive studies were also conducted before plant start-up to identify the potential environmental effects of full scale commercial operations. The majority of studies were focused on defining potential and actual thermal impacts from the cooling system discharge. A complete listing of published reports resulting from the ongoing assessments of plant thermal discharge impacts during commercial operations as well as the early ecological studies are provided in Attachment 1 to the Environmental Report Whitepaper for Heat Shock.

2. Clean Water Act (CWA) Section 401 Certification

License Renewal Environmental Report Section 4.2 describes DCPP's current CWA Section 401 Certification status. Diablo Canyon Power Plant currently holds a valid and enforceable administratively extended National Pollution Discharge Elimination Systems (NPDES) Permit No, CA0003751, Order 90-09.

3. Description of Cooling System and Intake Design

3.1 Once-Through Cooling (OTC) System

Environmental Report Chapter 3 Subsection 3.1.2 provides the general description of the Diablo Canyon Power Plant once-through cooling system and volumes of seawater drawn through the intake structure during normal operations. The general layout and function of the intake structure for Unit 1 and Unit 2 is typical to that of most power plants using once-through cooling. Operation of the intake relies on bulk debris screening racks followed by traveling mesh screens to filter out and remove debris.

3.2 Intake Design Affecting Entrainment

The stainless steel mesh traveling screens employed at Diablo Canyon do not filter out or impinge the larval stages or eggs of most marine species which may be present in the intake cooling water source. Entrained organisms smaller than the 3/8-inch square screen openings pass essentially unobstructed. Effectively all microscopic phytoplankton and zooplankton in the cooling water flow remain unfiltered and unimpeded by the intake debris management systems.

Entrained organisms passing through the screen mesh system are subsequently subjected to the sheer forces and pressures generated by the main or auxiliary cooling water pumps. Cooling water must be lifted by the pumps to the main steam condensers approximately 85' above mean sea level. Once at the condensers, a rapid thermal differential occurs as the seawater passing through the condenser tubes is heated approximately 20-degrees Fahrenheit. The flow is then directed back to the Pacific Ocean with turbulence occurring throughout the discharge structure as the cooling water cascades down several horizontal tiers and across vertical impact blocks. Those organisms entrained in the flow are subjected to the thermal differential across the condensers and the turbulence during discharge.

In addition to system physical forces and thermal gradients, entrained organisms and other organic materials are exposed to biological growth (macro fouling) while transiting the system. Barnacles, Mussels, and other plankton straining organisms routinely populate the cooling system conduit walls, piping, and other exposed surfaces both pre and post condenser. The biological growth within the system results in 'cropping' of entrained organic materials including larval organisms and eggs.

4. Evaluation of Plant Intake Entrainment and Impacts

4.1 Intake Entrainment Studies

Following the start of commercial operations, a CWA Section 316(b) cooling system intake impingement and entrainment (I&E) assessment was conducted for the Diablo Canyon Power Plant. Field sampling for the study occurred for a one-year long period during 1985 and 1986. The study was conducted in accordance with the requirements of Central Coast Regional Water Quality Control Board (CCRWQCB) NPDES Order No. WQ83-1. The conclusion of the entrainment portion of this initial 316(b) Demonstration Study (Tenera Environmental 1988) was the subject of significant controversy for Pacific Gas & Electric Company (PG&E). The controversy lead to involvement of the California State Attorney Generals Office, and subsequent settlement between parties that included a requirement for PG&E to conduct a new entrainment assessment study for Diablo Canyon. The results and conclusion of the 1985-1986 entrainment study were effectively set aside. The conduct and conclusions reached for the impingement component of the 1985-1986 assessment was not the subject of controversy, and therefore have remained valid and accepted. As described in Environmental Report Section 4.3, the results of the impingement study have supported the determination that associated losses resulting from operation of the power plant intake are insignificant, and no cost effective structural or operational strategies are available that could further reduce marine fish and shellfish impingement at the facility.

A second 316(b) demonstration study focused on entrainment assessment was conducted for Diablo Canyon from 1996-1999. This study was designed and implemented under the direction of a Technical Working Group (TWG) established by the CCRWQCB. The TWG included staff of the CCRWQCB, independent consultants recognized as subject matter experts in marine biological sciences and marine ecological study design, representatives and marine biological consultants from PG&E, and representatives from the California State Department of Fish & Game, League for Coastal Protection, and the USEPA.

The study comprised two distinct components. The first component involved intake entrainment sampling conducted on a weekly basis for two and a half years from four sampling stations located immediately in front of the cooling water intake structure (**Figure 4**). The entrainment sampling and subsequent sample sorting and analysis was intended to determine the representative species and relative abundance of fish and shellfish larvae drawn directly into the power plant intake and subsequently passed through the once-through cooling system.

The second component involved an extensive offshore sampling program conducted biweekly for a two year period. The sampling was implemented to investigate the occurrence and abundance of larvae in the central coast region of the Pacific Ocean that serves as the power plant cooling water source. Ocean current measurements (metering) was also completed to facilitate estimations of the extent of the cooling system source water body. The offshore component of the study involved sampling from a 17.4 kilometer by 3-kilometer grid comprised of 64 individual sampling stations centered roughly on the power plant (**Figure 4**).

Details of the design, methodology, and conclusions of the 1996-1999 power plant 316(b) entrainment and source water assessment are provided in the study report (Tenera Environmental 2000). The results from the entrainment sampling and source water sampling were used together to evaluate the overall impact of plant entrainment. The study approach used several data analysis methodologies in an attempt to adequately define entrainment losses in more than just absolute numbers of larvae and eggs. Three methods were implemented each with inherent advantages and disadvantages. The methods included; 1) derivation of Adult Equivalent Loss (AEL) for targeted species that forecasts the number of adults, using available knowledge of mortality rates (i.e. natural larval mortality), that would potentially be generated from the larvae lost to entrainment, 2) Fecundity Hindcasting (FH) in which the larvae lost to entrainment are attributed to the number of female adults required to produce them, and 3) the Empirical Transport Model (ETM) approach which provide an estimate of the proportion of larvae lost due to power plant entrainment relative to the number of larvae available in a given source water body.

Two of the assessment methodologies, AEL and FH, have inherent deficiencies due to the lack of knowledge of the complete life histories for many of the species susceptible to entrainment by the power plant. FH also is subject to uncertainly due to a lack of firm understanding of the full reproductive potential of mature females for many species in the natural environment. Due to the uncertainties in the methods, assessments of entrainment losses require best technical estimates for the unknown variables in species life cycles or adult reproduction which increases statistical error. The complexity and species abundance of the open ocean ecological system that serves as the source water for Diablo Canyon further compounded the difficulty in using these methods to adequately characterize entrainment losses.

The third assessment method involving the Empirical Transport Model (ETM) approach was determined by the study Technical Working Group to be the most effective method for assessing entrainment losses, however, estimates for variables based on best available, but still incomplete, information remained a source of error. The determination of extent of the source water for the target species in the study also relied heavily on linear based estimates of ocean currents; however actual ocean current patterns are much more complex.

The determinations of source water body for individual species using ETM also varies significantly based on several factors including the duration that larvae are distributed in significant numbers in the water subjected to movement by ocean currents. In addition to reliance on linear current estimates, other issues also influence the adequacy of source water estimates such as whether or not larvae are a distributed relatively uniformly throughout the large volumes of water flowing past the location of the power plant, and fact real world complex current patterns likely generate areas of both larval concentration and scattering along the coast line. Regardless, the ETM method provides an assessment of the susceptibility of larvae transported by ocean currents to be drawn into the power plant over time.

For nearshore species the source water is defined in length of coastline that currents transit related to the average length of time the larvae of a species are available in the water column. The average length of time larvae are available in the source water was derived from the average age of the actual larvae sampled from the water column. Maximum larval ages and subsequent availability were also derived from the study data. For offshore species the source water is expressed as an area of the ocean again derived from metered current speeds in conjunction with the larval duration. Species with larvae that have longer durations are at a greater risk for entrainment because the larvae are subsequently susceptible to being drawn into the intake for a longer period of time. In general, the longer the average larval duration (average age), the larger the source water body for the species.

The ETM approach ultimately generates an average Probability of Mortality (P_M) due to entrainment for individual taxon within the source water area derived for that taxon. The offshore sampling in conjunction with ocean current metering data was used to determine the source water body for the target taxa in the study, and ultimately derive the Proportional Entrainment (PE) of those taxa using the intake entrainment sampling results. Average annual larval mortality (expressed as a percentage) for each taxa was calculated after the derived PE was weighted by the estimated fraction of the total larval population susceptible to entrainment.

Larval mortality expressed as an average annual percentage provides a means for assessing overall entrainment impacts on the ecological system. For the Diablo Canyon study, the TWG determined that the ETM approach, though still including assumptions and uncertainties, provided the most defensible assessment of entrainment of the three methods employed. Additionally, the ETM method provided the most complete data set from study. Percentage estimates of annual larval mortality were derived for all the target taxa using the ETM. Adult loss estimates using FH and AEL were only derived for ½ of the target taxa due to the inherent deficiencies in the methods.

The study design focused on sixteen target taxa, fourteen fish and two shellfish. The larvae of the selected taxa were anticipated to be entrained in sufficient abundance to allow for impact assessment (allowing model constraints to be met and confidence intervals to be calculated), were identifiable to species level, and have local adult and larval populations. However, other selection criteria were also considered by the TWG including but not limited to commercial or recreational value, and critical need to the structure and function of the ecological system. The following lists the sixteen target taxa selected for focused assessment in the DCPP entrainment and source water study conducted from 1996-1999 (Table 1):

TABLE 1

Species Susceptible to Entrainment
Target Study Taxa - DCPP Entrainment Demonstration Study

Fish (Vertebrate)	Shellfish (Invertebrate)
Rockfishes (Family Scorpaenidae) KGB Rockfish Complex KGB - Kelp/Gopher/Black & Yellow Rockfish Blue Rockfish Complex **Painted Greenling** (*Oxylebius pictus*) **Sculpins** (Family Cottidae) Smoothhead Sculpin (*Artedius lateralis*) Snubnose Sculpin (*Orthonopias triacis*) Cabezon (*Scorpaenichthys marmoratus*) **White Croaker** (*Genyonemus lineatus*) **Monkeyface Prickleback** (*Cebidichthys violaceus*) **Kelpfishes** **Blackeye Goby** (*Coryphopterus nicholsi*) **Flatfishes** (Family Paralichthyidae) Sanddabs (*Citharichthys* spp.) California Halibut (*Paralichthys californicus*) **Pacific Sardine** (*Sardinops sagax*) **Northern Anchovy** (*Engraulis mordax*)	**Cancer Crabs** Brown Rock Crab (*Cancer antennarius*) Slender Crab (*Cancer gracilis*)

A one-year duration entrainment and source water study has more recently been conducted for Diablo Canyon with field sampling implemented from mid 2008 to mid 2009. Laboratory work involving sample sorting and identification is expected to be completed by end of year 2009. The purpose of the study is to assess current power plant entrainment including taxa represented and abundance, and provide an additional assessment of the source water body and P_M for the larvae of the target taxa. The study is scaled down in comparison to the 1996-1999 entrainment and source water assessment with only two entrainment sampling stations utilized instead of four, and source water sampling conducted in a six station grid extending 3-kilometers directly offshore from the opening of the power plant intake cove. The study design included review by CCRWQCB and the agency's scientific consultants, and incorporated improved current metering instrumentation and additional metering stations to better assess ocean currents and patterns in the coastal region.

The in progress study is using the same target taxa list to provide for some direct comparison to the 1996-1999 assessment. The ETM method will again be used to determine power plant entrainment P_M for the target taxa. The more advanced current metering instrumentation employed and improved current assessment methodologies available have the potential to increase the accuracy of defining source water areas for the target taxa. The consolidated sampling and laboratory data, and alternative current assessment methodologies available, will be reviewed by CCRWQCB scientific consultants prior to finalization of the study. Completion of the study report is anticipated in the 2nd quarter of 2010.

4.2 Fish and Shellfish Resources Susceptible to Entrainment

The larvae and eggs of hundreds of individual fish and shellfish species present either continuously or periodically in the nearshore ocean region surrounding the power plant are entrained in the cooling water flow. Not all organisms which may be entrained by the intake during plant operations have been identified as some organisms are entrained in only small numbers. The entrainment assessment studies conducted for Diablo Canyon focused on fish and shellfish species most susceptible to entrainment in significant numbers, and which could be positively identified from field samples.

The completed entrainment assessment identified a total of 178 different taxonomic categories of fish (Reference Table 5.1-1, Tenera Environmental 2000). As anticipated, larvae from species that occur in rocky habitat located in relatively shallow nearshore areas, the marine habitat immediately surrounding the power plant intake (and occurring in coastal locations north and south of the facility along the California coast) were found to be the most susceptible to entrainment.

4.3 Assessment of Entrainment Losses

<u>Losses in Absolute Numbers of Larvae</u>

The 1996-1999 entrainment sampling data was used to develop an estimate of the average number of larvae for all representative species of fish entrained per volume of seawater drawn into the power plant during normal operations. The estimate was standardized to the number of larvae entrained per cubic meter (m^3) of cooling water withdrawn. The value derived provides a method for direct comparison with aggregate entrainment for other once-through cooling facilities.

Average larval fish entrainment for Diablo Canyon is estimated at 0.5051 larval fish per m^3 of cooling water. Aggregate cooling system flow volumes over time are derived from circulating pump design capacities and total hours of pump operations. During the 1996-1999 entrainment sampling period, actual cooling system flows produced fish larval entrainment estimates of 1.48-billion annually. If both generation units operated at 100% capacity for an entire year, aggregate larval fish entrainment estimates would approach 1.77-billion. Average cooling system flows recorded during the 2000-2005 period yield average annual entrainment numbers for that period of 1.60-billion.

The entrainment estimates for Diablo Canyon, as well as other once-through cooled power plants located in California, are provided in data tables developed for the California State Water Resources Control Board (Steinbeck 2008). The data is an information resource being used in the agency's effort to develop a uniform State Policy regulating once-through cooling for power plants that withdraw from ocean or estuarine source waters. The consolidated data provides a relative perspective of Diablo Canyon entrainment. The power plant is the largest once-through cooled generation facility in the State with a design cooling system circulating capacity of 2.53-billion gallons of seawater per day. The 2000-2005 data shows that Diablo Canyon accounted for 22% of cooling water withdrawals from waters of the State during the period, however that significant volume resulted in only 8% of total statewide entrainment for that same period. Diablo Canyon's location on the open ocean is primarily responsible for the lower average entrainment rate in comparison to many other west coast power plants. Those located in bays or estuaries generally experience higher total entrainment numbers. The more enclosed water bodies often encompass tidal marshlands, mudflats, or other habitat that support aquatic populations with significant levels of localized larval production. Those factors, as well as other intrinsic environmental conditions, subsequently results in higher larval fish and shellfish concentrations in the immediate source water for those power plant intakes located in bays and estuaries.

In absolute numbers, the entrainment of fish larvae appears significant for Diablo Canyon regardless of comparisons with other facilities. However, these numbers must also be placed in context of the very high natural mortality of marine organisms in early life stages, and fact that enormous numbers of eggs, and subsequently larvae, are generated from the successful reproduction of spawning marine species. High reproductive numbers are a reflection of the very low probability of an individual egg or larvae maturing through juvenile stages, and ultimately reaching reproductive adulthood, for most aquatic organisms. From the perspective of adult replacement, only a very low number of eggs or larvae need survive to adult stages to replenish the population. For example, the females of some fish species can produce millions of eggs during their reproductive life. Only two need to successfully be fertilized, mature through larval and juvenile stage, and reach adulthood to replace in number the female which spawned and a single male counterpart.

Entrainment Survivability

Entrainment mortality for Diablo Canyon is assumed to be 100% for all planktonic organisms. The 100% mortality criteria was an administrative component of the 1996-1999 study design for evaluating entrainment impacts by the power plant, and has generally been adopted as the conservative baseline for accessing entrainment losses industry wide by California State and Federal regulatory agencies.

It is likely however that here is appreciable percentage survivability for many organisms that are passed through the power plant cooling system. Phytoplankton such as diatoms with tough durable exteriors likely pass through the system relatively unscathed. More durable harder shelled zooplankton also likely experience some survivability. This conclusion is supported by evidence of the ongoing proliferation of organisms within the discharge portion of the plant cooling system. Significant populations of barnacles, mussels, saltwater worms, and other marine organisms inhabit the discharge conduits and discharge structure. These organisms had to themselves pass through the power plant intake systems, including the circulating water pumps, transit along the inlet conduits and then through the condensers in larval and/or smaller less developed stages. This segment of the once-through cooling system is also continuously exposed to elevated seawater temperatures during power plant operations. Regardless, these organisms continue to settle and colonize on an ongoing basis as the sustained marine community could not otherwise exist in light of natural and predation mortality losses in any such population. Additionally, following system condenser inlet side cleanings (inlet conduit scrapings), surfaces are rapidly repopulated by fouling organisms that are entrained and transit successfully through the forces and pressures created by the circulating pumps. It is reasonable to conclude therefore that many organisms do in fact routinely survive transit through the cooling system, and potentially return to the ocean in viable condition.

Many of the assessment studies for entrainment impacts, including those conducted for Diablo Canyon, have focused on fish species. This has been the case for multiple reasons. Fish larvae are large in comparison to many planktonic organisms, and are therefore readily trapped in sampling nets. For power plant entrainment assessments standard 335-micron sampling netting have generally been used which capture nearly all larval fish. Fish are also often commercially or recreationally important in the location of interest, and the larvae of most species can generally be positively identified in samples to genus or species level at a high percentage. Many shellfish and other aquatic organism also have multiple life stages and complex life cycles that make positive identification in samples difficult and time consuming.

Additionally, maturation and reproduction cycles for indigenous fish may often be much longer than shellfish species, and generally much longer than the very small sized organisms that make up the bulk of the more ubiquitous zooplankton in aquatic systems. These smaller organisms often have very short regeneration periods, for some only days. Detrimental impacts to reproductive populations are therefore of most concern for those fish species susceptible to entrainment in significant percentages.

Relatively larger soft bodied larval fish are also most likely highly susceptible to detrimental impacts from the turbulence, sheer forces, and compression during transit thorough circulation water pump impellers, and in the case of Diablo Canyon, the turbulence and shear forces created by the steep stepped discharge system. The rapid temperature gradient experienced while transit through condenser tubes may also be more of a concern for soft bodied more delicate organisms.

Survivability for fish larva is therefore likely the lowest for the types of organisms susceptible to entrainment in the cooling water flow. This lends support to the focus on larval fish losses for assessing the potential adverse ecological level impacts from entrainment.

A factor that likely variably impacts most entrained organism is cropping by populations that inhabit the power plant's main seawater cooling system surfaces. Colonizing barnacles, mussels, and other filter feeders strain the cooling system flow and capture and consume entrained living organisms of many varieties as well as inanimate organic and inorganic materials suspended in the water column. Survivability of transit through the cooling system is potentially highest for all entrained organisms following seawater conduit fouling cleanings, and lowest when fouling growth is heavy and mature. It is notable however that filter feeder consumption of planktonic organism, including fish and shellfish larvae and eggs, is a ubiquitous process in the marine environment. Mussels, barnacles, and other filter feeders naturally extensively populate the rocky intertidal and subtidal habitat in the location of Diablo Canyon. These indigenous organisms continuously deplete larvae, eggs, and other organic matter suspended in the ocean waters which may originate locally, or which may be transported to the area from far afield by ocean currents.

Assessment of Source Water Larval Probability of Mortality

Using target taxa data from the 1997-1999 entrainment and source water sampling effort, an average of 10.8% of the available susceptible fish larvae in the source water body for Diablo Canyon are lost to entrainment. This estimate assumes entrainment larval mortality of 100%. The source water derived for the various taxa varied substantially, however the average alongshore distance or area was generally large.

As anticipated due to the shoreline and relatively shallow location of the intake structure, the taxa entrained in highest numbers (based on P_M estimates) included those species that are more common in rocky nearshore habitat. The power plant and associated intake cove are situated in approximately the center of a relatively pristine and isolated 14-mile coastline that incorporates extensive rocky intertidal and subtidal marine habitat. For the nine taxa of rocky reef fish in the entrainment assessment, source water impacts for the facility averaged over a length 46-miles (74-kilometers) out to 2-miles (3-kilometers) offshore, or an area of approximately 92 square miles. The nine taxa in this assessment included Smoothhead sculpin, Snubnose sculpin, Monkeyface prickelback, Clinid kelpfishes, Black eye goby, Cabezon, Painted greenling, KGB Rockfish, and Blue Rockfish.

Adult kelpfish had one of the highest entrainment P_M estimates (30-40%), however the source water body for the taxon was smaller than most others. The taxon with the next highest P_M estimate was the Monkeyface prickleback, a species also common to the rocky habitat near the power plant, and which had more limited source water. During the 1997-1999 sampling period, the rocky reef fish species with the largest calculated entrainment impact was the Smoothhead sculpin having an estimated P_M of 11.4% over a maximum source water area of approximately 75-miles.

For the majority of more offshore deeper water species P_M estimates were generally low with relatively large source water areas. For example Northern anchovy, an important commercial species, had P_M estimates of <1% with a source water area hundreds of square miles. FH and AEL loss estimates for Northern Anchovies were found to be the most significant numerically during the study, but entrainment impacts still considered of less significance due to the very low larval P_M. For the two shellfish taxa targeted in the study (Brown rock crab and Slender crab), larval P_M estimates were also very low within vast source water areas.

A table presenting the study estimates for larval P_M and associated source water determinations by sampling period for each of the target taxa is provided in CCRWQCB 2003. Estimates of losses using the FH and AEL methods for those target taxa in which estimates could be derived using available life history information are also provided in the table. Details regarding the development of the estimates for each target taxa are provided in the study report (Tenera Environmental 2000).

4.4 Ecological Impacts from Entrainment Losses

Impacts from entrainment losses can be considered in two perspectives. First is the absolute loss of larva and eggs due to entrainment during operation of the cooling system. The second is the potential or actual impact those losses have on the overall aquatic ecological system.

Absolute impacts can be assessed directly from intake sampling which accounts the larvae and eggs of various organisms drawn into the cooling system. Ecological level impacts are more difficult to assess especially in the absence of long term data related to the occurrence and abundance of species in the aquatic system potentially impacted by once-through cooling operations. Even seemingly large absolute larval losses however may not result in detrimental ecological impacts due to the fact that natural mortality alone is most often far more significant in absolute numbers. Generally, only a very small percentage of eggs and larvae survive to juvenile stages, and subsequently few juveniles survive to maturity, for the vast majority of species in aquatic ecological systems.

The thermal impacts assessment studies conducted for DCPP have included periodic observations of the occurrence and abundance of multiple fish species. Importantly, these have included those species in which larval entrainment is significant as defined by the 1996-1999 intake entrainment assessment. Diablo Canyon is somewhat of an exception to most power plants employing once-through cooling in that data exists from ecological surveys of the aquatic environment surrounding the power plant prior to commercial operation. These studies have continued throughout operation of the facility to date as well.

The following text was provided in a memorandum authored by J. Steinbeck of Tenera Environmental titled "Information on Trends from Adult Fish Monitoring at DCPP". The memorandum presents a summary assessment of the occurrence and abundance of fish observed during periodic surveys associated with the thermal monitoring program. The observations include those species expected to be the most adversely impacted by power plant entrainment losses. Additionally, fisheries catch data collected in studies independent from power plant monitoring provide further information related to adult fish abundance for commercially targeted species also susceptible to entrainment in larval stages by the power plant. The document was submitted by PG&E to the California State Water Resources Control Board (SWRCB) for consideration during the ongoing development of a State specific policy which may further regulate power plant intake impingement and entrainment.

Adult fish populations have been monitored in the areas around DCPP as part of the NPDES permit requirements for the thermal discharge beginning in 1976 almost ten years before the plant began commercial operation and the monitoring continues on a quarterly sampling schedule. Locations inside Diablo Cove are sampled to monitor effects of the thermal discharge on natural marine communities and then those data are compared with data from a cove (Patton Cove) south of the plant that is not affected by the warm water discharge. The data from Patton Cove provide a baseline for examining the effects of the thermal discharge but can also be used to look at changes that may be occurring due to natural variation in the marine environment and, to some extent, potential effects of entrainment by the plant cooling water intake system.

The highest levels of entrainment from a study at DCPP conducted from October 1996 through June 1999[1] were estimated for larvae from small fishes that occur on rocky reefs in shallow nearshore areas, the same habitat sampled at the stations in Patton Cove, which are all in relatively shallow water (10–40 ft). The fishes with high levels of entrainment losses included fishery targets such as cabezon and rockfishes, and non-fishery species such as sculpins and greenlings. The annual average abundances of several fishery and non-fishery species are presented (**Figure 1**). These fishes were selected as they were representative of fishes that are primarily bottom dwellers and are therefore best sampled by the methods used for the study, although the cryptic habits of most of the species result in underestimates of their actual abundances. Since DCPP operates at a high capacity factor, effects of entrainment might be expected to occur as a long-term trend showing declining abundances resulting from the reduced larval supply in the system, although larval supply from distant spawning populations can potentially be a source of developing larvae that can colonize benthic habitats in the vicinity of DCPP.

The data for several of the fishes show declines in the early 1990s or following 1997. El Niño conditions persisted through the 1991–1993 period resulting in very low recruitment for many species in 1992. The prolonged El Niño conditions during the early part of the decade were followed in 1997 by another major El Niño event, producing the warmest seawater temperature anomalies recorded since 1950. In addition, the early and mid-1990's saw the advent of trap fishing along the central coast of California (Bloeser 1999) that resulted in declines in cabezon (*Scorpaenichthys marmoratus*), rockfishes and other species. Live fish trapping has been identified as a cause of declines in adult abundances in other areas[2]. Declines in the abundances of cabezon and KGB-complex rockfishes (**Figures 1a and 1b**) during the early 1990s that might be due to a combination of fishing and El Niño conditions have appeared to level off following the implementation of regulations on the live fish fishery in the late 1990s and the closure of the areas around Diablo Canyon, including Patton Cove, due to heightened security following the terrorist events of September 2001. Environmental variability, larval drift, migratory behavior, fishing impacts, and the open nature of the coastal system can all affect localized abundances of fishes and the additional mortality caused by larval entrainment from DCPP is not strongly reflected in the long-term abundance data from species that would be expected to be affected.

Recent analyses of recreational fishery data show that catches from the local recreational partyboat fishery showed increases in the shallow water fishery in the late 1980s and 1990s, and stabilized at a lower level from 2003–2005 (**Figure 2**). A statewide analysis of recreational fishery trends by Stephens et al.[3] showed that the stocks in central California have not experienced the same declines seen elsewhere in the California, and Dotson and Charter[4] also reported an increase in commercial partyboat fishing success in central California relative to southern California ports (**Figure 3**). The species examined in these studies included many of the same rockfish species analyzed for the Diablo Canyon entrainment study, including the kelp/grass/black-and-yellow group of rockfishes that had the highest overall estimated entrainment.

[1] Tenera Environmental Inc. 2000. Diablo Canyon Power Plant 316(b) Demonstration Report. Submitted to Pacific Gas & Electric Co., San Francisco, CA.

[2] Starr, R. M., K. A. Johnson, E. A. Laman, and G. M. Cailliet. 1998. Fishery Resources of the Monterey Bay National Marine Sanctuary. Publ. No. T-042. California Sea Grant College System, University of California, La Jolla, CA. 102 pp.

[3] Stephens, J. S. Jr., D. Wendt, D. Wilson-Vandenberg, J. Carroll, R. Nakamura, E. Nakada, S. Rienecke, and J. Wilson. 2006. Rockfish Resources of the South Central California Coast: Analysis of the Resource from Partyboat Data, 1980-2005. CalCOFI Reports 47:140155.

[4] Dotson, R. C., and R. L. Charter. 2003. Trends in the Southern California Sport Fishery. CalCOFI Reports 44:94106.

In general, uniform or sustained declines in those fish species most susceptible to entrainment by the DCPP cooling system have not been apparent in the coastal region surrounding the power plant. Effects of natural variation, including the impacts of Pacific Coast warm water El Nino events, are evident in the long term data and provide perspective on both increases and decreases in individual species abundance over time. Notably, significant variation is witnessed both before and during power plant operations. Periods of decreasing abundance for taxa occur before power plant cooling system entrainment existed, and periods of increasing abundance are observed to occur in several species when cooling system entrainment impacts would be expected to be the most evident. For example, Snubnose sculpins display a marked period of increasing abundance beginning in the late 1990's, even though power plant capacity factors, and simultaneously cooling system intake withdrawal volumes, were being maximized.

For species targeted by commercial and recreational fishing, observed periods of decline in abundance coincide with increases in fisheries pressure. Once fisheries controls are implemented, declines in abundance moderate suggesting that significant loss of reproductive adults, which the Diablo Canyon intake does not cause, is far more impactful than entrainment on an ecological scale.

An overall assessment of the effects of entrainment on fish populations in varied California coastal habitats was conducted by the Electric Power Research Institute (EPRI). The assessment report provides a source of technical information for regulatory agencies and stakeholders in the ongoing development of the California statewide policy for regulating power plant once-through cooling. Additional evaluation regarding the ecological impacts of entrainment resulting from the operation of Diablo Canyon in an open coastal region is provided in the document (EPRI 2007).

A significant number of individual organisms comprising the ubiquitous microscopic zooplankton and phytoplankton that occurs throughout the ocean are also entrained by the power plant. These organisms remain planktonic, and are widely distributed by ocean currents in both nearshore regions and offshore deep water regions. Distribution and abundance of individual species is potentially relatively uniform across large expanses of the ocean. Additionally, these organisms have short regeneration cycles and therefore reproduce very rapidly and in large quantities. Localized nearshore entrainment losses for these organisms are not considered impactful on an ecological scale due to the vast distribution and short reproductive life cycles.

Cumulative Entrainment Impacts

The potential for cumulative impacts to regional marine ecological resources due to entrainment by multiple power plants is a topic of concern. The only other significant withdrawal of seawater in the region for cooling system operations occurs at the Morro Bay Power Plant (MBPP) located approximately 14 miles north of Diablo Canyon. The Morro Bay facility consists of two moderately sized 330MW fossil fueled boiler stream turbine generation units (Units 3 & 4). The units are currently not utilized for base load generation, and continued operation of the facility in the existing configuration during a license renewal period for Diablo Canyon is unlikely. The remaining operable MBPP units were built in the early 1960's, and are candidates for retirement due to age, technological obsolescence, and relative fuel inefficiency. Site assessment and planning has been conducted for a potential replacement of MBPP with combined cycle fossil generation. However, eventual implementation of such a project is speculative, and would likely require installation of an alternative cooling system (closed-cycle cooling) as a condition of final permitting and authorization to construct.

Cumulative entrainment impacts from co-location of DCPP and MBPP in the same coastal region has not been directly assessed. However, combined impacts are likely insignificant due to the small incremental larval mortality resulting from entrainment losses during past operations of MBPP. Additionally, the facility has generally operated with low station capacity factors following commercial operation of Diablo Canyon with the exception of the 2000-2002 period which included the California state energy crises.

The MBPP also withdrawals cooling water from an enclosed bay and associated tidal estuary and not the open Pacific Ocean. The enclosed bay is located near the southern edge of a much larger bay. Nearshore areas immediately south and to the north of the facility do not incorporate extensive rocky intertidal habitat, but instead are comprised primarily of sandy shoreline and benthic habitat. MBPP entrainment is therefore more impactful to the larvae and eggs of fish and shellfish more common to the sandy habitat surrounding the facility, which is significantly different from the extensive rocky intertidal and subtidal habitat common to the DCPP location.

4.5 Alternative Technologies Evaluated to Reduce Entrainment

Alternative technologies with potential to reduce entrainment of the eggs and larvae of marine species have been extensively reviewed for the Diablo Canyon Power Plant. These evaluations are provided in multiple references (TERA 1982, TENERA 1988, CCRWQCB 2003, Tenera 2000, Tetra Tech 2002, Burns Engineering 2003, Enercon Services 2009). The details and conclusions of specific evaluations are provided in the referenced documents

The availability and practicality of alternative technologies have been assessed using multiple criteria including; 1) is the alternative technology available and proven (i.e., demonstrated operability and reliability at a cooling water intake similar in size and environment to the Diablo Canyon intake system, 2) does the alternative technology have the potential to reduce the loss of aquatic organisms compared to the operating conditions of the present once-through cooling system, and 3) implementation of the alternative technology is feasible when considering site specific nuclear safety, permitting, engineering, construction, operability, and equipment reliability considerations.

Summary Assessments of Alternative Technologies:

- Retrofit to Closed-Cycle Cooling

  Retrofit of Diablo Canyon to closed-cycle cooling (cooling towers) would significantly reduce withdrawal of ocean water for power plant cooling. Reduction of intake seawater volumes would result in a corresponding reduction in the larvae, eggs, and generic zooplankton and phytoplankton entrained over time. However, the location of the facility on a narrow coastal terrace backed by a step mountain range, and limited make-up water resources, significantly constrains any potential application of closed-cycle cooling.

  Dry cooling and freshwater wet cooling have been determined infeasible for the plant site based on space, engineering, and operability limitations. Dry cooling (heat dissipation to the atmosphere via radiators) cannot be installed in any workable configuration due to the enormous surface areas that would be required for efficient thermal dissipation in conjunction with space and engineering constraints. Wet evaporative cooling using freshwater is not possible as there are insufficient sources of freshwater in the region. The facility would require approximately 85-95 million gallons of freshwater per day to adequately implement wet cooling. Currently, reclaimed freshwater from municipal sewage treatment within the coastal region could provide only 20-30 million gallons per day, the remainder would need to come from already limited agricultural and municipal freshwater supplies. The piping infrastructure to transport even those potential freshwater resources over the significant distances to the topographically isolated plant site currently do not exist, and would not realistically be possible or practical to build. Seawater reverse osmosis infrastructure capable of provide enough freshwater for cooling tower operations would also be impractical, and would require significant quantities of auxiliary electrical power as well as raw seawater. Due to the inherent limitations of dry cooling and freshwater wet cooling, saltwater (seawater) make-up evaporative wet cooling remains the only possibility.

Natural draft cooling towers cannot be installed at the facility due to space constraints and seismic issues in the region. The only remaining closed-cycle cooling configuration would therefore involve installation of non-plume abated mechanical draft cooling towers using saltwater make-up. Plume abated cooling towers, due to there additional size and air inlet requirements that preclude back-to-back positioning, cannot be installed in any workable configuration on the plant site.

This conceptual alternative of mechanical draft closed-cycle cooling towers would reduce seawater use significantly, estimated at >90%, however, onsite operation would result in alternate adverse environmental impacts. Adverse impacts would be generated by salt particulate drift, the necessity to discharge significant volumes of high temperature high salinity cooling tower blow down to receiving waters, and the requirement to procure replacement generation resulting from a station derate post project implementation. Additionally, a lengthy dual unit facility outage estimated at a minimum of 17-months would be required to implement such a retrofit (Enercon 2009). Availability and procurement of replacement baseload power to support the electric grid would be required for the duration, and likely would involve fossil fueled green-house gas (GHG) emitting generation facilities.

State and local permitting to authorize the installation of mechanical draft cooling towers is not realistically feasible at the coastal location as well. Additionally, in the unlikely event permitting could be obtained, the cost for such an unprecedented scale and complex nuclear power plant retrofit would be enormous approaching 4.6-billion in 2008 dollars (Enercon 2009). Such costs, under any analysis completed to date, are significantly disproportionate to any environmental benefits that might be achieved due to the reduction in seawater use and associated reduction in entrainment.

In addition to significant permitting challenges and costs, plant operability from both a safety perspective and reliability perspective would be speculative following implementation of such a project. An extended shake-out period would likely be necessary post-retrofit, and the high capacity factors and generation efficiency currently realized at the power plant may no longer be achievable for an extended period if not permanently. In addition to the environmental impacts that would result from salt drift, the salt laden cooling tower plumes generated on the confined plant site would periodically pose a significant threat to the operability of the existing exposed 230 kV auxiliary and 500 kV electrical transmission systems.

- Installation of Small Slot Cylindrical Wedge Wire Exclusion Screens

Wedge wire exclusion screens reduce entrainment by filtering out, essentially impinging, small organisms and eggs that would otherwise pass into a cooling system or other industrial intake drawing source water. The size of living organisms and debris filtered is dependent of the size of the screen slots selected for an individual application, and operability of the screens is dependent on a number of site specific factors. Additionally, the screening system was originally designed for use in freshwater aquatic environments not marine environments susceptible to extensive encrusting biofouling. A successful large scale saltwater application the size necessary for a power plant such as Diablo Canyon has not been demonstrated to date.

Use of wedge wire screens to reduce entrainment losses is dependent on a relatively constant current in the aquatic system to carry away impinged organisms periodically back flushed from the screen slot openings and surfaces. Without a current, flushed organisms and debris quickly become re-impinged on the screens. The systems have performed effectively in riverine environments due to the relatively constant unidirectional currents inherently produced by the flow of a river. Freshwater lake applications have also been successful in locations that also experience dependable flushing currents

Due to the need for flushing, a cylindrical wedge wire screen application in a marine environment would likely need to be installed in the relatively open ocean, and not in a small confined bay or estuary. However, ocean currents are not constant in any location, at times changing direction over short periods of time. Currents also occur at highly variable velocities often to low to effect adequate wedge wire screen system flushing. Tidal influences would also significantly affect the continuity of adequate flushing in any ocean application.

Placement in the open ocean would be a necessity at Diablo Canyon which would expose the equipment to extreme forces and stresses during high energy storm and ocean swell events. The possibly of maintaining the equipment in an operable condition is highly improbable at the plant site due to this issue. Significant disturbance of currently pristine marine benthic areas would also be required to install and anchor screening structures.

Compressed air is also generally used to back flush wedge wire screens. Offshore of the Diablo Canyon site, the equipment would be installed at depths of up to 70-80 feet due to the nearshore benthic marine topography. The effectiveness of compressed air back flushing would be challenged as proven wedge wire screening configurations work effectively only in depths of up to 30-40 feet. The shoreline infrastructure and shore to offshore connections for a system operating at much higher air pressures would be extensive, and necessarily additionally robust to overcome the significantly increased water pressure.

In addition to the significant structural and operability challenges, the survivability and continued viability of location specific organisms that would become impinged on the screening surfaces is only speculative. Marine biofouling of the screening surfaces would also be extensive, and resultant continuous operability and maintenance problems would need to be overcome.

Overall, the site specific challenges involving installation, maintenance, and operability preclude use of cylindrical wedge wire exclusion screens at the power plant. Any such equipment installation if attempted would also be nearly impossible to maintain intact due to the significant ocean swell events that occur annually at the site. The questionable survivability of larval marine organisms that would be filtered and become impinged on the screens is another significant feasibility concern, and could likely result in existing entrainment losses simply becoming impingement losses.

- Installation of Fine Mesh Traveling Screens

Significant retrofit of the intake structure would be necessary to accommodate fine mesh traveling screens. Modification requirements could include enlargement of the structure by a factor of 2-3 to provide for increased total screening surface area necessary to maintain through screen water velocities at acceptable levels. Such an installation would be significantly difficult and costly, and efficacy in reducing overall entrainment losses in an application similar to DCPP is currently an unknown.

As with cylindrical wedge wire screens, fine mesh traveling screens would likely simply cause dramatic increases in impingement losses in place of current entrainment losses. The survivability of larval during screen impingement, screen wash recovery and collection, and subsequent return to the ocean has not been adequately demonstrated for the vast majority of indigenous marine organisms. The technology is currently considered experimental on the scale required for a plant the size of Diablo Canyon in an open marine environment.

A primary concern with this alternative would also be potential detrimental effects on plant operability due to incidents of excessive screen debris loading. Currently the plant experiences periodic screen occlusion and operability concerns with existing 3/8-inch mesh traveling screens. Such incidents would likely increase due to dramatic increases in the filtration and impingement of debris suspended in the water column that currently passes unhindered through the screening systems and condensers. Fine and small debris is often suspended in the intake flow in significant quantities due to wave action and ocean turbulence even in the absence of severe local storms. This concern would be another reason the entire intake structure would likely need to be enlarged to accommodate increased numbers of screen drive mechanisms and associated screening surface area to effectively manage the current intake volumes during even moderately adverse conditions.

- Use of Variable Speed Circulating Water Pumps

Implementation of variable speed pumps can be effective at reducing total cooling water withdrawal during periods when plant generation is reduced below maximum capacity, and therefore thermal reject is also reduced. As with many nuclear facilities however, Diablo Canyon is routinely base loaded. During the initial license period, planned refueling outages, forced outages, or curtailments for emergent equipment maintenance or testing related issues have generally been the only periods when generation is reduced below full unit capacity. Currently, unnecessary seawater circulation pumps are most often cleared for the duration of refueling outages or for periods of significant generation curtailment, and the once-through system flow reduced accordingly. Installation of variable speed pumps would therefore not result in a significant decrease in overall seawater volumes currently withdrawn from the Pacific Ocean for plant use.

- Altering Refueling Outages to Avoid High Entrainment Periods

Larval susceptibility to entrainment occurs throughout the year however average concentrations in the source water are highest in the spring period. Consistently scheduling outages in the April-June period would take advantage of this by reducing cooling system flow during these relatively high larval abundance windows. However, because the plant operates at very high capacity factors (approximately 90% or > including refueling outages) outage scheduling is primarily driven by reactor core life and not specific schedule windows during the calendar year. Reliance on 18-month fuel cycles also prohibits consistent scheduling of individual unit outages during the same period. A unit outage that occurred during the spring at the end of one fuel cycle would be followed by an outage in the fall period the subsequent fuel cycle. Due to electrical grid support needs, dual unit refueling outages would generally not be favorable at any time during the year. The 18-month fuel cycles again would also limit the ability to consistently implement planned dual unit outages during the peak larval period which occurs each spring.

- Installation of an Offshore Intake

An offshore intake for Diablo Canyon would likely dramatically increase plant adult and juvenile fish impingement based on the performance of offshore intakes at other west coast electric generation facilities. Currently, Diablo Canyon impingement and related impacts are insignificant (Reference Environmental Report Section 4.3). Therefore, reduction in one environmental impact would be offset by the increase in another because of the alternative intake configuration. Relocation of the intake from shoreline to offshore would also likely result in reduced entrainment of the larvae of nearshore abundant species, but increase the entrainment of larvae that are more abundant offshore, again effectively negating potential benefit or in the case of entrainment even increasing overall impacts.

The additional runs of seawater piping and/or concrete conduits necessary to operate an offshore intake would also be susceptible to mass colonization with macro biofouling organisms (Barnacles and Mussels). The additional system surface areas would support significant populations of filter feeders. The potential for cropping loss for all entrained zooplankton and phytoplankton would also subsequently increase. Offshore benthic seawater conduits would also be difficult if not impossible to periodically clean due to the rapidly increasing depths that occur offshore of the facility. Biofouling coverage on the additional conduit surfaces would therefore likely be both dense and mature continuously.

5. Monitoring of Aquatic Resources Potentially Impacted by Power Plant Operations

An extensive marine ecological monitoring program has been conducted at Diablo Canyon. The program is ongoing, with studies conducted both prior to operation of the facility, as well as continuously since start of commercial operations. Reference Environmental Report Section 4.4, Heat Shock (Thermal Impacts), for more detailed information on the monitoring of aquatic resources potentially impacted by power plant operations.

6. Consultations with Regulatory Agencies

6.1 Regulatory Assessment of Entrainment

Extensive communications and consultations involving power plant entrainment have occurred between PG&E and the Central Coast Regional Water Quality Control Board (CCRWQCB). These include the Technical Working Group consultation process used during the development and implementation of the 1996-1999 demonstration study, as well as extensively during evaluations of data and conclusions. The agency continues to retain independent scientific consultants to review the ongoing Diablo Canyon thermal discharge marine monitoring program, and provide technical expertise and recommendations related to potential entrainment impacts and mitigation measures.

Differences regarding the significance of entrainment impacts continue between the power plant and the regulatory agency, and remain an issue in the ongoing NPDES permit renewal process for the facility. Federal and State regulatory proceedings involving development and implementation of CWA Section 316(b) I&E standards have been an additional hindrance to resolution of differences involving the assessment of entrainment impacts.

The CCRWQCB supports the position that entrainment and related losses of planktonic organisms alone represents an adverse environmental impact. This is partially due to assumptions that population level or ecological level effects are difficult to evaluate; and therefore adverse impacts may be occurring but are effectively undetected by current methodologies and available resources. The regulatory agency also does not consider the pre-operational and ongoing surveys conducted at control stations for the discharge thermal impacts monitoring program to provide any useful information related to population trends of indigenous species. There is agreement that available data collected is associated with studies that were not specifically intended to assess long term population abundance, or evaluate trends influenced by natural variation or other factors such as population losses due to fisheries pressures. However, the power plant disagrees that the available long term data set has no value in assessing trends over time. The lack of sustained declines in observed abundance for several species susceptible to entrainment, and periods of increasing trends in observed abundance for those same species, provides insight into factors contributing to natural variability (El Nino periods), and evidences the continued health and viability of the marine ecological system surrounding the facility. If power plant once-through cooling entrainment is in fact detrimental, significant related impacts should be displayed by overall reductions in abundance over time even for those species in which fisheries pressures are not a major factor.

Despite technical arguments and scientific assessments providing an alternative conclusion, the CCRWQCB has formally presented in NPDES permit related proceedings that the loss of eggs and larval organisms due to entrainment by Diablo Canyon represents an adverse environmental impact in and of itself; "In conclusion, the data available cannot be used to indicate any population declines due to entrainment. However, the relatively large proportional larval losses for nearshore taxa represents and adverse impact because of the larval loss itself, regardless of any resulting population or community level affect, is a loss of resource. PG&E disagrees with Regional Board staff's position. PG&E concludes that given the low entrainment estimates for offshore species, the conservative nature of the higher nearshore estimates, and the limited nature of the population trend data, the entrainment data do not indicate an adverse environmental impact." (CCRWQCB 2003).

6.2 USEPA Initial Phase II Rule Entrainment Standard

In 2004, USEPA promulgated the Phase II Rule for Implementation of CWA Section 316(b) for existing power generation facilities with once-through cooling systems that withdraw in excess of 50 million gallons per day (mgd) of source water. Existing facilities that operated at less than 15% of full power capacity were to be exempted from the remainder of the rule regardless of absolute losses from entrainment due to cooling system use (assumption being that the cooling system will not be extensively operated when power generation is significantly curtailed or not occurring). For those existing facilities that operated at 15% or more of capacity, a technological performance standard was developed that required reduction of intake entrainment losses of 60-90% from the facilities assessed baseline entrainment.

The initial Phase II Rule included language that if the cost of technology implementation to meet the performance standard was found to be significantly in excess to potential benefits, the facility could be subject to a site-specific determination of compliance. In January of 2007, the US Federal 2nd Circuit Court ruled (Riverkeeper Decision), that site specific cost benefit evaluation was not an appropriate component in the determination of compliance with requirements of Section 316(b) of the CWA. Additionally, mitigation to replace entrainment losses, including in kind replacement, was also determined to be an inadequate compliance component. The Phase II Rule was remanded to the US Environmental Protection Agency (USEPA), and implementation of the Phase II Rule subsequently suspended by the Federal Agency. The cost benefit ruling of the 2nd Circuit Court was appealed to the US Supreme Court. The high court ruling on the issue was released on April 01, 2009 allowing consideration of cost verse benefits by USEPA in the development of rulemaking and rule compliance strategies. The Supreme Court ruling may result in the development of a final rule that will be supportive of the conclusion that any attempt to reduce entrainment through the application of alternative cooling system technologies at a facility such as Diablo Canyon would be significantly disproportionate to any potential ecological benefits.

Uncertainty remains regarding final federal regulations for both assessing entrainment impacts, and subsequent compliance strategies which could be available to meet intake performance standards related to Section 316(b) of the CWA. However, losses for fish and shellfish in early life stages (eggs and larvae) due to entrainment at the Diablo Canyon, though significant in absolute numbers, have not been shown to result in quantifiable population level impacts to the marine ecological system. Reduction in entrainment at the facility through technology means (implementation of closed-cycle cooling) would also be enormously expensive under any circumstances, and effectively infeasible when considering real world challenges. These issues will likely influence the compliance strategies available for the facility in response to a finalized Phase II Rule.

6.3 California State Policy on Use of Coastal & Estuarine Waters for Cooling

The California State Water Resources Control Board (SWRCB) has developed a draft regulation titled "Statewide Water Quality Control Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling". Development of the policy has been in progress for several years, and finalization and adoption are currently projected during the 2010 calendar year. The policy will establish a standardized process across the existing nine State Regional Water Quality Control Boards (RWQCB) for review and implementation of Federal Clean Water Act Section 316(b) rules and regulations for once-through cooled power plant intake entrainment and impingement. The draft regulation essentially codifies the concept that entrainment losses are an adverse impact to aquatic systems whether or not population or ecological level impacts are detectible and/or definable.

The State policy would not consider the operating capacity of a facility in determining compliance with intake regulations. The initial Federal EPA Phase II Rule for existing facilities incorporated the benchmark operating capacity of 15% that subsequently determined necessity for the facility to comply with other rule requirements. The draft SWRCB policy would require implementation of the once-through cooling regulations at all power plants regardless of historic or projected operating capacity.

The policy's initial overall intent was the stepwise phase-out of the use of once-through cooling statewide. Recent drafts of the proposed regulation would effectively attempt to eliminate power plants that use once-through cooling over a nearly decades long period with older less efficient fossil fuel plants initially targeted for either cooling system retrofit, or plant retirement if new or alternative generation capacity is available. The California nuclear facilities, Diablo Canyon and the San Onofre Nuclear Generation Station (SONGS), would be the last facilities required to implement the policy as currently drafted. The final policy may include a cost benefit and/or feasibility test for the nuclear facilities that would ultimately not require retrofit to closed-cycle cooling or alternatively force retirement of the power plants. Details of the final regulatory policy remain speculative, however other California state initiatives, specifically the drive to reduce GHG emissions from electrical generation and other industrial sources, are anticipated to weigh heavily on the ongoing regulatory process, and likely avert final adoption and/or implementation of any policy that would effectively ban the operation of once-through cooling systems.

The potential to retrofit DCPP and SONGS to closed-cycle cooling has been assessed by multiple interests, and there is general agreement that such an effort at either facility would be both difficult and extremely costly under any circumstances regardless of feasibility. Additionally however, such projects are not realistically feasible when considering the site characteristics of the nuclear facilities, permitting challenges, engineering and operability issues, and costs. The final State policy may include some reasonable means for further considering and weighing closed-cycle cooling retrofit feasibility issues, and providing an alternative means of compliance that will allow the base loaded and low GHG emissions nuclear generating facilities to remain in operation with their installed once-through cooling systems. Alternative compliance means could include implementation of mitigation for facility specific entrainment losses, participation in statewide (non facility specific) general ecological enhancement or mitigation program funding, additional operating permit fees, or other potential means or combination of means of compliance.

Until a final policy is adopted related compliance issue will remain speculative. Extensive documentation related to the development process and progress of the State policy is available for review. Internet access is currently available at the following web address: http://www.waterboards.ca.gov/water_issues/programs/npdes/cwa316.shtml

6.4 Proposed Mitigation Measures to Offset Entrainment Losses

There have been no specific measures or programs implemented during the initial license period to date to reduce actual or potential impacts from entrainment losses due to operation of Diablo Canyon. Additionally, no population level or ecological level adverse entrainment impacts have been defined due to the use of once-through cooling by the facility. Regardless, potential mitigation to offset entrainment losses has been considered by regulatory agency independent scientific consultants (CCRWQCB 2005). The CCRWQCB requested an initial evaluation and recommendation of mitigation alternatives as part of the ongoing power plant NPDES permit renewal proceedings. The request occurred subsequent to the agency's determination that larval losses alone represented an adverse impact. The intent of the most substantive and complex of the proposed mitigation alternatives include those with potential to increase larval production through development of habitat, or attempts to protect (or improve current protections) of existing marine habitat. The enhanced habitat would theoretically result in additional egg and larval production in the regional marine environment, and ultimately lead to in kind replacement for losses from entrainment.

Development and installation of artificial reefs to provide additional rocky subtidal habitat within the marine environment was identified as a potential mitigation strategy shown to be generally successful in similar applications. Sizing of an artificial reef would be based on a scaling strategy such as the use of the Habitat Production Foregone (HPF) method that attempts to match the area of a mitigation project directly to larval losses. An alternative strategy identified would include the establishment and management of Marine Protected Areas (MPA) that could serve as ecological reserves for the relatively undisturbed recruitment and maturation of marine populations. Intent would be that those species identified as having larvae and/or eggs susceptible to entrainment by the power plant would proliferate and successfully produce greater numbers of eggs and larvae within the MPAs.

Such measures, if deemed appropriate and/or necessary, could provide potential mitigation for ongoing entrainment losses in absolute numbers of eggs and larvae that would occur during a license renewal period. Such measures may increase the larval production of existing locations set aside as MPAs or create new marine communities capable of supporting egg and larval production from a large number of spawning marine species. However, there is no existing evidence that such measure would actually alter or reduce ecological impacts from current entrainment losses; as such impacts have not been defined to date (PG&E, 2005). Evidence from existing studies support the conclusion that losses are limited to an incremental mortality of eggs and larvae for entrained organisms, and that egg development and larval recruitment success in the greater ecological system is potentially unaffected by those losses.

Habitat availability and quality is a seemingly key factor for successful larval recruitment, and ultimately the replenishment and development of stable adult populations. In the absence of factors such as excessive commercial or sport fishery pressures, healthy habitat will support the development of populations that are variable over time, but generally maximized at any one time to the limits supported by current availability of natural resources.

High egg and larval densities across large nearshore areas, or the absolute number available in the ecosystem in total, and/or for individual species, at any given time may not be key factors influencing long term population stability. Mitigation for entrainment that increases larval production in specific locations, or even increases the overall density of larvae in the source water body, may not then ultimately improve larval recruitment success in the ecological system. Increasing and/or preserving available undisturbed habitat may be the compensatory strategy that has some assurance of actually producing enhancements to the ecological system.

Notably, the potential large scale mitigation alternatives proposed for plant entrainment losses are both predicated on the availability of habitat, including habitat that would remain relatively undisturbed by human intervention. Development of an artificial reef would create new habitat, and establishment and enforcement of MPAs removes human intervention such as fishing pressures on reproductive populations. Promotion of these alternatives as viable mitigation supports the concept that availability of habitat for recruitment, development, and maturation of populations within the ecosystem is of great significance to maintaining the health and balance of marine communities.

The rocky intertidal and subtidal habitat surrounding the Diablo Canyon Power Plant has remained intact and relatively undisturbed due to the presence of the nuclear facility. Security enhancements, including recent establishment of a one-mile surface craft exclusion zone that incorporates the subtidal habitat directly adjacent the power plant, have even eliminated some previous commercial and sport fisheries pressures within the area. The 14-miles of inaccessible coastline within the greater Diablo Canyon lands also preserve intertidal zone health, and eliminates fishing directly from the shoreline along the entire nearshore area. Productive habitat is therefore already being partially preserved and protected simply because the facility exists. That fact is likely of at least some marginal benefit to the regional ecological system.

7. Conclusion - Impacts on Fish and Shellfish Resources Resulting From Entrainment During a Period of Extended Operation

Entrainment of the eggs and larvae of marine fish and shellfish species has been a significant regulatory issue for the Diablo Canyon Power Plant during the initial license period. However, adverse entrainment related ecological or population level impacts resulting from once-through cooling system operations have remained undefined.

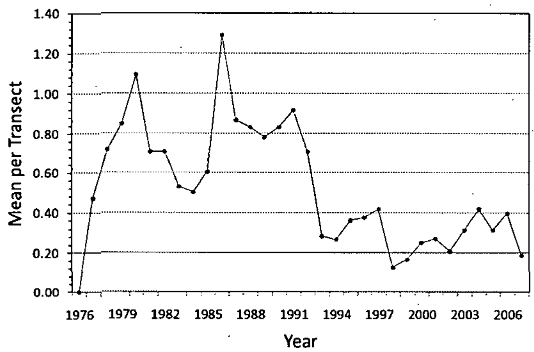
In absolute numbers, the quantity of fish and other larval organisms entrained over time by the facility and assumed to be entirely lost to the ecosystem appears substantial. Proportional Mortality (P_M) of larvae for some species likewise can seem appreciable. However, the fact that larval mortality is naturally very high in the marine environment supports the conclusion that the incremental larval mortality of entrained taxa is not of ecological significance. Available evidence of local fish population trends provided from long term receiving water monitoring data as well as regional independent fisheries assessments further support that conclusion. Whether or not compensatory mitigation for absolute entrainment larval losses would be required by regulatory interests during the operating life of DCPP, the ecological importance of those losses will remain limited.

In summary, entrainment related impacts to fish and shellfish resources from operation of the power plant once-through cooling system during a license renewal period, based on determinations of the level of ecological significance of egg and larval losses resulting from entrainment during the current operating license period, are projected to be SMALL.

9. Figures

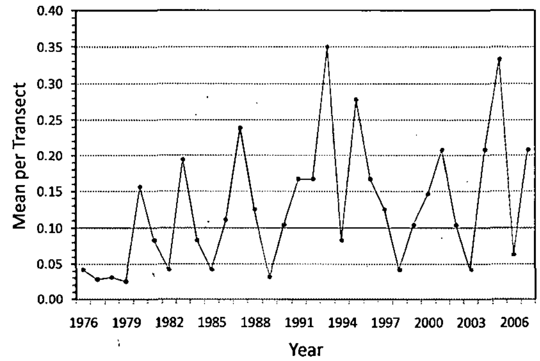
Fishes Targeted by Fisheries

a) Cabezon

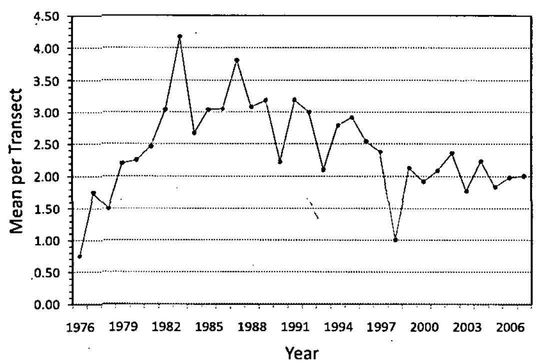


Fishes Not Targeted by Fisheries

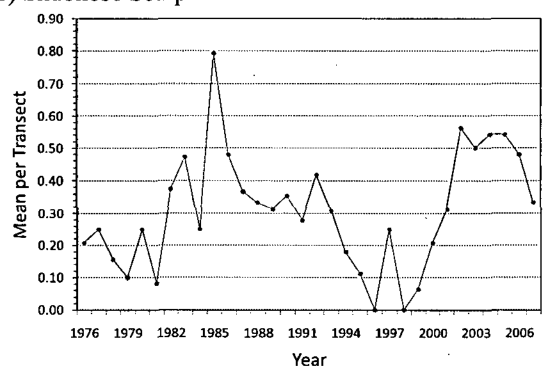
d) Smoothhead Sculpin



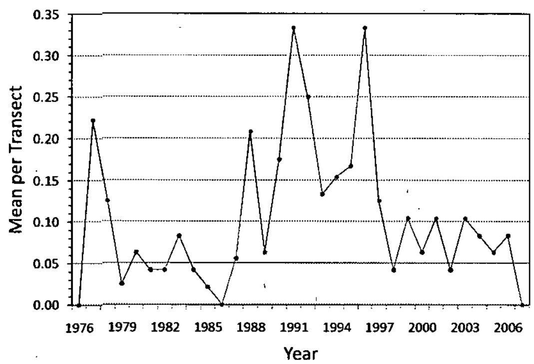
b) KGB Rockfishes



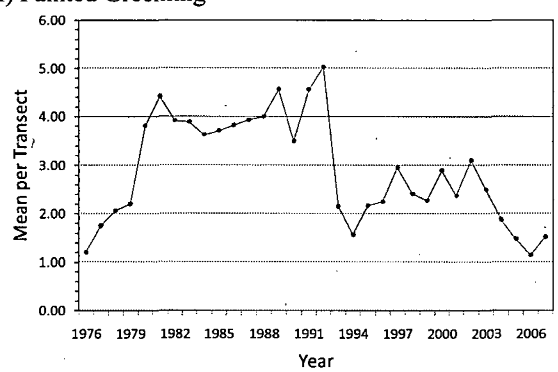
e) Snubnose Sculpin



c) Monkeyface Eel

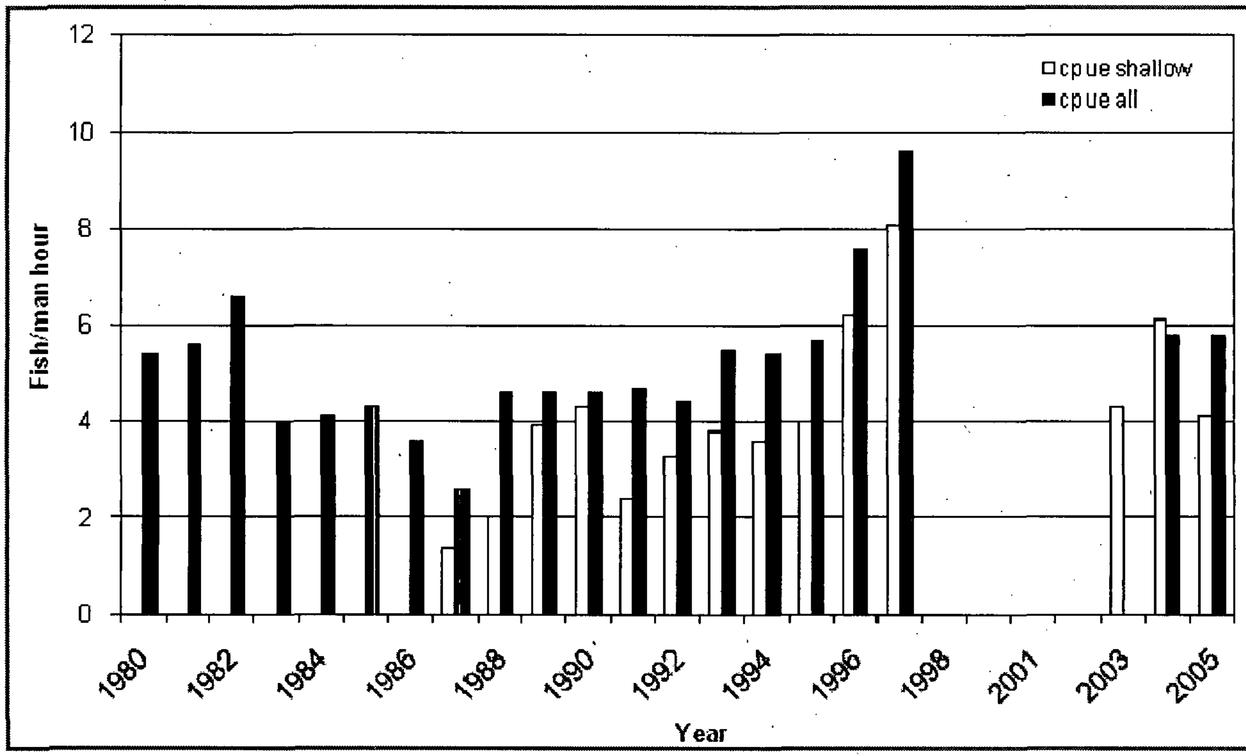


f) Painted Greenling



Annual mean number of fish per 50 m transect from three sampling stations in Patton Cove from 1976 through 2007. Data collected as part of Diablo Canyon Power Plant monitoring of thermal discharge impacts as required by the plant NPDES Permit.

Environmental Report Technical Data Report **Diablo Canyon Power Plant**
Figure 1 Receiving Water Monitoring Program Control Station Data (Tenera Environmental)



Party boat catch per unit effort (number of fishes per fisher per hour) for eleven rockfishes and two greenling species from ports on the south Central Coast, 1980–2005. Data from the following sources: 1980–1997 California Department of Fish and Game and 2003–2005 California Polytechnic State University (Stephens et al. 2006). Data from 1998–2002 collected by Pacific Fisheries Management Commission were not available.

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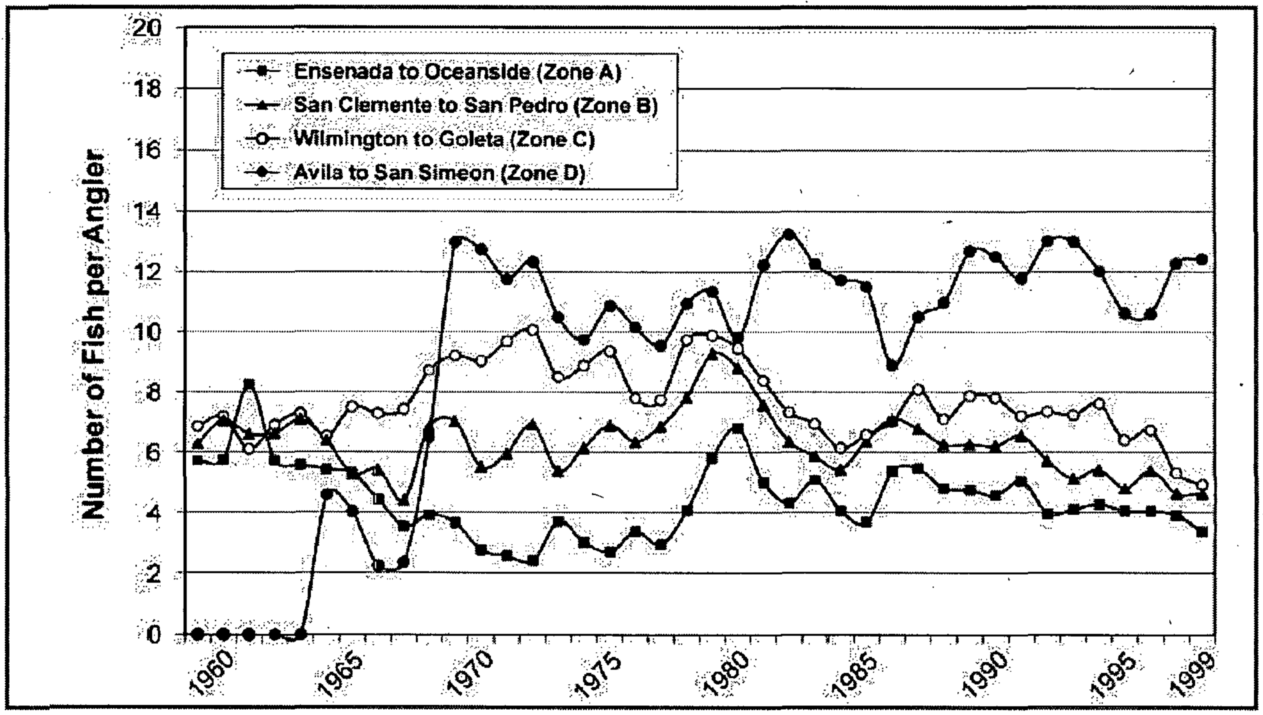
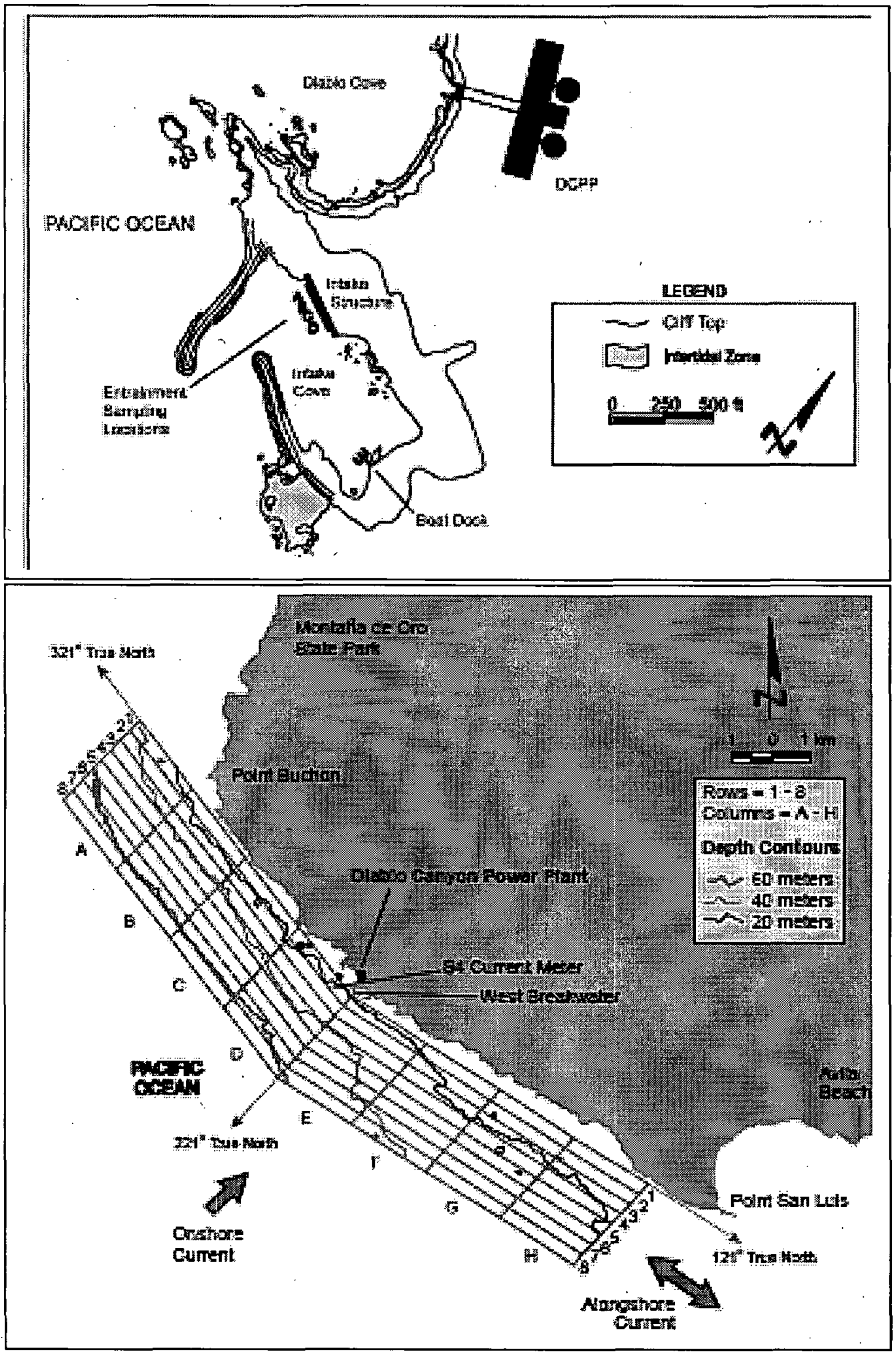
Diablo Canyon Power Plant

Figure 2
Fishery Catch Data
California Central Coast



Annual average commercial passenger fishing vessel (CPFV) catch per angler by geographic zone 1959 to 1998. (Figure 3 from Dotson and Charter 2003). The Diablo Canyon Power Plant is located north of Avila Beach in Zone D.

Environmental Report Technical Data Report Diablo Canyon Power Plant
Figure 3 Fishery Catch Data by Geographic Zone



Environmental Report Technical Data Report
Diablo Canyon Power Plant

Figure 4
DCPP 316(b) Demonstration Study
1996-1999 Sampling Locations

9. References

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Enclosure 2

Diablo Canyon Power Plant Cooling Water Intake Structure 316(b) Demonstration. Tenera Inc. 1988

PG&E Pacific Gas and Electric Company

Diablo Canyon Power Plant

Cooling Water Intake Structure 316(b) Demonstration

April 28, 1988

TENERA
Environmental Services

1995 University Avenue, Berkeley, California 94704, (415) 845-5200
Telecopy: (415) 845-8453

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EXECUTIVE SUMMARY

This report documents the results of a demonstration program conducted at Pacific Gas and Electric Company's Diablo Canyon Power Plant in compliance with Section 316(b) of the Clean Water Act and Provision D4b of the NPDES Permit issued by the California Regional Water Quality Control Board, Central Coast Region (Regional Board). The report was prepared in accordance with the Revised 316(b) Study Plan (Appendix A) submitted in response to the March 17, 1983, order of the State Water Resources Control Board (Order No. WQ83-1).

Section 316(b) of the Clean Water Act requires that "...the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Because no single intake design is the best technology for all sites, a site-specific analysis of intake-related organism losses and a site-specific determination of the best technology available for minimizing those losses is required. Intake-related losses are those resulting from entrainment (the drawing of organisms into the cooling water system) and impingement (the retention of organisms on the intake screens). The 316(b) program was specifically designed to provide the information necessary to support an analysis of the feasibility, engineering constraints, and biological effectiveness of the existing and alternative intake technologies. Based on the results of these analyses, the best technology available for minimizing entrainment and impingement losses is recommended for the cooling water intake at the Diablo Canyon Power Plant.

A one-year entrainment monitoring program was initiated in October 1985. Entrainment support studies were completed during 1985-86 to evaluate sampling gear efficiency and validate the most representative sampling location for routine monitoring. The one-year impingement monitoring program was initiated during April 1985 (preliminary Unit 1 impingement collections were conducted during February and March 1985). The impingement program was augmented by support studies which included underwater fish observation surveys and sampling gear efficiency evaluations. All sample collection and processing was performed in accordance with standard procedures subject to quality control and quality assurance audits. Data and analysis of information collected in the entrainment and impingement monitoring programs were also subject to quality control checks and verification.

Data on entrainment and impingement, combined with information on operational characteristics of the Diablo Canyon Power Plant cooling water system, provided a site-specific basis for assessing alternative cooling water intake system technologies. Alternative technologies were assessed with a hierarchical evaluation system to determine which alternative intake technologies would (1) reduce biological losses from the existing operating conditions, and (2) prove feasible at the Diablo Canyon Power Plant, based on site-specific engineering, operations, and reliability factors. The final phase of the assessment of alternative technologies considered the total economic cost of the feasible technologies in relation to corresponding environmental benefits anticipated.

The Diablo Canyon Power Plant

The Diablo Canyon Power Plant is located on the central California coast near San Luis Obispo, California. The central California site is approximately 190 miles south of San Francisco, 150 miles north of Los Angeles, and 12 miles west-southwest of San Luis Obispo.

The Diablo Canyon Power Plant is a two-unit nuclear power plant with a combined net capacity of 2,190 megawatts (MWe). Unit 1 commercial operation was attained in May 1985, and Unit 2 commercial operation was attained in March 1986.

Each unit consists of a nuclear heat source, a steam supply system, and auxiliary equipment. Although each of the units has an independent once-through seawater cooling system, the units share common intake and discharge structures. The reactors, structures and auxiliary equipment are substantially identical for the two units, however, the rated difference in capability of turbine generators (3,338 MWt for Unit 1; 3,411 MWt for Unit 2) account for net electrical output ratings of 1,084 and 1,106 MWe for Units 1 and 2, respectively.

At Diablo Canyon Power Plant the once-through (open-cycle) cooling water system withdraws seawater from the Pacific Ocean through an intake structure in Intake Cove. Seawater is pumped through the generating unit condensers, where heat exchange takes place during power generation. Circulating seawater subsequently flows through the discharge structure into the receiving waters of Diablo Cove. Total cooling water transit time from the plant's intake to the discharge structure is approximately 5 minutes. When the plant is operating at full capacity, cooling water temperatures are typically elevated approximately 11 C (20 F).

Cooling water for each unit is provided by two main circulating seawater pumps (each capable of pumping approximately 433,500 gpm). When all four circulating water pumps are operational, cooling water volume is estimated to be 2.45 billion gallons per day (9.29 million m^3 per day). Each of the units is also equipped with an auxiliary cooling system.

The common shoreline intake structure for Units 1 and 2 houses the bar racks, vertical traveling screens, auxiliary cooling water systems, and four main circulating water pumps. This intake configuration was designed to maximize fish avoidance and survival, based on studies conducted at PG&E's Contra Costa Power Plant.

The discharge structure is a series of three separate weirs. The cascading effect of the discharged circulating water promotes aeration and dissipation of hydraulic energy. The discharges for Units 1 and 2 are parallel and are separated by a concrete wall. Cutouts in the wall promote mixing and temperature reduction of the thermal effluent. The discharge acts as a surface jet, promoting the mixing of the thermal effluent with Diablo Cove receiving waters.

Key Organisms Studied

The Diablo Canyon Power Plant 316(b) studies focused on the following aquatic organism groups, as specified in the study plan:

- Fish (all life stages)
- Macroinvertebrates (e.g., crabs, amphipods, shrimp).

These groups were selected for study because their life history and distribution indicate that they are among the organisms most susceptible to cooling water system effects. These organism groups generally have longer generation times and a lower reproductive potential than phytoplankton, zooplankton, and many benthic organisms. Fish and macroinvertebrates were also selected because many of them are commercially or recreationally valuable.

Organism groups not selected for detailed study included:

- Phytoplankton
- Zooplankton (except for planktonic larvae of the fish and macroinvertebrates studied)
- Sessile benthic invertebrates (e.g., sea anemones, burrowing clams).

Based on U.S. EPA guidelines (EPA 1977), phytoplankton and zooplankton were excluded from detailed analyses because of their wide geographic distributions, short generation times, and population regeneration potential. Also, vigorous tidal and ocean currents continually replenish the phytoplankton and zooplankton populations near the plant, reducing the risk of localized population changes. On the same basis, a majority of benthic invertebrates were excluded because their bottom-dwelling habits minimize the involvement of juveniles and adults with the plant's cooling water system.

Assessment of Entrainment and Impingement Effects

The potential impact of the combined entrainment and impingement losses at the Diablo Canyon Power Plant on populations of fish and invertebrates of the source waterbody, the Pacific Ocean, has been assessed. Results of the assessment provide no evidence that incremental mortality attributable to entrainment and impingement results in adverse environmental impacts. Entrainment and impingement losses at the Diablo Canyon Power Plant:

- are not expected to substantially reduce the abundance of most existing populations; however, within the Diablo Canyon Intake Cove and immediate vicinity, there exists the potential for reductions in the abundance of cabezon, which has limited larval dispersal and low natural mortality rates

- are not expected to reduce sustained yield of local sport or commercial fisheries
- do not directly affect threatened or endangered species.

Therefore, it was concluded that the direct impact of the Diablo Canyon Power Plant on local fish and invertebrate populations and indirect impact on the community are minimal. This conclusion is based, in part, on the ecological assimilative capacity of the species involved. The species of fish and macroinvertebrates entrained and impinged typically have high reproductive potential (either in terms of numbers of young produced or frequency of reproduction), and the young, many of which are planktonic and widely distributed, are characterized by very high natural mortality rates. Life history reviews of the key species of fish and macroinvertebrates, in combination with information collected as part of the one-year entrainment and impingement monitoring programs and general fisheries surveys conducted in nearshore waters in the vicinity of the Diablo Canyon Power Plant, show that:

- Since the plant cooling water flows represent only a small fraction of the volume of the source waterbody, and since the species of fish and invertebrates collected in the entrainment and impingement monitoring program are distributed throughout the central coast nearshore environment, the potential for impact on these widely distributed populations is minimal.
- The survival of invertebrates and larval fish following passage through the Diablo Canyon Power Plant cooling water system is expected to be relatively high, based on information collected at other sites and the operating characteristics of the Diablo Canyon Power Plant cooling water system.
- The invertebrates and larval fish entrained are characteristically in the very early life stages, are planktonic, are widely distributed along the coast and are characterized by very low natural survival rates.
- Any localized changes in the abundance of fish and invertebrates resulting from entrainment mortality are diminished by the recruitment resulting from the rapid movement of water through the nearshore coastal area and mixing in the receiving waters.
- The number of fish and macroinvertebrates impinged at the Units 1 and 2 intake is low. The fish and macroinvertebrates that are impinged are predominantly juveniles, which have a relatively low probability of survival to maturity or recruitment to the local fishery.
- Many of the fish and macroinvertebrate species inhabiting the nearshore coastal regions adjacent to the plant have behavior, reproductive, or migratory patterns that minimize their susceptibility to entrainment and impingement at the plant.

- The Diablo Canyon Intake Cove and adjacent coastal waters do not represent a unique habitat for any of the fish or invertebrate species susceptible to entrainment and impingement.

Extensive habitat is available along the coast for the fish and invertebrate species susceptible to entrainment and impingement. These species have characteristically high reproductive potential and broad geographic distributions. Their planktonic larval dispersal stages naturally experience high mortality. Juveniles and adults have low susceptibility to impingement. Thus the local fish and invertebrate populations are considered to be resilient and able to sustain incremental entrainment and impingement mortality without adverse impacts.

Intake Technology Evaluation

A hierarchical evaluation system was used to assess which alternative intake technologies would reduce biological losses and be feasible for application to the cooling water system of the Diablo Canyon Power Plant. Alternative intake technologies were evaluated on the basis of the following four criteria:

- The alternative technology is available and proven (i.e., it has demonstrated operability and reliability at a cooling water intake of similar size and environment to that of Diablo Canyon Power Plant).
- Implementation of the alternative technology will reduce the loss of aquatic organisms under the present operating conditions.
- Implementation of the alternative technology is feasible at the Diablo Canyon Power Plant site, based on site-specific considerations of engineering, operations, and reliability.
- The total economic cost of the alternative technology is proportionate to the environmental benefits anticipated.

These criteria were applied to alternatives considered for application at the plant. All intake technologies considered available and proven for application at the plant (Criterion 1) were given a biological evaluation (Criterion 2). Feasibility analyses (Criteria 3 and 4) were carried out for alternatives that would reduce biological losses. Conclusions were then made regarding the best intake technology available for the cooling water system at the Diablo Canyon Power Plant. The judgment of the best technology available for the Diablo Canyon Power Plant is based, in part, on the conclusion that the impact of entrainment and impingement on the local aquatic community was undetectable.

Based on the evaluation of alternative intake technologies for the Diablo Canyon Power Plant, it was concluded that:

- There is no reasonable alternative intake location that would reduce entrainment and impingement losses.

- Behavioral barriers would not reduce the numbers of organisms exposed to either entrainment or impingement.
- Entrainment and impingement losses would not be substantially reduced by use of drum screens, centerflow traveling screens, or a fish pump return system.
- A screen mesh size of 3/8 in. (9.5 mm) is acceptable, because the survival potential of fish eggs and larvae impinged on fine-mesh screens has not been shown to exceed the survival potential of organisms entrained through the Diablo Canyon Power Plant cooling water system.
- Cooling water system structural modifications and discharge temperature regulation would not substantially reduce the mortality of entrained organisms.
- The existing bar rack biofouling control program is effective in reducing intake approach velocities and predation losses for entrained fish and invertebrates.
- Sediment accumulation within the intake structure is presently not contributing to increased water velocities.
- The kelp harvesting and exclusion programs and the removal of accumulated drift kelp and debris from the intake bar racks, are effective in reducing impingement losses.
- The biofouling control and heat treatment optimization programs underway at the Diablo Canyon Power Plant are effective in reducing the accumulation of fouling organisms colonizing the intake conduits while reducing the frequency and duration of heat treatment at the plant.
- No consistent seasonal pattern exists for all entrained organisms at the Diablo Canyon Power Plant, and therefore routine cooling water volume reductions during extended fuel reloading and maintenance outages will reduce entrainment and impingement whenever they occur during the year. The potential biological benefits of reducing cooling water flows when possible is currently being achieved, in large part, by the standard practice of removing one or both circulating water pumps from service on a unit during extended outages. Scheduling fuel reloading outages to coincide with the seasonal distribution in abundance of a particular organism is not feasible.
- Modifications to the intake screens, including installation of fish buckets, dual spraywash system, a fish return sluiceway, and continuous screen rotation, would reduce the losses of organisms due to impingement but would not reduce entrainment losses. Because of the low numbers of fish and macroinvertebrates impinged on existing intake screens at the Diablo Canyon Power Plant, and the relatively high costs involved, installation of modified intake screens is not warranted.

- Expansion and modification of the intake structure to achieve a 0.5 fps approach velocity would reduce impingement losses but would not reduce entrainment. Because of the low numbers of fish and macroinvertebrates impinged at the existing shoreline intake, the estimated cost of $204 million for modifying the intake structure is disproportionate to the benefits resulting from the reduced rate of impingement.

Based on the results of this evaluation of alternative technologies it was concluded that the existing cooling water system, intake location and configuration reflect the best technology available for the Diablo Canyon Power Plant given the cooling water system operational requirements, reliability considerations, current mode of unit operation, the low numbers of organisms impinged, and the costs associated with intake modifications.

CHAPTER 1
INTRODUCTION

This report documents the results of a demonstration program conducted at Pacific Gas and Electric Company's Diablo Canyon Power Plant (DCPP) in compliance with Section 316(b) of the Clean Water Act and Provision D4b of the NPDES permit issued by the California Regional Water Quality Control Board, Central Coast Region (Regional Board). The report was prepared in accordance with the Revised 316(b) Study Plan submitted in response to the March 17, 1983 order of the State Water Resources Control Board (Order No. WQ83-1).

Section 316(b) of the Clean Water Act requires that "...the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Because no single intake design is the best technology for all sites, a site-specific analysis of intake-related organism losses and a site-specific determination of the best technology available for minimizing those losses is required. Intake-related losses are those resulting from entrainment (the drawing of organisms into the cooling water system) and impingement (the retention of organisms on the intake screens). Two complementary monitoring programs quantified the entrainment and impingement of fish and macroinvertebrates at the plant. The programs were specifically designed to provide the information necessary to support an analysis of the feasibility, engineering constraints, and biological effectiveness of the existing and alternative intake technologies. Based on the results of these analyses, the best technology available for minimizing entrainment and impingement losses is recommended for the cooling water intake at the Diablo Canyon Power Plant.

1.1 Description of 316(b) Studies

1.1.1 Initiation of the 316(b) Studies

Pacific Gas and Electric Company (PG&E) submitted a revised 316(b) Study Plan for the Diablo Canyon Power Plant, which assessed the potential for adverse impact on aquatic biota and presented a plan for a monitoring study (Appendix A). Information provided by this study would be used to determine whether the existing cooling water intake structure represents the best technology available for minimizing adverse impacts, or whether modifications are appropriate.

1.1.2 Overview of the 316(b) Program

Two complementary study elements in the 316(b) study program provide a quantitative basis for determining entrainment and impingement of fish and macroinvertebrates at the Diablo Canyon Power Plant. The first study element provides data on the species and size composition and the seasonal and diel distribution of entrained and impinged organisms (abundance). The second element determines species-specific entrainment and impingement survival. The monitoring program schedule and corresponding operating status of the Units 1 and 2 cooling water systems during 1985 and 1986 are shown in Figure 1-1. A one-year entrainment monitoring program was initiated in October 1985. Entrainment support studies were completed during 1985-86 to evaluate sampling gear efficiency and determine the most representative sampling location for routine monitoring. A plankton monitoring program was conducted between April 1986 and September 1987 at sampling locations in the Diablo Canyon Intake Cove and offshore of the power plant to complement the entrainment monitoring program (TENERA 1988). The one-year impingement monitoring program was initiated in April 1985 with some preliminary Unit 1 impingement collections conducted during February and March 1985. The impingement program was augmented by support studies which included underwater fish observation surveys and sampling gear efficiency evaluations. All sample collection and processing was performed in accordance with standard procedures subject to quality control and quality assurance audits. Both data collected in the entrainment and impingement monitoring programs and data analysis were subject to rigorous quality control checks and verification.

Data on entrainment and impingement, combined with information on operational characteristics of the Diablo Canyon Power Plant cooling water system, provide a site-specific basis for an assessment of alternative intake and cooling water system technologies. Alternative technologies were assessed based on a hierarchical evaluation system to determine which alternative intake technologies would (1) reduce biological losses from the existing operating conditions (using the results of entrainment and impingement monitoring programs), and (2) be feasible at the Diablo Canyon Power Plant, based on site-specific engineering, operations, and reliability factors. The final phase of the assessment of alternative technologies considers the total economic cost of the feasible technologies and the corresponding environmental benefits anticipated.

1.1.3 Key Organisms Studied

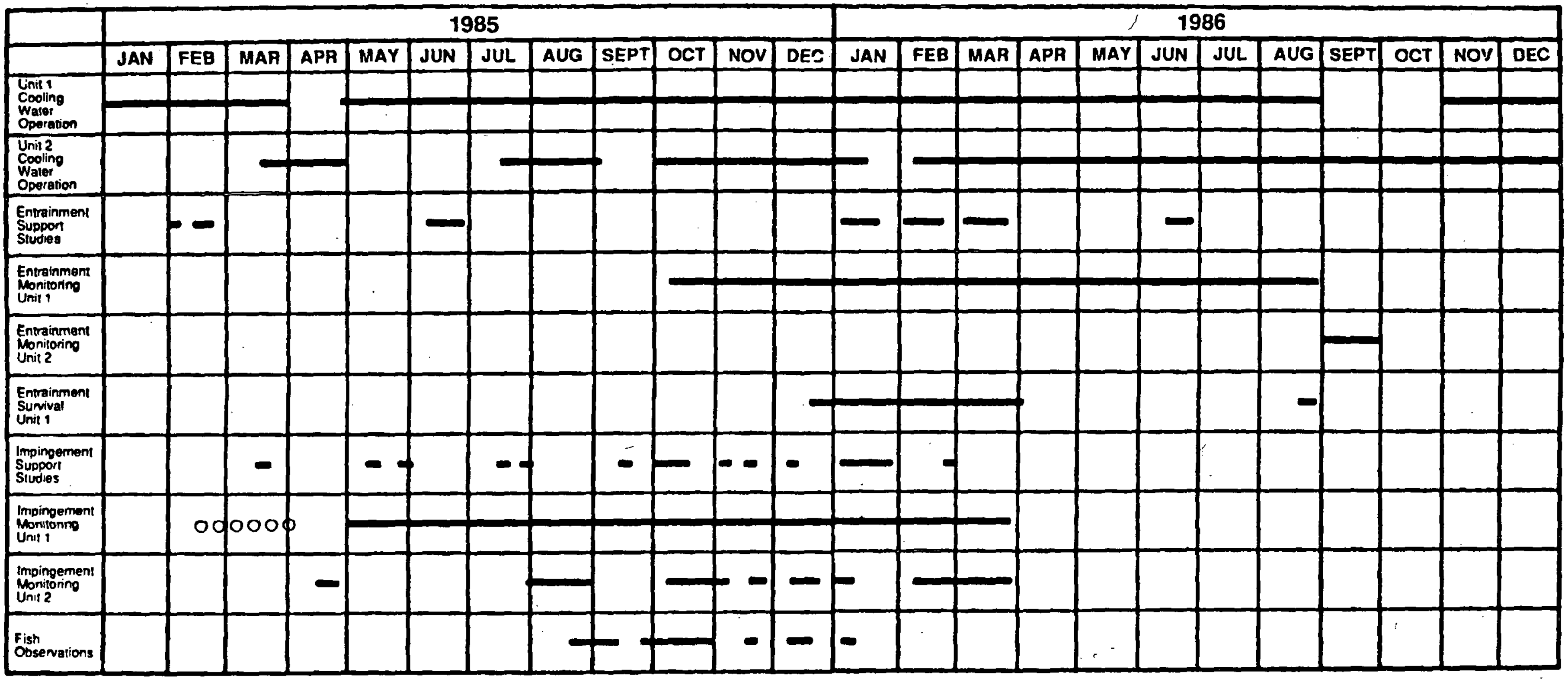
The Diablo Canyon Power Plant 316(b) studies focused on the following aquatic organism groups:

1. Fish (all life stages)
2. Macroinvertebrates (e.g., crabs, amphipods, shrimp).

These groups were selected for study because their life history and distribution indicate that they generally have longer generation times and a lower reproductive potential than phytoplankton, zooplankton, and many benthic organisms. Fish and macroinvertebrates were also selected because many of them are commercially or recreationally valuable.

Organism groups not selected for detailed study included:

1. Phytoplankton



Note: o Indicates preliminary investigations.

Figure 1-1

Summary of Field Collection Activities at the Diablo Canyon Power Plant, 1985 - 1986

2. Zooplankton (except for planktonic larvae of the fish and macroinvertebrates studied)

3. Sessile benthic invertebrates other than those included in the macroinvertebrates specified above (e.g., sea anemones, burrowing clams).

Based on U.S. EPA guidelines (EPA 1977), phytoplankton and zooplankton were excluded from detailed analyses because of their wide geographic distributions, short generation times, and population regeneration potential. Also, vigorous tidal currents continually replenish the phytoplankton and zooplankton populations near the plant, reducing the risk of localized population changes. On the same basis, a majority of benthic invertebrates were excluded because their bottom-dwelling habits minimize the involvement of juveniles and adults with the plant's cooling water system.

1.1.4 Types of Studies Performed

The 316(b) study program involved routine monitoring of cooling water system operation, entrainment, and impingement during one complete year after the plant began commercial operation. The objectives, methods, and general scope of each of the three elements of the 316(b) monitoring program are briefly outlined below.

1.1.4.1 Plant Operations and Physical Data

The objective of this element of the program was to compile information on the design and actual operation of the Units 1 and 2 cooling water system, with emphasis on those operational parameters necessary for the interpretation of information collected in the entrainment and impingement studies. Water quality and cooling water system operational data compiled during 1985 and 1986 in association with the biological monitoring programs included circulating water pump operation, intake and discharge water temperatures, intake water velocities, biofouling control procedures, tidal conditions, and dissolved oxygen concentrations.

1.1.4.2 Entrainment Studies

The entrainment studies include two complementary study elements: entrainment abundance and entrainment survival. Particular emphasis was placed on selected larval fish (ichthyoplankton) and macroinvertebrate taxa based on their sport and commercial importance and/or their role as prey for juvenile and adult fish inhabiting the area. Entrainment abundance studies provided information on (1) species composition of entrained ichthyoplankton and macroinvertebrates, (2) size (length) composition of the entrained ichthyoplankton, and (3) seasonal and diel patterns in the densities of entrained biota. Weekly samples were taken over a period of one year (October 1985-September 1986).

The entrainment survival program was designed to determine the proportion of larval fish and macroinvertebrates surviving entrainment through the Diablo

Canyon Power Plant cooling water system. The entrainment survival program was designed to collect larval fish, primarily rockfish, during the winter period of anticipated peak abundance. The low densities of larval fish, particularly larval rockfish, in the entrainment survival samples, however, precluded collecting an adequate number of larval fish to effectively quantify entrainment survival. In the absence of quantitative site-specific entrainment survival estimates for larval fish, results of entrainment survival studies conducted at other power plant sites are used to characterize potential survival of entrained organisms at the Diablo Canyon Power Plant.

1.1.4.3 Impingement Studies

The impingement studies include two complementary study elements: impingement abundance and impingement survival. All organisms collected during the impingement studies were documented, however, emphasis was placed on fish and selected target macroinvertebrate taxa. Macroinvertebrates selected as target organisms include representatives of the arthropods (particularly decapod crustaceans), molluscs, and echinoderms. These macroinvertebrate taxa were selected based on their sport and commercial importance and/or their role as important prey for juvenile and adult fish inhabiting the area. The impingement abundance studies determined:

- species composition of impinged organisms
- lengths and weights of selected impinged organisms
- diel and seasonal patterns of impingement
- the relationship between impingement and cooling system operational parameters
- sex ratio and gonadal maturity for selected species
- whether significant impingement occurs on intake structure bar racks.

The impingement survival program was designed to determine the proportion of fish and selected macroinvertebrates surviving impingement under various intake traveling screen operational modes. The numbers of fish impinged at the Diablo Canyon intake, however, were insufficient to effectively quantify impingement survival under various intake operational modes. Initial survival estimates of impinged fish and selected macroinvertebrates collected at the Diablo Canyon intake are used, in combination with results of impingement survival studies conducted at the Moss Landing Power Plant and at other sites, to provide the basis for evaluating the potential effectiveness of alternative intake technologies at the Diablo Canyon Power Plant.

1.2 Organization of the Report

This report, a 316(b) demonstration, is a summary and analysis of the data collected during the entrainment and impingement monitoring program conducted at the Diablo Canyon Power Plant. All elements specified in the monitoring program are discussed in Table 1-1.

This report includes a Summary, Chapters 1 through 6, and Appendices. The design and operation of the Diablo Canyon Power Plant and its cooling water system are described in Chapter 2. Information on entrainment and impingement losses developed in Chapters 3 and 4 is used to assess potential changes in selected aquatic populations. Information on life history characteristics and distribution patterns for a variety of fish and invertebrate species is used to assess potential effects resulting from entrainment and impingement losses in Chapter 5 and supplemented with further detail in Appendix C. The best technology available for the intake system is evaluated in Chapter 6. A full range of possible intake technologies is presented in Appendix D. Technologies considered proven and available are evaluated on the basis of their potential for reducing the biological losses associated with entrainment and impingement. A site-specific feasibility analysis is presented for technologies with the potential to reduce losses. Finally, based on the combination of biological, engineering, and cost considerations, the best technology available for the intake system is recommended.

1.3 References

TENERA. 1988. Seasonal and distributional patterns of larval fish in the vicinity of the Diablo Canyon Power Plant, 1986-1987. Prepared for PG&E.

U.S. Environmental Protection Agency (U.S. EPA). 1977. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: Section 316(b) P.L. 92-500. Draft. U.S. EPA, Office of Water Enforcement, Permits Division, Industrial Permits Branch, Washington, D.C.

TABLE 1-1

REPORT ORGANIZATION
STUDY ELEMENTS AND LOCATIONS

Study Element	Report Location
Study Plan	Appendix A
Plant Design and Operation	Chapter 2
Entrainment Abundance and Survival Studies	Chapter 3 Appendix B
Impingement Abundance and Survival Studies	Chapter 4
Impact Assessment	Chapter 5 Appendix C
Best Technology Available Evaluation	Chapter 6 Appendix D
Data Base (microfiche or paper copy)	Appendix E

CHAPTER 2

DESCRIPTION OF THE DIABLO CANYON POWER PLANT AND CHARACTERISTICS OF THE SOURCE WATERBODY

The Diablo Canyon Power Plant is located on the Pacific Ocean in central California (Figure 2-1). The power plant site (Latitude 35 degrees, 12' 44", Longitude 120 degrees, 51' 14" W) is approximately 190 miles south of San Francisco, 150 miles north of Los Angeles, and 12 miles west-southwest of San Luis Obispo.

The coastal marine terrace, where the plant is sited, is about 1,000 ft wide, with elevations ranging from 60 to 150 ft above mean sea level (MSL); the plant's grade elevation is 85 ft above MSL. The site area slopes upward, forming steep, rugged hillsides which attain an elevation of 1,500 ft within 1 mile of the site. Diablo Canyon passes immediately northwest of the site and runs ENE for about 4 miles, cutting into the San Luis Mountain Range.

The plant site consists of two parcels totaling 750 acres. The lands adjacent to the coastline for 8 miles to the southeast and 4 miles to the northwest of the site are also owned by PG&E. An undeveloped inland portion of Montana De Oro State Park, to the north of the site, extends to within approximately 1 3/4 miles of the site.

2.1 Plant Description and Operation

The Diablo Canyon Power Plant is a two-unit nuclear power plant which has a combined net capacity of 2,190 megawatts (MWe). Unit 1 commercial operation commenced in May 1985, and Unit 2 commercial operation commenced in March 1986.

Each unit consists of a nuclear heat source, a steam supply system, and auxiliary equipment. Although each of the units has an independent once-through (open-cycle) seawater cooling system, the units share common intake and discharge structures. The reactors, structures, and auxiliary equipment are substantially identical for the two units; however, the rated difference of turbine generators (3,338 MWt for Unit 1; 3,411 MWt for Unit 2) account for net electrical output ratings of 1,084 and 1,106 MWe for Units 1 and 2, respectively.

2.1.1 Units 1 and 2 Cooling Water System: Design and Operation

The purpose of the cooling water system is to remove waste heat, an unavoidable by-product of energy production. Diablo Canyon Power Plant utilizes an open-cycle cooling water system, whereby seawater is withdrawn from the source waterbody of the Pacific Ocean through an intake structure located in Intake Cove. Seawater is pumped through the generating unit condensers where heat exchange takes place during power generation. Circulating seawater subsequently flows through the discharge structure into Diablo Cove. Total cooling water transit time from the plant's intake to the discharge structure is approximately 5 minutes. When the

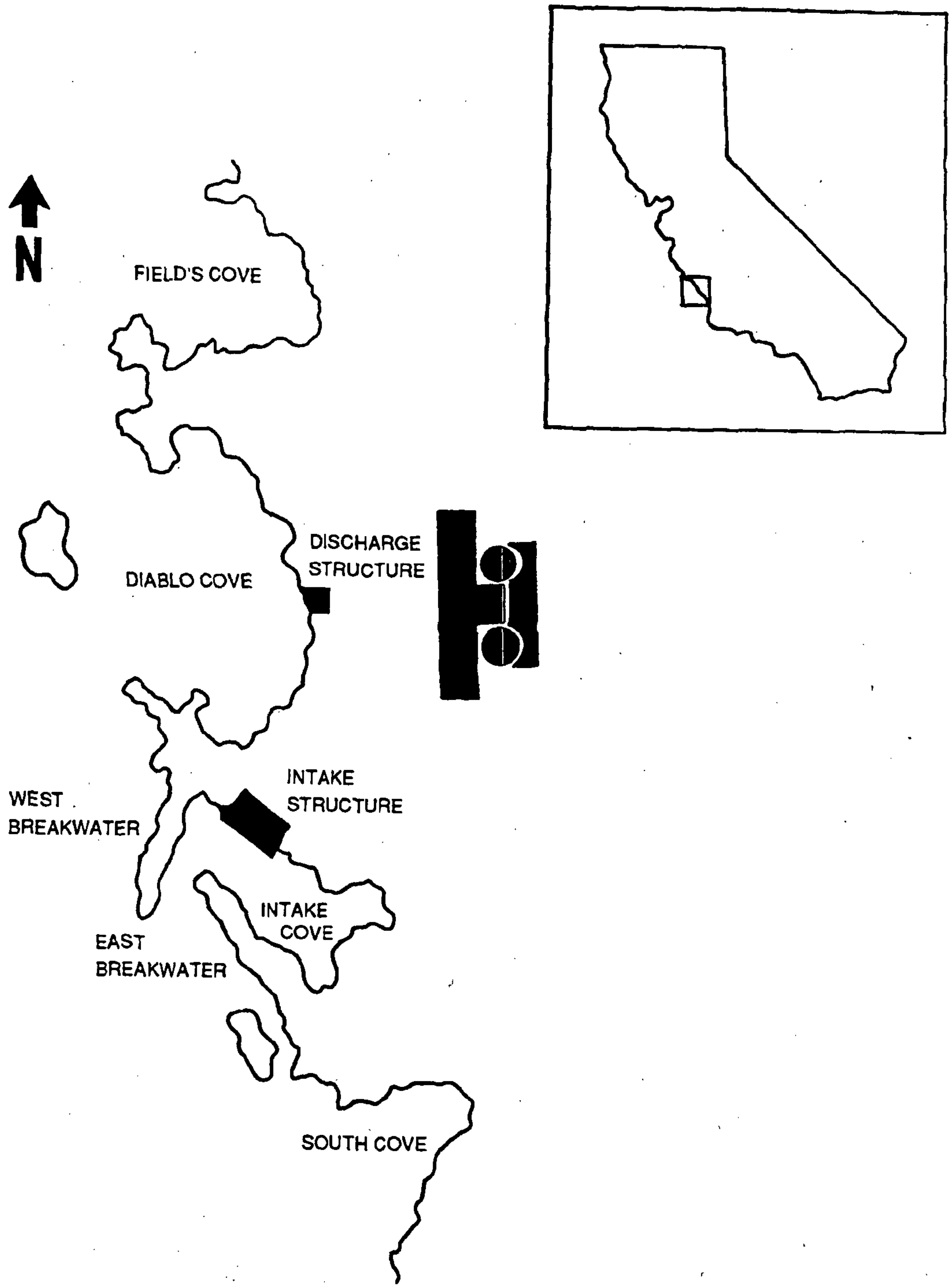


Figure 2-1

The Diablo Canyon Power Plant Site

plant is operating at full capacity, cooling water temperatures are typically elevated to a ΔT of approximately 11 C (20 F). The ΔT varies in response to unit power generation, intake water temperature, and transient plant operating conditions (e.g. heat treatments).

Cooling water for each unit is provided by means of two main circulating seawater pumps. The two units use up to 2.54 billion gallons per day (bgd) for the primary purpose of main condenser cooling. Each of the units is also equipped with a auxiliary cooling system. When the four main circulating water pumps and the four auxiliary pumps are operational, the latter system contributes approximately 1 percent of the total cooling water volume. Since the contribution is so small, the auxiliary system was not considered in characterizing entrainment and impingement losses. Diablo Canyon Power Plant circulating water conduits and the intake and discharge structures, for Units 1 and 2 are illustrated schematically in Figure 2-2. The intake structure for Units 1 and 2 is protected from turbulent Pacific Ocean waters by two breakwaters (Figure 2-2). Specifications for the major circulating water system components are presented in Table 2-1.

Intake Structure:

The shoreline intake structure for Units 1 and 2 houses the bar racks, vertical traveling screens, auxiliary cooling water systems and the main circulating water pumps. Sectional and plan views of the intake structure are shown in Figures 2-3 and 2-4. This intake configuration was designed to maximize fish avoidance and survival based on studies conducted at PG&E's Contra Costa Power Plant (Kerr 1953).

At the face of the intake structure, a concrete curtain wall extends 7.75 ft below mean sea level (MSL) to prevent floating debris from entering the structure. Seawater entering the intake structure first passes through the bar racks. These vertically inclined 3x3/8 in. flat steel bars with 3 in. centers are designed to exclude debris of moderate size. This bar rack design permits periodic mechanical cleaning with a metal trash rake.

From the bar racks, water flows into a series of pump bays, where the vertical traveling screens are housed. The screens, fabricated with 3/8-in. (0.9-cm) monel woven-wire mesh, retain smaller objects. There are seven vertical traveling screens for each unit. Six of the traveling screens filter seawater to the two main circulating water pumps and one smaller traveling screen filters seawater to the two auxiliary seawater pumps. Each of the six larger traveling screens are 10 ft wide and provide approximating 300 ft^2 of filtration area at mean sea level. The smaller traveling screen provides approximately 150 ft^2 of filtration area.

Debris, fish, and invertebrates retained by the screens are removed during periodic screen rotation and washing. Screenwashes can be initiated by timed cycles (typically every 4 hours for 15 minutes), by manual operation (typically a continuous wash which is particularly useful during periods of heavy kelp accumulation), or by

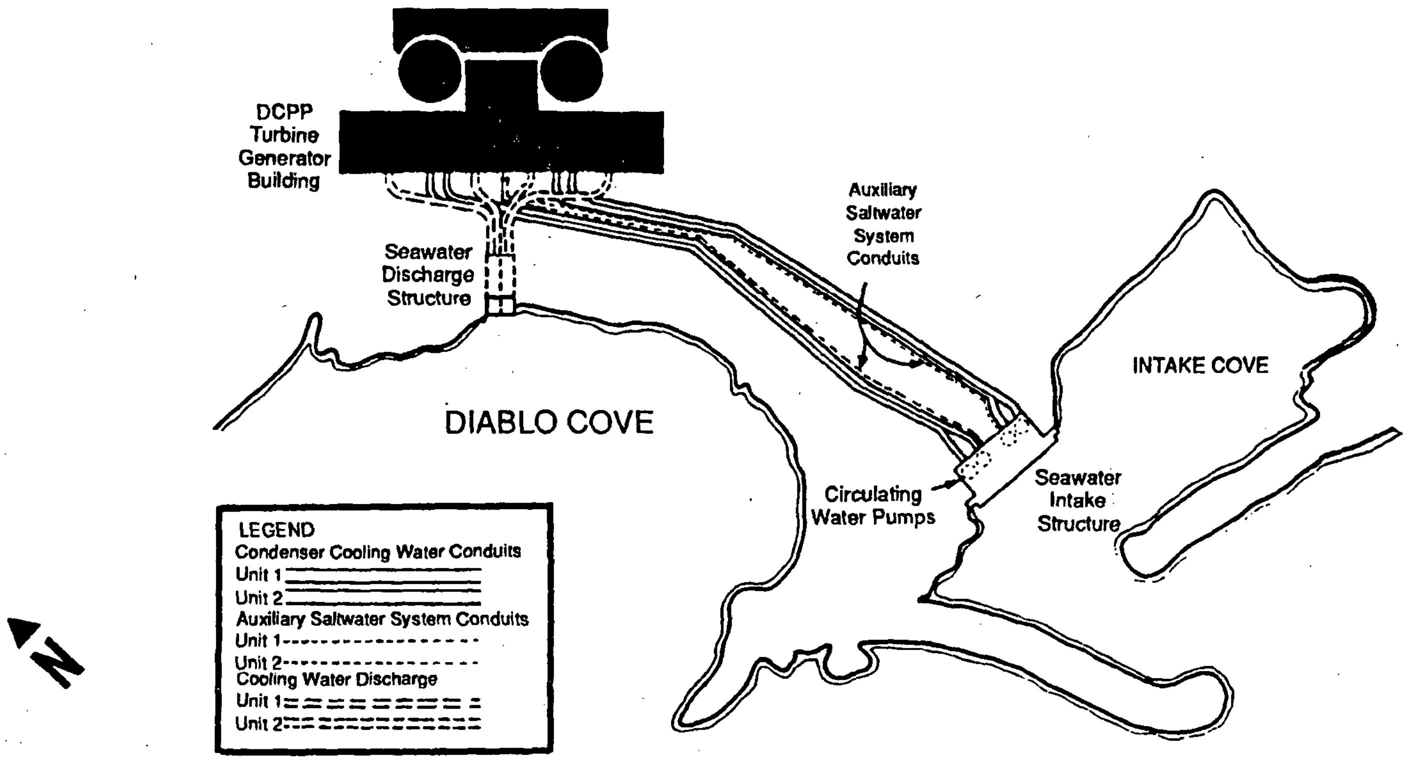


Figure 2-2

General Configuration of the Diablo Canyon Power Plant
Cooling Water System

TABLE 2-1

COOLING WATER COMPONENT SPECIFICATIONS

	Units 1 & 2 (Per Unit)
I. Main Circulating Water System	
A. Pump Bays	
Number	6
Width (ft)	10
Depth (ft)	30
B. Bar Racks	
Number	6
Spacing (in.)	3
Size (in.)	3 x 3/8
C. Traveling Screens	
Number	6
Mesh Size (in.)	3/8
Rotation (fpm)	5 or 10
Mesh panels per screen	57
D. Pumps	
1. Screenwash	
Number Unit 1:	2
Unit 2:	1
Capacity (gpm)	3,900
Pressure (psia)	95
Nozzles/screen	18
2. Circulating Water	
Number	2
Capacity (gpm)	867,000
(bgd)	*1.24
Designation Unit 1:	1-1, 1-2
Unit 2:	2-1, 2-2
E. Cooling Water Conduits	
Number	2
Cross Section (ft)	11.75 x 11.75
Transit Time (min)	5
Designation Unit 1:	1-1, 1-2
Unit 2:	2-1, 2-2
II. Auxiliary Seawater System	
A. Pump Bays	
Number	2
Width (ft)	5
Depth (ft)	30
B. Bar Racks	2
C. Traveling Screens	1
D. Circulating Water Pumps	
Number	2
Capacity (gpm)	11,000
E. Circulating Water Conduits	1
Designation Unit 1:	1
Unit 2:	2

* Maximum flow observed during the period of the entrainment and impingement monitoring programs.

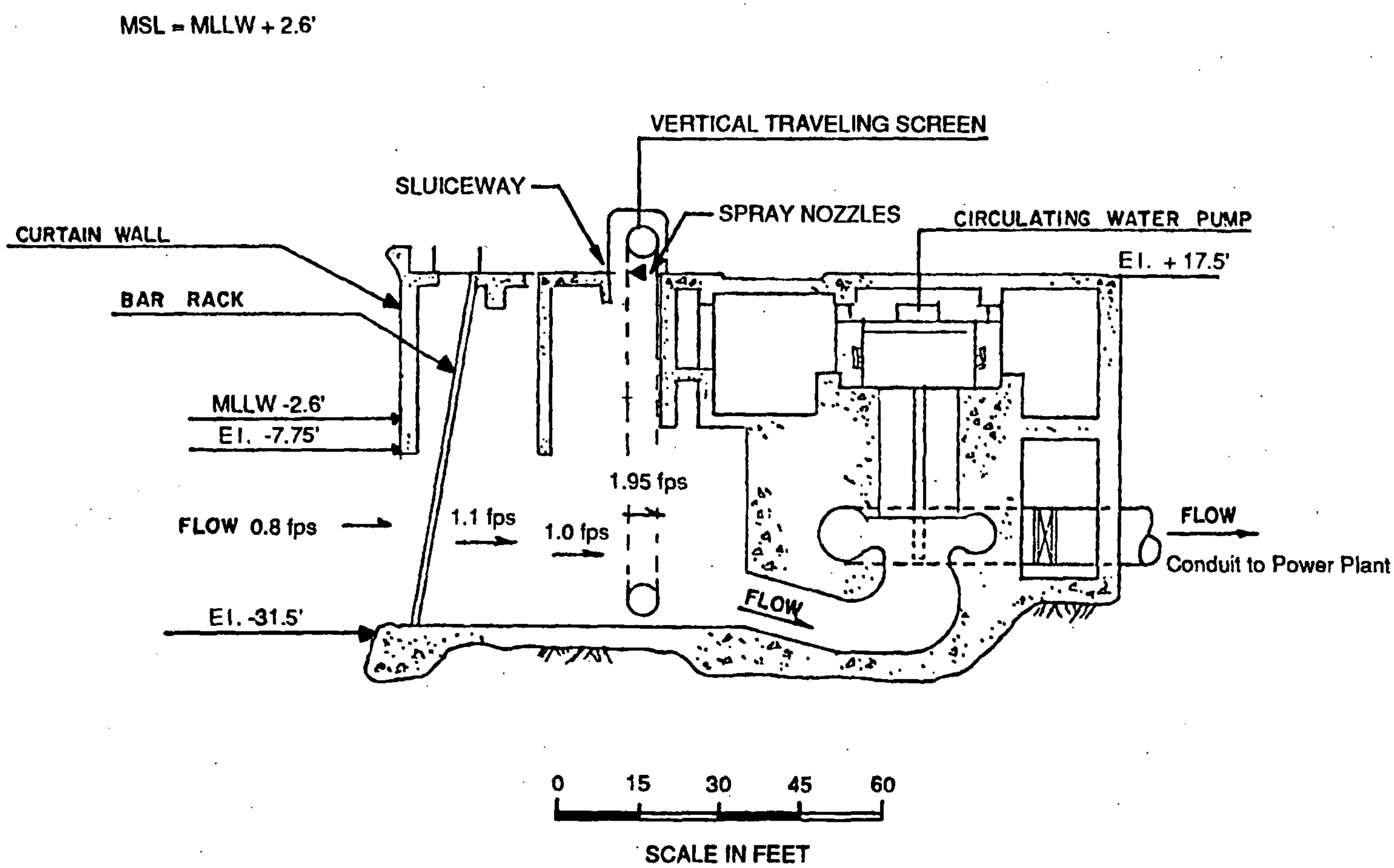


Figure 2-3

Sectional View of the Diablo Canyon Power Plant
Cooling Water Intake Structure

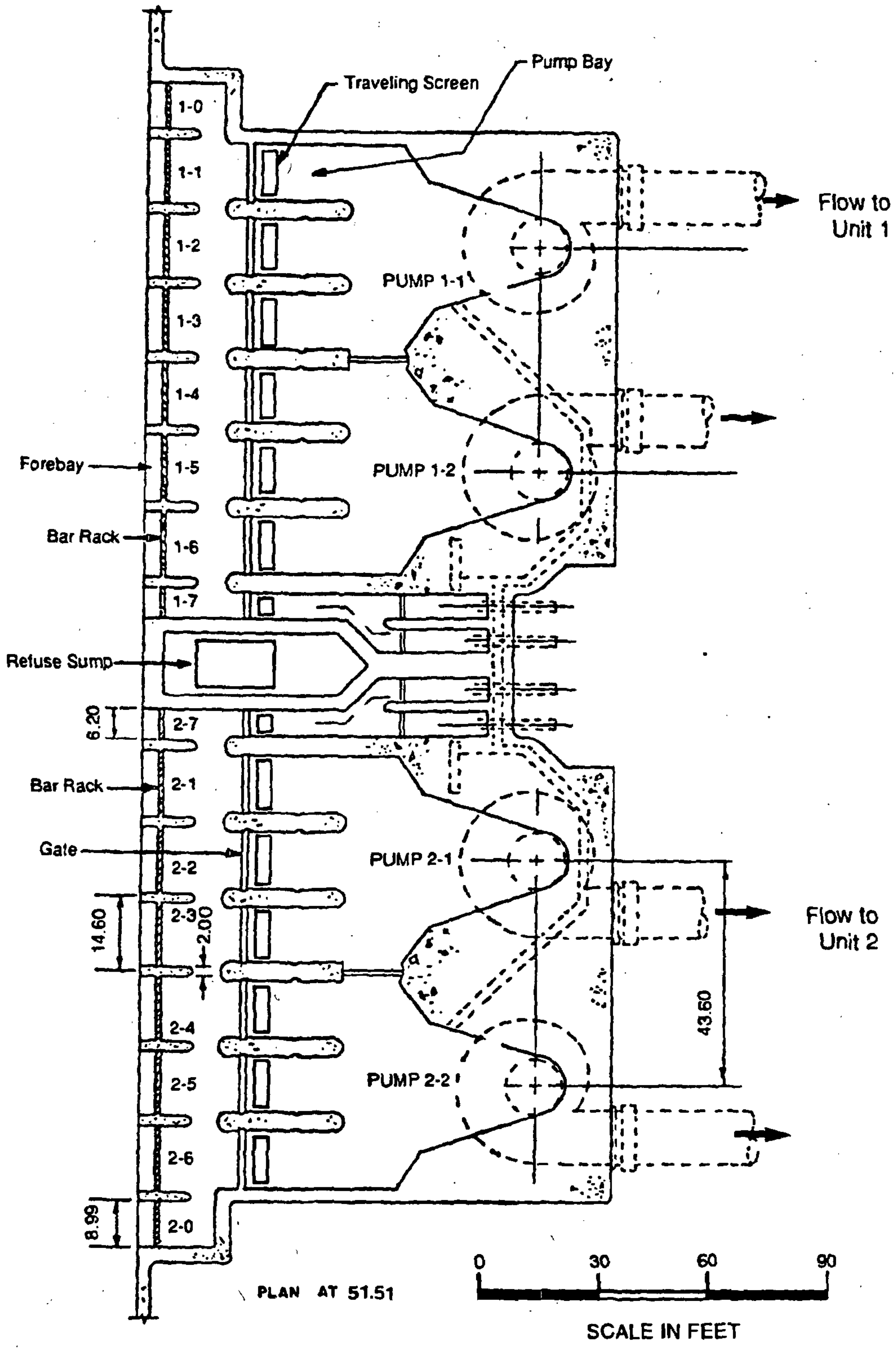


Figure 2-4

Plan View of the Diablo Canyon Power Plant
Cooling Water Intake Structure

automatic activation initiated when a water level differential of 8 in. across the intake screen occurs. The screens can be preset to rotate at a rate of either 5 or 10 ft/min, depending on debris accumulation.

During screenwashing, high-pressure spray nozzles (95 psi) wash debris and impinged organisms from the traveling screens. Debris and impinged organisms are washed from the Unit 1 and 2 traveling screens into sloping sluiceways that empty into a common refuse sump. From the refuse sump, the material can be routed to the Pacific Ocean through an 18 in. diameter pipe, or alternatively, debris can be collected in a stainless steel basket lining the refuse sump and subsequently disposed of in a landfill.

From the pump bays (Figure 2-4), water enters one of the two main circulating water pumps for each unit. The pumps are single-stage centrifugal pumps, each capable of supplying approximately 433,500 gpm at 96.5 ft of total head. The pumps are driven by 13,000-hp, 237.7-rpm motors. These pumps are not capable of variable speed operation.

There are two cooling water conduits for each unit. Cooling water routed through these conduits is provided by the associated circulating water pump. The concrete conduits are square (11.75 ft) from the intake structure (-18.0 ft elevation) to the top of the coastal bluff at an elevation of 60 ft. At this elevation, the tunnel run becomes horizontal and circular. Upstream of the pitot tap access, each conduit then becomes square once again and rises to the 63 ft elevation, where it is vented and routed toward the plant's condensers.

Seawater enters each condenser through two separate inlet water boxes (four per unit). Each condenser contains 58,126 titanium tubes, 1 in. in diameter and 40.75 ft in length. The number, small diameter and length of these tubes increase surface area and thereby promote heat transfer. Cooling water is transported from the condensers to the discharge structure through a series of conduits (Figure 2-2).

Discharge Structure:

The discharge structure contains three separate weirs (Figure 2-5). The cascading effect of the discharged circulating water promotes aeration and dissipation of hydraulic energy. The width of the discharge flow as it emerges into Diablo Cove is 27.5 ft for each unit, with the depth depending on the tide stage. Thus, the discharge may be defined as a surface jet, promoting the mixing of the thermal effluent with Diablo Cove receiving waters. The discharges for Units 1 and 2 are parallel and separated by a concrete wall. Cutouts in the wall help promote mixing of Units 1 and 2 thermal effluent.

Cooling water is pressurized from the outlet of the circulating water pumps to the discharge structure. Figure 2-6 illustrates the predicted values of cooling water pressure differentials and transit time to the discharge throttling gate for the major components of the circulating water system. Pressure increases from approximately

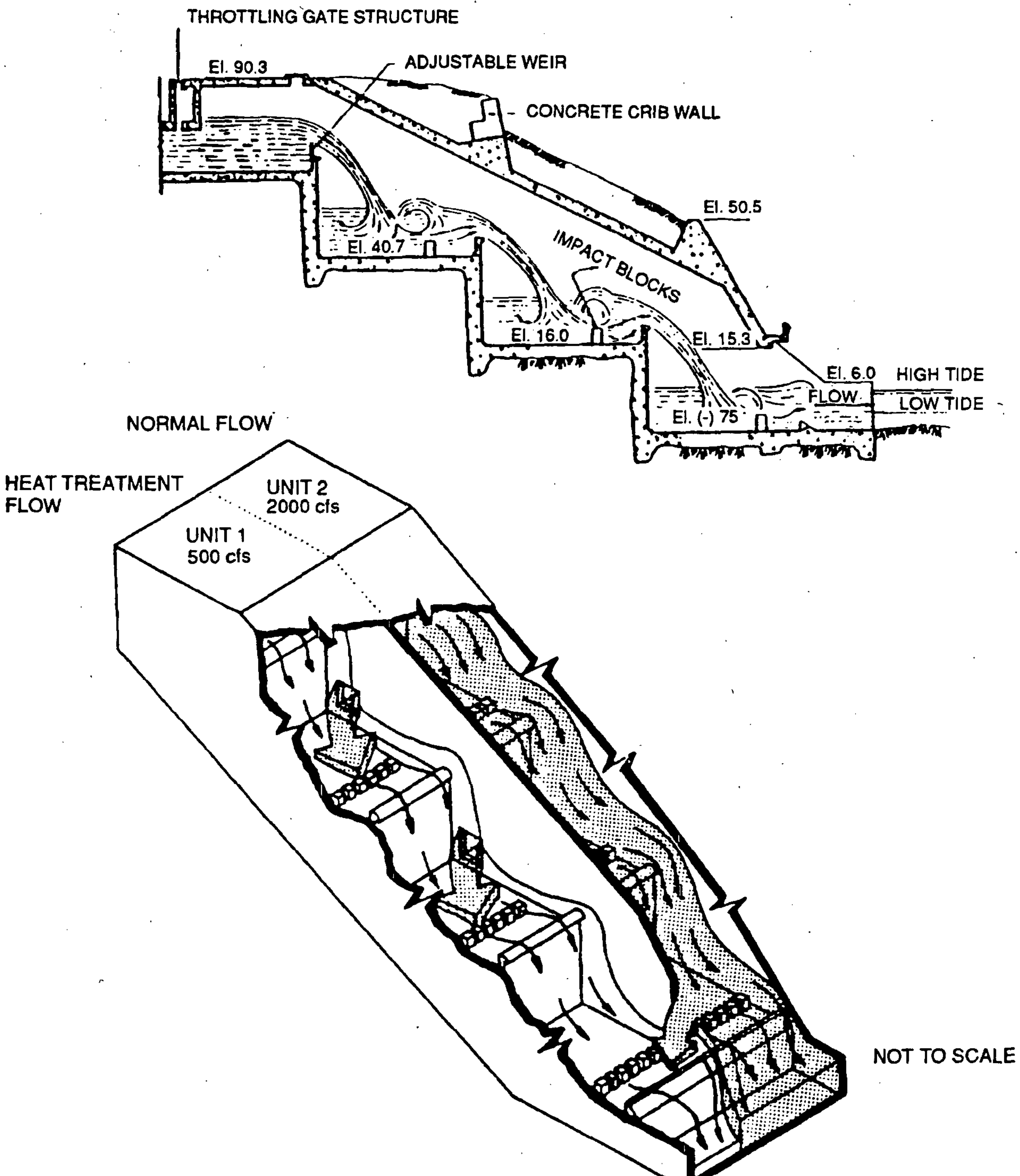


Figure 2-5

Schematic Drawing of the Diablo Canyon Power Plant
Discharge Structure Following Modifications
Completed in November 1982

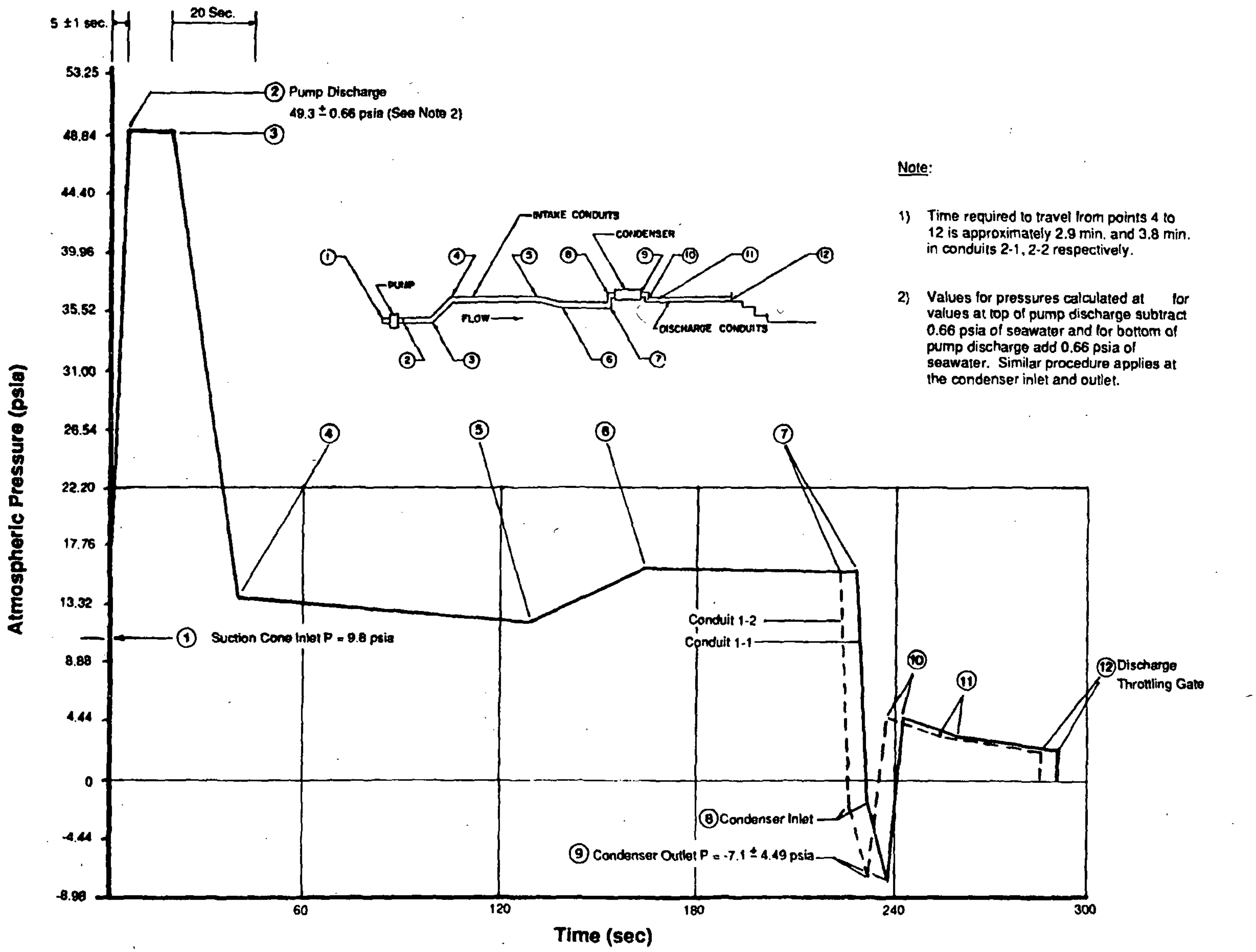


Figure 2-6

Pressure-Time Profile for the Diablo Canyon Power Plant
Cooling Water System
(Source: Wilson 1977)

24.8 psia at the pump intake to approximately 49.3 psia at the circulating pump outlet. Pressure drops through the cooling system to approximately -7.1 psia at the condenser outlet, and ultimately to atmospheric pressure at the discharge structure throttling gate.

2.1.2 Cooling Water System Maintenance Procedures

The cooling water system conduits and condenser tubes require maintenance because of fouling by macroinvertebrates and the accumulation and intrusion of slime. Operating procedures which have been implemented to maintain cooling water efficiency include chemical treatment (chlorination), heat treatment, and physical removal (conduit scraping and condenser backflushing).

Chlorination:

To help prevent condenser slime accumulation, and minimize colonization by biofouling organisms, chlorine is routinely injected into the cooling system just upstream of the circulating water pumps. During normal operation, chlorine is sequentially introduced into each circulating and auxiliary seawater pump bay for 30 minutes. Chlorination of individual condenser halves are separated by a minimum of 30 minutes.

Heat Treatment:

Heat treatments are utilized to minimize biofouling by colonizing invertebrates such as barnacles and mussels. Biofouling organisms contribute to cooling system inefficiency and increased maintenance, since the organisms can become dislodged and obstruct condenser tubes. Fouling organisms can increase frictional resistance and potentially restrict cooling water flow. Heat treatment (demusseling) exposes fouling organisms located in the intake conduits to lethal temperature doses. Demusseling requires recirculation of cooling water through a condenser to elevate temperature. The water is then routed back through the opposite condenser and its corresponding intake conduit and circulating water pump. Following heat treatment of one conduit, the process can be reversed thereby treating the opposite conduit.

From 1985 through 1987 a total of ten heat treatments were conducted according to the following schedule:

Start Date	Conduit 1-1	1-2	2-1	2-2
08/03/85	X	X		
11/11/85	X	X		
03/08/86	X	X		
08/10/86			X	X
11/08/86			X	X
05/10/87	X	X		
08/08/87	X	X		
10/17/87	X	X		
10/25/87			X	X

Physical Removal of Biofouling Organisms:

The biofouling community at the Diablo Canyon Power Plant is dominated by barnacle species whose shells remain intact on the conduit walls even after a heat treatment. Therefore, periodic scraping (physical removal) is necessary to minimize condenser tube blockage caused by the shells which ultimately slough from the conduit walls. Physical removal of biofouling organisms has been conducted once in each of the four circulating water conduits, with removal coinciding with scheduled unit refueling outages.

Kelp removal:

Due to excessive kelp buildup on the intake bar racks and vertical traveling screens, a kelp maintenance program was implemented during September 1986. The program consists of four elements: kelp harvesting, drift algal control, exclusion zone maintenance, and bar rack inspections.

Kelp harvesting is accomplished using a commercial kelp cutter to remove the upper 3 ft of surface canopy in the Intake Cove kelp bed. The kelp harvester is also utilized to collect drift kelp floating in the Intake Cove. An exclusion zone is maintained by physically removing giant kelp plants within an 80 ft x 80 ft area directly in front of the intake structure. From September 1986 (when the kelp maintenance program was first implemented) through December 1987, a total of 1,283 tons of kelp were removed from the Intake Cove utilizing kelp harvester and exclusion zone control techniques. Drift kelp accumulation on the intake bar racks is frequently observed by divers. A mechanical kelp rake can be used to remove kelp from the bar racks. Kelp accumulation on the bar racks and vertical traveling screens is particularly heavy during the late fall and early winter.

2.1.3 Plant Operations

Electrical generating load and pump operation are monitored routinely and recorded in plant operational logs. These records were used to prepare hourly, daily, and monthly averages of selected operational information. Figure 2-7 illustrates average weekly power levels and circulating water pump volume from January 1985 through December 1987.

A summary of Unit 1 and 2 outages is given in Table 2-2. Two refueling outages occurred during the three-year period from January 1985 through December 1987. Unit 1 refueling occurred from September through December 1986, and Unit 2 refueling occurred from April through mid-June 1987.

Cooling water volumes varied substantially between 1985 and 1987 (Figure 2-7). Cooling water volumes during the early part of 1985 primarily reflect operation of the Unit 1 cooling water system (maximum flow, 1.21 billion gallons per day; 4.56 million cubic meters per day). The increase in cooling water volumes to a level of approximately 2.45 billion gallons per day (9.29 million cubic meters per day) which began in July 1985 and continued intermittently through August 1986 reflects the combined flow associated with operation of Units 1 and 2. The reduction in cooling water volumes from full capacity which began in September 1986 and continued through the remainder of 1986 was the result of the Unit 1 refueling outage. The decline in cooling water volumes during the spring of 1987 was the result of the Unit 2 refueling outage.

2.1.3.1 Monitoring Procedures

Figure 2-8 illustrates weekly average intake and discharge NPDES reported temperatures from January 1, 1985 through December 31, 1987. Long-term temperature records are available for ambient water temperatures in the vicinity of the Diablo Canyon Power Plant. Figure 2-9 shows average monthly water temperatures in the area for the period from 1976 to 1987.

Velocity measurements of water approaching the intake structure were made during 1979 and 1986 by PG&E at Diablo Canyon Power Plant Units 1 and 2 (Wyman 1988). Maximum, minimum and average approach velocities were recorded at grid matrix points for each forebay. Typical approach velocity isotachs were developed for each forebay. Results indicated a high degree of variability between and within forebays. In general, however, velocities for the Unit 2 side of the intake structure were approximately 20 percent higher than those measured at the intake forebays on the Unit 1 side. The higher velocities observed on the Unit 2 side were substantiated by pump performance tests.

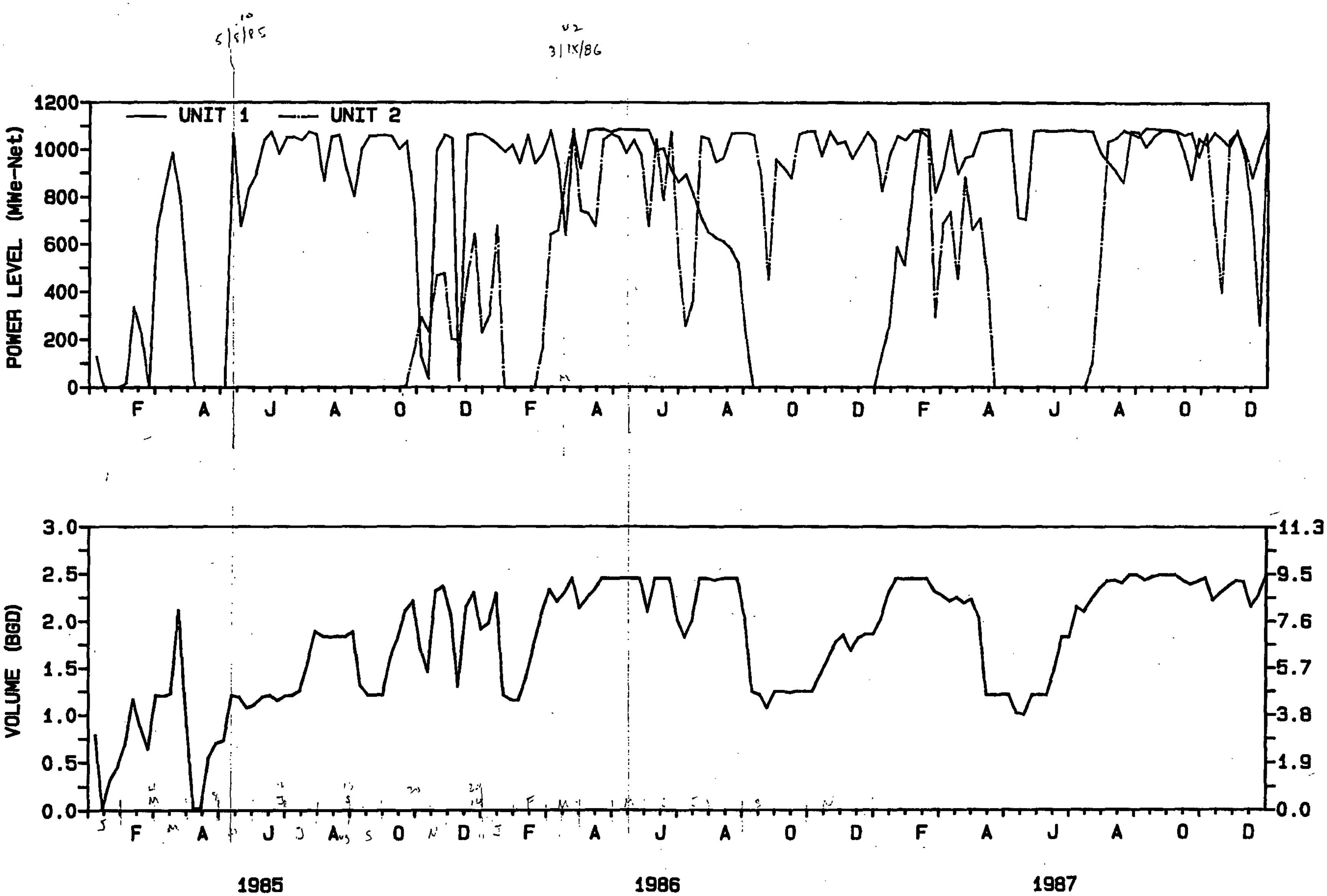


Figure 2-7

Average Weekly Power Level and Weekly Water Volume for Units 1 and 2, 1985-1987

TABLE 2-2

UNIT OUTAGES (SCHEDULED AND UNSCHEDULED) AT THE DIABLO CANYON POWER PLANT, 1985 - 1987

	Hours in Reporting Period	Unit 1 Hours	Unit 1 Percent	Unit 2 Hours	Unit 2 Percent
1985					
May	597	**51	0	*	*
June	720	0	0	*	*
July	744	0	0	*	*
August	744	20	3	*	*
September	720	0	0	*	*
October	745	65	9	*	*
November	720	241	33	*	*
December	744	151	20	*	*
1986					
January	744	0	0	*	*
February	672	0	0	*	*
March	744	57	8	**45	0
April	719	0	0	54	8
May	744	0	0	0	0
June	720	0	0	57	8
July	744	0	0	107	14
August	744	59	8	0	0
September	720	720	100	60	8
October	745	745	100	0	0
November	720	720	100	0	0
December	744	701	94	0	0

TABLE 2-2 — *Continued*

UNIT OUTAGES (SCHEDULED AND UNSCHEDULED) AT THE DIABLO CANYON POWER PLANT, 1985 - 1987

	Hours in Reporting Period	Unit 1		Unit 2	
		Hours	Percent	Hours	Percent
1987					
January	744	126	17	0	0
February	672	46	7	105	16
March	744	216	29	216	29
April	719	0	0	647	90
May	744	62	8	744	100
June	720	0	0	720	100
July	744	0	0	416	56
August	744	0	0	0	0
September	720	0	0	0	0
October	745	0	0	0	0
November	720	0	0	158	22
December	744	147	20	0	0

* - Pre-Operational

** - Commercial Operation: Unit 1 commenced May 7, 1985.
Unit 2 commenced March 13, 1986.

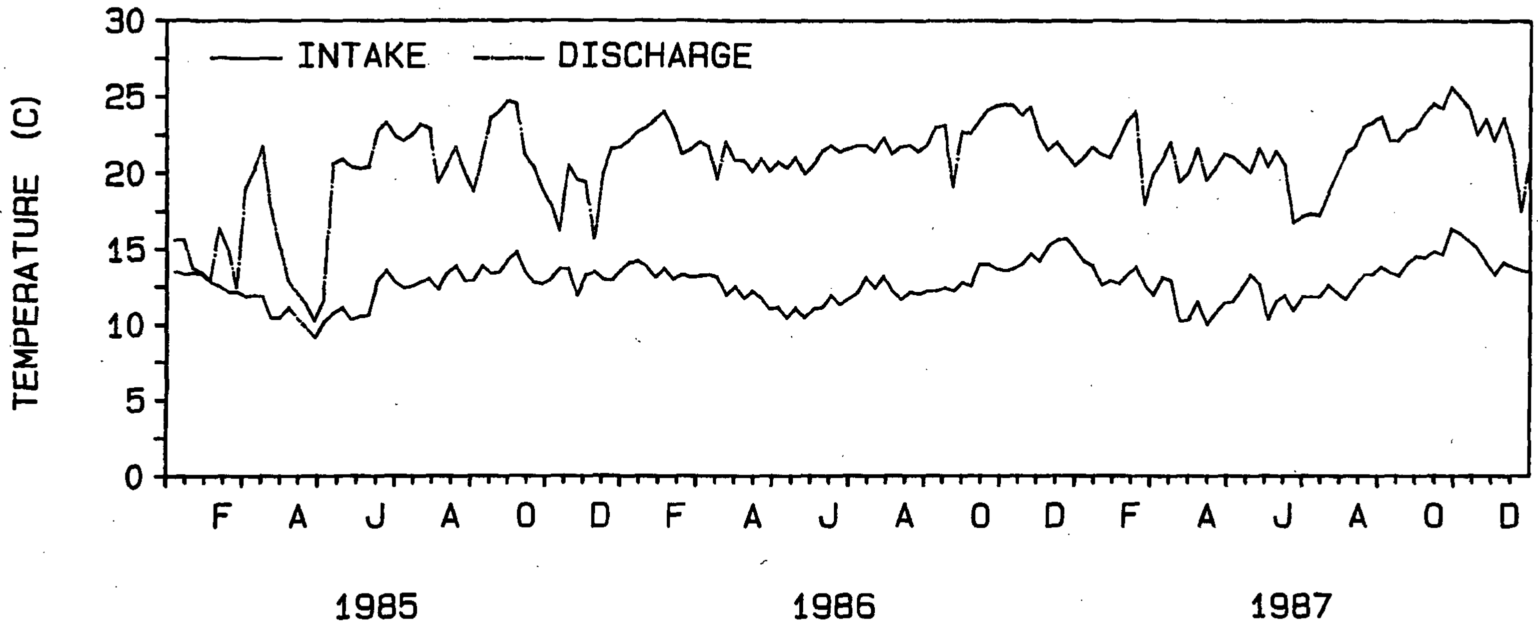
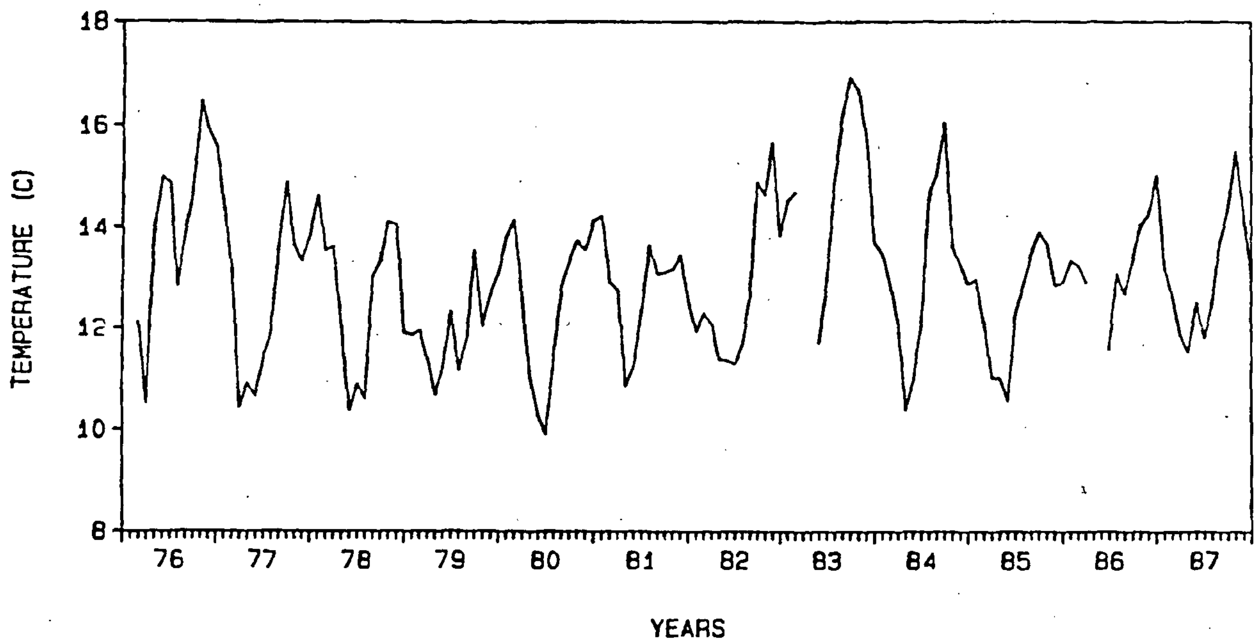


Figure 2-8

Weekly Mean Intake and Discharge Temperatures
for Unit 1 and 2 Combined, 1985-1987



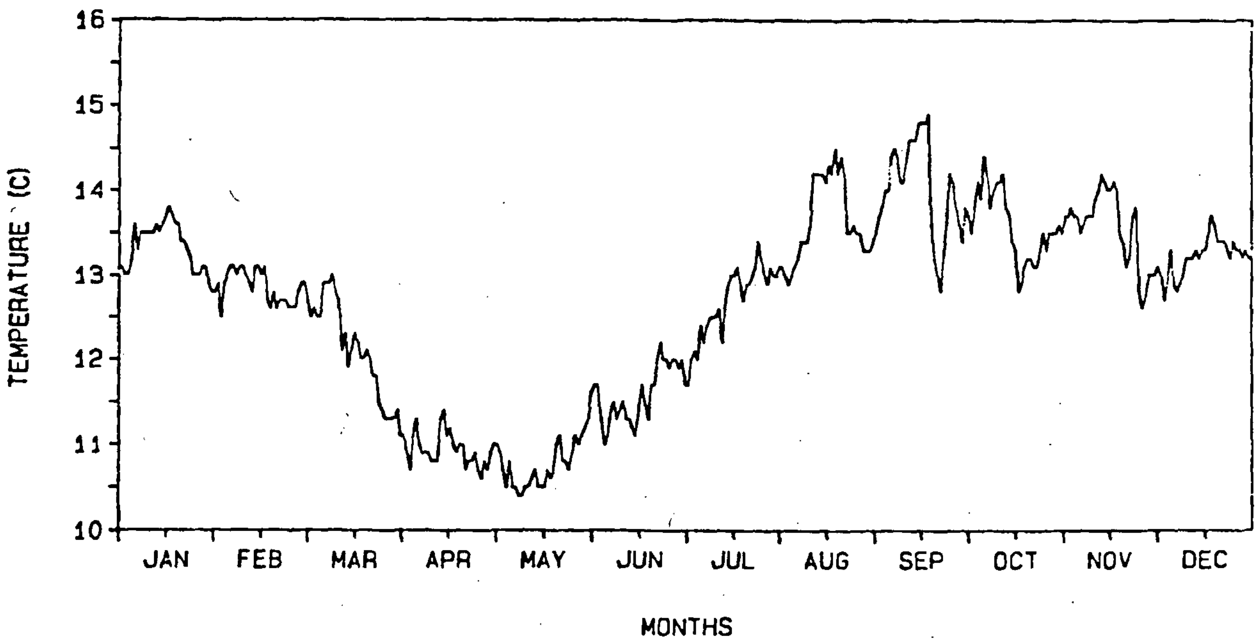


Figure 2-9

Monthly Mean (1976-1987)
and Daily Long-Term Mean (1977-1986)
of Ambient Seawater Temperatures

2.2 Physical, Chemical, and Biological Characteristics of the Source Waterbody

The shoreline near the Diablo Canyon Power Plant is characterized by sheer, wave-eroded cliffs, jutting headlands, and massive offshore rocks and reefs. These topographical features form a highly irregular coastline, which provide many different exposed and protected habitats for marine organisms. The shoreline in the vicinity of the plant is a series of semi-protected indentations composed of three identifiable coves from north to south, referred to as Field's, Diablo, and South Cove, respectively. To accommodate the cooling seawater intake structure, two breakwaters were built to provide a protected Intake Cove (Figure 2-2).

Aside from the topographical features of the coastline, several other factors affect the biological community in the immediate vicinity of the plant. Some of these natural factors include oceanographic seasons, current patterns, and tidal flow, as well as seasonal fluctuations in salinity, dissolved oxygen concentration, and temperature.

2.2.1 Hydrology

The source waterbody in the vicinity of the plant consists of oceanic waters from the nearshore coastal region moving into the Intake Cove. The origin of the source water is determined by factors such as oceanographic seasons, offshore and nearshore currents, global climatic events, and tidal flow.

The oceanographic seasons along the central California coast are the upwelling period (mid-February through July), oceanic season (end of July through mid-November), and the Davidson period (mid-November through mid-February). During the upwelling period nearshore surface waters are moved offshore and replaced by colder, nutrient-rich bottom waters. Lower surface temperatures and higher dissolved oxygen concentrations prevail during upwelling periods. During the oceanic season, salinities are slightly lower and water temperatures are more stratified, influenced by the cool southerly flow of the California current. In late summer or early fall, the northward flowing Davidson current develops inshore of the California current, creating a warming trend along the coast. The Davidson period is characterized by rising seawater temperatures that are uniform throughout the water column and by lower dissolved oxygen concentrations. Changing physical and water quality parameters indicative of the seasonal aspects of the source waterbody, affect the abundance and species composition of the biological community near the plant.

Offshore and nearshore currents affect abundance and distribution of organisms in the source waterbody. The major offshore currents along the Pacific Coast belong to the California current system. The California current and the Davidson counter-current are the predominant flow patterns in the system. During the oceanic period, the California current dominates and the flow is northeast to southwest. The Davidson period is characterized by southwest to northeast flow. The dominant current direction becomes variable with the onset of the upwelling periods. The California current system operates well offshore. Nearshore currents are much more variable and may be affected by eddies formed by coastal topography, winds, and tides. The nearshore current regime is not only variable, but also extremely complex, as documented by the drogue data collected in oceanographic studies conducted at the Diablo Canyon Power Plant. Current meter measurements conducted from June 1979 through June 1984 just off Diablo Cove indicate typical nearshore current flow rates of 0.3 knots southeasterly in February through June (upwelling period), 0.2 knots northwesterly in the fall (oceanic period) and transitional currents (varying directions) of about 0.2 knots in the late summer and mid-winter. Current direction and speed can have a direct effect on the distribution of planktonic larval fish and macroinvertebrates susceptible to entrainment. This concept is discussed further on a species-specific basis in Chapter 5 and Appendix C.

Oceanic seasons and current direction are sometimes affected by climatic events such as the El Niño event. This particular phenomenon, characterized by a drop-off in upwelling, has been observed twice between 1974 and 1987, occurring in 1976 and 1983. Measurable changes in current patterns and temperatures induced by El Niño events allow the immigration of warm-water fish and invertebrate species into the Diablo Cove area. Residual ecological effects of the 1983 El Niño event are still observable in Diablo Cove, but have generally disappeared from surrounding areas (PG&E 1988).

2.2.2 Morphology

The central California coast is relatively straight and uninterrupted from Monterey to Point Conception. Point Conception (located approximately 50 nautical miles from the Diablo Canyon Power Plant) provides a major geographical boundary and coastline configuration becomes east/west rather than north/south. Point Conception also provides an ecological boundary for many California marine species.

The central California shoreline is highly variable, ranging from jetting headlands (Pt. Buchon) and steep sea cliffs to long, sandy beaches (Pismo Beach). Points Estero, Buchon, San Luis, and Sal are prominent headlands located near the Diablo Canyon Power Plant. Point Estero and Point Buchon are located approximately 16 and 3.5 nautical miles, respectively, to the north of the power plant. These two points provide the northern and southern boundaries of Estero Bay. Montana de Oro State Park and the Morro Bay tidal estuary are both located within Estero Bay. San Luis Obispo Bay is a relatively shallow, coastal embayment located to the south of the Diablo Canyon Power Plant. It is bounded to the north by Pt. San Luis and to the south by Pt. Sal. These two points are approximately 7 and 15 nautical miles, respectively, south of the power plant. In general, the area from Port San Luis north to Montana de Oro can be characterized as having a highly irregular rocky shoreline. Offshore, to approximately the 10 fathom contour the bottom is characterized by high relief, rocky bottom with numerous pinnacles. To the south (Pt. San Luis) and north (Montana de Oro), extensive areas of sandy beach shorelines and gradually sloping bottoms characterize the coastal embayments of San Luis Obispo Bay and Estero Bay. Offshore, the subtidal benthic substratum is typically of high relief varying with depth and distance from shore. The substratum can exhibit considerable spatial variability depending on local bathymetry.

Strong wave action and persistent longshore currents combine with a varied bottom topography to produce a very dynamic and complex, nearshore habitat in the vicinity of the Diablo Canyon Power Plant. Open coast exposure and north Pacific Ocean swells combine with a convoluted shoreline to produce a high energy impacted coastline. Inlets and indentations in the coastline occasionally have cobble or coarse gravel beaches, and deeper coves generally have a small sandy beach. Bottom topography in depths less than 60 ft is irregular, with numerous rock outcroppings and pinnacles ranging from 9 to 36 ft in height. Sedimentary deposits are scarce in water less than 45 ft deep.

2.2.3 Water Quality

The marine environment in the area of the plant is affected by seasonal changes in water temperature, salinity, and dissolved oxygen concentration. These parameters can influence species composition and abundance of marine biota in the area. The variations in temperature, salinity, and dissolved oxygen correspond to the generalized water quality characteristics of the oceanographic seasons off the central California coast.

Water temperatures in the vicinity of the Diablo Canyon Power Plant are strongly influenced by seasonal shifts in major ocean currents. Ambient water temperatures at the Diablo Canyon site were measured between 1976 and 1987. Average weekly temperatures recorded during this period ranged from 9.9 to 16.9 C. Figure 2-9 illustrates the seasonal and annual fluctuations in ambient average monthly ocean water temperatures from 1976 through 1987 in the immediate vicinity of the power plant.

Salinities recorded in the vicinity of the plant also reflect the oceanographic seasons. Salinities are higher during the summer months (mean monthly values 34.1 ppt) compared with the winter months (February mean monthly value 32.8 ppt). Data collected offshore from the plant is typically in the range of 34 - 35 ppt.

Dissolved oxygen measurements are conducted by PG&E's Technical and Ecological Services Department (TES) during February, June and October of each year in compliance with NPDES permit requirements. Dissolved oxygen measurements were also routinely collected in the Intake Cove during selected entrainment and impingement sampling efforts. Figure 2-10 illustrates the dissolved oxygen measurements observed during February 1985 through December 1986 at the Diablo Canyon cooling water intake.

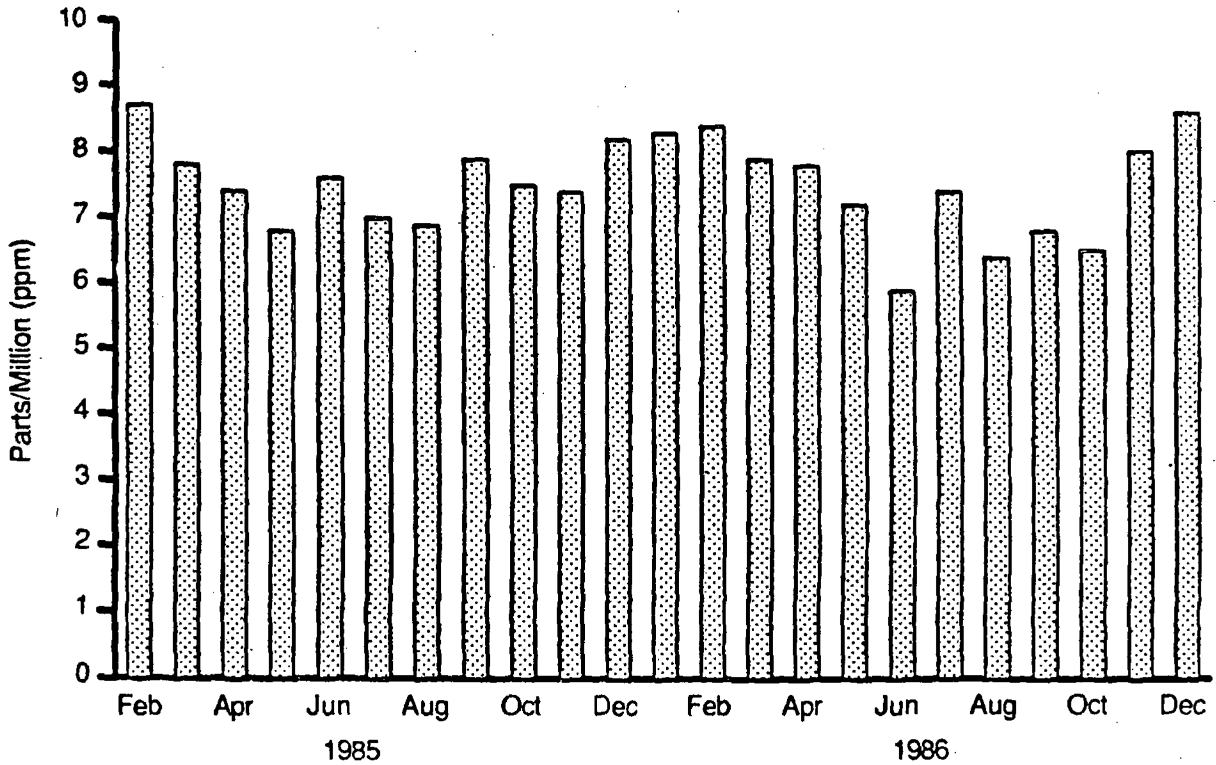


Figure 2-10

Average Monthly Dissolved Oxygen Concentrations Measured
at the Diablo Canyon Power Plant Intake Cove,
February 1985 - December 1986

2.2.4 Marine Habitats

This section presents a description of various marine habitats present along the central California coast, with emphasis on the vicinity of the Diablo Canyon Power Plant. Cooling water is drawn from the nearby marine inshore environment. This environment includes a variety of intertidal, subtidal, and pelagic habitats for marine flora and fauna. The following sections briefly describe these habitats and present a brief inventory of their biological communities. Species presented throughout this section are intended to provide examples of those organisms likely to be entrained and/or impinged at the Diablo Canyon Power Plant, and are not intended to be all inclusive. Intertidal and subtidal communities are further described in the Thermal Effects Monitoring Program Final Report (PG&E 1988).

2.2.4.1 Intertidal Habitats

The intertidal habitats of the power plant vicinity are generally characterized by cobble beaches and irregular rock cliffs and outcroppings. Although some areas are relatively protected from wave exposure, most are not. Hence, almost all of the resident organisms are typical of exposed rocky coasts (Ricketts and Calvin 1968).

The plant communities are dominated by foliose red algae (*Iridaea flaccida, Gigartina canaliculata* and *Gastroclonium coulteri*), encrusting red algae (*Lithothamnium* sp. and *Petrocelis franciscana*), coralline red algae (*Corallina* spp.), green algae (*Ulva lobata*), brown algae (*Pelvetia fastigiata*), and flowering surf grass (*Phyllospadix scouleri*).

Most of the invertebrate species in these habitats are herbivores that graze on the abundant intertidal vegetation. These include black abalone (*Haliotis cracherodii*), snails (*Tegula funebralis*), limpets (*Collisella scabra, Notoacmaea scutum,* and *Fissurella volcano*), chitons (*Mopalia* spp. and *Nuttalina californica*), crabs (*Pachygrapsus crassipes, Pugettia richii, Pachycheles pubescens*), and purple sea urchins (*Strongylocentrotus purpuratus*). Predatory invertebrates such as whelks (*Kelletia kelletii*), octopi (*Octopus* spp.), and seastars (*Pisaster ochraceus* and *Leptasterias* spp.) are also common. Sessile, filter feeding invertebrates such as barnacles (*Balanus* spp. and *Tetraclita squamosa*), and mussels (*Mytilus californianus*) are found in considerable concentrations in areas subject to extensive surf pounding.

The most common fishes found in intertidal habitats are sculpins (*Oligocottus* spp. and *Artedius* spp.), gunnels and pricklebacks (*Ulvicola santaerosae, Xerepes fucorum,* and *Xiphister* spp.) and clinids (*Gibbonsia* spp.). Marine mammals such as sea lions *Zalophus californianus*), harbor seals (*Phoca vitulina*), and elephant seals (*Mirounga angustirostris*) haul-out and rest in some areas near the power plant intake and discharge structures. Birds including the black oystercatcher (*Haematopus bachmani*), black turnstone (*Arenaria melanocephal*a), whimbrel (*Numenius phaeopsus*), and several species of gulls (*Larus occidentails* and *L. californicus*) actively forage on invertebrates and fish in this habitat.

2.2.4.2 Subtidal Habitats

The subtidal habitats are generally characterized by boulders and rocky pinnacles. There are also some areas of shifting cobble and one area of sand. The subtidal habitats in the vicinity of Diablo Canyon Power Plant support rich and diverse communities of plants and animals.

The plant communities are dominated by foliose red algae (*Botryoglossum farlowianum* and *Gigartina papillata*), erect coralline algae (*Calliarthron* spp.), large brown, canopy-forming algae (*Nereocystis luetkeana*), and smaller understory brown algae (*Laminaria dentigera* and *Pterygophora california*).

Conspicuous invertebrates include sponges (*Tethya aurantia* and *Leucosolenia eleanor*), sea anemones (*Anthopleura xanthogrammica* and *Corynactis californica*), chitons (*Tonicella lineata* and *Cryptochiton stelleri*), nudibranchs (*Doriopsilla albopunctata, Anisodoris nobili* and *Flabellinopsis iodinea*), snails (*Astraea gibberosa, Mitra idae*, and *Tegula brunnea*), red abalone (*Haliotis rufescens*), crabs (*Cancer antennarius, Pugettia producta*, and *Scyra acutifrons*), red sea urchins (*Strongylocentrotus franciscanus*), sea stars (*Patiria miniata, Henricia leviuscula*, and *Pisaster giganteus*), and tunicates (*Styela montereyensis* and *Pyura haustor*).

Common fish in these subtidal habitats include rockfish (*Sebastes serranoides, S. flavidus*, and *S. mystinus*), surfperch (*Embiotoca jacksoni, E. lateralis*, and *Brachyistius frenatus*), clinids (*Gibbonsia montereyensis* and *G. metzi*), cottids (*Scorpaenichthys marmoratus* and *Orthonopias triacis*), lingcod (*Ophiodon elongatus*) and flatfish (*Pleuronichthys coenosus* and *Citharichthys stigmaeus*), among others.

The most common marine mammals found here are the California sea lion (*Zalophus californianus*), harbor seal (*Phoca vitulina*) and the southern sea otter (*Enhydra lutris*). Sea otters are commonly observed rafting and foraging in nearshore coastal areas including Intake Cove. They feed on a variety of organisms, with abalone and sea urchins among their preferred prey.

2.2.4.3 Pelagic Habitat

Pelagic organisms found in the vicinity the of Diablo Canyon Power Plant are typical of similar habitats along the Pacific Coast between Point Conception and Washington. They consist of very small, free-floating plants (phytoplankton) and animals (zooplankton) as well as larger swimming animals (fish and marine mammals).

The major constituents of the phytoplankton are diatoms, dinoflagellates and coccolithophores. Marine phytoplankton also includes reproductive stages of the larger red and brown algae. Zooplankton includes representatives from virtually every group of marine invertebrates and fish, either as adults or as developmental stages. Common constituents of the zooplankton are copepods (*Calanus pacificus,* *Microstella* spp., and *Coryaeus* spp.), mysids (*Neomysis* spp. and *Holmesimysis sculpta*), cumaceans (*Cumella* spp. and *Cyclaspsis* spp.), amphipods (*Jassa falcata* and *Caprella* spp.), and salps (*Thetys* spp.). The larval stages of other species in the zooplankton, include barnacles (cirripedia), bryozoans (cyphonautes), crabs (Cancridae zoea), shrimp (Crangonidae zoea), snails (gastropod veligers), squid (*Loligo opalescens* larvae) and fish (ichthyoplankton).

Pelagic fish of central California coastal waters are characteristic of the general fish fauna found along the Pacific Coast from Baja California to Alaska. The major groups of pelagic fish present in coastal water are the anchovies, silversides, smelt, salmon, seabass, sharks, and rays (Hart 1973). Flatfish (including English sole, rex sole, and petrale sole), lingcod, and rockfish are important commercial fish in the central coast area (McAllister 1975, 1976). The most important rockfish species of commercial importance are the bocaccio, canary, and chilipepper (Krammer and Smith 1971). Rockfish, lingcod, California halibut, salmon and albacore are also important sportfish species in the central California coast area.

Others vertebrates found in the pelagic habitat are marine mammals such as porpoises (*Phocoenoides dalli* and *Phocoena phocoena*), and California grey whales (*Eschrichtius robustus*). Many grey whales are sighted from the Diablo Canyon Power Plant each year during their annual migrations. Sea birds such as shearwaters (*Puffinus griseus*), brown pelicans (*Pelecanus occidentalis*), cormorants (*Phalacrocorax auritus* and *P. penicillatus*), gulls (*Larus occidentalis* and *L. californicus*) and alcids (*Uria aalgae*) are also present.

2.2.5 Fisheries Surveys in the Vicinity of the Diablo Canyon Power Plant

A number of biological surveys have been conducted in the vicinity of the Diablo Canyon Power Plant since 1966. Table 2-3 summarizes selected marine environmental studies which have been conducted at the Diablo Canyon Power Plant. This section provides a brief summary of surveys and related data sources which have been used to help characterize potential impacts associated with the cooling water system as a result of impingement and entrainment.

Intertidal and Subtidal Surveys

An extensive biological sampling program designed to document seasonal abundances of nearshore fish and invertebrate species has been ongoing since 1976, conducted jointly by PG&E and TENERA. Biologists have observed and censused fish on a bi-monthly basis in permanently marked areas in and near Diablo Cove, and have tracked the year-to-year changes in adult fish populations and the recruitment of juveniles. These data include information not only on the species of commercial value (e.g. rockfishes and lingcod), but also on the many other, equally important, fish species which comprise the fish fauna in the vicinity of the power plant. Another concurrent fish sampling program was aimed mainly at the small but abundant intertidal fishes common along the rocky shoreline. These fish are

Table 2-3

Diablo Canyon Power Plant Marine Environmental Studies

Program Title	Year	Description	Conducting Organization	Selected References
		Field Biological Monitoring		
Preliminary Baseline Study of Diablo Cove	1969–1971	General quantitative and qualitative species inventory with emphasis on abalones, fishes, and bull kelp; extensive fish collections; intake cofferdam investigations.	CDF&G	Burge and Schultz (1973)
Zooplankton Studies	1972–1973	Weekly zooplankton tows to establish baseline data on zooplankton composition and abundance.	PG&E	Icanberry et al. (1978) Wilson (1978)
Pre-operational Baseline Studies of Selected Marine Plants and Animals	1973–1982	Quantitative quarterly sampling at random subtidal and intertidal locations and permanent abalone transects; algal biomass, baited station fish counts, bull kelp counts.	CDF&G	Gotshall et al. (1984, 1986)
316(a) Demonstration	1976–1982	Quantitative bimonthly sampling of permanent intertidal and subtidal stations; Other tasks: quantitative fish observations, algal biomass, settling plates, rock crab population studies, subtidal and intertidal photography, fish gut analysis.	Lockheed/ TERA/ Kaiser Engineers	LCMR (1978) PG&E (1978, 1979)
Thermal Effects Monitoring Program (TEMP)	1983–1987	Continuation of quantitative bimonthly sampling as per 316(a); annual bull kelp census, intertidal algal biomass studies, subtidal video transects, red and black abalone census.	TERA/ Kaiser Engineers	PG&E (1986b)
Intertidal Fish Survey	1979–1987	Quantitative survey of intertidal fishes in Diablo Cove at permanent vertical transects; concurrent algal and invertebrate data.	PG&E	Pimentel and Bowker (1984)
Fisheries Investigations	1978–1987	Underwater fish tagging, blue rockfish tagging, partyboat sportfishing sampling.	PG&E	Gibbs and Sommerville (1987)
Diablo Canyon Artificial Reef Project	1984–1986	Monitoring of biotic development of artificial reef (SLOCAR) with emphasis on young rockfish.	PG&E	Krenn and Wilson (1986)
		Laboratory Experimental Studies		
Thermal Effects Laboratory Experiments	1978–1980	Heat tolerance experiments on 45 species of fishes, invertebrates, and seaweeds; effects of temperature on growth and early development of 16 species; behavioral responses to elevated temperatures	Lockheed/ TERA/ Kaiser Engineers	PG&E (1983)
Heat Treatment Laboratory Experiments	1982	Exposure of 34 species of fishes, invertebrates, and seaweeds to temperatures simulating field conditions under power plant heat treatment.	TERA	PG&E (1985)
Chlorination Experiments	1977	Effects of chlorine residuals on selected indigenous marine animals.	PG&E	Wilson (1978), Behrens (1978)
NPDES Bioassay Experiments	1976–1987	Toxicity bioassay studies on organisms using discharged seawater from power plant.	PG&E	Behrens (1982)

Table 2-3 — *Continued*

Program Title	Year	Description	Conducting Organization	Selected References
		Physical Monitoring		
Physical Oceanography	1966–1985	Studies on nearshore currents, temperature and salinity relationships, and dissolved oxygen.	PG&E	White (1986)
Temperature and Light Monitoring	1976–1987	Continuous recording of temperatures at permanent intertidal and subtidal locations; light and tide measurements at selected subtidal stations in Diablo Cove.	Lockheed/ TERA/ Kaiser Engineers	PG&E (1986a, 1986b, 1987)
Offshore Current Monitoring	1978–1986	Continuous current measurement at a permanent station outside of Diablo Cove.	ECOMAR	Meek (1983)
Intake Approach Water Velocity Measurements	1979, 1986	Measurements of intake approach velocities made in 1979 and 1986.	PG&E	Wyman (1988)
		Predictive Analyses and Models		
Assessment of Alternatives to the Existing Cooling Water System. Diablo Canyon Power Plant.	1982	Alternative designs and their cost-benefit analyses for the DCPP cooling water system and its effects on the marine biota.	TERA/ Kaiser Engineers	PG&E (1982c)

normally found beneath rocks during low tide periods, and have been censused quarterly in Diablo Cove and the adjacent area since 1979.

Crab and Abalone Surveys

In addition to general surveys of the intertidal and subtidal biological communities, specialized research programs were directed at several species of commercial fishery value, including rock crabs and abalones. Rock crabs, primarily *Cancer antennarius*, were trapped on bi-monthly schedule, and data were collected on the size, weight, sex, and reproductive condition of each crab. In addition, individual crabs (over 15,000 during the 12-year study) were tagged and released so that information on their growth and movement could be obtained. Red and black abalone were censused annually in Diablo Cove, yielding estimates of their local population abundances.

Plankton Surveys

Physical, chemical, biological, and meteorological studies have been conducted by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) off the coast of California for the past 37 years. The basic station plan utilized by the CalCOFI during their quarterly cruises is illustrated in Figure 2-11. The inshore stations (50-60) along station lines 73 and 77 are nearest to the Diablo Canyon Power Plant. Selected biological and physical plankton tow data were obtained for the period 1951-1986.

To augment the Diablo Canyon Power Plant entrainment sampling program, weekly plankton tows were conducted from April 1986 through September 1987 in the Intake Cove and 1/2 mile offshore during morning and evening hours. Sampling methodology was consistent with earlier plankton tows conducted in the vicinity of the Diablo Canyon Power Plant (Icanberry et al. 1978). Both surveys were approximately 15 months in duration. Results from the two plankton tow programs combined with the CalCOFI data were used to characterize the assemblage of ichthyoplankton in nearshore coastal waters and provide support for estimating potential population impacts resulting from entrainment.

Commercial and Partyboat Fishery Surveys

Partyboat sampling has been an ongoing program conducted by PG&E since 1980 to assess the catch success, species and size composition of fish caught by recreational anglers. The current sampling is conducted from Point Sal to Morro Bay to document trends in catch-per-unit-effort, as well as size class and species composition of fishes caught from commercial recreational fishing vessels.

Information collected from the PG&E partyboat sampling effort was used in combination with California Department of Fish and Game (CDF&G) commercial and partyboat landings to help characterize local fish. CDF&G landing data for the period 1975 - 1985 was analyzed by catch block (10 square mile coastal areas) to

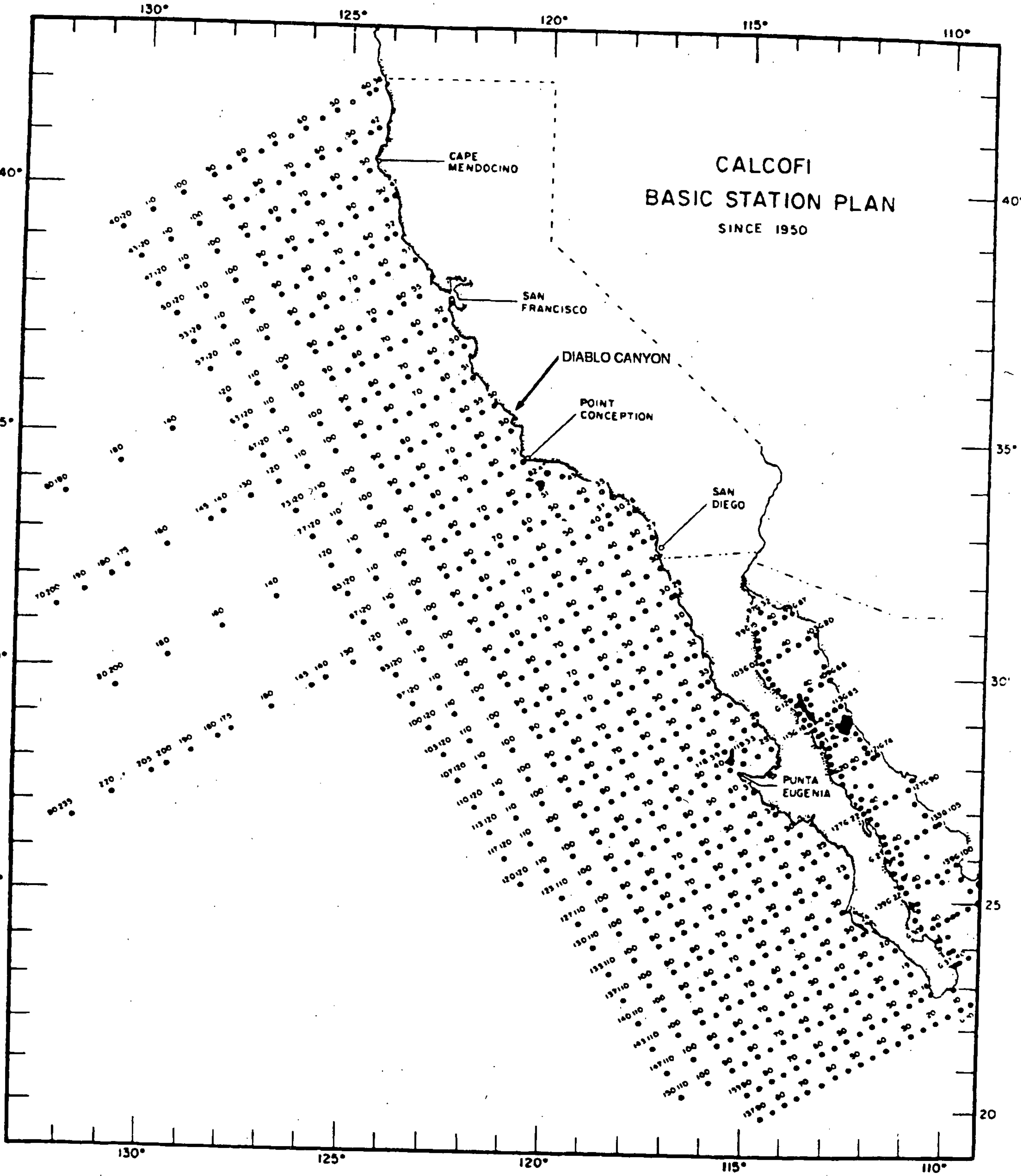


Figure 2-11

Basic CalCOFI Sampling Station Plan

determine landing trends and species composition of fish caught in the vicinity of the Diablo Canyon Power Plant. Market landings (tons/port) were also used to determine commercial landing trends for fish caught and sold in the central California coast area. Although commercial and partyboat landings are subject to various limitations, they can provide useful information regarding general species abundance. In this context, commercial and partyboat fishery data collected from two sources (PG&E and CDF&G) were used to help develop the impact assessment presented in Chapter 5.

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CHAPTER 3
ENTRAINMENT

Entrainment is the hydraulic capture and subsequent exposure of organisms to a cooling water system. The organisms involved are small (capable of passing through the 0.9-cm mesh of the intake screens) and include phytoplankton; ichthyoplankton (the early life stages of fish), and macroinvertebrates. As these entrained organisms pass through the cooling water system, they can be exposed to several types of stresses, including: mechanical stress from contact with the internal surfaces of pumps, pipes, and condenser tubes; pressure stress from exposure to relatively rapid pressure changes; shear stress from exposure to complex water flows; thermal stress from exposure to elevated temperatures in the condensers; and chemical stress from biocides used in biofouling control.

A major objective of the 316(b) program was to quantify entrainment of ichthyoplankton and selected macroinvertebrates into the Diablo Canyon Power Plant cooling water system. Two sampling programs were implemented to achieve this objective. The first, entrainment abundance, was designed to estimate the densities and taxa of organisms entrained. The second, entrainment survival, was designed to estimate the proportion of entrained organisms not surviving passage through the cooling system. Combining the results of the two studies provides the necessary information to characterize entrainment at the plant. These results also provide site- and species-specific information used to evaluate the potential effectiveness of intake modifications for minimizing the potential effects of entrainment and for evaluating available alternative intake technologies for the Diablo Canyon Power Plant (Chapter 6).

3.1 Entrainment Abundance

The entrainment abundance study provided quantitative information on the:

- species composition of entrained ichthyoplankton and selected macroinvertebrates;
- size (length) composition of the entrained ichthyoplankton;
- seasonal distribution patterns for entrained biota; and
- diel distribution patterns for entrained biota.

The densities of ichthyoplankton and selected macroinvertebrates entrained were determined by sampling a portion of the cooling water flow at least once per week for a one-year period.

3.1.1 Entrainment Abundance Support Studies

Prior to initiating the routine entrainment abundance monitoring program a number of intensive studies were undertaken to establish entrainment abundance sampling protocol. Entrainment abundance support studies were designed to:

1. Evaluate the efficiency of sampling gear and field processing; and
2. Determine the most representative sampling location for weekly, 24-hour entrainment abundance collections.

Entrainment Abundance Gear Evaluation — Release and Recovery

Collection efficiency of the entrainment abundance sampling gear and subsequent field handling techniques (net rinsedown, sample transfer and preservation) was tested by releasing a known number of stained larval fish directly into the sampling pump suction line. The pump was operated at a flow rate of approximately 900 l/min (the flow rate used for weekly entrainment collections) for sampling periods of 15 and 60 minutes. At the end of the test period, the 335-µm mesh net was rinsed, and the sample was collected in accordance with standard procedures. Direct release studies were conducted at the Diablo Canyon Power Plant using virtually identical sampling equipment and methodology to those used during direct release tests conducted at other PG&E sites.

During the two direct release studies at the Diablo Canyon Power Plant, larval fish (an assemblage of species, collected from entrainment samples at the Diablo Canyon Power Plant) were used as test organisms. These fish ranged in total length from 2 to 25 mm. In the first test, 47 of 50 larval fish released into the entrainment collection system were recovered after a 15 minute collection, representing a recovery of 94 percent. In the second test, 100 percent of 50 larval fish released were recovered after a 60 minute collection. Results of these tests are consistent with the findings of gear evaluations conducted previously at other plant sites.

Results of the gear evaluation tests conducted at Contra Costa, Potrero, and Moss Landing power plants using larval fish and brine shrimp were consistently high (90 percent recovery; Table 3-1). The larval fish used in those studies, primarily Pacific herring or striped bass, ranged in length from 4 to 25 mm. Sampling durations ranged from 15 to 60 min, and recovery of larval fish ranged from 86 to 100 percent (averaging 96 percent). Recovery of brine shrimp was also high (92-96 percent) for 30 and 60 minute collections using 335-and 505-µm mesh plankton nets.

Based on the results of these studies, a pump sampling system using a 10.2-cm diameter intake line, 335-µm mesh plankton net, and entrainment sampling duration of 30 to 60 min, were determined to be effective for use in the Diablo Canyon Power Plant entrainment monitoring program.

TABLE 3-1

Results of Collection Efficiency Tests of Entrainment Abundance Sampling Gear for Collection of 60 Minutes Duration or Less

Mesh Size (µm)	Duration of Collection (min.)	Number Released	Number Recovered	Percentage Recovery
		Larval Fish		
335	15	50	47	*94
335	15	50	46	92
505	15	25	23	92
335	30	50	45	90
335	30	50	43	86
335	60	100	100	*100
335	60	100	100	100
335	60	100	99	99
335	60	100	98	98
335	60	100	95	95
335	60	50	50	100
505	60	100	100	100
505	60	100	92	92
Total		975	938	96
		Brine Shrimp		
335	30	100	92	92
335	30	100	92	92
505	30	100	95	95
505	30	100	93	93
335	60	100	96	96
335	60	100	92	92
505	60	100	96	96
Total		700	656	94

* Conducted at Diablo Canyon Power Plant, 1985. All other data collected using identical equipment at other sites (Source: PG&E 1983).

Entrainment Abundance Gear Evaluation - Net Extrusion

A series of tests was conducted to test the collection efficiency of 335-μm mesh entrainment nets in retaining larval fish and macroinvertebrates. Cooling water was filtered through 335-μm entrainment nets and secondarily filtered by a smaller mesh, (150-μm) entrainment net for 15 minute periods. The contents of both nets were examined to determine the taxa and number of organisms passing through the 335-μm mesh net. Condition of the organisms collected was noted.

Results of these tests confirmed that the entrainment collections using 335-μm mesh nets retained 100 percent of the larval fish and macroinvertebrates identified as key target taxa for the 316(b) program. As expected, extremely small harpacticoid copepods were extruded through the 335-μm mesh net, however this group is omitted from detailed study based on U.S. EPA guidelines. It was concluded that the proposed sampling gear effectively collects and retains larval fish and macroinvertebrates and abrasion is minimized if sampling durations are limited to 60 minutes or less.

Entrainment Abundance Monitoring Station Selection

Entrainment samples were collected simultaneously from various locations within the cooling water system to determine the most representative sampling location for the weekly, 24-hour entrainment abundance study. Samples from the discharge provide a more representative assessment of organisms entrained because the circulating water is completely mixed. Intake samples, by contrast, reflect the vertical stratification and patchiness exhibited by planktonic organisms in the source waterbody. Provided that no organism losses occur during transit through the cooling water system, the discharge sampling location is expected to provide the true densities of entrained organisms. Results of entrainment studies conducted by PG&E at other power plants support the hypothesis that discharge sites provide the most representative location for sampling to estimate entrainment (PG&E 1981 a, b).

Sampling was conducted during February 13-21, 1985, June 10-20, 1985, and March 18-24, 1986. The first series of collections (conducted during February) provided information on the variability in ichthyoplankton densities between mid-depth, bottom and peripheral locations at the Unit 1 discharge sampling location. The second series of studies, conducted during June, emphasized a comparison of ichthyoplankton densities between three depths within the intake forebay, between intake forebays, between locations across the discharge, and between intake-discharge densities. The third series of collections provided information on Unit 1 and Unit 2 intake sampling location differences.

The experimental design was developed to test six null hypotheses:

1. mean densities at the discharge center and peripheral, mid-depth, sampling locations are not different (Intra-discharge comparison);

2. mean densities at the discharge central mid-depth and bottom sampling locations are not different (Intra-discharge comparison);
3. mean densities at mid-depth sampling locations are not different between the four Unit 1 intake forebays sampled (Intra-intake comparison);
4. mean densities at Unit 1 forebay 1-2 are not different between sampling depths (Intra-intake comparison);
5. mean densities at the intake and discharge are not different (Intake-discharge mass balance comparison); and
6. mean densities are not different between Unit 1 and Unit 2 intake locations.

Methods

Sampling locations used in the entrainment support studies were located within the Unit 1 intake structure adjacent to the intake bar racks and within the Unit 1 discharge throttling gate structure (Figure 3-1). During February and June 1985, intake sampling pipes were located in the center of Unit 1 forebays 1-1, 1-2, 1-4, and 1-5 at mid-depth. Two additional intake sampling pipes were located 0.3 m (1 ft) above the concrete base of the intake structure and 0.3 m (1 ft) below the curtain wall within intake forebay 1-2 (Figure 3-2). During March 1986, sampling was conducted from mid-depth locations in Unit 2 forebays 2-2 and 2-5 and ichthyoplankton densities were compared with mid-depth samples collected from Unit 1 forebays 1-2 and 1-5. All intake sampling pipes were oriented directly into cooling water flow.

Sampling at the Unit 1 discharge was conducted from a platform suspended within the throttling gate structure (Figure 3-1). Sampling pipes were located peripherally on both the north and south walls of the discharge structure at mid-depth (Figure 3-3). Two additional sampling pipes were located in the center of the Unit 1 discharge; one pipe at mid-depth and the second pipe located 0.3 m (1 ft) above the bottom of the discharge. All discharge sampling pipes were oriented directly into cooling water flow.

The velocity in the sampling inlet (10.2-cm diameter) equaled or exceeded the cooling water flow velocity, preventing back pressures around the sampling pipe inlet that might reduce organism collection efficiency. The pump discharged into a 10.2-cm diameter line leading to the mouth of a 0.5-m plankton net with 335-μm mesh, suspended in a cylindrical, polyethylene tank (Figure 3-4). The water bath was maintained at a level below the mouth of the plankton net. Sample volumes and flow rates were measured with a Sparling Master-Flo inline flowmeter (factory calibrated at ± 2 percent accuracy) in the pump discharge line. The flow rate was maintained at approximately 900 l/min.

Sampling was conducted primarily between 1800 and 2400 hours. A sampling duration of 15 min was maintained for all replicate collections. Two to five locations

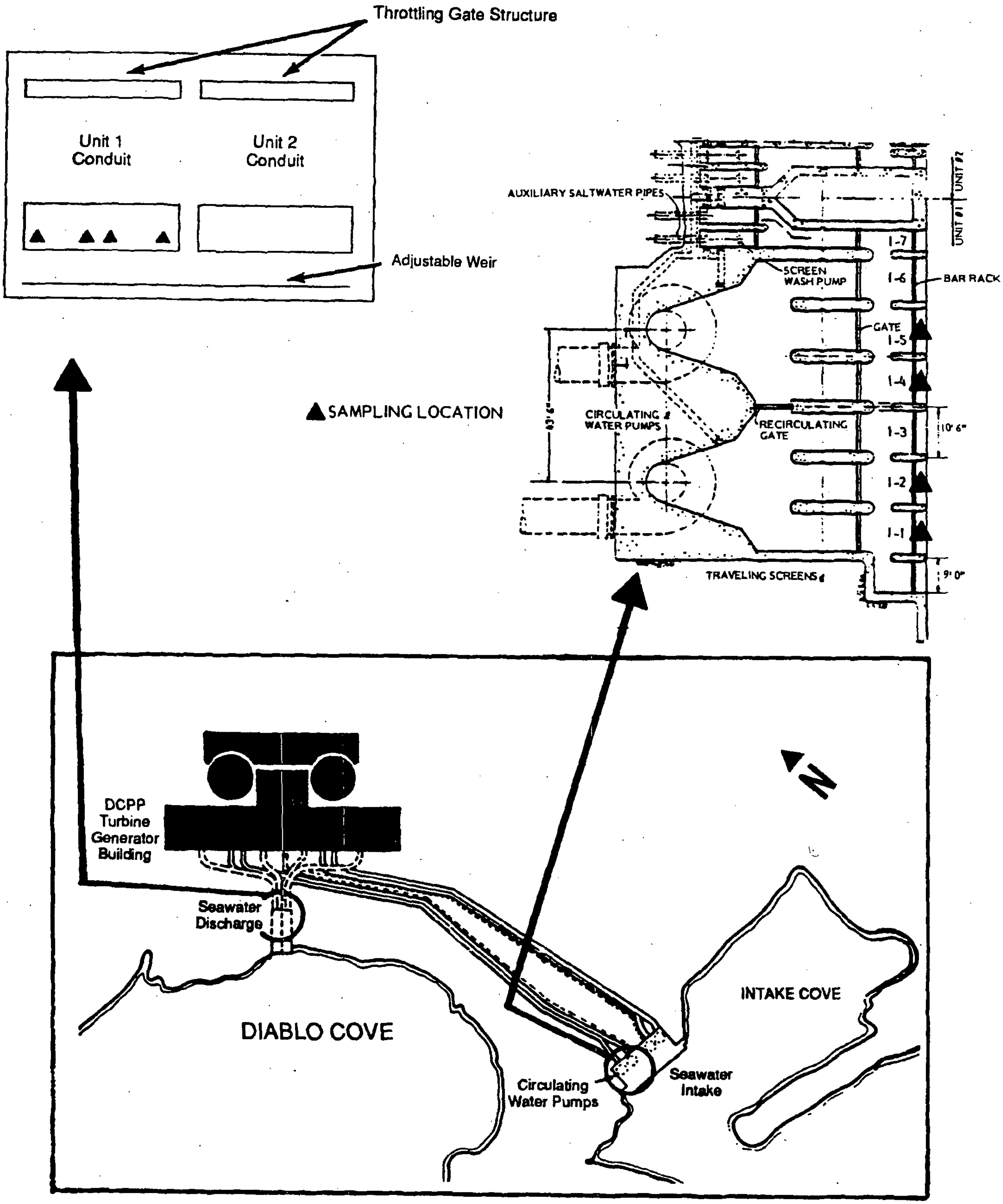

Figure 3-1

Sampling Locations Selected for Entrainment Studies
at Unit 1 of the Diablo Canyon Power Plant

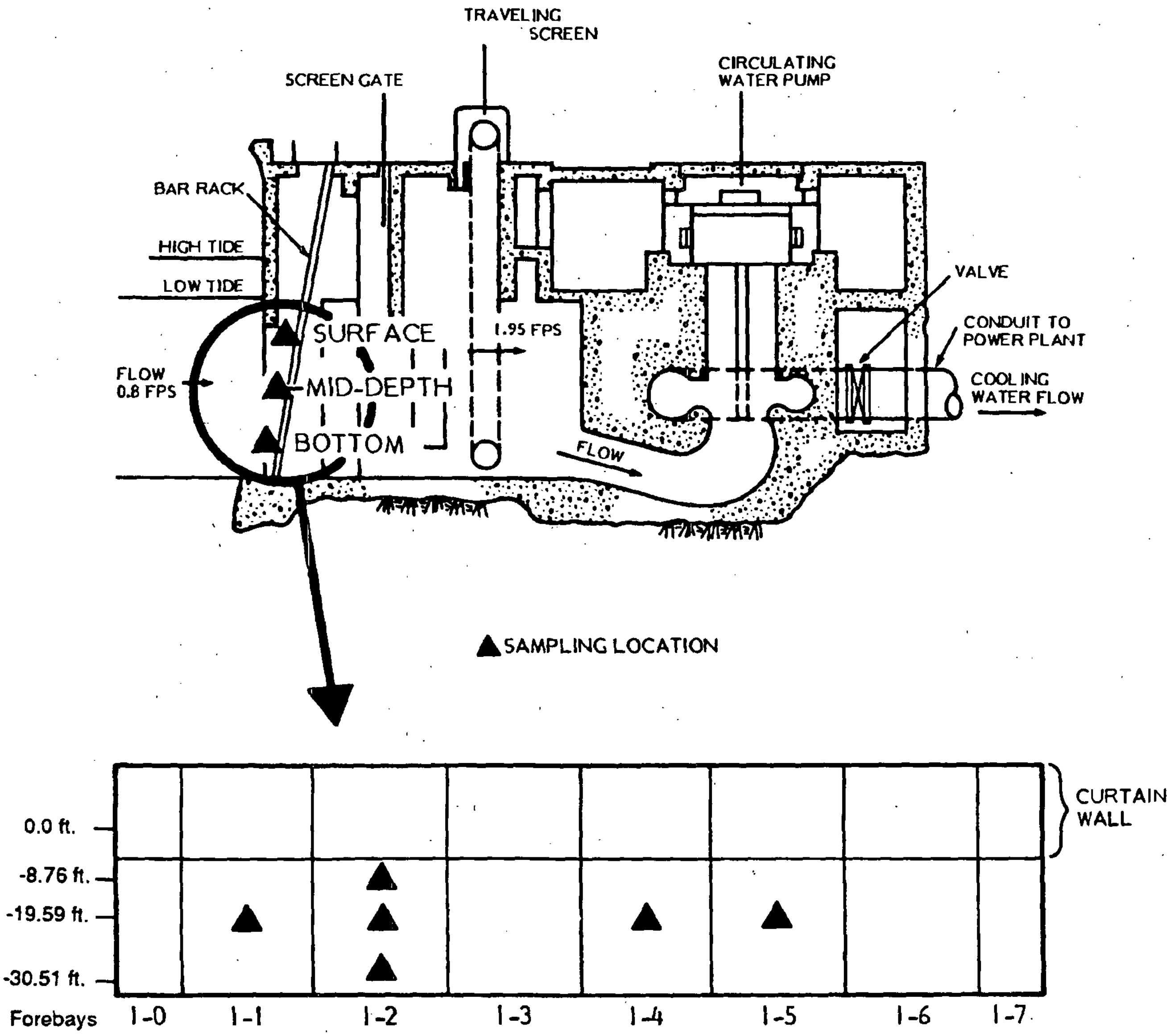

Figure 3-2

Sampling Locations Selected for Entrainment Studies
at the Unit 1 Intake Structure of the Diablo Canyon Power Plant

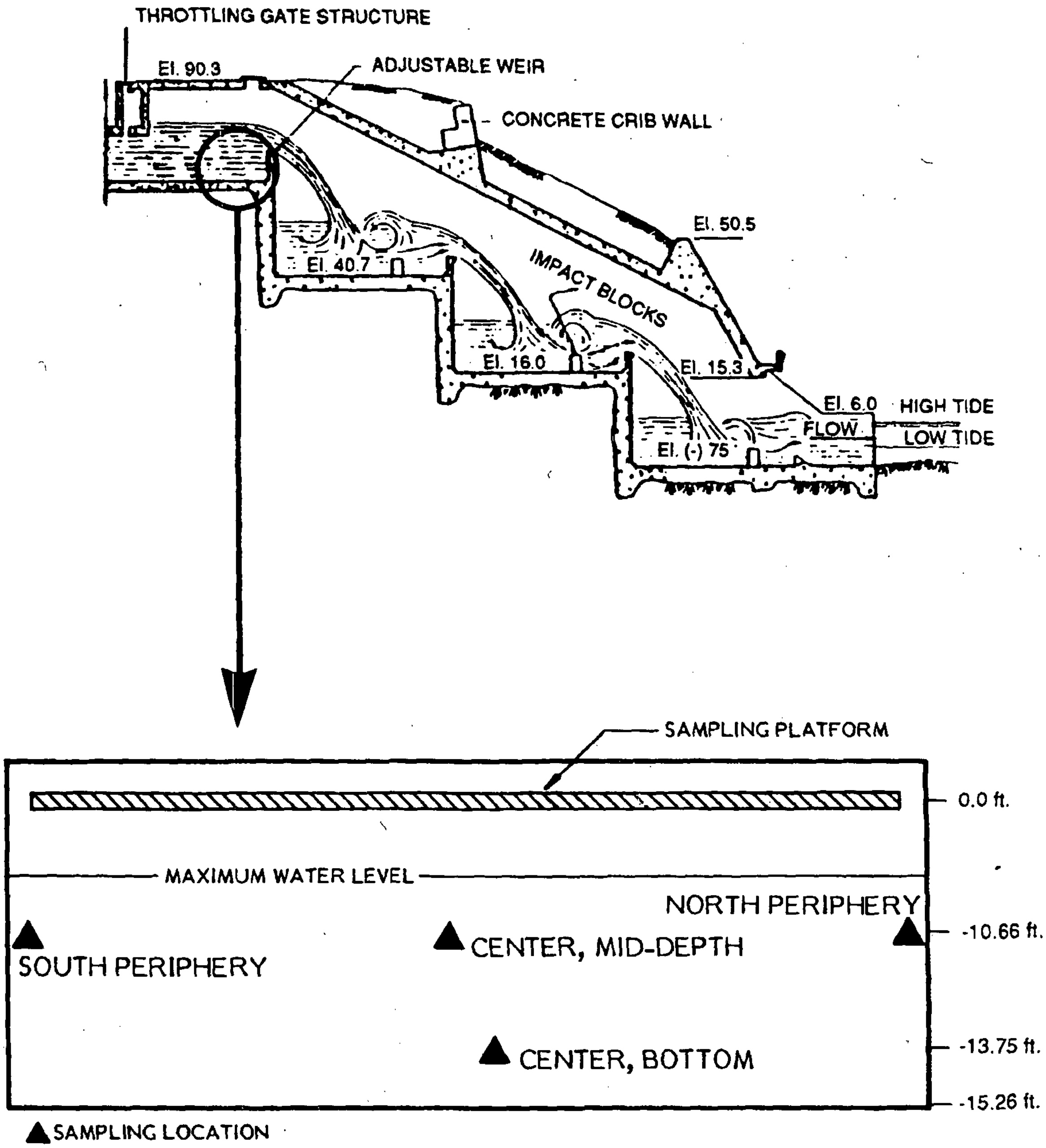

Figure 3-3

Sampling Locations Selected for Entrainment Studies
at the Unit 1 Discharge Conduit of the Diablo Canyon Power Plant

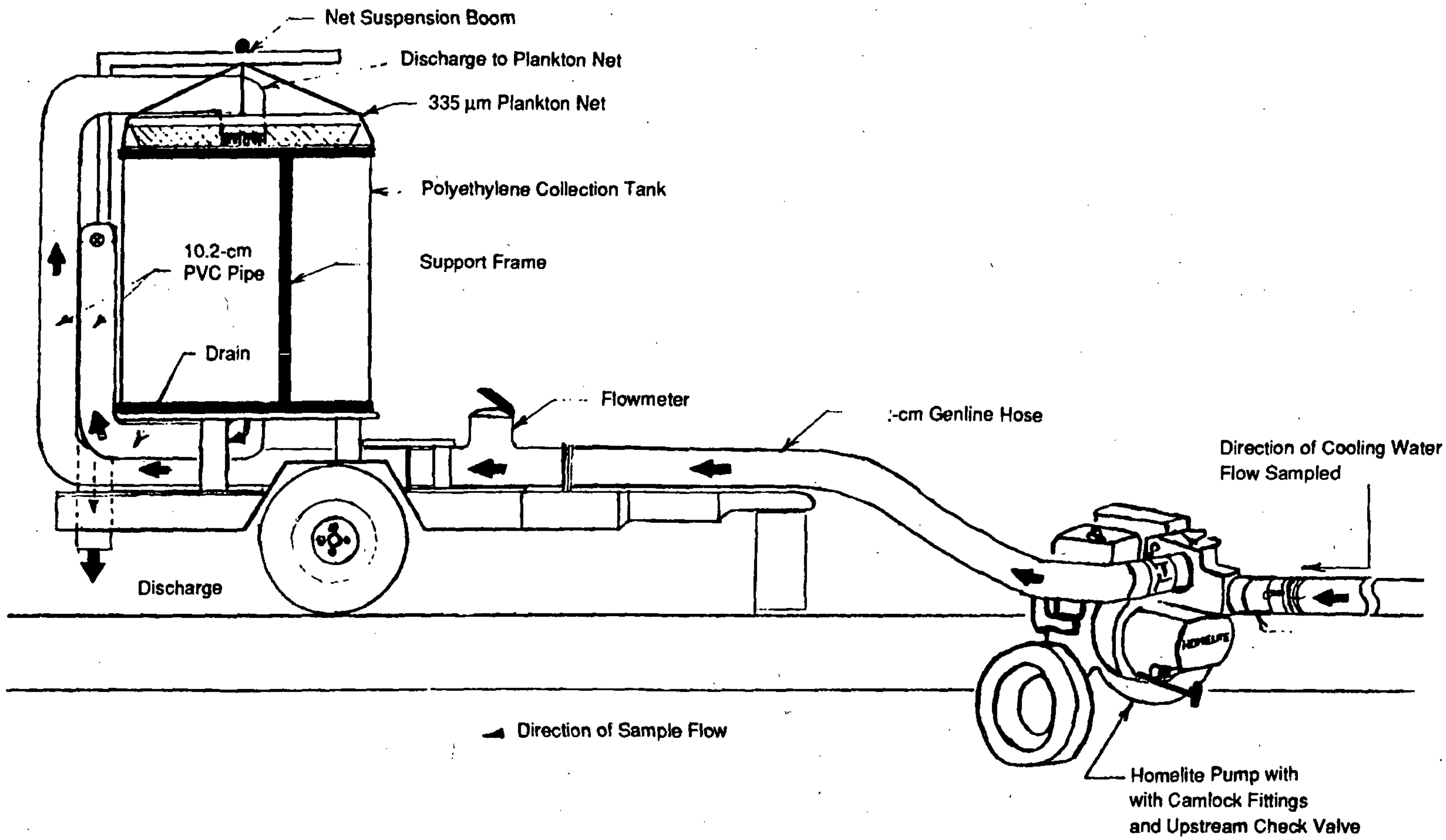

Figure 3-4

Entrainment Abundance Sampling Equipment Used at the Diablo Canyon Power Plant were sampled simultaneously (Table 3-2). Discharge sample start times which were to be compared statistically with intake samples were delayed by 5 minutes to allow for cooling water transit time from the intake to the discharge. Samples were processed for larval fish in accordance with methods described in Section 3.1.2. The sampling design and subsequent analysis of entrainment abundance support studies focused exclusively on the densities of ichthyoplankton collected in the entrainment samples.

Densities, expressed as the number of larval fish/m^3 of cooling water sampled, were computed for each sample. The density data were statistically analyzed using analysis of variance and paired T-tests. Among the assumptions of the analysis of variance are (1) the assumption of homogeneity of variance (i.e., equal variance) among treatment groups, and (2) the assumptions of normality and independence of experimental observations. To meet the assumption of homogeneity of variance, the ichthyoplankton densities used in the statistical analyses were transformed as follows:

$$Y = \log(\text{density} + 1)$$

where

$$\text{density} = x / v \quad (\text{expressed as No./m}^3)$$

$$x = \text{total number of larval fish collected in a sample}$$

$$v = \text{cooling water volume sampled in cubic meters.}$$

The assumption of normality was not a major concern, because the analysis of variance test comparing means is relatively insensitive to deviations from normality. Experimental observations were assumed to be independent because samples were independently collected.

Results

The Diablo Canyon Power Plant entrainment abundance support studies for station selection reflect the results of 595, fifteen minute samples. A total of 180 samples were collected at the Unit 1 discharge in February 1985. During June 1985, 244 samples were collected at the Unit 1 intake and 130 samples were collected from the Unit 1 discharge. During March 1986 a total of 41 samples were collected from mid-depth locations within Units 1 and 2 intake forebays.

Mean densities and standard deviations for station location entrainment support studies are summarized in Appendix E. Based on the results of this analysis it was concluded that:

- ichthyoplankton densities were not significantly different between sampling locations within the Unit 1 discharge during June 1985, when cooling water flow was typical (1.21 bgd) of normal plant operating conditions;

TABLE 3-2

ENTRAINMENT SUPPORT STUDY SAMPLING LOCATIONS

	Sampling Locations										
	Intake						Discharge				
	Mid-Depth						Center		Peripheral		
Date	1-1	2-2	1-4	1-5	Surface 1-2	Bottom 1-2	Middle	Bottom	North	South	Simultaneous Collections
Feb 13, 1985						X			X	21	
14							X	X			14
19							X			X	18
20							X	X			17
21							X	X			20
Jun 10, 1985							X		X	X	7
11							X		X	X	16
12							X		X	X	7
14		X			X	X	X		X		*6/5
14		X	X	X	X						4
17		X			X	X	X		X		8
18	X	X	X	X							17
19	X	X	X	X							8
19		X			X	X	X		X		6
20	X	X	X	X							5
20		X			X	X					10
25		X			X	X					**6
Mar 18, 1986	X	X	X	X							16
20	X	X	X	X							11
24	X	X	X	X							14

* 6 collections were used in the intake comparison; 5 collections used in the intake vs. discharge comparison.

** Collections between 0900-1200.

- ichthyoplankton densities were not significantly different between mid-depth sampling locations across four Unit 1 intake forebays tested;
- ichthyoplankton densities were not significantly different between mid-depth sampling locations at Unit 1 and Unit 2;
- vertical stratification exists in the ichthyoplankton densities at the intake; and
- ichthyoplankton densities were not significantly different between pooled intake samples (surface, mid-depth and bottom depths combined) and samples from locations within the Unit 1 discharge.

Considering the logistical difficulty in sampling from multiple collection systems, (surface, mid-depth and bottom) at the intake, combined with the lack of significant difference between intake and discharge densities, it was concluded that the discharge was the preferred sampling location for quantifying entrainment losses.

3.1.2 Entrainment Abundance Methods

The routine entrainment monitoring program was initiated in October 1985 and completed in September 1986. A total of 74 twenty four-hour collections were made during this period. Entrainment samples were collected with a pump and 335-µm mesh plankton net during sampling periods scheduled at least once per week throughout the year. Between October 10, 1985 and April 8, 1986, the routine entrainment samples were collected from the center, mid-depth location within the discharge structure. During April, both center pipes (mid-depth and bottom) became dislodged. The south peripheral, mid-depth sampling location was selected for entrainment sampling after April 8, 1986 because June 1985 support studies indicated that the mean larval fish density observed at this location closely approximated the mean larval fish density observed at the center, mid-depth location. A Unit 1 outage commencing September 1 required a second sampling relocation to the Unit 2 intake structure for the final month of the entrainment abundance monitoring program since no sampling platform existed in the Unit 2 discharge.

Based on the entrainment support studies results, sampling pipes were positioned at surface, mid-depth, and bottom locations within the Unit 2-2 forebay. Sampling was accomplished from a floating platform moored next to the Unit 2 intake structure. Three entrainment collection systems were utilized to collect simultaneous samples from the three locations. Surface and mid-water samples were combined at the time of collection, and the bottom sample was kept discrete to enable subsequent analysis of vertical stratification at the intake.

Routine entrainment samples were collected with a 10.2-cm recessed-impeller pump and a 10.2-cm intake pipe which was directed into the cooling water flow. The pump discharged into a 10.2-cm diameter line leading to the mouth of a 0.5-m plankton net with 335-µm mesh suspended in a cylindrical polyethylene tank. The water level in the tank was maintained below the mouth of the net. Sample volume and flow rate were measured with a Sparling Master-Flo inline flowmeter (factory calibrated at ±2 percent accuracy) located in the pump discharge line. Flowmeters were subject to periodic on-site calibration verifications during the entrainment monitoring program. The flow rate during entrainment sampling was maintained at approximately 900 l/min. To minimize abrasion of collected organisms and extrusion through the sampling net, entrainment discharge subsamples were collected and preserved at 1-hour intervals throughout each 24-hour sampling period. Each discrete entrainment subsample represents a collection duration of 60 min and a sample volume of approximately 54 m^3. To maintain consistent sample volumes during the September intake collections, subsample times at the three locations were reduced from 60 min to 20 min and flows were maintained at 900 l/min. At the end of each subsampling period organisms were collected by removing the plankton net and sample from the sampling system. Immediately following removal, a clean plankton net was inserted into the sampling system; this cycle was repeated throughout the 24-hour collection. After removal from the sampling system, the plankton net was rinsed with filtered water, concentrating the organisms and debris in a screen-walled codend attached to the net. The concentrated entrainment sample was washed into a labeled glass jar and preserved in 10 percent formalin. Five to seven days after collection, the samples were transferred to 80 percent isopropyl alcohol, stained with a saturated solution of rose bengal dye, and returned to the on-site laboratory for processing.

A total of 60, twenty four-hour entrainment samples were processed to identify and enumerate larval fish. Fragments of larval fish constituting less than 50 percent of total body length were not counted. Identification was taken to the lowest taxonomic level practical. Total lengths of fish larvae were measured to the nearest 1.0 mm. Fish eggs were counted for each sample.

A total of 52, twenty four-hour entrainment samples were processed to identify and enumerate invertebrates. Invertebrates were identified to the lowest taxonomic level practical. Because of the large numbers of invertebrates present in the samples, quantitative subsampling was required. Plankton samples were split with a Folsom splitter. The accuracy of the Folsom splitter was statistically tested using a chi-square goodness-of-fit test comparing the numbers of invertebrates (brine shrimp) found in consecutive split subsamples to the number expected to occur in each subsample when the number of organisms in the original sample was known. After refining the splitting techniques, a test was conducted to document splitter accuracy at various split fractions. Results of the splitter test are presented below:

Split Fraction

	1/2	1/4	1/8	1/16
Average Percent Error	1.3	2.6	3.8	3.2

Differences between estimated counts from the subsamples and the expected values were not significantly different ($P>0.05$). It was concluded that the Folsom splitter accurately partitioned samples into 1/2 to 1/16 subsamples for invertebrate sample processing. Entrainment samples were split to either a 1/16 subsample (87 percent of all samples processed) or a 1/8 subsample (13 percent of all samples processed). Invertebrate densities reported in the results section have not been adjusted, given the low average percent error.

Sample processing was subject to a strict quality assurance program. Detailed written procedures were developed for each aspect of entrainment sample collection, processing, and data verification. Ichthyoplankton sorting efficiency was maintained at a minimum 90 percent accuracy level. The entrainment program was subject to independent quality assurance audits during the study period. A review and independent verification of ichthyoplankton and macroinvertebrate identifications was performed as part of the quality assurance program.

3.1.3 Results of the Entrainment Abundance Program

Results of the entrainment monitoring program are reported as densities, expressed as the number of organisms per cubic meter of cooling water (No./m^3), computed for each taxa observed in entrainment samples. Entrainment densities were used to determine the diel and seasonal patterns of entrained organisms. Length statistics (mean, range, and standard deviation) were computed for those species constituting at least 1.0 percent composition of all ichthyoplankton collected during the one-year sampling period (Table 3-3).

Larval fish representing 28 families were identified from entrainment samples collected between October 1985 and September 1986 (Table 3-3). Sculpins (Cottidae), white croaker (Sciaenidae), rockfish (Scorpaenidae), and northern anchovy (Engraulidae) constituted a total of 71 percent of the total number of fish collected. An additional 23 families comprised 25 percent of all ichthyoplankton collected and 4 percent could not be identified to family. Cottidae, the most abundant family observed during the entrainment monitoring program included cabezon and smaller sculpins, which represented 6 percent and 35 percent, respectively, of the ichthyoplankton collected. Appendix E presents a phylogenetic listing of ichthyoplankton and invertebrate taxa identified from entrainment samples.

Fish eggs (Figure 3-5) were present in entrainment samples throughout the year. Eggs were identified as either northern anchovy or unidentified. Unidentified eggs represent a diverse assemblage of species and were most abundant during the summer (July through September) and least abundant during the spring (April through May). Northern anchovy eggs were most abundant during the winter period (January through February). Many of the fish species inhabiting the source waters produce demersal egg nests (e.g., cabezon) or their eggs are typically pelagic for short periods of time (e.g., rockfish) thereby reducing the susceptibility of their eggs to entrainment. Other species which spawn in the area (e.g., white croaker and northern anchovy) have high fecundity producing large numbers of planktonic eggs.

TABLE 3-3

PERCENT COMPOSITION OF LARVAL FISH FAMILIES COLLECTED DURING THE ENTRAINMENT ABUNDANCE MONITORING PROGRAM, OCTOBER 1985 - SEPTEMBER 1986

FAMILY NAME	COMMON NAME	PERCENT COMPOSITION
Cottidae	Sculpins	41
Sciaenidae	Croakers	14
Scorpaenidae	Rockfishes	9
Engraulididae	Anchovies	7
Clinidae	Clinids	6
Gobiidae	Gobies	5
Stichaeidae	Pricklebacks	5
Cebidichthyidae	Monkeyface-eels	3
Pleuronectidae	Flatfishes	1
Pholididae	Gunnels	1
Gobiesocidae	Clingfishes	1
Bothidae	Flatfishes	< 1
Cynoglossidae	Flatfishes	< 1
Syngnathidae	Pipefishes	< 1
Gasterosteidae	Tubesnouts	< 1
Atherinidae	Silversides	< 1
Hexagrammidae	Greenlings	< 1
Liparididae	Snailfishes	< 1
Agonidae	Poachers	< 1
Serranidae	Sea Basses	< 1
Bothidae	Flatfishes	< 1
Brotulidae	Brotulas	< 1
Clupeidae	Herrings	< 1
Synodontidae	Lizardfishes	< 1
Osmeridae	Smelts	< 1
Myctophidae	Lanternfishes	< 1
Bathylagidae	Deepsea Smelts	< 1
Embiotocidae	Surfperches	< 1
Unidentified		4

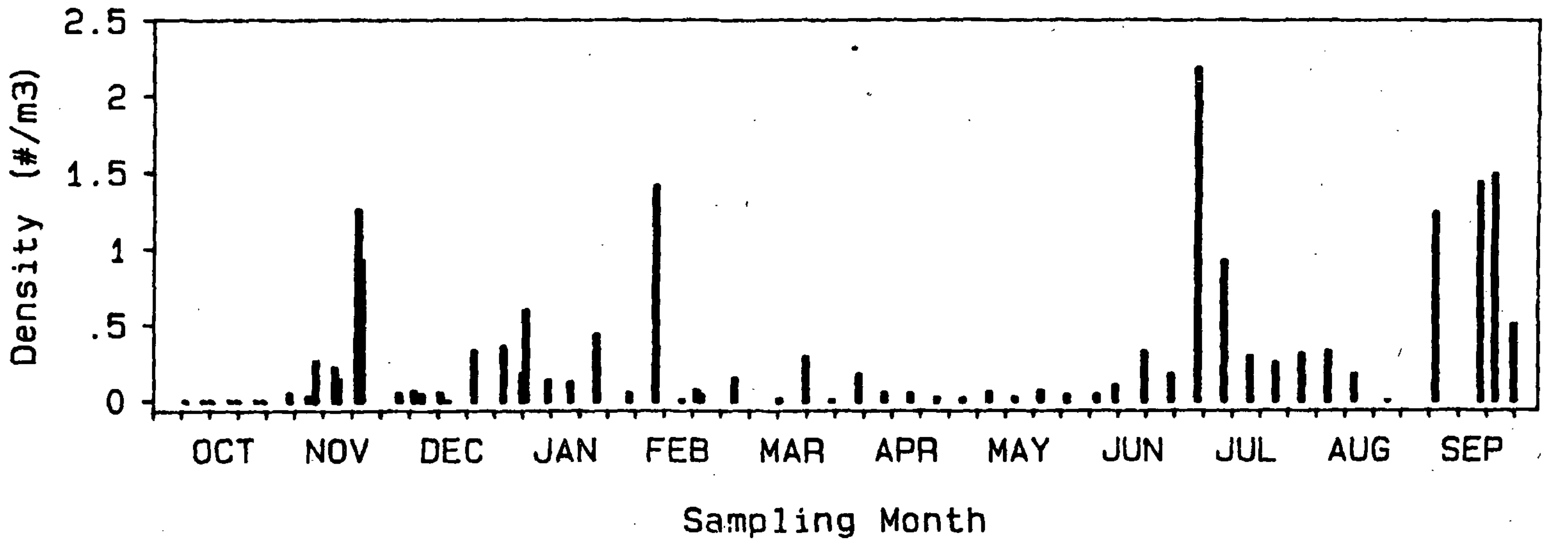

Figure 3-5

Mean Densities of all Fish Eggs Collected from Entrainment Samples at the Diablo Canyon Power Plant, October 1985 - September 1986

These dispersal spawners typically have eggs which are more susceptible to entrainment because development may require several weeks and their eggs can drift passively in the plankton for long periods of time.

Larval fish were collected in entrainment samples throughout the one-year sampling period (Figure 3-6). Densities of larval fish generally increased during the fall (October - December), followed by a decline during January and February. A second eggs increase in larval fish densities occurred during the early spring (March - April), with a subsequent decline throughout the late spring and summer. In general, densities varied between 0.05 and $0.30/m^3$.

Ichthyoplankton densities were highly variable both between sampling days as well as between subsamples within the same day. The high variance in densities of entrained larval fish was primarily attributable to the patchy seasonal distribution of several taxa in the vicinity of the Diablo Canyon Power Plant. Figure 3-6 illustrates the seasonal abundance of larval fish collected throughout the one-year sampling program. The peak in larval fish densities which appeared on January 4 ($0.86/m^3$) reflects the extremely patchy seasonal distribution of white croaker larvae. Two pronounced peaks in larval fish densities occurring on May 10 and 17 (densities of 0.78 and $0.89/m^3$, respectively) were primarily attributable to the occurrence of larval sculpin.

Larval fish collected in the routine entrainment monitoring program ranged in length from 1 to 50 mm. The mean length and ranges for selected larval fish taxa (constituting ≥1 percent of ichthyoplankton collected) are presented in Table 3-4. Mean lengths for many of the taxa including cottids, white croaker, rockfish, and flatfish were less than 5 mm (Table 3-4). Analysis of the length frequency distribution for all entrained larval fish combined (Figure 3-7) showed that the majority of larvae (95 percent) were less than 11 mm. The largest fish collected in routine entrainment samples were predominantly northern anchovy.

Densities of entrained larval fish increased during the evening (1800-2400), reaching a peak at 2000 hours, and then gradually decreased to the lowest levels which occurred between 0900 and 1200 hours (Figure 3-8). The diel distribution in larval fish densities observed in the entrainment collections at the Diablo Canyon Power Plant is similar to the diel distribution in entrainment observed at other power plant locations. The diel distribution in larval fish densities varied substantially between taxa (Figure 3-8). Rockfish (*Sebastes* spp.) and cabezon, for example, were characterized by dominant peaks in densities during the late evening hours, in contrast to white croaker, which evidenced no consistent diel trend.

Cottidae (Small Sculpins and Cabezon)

Cottidae were the most abundant larval fish collected in the Diablo Canyon Power Plant entrainment program (Table 3-3). Sculpins are small, cryptic fish abundant in the shallow, rocky intertidal and subtidal areas adjacent to the Diablo Canyon Power Plant. Sculpins, which comprise an assemblage of genera, constitute 35

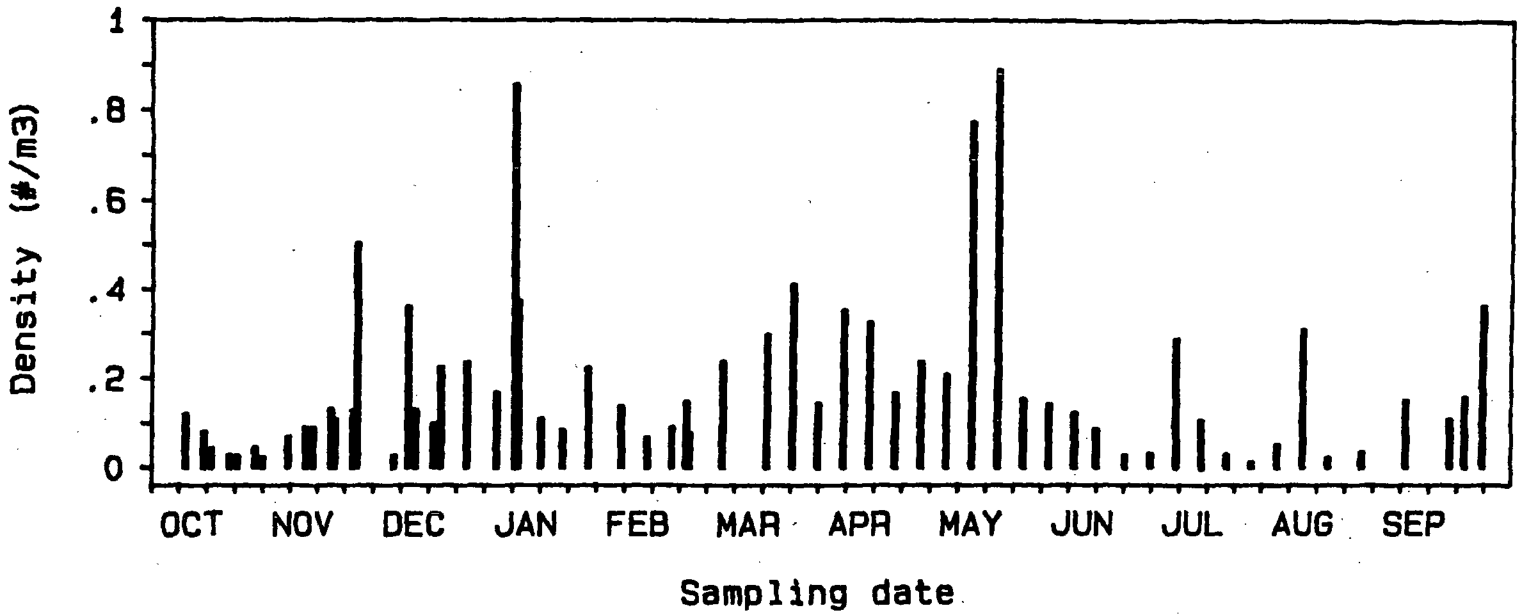

Figure 3-6

Mean Densities of all Larval Fish Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

TABLE 3-4

LENGTH SUMMARY STATISTICS FOR ENTRAINED LARVAL FISH*

Species	N	% Measured	X	Range	S.D.
Sculpins (excluding Cabezon)	5,269	97	3.7	1-11	0.95
Sculpins (including Cabezon)	6,237	98	3.8	1-11	0.92
Cabezon	968	100	4.3	2-7	0.61
White croaker	2,080	98	3.2	1-9	1.18
Rockfish	1,294	97	3.5	2-30	1.17
Northern anchovy	1,033	92	11.0	1-50	5.90
Kelpfish	1,358	96	6.1	3-28	2.11
Gobies	893	99	4.0	2-18	1.81
Pricklebacks	809	95	8.0	3-27	3.45
Monkeyface-eels	457	98	6.9	4-17	1.76
Flatfishes (Pleuronectidae)	161	100	3.2	2-31	2.62
Gunnels	131	98	11.0	7-22	3.28
Clingfishes	94	100	3.4	2-31	3.38

* Summary for larval fish constituting 1.0 percent, or more, of all ichthyoplankton collected.

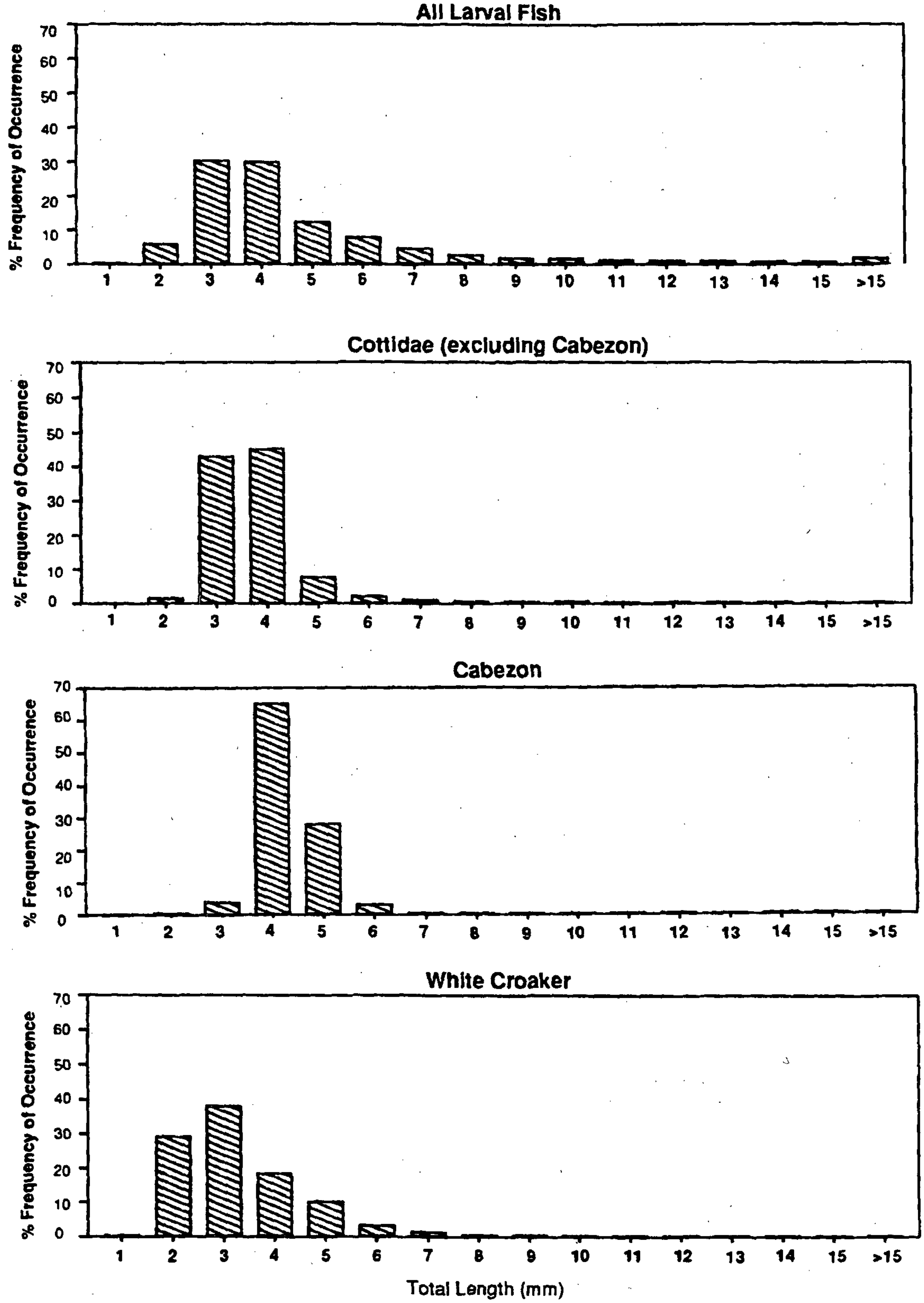

Figure 3-7

Length Frequency Distributions for Selected Larval Fish
Collected from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

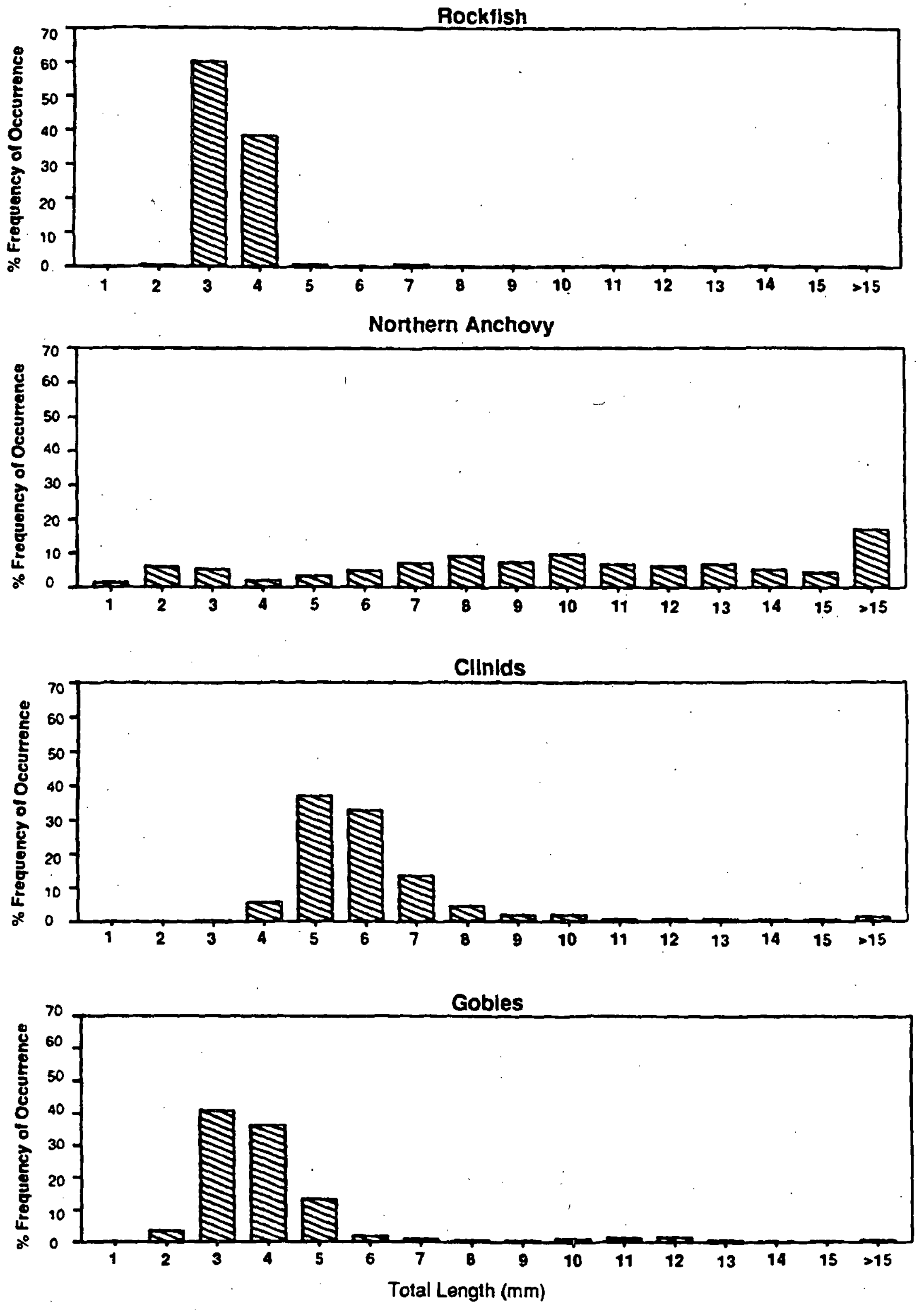

Figure 3-7 — *Continued*

Length Frequency Distributions for Selected Ichthyoplankton Collected from Entrainment Samples, October 1985 – September 1986

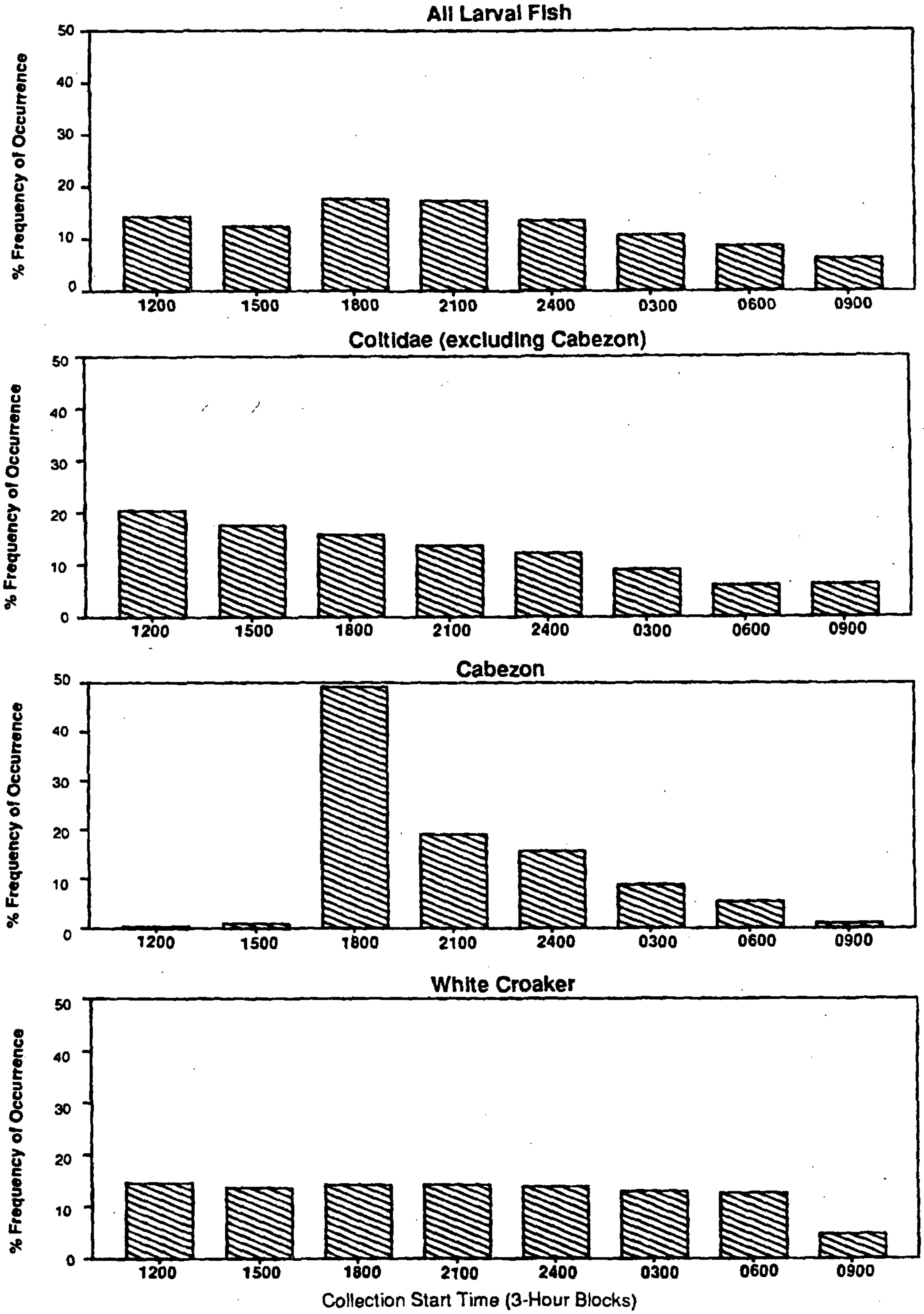

Figure 3-8

Diel Distribution for Selected Larval Fish Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

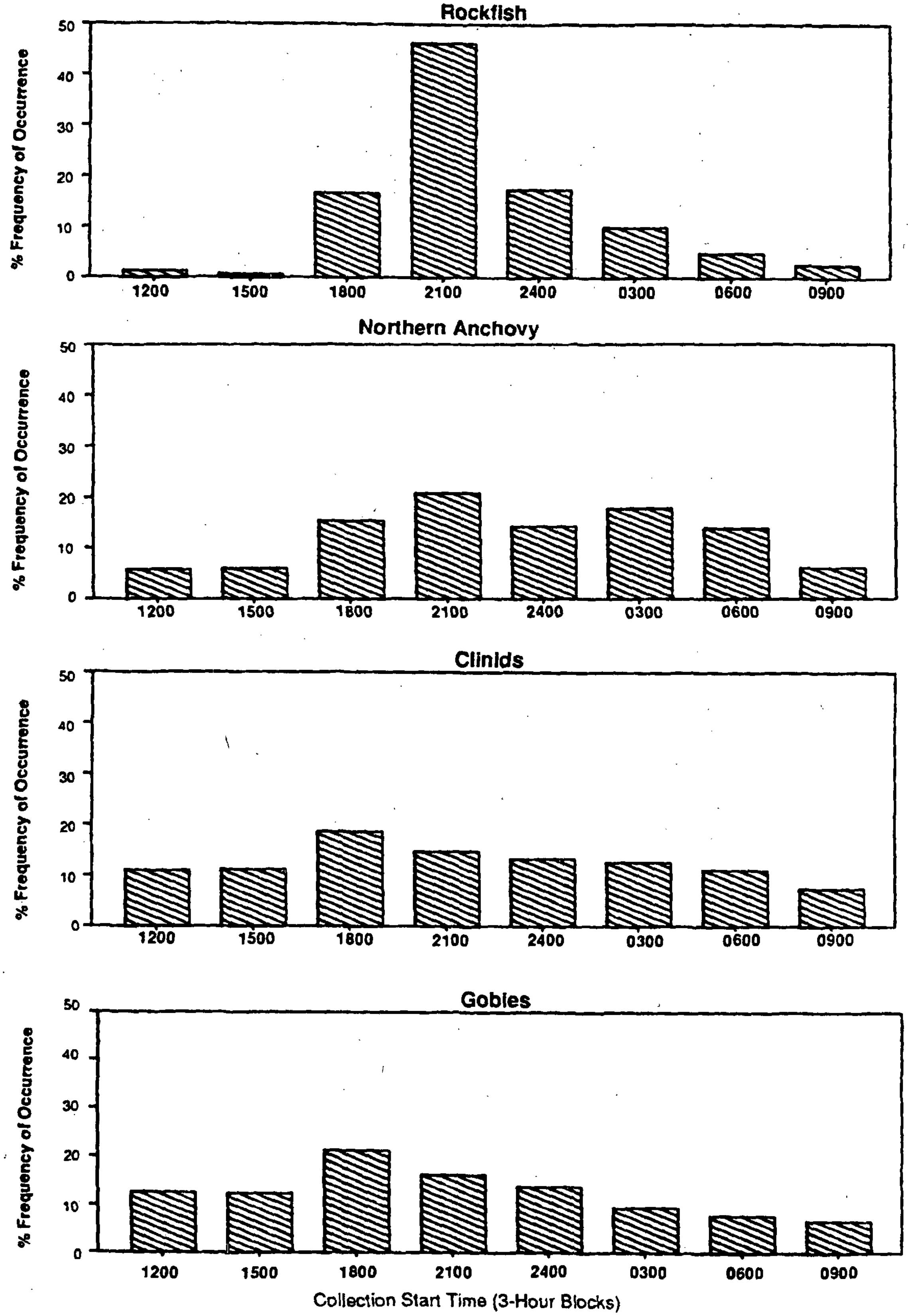

Figure 3-8 — *Continued*

Diel Distributions for Selected Ichthyoplankton
Collected from Entrainment Samples,
October 1985 – September 1986

percent of the larval fish collected. Cabezon (*Scorpaenichthyes marmoratus*), the largest of the cottids in the area, constituted 6 percent of all larval fish collected.

Sculpin larvae were present in entrainment samples throughout the year (Figure 3-9) with highest densities (>0.6/m^3) during May. Sculpin larvae were typically small (Figure 3-7; Table 3-4), averaging 3.7 mm (range 1-11 mm). Larval sculpins were collected in greatest numbers during the mid-day (1200-1800 hours), with declining densities through the night and early morning hours (Figure 3-8).

Cabezon larvae were present in entrainment samples during the fall and winter months (Figure 3-10). Densities of larval cabezon were typically low (<0.04/m^3), with the highest densities occurring from November through January (0.04 to 0.1/m^3).

Entrained cabezon were small (Figure 3-7), ranging in length from 2 to 7 mm (mean 4.3 mm: Table 3-4). The diel distribution in cabezon was characterized by low densities during the day, increasing substantially during the early evening (1800-2100 hours), followed by a gradual decline throughout the night and early morning hours (Figure 3-8).

Genyonemus lineatus (White Croaker)

White croaker were the second most abundant taxon collected (14 percent of the larval fish collected) in entrainment samples (Table 3-3). White croaker larvae were present in relatively low densities (<0.05/m^3) during the fall, winter, and early spring (Figure 3-11), but on two sampling days, November 26 and January 8, their densities increased to 0.38 and 0.46/m^3, respectively. Forty-five percent of all white croaker larvae collected in entrainment abundance samples during the year were collected on these two sampling days.

White croaker larvae ranged in length from 1 to 9 mm (mean 3.2 mm: Table 3-4). The length frequency distribution for entrained white croaker is shown in Figure 3-7. No diel pattern was evident for this species (Figure 3-8).

Sebastes spp. (Rockfish)

Rockfish, a diverse assemblage of species, was the third most abundant taxa collected during the entrainment monitoring period, constituting 9 percent of the larval fish collected (Table 3-3). Densities of rockfish larvae (Figure 3-12) were low during the winter (<0.05/m^3), increased to a level of approximately 0.1/m^3 during the early spring (March - May), and returned to levels less than 0.05/m^3 during the late spring and summer. Rockfish ranged in length from 2 to 30 mm (mean 3.5 mm: Table 3-4). Because of their small size (Figure 3-7) and a lack of information on the taxonomy of rockfish larvae, rockfish collected in the entrainment samples were not identified to species.

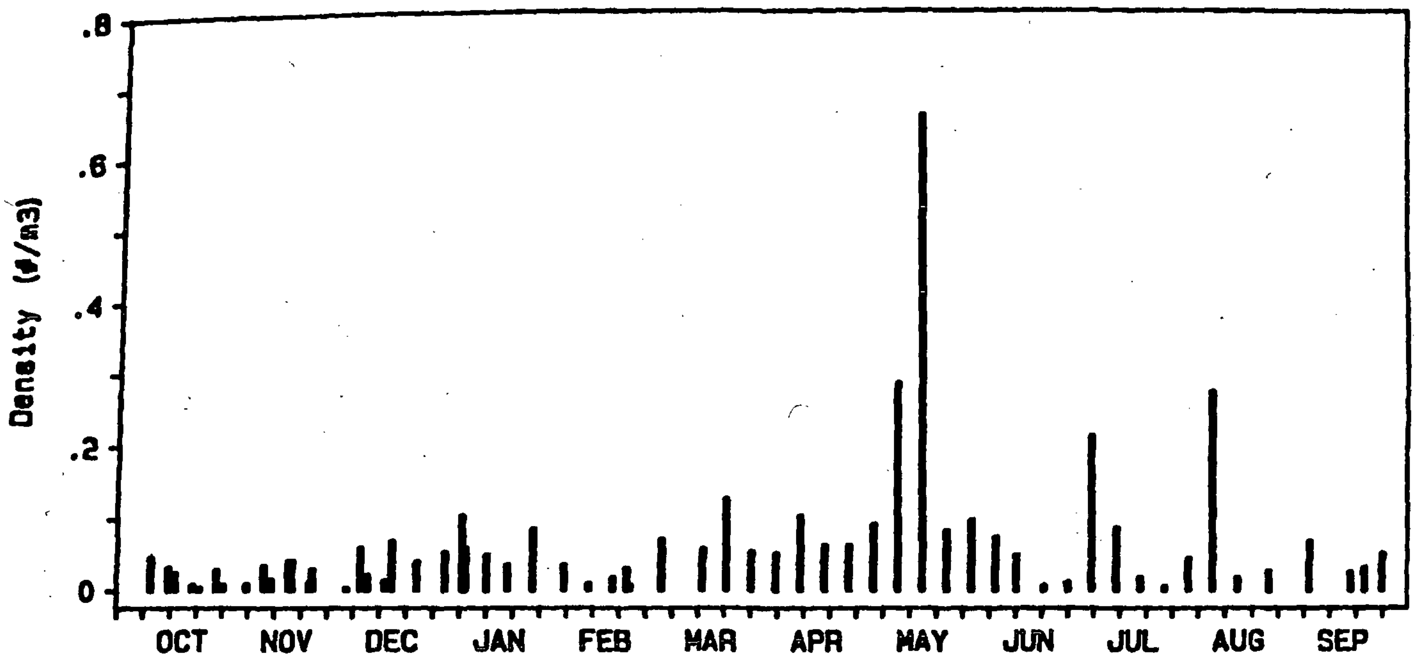

Figure 3-9

Mean Densities of Cottidae (excluding Cabezon) Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

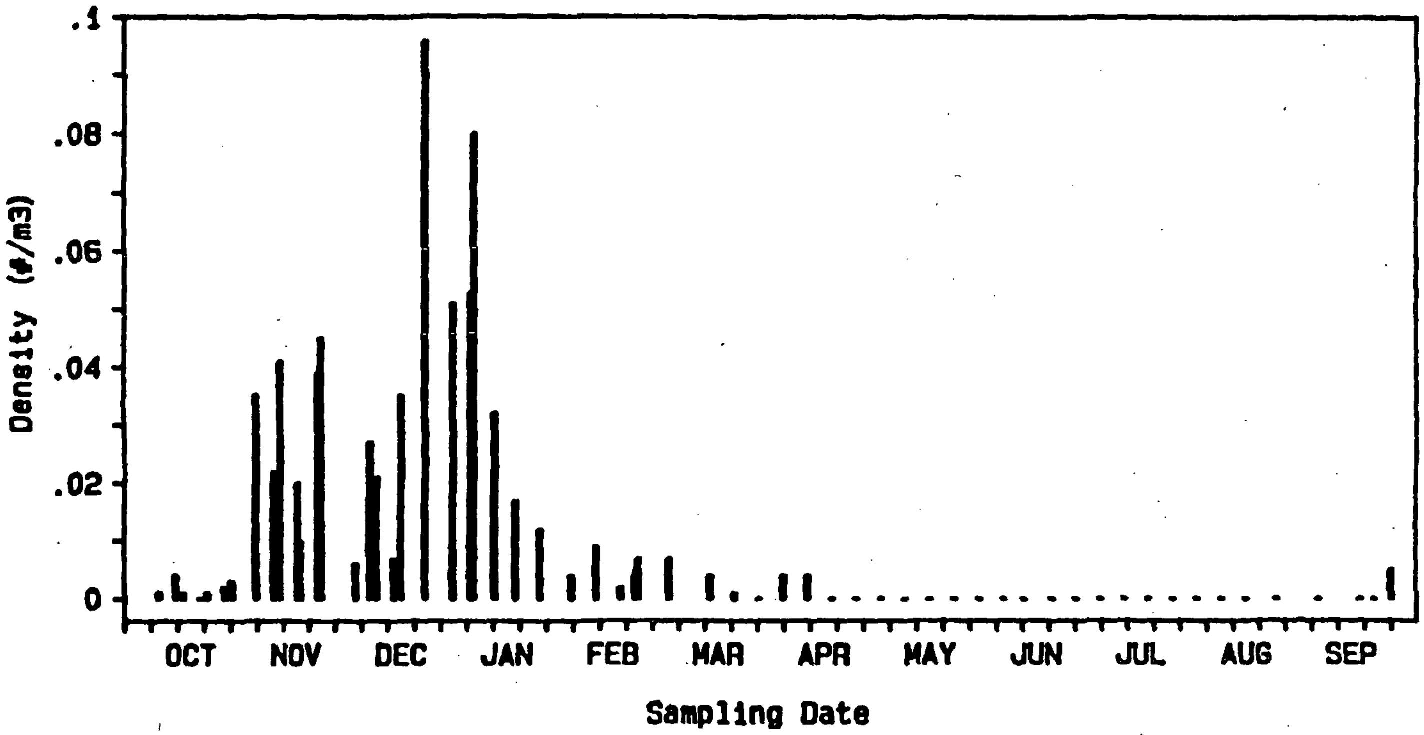

Figure 3-10

Mean Density of Cabezon Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

E7-265.0

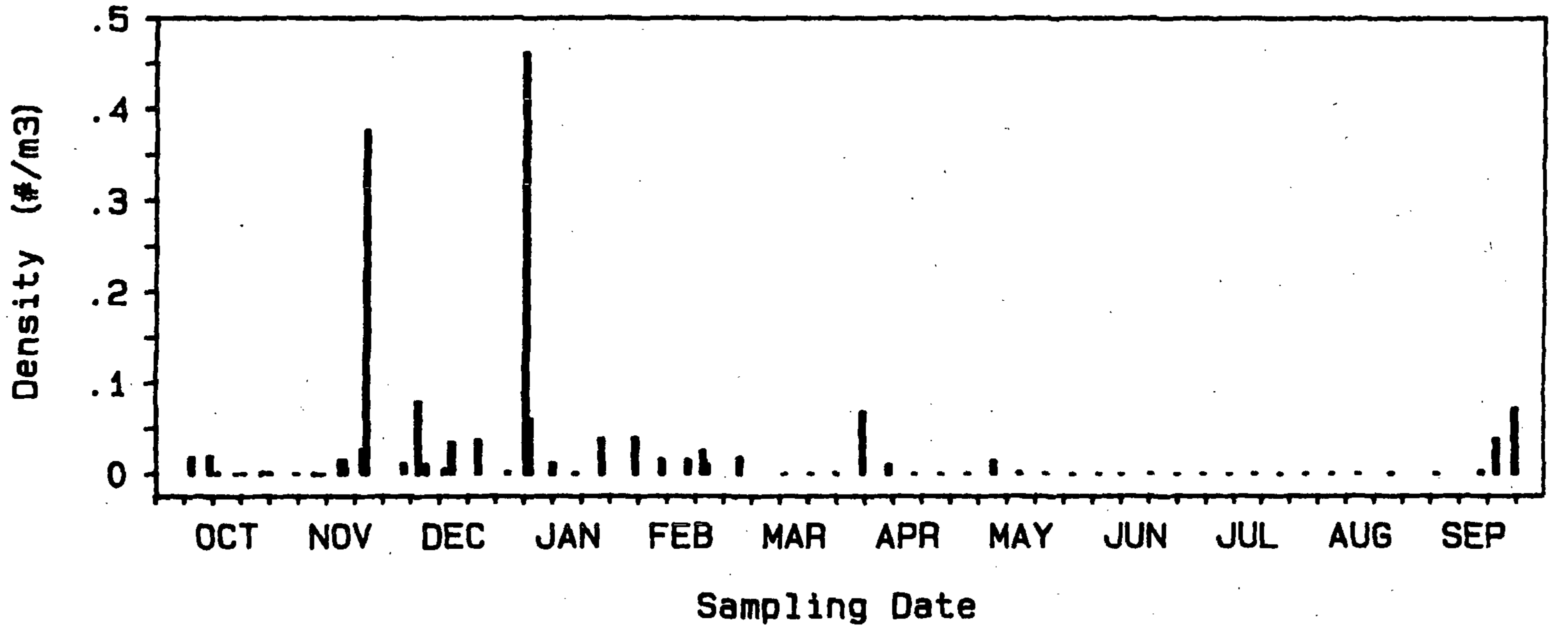

Figure 3-11

Mean Density of White Croaker Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

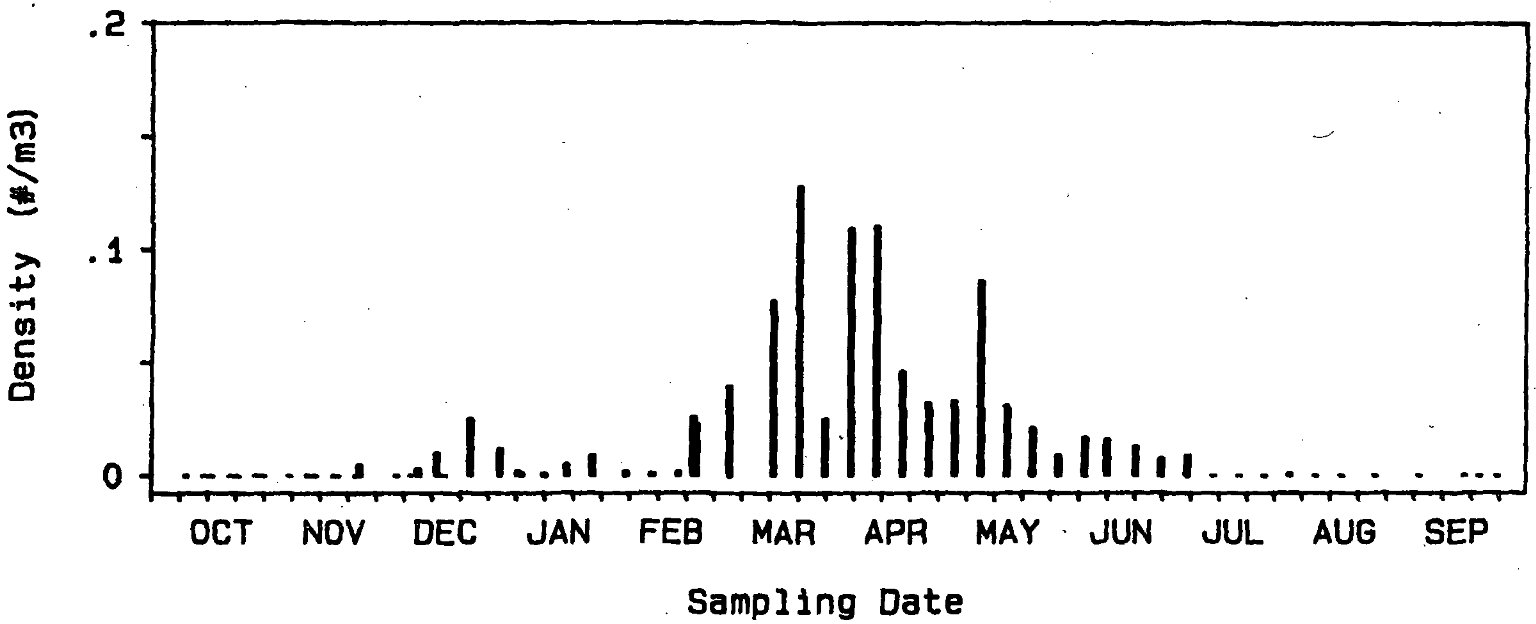

Figure 3-12

Mean Density of Rockfish Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

Entrainment of rockfish larvae exhibited a pronounced diel distribution (Figure 3-8). Rockfish densities were low during the day, increased to a peak during the evening (2100 to 2400 hours), followed by a gradual decline in densities through the night and early morning hours.

Engraulis mordax (Northern Anchovy)

Northern anchovy are an abundant pelagic species inhabiting bays and coastal waters. Northern anchovy was the fourth most abundant taxa in the entrainment program, constituting 7 percent of the larval fish collected (Table 3-3). They were most abundant in samples collected during November, December, and January (Figure 3-13). Densities of northern anchovy were less than $0.08/m^3$ throughout the one-year monitoring program with the exception of December 7 and January 4, when densities increased to 0.14 and $0.13/m^3$, respectively. Thirty-five percent of all northern anchovy larvae collected in entrainment abundance samples during the year were collected on these two sampling dates.

Northern anchovy ranged in length from 1 to 50 mm, with a mean length of 11.0 mm (Table 3-4). The length frequency distribution for northern anchovy is shown in Figure 3-7. Northern anchovy were the largest contributor to ichthyoplankton exceeding 7 mm in total length.

Northern anchovy occurred in higher densities at night than during the day (Figure 3-8).

Clinidae (Kelpfish)

The family Clinidae is a common group of relatively small, cryptic fish inhabiting the shallow, rocky areas in the Intake Cove and adjacent coastal waters. Clinidae constituted 6 percent of the larval fish collected during the entrainment monitoring program (Table 3-3). Clinidae were present in entrainment samples throughout the year (Figure 3-14). Densities were typically low ($<0.04/m^3$). The highest density of Clinidae ($0.09/m^3$) was observed on January 8.

Clinidae ranged in length from 3 to 28 mm, with a mean length of 6.1 mm (Table 3-4). The length frequency distribution for entrained Clinidae larvae is shown in Figure 3-7.

Clinidae were most abundant in samples collected during the early evening (1800 to 2100 hours) and least abundant during the daytime (Figure 3-8).

Gobiidae (Gobies)

Gobies are an assemblage of relatively small, cryptic fish species which inhabit the intertidal and shallow subtidal habitats of the Intake Cove and adjacent coastal waters. Gobies constituted approximately 5 percent of the larval fish collected during the entrainment monitoring program (Table 3-3).

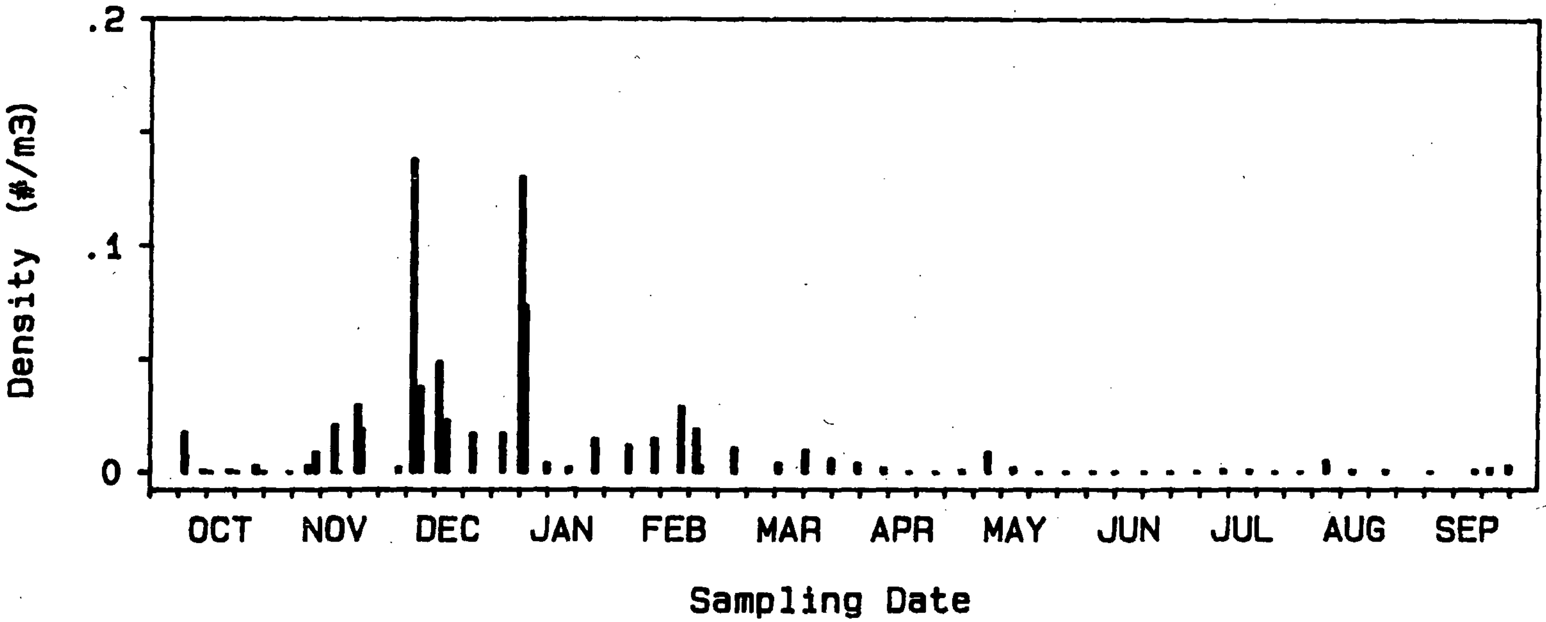

Figure 3-13

Mean Density of Northern Anchovy Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

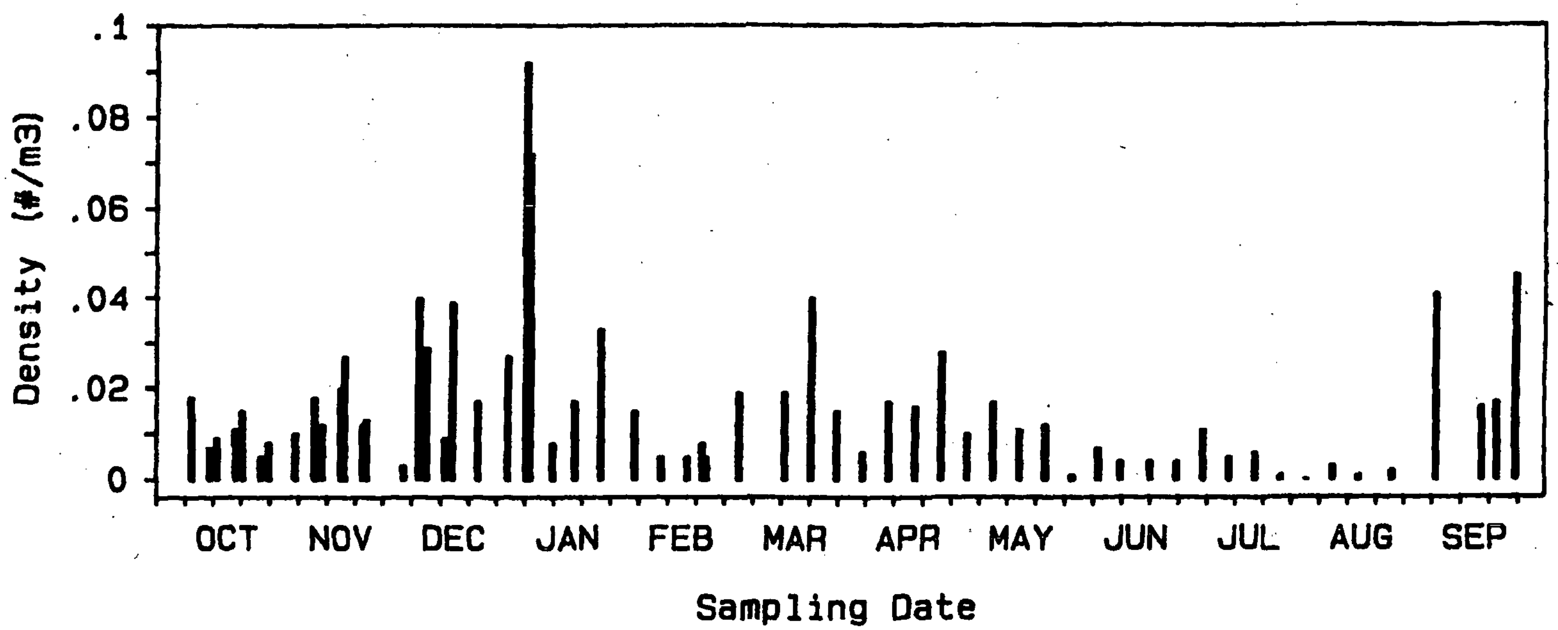

Figure 3-14

Mean Density of Clinids Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

Gobies were present in entrainment samples throughout the year (Figure 3-15) but showed no distinct seasonal pattern of occurrence. Goby densities were less than $0.05/m^3$ during all collections, with the exception of September 27, when densities approached $0.2/m^3$ during collections at the intake.

Gobies ranged in length from 2 to 18 mm, with a mean length of 4.0 mm (Table 3-4). Due to the small size of many of the goby larvae collected (Figure 3-7), many of the larvae could not be identified to species.

The diel distribution for entrained gobies is shown in Figure 3-8. Goby larvae were collected in greatest numbers during the evening (1800 to 2100 hours). Lowest densities were observed during the morning samples (0600 to 1200 hours).

Selected Macroinvertebrates

Densities of entrained macroinvertebrates collected at the Diablo Canyon Power Plant were substantially greater than densities of larval fish. Due to their small size and inadequacy of their taxonomic keys, many of the invertebrates could not be identified to genus or species. A complete taxonomic listing of the entrained invertebrates collected is presented phylogenetically in Appendix E.

The percent composition of two major invertebrate groups collected during the one-year entrainment abundance monitoring period is summarized below.

Group 1		
	Copepods	79%
	Ostracods	<1%
	Cladocerans	2%
	Mysids	<1%
	Cumaceans	<1%
	Euphausids	1%
	Chaetognaths	≤1%
	Subtotal	82%
Group 2		
	Amphipods	<1%
	Decapod Crustaceans	7%
	Molluscs	3%
	Echinoderms	<1%
	Isopods	<1%
	Cirripedia (Barnacles)	4%
	Bryozoans (Cyphonautes stage)	3%
	Polychaetes	<1%
	Other	≤1%
	Subtotal	18%

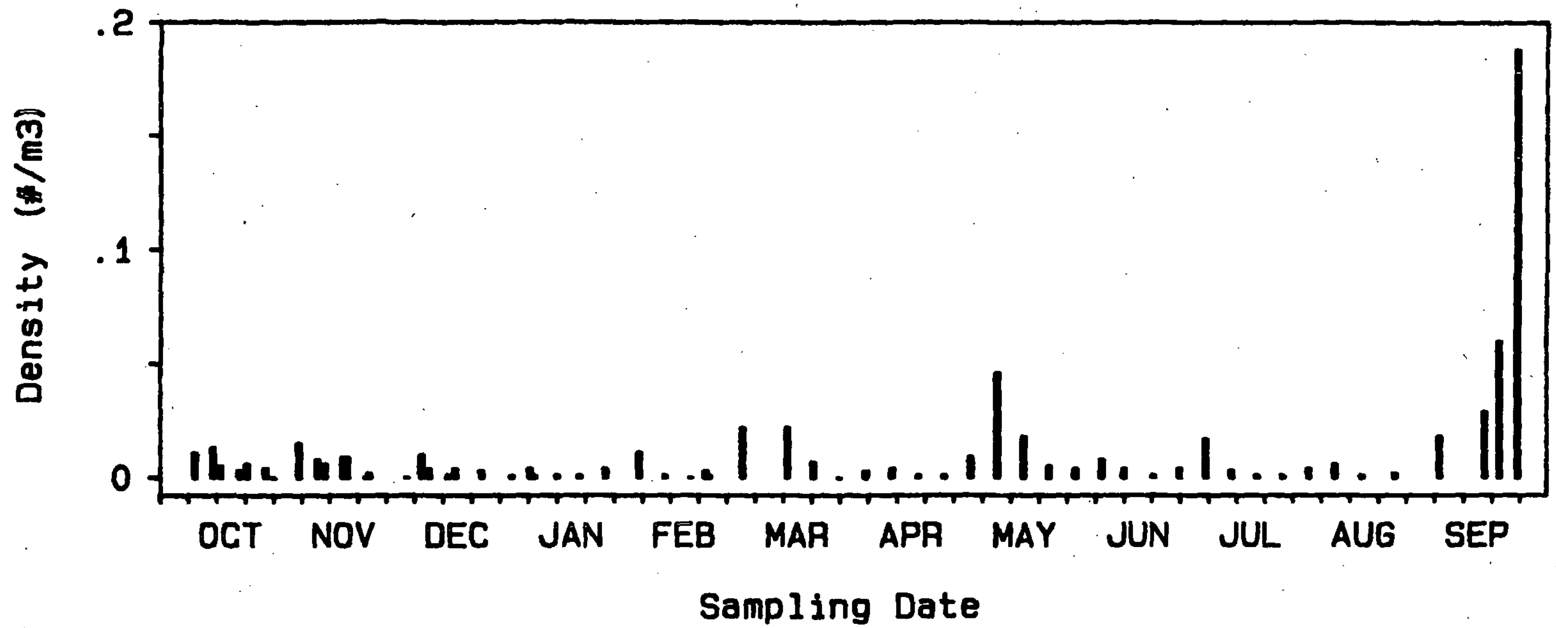

Figure 3-15

Mean Density of Gobies Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

The majority of invertebrates collected in the entrainment samples were copepods (79 percent). Group 1 constituted those taxa among the zooplankton community which were not selected as key target organisms for 316(b) demonstration purposes due to their high reproductive potential and broad geographic distribution (EPA 1977).

Selected macroinvertebrates from Group 2 which are discussed in further detail include the amphipods, decapod crustaceans (e.g., crabs, shrimps and prawns), and molluscs (e.g., snails, bivalves, and squid).

Amphipods

Amphipods were present in entrainment samples throughout the year (Figure 3-16). Of the three amphipod suborders collected (Gammaridea, Caprellidea, and Hyperidae), gammarid amphipods were numerically dominant (94 percent). Caprellids (skeleton shrimps) and Hyperids (a pelagic group of amphipods) accounted for approximately 6 and <1 percent, respectively, of all amphipods collected. Gammarid amphipod densities typically ranged between 1 and $2/m^3$ during the winter and spring. Densities increased during May and June followed by a decline in densities during late summer and fall. Peak gammarid amphipod densities were observed during May ($5/m^3$), June ($6/m^3$), and September ($8/m^3$). Entrained amphipods included both juvenile and adult stages.

Decapod Crustaceans

Decapods observed in entrainment abundance samples represented a highly diverse assemblage of crustaceans (crabs and shrimps). Decapod crustaceans (including the suborders Reptantia and Natantia) represented 7 percent of all invertebrates collected.

The Reptantia suborder can be subdivided into three sections - the brachyuran crabs, anomuran crabs and macruran crabs. Brachyuran crabs which were observed in the entrainment samples included cancer crabs, pea crabs, spider and decorator crabs, shore crabs, and pebble crabs. Anomuran crabs observed in entrainment samples included hermit crabs, porcelain crabs, sand crabs, and spiny mole crabs. Macruran crabs observed included ghost shrimp and mud shrimp.

Natantia collected at the Diablo Canyon Power Plant was comprised of an assemblage of taxa including caridean and penaeid shrimp. Table 3-5 presents the phylogeny and percent composition for the decapod crustaceans observed in entrainment abundance samples.

Brachyuran Crabs (True Crabs)

Brachyuran crabs were the most abundant decapod crustaceans collected in the entrainment samples and were observed throughout the monitoring period. Their abundance was highly variable, ranging from <1 to $110/m^3$ (Figure 3-17).

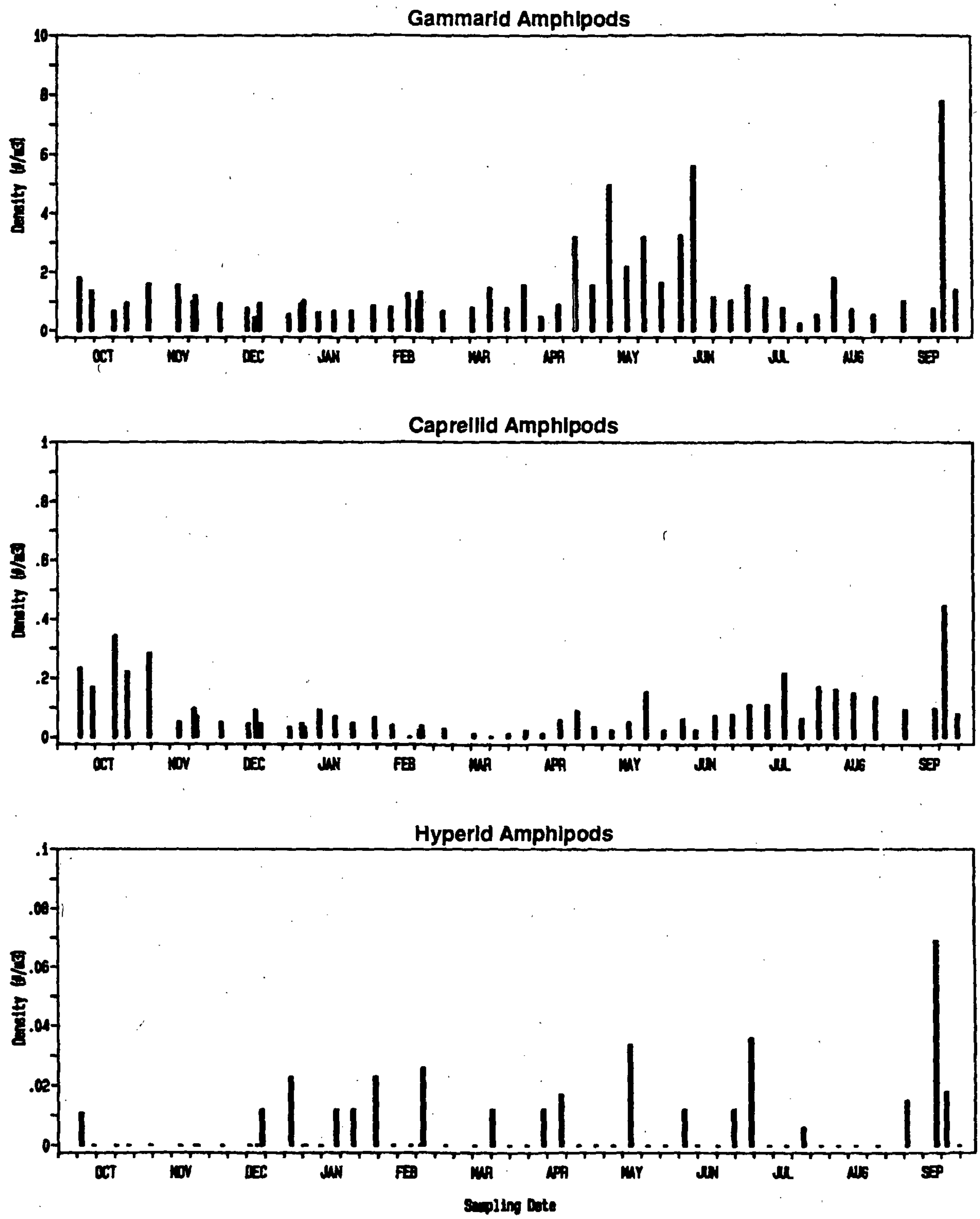

Figure 3-16

Mean Density of Amphipods Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

TABLE 3-5

DECAPOD CRUSTACEANS AND THEIR PERCENT COMPOSITION IN ENTRAINMENT SAMPLES COLLECTED AT THE DIABLO CANYON POWER PLANT, OCTOBER 1985 - SEPTEMBER 1986

Scientific Name	Common Name	Percent Composition Suborder
Reptantia		78
Brachyuran Crabs		
Cancridae	Cancer crabs	
Pinnotheridae	Pea crabs	
Majidae	Spider/Kelp crabs	
Grapsidae	Shore crabs	
Xanthidae	Pebble crabs	
Anomuran Crabs		
Paguridae	Hermit crabs	
Porcellanidae	Porcelain crabs	
Albuneidae	Spiny mole crabs	
Hippidae	Sand crabs	
Macruran Crabs		
Callianassidae	Ghost shrimp	
Upogebiidae	Mud shrimp	
Natantia		22
Caridean Shrimp		
Crangonidae	Bay shrimp	
Hippolytidae	Hippolytid shrimp	
Penaeidean Shrimp		
Sergestidae	Ocean shrimp	
		100

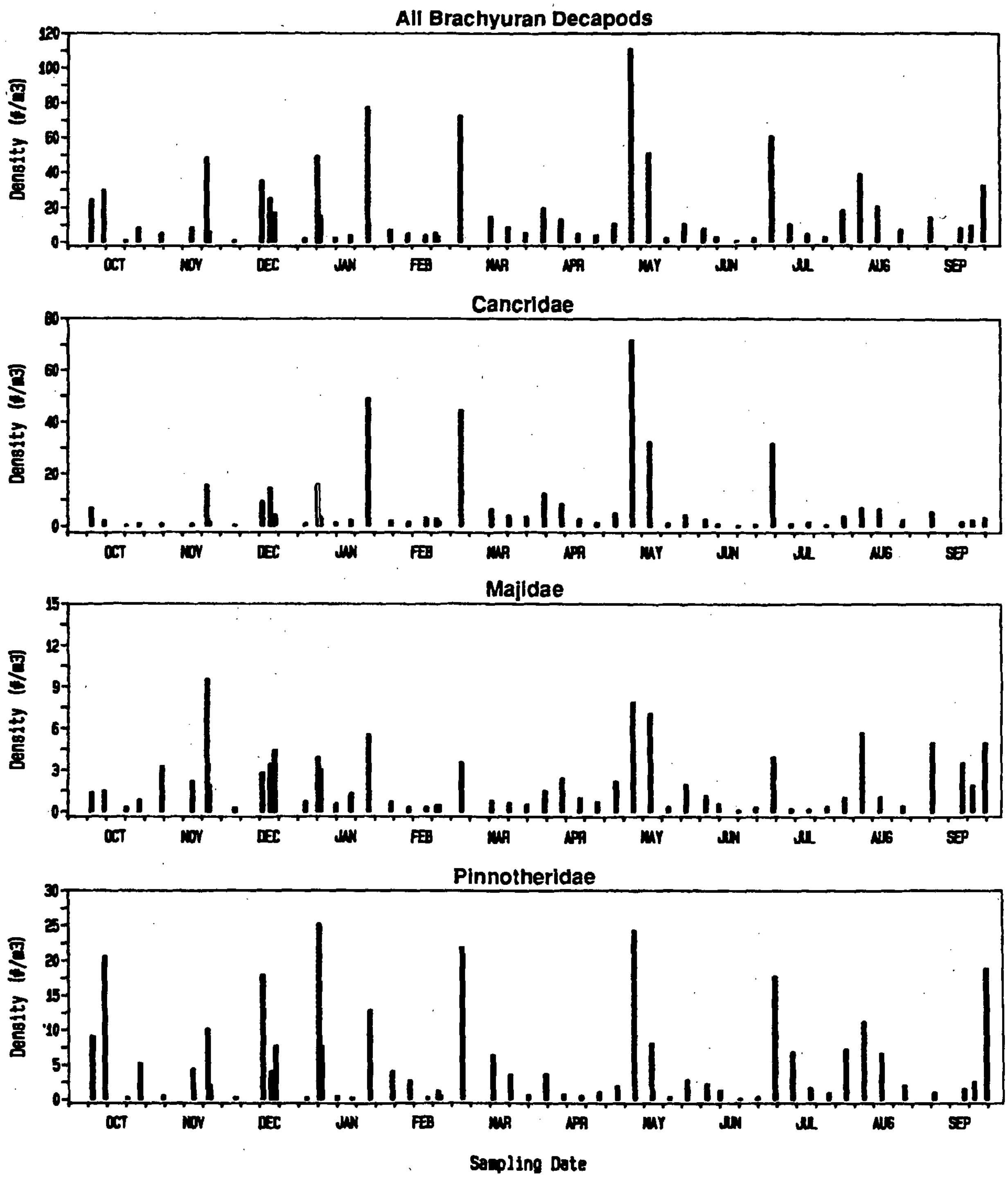

Figure 3-17

Mean Density of Brachyuran Decapods Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

The majority of brachyuran crabs collected (43 percent) were Cancer crabs. Cancer crabs, virtually all of which were zoeal stage, were present in the entrainment samples throughout the year, and no seasonal pattern was evident (Figure 3-17). Based on the relative abundance of adult *Cancer* spp. crabs in the vicinity of the Diablo Canyon Power Plant, it is likely that the majority of larval Cancer crabs entrained were rock crabs (*Cancer antennarius)*, yellow crabs (*C. anthonyi*) or red crabs (*C. productus*) although other species of Cancer crabs have been observed in the area. Peak densities of *Cancer* spp. (>40/m^3) occurred in entrainment collections in late January, early March, and mid-May. No diel pattern was evident in the densities of Cancer crabs collected in entrainment samples.

The seasonal abundance of spider and decorator crabs (Majidae) and pea crabs (Pinnotheridae) are also illustrated in Figure 3-17. There is no clear seasonal distribution for these two families. Majidae and Pinnotheridae constituted 11 and 31 percent, respectively, of the brachyuran crabs collected.

Anomuran Crabs

Four families of anomuran crabs (Paguridae, Porcellanidae, Albuneidae, and Hippidae) were observed in the entrainment samples. The majority (63 percent) of anomuran crabs collected were Paguridae followed by Porcellanidae (28 percent), Albuneidae (9 percent), and Hippidae (<1 percent). Figure 3-18 illustrates the seasonal abundance of anomuran crabs (all families combined), hermit crabs (Paguridae) and porcelain crabs (Porcellanidae) collected during the entrainment monitoring program.

Natantia

Natantia were present in entrainment samples throughout the year. Densities were generally higher during the spring and summer months than during the fall and winter. Although most shrimps belonging to the suborder Natantia were not identified to the family level, Crangonidae (bay shrimp), Hippolytidae (hippolytid shrimp), and Sergestidae (sergestid shrimp), were present in the samples. The seasonal distribution of all Natantia, combined is illustrated in Figure 3-19. The Natantia collected during the entrainment monitoring program included all larval stages (prezoea, zoea, and megalopa).

Molluscs

Molluscs observed in the entrainment abundance samples included Polyplacyophora (chitons), gastropods (snails, nudibranchs and opistobranchs), pelecypods (bivalves such as clams and mussels), and cephalopods (squid and octopus). Molluscs represented 3 percent of all invertebrates collected during the entrainment monitoring period. Gastropods, pelecypods, and cephalopods constituted 92, 8 and <1 percent, respectively, of the molluscs collected. Figure 3-20 illustrates the seasonal distribution for all molluscs combined and the three dominant classes. Gastropods typically ranged from approximately 5 to 20/m^3. On July 8, post veliger

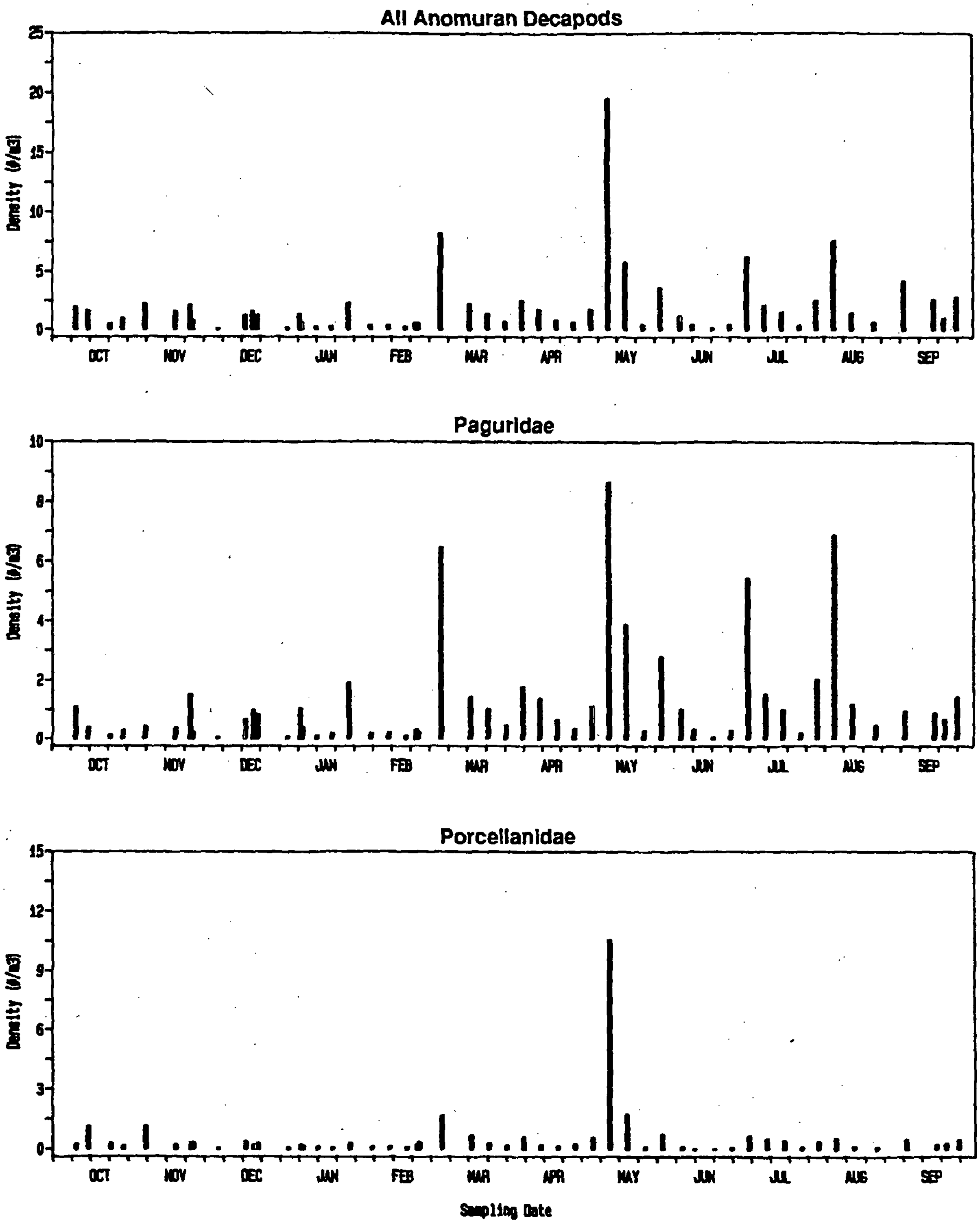

Figure 3-18

Mean Density of Anomuran Decapods Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

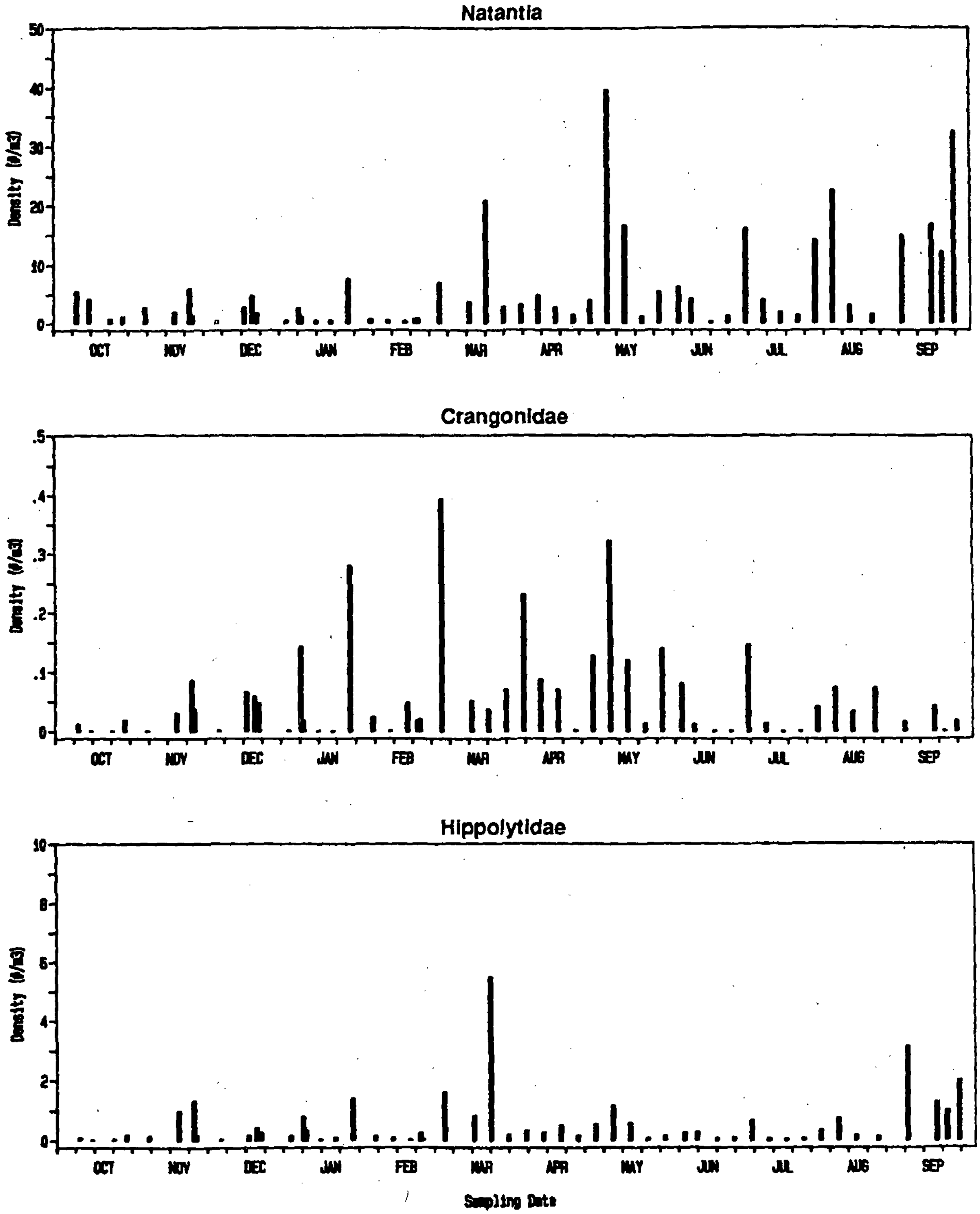

Figure 3-19

Mean Density of Shrimps Collected from Entrainment Samples
at the Diablo Canyon Power Plant, October 1985 - September 1986

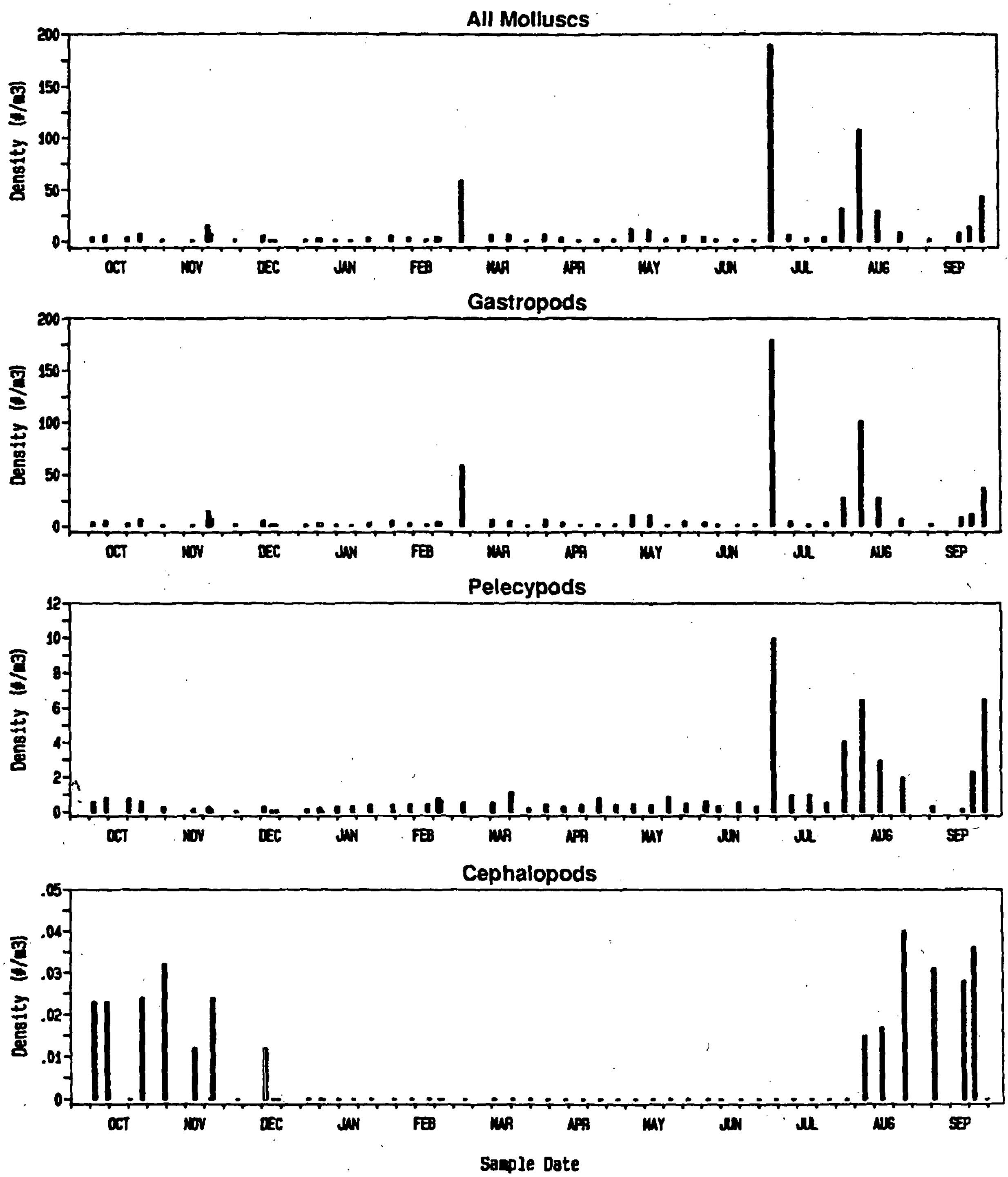

Figure 3-20

Mean Density of Molluscs Collected
from Entrainment Samples at the Diablo Canyon Power Plant,
October 1985 - September 1986

gastropod densities peaked at $189/m^3$. Although the species are unknown, the post veligers were determined not to be abalone. Pelecypod molluscs followed a similar seasonal distribution to gastropod molluscs, however, their densities were considerably lower (ranging from 0 to $2/m^3$). Cephalopod molluscs (70 percent squid and 30 percent octopus) were observed from July through December. Densities of cephalopods were low ($<0.05/m^3$) even during peak months of abundance. The high variability in densities of larval molluscs is indicative of the patchy temporal distribution of many of the planktonic invertebrates susceptible to entrainment.

3.2 Entrainment Survival

The Diablo Canyon Power Plant entrainment survival study was designed to provide a quantitative basis for estimating the potential survival of selected larval fish and macroinvertebrates following passage through the cooling water system. Specific objectives of the study, as outlined in the Diablo Canyon Power Plant 316(b) Study Plan (Appendix A), were:

1. To estimate the initial and long-term (96-hour) survival of selected fish and macroinvertebrates entrained into the Unit 1 and 2 cooling water system; and

2. To examine the relationship between entrainment mortality and discharge temperature, chlorine exposure during biofouling control, and size class (body length) of the organisms.

Since investigating entrainment survival of all species entrained was not feasible, the entrainment survival program was designed to collect larval fish during the winter period, when rockfish densities were expected to be at their maximum. Because of the low densities of entrained organisms (Section 3.1.3), particularly rockfish, the numbers of larval fish collected were insufficient to effectively quantify entrainment survival. The experimental design, methods, and results of the entrainment survival program are presented in the following sections. The limited results are used, in combination with results of entrainment survival studies conducted at other sites, to characterize entrainment survival potential at the Diablo Canyon Power Plant.

3.2.1 Experimental Design

The entrainment survival program was designed to determine the proportion of selected larval fish and macroinvertebrates not surviving entrainment. Protocol for this study included the paired collection of organisms from the intake and discharge of the cooling water system using identical sampling gear and methodology. The intake samples are used to account for mortality resulting from sampling and other natural causes not related to entrainment. The proportion of entrained individuals of each selected taxon not surviving entrainment can then be estimated by determining the proportion dead in the samples collected from the discharge relative to the proportion dead in the control samples collected from the intake. The experimental design was developed to quantify initial entrainment mortality and delayed mortality over a 96-hour observation period.

Primary emphasis of the entrainment survival program was focused on larval fish, primarily rockfish. A winter sampling effort was selected based on the seasonal distribution of larval fish observed in offshore plankton collections made in the vicinity of the Diablo Canyon Power Plant during 1976-77 (Icanberry et al. 1978). Because of the diel distribution observed for ichthyoplankton, particularly rockfish (Figure 3-8), the survival collections were conducted during the late evening hours to increase the probability of collecting larval fish.

The compilation of entrainment survival results from the Diablo Canyon Power Plant and other sites under various discharge temperature regimes provides the information necessary to assess the biological effectiveness of various alternative intake technologies described in Section 6.2.

3.2.2 Methods

Entrainment survival samples were collected from the Unit 1 cooling water system from December 1985 to March 1986. Intake collections were made at a mid-depth sampling location, which during the entrainment support studies (Section 3.1.1), was shown to have higher larval fish densities than samples collected from other depths at the intake. Discharge collections were made from the center, mid-depth location at the discharge throttling gate structure (Figure 3-3). Entrainment survival collections were limited to a 15-minute duration to reduce the stresses associated with sample collection. Logistics associated with entrainment survival collections limited sampling to approximately one collection per hour.

3.2.2.1 Field Collection

Entrainment survival samples were simultaneously collected from intake and discharge locations using a sampling system specifically designed to reduce organism stress (Figure 3-21). The entrainment survival collection system utilized a vacuum concept to concentrate and collect the organisms without incurring the added stress associated with passage through the collection pump. The entrainment survival collection device utilized an angled screen to divert larval fish and macroinvertebrates into a codend, which was subsequently used to transport the collected organisms.

Flow into the collection system was provided by a 10.2-cm recessed-impeller pump located downstream of the entrainment survival collection device. The volume of water sampled and the flow rate were measured using calibrated Sparling Master-Flo inline flowmeters. A flow rate of approximately 600 l/min was maintained during entrainment survival collections. The sample collection systems at both the intake and discharge were situated on specially built platforms near the water surface to reduce collection stress associated with pumping head.

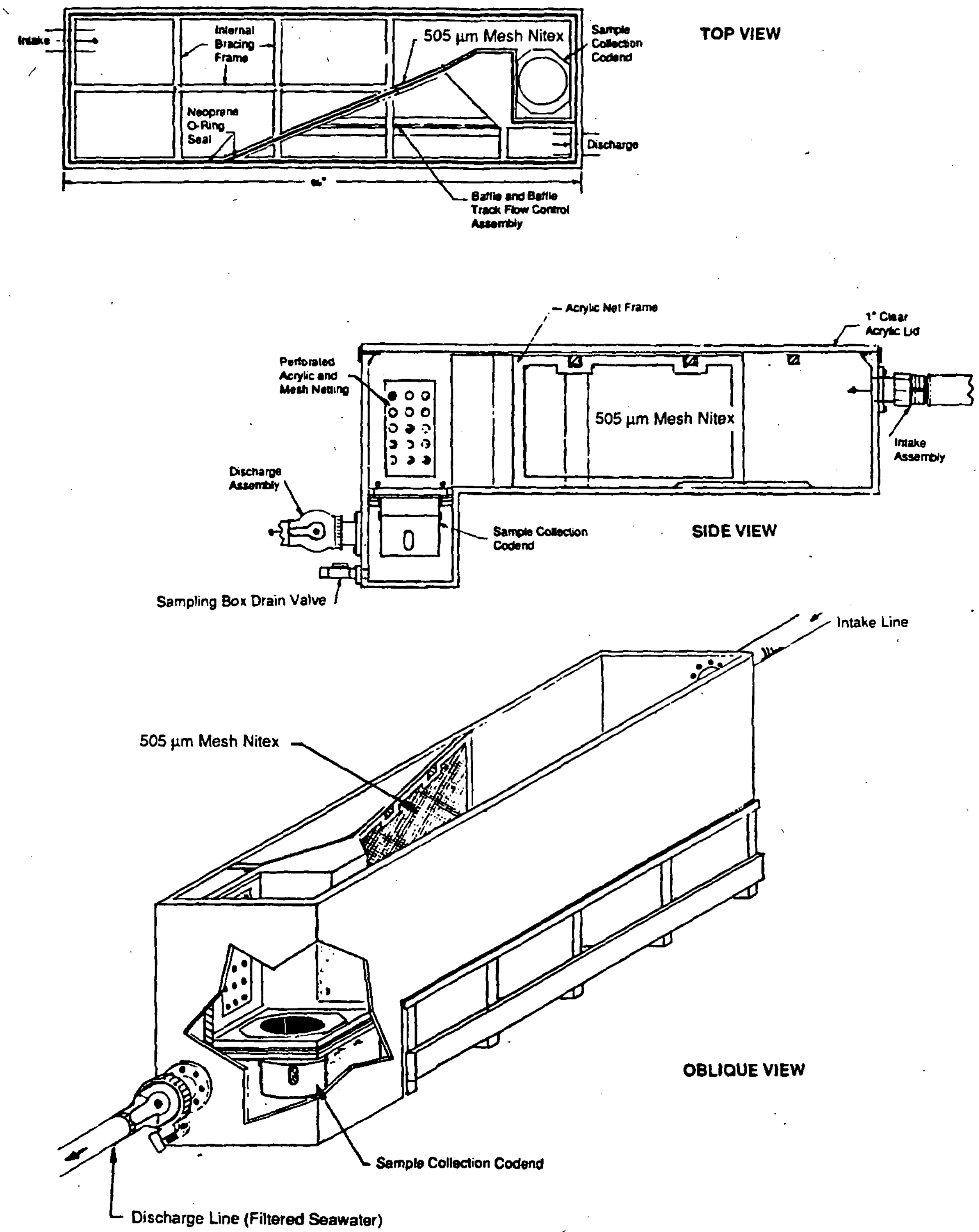

Figure 3-21

Entrainment Survival Sampling Equipment
Used at the Diablo Canyon Power Plant

At the beginning of each collection, the sampling system was filled with filtered seawater and sealed. When the intake and discharge sampling systems were both filled, the flow to be sampled was diverted into the collection box and the 15-minute sampling period began. Entrainment survival collections made at the discharge were delayed 5 minutes to allow for transit time of cooling water from the intake sampling location to the discharge. Cooling system operating conditions (the number of circulating water pumps in operation, intake and discharge temperatures) were recorded for each entrainment survival collection.

Organisms and debris entered the collection system and were diverted by the angled screen of 505-µm mesh into the back of the collection system, where they were retained in a screen-walled collection container. At the end of the 15-minute sampling period, the sampling pump was turned off and the collection device drained while the angled screen and sides of the collection device were gently rinsed with filtered seawater. The entrainment survival sample retained in the codend was immediately transported to the on-site seawater laboratory for processing.

3.2.2.2 Laboratory Processing

In the laboratory, intake and discharge samples were placed in an ambient-temperature water bath and sorted using a magnifying illuminator. Live larvae were removed from the sample using a large-bore pipette and were placed in filtered seawater. After all live larvae had been removed from the sample, dead larvae were placed in labeled vials and preserved in formalin for subsequent identification and length measurements. Live larvae were separated and placed in 750-ml, screen-walled containers (5 individuals/container) which were suspended in a flow-through seawater system. Organisms were observed at 3-, 6-, 12-, 24-, 48-, 72-, and 96-hour intervals from the time of collection. The numbers of live and dead larvae at each observation were recorded and dead larvae were preserved for later identification. Larvae were not fed during the delayed mortality holding period. At the completion of the test all larvae were identified, and total length was measured to the nearest 0.1 mm.

Entrainment Survival Support Studies

Several tests were conducted to verify and document the sampling methods. All aspects of the entrainment survival program were subject to a strict quality assurance program.

Control tests were performed to evaluate the mortality associated with (1) sample transport from the intake and discharge to the laboratory, (2) laboratory processing, and (3) subsequent survival in the laboratory seawater system over a 96-hour observation period. Larval cabezon, (*Scorpaenichthys marmoratus*) collected as eggs in the field and hatched in the laboratory, were used during these control tests. Results of these tests failed to show any mortality that was attributable to sample transport, initial processing and/or holding techniques for the 96-hour observation period.

Laboratory tests were also conducted on larval squid (*Loligo opalescens*) to evaluate their tolerance to short-duration exposures to elevated water temperatures typical of conditions encountered during entrainment. Larval squid, acclimated at an average temperature of 12.6 C, were exposed to elevated temperatures of 23.9 and 24.2 C. In one set of tests, the larval squid were exposed to the elevated temperature for 2 minutes before being returned immediately to the ambient temperature. In the second set of tests, the larval squid were exposed to the elevated temperature for 2 minutes followed by a gradual (15-minute) return to ambient temperatures. Control tests were performed for each replicate experiment. Activity levels and mortality were observed periodically over a 48-hour period.

Results of the larval squid tests failed to show any initial or delayed mortality (through 48 hours) that was attributable to exposure to elevated water temperatures similar to those that would be experienced by the organisms during entrainment. Furthermore, no consistent pattern was apparent in activity levels of the larval squid exposed to the elevated temperatures when compared to control levels. Results of these laboratory studies are consistent with the findings of similar tests with larval fish and other macroinvertebrates, and demonstrate that entrainment mortality is typically independent of discharge temperatures less than 30 C (86 F). The laboratory tests conducted with squid larvae included only the thermal component associated with entrainment, and did not simulate the effects of mechanical stresses (pressure changes, shear forces, etc.) actually experienced by organisms during entrainment. The numbers of larval squid collected during the field collections of the entrainment survival program were insufficient to quantify the mortality attributable to mechanical stresses.

Analytical Methods

An entrainment mortality probability model has been developed (PG&E 1981 a,b) to analyze results of entrainment survival studies. The model is based on the following assumptions:

1. All individuals have an equal probability of dying from natural causes.
2. All individuals have an equal probability of dying from sampling.
3. All individuals have an equal probability of dying from entrainment.
4. The probability of dying from natural causes and sampling is identical for all individuals collected from the intake and discharge.

On the basis of these assumptions, the proportion of organisms not surviving entrainment can be estimated as the relative difference between the observed proportions dead in the discharge and the intake (Fleiss 1973):

$$P_e = P_D - P_I/(1 - P_I)$$

where

P_e	=	estimated proportion not surviving entrainment
P_D	=	estimated proportion dead in discharge
P_I	=	estimated proportion dead in intake.

P_e is a ratio estimate, and its distribution is complex because both the numerator and denominator vary between samples. The limiting distribution of the ratio estimate, as sample size becomes large, is normal (Cochran 1977). Because P_e is a ratio estimate, it is not unbiased (Cochran 1977). The nature and extent of the bias was investigated in simulation studies. Simulation results showed that for intake sample sizes of 200 individuals and discharge sample sizes of 100 individuals, the bias in P_e was minimal, except when intake mortality P_I was large. For $P_I = 0.85$ and $P_e = 0.15$, P_e was underestimated by 30 percent. When intake and discharge sample sizes were increased to 400 and 300 individuals, respectively, the bias became negligible (PG&E 1981 a,b).

3.2.3 Results

A total of 95 larval fish representing 6 families were collected in the Diablo Canyon entrainment survival program (Table 3-6). Of the total number of larvae, 65 were collected at the intake and 30 were collected at the discharge. Northern anchovy and cabezon, the two most abundant taxa, collectively constituted 55 percent of the larval fish in the entrainment survival collections. Only one larval rockfish (*Sebastes* spp.) was collected during the study. The density of larval fish during the entrainment survival collections averaged 0.27 fish/m^3 sampled at the intake and 0.12/m^3 at the discharge. As noted above, species-specific sample sizes of several hundred are required to produce valid entrainment survival estimates.

Examination of larval fish and macroinvertebrates (including amphipods and mysids) confirmed that organisms were alive in samples collected from the Unit 1

TABLE 3-6

SUMMARY OF INITIAL SURVIVAL OBSERVATIONS FOR ENTRAINED LARVAL FISH

Taxa		Intake				Discharge			
Scientific Name	Common Name	Number Collected	Number Alive	Length (mm) Mean	Range	Number Collected	Number Alive	Length (mm) Mean	Range
Engraulis mordax	Northern anchovy	18	3	13.2	6-18	9	0	11.6	7-16
Clinidae	Clinid	7	0	6.3	5-9	1	0	7.0	--
Gibbonsia spp.	Kelpfish	8	2	6.0	5-8	4	1	8.0	6-11
Heterostichus rostratus	Giant kelpfish	1	0	5.0	--	0	0	--	--
Sebastes spp.	Rockfish	1	0	3.0	--	0	0	--	--
Hexagrammos decagrammus	Kelp greenling	0	0	--	--	1	1	7.0	--
Oligocottus spp.	Sculpin	2	2	4.5	4-5	3	2	4.2	4-5
Scorpaenicthys marmoratus	Cabezon	18	13	3.4	3-6	8	7	4.4	4-6
Cottidae	Sculpin (unid)	6	0	3.0	2-4	3	0	3.0	3-3
Genyonemus lineatus	White croaker	2	1	6.5	5-8	0	0	--	--
Unidentified Larvae		2	1	--	--	1	0	--	--
Total		65	22			30	11		

cooling water discharge are shown below. Initial survival observations for larval fish (all taxa combined) collected at the intake and discharge are shown below.

	Number Alive	Number Dead	Initial Percentage Survival
Intake Collections	22	43	34
Discharge Collections	11	18	37

Intake temperatures averaged 13.7 C (S.D. = 0.4) and discharge temperatures averaged 24.0 C (S.D. = 0.5) during the entrainment survival collections.

Although the number of larval fish collected was small, general trends in species-specific survival were evident. Initial survival of northern anchovy larvae was low in contrast to larval cabezon which had high initial and long-term survival. The numbers of larval fish collected were insufficient to detect trends in size-specific survival patterns for the various species entrained.

It was concluded from these studies that entrainment survival at Diablo Canyon Power Plant could not be adequately quantified because of the low numbers of larval fish collected. Interpretation of the entrainment survival results was difficult due to the high variability between species (i.e., cottids typically exhibit high survival compared to northern anchovy). Although the number of organisms observed was insufficient to quantify entrainment survival, it was evident that larval fish and mysids were alive in samples collected from the Unit 1 discharge.

3.2.4 Entrainment Survival Discussion

Entrained larval fish and invertebrates are exposed to a variety of potential stresses which affect their survival including physical, thermal, and chemical (biocidal) stress. In the past, few organisms were believed to survive entrainment, but a number of detailed quantitative investigations at power plants indicate that high entrainment survival has been observed under many plant operating conditions (see Appendix B for a discussion of entrainment survival).

Results of entrainment survival studies conducted at other power plants demonstrate that at discharge temperatures below 30 C (86 F), survival of entrained fish larvae and invertebrates is high (>75 percent survival). Zooplankton studies conducted at Morro Bay Power Plant, for example, indicated an average net mortality of 6 percent for adult copepods (Icanberry and Adams 1974). Mortality for other invertebrate groups (immature and soft-bodied forms) was even less. Entrainment mortality at three other power plants (based on abundance and survival estimates by group) was also low, 5, <1, and 9 percent at Humboldt, Potrero, and Moss Landing power plants, respectively. Survival of striped bass larvae and juveniles were estimated to be 80 percent at the Pittsburg and Contra Costa power plants. Survival of Pacific herring, a sensitive clupeid species, averaged 79 percent at the Potrero Power Plant (PG&E 1980). Survival of the opossum shrimp, *Neomysis mercedis,* averaged 90 percent at Pittsburg and 72 percent at Contra Costa, and survival of gammaridean amphipods averaged 96 percent at Pittsburg and 95 percent at Contra Costa (PG&E 1981a, b). Entrainment survival was also high for macroinvertebrates collected at the Moss Landing Power Plant: 99 percent for amphipods and 93 percent for mysids (PG&E 1983). During each of these studies, entrainment survival for larval fish exceeded 75 percent and survival of macroinvertebrates exceeded 90 percent.

The laboratory thermal tolerance studies show that most species of larval fish and macroinvertebrates tested are capable of tolerating exposure to temperatures less than 30 C (86 F) for durations typical of cooling water transit times, although thermal tolerance varies widely among species and among life stages within species (see Appendix B). An analysis of 9,980 hourly discharge temperature records for Units 1 and 2 for the period from July 1 through December 31, 1987 was conducted. During this period, Unit 1 conduits were heat treated on three occasions and Unit 2 conduits were heat treated once. Discharge temperatures did not exceed 30 C at Unit 2 and were greater than 30 C approximately 0.1 percent of the time at Unit 1 (Figure 3-22). Thermal stresses are therefore not expected to cause significant entrainment mortality at the Diablo Canyon Power Plant.

Laboratory studies of zooplankton thermal tolerance suggest that discharge temperatures in the range expected at Diablo Canyon Power Plant (up to 29 C or 84 F) are tolerable when exposure times are short. Lauer et al. (1974) reported that *Acartia tonsa,* a common copepod of California estuaries and to a lesser extent marine waters, can tolerate 15-minute exposures to temperatures as high as 33.5 C (92.3 F). Adams and Price (1974) exposed larval red abalone (*Haliotis rufescens*) to elevated temperature regimes similar in nature to those expected at the Diablo Canyon Power Plant for abalone veligers acclimated to about 17.5 C or 63.5 F (the maximum ambient temperature reported at the Diablo Canyon Power Plant during the period 1972-1974). They found that ΔTs as high as 13.3 C (24 F) for 10 minutes were required before significant ($P<0.05$) increases in mortality were observed. Thermal effects experiments on the fertilization, embryonic development, and settlement of red abalone were completed and reported in recent thermal effects studies (TERA 1982). The tests confirmed earlier findings that the veliger stages were tolerant of short-term exposures, up to three hours, to temperatures of 8 to 24.8 C (46 to 76.6 F), but found that the early stages were less thermally tolerant. Laboratory thermal tolerance tests similar to those performed with red abalone indicated that the early developmental stages of black abalone are more temperature tolerant than the red abalone's early life stages. The optimum temperature for early development of black abalone from fertilized egg through mid-cephalic tentacle larvae occurred within the range of 10 to 22 C (50 to 72 F). As was found in the red abalone tests, the later larval stages of black abalone are more

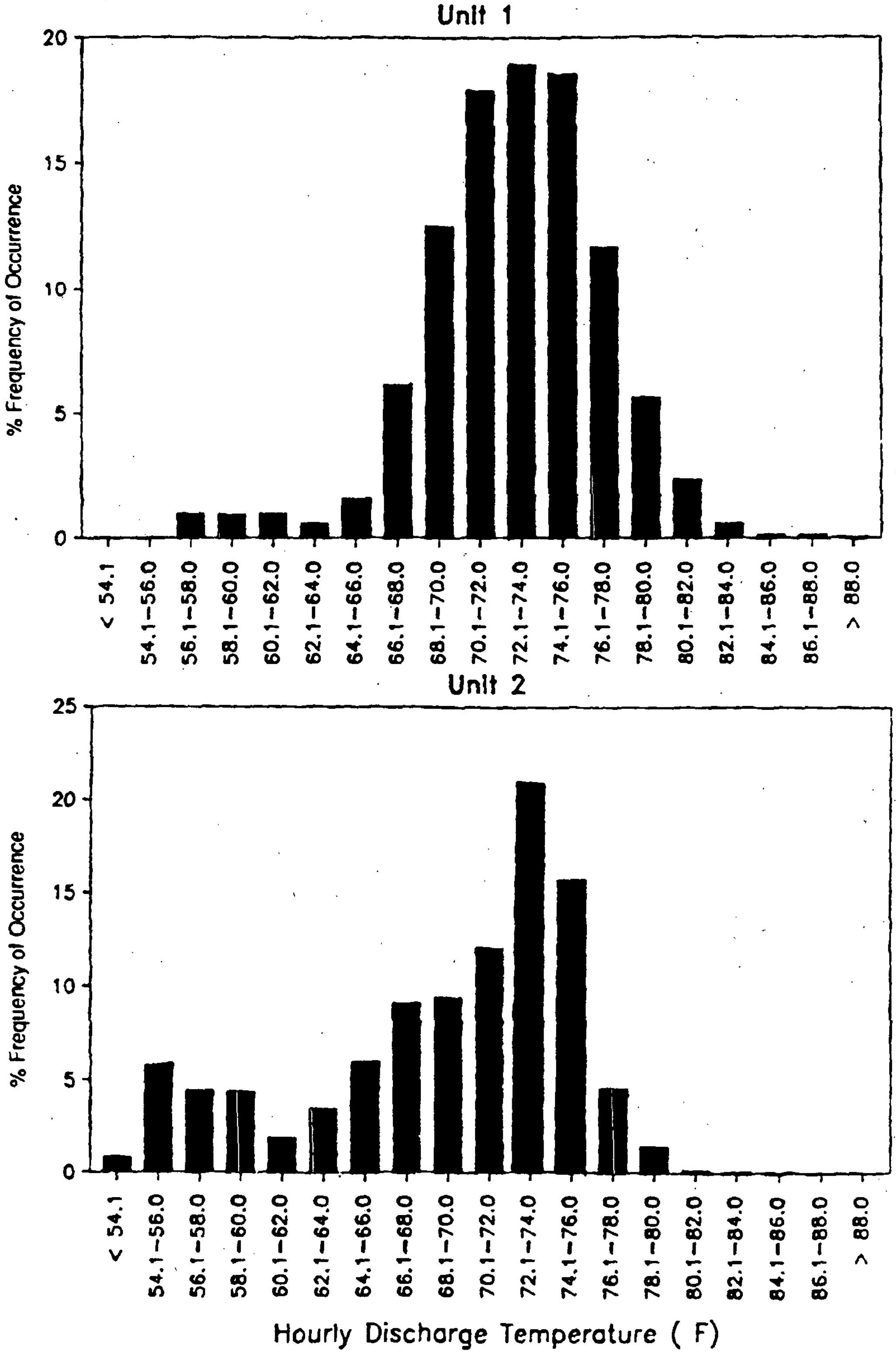

Figure 3-22

Frequency Analysis of Hourly Discharge Temperatures for the Diablo Canyon Power Plant, July - December 1987 thermally tolerant than the earlier embryonic stages. The laboratory data indicate that larvae exposed to temperatures between 8 and 24 C (46 to 75 F) for periods of less than three hours demonstrated no increased mortality due to temperature differences. Based on these and other thermal tolerance studies reported in the literature, it is unlikely that thermal entrainment exposures for the duration experienced at the Diablo Canyon Power Plant will cause a significant increase in the mortality of entrained plankton.

Entrained organisms appear to be tolerant of the physical stresses associated with condenser passage, based on the results of condenser-simulator studies. The only physical stress that has been isolated and quantified in the laboratory is pressure. Pressure increases at the circulating water pump are not expected to cause significant entrainment mortality, but pressure decreases greater than one atmosphere (approximately 15 psi) across the condensers may damage entrained organisms. The pressure profile for the Diablo Canyon Unit 1 cooling water system (Figure 2-6) shows that a pressure increase occurs at the circulating water pump discharge. Pressure decreases occur during passage through the condensers. These pressure changes could potentially adversely affect entrainment survival, particularly for larval fish (discussed in Appendix B). In addition to pressure changes, organisms entrained at the Diablo Canyon Power Plant are subject to stress associated with turbulence and shear forces during transit through the discharge structure. However, actual field tests of entrainment survival showed no significant entrainment mortality for zooplankton exposed to the pressure changes and turbulence associated with the Diablo Canyon Power Plant cooling water system (Wilson 1977). These field tests were conducted when circulating water pumps were in operation but no heat was being added at the condensers (Wilson 1977). Percent mortality of all zooplankton grouped together in discharge samples was less than 4 percent. This mortality level was not significantly (P=0.05) more than that observed in intake (control) samples. This suggests that mechanical effects of entrainment at the Diablo Canyon Power Plant are minimal. Since it is likely that thermal mortality will be similarly negligible, the probability of invertebrates surviving entrainment is high.

Entrainment survival will be reduced during periods of biofouling treatment (which includes heat treatment and chlorination). Heat treatment is done periodically by recirculating cooling water until temperatures are between 37 and 40 C (100-105 F) for 1-1.5 hours. Between 1985 and 1987, a total of 10 heat treatments were conducted at the Diablo Canyon Power Plant. The dates and conduits heat treated are summarized in Chapter 2 (Section 2.1.2). At the Diablo Canyon Power Plant, chlorination is used for slime control. It is conservatively assumed that no organisms survive entrainment during the short periods that they are exposed to heat treatment and chlorination.

On the basis of results drawn from the laboratory and field studies discussed above, and on the species composition and abundance entrained, it was concluded that overall entrainment survival at the Diablo Canyon Power Plant is high. Based on operating conditions experienced during the entrainment monitoring period at Diablo Canyon Power Plant (thermal exposure limited to 5-minute durations at <30 C and minimal periods of chlorination), survival of entrained ichthyoplankton and macroinvertebrates is expected to exceed 75 and 90 percent, respectively.

3.3 Entrainment Summary

The one-year entrainment abundance program provided quantitative information on the species composition and seasonal distribution of entrained ichthyoplankton and selected macroinvertebrates. The program also provided quantitative information on the size and diel distribution patterns of entrained ichthyoplankton.

Larval fish (representing 28 families) were collected throughout the one-year monitoring period. Sculpins and cabezon (Cottidae), white croaker (Sciaenidae), rockfish (Scorpaenidae), and northern anchovy (Engraulidae) represented 41, 14, 9 and 7 percent, respectively, of all larval fish collected. The seasonal density distribution for all larval fish combined was highly variable and not predictable. Densities (No./m^3) were typically low, generally ranging from 0.05 to 0.30/m^3. The high variance in ichthyoplankton densities was primarily attributable to patchy seasonal distributions of several taxa in the vicinity of the Diablo Canyon Power Plant. Cabezon were collected with highest densities (0.04 to 0.10/m^3) from November through January. Although white croaker were the second most abundant taxa collected, 45 percent of all white croaker were collected on two sampling dates (November 26 and January 8). Rockfish showed a pronounced seasonal distribution with the highest densities (0.05 to 0.15/m^3) occurring from February through May. Northern anchovy were dominant in samples collected between November and January, when densities ranged between 0.01 to 0.14/m^3.

Larval fish lengths ranged from 1 to 50 mm, 95 percent of which were less than 11 mm. Larval fish greater than 11 mm in total length were predominantly northern anchovy.

Densities of larval fish increased during the evening then gradually decreased during the early morning hours. Rockfish and cabezon showed the most pronounced diel distributions of the entrained larval fish. Approximately 70 and 65 percent of cabezon and rockfish, respectively, were collected between 1800 and 2400 hours.

Macroinvertebrates selected as key target organisms included amphipods, decapod crustaceans, and molluscs. These three taxonomic groups combined constituted 10 percent of all invertebrates collected in the entrainment samples and 56 percent of the macroinvertebrate group considered to be key taxa. Amphipods, decapods, and molluscs were present throughout the year although none of the three groups displayed pronounced seasonal distributions. Densities were highly variable and unpredictable. Amphipod densities typically ranged from 0.5 to 3.0/m^3. Brachyuran crab (the predominant group of decapods observed) densities varied substantially between and within sampling days, ranging from <10 to approximately 120/m^3. Mollusc densities were typically less than 25/m^3.

Entrainment survival studies were conducted on larval fish and macroinvertebrates from December 1985 through March 1986 to estimate the potential survival of organisms (primarily larval fish) following passage through the cooling water system. Densities of larval fish were insufficient to quantify entrainment survival estimates.

Although not quantified, entrainment mortality is assumed to be 100 percent during heat treatments and chlorination, however, these plant operating conditions are either infrequent or affect only a small portion of total daily cooling water volume.

Most species of fish and macroinvertebrates typical of those entrained at the Diablo Canyon Power Plant are capable of tolerating exposure to temperatures less than 30 C (86 F) for short durations (e.g., 5 min cooling water transit time at the Diablo Canyon Power Plant). An analysis of hourly discharge temperature data collected during typical plant operating conditions (June - December 1987), including eight heat treatments, revealed that temperatures exceeding 30 C (86 F) were rare at the Diablo Canyon Power Plant, occurring less than 0.1 percent of the time at Unit 1 and not at all at Unit 2.

Entrained organisms are generally tolerant of the physical stresses associated with condenser passage. No significant entrainment mortality was detected for zooplankton exposed to the pressure changes, sheer forces, and turbulence associated with passage through the Diablo Canyon Power Plant cooling water system.

Based on the results of entrainment survival at other power plants, combined with observations on zooplankton survival and thermal effects experiments conducted at the Diablo Canyon Power Plant, entrainment survival for fish and macroinvertebrates is estimated to be high during typical plant operating conditions. (>75 and >90 percent for larval fish and macroinvertebrates, respectively).

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CHAPTER 4
IMPINGEMENT

Impingement occurs when an organism is held against the intake screens used to remove debris from the cooling water. The damage incurred depends on the species, life stage, size of the organism, and on the intake water velocities, the duration of impingement, and the techniques used to return organisms to the waterbody.

The 316(b) study plan for the Diablo Canyon Power Plant (Appendix A) described two studies designed to provide a quantitative basis for characterizing the impingement of fish and macroinvertebrates at the plant. The first, impingement abundance, provides information on the species composition and seasonal distribution of organisms impinged on the Units 1 and 2 intake screens. The second, impingement survival, provides a basis for computing species-specific estimates of the proportion of organisms surviving impingement. Combining the results of the two studies provides the necessary foundation to characterize impingement at the plant. These results provide site- and species-specific information necessary to evaluate the potential effectiveness of intake modifications and alternative technologies for minimizing the effects of impingement at the Diablo Canyon Power Plant.

4.1 Impingement Abundance

The impingement abundance study was designed to provide the quantitative information necessary to:

- Determine the species composition of the impinged organisms;
- Determine the lengths and weights of fish and selected macroinvertebrates;
- Determine the diel and seasonal patterns of impinged organisms;
- Examine the relationship between impingement and cooling water system operational parameters;
- Determine the sex ratio and degree of gonadal maturity for selected species; and
- Determine whether or not any significant impingement occurs on the intake bar racks.

In the impingement abundance study, the numbers of fish and macroinvertebrates impinged on the Units 1 and 2 intake screens were quantified during weekly sampling efforts. Lengths and weights were determined for all fish and selected macroinvertebrates, based on commercial, recreational and/or ecological importance. Table 4-1 summarizes the method of documentation used for the assemblage of macroinvertebrates collected during the impingement study. The experimental design permitted detection of seasonal and diel patterns in the numbers, sizes, and

TABLE 4-1

LABORATORY PROCESSING CRITERIA FOR ORGANISMS COLLECTED IN IMPINGEMENT ABUNDANCE SAMPLES

Variables Documented*						
Abundance Noted as Total Count	Abundance Noted as Present/ Absent	Length	Weight	Condition	Sex	Organisms Type/Comments
x		x	x	x	x	Chondrichthyes - sharks, skates, rays Measured total length
x		x	x	x	x	Osteichthyes - bony fishes Measured fork length
x		x	x	x	x	Caridea shrimp and pelagic red crabs *(Pleuroncodes* spp.) Measured rostrum tip to end of carapace (not measured if rostrum was broken)
x		x	x	x	x	Decapod crabs Measured carapace width at widest point
x		x	x	x	x	Cephalopod Molluscs - octopus and squid Measured mantle length
x		x	x	x	x	Rock scallop *(Hinnites giganteus)* Measured maximum shell width
x		x	x	x	-	Sea urchins Measured test diameter
x		-	-	-	-	Miscellaneous Group 1 - Scyphozoans, annelids and other worms, isopods, pagurids, chitons, gastropods, nudibranchs/opistobranchs, heteropods, bivalves (except *Hiatella* spp. and *Hinnites giganteus*), brachiopods, asteroids, ophiuroids, holothuroids, solitary tunicates, salps, and ghost shrimp.

TABLE 4-1 — *Continued*

LABORATORY PROCESSING CRITERIA FOR ORGANISMS COLLECTED IN IMPINGEMENT ABUNDANCE SAMPLES

Variables Documented*						
Abundance Noted as Total Count	Abundance Noted as Present/ Absent	Length	Weight	Condition	Sex	Organisms Type/Comments
	x	-	-	-	-	Miscellaneous Group 2 - Sponges, hydroids, anemones, barnacles, bryozoans, compound/colonial tunicates, and the bivalve *Hiatella artica*

* Documentation:

Length measurements - to the nearest 1.0 mm
Weight measurements - to the nearest 0.1 gram
Condition - Noted as alive, dead, mulitated or fragmented
Sex - Noted if possible to determine

species composition of impinged organisms, and provided a framework for correlating these with varying plant operational parameters.

To augment the impingement abundance program, support studies were conducted throughout the year to evaluate the recovery efficiency of the intake traveling screens and sluiceways, sample collection gear, and sample processing techniques. Diver observations were conducted in the vicinity of the intake structure when water visibility permitted.

4.1.1 Methods

A one-year impingement monitoring program was initiated at the Diablo Canyon Power Plant in April 1985. Impingement samples were collected during 24-hour sampling periods scheduled once per week from Unit 1 and/or Unit 2 intake screens when at least one circulating water pump was operational for the unit(s) being sampled. Discrete impingement samples were made, when intake operations permitted, for each 4-hour screenwash cycle to characterize diel patterns in impingement. Intake water temperature, dissolved oxygen, tidal height, and the number of operating circulating water pumps were recorded during each screenwash throughout each 24-hour sampling period.

Before each 24-hour impingement sampling period, all screens were rotated and washed to remove previously impinged organisms and debris. During the sampling period the screens remained stationary for approximately 3-3/4 hours and were then rotated and washed for 15 minutes. This cycle was repeated throughout the 24-hour sampling period. During periods when heavy kelp accumulation was experienced or anticipated (typically during fall and winter) intake screens were rotated and cleaned on a continuous basis. During periods of continuous screen rotation, the screenwash was stopped for 15 minutes every 4 hours to permit impingement sample collection. Samples were collected from the screenwash sump in a collection basket lined with 1/4-in. (6.4-mm) steel mesh. Impingement samples were collected separately for the Unit 1 and Unit 2 intake screens.

The fish and macroinvertebrates collected were sorted from the detritus by hand and returned to the on-site laboratory for processing. Table 4-1 summarizes the laboratory processing criteria used for the assemblage of fish and invertebrates collected. Fish and selected macroinvertebrates were identified to species, counted, measured, and weighed. Carapace width was measured to the nearest millimeter for *Cancer* spp., as was mantle length for cephalopods. The presence of colonial invertebrates was recorded by taxon for each impingement collection. Sex and reproductive condition of selected fish and macroinvertebrate species were periodically examined to assess maturity and spawning condition. All sample collection and processing activities were subject to a strict quality assurance program. The accuracy of taxonomic identifications and length/weight measurements for fish and macroinvertebrates was routinely verified as part of the quality assurance program. Sample processing was frequently checked to verify that all fish and macroinvertebrates were sorted from screenwash detrital material.

Initial survival observations were recorded for fish and selected macroinvertebrates collected during the routine impingement monitoring program (Section 4.2). Organisms were considered dead if they showed no opercular movement or response to gentle probing immediately following each impingement collection. Organism mutilation which would affect total biomass estimates was also recorded for selected species during each collection.

Subtidal inspections using scuba were conducted at periodic intervals throughout the study to characterize debris loading and fish impingement on the bar racks, and the relative abundance, species composition, and behavior of fish inhabiting the forebays and other areas immediately adjacent to the bar racks.

4.1.2 Impingement Abundance Support Studies

Several tests were conducted to document the efficiency of the impingement sample collection and processing techniques. Periodically, a known number of marked dead fish were released directly into the screenwash sluiceway prior to screen rotation and washing. The proportion of marked organisms subsequently recovered in the collection baskets during sample processing measured sample collection and processing efficiency. Three direct release tests were conducted during 1985 at the Units 1 and 2 screenwash sluiceways in which 100 percent of the fish released were recovered in the impingement collection basket. Based on the results of these tests, it was concluded that the impingement collection basket would be effective for use in the routine impingement monitoring program.

A second series of tests was conducted in which a known number of tagged dead fish were released between the bar racks and the traveling screens prior to a 24-hour impingement collection. The number of tagged fish subsequently collected in the impingement samples provided information on the collection efficiency of the system. Results of the initial series of direct release studies, conducted between May and July, showed that recovery of released dead organisms was substantially lower (less than 50 percent recovery) than results of similar direct release tests conducted at other power plant intakes. Because of the relatively low recovery of released organisms, a more intensive series of direct release tests was performed along with surface and underwater observations of the organisms during impingement and subsequent screen rotation and washing. The direct observation suggested that, in part, the low recovery of impinged organisms was the result of debris (kelp) accumulating in the intake forebay which had not been removed by rotation of the intake screens. When the screens were rotated for washing, impinged material (including kelp and organisms) fell off the screen mesh after the material passed through the air-water interface, thereby accumulating in the intake forebay rather than being washed from the screen into the collection basket. The intake screens were subsequently modified to improve the removal of impinged kelp. Results of subsequent direct release tests indicated that recovery efficiency had increased substantially. Recovery efficiency in later tests increased to between 60 and 95 percent (Table 4-2). Results of these direct release tests were consistent with results of similar tests conducted at other power plants.

4.1.3 Results of the Impingement Abundance Study

Fish

A total of 80 skates and rays (Chondrichthyes) and 323 bony fishes (Osteichthyes), representing 57 species (29 families) were collected and identified during the one-year impingement abundance monitoring program from Units 1 and 2 combined; a complete species list is presented in Appendix E. The three most abundant fish species collected included the yellowtail/olive rockfish (representing 20 percent of the fish collected), thornback ray (14 percent), and plainfin midshipman (5 percent). The four families of fish represented in greatest numbers in the routine impingement collections were rockfish (Scorpaenidae), thornback rays (Platyrhinidae), surfperch (Embiotiocidae), and sculpins (Cottidae) (Table 4-3).

The seasonal distribution of fish impinged during the one-year monitoring program is shown in Figure 4-1 for all skates and rays and in Figure 4-2 for all bony fishes. Skates and rays were collected in impingement samples periodically throughout the year. Impingement densities (number per million m^3 of cooling water), for skates and rays (Figure 4-1) remained below 1 fish per million m^3 with the exception of one sampling day in October 1985, when the impingement density approached 1.5 per million m^3.

Impingement densities of bony fishes (Figure 4-2) were less than 1.2 per million m^3 during the spring (April-early June), increased during late June and July to levels approaching 4 to 5 fish per million m^3, and returned to densities typically less than 2 fish per million m^3 of cooling water during the remainder of the year.

Fish collected in the routine impingement monitoring program ranged in length from a 42-mm (1.7-in.) kelp pipefish to a 572-mm (22.5-in.) thornback ray. The mean length and ranges for selected fish and macroinvertebrate taxa are shown in Table 4-4.

Life history information was reviewed for selected fish taxa including rockfish and surfperch to assess the potential reproductive condition of impinged fish. The length frequency and seasonal impingement abundance was examined for each selected fish species relative to their length at first reproduction and seasonal period of reproduction as reported in the literature.

TABLE 4-2

IMPINGEMENT DIRECT RELEASE STUDIES
CONDUCTED AT THE DIABLO CANYON POWER PLANT

UNIT 1: Bar Racks

Date	Number of Dead Anchovies Released*	Recovery (Within Hours) 4	8	12	16	20	24	Total Percent Recovery
18 Sep 85	140	64	9	7	5	1	—	61
02 Oct 85	120	48	31	15	5	2	5	65
16 Oct 85	40	17	11	6	3	1	—	93
21 Nov 85	120	66	3	1	1	—	1	60
11 Dec 85	120	108	3	—	—	—	—	93
05 Mar 86	20	12	7	—	—	—	—	84
26 Mar 86	45	—	22	2	—	1	2	60

UNIT 1: Bar Racks

Date	Number of Dead Anchovies Released*	Recovery (Within Hours) 4	8	12	16	20	24	Total Percent Recovery
26 Feb 86	45	15	—	4	1	1	—	49
05 Mar 86	120	48	51	1	—	—	1	83
26 Mar 86	75	—	55	3	2	1	2	83

* Anchovies were treated with formalin and diver released.

TABLE 4-3

PERCENT COMPOSITION OF FISH FAMILIES COLLECTED DURING THE IMPINGEMENT ABUNDANCE MONITORING PROGRAM, APRIL 1985 - MARCH 1986 UNIT 1 AND UNIT 2 COMBINED

FAMILY NAME	COMMON NAME	PERCENT COMPOSITION
CHONDRICHTHYES		
Platyrhinidae	Thornback rays	14
Torpedinidae	Electric rays	3
Rajidae	Skates	1
Dasyatididae	Stingrays	1
Chimaeridae	Ratfishes	< 1
OSTEICHTHYES		
Scorpaenidae	Rockfishes	27
Embiotocidae	Surfperches	8
Cottidae	Sculpins	6
Batrachoididae	Toadfishes	5
Synganthidae	Pipefishes	4
Bothidae	Flatfishes	3
Clinidae	Clinids	3
Gasterosteidae	Tubesnouts	3
Sciaenidae	Croakers	2
Scombridae	Mackerels	1
Carangidae	Jacks	1
Stichaeidae	Pricklebacks	1
Pomacentridae	Damselfishes	1
Atherinidae	Silversides	1
Gobiesocidae	Clingfishes	1
Labridae	Wrasses	< 1
Pholididae	Gunnels	< 1
Hexagrammidae	Greenlings	< 1
Pleuronectidae	Flatfishes	< 1
Cynoglossidae	Flatfishes	< 1
Liparididae	Snailfishes	< 1
Engraulididae	Anchovies	< 1
Agonidae	Poachers	< 1
Zaniolepididae	Combfishes	< 1

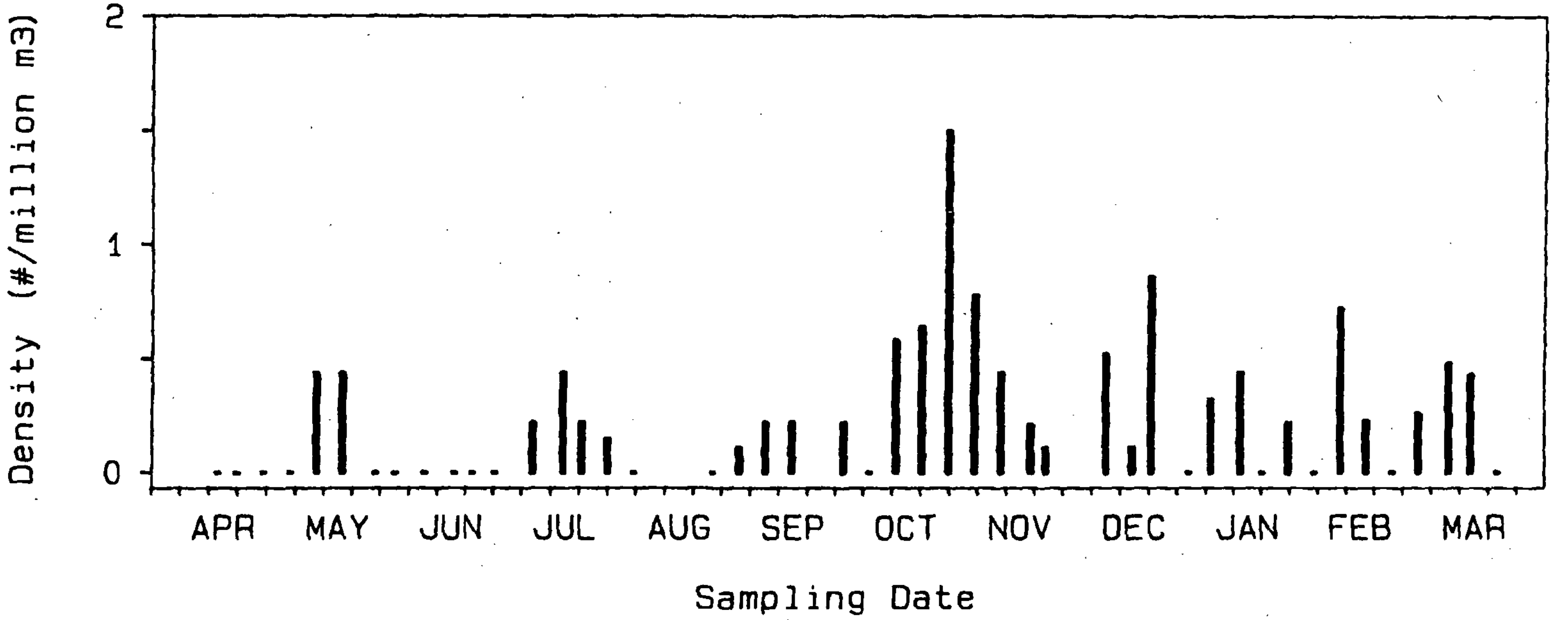

Figure 4-1

Mean Density of Skates and Rays Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

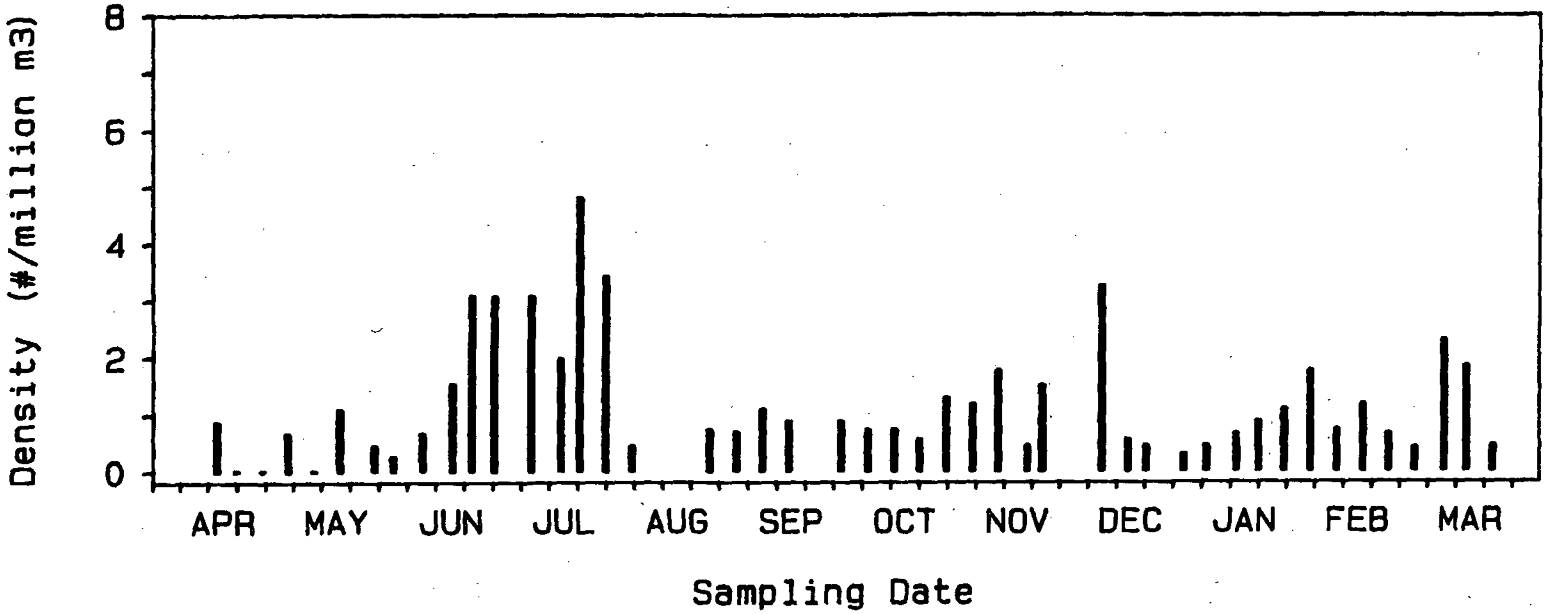

Figure 4-2

Mean Density of Bony Fishes Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

TABLE 4-4

SUMMARY STATISTICS FOR SELECTED FISH AND INVERTEBRATES COLLECTED IN UNIT 1 AND 2 IMPINGEMENT SAMPLES, APRIL 1985 - MARCH 1986

Taxa				Length Statistics (mm)		
Scientific Name	Common Name	Number Measured	Total Biomass (g)	Mean	S.D.	Range
Fish						
Embiotocidae	Surfperch	44	1540	104	34	64-261
Sebastes spp.	Rockfish	118	2,648	90	48	44-306
Cottidae	Sculpins	41	208	75	16	48-135
Platyrhinoidis triseriata	Thornback ray	55	12,163	330	64	120-572
Invertebrates						
Cancer antennarius	Rock crab	1,245	7,884	22	13	7-130
Scyra acutifrons	Sharpnose crab	1,119	4,556	16	7	4-45
Stronglyocentrotus purpuratus	Purple sea urchin	697	3,404	19	10	2-56
Pugettia richii	Kelp crab	654	3,301	19	8	5-43
Pugettia producta	Spider crab	424	6,351	25	16	7-85
Octopus spp.	Octopi	252	4,081	129	41	45-275
Penaeus californiensis	Shrimp	64	2,102	54	6	44-72

The results of this comparison are presented below:

Taxon	Length at First Reproduction (mm)	Number Impinged and Mature	Number Impinged and Mature During Reproductive Season
Rockfish			
Yellowtail	260	0	0
Olive	281	1	1
Blue	182	2	1
Kelp	277	1	1
Surfperch			
Shiner	82	17	17
Walleye	65	5	5
Kelp	81	6	6

The majority of rockfish impinged were juveniles and not yet reproductively mature. Although impinged surfperch were of reproductive size, the total number of surfperch impinged at the plant is low.

Examination of the diel patterns in rockfish impingement indicated that densities were greatest during the early afternoon hours and lowest in the early evening. Thirty-five percent of the rockfish observed in diel samples were collected between 1100 and 1500 hours. The percent frequency of occurrence of rockfish densities observed in diel samples ranged from 4 percent (collections between 1900 and 2300 hours) to 35 percent (collections between 1100 and 1500 hours).

A statistical comparison was made of the densities of selected fish impinged on the Unit 1 and Unit 2 intake screens. Densities of impinged fish, expressed as the number per million cubic meters of cooling water, were compared on ten sampling dates when cooling water system operations and intake screen operations were comparable. Densities of skates and rays were significantly greater ($P=0.02$) on the Unit 2 intake screens than at Unit 1. No significant differences were detected in impingement of bony fishes as a group or in rockfish specifically. The numbers of fish impinged were insufficient to effectively evaluate the potential influence of factors such as dissolved oxygen, tidal height, temperature, debris loading, and intake water velocities on the general patterns of impingement.

The low densities and numbers of fish observed in impingement collections during this study are consistent with the findings of earlier impingement surveys conducted at the Diablo Canyon Power Plant (PG&E 1979). Factors contributing to the low numbers of fish impinged include the low approach velocities to the intake, the design and configuration of the shoreline intake structure, and the siting of the intake in an area where the natural abundance of fish susceptible to impingement is relatively low.

The routine impingement collections were augmented by periodic underwater inspections by divers. These observations provide additional information on the relative abundance and species composition of fish inhabiting the area immediately adjacent to the bar racks and intake forebays and on bar rack impingement. Diver observations in the immediate area of the intake bar racks indicate that a relatively diverse community of fish and invertebrates is present. The cooling water intake structure provides habitat for surfperch, rockfish, kelpfish, and a number of other species. Fish have been frequently observed residing and foraging within the intake forebays and along the bar racks. The fish move readily between forebays and throughout the intake structure independently of cooling water system operations. Large schools of juvenile rockfish were commonly observed immediately in front of the bar racks, especially during July and August. On one occasion (August 21, 1985) more than 100 juvenile yellowtail/olive rockfish were observed in front of a centrally located Unit 1 intake forebay. During the two August impingement samples, only two rockfish were collected. The impingement of juvenile bocaccio and shortbelly rockfish suggests that the area provides a suitable nursery ground for offshore as well as inshore rockfish species. Impingement of fish observed on the bar racks was typically limited to a low number of thornback and electric rays.

The percent composition of rockfish species collected in Units 1 and 2 impingement samples is shown below:

Common Name	Number Collected	Percent Composition
Yellowtail	48	41
Olive	27	23
Yellowtail/Olive	10	9
Kelp	9	8
Blue	7	6
Gopher	3	3
Bocaccio	2	2
Black	2	2
Shortbelly	1	< 1
Unidentified	7	6
Total	117	100

The seasonal distribution of impinged rockfish (*Sebastes* spp.) is shown in Figure 4-3. Rockfish were collected throughout the one-year sampling period. Densities of rockfish were greatest during late June and July (2-3 fish per million m^3). During the remainder of the one-year sampling period, densities of rockfish were typically

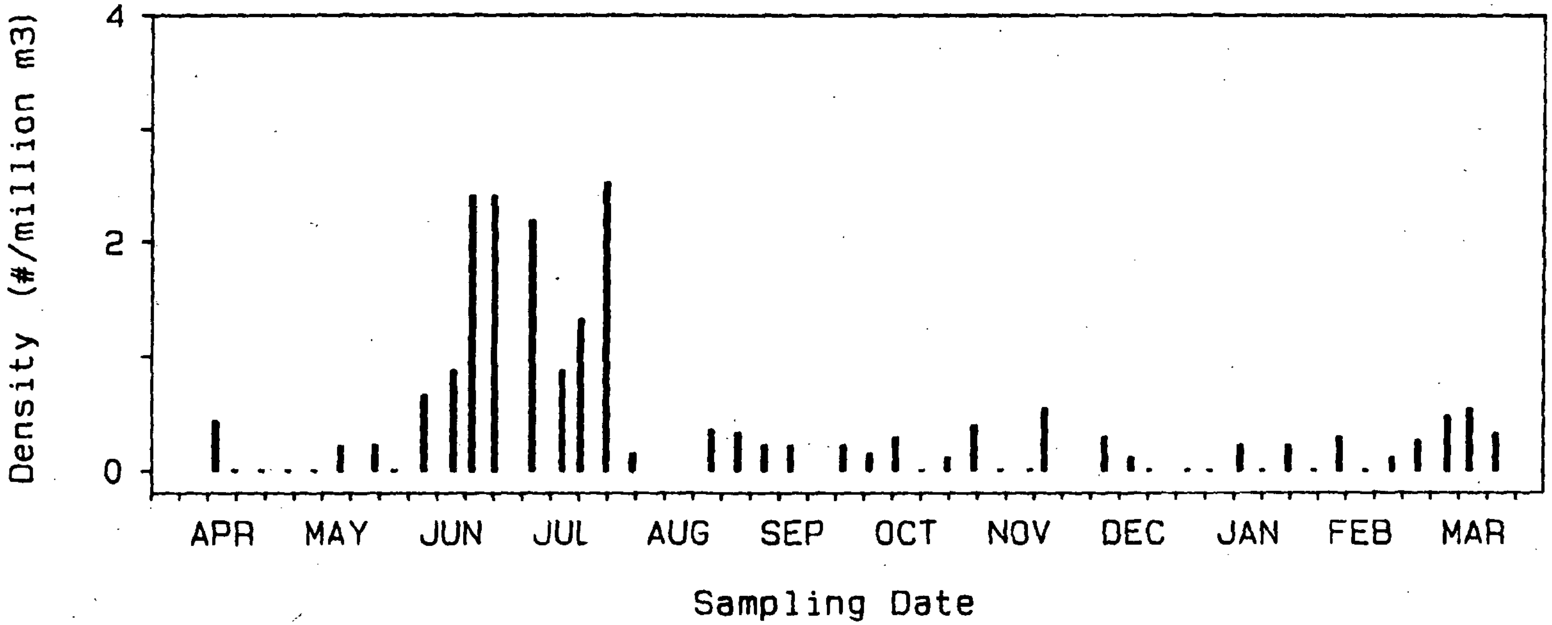

Figure 4-3

Mean Density of Rockfish Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

less than 0.05 fish per million m^3. Rockfish collected in impingement samples ranged in length from 44 to 306 mm, with a mean length of 90 mm (Table 4-4). Analysis of the length frequency distribution for impinged rockfish (Figure 4-4) showed that the majority (75 percent) were less than 91 mm (3.6 in.).

Macroinvertebrates

The three most abundant macroinvertebrates collected were the rock crab (*Cancer antennarius*), sharpnose crab (*Scyra acutifrons*), and the purple sea urchin (*Strongylocentrotus purpuratus*). The mean length and ranges for selected macroinvertebrate taxa are presented in Table 4-4.

The sex ratio and frequency of gravid females of selected crab taxa collected in impingement samples is shown below:

Taxon	Number	Percent Occurrence			
		Males	Females		
			Not Gravid	Gravid	Un-specified
Cancer antennarius	1,294	47	35	0	18
Pugettia producta	425	52	43	2	3
Pugettia richii	698	54	28	16	2
Scyra acutifrons	1,143	55	24	18	3

Cancer antennarius were present in substantially larger numbers during the evening and night collections than in morning and mid-day samples. Seventy-two percent of the *C. antennarius* collected in diel impingement samples were observed between 1900 and 0700 hours. A similar diel distribution was observed for *Pugettia richii* in which 64 percent were collected between 1900 and 0700 hours.

A statistical comparison was made of the densities of rock crabs, spider crabs, purple sea urchins, octopi, kelp crabs, and sharpnose crabs impinged on the Unit 1 and Unit 2 intake screens. Ten sampling days were selected for the analysis when cooling water system operation and intake screen operation at the two units was comparable. Densities of each selected taxa, expressed as the number of individuals impinged per million cubic meters of cooling water, were analyzed using a paired T-test. No significant difference (P=0.05) in impingement between the two units was detected for rock crabs (*Cancer antennarius*), spider crabs (*Pugettia richii*), purple sea urchins (*Strongylocentrotus purpuratus*), and octopi (*Octopus* spp.). Significant differences in impingement were detected for kelp crabs (*Pugettia producta*; P=0.03) and sharpnose crabs (*Scyra acutifrons*; P=0.01). Impingement was greater for Unit 2 than Unit 1 for both the spider crab and sharpnose crab. Approach velocities and

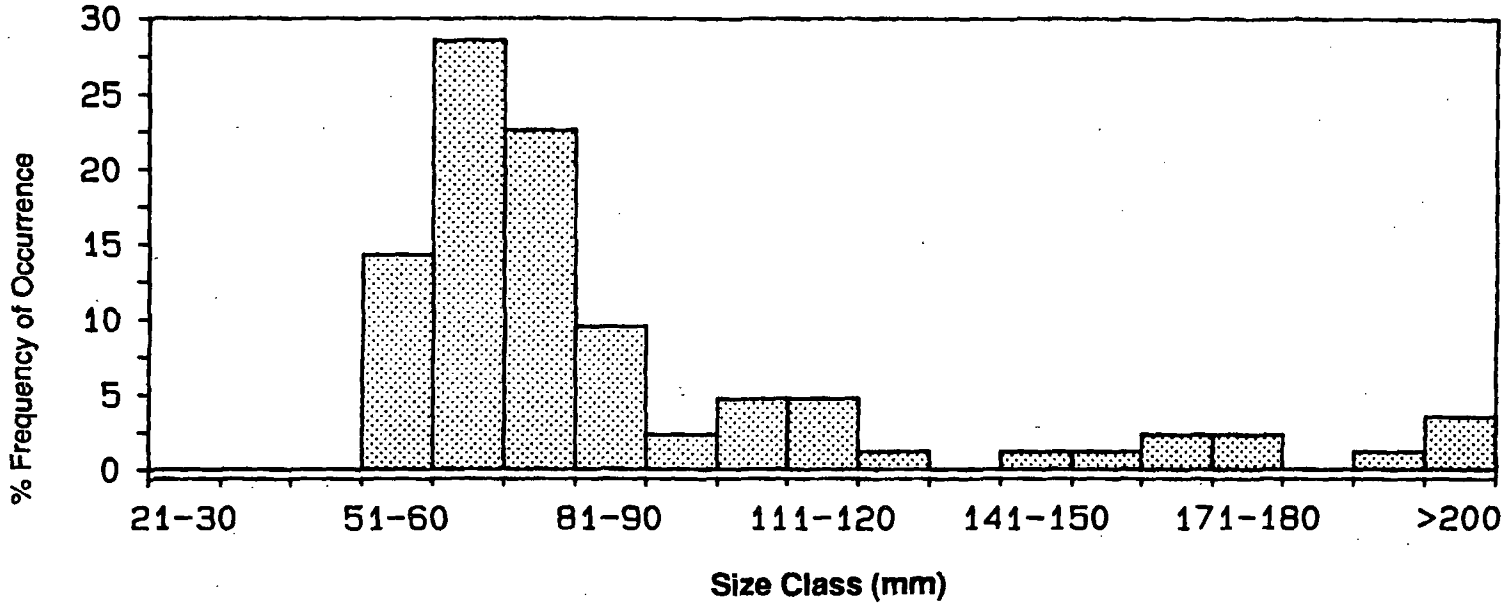

Figure 4-4

Length Frequency Distribution for Rockfish Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986 debris loading are greater at Unit 2 than at Unit 1 (Wyman 1988) which may contribute to the observed differences in these two species.

Increases in the impingement of several selected macroinvertebrate taxa were correlated with periods of increased impingement of kelp which occurred following fall and winter storm activity and intake maintenance activity (bar rack cleaning, kelp harvesting in the Intake Cove, etc.). No pattern was apparent between impingement of selected macroinvertebrates and variables such as tide height or dissolved oxygen.

The seasonal distribution of impinged rock crabs (*Cancer antennarius*) is shown in Figure 4-5. Rock crabs, the most abundant macroinvertebrate collected, were present throughout the year, although the period of highest impingement occurred during the fall (peak impingement of 16 per million m^3 occurred in November). Carapace widths for impinged rock crabs ranged from 7 to 130 mm, and averaged 21.6 mm (Table 4-4). The frequency distribution of rock crab carapace width (Figure 4-6) showed that 94 percent were less than 41 mm (1.6 in.). Of the rock crabs collected during the one-year impingement program, 97 percent were juveniles (carapace width <50 mm).

Sharpnose crabs (*Scyra acutifrons*) were present throughout the year in densities less than 12/million m^3 (Figure 4-7) with no pronounced seasonal pattern to impingement. Carapace widths for impinged sharpnose crabs ranged from 4 to 45 mm, and averaged 16 mm (Table 4-4).

Purple sea urchin (*Strongylocentrotus purpuratus*) were collected in impingement samples throughout the year (Figure 4-8). Sea urchin densities generally ranged from approximately 1 to 3 urchins per million m^3 of cooling water. Higher densities (6-9 per million m^3) were observed in samples collected between November and January, although between-day variation in impingement densities was also high during this winter period. Sea urchin widths ranged from 2 to 56 mm, and averaged 18.5 mm (Table 4-4).

The seasonal distributions for impinged spider crabs, (*Pugettia richii*) and kelp crabs, *P. producta*), are shown in Figures 4-9 and 4-10. Spider crabs were impinged throughout the year at densities ranging from 2 to 10 crabs per million m^3. *P. richii* densities exceeded 30 crabs per million m^3 on three sampling dates between October and December. Examination of cooling water system and intake operational data, water quality (dissolved oxygen, tidal height, temperature), and debris loading on the intake screens showed that the three impingement collections with unusually high spider crabs densities (Figure 4-9) coincided with periods of high debris (kelp) loading on the intake screens resulting from bar rack maintenance and winter storm activity. Impingement densities of kelp crabs had a seasonal distribution similar to that observed for spider crabs. Densities of kelp crabs were generally higher during the late summer, fall, and winter than during the spring and early summer. Spider crab carapace widths ranged from 5 to 43 mm and averaged 19 mm (Table 4-4). Mean carapace widths increased gradually from 12 to 20 mm between April and

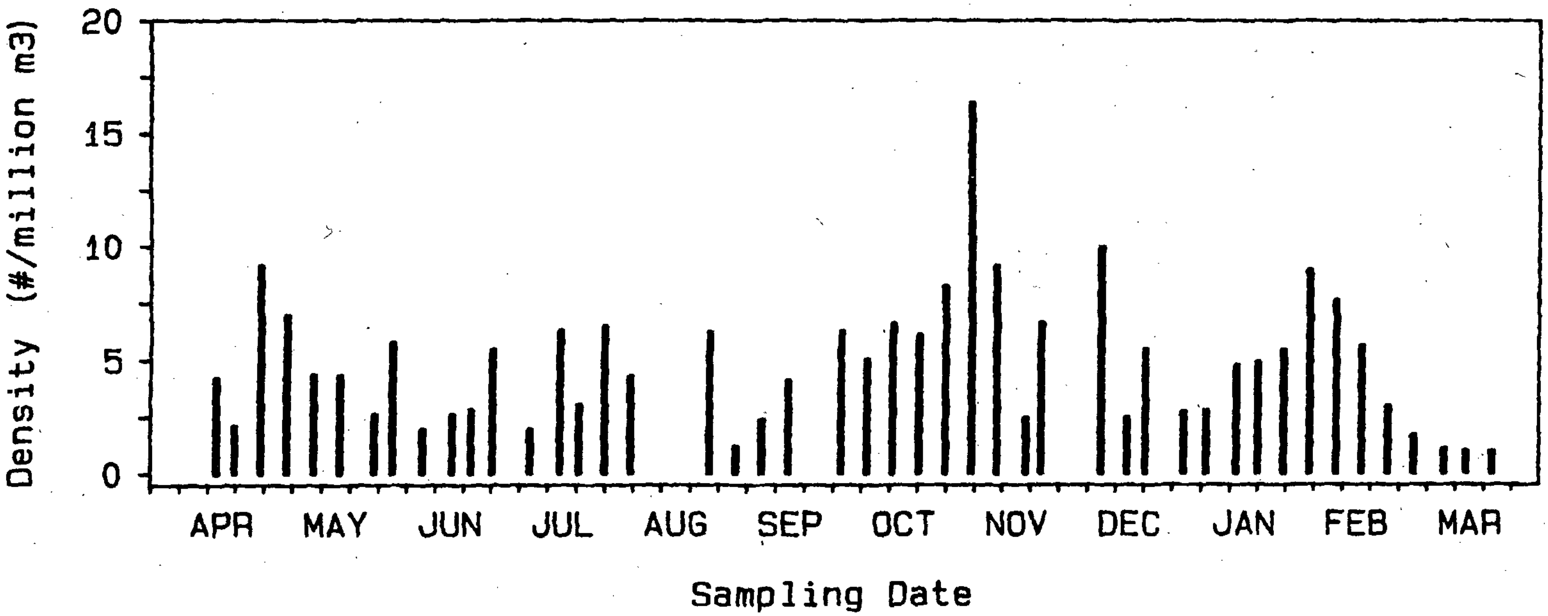

Figure 4-5

Mean Density of Brown Rock Crabs Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

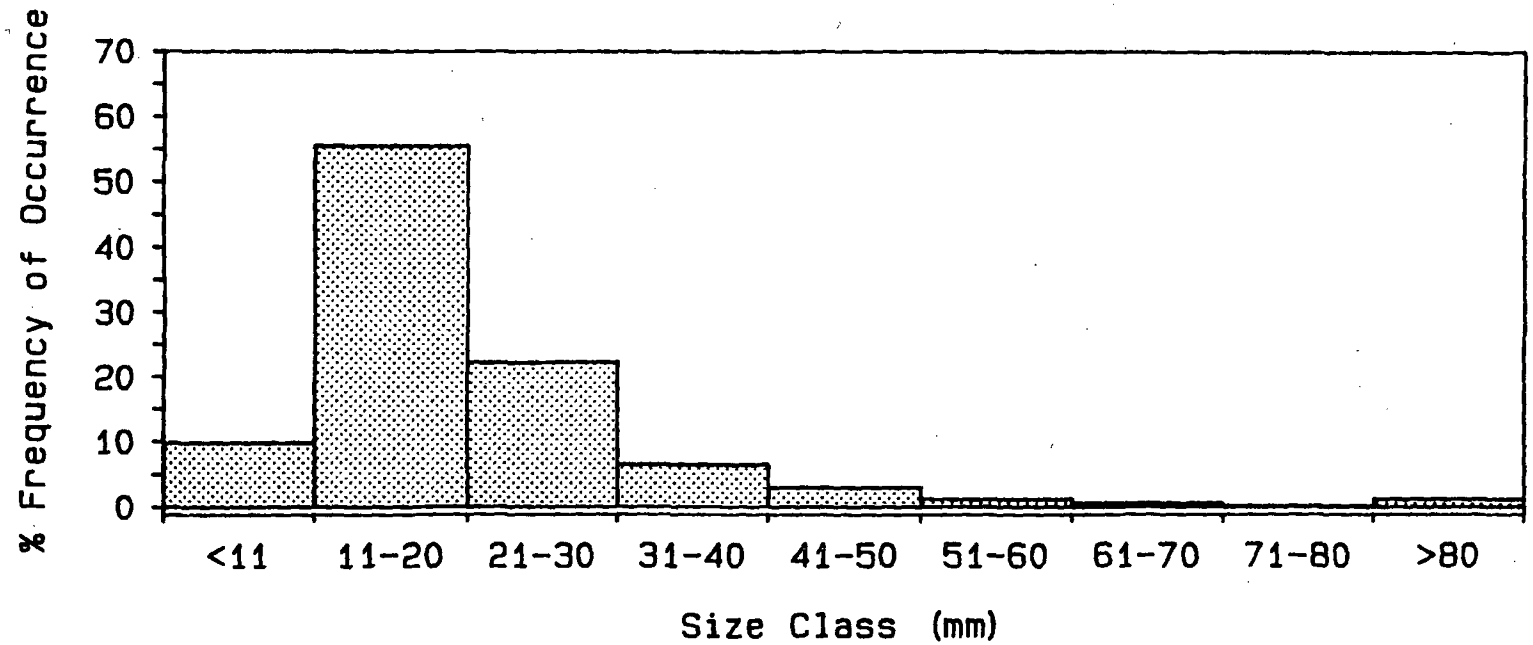

Figure 4-6

Length Frequency Distribution for Brown Rock Crabs Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

E7-265.0

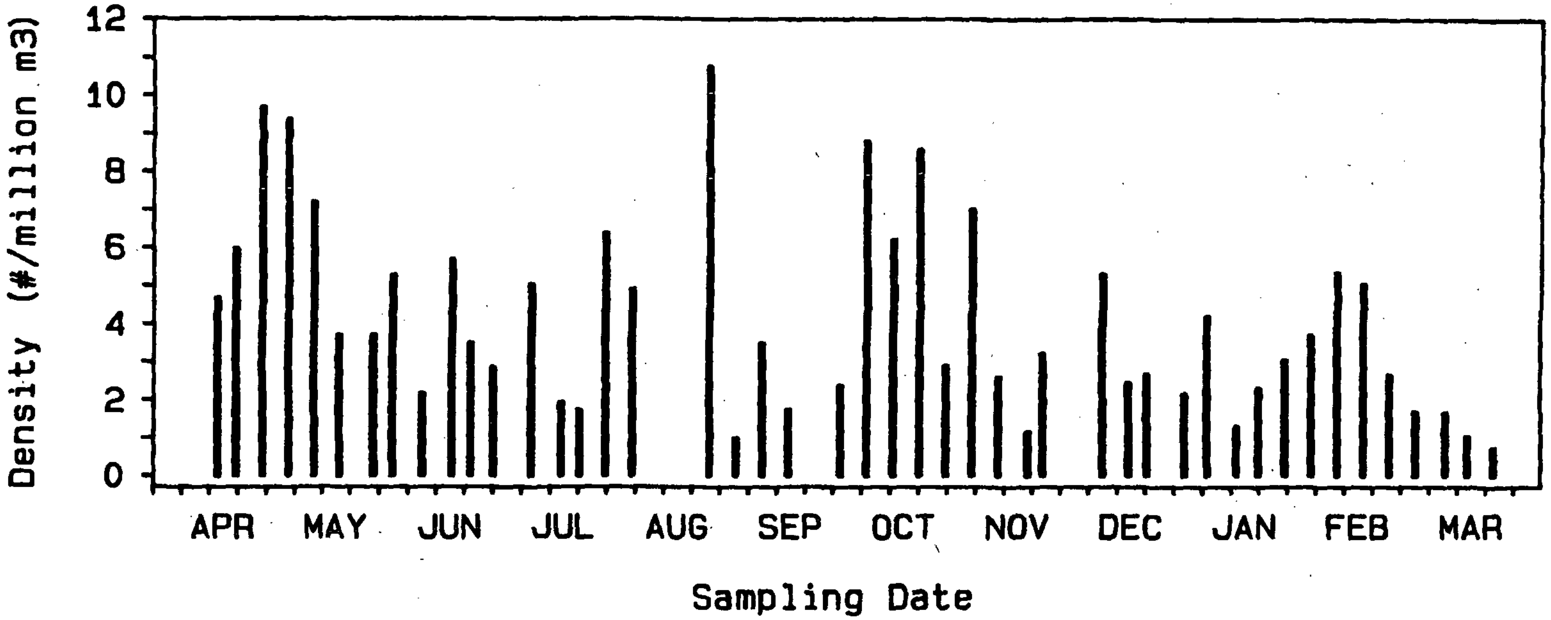

Figure 4-7

Mean Density of Sharpnose Crabs Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

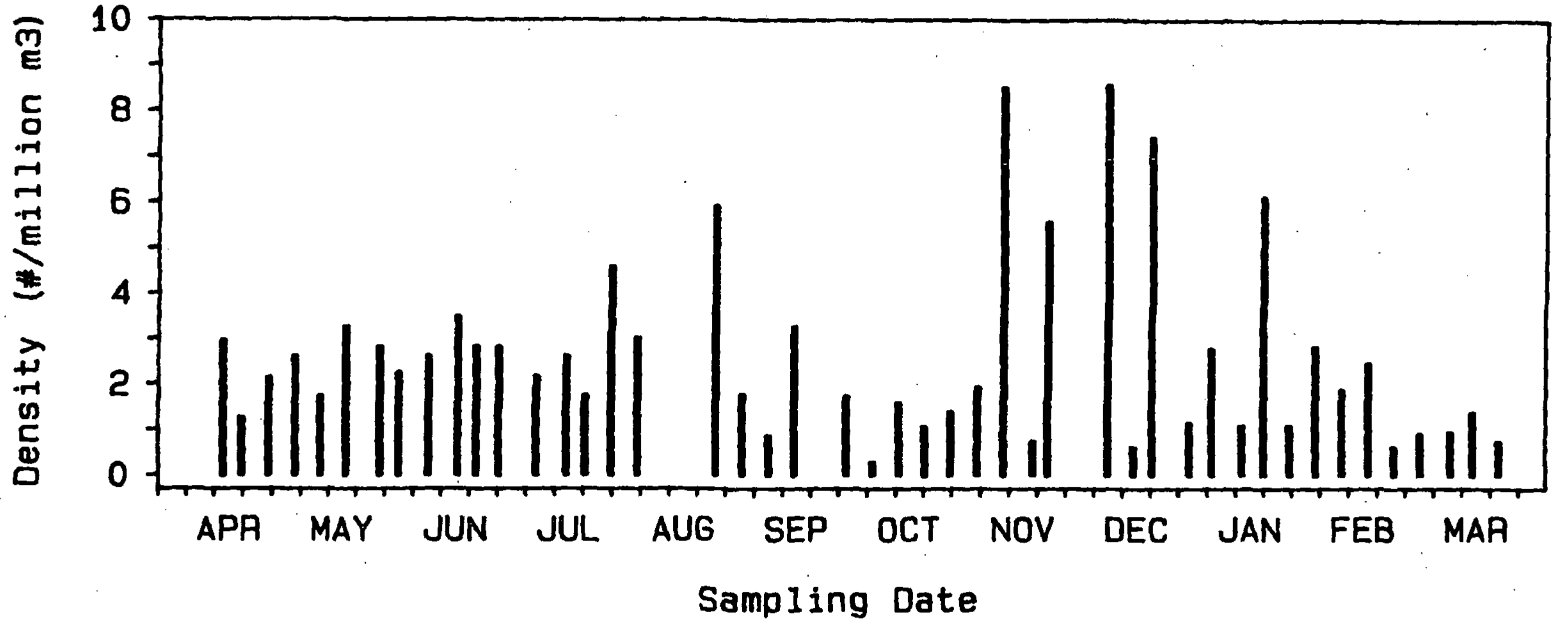

Figure 4-8

Mean Density of Purple Sea Urchins Collected from Impingement Samples
at the Diablo Canyon Power Plant, April 1985 - March 1986

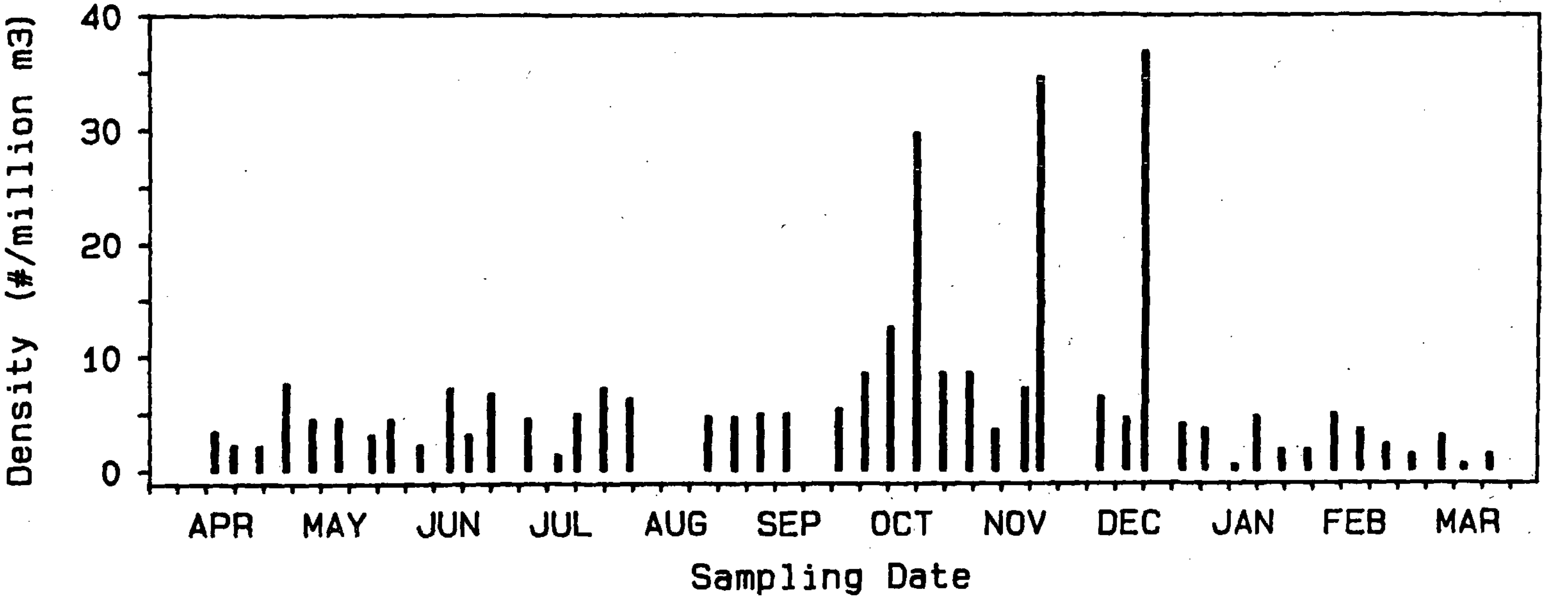

Figure 4-9

Mean Density of Spider Crabs Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

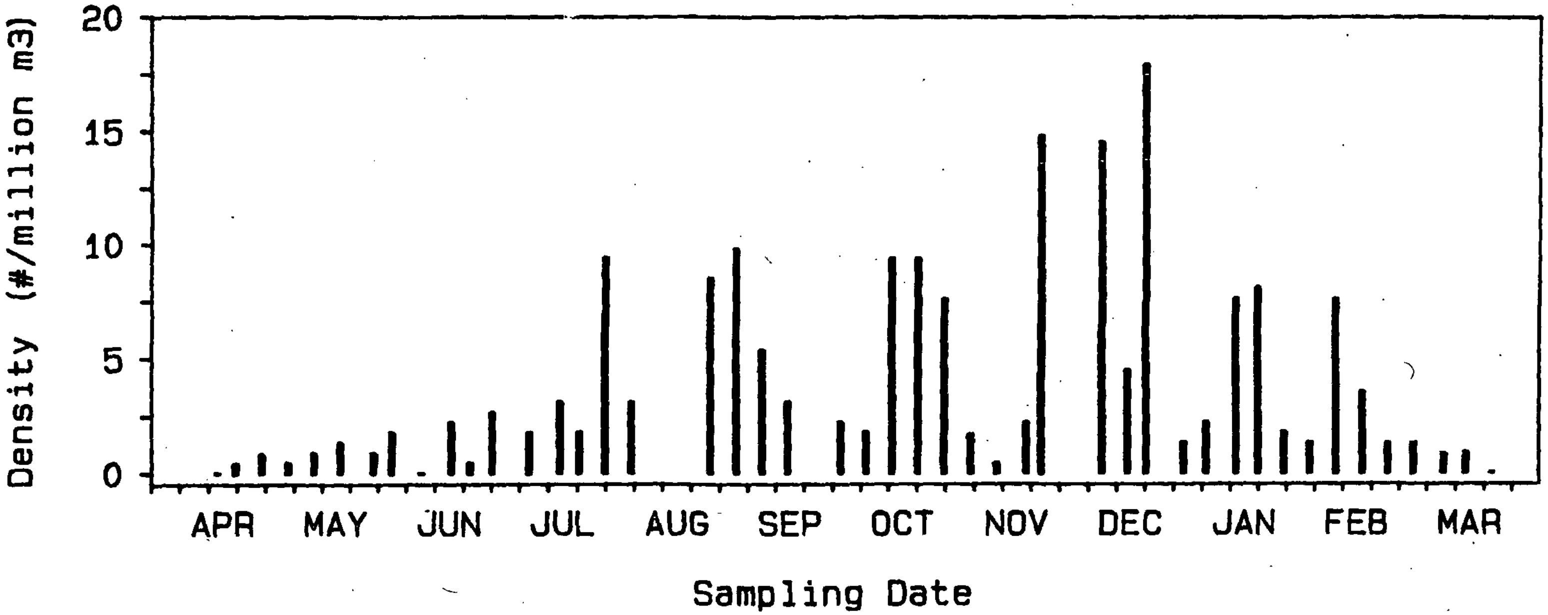

Figure 4-10

Mean Density of Kelp Crabs Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986

October and then remained relatively constant through the remainder of the fall and winter. Carapace width trends for kelp crabs (Table 4-4) were similar to those observed for spider crabs.

Octopus spp. were collected in impingement samples primarily during the winter (December through February), with one pronounced peak in early December (Figure 4-11). The majority of *Octopus* spp. were juveniles. The mean mantle length for impinged *Octopus* spp. was 128.8 mm, with a range from 45 to 275 mm (Table 4-4).

4.2 Impingement Survival

The Diablo Canyon Power Plant impingement survival study was designed to provide a quantitative basis for estimating the potential survival of fish and macroinvertebrates impinged on the intake screens of Units 1 and 2. Specific objectives of the study, as outlined in the Diablo Canyon Power Plant 316(b) Study Plan (Appendix A), were the following:

1. To estimate the initial and long-term (96-hour) survival of fish and macroinvertebrates impinged on intake screens under a routine screenwash operational cycle; and
2. To examine the relationship between various screenwash operational cycles and initial and long-term impingement survival.

The impingement survival program was designed to monitor those fish and macroinvertebrate species impinged in greatest numbers. The impingement survival study was designed to estimate, by species, the proportions of fish and macroinvertebrates not surviving impingement. Initial survival observations were recorded, when intake screenwash operation permitted, for fish and selected macroinvertebrates collected during the routine impingement monitoring program (Section 4.1.1). Because of the low numbers of impinged organisms collected, particularly fish, quantitative delayed (96-hour) impingement survival studies were not conducted although qualitative observations were made of delayed survival.

Impingement survival observations made at the Units 1 and 2 intake were used, in combination with results of impingement survival studies conducted at the Moss Landing Power Plant (PG&E 1983) and other sites, to evaluate the potential effectiveness of alternative intake technologies at the Diablo Canyon Power Plant.

4.2.1 Experimental Design

Initial survival of fish and selected macroinvertebrates (crabs and urchins) was recorded during impingement abundance collections conducted at the Diablo Canyon Power Plant. Impingement data used to characterize impingement survival at the Diablo Canyon Power Plant was limited to those 4-hour collections when screenwashes were operated intermittently (15 minutes every 3 3/4 hours) rather than continuously (3 3/4 hours). Sampling logistics, high debris loading, and the low

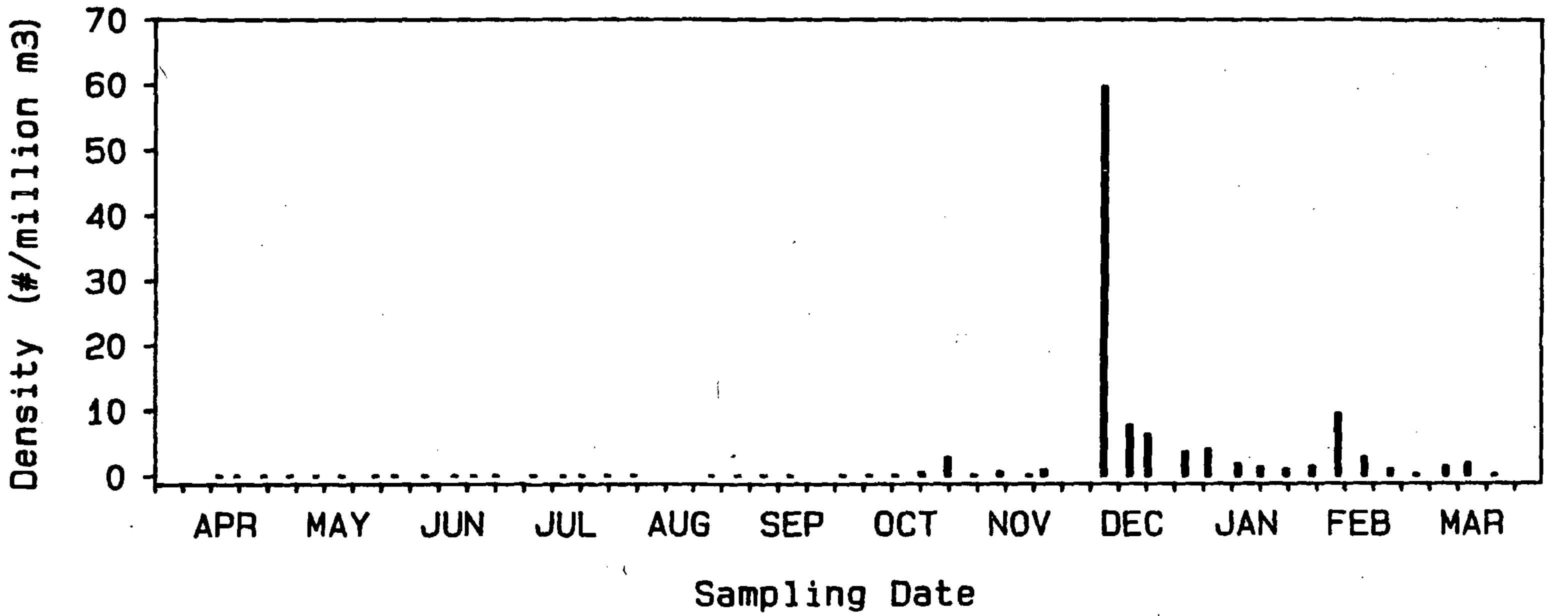

Figure 4-11

Mean Density of Octopi Collected from Impingement Samples at the Diablo Canyon Power Plant, April 1985 - March 1986 numbers of impinged fish prohibited the collection of valid impingement survival observations during periods of continuous screenwash. Immediately following each 4-hour screenwash, all organisms were removed from the impingement collection basket (Section 4.1.1) and examined to determine whether they were alive or dead (initial survival observation). Organisms were considered dead if they showed no opercular movement or response to gentle probing. Initial survival was estimated from the proportion of each selected taxon considered alive. Delayed mortality observations were not made for organisms impinged during the Diablo Canyon monitoring program.

Substantially larger numbers of fish and macroinvertebrates were collected in impingement survival studies conducted at the Moss Landing Power Plant, which provided the sample size necessary to quantitatively examine species-specific trends in initial and delayed impingement survival under various screenwash operational modes. Impingement survival was determined for three modes of cooling water intake screen operation: continuous screen rotation, 1-hour intermittent rotation, and 3-hour intermittent rotation. The proportion of organisms not surviving impingement was estimated from the number of each species that was alive and dead immediately following and 96 hours after removal from the intake screens.

Control samples were collected to account for mortality from sampling and other causes not related to impingement. The experimental design provided an opportunity to determine the relationship between the duration of impingement (i.e., intake screen rotation frequency) and the initial and long-term (96-hour) survival of those species impinged in greatest abundance at the Moss Landing Power Plant.

The compilation of impingement survival results from the Diablo Canyon Power Plant, Moss Landing Power Plant, and other sites under various modes of intake screen operation provide the information necessary to assess the potential biological effectiveness of alternative screen operational modes and modifications for the alternative intake technologies described in Section 6.2.

4.2.2 Results

Initial survival estimates for selected fish and macroinvertebrate taxa collected during routine impingement monitoring at the Diablo Canyon Power Plant Units 1 and 2 intake are summarized in Table 4-5. Because of the limited number of individuals of each species collected, survival estimates have been compiled for families of fish. The numbers of fish collected were insufficient to quantify either species-specific or size-specific trends in impingement survival or delayed impingement survival. Initial survival observations were recorded for approximately 54 percent (173 individuals) of the Osteichthyes and 29 percent (23 individuals) of the Chondrichthyes collected in the one-year impingement monitoring program.

Initial survival of skates and rays (Chondrichthyes) following impingement (Table 4-5) was relatively high, averaging 78 percent. Initial survival estimates for impinged

TABLE 4-5

PERCENTAGE SURVIVAL OF FISH AND SELECTED MACROINVERTEBRATES COLLECTED IN IMPINGEMENT SAMPLES AT THE DIABLO CANYON POWER PLANT UNITS 1 AND 2 INTAKE FOLLOWING A 4-HOUR SCREEN ROTATION CYCLE, 1985-1986

Scientific Name	Common Name	Number Observed	Length (mm) Mean	Length (mm) Range	Initial Survival (%)
CHONDRICHTHYES					
Platyrhinidae	Thornback rays	9	329	263-444	100
Torpedinidae	Electric rays	11	224	190-296	73
Rajidae	Skates	2	161	155-167	50
Chimaeridae	Ratfish	1	467	—	0
OSTEICHTHYES					
Scorpaenidae	Rockfish	80	79	44-230	26
Embiotocidae	Surfperch	31	107	73-261	0
Cottidae	Sculpins	10	75	60-112	60
Batrachoididae	Toadfishes	5	229	153-298	40
Synganthidae	Pipefishes	7	284	42-480	14
Bothidae	Flatfishes	5	162	46-210	0
Clinidae	Clinids	6	101	57-181	17
Gasterosteidae	Tubesnouts	7	103	65-164	29
Sciaenidae	Croakers	2	95	89-101	0
Scombridae	Mackerels	3	316	308-320	0
Osmeridae	Smelts	1	188	—	0
Ophididae	Cusk-eels	1	17	—	0
Pomacentridae	Damselfishes	4	111	65-132	0
Labridae	Wrasses	1	135	—	0
Pholididae	Gunnels	2	152	—	50
Hexagrammidae	Greenlings	2	136	85-186	100
Pleuronectidae	Flatfishes	3	125	53-163	34
Cynoglossidae	Flatfishes	2	67	43-91	0
Zaniolepididae	Combfishes	1	165	—	100
MACROINVERTEBRATES					
Cancer antennarius	Rock crab	444	20	7-102	75
Cancer jordani	Hairy cancer crab	34	15	8-26	53
Pugettia producta	Kelp crab	106	26	7-85	83
Pugettia richii	Spider crab	237	15	5-43	80
Stronglyocentrotus purpuratus	Purple sea urchin	244	24	4-49	92
Strongylocentrotus franciscanus	Red sea urchin	7	28	15-36	100

bony fishes (Osteichthyes) were highly variable between families. Although the numbers of fish observed are insufficient to accurately quantify impingement survival, the data do suggest that survival of hardy species such as sculpin and toadfish is relatively high. Rockfish, the fish species observed in highest numbers (80 individuals), had an initial survival rate of 26 percent. Initial survival was 0 percent for surfperch (31 individuals observed). Impingement survival of macroinvertebrates was relatively high. Rock crabs (*Cancer antennarius*) had an initial impingement survival rate of 75 percent (444 individuals observed). The spider crabs *Pugettia richii* and *P. producta* had initial survival rates of 80 and 83 percent, respectively. The impingement survival rate for the purple sea urchin was 92 percent. Qualitative observations were made of delayed (24-36 hour) impingement survival. In general, hardy species such as skates and rays, sculpins, crabs (e.g., rock crab, kelp crab, sharpnose and spider crabs), and sea urchins were observed to survive impingement.

Impingement survival observations (Table 4-5) reflect the survival of organisms removed from the intake screens, but the estimates do not include effects associated with transit through a fish return sluiceway. In addition, infection resulting from abrasion or scale loss experienced during impingement was observed in the post-impingement observation period, but was not tested experimentally. For these reasons, impingement survival study results represent the survival potential for organisms removed from the intake screens and not necessarily the survival of organisms returned to the receiving waters. Because of the screenwash sluiceway design and the methods of collection and disposal of impinged organisms and debris (Section 2.1.1), no organisms survive impingement under the existing intake configuration.

4.2.3 Discussion

Results of quantitative initial and delayed survival studies are available for the Moss Landing Power Plant for comparison with the survival observations made at the Diablo Canyon Power Plant.

The initial and long-term survival estimates for impinged organisms at the Moss Landing Power Plant, adjusted for control mortality, are summarized in Table 4-6. Impingement survival estimates were computed for three operational modes at Moss Landing Power Plant Units 6 and 7 (through-screen velocity 1.5 fps; 0.5 m/sec). These results are considered to be indicative of impingement survival potential at the Diablo Canyon Power Plant intake, which has similar through-screen velocities (1.9 fps; 0.6 m/sec).

The results of impingement survival studies at Moss Landing Units 1-5 (design through-screen velocity 2.4 fps; 0.7 m/sec) are also presented in Table 4-6 for comparison and to provide additional information on those species collected in low numbers.

TABLE 4-6

PECENTAGE SURVIVAL OF FISH AND MACROINVERTEBRATES COLLECTED IN IMPINGEMENT SAMPLES AT THE MOSS LANDING POWER PLANT IN THREE SCREENWASH OPERATIONAL MODES, 1979 - 1980

Taxon		Size Range (mm)	Screen Operational Mode: 3-Hour Intermittent			Screen Operational Mode: 1-Hour Intermittent			Screen Operational Mode: Continuous			Control[a]		
				Survival (%)			Survival (%)			Survival (%)			Survival (%)	
Common Name	Scientific Name		No.	Initial	96-Hr	No.	Initial	96-Hr	No.	Initial	96-Hr	No.	Initial	96-Hr
				Units 1-5										
Pacific herring	*Clupea harengus pallasi*	65-115	163	4	0	94	14	0	19	42	0	-	-	-
Northern anchovy	*Engraulis mordax*	63-135	2,414	18	0	490	23	0	319	32	0	60	100	92
True smelts	Osmeridae	110	-	-	-	1	0	0	-	-	-	-	-	-
Plainfin midshipman	*Porichthys notatus*	45-290	64	95	95	2	50	50	-	-	-	51	100	100
Silversides	Atherinidae	61-229	227	33	4	74	51	8	36	78	7	151	100	46
Rockfish	*Sebastes* spp.	50-190	22	27	5	5	80	61	8	100	64	222	100	98
Sculpins	Cottidae	73-162	20	75	53	17	100	81	17	100	94	62	100	94
Surfperch	Embiotocidae	35-255	310	9	1	163	23	1	46	43	9	222	100	81
Gobies	Gobiidae	80-111	10	70	74	4	50	53	1	100	0	17	100	94
Flatfish	Pleuronectiformes	59-365	11	82	70	6	66	72	8	50	41	248	100	92
Crabs	*Cancer* spp.	15-114	19	53	47	23	83	70	51	82	74	46	100	100

TABLE 4-6 — *Continued*

PECENTAGE SURVIVAL OF FISH AND MACROINVERTEBRATES COLLECTED IN IMPINGEMENT SAMPLES AT THE MOSS LANDING POWER PLANT IN THREE SCREENWASH OPERATIONAL MODES, 1979 - 1980

Taxon			Screen Operational Mode											
			3-Hour Intermittent			1-Hour Intermittent			Continuous			Control(a)		
				Survival (%)			Survival (%)			Survival (%)			Survival (%)	
Common Name	Scientific Name	Size Range (mm)	No.	Initial	96-Hr	No.	Initial	96-Hr	No.	Initial	96-Hr	No.	Initial	96-Hr
			Units 6 and 7											
Pacific herring	*Clupea harengus pallasi*	80-125	24	13	0	10	60	0	-	-	-	-	-	-
Northern anchovy	*Engraulis mordax*	70-135	2,690	16	1	239	27	0	108	18	0	60	100	92
True smelts	Osmeridae	100-150	2	100	0	1	0	0	2	50	0	-	-	-
Plainfin midshipman	*Porichthys notatus*	46-61	6	100	100	-	-	-	-	-	-	51	100	100
Silversides	Atherinidae	72-270	15	53	0	11	64	0	3	33	0	169	100	46
Rockfish	*Sebastes* spp.	62-185	23	39	13	13	85	47	12	83	77	222	100	98
Sculpins	Cottidae	110-175	29	100	97	18	100	100	24	100	97	62	100	94
Surfperch	Embiotocidae	40-130	19	37	6	27	81	46	12	92	83	222	100	81
Gobies	Gobiidae	75-165	13	100	98	6	100	32	1	100	0	17	100	94
Flatfish	Pleuronectiformes	59-365	42	71	52	3	33	36	8	50	41	248	100	92
Crabs	*Cancer* spp.	18-85	8	100	88	5	80	80	7	85	43	46	100	100

(a) Units 1-5 and Units 6 and 7 combined.

(-) Inidicates no data were available.

Initial and long-term impingement survival of surfperch (Embiotocidae) at Moss Landing Power Plant Units 6 and 7 following a 3-hour screen rotation cycle were low, 37 and 6 percent, respectively. Initial survival was observed to be 0 percent for surfperch impinged at the Diablo Canyon Power Plant intake following a 4-hour screen rotation cycle (Table 4-5). Decreasing the duration of impingement by increasing the frequency of intake screenwash and screen rotation increases the survival of impinged surfperch. During a 1-hour rotational cycle, however, the observed long-term survival of impinged surfperch at the Moss Landing Power Plant Units 6 and 7 intake (Table 4-6) increased to 46 percent, and it further increased to 83 percent with continuous intake screen rotation.

The impingement survival of northern anchovy, Pacific herring, and silversides collected at the Moss Landing Power Plant was low (Table 4-6). Initial and long-term survival of 2,690 northern anchovy observed after a 3-hour screen rotation cycle at the Moss Landing Units 6 and 7 intake were 16 and 1 percent, respectively, and long-term survival was not improved by decreasing the duration of impingement. There is no evidence that changes in intake screen design or operations at the Diablo Canyon Power Plant would contribute to a substantial reduction in the impingement losses of northern anchovy and silversides since they only represented 1 percent of the impinged fish collected. No Pacific herring were collected in impingement abundance samples at the Diablo Canyon Power Plant.

Impingement survival of plainfin midshipman was high at the Moss Landing Power Plant. No initial or long-term impingement mortality was observed for 6 plainfin midshipman impinged during a 3-hour screen rotation cycle at the Units 6 and 7 intake. Initial survival of 5 plainfin midshipman (family Batrachoididae) collected at the Diablo Canyon Power Plant following a 4-hour screen rotation cycle was 40 percent (Table 4-5). Initial and long-term survival of 64 plainfin midshipman collected at the Moss Landing Power Plant Units 1-5 intake, where velocities are considerably higher than those at the Diablo Canyon Power Plant intake, were both 95 percent (Table 4-6). The number of plainfin midshipman observed during the Diablo Canyon impingement program was insufficient to investigate potential factors contributing to the lower than expected impingement survival rate. Based on impingement survival results conducted at the Moss Landing Power Plant (PG&E 1983), it was concluded that plainfin midshipman survival is high and not improved substantially by alterations in intake screen operations.

For flatfish (Pleuronectiformes), initial and long-term survival after a 3-hour screen rotation cycle at the Moss Landing Power Plant Units 6 and 7 intake (Table 4-6) were 71 and 52 percent, respectively. At the Moss Landing Power Plant Units 1-5 intake, initial and long-term survival of impinged flatfish were 82 and 70 percent after a 3-hour screen rotation cycle. Although the number of flatfish observed at the Diablo Canyon Power Plant intake was low, it appears that initial survival of flatfish was substantially lower than survival observed at the Moss Landing Power Plant. No initial survival was reported for flatfish in the families Bothidae (5 individuals observed) and Cynoglossidae (2 individuals) at the Diablo Canyon Power Plant intake (Table 4-5). One out of three flatfish of the family Pleuronectidae was initially alive following impingement at the Diablo Canyon Power Plant intake (Table 4-5). The effect of increasing screen rotation frequency on survival of impinged flatfish is uncertain because of the small number collected in impingement studies at both the Diablo Canyon and Moss Landing power plants.

For rockfish (*Sebastes* spp.), initial and long-term survival rates after a 3-hour screen rotation cycle at the Moss Landing Power Plant Units 6 and 7 intake were 39 and 13 percent, respectively. Initial survival of rockfish (family Scorpaenidae) following a 4-hour screen rotation cycle at the Diablo Canyon Power Plant intake (Table 4-5) was 26 percent. Long-term impingement survival of rockfish increased with increasing screen rotation frequency at the Moss Landing Power Plant Units 6 and 7 intake, from 13 percent under a 3-hour rotation cycle to 77 percent under continuous screen rotation (Table 4-6). Although the numbers of rockfish collected at the Moss Landing Power Plant under 1-hour and continuous screen rotation cycles were low, there appeared to be a general trend for increasing survival with increasing screen rotation frequency. A reduction in the duration of impingement by increasing intake screen rotation frequency would likely improve survival of rockfish impinged at the Diablo Canyon Power Plant.

Long-term impingement survival of gobies and sculpins after a 3-hour screen rotation cycle was high at the Moss Landing Power Plant (Table 4-6). Long-term survival of gobies and sculpins was 98 and 97 percent at the Moss Landing Power Plant Units 6 and 7 intake. Initial survival of 10 sculpins (family Cottidae) collected following a 4-hour screen rotation cycle at the Diablo Canyon Power Plant (Table 4-5) was 60 percent. The low number of sculpins in impingement samples at the Diablo Canyon Power Plant precluded examination of factors contributing to the observed impingement mortality.

Impingement survival of macroinvertebrates, including rock crabs and sea urchins, at the Diablo Canyon Power Plant intake following a 4-hour screen rotation cycle was generally greater than 75 percent (Table 4-5). Both initial and long-term impingement survival of crabs (*Cancer* spp.) were also high at the Moss Landing Power Plant Units 6 and 7 intake, although the number of crabs observed was small (Table 4-6). Long-term survival of impinged crabs at the Units 6 and 7 intake was 88 percent after a 3-hour screen rotation cycle. The corresponding long-term survival data for the Units 1-5 intake, which was based on observations of a larger number of crabs, indicate that survival was 47 percent after a 3-hour rotation cycle, and survival increased with increasing screen rotation frequency. Long-term survival following impingement in the 1-hour and continuous rotation cycles at the Units 1-5 intake was 70 and 74 percent, respectively. Although impingement survival estimates for macroinvertebrates collected at the Diablo Canyon Power Plant were relatively high following a 4-hour screen rotation cycle, available evidence suggests that survival can be increased by rotating the intake screens more frequently, thus decreasing the duration of impingement.

Impingement survival data collected at the Diablo Canyon and Moss Landing power plants show that initial and long-term survival varies considerably between species. Species such as skates and rays, sculpins, rock crabs and sea urchins are able to survive impingement on intake screens. In contrast, impingement survival of sensitive species such as northern anchovy and smelts is typically low and is not substantially improved by modifications to the operating modes of conventional vertical traveling intake screens such as those at the Diablo Canyon Power Plant. Impingement survival for either the sensitive species or the hardy species does not appear to be substantially enhanced by increasing the frequency of screen rotation and cleaning and thus decreasing the maximum duration of impingement. Survival of surfperch, rockfish, and rock crabs, however, can be enhanced by increasing the frequency of screen rotation. Available impingement survival data for other groups such as flatfish are inadequate to determine the relationship between impingement survival and intake screen operation.

4.3 Impingement Summary

The number of impinged fish and macroinvertebrates was monitored at the Diablo Canyon Power Plant Units 1 and 2 over a period of 12 months (April 1985-March 1986). A total of 80 skates and rays (Chondrichthyes) and 323 bony fishes (Osteichthyes), representing 57 species (29 families) were collected. The three most abundant fish species collected included the yellowtail/olive rockfish, thornback ray and plainfin midshipman. The three most abundance macroinvertebrates collected were the rock crabs, sharpnose crabs, and the purple sea urchins.

Impingement densities for skates and rays typically remained below 1 fish per million m^3. Impingement densities of bony fishes were less than 1.2 per million m^3 during the spring (April-early June), increased during late June and July to levels approaching 4 to 5 fish per million m^3, and returned to densities typically less than 2 fish per million m^3 of cooling water during the remainder of the year. Impingement densities of rock crabs ranged from 1 to 16 per million m^3 throughout the year. Sharpnose crab and purple sea urchin densities were both less than 12 per million m^3 during the impingement monitoring program.

The impingement survival study was designed to estimate, by species, the proportions of fish and macroinvertebrates not surviving impingement. Initial survival observations were recorded for fish and selected macroinvertebrates collected during the routine impingement monitoring program. Because of the low numbers of impinged organisms, particularly fish, quantitative delayed (96-hour) impingement survival studies were not conducted. Impingement survival observations made at the Units 1 and 2 intake were used, in combination with results of impingement survival studies conducted at the Moss Landing Power Plant (PG&E 1983) and other sites, to evaluate the potential effectiveness of alternative intake technologies at the Diablo Canyon Power Plant.

Initial survival estimates for impinged bony fishes (Osteichthyes) were highly variable between families. Although the numbers of fish observed are insufficient to accurately quantify impingement survival, the data show that survival of hardy species such as sculpins and toadfish is relatively high. Rockfish, the fish species observed in highest numbers (80 individuals), had an initial survival rate of 26 percent. Initial survival for surfperch (31 individuals observed) impinged under the intermittent screen operational mode was 0 percent. Initial survival of the most abundant macroinvertebrates collected in impingement abundance samples was relatively high. Rock crabs (*Cancer antennarius*) had an initial impingement survival rate of 75 percent. The spider crabs (*Pugettia richii*) and the kelp crabs (*P. producta*) had initial survival rates of 80 and 83 percent, respectively. The impingement survival rate for the purple sea urchin was 92 percent. Qualitative observations were made of delayed (24-36 hour) impingement survival. In general, hardy species such as skates and rays, sculpins, most crab species (e.g., rock crabs, kelp crabs, sharpnose and spider crabs), and sea urchins were observed to survive impingement.

The survival rates of organisms impinged at the Diablo Canyon Power Plant intake reflect only potential survival since the survival estimates do not include effects associated with transit through the fish return sluiceway. In addition, infection resulting from abrasion or scale loss experienced during impingement was observed in the post-impingement observation period, but was not tested experimentally. For these reasons, impingement survival study results represent the survival potential for organisms removed from the intake screens and not the survival of organisms returned to the receiving waters. Because of the screenwash sluiceway design, and the methods of collection and disposal of impinged organisms and debris, no organisms survive impingement under the existing intake configuration.

Impingement survival data collected at the Diablo Canyon and Moss Landing power plants show that initial and long-term survival varies considerably between species. Species such as skates and rays, sculpins, rock crabs, and sea urchins are able to survive impingement on intake screens. In contrast, impingement survival of sensitive species such as northern anchovy and smelt are typically low and is not substantially improved by modifications to the operating modes of conventional vertical traveling intake screens such as those at the Diablo Canyon Power Plant. Impingement survival for either the sensitive species or the hardy species does not appear to be substantially enhanced by increasing the frequency of screen rotation and cleaning and thus decreasing the maximum duration of impingement. Survival of surfperch, rockfish, and rock crabs, however, may be enhanced by increasing the frequency of screen rotation.

4.4 References

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CHAPTER 5
IMPACT ASSESSMENT

This chapter assesses the impact of the combined entrainment and impingement losses at the Diablo Canyon Power Plant on populations of fish and macroinvertebrates of the source waterbody, the Pacific Ocean. The impacts on individual species are evaluated using available information on the distribution, abundance, behavior, and life histories of the species. A cooling water intake can be judged to represent a minimization of environmental damage if the numbers of organisms entrained and impinged will not result in adverse environmental impact (U.S. EPA 1977). Adverse environmental impacts occur when the intake:

- substantially reduces the abundance of existing populations;
- reduces sustained yield of sport or commercial fisheries; or
- impacts threatened or endangered species directly or indirectly

For an individual species, a potential for significant adverse impact exists if the source waters constitute a zone of high biological value for that species. This could be inferred if the waters are important migratory pathways, nursery areas, or feeding grounds for the species, or if the waters otherwise contain unusually high concentrations of the species during all or part of its life history. Species which have a relatively high susceptibility to population changes resulting from entrainment or impingement losses have life history characteristics such as the following:

- a very low reproductive potential as a result of low fecundity;
- a low natural mortality rate for the early life stages;
- geographical restriction of the species at all life stages to the immediate vicinity of the power plant; or
- a population already severely stressed or depressed as a result of factors such as excessive fishing pressure.

In contrast, species which have a low susceptibility to population changes resulting from plant-induced losses have life history characteristics such as:

- high reproductive potential;
- planktonic larvae which are widely distributed;
- early life stages with very high natural mortality rates;
- a wide geographical distribution, with a large proportion of the population located outside the immediate area influenced by cooling water system operation; or
- not being subject to pressures from intensive harvest in the sport and commercial fisheries.

In addition to these life history characteristics, the potential impact of the Diablo Canyon Power Plant cooling water system on a species depends in part on the proportion of the population susceptible to entrainment and/or impingement and on the survival of those organisms that are entrained or impinged. Table 5-1 presents a summary of life history characteristics for the principle fish and macroinvertebrates selected for consideration in the impact assessment for the Diablo Canyon Power Plant.

Since the intake is located in a small cove on an open rocky coast experiencing high wave, current, and tidal action, the impact of losses will be distributed over a considerable region of coastal waters (the "source waters"), rather than being confined to a more limited waterbody. The organisms cropped by entrainment and impingement might have traveled a considerable distance had they survived, and their replacements might come from a considerable distance away. Exactly how far these distances might be and thus how big a source waterbody should reasonably be considered varies according to the dispersal abilities of the individual species.

The intake vicinity is not of unusually high biological value for any species, and is typical of the rocky reef section of coast from Point San Luis to Montana De Oro. For many species with high dispersal ability, the source waters may more realistically be considered to be a broader section of coastal waters extending well beyond this section of coast. The type of rocky bottom coastal environment found in the vicinity of the Diablo Canyon Power Plant is also found along much of the California coast from Point Conception to Monterey, as well as along sections of coast to further south and north.

Another important consideration in this assessment is whether entrainment and impingement affect rare, threatened, or endangered species. Comparison of state and federal lists of rare, threatened, and endangered species with the species composition of entrained and impinged organisms (see Appendix E for a complete listing of collected species) shows that no rare, threatened, or endangered species are affected directly by the operation of the Diablo Canyon Power Plant cooling water system.

The following sections assess the potential for significant adverse impacts on biological populations in the source waterbody due to entrainment and impingement in the Diablo Canyon Power Plant cooling water system. The assessment is based on entrainment and impingement monitoring data collected during one year of plant operation, as well as data from offshore plankton tows, commercial and sport fishery statistics, underwater fish surveys, and relevant life history information.

The Diablo Canyon Power Plant impact assessment focuses on those fish and invertebrate species collected during the entrainment (Chapter 3) and impingement (Chapter 4) monitoring studies. For many species, however, lack of information concerning population size and the factors influencing population size has precluded a quantitative approach to impact assessment. In these cases, an intuitive approach was followed, using information about general trends in abundance, distribution,

TABLE 5-1

LIFE HISTORY CHARACTERISTICS FOR PRINCIPLE FISH AND MACROINVERTEBRATES SELECTED FOR CONSIDERATION IN THE DIABLO CANYON POWER PLANT IMPACT ASSESSMENT

		Geographic Range	Sport/Commercial Harvest	Widely Distributed
Macroinvertebrates				
Amphipods	Amphipoda	*		X
Decapod Shrimp	Crustaceans	*	X	X
Market Squid	*Loligo opalescens*	Baja California - British Columbia	X	X
Octopi	*Octopus* spp.	Baja California - Alaska	X	X
Dungeness crab	*Cancer magister*	Southern California - Alaska	X	X
Brown rock crab	*Cancer antennarius*	Baja California - Washington	X	X
Red rock crab	*Cancer productus*	San Diego, California - Alaska	X	X
Yellow rock crab	*Cancer anthonyi*	Baja California - Oregon	X	X
Fish				
Chinook salmon	*Oncorhynchus tshawytscha*	San Diego, California - Alaska/Japan	X	X
Northern anchovy	*Engraulis mordax*	Baja California - British Columbia	X	X
White croaker	*Genyonemus lineatus*	Baja California - British Columbia	X	X
Cabezon	*Scorpaenichthys marmoratus*	Baja California - Alaska	X	X
Sculpins	Cottidae	*		X
Blue rockfish	*Sebastes mystinus*	Baja California - Alaska	X	X
Olive rockfish	*Sebastes serranoides*	Baja California - Northern California	X	X
Yellowtail rockfish	*Sebastes flavidus*	San Diego, California - Alaska	X	X

* Diverse taxonomic group with broad geographic distributions.

and life history to estimate the impact of cooling water intake operation. For other species, a quantitative approach to impact assessment was followed, whereby intake-related cropping was compared to measures of the waterbody population size to permit estimation of the proportion of the population cropped. Species for which the quantitative approach to impact assessment was used include rock crabs (*Cancer* spp.), white croaker (*Genyonemus lineatus*), northern anchovy (*Engraulis mordax*), sculpin and cabezon (Cottidae), and rockfish (*Sebastes* spp.). In these more detailed assessments, intake-related cropping is related quantitatively to estimates of population size and/or density in the source waters and, where commercial or sport fisheries exist, to the sizes of nearby sport and commercial catches.

The following sections discuss information on general population trends, relevant life history information, and behavioral and distributional data for key organism groups, in order to assess whether available evidence indicates that population changes have occurred as the result of entrainment or impingement losses at the Diablo Canyon Power Plant.

5.1 Phytoplankton, Zooplankton, and Benthic Invertebrates

Several organism groups are not considered in detail in the impact evaluation. These include (1) phytoplankton, (2) zooplankton (excluding larval fish and selected macroinvertebrates), and (3) sessile benthic invertebrates.

After considering U.S. EPA guidelines (1977), and the potential for significant impact of the Diablo Canyon Power Plant cooling water system, phytoplankton and zooplankton were excluded from detailed consideration in the Diablo Canyon 316(b) Study Plan (Appendix A) because of their wide geographic distributions, short generation times, and population reproductive potential, and because the tidal and oceanographic currents in the area continually transport phytoplankton and zooplankton throughout the area near the plant. In addition, the survival of entrained zooplankton and macroinvertebrates is high. Experiments by Icanberry and Adams (1974) at various coastal marine power plants showed that over a range of discharge temperatures of 64-86 F (18-30 C), no significant relationship exists between monthly net entrainment mortality and monthly average discharge temperatures. Discharge temperatures at Diablo Canyon Units 1 and 2 rarely exceed 86 F (30 C; Figure 3-22); therefore, little thermal mortality will occur among entrained zooplankton.

The mechanical effects of entrainment on zooplankton were examined at the Diablo Canyon Power Plant during periods when circulating water pumps were in operation but no heat was being added at the condensers (Wilson 1977). Mortality of all zooplankton grouped together in discharge samples was less than 4 percent. This suggests that mechanical effects of entrainment at the Diablo Canyon Power Plant are minimal. Since it is likely that thermal mortality will be similarly negligible at discharge temperatures less than 30 C (86 F), the probability of invertebrates surviving entrainment at the Diablo Canyon Power Plant is high.

Although the numbers of zooplankton entrained may be high, the survival of zooplankton following passage through the cooling water system is also high (~95 percent), and therefore the probability of direct impact on their populations and the indirect impact on the aquatic community is low. Localized changes in phytoplankton and zooplankton populations would be very improbable because of the extensive natural movement of water through the areas offshore of the intake and discharge of the plant. No changes in species composition or overall abundance of either phytoplankton or zooplankton are expected to occur as a result of entrainment or impingement. On the same basis, the majority of benthic invertebrates were excluded because their bottom-dwelling habits minimize the involvement of juveniles and adults with the plant's cooling water system and because of the high potential survival of entrained larvae.

5.2 Macroinvertebrates

The potential for significant adverse impacts was examined for several entrained and impinged macroinvertebrate species because of their importance in aquatic food webs and because some are taken in sport and/or commercial fisheries. Most of these species have widely distributed planktonic larvae or are themselves free-swimming. Therefore, as long as the vicinity of the power plant is not an unusually favorable habitat for these species, impacts due to cropping at the cooling water intake are minimal.

For several groups of smaller macroinvertebrate species, the numbers entrained were not considered to indicate potential for significant impacts due to the abundance and wide distribution of these species along the central California coast. These groups included mysids, cumaceans, and isopods (small, widespread crustaceans). Also included in this group are euphausids, which, although entrained in somewhat greater numbers, are pelagic as both adults and larvae and are therefore well distributed along the coast.

No significant impacts are anticipated from entrainment of amphipods. These shrimp-like crustaceans are an important component of marine food chains. The high abundance of amphipods, their wide distributions, planktonic dispersal, and short generation times will distribute the impact of entrainment losses over a broad area and allow rapid replacement of losses. Furthermore, studies of entrainment mortality of amphipods at the Contra Costa and Pittsburg power plants showed only about 4-5 percent mortality for entrained amphipods.

No detectable impacts are anticipated from the entrainment of decapod shrimp larvae. The adults of these species are principally associated with epibenthic habitat in muddy and sandy areas and are therefore not highly susceptible to entrainment in the rocky habitat adjacent to the Diablo Canyon Power Plant cooling water intake. These species are very widespread and common, typically have moderate fecundities, and have planktonic, free-swimming larval stages generally lasting 2 to 5 months (Krygier and Horton 1975). Any impacts from entrainment will be spread over larval populations inhabiting a large volume of coastal water relative to the volume of water entrained. Therefore, local losses will be rapidly replaced.

Market squid, *Loligo opalescens*, are common off central California and support a commercial fishery, especially in the Monterey Bay area. Since young squid can swim at hatching, it is not surprising that they were uncommon in entrainment and impingement samples. The small number of adult squid found in impingement samples (15 individuals) indicates that the numbers lost as a result of impingement is insignificant relative to the population size and the wide distribution of this species, which supports a sizeable fishery.

Crabs commonly found along the central California coast include several species of Cancer crabs, shore crabs, kelp crabs, spider crabs, and pea crabs. These groups are common and widespread and typically have high fecundities. Larval stages which are planktonic and widely dispersed remain in the plankton a month or more. The Diablo Canyon Power Plant vicinity is not a unique or unusually favorable habitat for crab species. Therefore, the loss of a small portion of the larvae entrained by the cooling water system is insignificant relative to the much larger numbers of larvae in the much greater volume of well-mixed coastal waters, and any local losses will be rapidly replaced. Because of the high fecundities of these species and correspondingly high larval mortality, the entrainment of crab larvae effectively results in the loss of a much smaller number of potential adult crabs. Most of the entrained crab larvae were Cancer crabs, which is consistent with the relatively high abundance of rock crabs in the area, their wide distribution, and their long planktonic dispersal period. Because of the importance of Cancer crabs to local sport and commercial fisheries and to marine food chains, this group was evaluated in greater detail in Appendix C, with the results summarized in this section.

Crabs are subject not only to entrainment as larvae but also to impingement as juveniles and adults. Impingement losses can have a more localized effect than entrainment losses, since a juvenile or adult lost through impingement is replaced only after a time lag during which newly settled larvae grow to the same size as the impinged organisms, except to the extent that adult/juvenile migration replaces losses.

The crabs found impinged in the greatest numbers included *Cancer* spp. (primarily *Cancer antennarius*), spider crabs (*Pugettia richii*), kelp crabs (*P. productus*), and sharpnose crabs (*Scyra acutifrons*). The greatest impingement losses were experienced by juvenile *Cancer* spp.

Cancer Crabs

Off the California coast, *Cancer* spp. are widespread as adults and as planktonic larvae. They support commercial and sport fisheries and are important components of marine food chains. *Cancer* spp. were the most commonly impinged and entrained crabs. The potential impacts on this group are evaluated in greater detail in Appendix C, and the major results are summarized below.

There are four dominant species of Cancer crabs off the central California coast: the market or Dungeness crab (*Cancer magister*), and the brown, red, and yellow rock crabs (*C. antennarius*, *C. productus*, and *C. anthonyi*). Dungeness crab is the largest and most commercially important of the four species. Dungeness crabs are commonly found mostly to the north, prefer sandy bottom areas, and were not found in abundance in either entrainment or nearshore plankton tow samples. Dungeness crab were not collected in impingement samples at the Diablo Canyon Power Plant. Therefore, Dungeness crabs are not susceptible to significant impacts from entrainment and impingement at the Diablo Canyon Power Plant.

The remaining three rock crab species cannot be readily distinguished in the plankton and are all common in the vicinity of the Diablo Canyon Power Plant. Rock crabs are abundant and widely distributed as larvae and adults along the California coast. Rock crabs have very high fecundities with planktonic larval stages which are dispersed over large areas by coastal oceanographic currents. Plankton tow data verify that although larval *Cancer* spp. densities are highest inshore, they are no higher in the cooling water system than in the adjacent Intake Cove and are higher at nearshore locations off Point Conception and the San Diego area than off Diablo Canyon (Appendix C). This evidence indicates that the Diablo Canyon Power Plant vicinity is not an unusually high-density area for rock crab larvae. Since the Diablo Canyon Power Plant vicinity is not a unique habitat for rock crab larvae compared with other coastal regions, the impacts of entrainment losses are very small relative to the large numbers of larvae present off central California. Since the planktonic period for these crabs typically lasts about 120 days, the source waters and their resident crab populations are both very large; that is, entrained larvae could have eventually settled over a wide area and replacements for entrained and impinged crabs could have been produced over a wide area.

One approach useful in evaluating the potential impacts resulting from entrainment and impingement losses at the Diablo Canyon Power Plant is based on an estimate of the numbers of equivalent adult organisms mathematically represented by the loss of larval and juvenile life stages. The objective of the equivalent adult approach to power plant impact assessment is to translate the number of young organisms cropped by a plant into an equivalent number of adults, using estimates of the appropriate natural survival values for the population. Such an estimate has two useful applications.

1. The estimated equivalent adults can be used to relate cropping by the power plant to estimates of adult standing stock, if these are available.

2. For populations supporting a fishery, the estimated adult equivalents can be compared to cropping associated with the fishery.

The expected number of equivalent adults that would have been produced by a given number of entrained larvae equals the number of adults whose expected lifetime reproduction would produce exactly that number of larvae, of the same age, assuming that population size and age-specific mortality and fecundity rates are relatively stable. The equivalent adults represented by impingement equals the number of impinged juveniles multiplied by the average survival rate from juvenile to adult.

A conservative (high) estimate of the total equivalent rock crab adults of fishery entry size (approximately 100 mm carapace width and 3 years old) attributable to entrainment, assuming 90 percent entrainment survival (Section 3.2; Appendix B), and impingement is about 6,600 adults of fishery entry size. Estimated entrainment losses represent the largest and most uncertain contribution to the estimates of total equivalent adults.

The Morro Bay-Avila Beach coastal region supports a relatively small sport and commercial fishery for rock crabs. Frey (1971) concluded that because of the wide distribution and limited commercial appeal, the rock crab resources are not fully exploited in the commercial fishery. Although commercial catch data cannot be directly related to rock crab population size, commercial landings do provide a useful index for comparison with estimated equivalent adult losses attributable to entrainment and impingement. Commercial rock crab landings in the areas immediately adjacent to the power plant (CDF&G catch blocks 614, 615, 623; Figure C-1) averaged approximately 55,000 rock crabs per year between 1980 and 1985. The estimated 6,600 equivalent adult losses attributable to entrainment (assuming survival) and impingement can be compared with the average annual rock crab landings of 218,000 crabs for the Morro Bay-Avila Beach areas combined (catch blocks 600-650 over the period 1980-1985.). No measurable reduction in the rock crab population, or sport and commercial harvest, is expected to result from operation of the plant's cooling water system.

Because of the high abundance of rock crabs in coastal waters, their high fecundity and planktonic dispersal and correspondingly high natural mortality rates, and the high entrainment survival potential at the plant, there is little potential for significant impact on *Cancer* spp. populations due to larval entrainment at the Diablo Canyon Power Plant. The impingement of *Cancer* spp., 97 percent of which were juveniles, is judged to have even less potential for significant impact than does entrainment (Appendix C), especially since the majority of the impinged crabs would, if not impinged, still not have survived to either maturity or fishery size. Impingement will have little impact on rock crab populations considering that the benthic habits of adult and juvenile crabs reduce their exposure to impingement.

Conclusions - Macroinvertebrates

The direct impact of entrainment and impingement on macroinvertebrate populations, including amphipods, squid, shrimp, and crabs, and the indirect impact on the community are concluded to be low for the following reasons:

1. Although the numbers of macroinvertebrates entrained may be relatively high, the survival of invertebrates following passage through the Diablo

Canyon Power Plant cooling water system is also expected to be high (90 percent);

2. Entrained shrimp and crabs are predominantly early-stage planktonic larvae, and each adult female produces relatively large numbers of planktonic larvae which are subject to very high natural mortality rates;

3. The principal macroinvertebrate taxa susceptible to entrainment and impingement at the Diablo Canyon Power Plant are generally abundant and widely distributed in the nearshore coastal waters of California;

4. Any localized changes in the abundance of entrained invertebrates are diminished by the rapid movement of water through the discharge area and mixing in the receiving waters;

5. The numbers of macroinvertebrates impinged at the Units 1 and 2 intake are low. The macroinvertebrates impinged were predominantly juveniles which have a low probability of survival to maturity or recruitment to the local fishery;

6. The incremental mortality associated with rock crab entrainment and impingement will not result in a detectable change in local sport and commercial landings; and

7. Those macroinvertebrates that do not survive entrainment are returned to the receiving waters where they continue to provide a food resource for fish and invertebrates.

In addition, since the plant cooling water flows represent only a small fraction of the waterbody's volume, and since macroinvertebrate populations are distributed throughout the central California coast nearshore environment, the impact on the widely distributed populations is minimal. There is extensive habitat available for the most commonly impinged and entrained macroinvertebrates, and these species generally have high reproductive potential, broad geographic distributions, low susceptibility of reproductive adults to impingement (Chapter 4), and high expected survival following entrainment. Therefore, entrainment and impingement losses at the Diablo Canyon Power Plant will not preclude maintenance of the existing populations or result in a detectable reduction in either sport or commercial harvests in the area.

5.3 Fish

The major groups of fish found along the central California coast in the vicinity of the Diablo Canyon Power Plant include the anadromous fish and fish that are either permanent or seasonal residents. The anadromous fish include species such as chinook (king) and coho salmon. Some of the permanent and seasonal resident fish include the pelagic, schooling bait and forage fish such as northern anchovy, Pacific herring, and smelt, as well as such deeper water pelagic groups as deep sea smelt and lampfish. The majority of seasonal and permanent residents include marine inshore (neritic) groups such as rockfish, white croaker, cottids, and gobies, many of which prefer the rocky inshore kelp bed habitat found near the Diablo Canyon Power Plant and elsewhere along the central California coast.

No anadromous fish were found in entrainment or impingement samples collected at the Diablo Canyon Power Plant, since there are no significant runs of these species on nearby rivers to attract spawning adults or produce migrating juveniles. The adults are strong swimmers generally found offshore. Therefore, operation of the cooling water system has no impact on anadromous fish.

Seasonal and permanent resident fish may be broadly grouped into pelagic and inshore fishes. In general, both the adults and larvae of the pelagic fishes are widespread and swim over considerable distances. For these species, then, the impacts of entrainment and impingement should be spread over large, widespread populations and should be minimal since the Diablo Canyon Power Plant vicinity is not a unique habitat (such as a feeding or spawning ground or a key migratory pathway). For inshore species, entrainment and impingement losses may be more localized, due to the more limited migratory behavior of adults and juveniles. Larval dispersal for some of these species is also limited.

For all fish species, impingement will not produce significant impacts because very small numbers of fish were impinged. Other than rockfish and cottids, both discussed in more detail below, the fish species most abundant in impingement collections were thornback ray (*Platyrhinoidis triseriata*), shiner surfperch (*Cymatogaster aggregata*), and plainfin midshipman (*Porichthys notatus*). These species are very common and in fact are more common over sandy and muddy bottom habitats than in rocky areas such as the Diablo Canyon Power Plant vicinity. Therefore, the remaining discussion of entrainment and impingement impacts, other than for rockfish and cottids, focuses predominantly on entrainment.

5.3.1 Pelagic Fishes

Besides northern anchovy (*Engraulis mordax*), for which potential impacts are discussed in greater detail in Appendix C and summarized below, the principal pelagic species found in entrainment and/or impingement samples were Pacific herring (*Clupea harengus pallasi*), smelt (family Osmeridae), jacksmelt (family Atherinidae), jack mackerel (*Trachurus symmetricus*), Pacific mackerel (*Scomber japonicus*), lampfish (family Myctophidae), and deepwater smelt (family Bathylagidae). All of these species and species groups were entrained or impinged in very small numbers, are widespread, and have their main centers of adult and larval abundance in areas outside the Diablo Canyon Power Plant vicinity, principally in deeper waters. Therefore, there is very little potential for significant impacts on these groups due to entrainment and impingement losses.

5.3.1.1 Northern Anchovy

The northern anchovy is a planktivorous, pelagic schooling species found in the Pacific Ocean from Baja California to Alaska (Miller and Lea 1972). Over this range there are several genetically separate subpopulations each with its own distribution and spawning area. Anchovy in the vicinity of the Diablo Canyon Power Plant belong to the central subpopulation, which has its center of abundance and spawning off southern California but also extends north into waters off central California. Tagging experiments have shown that northern anchovy move back and forth between waters off southern and central California.

The northern anchovy fishery is the largest in California in terms of biomass. The vast majority of landings have been in southern California and can be attributed to the central subpopulation.

Northern anchovy have a high fecundity, and during spawning they release their eggs to drift with the currents. The early larvae are also planktonic and both egg and larval mortality rates are high. The center of spawning for the central subpopulation is in southern California waters.

Northern anchovy was the fourth most abundant fish taxa in the entrainment program, constituting 7 percent of all larval fish collected. Densities of northern anchovy were typically low (less than $0.08/m^3$) during the one-year entrainment monitoring program. The potential survival of entrained northern anchovy larvae is expected to be high (approximately 75 percent; Section 3.2) based on results of entrainment survival studies conducted at other power plants (Appendix B) and the discharge temperatures observed at the Diablo Canyon Power Plant.

Northern anchovy constituted less than 1 percent of the fish collected during the one-year impingement monitoring program. An estimated 8 northern anchovy were lost as a result of impingement during the one-year period, based on actual operation of the Diablo Canyon Power Plant cooling water system between April 1985 and March 1986.

Northern anchovy larval densities in entrainment samples are not unusually high relative to densities in nearby waters, and are in fact lower than densities that have been observed further offshore. Average annual densities from evening plankton tows conducted in the Intake Cove and offshore in 1986-87 were 5.9 and 22.3 per 1,000 m^3, respectively, versus 9.8 per 1,000 m^3 in the entrainment samples. In 1974-75, the average monthly density at stations 300 and 1,500 m (combined) offshore was 39.4 per 1,000 m^3. Not only were densities in the entrainment samples similar to those in nearby inshore waters, but, as noted above, northern anchovy larvae are much more abundant farther offshore and to the south of Point Conception, off southern California (Appendix C). Based on this comparison, it was concluded that the Diablo Canyon Intake Cove and adjacent nearshore coastal waters do not represent a unique biological environment for northern anchovy.

The estimated annual number of northern anchovy larvae in the central subpopulation over the period 1963-1981 varied from 13.3 to 47.5 x 10^{12} larvae. The number of northern anchovy larvae entrained at the Diablo Canyon Power Plant in a year represent less than 0.0002 percent of the estimated average larval population over these years (Appendix C).

The estimated equivalent 1-year-old adult losses attributable to larval northern anchovy entrainment during the one-year monitoring program conducted at the Diablo Canyon Power Plant, assuming an entrainment survival rate of 75 percent, is approximately 18,800 fish (Appendix C).

The equivalent 1-year-old northern anchovy adults represented by the larvae entrained in one year can be compared to recent estimates of the spawning biomass of the central subpopulation and recent statewide commercial catch statistics for northern anchovy. The estimated number of equivalent adult northern anchovy represented by entrainment cropping over one year represents less than 0.0001 percent of spawning adults in the central subpopulation for the period 1982-85. When compared to commercial catch, this same number of equivalent adults approximately less than 0.01 percent of the annual statewide landings reported over the period 1975-84.

Since only eight northern anchovy were estimated to be impinged during the one-year study period, this species is not at risk of population impacts resulting from impingement. This is consistent with the more offshore distribution of northern anchovy adults and juveniles.

In summary, there is no evidence of significant impacts on the northern anchovy population resulting from entrainment and impingement at the Diablo Canyon Power Plant. The central subpopulation of northern anchovy is large and widespread, with the greatest abundance and spawning occurring in waters to the south of, and markedly offshore from, the Diablo Canyon Power Plant.

5.3.2 Inshore Fishes

The inshore fish species that were common in entrainment and/or impingement samples may be divided into two groups: those with widely dispersed planktonic larvae, and those with limited or no planktonic dispersal. For any species in the first group, wide planktonic dispersal would spread losses, especially entrainment losses, over a wide geographic area and, therefore, reduce the potential for detectable population impacts. For those species with limited dispersal, potential impacts could be localized. Although the various inshore species fall along a continuum of planktonic dispersal ability, this grouping is useful in assessing the risk of significant impacts and clarifying the factors and assumptions that influence this assessment.

Other than rockfish and white croaker, the inshore species with broad planktonic dispersal which were found in entrainment samples included the following groups:

greenling and lingcod (family Hexagrammidae)

sandabs and halibut (family Bothidae)

turbot/sole/flounder (family Pleuronectidae)

None of these species groups made up a substantial portion of the total entrained ichthyoplankton (less than 1 percent each; Table 3-3) and all have high fecundity, wide distributions, and, especially for the flatfish species (Bothidae and Pleuronectidae), high population abundances. These species are sought by commercial and sport fishermen, but the preferred adult habitats and fishing grounds are outside the immediate vicinity of the Diablo Canyon Power Plant. Flatfish species, in particular, prefer sandy bottom areas.

Excluding cottids, inshore species with limited planktonic dispersal found most frequently in entrainment samples were:

clingfish (*Gobiesox* spp.)

kelpfish (family Clinidae)

pricklebacks (family Stichaeidae)

gunnels (family Pholididae)

gobies (family Gobiidae)

monkeyface eel (*Cebidichthys violaceus*)

It should be noted that the inshore species with limited planktonic dispersal that were common in entrainment samples are mostly small, common species that are not significantly exploited by either commercial or sport fisheries. However, cabezon, the largest of the cottids, are sought by sport and commercial fishermen. Other than cottids, the only groups entrained in large numbers were kelpfish (*Gibbonsia* spp.), pricklebacks (family Stichaeidae), and gobies (family Gobiidae). These groups are all extremely common in shallow subtidal and intertidal rocky habitats off central California, and for each group the entrained organisms belonged to several species. Although the discussion regarding potential localization of impacts for cottids (Section 5.3.2.2) applies in some degree to these other groups with limited planktonic dispersal, the potential impact of entrainment and impingement losses is judged to be minor in a regional (central California coast) or local (Port San Luis to Montana De Oro) context. However, for those species with the most limited planktonic dispersal, the potential exists for minor depression of larval and perhaps adult densities in the Diablo Canyon Intake Cove area.

A more detailed impact assessment was undertaken for three inshore groups of fishes because these groups were commonly found in entrainment and/or impingement samples and are of ecological and/or economic importance. Among these three groups are two groups with widely dispersed planktonic larvae, rockfish (genus *Sebastes*) and white croaker (*Genyonemus lineatus*), and one group with limited planktonic dispersal (sculpin and cabezon, family Cottidae). The more detailed evaluation for these groups presented in Appendix C is summarized in this section.

5.3.2.1 White Croaker

White croaker (*Genyonemus lineatus*) are found in coastal waters from Baja California to British Columbia, typically swimming in loose schools along sandy bottoms to a depth of about 600 ft. Adults and juveniles prefer shallow waters, less than 200 ft. White croaker are important in pier and skiff sport fisheries in central and southern California, but are considered a nuisance species by partyboat fishermen. Spawning occurs mainly in winter; the adults move inshore to spawn and the larvae then move even further inshore and to the bottom.

Since they prefer a sandy bottom habitat, white croaker adults and juveniles are not common off the Diablo Canyon Power Plant. They are common south of Point Conception, in nearby sandy bottom areas to the south around Avila Beach and to the north around Morro Bay and Monterey Bay. No white croaker adults or juveniles were found in impingement samples. The potential impact of Diablo Canyon Power Plant cooling water intake operation on this species is primarily attributable to larval entrainment.

White croaker larvae are much more abundant in sandy bottom coastal waters from Point Conception south than in the vicinity of the Diablo Canyon Power Plant (Appendix C). The high white croaker larval densities off southern California translate into a large estimated population in absolute numbers. Love et al. (1984) estimated the total number of white croaker larvae from Point Conception to Playa del Rey and from Point Conception to the Mexican border to have been 11.5 and 32.0 billion, respectively, during 1979-80. Data from oblique plankton tows from 1978 through 1984 were analyzed by Lavenburg et al. (1986) to estimate the total white croaker larval peak winter population in the southern California Bight inshore of the 36 m contour. The peak winter/spring larval population estimates over six years ranged from about 20 billion to 200 billion.

White croaker larval densities off Diablo Canyon Power Plant have been found to be about an order of magnitude lower than those off southern California, at similar water depths. There is no indication that the Diablo Canyon Power Plant vicinity is a unique habitat for any white croaker life stage, and, in fact, is significantly less favorable habitat since sandy bottom areas are limited.

It is useful to assess the impacts of entrainment losses not only by comparing larval densities and numbers in the entrainment samples with those in nearby waters, but also by estimating the numbers of mature adult fish that the entrained larvae would have produced. Mature adult white croaker are considered to be fish 1 year old and older, since the majority of white croaker are mature by the time they reach the average size of a 1-year-old fish (Love et al. 1984). Estimated numbers of equivalent adults can then be compared to estimated natural adult densities and population sizes, as well as to sport and commercial catches.

Assuming that on the average each newly mature female white croaker produces exactly enough surviving offspring to replace itself, the number of newly mature equivalent adults lost as a direct result of larval entrainment, assuming 75 percent entrainment survival (Section 3.2), is 465 white croaker. This estimate is conservative because it assumes a low estimate of lifetime fecundity and a high estimate for pre-entrainment larval mortality resulting in a low estimate for post-entrainment larval mortality (Appendix C).

The estimate of equivalent adults represented by larval white croaker entrainment at the Diablo Canyon Power Plant can be compared to white croaker sport and commercial catches in nearby CDF&G catch blocks. However, white croaker prefer sandy bottom inshore areas and are not heavily fished in the vicinity of the Diablo Canyon Power Plant.

White croaker are not a significant component of either the local commercial or sport partyboat fisheries and although they are important in pier and skiff (private boat) fisheries (primarily in Southern California), these fisheries are not large in the Morro Bay-Avila Beach area and are not well documented. Based on a sportfishing survey conducted from Point Arguello to Oregon it was estimated that about 62,000 white croaker were caught off the Avila Pier in 1958. Annual sport and commercial white croaker landings from 1980 through 1985 averaged only 312 fish for catch blocks 614, 615, and 623 which are located immediately adjacent to the Diablo Canyon Power Plant site. Annual sport and commercial landings over the coastal region in the general vicinity of the plant (catch blocks 607, 608, 614, 615, 616, 622, 623, 624, and 632 for the period 1980 through 1985), including the sandy-bottomed areas preferred by white croaker, averaged 10,615 fish. The equivalent adult loss attributable to entrainment mortality of 465 white croaker will not result in a detectable reduction in the limited local sport and commercial harvest of white croaker.

The probability of direct impact on the white croaker population and the indirect impact on the aquatic community is low. Any localized changes in the abundance of white croaker resulting from entrainment mortality are diminished by the rapid movement of water through the discharge area and mixing in the receiving waters. The larvae which are susceptible to entrainment are planktonic, and the reproductive potential of adult female white croaker is very high (hundreds of thousands of eggs per female per year), suggesting that natural survival rates of larval white croaker are very low. The coastal waters adjacent to the Diablo Canyon Power Plant and the Intake Cove do not represent a unique habitat for white croaker, as evidenced by the fact that no white croaker juveniles or adults were collected in impingement samples. In addition, since the plant cooling water flows represent only a small fraction of the waterbody's volume, and since white croaker are distributed throughout the coastal nearshore waters of California, the potential for impact on the widely distributed white croaker population is minimal.

Because of the extensive habitat available for white croaker along the coast, their high reproductive potential, their broad geographic distribution and planktonic larval dispersal stage which experiences high natural mortality, and the low susceptibility of juveniles and adults to impingement, the white croaker population is resilient and able to sustain incremental entrainment mortality without adverse impacts. White croaker are not subject to an intensive local sport or commercial fishing harvest in the coastal waters in the area of the Diablo Canyon Power Plant, and combined losses attributable to entrainment and impingement will not result in a detectable reduction in yield to the local fishery. Entrainment losses, therefore, will not preclude maintenance of the existing population and the local fishery.

5.3.2.2 Cabezon and Other Sculpins (Family Cottidae)

Sculpins, or cottids (family Cottidae), are bottom-dwelling, mostly inshore, fishes typically inhabiting crevices, tidepools, and algae-covered substrate in rocky areas. Along the California coast, most cottids are found from the intertidal zone to depths of 100 feet, although some species may be found at depths of 200 or 300 feet, and a very few occupy even greater depths (Miller and Lea 1972). There are about 45 cottid species off California, but only one, cabezon (*Scorpaenichthys marmoratus*), is large enough to be of economic and sport value (Frey 1971). Other cottids sometimes taken by sport fishermen off California are the red and brown Irish lords (*Hemilepidotus hemilepidotus* and *H. spinosus*), the Pacific staghorn sculpin (*Leptocottus armatus*), and the buffalo sculpin (*Enophrys bison*), of which only the Pacific staghorn sculpin is taken with any frequency (Frey 1971). Twenty-two sculpin species have been identified in the Diablo Canyon Power Plant area in underwater surveys and/or entrainment and impingement samples. There is limited information on the life histories of cottids other than cabezon, and identification of the larvae to species is difficult. While cabezon larvae could be identified in entrainment samples, the majority of sculpin larvae could not be identified to species, so the impact assessment focuses on cabezon and, in parallel, on other sculpins collectively.

Virtually all of the cottids in the area have wide distributions along the Pacific Coast. Of the 22 species observed in the Diablo Canyon Power Plant area, 21 have known ranges extending north of California into waters off Oregon (and typically off Alaska) and/or south into Baja California.

Planktonic transport of cabezon and other cottid larvae between more distant adult habitats and the rocky coastal area adjacent to the Diablo Canyon Power Plant is certainly possible. Cabezon larvae have been found to be widely distributed, out as far as 200 miles from shore (O'Connell 1953), although the majority of larvae are concentrated in inshore waters. Many inshore cottid species off California appear to have planktonic periods that last weeks to months (Yoshiyama et al. 1986). Comparison of the times of spawning and larval settlement also indicate that planktonic periods of a month or more are likely for many inshore cottid species. Most cottids deposit their eggs demersally in the shallow intertidal and inshore coastal regions (Tasto 1975; Marliave 1981; DeMartini 1978), and their larvae are typically more restricted to inshore waters than most other fish larvae (O'Connell 1953). Therefore, although larval cottid dispersal occurs, there is a reasonable probability that the rocky coastal region between Point San Luis and Montana De Oro, and even the more localized area around Diablo Canyon Power Plant, is largely closed to migration of cottids via planktonic transport, so that a conservative impact assessment will assume that the impact of cottid losses via entrainment and impingement at the Diablo Canyon Power Plant is localized to this area.

Juvenile cabezon and other cottids represented a small proportion of the fish impinged at the Diablo Canyon Power Plant (Table 4-3). The numbers of cabezon and sculpins impinged during the one-year monitoring program are judged to have an insignificant potential for impacting local cottid populations. Therefore, the following discussion focuses only on entrainment losses.

Cottids and cabezon are abundant and widely distributed throughout nearshore waters along the Pacific Coast. Evidence indicates that for at least some cottid species, the majority of larvae may be concentrated within 20 meters of rocky shores. Comparison of larval densities in entrainment samples, the Intake Cove, and nearshore locations 1/2 mile and 300 and 1,500 meters (combined) offshore indicates that both cabezon and other cottid larval densities are in fact higher in the Intake Cove and the Diablo Canyon Power Plant cooling water system itself than at the nearshore stations, and are much higher at all these locations than at CalCOFI sampling stations (at least 18.5 km offshore). While cottid and cabezon larvae appear to be concentrated inshore, there is no evidence to indicate that the Intake Cove represents a unique habitat when compared to the abundant rocky areas along this section of coast where cottid larvae are typically found, or that cottid larvae in the Intake Cove are attracted by or concentrated at the cooling water intake.

In addition to comparing larval densities in entrainment collections with densities in nearby waters, the potential impacts of entrainment on cabezon can be evaluated by estimating the numbers of newly mature, equivalent adults the entrained larvae would have produced had they not been entrained. Deriving equivalent adult estimates requires knowledge of either survival from the age of entrainment to maturity, or the fecundities and survival of adult fish plus survival from spawning to the age of entrainment. Quantitative population dynamics information is only partially known for cabezon and is even less available for other cottid species. Equivalent adult estimates are useful, however, in establishing broad upper bounds on the numbers of potential adult fish lost as a result of entrainment.

The equivalent adults lost as a direct result of entrainment of a given number of larvae is that number of newly mature adults that would have been produced by the larvae had they survived, assuming some constant regime of age-specific mortality rates. If the population size and mortality rates are assumed to be stable, the number of equivalent adults equals the number of newly mature fish that, over their remaining lifetime, would produce exactly the numbers (and ages) of larvae that were entrained, i.e., would exactly replace the age group that was lost as a result of entrainment at the Diablo Canyon Power Plant.

The calculation of expected total lifetime reproduction for a newly mature 3-year-old female cabezon is discussed in Appendix C. An annual adult survival rate of 75 percent appears to be a conservative (low) estimate, since cabezon are large, cryptic, bottom-dwelling fish that have been observed to live at least 13 years. The resulting conservative (low) estimate of cabezon fecundity is 216,200 eggs produced over the reproductive lifetime of a newly mature 3-year-old female cabezon (108,100 eggs per newly mature female, assuming a 1:1 sex ratio).

The estimated number of cabezon larvae lost as a result of entrainment at the Diablo Canyon Power Plant, assuming 75 percent entrainment survival, would then represent the lifetime egg production of 60 adult fish, assuming there had been no egg and larval mortality prior to entrainment. If, for example, there had been 90 percent egg and larval mortality prior to entrainment, it would take ten times as many adults to produce the same number of larvae surviving to entrainment, and the number of equivalent adults represented by the entrained larvae would be 600 cabezon. Since adult and larval survival rates and the ages of the entrained larvae are poorly known, this estimate was based on the very conservative assumption of high (90 percent) pre-entrainment larval mortality (consequently, low post-entrainment mortality), in addition to the conservative assumptions of only one spawning per year and 75 percent annual adult survival.

Given the limitations and uncertainties inherent in the quantitative data available on population dynamics for other cottid species (sculpins), it is not possible to calculate the equivalent adults represented by the cottid larvae entrained at the Diablo Canyon Power Plant partly because different cottid species have different survival rates, longevities, and fecundities, and most of the entrained cottid larvae were not identified to species. In addition, the life histories of these various species are not nearly so well known as life history of the cabezon. In general, since these species have lower fecundities than cabezon, a greater proportion of the offspring must survive to maturity to provide population replacement, so that it would take fewer entrained larvae to represent one equivalent adult than for cabezon. However, for these smaller cottids, a newly mature equivalent adult would be a much younger fish than for cabezon.

There are no reliable estimates of adult cabezon densities in the vicinity of the Diablo Canyon Power Plant against which to compare the estimated equivalent adults lost as a result of entrainment. However, baseline studies in the Diablo Canyon Power Plant vicinity conducted by CDF&G in 1970 and 1971 provide some indication of field densities, although the cryptic habits of cabezon probably resulted in under-representation of natural densities. Along with other fish, cabezon were counted in a series of underwater transects at different depths in winter, summer, and fall of 1970 and 1971 (Burge and Schultz 1973). Most of the 55 separate transects surveyed were in the 10- to 40-foot depth zone. No differentiation was reported between adult and juvenile cabezon. In a second set of surveys conducted by CDF&G, fish were collected after poisoning with rotenone 3,000-4,000 ft^2 areas at 3 depths on 3 occasions in Diablo Cove and 3 depths, on 1 occasion in North Cove. The total number of juvenile and adult cabezon collected was 231 (Burge and Schultz 1973).

Of all the cottids entrained, impinged, or observed in the Diablo Canyon Power Plant vicinity, only the cabezon is significant in any fishery. The annual commercial catch of cabezon over the three catch blocks encompassing inshore waters along the rocky coastline and over other adjacent catch blocks in the Avila Beach - Morro Bay area averaged 350 and 1,704 per year, respectively, over the period 1980 to 1985. The annual partyboat catch averaged 173 and 407 per year for the same areas from 1981 to 1985. Because cabezon inhabit shallow rocky areas along the coast, they represent an incidental component in the partyboat and commercial fisheries in the area; therefore landings data underestimate population abundance.

Both the commercial and sportfishing landings for cabezon from coastal waters in the vicinity of the Diablo Canyon Power Plant reflect a trend toward declining catches in recent years (Table C-5). Since the decline in cabezon catches occurred prior to initiation of commercial operation of Diablo Canyon Units 1 and 2, the decline can not be attributable to either entrainment or impingement mortality.

In summary, because cabezon and other cottid larvae are generally most abundant in inshore coastal waters and because they were common in entrainment samples and, especially in the immediate Intake Cove vicinity, a potential for impacts exists. A more precise evaluation of potential impacts requires more detailed information on the ages, dispersal, age-specific survival, and species identities of the entrained cottid larvae. There is no evidence that the Intake Cove vicinity represents a unique habitat for the various cottid species that are common and widespread in similar rocky inshore habitats along the central California coast. Therefore, the greatest impact that could be reasonably expected to occur would be reduced larval and adult densities in the Intake Cove and very immediate vicinity, for those entrained cottid species with the most limited larval dispersal.

5.3.2.3 Rockfish

Rockfish (*Sebastes* spp.) are a diverse genus of fish represented by over 60 species off the California coast. Many of these species are very widespread and abundant. Adult rockfish have wide geographic ranges, typically extending south to waters off Baja California and/or north to waters off at least Oregon and often to Alaska. Sixteen rockfish species were identified as adults and/or juveniles in the vicinity of Diablo Cove by Burge and Schultz (1973), and 29 species have been observed in the partyboat catch off Diablo Canyon from 1980 through 1986 (Gibbs and Sommerville 1987). Rockfish are sought by commercial and sport fisherman over most of the California coast, especially north of Point Conception.

Rockfish are ovoviviparous and release newly hatched or hatching individuals to the environment. Although most rockfish spawn during winter months, there is considerable variability among and within rockfish species with regard to timing of spawning (Phillips 1964; Miller and Geibel 1973; Love and Westphal 1981). The largest adults of a species tend to spawn earliest in the season and frequently bear the greatest number of young (Phillips 1964). Some species of rockfish show evidence of multiple spawning in a single season. Rockfish are prolific, with approximately 50,000 to several million live young being produced each year per female of the various species (Love and Westphal 1981; Phillips 1964; DeLacy et al. 1964; Gunderson et al. 1980; MacGregor 1970; Miller and Geibel 1973). Rockfish larvae typically spend 2, 3, or more months in the plankton and are widely distributed. Rockfish larvae are most common off the California coast from January through March, and least common in summer and early fall (Ahlstrom et al. 1978). Most young-of-the-year juveniles of inshore rockfish settle out from the plankton during May through August (Singer 1985).

Off California, rockfish may be found in "virtually every habitat from intertidal regions to depths of well over 1,000 m" (Love and Westphal 1981). The larvae are widely distributed, having been found at the farthest CalCOFI sampling stations 250 miles offshore, but are seldom found at depths below 100 m (Ahlstrom 1961). Larvae from various species range in size from about 3.8 - 7.5 mm total length (TL) at extrusion (Miller and Geibel 1973; Moser et al. 1977; Ahlstrom et al. 1978; Moser and Butler 1981, 1987; Stahl-Johnson 1984). The larvae of only 15 species can currently be distinguished, and there are complete descriptive series for the larvae of only 8 species (Moser et al. 1977; Moser and Butler 1987).

Offshore species tend to have longer planktonic periods and greater juvenile and adult migrations, often including temporary residence by juveniles in inshore nursery areas, followed by abrupt or gradual movement offshore with age (Miller and Geibel 1973; Moser et al. 1977; Moser and Ahlstrom 1978; Ahlstrom et al. 1978; Lenarz 1980; Wilkins 1980). Burge and Schultz (1973) considered the rocky kelp bed habitat located off Diablo Canyon Power Plant to be a nursery area for the juveniles of both inshore rockfish species and also certain offshore species. The juveniles of offshore species, including bocaccio, chilipepper, widow, yellowtail, and canary rockfish have been observed in nearshore habitats, especially during the summer. This use of inshore rocky kelp bed habitat as a nursery area for a variety of rockfish species has been observed in studies conducted elsewhere (Miller and Geibel 1973). Baseline surveys found blue rockfish to be the most common rockfish in the Diablo Cove area, both as juveniles and as adults (Burge and Schultz 1973). Other common rockfish were olive, black-and-yellow, black, kelp, and gopher.

Nearshore waters off the Diablo Canyon Power Plant are well-mixed by currents, wind, and tides; as a result, rockfish larvae are widely distributed in these waters. Impacts of rockfish entrainment and impingement are likely to be spread over a large volume of source waters and, therefore, large natural rockfish populations. Rockfish larvae lost as a result of entrainment could have eventually settled over a wide area, and replacements for entrained and impinged rockfish could have been produced over a wide area. Because rockfish larvae in entrainment samples were very small (Figure 3-7) and were not identified to species, potential impacts are assessed for rockfish as a group, although it is likely that most of the entrained larvae belonged to the dominant inshore kelp bed species, such as blue (*Sebastes mystinus*), olive/yellowtail (*S. serranoides/flavidus*), black-and-yellow (*S. chrysomelas*), and kelp (*S. atrovirens*) rockfish, which accounted for virtually all rockfish impinged.

Examination of rockfish larval densities offshore of the Diablo Canyon Power Plant in 1974-75 and 1986-87, in the Intake Cove in 1986-87, and in entrainment samples in 1985-86 indicates that densities were generally lower during the entrainment sampling period. Abundance of many of the fish taxa inhabiting the coastal waters in the vicinity of the Diablo Canyon Power Plant have shown general declining trends over time; however, the densities of larval rockfish entrained during the 1985-86 sampling period were representative of larval fish densities in recent years. Results of a nearshore plankton monitoring program conducted in the vicinity of the Diablo Canyon Power Plant and a discussion of the general trends in ichthyoplankton densities from CalCOFI and other plankton sampling programs are presented in a separate technical report (TENERA 1988).

Rockfish observations by divers from 1976 through early 1988 have shown a noticeable decline in juvenile rockfish densities in the vicinity of the Diablo Canyon Power Plant (TENERA unpublished data) and more generally along the California coast. There seems to be reasonable evidence to link this decline to recent El Niño events (1976-77 and 1982-83) and/or severe winter storm activity. Over the past decade the *Nereocystis* spp. kelp canopy and also the *Pterygophora* spp. sub-canopy have greatly diminished in the regularly surveyed areas adjacent to the power plant. Concomitant with this decline of the canopy has been a decline in observed abundance of both blue and olive rockfish, which are midwater schooling species usually associated with the kelp canopy in shallower habitats. The most common adult rockfish in recent Diablo Cove observations have been both black-and-yellow rockfish, a demersal/cryptic species, and blue rockfish. Other common rockfish have been olive and grass rockfish. Grass rockfish frequent dense, shrubby vegetation in very shallow water and were uncommon in the earlier baseline surveys. The greatest decline has been in the densities of juveniles during the summer. The decline in the rockfish populations along the California coast, which began in the late 1970's, preceded the commercial operation of the Diablo Canyon Power Plant, and hence the rockfish decline is not associated with either incremental entrainment or impingement mortality at the plant.

The losses of entrained rockfish larvae can be placed in perspective by comparing them to naturally occurring rockfish population densities in various portions of the coastal waters off central California (standing stock comparison). The annual number of rockfish larvae in coastal waters from San Francisco to southern Baja California has been estimated, based on CalCOFI plankton tow results, to have ranged from 37,867 x 10^9 to 218,978 x 10^9 over 14 different years from 1950 through 1975 (MacGregor 1986). The majority of these larvae were found within 20 miles offshore. MacGregor (1986) estimated the average annual number of rockfish larvae in coastal waters along CalCOFI sampling lines 73 (Point Piedras Blancas) through 80 (Point Conception), encompassing 120 miles of coastline, to have been 17,836 x 10^9 over the period 1950-1975. For waters adjacent to line 77 (Point San Luis) alone, encompassing 40 miles of coastline, the average standing stock was estimated to be 6,159 x 10^9 rockfish larvae. The estimated annual entrainment loss of rockfish larvae equals approximately 0.0002 percent of the estimated average annual number of rockfish larvae in coastal waters off the 40 miles of coast centered on CalCOFI station line 77 (Point San Luis), and approximately 0.00008 percent of the estimated annual average number of larvae off the 120 miles of coast extending from roughly Point Piedras Blancas in the north to Point Conception in the south. Based on these comparisons, it was concluded that entrained larvae represent an extremely small percentage of the larval rockfish population in the source waters. If rockfish larval densities return to recent historical levels, entrainment losses could increase but would still be an insignificant portion of the larval populations in nearby coastal waters.

Losses due to entrainment can also be evaluated by estimating the numbers of equivalent adults that could have been produced from the entrained larvae had they survived. Due to the lack of detailed quantitative information on the natural survival rates of adult, juvenile, and larval rockfish, equivalent adults can only be approximately estimated. Furthermore, because of the limitations in accurately identifying rockfish larvae to species when they are 3-5 mm TL (the size class typically entrained; Figure 3-7), there is no accurate means to allocate cropping losses proportionately among species.

The estimated entrainment loss of rockfish larvae results in the loss of a much smaller number of potential adults because the natural survival of rockfish larvae and juveniles is low. Females, which live up to 15 or 20 years (or more), produce large numbers of larvae each year, of which only a few survive to maturity. In a population that is exactly replacing itself, only one newly mature adult female will, on average, be produced from the entire lifetime reproductive output of each newly mature female. Assuming that the rockfish populations are stable, the number of equivalent newly mature adult fish that entrained larvae would have produced had they survived, equals the number of males and females whose lifetime reproductive output would exactly replace the number of entrained larvae. The total number of larvae expected to be produced during the lifetime of a newly mature female is a function of fecundity, annual survival rates of mature females, and the fraction of females spawning at each age.

The numbers of newly mature adult rockfish that would have survived from larval rockfish entrained at the Diablo Canyon Power Plant were estimated (Appendix C) by assuming that:

- All entrained rockfish had the same fecundities and survival rates as blue rockfish.

- Survival from extrusion to age of first reproduction is exactly sufficient to produce a stable population, i.e., an overall survival rate of 2/215,000.
- Adult survival is 75 percent per year.
- Entrained larvae had experienced 75 percent natural mortality prior to entrainment.
- Entrainment survival is 75 percent.

Using the above assumptions to calculate equivalent adults, the estimated annual entrainment of larvae represents an estimated 540 newly mature adults.

Rockfish represented 27 percent of all fish collected from impingement abundance samples (Chapter 4). Of the *Sebastes* spp. impinged, the most common species were the yellowtail, olive, blue, and kelp rockfishes. Yellowtail and olive rockfishes were often grouped together because of the difficulty in distinguishing juveniles of these species. Total estimated annual rockfish impingement for the period April 1985 through March 1986 at the Diablo Canyon Power Plant, based on actual cooling system operations, can be converted to equivalent adults by assuming that these fish would have experienced 75 percent annual survival over the 2.5 years, from their first season of settlement (age 0.5 year) to age 3. This annual survival rate represents the lower end of the range (75-90 percent) considered to realistically represent natural survival rates for adult rockfish and is considered to be a maximum survival rate for juveniles. The total estimated number of equivalent adults represented by impinged rockfish is 422 fish.

The total estimated loss of 962 equivalent adult rockfish resulting from entrainment (540) and impingement (422) combined can be placed in perspective by comparing it to sport and commercial catches of rockfish along the rocky coastal area surrounding the Diablo Canyon Power Plant. From 1980 through 1985, 2,836,830 rockfish were landed on commercial passenger partyboat fishing vessels out of Port San Luis and Morro Bay ports combined (as reported by CDF&G). The rocky coastal area between Point San Luis and Montana De Oro, roughly centered on the Diablo Canyon Power Plant, is encompassed by CDF&G catch blocks 614, 615, and 623 (Figure C-2). The total number of rockfish reported by CDF&G for these 3 catch blocks for the same 6-year period was 819,342 (29 percent of that reported for the combined Port San Luis/Morro Bay ports), which equates to an average annual sport catch of 136,557 rockfish in these catch blocks and 472,805 rockfish landed at Port San Luis and Morro Bay.

The estimated 962 equivalent 3-year-old adult rockfish represented by the annual entrainment and impingement combined then accounts for 0.7 percent of the reported annual average partyboat catch of rockfish from catch blocks 614, 615, and 623 during the period 1980-85, or about 1.5 percent of the estimated blue rockfish catch alone (CDF&G unpublished data). The estimated number of 962 equivalent adult rockfish is low (0.2 percent) compared to the annual average rockfish landings from commercial passenger fishing vessels out of Port San Luis and Morro Bay.

Consequently, entrainment and impingement losses will not result in a detectable reduction in sportfishing harvest in the coastal waters adjacent to the power plant.

The commercial catch reported by CDF&G for the same three catch blocks during 1980-1985 averaged about 109,000 pounds per year and declined between 1982 and 1985. Total commercial rockfish landings for the Avila Beach area averaged 1.18 million pounds per year over the period from 1980 to 1986. Although much of the commercial rockfish catch was not identified to species, it is known to include a greater proportion of deeper water (mostly larger) species than reported for the sport fishery. Assuming an average weight of 4 lb per fish gives an estimate of 27,000 fish per year over the three catch blocks encompassing the rocky coastal area, or about one-fifth of the reported partyboat catch from the same catch blocks. The same conversion yields a commercial harvest of 295,000 rockfish per year for total Avila Beach area landings. Rockfish species important in the commercial fishery are unlikely to experience significant impacts due to incremental mortality resulting from entrainment and impingement at the Diablo Canyon Power Plant because the commercial catch of rockfish contains mainly offshore species and thus represents a different mix of species than either those collected in the entrainment/impingement samples or in the local partyboat catch. Entrainment and impingement losses will not result in a detectable reduction in commercial rockfish harvest in the coastal waters adjacent to the power plant.

It was concluded that the direct impact of the Diablo Canyon Power Plant on local rockfish populations and the indirect impact on the community are minimal for the following reasons:

- Rockfish inhabit a wide variety of marine habitats. They are a resilient genus; high fecundity and wide dispersal give a population the potential to recover from losses.
- Estimated annual larval entrainment represents about 0.0002 percent of the estimated annual numbers of rockfish larvae off 40 miles of coast centered on CalCOFI station line 77 (Point San Luis) over the period 1950-1975.
- The estimated numbers of equivalent adults represented by annual entrainment and impingement losses equals about 0.7 percent of the annual commercial passenger fishing vessel (recreational) catch of rockfish (all species) in the three catch blocks encompassing the rocky coastal area between Point San Luis and Montana De Oro over the period 1980-1985 and approximately 0.2 percent of the average annual commercial passenger partyboat landing for Port San Luis and Morro Bay ports. Entrainment and impingement losses will not result in a detectable reduction in sportfishing or commercial fishing harvest in the coastal waters adjacent to the Diablo Canyon Power Plant.

Rockfish in general have relatively high fecundities, long lifespans, and high adult survival rates; these factors all imply low natural survival for rockfish larvae. This generalization applies to all rockfish species observed in the impingement collections and the nearby field surveys. The rockfish most common in the Diablo Canyon Power Plant vicinity are abundant over wide geographic ranges. In addition, rockfish larvae are widely distributed in the plankton off the California coast. The above conditions suggest that rockfish populations are resilient to entrainment and impingement losses of the magnitude observed at the Diablo Canyon Power Plant.

5.4 Conclusions

The impact of the combined entrainment and impingement losses at the Diablo Canyon Power Plant on populations of fish and invertebrates of the source waterbody, the Pacific Ocean, has been assessed. Results of the assessment provide no evidence that incremental mortality attributable to entrainment and impingement result in adverse environmental impacts. Entrainment and impingement losses at the Diablo Canyon Power Plant:

- will not substantially reduce the abundance of most existing populations, however, within the Diablo Canyon Intake Cove and its immediate vicinity there exists the potential for reductions in the abundance of cabezon and/or other cottid species, which may have limited larval dispersal
- will not reduce sustained yield of local sport or commercial fisheries
- do not directly affect threatened or endangered species.

Therefore, it was concluded that the direct impact of the Diablo Canyon Power Plant on local fish and invertebrate populations and the indirect impact on the community are minimal. This conclusion is based, in part, on the ecological assimilative capacity of the species involved. The species of fish and macroinvertebrates entrained and impinged typically have high reproductive potential (either in terms of numbers of young produced or frequency of reproduction), and the young, many of which are planktonic and widely distributed, are characterized by very high natural mortality rates. Life history reviews of the key species of fish and macroinvertebrates, combined with entrainment and impingement monitoring and general fisheries surveys conducted in nearshore waters in the vicinity of the Diablo Canyon Power Plant show that:

- Since the plant cooling water flows represent only a small fraction of the source waterbody's volume, and since the species of fish and invertebrates collected in the entrainment and impingement monitoring program are distributed throughout the central coast nearshore environment, the potential for impact on these widely distributed populations is minimal.
- Survival of invertebrates and larval fish following passage through the Diablo Canyon Power Plant cooling water system is expected to be relatively high, based on information collected at other sites and the operations of the Diablo Canyon Power Plant cooling water system.

- The planktonic stages of invertebrates and larval fish entrained are characterized by very early life stages having low natural survival rates.
- Any localized changes in the abundance of fish and invertebrates resulting from entrainment mortality are diminished by the rapid movement of water through the nearshore coastal area and mixing in the receiving waters.
- The number of fish and macroinvertebrates impinged at the Units 1 and 2 intake is low. The fish and macroinvertebrates that are impinged are predominantly juveniles, which have a relatively low probability of natural survival to maturity or recruitment to the local fishery.
- Many of the fish and macroinvertebrate species inhabiting the nearshore coastal regions adjacent to the plant have behavior, reproductive, or migratory patterns that minimize their susceptibility to entrainment and impingement at the plant.
- The Diablo Canyon Intake Cove and adjacent coastal waters do not represent a unique habitat for any of the fish or invertebrates susceptible to entrainment and impingement.

The ecological roles or trophic functions of key organism groups affected by the Diablo Canyon Power Plant are not expected to be affected significantly by the incremental mortality attributed to entrainment and impingement. Species of ichthyoplankton and macroinvertebrates susceptible to entrainment feed on lower trophic forms such as phytoplankton and small zooplankton (which have high survival, estimated at greater than 90 percent, following passage through the plant) and are in turn prey to adults of their species and to a wide variety of other species of fish and invertebrates. Those organisms that do not survive entrainment are returned to the receiving waters where they continue to provide a food resource for fish and invertebrates. Since the effect on the species populations discussed in this chapter and Appendix C is considered to be undetectable, changes in ecological roles or functions due to entrainment and impingement losses at the Diablo Canyon Power Plant are also concluded to be insignificant.

Because of the extensive habitat available along the coast for fish and invertebrate species susceptible to entrainment and impingement, their characteristically high reproductive potential, their broad geographic distributions and planktonic larval dispersal stages which experience high natural mortality, and the low susceptibility of juveniles and adults to impingement, the local fish and invertebrate populations are considered to be resilient and able to sustain incremental entrainment and impingement mortality without adverse impacts. Consequently, the direct impact on the populations and indirect impact on associated species is low. Entrainment and impingement losses, therefore, will not preclude maintenance of the existing populations and the local fishery.

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CHAPTER 6
EVALUATION OF ALTERNATIVE INTAKE TECHNOLOGIES

The purpose of this chapter is to evaluate alternative intake technologies for the Units 1 and 2 cooling water structure of the Diablo Canyon Power Plant. Alternative intake technologies were evaluated for their ability to reduce biological losses, and for their feasibility and cost-effectiveness for implementation at the Diablo Canyon Power Plant. A hierarchical evaluation system is used to assess which alternative intake technologies would reduce biological losses and be feasible for application to the cooling water system of the plant. Alternative intake technologies were evaluated on the basis of the following four criteria:

1. The alternative technology is available and proven (i.e., it has demonstrated operability and reliability at a cooling water intake having a size and environment similar to that at the Diablo Canyon Power Plant site).
2. Implementation of the alternative technology will result in a reduction in the loss of aquatic organisms from the present operating conditions described in Chapter 2.
3. Implementation of the alternative technology is feasible at the Diablo Canyon Power Plant site, based on site-specific considerations of engineering, operations, and reliability.
4. The total economic cost of the alternative technology is proportionate to the environmental benefit anticipated.

This hierarchical set of criteria were applied to alternatives considered for application at the plant. All intake technologies that were considered to be available and proven for application at the plant (Criterion 1) were given a biological evaluation (Criterion 2). Feasibility analyses (Criteria 3 and 4) were carried out for alternatives that would reduce biological losses. The process is illustrated in Figure 6-1. The chapter ends with a discussion of, and judgment as to, the best intake technology available for the cooling water system at the Diablo Canyon Power Plant.

A generic review of cooling water intake technologies is presented in Appendix D. Evaluation of whether an intake technology is available and will minimize entrainment and/or impingement losses requires site-specific analyses which are presented in this chapter. The design and operation of the Units 1 and 2 cooling water system are described in Chapter 2, along with a discussion of the physical and biological characteristics of the source waterbody. Chapters 3 and 4 present information characterizing entrainment and impingement at the plant. This background information provides the site-specific framework necessary for evaluating the potential biological effectiveness and engineering feasibility of each intake technology considered.

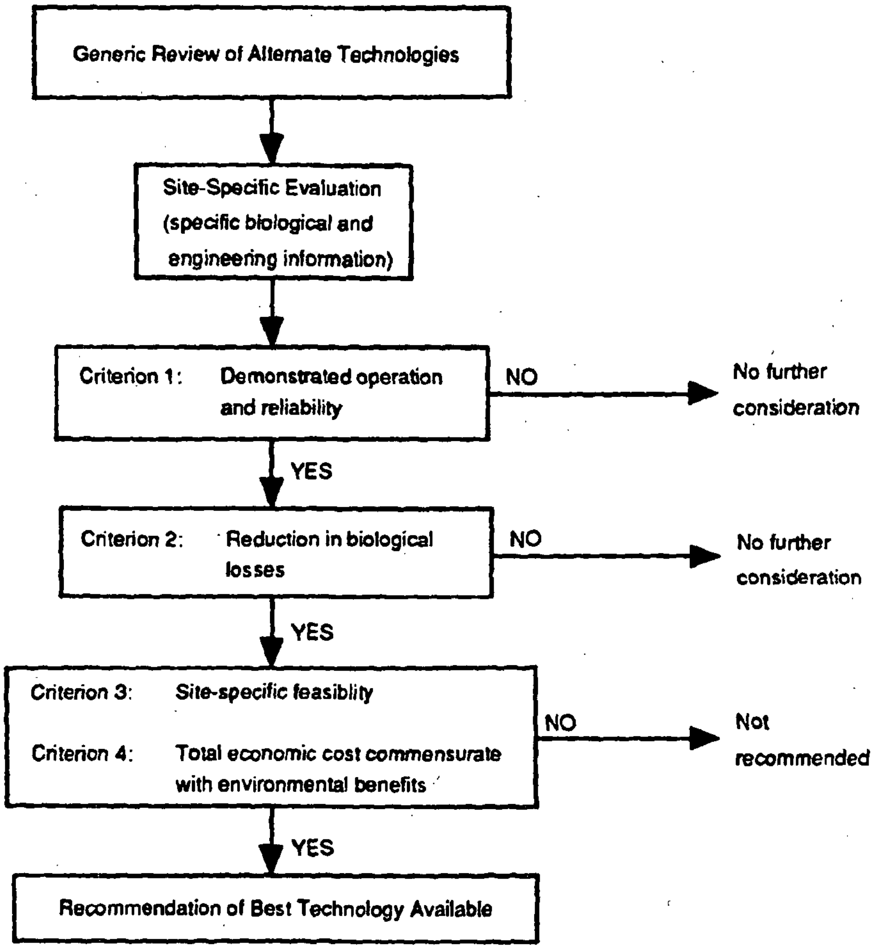


Figure 6-1

Schematic Representation of the Procedure Used to Evaluate Alternative Intake Technologies for the Diablo Canyon Power Plant

6.1 Demonstrated Operation Criterion

Certain intake technologies were determined to be proven and available for consideration at the Diablo Canyon Power Plant (Table 6-1). These include offshore and onshore intake locations and configurations, a once-through cooling water system, light, sound, air bubble screens, and velocity caps. Drum screens, center-flow screens, and vertical traveling screens are also appropriate for further consideration. Fish return systems, including sluiceways, fish pump systems, and vertical traveling screen modifications are regarded as proven and available technologies. Operational modifications such as curtailment, cooling water system structural modifications, temperature regulation, maintenance dredging of the intake area, and circulating water pump volume reduction when a unit is operating at reduced loads or is out of service are also considered to be available alternatives. Other alternative technologies reviewed in Appendix D failed to satisfy the first evaluation criterion, and hence are not considered further in the analysis. Those technologies are discussed briefly in this section.

6.1.1 Closed-Cycle Cooling

Closed-cycle cooling systems have had widespread application where freshwater is available as a make-up water source. Operational problems and environmental considerations (including air quality impacts from cooling tower drift and effects on vegetation from salt deposition) have limited the application of closed-cycle cooling where brackish water (salinities 0.5-26 ppt) is used as a make-up source. A survey of operating experience with saltwater closed-cycle cooling systems prepared for the Utility Water Act group by the Stone & Webster Engineering Corporation (Stone & Webster 1978) concluded that there are no operating or proposed electric generating facilities in the United States that use seawater in closed-cycle cooling systems. Seawater is characterized by salinities in the range of 26-36 ppt, and salinities at the Diablo Canyon Power Plant are within this range throughout the year (Chapter 2). The only power generating facility in the world that uses seawater in a closed-cycle cooling system with cooling towers is the Fleetwood Power Station in England, a small peaking plant (three 32-MWe units) with a low capacity factor (Stone & Webster 1978). The units are cooled by two natural draft cooling towers with a circulating water flow rate of 67 cfs (1.9 m^3/sec). Salinity of the cooling water at the Fleetwood Power Station typically ranges from 26 to 27 ppt. The circulating water is normally concentrated 1.2-1.5 times. Operational problems associated with corrosion and material deterioration have been reported.

A detailed evaluation of operational experience with the application of large volume closed-cycle seawater cooling systems at the Diablo Canyon Power Plant has been performed (TERA 1982). The report was prepared in response to Order No. 82-24 of the California Regional Water Quality Control Board - Central Coast Region which required that a technical report be submitted containing information on, and an evaluation of alternative plans, including the feasibility of closed-cycle seawater cooling towers, to reduce the heat and volume of cooling water discharged from the Diablo Canyon Power Plant.

TABLE 6-1

OPERATIONAL FEASIBILITY OF INTAKE TECHNOLOGIES AND OPERATIONAL ALTERNATIVES CONSIDERED FOR THE DIABLO CANYON POWER PLANT

Intake Technologies	Operation Demonstrated	Operation Not Demonstrated
Cooling Water System	Once-through	Closed-cycle (Seawater)
Intake Location	Offshore/Onshore	
Intake Configuration	Shoreline Recessed	
Behavioral Barrier	Light Sound Bubble Screen Velocity Cap	Velocity Gradient Electrical Barrier Louvers Chemicals Magnetic Field Chains and Cables
Physical Barrier	Drum Screen Centerflow Screen Vertical Traveling Screen	Media Filter Porous Dike Radial Well Stationary Screen Horizontal Traveling Screen Angled Screen - Louver Caisson
Fish Collection, Removal, and Conveyance Systems	Vertical traveling screen modifications Gravity Sluiceway Fish Pump	
Operational Alternatives		
Maintenance and Operational Modifications	Dredging Single-pump operations Fuel Reloading Outages Alternative Biofouling Control Cooling System Modifications Temperature Regulation	Variable speed circulating water pumps

It is concluded from information presented in the Stone & Webster survey and the site-specific evaluation of the Diablo Canyon Power Plant performed by TERA (1982) that seawater closed-cycle systems do not satisfy the criterion of demonstrated operation and are not considered a proven and available alternative technology for use at the Diablo Canyon Power Plant.

6.1.2 Behavioral Barriers

Velocity gradients, magnetic and chemical barriers, and chain and cable barriers have not been used on power plant intake structures and are therefore considered to be in an experimental stage of development (Cannon et al. 1979; EPRI 1986). Electric barriers have been used with limited success in freshwater, but because of low electrical resistance no application of electric fish barriers has been made in salt or brackish waters. Louvers have been used effectively at several large agricultural water diversions, but their application to power plant cooling water intakes has not been attempted. Louvers do not provide a positive barrier either to entrained organisms or to debris that could block the condenser tube system and lead to reduced operating reliability and increased maintenance. Velocity gradients, electric barriers, louvers, magnetic barriers, chemicals, and chain and cable barriers are not available and proven technologies for the Diablo Canyon Power Plant.

6.1.3 Physical Barriers

Media filters such as sand filters, porous dikes, and radial well intakes have never been used in providing power plant cooling water from a marine source in the volumes required to operate the Diablo Canyon Power Plant. Prototype tests have been conducted that have identified debris accumulation, biofouling, and sedimentation as major constraints in the application of media filters in the marine environment. In the absence of demonstrated performance capabilities and operational reliability in a once-through power plant cooling water system, media filters are not an available technology for the Diablo Canyon Power Plant.

Stationary screens, such as perforated plate and pipe systems and cylindrical wedge-wire screens, were also eliminated from consideration because they do not show either demonstrated performance or operational reliability in once-through cooling systems in a marine environment. Accumulation of debris and colonization by fouling organisms have been identified as factors that would substantially decrease the operational reliability of fixed-screen intake structures sited in a marine environment.

Horizontal traveling screens were not considered to be an available technology for the Diablo Canyon Power Plant because of a lack of demonstrated operational reliability (Farr and Prentice 1974).

An angled screen-louver intake structure and a caisson intake design were not considered to be available technologies for the Diablo Canyon Power Plant because their performance has not been demonstrated to be an effective retrofit alternative to an existing shoreline intake structure. One U.S. utility has an angled traveling screen-louver intake structure in a marine environment, which is used in combination with an offshore intake. A caisson intake design was proposed for use at a marine site (California Public Utilities Commission 1978), but was not constructed.

6.1.4 Variable Speed Circulating Water Pumps

Installation of variable-speed motors on the circulating water pumps represents one approach to reducing cooling water flows to the minimum level necessary to maintain efficient operation of the unit at a specific generating load. The pumps currently in use are limited to no-flow or full-flow operation. Variable-frequency motors are operated at cooling water flow rates that match reduced unit loads, thereby reducing the numbers of organisms entrained and impinged. Thus, as loads fluctuate, the circulating water flow rate could be adjusted to provide only the flow needed for condenser cooling within operating limits imposed by ΔT and back pressure operating criteria. The magnitude of the resultant reductions in entrainment and impingement losses would depend on the reduction in cooling water flows and the abundance of organisms at the times when system demand permitted operation of the circulating water pumps at reduced flow rates.

Although variable speed circulating water pumps have been used on a limited basis at several load-tracking fossil-fueled power plant units with generating capacities up to 345 MWe, this alternative has not been used at any base-loaded nuclear facility with generating capacity or cooling water system requirements comparable to the Diablo Canyon Power Plant. The feasibility of installing variable speed circulating water pump motor controls on the Diablo Canyon Power Plant was discussed with two domestic vendors in 1988. Neither vendor has commercially available "off the shelf" equipment with proven operational performance for this application. One vendor indicated that they could not provide a custom design for such a large installation. The second vendor indicated a willingness to provide a custom design which would require new motors suitable for variable speed operation. The variable speed drive system controls would require construction of a new motor control building. In addition, extensive redesign of the 12 KV electric service to the existing motors circulating water pump motors would be required. The scope of such modifications cannot be determined without a more detailed engineering feasibility and design study. The overall operational reliability of this type of installation is likely to be less than the existing circulating water pump motor controls because of the increased complexity of variable speed drive systems. The required maintenance also will be greater because of the added complexity.

The motor vendor was unable to provide a cost estimate for a variable speed drive system of this magnitude, but based upon the custom nature of the design and PG&E's experience with other electrical equipment of similar scale, it is estimated that equipment costs alone would be approximately $2.5 million per variable speed drive, with replacement motors. The total estimated cost of four variable speed circulating water pumps, including engineering design, procurement, installation, and replacement power would be approximately $20 million.

Examination of the hydraulic model test results for the existing circulating water pumps revealed that the available suction head in the present installation is insufficient to permit operation at reduced speed without subjecting the pump to serious cavitation. As a consequence, the present circulating water pumps are not capable of reliable service at reduced speed.

Based on discussions with potential vendors regarding the absence of commercially available variable speed circulating water pump motors and controls and the fact that this alternative has not been used on units of similar size as Diablo Canyon Power Plant Units 1 and 2, it was concluded that variable speed circulating water pumps do not satisfy the criterion of demonstrated operation, and are not considered a proven and available alternative technology for use at the Diablo Canyon Power Plant.

6.2 Biological Benefit Criterion

Each technology that satisfied the demonstrated operation criterion (Table 6-1) was evaluated to determine whether it would reduce the entrainment and impingement losses reported in Chapters 3 and 4. Results of the evaluation are summarized in this section.

6.2.1 Intake Location

Alternative intake locations for the Diablo Canyon Power Plant include submerged offshore and alternative shoreline intake locations. The existing shoreline intake location and configuration (Chapter 2) is the technology against which each alternative is compared.

6.2.1.1 Offshore Intake Location

The efficiency of an offshore intake in reducing entrainment depends, to a large degree, on the vertical stratification of entrainable organisms in the water column at the point of water withdrawal. In such a system, a reduction in entrainment is achieved by locating the offshore submerged intake at a location where the density of entrainable organisms is less than at other locations. Although the available data are limited, they show that entrainable organisms are distributed throughout the water column as a result of strong tidal and current mixing and the relatively shallow depths offshore of the Diablo Canyon Power Plant.

Larval fish surveys were conducted at two sampling locations offshore of the Diablo Canyon Power Plant site during 1974 and 1975 by Icanberry et al. (1978). Comparison of larval fish densities at sampling stations located 300 m (1,000 ft) and 1,500 m (5,000 ft) offshore showed no statistically significant differences in total larval fish densities between the inshore and offshore locations. Statistical differences were found between locations for two of the six most abundant fish taxa. Densities of larval sculpin (*Artedius* spp.) were found to be greater at the inshore station and densities of larval northern lampfish (*Stenobrachius leucopsarus*) were found to be greater at the offshore station. Results of these larval fish studies provide no evidence that larval fish densities are consistently lower at alternative offshore intake locations.

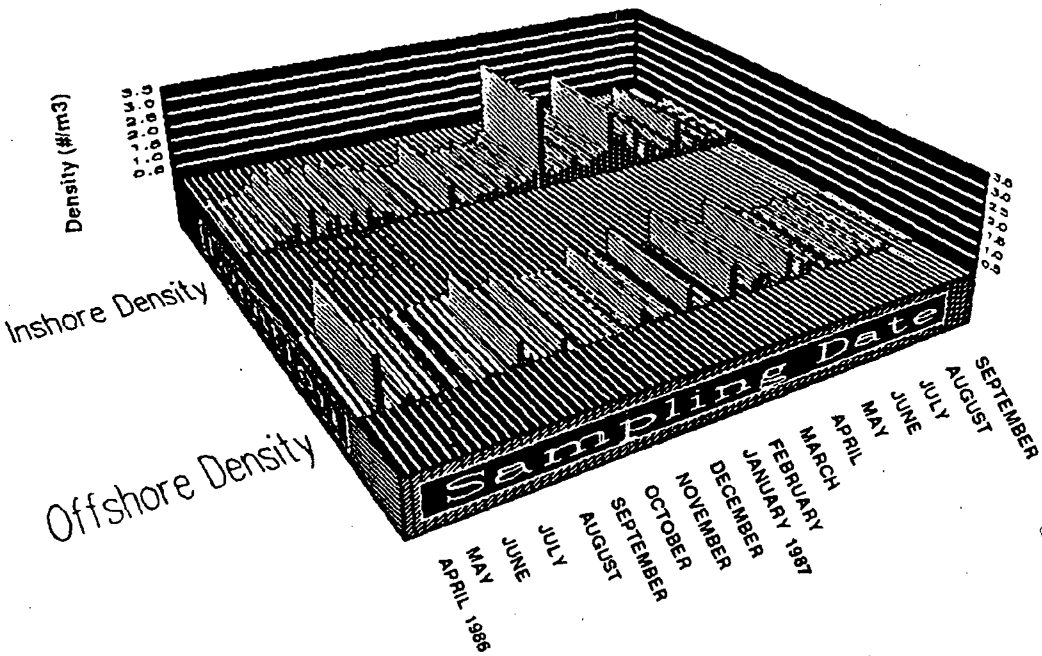
Densities of larval fish collected during 1986 and 1987 were compared for a sampling location within the Diablo Canyon Power Plant Intake Cove and a sampling location offshore in close proximity to Icanberry's 300 m station. Results of the comparison (Figure 6-2) indicate that although the plankton densities at both locations are characterized by high variability, densities were generally higher in the Intake Cove than at the offshore location. A more detailed examination of the trends in species-specific densities between the two locations indicated that the higher densities observed in the Intake Cove were largely attributable to the presence of cottid (sculpin) larvae. The percent composition of selected larval fish taxa at the two locations is presented below:

Taxon	Percent Composition	
	Intake Cove	Offshore
Sculpins	43	24
White croaker	8	19
Rockfish	5	17
Northern anchovy	2	7

No significant differences in larval fish densities were detected between the two sampling locations when larval sculpin were excluded from the analysis. Based on results of these plankton data and information reported by Icanberry et al. (1978) for the Diablo Canyon Power Plant area, it was concluded that relocation of the existing shoreline intake structure to a location offshore would reduce the susceptibility of larval sculpin to entrainment while increasing the susceptibility of other species, such as rockfish and northern anchovy to entrainment. Extending the cooling water intake structure and conduit 2,000 to 3,000 feet offshore would provide a large surface area for the colonization of marine biofouling organisms that are effective predators on entrained larval fish and invertebrates. Based on a consideration of the species-specific trends in larval fish densities and the increased susceptibility to predation by fouling organisms, it was concluded that relocating the Diablo Canyon Power Plant intake to an offshore location is not an effective alternative for reducing entrainment losses.

For reducing the number of impinged organisms, the effectiveness of a submerged offshore intake depends on locating the intake in an area where such impingeable organisms are not abundant. Many of the dominant groups of fish and invertebrates

EVENING PLANKTON TOWS



MORNING PLANKTON TOWS

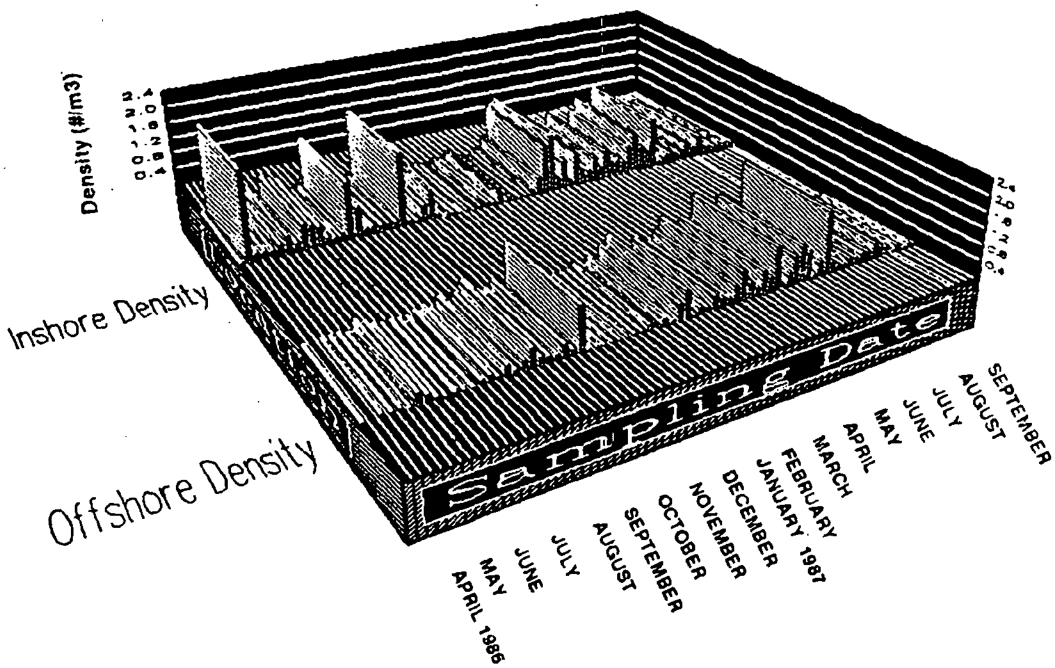


Figure 6–2

Evening and Morning Plankton Tows Conducted at Intake Cove and Offshore Locations in the Vicinity of Diablo Canyon Power Plant, April 1986 – September 1987 (e.g., flounder and sole, rockfish, white croaker, surfperch, crabs, shrimp) are typically found in association with the offshore bottom habitat in the vicinity of the Diablo Canyon Power Plant site. Many of the typically pelagic fish species, such as northern anchovy are commonly found in large schools which move through the water column, often concentrating near the bottom substrates during the daytime. Submerged offshore intakes generally have higher approach velocities than onshore systems and use conduits within which fish can become entrapped, resulting in an increase in the number of organisms impinged (Appendix D). Furthermore, it is likely that the physical presence and nature of an offshore intake in the coastal waters offshore of the Diablo Canyon Power Plant site would attract many of the fish and invertebrates inhabiting the nearshore coastal waters to the offshore intake location. An offshore intake structure and cooling water conduit would provide habitat similar to an artificial reef. Detailed surveys and observations of the colonization of reef structures formed from the Diablo Canyon Power Plant breakwater that was partially destroyed by storm activity (Wilson et al. 1988) provide regional confirmation on the attraction of juvenile rockfish to reef habitat. The attraction of juvenile fish, including species such as rockfish, cabezon, crab, and surfperch, to an offshore intake structure would increase their susceptibility to impingement. Thus, use of a submerged offshore intake system would probably result in higher rates of impingement than those observed at the existing intake.

In summary, an offshore intake appears to offer little or no potential for reducing the overall losses of fish and invertebrates entrained or impinged at the Diablo Canyon Power Plant. The susceptibility of planktonic organisms to entrainment would not be reduces by relocating the intake offshore, where currents and turbulence to vertical mixing of planktonic organisms in the mid- and upper-portions of the water column. The offshore intake would also contribute to the entrapment of fish and invertebrates, many of which may be behaviorally attracted to the offshore intake. In the absence of any evidence of a clear potential for reducing entrainment and impingement losses, an offshore intake location is not an acceptable alternative for the Diablo Canyon Power Plant.

6.2.1.2 Alternative Onshore Location

The general similarity of the rocky coastal habitat along the shoreline adjacent to the Diablo Canyon Power Plant site suggests that entrainment and impingement would not be substantially different at other available shoreline locations. The pattern of currents and wave mixing in the area supports the conclusion that the densities of organisms are similar throughout the local shore zone. The majority of larval fish and invertebrates entrained at the Diablo Canyon Power Plant are characterized by planktonic life stages that promote wide geographic dispersal throughout the nearshore coastal waters adjacent to the site. The distribution of many of the juvenile and adult fish and macroinvertebrates impinged at the plant (Chapter 4) is determined by habitat preferences. The rocky coastal habitat in the Diablo Canyon Intake Cove is not unique; similar rocky intertidal and subtidal habitat exist to the north and south of the existing intake location. There is no evidence to suggest that relocation of the Diablo Canyon Power Plant shoreline intake structure to an alternative site would contribute to a reduction in either entrainment or impingement losses.

6.2.2 Alternative Intake Configurations

An approach channel (recessed) intake screen configuration was evaluated as an alternative to the existing shoreline intake screen configuration. The recessed intake consists of an intake conduit or channel leading from the point of water withdrawal to intake screens located inland. Approach channel intake configurations are used to provide a protected area for intake screens, to separate intake and discharge locations to minimize thermal recirculation, or for other engineering concerns. Fish can become trapped within the confined intake conduit, where velocities are generally high, and may become stressed or fatigued, and eventually impinged. The shoreline intake configuration puts the intake screens on or near the shoreline and promotes greater behavioral avoidance and thereby reduces entrapment and impingement of organisms. The numbers of larval fish and invertebrates entrained, are independent of intake configuration, because these organisms are planktonic.

The Moss Landing Power Plant impingement monitoring program provided a direct comparison between impingement with the recessed intake screens of Units 1-5 and the shoreline intake screens of Units 6 and 7. Impingement rates for fish (all species combined) were approximately 1.6 times greater at the Units 1-5 recessed intake screens than at the Units 6 and 7 shoreline intake screens (PG&E 1983).

Underwater observations of juvenile fish at the Diablo Canyon Power Plant shoreline intake structure (Chapter 4) confirmed that fish were able to avoid entrapment within the intake structure and readily pass into and out of the intake through the bar racks and laterally across the intake structure. Observations at power plants with recessed intake structures indicate that fish entrapment and subsequent impingement is greater, in part because of higher velocities and longer forebays, than at shoreline intake structures with design characteristics similar to those at the existing Diablo Canyon Power Plant intake. Therefore, a recessed intake screen configuration is not an acceptable alternative to the existing shoreline intake configuration of the Diablo Canyon Power Plant Units 1 and 2 intake structure for reducing either entrainment or impingement.

Although the numbers of fish impinged at the Diablo Canyon Power Plant is low and observations confirm that juvenile and adult fish are capable of avoiding entrapment at the present intake approach velocities, the intake approach velocity (0.8-1.0 fps) is higher than the U.S. Fish and Wildlife Service guideline of 0.5 fps. The velocity of the water entering the intake structure is directly proportional to the rate of flow and inversely proportional to the cross-sectional area through which the water is passing. Therefore, velocities entering the intake structure can be reduced by increasing the cross-sectional area exposed to the flow. The total cross-sectional area needed to obtain a design approach velocity of 0.5 fps would be approximately

1.8 times that of the existing shoreline intake structure. A reduction in approach velocities could increase the survival rate of the fish that are impinged. An increase in cross-sectional area of the intake and a corresponding reduction in velocity would not, however, contribute to a reduction in entrainment of either larval fish or invertebrates.

The U.S. Fish and Wildlife Service and the U.S. Environmental Protection Agency, in providing guidelines for the design of cooling water intake structures, recommend an approach velocity of 0.5 fps to minimize impingement losses for a broad range of fish species. A detailed review of the intake velocities at the Diablo Canyon Power Plant (Wyman 1988), the literature on laboratory swimming performance of juvenile fish, and diver observations of impingement avoidance at the intake showed that fish and macroinvertebrate impingement should be virtually independent of intake approach velocities of less than 1.0 fps. Impingement is predicted to increase at intake approach velocities greater than 1.5 fps, particularly among juvenile fish less than approximately 80 mm in length. A reduction in approach velocities to 0.5 fps would not substantially reduce fish impingement rates.

A reduction in approach velocities could potentially reduce the damage to fish that are impinged and thereby increase survival rates if the fish are properly returned to the source water body. To achieve a potential reduction in impinged fish and macroinvertebrate losses, fish handling and sluiceway return facilities would have to be installed at the Diablo Canyon Power Plant intake. Fish handling and return systems are discussed in Section 6.2.5.

The additional length of shoreline intake structure would increase the area of attractive habitat for young fish (e.g., juvenile rockfish and surfperch) and, by doing so, increase the risk of impingement. However, there are no data available to evaluate the significance of these factors on fish and macroinvertebrate impingement rates.

Although the existing impingement losses are low, it was concluded that this alternative has the potential for reducing losses of fish and macroinvertebrates due to impingement but would have little, if any, effect on losses due to entrainment.

6.2.3 Behavioral Barriers

Light, sound, and air bubbles were evaluated for their potential effectiveness in reducing biological losses.

A considerable amount of research and experimentation has recently been directed at evaluating and improving the effectiveness of behavioral barriers such as light, sound, and air bubbles (EPRI 1986, 1987). Results of this research effort failed to demonstrate that behavioral barriers, used singly and in combination, are effective in consistently reducing fish impingement at power plant cooling water intakes and other water diversions (Appendix D). Effectiveness of light, sound, and air bubbles varied substantially between sites and between species. Furthermore, effectiveness of behavioral barriers generally declined over time as organisms became accustomed to the stimuli. Behavioral barriers do not reduce the numbers of entrained organisms or the impingement rates of macroinvertebrates. Behavioral barriers are not an effective alternative for reducing entrainment or impingement losses at the plant.

The velocity cap was not considered, since its applicability is restricted to offshore intakes, which were rejected for use at the plant (Subsection 6.2.1.1).

6.2.4 Physical Barriers

The applicability of drum screens are vertical traveling screens, and centerflow screens for reducing biological losses associated with entrainment and impingement at the Diablo Canyon Power Plant is evaluated in the following sections.

6.2.4.1 Drum Screens

Drums screens not reduce the numbers of organisms entrained or impinged (Chapters 3 and 4) when compared to the present intake structure. There is no information available to suggest that survival of organisms impinged on drum screens would be significantly different from impingement survival on conventional vertical traveling screens. In the absence of any predicted biological advantages, drum screens are not an acceptable alternative intake technology applicable to the Diablo Canyon Power Plant.

6.2.4.2 Vertical Traveling Screens

Vertical traveling screens are arrangements of screen panels on endless chains that can alternatively be put into the cooling water stream to screen debris and organisms and removed from the stream so the accumulation of debris and organisms can be washed off. Vertical traveling screens are almost universally used in power plant cooling water intakes in the United States. Vertical traveling screens with 3/8-inch (9.5-mm; 0.4 - in.) mesh are in operation at the Diablo Canyon Power Plant (see Section 2.1) and are the standard technology with which each alternative screening technology considered in this analysis is compared.

6.2.4.3 Centerflow Traveling Screens

The centerflow traveling screen represents a relatively new intake screen technology in the United States, although it has been used extensively in European industrial and electricity generating facilities. Centerflow screens are oriented parallel to the approaching waterflow, and water enters through the center of the screen and exits through both vertical faces (Appendix D). As with vertical traveling screens, the screen panels are attached to a continuous drive chain but, unlike vertical traveling screens, each screen panel forms a concave basket which increases the available screening surface area. Screen mesh sizes range from 0.02 to 0.4 in. (0.5-9.5 mm), with many units having 0.04- to 0.1-in. (1.0- to 2.5-mm) mesh. (The effects of fine-mesh screening are treated in Subsection 6.2.5.3). As a result of potentially rapid debris accumulation on the small mesh commonly used in centerflow screens they are designed for continuous screen rotation.

The hydraulic flow patterns associated with centerflow screens are more complex than those associated with vertical traveling screens. Water flows into the screen chamber through a keyhole-shaped opening in the front wall of the screen structure and turns 90° to complete its transit to the circulating water pump. Effective screening occurs on both the ascending and descending sides of centerflow screens, increasing the available screen surface area. As a result, the average through-screen velocity of the centerflow screen is less than the approach velocity to the screen. However, through-screen velocities are highly variable across the screen face because of flow patterns and screen orientation, and velocities tend to increase with distance downstream from the chamber entrance. The high velocities at the entrance to the screen may also serve as a behavioral barrier, preventing the escape of fish trapped within the screen structure itself. Centerflow traveling screens do not offer any major biological advantages over conventional or modified vertical traveling screens (Cada et al. 1979). The numbers of organisms impinged on centerflow screens would not be reduced, and significantly increased impingement survival has not been satisfactorily demonstrated for these systems.

The turbulence of the flow may negate the potential biological benefits of reduced average through-screen velocities. Irregular velocity patterns, turbulence, and attendant head losses are inherent in the waterflow patterns of centerflow screens. The highest water velocities occur in the entrance area, and this could contribute to fish entrapment. Within the screen chamber, velocity varies irregularly as the water changes direction, resulting in nonuniform flow through the screening surface.

Several alternative design configurations for the centerflow screen concept have been proposed to minimize the probability of organisms becoming entrapped within the screen structure (Appendix D). In addition to the single-entrance/dual-exit design there is a double-entrance/single-exit design in which water enters the screen from two sides and passes out through one end. This design can be either located within a screenwell or supported from a platform with no confining concrete housing. A double-entrance/double-exit screen design has also been proposed. To date, no biological and engineering data are available from operating power plant intake structures to compare the relative effectiveness of these alternative configurations and hence these alternatives do not meet the demonstrated feasibility criterion.

In summary, centerflow traveling screens are not an acceptable alternative intake technology for the Diablo Canyon Power Plant.

6.2.5 Fish Collection, Removal, and Conveyance Systems

Several modifications to conventional vertical traveling screens have been considered in recent years in an attempt to increase their biological effectiveness.

Some information is available on the effectiveness of various screen rotation frequencies for improving impingement survival of marine fish and macroinvertebrates species present in the vicinity of the Diablo Canyon Power Plant from studies conducted at the Moss Landing Power Plant (see Section 4.2). Information is also available for impingement survival of freshwater and estuarine fish, both resident and migratory species, which is reviewed and summarized in Appendix D. Data from these and other studies is used below in a general way to provide additional information useful in examining the potential effectiveness of modified vertical screens at the Diablo Canyon Power Plant.

The effectiveness of screen modifications for reducing impingement losses is discussed in Subsections 6.2.5.1 through 6.2.5.6. Modifications to intake screen operations, such as increasing screen rotation frequency to reduce the duration of impingement, are discussed in Section 6.2.5.1. Modifications to the intake screens which include the installation of fish buckets, low-pressure spraywashes, and sluiceway return systems designed to reduce the stress on fish that are impinged are discussed in Section 6.2.5.2. Section 6.2.5.3 presents a discussion of fine-mesh screens which are intended to exclude larval fish and many invertebrates from entrainment through the cooling water system by impinging these organisms on fine-mesh intake screens. Fish return conveyance systems such as fish pump and gravity screenwash sluiceways designed to return impinged organisms to the waterbody are discussed in Section 6.2.5.4. The effectiveness of combinations of structural and operational intake screen modifications in reducing impingement losses is discussed in Section 6.2.5.5. Conclusions of the evaluation of fish collection, removal, and conveyance systems are summarized in Section 6.2.5.6.

6.2.5.1 Modifications in Operation

Operational modifications to vertical traveling screens, such as the use of continuous screen rotation and low-pressure spraywashes, are alternatives which have been proposed to increase the biological effectiveness of conventional vertical traveling screens. Increasing the screen rotation frequency from 3-hour intervals to continuous rotation did not result in consistently improved impingement survival for invertebrates such as *Palaemon macrodactylus*, *Crangon franciscorum*, and *Rhithropanopeus harrisii* in studies conducted at the Pittsburg Power Plant (PG&E 1981) or for crabs (*Cancer* spp.) at the Moss Landing Power Plant Units 6 and 7 (PG&E 1983; Section 4.2). In addition, no consistent improvement in impingement survival was found for fish species impinged on screens operated in various modes at three Hudson River power plants (King et al. 1978). Furthermore, although lowering the pressure of screenwash sprays (50 psi) resulted in better initial and long-term (48-hour) survival of impinged white perch on several occasions, the results of screenwash pressure studies reported by King et al. (1978) were generally inconclusive.

The effectiveness of a low-pressure spraywash system in removing impinged fish from modified vertical traveling screens were examined by Public Service Electric and Gas Company (1977, in Cannon et al. 1979) at the Salem Nuclear Generating Station. The number of impinged fish washed into a fish return sluiceway by a low-pressure spraywash (15 psi) was compared with the number washed into a debris sluiceway by a high-pressure spraywash (100 psi). A total of 3,770 fish were collected, of which 23.3 percent were removed from the modified screens by the low-pressure spraywash. These results indicate that low-pressure spraywash systems may be ineffective in removing impinged fish from an intake screen. Additional development and evaluation of low-pressure spraywash systems for intake screens would be required at the Diablo Canyon Power Plant, where screens are subject to high periodic kelp and debris loading.

Continuous screen rotation did not result in consistently improved impingement survival of the marine organisms examined at the Moss Landing Power Plant (Section 4.2): among impinged fish, hardy species such as plainfin midshipman and crabs appeared to have a high rate of survival regardless of screenwash frequency. Increasing screen rotation frequency at the Moss Landing Units 6 and 7 intake did, however, contribute to a substantial increase in impingement survival for both surfperch and rockfish (Section 4.2), which together constituted over 35 percent of the fish impinged at the Diablo Canyon Power Plant (Table 4-3). Impingement studies conducted at the Moss Landing Power Plant also suggest that impingement survival of species such as northern anchovy, Pacific herring, smelt, and silversides, which together constituted less than 2 percent of the impinged fish at the Diablo Canyon Power Plant, would probably not be improved substantially by increased screen rotation frequency.

Although available data are incomplete, increasing intake screen rotation frequency represents a potential alternative technology for increasing impingement survival of several groups of fish at the Diablo Canyon Power Plant.

6.2.5.2 Fish Buckets and Accessories

Modification to vertical traveling screens reduce mortality of impinged organisms include the following features (Figure 6-3):

1. Watertight fish collection buckets along the base of each screen panel to prevent repeated impingement of organisms and to provide a holding area for organisms during screen rotation;
2. A low-pressure wash system to remove impinged organisms from the screen, reducing the stress and abrasion that results from exposure to the high-pressure spraywash required for the removal of debris;
3. A second sluiceway/fish return system to transport organisms removed from the screen by the low-pressure spraywash back to the receiving waterbody; and
4. Modifications to bearings and motors to permit continuous rotation and cleaning, minimizing the time an organism is impinged on the screen.

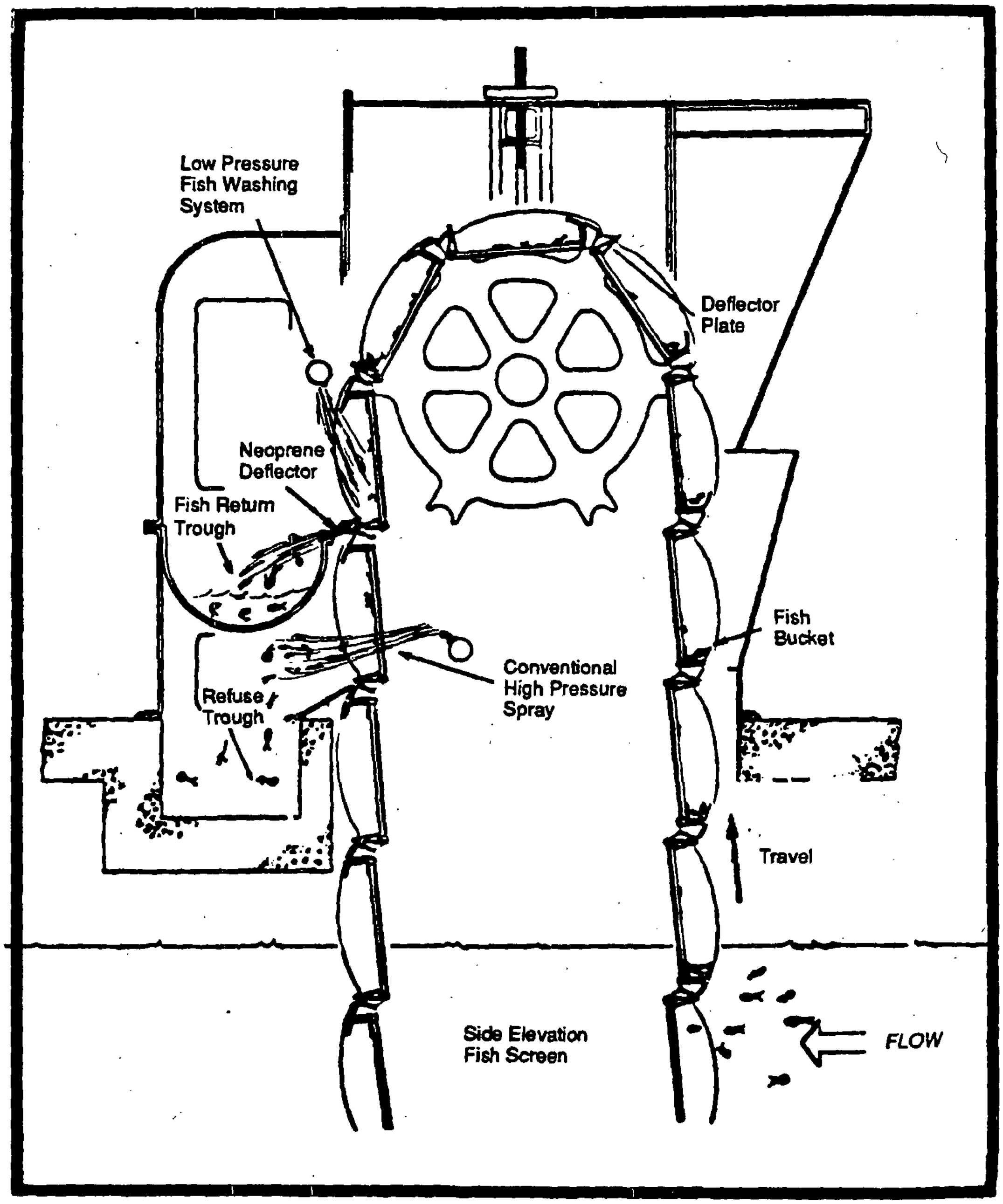


Figure 6-3

Ristroph Modified Traveling Screen with Fish Buckets, a Modified Spray Water System, and a Sluiceway for Fish (Courtesy of Envirex)

Limited information is available to assess the potential of these modifications for improving impingement survival for the species of fish impinged in greatest abundance at the Diablo Canyon Power Plant. Among these, species such as thornback rays, sculpin, plainfin midshipman, and crabs appeared to have high survival potential (Table 4-5), fragile species such as northern anchovy have low survival potential which would not be increased substantially by the addition of fish buckets, low-pressure spraywashes, and continuous screen rotation. However, because of the potential effectiveness of increasing screen rotation frequency for improving impingement survival of surfperch and rockfish modified traveling screens and a fish return system would reduce the total number of organisms cropped as a result of impingement.

6.2.5.3 Fine-Mesh Screens

Fine-mesh screening, frequently used in centerflow screens, has received attention as a modification for vertical traveling screens and has been investigated in laboratory studies to determine its potential for protecting larval fish at power plant intakes (Magliente et al. 1978). Both laboratory and field studies are necessary to evaluate the survival of fish eggs and larvae impinged on fine-mesh screens.

Information from laboratory tests (Tomljanovich et al. 1978) shows that traveling screens equipped with 1.0-mm (0.04-in.) screen mesh would substantially reduce entrainment of fish eggs and larvae at the Diablo Canyon Power Plant and that entrainment of larval fish and macroinvertebrates could be virtually eliminated by use of 0.5-mm (0.02-in.) intake screen mesh. Impingement survival for fish larvae, however, is species-specific: under laboratory conditions, the survival rates for larvae at 48 hours after a 16 minute impingement on fine-mesh screens ranged from less than 1 percent for striped bass to 96 percent for bluegill and smallmouth bass (Table 6-2) (Tomljanovich et al. 1978). In addition, survival of larval fish impinged on a fine-mesh intake screen that is operated in an intermittent screen wash mode or is subject to high detrital loads, such as those periodically experienced at the Diablo Canyon Power Plant, may be very low (Tomljanovich et al. 1977).

The most comprehensive studies to date on the survival of fish larvae impinged on fine-mesh screens have been conducted by the Alden Research Laboratory and Stone & Webster Engineering Corporation (ARL/S&W 1980). A series of laboratory flume studies were performed using a total of 1,288 prolarval (5.4-6.3 mm) and 10,086 postlarval (6.4 to 17.1 mm) striped bass (*Morone saxatilis*). The bass larvae were impinged on fine-mesh (0.35- and 0.5-mm) polyester screens at approach velocities ranging from 0.5 to 3.0 fps (15-90 cm/sec) for durations ranging from 2 to 16 minutes. Impingement mortality 96 hours after testing ranged from 51.2 to 100 percent for the prolarval group (Table 6-3). Mortality increased both with increasing approach velocity and with increasing impingement duration. At all velocities, impingement mortality of prolarval striped bass was in excess of 90 percent following impingement for eight minutes. Although fewer test conditions were examined with postlarval bass, it is apparent from Table 6-3 that larger larvae had

TABLE 6-2

MEAN SURVIVAL (%) OF LARVAL FISH IMPINGED ON A SIMULATED FINE-MESH CENTERFLOW SCREEN UNDER LABORATORY CONDITIONS

Taxon: Common Name	Taxon: Scientific Name	Impingment (a) Survival (%): Initial	Impingment (a) Survival (%): 48-hr	Control Survival (%) 48-hr
Jewelfish	*Hemichromis bimaculatus*	43	30	100
Threadfin shad	*Dorosoma petenense*	55	20	98
Golden shiner/ Fathead minnow	*Notemigonus crysoleucas/ Pimephales promelas*	89	79	99
White sucker	*Catostomus commersoni*	74	36	100
Channel catfish	*Ictalurus punctatus*	97	88	99.5
Striped bass	*Morone saxatilis*	7	1	44
Bluegill	*Lepomis macrochirus*	96	96	99
Smallmouth bass	*Micropterus dolomieui*	100	96	100
Largemouth bass	*Micropterus salmoides*	70	52	93
Walleye	*Stizostedion vitreum*	9	2	71

(a) 16-minute impingement duration; screen mesh sizes 0.5, 1.0, 1.3, 1.8, and 2.5 mm combined; test velocities 15, 31, and 46 cm/sec combined.

Source: Tomljanovich et al. 1978.

TABLE 6-3

SUMMARY OF 96-HOUR MEAN MORTALITY (%) FOR STRIPED BASS IMPINGED ON 0.35- TO 0.5-mm SCREEN UNDER LABORATORY CONDITIONS

Life Stage	Velocity(a) (fps)	Duration of Impingement (min.) 2	4	8	16
Prolarvae (b)	0.5	74.2	51.2	91.8	84.6
	1.0	63.4	62.9	90.7	96.0
	1.5	70.7	92.0	98.7	100.0
	2.0	97.3	100.0	100.0	100.0
	3.0	-	-	-	-
Postlarvae(b)	0.5	-	-	-	43.9
	1.0	-	-	-	58.9
	1.5	-	-	-	97.6
	2.0	-	-	-	-
	3.0	18.4	49.1	-	-

(a) Velocity is the average approach velocity to the screen.

(b) A total of 1,288 prolarvae (length 5.4-6.3 mm) and 10,086 postlarvae (6.4-17.1 mm) were tested.

Note: (—) indicates no test.

Source: Alden Research Laboratories and Stone & Webster Engineering Corporation 1980.

lower mortality rates than smaller larvae. These results reflect only the mortality associated with impingement on fine-mesh screens under controlled laboratory conditions.

The smaller intake screen mesh would increase impingement of larval and juvenile fish and invertebrates that are presently entrained at the Diablo Canyon Power Plant. However, no specific information is available concerning impingement survival on fine-mesh screens of marine ichthyoplankton such as the young of sculpins, white croaker, rockfish, northern anchovy, clinids, and goby which constituted 82 percent of the larval fish collected in entrainment samples at the Diablo Canyon Power Plant (Table 3-3). Fish larvae impinged on fine-mesh screens at the plant would be subjected to debris loading during impingement, exposure to a pressure spraywash, and abrasion during transit through a fish return sluiceway. Based on the high mortality of larvae impinged under laboratory conditions and the severity of additional stress occurring under actual operating conditions (especially from high loading by kelp and algae, which are common at the Diablo Canyon Power Plant cooling water intake), the survival of impinged fish larvae would be negligible.

Fine-mesh intake screen material would exclude fish larvae and small macroinvertebrates from the cooling water system. There is no evidence that the survival of impinged fish larvae, which is low, would be greater or less than survival of entrained fish larvae. Survival of entrained larval fish and invertebrates is expected to be high at the Diablo Canyon Power Plant based on a consideration of the discharge temperature regimes and results of entrainment survival studies conducted at the plant and at other facilities (Section 3.2; Appendix B). Another important consideration in the use of fine-mesh intake screens for the Diablo Canyon Power Plant concerns reliable operation of the plant. The marine waters from which the plant withdraws cooling water experience high periodic detrital (kelp) loadings. The existing 3/8-in. (9.5-mm) intake screens permit the finer particles of detritus and small organisms to pass through the system without adverse effects on cooling system reliability, while the larger material is screened out. A fine-mesh screen might be so rapidly fouled by fine materials that the screen cleaning systems would be rendered ineffective, leading to possible failure of screens from hydraulic pressure differential. Biofouling accumulation on fine-mesh intake screens operated in a marine environment (Brueggemeyer et al. 1987) has also been identified as an operational and maintenance problem. The biological effectiveness and operational performance of fine-mesh intake screens operated in a marine environment similar to that at the Diablo Canyon Power Plant has not been evaluated.

The uncertainties regarding operational reliability and biological effectiveness of fine-mesh screens in a coastal marine environment area preclude the conclusion that fine-mesh screens would be a biologically effective and operationally acceptable alternative intake technology for use at the Diablo Canyon Power Plant.

6.2.5.4 Fish Return Conveyance Systems

Two fish return systems were evaluated for the Diablo Canyon Power Plant intake: a fish pump return system to divert fish entrapped within the intake prior to their being impinged and a modified screenwash/gravity return system for those fish which are impinged.

The use of fish pumps as an alternative fish return conveyance system was evaluated. The low design approach water velocity (0.8-1.0 fps; 24-30 cm/sec) minimizes fish entrapment. Underwater observations of juvenile and adult fish within the Diablo Canyon Power Plant intake structure confirm the fact that fish readily move out of the intake current and thereby avoid being entrapped within the intake structure. For these reasons, a fish pump return system would not substantially reduce the numbers of fish impinged at the Diablo Canyon Power Plant. A fish pump return system would not contribute to a significant reduction in the number of macroinvertebrates impinged or the number of organisms cropped as a result of entrainment. It is concluded that no further consideration should be given to a fish pump return system for diverting fish from the Diablo Canyon Power Plant intake structure.

There are two basic types of sluiceways for the return of impinged organisms and debris to the waterbody, one using a trash pump to transport collected material away from the intake and one using gravity flow. The pump-augmented return has the advantage of minimizing recirculation and reimpingement of debris on intake screens, but often results in mechanical abrasion and high mortality of organisms.

At the Diablo Canyon Power Plant, debris, along with fish and invertebrates retained by the intake screens, is washed during screen rotation into a sluiceway that empties into a large container lined with stainless steel mesh. This container which is periodically emptied into a debris box for disposal. The existing screenwash sluiceway serving the intake does not return impinged organisms to the receiving waterbody, hence no impingement survival is possible. The existing configuration of the intake does include a pump-augmented fish and debris return sluiceway which could be operated to return impinged organisms to the nearshore coastal waters. Abrasion and stress resulting from passage through the fish return system increases the susceptibility of the organisms to disease and predation in the receiving waterbody, thereby further reducing the effectiveness of the fish return systems.

6.2.5.5 Combinations of Screen Modifications

Combinations of intake screen modifications include components such as high- and low-pressure spraywashes, dual screenwash sluiceways, fish buckets, screen mesh of various sizes, and continuous screen rotation. Biological and operational performance evaluations of modified intake screens in a marine environment similar to that at the Diablo Canyon Power Plant have not been conducted. Detailed data on the survival of marine fish and macroinvertebrates such as rockfish, surfperch, sculpins, and *Cancer* spp. susceptible to impingement at the Diablo Canyon Power

Plant are not available, however, to evaluate the potential effectiveness of intake screen modifications for reducing impingement losses at the plant.

Impingement survival on modified vertical traveling screens located on the Columbia River was reported for juvenile chinook salmon by Page et al. (1976, 1978). Initial and long-term (96 hour) survival of impinged chinook salmon averaged 96 and 95 percent, respectively. Although chinook salmon have been reported in the areas adjacent to the Diablo Canyon Power Plant, none were collected in impingement samples during the study (Section 4.1), so there is little potential for improvement here.

Texas Instruments, Inc. (1977) examined the survival of young-of-the-year and yearling fish impinged on a modified vertical traveling screen (low-pressure spraywash, dual screenwash sluiceways, fish buckets) equipped with 0.1-in. (2.5-mm) nylon screen mesh at a power plant located on the Hudson River, New York. The vertical traveling screen was rotated continuously during the impingement survival studies. Most of the 3,616 fish collected were bay anchovy, blueback herring, or white perch. Mean initial survival of all species was 41 percent, and mean survival after 84 hours was 20 percent for all species. A summary of impingement survival results is presented in Table 6-4. Species-specific survival patterns are apparent, with high long-term survival for species such as white catfish, white perch, and Atlantic tomcod and low survival for species such as bay anchovy and rainbow smelt. The results of these studies are consistent with the findings of similar impingement survival studies conducted by Ecological Analysts (1979) on herring and anchovy at an operating power plant intake equipped with continuously rotating 2.5-mm (0.1-in.) mesh intake screens equipped with low- and high-pressure spraywash systems and fish buckets (Table 6-5).

Based on impingement survival data collected at the diablo Canyon and Moss Landing power plants and at other facilities, it was concluded that operation of modified intake screens in combination with fish return sluiceways would enhance impingement survival of many of the fish and macroinvertebrates impinged at the Diablo Canyon Power Plant including skates and rays, rockfish, sculpin, plainfin midshipman, tubesnouts, rock crabs, and sea urchin (Table 4-5). On the basis of data collected in the impingement survival studies (Section 4.2; Tables 4-5 and 4-6), it was estimated that losses of impinged fish and selected macroinvertebrates may potentially be reduced by approximately 75 percent under conditions of intermittent rotation assuming that there is no incremental mortality associated with passage through the fish return system. By means of an increase on intake screen rotation to continuous operation, impingement losses of fish and selected macroinvertebrates could potentially be reduced an estimated 85 percent, assuming no incremental mortality resulting from passage through the fish return system.

6.2.5.6 Summary

Modifications of vertical traveling screens that include fish buckets, a low-pressure wash system, provisions for continuous rotation, and a fish return system represent

TABLE 6-4

INITIAL AND LONG-TERM IMPINGEMENT SURVIVAL OF YOUNG-OF-THE-YEAR AND YEARLING FISH IMPINGED ON A CONTINUOUSLY ROTATING FINE-MESH (2.5-mm) MODIFIED VERTICAL TRAVELING SCREEN

Taxon		Age (a)	Number	Survival (%)	
Common name	Scientific Name	Class	Collected	Initial	84-hr
Striped bass	*Morone saxatilis*	1	13	85	75
White perch	*Morone americana*	1	223	45	26
White perch	*Morone americana*	2	37	41	18
Atlantic tomcod	*Microgadus tomcod*	1	78	92	58
Blueback herring	*Alosa aestivalis*	1	509	93	19
Blueback herring	*Alosa aestivalis*	2	1	100	0
Bay anchovy	*Anchoa mitchilli*	1	2,415	25	1
Bay anchovy	*Anchoa mitchilli*	2	65	55	13
Alewife	*Alosa pseudoharengus*	1	107	69	6
American shad	*Alosa sapidissima*	1	4	100	0
Hogchoker	*Trinectes maculatus*	1	4	100	100
American eel	*Anguilla rostrata*	2	4	100	100
Banded killifish	*Fundulus diaphanus*	1	1	100	(b)ND
White catfish	*Ictalurus catus*	1	27	100	100
Spottail shiner	*Notropis hudsonius*	1	2	100	100
Sea lamprey	*Petromyzon marinus*	1	1	100	100
Largemouth bass	*Micropterus salmoides*	1	1	100	100
Yellow perch	*Perca flavescens*	1	1	100	100
Weakfish	*Cynoscion regalis*	1	3	67	67
Bluefish	*Pomatomus saltatrix*	1	4	100	0
Rainbow smelt	*Osmerus mordax*	1	20	10	0
Rainbow smelt	*Osmerus mordax*	2	4	25	0
Menhaden	*Brevoortia spp.*	1	1	100	ND
Gizzard shad	*Dorosoma cepedianum*	2	5	100	0
Unid. clupeids	Clupeidae	1	80	51	ND
Centrarchids	Centrarchidae	1	5	100	100
Northern pipefish	*Syngnathus fuscus*	1	1	0	ND

(a) Age class: 1 = young-of-the-year; 2 = yearling or older.

(b) ND = no data

Source: Texas Instruments Incorporated 1977.

TABLE 6-5

INITIAL AND 96-HOUR SURVIVAL OF LARVAL AND JUVENILE CLUPEIFORMES IMPINGED ON A CONTINUOUSLY ROTATING FINE-MESH VERTICAL TRAVELING SCREEN AT THE INDIAN POINT GENERATING STATION

Taxon		Length	Mean Number	Impingement Survival (%)	
Common Name	Scientific Name	(mm)	Collected	Initial	96-hour[a]
Blueback herring	*Alosa aestivalis*	48	234	77	1
American shad	*Alosa sapidissima*	55	23	87	0
Alewife	*Alosa pseudoharengus*	60	7	86	0
Alewife	*Alosa* spp.	8	62	0	0
Bay anchovy	*Anchoa mitchilli*	18	65	0	0

(a) 96-hour survival = Number alive at end of 96 hours/Initial number alive.

Note: Stunned fish were counted as being alive.

Source: Ecological Analyst 1979.

an alternative technology with the potential for increasing impingement survival of several of the species of fish and invertebrates impinged at the Diablo Canyon Power Plant. Available impingement survival data from studies conducted at the Diablo Canyon Power Plant and other sites indicate that installation and operation of modified intake screens and a fish return sluiceway system could reduce impingement losses by approximately 75 to 85 percent depending on the mode of intake screen operation. Therefore, modified intake screens represent alternative technologies that will reduce impingement losses from the present operating conditions. It should be noted, however, that the numbers of fish and macroinvertebrates impinged on the existing intake screens at the Diablo Canyon Power Plant are low (Section 4.1) and existing impingement losses will not have a detectable population impact (Chapter 5).

The potential effectiveness of modified intake screens with fine-mesh screen material (0.2 in.; 0.5 mm) designed to exclude (impinge) larval fish and invertebrates from passage through the cooling system was evaluated. The absence of data on impingement survival of fish eggs, larvae, and invertebrates similar to those species susceptible to entrainment at the plant, and uncertainty regarding operational reliability of fine-mesh screens in a marine environment preclude the conclusion that fine-mesh intake screens would be effective in reducing biological losses. This conclusion is supported by laboratory data and limited field information on survival of freshwater larval fish in which survival was found to be low following impingement on fine-mesh screens, particularly when accompanied by high debris loads such as those experienced at the Diablo Canyon Power Plant.

In the absence of a demonstrated potential for long-term survival for impinged ichthyoplankton such as sculpins, surfperch, rockfish, white croaker, northern anchovy, and flatfish, fine-mesh screens are not considered to represent an acceptable alternative intake technology for use in reducing the combined losses resulting from entrainment and impingement.

No studies have been conducted of long-term survival of fish impinged on centerflow screens operated in a power plant cooling water intake, and it is unlikely that survival would be any higher than for vertical traveling screens. A fish pump return system is not expected to reduce losses of fish or macroinvertebrates at the Diablo Canyon Power Plant.

6.2.6 Intake Maintenance and Operational Modifications

Maintenance activities and operational modifications which may reduce entrainment and impingement losses include dredging in front of the cooling water intake, bar rack maintenance and kelp removal, reductions in circulating water pump volume, seasonal curtailment of cooling water system operation, use of alternative biofouling schemes, structural modifications of the cooling system, and through-plant temperature regulation.

6.2.6.1 Maintenance Dredging

Sediment accumulation within a cooling water intake structure may reduce the open area of the intake, resulting in increased water velocities. Increased velocities approaching the intake structure will, in many cases, result in increased rates of impingement. Depth measurements made in the intake structure of the Diablo Canyon Power Plant (Wyman 1988) indicated that sediment has not accumulated to a level that would reduce the available cross-sectional area of the intake. There is no evidence that maintenance dredging of the plant intake is presently required or would reduce approach velocities and potentially reduce the number of impinged organisms at the Diablo Canyon Power Plant. Sediment accumulation in the intake structure is not presently a maintenance problem or contributing to increased impingement losses.

6.2.6.2 Bar Rack Maintenance and Kelp Removal

Colonization of the intake bar racks (Figure 2-3) by marine fouling organisms including barnacles and mussels will contribute to higher intake approach velocities which are a factor influencing impingement. Additionally, fouling organisms prey on larval fish and invertebrates entrained at the power plant. Although the incremental reductions in entrainment and impingement losses cannot be quantified, observations made at the Diablo Canyon Power Plant and at other sites support the conclusion that intake bar rack maintenance is an important contributor to reducing organism losses at power plants sited in marine environments. PG&E has implemented a bar rack cleaning and maintenance program as part of routine intake structure operations at the Diablo Canyon Power Plant. Bar rack maintenance activities include periodic inspections and cleaning to remove marine fouling organisms. This routine preventative maintenance program is effective in controlling biofouling accumulations on the intake bar racks.

The Diablo Canyon Power Plant intake periodically experiences high debris loading. High debris loads are generally associated with winter storm activity and seasonal algal die off which results in increased drift kelp accumulations on the intake bar racks and intake screens. The accumulation of the kelp on the bar racks and intake screens reduces the available cross-sectional opening of the intake structure and thereby contributes to increased approach velocities. Drift kelp accumulations on the intake bar racks disrupts the velocity distribution across the intake structure creating areas adjacent to the bar racks where intake velocities are substantially reduced and adjacent velocity "hot spots" where intake approach velocities are substantially greater than design values. The accumulation of drift kelp and other debris on the bar racks, and the associated disruption in approach velocity distribution patterns, contributes to increased entrapment and impingement of fish and macroinvertebrates at the plant. Results of the Diablo Canyon Power Plant impingement monitoring program (Section 4.1) identified a number of periods of increased impingement of fish and macroinvertebrates which were correlated with periods of increased kelp and debris loading at the plant.

In an effort to control and reduce drift kelp accumulations on the intake bar racks, PG&E has initiated a kelp removal and program (Section 2.1.2). The kelp removal program involves the harvesting of drift kelp and a portion of the kelp canopy from plants growing within the Diablo Canyon Intake Cove and the removal of kelp plants by divers from an exclusion zone in the immediate vicinity of the intake structure. During periods of the year when kelp and debris are accumulating on the bar racks, PG&E uses a mechanical rake to physically remove drift kelp from the bar racks as part of the routine intake maintenance program.

Although not quantified, observations made during diver surveys and during impingement sampling support the conclusion that existing intake bar rack maintenance and kelp removal efforts contribute to a reduction in the numbers of fish and macroinvertebrates impinged. The routine bar rack maintenance activities reduce the accumulation of biofouling organisms and drift kelp which contribute to increased and irregular intake approach velocities and thereby reduce the susceptibility of organisms to entrapment and subsequent impingement. Kelp harvesting and removal programs reduce the presence of kelp in the immediate vicinity of the intake which otherwise would serve as a behavioral attractant for fish including rockfish, and macroinvertebrates to the intake area where their susceptibility to impingement would be increased. In combination, the intake bar rack maintenance and kelp removal program currently employed at the Diablo Canyon Power Plant contribute to a reduction in fish and macroinvertebrate impingement losses.

6.2.6.3 Circulating Water Pump Volume Reduction

A reduction in the number of circulating water pumps in operation has been suggested as an alternative operational strategy for reducing cooling water volumes and intake approach velocities, and hence reducing the number of organisms entrained and impinged at the Diablo Canyon Power Plant. Changes in condenser back-pressure resulting in reduced turbine cycle thermal efficiency, along with increased temperature differentials through the condenser system (Δ-T), will occur when cooling water flow rates are reduced during generation. Although a reduction in cooling water volume will result in a decrease in the number of entrained organisms, the associated increase in Δ-T might substantially reduce the survival of organisms that are entrained.

Reducing the operation of the circulating water pumps during periods when generation is low or is not occurring would reduce the numbers of organisms entrained and impinged at the Diablo Canyon Power Plant. Entrainment losses would be reduced in approximately the same proportion as the reduction in cooling water flow rates. The Diablo Canyon Power Plant is designed and operated as a base-loaded plant with electrical generation at a relatively constant level, typically 90-100 percent capacity, for extended periods of time. The operational characteristics of Units 1 and 2 limit the potential effectiveness of single pump operation as alternatives for reducing entrainment and impingement losses. A series of calculations were made using actual 1986-1987 unit-specific generation data to estimate the potential reductions that could be achieved with alternative circulating water pump operational modes. Single pump operation was evaluated by assuming one circulating water pump would operate when unit loads ranged from >0 to 42 percent and both circulating water pumps would operate when unit loads exceeded 42 percent capacity. A base operational case was estimated by assuming that both circulating water pumps operate when unit load exceeds 0 percent. Results of this analysis, expressed in a percent reduction in cooling water flow from the base condition are presented below:

	% Reduction in Cooling Water Flow
Unit 1	
1986	3.3
1987	4.6
Average	4.0
Unit 2	
1986	3.3
1987	3.1
Average	3.2

The potential reductions achieved in entrainment and impingement losses at the Diablo Canyon Power Plant resulting from alternative cooling water system operational modes would be proportional to the estimated volume reductions shown above. Based on results of these analyses it is concluded that alternative circulating water pump operational modes offer the potential for reducing entrainment and impingement losses approximately 3 to 4 percent.

6.2.6.4 Fuel-Reloading Outages

Diablo Canyon Power Plant Units 1 and 2 are periodically removed from service for refueling and maintenance. The unit outages occur at an interval of approximately 18 months. Two refueling outages have occurred at the Diablo Canyon Power Plant: a Unit 1 outage between August and December 1986 and a Unit 2 outage between April and July 1987. Review of operational records during these outages confirmed that one or both of the two circulating water pumps for the unit were removed from service, thereby reducing the numbers of entrained and impinged organisms during each unit outage. The percentage of time during the unit outages that circulating water pumps were removed from service is summarized below:

	Percentage of Time Each Pump Was Removed From Service During Fuel-Reloading Outage
Unit 1	
Pump 1-1	72
Pump 1-2	87
Unit 2	
Pump 2-1	91
Pump 2-2	65

The overall averages reduction in cooling water flow for the unit outages, compare to full pump operation, is 79 percent.

The potential reduction in the numbers of entrained larval fish attributable to fuel-reloading outages was estimated by assuming a 79 percent reduction in cooling water flow to the unit during a two-month outage period. The percentage reduction in entrainment of selected larval fish taxa was used as a criterion for evaluating the potential reduction in losses. Results of the analysis are presented in Table 6-6. It is apparent from the seasonal distribution data presented in Chapter 3 for entrained larval fish and macroinvertebrates, that no pronounced seasonal pattern exists for entrained organisms at the Diablo Canyon Power Plant. Fuel-reloading outages will reduce entrainment and impingement whenever they occur during the year.

6.2.6.5 Alternative Demusseling Methods

The biofouling control procedure currently used at the Diablo Canyon Power Plant consists of intermittent chlorination for slime control, heat treatment, and mechanical removal (scraping). Demusseling of the cooling water system intake conduits is currently accomplished by use of heat treatment. As described in Section 2.1.2.0, this process is accomplished by altering the flow in the conduits of one unit so that the temperature in one of the conduits is elevated above a selected level. This level, determined by experimentation, is sufficient to cause a high level of mortality in the predominant biofouling species. Following a heat treatment period, these attached organisms eventually become detached from the walls of the conduits. Prior to its application at Diablo Canyon Power Plant, heat treatment had been employed at a number of PG&E's power plants for many years and has proven its effectiveness in controlling the biofouling populations in the cooling water intake conduits.

TABLE 6-6

ESTIMATED PERCENTAGE REDUCTION IN LARVAL FISH ENTRAINMENT ASSUMING A UNIT-SPECIFIC FUEL-RELOADING OUTAGE AT THE DIABLO CANYON POWER PLANT

Fuel-Reloading Outage	Rockfish	Cabezon	Sculpin	Northern Anchovy	White Croaker
December - January	2	25	5	23	18
January - February	2	12	4	15	17
February - March	14	3	5	9	6
March - April	26	2	4	8	5

Note: Percentage reduction estimates assume a reduction in cooling water flow of 79 percent compared to full flow operations during a two-month outage.

Although this approach to controlling biofouling was originally proposed for Diablo Canyon Power Plant, PG&E, in 1985, prepared two studies of alternatives to heat treatment for demusseling at Diablo Canyon Power Plant. These studies were prepared in response to Provision D.6 of RWQCB-CCR Order 82-24, as amended March 17, 1983, and to a request for additional studies as described in the Board's letter to PG&E dated April 13, 1983. These studies were requested because of the Board's concerns regarding the potential environmental effects in the receiving waterbody of the temperature of the discharge during heat treatment operations.

The environmental effects of heat treatment were discussed in a report entitled Assessment of Alternative Demusseling Methods, Diablo Canyon Power Plant, (TERA 1985). The objective of this study was to consider any possible method that could be used for biofouling control at the Diablo Canyon Power Plant. Seventeen such methods were initially identified, including chemical, hydraulic, manual cleaning, mechanical cleaning, and thermal methods. A screening analysis was then applied to these seventeen methods to determine the technical feasibility of the alternatives. Technical feasibility was determined by using the following criteria: land-terrain limitations, regulatory constraints (federal, state or local regulations that would preclude application at the Diablo Canyon Power Plant), technical incompatibility (requiring major modifications to or replacement of critical components of the heat cycle of the Diablo Canyon Power Plant), and treatment effectiveness. As a result of this screening process, five of the seventeen methods were determined to merit further consideration as alternatives to heat treatment for demusseling. The five technically feasible methods identified were: chlorination, ozonation, anti-fouling coatings, manual cleaning, and a shellfish filter.

The comparative analysis involved evaluations of each of the five methods and heat treatment with respect to: treatment effectiveness, technical compatibility, cost and environmental effects. Of the six methods considered, manual cleaning was the most effective method for controlling biofouling in the intake conduits. However, this method did not provide for macrofouling control in certain auxiliary systems. Overall, the most effective method for biofouling control was determined to be heat treatment. The shellfish filter was determined to be incompatible with the present plant configuration without major redesign and reconstruction of the cooling water system. Ozonation would also involve substantial design modifications and construction activities. All other alternatives were found to be technically compatible with the existing plant structures. Capital and annual costs were evaluated and determined to range from approximately $370,000 to $30 million for capital costs and $338,600 to $19.3 million for annual operating costs. The analysis of environmental effects determined that manual cleaning, shellfish filter, and thermal treatment would not have significant environmental effects on the receiving waterbody organisms at the Diablo Canyon Power Plant. The anti-fouling coatings that were shown to be most effective for application at the Diablo Canyon Power Plant, had relatively little information available concerning residual effects in the water discharged and on the sediments in and around Diablo Cove. Given the fact that most of the coatings contain and release toxic metal compounds, this was considered to have potential adverse effects. Both chlorine and ozonation were considered to have the greatest adverse effect on the entrained organisms and, in the case of chlorine, to have potential adverse effects also on the receiving waterbody populations.

The environmental effects of heat treatment can be separated into effects on entrained organisms and receiving waterbody populations. The effect on entrained organisms is limited because of the duration of heat treatment and reduced flow. The effects on receiving waterbody populations are primarily a function of the temperature and mixing of the discharge water as it enters Diablo Cove. For both entrained and receiving waterbody organisms, potential environmental effects are primarily a function of two parameters: maximum temperature and the frequency of heat treatment. Accordingly, PG&E has undertaken a research program to determine the thermal sensitivity of the critical biofouling organisms occurring at Diablo Canyon Power Plant, and has defined the minimum times and temperatures needed to produce an effective demusseling. In continuing studies, PG&E has designed and operated an experimental facility at the Diablo Canyon Power Plant site that provides an indication of fouling levels in the conduits. This facility is used to determine the frequency of heat treatment at Diablo Canyon Power Plant. These efforts have resulted in a high degree of optimization of both the temperatures and frequency required for effective demusseling at Diablo Canyon Power Plant.

The heat treatment optimization program at the Diablo Canyon Power Plant is designed to provide effective fouling control in the cooling water system intake conduits, and thereby reduce predation losses on entrained fish and invertebrates, while also minimizing the frequency and duration of heat treatment. The existing heat treatment optimization program contributes to a reduction in losses of entrained organisms.

6.2.6.6 Cooling System Modifications

Structural modification of cooling system components (pumps, conduits, condensers) is not considered to be an effective alternative to reduce the mortality of entrained organisms. Too little quantitative information is available to isolate specific sources of mortality within a cooling water system. Design parameters for specifying pressure regimes, circulating water pump design and operation, tolerable shear stresses, and cooling system designs for minimizing mechanical abrasion have not been developed.

6.2.6.7 Discharge Temperature Regulation

An analysis of hourly discharge temperatures for the period June through December 1987 (Figure 3-22) showed that discharge temperatures were below 86 F (30 C) 99.9 percent of the time at Unit 1 and 100 percent of the time at Unit 2. Exposure to discharge temperatures above 86°F (30°C) during cooling system transit are generally considered to be lethal to entrained organisms (Appendix B). No survival is expected for entrained organisms exposed to elevated temperatures during heat treatment, which have low frequency and duration (Section 6.2.6.5). Therefore, thermal stresses are not expected to be a significant cause of mortality to entrained fish or invertebrates. Discharge temperature regulation would not result in a significant reduction of the number of organisms lost to entrainment through the plant's cooling system on the basis of data and observations presented in Chapter 3.

6.2.7 Conclusion: Biological Evaluation

Based on results of the biological evaluation (Section 6.2), the following was concluded:

1. There is no reasonable alternative intake location that would reduce entrainment and impingement losses.
2. Behavioral barriers would not reduce the numbers of organisms exposed to either entrainment or impingement.
3. Entrainment and impingement losses would not be substantially reduced by use of drum screens, centerflow traveling screens, or a fish pump return system.
4. A screen mesh size of 3/8 in. (9.5 mm) is acceptable, because the survival potential of fish eggs and larvae impinged on fine-mesh screens have not been shown to exceed the survival potential of organisms entrained through the Diablo Canyon Power Plant cooling system.
5. Cooling system structural modifications and discharge temperature regulation would not substantially reduce the mortality of entrained organisms.
6. The existing bar rack biofouling control program is effective in reducing intake approach velocities and predation losses for entrained fish and invertebrates.
7. Sediment accumulation within the intake structure is presently not contributing to increased water velocities.
8. The kelp harvesting and exclusion program and the removal of accumulated drift kelp and debris from the intake bar racks, activities which are currently part of the routine intake maintenance program at the plant, are effective in reducing impingement.
9. The biofouling control program and heat treatment optimization efforts underway at the Diablo Canyon Power Plant are effective in reducing the accumulation of fouling organisms colonizing the intake conduits while also reducing the frequency and duration of heat treatment at the plant.

The following alternative intake technologies would reduce entrainment and/or impingement losses at the Diablo Canyon Power Plant and were therefore selected for feasibility analysis:

1. seasonal curtailment of cooling system operation;
2. modified vertical traveling intake screens and a gravity screenwash sluiceway;
3. expansion of the shoreline intake structure with modified vertical traveling intake screens and gravity sluiceway; and
4. short-term reductions in circulating water pump operation when the units are operating at low loads or are out of service;

6.3 Feasibility Analysis

Each alternative technology that satisfied the biological reduction criterion (Section 6.2) and differed in design or operation from that presently in use at the Diablo Canyon Power Plant was evaluated with regard to engineering feasibility, operation, and reliability. In addition, the total economic cost in 1987 dollars associated with each feasible alternative was estimated. Cost estimates reflect direct capital costs and indirect costs (e.g., the loss of generating capacity) whenever possible.

It must be noted that those alternatives which involve significant modifications to the existing intake structure would be subject to review and approval by the Nuclear Regulatory Commission. Such review could involve hearings to review the safety significance of the proposed modification. The cost for such proceedings have not been factored into the following discussions, but would be expected to add significant cost to the evaluation of any alternative.

6.3.1 Seasonal Planned Reduction of Cooling System Operation

The seasonal planned reduction alternative would involve the selective scheduling of unit fuel reloading outages to coincide with the peak periods of abundance for key species in the area. Ideally, the option would be to schedule refueling outages for specific times of the year when densities of entrained organisms are greatest. However, fine seasonal distribution in densities of entrained fish is highly variable between years and difficult to predict as would be required to schedule refueling outages. The planned reduction of cooling system operation presents several difficulties. The option is most closely suited for those plants which are used for peaking or other intermittent operation. The Diablo Canyon Power Plant is a base-loaded nuclear generating station, designed to operate at full power for extended periods. Plant systems have not been designed for intermittent operation. Further, the economics of operation of nuclear units are dependent upon their use as base-loaded facilities.

Currently, the planned outage schedule for Diablo Canyon is based on the unit refueling schedule. The refueling plans are such that each unit will be operated for 18 months, followed by a 2- to 3-month, planned refueling outage. These unit outages are scheduled such that both units are not undergoing a refueling at the same time. Thus, the 18 month plus 2-3 month staggered schedules would result in

Unit 1 and 2 being taken out of service on a "rolling" schedule (i.e. - not during particular calendar months within a given year). Because no other major outages are routinely planned for the Diablo Canyon Power Plant, the refueling outages take on a great deal of importance. Such outages at nuclear power plants require a great deal of planning and coordination to assure that all planned maintenance projects are completed in a timely manner. It would not be feasible to attempt to schedule such a large, complex outage to coincide with a particular time-frame during the year. Thus, this option is not a feasible method for reducing biological losses at the Diablo Canyon Power Plant.

The Diablo Canyon Power Plant is a key component of PG&E's power supply system. Thus, the seasonal planned outage option at the Diablo Canyon Power Plant would adversely affect the reliability and supply of electrical energy to commercial and residential uses in central and northern California. This option at the Diablo Canyon Power Plant is infeasible, because of the relatively high demand of electrical energy in the central and northern California load centers and the uncertain availability from other sources of surplus energy to replace it. Even if power were readily available, the limited capacity of transmission lines for the distribution of electrical energy into the central and northern California load centers would cause this option to have a substantial impact on PG&E's ability to meet its obligations to provide reliable service to these areas.

Since the Diablo Canyon is a base-loaded facility, daily power curtailment (e.g., at night or when load is low) is not a viable alternative for reducing biological losses.

The various strategies for planned outages of cooling system operation would result in a reduction of both entrainment (Table 6-6), and impingement losses, in an amount that would depend on the abundance of organisms present during the period of curtailment and the duration of the outage. However, such options at the Diablo Canyon Power Plan beyond those which occur normally, are not acceptable, because they remove the generating capacity of the plant from reliable service when it is needed to serve system loads. The availability of replacement power is uncertain. Planned outage of power generation as a method of reducing entrainment and impingement losses at the Diablo Canyon Power Plant is not a feasible alternative.

6.3.2 Modified Traveling Screens and Fish Return Systems

As discussed in Section 6.2.5, impingement mortality of certain species could be reduced through modifications to the existing conventional vertical traveling screens and a change in intake screen operation, from the current intermittent operation, to continuous rotation. This retrofit program would involve modifying the existing intake screen configuration to include installation of the following items:

- a watertight fish collection basket along the base of each screen panel,
- neoprene deflectors and seals between the fish baskets and the screen,
- both low-pressure and high-pressure wash systems, and

- a gravity-flow fish return sluiceway.

Additionally, a number of components, such as foot shaft bushings, main carrier chains, boot plates, main frame roller guides, head shaft roller bearings, and reducer drives, would need to be upgraded for the screen to continuously operate in a reliable manner. A differential control and two-speed motor would be included so that when the screen is operated continuously it rotates at slow speed, and as fish and/or debris loads increase, the screen rotation rate can be automatically increased. This design would require expansion and modification of motor control centers, addition of a second circuit to each motor, and additional conduits.

Both conventional and modified vertical traveling screens are available commercially and the installation procedures are similar for the two screen types. The existing traveling screens could be modified or new vertical traveling screens installed. A comparison of the cost estimates for the above two alternatives shows that the capital costs are approximately the same, therefore, the cost estimate assumes the purchase of new vertical traveling screens at the Diablo Canyon Power Plant. Replacement of the screens could be scheduled during routine maintenance of the present screens to avoid forced unit outage costs.

Traveling screen modifications to reduce impingement mortality must be accompanied by a sluiceway designed to return organisms to the receiving waterbody. Most installations of modified traveling screens use a dual sluiceway return system - a gravity sluiceway return system for impinged organisms removed from the screens by the low-pressure spraywash, and another sluiceway for debris removed by the high-pressure spraywash (Figure 6-3). This type of design was selected for this alternative.

Installation of modified traveling screens and a fish return system at the Diablo Canyon Power Plant would not result in significant losses of generating capacity. However, the continuous operation of the traveling screens and screenwash sprays would consume additional electrical energy.

PG&E has conducted tests of modified screens and fish return systems at the Pittsburg Power Plant. During these tests, conducted from November 1982 to January 1984, maintenance records were kept for work performed on the modified screen as well as on the adjacent conventional screens to determine if maintenance requirements of the modified screen would impair plant availability or reliability (criterion 3). The modified screen had more maintenance requirements than the conventional screens. Although PG&E followed routine maintenance requirements for the modified screen and these requirements did not impair plant availability or reliability, there were two failures of the modified screen. Both failures were related to continuous operation of the modified screen. The first failures was due to a worn motor bearing which occurred 13 weeks after beginning continuous operation. The second failure, which occurred after 14 months of operation, was due to failure of the basket chains. During the examination of the screen, PG&E personnel observed that the basket chain had fractured in two locations and that some of the baskets had become bent. In addition, excessive wear of the basket end plates, the drive sprockets, and the boot plate was noted. This indicted that the modified screen failure may have been due to the basket chain stretching. Additional information on screen maintenance requirements for modified screens operating in a marine environment with periodic high debris loads experienced at the Diablo Canyon Power Plant would need to be compiled before a conclusion could be drawn regarding the impact of increased screen maintenance (routine preventive maintenance, screen overhaul, and repair frequency following mechanical failure) on plant operations. The types of problems discussed above regarding increased wear and maintenance requirements are anticipated to be amplified in the marine environment at the Diablo Canyon Power Plant.

Modification of the existing vertical screen system to implement this alternative would result in a total estimated capital cost of $8,250,000. As shown in Table 6-7, this cost includes equipment and materials, construction, engineering and indirect and overhead costs (1987 dollars). This cost includes direct and indirect capital costs associated with screen installation and incorporation of a dual spraywash system. Cost estimates also include modification and reconstruction of a portion of the existing intake to include necessary spraywash pumps, valves, piping and electrical controls, and a gravity sluiceway collector for the low-pressure spraywash system to return impinged organisms to the waterbody.

The additional operation and maintenance (O&M) cost for operating the modified vertical traveling screens in continuous operation mode is also shown in Table 6-7 to be $250,000 per year.

The above costs assume that the construction would be accomplished during scheduled plant outages. The O&M costs for this alternative depend primarily on the frequency of screen rotation. Thus, the O&M costs of a modified screen operated periodically in a continuous rotation mode will be higher than costs of the existing conventional screens operated intermittently year-round. The total O&M costs of modified vertical traveling screens at the Diablo Canyon Power Plant would substantially exceed those of a conventional vertical traveling screen system.

6.3.3 Expansion of the Shoreline Intake Structure with Modified Vertical Traveling Intake Screens and Gravity Sluiceway

The approach velocity at the existing shoreline structure at Diablo Canyon Power Plant is 0.8 to 1.0 fps. Such velocities have not been found to have a significant relationship to impingement rates for key species at Diablo Canyon Power Plant (Chapter 4). However, the present velocity is higher than the general guideline value of 0.5 fps for fish protection. Thus, designs have been considered which would achieve a 0.5 fps intake velocity. This alternative also includes the modified vertical traveling intake screens and gravity fish return sluiceway discussed above in Section 6.3.2.

TABLE 6-7
SUMMARY OF COSTS OF INSTALLATION OF MODIFIED VERTICAL TRAVELING INTAKE SCREENS

	Cost Element (1, 2)	Cost x $\$10^3$ (3)
1.	Equipment and Material (Associated Mechanical and Electrical Equipment and Bulk Materials)	3,500
2.	Construction (Site Preparation and Equipment/Bulk Material Installation)	2,890
3.	Engineering (Design, Specification, Procurement, etc.)	210
4.	Indirects and Overheads (Corporate Indirects, General Administration, Advalorem Tax, AFUDC, etc.)	1,650
5.	Gross Financial Cost (Items 1 through 4)	8,250
6.	Effective Gross Financial Cost of Power Replacement(4)	0
7.	Annual Operating and Maintenance Costs (O&M)(5)	250

Notes:

1. All above cost elements include distributable costs and contingency.
2. Above costs do not account for escalation.
3. Cost is at third quarter 1987 price level.
4. It is assumed that the construction can be done during scheduled plant outages.
5. This is an additional O&M cost compared to that of existing conventional screens.

Reduction in the intake approach velocity to 0.5 fps would require expansion of the intake structure and addition of more traveling screens to the structure to increase the surface through which the water would flow. To accommodate this design, the existing shoreline intake structure could be expanded to modify the area of intake for the Units 1 and 2 cooling water flow. Figure 6-4 shows a plot plan for the conceptual design. Figure 6-5 shows a plan view of the modified intake structure. Figure 6-6 shows an elevation section through the modified structure. As indicated in these figures, the modification would involve expanding the intake structure towards the ocean side with approximately 45° flare and deepening the existing intake invert slab elevation to (-) 46.0 feet.

Construction of the expanded intake structure would result in a major construction effort and require installing a cofferdam and dewatering the existing intake structure. Disruption associated with construction and dredging activities would contribute to localized impacts on kelp and benthic organisms inhabiting the Intake Cove.

During intake construction, the circulating water flow required for the operation of Units 1 and 2 would be disrupted, resulting in a complete loss of generating capability from both units for a period of approximately one year. This loss would represent a severe generation penalty, as shown by the cost of power replacement in Table 6-8. Operating one unit while modifying the other unit is not preferable because the construction of the cofferdam would be difficult without reducing flow to the operating unit. In either case, the cumulative cost of power replacement would not change appreciably from that reported in Table 6-8 because the construction durations for each unit would not change substantially.

While the units are shut down, the auxiliary saltwater (ASW) system would have to remain operable in order to preserve the function of those systems necessary to maintain the plant in a safe shutdown mode. Therefore, construction would require an extension of the auxiliary saltwater system to provide continuous flow to the ASW pumps. Since the ASW system is a nuclear safety related system, necessary safety related design considerations such as earthquakes, control of heavy loads and interaction between safety and non-safety related items would have to be evaluated as part of intake structure design and modification.

In order to achieve the 0.5 fps design approach velocity in a uniform manner across the expanded intake structure, it might be necessary to include flow straighteners or to extend piers to channel the flow to existing circulating water pumps. A screen wall support structure similar to the existing configuration would have to be constructed and equipped with vertical traveling intake screens. The existing circulating water pumps would remain in their present position. In addition to the traveling screens, other items such as bar racks, the gantry crane and the kelp removal crane would be placed at the front end of the expanded intake. The electrical controls and motor control centers would be upgraded to accommodate the increased number of intake screens. More screen rake drives would be needed. The new drive locations and crane location would require an extension from the existing

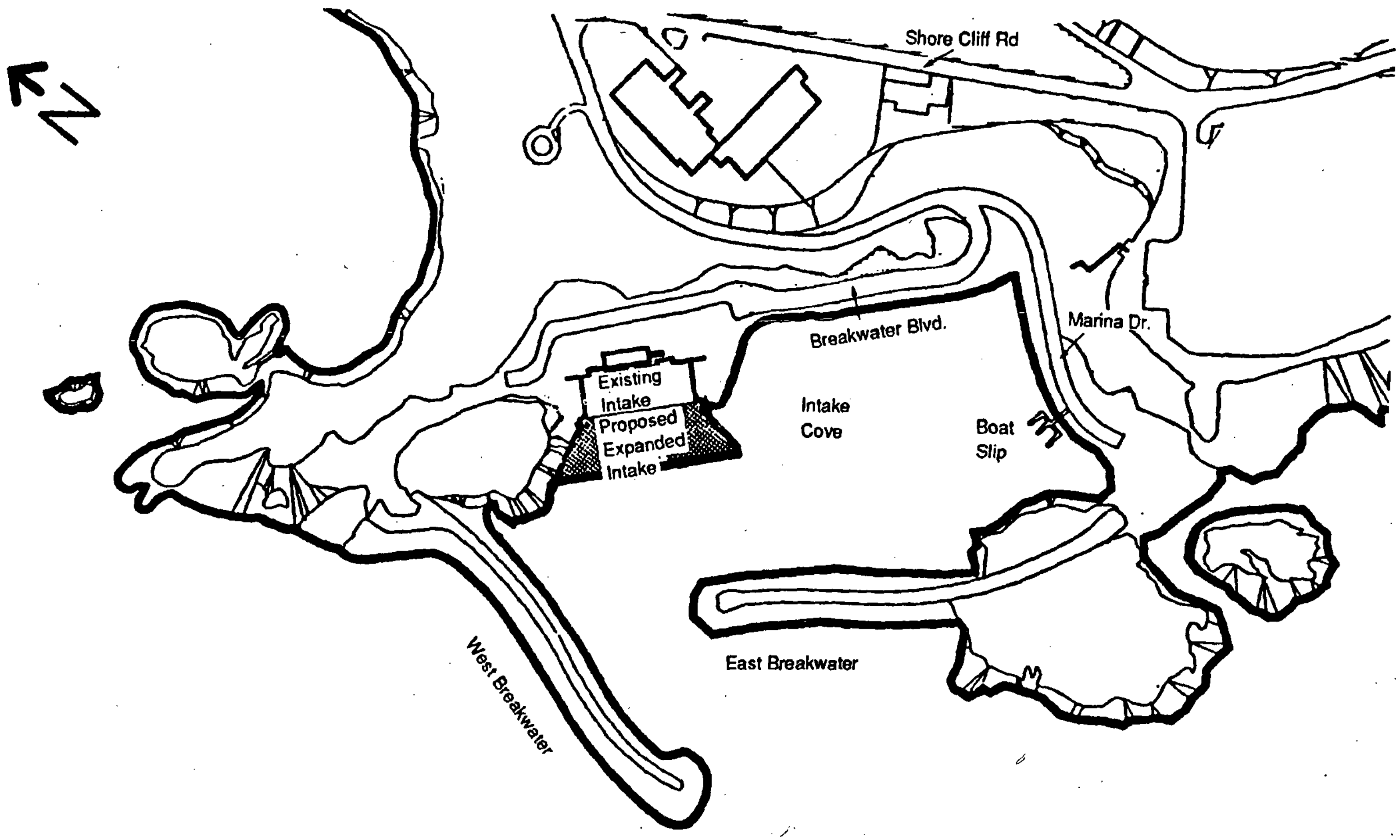


Figure 6-4

Conceptual Design of the Proposed Expansion of the Intake
at the Diablo Canyon Power Plant

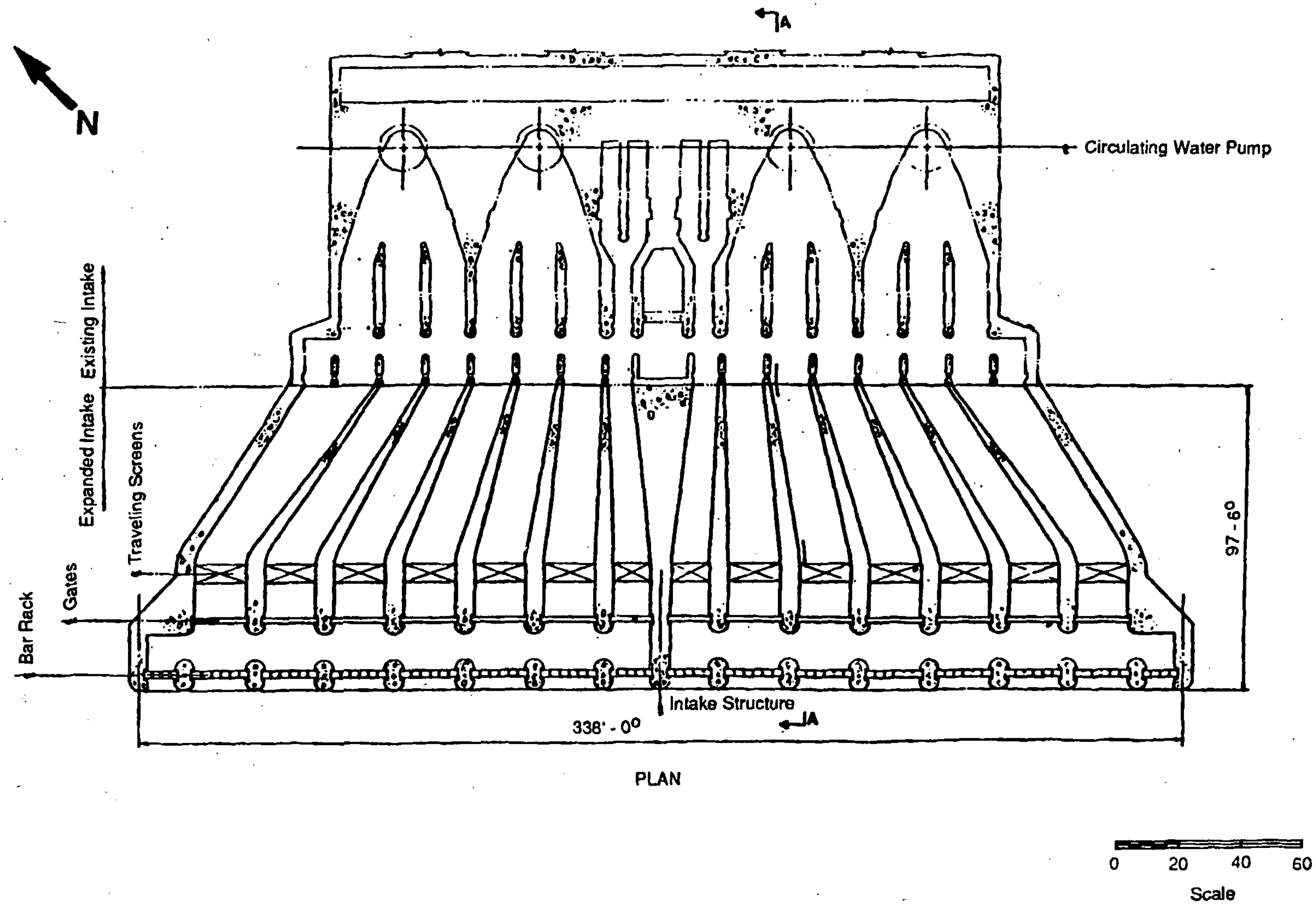


Figure 6-5

Plan View of the Proposed Expansion of the Intake at the Diablo Canyon Power Plant

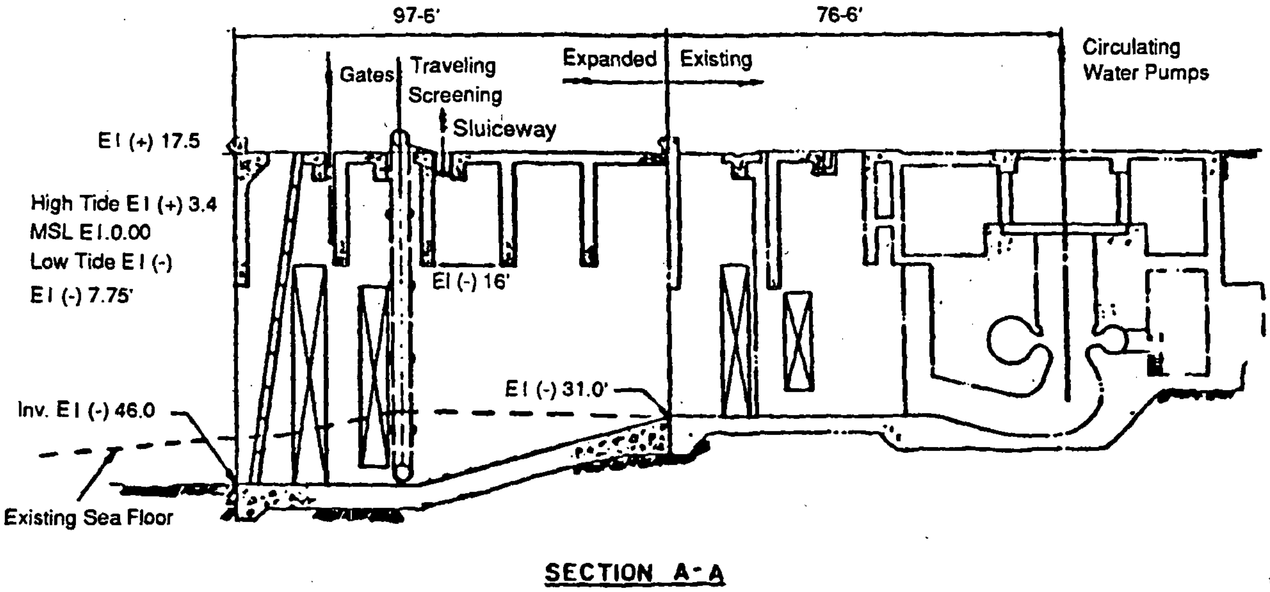


Figure 6-6

Sectional View of the Proposed Expansion of the Intake
at the Diablo Canyon Power Plant

embedded conduits into the expanded structure. The cathodic protection system would have to be expanded to protect the new bar racks and screens, and the differential level transmitters used to control the screen rake drives would have to be relocated and new embedded conduits added. Additionally, the security system would have to be expanded and new lighting would be required.

Prior to finalizing the design of the expanded intake structure, a detailed engineering evaluation would be necessary to ensure compatibility between hydraulic flow patterns, cooling water volumes, and pressure regimes associated with the expanded intake structure and the existing Units 1 and 2 condenser system. Additionally, other environmental and safety design considerations such as earthquakes, tsunamis, and probable maximum loads would require evaluation which would result in additional costs to that shown in Table 6-8.

Table 6-8 summarizes the estimated direct and indirect costs of constructing an expanded intake structure for Units 1 and 2. The estimated capital cost of the expanded intake structure is $31.25 million. In addition, the effective gross financial cost of power replacement during the project one-year outage of Units 1 and 2 that would be required during construction of the expanded intake structure is $173 million. The total direct and indirect cost of this alternative is approximately $204 million.

6.3.4 Reductions in Circulating Water Pump Operation

A reduction in the number of circulating water pumps in operation is one strategy for reducing cooling water volume and intake approach velocities, and hence the rates of entrainment and impingement. Single-pump circulating water pump operation at Units 1 and 2 would reduce approach velocities and would result in a reduced entrainment and impingement rate. A reduction in cooling water volume of 50 percent, for example, as a result of operating one pump per unit, would reduce the number of entrained organisms by 50 percent. During unit fuel-reloading outages, one or both circulating water pumps are routinely removed from service under present operating practices when practicable .

The normal circulating water pump operation at the Diablo Canyon Power Plant is the minimum level necessary to sustain full unit generation. The Diablo Canyon Power Plant is operated as a base-loaded facility. There are no large periods of time when the units are operated at reduced load levels. Such reductions typically occur only during planned outages, or during power escalation.

Reduction in circulating water pump operation from two pumps per unit to one would necessitate a reduction in load capacity to 42 percent or less. The operating time of a single pump with unit loads of less than 42 percent capacity would be quite small (Section 6.2.6.3). As discussed above in Section 6.3.1, such a reduction on a planned, extended basis would greatly impact PG&E's ability to meet its load demand. At 42 percent load the circulating water temperature rise and tube bundle steam loadings (steam approach velocities) are identical to those encountered at full

TABLE 6-8

SUMMARY OF COSTS FOR EXPANSION OF
UNITS 1 AND 2 SHORELINE INTAKE STRUCTURE

	Cost Element (1, 2)	Cost x $\$10^3$ (3)
1.	Equipment and Material (Associated Mechanical and Electrical Equipment and Bulk Materials)	9,470
2.	Construction (Site Preparation and Equipment/Bulk Material Installation)	14,520
3.	Engineering (Design, Specification, Procurement, etc.)	1,010
4.	Indirects and Overheads (Corporate Indirects, General Administration, Advalorem Tax, AFUDC, etc.)	6,250
5.	Gross Financial Cost (Items 1 through 4)	31,250
6.	Effective Gross Financial Cost of Power Replacement (4)	173,000

Notes:

1. All above cost elements include distributable costs and contingency.
2. Above costs do not account for escalation.
3. Cost is at third quarter 1987 price level.
4. The power replacement cost is based on an estimated construction period, discounting for a scheduled outage period of three for one unit and using an estimated power replacement cost of $540,000 per day.

load with two operating pumps. Continued operation with one pump at higher loads would threaten to exceed the circulating water temperature rise limits authorized by the NPDES permit. It would also increase the steam loading on the active tube bundles, thereby significantly increasing the likelihood of condenser tube failure from fluid elastic vibration fatigue.

The use of a single pump per unit at the Diablo Canyon Power Plant with the units operating at reduced load would also present certain technical operating difficulties. The motors which operate the circulating water pumps are large (13,000 hp) which undergo substantial stress and wear during the startup. In order to achieve appropriate performance of the unit at reduced load (e.g. at 42 percent power, or less) or to increase load above 42 percent in response to increased demand, the second circulating water pump would be needed from time-to-time. Intermittent re-starts of the second pump would greatly increase the wear, reduce pump motor reliability, and would increase the frequency of maintenance.

A second difficulty arises directly from the operation of a single pump. With one circulating water pump operating, there is no backup on-line. Thus, if the operating pump were to fail, the unit would undergo a forced outage. Operating conditions which increase the likelihood of forced outages are avoided.

The condensers installed at the Diablo Canyon Power Plant are designed for the full operating circulating water flow rate. Sustained condenser operation at reduced loads would not result in optimum power output from the units. Certain physical restrictions inherent in the cooling water system design would limit the extent to which single-pump operations could be implemented. The ability to maintain water level and flow in the condenser tubes would have to be assessed in detail. The required circulating water flow rates for each unit are a function of the critical condenser tube velocity and the particular heat transfer characteristics of each condenser. While such detailed analyses are not within the present scope of this assessment, consideration of these factors would be required before reductions in circulating water flow rates of as much as 50 percent could be considered to be technically feasible. Operation of the condenser at reduced circulating water rates would result in increased temperature differentials through the condenser system and reduced turbine cycle thermal efficiency. These operational constraints severely limit the performance efficiency of a generating unit.

Because of the generating penalty, loss of reliability, and operational inefficiency of generating units that would accompany reduced circulating water pump operation during periods of high load, further investigation of single-pump operation as an approach to reducing biological losses is not warranted.

6.4 Summary and Conclusions

The biological benefits, costs, and engineering constraints of the alternative intake technologies considered in Section 6.3 are summarized below. On the basis of this information, a recommendation is made as to the best intake technology available for the Diablo Canyon Power Plant.

An examination was made of the relative effect of operation of the plant's cooling water system on fish and macroinvertebrate populations (Chapter 5). No evidence was found to indicate that operation of the existing cooling water system at the Diablo Canyon Power Plant has resulted in an adverse impact on the populations of fish and invertebrates inhabiting the coastal waters in the vicinity of the power plant. Most of the organisms entrained and impinged were of species that have high reproductive potentials and planktonic early life stages that are distributed widely by ocean currents along the Pacific Coast. The high reproductive rate and wide dispersal of a majority of the taxa entrained and impinged reduces the risk of localized population effects. In addition, the species whose larvae are entrained typically have very high natural mortality rates.

For these reasons, it was concluded that the impact of the Diablo Canyon Power Plant operation on marine life is undetectable. There is no certainty that implementation of alternative intake technologies designed to further reduce entrainment or impingement mortality would result in a detectable increase in population abundances for fish and invertebrate species inhabiting adjacent coastal waters. The recommendations and discussion of alternative intake technologies presented here are based, in part, on this conclusion.

6.4.1 Discussion

Alternative intake technologies considered for the Diablo Canyon Power Plant included seasonal fuel-reloading outages; modifications of the Units 1 and 2 intake screens, screenwash sluiceway, and operation; expansion of the existing shoreline intake structure and installation of modified intake screens; and reductions in circulating water flow rates. Each of these alternatives is expected to offer some potential for reducing the losses of organisms resulting from entrainment and/or impingement.

The occurrence of periodic fuel-reloading outages and a corresponding reduction in cooling system operation results in reductions of both entrainment and impingement losses. The magnitude of entrainment and impingement reductions depends on the abundance of organisms present during the 2 to 3 month fuel-reloading outages. During the fuel-reloading outage one of the two circulating water pumps is removed from service, thereby reducing the numbers of entrained and impinged organisms during the unit outage. An analysis of the seasonal distribution data for selected larval fish susceptible to entrainment (Table 6-6) showed that although cooling water volume reduction during fuel-reloading outages contributes to a reduction in the numbers of organisms entrained the magnitude of the reduction varies depending on the species and season of the outage. The seasonal distribution data for entrained larval fish and macroinvertebrates showed that no pronounced seasonal pattern exists for entrained organisms at the Diablo Canyon Power Plant. It was concluded that cooling water volume reductions during fuel-reloading outages will reduce entrainment and impingement whenever they occur during the year. The refueling schedule at the Diablo Canyon Power Plant is such that each unit will be removed from service for refueling and maintenance on a "rolling" schedule (not during a particular calendar month within a given year). It was concluded that scheduling such a large, complex refueling and maintenance outage to coincide with the variable seasonal distribution and abundance of a particular fish or macroinvertebrate species susceptible to entrainment or impingement is not feasible, given engineering constraints, logistic coordination requirements, the reliability and supply of electrical energy to meet system demands, and cost considerations, at the Diablo Canyon Power Plant. The routine practice of reducing cooling water volumes during fuel-reloading outages, whenever they occur during the year, contributes to a reduction in the numbers of fish and macroinvertebrates entrained and impinged at the Diablo Canyon Power Plant, and should be continued.

Modifications of the existing vertical traveling screens at the Units 1 and 2 shoreline intake structure to include fish buckets, a low-pressure spraywash system and gravity screenwash sluiceway, and provisions for continuous rotation have the potential for increasing impingement survival of fish and macroinvertebrates (e.g., surfperch, rockfish, skates and rays, crabs, and sculpins). Modifications to the intake screens will not reduce the entrainment of either larval fish or invertebrates. Incorporation of screen modifications and a fish return system in the intake, however, would reduce impingement mortality by up to 75-85 percent. Additional mortality resulting from passage through the fish return system, including increased susceptibility to disease and predation at the sluiceway discharge, would reduce the expected biological benefits of this alternative. Although the estimated percentage reduction in impingement mortality projected for operation of modified intake screens is relatively high at the Diablo Canyon Power Plant, the absolute reduction in the numbers of organisms lost as a result of impingement is very low. For example, although it was estimated that modified intake screens could contribute to an 80 percent reduction in impingement losses for rockfish this represents an annual reduction in the estimated number of equivalent adult rockfish lost of only 354 fish (442 equivalent adult rockfish lost to impingement on the existing intake screens compared to an estimated loss of 88 rockfish equivalent adults assuming 80 percent survival on modified intake screens). Similarly, the 75 percent reduction in impingement losses of rock crabs represents an absolute annual reduction of approximately 123 equivalent adult rock crab (164 equivalent adults impinged on the existing intake screens compared with 41 equivalent adults lost on modified intake screens assuming 75 percent impingement survival). The estimated cost of modifying the intake screens to include fish-handling facilities would be approximately $8.3 million (1987 dollars). Annual O&M costs were estimated to be approximately $250,000. Additional costs of engineering studies that would be needed to ensure reliable intake screen performance under periodic high detrital loading experienced at the Diablo Canyon Power Plant were not quantified, because of lack of experience industry wide with modified intake screens in a marine environment. Because of the low impact of impingement losses, and the relatively high costs involved, installation of modified intake screens is not recommended.

Expansion of the existing shoreline intake structure at Units 1 and 2 and installations of modified intake screens and a fish return sluiceway, would result in reduced approach velocities and potentially a reduced rate of fish cropping by impingement. Although not quantified, the reduction in impingement is anticipated to be small (approximately the same reductions as discussed above for modified intake screens). The numbers of organisms entrained would not be reduced by an expansion of the shoreline intake structure. Because of the low impact of impingement losses at the Diablo Canyon Power Plant, the total cost of constructing such a shoreline intake, estimated to be approximately $204 million (1987 dollars), is considered to be disproportionate to the benefits resulting from the reduced rate of fish impingement.

Reduction in circulating water pump operation to coincide with periods of reduced electrical generation or when a unit is out of service for extended periods has also been identified as a biologically effective method of reducing the losses of organisms through entrainment and impingement. Reducing cooling water flow during extended unit outages is standard operation at the plant. Removing one of a unit's two circulating water pumps from operation would limit the generation of the unit to 50 percent of capacity, reduce unit reliability, and contribute to operational inefficiency of the unit.

The base-loaded operational regime at power levels exceeding 42 percent capacity significantly restricts the potential biological benefits of single-pump cooling water system operation at the Diablo Canyon Power Plant. An analysis using actual unit operations during 1986 and 1987 indicated that this alternative could potentially reduce cooling water volumes, and hence entrainment, by approximately 3 to 4 percent. The potential biological benefits of reducing cooling water flows is currently being achieved, in large part, by the standard practice of removing one circulating water pump from service on a unit during extended outages. Because of the generating penalty, loss of reliability, and operational inefficiency of generating units that would accompany reduced circulating water pump operation during periods of high load, further investigation of single-pump operation as an approach to reducing biological losses is not warranted.

6.4.2 Conclusions

The judgment of the best technology available for the Diablo Canyon Power Plant is based on a consideration of the undetectable impact of entrainment and impingement on the local aquatic community (Chapter 5), demonstrated operation and reliability of various alternative technologies, and the biological effectiveness of these technologies for further reducing entrainment and impingement cropping, engineering and operational feasibility, and cost-effectiveness of the alternative technologies.

Based on the evaluation of alternative intake technologies for the Diablo Canyon Power Plant, it was concluded that:

- There is no reasonable alternative intake location that would reduce entrainment and impingement losses.
- Behavioral barriers would not reduce the numbers of organisms exposed to either entrainment or impingement.
- Entrainment and impingement losses would not be substantially reduced by use of drum screens, centerflow traveling screens, or a fish pump return system.
- A screen mesh size of 3/8 in. (9.5 mm) is acceptable, because the survival potential of fish eggs and larvae impinged on fine-mesh screens have not been shown to exceed the survival potential of organisms entrained through the Diablo Canyon Power Plant cooling water system.
- Cooling water system structural modifications and discharge temperature regulation would not reduce the mortality of entrained organisms substantially.
- The existing bar rack biofouling control program is effective in reducing intake approach velocities and predation losses for entrained fish and invertebrates.
- Sediment accumulation within the intake structure is presently not contributing to increased water velocities.
- The kelp harvesting and exclusion programs and the removal of accumulated drift kelp and debris from the intake bar racks, are effective in reducing impingement losses.
- The biofouling control program and heat treatment optimization efforts underway at the Diablo Canyon Power Plant are effective in reducing the accumulation of fouling organisms colonizing the intake conduits which prey on entrained organisms while also reducing the frequency and duration of heat treatment at the plant.
- No pronounced seasonal pattern exists for entrained organisms at the Diablo Canyon Power Plant, and therefore routine cooling water volume reductions during extended fuel reloading and maintenance outages will reduce entrainment and impingement whenever they occur during the year. The potential biological benefits of reducing cooling water flows when possible is currently being achieved, in large part, by the standard practice of removing one or both circulating water pumps from service on a unit during extended outages. Scheduling fuel reloading outages to coincide with the seasonal distribution in abundance of a particular organism is not feasible.

- Modifications to the intake screens, including installation of fish buckets, dual spraywash system, a fish return sluiceway, and continuous screen rotation, would reduce the losses of organisms due to impingement but would not reduce entrainment losses. Because of the low numbers of fish and macroinvertebrates impinged on existing intake screens at the Diablo Canyon Power Plant, and the relatively high costs involved, installation of modified intake screens is not warranted.
- Expansion and modification of the intake structure to achieve a 0.5 fps approach velocity would reduce impingement losses but would not reduce entrainment. Because of the low numbers of fish and macroinvertebrates impinged at the existing shoreline intake, the cost of $204 million for modifying the intake structure is disproportionate to the benefits resulting from the reduced rate of impingement.

Based on results of this evaluation of alternative technologies it was concluded that the existing cooling water system, intake location and configuration reflect the best technology available for the Diablo Canyon Power Plant given the cooling water system operational requirements, reliability considerations, current mode of unit operation, the low numbers of organisms impinged, and the costs associated with intake modifications.

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DIABLO CANYON POWER PLANT

REVISED

316(b) STUDY PLAN

Submitted to:

Pacific Gas and Electric Company
77 Beale Street
San Francisco, California 94106

June 13, 1983

B-83-262

TERA CORPORATION

2150 Shattuck Avenue
Berkeley, California 94704
415·845·5200
Telex: 338592

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1.0 INTRODUCTION

This report has been prepared in response to the March 17, 1983 order of the State Water Resources Control Board (Order No. WQ 83-1, NPDES Permit No. CA0003751), which in Section IV.C requested PGandE to submit an updated plan of study to the Regional Board within 90 days of the order or before the start of commercial operation of the Diablo Canyon Power Plant, whichever is earlier. The purpose of this report is to update and revise the previous 316(b) Study Plan for the Diablo Canyon Power Plant (PGandE 1977a) with current information on cooling system modifications, continuing waterbody studies, new assessment techniques, and additional alternative cooling system technologies. As required, this updated plan includes a schedule for the submittal of progress reports to the Regional Board and a plan for an evaluation of alternative technologies available to minimize any adverse impacts identified in the assessment of the existing intake structure.

2.0 DESCRIPTION OF THE DIABLO CANYON POWER PLANT AND ITS COOLING SYSTEM

2.1 SITE DESCRIPTION

The Diablo Canyon Power Plant is located on a 750-acre site on the Pacific Coast of California about halfway between Los Angeles and San Francisco, in an undeveloped section of the coastline remote from any city or small village (Figure 2-1). The site is in a mountainous area with steep, rugged, and rocky slopes at the edge of the ocean. The only major highways near the site are U.S. Highway 101 and California State Highway 1, which run north and south about 9 miles east of the site. County roads run through Clark Valley, 4 miles north and through See Canyon, 5 miles east. The Southern Pacific Railroad runs through San Luis Obispo, about 12 miles ENE, running generally north and south. The Pacific Ocean is the only nearby major body of water. Passing within 2½ miles of the plant, the small Coon Creek flows WNW to the ocean, and Diablo Creek is immediately north of the reactor buildings.

The plant is located on a sloping marine terrace about 1,000 ft wide, with elevations ranging from 50 to 150 ft above MSL. The coast in this area is rugged, with tidal pools and offshore rocks. Cliffs rise steeply from the high water line to the marine terrace. The site area slopes upward to the Irish Hills, which are a part of the San Luis Mountains. Diablo Canyon passes through the site and runs ENE for about 4 miles, cutting into the San Luis Mountain Range.

2.2 PLANT DESCRIPTION

2.2.1 GENERAL

The Diablo Canyon Power Plant is a two-unit nuclear power plant. Units 1 and 2 have a gross rated capacity of 1,133 and 1,165 MWe, respectively. Construction of the plant began in 1968. The plant layout on the site is shown in Figure 2-2. The major facilities at the site are two reactor containment structures, two fuel

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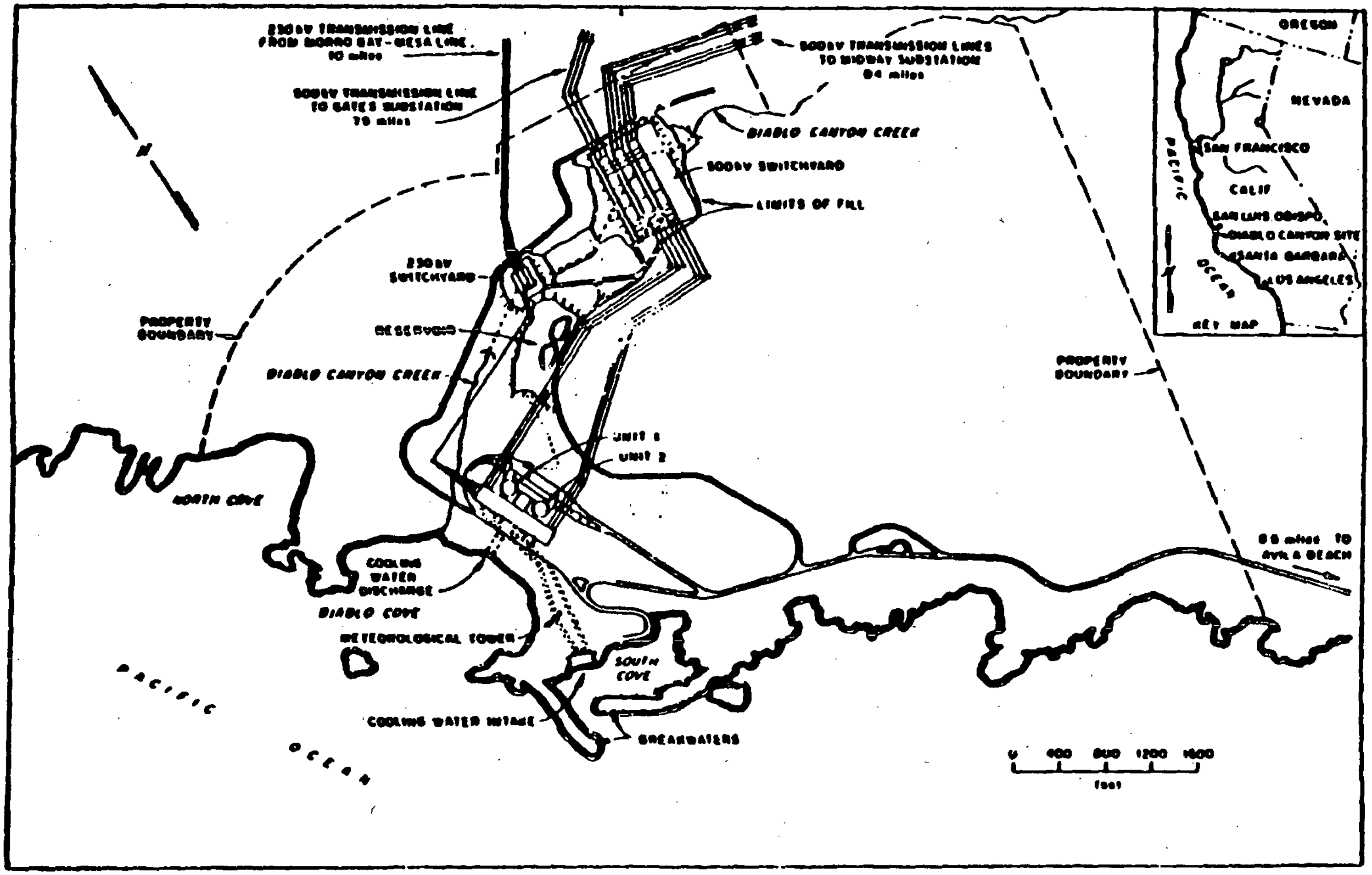


Figure 2-1. Plot plan of the Diablo Canyon Power Plant site. (PGandE 1977a)

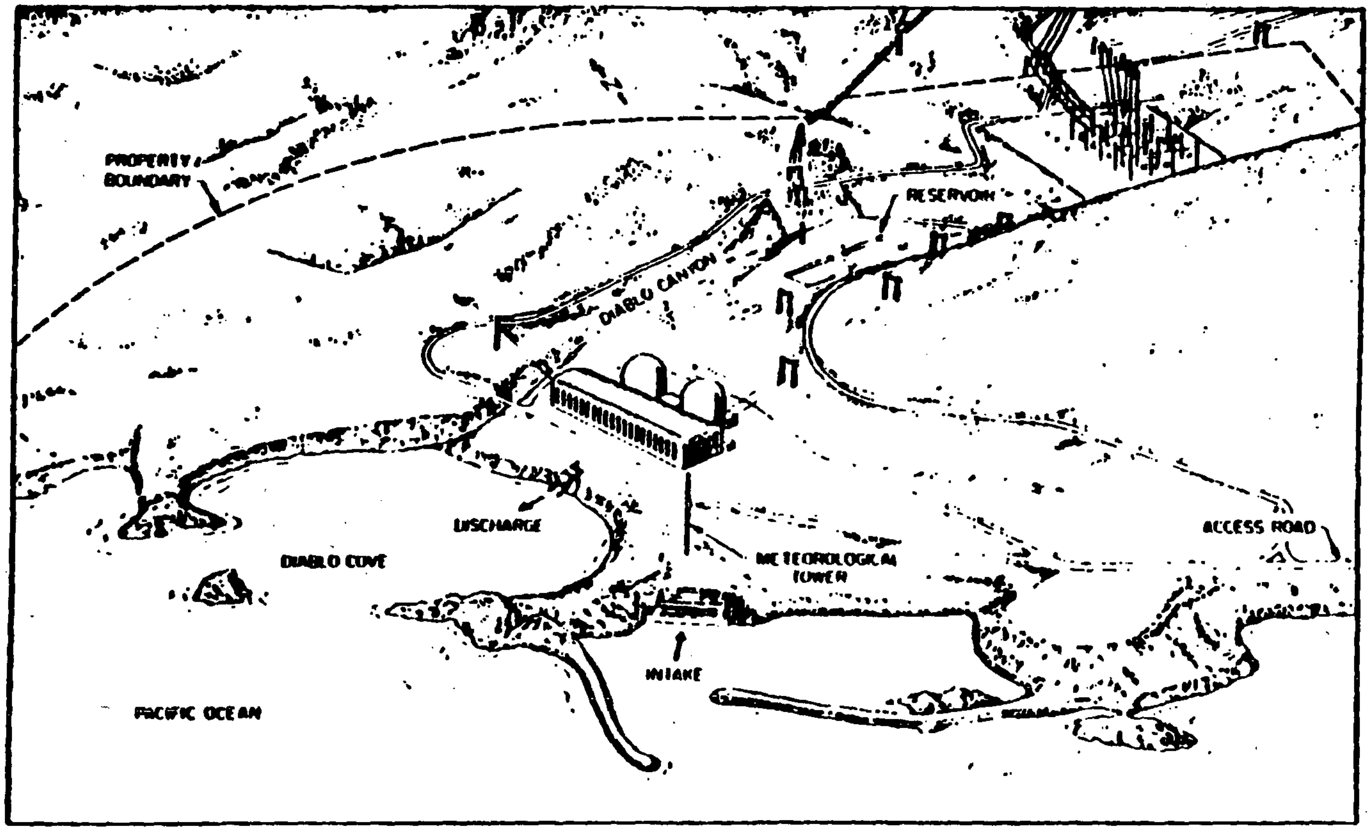


Figure 2-2. Diablo Canyon Power Plant site. (PGandE 1977a)

handling buildings, a common auxiliary building, and a turbine building housing the two turbine generator units. The plant has not commenced operation.

2.2.2 CIRCULATING WATER SYSTEM

2.2.2.1 GENERAL DESCRIPTION

Ocean water for cooling is pumped through the intake structure from the Intake Cove located to the south of Diablo Cove (Figures 2-3 and 2-4). Each of the power plant's two generating units are cooled by two condensers supplied with seawater by two circulating water pumps located in the intake structure. The combined flow rate through the two condensers ranges from 778,000 to 854,000 gpm for Unit 1 and 811,000 to 895,000 gpm for Unit 2. These flow ranges represent calculated flows based on actual field measurements and take into account such operating parameters as tidal influence and pump wear. As the seawater passes through the condensers, its temperature will be raised approximately 11°C (20°F) with the plant operating at full load. The cooling water temperature rise (delta-T) varies slightly between Units 1 and 2 due to differences in cooling water flow rates and power outputs between the two units. It has been calculated that under the lowest flow rate expected and for the maximum power level the temperature rise will be 10.8°C (19.5°F) for Unit 1 and 10.7°C (19.3°F) for Unit 2. The temperature rise values were calculated for conditions of low tide, a condenser tube cleanliness factor of 0.9 and a 5 percent allowance for pump wear. The temperature rise under normal operating conditions is expected to be less.

After leaving the condensers, the cooling water flows by gravity through two discharge conduits to the discharge structure located on the shoreline of Diablo Cove (Figures 2-1 and 2-2).

2.2.2.2 INTAKE DESCRIPTION

Sectional and plan views of the intake structure are shown in Figures 2-3 and 2-4. The major elements of the intake system are considered below.

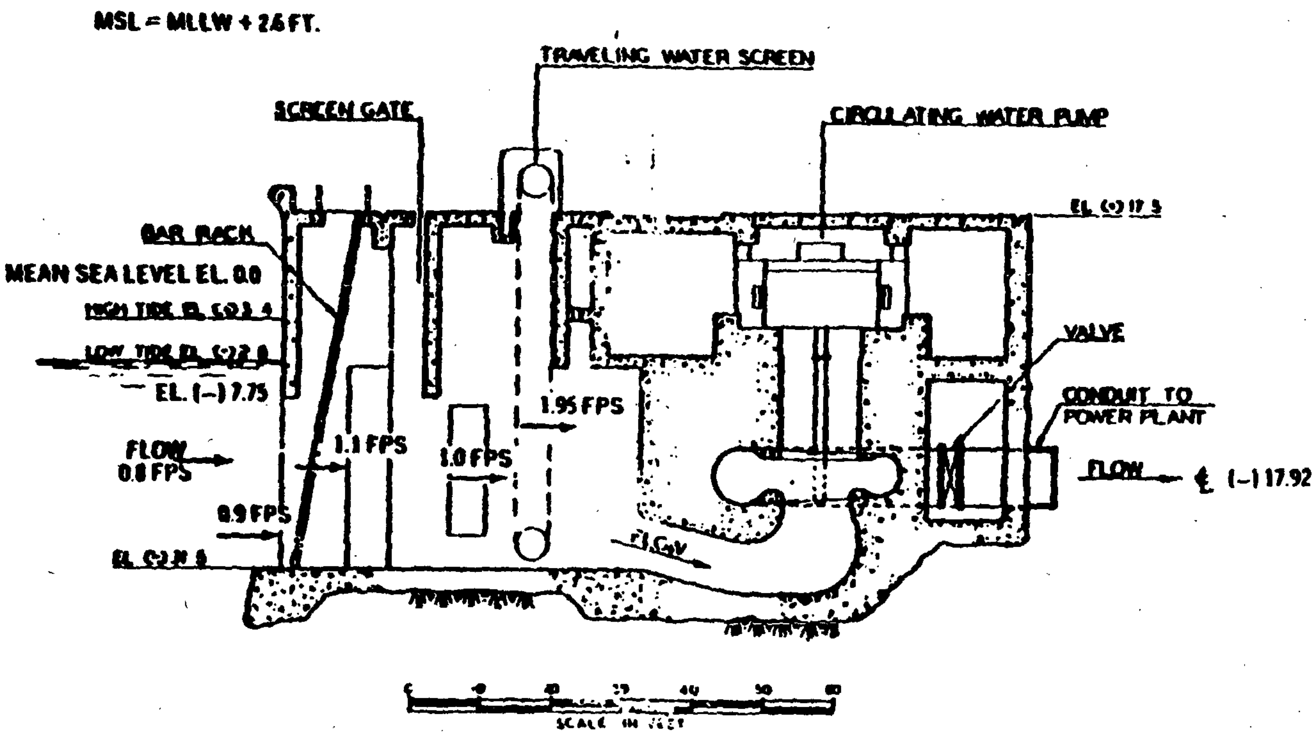


Figure 2-3. Typical section, cooling water intake structure, Diablo Canyon Power Plant. (PGandE 1977a)

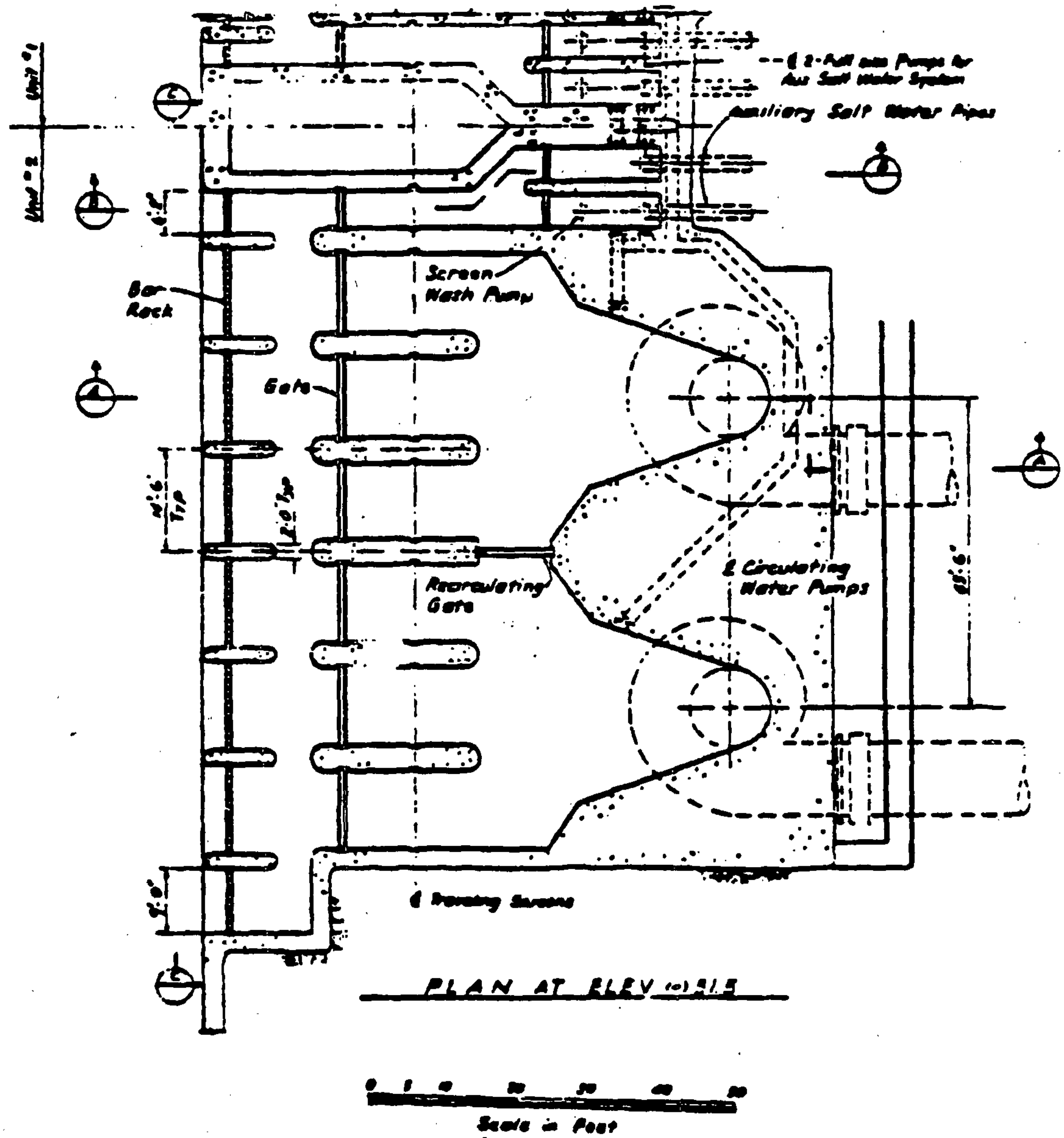


Figure 2-4. Plan view of cooling water intake structure, Diablo Canyon Power Plant.
(PGandE 1977a)

At the front face of the intake structure, a skimmer wall extends down to -7.75 ft (MSL datum) to keep out larger debris such as logs and kelp (Figures 2-3 and 2-4). Water entering the intake structure passes first through bar racks, consisting of 3 x 3/8-inch flat bars at 3 3/8-inch centers. These inclined bars deflect floating debris of moderate size that can be mechanically raked from the bars if necessary. The bar racks help keep debris away from the screens.

Bays or ports, about 20 ft high by 6 ft wide, are provided through the concrete walls supporting the traveling water screens so that fish small enough to pass through the 3-inch wide bar rack openings can move freely from one area to the other (Figures 2-3 and 2-4). Observation of fish small enough to pass through the bar racks at PGandE power plants, both from surface observers and by diving biologists, indicate that these fish can swim back out through the bar racks.

The cooling water is screened before entering the circulating water system to prevent debris lodging in the condenser tubes or water boxes. After passing through the bar racks, water flows through the traveling screens that are arranged in a line across the screen structure perpendicular to the flow and parallel to the shoreline (Figures 2-3 and 2-4). The screens consist of monel wire having 3/8-inch square openings. This intake configuration was designed to maximize fish survival based on studies conducted at PGandE's Contra Costa Power Plant (Kerr 1953) and has been used at PGandE power plants since 1953. Each circulating water pump is serviced by three traveling screens with openings approximately 11 ft in width for each screen (Figures 2-3 and 2-4).

The screen travel is under an automatic control, with activation at a water level differential of (-)0.5 ft (inside level minus outside level). If the differential does not approach 0.5 ft, the screens are washed approximately every 4 hours. The screens travel at a rate of 5 fpm or 10 fpm, depending on the amount of debris.

While in operation, the screens are sprayed with high-pressure seawater directed through nozzles. The screen water is supplied by two screenwash pumps. Each screenwash pump has a capacity of 3,900 gpm at 260 ft head.

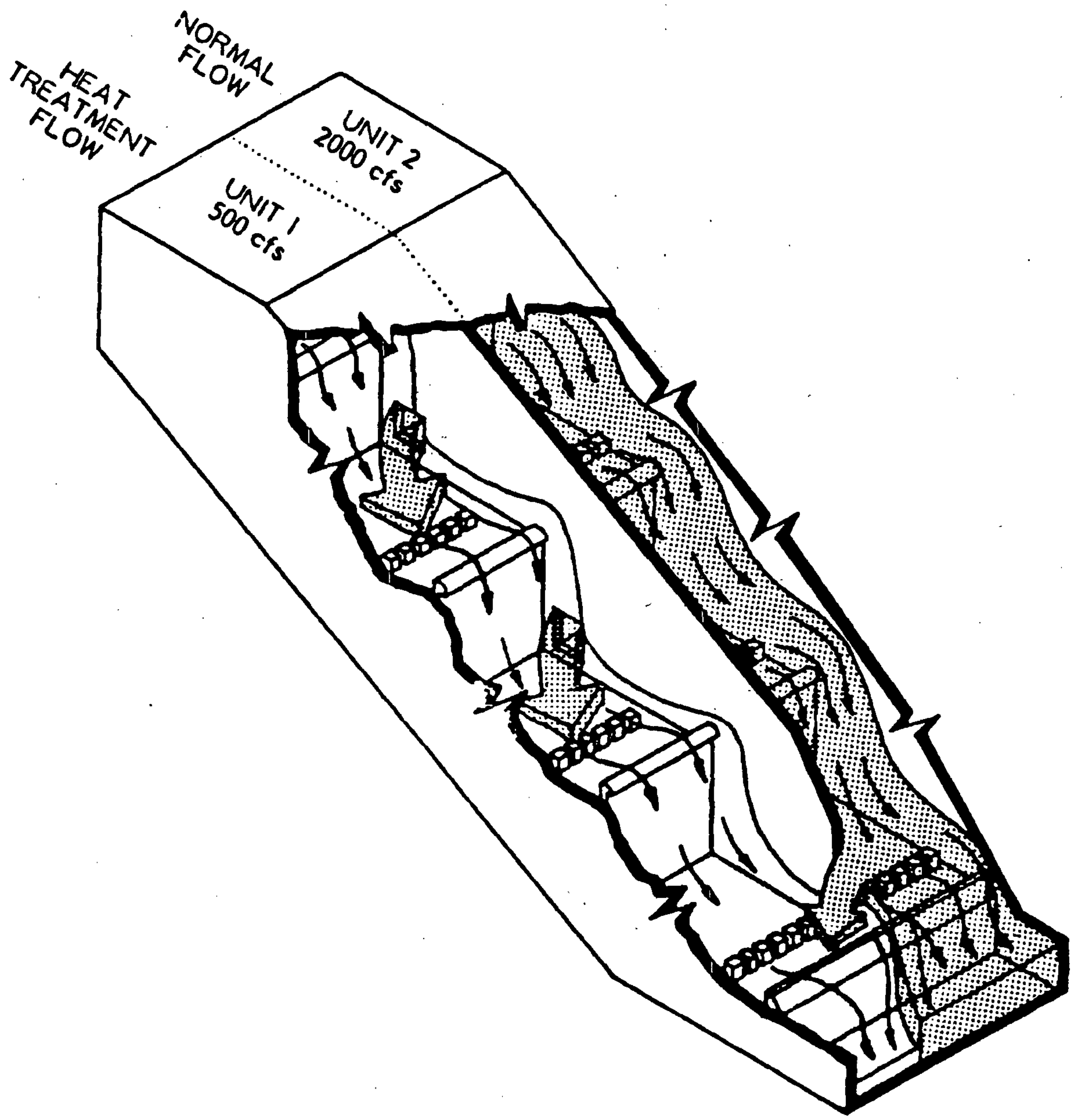
Debris and impinged organisms are washed from the screens into the sloping gutter that runs along the outer side of the screens, and is collected in the refuse sump. From the refuse sump, the material is returned to the cove outside the breakwater through an 18-inch diameter pipe by two open impeller centrifugal pumps. The capacity of each refuse pump is 4,000 gpm and the developed head is 50 ft. The pumps are of the nonclog type and are able to pass a sphere of 4-in diameter through them.

2.2.2.3 DISCHARGE SYSTEM DESCRIPTION

The plant is located on a marine terrace with the bottom of the condenser about 90 ft above MSL; therefore the circulating water pumps must pump against a substantial head to raise water to the condensers. The water pressure passing through the system will vary from about 40 psig at the circulating pump discharge to atmospheric, or slightly less, at the condenser outlet. The outlet conduit is vented to the atmosphere a short distance downstream of the condensers. A simple closed conduit was not used in order to avoid the development of a vacuum in the condenser that could cause a vapor lock and attendant loss of cooling capacity. A cascade-type discharge structure was constructed to return the cooling water to the ocean.

The cascade-type discharge structure, a drop of approximately 77 ft, dissipates the hydraulic energy of the cooling water. The width of the flow as it emerges into Diablo Cove is 27.5 ft for each unit, with the depth depending on the tide stage. The velocity of the flow will be about 7-10 fps, also depending on the tide stage. Thus, the discharge may be defined as a surface jet, promoting the mixing of the thermal effluent with Diablo Cove receiving waters. The discharge structures for Units 1 and 2 are parallel, and are separated only by a wall (Figure 2-5).

To control biological fouling of the intake conduits, the cooling water flow will be reduced and the temperature will be increased in each unit during short-term periodic "heat treatment" operations (see Section 2.3.3).



NOT TO SCALE

June, 1983

FIGURE 2-5

SCHEMATIC DRAWING OF DIABLO CANYON DISCHARGE STRUCTURE FOLLOWING MODIFICATIONS COMPLETED IN NOVEMBER 1982

Recently an extensive series of scale-model hydraulic tests and analyses of the discharge structure were completed indicating that a modification to the discharge structure could be constructed which would significantly reduce the discharge temperatures during heat treatment operations. The modifications, as shown in Figure 2-5, include openings in the wall which divides the separate tunnels of Unit 1 and Unit 2 discharge streams to allow mixing of heat treatment water from one unit with the water from the second unit in the opposite tunnel. In addition, a large weir at the base of the discharge structure was constructed to promote additional mixing of the two cooling streams before they enter the receiving waters. These modifications were made in an effort to achieve compliance with the current NPDES permit, which limits discharge temperatures during heat treatment to 30°C (86°F). The modifications of the discharge structure were completed in November 1982.

2.3 PLANT OPERATION (BASED ON PREDICTIONS)

2.3.1 VELOCITIES THROUGH THE COOLING WATER SYSTEM

The following tabulation gives the calculated water velocities from the bar rack to the discharge structure exit channel.

	Velocity (fps)
Through bar rack	1.1
Approaching traveling screens	1.0
Through 3/8-in mesh traveling screens	1.95
Intake structure to condenser	7.0
Through 11.75-ft square conduits	7.0
Through 11.75-ft diameter circular conduits	8.85
Average through condenser	7.0
Discharge conduits	7.0
Discharge structure exit channel	8.5

The calculated velocities approaching the skimmer wall will be 0.8 fps at MSL, accelerating to 0.9 fps when passing under the skimmer wall and approaching the bar racks (Figure 2-3). The velocity through the bar racks is 1.1 fps, and the velocity at the face of the traveling screen is 1.0 fps.

2.3.2 PLANT TEMPERATURE DATA

The maximum ambient seawater temperature at Diablo Canyon considered to be representative of intake water temperature during 1972-1982 is approximately 18°C (64°F) (Section 3.2). Based on a full-load delta-T of 11°C (20°F) (Section 2.2.2.1), the maximum discharge temperature expected at Diablo Canyon is approximately 29°C (84°F).

Based on the predicted time-temperature profile of water flow through the Diablo Canyon cooling system, the in-plant time of exposure to elevated temperatures (condenser to discharge) is about 45 seconds. Beyond the discharge, temperature decay is expected to be very rapid owing to mixing with Diablo Cove ocean water.

2.3.3 DEFOULING-HEAT TREATMENT

In the marine environment organisms will attach to the interior of the cooling water system surfaces. These organisms must be removed or they will eventually grow until the flow of cooling water is severely reduced.

Approximately every four to six weeks PGandE will perform heat treatment on the two condensers for each unit using thermal shock. This consists of adjusting the gates and valves at the intake structure and at the head of the discharge cascade to recirculate part of the cooling water flow. Only one of the two pumps for this unit will be in operation during defouling, which will supply ½ of the normal flow. In effect, the water flows through one half of the condenser to the discharge structure, where the gates are adjusted so that ¼ of the normal flow passes out to Diablo Cove. The other ¼ of the normal flow for that condenser passes through the other half of the condenser in reverse flow, and back to the intake structure, where it passes, in reverse direction, through the idle pump. A gate is closed between the pump and the bar racks to prevent the return flow from entering Intake Cove, and the gate between paired pumps is open to permit the recirculated flow to enter the suction stream of the active pump. The power of the unit is reduced to 50 percent, and the temperature increases about 28°C (50°F) in the cooling system to 41-43°C (105-110°F). Although the duration of the heat treatment is about 1 hour, approximately 2-3 hours are required to build up the necessary 28°C (50°F) rise in cooling temperature.

Experimental research is currently underway to investigate the minimum temperature dose rates required to achieve defouling of the cooling water system. The monthly defouling temperature dose of 41-43°C (105-110°F) for one hour described above was estimated to conservatively assure system reliability and was based on general operating experience at other marine power plants. The heat treatment research may provide evidence for a reduced heat treatment dose and schedule based on the temperature tolerance, seasonal recruitment patterns, and growth rates of the dominant species of the Diablo Canyon fouling community.

2.3.4 CHLORINAT.ON

Chlorinating procedures to control condenser slime buildup will consist of short-term (10 minutes or less) sequential treatments of each of the four condenser halves. Chlorination of individual condenser halves will be separated by approximately 30 minutes. Chlorine residuals will be minimized by the dilution effects of the other three condenser halves not being chlorinated at a given time. Residuals will be maintained within levels specified in the NPDES permit.

3.0 WATERBODY DESCRIPTION AND EVALUATION OF POTENTIAL IMPACT

3.1 INTRODUCTION

This section presents an inventory of the environmental conditions along the central California coast with emphasis on the vicinity of the Diablo Canyon Power Plant. This presentation provides a basis for the assessment of the potential impact of entrainment and impingement on various aquatic community components at the power plant.

Considered first are the abiotic characteristics of the local aquatic environment. Next the various biological communities are examined, following a habitat approach.

3.2 ABIOTIC CHARACTERISTICS

The shoreline in the plant vicinity is characterized by sheer wave-eroded cliffs, jutting headlands, and massive offshore rocks and reefs. These topographical features form a highly irregular coastline, providing many different exposed and protected habitats that in turn affect the abundance and composition of marine plants and animals. The shoreline in the immediate vicinity of the plant is a series of semiprotected indentations composed of three identifiable coves. These are Field's (North) Cove, Diablo Cove, and South Cove (Figure 2-1). In addition, Intake Cove was formed by adding breakwaters to a natural indentation between Diablo Cove and South Cove.

Strong wave action and persistent longshore currents combine with a varied bottom topography to produce a very dynamic and complex nearshore habitat. Open coast exposure and North Pacific Ocean swells combine with a convoluted shoreline to produce a high energy impacted coastline. Inlets and indentations in the coastline will occasionally have cobble or coarse gravel beaches, and deeper coves generally have a small sandy beach.

Bottom topography in the area in depths less than 60 ft is irregular, with numerous rock outcroppings and pinnacles ranging from 9 to 36 ft in height. Sedimentary deposits are scarce in water less than 45 ft deep.

Water temperatures in the area are strongly influenced by seasonal shifts in major ocean currents. Spring and summer temperatures are lower than expected owing to the presence of normally strong upwelled cold bottom water. Reduction of upwelling by the fall produces maximum water temperatures in mid-October to December. Ninety-five percent of Diablo Cove's monthly average bottom water temperatures measured from March 1972 to December 1974 was between 10°C and 14°C (50 and 57°F). The maximum ambient temperature recorded in the subtidal area adjacent to the plant during the period from 1972 to 1982 was approximately 18°C (64°F). Temperatures have been recorded in the intertidal areas in excess of 19°C (66°F).

3.3 BIOLOGICAL CHARACTERISTICS AND EVALUATION OF POTENTIAL IMPACT

3.3.1 INTRODUCTION

The irregular coastline in the Diablo Canyon vicinity, as described in Section 3.2, provides a variety of intertidal, subtidal, and pelagic habitats for marine plants and animals. These habitats, their resident communities, and the potential impact of the Diablo Canyon Power Plant are described in the following subsections.

Extensive waterbody monitoring studies have been continously conducted since the mid-1960s in the vicinity of Diablo Canyon by PGandE, California Department of Fish and Game, and independent consultants (W.J. North, TERA Corporation, ECOMAR, and LCMR). These research programs continue to document the waterbody's intertidal, subtidal, and pelagic communities and have collectively produced the most comprehensive and long-term data bases on the marine ecology of the central California coast. These data will provide the basis for impact assessments of both the thermal discharge in the receiving waters and the impact of the cooling system on the source waterbody by direct comparison of the preoperational and operational species and community patterns (Section 4.3).

A brief summary of the quantitative monitored waterbody characteristics which will provide the basis of the 316(b) community impact assessments include by habitat:

- Intertidal species composition and abundances of algal populations and biomass, invertebrate populations, fish populations, and black abalone recruitment, growth, mortality, and migration studies.
- Subtidal species composition and abundances of algal populations, invertebrate populations, fish populations, settling plate larval recruitment, rock crab recruitment, migration, growth, and population dynamics, and coastwide aerial photographic kelp bed surveys.
- Midwater and pelagic species composition and abundances of diver-observed fish populations, party boat sportfish landings (including rockfish biology studies), and studies of sea otter population dynamics, migration, and foraging patterns.

The results of these waterbody monitoring studies have been routinely reported to the Regional Board in numerous reports and are well documented (see Chapter 6 in PGandE 1982). It should also be noted that since 1977 a large volume of laboratory thermal tolerance research has been completed on various life stages of a wide variety of the waterbody's indigenous species. The findings have been published as a compendium of results (TERA 1982c) and contain information on the thermal tolerance of larval and juvenile species which will be entrained in the cooling water system.

3.3.2 INTERTIDAL AND SUBTIDAL HABITATS

3.3.2.1 INTRODUCTION

Studies of the intertidal and subtidal communities in the immediate vicinity of the Diablo Canyon Power Plant have been ongoing since 1966. North (1966) found approximately 80 and 150 different taxa of plants and animals, respectively, during his early intertidal and subtidal pilot studies in the area. Subsequent studies by North and Associates have approximately doubled the total species listed (Cayot and North 1968, 1969; North 1972; North and Anderson 1973; North et. al. 1975). In addition, studies by the California Department of Fish and Game (CDF&G) have provided quantitative information on the plants and animals observed at permanent intertidal and subtidal transects in the Diablo Canyon vicinity (Burge and Schultz 1973; Gotshall et al. 1974, 1976, 1977). Recently, from April 1976 to the present, PGandE's 316(a) demonstration field program has quantitatively monitored intertidal and subtidal algae and invertebrate species abundances at regular intervals at selected fixed locations in the Diablo Canyon vicinity (PGandE 1976a, 1977b).

All the above studies have supported the conclusion that the aquatic communities near Diablo Canyon are dynamic, responding to a variety of abiotic and biotic factors. Since 1966 great changes in the biota have occurred. During 1969 and 1970, severe climatic events, record rainfall, and severe storm swells adversely affected certain plant and animal species, resulting in substantial changes in the respective species lists for sites near Diablo Canyon (North 1972). In 1974, sea otters migrated into the Diablo Canyon vicinity from the north (Colson 1975). The otters, foraging on larger invertebrates, particularly sea urchins and abalone, have caused dramatic changes in the aquatic communities (North et al. 1975). As a result of the sea otters' predatory removal of these herbivorous invertebrates which selectively feed upon various algal species, significant changes in the subtidal plant communities have been observed. The bull kelp, Nereocystis lutekeana, reached its peak abundance in Diablo Cove in 1976 and declined dramatically in the following years. These large-surface canopy-forming kelp have been replaced in abundance by several low-growing kelp and algal species, possibly in response to an absence of bottom-dwelling herbivorous invertebrates. These shrub-like algae have effectively occupied the available open space for settlement and growth and appear to be preventing the settlement and growth of extensive stands of the bull kelp.

The severe 1982-1983 winter storms dislodged a number of the shrub-like algae and created open space in the subtidal habitat which may allow the bull kelp to recolonize Diablo Cove in large numbers. The absence of large stands of the bull kelp has eliminated a surface canopy habitat for the Cove's midwater fish species. These changes have resulted in observed shifts in the relative abundances of several of the Cove's fish species towards a greater proportion of demersal (bottom-dwelling) species.

A small stand of the giant kelp, Macrocystis pyrifera, appeared inside the intake cove in the mid-1970s and has continued to expand since that time. The giant kelp, which is generally considered a warm-water species, is not commonly found in the study area. Its presence in the intake cove has created a surface canopy and kelp bed habitat which had not existed previously in the vicinity of the intake area.

The aquatic habitat descriptions provided in the following subsections reflect conditions as they have existed in recent years since the sea otter invasion. Some of the early biological investigations serve as background information only. The information presented below was derived mainly from reports issued since 1974.

3.3.2.2 INTERTIDAL HABITAT

The intertidal habitats of the Diablo Canyon vicinity are generally characterized by cobble beaches and irregular rock surfaces. Although some areas are somewhat sheltered, almost all the resident organisms are typical of exposed rocky coasts (North 1966).

The dominant algal species of the rocky intertidal zone are the foliose and fleshy red algae (Iridaea flaccida, Gigartina papillata, G. canaliculata, G. agardhii, Gelidium coulteri, Endocladia muricata, and Gastroclonium coulteri), coralline red algae (Corallina spp.), encrusting red algae (Lithothamnium sp. and Petrocelis franciscana), sea lettuce (Ulva lobata), and the flowering surf grass Phyllospadix scouleri (PGandE 1976a). Also in the higher intertidal zone the brown alga Pelvetia fastigiata and the red alga Endocladia muricata are abundant. Most of the invertebrate species in these habitats are motile herbivores that graze on the abundant intertidal vegetation. The black abalone (Haliotis cracherodii) and the black turban snail (Tegula funebralis), often found wedged in crevices and beneath rocky overhangs, are two of the most conspicuous herbivores. Juvenile kelp crabs (Pugettia spp.) are frequently encountered in close association with mats of surf grass and algae. Also common are limpets (several species, including Collisella scabra, C. limatula, Notoacmaea scutum, and Fissurella volcano), chitons (Mopalia spp. and Nuttallina californica), sea anemones (Anthopleura elegantissima and A. xanthogrammica), several species of snails (such as Tegula brunnea and Mitrella aurantiaca), and barnacles (Balanus sp. and Tetraclita squamosa) (PGandE 1976a, North 1966; Gotshall et al. 1976).

Other invertebrates in these areas include the sea stars Pisaster ochraceus and Henricia leviuscula, several gastropod species (Nucella sp. and Ocenebra sp.), and the small anemone Epiactis prolifera (PGandE 1976a; Gotshall et al. 1976).

Exposed points and outcroppings are entirely unprotected and subject to surf-pounding on all sides; thus, the animals that inhabit these areas are adapted to tolerate such high-energy conditions. This is the only habitat in the Diablo Canyon area where sessile filter-feeding invertebrates are found in considerable concentrations. California mussels (Mytilus californianus) and gooseneck barnacles (Pollicipes polymerus) flourish at the upper intertidal levels (PGandE 1976a). Limpets (Acmaeidae) and barnacles (Balanus spp. and Tetraclita squamosa) range from the upper zones down to the subtidal (Gotshall et al. 1976). Other species common to this habitat are the sea stars Pisaster ochraceus and Leptasterias hexactis and purple urchin Strongylocentrotus purpuratus.

The 1982-1983 winter storms severely disrupted the interidal habitat, particularly in south Diablo Cove. Large amounts of cliff and pinnacle material were dislodged by high wave and tide conditions, and the resulting rock rubble was deposited on the intertidal area, burying intertidal organisms under rock up to 3 ft deep. Substantial algal recolonization of the bare rock has been documented which offers evidence of the high resiliency and capacity to withstand environmental disturbance of the intertidal communities and of the enormous supply and transport processes of spore and larval forms for recruitment.

3.3.2.3 SUBTIDAL HABITATS

The subtidal zone in the Diablo Canyon area supports rich and diverse plant and animal communities. The substrate is irregular, ranging from shifting cobble in the deeper cove areas to boulders and rocky pinnacles further inshore to one sandy region in the southeastern part of Diablo Cove.

The most abundant and ubiquitous algal assemblages (excluding the large brown kelps) in the shallow subtidal zone are erect corallines (chiefly Calliarthron spp.) and the fleshy red alga Botryoglossum farlowianum. Forests of the canopy-forming bull kelp (Nereocystis leutkeana) with understories of Pterygophora californica, Laminaria dentigera, and Dictyoneurum californicum are scattered throughout the deeper subtidal zone. Further inshore in the southeast section of Diablo Cove, the brown algal species Cystoseira osmundacea and Egregia menziesii are common. Many species found in the shallow subtidal zone were also encountered intertidally; these include iridaea spp., Laurencia spectabilis, Gigartina spp., Gastroclonium coulteri, Ulva lobata, and others (PGandE 1976a). A dense stand of Macrocystis pyrifera is found in the intake cove.

Many animal phyla are represented in the subtidal habitat. Numerically dominant macroinvertebrates include the ubiquitous bat star (Patiria miniata) and several gastropod species (such as Astraea gibberosa and Mitra idae) (PGandE 1976a; Gotshall et al. 1976). Other frequently occuring species are the bright orange sponge Tethya aurantia, sea stars (Henricia leviuscula, Orthasterias koehleri, Leptasterias spp., Pycnopodia helianthoides, and Pisaster giganteus), anemones (mostly Anthopleura xanthogrammica), nudibranchs (Doriopsilla albopunctata), chitons (Tonicella lineata), and the solitary stalked tunicate Styela montereyensis (Gotshall et al. 1976, 1977). The giant red urchin Strongylocentrotus franciscanus populations are not as extensive as they were in past years (North et al. 1975) and are no longer common in the area. The continued sea otter predation has reduced the size composition of the urchin population to only those individuals which are small enough to obtain refuge from predation in rock crevices and under cobble and boulders. Similar predation pressures have held the historically abundant adult red abalone populations (Haliotis rufescens) to depauperate levels, though new recruitment of the species has recently occurred as evidenced by the presence of juvenile red abalone small enough to find predatory refuge in subtidal crevices and beneath large boulders. As the sea otters' preferred prey items (urchins and abalone) have become scarce, their foraging has included other prey items such as rock and kelp crabs, limpets and snails. Long-term subtidal community changes in response to sea otter predation are still occurring and may require several years to achieve ecological equilibrium.

Rock crabs (Cancer spp.) are abundant throughout the subtidal zone, often found inhabiting crevices and holes, and hiding among kelp fronds. The kelp crab (Pugettia producta) is abundant in association with brown algae.

3.3.2.4 POTENTIAL IMPACT ON INTERTIDAL AND SUBTIDAL ORGANISMS

The potential impact of entrainment and impingement on intertidal and subtidal organisms is limited by the bottom-dwelling habits of those organisms. Meroplanktonic larval stages of invertebrates may be entrained, as may be those benthic or epibenthic forms that enter the water column on a daily basis for feeding or other purposes. Larger meroplanktonic forms or otherwise mobile macroinvertebrtates may be impinged on the intake screens. The impact of entrainment and impingement depends mainly on the effect of organism losses on the existing populations in the local marine environment.

The effect of entrainment on local populations is largely a function of the probability of surviving entrainment. As will be shown in Subsection 3.3.3.2, the survival of those meroplanktonic larval molluscs, crustaceans, and polychaetes entrained at the nearby Morro Bay Power Plant is high (generally 95 percent or greater). In addition, meroplankton other than barnacle nauplii constitute only a small fraction of the total zooplankton entrained at Morro Bay and Diablo

Canyon (less than 5 percent) (see Subsection 3.3.3.2). As a result, the potential impact of entrainment on meroplankton is minimal. The recently completed thermal effects laboratory tests which included the entrainable life stages of selected species (TERA 1982c) generally confirm the conclusion that the probability of surviving entrainment thermal effects is high. However, an assessment of the combined thermal and mechanical entrainment effects will require information which can only be collected in the waterbody monitoring studies following thermal operation of the cooling water system. Any losses of these early life stages would be expected to have little effect on adult populations because of the natural mortality rates occurring between those life stages.

The impingement of macroinvertebrates at Diablo Canyon has been investigated during periods of cooling system testing. Data for the period January 1977-June 1977 are presented in Table 3-1 (Behrens and Larson 1978). The most frequently impinged organisms are those that inhabit the immediate intake structure or intake area. These include tunicates, bryozoans, and gastropods (Tegula brunnea being the most abundant). In general, the impact of impingement is expected to be highly localized and is not expected to extend beyond the immediate intake area.

The impact of entrainment and impingement on commercially or recreationally important intertidal or subtidal species is expected to be negligible. During the January-June 1977 impingement study, only three red abalone (Haliotis rufescens) and four giant red sea urchins (Strongylocentratus franciscanus) were collected (sampling occured for a total of 140 days during the study period). No black abalone (Haliotis cracherodii) were collected. Crabs (mainly Cancer antennarius) were impinged in somewhat larger numbers.

However, when compared with the numbers of crabs inhabiting the Diablo Canyon area, the impinged numbers are negligible. The entrainment of meroplanktonic larval stages of economically important invertebrate species is not expected to adversely impact the local populations since, based on data for the nearby Morro Bay Power Plant, the probability of those forms surviving

TABLE 3-1 INVERTEBRATE IMPINGEMENT SUMMARY FOR DIABLO CANYON POWER PLANT UNITS 1 AND 2, JANUARY 1977 - JUNE 1977

Taxon	JAN Unit 1 (11)	JAN Unit 2 (0)	FEB Unit 1 (20)	FEB Unit 2 (14)	MAR Unit 1 (23)	MAR Unit 2 (23)	APR Unit 1 (21)	APR Unit 2 (4)	MAY Unit 1 (13)	MAY Unit 2 (6)	JUN Unit 1 (0)	JUN Unit 2 (3)
Phylum Porifera (sponges)	•		•	•	•	•	•		•	•		•
Phylum Coelenterata												
Hydrozoa	•		•	•	•	•	•		•	•		
Anthozoa (sea anemones)			2						2			
Scyphozoa (jellyfish)	1		2	1	3		2	4	3	1		2
Phylum Annelida												
Polychaeta	1		6				1		13			2
Phylum Arthropoda (class Crustacea)												
Isopoda (mainly _Idotea_ sp.)			1						2			
Cirripedia (barnacles)	•		•				•		•			
Decapoda												
Betaeus (shrimp)	1						1					
Pugettia producta (kelp crab)	41		25	5	48		29		26	3		4
P. richii	2		3	1	3		8		7	10		1
Loxorhynchus crispatus (masking crab)	2		[illegible]				2	1	7	4		2
Cancer antennarius (rock crab)	5		7	5	5		6		15	4		
C. gracilis (crab)			1									
C. jordani (crab)												8
Cancer sp. (juveniles)	1		3	2			1		6	15		
Pagurus sp. (hermit crab)					1							
Pachycheles sp. (porcelain crab)			2									
Scyra acutifrons (crab)	3		4	3								
Mimulus foliatus (crab)				1					1			
Pachygrapsus crassipes (lined shore crab)					1				1			
Phylum Mollusca												
Cephalopoda (octopus and squid)	•		•	•	•				•	•		
Gastropoda												
Prosobranchia (snails) (especially _Tegula brunnea_ and _Collisella_ spp.	32		48	15	16	17	40		14	2		
Opisthobranchia	5		7	5	1		4		1	2		
Bivalvia	8		17	15	4		8		29	1		
Phylum Echinodermata												
Echinoidea (sea urchins) (mainly _Strongylocentrotus purpuratus_)	8		13	5	4		8		20	2		
Asteroidea (sea stars) (mainly _Pisaster ochraceus_)	5		7	4	7	2	8	1	4	2		2
Ophiothrix spiculata (brittle star)							1		1			
Parastichopus californicus (sea cucumber)	6		5	2			2		1			
Phylum Ectoprocta (bryozoans)	•		•	•	•	•	•	•	•	•		•
Phylum Chordata (tunicates)	•		•	•	•	•	•	•	•	•		•

Note: Numbers in parentheses indicate number of days sampled.
• = present.

entrainment is very high. Thus, impingment and entrainment at Diablo Canyon should have little impact on local populations of economically important invertebrate species.

In conclusion, although a great variety of intertidal and subtidal invertebrates is found in the vicinity of the Diablo Canyon Power Plant, the impact of entrainment and impingement at the plant is expected to be low. Therefore, the plant should be considered low potential impact to intertidal and subtidal invertebrates.

3.3.3 PELAGIC HABITATS

3.3.3.1 PHYTOPLANKTON

THE PHYTOPLANKTON COMMUNITY OF NEARSHORE WATERS IN THE VICINITY OF DIABLO CANYON

The phytoplankton community of the Diablo Canyon vicinity is dominated by diatoms and dinoflagellates, their respective periods of dominance being dependent on trends in ocean currents. During the Oceanic and Davidson Current periods, typically late summer to early spring, dinoflagellates reach their greatest densities, often resulting in bloom conditions or "red tides." During periods of upwelling, spring and summer months, diatoms become the dominant phytoplankton. However, phytoplankton densities during diatom dominance never reach the peak levels noted during dinoflagellate blooms.

PGandE (1977c) examined the seasonal distribution of phytoplankton in the nearshore marine environment off Diablo Canyon. Biweekly samples were collected from April 1974 to May 1975. From October 1974 to February 1975, dinoflagellates dominated the phytoplankton, resulting in peak overall densities greater than 100,000 cells/liter. Gonyaulax was by far the dominant dinoflagellate genus, comprising over 60 percent of the total phytoplankton counted during the entire study period. Dinoflagellate dominance occurred, as mentioned above, during the Oceanic and Davidson Current periods. During the spring, diatom densities rose from winter lows to peak levels of over 200,000 cells/liter. Dominant genera were Chaetoceros, Nitzschia, Navicula, Rhizosolenia, and Thalassiosira. By midsummer diatom densities began to decline. As fall approached, both densities and numbers of species continued to decline. By late fall only a few species of diatoms remained in relatively low numbers, and dinoflagellates began to become dominant.

POTENTIAL IMPACT ON THE PHYTOPLANKTON COMMUNITY

Phytoplankton studies at other estuarine and marine power plant sites have led to the following generalizations regarding potential plant impact:

1. During cooler months, the photosynthetic rates of entrained phytoplankton may increase, but no changes in the species composition or overall abundance of algal populations so affected would be expected (Brooks et al. 1974; Jensen and Martin 1974; Smith et al. 1974; Hamilton et al. 1970; Heffner et al. 1971);

2. During the warmer months, the photosynthetic rates of entrained phytoplankton may decrease temporarily without altering the photosynthetic capacity of the receiving waterbody phytoplankton populations (Brooks et al. 1974; Jensen and Martin 1974; Smith et al. 1974; Hamilton et al. 1970; Heffner et al. 1971);

3. Discharge temperatures in excess of 32°C (90°F) are generally required before reductions in the photosynthetic capacity of entrained phytoplankton populations occur (Hamilton et al. 1970; Brooks et al. 1974). Some studies indicate that the critical discharge temperature may be closer to 38°C (100°F) (Heffner et al. 1971, New York University 1975). Patrick (1969) reported lethal temperatures for most algal species studied ranging from 33.1° to 45°C (91.5° to 113°F), with the majority near 43.9°C (111°F).

Based on these generalizations, it is unlikely that the entrainment of phytoplankton at the Diablo Canyon Power Plant, where maximum discharge temperatures are not expected to exceed approximately 29°C (84°F) (Subsection 2.3.2), will result in any adverse impact on the phytoplankton community in the plant vicinity. The rapid dilution of discharge waters offshore of the discharge structure will prevent entrained organisms from being exposed to elevated temperatures for extended periods. Any localized changes in the phytoplankton community would be diminished by the rapid movement of water through the discharge area. The short generation times of many algal species (Fogg 1965) would rapidly compensate for any localized changes.

The local phytoplankton community appears to be an extension of the offshore ocean community and is therefore not unique. In such a context, the potential for plant impact is minimal. Therefore, since it is unlikely that the Diablo Canyon Power Plant will have any adverse impact on the local phytoplankton community, the plant should be considered to have low potential impact on phytoplankton.

3.3.3.2 ZOOPLANKTON

THE ZOOPLANKTON COMMUNITY OF NEARSHORE WATERS IN THE VICINITY OF DIABLO CANYON

The zooplankton community potentially entrained at the Diablo Canyon Power Plant is representative of the nearshore ocean zooplankton community. That community has been examined at Diablo Canyon, in conjunction with the phytoplankton study described above (PGandE 1976b).

The major zooplankton taxa encountered by PGandE (1977c) are shown in Table 3-2. Calanoid copepods were the dominant zooplankton, although other abundant forms included cyclopoid and harpacticoid copepods, barnacle nauplii, cladocerans, larvaceans (Urochordates), polychaete larvae, and euphausids.

The seasonal abundance of the major zooplankton taxa were related to the periods of occurrence of major ocean current patterns. Calanoid copepod nauplii and copepodites were not abundant in early summer during the upwelling season. Then they declined and maintained variable populations throughout the Oceanic and Davidson Current seasons. Cyclopoid and harpacticoid copepodites followed a similar trend. Oikopleura spp. densities peaked during June (upwelling season)

TABLE 3-2 PERCENT COMPOSITION AND PERCENT OCCURRENCE OF MAJOR ZOOPLANKTON TAXA FROM HAULS CONDUCTED 18 MARCH 1974 TO 28 MAY 1975, AT DIABLO CANYON

Taxon	Percent Composition	Percent Occurrence
Calanoida nauplii	35.4	94.6
Calanoida copepodites	22.3	97.6
Cirripedia nauplii	6.9	92.9
Oikopleura spp.	5.9	70.8
Cyclopoida and Harpacticoida copepodites	4.5	95.2
Unknown cyclopoid copepods	2.8	47.6
Euphausia spp. calyptopis stage	2.6	51.2
Acartia tonsa	2.4	54.2
Oithona similis	1.8	64.9
Evadne spp.	1.7	53.0
Acartia longiremis	1.6	44.6
Corycaeus spp.	1.6	76.8
Euterpina spp.	1.5	57.1
Polychaete larvae	1.2	82.1
Fritillaria spp.	1.1	48.8
Acartia clausi	1.0	25.0

Source: PGandE 1977c

and September (Oceanic season). Peak zooplankton biomass occurred during May-June 1974 and February 1975, correlating with two periods of upwelling. This may have been in response to the increased phytoplankton abundance occurring during those periods.

During 1971 and 1972, PGandE (1973) collected zooplankton in the cooling system of the Morro Bay Power Plant, located less than 15 miles north of Diablo Canyon. The major taxa collected are listed in Table 3-3 along with their percent composition. As in the Diablo Canyon study discussed above, calanoid copepods dominated the zooplankton community. Barnacle nauplii were more abundant in the Morro Bay samples, as were harpacticoid copepods and several other copepod taxa. This may have been due to the fact that the Morro Bay samples represented the nearshore or embayment community, and the Diablo Canyon samples represented a more offshore community. Whatever the cause, the differences in the two species lists and relative compositions are not great, indicating a basic similarity of the zooplankton communities at the two sites.

Meroplanktonic forms other than barnacle nauplii and polychaete larvae numerically constituted a minor component of the entrained zooplankton community at Morro Bay. Trochophore larvae comprised less than 0.2 percent of the entrained zooplankton. Cancer sp. zoeae comprised 1.3 percent. All other larval stages of benthic or epibenthic invertebrates combined comprised less than 1 percent of the entrained zooplankton.

POTENTIAL IMPACT ON THE ZOOPLANKTON COMMUNITY

The potential impact of the Diablo Canyon Power Plant cooling water system on the local zooplankton community is dependent on (1) the abundance and species composition of entrained zooplankton, and (2) the survival of those zooplankton entrained.

During 1971 and 1972, PGandE (1973) conducted monthly zooplankton studies in the nearby Morro Bay Power Plant cooling system. The species composition of

TABLE 3-3 PERCENT COMPOSITION OF THE MAJOR ZOOPLANKTON COLLECTED FROM THE MORRO BAY POWER PLANT COOLING WATER SYSTEM DURING 1971-1972

Taxon	Percent Composition
Acartia sp. copepodites	15.0
Barnacle nauplii	14.6
Harpacticoida	11.8
Calanus sp. nauplii	9.8
Acartia tonsa	9.5
Acartia sp. nauplii	7.2
Oithona similis	6.3
Acartia clausi	3.8
Polychaete larvae	2.4
Calanus finmarchicus	1.8

Source: PGandE 1973.

the entrained zooplankton community as reported by PGandE (1973) was presented above.

The survival of entrained zooplankton was described by Icanberry and Adams (1974) and PGandE (1973). In general, zooplankton entrainment survival at Morro Bay is high. The average net mortality (discharge percent mortality minus intake percent mortality) was 8 percent. Adult copepods, composing 40 percent of the zooplankton sampled, sustained an average net mortality of 9.7 percent. Immature copepods and barnacle nauplii, composing 49 percent of the zooplankton, sustained an average 7.4 percent net mortality.

The yearly net mortalities for the most abundant zooplankton taxa are shown in Table 3-4. The seven most abundant taxa, representing 74 percent of the entrained zooplankton, sustained 11 percent yearly net entrainment mortality.

Meroplanktonic forms other than barnacle nauplii constituted a minor portion of the entrained zooplankton (less than 5 percent), and their survival was high. Trochophore larvae, Pagurus sp. zoeae, Cancer sp. zoeae, Pinnotheridae zoeae, and Xanthidae zoeae all sustained negligible entrainment mortality.

At Morro Bay there was no consistent relationship of discharge temperature and entrainment mortality over the range of discharge temperatures examined (20.3° -28.3°C, 68.5°-83.0°F). However, at the highest discharge temperature tested (28.3°C), entrainment mortality was also greatest (29.4 percent).

Laboratory studies of zooplankton thermal tolerance suggest that discharge temperatures in the range expected at Diablo Canyon (up to 29°C or 84°F) are tolerable when exposure times are short, as they are at Diablo Canyon. Lauer et al. (1974) reported that Acartia tonsa, a common copepod of California estuarine and to a lesser extent marine waters, can tolerate 15-minute exposures to temperatures as high as 33.5°C (92.3°F). Adams and Price (1974) exposed larval red abalone (Haliotis rufescens) to elevated temperature regimes similar in nature to those expected at Diablo Canyon for abalone veligers acclimated to

TABLE 3-4 AVERAGE NET PERCENT MORTALITY OF ZOOPLANKTON ENTRAINED INTO THE MORRO BAY POWER PLANT COOLING SYSTEM DURING 1971-1972

Taxon	Average Net Percent Mortality
Acartia sp. copepodites	16.8
Barnacle nauplii	4.8
Harpacticoida	2.1
Calanus sp. nauplii	3.8
Acartia tonsa	17.9
Acartia sp. nauplii	2.2
Oithona similis	16.5
Acartia clausi	6.1
Polychaete larvae	0.0
Calanus finmarchicus	0.0

Source: PGandE 1973.

about 17.5°C or 63.5°F (the maximum ambient temperature reported at Diablo Canyon during the period 1972-1974). They found that delta-Ts as high as 13.3°C (24°F) for 10 minutes were required before significant ($p = 0.05$) increases in mortality were observed. Thermal effects experiments on the fertilization, embryonic development, and settlement of red abalone were completed and reported in the recent thermal effects studies (TERA 1982c). The new tests confirmed the early finding that the veliger stages were tolerant of short-term exposures, up to three hours, to temperatures of 8° to 24.8°C (46° to 76.6°F), but found that the early stages were less thermally tolerant. Fertilization success was very low at temperatures above 22°C (72°F), and embryonic development was normal up to temperatures of 22°C (72°F) with no success at 24°C (75°F). Laboratory thermal tolerance tests similar to those performed with red abalone indicated that the early developmental stages of the black abalone are more temperature-tolerant than the red abalone's early life stages. The optimum temperature for early development of black abalone from fertilized egg through mid-cephalic tentacle larvae occurred within the range of 10° to 22°C (50° to 72°F). As was found in the red abalone tests, the later larval stages of the black abalone are more thermally tolerant than the earlier embryonic stages. The laboratory data indicate that larvae exposed to temperatures between 8° to 24°C (46° to 75°F) for periods of less than three hours demonstrated no increased mortality due to temperature differences.

Though the new thermal effects research indicates a lower temperature tolerance among the earlier life stages of the red and black abalone, the no-effect threshold temperatures of these life stages are still above the expected power plant's normal cooling system temperatures. Based on these and other zooplankton thermal tolerance studies reported in the literature, it is unlikely that thermal entrainment exposures will cause any measurable impact on the zooplankton community.

The mechanical effects of entrainment on zooplankton have been examined by PGandE biologists at Diablo Canyon during periods when circulation pumps were in operation but no heat was being added at the condensers (Wilson 1977). Percent mortality of all zooplankton grouped together in discharge samples was less than 4 percent. This mortality level was not significantly ($p = 0.05$) less than that observed in intake (control) samples. This suggests that mechanical effects of entrainment are minimal. Since it is likely that thermal mortality will be similarly negligible, the probability of zooplankton surviving entrainment should be very high.

It is therefore unlikely that entrainment will cause any adverse impact on zooplankton populations. Currents in the plant vicinity as well as high reproductive turnover continually replenish the local zooplankton community. In such a context, it is unlikely that any localized reductions would occur, even if entrainment survival was low. Since evidence points to the opposite, that is, to high entrainment survival, the probability of localized reductions is even lower. As in the case of phytoplankton, since the zooplankton community is widely distributed and not unique to the Diablo Canyon vicinity, the potential for impact is minimal. Therefore, the Diablo Canyon Power Plant should be considered to have low potential impact on zooplankton.

3.3.3.3 FISH

FISH OF CENTRAL CALIFORNIA COASTAL WATERS

The fish of central California coastal waters are characteristic of the general fish fauna found along the Pacific Coast from Baja California to Alaska. The major groups of fish present in coastal waters are the flatfish, rockfish, anchovies, silversides, smelt, herring, salmon, seabass, gobies, surfperch, sculpin, lingcod, sharks, and rays (Hart 1973). The Pacific herring and northern anchovy are the most abundant in California waters (Skinner 1962). Pacific herring are concentrated to the north, particularly in Tomales Bay and San Francisco Bay to Alaska (Miller and Schmidtke 1956). Northern anchovy are most concentrated between Point Reyes and Monterey Bay. The flatfishes, lingcod, staghorn sculpin, white croaker, and night smelt are generally distributed from southern California to Alaska (Hart 1973). The surfperches and California halibut are

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Note: Common names of fish follow Miller and Lea 1972; Hart 1973; and Robins et al. 1980.

generally distributed from California to British Columbia (Hart 1973). The rockfish have a considerably variable distribution (depending on the species) between Baja California and Alaska (Miller and Lea 1972).

Surveys of larval fish by Ahlstrom (1965) in coastal waters off Point Arguello indicate northern anchovy, rockfish, hake, lanternfish, Pacific sardine, and deep-sea smelt to be the most abundant species present. The majority of larvae are in the upper mixed layer of water and are seldom found below the thermocline. Most of the species are distributed from the coast to between 50 and 100 miles or more offshore. Lanternfish were more abundant offshore. Anchovies were highest in abundance from Point Buchon south to at least 100 miles offshore. Rockfish were generally distributed to about 50 miles offshore. Hake and deep-sea smelt were most abundant offshore and to the south of Point Buchon. Pacific sardine, although far reduced from their former abundance, are common south of Point Buchon.

The most important commercial fish in this area of the central coast are the flatfish (including English sole, rex sole, and petrale sole), lingcod, and rockfish (McAllister 1975, 1976). The most important rockfish species of commercial importance are the bocaccio, canary, and chillipepper rockfish (Kramer and Smith 1971).

The most important sportfish are the rockfish. Blue rockfish and olive rockfish are the primary species sought (Kramer and Smith 1971). The average annual catch of blue rockfish in California waters is about 300,000 fish (Gotshall 1969). The primary large sportfish of California inshore waters, including the white seabass, corbina, sea bass, groupers, sheephead, California halibut, halfmoon, California yellowtail, barracuda, and California bonito, have small dispersed populations primarily to the south of Point Conception (Kramer and Smith 1973).

FISH IN THE DIABLO CANYON AREA

The most extensive fish survey in the Diablo Canyon area was reported by Burge and Schultz (1973). The survey methods included diver transect counts and

TABLE 3-5 THE 40 MOST ABUNDANT FISH COLLECTED DURING FISH SAMPLING IN THE DIABLO CANYON AREA, 1970-1971

Rank	Common Name	Scientific Name	Number	Percent Frequency
1	Blue rockfish	Sebastes mystinus	1,421	13.6
2	Speckled sanddab	Citharichthys stigmaeus	1,047	10.0
3	Rockweed gunnel	Xererpes fucorum	939	9.0
4	Tube snout	Aulorhynchus flavidus	728	7.0
5	Black prickleback	Xiphister atropurpureus	558	5.3
6	Rock prickleback	Xiphister mucosus	541	5.2
7	Painted greenling	Oxylebius pictus	524	5.0
8	Canary rockfish	Sebastes pinniger	393	3.7
9	Coralline sculpin	Artedius corallinus	326	3.1
10	Crevice kelpfish	Gibbonsia metzi	274	2.6
11	Snubnose sculpin	Orthonopias triacis	273	2.6
12	Cabezon	Scorpaenichthys marmoratus	230	2.2
13	Blackeye goby	Coryphopterus nicholsii	201	1.9
14	Spotted cusk-eel	Chilara taylori	185	1.8
15	Black rockfish	Sebastes melanops	150	1.4
16	Olive rockfish	Sebastes serranoides	148	1.4
17	Black and yellow rockfish	Sebastes chrysomelas	141	1.4
18	Bocaccio	Sebastes paucispinis	137	1.3
19	Red brotula	Brosmophycis marginata	137	1.3
20	Mosshead warbonnet	Chirolophis nugator	135	1.3
21	Gopher rockfish	Sebastes carnatus	133	1.3
22	Ronquil	Rathbunella alleni	130	1.2
23	Smoothead sculpin	Artedius lateralis	124	1.2
24	Northern anchovy	Engraulis mordax	115	1.1
25	Scaly head sculpin	Artedius harringtoni	88	0.8
26	Northern clingfish	Gobiesox maeandricus	88	0.8
27	Striped kelpfish	Gibbonsia metzi	79	0.8
28	Longfin sculpin	Jordania zonope	77	0.8
29	High cockscomb	Anoplarchus purpurescens	71	0.7
30	Brown Irish lord	Hemilepidotus spinosus	69	0.7
31	Copper rockfish	Sebastes caurinus	60	0.6
32	White-belly rockfish	Sebastes vexillaris		
33	Penpoint gunnel	Apodichthys flavidus	56	0.5
34	Kelp greenling	Hexagrammos decagrammus	55	0.5
35	Senorita	Oxyjulis californica	51	0.5
36	Spotted kelpfish	Gibbonsia elegans	47	0.5
37	Wooly sculpin	Clinocottus analis	44	0.4
38	Fluffy sculpin	Oligocottus snyderi	40	0.4
39	Crisscross prickleback	Plagiogrammus hopkinsi	40	0.4
40	Striped perch	Embiotoca lateralis	39	0.4
Total				94.6

Source: Adapted from Burge and Schultz 1973.

chemical (rotenone) sampling. The numbers and percent frequency by species of the 40 most abundant fish are presented in Table 3-5. The most abundant groups collected were the rockfish, pricklebacks, sculpins, flatfish, gunnels, tube snouts, greenlings, kelpfish, cabezon, and gobies. No definitive seasonal patterns were apparent except that juvenile Sebastes spp. were most abundant in summer and fall.

Several distributional trends were apparent from the study. Most surfperches, clingfish, rock greenling, senorita, black and yellow rockfish, and kelpfish were generally limited to shallow water stations. Pile surfperch, painted greenling, gopher rockfish, black, olive, vermilion, and canary rockfish were more frequently observed at deeper stations. Certain fish were found to be associated with kelp, including the clingfish, kelp greenling, and blue and olive rockfish.

Seasonal and annual changes in the species composition and distribution of the fish communities in the vicinity of Diablo Canyon are continuing to be documented. These patterns and trends have been routinely reported to the Regional Board and other concerned agencies. An expanded study of the intertidal fish community was initiated in 1978 and is continuing to document the species composition and habitat preference of Diablo Cove intertidal fish species. The study's findings have greatly expanded our understanding of intertidal fish habitat and the abundance and distribution of these seclusive fish species. The studies also provided new abundance data on species such as gravel divers (Scytalina cerdale), which are more common than previously recognized.

Beginning in 1979, a sportfishing sampling program was implemented. The purposes of this study are to monitor the catch and efforts of local party boat fishing and to collect life history data on species important in the catch. The study concentrates on fishing vessels originating from Port San Luis, which typically fish the area offshore of Diablo Canyon. Data collected to date indicated that catch success, expressed as catch per unit effort, has remained very stable over the four years of study. Catch and effort data will provide useful baseline data against which to assess population level effects of impingement and entrainment. In addition to catch and effort data, stomach content, gonad, and otolith specimens have been collected from species which are numerically dominant in the catch. These data are currently being processed and will provide basic life history information, including fecundity estimates, age-length relationships, age at maturity, spawning season, and food habits.

Surveys of larval fish near Diablo Canyon and offshore indicate overlapping communities. A survey of the ichthyoplankton in the Diablo Canyon area was performed by PGandE from 18 March 1974 to 28 May 1975 (PGandE 1976b). The major groups of larvae collected included Sebastes spp., Sciaenidae, Blennioidei, Engraulis mordax, Artedius spp., Stenobrachius leucopsarus, Scorpaenichthys marmoratus, and Gobiidae (Table 3-6). A survey of fish larvae offshore of Diablo Canyon (Ahlstrom 1965) indicated a similar species composition for the most inshore stations. Sebastes spp., Engraulis mordax, and Stenobrachius leucopsarus were the most abundant (Table 3-7). Blennioidei, Artedius spp., Scorpaenichthys marmoratus, and Gobidae were noticeably more abundant in the nearshore survey. Fish eggs were also one of the most abundant groups in the nearshore survey.

Seasonal distribution and abundance of the larvae in the Diablo Canyon area indicate larval fish are more abundant during the winter (PGandE 1976b). Densities range from 53.2 to 163.5 per 100 m^3 from December through March with peak density in February. Sebastes spp., Sciaenidae, Blennioidei, and Artedius spp. were most abundant during this period.

Fish eggs were most abundant from June through December. Densities during this period ranged from 25.6 to 475.0 per 100 m^3, with a peak during September.

Preoperational impingement sampling at the Diablo Canyon Power Plant intake traveling screens yielded information on species composition in the Intake Cove at Diablo Canyon. Catch composition for the period January through June 1977 is presented in Table 3-6. Rockfish and surfperch were the fish most commonly collected.

TABLE 3-6 PERCENT COMPOSITION AND OCCURRENCE OF TAXA COMPRISING 85.9 PERCENT OF THE LARVAL FISH NUMBERS FROM HAULS CONDUCTED 18 MARCH 1974 - 28 MAY 1975, AT DIABLO CANYON. QUANTIFIED (No./m3) DATA WERE USED TO CALCULATE PERCENT COMPOSITION

Taxon	Percent Composition	Percent Occurence
Sebastes spp.	38.0	69.6
Sciaenidae	20.4	31.5
Blennioidei (all sp. types)	11.0	74.4
Engraulis mordax	8.6	29.2
Artedius spp.	3.5	29.8
Stenobrachius leucopsarus	3.2	22.6
Gobiidae	2.3	16.7
Scorpaenichthys marmoratus	1.2	19.6

Source: PGandE 1976b.

TABLE 3-7 PERCENT OCCURRENCE OF THE 10 MOST COMMON FISH LARVAE TAKEN IN CALCOFI STATION LINES 73 AND 77 DURING 1950-1960

Rank	Scientific Name	Common Name	Percent Occurrence
1	*Sebastes* spp.	Rockfish	24.8
2	*Engraulis mordax*	Northern anchovy	19.0
3	*Lampanyctus leucopsarus*	Lanternfish	17.7
4	*Leuroglossus stilbius*	Deep-sea smelt	7.5
5	*Tarletonbeania crenularis*	Lanternfish	6.2
6	*Merluccius productus*	Pacific hake	4.0
7	*Trachurus symmetricus*	Jack mackerel	3.8
8	*Citharichthys* spp.	Sanddab	2.1
9	*Bathylagus* spp.	Deep-sea smelt	1.3
10	*Icichthys lockingtoni*	Butterfish	1.0
	Other		12.6
Total			100.0

Source: Ahlstrom 1965; adapted in PGandE 1973.

EVALUATION OF POTENTIAL IMPACT
DUE TO ENTRAINMENT AND IMPINGEMENT

The shallow habitats in and around Diablo Canyon, especially the kelp beds, are important as nursery grounds for young sport and commercial fish (Miller and Geibel 1973). Based on surveys in the area, large numbers of juvenile fishes, especially rockfish, use the area as nursery grounds. Fish eggs and larvae are also abundant during most of the year, with concentrations often reaching or exceedng 1 per m^3 of water.

Impingement data collected to date at Diablo Canyon do not indicate a substantial risk to the juvenile fishes. Numbers of individuals in impingement samples collected were very low (Table 3-8) in comparison to the apparent abundance of the species in the area. Data collected, however, were only for the period January through May; peak abundance would be expected in the summer and fall (Burge and Schultz 1973; Miller and Geibel 1973).

The potential for entrainment of fish eggs and larvae exists. Expected seasonal occurrence of fish eggs and larvae based on available ichthyoplankton data is presented in Table 3-9 from inshore waters near Diablo Canyon. Larval rockfish, Sciaenidae, Blennioidei, and Cottidae (Artedius spp.) would be especially abundant during the winter months.

Based on these considerations, the Diablo Canyon Power Plant is considered to have a high potential impact on fish.

3.3.3.4 MARINE MAMMALS

MARINE MAMMALS OF THE DIABLO CANYON VICINITY

The major marine mammals found in the Diablo Canyon vicinity include the sea otter (Enhydra lutris), harbor seal (Phoca vitulina), and sea lion (Zalophus californianus). Sea otters were first observed in the Diablo Canyon vicinity during the early 1970s; by summer of 1974 they had migrated as far south as

TABLE 3-8 OVERALL TOTAL COUNTS OF FISH COLLECTED ON THE DIABLO CANYON POWER PLANT INTAKE TRAVELING SCREENS, FROM JANUARY TO JUNE 1977

Species	JAN Unit 1 (13)	JAN Unit 2 (0)	FEB Unit 1 (20)	FEB Unit 2 (5)	MAR Unit 1 (23)	MAR Unit 2 (21)	APR Unit 1 (21)	APR Unit 2 (4)	MAY Unit 1 (13)	MAY Unit 2 (6)	JUN Unit 1 (0)	JUN Unit 2 (3)
Squalus acanthias									1			
Torpedo californica			1		1							
Platyrhinoidis triseriata			1									
Raja binoculata	1		1									
Hydrolagus colliei			1		2							
Engraulis mordax			1									
Spirinchus starksi							1		1			
Porichthys notatus			2	1	2		1		3			
Chilara taylori			1									
Atherinops affinis	2		4									
Aulorhynchus flavidus			2		3				2	1		
Sebastes mystinus	6		9	3	5		1		1			
S. paucispinis			1		1		1					
S. flavidus						1						
S. carnatus	2		4	1		1	1					
S. melanops	2			2			1		1	1		
S. serranoides/flavidus	5		3	1	2		3					
S. chrysomelas	1											
S. atrovirens	1		1				1					
S. caurinus						1	1					
Sebastes spp.										3		4
Oxylebius pictus			1									
Hexagrammos decagrammus			1									
Artedius lateralis							1					
Leptocottus armatus					1							
Orthonopias triacis	2				1		2					
Scorpaenichthys marmoratus	1								1			
Heutichthys oculofasciatus			1									
Syngnathus leptorhynchus			1		1		1		2			
Geuyoneeus lineatus							1					
Brachyistius frenatus	2		9	1	9	6	2					
Oxyjulis californica							1					
Gibbonsia metzi	1		1						1			
Stichaeopsis sp.			1									
Icichthys lockingtoni												1
Apodichthys flavidus												1
Peprilus simillimus				1								
Symphurus atricauda			2									
Citharichthys stigmaeus	1											
Damalichthys vacca			1		1							
Embiotoca jacksoni			1	1			1					
E. lateralis	6		3	3	9		4					1
Cymatogaster aggregata					1							
Hyperprosopon ellipticum						1						
Scorpaenidae unidentified			3	1					1			

Note: Numbers in parentheses indicate number of days sampled.
+ = present.

TABLE 3-8 (CONT.)

Species	JAN Unit 1 (13)	JAN Unit 2 (0)	FEB Unit 1 (20)	FEB Unit 2 (19)	MAR Unit 1 (21)	MAR Unit 2 (23)	APR Unit 1 (21)	APR Unit 2 (4)	MAY Unit 1 (13)	MAY Unit 2 (6)	JUN Unit 1 (0)	JUN Unit 2 (3)
Cottidae unidentified									1			
Embiotocidae unidentified					1							
Fish eggs	+		+	+			+		+			
Unidentified fish					2	1	1					
Total fish caught	33		57	15	42	11	25		15	5		7

Note: Numbers in parentheses indicate number of days sampled.
+ = present.

TABLE 3-9 EXPECTED OCCURRENCE OF FISH EGGS AND LARVAE AT DIABLO CANYON POWER PLANT BASED ON ICHTHYOPLANKTON SURVEY DATA COLLECTED FROM MARCH 1974 THROUGH MAY 1975

Species or Group	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Fish eggs	———	———	———	- - -	- - -	———	———	———	———	———	———	———
Sebastes spp.	———	———	———	———	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Sciaenidae	- - -	———	- - -						- - -	———	- - -	- - -
Blennioidei	- - -	———	———	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Engraulis mordax	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Artedius spp.	- - -	———	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Stenobrachius leucopsarus	- - -	- - -	- - -	- - -							- - -	- - -
Scorpaenichthys marmoratus	- - -	- - -	- - -							- - -	- - -	

Note: Solid line (———) = abundant (concentration > 100/1,000 m^3); dashed line (- - -) = common (1/1,000 m^3 < concentration < 100/1,000 m^3).
Source: PGandE 1976b.

Diablo Cove (Colson 1975). The otters are known to feed on red and black abalone (Haliotis spp.), giant red sea urchins (Strongylocentrotus franciscanus, and a number of small molluscs (including Astraea and Tegula) (Colson 1975). Declines in abalone and urchin populations in the area have been attributed to the expanding sea otter population. Harbor seals have been observed in numerous areas in the Diablo Canyon vicinity. Colson (1975) noted haul-out areas at Seal and Pecho Rocks. Burge and Schultz (1973) reported sightings of about 15 sea lions on Diablo Rock, and several hundred on Lion Rock during optimum haul-out conditions. PGandE biologists have observed sea lions within the intake cove near the east breakwater (Colson 1974).

POTENTIAL IMPACT ON MARINE MAMMALS

Although marine mammals are abundant in the immediate vicinity of the Diablo Canyon Power Plant, the impact of the plant on mammal populations should be negligible. All the marine mammals are strong swimmers and can avoid impingement. Most sea otters, harbor seals, and sea lions are found offshore, outside the immediate intake area. Thus, the plant should be considered low potential impact for marine mammals.

4.0 PROPOSED 316(b) STUDY PLAN FOR THE DIABLO CANYON POWER PLANT

The proposed 316(b) study plan for the Diablo Canyon Power Plant presented in the following sections has been developed in accordance with state and federal guidelines for conducting biological studies required by Section 316(b) of the Clean Water Act (Act), and Order WQ 83-1 of the State Water Resources Control Board. Section 316(b) of the Act requires that "... the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Because no single intake technology can be considered to be the best technology available for all sites, compliance with the Act requires a site-specific analysis of intake-related organism losses and a site-specific determination of the best technology available. Intake-related organism losses considered in this study program are those resulting from entrainment (the drawing of organisms into the cooling water system) and impingement (the retention of organisms on the intake screens). The study program includes an assessment of alternative intake technologies, including a site-specific evaluation of each technology according to operating, engineering, and biological criteria, which will provide a sufficient basis for regulatory agencies to determine whether the existing cooling water intake structure or modifications of the intake structure reflect the best technology available.

Two complementary study elements have been included in the 316(b) study program which are designed to provide a quantitative basis for determining entrainment and impingement of fish and macroinvertebrates at the Diablo Canyon Power Plant. The first study element is designed to provide data on the species and size composition, seasonal and diel distribution of entrained and impinged organisms (abundance). The second element is designed to provide a basis for determining species-specific entrainment and impingement survival.

Data compiled on entrainment abundance and survival and impingement abundance and survival, in combination with detailed information on the operational characteristics of the Diablo Canyon cooling water systems, provides the site-specific basis for the assessment of alternative intake and cooling system technologies. The assessment of alternative technologies will be based on a hierarchical evaluation system developed to assess which alternative intake technologies would (1) reduce biological losses from the existing operating conditions (determined using the results of the entrainment, impingement, and operating monitoring studies), and (2) be feasible at the Diablo Canyon Power Plant, based on site-specific considerations of engineering, operations, and reliability. The final phase of the assessment of alternative technologies will include a consideration of the total economic cost of the feasible technologies and the corresponding environmental benefits anticipated.

The 316(b) study plan described below briefly outlines the objectives and methods of the major elements of the proposed program. The program is designed specifically to provide the information necessary to support an analysis of feasibility and engineering constraints and biological effectiveness of the existing and alternative intake technologies considered for application at the plant. Section 4.1 presents a brief discussion of the criteria and rationale for the selection of specific aquatic organism groups for detailed study. The basic objectives and methods of the cooling water system operation, entrainment, and impingement monitoring programs are described in Section 4.2. Section 4.3 presents a brief overview of the existing preoperational baseline monitoring program. Information from this program will be used to evaluate potential changes in abundance or other characteristics of the resident aquatic populations due to entrainment or impingement losses following commercial operation of the facility. The approach and scope of the assessment of alternative intake technologies are presented in Section 4.4. A general schedule for the program is outlined in Section 4.5.

4.1 ORGANISM GROUPS SELECTED FOR STUDY

The proposed Diablo Canyon Power Plant 316(b) entrainment and impingement studies have been focused on the following aquatic organism groups:

(1) Fish (all life stages)

(2) Macroinvertebrates (e.g., decapods and amphipods).

These groups were selected because they may be entrained and impinged in abundance and because aspects of their life history and distribution place them among the organisms most susceptible to cooling water intake effects (Section 3.3). These organism groups generally have longer generation times and lower reproductive potential than phytoplankton, zooplankton, and most benthic organisms. Fish and macroinvertebrates were also selected because, in many cases, they are commercially or recreationally valuable or important in the food chain.

Organism groups not proposed as target groups in the entrainment and impingement studies include:

(1) Phytoplankton

(2) Zooplankton (small holoplanktonic and meroplanktonic invertebrates) other than those included in the macroinvertebrates selected above

(3) Benthic invertebrates (e.g., gastropods, annelids, polychaetes) other than those included in the macroinvertebrates selected above.

After considering U.S. EPA guidelines (1977), phytoplankton and zooplankton were excluded because of their wide geographic distributions, short generation times, and population reproductive potential, and because the tidal and oceanographic currents in the area continually transport phytoplankton and zooplankton throughout the area near the plant. Localized changes in phytoplankton and zooplankton populations would be very improbable because of the extensive natural movement of water through the areas offshore of the intake and discharge of the plant. No changes in species composition or overall abundance of either phytoplankton or zooplankton are expected to occur as a result of entrainment (Section 3.3.2). On the same basis, the majority of benthic invertebrates were excluded because their bottom-dwelling habits minimize the involvement of juveniles and adults with the plants' cooling water systems and the high potential survival of entrained larvae (Section 3.3.2).

No threatened or endangered species are expected to be affected either directly or indirectly by entrainment or impingement at the Diablo Canyon Power Plant.

4.2 316(b) MONITORING PROGRAM

The 316(b) study program involves routine monitoring of cooling water system operation, entrainment, and impingement during one complete year after the plant has begun commercial operation. The objectives, methods, and general scope of each of the three elements of the 316(b) monitoring program are briefly outlined below.

4.2.1 COOLING WATER SYSTEM AND PLANT OPERATION

The objective of this element of the program is to compile information of the design and operation of the Diablo Canyon Power Plant cooling water systems with emphasis on those design and operational parameters necessary for the interpretation of information collected in the entrainment and impingement studies (Sections 4.2.2 and 4.2.3). Information will be compiled on the design of the cooling water systems as shown in Table 4-1 which, in combination with figures and text, will provide a basic characterization of the major features of the intake structure and cooling systems. Operational procedures including intake screen rotation frequency and spraywash pressures, circulating water pump operation, cooling water system pressure regimes, and biofouling control procedures will be documented (including both chlorination and heat treatment).

In association with the one year entrainment and impingement study period, electrical generating load, circulating water pump operation, and system outages (scheduled and unscheduled) will be monitored routinely during daily activities and recorded in operational logs. Data from the daily operating logs will be compiled to develop monthly averages of capacity and cooling water volumes to characterize basic plant operation during the study period. Intake water velocity profile measurements will be made periodically under a variety of tidal stages for use in analyzing results of the impingement studies. Intake and discharge water temperatures will be continuously recorded throughout the study period

TABLE 4-1 TYPICAL DESIGN SPECIFICATIONS USED IN CHARACTERIZING THE COOLING WATER SYSTEMS AT THE DIABLO CANYON POWER PLANT (EXAMPLE)

Specification	Unit 1	Unit 2
Bar racks		
Number		
Location		
Spacing O.C., in.(cm)		
Bar size, in.(cm)		
Traveling screens		
Location		
Number		
Manufacturer		
Mesh size, in.(mm)		
Pumps		
Location		
Number per unit		
Manufacturer		
Type		
Capacity, each pump		
cfs		
m^3/sec		
gpm		
Pressure conduits to condenser		
Number		
Diameter, ft(m)		
Length, ft(m)		
Condenser		
Number of tubes		
Tube material		
Tube O.D., in.(cm)		
Tube length, ft(m)		
Design delta-T, F(C)		
Inlet pressure, psia		
Pressure drop, psi		
Discharge conduits		
Number		
Size, ft(m)		
Length, ft(m)		
Approximate travel time, sec		
Intake to pumps		
Pumps to condenser		
Through condenser		
Condenser to discharge		
Total through plant		
Total heated		
Total chlorinated		
Design water velocities, fps(cm/sec)		
Approach to bar racks		
Through bar racks		
Approach to screens		
Through screens		
Pumps to condenser		
Through condenser		
Condenser to discharge		

(with appropriate calibration and system documentation) and total residual chlorine concentrations during chlorination will be monitored for use in analyzing results of the entrainment survival studies. Measurements of salinity, water temperature, tidal stage and dissolved oxygen will be routinely made whenever biological samples are collected.

4.2.2 ENTRAINMENT STUDIES

The proposed entrainment studies include two complementary study elements -- entrainment abundance and entrainment survival. The entrainment studies will focus emphasis on planktonic early life stages of fish (ichthyoplankton) and macroinvertebrates as discussed in Section 4.1. The major objectives and general methods proposed for use in the entrainment studies are discussed briefly for both study elements.

ENTRAINMENT ABUNDANCE STUDIES

The entrainment abundance study is designed to provide quantitative information on (1) the species composition of entrained ichthyoplankton and macroinvertebrates, (2) the size (length) composition of the entrained ichthyoplankton, and (3) the seasonal and diel patterns in the densities of entrained biota. In addition to the basic monitoring program a number of intensive sampling efforts will be undertaken, each focused on providing specific information upon which the sampling design of the basic monitoring program will be based (entrainment abundance support studies). An overview of each of the proposed study efforts is presented below.

ENTRAINMENT ABUNDANCE SUPPORT STUDIES

Based on results of entrainment studies conducted by PGandE at other power plants it is expected that the entrainment monitoring program will include sample collection from the discharge of one unit as the preferred sampling location. Because of turbulence and through-plant mixing, organisms are expected to be distributed more uniformly in the discharge than in the intake.

Samples collected from the discharge, therefore, are expected to represent more accurately the true densities of entrained organisms than samples collected from the intake, provided that no losses of organisms are occurring during transit through the cooling system. Prior to establishing the sampling design to be used in the entrainment monitoring program it is proposed that a series of three specific intensive studies be performed to verify the acceptability of the proposed discharge sampling location and to provide documentation on the sampling methods selected for the Diablo Canyon entrainment abundance monitoring program.

The first study is designed to document the collection efficiency of the sampling nets and sample processing techniques proposed for the entrainment program. The basic sample collection equipment proposed for use in the entrainment monitoring program includes a 4-inch diameter recessed-impeller pump which would have a 4-inch diameter PVC intake pipe directed into the cooling water flow. The pump discharge would then pass through a 4-inch pipe with an inline flow meter into the mouth of a 0.5-m (1.6-ft) plankton net with 333-μm mesh suspended in a cylindrical polyethylene tank. Sampling flow rate is expected to be approximately 0.9 m3/min (0.5 cfs).

The collection efficiency and potential mutilation of organisms by the proposed sample collection techniques will be tested in an experiment where a known number of stained organisms are released directly into the suction line of the sampling pump and the numbers subsequently recovered recorded. Prior experience with this equipment indicates that collection efficiency is very high (consistently greater than 90 percent) for both ichthyoplankton and fragile invertebrates when sampling duration is limited to 60 minutes or less. The purpose of this experiment is to verify these previous conclusions for the sampling equipment to be used at the Diablo Canyon Power Plant.

The second experiment is designed to test the hypothesis that organism densities in the intake and discharge are the same (i.e., that entrained organisms are not lost during cooling system passage). To test this hypothesis, cooling water samples will be simultaneously collected using the sampling equipment described above from several locations within the intake structure and several locations within the discharge. The collections will be replicated and the mean densities of selected organisms computed (log transformed to meet the assumption of the normalized Poisson distribution expected) for each sampling location and compared statistically in a two-way analysis of variance.

Because Diablo Canyon Units 1 and 2 draw cooling water from a common intake structure, no difference in the densities and species composition of entrained organisms are expected between the two units. The third experiment, an inter-discharge density comparison study, is proposed to test this hypothesis. Paired samples will be collected simultaneously from the same location in the cooling system of each unit (e.g., the center of the discharge). The collections will be replicated and the densities of selected organisms (log transformed) will be analyzed statistically with a paired t-test.

Results of these three studies will provide the necessary basis and documentation to establish the specific sampling design to be used in the entrainment monitoring program.

ENTRAINMENT MONITORING PROGRAM

The entrainment monitoring program will include weekly sampling at the plant for a period of one year. During each week a series of eight 3-hour composite samples will be collected using the pump sampling equipment described above. Pending results of the entrainment abundance support studies it is anticipated that sample collection will be from the discharge of one unit. Intake water temperature, salinity, tidal stage, dissolved oxygen concentration, and sample volume will be recorded for each sample collected.

After collection each sample, appropriately labeled with accompanying documentation, will be preserved with 10 percent buffered formalin and returned to the laboratory for processing. Ichthyoplankton, including fish eggs, and macroinvertebrates will be sorted from each sample and identified to the lowest taxonomic level practical with available keys, and life stage noted. Total lengths of fish larvae and juveniles will be measured to the nearest millimeter. All sample collection and processing operations will be documented in a strict quality assurance program.

Densities, expressed as the number of organisms per cubic meter of cooling water will be computed for each taxon observed in each 3-hour sample. Mean densities for each 24-hour sampling day will also be computed as the simple average of the densities in the eight 3-hour samples. These densities, in addition to the corresponding length statistics for ichthyoplankton, will provide the basic information needed to determine the seasonal and diel distributions of entrained organisms. The entrainment abundance data base developed from these studies will be documented and will accompany the 316(b) demonstration as a supporting appendix.

ENTRAINMENT SURVIVAL PROGRAM

The objective of the entrainment survival program is to determine the proportion of larval fish and macroinvertebrates surviving entrainment. In addition, the program is designed to provide quantitative information on the relationship between entrainment mortality and discharge temperature, exposure to chlorine during biofouling control, and body size (length) of the organisms. Because investigating the entrainment survival of all species of larval fish and macroinvertebrates is not feasible, the studies will focus emphasis on selected species of larval fish and macroinvertebrates based on their relative abundance in entrainment samples, their importance in local recreational and commercial fisheries, and their importance as a food source for other local species.

The basic sampling design includes the simultaneous collection of organisms from the intake and discharge of the plant using sample collection devices specifically designed (and proven acceptable in studies conducted at other power plants) to collect larval fish and macroinvertebrates with a minimum of sampling stress. The proportion of entrained individuals of each selected taxon not surviving entrainment can then be estimated by comparing the mortality in the discharge sample with the mortality in the intake sample. The control samples collected from the intake will be used to account for mortality resulting from sampling and other natural causes not related to entrainment.

Cooling system operating conditions (the number of circulating water pumps in operation, intake and discharge temperatures, and residual chlorine concentration) will be recorded during entrainment survival sampling. The sampling regime will include collections made during periods of condenser chlorination to evaluate the potential effect of the biofouling control procedures on entrainment survival of non-target organisms.

Intake and discharge samples will be sorted immediately after collection. Live and dead organisms of selected species will be separated and noted. Live organisms, those displaying body movement, will be placed in ambient water temperature holding tanks and held for a 96-hour observation period to detect possible delayed effects of entrainment. After all live organisms have been placed in the holding tanks, the dead organisms will be removed from the sample and preserved for later identification and measurement.

All fish larvae and macroinvertebrates, including those held for 96 hours, will be identified, to species when possible, and counted. Total lengths will be measured (except for mutilated fish) so that the relationship between larval size and entrainment survival can be examined.

The data base and documentation of the entrainment survival studies will accompany the 316(b) demonstration as a supporting appendix.

4.2.3 IMPINGEMENT STUDIES

The proposed impingement studies include two complementary study elements -- impingement abundance and impingement survival. The impingement studies will focus emphasis on juvenile and adult stages of fish and macroinvertebrates as discussed in Section 4.1. The major objectives and general methods proposed for use in the impingement studies are discussed briefly for both study elements.

IMPINGEMENT ABUNDANCE STUDIES

The impingement abundance study is designed to provide quantitative information on the numbers and species composition of fish and macroinvertebrates impinged on intake screens at the Diablo Canyon Power Plant. The study is designed to:

(1) Determine the species composition of the organisms impinged

(2) Determine the lengths and weights of impinged organisms

(3) Determine the diel and seasonal patterns of impingement

(4) Examine the relationship between impingement and cooling system operational parameters

(5) Determine the sex ratio and degree of gonadal maturity for selected species

(6) Determine whether or not any significant impingement occurs on intake bar racks.

In addition to the basic monitoring program a number of intensive sampling efforts will be undertaken, each focused on providing specific information upon which the sampling design of the basic monitoring program will be based (impingement abundance support studies). An overview of each of the proposed study efforts is presented below.

IMPINGEMENT ABUNDANCE SUPPORT STUDIES

Periodically throughout the impingement abundance monitoring program the collection and processing efficiency of the equipment and personnel will be documented as part of the quality assurance program. To determine the efficiency of the impingement abundance sample collection techniques, various experiments will be conducted. The first experiment will involve releasing marked dead fish between the bar racks and the travelling intake screens and documenting the number subsequently impinged and washed into the screenwash sluiceway and into the collection nets. In the second experiment, marked dead fish and macroinvertebrates will be released directly into the screenwash sluiceways during screen rotation and cleaning. The proportion of marked organisms subsequently collected in the collection nets will provide information on the sample collection efficiency.

Frequently large quantities of detrital material is collected in association with impingement collections which requires that the material be sorted (processed) to isolate impinged organisms. Sample processing will be routinely checked to determine the number of fish and macroinvertebrates not separated from the material collected in the screenwash. After routine sorting of the impingement sample, a second team will resort the detrital material with the proportion of organisms remaining in the detrital material after the first sort used as an indication of sample processing efficiency.

The accuracy of taxonomic identification for fish and invertebrates will be monitored regularly as part of the 316(b) quality assurance program.

IMPINGEMENT MONITORING PROGRAM

The impingement monitoring program will include weekly sampling at the intake structure screenwash sluiceway for a period of one year. During each week a series of eight 3-hour composite samples will be collected to characterize the diel pattern in impingement abundance. Intake water temperature, salinity, tidal stage, dissolved oxygen concentration, and circulating water pump operation will be recorded for each impingement sample collected.

Before each sampling period, all screens will be rotated and washed to remove previously impinged organisms and debris. The intake screens will then remain stationary for 2-3/4 hours and will then be rotated for 15 minutes while impinged organisms are washed into a collection device. This cycle of stationary period and rotation will then be repeated though the 24-hour sampling period. Samples will be collected from the screenwash sluiceways in containers lined with 1/4-inch steel mesh.

Fish and macroinvertebrates will be sorted by hand from the detritus collected in each sample. Fish will be identified to species, counted, and measured (fork length for up to 50 individuals of each species in each 3-hour sample). Macroinvertebrates will be identified and counted. A composite weight to the nearest gram will be measured for each species.

Bar racks will be inspected periodically during the study to determine if impingement is occurring there.

The gonads of a subsample of the most abundantly impinged fish species will be examined periodically to assess spawning condition.

The number of each species collected each sampling day, in addition to the corresponding length statistics, will provide the basic information needed to characterize the diel and seasonal patterns in impingement at the plant. The impingement abundance data base developed from these studies will be documented and will accompany the 316(b) demonstration as a supporting appendix.

IMPINGEMENT SURVIVAL PROGRAM

The basic objective of the impingement survival program is to determine the proportion of fish and macroinvertebrates not surviving impingement. Specific objectives of this program element are:

(1) To estimate the initial and delayed (96-hour) mortality of fish and macroinvertebrates impinged under a routine screenwash operational cycle

(2) To examine the relationship between various operational cycles and initial and delayed impingement mortality.

The impingement survival program has been designed to emphasize those fish and macroinvertebrate species impinged in greatest numbers. The proportion of organisms not surviving impingement will be estimated from the numbers of each species that are alive and dead immediately following removal from the intake screens and 96 hours after impingement. Control organisms collected from the general vicinity of the plant will be used to account for mortality resulting from sampling stress and holding in the laboratory and other causes not related to impingement.

The proposed experimental design will provide the opportunity to determine the relationship between the duration of impingement (intake screen rotation frequency) and the survival of those species impinged in greatest abundance. This objective will be accomplished by determining impingement survival for fish and macroinvertebrates collected in each of three intake screen operating modes:

(1) A 3-hour screen rotation cycle (an operating cycle typical of that proposed for the impingement abundance collections)

(2) A 1-hour intermittent screen rotation cycle in which the intake screens will be stationary for 45 minutes and then rotated and cleaned for 15 minutes

(3) A continuous screen rotation cycle.

Sampling impingement survival under these three modes of intake screen operation will provide information valuable in assessing the potential biological effectiveness of alternative screen operational modes and modifications in the assessment of alternative intake technologies described in Section 4.4.

4.3 WATER BODY MONITORING TO DETERMINE POTENTIAL POPULATION CHANGES RESULTING FROM ENTRAINMENT OR IMPINGEMENT LOSSES

As discussed in Section 3 there exist a number of detailed preoperational monitoring programs, conducted in the vicinity of the Diablo Canyon Power Plant, which establish a quantitative baseline against which changes in the local populations potentially resulting from entrainment or impingement losses can be compared. Baseline data have been compiled for a wide variety of species and habitats including seasonal and long-term trends in the species composition and abundance of algal, fish, and invertebrate populations inhabiting the intertidal, subtidal, and midwater or pelagic habitats. Baseline information has also been collected in settling plate studies for both algae and invertebrates, in addition to information on migration, recruitment, and population dynamics for species such as black abalone, rock crabs, rockfish, and kelp. Party boat sportfish landings have also been monitored in the area offshore of the plant. In addition to the preoperational baseline monitoring data available for the site, there has been a long-term program to mark fish in the vicinity of the plant, which will provide a basis for conducting a mark-recapture study to estimate the susceptibility of juvenile and adult fish to impingement. Baseline information collected in these preoperational studies will provide a detailed site- and species-specific basis for assessing the potential impacts on these populations as a result of cooling water system operation.

Comparison of the trends in the local populations and species composition of the communities inhabiting various areas in the immediate vicinity of the plant during the preoperational and operational phases of the environmental monitoring program will provide the most effective measure of potential impacts resulting from entrainment and impingement losses available.

4.4 ASSESSMENT OF ALTERNATIVE INTAKE TECHNOLOGIES

The assessment of alternative intake technologies which could potentially reduce entrainment and/or impingement losses at the Diablo Canyon Power Plant will follow a hierarchical evaluation system. The major steps undertaken in this evaluation include:

(1) Identification of alternatives

(2) Preliminary assessment of each alternative

(3) Description and conceptual design of the technically feasible alternatives

(4) Environmental assessment of each feasible alternative (effectiveness in reducing entrainment and/or impingement losses and other environmental considerations)

(5) Comparative analysis of alternatives including consideration of total cost and corresponding environmental benefits.

The first step in the assessment of alternatives will be the identification of all possible alternatives to reduce the losses of aquatic organisms as a result of entrainment or impingement at the plant. This initial identification of possible alternatives will make no prejudgment as to the feasibility of the concepts for use at the power plant or the potential cost of the alternatives. A listing of potential alternatives, many of which have already been examined for possible application at the Diablo Canyon Power Plant, is presented in Table 4-2 as an example of the range and scope of the alternatives considered in the preliminary assessment.

The next step in the assessment will be to conduct a preliminary assessment of all alternatives to identify those that are feasible for use at the power plant. The first question concerning the feasibility of each of the alternatives is whether the alternative would be effective in reducing entrainment or impingement losses. The next question to be addressed in determining feasibility will be whether or not the alternative is practicable for use at the plant; that is, are there any physical constraints that would prevent implementation of a given alternative, such as land availability or technical incompatibility with other integral systems at the plant. This preliminary assessment will also evaluate whether or not similar alternatives are redundant in function and purpose. If two or more alternatives of a particular type of alternative would be expected to serve the same function, it is proposed that a selection be made of one of the alternatives to be evaluated in greater detail.

The result of the preliminary assessment will be a list of alternatives which are both capable of reducing the losses of fish and macroinvertebrates resulting from cooling system operation and which are considered to be feasible for use at the plant. Each of the alternatives considered to be feasible will be developed into a conceptual design in order to establish the physical requirements related to the alternative. The conceptual design will provide the necessary basis to define the characteristics, space requirements, costs, and potential effectiveness of each

TABLE 4-2

INTAKE TECHNOLOGIES AND OPERATIONAL ALTERNATIVES POTENTIALLY CONSIDERED FOR THE DIABLO CANYON POWER PLANT

STATUS

Alternative Intake Technology	Pending Results of 316(b) Studies	Evaluation Ongoing	Evaluation Complete (a)
Cooling			
Water Systems			
Wet cooling towers			X
Dry cooling towers			X
Wet/dry cooling towers			X
Cooling ponds/canals			X
Once-through cooling with offshore discharge			X
Refrigeration system			X
Binary cycle heat engine			X
Soil warming			X
Greenhouse heating			X
Mariculture			X
LNG vaporization			X
Residential/industrial heating			X
Desalination of seawater			X
Hydrostatic head recovery			X
Existing once-through cooling system	X		
Intake Location			
Offshore	X		
Onshore	X		
Intake Configuration			
Shoreline	X		
Recessed	X		
Behavioral Barrier			
Light	X		
Sound	X		
Bubble screen	X		
Velocity cap	X		
Velocity gradient	X		
Electrical barrier	X		
Louvers	X		
Chemicals	X		
Magnetic field	X		
Chains/cables	X		
Physical Barriers			
Drum screen	X		
Centerflow screen	X		
Vertical traveling screen	X		
Media filter	X		
Porous dike	X		
Radial well	X		
Stationary screen	X		
Horizontal traveling screen	X		
Angled screen/louver	X		
Caisson	X		
Fish Collection, Removal, and Conveyance Systems			
Vertical traveling screen modifications	X		
Gravity sluiceway	X		
Fish pump	X		
Operational Alternatives			
Dredging	X		
Intake boom	X		
Circulating water pump volume reduction	X		
Curtailment	X		
Alternative biofouling control procedures:			
Chlorination		X	
Heat treatment		X	
Toxic coating	X		
Cooling system modifications		X	
Temperature regulation	X		

(a)TERA 1982 a

feasible alternative for reducing entrainment and impingement losses. The second important function of the conceptual design will be to ensure that the alternative can be integrated into the current plant design without adversely affecting the reliability of the cooling water system.

The preliminary assessment will consider each alternative independent of the other alternatives being evaluated. However, recognizing that certain alternatives would, in fact, be logically combined to further reduce organism losses, additional analyses will be presented which consider some specific combinations of feasible alternatives.

An environmental assessment will be presented in the 316(b) demonstration for each feasible alternative based on results of the conceptual designs. The various environmental elements such as air quality, land use, terrestrial ecology as well as an assessment of the effectiveness of each feasible alternative for reducing entrainment and impingement losses will be documented in the demonstration. The purpose of the environmental assessment is to identify all significant environmental impacts which may be associated with a given alternative and to quantify to the extent possible the reduction in entrainment and impingement losses anticipated for each alternative compared to the existing cooling water intake system design and operational proceedures.

The assessment will also include a summary comparison of the benefits, in terms of reduced entrainment and impingement losses, and the costs, in terms of capital and annual expenses and other environmental impacts related to each feasible alternative.

As noted in Table 4-2, a number of possible alternative cooling water system designs have already been evaluated for their possible application at the Diablo Canyon Power Plant. The results of this detailed assessment of alternative cooling systems have been documented in a comprehensive report submitted to the Regional Board in 1982 (TERA 1982a and b).

Several potential alternative technologies are currently under investigation at the plant. Testing and evaluations are currently underway in an effort to determine the minimum time-temperature dose which will achieve effective biofouling control. This research may provide evidence for a reduced heat treatment dose and schedule which could then be evaluated as a feasible alternative in the assessment of alternative technologies presented in the 316(b) demonstration. Similarly, an investigation is underway to determine the minimum time-dose relationship for chlorination as part of PGandE's overall chlorine minimization program.

Consideration and evaluation of a number of other potential alternative technologies are being held in abeyance pending results of the 316(b) entrainment, impingment, and operating monitoring program results. A large body of published information and results of prototype testing and evaluation of the biological effectiveness and engineering performance of various alternative technologies at power plants located throughout the country is currently being compiled. Compilation of data and information on alternative technologies will continue throughout the Diablo Canyon 316(b) program to provide the most detailed, up-to-date, and comprehensive information base possible for use in the assessment of alternative technologies presented in the 316(b) demonstration.

4.5 SCHEDULE

The 316(b) studies are intended, in part, to characterize entrainment and impingement under cooling water system operating conditions considered to be typical of standard operating conditions in the future (operating performance and reliability over an extended time period without prolonged scheduled or unscheduled unit outages). Therefore, the study program will not begin until both units at the plant have achieved commercial operation and have operated a sufficient length of time to help ensure reliable operation throughout the one-year 316(b) monitoring program described in Section 4.2. Prior to initiating the 316(b) study program a meeting will be held with representatives of the Regional Board and appropriate resource agencies to review this study plan.

Progress reports will be submitted to the Regional Board annually after initiation of the 316(b) study program. The final 316(b) demonstration will be submitted to the Regional Board within 36 months after the Diablo Canyon Power Plant begins commercial operation.

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APPENDIX B

REVIEW OF LABORATORY AND FIELD ENTRAINMENT SURVIVAL STUDIES

B.1 Introduction

Steam electric generating stations (both fossil and nuclear fueled) drawing cooling water from a waterbody entrain a variety of aquatic organisms into the cooling water flow. Plankton and weak-swimming nekton capable of passing through intake screens are carried along with the cooling water through the plant and are subjected to a variety of thermal, physical, and chemical (biocidal) stresses. Upon reaching the circulating water pumps, entrained organisms are exposed to pressure increases, velocity shear forces, physical buffeting, and abrasion. Passing through the condensers, organisms are subjected to rapid temperature increases and pressure decreases. They may also be exposed to chlorine during cooling system passage, if this biocide is used to prevent fouling of condenser tube surfaces. In once-through cooling systems, entrained organisms are then subjected to decreasing temperatures as the thermal effluent mixes with ambient temperatures of the receiving waterbody.

Entrainment survival at power plants was initially thought to be low or negligible, based on the results of several early field studies (Marcy 1971, 1973; Carpenter et al. 1974). Consequently, fine-mesh screening was proposed as a mechanism for preventing entrainment of the larger plankton and weak-swimming nekton. However, later studies have shown entrainment survival of a variety of aquatic organisms to be high under many plant operating conditions, suggesting that exclusion by means of fine-mesh screening may not be the optimal means of minimizing impact on aquatic organisms.

The purpose of this review of the results of laboratory and field studies pertinent to entrainment survival is to form a basis for estimating survival at power plants for which no site-specific data exist and to supplement the results of limited site-specific survival studies. The review is applicable to power plants with once-through cooling systems. The review demonstrates that high entrainment survival of a variety of aquatic organisms is likely.

B.2 Review of Laboratory Studies Pertinent to Entrainment Survival

Physical, thermal, and chemical (biocidal) stresses potentially influence entrainment survival. The effects of these stresses which have been isolated in laboratory studies are discussed in this section.

B.2.1 Physical Stresses

Entrained organisms are subjected to physical stresses throughout the cooling system, although such stresses may be greatest in the circulating water pumps and condensers. Although the separate effects of most physical stresses (mechanical buffeting, abrasion, and velocity shear forces) have not been isolated in the laboratory, the effects of the combined physical stresses associated with passage of entrained organisms through actual or simulated condenser tubes have been quantified by several investigators.

B.2.1.1 Condenser Passage Experiments

Coutant and Kedl (1975) passed young striped bass and larvae of five other species of fish through an experimental condenser tube designed to simulate the physical forces. Mortalities of organisms passed through the condenser simulator at velocities of 7-19 fps (2-6 m/sec) were no greater than mortalities of controls. When temperature stress was added (6-minute exposures), resulting mortality was comparable to that observed in laboratory thermal tolerance studies (6-minute exposures). The authors concluded that physical damage to larvae of most species due to passage through a typical power plant condenser tube is minimal (<5 percent mortality).

The investigators of a condenser simulator study conducted at New York University (NYU 1979) concluded that "the mechanical effects of condenser tube passage alone had little or no effect on survival of striped bass yolk-sac larvae and larvae..." In addition, the study showed that "the combined effect of increased temperature, condenser tube passage, and biocide (chlorine) application was essentially additive for striped bass..."

Shear forces develop when spatial differences in velocity exist in a moving fluid. The greatest shear forces occur in close association with solid surfaces, such as pipe walls, pump impellers, traveling screens, and water boxes (Marcy et al. 1978). The only known laboratory studies on the effects of shear stresses on early life stages of fish are those reported by Morgan (1974) and Morgan et al. (1973, 1976). However, results of these studies do not provide conclusive evidence on which accurate entrainment survival estimates can be based.

B.2.1.2 Changes in Hydrostatic Pressure

Changes in hydrostatic pressure within the cooling water system may stress entrained organisms. Pressure increases occur at the circulating water pumps, and pressure decreases occur across the condenser tubes. Increases and decreases are usually on the order of one atmosphere (14.7 psi) or less.

Sudden increases in pressure of up to 250 psi above atmospheric pressure for 15 minutes had no significant effect on the development and survival of eggs and larvae of striped bass (determined 24 hours after exposure, NYU 1974a). Striped bass juveniles tolerated pressure increases of up to 495 psi above atmospheric pressure for 12 minutes (NYU 1975). Such pressure increases are far greater than those found in once-through cooling systems.

Results of NYU (1974a, 1975) studies indicated that striped bass eggs, larvae, and juveniles were more sensitive to decreases than to increases in pressure. Sudden pressure drops often resulted in significantly lower survival of test organisms than of control organisms. Pressure decreases tested ranged from 8.7 to 30 psi. Survival of striped bass eggs and larvae was reduced by 0-13 percent after exposure to pressure decreases of up to 13 psi from atmospheric pressure (survival measured 24 hours after exposure). Survival of juveniles was reduced by 71 percent after a 13 psi decrease from atmospheric pressure.

Adult stages of amphipods (*Gammarus* spp.) and the opossum shrimp (*Neomysis americana*) were also tested at NYU (1975), and were found to be tolerant of both decreases and increases in pressure. Neither taxon showed significantly reduced survival after exposure to a pressure decrease from an acclimation pressure of 44.7 psi to 1.5 psi for 15 seconds, followed by a pressure increase to 35-510 psi for 12 minutes. Survival, measured 24 hours after exposure, was reduced by only 5-9 percent. Survival of *Gammarus* spp. exposed to a pressure decrease from 44.7 to 1.5 psi for 15 seconds was reduced by 2 percent.

The NYU (1974a, 1975) pressure studies indicate that pressure decreases are more likely than pressure increases to affect entrained organisms adversely, particularly for fish larvae. Pressure decreases are less tolerable to organisms than increases because of a tendency for gas cavities, such as air bladders, to explode and for dissolved gases in blood or other body fluids to come out of solution, forming bubbles which can cause physical trauma.

B.2.2 Thermal Stresses

Entrained organisms are subjected to a rapid rise in temperature as they pass through the condensers. The exposure duration to elevated temperatures is short, usually one to ten minutes, depending on the circulating water system configuration, followed by a return to ambient temperature as the warm-water discharge is mixed with the receiving waterbody.

Thermal stresses experienced during cooling system passage, and subsequently in the discharge waters, depend upon the temperature rise above ambient (ΔT), the absolute value of the maximum temperature, and the duration of exposure. With brief exposures such as those typical of power plant passage, the maximum temperature and the maximum ΔT tolerated may be higher than those tolerated during extended exposures.

Specialized terminology used in the following sections is defined in this paragraph. A safe temperature is a temperature reported to cause no significant mortality upon exposure for a specified period of time. A TL50 is a temperature leading to mortality of 50 percent of the test organisms upon exposure for a specified period of time. A lethal temperature is a temperature reported to cause 100 percent mortality of the test organisms upon exposure for a specified period of time. A threshold lethal temperature is a maximum safe temperature, above which significant mortality may be expected. Threshold lethal temperatures can be approximated by subtracting 2 C (35.6 F) from TL50s (U.S. EPA 1976).

B.2.2.1 Fish Eggs

Investigations of short-term thermal tolerance have been made for the eggs of eight species of fish representing five families (Table B-1). Safe temperatures reported for short exposures (5-60 minutes) of fish eggs range from 19 to 35 C (66.2-95.0 F) (Table B-1). Most of the reported safe temperatures less than 30 C (86.0 F) were the highest temperatures tested in the experiments. Consequently, threshold lethal temperatures are probably higher than the safe temperatures reported in these cases. This assertion is supported by the observation that threshold lethal temperatures exceed 30 C (86.0 F) in the majority of the cases. Notable exceptions were alewife blastulae acclimated to 12-13 C (53.6-55.4 F), whose 30-minute TL50 was 26-27 C (78.8-80.6 F); northern anchovy blastulae acclimated to 16 C, whose 60-minute TL50 was 30-31 C (86.0-87.8 F); and Atlantic tomcod embryos acclimated to 2-3 C (35.6-37.4 F), whose 10- to 60-minute TL50s ranged from 20 to 31 C (68.0-87.8 F). All three of these species spawn in relatively cold water, especially Atlantic tomcod, a cold-water fish of the north Atlantic coast of North America that spawns in mid-winter at temperatures below 5 C (41.0 F).

The data presented in Table B-1 support the general assertion that short exposures to elevated temperatures remaining below 30 C (86.0 F) for durations typical of power plant cooling water transit times, will not harm the eggs of most species of fish. The eggs of some species will tolerate exposures to temperatures of up to 30 C (86.0 F), but few, if any, species can be expected to tolerate exposure to temperatures over 35 C (95.0 F).

B.2.2.2 Fish Larvae

Investigations of short-term thermal tolerance have also been made for larvae and early juvenile stages of 20 species of fish (Table B-2). Fish larvae and juveniles are capable of tolerating short exposures (5-60 minutes) to temperatures 10-20 C (50.0-68.0 F) above ambient during most seasons and 7-10 C (44.6-50.0 F) above the mid-summer maximum ambient temperatures. All the reported safe temperatures less than 25 C (77.0 F) were obtained in experiments in which acclimated temperatures were very low (0-10 C) (32.0-50.0 F); at higher acclimation temperatures, the safe temperatures would probably be higher. Lethal threshold temperatures for 14 species, ranged from 28 to 38 C (82.4-100.4 F), with one exception: the lethal threshold for the cold-water Atlantic tomcod was less than 28 C (82.4 F). However, Atlantic tomcod larvae were capable of tolerating temperature increases (ΔT) of up to 21 C (69.8 F) over acclimation temperatures of 3-8 C (37.4-46.4 F).

TABLE B-1

SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR FISH EGGS

Taxon: Common Name	Taxon: Family Species	Life stage	Temperature (C)	Duration (min)	Thermal Tolerance Limits: Safe	Thermal Tolerance Limits: TL50	Thermal Tolerance Limits: Lethal	Reference
	Clupeidae							
Alewife	*Alosa pseudoharengus*	Blastula	12-13	30		26-27		EA 1978b
		Tail-bud embryo	12-13	30		32-33		EA 1978b
		Tail-free embryo	12-13	30		32-34		EA 1978b
		4-8 cell	12	(a)	19[b]			Schubel 1974
		Early blastula	13	(a)	23[b]			Schubel 1974
		Late gastrula	13-14	(a)	23-24[b]			Schubel 1974
		Late embryo	15	(a)	25[b]			Schubel 1974
Blueback herring	*Alosa aestivalis*	Late blastula to Early gastrula	18	(a)	28[b]			Schubel 1974
		Early embryo	15-18	(a)	28[b]			Schubel 1974
		Late embryo	18	(a)	28[b]			Schubel 1974
		Early to late embryo	18-21	(a)	28-31[c][d]			Schubel and Koo 1976
American shad	*Alosa sapidissima*	Late cleavage	17	variable	27[b]			Schubel 1974
		Early embryo	17	variable	27[b]			Schubel 1974
		Mid to late embryo	17	variable	27[b]			Schubel 1974
		Early to mid embryo	20-21	variable	30-31[c][d]			Schubel and Koo 1976
	Engraulidae							
Northern anchovy	*Engraulis mordax*	Blastodisc	16	5		33		Brewer 1976
		Blastopore closure	16	5		36		Brewer 1976
		Blastodisc	16	60		30		Brewer 1976
		Blastopore closure	16	60		31		Brewer 1976
	Percichthyidae							
Striped bass	*Morone saxatilis*	Gastrula	16-18	30		32		EA 1978b
		Tail-bud embryo	16	30		34		EA 1978b
		Tail-free embryo	19	30		35		EA 1978b
		Late embryo	17	30		35		EA 1978b
		Early to late embryo	15-18	(a)	25-28[b]			Schubel 1974
		Early to mid embryo	17-20	(a)	32-35[b]			Schubel and Koo 1976
White perch	*Morone americana*	Early gastrula to early embryo	14-15	(a)	25-25[b]			Schubel 1974

TABLE B-1 — *Continued*

SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR FISH EGGS

Taxon					Thermal Tolerance Limits			
Common Name	Family Species	Life stage	Temperature (C)	Duration (min)	Safe	TL50	Lethal	Reference
	Cyprinidae							
Carp	*Cyprinus carpio*	Egg (various stages)	25	10			40	Frank 1974
		Egg (various stages)	25	10	~35			Frank 1974
	Gadidae							
Atlantic tomcod	*Microgadus tomcod*	Tail-bud embryo	2-3	10-60		20-27		EA 1978b
		Eyed-up embryo	2-3	10-60	24-31			EA 1978b

(a) 4- to 60-minute exposure followed by gradual cooling to within 1 C of acclimation temperature.
(b) Highest temperature tested resulted in mortality not significantly different from control mortality.
(c) Temperature 5 C higher significantly increased mortality.
(d) In one experiment, a brief (<5 min) exposure to 29 C (8 C Δ T) resulted in increased mortality.

The data presented in Table B-2 support the assertion that, in general, larvae and juveniles of most fish species are not harmed by short exposures to elevated temperatures remaining below 30 C (86.0 F). Threshold lethal temperatures for larvae and juveniles acclimated to temperatures above 10 C (50.0 F)exceed 30 C (86.0 F) in most cases, although temperatures above 35 C (95.0 F) are likely to be lethal to most species.

B.2.2.3 Macroinvertebrates

Laboratory studies of zooplankton thermal tolerance suggest that discharge temperatures in the range expected at the Diablo Canyon Power Plant (up to 30 C or 86 F) are tolerable when exposure times are short, as they are at the Diablo Canyon Power Plant. Lauer et al. (1974) reported that *Acartia tonsa*, a common copepod of California estuaries and to a lesser extent marine waters, can tolerate 15-minute exposures to temperatures as high as 33.5 C (92.3 F). Adams and Price (1974) exposed larval red abalone (*Haliotis rufescens*) to elevated temperature regimes similar to those expected at the Diablo Canyon Power Plant for abalone veligers acclimated to about 17.5 C or 63.5 F (the maximum ambient temperature reported at the Diablo Canyon Power Plant during the period 1972–74). They found that ΔTs as high as 13.3 C (24 F) for 10 minutes were required before significant ($p = 0.05$) increases in mortality were observed. Thermal effects experiments on the fertilization, embryonic development, and settlement of red abalone were completed and reported in the recent thermal effects studies (TERA 1982c). The new tests confirmed the early finding that the veliger stages were tolerant of short-term exposures, up to three hours, to temperatures of 8 to 24.8 C (46 to 76.6 F), but found that the early stages were less thermally tolerant. Fertilization success was very low at temperatures above 22 C (72 F), and embryonic development was normal up to temperatures of 22 C (72 F) with no success at 24 C (75 F). Black abalone, tested in laboratory thermal tolerance experiments similar to those performed with red abalone were found to be more temperature-tolerant than the red abalone's early life stages. The optimum temperature for early development of black abalone from fertilized egg through mid-cephalic tentacle larvae occurred within the range of 10 to 22 C (50 to 72 F). As was found in the red abalone tests, the later larval stages of the black abalone are more thermally tolerant than the earlier embryonic stages. The laboratory data indicate that larvae exposed to temperatures between 8 to 24 C (46 to 75 F) for periods less than three hours demonstrated no increased mortality due to temperature differences. Though the new thermal effects research indicates a lower temperature tolerance among the earlier life stages of the red and black abalone, the no-effect threshold temperatures of these life stages are still above the expected power plant's normal cooling system temperatures.

Short-term thermal tolerances of 13 species of other macroinvertebrates have been investigated and are reported in Table B-3. Safe temperatures reported for short exposures (5-60 minutes) of macroinvertebrates range from 10 to 39 C (50.0-102.2 F). Threshold lethal temperatures for these 13 species exceed 30 C (86.0 F) in most cases. The data presented in Table B-3 support the assertion that many

TABLE B-2

SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR FISH LARVAE AND JUVENILES

Taxon: Common Name	Taxon: Family / Species	Life stage (size in mm)	Temperature (C)	Duration (min)	Thermal Tolerance Limits: Safe	Thermal Tolerance Limits: TL50	Thermal Tolerance Limits: Lethal	Reference
	Clupeidae							
Alewife	*Alosa pseudoharengus*	Yolk-sac larva	14-24	10-60		32-37		EA 1978b
		Larva	22	30		31		EA 1978b
Blueback herring	*Alosa aestivalis*	Juvenile (34)	25	60		34		EA 1978b
		Yolk-sac larva	20-21	(a)			27-41[b]	Schubel et al. 1977
American shad	*Alosa sapidissima*	Juvenile (66)	24	60		33		EA 1978b
		Yolk-sac larva	21	(a)			28-41[b]	Schubel et al. 1977
Atlantic menhaden	*Brevoortia tyrannus*	Larva	10-15	0-40	22-25			Hoss et al. 1974
	Engraulidae							
Northern anchovy	*Engraulis mordax*	Yolk-sac larva	16	5		37		Brewer 1976
		Yolk-sac larva	16	60		32		Brewer 1976
Bay anchovy	*Anchoa mitchilli*	Juvenile (45)	24	60		33		EA 1978b
	Cyprinidae							
Goldfish	*Carassius auratus*	Yolk-sac larva	20	10-30		38-39		EA 1978b
		Larva	23	10-30		37-38		EA 1978b
Spottail shiner	*Motropis hudsonius*	Early juvenile (13-36)	23-26	5-30		36-38		EA 1978b
		Juvenile (20-65)	9-26	60		31-36		EA 1978b
	Ictaluridae							
White catfish	*Ictalurus catus*	Larva	25	10-30		36-37		EA 1978b
		Early juvenile	24-25	10-60		36-38		EA 1978b
		Juvenile (73-77)	8-17	60		31		EA 1978b

(a) 4- to 60-minute exposure followed by gradual cooling to within 1 C of acclimation temperature.

(b) Results inconsistent; in some cases exposures up to 36 C caused no significant increase in mortality.

(c) 0.1- to 6-minute exposure followed by gradual cooling to acclimation temperature.

(d) In one case, winter flounder larvae acclimated to 3 C and exposed to 17 C for 13 minutes incurred mortality significantly different from controls.

TABLE B-2 — *Continued*

SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR FISH LARVAE AND JUVENILES

Taxon: Common Name	Taxon: Family Species	Life stage (size in mm)	Temperature (C)	Duration (min)	Thermal Tolerance Limits: Safe	Thermal Tolerance Limits: TL50	Thermal Tolerance Limits: Lethal	Reference
Brown bullhead	*Ictalurus nebulosus*	Larva	25	10-60		36-38		EA 1978b
		Early juvenile	26	10-30		36-38		EA 1978b
		Juvenile (44)	24	60		36		EA 1978b
	Gadidae							
Atlantic tomcod	*Microgadus tomcod*	Yolk-sac larva	2-5	10-60		25-27		EA 1978b
		Larva	3-8	10-60		23-28		EA 1978b
	Cyprinodontidae							
Striped killifish	*Fundulus majalis*	Juvenile	22	10		39-40		Hoss et al. 1971
	Atherinidae							
Atlantic silverside	*Menidia menidia*	Larva	17-20	13	31-34			Austin et al. 1975
	Percichthyidae							
Striped bass	*Morone saxatilis*	Yolk-sac larva	15-19	10-30		32-36		EA 1978b
		Larva	20-24	10-60		33-36		EA 1978b
		Early juvenile	18-24	10-60		32-37		EA 1978b
		Yolk-sac larva	19-21	(a)	29(b)			Schubel et al. 1977
		Larva (5-13)	17-21	(c)	~32			Kelly and Chadwick 1971
		Early juvenile (20-38)	16-22	(c)	~32			Kelly and Chadwick 1971
		Larva	22	30	29			Coutant and Kedl 1975
White perch	*Morone americana*	Yolk-sac larva	15-22	10-60		31-38		EA 1978b
		Early juvenile	27	10-30		37		EA 1978b
	Percidae							
Yellow perch	*Perca flavescens*	Yolk-sac larva	15	10-30		30-32		EA 1978b
		Larva	15	10-30		32-35		EA 1978b
	Sparidae							
Pinfish	*Lagodon rhomboides*	Larva	15-20	0-40	27-32			Hoss et al. 1974
		Larva	5-10	0-40	20-25			Hoss et al. 1974
	Sciaenidae							
Spot	*Leiostomus xanthurus*	Larva	5-15	0-40	17-27			Hoss et al. 1974

TABLE B-2 — *Continued*

SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR FISH LARVAE AND JUVENILES

Taxon: Common Name	Taxon: Family / Species	Life stage (size in mm)	Temperature (C)	Duration (min)	Thermal Tolerance Limits: Safe	Thermal Tolerance Limits: TL50	Thermal Tolerance Limits: Lethal	Reference
	Pleuronectidae							
Winter flounder	***Pseudopleuronectes americanus***	**Larva**	0-12	13	14-28[d]			Valenti 1974 cited in Schubel et al. 1978
	Bothidae							
Gulf, Summer, Southern Flounder	***Paralichthys* spp.**	**Larva**	5-10	0-40	23-28			Hoss et al. 1974
		Larva	15	0-40	30			Hoss et al. 1974

TABLE B-3

SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR MACROINVERTEBRATES

Group/Species	Acclimation Temperature (C)	Exposure Duration (min)	Thermal Tolerance Limits: Safe	TL50	Lethal	Reference
Amphipoda (amphipods)						
Gammarus spp.	3	30		28		Lauer et al. 1974
	11	5-60		30-33		Lauer et al. 1974
	20	5-60		34-36		Lauer et al. 1974
	26	5-60		37-39		Lauer et al. 1974
Gammarus spp.	26	5-60	34			Ginn et al. 1976
	27	5	38			Ginn et al. 1976
Gammarus spp.	5-25	4[(a)]	10-30			Burton et al. 1976
Gammarus limnaeus	1-3	60	26			Krog 1954
	15-22	60	30-32			Krog 1954
Gammarus tigrinis	25	5-60	33-35			Krog 1954
Gammarus daiberi	25	5-60	33-35			Krog 1954
Gammarus spp.	25	10-60		35-39		EA 1978b
Monoculodes edwardsi	26	5-30		36-37		Lauer et al. 1974
Mysidacea (opossum shrimp)						
Neomysis americana	24-26	5-30		33-34		Lauer et al. 1974
Neomysis americana	24	10-30		31-34		EA 1978b

(a) Constant temperature exposure was followed by gradual cooling to acclimation temperature over 16 minutes.
(b) Reproduction (release of young) was inhibited at temperatures above 28 C.
(c) Some exposures to temperatures greater than the reported safe level were tolerated.
(d) Highest temperature tested resulted in no mortality.

TABLE B-3 — *Continued*

SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR MACROINVERTEBRATES

Group/Species	Acclimation Temperature (C)	Exposure Duration (min)	Thermal Tolerance Limits			Reference
			Safe	TL50	Lethal	
Neomysis americana	5	4[a]	10[d]			Burton et al. 1976
Neomysis awatschensis	14-22	2-6[a]	30-31[b]			Hair 1971
Neomysis mercedis	17-21	10		30-31		EA (unpublished data)
Caridea (shrimps)						
Crangon septemspinosa	16-24	10-60		31-33		EA 1978b
Palaemonetes spp.	5-30	4[a]	10-35[d]			Burton et al. 1976
Brachyura (crabs)						
Callinectes sapidus	15-30	4[a]	20-35[d]			Burton et al. 1976
Rhithropanopeus harrisii	15-30	4[a]	20-35[d]			Burton et al. 1976
Insecta (insects)						
Hydropsyche sp. (caddisfly)	7-24	1-30	28[c]			Sherberger et al. 1977
Isonychia sp. (mayfly)	4-24	1-40	27[c]			Sherberger et al. 1977
Chaoborus sp. (midge)	25	30	39			NYU 1974b
Chaoborus sp. (midge)	19-26	10-60		39-43		EA 1978b

macroinvertebrates can tolerate short exposure to elevated temperatures in excess of 30 C (86.0 F). In general, lethal threshold temperatures for macroinvertebrates are higher than those for fish eggs and larvae.

B.2.3 Chemical (Biocidal) Stresses

Entrained organisms may be exposed to chlorine when it is intermittently injected into the cooling water flow (a routine maintenance procedure used to control fouling organisms). Average concentration at the condenser inlet is usually less than 0.5 mg/liter total residual chlorine. Organisms entrained during chlorination are exposed to chlorine for periods ranging from a few seconds to several minutes.

The effects of short exposures to chlorine on freshwater and marine organisms have been extensively reviewed (Brungs 1973; Mattice and Zittle 1976; Morgan and Carpenter 1978; Envirosphere Company 1978, 1979). Chlorine tolerance has been shown to vary widely among species of aquatic organisms. The extent of this variability has made it difficult to establish chlorine criteria to protect aquatic life.

Mattice and Zittel (1976) were the first to review the literature and organize the chlorine toxicity data to provide models for estimating exposure-dependent threshold lethal concentrations for the most sensitive marine and freshwater organisms. Envirosphere Company (1978, 1979) subsequently refined and updated the Mattice and Zittel models. Using the Envirosphere Company models, the effects of specific power plant chlorine exposures can be predicted. For example, for an exposure of 5 minutes, the predicted threshold lethal concentration is 0.34 mg/liter total residual chlorine (TRC) for marine organisms and 0.99 mg/liter TRC for freshwater organisms. As exposure duration increases to 60 minutes, the predicted threshold lethal concentrations decrease to 0.14 mg/liter TRC for marine organisms and 0.25 mg/liter for freshwater organisms. If a specific chlorine exposure exceeds the lethal threshold, mortality of entrained organisms can be expected. The amount by which the exposure exceeds the lethal threshold will determine the extent of the resulting entrainment mortality.

B.3 Review of Field Studies Pertinent to Entrainment Survival

Discussed in this section are pertinent results of entrainment survival studies conducted at PG&E power plants and at plants outside of the PG&E system. Cooling water samples were withdrawn from the discharge of a power plant and from a suitable control area, usually the plant intake. Entrainment mortality was estimated by comparing the proportions dead in the discharge and control samples, initially or at the end of the delayed-effects observation period (to 96 hours).

B.3.1 Entrainment Survival Studies at PG&E Plants

Entrainment survival studies have been conducted at seven PG&E power plants located in California. Studies occurred during 1971 and 1972 at the Humboldt, Potrero, Moss Landing, and Morro Bay power plants (Icanberry and Adams 1974), during 1977 at the Diablo Canyon Power Plant (Wilson 1977), and during 1978-79 at the Potrero, Contra Costa and Pittsburg power plants (PG&E 1980a,b,c).

The results of entrainment survival studies conducted during 1971-72 are summarized below:

	Power Plant									
	Humboldt Bay		Potrero		Moss Landing		Morro Bay		Combined Data	
Taxonomic Category	Total #	% Mortality	Total #	% Mortality	Total #	% Mortality	Total #	% Mortality	Total #	% Mortality
Adult copepods	3692	6.38	2878	0.19	2283	13.01	2799	5.80	11652	6.20
Immature forms[a]	1468	0.48	2845	0.14	2543	4.78	1911	3.33	8767	2.15
Soft-bodied forms[b]	115	2.71	59	4.76	261	13.22	330	0.00	765	1.34
Hard-bodied forms[c]										

(a) Category includes copepodites, copepod nauplii and barnacle nauplii.

(b) Category includes polychaete larvae, phoronid larvae, trochophore larvae, etc.

(c) Category includes crustacean larvae, mysids, euphausids, etc.; they were not present in enough numbers for accurate estimates of mortality.

Mortality differences between the intake and discharge at the four plants averaged 6 percent. Adult copepods were most abundant in the samples and experienced the highest overall mortality. Soft bodied forms were least abundant, however they incurred the least mortality. Adult copepods, composing 55 percent of the zooplankton sampled, sustained a average net mortality of 5.8 percent. Immature copepods and barnacle nauplii, composing 38 percent of the zooplankton, sustained an average 3.3 percent net mortality. Meroplanktonic forms other than barnacle nauplii constituted a minor portion of the entrained zooplankton (less than 5 percent), and their survival was high. Crab larvae (zoeae) sustained negligible entrainment mortality.

During 1977, the mechanical effects of entrainment on zooplankton were examined by PG&E biologists at the Diablo Canyon Power Plant during periods when circulating water pumps were in operation but no thermal component was present (Wilson 1977). Percent mortality of all zooplankton grouped together in discharge samples was less than 4 percent. This mortality level was not significantly ($p=0.05$) less than that observed in intake (control) samples. This suggests that mechanical effects of entrainment are minimal at the Diablo Canyon Power Plant.

During the 1978-1979 PG&E studies, both control and discharge samples were collected using high-capacity pumps; and live fish larvae were held for 96 hours to allow detection of any delayed effects of entrainment. At the Potrero Power Plant, entrainment survival of Pacific herring larvae was estimated to be 79 percent. Ninety-five percent confidence limits on the true proportion surviving placed the range of survival at 63-95 percent. No delayed effects of entrainment were detected. Survival of larvae collected from the intake and discharge did not differ significantly over the 96-hour observation period. Discharge temperatures during the study did not exceed 20 C (68.0 F).

Results of the 1978-1979 entrainment survival studies at the Pittsburg and Contra Costa power plants indicate that at discharge temperatures below 30 C (86.0 F), survival is high (Table B-4). Survival of striped bass larvae and early juvenile stages at temperatures less than 30 C (86.0 F) ranged from 60 to 81 percent at Pittsburg and Contra Costa power plants. Survival of the opossum shrimp, *Neomysis mercedis*, ranged from 72 to 90 percent, and that of gammaridean amphipods ranged from 95 to 96 percent (Table B-4). Survival of all taxa decreased at higher discharge temperatures. Opossum shrimp appeared to be the most sensitive of the three taxa to elevated temperatures.

Stevens and Finlayson (1978) studied entrainment survival of striped bass larvae at the Pittsburg and Contra Costa power plants in 1976, and estimated survival to be 86 percent when discharge temperatures remained at or below 31 C (87.8 F). The high survival observed by Stevens and Finlayson (1978) is consistent with that reported by PG&E (1980a,b).

Kerr (1953) passed 100 live young king salmon and striped bass through a condenser tube of PG&E's Contra Costa Power Plant operating at full load. Young salmon (34-61 mm in length) and striped bass (21-46 mm in length) withstood condenser passage and an 8.9 C (48.0 F) temperature rise for 3 1/2 to 5 minutes with no fatalities after 96 hours.

The above studies indicate that at low discharge temperatures (<30 C; 86.0 F) entrainment survival at the PG&E power plants investigated is high. Survival has been estimated to be high even for Pacific herring, a delicate clupeid species. Clupeids have been shown to be among the taxa most sensitive to entrainment stresses (see Section B.3.2.1). Consequently, the survival of the species not tested is likely to be as high as or higher than that of Pacific herring.

B.3.2 Entrainment Survival at Plants Outside the PG&E System

Entrainment survival studies have been conducted at a variety of freshwater, estuarine, and marine power plants across the United States. EA (1979a) critically reviewed and summarized survival studies concerning ichthyoplankton. The results of that review are presented here, along with a summary of survival studies dealing with macroinvertebrates.

B.3.2.1 Ichthyoplankton

Ichthyoplankton entrainment survival studies conducted with 21 taxa at 11 different power plants, six on freshwater systems, three on brackish-water systems, and two on marine systems, are summarized in Table B-5. The entrainment survival estimates in Table B-5 represent, for the most part, survival of physical entrainment stresses. As indicated in the table, in some cases it was not possible to distinguish

TABLE B-4

ENTRAINMENT SURVIVAL ESTIMATES FOR STRIPED BASS LARVAE, OPOSSUM SHRIMP, AND GAMMARIDEAN AMPHIPODS AT THE PITTSBURG AND CONTRA COSTA POWER PLANTS

		Survival (%)			
		Pittsburg		Contra Costa	
Taxon	Discharge Temperature (C)	Units 1-4	Units 5-6	Units 1-5	Units 6-7
Striped bass (*Morone saxtilis*)	<30	62	60	81	79
	30-31.9	31	43	35	42
	32-33.9	0(a)	23	21	25
	≥34	0(a)	—	5	5
Opossum shrimp (*Neomysis mercedis*)	<30	—	90	—	72
	30-31.9	—	28	—	46
	32-33.9	—	0	—	0
	≥34	—	0	—	0
Gammaridean amphipods	<30	—	96	—	95
	30-31.9	—	100	—	88
	32-33.9	—	41	—	79
	≥34	—	21	—	16

(a) Low sample size — estimates imprecise.

Note: (—) indicates no data available.

TABLE B-5

ICHTHYOPLANKTON ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PG&E SYSTEM

Power Plant	Waterbody	Salinity	Taxon		Life Stage Length (mm)	Survival (%)[a]	Reference
			Common Name	Family or Species			
Connecticut Yankee	Connecticut River	Fresh	Herrings	Clupeidae	(<15)	29	Marcy 1976
					(>20)	13	
Bowline Point	Hudson River	Brackish	Stripped bass	*Morone saxatilis*	Larva	88	EA 1978a
					Juvenile	90	
			White perch	*Morone americana*	Larva	82	EA 1978a
					Juvenile	80	
			Herrings	Clupeidae	Larva	77	EA 1978a
			Atlantic tomcod	*Microgadus tomcod*	Yolk-sac larva	92	EA 1978a
					Larva	54	
			Silversides	*Menidia* spp.	Larva	43[b]	EA 1978a
Roseton	Hudson River	Fresh	Striped bass	*Morone saxatilis*	Larva	60	EA 1978g
					Juvenile	100	
			White perch	*Morone americana*	Larva	51	EA 1978g
			Herrings	Clupeidae	Larva	29	EA 1978g
			Atlantic tomcod	*Microgadus tomcod*	Yolk-sac larva	31[c]	EA 1978g
			Tesselated darter	*Etheostome olmetedi*	Larva	98[b]	EA 1976b, 1978f
			Minnows	Cyprinidae	Larva	89	EA 1976b, 1978f
Lovett	Hudson River	Brackish	Striped bass	*Morone saxatilis*	Larva	75	EA 1978d
			White perch	*Morone americana*	Larva	74	EA 1977, 1978d
			Herrings	Clupeidae	Larva	57	EA 1978d
Danskammer Point	Hudson River	Fresh	Striped bass	*Morone saxatilis*	Larva	95	EA 1976a
			White perch	*Morone americana*	Larva	100	EA 1976a
			Herring	Clupeidae	Larva	56	EA 1976a
			Minnows	Cyperinidae	Larva	52	EA 1976a

TABLE B-5 — *Continued*

ICHTHYOPLANKTON ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PG&E SYSTEM

Power Plant	Waterbody	Salinity	Taxon: Common Name	Taxon: Family or Species	Life Stage Length (mm)	Survival (%)[a]	Reference
Indian Point	Hudson River	Brackish	Striped bass	*Morone saxatilis*	Yolk-sac larva	63	EA 1978c
					Larva	85	
			White perch	*Morone americana*	Larva	77	EA 1978c
				Morone spp.	Larva	86[d]	Lauer et al. 1974
			Herrings	Clupeidae	Larva	40	EA 1978c
Port Jefferson	Long Island Sound	Salt	Winter flounder	*Pseudopleuronectes americana*	Larva	100	EA 1978e
			Sand lances	*Ammodytes* spp.	Larva	27	EA 1978e
			American eel	*Anguilla rostrata*	Juvenile	100	EA 1978e
Brunswick	Cape Fear Estuary	Salt	Bay anchovy	*Anchoa mitchilli*	—	27[b][d]	Copeland et al. 1975
			Spot (Croaker)	*Leiostomus xanthurus*	—	75[b][d]	Copeland et al. 1975
			Atlantic croaker	*Micropogon undulatus*	—	64[b][d]	Copeland et al. 1975
			Gobies	*Gobionellus* spp.	—	60[b][d]	Copeland et al. 1975
			Gobies	*Gobiosoma* spp.	—	35[b][d]	Copeland et al. 1975
			Silversides	Atherinidae	—	27[b][d]	Copeland et al. 1975
Quad Cities	Mississippi River	Fresh	Freshwater drum	*Aplodinotus grunniens*	Yolk-sac larva to juvenile	62	Restaino et al. 1978
			Minnows	Cyprinidae	Yolk-sac larva to juvenile	51	Restaino et al. 1978
			Carp	*Cyprinus carpio*	Larva	79	Restaino et al. 1978
			Suckers	Catostomidae	Larva	60	Restaino et al. 1978
Monticello	Mississippi River	Fresh	Fathead minnow	*Pimephales promelas*	(30-60)	78	Knutson et al. 1976
Ginna	Lake Ontario	Fresh	Alewife	*Alosa pseudoharengus*	(<15)	23	EA 1979b

(a) Survival in absense of thermal effects. Values represent annual estimates, or means of annual estimates for those studies conducted for more than one year.
(b) Some thermal effects may be included.
(c) Represents weighted average of 22 percent for two circulating pumps operating and 77 percent for three circulating pumps operating.
(d) Survival recomputed using Equations B-1 and B-2 in text.
Source: EA 1979a.

whether or not thermal stresses were present. The entrainment survival estimates in Table B-5 pertain to fish larvae and early juvenile stages only; no survival data pertaining to fish eggs are available.

The entrainment survival estimates in Table B-5 range from a low value of 13 percent estimated for freshwater clupeids (>20 mm) entrained at the Connecticut Yankee Power Plant (Marcy 1976) to a high of 100 percent for striped bass juveniles at Roseton Power Plant (EA 1978g), white perch larvae at Danskammer Point Power Plant (EA 1976a), and winter flounder larvae and American eel juveniles at Port Jefferson Power Plant (EA 1978e). Nearly three-quarters of the survival estimates in Table B-5 exceed 50 percent.

Table B-6 summarizes entrainment survival data by taxonomic category. Of the 13 families represented in this listing, Clupeidae,* Engraulidae, Atherinidae, and Ammodytidae appear relatively sensitive to entrainment (23-43 percent survival). Entrainment survival estimates for the Gadidae, Gobiidae, and Catostomidae were intermediate (35-60 percent), and those for Anguillidae, Cyprinidae, Percichthyidae, Percidae, Sciaenidae, and Pleuronectidae were high (62-100 percent).

The results of field studies of entrainment survival reported in Tables B-5 and B-6 demonstrate that entrainment survival under certain plant operating conditions for hardy species may be as high as 100 percent. Survival has been shown to vary widely among species.

B.3.2.2 Macroinvertebrates

Macroinvertebrate entrainment survival studies conducted with 10 taxa at six different power plants, three on freshwater systems and three on brackish water systems, are summarized in Table B-7. The entrainment survival estimates presented in Table B-7 represent, in most part, survival of physical entrainment stresses, although, as noted in the table, in some cases thermal effects may have been included.

Entrainment survival estimates presented in Table B-7 range from 73 percent for *Monoculodes edwardsi* entrained at Lovett Power Plant to 100 percent for *Gammarus daiberi* entrained at Bowline Point, *Neomysis americana* entrained at Lovett, and *Chaoborus punctipennis* entrained at Danskammer Point, three plants located on the Hudson River. Almost three-quarters of the survival estimates reported exceed 90 percent. These data indicate that entrainment survival is high for a variety of macroinvertebrates, and is generally higher than that of larval fish (Section B.3.2.1).

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* Clupeids entrained in a freshwater environment appear to be more vulnerable to entrainment damage than those in brackish water. The median clupeid survival at fresh- and brackish-water sites were 26 and 52 percent, respectively. The range of survival values was 21-56 percent at freshwater sites and 40-77 percent at brackish-water sites.

TABLE B-6

TAXONOMIC SUMMARY OF ICHTHYOPLANKTON ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PG&E SYSTEM

Taxon				Survival[b]	
Order	Common Name	Family Species	N[a]	Median	Range
Anguilliformes		**Anguillidae**	1	100	—
	American eel	*Anguilla rostrata*	1	100	—
Clupeiformes		**Clupeidae**	7	40	21-77
	Alewife	*Alosa pseudoharengus*	1	23	—
		Engraulidae	1	27	—
	Bay anchovy	*Anchoa mitchilli*	1	27	—
Cyprinidontiformes	Silversides	**Atherinidae**	2	35	27-43
		Menidia spp.	1	43	—
Cypriniformes		**Cyprinidae**	4	78	51-89
	Fathead minnow	*Pimephales promelas*	1	78	—
	Carp	*Cyprinus carpio*	1	78	—
	Suckers	**Catostomidae**	1	60	—
Gadiformes		**Gadidae**	2	52	31-73
	Atlantic tomcod	*Microgadus tomcod*	2	52	31-73

(a) Number of power plants for which estimates have been made.
(b) Average of all life stages.
Source: EA 1979a.

TABLE B-6 — *Continued*

TAXONOMIC SUMMARY OF ICHTHYOPLANKTON ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PG&E SYSTEM

Taxon: Order	Common Name	Family Species	N[a]	Survival[b] Median	Range
Perciformes	Sand lances	**Ammodytidae**	1	27	—
		Ammodytes spp.	1	27	—
	Gobies	**Gobiidae**	1	48	35-60
		Gobionellus spp.	1	60	—
		Gobiosoma spp.	1	35	—
		Percichtyidae	5	82	51-100
	White perch	*Morone americana*	5	77	51-100
	Striped bass	*Morone saxatilis*	5	80	74-95
		Morone spp.	1	86	—
Perciformes		**Percidae**	1	98	—
	Tessellated darter	*Etheostoma olmstedi*	1	98	—
		Sciaenidae	2	64	62-75
	Freshwater drum	*Aplodinotus grunniens*	1	62	—
	Spot (croaker)	*Leiostomus xanthurus*	1	75	—
	Atlantic croaker	*Micropogon undulatus*	1	64	—
Pleuronectiformes		**Pleuronectidae**	1	100	—
	Winter flounder	*Pseudopleuronectes americanus*	1	100	—

TABLE B-7

MACROINVERTEBRATE ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PG&E SYSTEM

Power Plant	Waterbody	Salinity	Taxon	Survival [(a)] Percent	Reference
Fort Calhoun	Missouri River	Fresh	Total drifting macroinvertebrates	88[(b)(c)]	Carter 1978
			Ephemeroptera	92[(b)(c)]	Carter 1978
			Hydropsychidae	92[(b)(c)]	Carter 1978
			Other Trichoptera	92[(b)(c)]	Carter 1978
			Chironomidae	84[(b)(c)]	Carter 1978
			Other Diptera	87[(b)(c)]	Carter 1978
			Other organisms	88[(b)(c)]	Carter 1978
Roseton	Hudson River	Fresh	*Gammarus daiberi*	96	Cannon et al. 1978
			Chaoborus punctipennis	96	Cannon et al. 1978
Bowline Point	Hudson River	Brackish	*Gammarus daiberi*	100	Cannon et al. 1978
			Monoculodes edwardsi	92	Cannon et al. 1978
			Chaoborus punctipennis	98[(c)]	Cannon et al. 1978
			Neomysis americana	94	Cannon et al. 1978
Danskammer Point	Hudson River	Fresh	*Gammarus daiberi*	88	Cannon et al. 1978
			Chaoborus punctipennis	100	Cannon et al. 1978
Lovett	Hudson River	Brackish	*Gammarus daiberi*	96	Cannon et al. 1978
			Monoculodes edwardsi	73	Cannon et al. 1978
			Chaoborus punctipennis	99	Cannon et al. 1978
			Neomysis americana	100	Cannon et al. 1978
Indian Point	Hudson River	Brackish	*Gammarus* spp.	99[(b)]	Lauer et al. 1974
			Monoculodes edwardsi	98[(b)]	Lauer et al. 1974
			Neomysis americana	92[(b)]	Lauer et al. 1974

(a) Survival in absence of thermal effects. Values represent annual estimates, or means of annual estimates for those studies conducted for more than one year.

(b) Entrainment survival recomputed using Equations B-1 and B-2 in text.

(c) Some thermal effects may be included.

B.4 Summary and Conclusions

Entrainment survival is influenced by physical, thermal, and chemical (biocidal) stresses potentially incurred by entrained organisms during cooling water systempassage. The effects of some of these different stresses have been isolated in laboratory studies.

Entrained organisms appear to be tolerant of the physical stresses associated with condenser passage. Pressure increases at the circulating water pumps are not expected to cause significant entrainment mortality, but large pressure decreases (greater than about one atmosphere) across the condensers may damage entrained organisms, particularly larval fish.

Discharge temperatures greater than 30 C (86.0 F) generally reduce entrainment survival, although thermal tolerance varies widely among species, and among life stages within species. Some species acclimated to temperatures of 26 C (78.8 F) or less are capable of tolerating short exposures (5-60 minutes) to elevated temperatures as high as 40 C (104.0 F). Entrainment survival of fish larvae and macroinvertebrates at PG&E power plants has been shown to be high when discharge temperatures remain below 30 C (86.0 F). Survival of striped bass larvae at the Pittsburg and Contra Costa power plants ranged from 60 to 81 percent. Survival of opossum shrimp, *Neomysis mercedis*, ranged from 72 to 90 percent, and that of gammaridean amphipods from 95 to 96 percent. Survival of Pacific herring, a sensitive clupeid species, averaged 79 percent at the Potrero Power Plant.

Entrainment survival may be reduced during condenser chlorination. Studies have shown that the maximum chlorine concentration tolerated by a given species or life stage is a function of the exposure duration. Chlorine tolerance varies widely among species, the maximum concentrations tolerated by the most sensitive marine and freshwater species are 0.34 and 0.99 mg/liter total residual chlorine (TRC) respectively, when exposure duration is five minutes. But as exposure duration increases to 60 minutes, the maximum concentrations tolerated by the most sensitive marine and freshwater organisms decrease to 0.14 and 0.25 mg/liter TRC, respectively.

Field studies of entrainment survival demonstrate that entrainment survival of hardy species may be as high as 100 percent. Survival has been shown to vary widely among species. The families of fish whose larvae are most sensitive include Clupeidae, Engraulidae, Atherinidae, and Ammodytidae. Survival of entrained macroinvertebrates is as high as or higher than that of fish larvae. No field data are available on survival of entrained fish eggs, however, laboratory data suggest that the fish egg mortality is minimized when exposure durations are limited to 10 minutes at temperatures <30 C (86.0 F).

B.5 References

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APPENDIX C

LIFE HISTORY CHARACTERISTICS AND POPULATION ABUNDANCE INFORMATION FOR SELECTED MACROINVERTEBRATE AND FISH TAXA

The following sections briefly discuss life history characteristics and general trends in population abundance for selected macroinvertebrates and fish taxa susceptible to entrainment or impingement at the Diablo Canyon Power Plant. Additional information on the species and aquatic communities of the Diablo Canyon area and adjacent coastal waters is presented in Chapters 2 and 5. Information on entrainment and impingement of selected macroinvertebrates and fish is presented in Chapters 3 and 4.

C.1 Macroinvertebrates

Macroinvertebrates selected as key taxa for consideration were the amphipods, crabs, shrimp, and market squid. These taxa include species which are important elements in the aquatic community food webs and some which are harvested in sport and commercial fisheries.

C.1.1 Amphipods

Amphipods are diverse and abundant shrimp-like crustaceans that occur in nearly all marine habitats. Most are benthic species that periodically (daily and seasonally) migrate into the water column to breed, feed, or disperse. Fecundities are relatively low, in general, but short generation times often result in the production of large numbers of individuals, particularly in summer and fall. Most amphipods are microphagous, feeding on suspended and deposited detritus. They are an important link in the food chain because they are abundant and provide food for many marine animals, including fish, invertebrates, and shorebirds.

Gammarid amphipods (family Gammaridae) were entrained at the Diablo Canyon Power Plant. No amphipods were collected in the impingement samples other than those individuals associated with drift kelp and debris collected in the impingement samples. Gammarid amphipods are typically found in greatest abundance as part of the epibenthic fouling community. Although common in the vicinity of the Diablo Canyon Power Plant, the population abundance and dynamics of Gammarid amphipods in the area are unknown. Amphipods susceptible to entrainment at the plant are thought to be inhabitants of the Diablo Canyon Intake Cove, part of the fouling community colonizing the cooling water intake structure itself, and inhabitants of nearshore coastal waters. The extensive rocky intertidal and shallow subtidal Diablo Canyon Intake Cove and nearshore waters provide excellent habitat to support a large and diverse amphipod community.

In a series of detailed entrainment survival studies conducted with amphipods at the Contra Costa and Pittsburg power plants (Appendix B), mortality for entrained amphipods was approximately 4-5 percent. Similar mortality is anticipated for entrained amphipods at the Diablo Canyon Power Plant, where discharge temperatures very rarely exceed the lethal threshold (approximately 30 C; 86 F Figure 3-22). Although the numbers of amphipods entrained may be high, the survival of amphipods following passage through the cooling water system is also estimated to be high (>90 percent), and therefore the probability of direct impact on their populations and the indirect impact on the aquatic community are low. Any localized changes in the abundance of Gammarid amphipods resulting from entrainment mortality are diminished by the rapid movement of water through the discharge area and mixing in the receiving waters. The short generation times of amphipods, and thus the large numbers of individuals produced, would compensate rapidly for any localized changes. In addition, since the plant cooling water flows represent only a small fraction of the waterbody's volume the potential for impact on the widely distributed amphipod populations is minimal. Although they move into the water column for feeding, breeding, or dispersal, they are either predominantly tube-dwelling or cling to substrates, which reduces their susceptibility to entrainment.

Those amphipods that are lost to entrainment are returned to nearshore coastal waters, where they can still serve as food for predaceous invertebrates and fish. Consequently, the direct impact on amphipod populations and the indirect impact on associated species is probably low. Because of the extensive habitat available for amphipods, their reproductive potential, their broad geographic distributions, the relatively low susceptibility of reproductive adults to entrainment, and the low entrainment mortality, the amphipod populations are considered to be resilient. Entrainment losses, therefore, will not preclude maintenance of the existing population.

C.1.2 Market Squid (*Loligo opalescens*)

The market squid, *Loligo opalescens*, is distributed from British Columbia to Baja California. Although the size of the squid population is unknown, available evidence suggests that population biomass is large throughout its range. Spawning adults support a commercial fishery, but the fishery is restricted to limited geographical areas and is considered to be an under-harvested resource (Frey 1971). The commercial fishery for *Loligo opalescens* is centered in Monterey, where landings in 1976 exceeded 5 million lb (2.3 million kg) (Oliphant 1979). Commercial landings in the Morro Bay – Avila Beach area are substantially less. Commercial landings of market squid at Avila averaged 204 lb (range 21 to 508 lb) between 1980 and 1986 (CDFG unpublished data).

A total of 15 *Loligo opalescens* were collected in impingement samples at the Diablo Canyon Power Plant during the 1-year study (Appendix E). A total of 112 larval squid were collected during the 1-year entrainment monitoring program. On the basis of the low numbers impinged and entrained, it was concluded that operation of the Diablo Canyon Power Plant cooling water system does not preclude maintenance of the existing population or contribute significantly to a reduction in the sustained yield to the commercial fishery.

C.1.3 Shrimp

The bay shrimp, *Crangon nigromaculata*, was selected for consideration in the impact assessment because it is common in bays and nearshore coastal waters and represents an important prey item for many marine fish species. Also considered in this section are caridean shrimp such as the spot prawn *Pandalus platyceros* and the California spiny lobster *Panulirus interruptus*, because of their importance as a sport and commercial fishery resource.

Crangon nigromaculata, referred to as bay shrimp, ranges from northern California to Baja California. It inhabits bays and estuaries and is occasionally found along the open coast to depths up to 175 ft (50 m). It is a migratory estuarine species, capable of active swimming, but is more usually associated with the epibenthic habitat in muddy and sandy areas. *Crangon nigromaculata* is not harvested commercially in the Diablo Canyon-Avila Beach areas. Some individuals are collected by sport fishermen for use as bait, although no records are available on the numbers harvested (Laurent 1987, personal communication). The larval stages are free-swimming, and spend from 2 to 5 months in this planktonic stage before metamorphosing into epibenthic postlarvae (Krygier and Horton 1975). During this planktonic life stage they are susceptible to entrainment into the power plant's cooling water system. As with other invertebrates which have high fecundities and planktonic larvae, the early life stages of bay shrimp have a very high natural mortality rate. Entrainment losses will not have an impact on the population of bay shrimp for the following reasons: bay shrimp are generally abundant and widely distributed; their planktonic larvae are transported throughout the nearshore coastal region by tidal exchange; the population is not subject to intensive sport or commercial fishing pressure; and the early life stages have such high natural mortality.

Pandalus platyceros, the spot prawn, is distributed from Alaska to San Diego, California, in waters more than 150 ft (45 m) deep. Although no information is available on the abundance of *P. platyceros*, it does support a commercial fishery at the port of Morro Bay, which had landings of approximately 10,000 lb per year, (4,500 kg) through 1979, increasing to 49,000 lb (22,000 kg) in 1981. *Pandalus platyceros* are not susceptible to entrainment in large numbers at the Diablo Canyon Power Plant, and none were collected in impingement samples.

The California spiny lobster, *Panulirus interruptus*, supports a sport and commercial fishery in the coastal waters between Point Conception and the Mexican border. The lobsters are generally found in rocky habitats offshore. *Panulirus interruptus* are not entrained in large numbers, and were not collected in impingement samples at the Diablo Canyon Power Plant during the study period.

Although no experimental data are available on the survival of larval shrimp entrained at the Diablo Canyon Power Plant, it is expected that entrainment survival will be similar to that for amphipods and zooplankton, approximately 90 percent at discharge temperatures less than 30 C (86 F).

C.1.4 Crabs

Four groups of crabs were present in entrainment and impingement samples collected at the Diablo Canyon Power Plant: the shore crabs (Grapsidae), the spider and kelp crabs (Majidae), the pea crabs (Pinnotheridae) and the rock crabs (*Cancer* spp.). Of these four taxa, the pea crabs and the rock crabs were most abundant in entrainment samples (Chapter 3), and rock crabs and spider crabs were most abundant in impingement samples. Two taxa were selected for discussion: pea crabs because of their common occurrence in the plankton community, and rock crabs because of their relatively high abundance in both entrainment and impingement collections at the Diablo Canyon Power Plant (Chapter 3).

C.1.4.1 Pea Crabs (Pinnotheridae)

Pea crabs are commensal, living in association with a host organism. Species of pea crabs inhabit the burrows of gobies and burrowing shrimp and the mantle cavity of many bivalves (e.g., mussels, clams). Although the adults are commensal with their benthic hosts, and hence not susceptible to entrainment or impingement, the early zoeae and megalopae are planktonic and widely distributed by tidal and ocean currents. Upon moulting from the megalops stage into the first crab stage, the pea crab leaves the planktonic stage and becomes associated with its host. Adult pea crabs are small, having an average carapace width of approximately 1 cm (0.4 in.) (Pearce 1966). Pea crabs are fecund: Pearce (1966) reports that eggs are almost always present in some stage of development and that within a week after egg deposition new eggs begin to develop in the gonadal tissue.

Pea crabs have a cosmopolitan distribution along both the Pacific and Atlantic coasts of North America, and the coasts of the British Isles, the Persian Gulf, and Japan. They have been collected from the intertidal zone to depths of 250 m (800 ft). Despite the fact that pinnotherids are common and widely distributed, very little is known regarding their population dynamics and abundance. In several studies summarized by Pearce (1966), however, they have been reported to be extremely abundant. The abundance and distribution of planktonic larvae and commensal adults in the Diablo Canyon Power Plant area are poorly known.

The planktonic zoeae and megalopae of pea crabs were the second most numerous Brachyuran collected in entrainment samples at the Diablo Canyon Power Plant (Chapter 3). Data from entrainment survival studies conducted at the Morro Bay Power Plant (PG&E 1973) indicate that entrainment mortality of pea crabs (*Pinnixa* spp.) was less than 4 percent. The significance of the incremental mortality on the early life stages of pea crabs resulting from entrainment at Diablo Canyon Power Plant is unknown, but several life history characteristics suggest that the losses resulting from entrainment will not substantially affect the pea crab population in the vicinity of the power plant. Pea crabs are common and widely distributed along the Pacific coast, and the planktonic larvae, being dispersed by tidal and ocean currents, are capable of rapidly recolonizing available habitat. This fact significantly reduces the risk of a localized population impact. Furthermore, the mature adults, which have a high reproductive potential, are commensal with benthic hosts and hence unaffected by either entrainment or impingement (no adult pinnotherids were collected in the impingement samples). In addition, the natural survivorship of a cohort of planktonic pea crab larvae is low, so very few of the larvae cropped as a result of entrainment would have survived to become adults in nature. Pea crabs are not subject to either sport or commercial fishing harvest. On the basis of these life history characteristics, it was concluded that pea crabs have the ecological assimilative capacity to maintain their existing population in the Diablo Canyon Power Plant region.

C.1.4.2 Cancer Crabs

Two groups of crabs within the genus *Cancer* were considered in assessing the potential impacts of entrainment and impingement losses at the Diablo Canyon Power Plant. The first species considered is the Dungeness crab, also known as the market crab. The second group includes the assemblage of rock crabs collected during the monitoring programs conducted at the plant.

Dungeness Crab

The Dungeness crab, *Cancer magister*, has been reported from Alaska to Southern California, but it is rare south of Point Conception. Adults live in sandy subtidal regions to depths of 50 fathoms (90 m), and juveniles occur in shallow, wave-protected areas having sand or mud bottoms. Dungeness crabs reside in limited abundance in nearshore waters adjacent to the Diablo Canyon Power Plant.

The life history of the Dungeness crab is well known (Frey 1971). Reproduction begins in the spring, when hard-shelled males mate with freshly molted females. Females extrude embryos in the fall and carry them until they hatch in the winter. The newly hatched larvae pass through 5 zoeal and 1 megalops stage before metamorphosing into juvenile crabs. Three to four months of development are required to complete the larval stages: juveniles appear on the bottom in late spring and early summer. Maturity is reached about 18 months after metamorphosis. Maximum age is about six years. Natural predators of Dungeness crabs include fish, octopi, and other crabs.

The Dungeness crab is the focus of a relatively small sport and commercial fishery in the coastal waters near Morro Bay-Avila Beach. The fishery in the area, which is restricted to males, reached its peak in the 1950-1951 season (434,000 lb; 197,000 kg) and then declined drastically in 1961-1962 (Frey 1971). The commercial fishery, which is centered in the offshore coastal waters, decreased markedly in the 1976 season, when landings totaled 4 tons with an estimated value of $8,000 (Oliphant

1979). An average of 28,600 lb (12,900 kg) of adult Dungeness crabs were landed annually at Morro Bay between 1973 and 1981. The general trend in the offshore commercial Dungeness crab fishery has been one of long-term cyclic fluctuations.

The major portion of the adult population is found in northern California coastal waters, where spawning occurs offshore, although a reproducing population does inhabit the Morro Bay-Avila Beach area. The planktonic larvae are transported throughout the coastal zone by tidal and oceanic currents. Because they are planktonic, larval crabs are susceptible to entrainment at the Diablo Canyon Power Plant. In addition, juveniles which inhabit shallow areas are susceptible to impingement. Only one juvenile *C. magister* was collected in the impingement monitoring program.

Crabs entrained at the plant are planktonic zoeae and megalopae, which are widely distributed throughout the coast region by tidal and oceanic currents. No estimates are available on the actual number of larval crabs spawned each year, but the adult female stock is substantial, and each individual female is capable of producing a brood size between 700,000 and 2,500,000 offspring. With such high fecundity, the cropping attributable to entrainment of larval crabs would be undetectable. In addition, spawning occurs offshore, and only a portion of the larval populations is transported inshore, where they would be susceptible to entrainment at the Diablo Canyon Power Plant. The volume of water circulated through the power plant is negligible in comparison with the volume of water in the nearshore coastal environment. Survival of entrained *Cancer* spp. larvae is expected to be high based on results for zooplankton entrainment survival studies conducted at the Diablo Canyon Power Plant (Wilson 1977). Since the cooling water intake of the plant is isolated from the primary spawning and nursery grounds for Dungeness crabs, the potential for impact on the population is further reduced. On the basis of these factors it was concluded that entrainment and impingement of larval and juvenile Dungeness crabs as a result of operation of the Diablo Canyon Power Plant would not preclude maintenance of the existing population and would not result in a reduction in the optimum sustained yield to the sport or commercial fishery in the Morro Bay-Avila area.

Rock Crabs (*Cancer* spp.)

Three species of cancer crabs are sometimes referred to as rock crabs. These are the red crab, *Cancer productus*, distributed from Kodiak, Alaska, to Magdalena Bay, Baja California, the rock crab, *C. antennarius*, which is recorded from Sequim, Washington to Todos Santos Island, Baja California (Gotshall and Laurent 1979), and the yellow crab, *C. anthonyi*, which can be found from Eureka, California to Baja California (Frey 1971).

Because entrained cancer crab larvae were not be identified to species and because all 3 rock crab species have similar ranges and life histories, the potential impacts are discussed for the 3 species as a group. However, *C. antennarius* is the most common of the 3 species in inshore waters off Diablo Canyon. These crabs live in the low intertidal and shallow subtidal regions of bays and outer coastal areas. Although the crabs can be found in a variety of habitats, adults are particularly common around rocks and pilings, and juveniles are known to use both the mudflats and rocky intertidal as nursery grounds. Rock crab larvae provide food for a variety of fishes. Juveniles and adults are prey to fish, octopi, birds, and other *Cancer* spp. Rock crabs are commercially harvested in the Morro Bay-Avila Beach area. They also support a local sport fishery, being taken around piers and jetties with baited nets and traps.

Off California, rock crabs species are abundant as demersal juveniles and adults and as larvae in the plankton. After spending about 4 months as larvae in the plankton (Trask 1970), rock crabs settle in inshore rocky and sandy areas. Vertical migration patterns for early and late larval stages promote seaward and shoreward transport, respectively (Shanks 1986). Maturity and maximum fecundity are reached at approximately ages 1 1/2 and 3 years, respectively. Fecundity may decline in older crabs, and rock crabs older than about 5 or 6 years are very rare. The observed batch fecundity for rock crabs is 400,000 to 2.8 million eggs, and a female may produce more than one batch per year.

There are some rock crabs carrying eggs at any time of the year, but in the vicinity of Point Conception, most egg-carrying females have been observed during winter/spring for *C. antennarius* and during summer for *C. anthonyi* (CDF&G 1982). Cancer crab larvae may be found in the plankton during any season, with the highest densities typically occurring in late winter/spring. The highest midwater and neuston cancer crab densities off Little Cojo Bay, about 40 miles south of the Diablo Canyon Power Plant, occurred in December through June (especially February), while the highest epibenthic densities occurred from December through May (CDF&G 1982).

Because of the wide distribution and long duration of cancer crab planktonic larval stages, and because of the offshore transport of early larval stages, recruitment occurs throughout the nearshore habitat from larvae produced over a wide geographic range.

Standing Stock Comparison

One step in assessing the impacts of entrainment and impingement on rock crab populations is to compare the densities of rock crab larvae collected in the entrainment program with larval densities elsewhere along the coast. If larval densities in the entrained water are no higher than those elsewhere along the coast, it may be concluded that the Diablo Canyon Power Plant area does not provide a unique or unusually productive habitat for cancer crab larvae.

A comparison was made of cancer crab larval densities in the entrainment samples with those in nearshore plankton tows offshore of the Diablo Canyon Power Plant and elsewhere. Cancer crab larval densities in entrainment collections compared with those in the Diablo Canyon Intake Cove on 20 sampling dates from April 22 through October 1, 1986. This comparison shows that the density in the entrainment collections exceeded that in Intake Cove plankton tows on only 6 of 20 sampling dates. A subsequent comparison of average cancer crab larval densities at the Intake Cove and at an inshore station located approximately 600 meters from the Intake Cove were approximately 43,000 and 26,000 per 1,000 m^3, respectively, with the density at the Intake Cove exceeding that at the inshore station in 3 of the 5 pairs of plankton tows. Cancer crab densities in monthly plankton tows at 6 stations off Little Cojo Bay in 1980-81 are summarized below:

Cancer Crab Densities at Six Little Cojo Bay Stations
(larvae/1000 m^3)

	Average Over 12 Months		Peak Month
	Range Among 6 Stations	Range Among 4 Stations Within 1 Mile of Shore	Average Over 6 Stations
Neuston	2,797-125,851	10,822-125,851	~100,000
Midwater	65-20,930	3,146-20,930	~20,000
Epibenthic	1,452-125,217	1,452-125,217	~100,000

Source: CDF&G 1982.

When compared to densities in waters in the vicinity of both the Diablo Canyon Power Plant and Little Cojo Bay average densities of 8,698 per 1,000 m^3 observed at the Diablo Canyon Power Plant are average or below average.

Other cancer crab larval densities are also reported by Shanks (1986) for neuston samples at 4 stations along a line extending seaward off Del Mar. The daytime and night densities (all stages) averaged only 280 and 668 per 1,000 m^3, or approximately 10 percent of the Diablo Canyon Power Plant entrainment densities in the same month of the year (November). The same source reports that in March 1980 cancer crab larval densities in the neuston off Dana Point for all stages combined varied diurnally from 0 to about 4,000 per 1,000 m^3 at a station about 20 miles offshore and from 0 to about 200,000 per 1,000 m^3 offshore at the 500 m isobath.

These data further suggest that densities of larval cancer crabs in the cooling waters of the Diablo Canyon Power Plant and vicinity are not usually high, compared to larval crab densities at other nearshore coastal locations.

Entrainment and Impingement Impacts on the Adult Population

The second step in evaluating potential impacts of entrainment and impingement is to estimate the equivalent adults that could have been produced. The expected number of equivalent adults that could have been produced by a given number of entrained larvae equals the number of adults whose expected lifetime reproduction would produce exactly that number of larvae, of the same age, assuming that population size and age-specific mortality and fecundity rates are relatively stable. The additional equivalent adults represented by impingement (97 percent juveniles) equals the number of impinged juveniles multiplied by the average survival rate from juvenile to adult. Lack of precise knowledge regarding the survival rates of all rock crab life history stages makes equivalent adult estimates uncertain, so that conservatively high estimates of equivalent adults were derived as described below.

A conservative (high) estimate of equivalent adults lost requires underestimating the expected lifetime reproduction per adult, so that the number of adults required to produce a given number of larvae is overestimated. Rock crab females produce between 400,000 and 2.8 million eggs per batch. Fecundity is lowest at first maturity, about age 1 1/2 years, peaks at about age 3, and then declines. Due to multiple spawning, the average number of batches per year is somewhat greater than 1, but very few rock crabs live longer than 5 or 6 years.

A low estimate of lifetime reproduction can be achieved by assuming that each female produces only 1 batch of eggs per year and ignoring reproduction beyond age 3 1/2, i.e., assuming that any female can produce at most only 3 batches of eggs, one each at ages 1+, 2+, and 3+, respectively. The sizes of these three batches are assumed to be 400,000 (the minimum), 1.6 million (half-way between the minimum and the maximum), and 2.8 million eggs. Since up to 25 percent egg mortality has been observed in *C. magister* due to growth of epibiotic bacterial filaments (Fisher 1976), the assumed batch sizes are converted to hatching larvae by multiplying by 0.75, giving larval hatches per batch of 300,000, 1.2 million, and 2.1 million for females of ages 1+, 2+, and 3+, respectively.

Since survival of adult rock crabs is not well known, a conservative estimate of 10 percent per year is used. This annual adult survival rate estimate plus the estimates of hatching larvae for 3 years of egg batches make it possible to calculate a conservative (low) estimate of expected lifetime production of hatching larvae by a newly mature (about 50 mm carapace width at 1 1/2 years old) female rock crab as:

$$300{,}000 + (1.2 \text{ million} * 0.1) + (2.1 \text{ million} * .01)$$

or about 440,000. Assuming a sex ratio of 1:1, this yields an estimate of 220,000 hatching larvae per newly mature adult. Even if only one of every 220,000 hatching larvae survives from hatch to maturity (to become an equivalent adult), it may still take fewer than 220,000 entrained larvae to represent a single newly mature adult, since some of the larval mortality will have occurred before rather than after entrainment. A conservative estimate of the number of equivalent adults represented by entrainment therefore requires a low estimate of survival from hatch to the typical age/size of entrainment, i.e., a high estimate of post-entrainment survival.

A minimum estimate of survival through the approximately 120-day larval period is 1/220,000, since this would be the survival rate if all pre-adult mortality occurred in the larval stages and there was no juvenile mortality. Assuming that the daily survival rate of larvae is the same for all larval stages the daily larval survival rate, S, is calculated as:

$$S^{120} = 1/220{,}000$$

$$S = 0.9026$$

Based on examination of a subsample of entrained cancer crab larvae it was determined that virtually all of the entrained cancer crab larvae were first or second instar larvae (Zoea I and II). Therefore, assuming a constant daily larval survival rate of 90.26 percent, the minimum estimated survival rate from hatch through age 30 days (a conservatively high estimate of the duration of instar I plus half of instar II) is 0.0462, in which case every 10,164 entrained larvae represent one equivalent adult. Assuming an entrainment survival rate of 90 percent for rock crab larvae, the estimated number of equivalent adult rock crabs lost as a result of entrainment at the Diablo Canyon Power Plant is 0.219 million.

To express the adults represented by entrained larvae as the number of adults entering the crab fishery (carapace width about 100 mm, age about 3 years) rather than crabs at first maturity (carapace width about 50 mm, age about 1 1/2 years), the above estimates must by decreased by 1 1/2 years of adult mortality. Thus if annual adult survival is assumed to be 10 percent, the numbers of equivalent adults of fishery entry size equals only about 3 percent of the numbers of equivalent newly mature adults. The equivalent loss of adult rock crabs entering the fishery is 6,600 individuals assuming a 90 percent survival rate for crab larvae entrained at the Diablo Canyon Power Plant.

The estimated equivalent adults represented by annual entrainment of larvae can be added to the equivalent adults represented by annual impingement of juveniles. This estimate is uncertain because information on juvenile survival rates is lacking. Since about 65 percent and 85 percent of the impinged cancer crabs had carapace widths less than 20 and 30 mm (Figure 4-6), respectively, it is assumed that these crabs had, on the average, between 1/2 and 1 year before reaching maturity. A maximum estimate of their survival over this period is 30 percent. Assuming a 30 percent survival rate, the estimated number of rock crabs impinged in a year, 97 percent juveniles, represent 2,955 newly mature adults.

A maximum estimate of the total equivalent newly mature adults represented by one year's entrainment, assuming 90 percent survival, and impingement is approximately 222,000 newly mature adults or about 6,600 adults of fishery entry size. Estimated entrainment losses represent the largest and most uncertain contribution to these estimates. It is likely that annual adult survival is greater than 10 percent (giving greater lifetime egg production), that adult females average more than one batch per year, that a significant percentage of females produce more than three egg batches over their lifetime, and that the average entrained larva has been in the plankton less than 30 days and so faces more than 90 days of larval mortality beyond the typical age of entrainment (as well as juvenile mortality) before attaining maturity.

Entrainment and Impingement Losses Compared to Commercial Catch

For comparison, the commercial catch of rock crabs in areas adjacent to the Diablo Canyon Power Plant over the period of 1980-85 are shown below. The sport catch in the Morro Bay-Avila Beach area is assumed to be considerably less. Commercial rock crab landings in the areas immediately adjacent to the power plant (Blocks 614, 615, 623; Figure C-1) averaged approximately 55,000 rock crab per year over the period 1980-1985. Frey (1971) concluded that because of the wide distribution and lack of commercial appeal, the rock crab resources are not fully exploited in the commercial fishery so that commercial landings may not be a true indicator of population abundance. The estimated equivalent adult loss of 6,600 crabs during the one-year monitoring program for entrainment (assuming entrainment survival) and impingement represents approximately 12 percent of the estimated average annual commercial harvest reported for the areas immediately adjacent to the power plant, and less than 3 percent of the estimated average annual rock crab landings of 218,000 crabs for the Morro Bay-Avila Beach areas combined (Blocks 600-650).

Commercial Catch in Pounds
(in parentheses: number of crabs to nearest 1,000)*

	Blocks 614, 615, 623	Blocks 607, 608, 616, 622, 624, 632	Blocks 600-650
1980	43,468 (29,000)	44,296 (30,000)	112,601 (75,000)
1981	123,531 (82,000)	44,776 (30,000)	241,306 (161,000)
1982	85,880 (57,000)	28,986 (19,000)	269,349 (180,000)
1983	99,250 (66,000)	30,231 (20,000)	335,374 (224,000)
1984	77,813 (52,000)	100,018 (67,000)	477,246 (318,000)
1985	65,173 (43,000)	317,230 (211,000)	528,194 (352,000)
Mean	82,519 (55,000)	94,256 (63,000)	327,345 (218,000)

* Assuming an average weight of 1.5 lb per crab.

C.2 Fish

Fish taxa selected for detailed consideration in the Diablo Canyon Power Plant impact assessment include northern anchovy (*Engraulis mordax*), white croaker (*Genyonemus lineatus*), cabezon and sculpin (Cottidae), and rockfish (*Sebastes* spp).

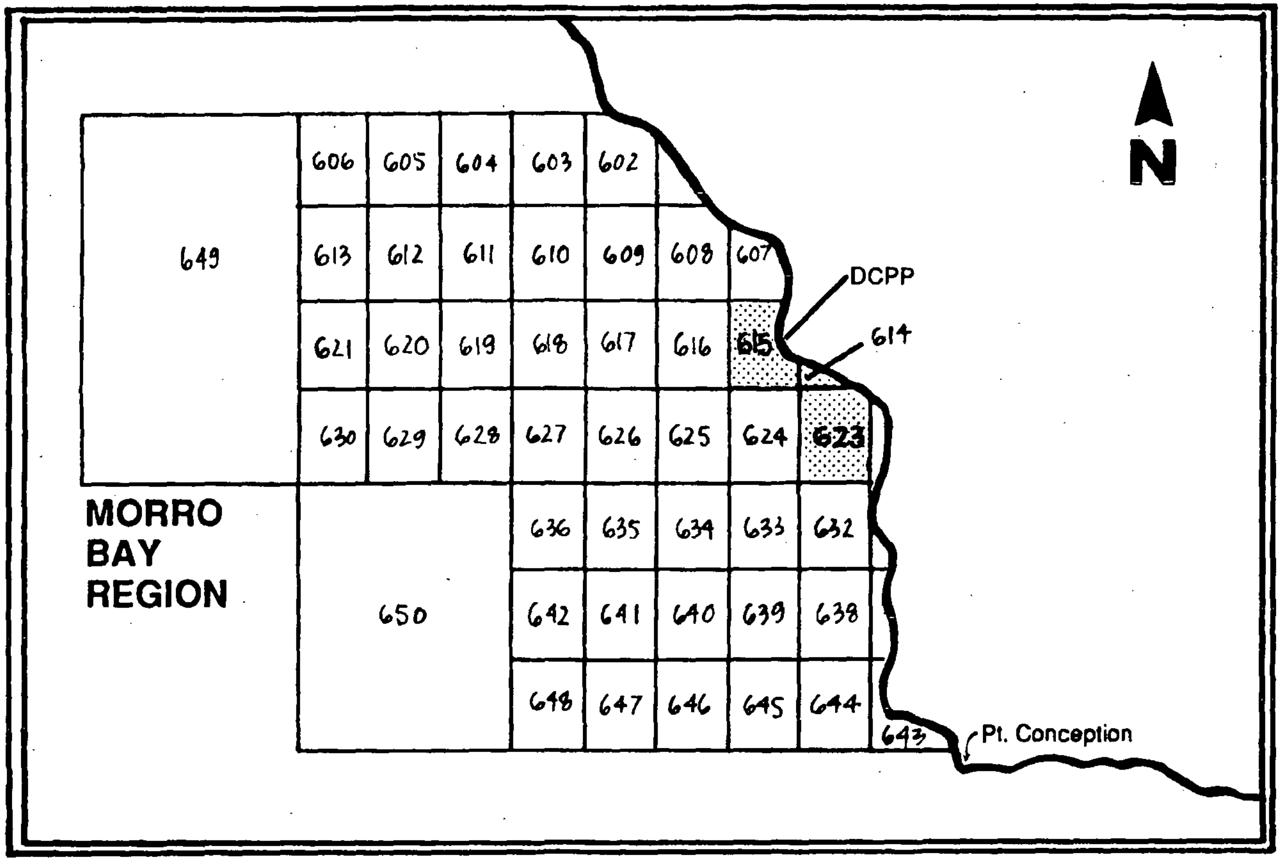

Figure C-1

California Department of Fish and Game Southern California Catch Blocks

C.2.1 Northern Anchovy (*Engraulis mordax*)

The northern anchovy is a planktivorous, pelagic, schooling species found in the Pacific Ocean from Baja California to Alaska (Miller and Lea 1972). Over this range there are several genetically separate subpopulations, each with its own geographic distribution and spawning area. Anchovy offshore of the Diablo Canyon Power Plant belong to the central subpopulation, which has its center of abundance and spawning off southern California and also extends north into waters off central California. Tagging experiments have shown that northern anchovy move back and forth from waters off southern and central California.

The northern anchovy fishery is the largest in California in terms of biomass. The vast majority of landings have been in southern California and can be attributed to the central subpopulation.

Adult northern anchovy are generally found in offshore waters, but spawn closer to the coast. In the winter and spring of 1978-79, plankton tows conducted from San Francisco to Baja California collected various size classes of northern anchovy; the majority were found 40-170 km (25-105 mi) offshore. The vast majority of larvae were collected off southern California. In the Southern California Bight from the Santa Barbara Channel to waters off San Onofre, northern anchovy larvae made up 67 percent of all ichthyoplankton collected in tows from 8-75 m water depths in 1978-84, with the greatest numbers being taken near the 75 m depth contour (Lavenburg et al. 1986).

North of Point Conception in the vicinity of the Diablo Canyon Power Plant, northern anchovy, while less abundant, are still a dominant species in the ichthyoplankton, being typically found at moderate distances from shore. In CalCOFI plankton tows taken from 3-60 mi offshore in the Point Arguello area and encompassing the waters off the Diablo Canyon Power Plant, northern anchovy were the most common ichthyoplankton, composing over 25 percent of ichthyoplankton collected every year from 1953 through 1963 (Ahlstrom 1965a). In plankton tows 300 and 1,500 meters off Diablo Canyon Power Plant in 1974-75, northern anchovy constituted 8.6 percent of all ichthyoplankton (Icanberry et al. 1978). They comprised 11.1 percent and 1.3 percent of ichthyoplankton collected during 1986-87 (TENERA 1988) in evening plankton tows approximately 600 m off the Diablo Canyon Power Plant and in the Intake Cove, respectively. Northern anchovy composed 7 percent of the ichthyoplankton collected in entrainment samples from 1985-86 (Table 3-3).

Northern anchovy have a high fecundity and during spawning they release their eggs to drift with the currents. The early larvae are also planktonic. Egg and larval mortality rates are high.

Standing Stock Comparison

Northern anchovy larval densities in entrainment samples are not unusually high relative to densities in nearby waters and are in fact lower than densities that have been observed further offshore. The annual averages of the monthly densities observed during evening plankton tows in the Intake Cove and offshore in 1986-87 were 5.9 and 22.3 per 1,000 m^3, respectively, versus 9.8 per 1,000 m^3 in the entrainment samples. In 1974-75, the average monthly density at stations 300 and 1,500 m (combined) offshore was 39.4 per 1,000 m^3. Thus not only were densities in the entrainment samples similar to those in nearby inshore waters, but, as noted above, northern anchovy larvae are much more abundant farther offshore and to the south of Point Conception, off southern California. Based on this comparison, it was concluded that the Diablo Canyon Intake Cove and adjacent nearshore coastal waters do not represent a unique biological environment for northern anchovy.

The estimated annual number of northern anchovy larvae in the central subpopulation over the period 1963-1981 varied from 13.3 to 47.5 x 10^{12} larvae, so that the estimated number of larvae entrained in a year represent less than 0.0002 percent of the estimated annual larval population over these years.

Equivalent Adults Represented by Entrained Larvae

The methods used in computing equivalent adult fish represented by northern anchovy larvae entrained at the Diablo Canyon Power Plant are described in this section. The original derivation of the northern anchovy equivalent adult estimation procedures and the population dynamics parameters used in these calculations are based on previous work reported by PG&E (1980). The objective of the equivalent adult approach to power plant impact assessment is to translate the number of young fish cropped by a plant into an equivalent number of adult fish, using estimates of the appropriate natural survival values for the population. Such an estimate has two useful applications:

1. the estimated equivalent adults can be used to relate cropping by the power plant to estimates of adult standing stock, if these are available; and
2. for populations supporting a fishery, the estimated adult equivalents can be compared to cropping associated with the fishery.

The equivalent adult method has been applied to northern anchovy in part, because there is a commercial fishery for northern anchovy in the Morro Bay-Avila Beach area.

A model developed by Goodyear (1978) after Horst (1975) for computing equivalent adult loss associated with larval entrainment is briefly described below, and this provides the foundation for the estimation of equivalent adult losses. The derivation of each term needed for making the calculations is explained, using information obtained during the Diablo Canyon Power Plant monitoring study or from the literature for northern anchovy.

In the model of Horst (1975), the number of equivalent adults lost, N_a, is calculated as

$$N_a = SN \qquad \text{(C-1)}$$

where:

S = probability of survival from larval stage to adult

N = number of larvae that do not survive entrainment.

By treating all larvae as a single class, Horst gives each entrained organism equal weight in computing equivalent adults. This can impart considerable bias into the predictions if survival to adulthood varies among entrained age or size classes. In fact, young larvae have low natural survival rates and contribute fewer equivalent adults than an equal number of entrained older larvae. To compensate for this bias, Goodyear (1978) divided larvae into separate length classes, computed equivalent adults for each length class, and summed to get a more accurate estimate of equivalent adult losses from larval entrainment:

$$N_a = \sum_{k=1}^{n} F_k N_k S_k \qquad \text{(C-2)}$$

where

k = an ordinal number assigned to each length class (classes = 1, 2, 3 ...)

n = total number of length classes considered

F_k = entrainment mortality rate for length class k

N_k = number of organisms entrained of length class k

S_k = survival from length class k to adulthood.

The Goodyear model was applied to northern anchovy length classes at 1 mm increments beginning with length class 5 (5 mm), which includes all entrained larvae ≤ 5 mm long. The estimated number of larvae entrained per year in each length class, N_k, was calculated as the total estimated larval entrainment multiplied by the fraction of anchovy larvae in all entrainment samples combined that belonged to that length class (e.g., 6 percent were in the 12 mm length class). The derivation of the survival rates shown in Table C-1 is summarized below.

TABLE C-1

FACTORS TO COMPUTE EQUIVALENT ADULT (ONE-YEAR OLD) NORTHERN ANCHOVY REPRESENTED BY THE DIFFERENT LARVAL LENGTH CLASSES ENTRAINED AT THE DIABLO CANYON POWER PLANT, OCTOBER 1985 THROUGH SEPTEMBER 1986

Length Class (k)*	Survival From Egg to Length Class k (Se,k)	Survival From Length Class k to Adulthood (Sk)
<5	0.28662	0.00069
6	0.24838	0.00079
7	0.21524	0.00091
8	0.18652	0.00105
9	0.16164	0.00121
10	0.14007	0.00140
11	0.12138	0.00162
12	0.10519	0.00187
13	0.09115	0.00215
14	0.07899	0.00249
15	0.06845	0.00287
16	0.05932	0.00331
17	0.05141	0.00382
18	0.04455	0.00441
19	0.03860	0.00509
20	0.03345	0.00587
21	0.02899	0.00677
22	0.02483	0.00791
23	0.02177	0.00902
24	0.01887	0.01041
25	0.01635	0.01201
26	0.01417	0.01386
27	0.01228	0.01599
28	0.01064	0.01846

TABLE C-1 — *Continued*

FACTORS TO COMPUTE EQUIVALENT ADULT (ONE-YEAR OLD) NORTHERN ANCHOVY REPRESENTED BY THE DIFFERENT LARVAL LENGTH CLASSES ENTRAINED AT THE DIABLO CANYON POWER PLANT, OCTOBER 1985 THROUGH SEPTEMBER 1986

Length Class (k)*	Survival From Egg to Length Class k (Se,k)	Survival From Length Class k to Adulthood (Sk)
30	0.00799	0.02458
31	0.00692	0.02836
32	0.00600	0.03273
34	0.00451	0.04358
35	0.00390	0.05029
36	0.00338	0.05803
38	0.00254	0.07728
50		0.33621 **

* Length in mm.

** For larvae of this size, the survival to adulthood was assumed to equal the estimated annual adult survival rate of 0.33621.

Since in most cases, the data needed to compute S_k directly are unavailable, it is estimated indirectly as:

$$S_k = S_T/S_{e,k} \tag{C-3}$$

where

S_T = survival from egg to adulthood

$S_{e,k}$ = survival from egg to length class k.

The estimation of S_T is derived directly from the population theory for determining reproductive success required to maintain a stable population (Vaughan and Saila 1976). For a population to remain at equilibrium with a sex ratio of 1:1, each female must produce enough eggs through her lifetime so that two individuals will survive to maturity to replace her and one adult male. The survival from egg to adulthood needed to achieve this equilibrium is twice the reciprocal of average lifetime fecundity,

$$S_T = 2/F_a \tag{C-4}$$

where;

F_a = average lifetime fecundity of an adult female.

Substituting Equation C-4 into Equation C-3 yields

$$S_k = 2/S_{e,k}\,(F_a). \tag{C-5}$$

The two terms F_a and $S_{e,k}$ will be derived below.

Average lifetime fecundity is a function of age of recruitment, frequency of spawning, fecundity of each age class, and survival within each age class. Defining the beginning of the adult stage as the age of first spawning, average lifetime fecundity was computed as:

$$F_a = \sum_{j=r}^{m} P_j E_j S_j \qquad \text{(C-6)}$$

where;

j = an ordinal number assigned to each age (year) class

r = age of recruitment into the adult population

m = number of age classes in the population

P_j = fraction of females that are mature in age class j

E_j = average fecundity of mature females in age class j

S_j = survival from recruitment to age class j.

The estimate of average lifetime fecundity, F_a, for northern anchovy is shown below along with values for the terms of Equation C-6. The age of recruitment into the adult population, r, was set at one, because females have been shown to reach sexual maturity at that age. Values for P_j, the fraction of females that are mature in each class, were taken from Clark and Phillips (1952).

Factors Used to Estimate Average Lifetime Fecundity of Northern Anchovy

Age Class j	Standard Length SL_j (mm)	Weight W_j (g)	Eggs per Female E_j	Proportion of Females Mature P_j	Survival from Age 2 to j S_j	Relative Contribution $E_jP_jS_j$
1	121	18.5	21,225	0.167	1.000	3,545
2	133	24.0	27,510	0.292	0.3362	2,701
3	140	27.6	31,665	0.567	0.1130	2,030
4	146	31.0	35,530	0.918	0.0380	1,240
5	152	34.6	39,680	0.975	0.0128	494
6	154	35.8	41,125	0.990	0.0043	175
Average Lifetime Fecundity, F_a						10,185

Northern anchovy are capable of spawning more than once a year, but the average number of spawns is not known. The number used below is two, based on Frey (1971) and on evidence from seasonal abundances of entrained eggs collected at the Potrero Power Plant (PG&E 1980). This estimate was used in computing E_j, the average fecundity of northern anchovy in age class j.

$$E_j = W_j F \tag{C-7}$$

where

W_j = weight (g) per female in age class j

F = a fecundity constant of 574 eggs per gram of female weight (MacGregor 1968)

2 = number of spawns per female per year.

The weight of females was computed from the following power function (Collins 1969):

$$W_j = 0.00003582\,(SL_j)^{2.74285}. \tag{C-8}$$

Values for SL_j were taken from Collins (1969).

Values for S_j were computed as:

$$S_j = e^{-z(j-r)} \tag{C-9}$$

The yearly instantaneous mortality, z, was set at 1.09. Average lifetime fecundity (F_a) for northern anchovy was computed to be 10,185 (PG&E 1980).

Survival from egg to larval length class k, $S_{e,k}$, was estimated with the formula

$$S_{e,k} = H\,(N_k/N) \tag{C-10}$$

where

H = the fraction of eggs that hatch

N_k = the number of larvae of length class k

N_O = initial number of larvae (at hatching).

Northern anchovy entrainment length frequency data collected at the Potrero Power Plant from March 1978 through March 1979 (PG&E 1980) were used to compute values for the survivorship to length class k (N_k/N_O) for use in Equation C-10.

The model used, from Goodyear (1978), was

$$N_k/N_O = e^{-d(L_k - L_O)} \tag{C-11}$$

where

d = mortality rate coefficient

L_k = total length (mm) at length class k

L_O = total length at hatching, set at 2.5 mm.

The mortality rate coefficient, d, was computed as 0.1432 (PG&E 1980).

Substituting Equation C-11 into Equation C-10 yields

$$S_{e,k} = He^{-d(L_k - L_O)} \tag{C-12}$$

The fraction of eggs that hatch into larvae was computed from data provided by Lasker and Smith (1977) as the mean number of 2.5 mm larvae divided by the mean number of eggs collected in CalCOFI surveys from 1955 through 1960 (Lasker and Smith 1977), resulting in a value of H of 0.41.

Equivalent Adult Losses

The estimated equivalent adult losses attributable to larval entrainment during the one year monitoring program conducted at the Diablo Canyon Power Plant assuming an entrainment survival rate of 75 percent is approximately 18,800 fish.

Comparison of Entrainment Loss of Equivalent Adult Northern Anchovy with Adult Standing Crop and Commercial Catch

The estimated equivalent one-year old northern anchovy adults represented by the larvae entrained in one year can be compared to recent estimates of the spawning biomass of the central subpopulation and recent statewide commercial catch statistics for northern anchovy, both of which are shown below.

Estimated Spawning Biomass for the
Northern Anchovy Central Subpopulation

Year	Metric Tons	Millions of Fish*
1980	1,775,000 **	102,011
1981	2,803,000 **	189,392
1982	378,000	33,750
1983	652,000	58,214
1984	309,000	25,707
1985	522,000	36,025

* Assuming that the average weight equals that reported along with each spawning biomass estimate in the various CalCOFI annual reports.

** Using the larval census estimate, which has subsequently been judged to overestimate spawning biomass relative to the egg production method of estimation, which has been used in more recent years.

Source: Spawning Biomass Estimates for the Northern Anchovy, CalCOFI Annual Reports 1982-86.

Short Tons of Northern Anchovy Landed
in California, 1975-84

Year	Short Tons	Millions of Fish*
1975	158,510	10,567
1976	124,919	7,553
1977	111,477	6,741
1978	12,607	762
1979	53,874	3,258
1980	47,339	2,862
1981	57,593	3,482
1982	46,364	2,803
1983	4,740	287
1984	3,203	194

* Assumes an average weight of 15 g per fish.

Source: CDF&G 1985 Annual Report.

The estimated number of equivalent adult northern anchovy represented by entrainment cropping over one year represents less than 0.0001 percent of the spawning central subpopulation, as estimated over the period 1982-85. When compared to the commercial catch, this same number of equivalent adults equals less than 0.01 percent of the annual statewide landings reported over the period 1975-84.

Since only eight northern anchovy were estimated to be impinged during the one-year monitoring program, this species does not appear to be at risk for significant impingement impacts. This is consistent with the more offshore distribution of northern anchovy adults and juveniles relative to some of the non-pelagic inshore species that were most common in impingement samples.

C.2.2 White Croaker (*Genyonemus lineatus*)

White croaker are found from Baja California to British Columbia, typically swimming in loose schools along sandy bottoms at depths up to 175 m (Love et al. 1984). Adults and especially juveniles appear to prefer shallower water less than 60 m. Off southern California, adult white croaker migrate shoreward and spawn in a narrow coastal band of water having shoreward and seaward boundaries of this band at the 8-12 m and 22-36 m isobaths, respectively (Love et al. 1984). Shortly after hatching, white croaker larvae move further inshore and concentrate near the bottom (Barnett et al. 1984; Watson 1982). This behavioral pattern could increase their probability of being entrained. At the end of the pelagic phase, juveniles off southern California move into benthic habitats (Love et al. 1984). White croaker spawn throughout the year, but highest larval densities are typically observed during the winter (Figure 3-11; Love et al. 1984).

White croaker are important in the pier and skiff sport fisheries in central and southern California, but are considered a nuisance by partyboat fishermen. The commercial catch of this species off California has grown to reach 200,000 kg/year (Love et al. 1984; Oliphant 1987, personal communication). From 1980 through 1985, the commercial catch of white croaker in catch blocks 600-650 (Point Piedras Blancas to Point Arguello) has averaged about 17,000 lb per year.

No juvenile or adult white croaker were found in impingement samples from the Diablo Canyon cooling water intake. The nearest inshore sandy bottom habitat is approximately 7 miles to both the north and south, at the extremities of the rocky coastal area that includes the Diablo Canyon Intake Cove.

Larval Standing Stock Comparison

White croaker larvae are rare in offshore plankton tows (Ahlstrom 1965a,b) but are more common inshore, especially along the bottom (Lavenberg et al. 1986; Barnett et al. 1984; Love et al. 1984; Watson 1982; CDF&G 1982).

Numerically, sciaenid larvae other than white sea bass composed less than 0.1 percent of all fish larvae taken in plankton tows along the inshore ends of CalCOFI lines 73 and 77 off points Piedras Blancas and San Luis, respectively (as far in as about 3 miles offshore) from 1950 through 1960 (Ahlstrom 1965a). In contrast, 20.5 percent of all fish larvae taken in inshore plankton tows 300 and 1,500 meters offshore of the Diablo Canyon Power Plant in 1974-75 were sciaenid larvae, presumably mainly white croaker this far north (Icanberry et al. 1978). On an annual average basis, white croaker larvae composed 12.8 percent of all ichthyoplankton in evening plankton tows in both the Diablo Canyon Intake Cove and offshore during 1986-87 (TENERA 1988), and 14 percent of the estimated total ichthyoplankton entrained at the plant (Table 3-3). Plankton tows in the nearshore zone of the Southern California Bight in 1979-80, mostly at shallow (8 and 22 m depth) stations, showed that white croaker larvae composed 11.7, 43.6, and 17.9 percent of total fish larvae in the southern, central, and northern sections of the bight (Love et al. 1984). In contrast, white croaker larvae in plankton tows in the same areas during the period from 1978 through 1984 over a wider range of water depths of (8 to 75 m) constituted 6.6 percent of the larval fish collected (Lavenburg et al. 1986). In summary, results from the Diablo Canyon Intake Cove vicinity agree with the southern California data in showing white croaker larvae to be concentrated inshore of approximately the 22-36 meter isobaths. At the Diablo Canyon Power Plant these isobaths occur approximately 1/2 mile offshore.

The various data sources also agree that white croaker larvae densities peak during the winter. Love et al. (1984) concluded, based on gonosomatic indices and plankton data, that white croaker spawn year-round off southern California, with peak spawning in the winter and spring, especially January through March.

Entrainment monitoring, as well as inshore plankton tow results off the Diablo Canyon Power Plant, showed that white croaker spawn primarily in winter. In 15 months of plankton tows in 1974 and 1975, 300 and 1,500 meters off Diablo Cove, Icanberry et al. (1978) found the highest densities of sciaenid larvae (presumably mainly white croaker) occurred in December. During December the larval sciaenid density was 465 per 1,000 m^3, versus an annual average of 80 per 1,000 m^3. In 1986-87, evening plankton tows in the vicinity of the Diablo Canyon Power Plant showed the peak months for white croaker larval densities to be December through March at the offshore station and January through March in the Diablo Canyon Intake Cove (TENERA 1988). The Intake Cove density peak was most pronounced and presumably reflected inshore migration of larvae. The entrainment monitoring during 1985-86 showed that white croaker larval densities were highest during the period from November through January.

White croaker adults and larvae are widely distributed in inshore areas along the California coast, with the greatest densities and population sizes occurring off southern California. The large numbers and broad distribution of white croaker larvae off southern California are well documented by extensive plankton tow data that permit estimates to be made of the larval population size in this area. Plankton tows from August 1979 through July 1980 indicated annual average white croaker larval densities of 740, 2203, and 411 per 1000 m^3 in the Point Conception-Playa del Rey, Redondo Beach-Laguna Beach, and San Onofre-Mexican border coastal regions, respectively (Love et al. 1984). Oblique plankton tows off San Onofre between 1977 and 1979 showed mean larval white croaker densities of 372 per 1000 m^3 near the bottom and 27 per 1000 m^3 throughout the rest of the water column at inshore sampling locations, and lower densities further offshore (Barnett et al. 1984). Plankton tows at 5 inshore stations (50 m depth and shallower) near Little Cojo Bay in the vicinity of Point Conception showed similarly high concentrations of white croaker larvae (CDF&G 1982). Among the 5 inshore plankton stations near Little Cojo Bay, the average annual larval white croaker densities in 1980-81 ranged from 159 to 1504 per 1000 m^3 throughout the entire water column and from 722 to 4368 per 1,000 m^3 within 21 cm of the bottom. In the same surveys, annual average densities about 1/2 mile offshore throughout the water column and within 21 cm of the bottom, respectively, were 65 and 27 per 1000 m^3, demonstrating the tendencies of the larvae to be concentrated inshore and to move to the bottom as they move inshore.

The high white croaker larval densities off southern California translate into a large estimated population in absolute numbers. Love et al. (1984) estimated the total number of white croaker larvae from Point Conception to Playa del Rey and from Point Conception to the Mexican border to have been 11.5 and 32.0 billion, respectively, during 1979-80. Data from oblique plankton tows from 1978 through 1984 were analyzed by Lavenburg et al. (1986) to estimate the total white croaker larval population in the southern California Bight inshore of the 36 m contour. The peak winter population estimates over six years ranged from about 20 billion to 200 billion.

Farther north off Diablo Canyon Power Plant, larval white croaker densities are highest in inshore waters, but not as high as off southern California. At two stations 300 and 1,500 m off Diablo Cove, the average of 12 monthly larval sciaenid densities (presumably mostly white croaker at this latitude) in oblique plankton tows covering roughly the top half of the water column was 80.4 per 1000 m^3 in 1974-75 (Icanberry et al. 1978). In 1986-87, the average annual larval white croaker larval densities in evening tows was 108.2 per 1000 m^3 in the Diablo Canyon Intake Cove and 46.7 per 1000 m^3 offshore. Although white croaker larvae are spawned in nearshore waters and move even further inshore as they grow, there is no reason to believe that their densities are higher in the Diablo Canyon Intake Cove than in other inshore locations.

In summary, white croaker larvae off the Diablo Canyon Power Plant are apparently concentrated inshore, with peak densities in winter and early spring, similar to the situation off southern California. Densities in the nearshore water off the Diablo Canyon Power Plant are substantially lower than those off Southern California. Inshore densities near the Diablo Canyon Power Plant appear to have been lower in 1986-87 than in 1974-75, and entrainment densities appear to be no higher and perhaps lower than the nearby inshore densities.

Equivalent Adults Represented by Entrained Larvae

It is valuable to assess the impacts of entrainment losses not only by comparing larval densities and numbers in the entrainment samples with those in nearby waters, but also by estimating the numbers of mature adult fish that the entrained larvae would have produced. Mature adult white croaker are defined as fish 1-year-old and older, since the majority of white croaker are mature by the time they reach the average size of a 1 year old fish (Love et al. 1984). Estimated numbers of equivalent adults can then be compared to estimated natural adult densities and population sizes, as well as to sport and commercial catches.

Assuming that the white croaker population is stable, the number of 1 year old equivalent adults the entrained larvae would have produced had they survived is equal to the number of males plus females whose expected lifetime reproductive output would exactly replace (equal) these entrained larvae. This number can be estimated based on adult maturity, fecundity, and survival, plus information on daily larval survival.

Love et al. (1984) report a length versus age relationship for female white croaker from the southern California Bight that fits the following von Bertalanffy equation:

$$\text{total length in cm} = 60.72 * (1\text{-}e^{(-.037*(\text{age in years} + 7.54))})$$

This equation can be used to estimate average lengths of females at ages 1 – 12, where 12 is the maximum known age. Love et al. (1984) also related batch fecundity to length for 44 white croaker via the following equation:

$$\text{batch fecundity} = .000093 * (\text{TL in cm}^{6.08})$$

Applying this relationship to the typical lengths of white croaker females aged 1 through 12 gives the average age-specific batch fecundities presented in the following table.

White Croaker Length, Age, and Batch Fecundity

Age (Years)	Total Length in cm	Batch Fecundity
1	16.5	2,300
2	18.1	4,100
3	19.6	6,700
4	21.1	10,500
5	22.5	15,500
6	23.9	22,300
7	25.3	31,600
8	26.6	37,000
9	27.8	37,000
10	29.0	37,000
11	30.1	37,000
12	31.3	37,000

Since no females over 26 cm in length were included in developing the fecundity-length relationship, all ages corresponding to lengths over 26 cm are assigned the average batch fecundity attributed to 26 cm females. This should underestimate the expected lifetime fecundity of a newly mature female and thus overestimate the numbers of equivalent adults represented by entrained larvae.

Love et al. (1984) give the percent mature for females as approximately 17, 25, 73, 87, 90, 95, and 100 percent for sizes 13, 14, ... 19 cm, respectively (Love et al. 1984, Figure 6). In the estimation of equivalent adults, the maturity-length relationship is converted to a maturity-age relationship by setting the percent mature equal to 80 percent, 95 percent, and 100 percent for ages 1, 2, and 3+, respectively. This approach is conservative (underestimating lifetime reproductive output, thus overestimating equivalent adults), in that it assumes that 80 percent of one-year-old (16.5 cm TL) females are mature, whereas, Love et al. (1984) gives the percent mature as 87 and 90 percent for 16 and 17 cm (TL) females, respectively. It is assumed, as stated by Love et al. (1984), that the number of spawns per year is approximately 18 for fish 1 and 2 years old and approximately 24 for fish 3+ years old.

The instantaneous daily mortality rate"z", for white croaker adults has been estimated as -0.00115, based on size distribution in lampara seine samples (Thomas et al. 1980 cited in Southern California Edison 1982). The formula for decrease in numbers calculated using the instantaneous mortality rate, z, is

$$N(t) = N(0)e^{zt}$$

An instantaneous daily mortality rate (z) of -0.00115 translates to an annual survival rate of approximately 65.7 percent.

The above estimated survival and fecundity rates are used in Table C-2 to derive a conservative (low) estimate of the expected lifetime reproductive output of a newly mature (1 year old, 16.5 cm length) white croaker female as about 535,000 eggs.

If it is assumed that no egg or larval mortality occurred between spawning and larval entrainment and that entrainment survival of white croaker larvae is 75 percent, then the estimated number of larvae entrained per year represents the expected lifetime reproductive output of about 23 one-year old females. If the sex ratio is 1:1, then this is equivalent to 47 one-year-old fish. If it is assumed that there had been a ten-fold decline in the size of a larval cohort between spawning and the average age of entrained white croaker larvae, then the entrained larvae would represent the expected lifetime reproductive output of about 465 one-year-old fish. Greater pre-entrainment mortality than this appears unlikely, since the entrained white croaker larvae averaged only 3 mm in length. Size at hatch is about 2 mm, so the entrained larvae must have been very young. Assuming a daily white croaker larval instantaneous mortality rate (z) of -0.10 (Barnett et al. 1980 cited in Southern California Edison 1982), a ten-fold decline in the larval population would require about 23 days. It would require about 12 days if z is conservatively assumed to be twice as high.

The conservative estimate of 465 equivalent adults represented by larval white croaker entrained at the Diablo Canyon Power Plant can be compared to white croaker adult densities and to sport and commercial catches in nearby CDF&G catch blocks. However, white croaker prefer sandy bottom inshore areas and are not heavily fished in the immediate vicinity of the Diablo Canyon Power Plant. Therefore, the adults are expected to be uncommon in surveys off the Diablo Canyon Power Plant and also in the commercial and partyboat catch records for nearby catch blocks.

The annual sport partyboat and commercial catch of white croaker from 1980 through 1985 within catch blocks 614, 615, and 623 and over adjacent catch blocks 607, 608, 616, 622, 624, and 632 is shown in Table C-3. The greatest commercial catches in the general vicinity of the plant have been in catch block 607, which includes sandy bottom habitat off Morro Bay.

As the landing statistics in Table C-3 indicate, white croaker are generally not sought by commercial or partyboat fishermen in coastal waters adjacent to the power plant site. However, white croaker are sought by the less well-documented skiff and shore fisheries in sandy bottom coastal areas. Miller and Gotshall (1965)

TABLE C-2

EXPECTED LIFETIME REPRODUCTIVE OUTPUT OF A NEWLY MATURE 1-YEAR-OLD (16.5 CM) FEMALE WHITE CROAKER

Age in Years	Spawns per Year (P)	Batch Fecundity (F)	Fraction Mature (M)	Cumulative Survival (S)	P*F*M*S
1	18	2,300	.80	1.00	33,100
2	18	4,100	.95	0.657	46,100
3	24	6,700	1.00	0.432	69,500
4	24	10,500	1.00	0.284	71,600
5	24	15,500	1.00	0.186	69,200
6	24	22,300	1.00	0.122	65,300
7	24	31,600	1.00	0.080	60,700
8	24	37,000	1.00	0.053	47,100
9	24	37,000	1.00	0.034	30,200
10	24	37,000	1.00	0.023	20,400
11	24	37,000	1.00	0.015	13,300
12	24	37,000	1.00	0.010	8,900
Total					535,400

Source: Love et al. (1984)

TABLE C-3

ANNUAL SPORT (PARTYBOAT) AND COMMERCIAL CATCH OF WHITE CROAKER IN THE VICINITY OF THE DIABLO CANYON POWER PLANT

Year	Catch Blocks 614, 615, 623		Catch Blocks 607, 608, 616, 622, 624, 632	
	Sport	Commercial*	Sport	Commercial*
1980	NA	437	NA	32,563
1981	15	63	0	31,038
1982	0	1,233	0	45
1983	0	120	46	0
1984	0	0	0	0
1985	2	0	0	0

* Assuming the average white croaker in commercial landings weighed one pound.

surveyed the sportfish catch from Oregon to Point Arguello in 1957-1961; their results show white croaker to have been the second most important ocean fish in terms of numbers caught, and the most important species in the pier fishery from Yankee Point to Point Arguello. The average annual catch was about 218,000 fish by pier fishing and 289,000 by all methods surveyed (Oregon to Point Arguello), and an estimated 62,000 white croaker were caught off the Avila Beach pier in 1958.

C.2.3 Sculpin and Cabezon (Cottidae)

Sculpins, or cottids (family Cottidae), are bottom dwelling, mostly inshore, fishes typically inhabiting crevices, tidepools, and algae-covered substrate in rocky areas. Along the California coast, most cottids are found from the intertidal zone to depths of 100 feet, although some species may be found at depths of 200 or 300 feet, and a very few occupy even greater depths (Miller and Lea 1972). There are about 45 cottid species off California, but only one, cabezon (*Scorpaenichthys marmoratus*) is large enough to be of economic and sport value (Frey 1971). Other cottids sometimes taken by sport fishermen off California are the red and brown Irish lords (*Hemilepidotus hemilepidotus* and *H. spinosus*), the Pacific staghorn sculpin (*Leptocottus armatus*), and the buffalo sculpin (*Enophrys bison*), of which only Pacific staghorn sculpin are taken with any frequency (Frey 1971).

Burge and Schultz (1973) report observing and collecting cabezon and 20 other species of cottids in the Diablo Canyon Power Plant area in 1970 and 1971. They note that because most cottids are small and cryptic, bottom-dwellers, cottids were both undercounted and difficult to identify to species in surveys. These authors report that the most common subtidal cottid in collections was Artedius corallinus (coralline sculpin), followed by Orthonopias triacis (snubnose sculpin), Scorpaenichthys marmoratus (cabezon), and Artedius lateralis (smoothhead sculpin). In more recent intertidal sampling, the most common sculpin was Oligocottus snyderi (fluffy sculpin), which accounted for 5.9 percent of fish collected in an intertidal distribution study (Kelly et al. 1985).

Most of the cottids in the Diablo Canyon Power Plant vicinity inhabit shallow waters. Twelve of the cottid species identified in the baseline surveys (Burge and Schultz 1973) have been described as inhabiting shallow waters from the intertidal zone to 100 feet, and of these, nine are considered to be common (Miller and Lea 1972). The other nine cottid species identified in the baseline studies have deeper bathymetric limits, although most also occupy shallow depths. Of these nine, two are considered to be common (including cabezon) and six uncommon by Miller and Lea (1972). Two additional species not collected in the baseline studies were collected in entrainment sampling. These are Leptocottus armatus (staghorn sculpin), which is common and found at depths up to 300 feet, and Oligocottus maculosus (tidepool sculpin), which is common and found in shallow and intertidal water.

There is limited information on the life histories of cottids other than cabezon and identification of the larvae to species is difficult. Virtually all of the cottids in the

Diablo Canyon Power Plant area have wide distributions along the Pacific coast. Of the 23 species observed in the Diablo Canyon Power Plant area, 21 have known ranges extending north of California into waters off Oregon (and usually off Alaska) and/or south into water off Baja California.

Cottid eggs are laid in demersal masses in shallow water or intertidally and are sometimes guarded (Tasto 1975; Marliave 1981; Burge and Schultz 1973;). Newly hatched larvae are relatively large and well developed. Although the planktonic period may last several months and cabezon larvae have been found out as far as 200 miles, cottid larvae are generally concentrated in very inshore waters. Cabezon live up to 13 years (Frey 1971), and cabezon up to age 5 or 6 have been collected off the Diablo Canyon Power Plant (Burge and Schultz 1973). However, most other cottids do not live as long, with few individuals older than 3 years having been found off the Diablo Canyon Power Plant and elsewhere (Burge and Schultz 1973; Moring, 1981; Green 1971; Tasto 1975; Freeman et al. 1985).

Most plankton data and observations of spawning adults and recruiting juveniles support the generalization that cabezon spawn in the winter and recruit to demersal inshore populations in spring (O'Connell 1953; Ahlstrom 1965a; Burge and Schultz 1973; Icanberry et al. 1978; TENERA, unpublished data). The CalCOFI tows in the Point Arguello area during 1950-63 reported by Ahlstrom (1965a) showed the months of highest cabezon larval densities to be January-March. In 1986-87 plankton tows off Diablo Cove and also in the Intake Cove itself, peak cabezon larval densities occurred in November through February. The entrainment monitoring in 1985-86 also showed cabezon larval densities to peak in November through February (Figure 3-10). O'Connell (1953) reported that recruitment of juveniles, starting at about 40 mm TL, can occur from early February through late August, and surveys in the Diablo Cove area in 1970 and 1971 detected considerable numbers of cabezon juveniles from May through September (Burge and Schultz 1973).

Off the California coast non-cabezon cottids, consisting of many species, spawn mainly in winter and early spring (Grossman and deVlaming 1984). However, cottid larvae have been relatively common in inshore plankton tows, and present in offshore tows, during all months of the year except the late fall (Ahlstrom 1965a; Icanberry et al. 1978; TENERA unpublished data). This can be explained not only by the large number of co-occurring cottid species, but also by prolonged spawning and/or settlement for some species; for example, the intertidal cottid *Oligomaculosus snyderi* has been found to spawn over a period of 6-8 months (Grossman and deVlaming 1984) and to settle over a period of four months (Freeman et al. 1985) off central California. The CalCOFI plankton tows from 1950-63 reported by Ahlstrom (1965a) showed non-cabezon cottid larvae to be most abundant in March-May, but to be common throughout the year.

In the vicinity of the Diablo Canyon Power Plant, collections from Diablo and North coves indicated spring spawning and summer recruitment in most non-cabezon inter- and sub-tidal cottids (Burge and Schultz 1973), while a more recent intertidal fish study observed most intertidal species spawning in early spring and settling as juveniles in late spring through midsummer (Kelly et al. 1985). At the Diablo Canyon Power Plant, entrainment of non-cabezon cottid larvae in 1985-86 peaked in May and was relatively high from March through August (Figure 3-9), although inshore field densities in 1986-87 were highest during May-August in the intake cove and August-October offshore (TENERA 1988). Collections from Diablo and North coves indicated spring spawning and summer recruitment in most non-cabezon inter- and sub-tidal cottids (Burge and Schultz, 1973). In contrast to the information summarized above, non-cabezon cottid larval densities were highest in January-March at stations 300 and 1500 m offshore from Diablo Canyon Power Plant in 1974-75 (Icanberry et al. 1978). In all cases, the plankton data show some non-cabezon larvae to be present in the plankton throughout the year.

As noted above, cottid larvae tend to have very inshore distributions. Oblique plankton tows along both onshore-offshore transects (0 to 500 m offshore) and alongshore transects, in inshore rocky and sandy bottom habitats off British Columbia, revealed that the larvae of such typical inshore families as cottids, stichaeids, pholids, and gobiesoccids were concentrated inshore and also apparently resisted alongshore transport into the sandy bottom areas within 1 km distance (Marliave 1986). This maintenance of position was attributed to rheotactic and aggregating behavior. Plankton data from the Diablo Canyon vicinity also show the inshore concentration of cottid larvae.

Off central California, CalCOFI plankton tows along station lines 73 (off Point Piedras Blancas) and 77 (off Point San Luis) from 1950 through 1960 showed cabezon to make up only about 0.01 percent of all ichthyoplankton (Ahlstrom 1965a), versus about 1.2 percent in tows 300 and 1,500 meters offshore (combined) in the Diablo Canyon Power Plant vicinity in 1974-75 (Icanberry et al. 1978). Cabezon larvae composed 5.1 percent and 7.4 percent of the ichthyoplankton collected in tows offshore and in the Diablo Canyon Intake Cove, respectively, in 1986-87, and 6.0 percent in the entrainment program conducted at the power plant in 1985-86. Similarly, the 1950 through 1960 tows along CalCOFI station lines 73 and 77 showed that sculpin larvae (excluding cabezon) constituted only about 0.08 percent of all ichthyoplankton, versus about 9.6 percent in tows 300 and 1,500 m off Diablo Canyon Power Plant in 1974-75; 14.6 percent and 46.4 percent in tows offshore and in the Diablo Canyon Intake Cove, respectively, in 1986-87; and 35.0 percent in the entrainment samples collected in 1985-86.

Planktonic transport of cabezon and other cottid larvae between more distant adult habitats and the rocky coastal area adjacent to the Diablo Canyon Power Plant is certainly possible. Cabezon larvae have been found to be widely distributed, out as far as 200 miles from shore (O'Connell 1953), and many inshore cottid species off California appear to have planktonic periods that last weeks to months (Yoshiyama et al. 1986). Comparison of the times of spawning and larval settlement discussed earlier also indicate that planktonic periods of a month or more are likely for many inshore cottid species. However, cottids deposit their eggs demersally inshore, their larvae are more restricted to inshore waters than most fish larvae, and most larvae of inshore species found far offshore probably perish (O'Connell 1953). Therefore, there is a reasonable probability that the rocky coastal area from Avila Beach to Morro Bay, and even the more localized area around the Diablo Canyon Power Plant, is largely closed to migration of cottids via planktonic transport, so that a conservative impact assessment will assume that the impact of cottid losses via entrainment and impingement at the Diablo Canyon Power Plant is localized to this area.

Adult and Juvenile Standing Stock

There are no reliable estimates of adult cabezon densities in the vicinity of the Diablo Canyon Power Plant. However, baseline studies in the Diablo Canyon Power Plant vicinity conducted by CDF&G in 1970 and 1971, and TENERA between 1976 and 1987, provide some indication of field densities, although the cryptic coloration and bottom dwelling habits of cabezon may have resulted in under representation of natural densities.

Along with other fish, cabezon were counted in a series of underwater transects at different depths in winter, summer, and fall of 1970 and 1971 (Burge and Schultz 1973). Most of the transects were in the 10 – 40 foot depth zone. Altogether there were 55 separate transect surveys (one transect surveyed at 4 different times being counted as 4 transect surveys). The total number of cabezon recorded was 38, giving an average density of approximately 47 cabezon per acre, of which some may have been juveniles.

When fish were collected after poisoning 3,000-4,000 ft^2 areas with rotenone at three depths on three occasions in Diablo Cove, and three depths on one occasion in North Cove, the total number of juvenile and adult cabezon collected was 231 (Burge and Schultz 1973). Based on these results and assuming 25 to 50 percent of the cabezon collected were adults, cabezon densities are estimated to have ranged from 50-100 adults per acre, close to the density estimate derived from the underwater transect survey data.

More recent underwater surveys (1976-1987) detected an average density of adult cabezon in the vicinity of the Diablo Canyon Power Plant of 17.3 per acre during the summer and 30.8 per acre during the remainder of the year (TENERA unpublished data).

Standing Stock Comparison

The first approach to placing entrainment losses in perspective is to compare entrainment densities of larval cabezon and other cottids to larval densities in nearshore waters. Unlike some fish species, it is inappropriate to base such a comparison on larval densities at offshore locations, such as standard CalCOFI stations, since cottid larval populations are concentrated inshore. An intensive inshore-offshore series of plankton tows from 0 to 500 m offshore off British Columbia showed that all larval stages of two of the most common cottid species (one subtidal and one intertidal) were concentrated within 4 m of shore (Marliave 1986). Larvae of other common intertidal and subtidal cottids in the genus *Artedius* significantly declined in density between 20 and 500 meters offshore (Marliave 1986). Combining all cottid species and considering only those surveys in which all stations along the onshore-offshore gradient were sampled at the same time, the numbers of larvae caught at the 0-, 4-, 20-, and 500-meter (offshore) stations were 3803, 616, 56, and 1, respectively.

The above results suggest that the 300 and 1,500 m (offshore) tows of Icanberry et al. (1978), and the offshore tows in 1986-87 under-represent typical larval cottid densities in the vicinity of the Diablo Canyon Power Plant. However, these data, along with data from tows in the Diablo Canyon Intake Cove, comprise our only applicable field data on larval cottid densities and are useful in establishing a lower bound for cottid larval abundance in the area.

The evidence summarized in the following table suggests cabezon larval densities may be higher in the entrainment samples and in the Diablo Canyon Intake Cove than in nearby coastal waters outside the Intake Cove. Entrainment densities were similar to those in the Intake Cove and are probably typical of cabezon larval densities in the inshore waters along rocky coasts, including the section of rocky coast that includes the Diablo Canyon Power Plant. Comparison of the 1974-75 and 1986-87 plankton tow results suggests that cabezon larval densities were similar in the two years. The average cabezon larval densities over the 6 months (April through September, 1986) when the entrainment monitoring and field plankton tows coincided averaged 0.00, 0.00, and 0.60 per 1,000 m^3 at the offshore station, in the Intake Cove, and in the entrainment samples, respectively. This comparison further demonstrates the shoreward increase in larval cabezon densities.

A comparison of non-cabezon cottid larval (sculpin) densities at different times and locations in the vicinity of the Diablo Canyon Power Plant is shown in the table below. This comparison shows that sculpin larvae were as numerous in 1986-87 as in 1974-75. While the larvae were concentrated inshore, they were less dense in the entrainment than in the Diablo Canyon Intake Cove. Over the 6 months (April through September 1986) when the entrainment monitoring and field plankton tows coincided, sculpin larval densities averaged 57.8, 257.5, and 96.2 per 1,000 m^3 at the offshore station, in the Intake Cove, and in the entrainment samples, respectively. This comparison, like that for cabezon, demonstrates the shoreward increase in cottid densities. Unlike cabezon, it also demonstrates relatively lower densities in the entrainment samples as opposed to the center of the Diablo Canyon Intake Cove, suggesting that sculpin may avoid the cooling water system intake. A definite peak in sculpin densities occurred in May in the entrainment samples (Figure 3-9). Peak sculpin densities in the Intake Cove and offshore occurred in June-August and August, respectively, suggesting that the assemblage of sculpin species in the entrainment samples may have been different from that at the other locations. However, because of their small size and a lack of adequate taxonomic keys, the majority of sculpin larvae could not be identified to species.

Survey	Annual Average Density (larvae per 1,000 cubic meters)	
	Cabezon	Sculpin
300 and 1,500 m offshore (1974-75)*	3.3	28.7
Offshore (1986-87)	3.8	33.7
Intake Cove (1986-87)	24.3	23.7
Entrainment (1985-86)	18.9	87.2

* Source: Icanberry et al. 1978.

Sport and Commercial Catch

Because cabezon inhabit shallow rocky areas along the coast, they represent an incidental component in the partyboat and commercial fisheries in the area, therefore landings underestimate population abundances. Table C-4 shows the commercial catch in the 3 catch blocks encompassing the nearshore rocky habitat in the vicinity of the power plant (CDF&G catch blocks 614, 615, and 623), and in the 6 adjacent catch blocks. Pounds of cabezon landed are converted to fish assuming an average weight of 5.3 lb per cabezon (the estimated average given by Miller and Gotshall (1965) for the partyboat catch between Oregon and Point Arguello during the period of 1957 through 1961). The estimated average annual cabezon landings were 350 fish over the three catch blocks adjacent to the plant, and 1,704 fish in the adjacent catch blocks. Cabezon landings have declined over time, although without data on effort expended in the fishery it is impossible to state whether the decline in landings reflects changes in fish density, fishing intensity, fishing methods, or fishing locations, especially since cabezon is not a primary commercial species. It should be noted that most of the commercially-caught cabezon from adjacent catch blocks were attributed to catch block 607 which is located just off Morro Bay.

Table C-4 shows the partyboat (sport) catch of cabezon from 1981 through 1985 in the same two groups of catch blocks. The average catch per year in the 3 catch blocks encompassing the power plant site and in the adjacent catch blocks is 173 and 407 fish, respectively. The general trend in CPUE is downward. Most of the catch was reported from catch block 632, off Point Sal. However, in a sportfishing survey covering the period 1957 through 1961 from Oregon to Point Arguello (Miller and Gotshall 1965), many more cabezon were caught by all other methods combined (shore fishing 28,051; skiff fishing 5,248; pier fishing 2,048; and skindiving 1,270; for a total of 36,617) than from partyboats (total of 1,696). Therefore, the reported partyboat catch over the period 1981-1985 may significantly under-represent the total sport catch of cabezon in the vicinity of the Diablo Canyon Power Plant, although probably less so than in other areas, due to limited public shore access between Avila Beach and Morro Bay.

TABLE C-4

COMMERCIAL LANDINGS AND PARTYBOAT SPORT CATCH OF CABEZON IN THE CDF&G CATCH BLOCKS ADJACENT TO THE DIABLO CANYON POWER PLANT

Commercial Catch of Cabezon (Numbers of Fish)

Year	Blocks 614, 615, 623	Blocks 607, 608 616, 624, 622, 632
1980	962	6,254
1981	596	2,239
1982	529	1,649
1983	10	68
1984	0	10
1985	0	6

Note: Assuming an average weight of 5.3 lb. per fish.

Party Boat Catch of Cabezon (Number of Fish)

	Catch Blocks 614, 615, 623		Blocks 607, 608 616, 624, 622, 632	
	Catch	CPUE	Catch	CPUE
1981	153	.013	1,324	.080
1982	299	.018	290	.043
1983	270	.035	266	.019
1984	109	.012	108	.009
1985	34	.003	45	.003

Note: CPUE is catch per angler hour.

Equivalent Adults Represented by Entrained Larvae

In addition to comparing larval densities in the entrainment with densities in nearby waters, the potential impacts of entrainment on cabezon and sculpin can also be evaluated by estimating the numbers of newly mature, equivalent adults that the entrained larvae could have produced had they not been entrained. The estimated annual impingement losses were minor — less than 80 juvenile cabezon and 280 other cottids (sculpin) per year.

Deriving equivalent adult estimates requires knowledge of either survival from the age of entrainment to maturity, or the fecundities and survivals of adult fish plus survival from spawning to the age of entrainment. Quantitative population dynamics information is only partially known for cabezon and is even less available for sculpin species. Because of these uncertainties, equivalent adult estimates are less reliable than larval density comparisons for assessing potential entrainment/impingement impacts. Equivalent adult estimates are useful, however, in establishing upper bounds on the numbers of potential adult fish lost as a result of entrainment and in clarifying what impact levels are implied by different assumptions regarding poorly known aspects of cottid population dynamics.

The equivalent adults lost as a direct result of entrainment of a given number of larvae is that number of newly mature adults that could have been produced by the larvae had they survived, assuming a constant regime of age-specific mortality rates. If the population size and mortality rates are assumed to be stable, the number of equivalent adults equals the number of newly mature fish that, over their remaining lifetime, would produce exactly the numbers (and ages) of larvae that were entrained, i.e., would exactly replace the larvae lost as a result of entrainment. The calculation of expected total lifetime reproduction for a newly mature 3-year-old female cabezon is shown in Table C-5. To provide a conservative (low) estimate of expected lifetime fecundity (and, therefore, high estimate of equivalent adults), fecundity for each year class is derived from the lower age-specific estimates reported by O'Connell (1953) or Burge and Schultz (1973), and assuming only one spawning per year is assumed, even though more frequent spawning is considered typical (O'Connell 1953). An annual adult survival rate of 75 percent appears to be a reasonably conservative (low) estimate, since cabezon are large, bottom-dwelling fish that have been observed to live at least 13 years. The resulting conservative (low) estimate of cabezon fecundity is 216,200 eggs produced over the reproductive lifetime of a newly mature 3-year-old newly mature adult cabezon (108,100 eggs per newly mature female assuming a 1:1 sex ratio).

The estimated number of cabezon larvae entrained at the Diablo Canyon Power Plant over one-year would then represent the estimated lifetime egg production of 60 adult fish, assuming an entrainment survival rate of 75 percent and that there had been no egg and larval mortality prior to entrainment. If, for example, there had been 90 percent egg and larval mortality prior to entrainment, it would take ten times as many adults to produce the same number of larvae surviving to entrainment, and the number of equivalent adults represented by the entrained

TABLE C-5

CALCULATION OF TOTAL REMAINING
LIFETIME REPRODUCTION FOR 3-YEAR-OLD FEMALE CABEZON

Age	Cumulative Survival* S	Fraction Mature** M	Batch Fecundity*** F	Eggs (S*M*F)
3	1.0	0.60	41,900	25,100
4	0.75	0.80	51,900	31,100
5	0.56	1.00	64,000	35,800
6	0.42	1.00	68,600	28,800
7	0.32	1.00	74,700	23,900
8	0.24	1.00	77,800	18,700
9	0.18	1.00	85,400	15,400
10	0.13	1.00	91,600	11,900
11	0.10	1.00	97,700	9,800
12	0.08	1.00	106,900	8,600
13	0.06	1.00	119,100	7,100
Remaining lifetime reproduction				216,200

* Assuming 75 percent survival per year, as for the low estimate for blue rockfish.

** O'Connell, 1953, figure 40.

*** Batch Fecundity = 27,300 + (15.3x weight in grams) from O'Connell 1953. Weight was estimated from a length-weight relationship developed by O'Connell. Total length at each age was estimated from O'Connell (1953) and Burge and Schultz (1973) taking the lower length for each age from the two sources. Standard lengths reported by Burge and Schultz were converted to TL using TL = SL (1.212) as suggested in O'Connell (1953).

larvae would be 600. This is the figure used in later discussion, although a more precise estimate would require knowledge of cabezon egg and larval survival rates and the age distribution of entrained larvae.

Given the limitations and uncertainties inherent in the quantitative data available on sculpin population dynamics, it is not possible to calculate the equivalent adults represented by sculpin larvae entrained at the Diablo Canyon Power Plant. This is partly because different sculpin species have different survival rates, longevities, and fecundities, and also because most of the entrained sculpin larvae could not be identified to species. In addition, the life histories of these various species are not nearly so well known as the life history of the cabezon, although they almost certainly all have lower annual adult survival rates and fecundities than cabezon. Of the 20 sculpin species collected in the vicinity of Diablo Cove, ages have been estimated for only two species, *Hemilepidotus spinosus* (brown Irish lord — up to 7 years) and *Jordania zonope* (up to 5 years). Populations of some common intertidal sculpin (including species found in the Diablo Canyon Power Plant area) consist mainly of 0- (young-of-the-year) and 1-year-old individuals, with some 2- and 3-year old fish (Moring 1981; Freeman et al. 1985). Staghorn sculpin (*Leptocottus armatus*), a subtidal species found near the Diablo Canyon Power Plant, have been reported to reach 3+ years (Tasto 1975 cites Jones 1962). In general, the smaller cottids appear to reach maturity after about 1 year (Moring 1979; Freeman et al. 1985; Tasto 1975). Reported fecundities for smaller cottids include an average of 3,200 eggs among 1-year old staghorn sculpin about 6 in. long (Tasto 1975) and 16,300-43,000 eggs for buffalo sculpin (*Enophrys bison*) about 10 in. long (DeMartini and Patten 1979). Of the 22 sculpin taxa reported from the Diablo Canyon Power Plant vicinity (20 from baseline surveys, 2 more in the entrainment monitoring program), 9 attain a length of greater than 6 in. and 2 attain a length of greater than 12 in. The five species accounting for 78 percent of the sculpin collected after ichthyociding by CDF&G in Diablo Cove during 1970-71 were, in order of decreasing abundance, *Artedius corallinus, Orthonopias triacis, Artedius lateralis, Jordania zonope,* and *Hemilepidotus spinosus* (Burge and Schultz 1973). The maximum attained lengths for these 5 species are approximately 6, 4, 5, 5, and 10 inches, respectively. Their fecundities may be surmised to be considerably less than that of cabezon.

In summary, sculpin mature after about one year and are expected to have low fecundities and adult survival rates relative to cabezon. Thus the number of equivalent adults represented by a given number of entrained sculpin larvae would be considerably larger than for cabezon. However, the equivalent adult sculpin would be much younger than cabezon (typically 1 year instead of 3 at first maturity) and smaller (3-6 in. long instead of 14-20 in. at maturity assumed for cabezon). Furthermore, these species are typically much more abundant than cabezon. Because only a few age classes (often one age class in intertidal sculpin) make the dominant contribution to annual reproduction, populations of these species are likely to experience substantial year-to-year fluctuations in response to environmental conditions affecting reproduction and recruitment, of which entrainment is but one factor.

C.2.4 Rockfish (*Sebastes* spp.)

Rockfish are a diverse genus of fish represented by over 60 species in coastal waters off California. Adult rockfish have wide geographic ranges, typically extending south to waters off Baja California and/or north to waters off at least Oregon and often to Alaska. Sixteen rockfish species were identified as adults and/or juveniles in the vicinity of Diablo Cove by Burge and Schultz (1973), and 29 species have been observed in the partyboat catch off the Diablo Canyon Power Plant from 1980 through 1986 (Gibbs and Sommerville 1987).

Burge and Schultz (1973) considered the rocky kelp bed habitat located off the Diablo Canyon Power Plant to be a nursery area for the juveniles of both inshore rockfish species and also certain offshore species. The juveniles of offshore species including bocaccio, chilipepper, widow, yellowtail, and canary rockfish have been observed in nearshore habitats, especially during the summer. This use of inshore rocky kelp bed habitat as a nursery area for a variety of rockfish species has been observed in studies conducted elsewhere (Miller and Geibel 1973). Baseline surveys found blue rockfish to be the most common rockfish in the Diablo Cove area both as juveniles and as adults (Burge and Schultz 1973). Other common rockfish were olive, black-and-yellow, black, kelp, and gopher.

Rockfish are ovoviviparous and release newly hatched or hatching individuals to the environment. Although most rockfish spawn during winter months, there is considerable variability among and within rockfish species with regard to timing of spawning (Phillips 1964; Miller and Geibel 1973; Love and Westphal 1981). The largest adults of a species tend to spawn earliest in the season, and usually, but not always, bear the greatest number of young (Phillips 1964). Some species of rockfish show evidence of multiple spawning in a single season. Rockfish are prolific, with approximately 50,000 to several million live young being produced each year by a female of the various species (Love and Westphal 1981; Phillips 1964; Gunderson et al. 1980; MacGregor 1970; Miller and Geibel 1973). Rockfish larvae are most common off the California coast from January through March, and are least common in summer and early fall (Ahlstrom et al. 1978). The larvae are widely distributed, having been found at the farthest CalCOFI sampling stations 250 miles offshore, but are seldom found at depths below 100 m (Ahlstrom 1961). Larvae from various species range in size from about 3.8 – 7.5 mm total length (TL) at extrusion (Miller and Geibel 1973; Moser et al. 1977; Ahlstrom et al. 1978; Moser and Butler 1981; Moser and Butler 1987; Stahl-Johnson 1984). The larvae of only 15 species can currently be distinguished, and there are complete descriptive series for the larvae of only 8 species (Moser et al. 1977; Moser and Butler 1987).

Most young-of-the-year juveniles of inshore rockfish species settle out from the plankton during May through August (Singer 1985). The duration of the larval planktonic period appears to vary from about 2 to 6 (or more) months among species, and at the time of settling the juveniles range in size from about 20 to 65 mm TL (Moser and Ahlstrom 1978; Moser and Butler 1981; Miller and Geibel 1973; Moser et al. 1977; Ahlstrom et al. 1978; Larson 1980a).

Off California, rockfish may be found in "virtually every habitat from intertidal regions to depths of well over 1,000 m" (Love and Westphal 1981). Offshore species tend to have longer planktonic periods and greater juvenile and adult migrations, often including temporary residence by juveniles in inshore nursery areas followed by abrupt or gradual movement offshore with age (Miller and Geibel 1973; Moser et al. 1977; Moser and Ahlstrom 1978; Ahlstrom et al. 1978; Lenarz 1980; Wilkins 1980). Age composition data indicate northward movement by adults of some offshore species, which has been suggested to be a means of compensating for southward drift of the larvae (Gunderson and Lenarz 1980a).

The inshore species may be roughly grouped into demersal/cryptic and midwater/schooling species. The inshore species have generally been found to show very limited movement as adults (Hallacher 1977; Larson 1977, 1980a,b,c; Miller and Geibel 1973; Miller and Hardwick 1973; Love and Westphal 1981). Copper rockfish have been found to move up to 2 miles over deeper reefs (Miller and Hardwick 1973), and demersal gopher and black-and-yellow rockfish have been found to move up to 1 mile from natural habitats to colonize an artificial reef (Matthews 1986). Some juvenile rockfish appear to leave inshore nursery areas after 1 or 2 years (Moser 1967; Miller and Geibel 1973; Burge and Schultz 1973), however, subsequent dispersal and survival are not well known.

Larval Standing Stock Comparison

Rockfish represented approximately 8 percent of all ichthyoplankton collected in during the one-year (October 1985 through September 1986) entrainment monitoring program. Peak rockfish abundance occurred during March and April, when 61 percent of the total number of entrained rockfish were collected. The seasonal distribution of rockfish collected during the entrainment monitoring period is illustrated in Figure 3-10. Over 98 percent of the entrained rockfish larvae were less than 5 mm TL (Figure 3-6). Based on the sizes of entrained rockfish larvae, it is reasonable to assume that the larvae were newly extruded, originating from a nearby area or from within the intake cove itself. Because of their small size, identification to species was not practical or, in most cases, possible. The losses of entrained larvae can be placed in perspective by comparing them to naturally occurring rockfish population densities (standing stock comparison).

California Cooperative Oceanic Fisheries Investigations (CalCOFI) has conducted oceanographic cruises to collect physical, chemical, biological, and meteorological data off the California coast for 37 years. Plankton tows, an integral part of the cruises, are made at various intervals along the transect lines and station points depicted in Figure 2-11. The annual number of rockfish larvae in coastal waters from San Francisco to southern Baja California has been estimated, based on CalCOFI plankton tow results, to have ranged from $37,867 \times 10^9$ to $218,978 \times 10^9$

over 14 different years from 1950 through 1975 (MacGregor 1986). These estimates are based on plankton tows conducted during 14 different years between 1950 and 1975. The majority of these larvae were found within 20 miles of shore. MacGregor (1986) estimated the annual average annual number of rockfish larvae in coastal waters along CalCOFI sampling lines 73 (Point Piedras Blancas) through 80 (Point Conception), encompassing 120 miles of coastline, have been 17,836 x 10^9 over the period 1950-1975. For waters adjacent to line 77 (Point San Luis) alone, encompassing 40 miles of coastline, the annual average number of rockfish larvae was estimated to be 6,159 x 10^9. The peak months of abundance have been January through April (79.4 percent of the total larvae were collected during this period, over CalCOFI lines 60-137), and especially February (29.6 percent of the total). MacGregor's estimates of average annual numbers of rockfish larvae in various portions of the coastal waters off central California can be used to help place the estimated entrainment losses at Diablo Canyon Power Plant in perspective. The estimated annual entrainment loss of rockfish larvae equals approximately 0.0002 percent of the estimated average annual number of rockfish larvae in coastal waters off the 40 miles of coast centered on CalCOFI line 77 (Point San Luis), and approximately 0.00008 percent of the estimated annual average number of larvae off the 120 miles of coast extending from roughly Point Piedras Blancas in the north to Point Conception in the south.

Whether the historical CalCOFI estimates present an accurate picture of larval rockfish abundance for comparison with the 1985-86 entrainment monitoring results is subject to some debate. Rockfish densities off the Diablo Canyon Power Plant were investigated by Icanberry et al. (1978) during 1974 and 1975. Annual average larval rockfish densities were found to be 129.0 per 1,000 m^3 at stations 300 and 1,500 meters offshore (combined). Plankton tows conducted in close proximity to Icanberry's 300 m station during 1986 and 1987 (TENERA 1988) showed an annual average larval rockfish density of 25.2 per 1,000 m^3 in evening tows. Tows in the Intake Cove during the same period showed an average evening density of 9.8 per 1,000 m^3. For 6 months when field tows and entrainment monitoring overlapped (April through September 1986), larval rockfish densities averaged 9.3 per 1,000 m^3 offshore (peaking in May), 12.7 per 1,000 m^3 in the Intake Cove (peaking in May), and 21.1 per 1,000 m^3 in the entrainment samples (peaking in April).

The fact that Icanberry et al. (1978) found annual average larval rockfish densities substantially higher than those observed at comparable distances offshore in 1986 and 1987 suggests that larval rockfish densities during the entrainment monitoring period were less than densities in earlier years, which is consistent with underwater survey results showing a decline in juvenile and adult rockfish densities in the Diablo Cove area from 1976 to 1987 beginning well before commercial operation of the Diablo Canyon Power Plant. However, it is also possible that the contrast between nearshore rockfish larval densities sampled in 1974-75 and those observed in 1986-87 could be attributable to higher than average densities in 1974-75. The percentage of all fish larvae in plankton tows that were rockfish was 19.6 percent in ten years of CalCOFI plankton tows covering more offshore locations (Ahlstrom

1965a), whereas rockfish constituted 38 percent of the larval fish collected in tows 300 and 1,500 m offshore in 1974-75 (Icanberry et al. 1978). Rockfish larvae constituted approximately 13.8 percent of the larval fish collected offshore in 1986-87 and 1.8 percent in plankton tows from the Diablo Canyon Intake Cove. The preceding percentages indicate that rockfish larvae may have been both unusually abundant in 1974-75 and unusually scarce in 1986-87 when compared with the period 1950-60. The average daily distribution of rockfish collected during 24-hour entrainment sampling efforts (Figure 3-8) indicates an obvious diel component, which may help explain some of the density differences observed between studies with varying methodologies.

Equivalent Adults Represented by Entrained Larvae

Losses due to entrainment can be evaluated by estimating the numbers of adults that could have been produced from the entrained larvae had they survived. Due to the lack of detailed quantitative information on the natural survival rates of adult, juvenile, and larval rockfish, equivalent adults can only be approximately estimated. Furthermore, because of the limitations in accurately identifying rockfish larvae to species when they are 3-5 mm TL (the size class typically entrained), there is no accurate means to allocate cropping losses proportionately among species.

The estimated entrainment loss of rockfish larvae results in the loss of a much smaller number of potential adults because the survival of rockfish larvae and juveniles is low. Females, living up to 15 or 20 years (or more), produce large numbers of larvae each year, of which only a few survive to maturity. In a population that is exactly replacing itself, only one newly mature adult female will, on average, be produced from the entire expected lifetime reproductive output of each newly mature female. Assuming that the rockfish populations are stable, the number of equivalent newly mature adult fish that entrained larvae would have produced had they survived, equals the number of males and females whose lifetime reproductive output would exactly replace the number of entrained larvae. The total number of larvae expected to be produced during the lifetime of a newly mature female is a function of fecundity, annual survival rates of mature females, and the fraction of females spawning at each age.

Because of the abundance of blue and olive rockfish in the vicinity of the Diablo Canyon Power Plant, and the availability of life history information on these species, the expected lifetime spawn of a newly mature female was calculated for these two species. Blue rockfish have annual average fecundities ranging from 50,000 to 300,000 (Miller and Geibel 1973), while reported olive rockfish fecundities range from 30,000 to 490,000 (Love and Westphal 1981).

Annual survival rates are difficult to measure for rockfish due to difficulty in getting sufficient tag returns or age-unbiased samples. Miller and Geibel (1973) cite Gotshall (1969) as estimating the annual survival rate of adult blue rockfish at 77 percent and 30 percent based on age structure and tagging, respectively. Gotshall attributed the discrepancy to tag loss and under-reporting of tags, so that the 77 percent figure may be more accurate (this was also acknowledged by D. Gotshall 1987, personal communication). Recently, more accurate aging methods are detecting older fish and thus higher natural survival rates for many fish species, including rockfish. The Pacific Fisheries Management Council's stock assessment reports have recently assumed an annual instantaneous mortality rates ranging from -0.20 to -0.15 (82 percent to 86 percent survival per year) for adult widow rockfish, a species closely related to blue and olive rockfish (W. Lenarz 1987, personal communication).

For purposes of calculating the expected lifetime spawn of a newly mature female blue or olive rockfish, the following calculations use low (75 percent) and high (90 percent) estimates of annual adult survival rates that bound the 77-86 percent range described above. These rates are combined with reported length/fecundity, age/length, and age/ percent spawning relationships for blue rockfish (Miller and Geibel 1973) and olive rockfish (Love and Westphal 1981) to calculate expected lifetime reproduction for a newly mature female. Table C-6 presents the estimated range of expected lifetime spawn for newly mature female blue and olive rockfish.

A three-year-old female blue rockfish typically averages 170 mm TL. Fish of this size are just entering the fishery, but only about 5 percent of three-year-old fish were found to be mature (Miller and Geibel 1973). A three-year-old olive rockfish is on the average 290 mm long and has probably been in the fishery for at least a year. Sport catch data from the southern California private boat catch in 1977-78 (Racine 1982) yield size ranges of 150-435 mm and 140-530 mm for blue and olive rockfish, respectively, while the 1980-86 Diablo Canyon (Port San Luis) partyboat survey yielded size ranges of about 180-450 mm and 210-550 mm for blue and olive rockfish, respectively (Gibbs and Sommerville 1987).

The annual survival rate assumed for adult rockfish strongly affects the calculated expected lifetime spawn for a three-year-old female. Table C-6 indicates that on the average, assuming a stable population exactly replacing itself, at most 2 (one male, one female) of every 215,000 to 780,000 newly extruded blue rockfish larvae would be expected to survive to age 3, i.e., to first possible (but still unlikely) reproduction, while the range for olive rockfish would be at most 2 of every 412,000 to 1.343 million. The qualifier "at most" is included because reproduction from ages below 6 and above 14 were not included in the calculation of total offspring.

The numbers of equivalent adult rockfish that would have survived from among the larval rockfish entrained at the Diablo Canyon Power Plant are initially estimated by assuming that:

- All entrained rockfish had the same fecundity and survival rates as blue rockfish.
- Survival from extrusion to age of first reproduction is exactly sufficient to produce a stable population, i.e., an overall maximum survival rate ranging from 2/780,000 to 2/215,000, as derived above.

TABLE C-6
EXPECTED LIFETIME SPAWN OF BLUE AND OLIVE ROCKFISH

BLUE ROCKFISH

Age (yr)	Size (mm)	F	S 75%	S 90%	FS	FxSxFS (1000) 75%	FxSxFS (1000) 90%
3	170	<50	1.00	1.00	.05	<2.5	<2.5
4	205	<50	.75	.90	.22	<8.3	< 9.9
5	240	<50	.56	.81	.33	<9.3	<13.4
6	260	60	.42	.73	.62	16.0	27.0
7	280	100	.32	.66	.85	27.0	56.0
8	300	150	.24	.59	.88	32.0	78.0
9	315	190	.18	.53	~1.00	34.0	101.0
10	330	230	.13	.48	~1.00	30.0	110.0
11	340	250	.10	.43	~1.00	25.0	108.0
12	350	270	.08	.39	~1.00	22.0	105.0
13	355	290	.06	.35	~1.00	17.0	102.0
14	360	300	.04	.31	~1.00	12.0	93.0
6-14 Year Total						215.0	780.0

OLIVE ROCKFISH

Age (yr)	Size (mm)	F	S 75%	S 90%	FS	FxSxFS (1000) 75%	FxSxFS (1000) 90%
3	290	<50	1.00	1.00	.17	<8.5	<8.5
4	330	70	.75	.90	.60	32.0	38.0
5	360	120	.56	.81	.65	44.0	63.0
6	390	170	.42	.73	~1.00	71.0	124.0
7	410	220	.32	.66	~1.00	70.0	145.0
8	430	260	.24	.59	~1.00	62.0	153.0
9	440	300	.18	.53	~1.00	54.0	159.0
10	450	330	.13	.48	~1.00	43.0	158.0
11	460	360	.10	.43	~1.00	36.0	155.0
12	470	390	.08	.39	~1.00	31.0	152.0
13	480	430	.06	.35	~1.00	26.0	151.0
14	490	470	.04	.31	~1.00	19.0	146.0
6-14 Year Total						412.0	1,343.0

F = Annual Fecundity (x 1000)

S = Cumulative fraction surviving from age 3 on, assuming 75 percent and 90 percent annual survival

FS = Fraction spawning (mature)

FxSxFS = Age specific reproductive potential

NOTE: Blue rockfish length vs. age, percent mature vs. age, and fecundity vs length (here converted to age) derived from Miller and Geibel, 1973; figures 18, 27, and 28. Olive rockfish length vs age, percent mature vs. age, and fecundity vs length (here converted to age) derived from Love and Westphal, 1981: von Bertalanffy parameters in Table 2, Figure 9, and Figure 10, respectively.

- Adult survival is 75 percent per year.
- Entrainment survival for rockfish larvae is 75 percent.
- All larval mortality occurs after the age of entrainment (this initial assumption is later modified).

Using the above assumptions, the estimated number of entrained larvae, lost, assuming 75 percent entrainment survival, would have produced between 37 and 135 newly mature equivalent adults.

To the extent that some portion of the overall extrusion-to-adult mortality occurs in the short period prior to entrainment, the estimate of (remaining) post-entrainment mortality must be lowered. This leads to an inversely proportionate increase in the estimated number of equivalent adults represented by larvae entrained. The survival rates of rockfish larvae of various ages are not known. Rockfish larvae of various species typically grow from about 3.8-7.5 mm at extrusion to about 20-65 mm (juveniles) at settlement 2-6 months or more later. Therefore, it is likely that the entrained larvae, more than 90 percent of which were in the 3 and 4 mm length classes, were on the average no more than a week old.

Barnett et al. (1980b cited by Southern California Edison Company 1982) estimated daily survival of early white croaker larvae as 90.5 percent ("z" = -0.10), which would produce 50 percent cumulative mortality over about 7 days. Newly extruded rockfish larvae are initially larger and more developed than newly hatched white croaker larvae, therefore 50 percent may be a reasonable upper estimate of the mortality experienced by rockfish larvae prior to the average age/size of entrainment. An alternative means of estimating minimum cumulative survival over one week is to underestimate the total survival rate over a 90-day "typical" larval period as only 2/780,000, using the higher of the previously derived extrusion-to-adult mortality rates and assuming that all the mortality occurs in the larvae, i.e., that juveniles experience no mortality. If it is further assumed that daily larval mortality rates are approximately constant over the 90-day larval period, the daily larval survival rate, S, is calculated as:

$$S^{90} = 2/780{,}000 \text{ or } S = 0.867$$

A daily survival rate of 86.7 percent gives 37 percent survival over 7 days. Comparing the two methods of estimating pre-entrainment larval survival in the absence of empirical data, a conservative estimate is that the entrained larvae had experienced at most 75 percent mortality prior to entrainment. This would mean that the previously estimated number of equivalent adults represented by entrained larvae would be multiplied by 4, giving an estimate of equivalent 3-year old adults of 540 rockfish assuming 75 percent survival of larval rockfish entrained at the Diablo Canyon Power Plant.

Further information supports the assumption that rockfish larvae averaging 7 days old at entrainment would have experienced at most 75 percent natural mortality prior to entrainment. Based on the size distribution of rockfish larvae from CalCOFI plankton tows, it has been estimated that shortbelly (*Sebastes jordani*), mexican (*S. macdonaldi*), cowcod (*S. levis*), and bocaccio (*S. paucispinis*) rockfish larvae decrease in numbers by 61 percent, 58 percent, 54 percent, and 43 percent, respectively, for every millimeter of length (MacGregor 1986). Since the majority of larvae entrained at the Diablo Canyon Power Plant were in the 3-and 4-mm size classes (Figure 3-7), it is very unlikely that, on the average, these larvae had grown more than 1 to 2 mm.

Using the blue rockfish equivalent adult calculations, conservatively assuming low (25 percent) pre-entrainment survival, low (75 percent/year) adult survival, and 75 percent, the estimated number of equivalent adults attributable to entrainment losses at the Diablo Canyon Power Plant is 540 rockfish.

Smaller numbers of equivalent adults would be calculated for olive rockfish because the greater fecundity and greater calculated lifetime spawn for this species results in a lower larvae-to-adult survival required for exact population replacement. Therefore, more newly extruded larvae would be necessary to produce a single 3-year-old adult. The estimated number of equivalent adult olive rockfish using the same reasoning described above is 281 individuals. There are insufficient data available to make lifetime fecundity calculations for black-and-yellow and gopher rockfish. These species are slightly smaller than blue and olive rockfish and have perhaps slightly lower fecundity per gram of body weight (MacGregor 1970), so that they would have somewhat lower age-specific fecundities. Since these species have similar ages at maturity to that of blue and olive rockfish, they may have lower lifetime fecundities. Echeverria (1987) reports that 50 percent maturity for female black-and-yellow rockfish (*S. chrysomelas*) is achieved at 3 years and 150 mm TL, while 100 percent maturity is achieved at 5 years and 190 mm TL. For gopher rockfish (*S. carnatus*) the figures are 50 percent maturity at 4 years and 170 mm TL and 100 percent maturity at 5 years and 210 mm TL. However, these cryptic, bottom-dwelling species may have higher adult survival rates that compensate for their lower fecundity, and consequently, their expected lifetime reproduction may be similar to that for the midwater species.

Cropping Losses Attributable to Impingement

Rockfish represented approximately 27 percent of all fish (Chapter 4) collected from impingement abundance samples. Of the *Sebastes* spp. impinged, the most common species were the yellowtail, olive, blue, and kelp rockfishes. Yellowtail and olive rockfishes were often grouped together because of the difficulty in identifying juveniles of these species. The majority (75 percent) of the impinged rockfish were less than 91 mm (i.e., young-of- the-year juveniles), as would be expected for inshore olive, blue, and other rockfish juveniles settling out of the plankton in early summer. Greater than 95 percent of the impinged individuals were less than 200 mm, below the size of first reproduction, and virtually all were in their first or second year.

Total annual rockfish impingement for the period April 1985 through March 1986 at the Diablo Canyon Power Plant, based on actual cooling system operation, is estimated to be 867 fish. The estimated impingement of 867 fish, mostly juveniles, can be converted to equivalent adults by assuming that these fish would have experienced 75 percent annual survival over the 2.5 years, from their first summer of settlement (age 0.5 year) to age 3. This annual survival rate represents the lower end of the range (75-90 percent) considered to realistically represent natural survival rates for adult rockfish. Since 25 percent of the impinged rockfish appeared to be older than young-of-the-year, they would experience less than 2.5 years of mortality before reaching age 3. However, rockfish between the ages 0.5 and 3 are very likely to experience significantly higher mortality rates than adult rockfish, so that assuming that the average impinged rockfish experienced 75 percent annual survival over 2.5 years should provide a conservative (high) estimate of equivalent adults represented by impinged rockfish. Applying the 75 percent survival per year (instantaneous z per year = -0.2877) converts the 867 impinged juveniles to:

$$867 * e^{(-0.2877 * 2.5)} = 422 \text{ equivalent 3-year-old adult fish}$$

A more realistic estimate would be that well under half of the newly recruited juveniles would survive to age 3. This conservative estimate of 422 equivalent adults represented by impinged juveniles is added to the estimated 540 equivalent rockfish adults represented by entrained larvae to give a combined estimate of 962 equivalent 3-year-old rockfish adults.

Comparison of Potential Losses to Adult and Juvenile Standing Stock and Fishery Landings

The estimated equivalent adult loss of 962 rockfish resulting from entrainment (540) and impingement (422) combined can be placed in perspective by comparing it to typical rockfish densities observed by divers and also to sport catches of rockfish in the vicinity of the Diablo Canyon Power Plant. Fish survey results for Diablo Cove and vicinity have been reported by Burge and Schultz (1973) and PG&E (1988). Rockfish densities have also been documented for the Point San Simeon area during 1982 and 1983 by Bodkin et al. (1987) and for artificial and natural reefs in shallow waters close to the Diablo Canyon Power Plant (Wilson et al. 1988).

Fish Observations

During baseline surveys of the Diablo Cove vicinity in 1970-71, fish were periodically counted within eleven 3 m x 20 m quadrats (Burge and Schultz 1973). One, eight, and two of the quadrats were located in the 0- 10-ft, 10- 40-ft, and 40- 75-ft depth zones, respectively. The 0- 10-ft zone is a very high-energy habitat inshore of the kelp canopy and is typically covered by foliose, low-growing algae. The 10- 40-ft zone is a typical high-energy kelp bed region with high relief bedrock, supporting many juvenile and adult rockfish. The 40- 75-ft zone is transitional, with bedrock outcroppings interspersed with expanses of gravel and sand. Further offshore, there is mostly sand/mud, except for isolated reefs. Burge and Schultz (1973) report that in 1970 and 1971, respectively, 84.5 and 93.6 percent of adult fish counted were rockfish, mostly blue rockfish. The seasonal counts of adult and juvenile rockfish were greater during 1971, which Burge and Schultz attributed to "increased water visibility, calmer ocean conditions, and increased familiarity with the fishes and their habitats during the 1971 survey." Therefore, the 1971 counts are assumed to be more reliable and representative than the 1970 counts. In general, it is likely that actual fish densities were higher, due to finite visibilities. The following table summarizes these rockfish densities per acre based on seasonal fish counts and acreage surveyed within each depth zone.

Density of Total Rockfish (per acre)
Calculated by Depth Zone and Season

	1970			1971		
	Winter	Summer	Fall	Winter	Summer	Fall
Adults:						
<10 Feet	ND	1,753	540	ND	1,350	2,024
10-40 Feet	3,328	1,079	8,119	28,733	33,012	17,942
40-75 Feet	135	3,609	472	371	2,664	1,484
Juveniles:						
<10 Feet	ND	2,698	6,745	ND	33,725	10,118
10-40 Feet	5,171	12,478	24,451	26,013	70,341	74,423
40-75 Feet	472	77,568	4,485	8,431	126,469	18,549

Source: Burge and Schultz, 1973
(ND – No Data)

The greatest adult densities observed by Burge and Schultz were usually in the 10-40-foot depth zone. Peak juvenile densities occurred in summer just after recruitment, and juvenile densities were also high in the fall but very low in the winter. The summer surveys were thus most representative of the initial strength of juvenile recruitment. These juvenile densities are in the same range as those estimated by Miller and Geibel (1973) for an inshore reef/kelp bed off Hopkins Marine Station, Monterey; these authors estimated densities of 50,000- 60,000 juvenile rockfish per acre (mostly blue rockfish) from May-December, and a standing crop of about 300 blue rockfish per acre within 6 feet of the bottom.

More recent observations from 1976 through early 1988 by divers have shown a noticeable decline in rockfish densities within Diablo Cove (TENERA unpublished data). There seems to be reasonable evidence to link this decline to the recent El

Nino and winter storm activity. Over this period the *Nereocystis* spp. kelp canopy and also the *Pterygophora* spp. sub-canopy have greatly diminished in the regularly surveyed areas in and around Diablo Cove. Concomitant with this decline of the canopy has been a decline in observed abundance of blue and olive rockfish, which are mid-water schooling species usually associated with the kelp canopy in shallower habitats. As a result, the most common adult rockfish in recent observations have been both black-and-yellow rockfish, a demersal/cryptic species, and blue rockfish. Other common rockfish have been olive and grass rockfish. Grass rockfish frequent dense, shrubby vegetation in very shallow water. The greatest decline has been in the densities of juveniles during the summer, presumably because a reduction in kelp cover has reduced the favorability of the habitat as a nursery area.

Based on rockfish observations over 200 m^2 transects during the period 1976 through 1987, the average adult and juvenile rockfish densities (all species) throughout the water column were 243 and 2,177 per acre, respectively, in the "summer" (June-October) during juvenile recruitment, and 207 and 485 per acre during the rest of the year. During recent surveys, 1985 through 1987, the adult and juvenile densities averaged 174 and 606 per acre in June – October and 216 and 441 per acre during the rest of the year.

Rockfish surveys in other areas off central and southern California also point to a decline in densities of rockfish beginning approximately in the late 1970's, especially for blue and olive (midwater) species. Studies of the fish assemblage at King Harbor (Redondo Beach) have shown a substantial decline in the abundance of juvenile blue and olive rockfish since the 1978-79 El Nino (Stephens et al. 1986). Blue and olive rockfish juveniles successfully recruited off the Palos Verdes peninsula in southern California during the cool-water years in the early 1970's (Love et al. 1985 cite Stephens and Zerba 1981), and the populations of these species subsequently declined starting about 1977 (Stephens et al. 1984).

Observations of beaches in the vicinity of Point San Simeon from February 1980 through January 1986 showed virtually no fish washed ashore except immediately following each of three large-wave episodes in the winter of 1983, when large numbers of rockfish, especially blue rockfish, were found (Bodkin et al. 1987). These storms coincided with the major 1982-1983 El Nino, and either event could help account for the documented decline in rockfish densities in the San Simeon area between 1982 and 1983 (Bodkin et al. 1987). The following adult rockfish densities were observed along transects in kelp forests in the vicinity of Point Piedras Blancas in 1982 and 1983 (Bodkin 1984; Bodkin et al 1987):

Sebastes Spp. Estimated Mean Adult Densities
Number per Acre

Common Name	Scientific Name	1982	1983
Blue	*S. mystinus*	603	181
Gopher	*S. carnatus*	45	19
Black and yellow	*S. chrysomelas*	55	84
Vermillion	*S. miniatus*	4	2
Olive	*S. serranoides*	16	8

The 1982 densities of adult rockfish in kelp beds in the vicinity of Point San Simeon lay between the high densities in the Diablo Cove vicinity in 1970-71 (Burge and Schultz 1973) and the lower densities in the Diablo Cove vicinity over the 1976-87 period (TENERA unpublished data). Densities near Point San Simeon in 1983 were approximately 1 1/2 times greater than densities observed near Diablo Cove during 1985-87 surveys.

The summer abundances of juvenile rockfish were surveyed on natural and artificial reefs a few miles south of the Diablo Canyon Power Plant in the summers of 1986 and 1987 (Wilson et al. 1988). Both kinds of reefs were located in about 50 feet of water, with moderate (maximum of 15 feet) relief. Averaging the densities over the two years (which were similar) and adding benthic and midwater counts, numbers of juvenile blue, olive/yellowtail, and all other rockfish juveniles per acre on the artificial reefs averaged 747, 583, and 67 per acre, respectively. For the natural reefs, overall density of rockfish juveniles was 150 per acre in 1986 (about 90 percent blue rockfish) and 154 per acre in 1987 (almost 50 percent gopher/black-and-yellow rockfish). Thus, juvenile densities on the artificial and natural reefs, respectively, were about twice and 1/4 those in Diablo Cove during the same period.

Sport and Commercial Catch

The estimated equivalent adults represented by annual entrainment and impingement can also be compared to annual sport catches of rockfish in the vicinity of Diablo Canyon. From 1980 through 1985, 2,836,830 rockfish were landed on commercial partyboat fishing vessels out of Port San Luis and Morro Bay ports combined (as reported by CDF&G). The rocky coastal area from Point San Luis to Montana De Oro roughly centered on the Diablo Canyon Power Plant is encompassed by CDF&G catch blocks 614, 615, and 623 (Figure C-1). The total number of rockfish reported by CDF&G for these three catch blocks for the same 6-year period was 819,342 (29 percent of that reported for the combined Port San Luis/Morro Bay ports), which equates to an average annual sport catch of 136,557 rockfish in these catch three blocks. The 7-year PG&E sampling program (1980-1986) of rockfish caught on partyboats operating out of Port San Luis and fishing in coastal waters adjacent to the power plant totaled 50,113 rockfish, of which 50 percent were blue, 17 percent were yellowtail, and 3 percent were olive. For the vast majority of the rockfish reported in the CDF&G survey, the species was not identified, but it is reasonable to assume that the species mix was close to that observed during the PG&E surveys. Using the percent composition of rockfish documented during the PG&E partyboat surveys, average annual blue, yellowtail, and olive rockfish caught in catch blocks 614, 615, and 623 over the period 1980-1985 would then be estimated at 68,279, 23,215, and 4,097 fish respectively. The PG&E partyboat sampling program (Gibbs and Sommerville 1985) has documented a decline in the fishery since 1982, evidenced by lower catch per unit effort (CPUE) statistics. Partyboat rockfish landings for catch blocks 614, 615 and 623 reported by CDF&G are depicted in Figure C-2, showing a decline in CPUE between 1983 and 1985.

The estimated 962 equivalent 3-year-old adults represented by the annual entrainment and impingement then amounts to about 0.7 percent of the reported annual average partyboat catch of rockfish from catch blocks 614, 615, and 623 during the period 1980-85, or about 1.5 percent of the estimated blue rockfish catch alone (CDF&G unpublished data).

The commercial catch reported by CDF&G for the same three catch blocks (614, 615, and 623) during 1980-1985 averaged about 109,000 pounds per year and declined between 1982 and 1985. Total commercial rockfish landings for the Avila Beach area averaged 1.18 million pounds per year over the period from 1980 to 1986. While much of the commercial rockfish catch was not identified to species, it is known to include a large proportion of deeper water (mostly larger) species. Assuming an average weight of 4 lb per fish gives an average of about 27,000 fish per year in the commercial catch from the three catch blocks encompassing the power plant vicinity, or about one-fifth of the reported partyboat catch from the same catch blocks. The same conversion yields 295,000 rockfish per year for total Avila Beach area commercial landings. Rockfish species important in the commercial fishery are very unlikely to experience significant impacts due to entrainment and impingement at the Diablo Canyon Power Plant. This is because the commercial catch of rockfish contains mainly offshore species and thus represents a different mix of species than either the entrainment/impingement samples or the local partyboat catch.

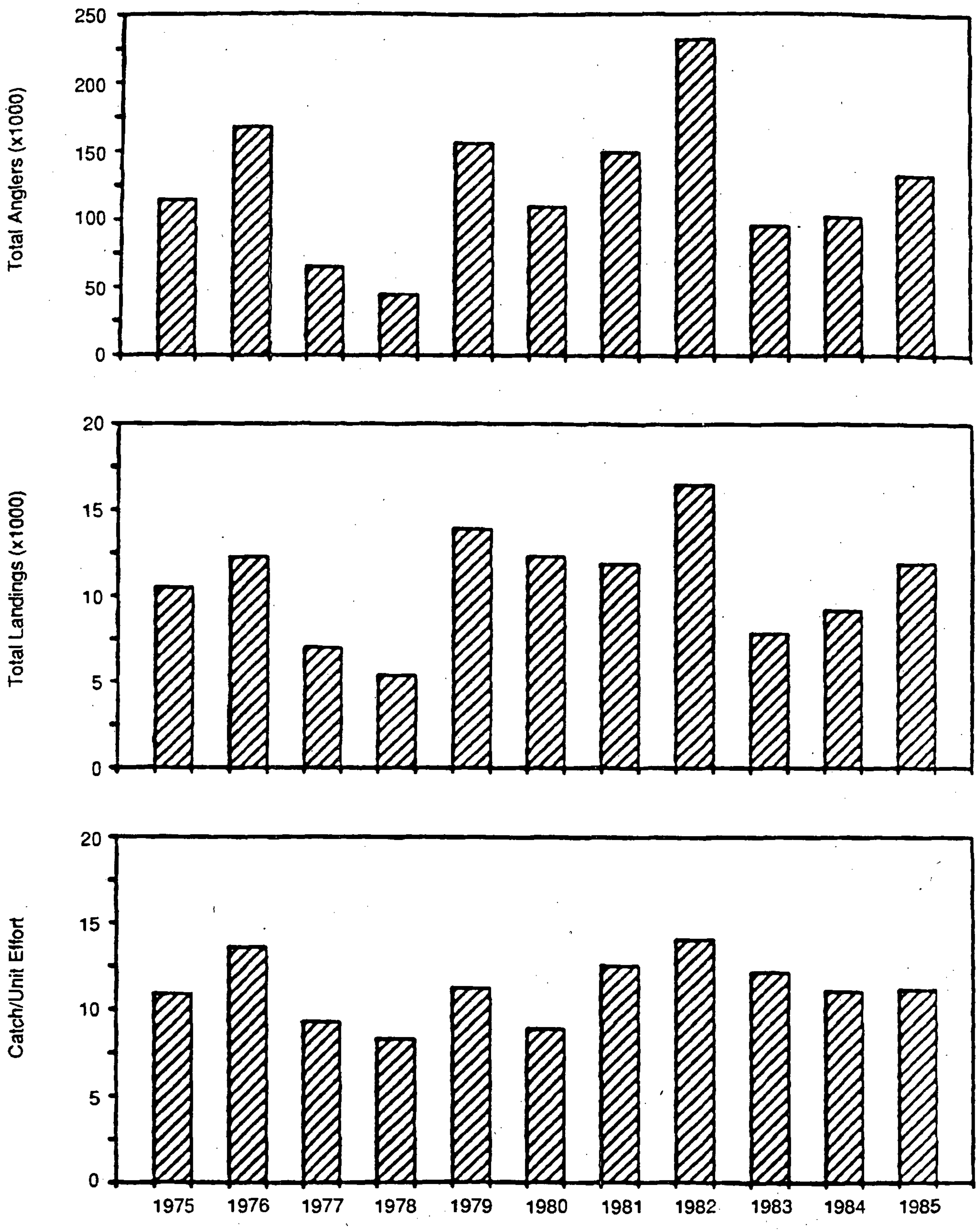

Figure C-2

Rockfish Anglers, Landings, and CPUE from
California Department of Fish and Game Commercial Partyboat Fishery
for Catch Blocks 614, 615, and 623 Combined, 1975-1985

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APPENDIX D

REVIEW OF TECHNOLOGIES FOR MINIMIZING LOSS OF AQUATIC ORGANISMS IN THERMAL POWER PLANT COOLING WATER SYSTEMS

D.1 Introduction

Section 316(b) of the Clean Water Act (PL 92-500 and 95-217) requires that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impacts. A number of cooling water intake technologies are currently in use or proposed for use in power plant cooling water systems to minimize the loss of aquatic organisms. These technologies involve (1) cooling system alternatives, (2) intake location in the source waterbody, (3) intake structure design parameters, (4) intake guidance and diversion technologies, and/or (5) intake maintenance and operation.

The loss of aquatic organisms results from entrainment, entrapment, and impingement. Entrainment is the pumping of organisms into and through cooling systems. Entrapment results from physical blocking of larger entrained organisms by a barrier, generally within the intake structure. Impingement occurs when aquatic organisms are held against a screen by the cooling water flow. One way to minimize impacts on aquatic organisms is to reduce the probability of their encountering the intake, thereby reducing the number of organisms entrained or impinged. A second technique uses screens that reduce the probability of entrainment and impingement for organisms encountering the intake. A third approach is to reduce the mortality rate of the organisms entrained or impinged. The biological and engineering considerations involved in selecting and implementing alternative technologies to achieve the goal of reducing organism losses resulting from entrainment and impingement are discussed in this review. The review lists technologies for thermal power plant cooling water systems and information drawn from studies conducted at hydroelectric facilities, and discusses the strengths and weaknesses of each alternative.

A broad array of engineering issues, environmental issues, and other factors must be addressed when designing a cooling water system for fish protection. Some of these issues are outside the scope of this review. For example, economic considerations influencing intake designs and options are not addressed. Some utilities previously acquired land or land options in anticipation of future expansion. This land had been acquired before fisheries issues were a significant consideration in cooling system design, and ownership of these sites may limit a utility's flexibility with regard to intake siting and design.

An attempt has been made to identify intake designs that are feasible from an engineering and construction standpoint, biologically effective in reducing organism losses, and directly applicable to power plants. Intake designs that have not proven effective are also identified, so that unsuccessful alternatives can be eliminated from detailed site-specific intake evaluations. Information has been gathered from published literature and reports, discussions with plant operators, design engineers, utility and regulatory personnel, and equipment vendors.

This Appendix is an updated and expanded version of Appendix D to the Morro Bay Power Plant 316(b) demonstration (PG&E 1983) titled Review of Technologies for Thermal Power Plant Cooling Water Systems. Mussalli (1984) and Taft (1986) have also reviewed intake technologies in reports prepared for EPRI.

D.2 Cooling Water Systems

There are two basic power plant cooling system designs — once-through (open-cycle) and closed-cycle cooling. In once-through systems, water is pumped directly from the source to the condenser and then discharged to the receiving water. In closed-cycle systems, cooling water is recirculated between the condenser and a cooling tower, cooling pond, or heat exchanger. Because of the large size and high cost of the heat exchanger required, cooling systems relying on water-to-air heat exchangers for heat rejection are used only in small installations. Evaporative closed-cycle cooling systems, using cooling towers or cooling ponds, withdraw make-up water from the source during operation to "make-up" for the water lost by evaporation during cooling system operation. The selection and design of a thermal power plant cooling system depends on site conditions, including water availability, water temperature and quality, engineering constraints, and regulatory limitations.

D.2.1 Open-Cycle or Once-Through Cooling

Once-through cooling may be feasible if a reliable water supply of sufficient volume is available. If the option is available, once-through cooling systems are usually used in preference to closed-cycle cooling systems because of their greater thermal efficiency and generally lower cost. Variations in water quality and suspended sediments do not generally influence the decision to use once-through cooling. However, construction cost can play a significant factor. If, due to navigational, recreational, aesthetic, political, geological, or environmental issues, a very long intake conduit is required to obtain a reliable water supply, costs can become prohibitive.

D.2.2 Closed-Cycle Cooling

Closed-cycle cooling decreases the volume of water withdrawn from the source and thus reduces the numbers of phytoplankton, zooplankton, and ichthyoplankton entrained. However, all organisms entrained are lost to the source waterbody. In many cases, these organisms are killed by repeated exposure to increased temperatures, biocides, and mechanical abrasion. In other cases, the organisms are transferred into a cooling pond, where increased ambient temperatures in the cooling pond may harm them. However, some cooling ponds have been developed as recreational sites. Others have used the increased water temperatures to create fish farms. Therefore, the effectiveness of closed-cycle cooling in reducing entrainment and impingement losses as an alternative to once-through cooling must be determined on a site-specific basis.

Evaporative closed-cycle systems using freshwater are widely employed in the United States where water availability is limited. In situations with extremely limited water availability, non-evaporative heat exchangers have been considered. These systems dissipate heat to the atmosphere in water-to-air heat exchangers, and require minimal water.

D.2.2.1 Wet Cooling Towers

Evaporative (wet) cooling towers are commonly employed at plant sites which do not have access to a sufficiently large waterbody to permit once-through cooling. With this method, heated water from the condenser is brought into direct contact with incoming atmospheric air, which is drawn into the towers by electrically-driven fans (mechanical draft) or by a difference of densities between ambient air and the warm, moist air inside the towers (natural draft). Cooling in a wet cooling tower occurs principally by evaporation. Cooled water is withdrawn from the tower basin for recirculation or discharge, and the plume of heated air and accompanying water vapor is released into the atmosphere.

Evaporative cooling towers, either mechanical draft or natural draft, can be used in open- or closed-loop (cycle) systems. Open-loop systems (Figure D-1) are those in which all or a portion of the heated discharge water passes through the cooling tower en route to the receiving waterbody. Figure D-1 shows a simplified view of an open-loop cooling system using an evaporative cooling tower. The flow path labeled "bypass" permits a portion of the total cooling water flow to bypass the evaporative cooling device. The extreme case in which there is no bypass flow results in 100 percent of the cooling water passing through the cooling tower. The other extreme (i.e., 100 percent bypass) would be the same as once-through cooling. An open-cycle cooling system can be used where a large body of water is accessible.

A simplified closed-cycle system is also shown in Figure D-1. Hot water from the condenser is directed to the cooling tower, where it is cooled and returned to the condenser. Water is lost from the system through evaporation and drift (water particle carryover) from the cooling tower, with the former being by far predominant. Evaporation causes any dissolved solids in the water to concentrate. To prevent excessive concentration, (usually limited by the point at which dissolved materials come out of solution and adhere to heat transfer surfaces), a certain amount of water is continuously discharged or "blown down." This is represented by the line in Figure D-1 labeled "Blowdown." The concentration of solids in the water in the closed system is determined by the "cycles of concentration." Systems with fewer cycles of concentration require larger blowdown flow rates. Water from an external source is continuously supplied to make up for the water lost through evaporation, drift, and blowdown.

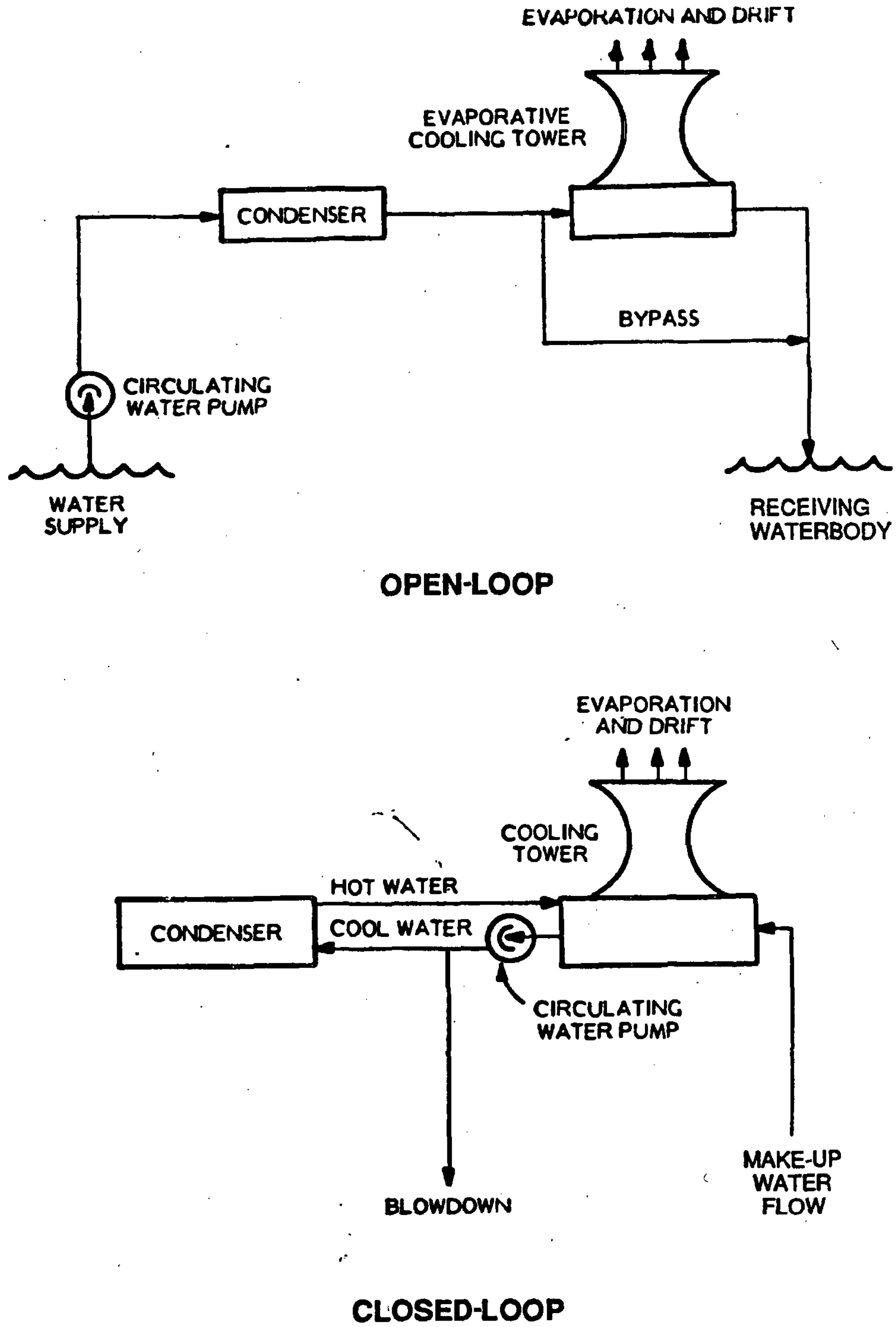


Figure D–1

Open- and Closed-Loop Cooling Water System Configurations

The performance (amount of heat dissipated) of wet evaporative cooling towers depends on meteorological conditions at the site, with the most important parameter being the "wet bulb temperature." A normal thermometer measures "dry bulb temperature." Wet bulb temperature is measured by covering the thermometer bulb with an absorbent material wet with distilled water. Evaporation from the absorbent material will cool the thermometer bulb below the measured dry bulb temperature. The amount the temperature is depressed depends upon the humidity of the air. In very dry air (low humidity) evaporation is rapid, and there is a large difference between the dry bulb temperature and the wet bulb temperature. Conversely, if the humidity is high, evaporation takes place slowly and the wet bulb temperature is close to the dry bulb temperature.

Figure D-2 presents a simplified view of a mechanical draft cooling tower cell. Wet mechanical draft towers have several cells, each with its own fan and water distribution system. Air entering at the bottom of the tower is pulled through the tower by the fans. The water to be cooled is sprayed into the air stream. Because of the high surface area of the water droplets evaporation takes place rapidly. The cooled water falls by gravity to the basin below the tower.

Natural draft evaporative cooling towers (Figure D-3) employ a hyperbolic-shaped chimney to draw the air past the water sprayed into the tower. The wet natural draft cooling tower performs well in climates where the year-round relative humidity is comparatively high and temperatures are low, as this type of tower works on the principle of differential density between the warm, moist air inside the tower and the ambient air outside the tower. The warm, less dense air in the cooling tower will rise and be displaced by the cooler, denser air through ports at the bottom of the tower.

Both mechanical and natural draft cooling towers release impurities in the form of "drift." Drift is simply water droplets carried out of the cooling tower exhaust with the air flow. These droplets contain the same dissolved solids present in the circulating water. Drift eliminators are used to limit the amount of drift. Cooling tower manufacturers will guarantee the performance of cooling tower drift eliminators to limit the drift to between 0.002 percent and 0.0005 percent of the circulating water flow. For a closed-cycle, saltwater cooling tower system operating with a cycle of concentration of 1.5 and a circulating water flow of 1,600,000 gpm there would be a drift of 32 gpm. The amount of dissolved solids released would exceed 2,500 tons per year.

The land space requirements for a cooling tower include the land for the towers plus a clear zone surrounding them to permit unimpeded air flow. Natural draft towers are circular, with diameters varying from 300 ft to 500 ft. Mechanical draft towers can be purchased in either round or rectangular configurations. The round configuration requires less total land space for the same capacity.

The principal advantages of natural draft evaporative towers relative to mechanical draft towers are:

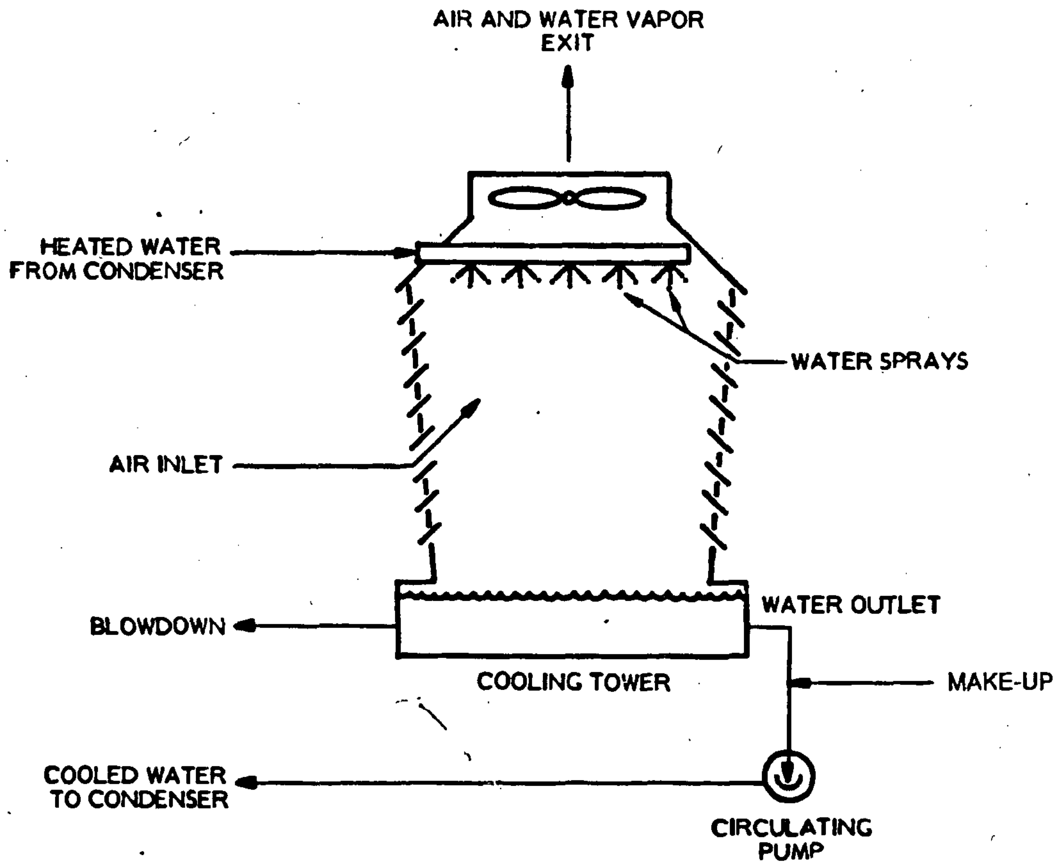


Figure D-2

Wet Cooling Tower Showing Mechanical Draft

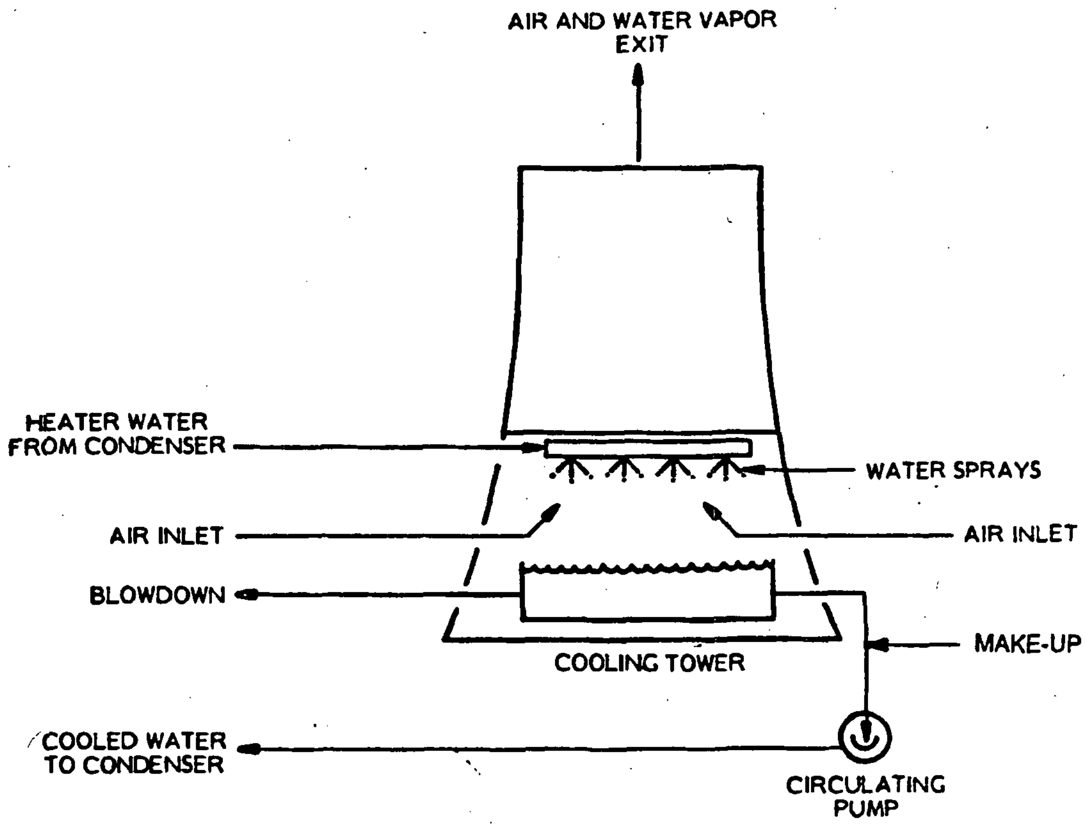


Figure D-3

Wet Cooling Tower Showing Natural Draft

- They do not constitute a continuous drain on energy resources nor a demand on the power system.
- The tower height reduces the possibility of local fogging at ground level under adverse weather conditions and usually results in greater dispersion of the cooling tower drift.
- Maintenance costs are low and availability is high.

The principal advantages of mechanical draft evaporative towers relative to natural draft units are:

- Air flow and outlet water temperature are more directly controlled.
- Circulating water pumping costs are lower.
- Ambient relative humidity has a minimal effect on tower performance.
- Capital costs are lower.

Cooling tower systems can use make-up water from a variety of sources. The higher the quality (low level of dissolved impurities), the more cycles of concentration allowed. For very high-quality water (e.g., from groundwater sources) the cycles of concentration can be as high as 20-25. At the other extreme, systems using seawater make-up are limited to a maximum cycle of concentration of about 1.5 by the high levels of dissolved impurities. Experience with saltwater cooling towers is limited. There are no operating closed-cycle cooling tower systems using seawater at power plants in the United States. The only power generating facility in the world using seawater in a closed cooling tower system is the 96-MWe generating station at the Fleetwood Power Station in England, which uses two natural draft cooling towers. The Fleetwood Plant is a small peaking plant with three 32-MWe units. The circulating water flow rate is 67 cfs (1.9 m^3/sec) per unit, and salinity of the cooling water make-up typically ranges from 26 to 27 ppt (Stone & Webster Engineering Corp. 1978). The system operates with 1.2-1.5 cycles of concentration. To prevent severe corrosion, the circulating water pumps are made of a special alloy. Shell-like deposits of calcium and magnesium carbonate have been found in sections of the condensers. These deposits must be removed annually by chemical treatment (Stone & Webster Engineering Corp. 1978).

Another major consideration when using saltwater cooling towers is the effect of salt drift on equipment and structures at the plant as well as on the surrounding environment. While the rate of drift is low, the accumulated amount over a period of time would be significant. Of principal concern is the accumulation of salt drift on electrical equipment in the switchyard. Frequent maintenance would be required to prevent arcing and other electrical faults.

For the above reasons freshwater (salinity less than 10,000 ppm) has been used in cooling tower systems wherever possible. Brackish water (salinity between 1,000 ppm and 26,000 ppm) has also been used. Cooling tower systems have also been employed which use the effluent from municipal water treatment systems for make-up to the system.

D.2.2.2 Dry Cooling Towers

Dry cooling towers employ finned-tube heat exchangers with atmospheric air as the cooling medium for the dissipation of heat. Since water is not released to the environment, the prime advantage of the dry cooling tower over evaporative towers is conservation of water. Air circulation through the heat exchanger can be either by forced or natural draft.

There are two steam condensing systems available for dry cooling in power plant applications: direct and indirect systems. Direct systems use extended-surface, air-cooled condensers in which the turbine exhaust steam is condensed directly in the cooling tower (Figure D-4). Large ducts are needed to convey exhaust steam to the heat exchanger coils. Indirect dry cooling tower systems use contact, jet condensers rather than conventional surface condensers (Figure D-5). Cooled circulating water is sprayed into the jet condensers, where it mixes with the turbine exhaust steam, causing condensation. Circulating water pumps recycle most of the heated condensate to the dry cooling tower and return the remaining condensate as boiler feedwater.

Mechanical draft cooling towers are generally favored for direct systems. Because of the relatively high condensing heat transfer coefficients inside the air-cooled tubes, the increased overall heat transfer rate obtained with a fast-moving air stream driven by fans permits tower size reduction, which more than offsets the cost of the air-moving equipment. However, indirect systems, because of the lower convective heat transfer coefficients inside the air-cooled tubes, do not strongly favor the use of mechanical draft cooling towers. Some European power stations have included natural draft hyperbolic cooling towers.

Beginning in the 1960's, direct dry cooling tower systems for power plants were installed in Europe. These applications are for power plants ranging from 3 to 50 MWe. In 1970, the largest European direct dry cooling tower system for a 160-MWe power plant was commissioned in Spain.

In the United States, the 20-MWe Neil Simpson plant located in Wyodak, Wyoming, employs a direct dry tower system with mechanical draft air circulation. This plant has been in operation since 1969. Also, due to the lack of a supply of make-up water and because the ambient air temperature is mild in summer and cold in winter, Pacific Power and Light has built a 330-MWe direct mechanical draft dry cooling tower power plant in Wyodak. This 330-MWe Wyodak unit is the largest single-unit power plant employing a direct dry tower system in the world.

At present, there are no plans to incorporate direct dry tower systems at power plants with capacities greater than the Wyodak 330-MWe unit. There are two major reasons. First, the direct system uses very large and costly turbine exhaust steam

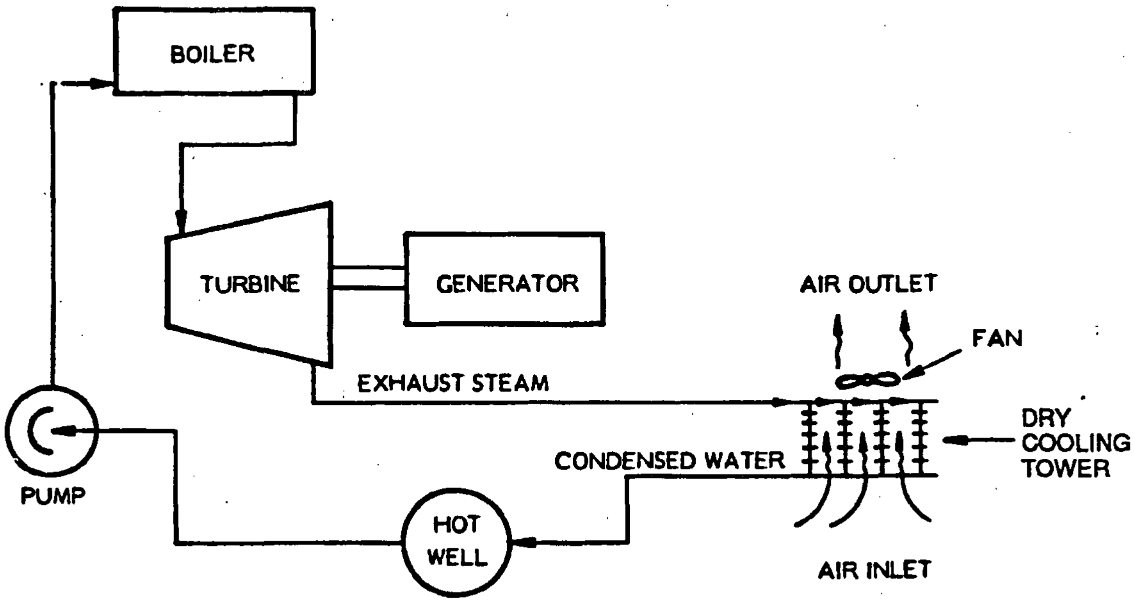


Figure D-4

Dry Cooling Tower Showing a Direct Steam Condensing System

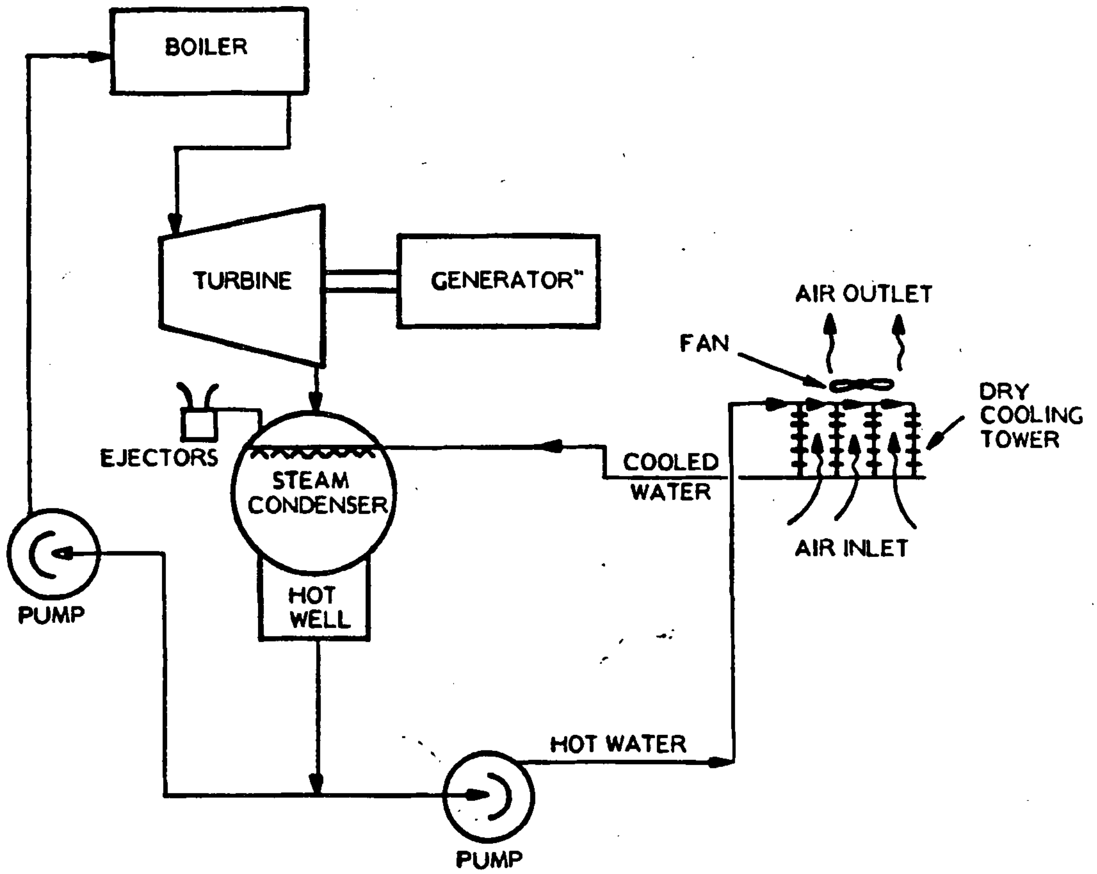


Figure D-5

Dry Cooling Tower Showing an Indirect Steam Condensing System ducts. Previous design limits have been for about the 200 MWe size. Second, turbine manufacturers (world-wide) have not been able to supply a large turbine which could withstand the high exhaust pressure typical of direct systems (10 to 15 inches of mercury, absolute, or Hg abs).

The largest indirect dry cooling tower systems are in South Africa, Hungary, and the USSR. Numerous smaller indirect units are also in operation in Europe. Many of these units employ natural draft cooling towers. At this time, extension of indirect dry cooling to power stations of larger ratings than 220 MWe is not occurring. The reasons are essentially the same as those mentioned above for direct air-cooled units.

All applications of dry cooling to electric generating stations have involved fossil-fueled units. No nuclear power stations use dry cooling towers as the primary means of heat dissipation. Because of the lower main steam temperatures and pressures associated with water-cooled nuclear reactors as compared to fossil station conditions, the heat rejection system (condenser-cooling tower combination) would be 150 percent larger than for a fossil-fueled plant similar in size.

Dry cooling towers are not as efficient as "wet" cooling towers. They have high capital costs, high maintenance costs, large air throughputs, decreased plant output at high dry bulb temperatures, and create high turbine exhaust pressures of 5 to 15 inches of mercury (depending on the ambient air temperature) whether direct or indirect cooling is used. Comparable turbine exhaust pressures are 1.0 to 2.5 inches of mercury for once-through cooling and 2.5 to 4.5 inches of mercury for wet cooling towers. Loss of turbine capacity, increased annual fuel consumption due to higher turbine heat rate, and increased auxiliary power costs are all results of these factors. Thus, the overall efficiency of power plants using dry cooling towers is lower than an equivalent plant using once-through or wet evaporative cooling tower systems.

D.2.2.3 Wet/Dry Cooling Towers

Wet/dry cooling towers are mechanical draft cooling systems incorporating two basic modes of heat transfer into a single tower. In the wet section of the tower, condenser circulating water is contacted by ambient air, and cooling is achieved through evaporative and sensible heat transfer. In the dry section of the tower, ambient air outside a finned-tube heat exchanger cools the hot condenser circulating water (inside the finned tubes) by sensible heat exchange. The two air streams (wet and dry) are mixed and discharged from the system through a fan at the top of the tower.

Figure D-6 is a simplified illustration of a wet/dry tower. Dampers control the air flow through the wet and dry sections, with the relative proportion of wet and dry cooling depending upon ambient air temperature. Wet/dry cooling towers reduce annual water consumption by taking advantage of dry cooling during periods when low ambient temperatures prevail, and reduce visible water vapor plumes.

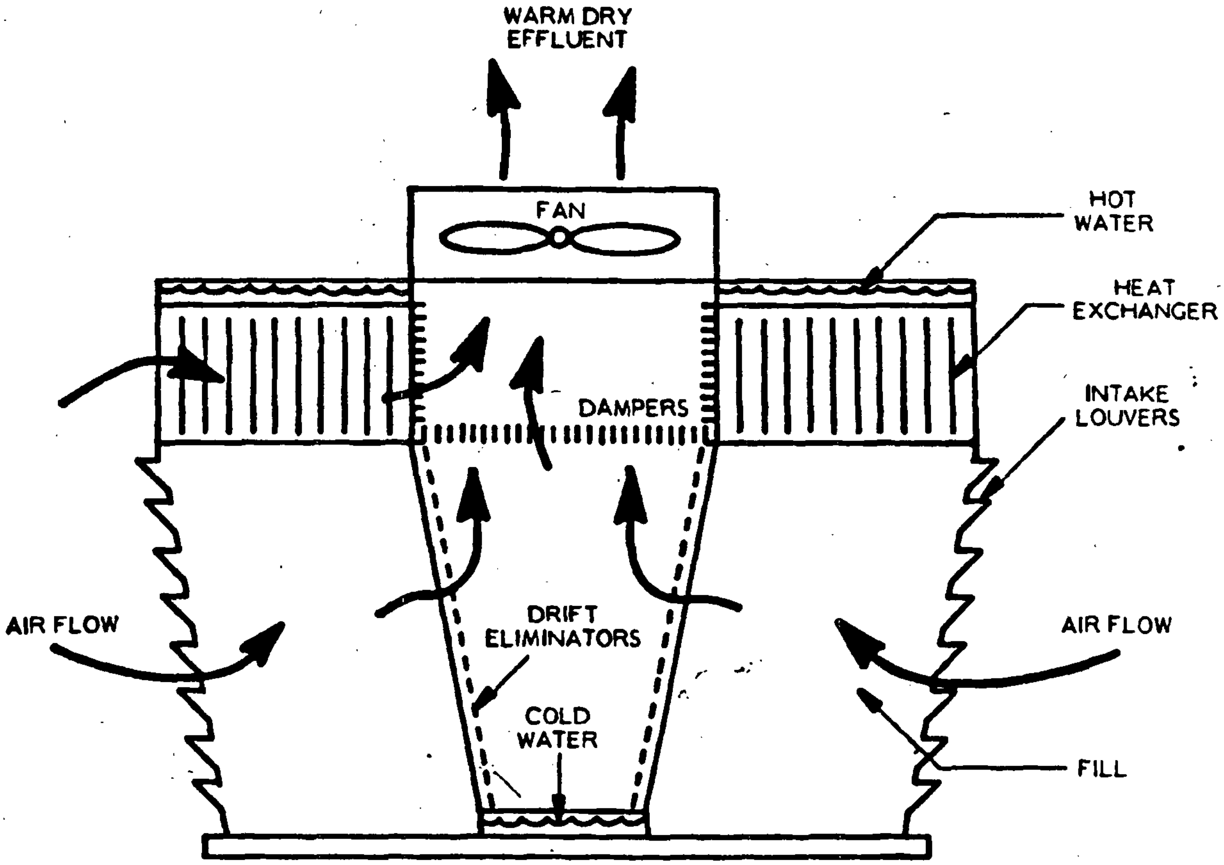


Figure D-6

Wet/Dry Cooling Tower

The combination of wet evaporative cooling with dry cooling can reduce the economic penalty of a completely dry system and maintain the turbine backpressure within the limits of 5 in. Hg abs by reducing the turbine backpressure during periods of high air temperatures. By using the wet portion of the tower when the air temperatures are high, the maximum backpressure can be reduced to less than 5 in. Hg abs. This would improve the average efficiency and overcome the technical difficulty of designing turbines to operate with backpressures above 5 in. Hg abs. However, it should be pointed out that this advantage of a combined wet-dry cooling tower has not been proven for large electric generating stations.

Public Service Company of New Mexico, facing a limited water supply, installed a wet/dry cooling tower on its 500-MWe San Juan Unit 3. The design results in roughly a 1,200 gpm (2.7 cfs; 0.075 m^3/sec) maximum make-up rate compared to a wet tower rate of 4,400 gpm (9.8 cfs; 0.28 m^3/sec) (Rittenhouse 1979). The value of the savings in water must be considered in relation to the relatively high capital costs of the wet/dry cooling tower as opposed to wet cooling towers.

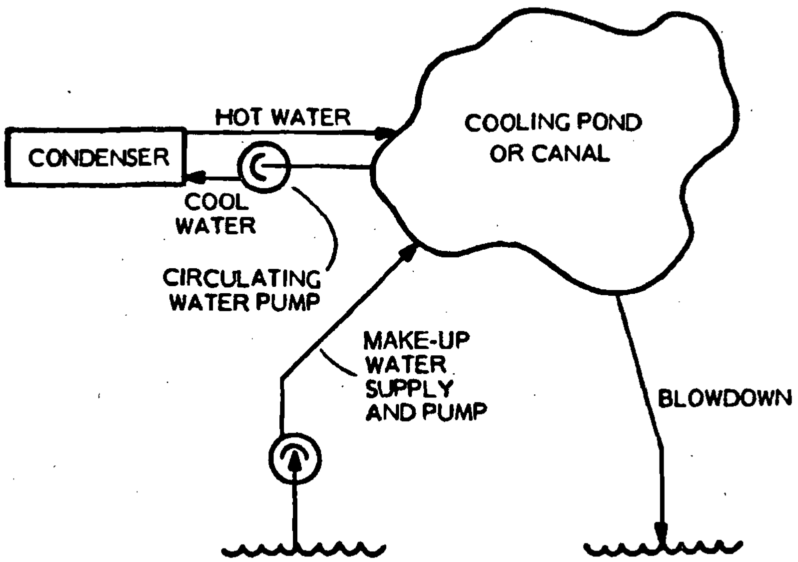
The wet/dry cooling tower has been operational since 1979. Some freezing problems have been encountered and, as anticipated, the unit is limited by backpressure at times of high ambient air temperature during the summer. Nevertheless, the unit has provided a satisfactory solution in a situation where insufficient water was available for a wet cooling tower (T. Garrett 1988, personal communication).

Wet/dry cooling systems are relatively new in the power industry. They are more costly to install than wet evaporative towers and the wet/dry design uses considerably more auxiliary power than the wet tower because of the large amount of air-to-water heat transfer surface required. Another important factor regarding wet/dry cooling towers is the space required to site the tower. The less efficient heat transfer requires that the towers be much larger than an equivalent capacity wet mechanical draft tower. It is estimated that about four times as many cooling towers would be required for this alternative than for the wet mechanical draft alternative.

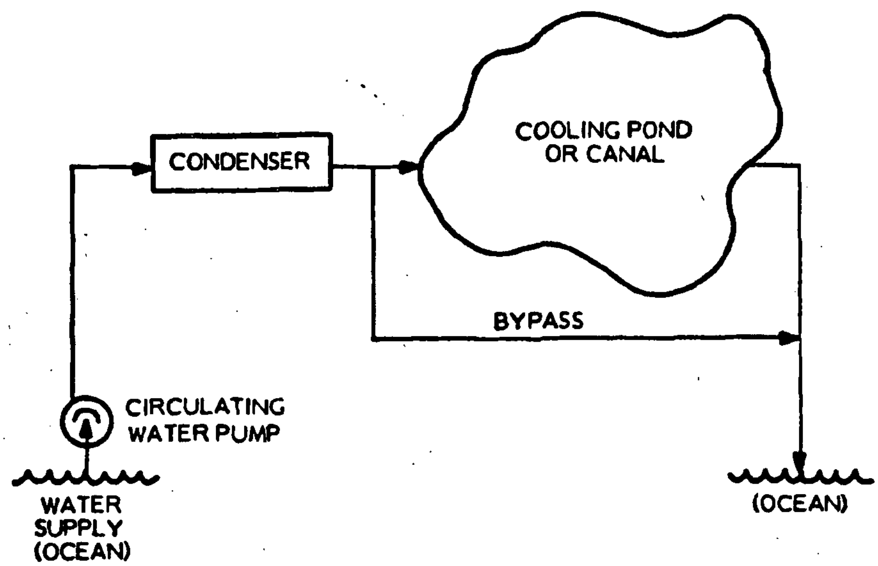
D.2.2.4 Cooling Ponds or Canals

Cooling ponds or canals are manmade waterbodies used to absorb waste heat and dissipate the heat to the atmosphere by evaporation from the pond or canal surface. They can be used in closed or open cycles. Open-cycle systems use cooling ponds or canals as an intermediate cooling device between the power plant and the ultimate heat sink. Figure D-7 shows a simplified diagram of an open-cycle cooling pond or canal system. By installing a bypass around the pond or lake, a portion of the cooling water flow can be redirected when there is insufficient cooling surface available or to control the temperature in the pond or canal.

Figure D-7 also presents a simplified diagram of a closed-cycle cooling pond or canal system. Cold water is pumped from the pond or canal, through the condenser and back to the pond or canal. Baffles or separators prevent "short circuiting" of the hot



OPEN-CYCLE



CLOSED-CYCLE

Figure D-7

Open-and Closed-Cycle Cooling Pond or Canal System

water directly back into the cool water pipes. Since water is lost from the system through evaporation, a continuous "blowdown" or discharge is required to prevent the build-up of impurities (dissolved solids). A source of make-up water is required to replenish the pond or canal.

Large land areas are required for cooling ponds or canals. While the exact land area required varies from one site to another (primarily due to meteorological conditions), an effective pond or canal area requirement of from 1 to 5 acres per megawatt of electrical capacity has been estimated (MacFarlane et al. 1975).

An open-cycle cooling pond or canal system can be installed on less land than a closed-cycle system. However, the amount of cooling achieved before the cooling water is discharged depends on the meteorological conditions, and on the size of the pond or canal, the surface area, and the amount of time the cooling water spends in the pond or canal en route to the receiving water. With an 80 F condenser outlet temperature and 65 F wet bulb temperature, about 1,000 acres of pond surface area is needed to reduce the discharge temperature by 0.1 F for an open-cycle system.

The effectiveness (the amount of heat dissipated) of cooling ponds and canals can be increased by adding spraying devices to increase the evaporation rate. By spraying water from the pond into the air, the surface area of water exposed to the air is greatly increased, as is the evaporation rate. Thus, more cooling capacity can be installed per acre of land by adding sprays. As for wet cooling towers, the evaporation rate (hence heat rejection capacity) depends upon the ambient wet bulb temperature.

The addition of sprays to a cooling pond or canal can cause a "drift" problem from the pond. Drift is composed of water droplets carried away from the pond or canal by the wind. The amount of drift depends on the force of the wind and the height to which the water is sprayed. The problem with drift is that the water droplets contain dissolved solids which will be deposited on adjacent land areas.

Advantages associated with cooling ponds or canals include:

- Construction costs are reasonable where the soil is impermeable; however, if a liner is required, construction costs increase considerably.
- They provide a settling basin, thereby removing suspended solids.
- Evaporative losses may be partly compensated for by collection of rainfall and runoff (closed systems only).

Disadvantages associated with cooling ponds or canals include:

- They require large land areas.
- They require soil basins of low permeability or a liner to prevent seepage from the pond bottom.

- There is a possibility of fogging in the area.
- There is a concentration of dissolved solids in the pond when it is operated as a closed-cycle system, requiring proper blowdown disposal.

When the plant is in operation, the average closed-cycle surface water temperature increases to the level required to dissipate the imposed heat load. The rate of surface heat dissipation is equal to the product of the surface area, the surface heat transfer coefficient, and the difference in temperature between the pond surface and the equilibrium temperature. The surface heat exchange coefficient is a function of local meteorological conditions and the pond water surface temperature. The water consumption for cooling ponds is approximately one-third larger than that for wet cooling towers.

D.2.2.5 Summary of Closed-Cycle Cooling

The use of closed-cycle cooling requires consideration of air quality impacts from cooling tower drift, terrestrial effects of salt deposition, land use requirements, aesthetic considerations, and economic factors.

A survey of operating experience with saltwater closed-cycle cooling systems prepared for The Utility Water Act Group (Stone & Webster Engineering Corporation 1978) found no operating or proposed electric generating facilities in the United States using seawater (salinity 26-36 ppt) make-up in closed-cycle cooling systems. Stone & Webster's review (1978) also showed that no seawater closed-cycle unit has ever operated anywhere in the world for units of the size presently being constructed or planned by the utility industry (i.e., 700 MWe fossil or 1,150 MWe nuclear).

About 25 power plants in the United States, ranging in capacity from 10 to 1,510 MWe and with circulating water rates of 4,900-540,000 gpm (11-1200 cfs; 0.3-34 m^3/sec), use brackish water (0.5-26 ppt) make-up in evaporative closed-cycle cooling systems. A survey of operating experience at these plants indicated that operational difficulties attributable to the use of brackish water included: (1) degradation of materials of the cooling tower, spray modules, or other plant structures, (2) switchyard and/or transmission line arcing, and (3) off-site property effects. The magnitude of these problems varied widely, from corrosion of handrails to forced outages of the units. Corrections ranged from replacement of the complete cooling system to conversion to freshwater make-up. Although the difficulty could not be attributed solely to the use of brackish water, nonattainment of design thermal performance was reported in a number of cases.

Non-evaporative closed-cycle cooling systems using heat exchangers are attractive as water-saving devices. Although technically feasible, they are costly and generally offer poorer plant performance than evaporative systems. The California Energy Commission reports that, "Effective heat transfer in dry cooling towers requires significantly more heat exchanger surface than wet cooling systems (closed-cycle).

Construction costs are therefore much higher. Although dry cooling systems use essentially no water, they work less effectively the higher the air temperature." (Stamets 1977).

D.2.3 Cooling System Retrofits

Retrofitting a once-through cooling system at an existing power plant with a closed-cycle system requires extensive investigation and evaluation. Since the cooling system is a major part of the initial plant design, changes require careful examination of overlapping operational, environmental, and economic considerations. Changes could be more complex, and more expensive, than design and construction of a new plant.

Operational evaluations involve thermal performance, operating requirements, service life of system components, electrical conductor contamination by cooling tower deposition, and plant reliability.

Environmental considerations center on air quality effects of cooling tower drift, terrestrial effects from salt deposition, land use requirements, and aesthetics.

Economic evaluation involves capital costs for cooling system conversion, plant performance penalties, increased operation and maintenance costs, higher site-related costs, and costs associated with the effect on system reliability of reduced generating capacity of the modified unit(s). For some sites (particularly older, inner city plants), the cost of acquiring land for cooling towers may be prohibitive.

D.3 Intake Location in the Source Waterbody

Both surface water and groundwater are used as cooling water sources for power plants in the United States. Each source has characteristics affecting the location, design, and operation of intakes.

Selecting the location of cooling water intakes to avoid areas of high fish and invertebrate population densities is desirable. This involves considering the type of waterbody (i.e., lake, river, estuary, open ocean) and the location of the intake structure within the waterbody (onshore or offshore). The most favorable intake locations are in areas of low biological value (U.S. EPA 1977). Few, if any, intake locations are completely free of entrainable and impingeable organisms, but those near migratory routes, spawning areas, nursery areas, or feeding grounds should be avoided when possible.

A cooling water intake may be:

1) A shoreline intake where the screens, trashrack, and associated structures are located near the shoreline. In such situations the intake pumpwell is often close to the screens so the screens and pumpwell can be combined into a single structure,

2) An offshore intake where the inlet and pumpwell are separated and connected by pipes. The screens are often placed near the pumpwell but in some cases screens are at the point of offshore water withdrawal, or

3) An approach channel intake (recessed intake) where cooling water is diverted from the source to the intake screens by a conveyance channel. This approach is common among older plants but has been viewed less favorably in U.S. EPA publications addressing intake design (U.S. EPA 1976). Recent modifications of this approach use the intake channel to establish a controlled flow field, improving the biological performance of protection systems for fish and aquatic life.

All three intake locations are currently used in the United States.

D.3.1 Shoreline Intake Structures

Shoreline intake structures are exemplified by the one shown in Figure D-8. Locating a shoreline intake requires considering the vertical and horizontal distributions of aquatic organisms to avoid siting the intake in an area of high biological productivity. Consideration of the hydrology of the area is important to minimize recirculation and allow for variations in the water level. Sediment deposition and debris accumulation along shorelines must be considered. The modifications to the natural environment created by intake system operations must be considered in detail.

Shoreline intake designs should:

1. Avoid locating the intake in high productivity or high population density areas for fish and shellfish, where there is susceptibility for debris or sediment accumulation, or where the intake will create high productivity or high population density areas.
2. Locate the intake to minimize recirculation of cooling water, entrained organisms, and debris.
3. Evaluate the effect of cooling water intake and heated discharge on water source flow fields and organism location, type, and distribution.
4. Evaluate the probability of ice dams, frazil ice, and movement of unconsolidated inorganic materials in the water source.

D.3.2 Offshore Intake Structures

Offshore intake structures similar to that shown in Figure D-9 are primarily used to supply cooling water to power plants using once-through cooling systems. Offshore intakes provide a reliable supply of water when shipping activities or ice floe formation and breakup can threaten the reliability and/or the physical structure of a shoreline intake. They are also used to isolate the cooling water intake from the discharge to minimize thermal recirculation, to avoid disruption of lateral drift of

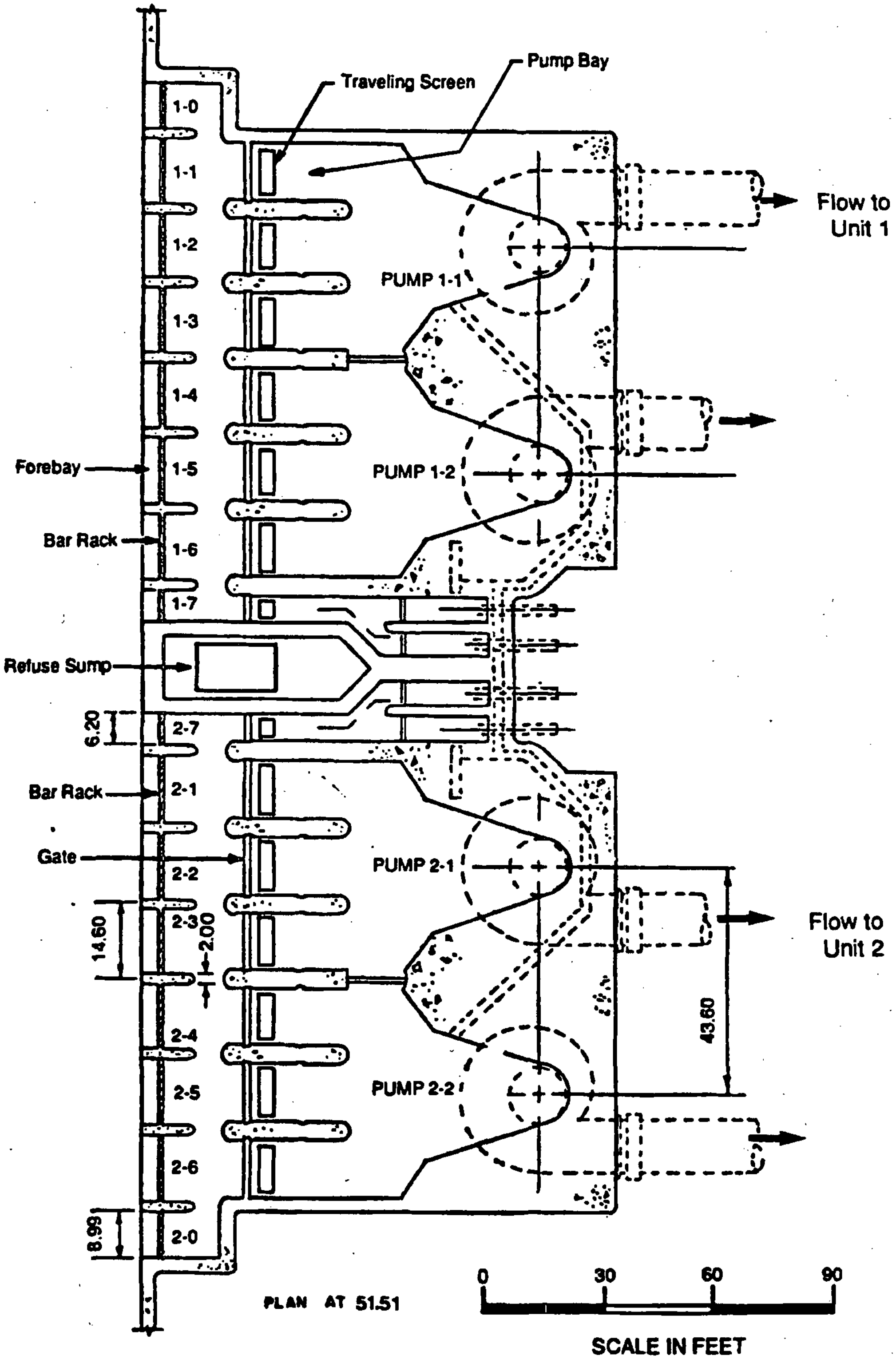


Figure D-8

Typical Shoreline Intake Configuration

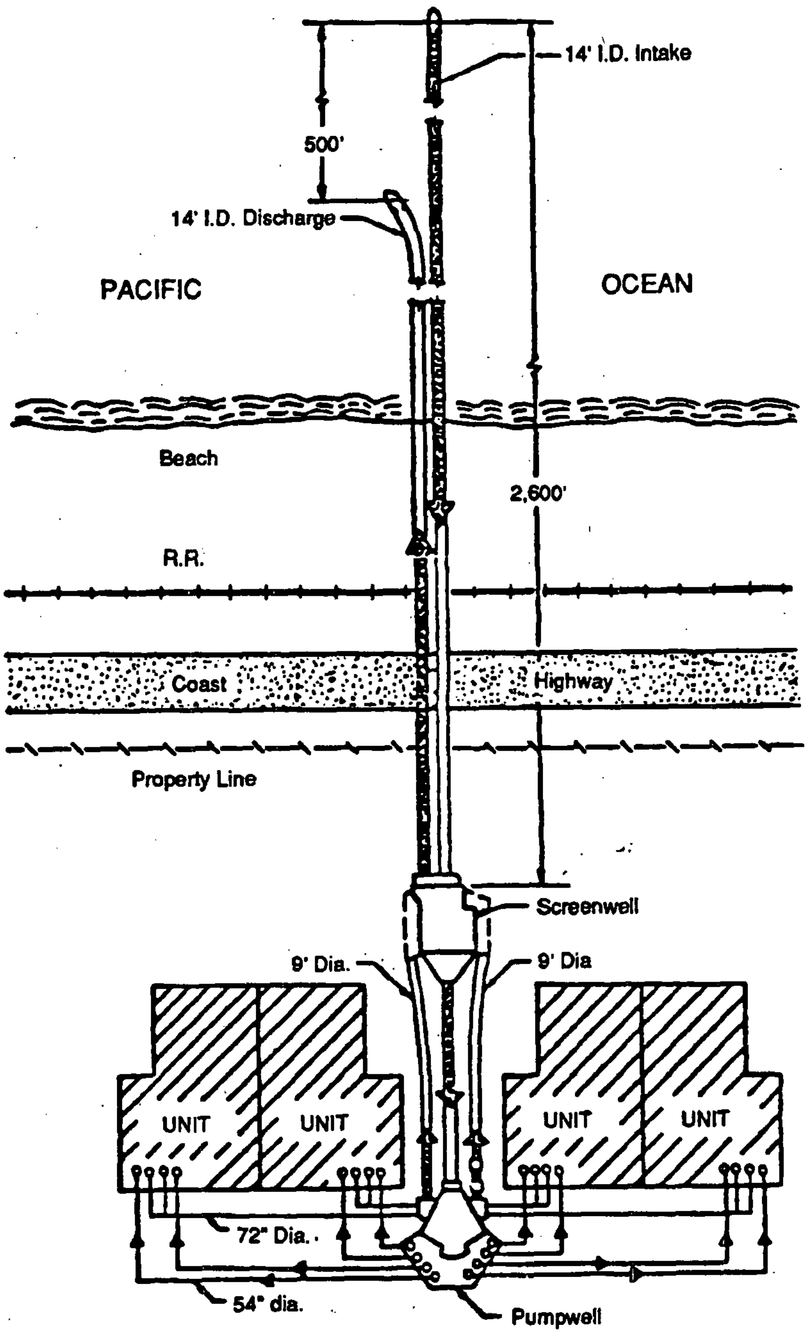


Figure D-9

Plan View of an Offshore Intake (From Sonnichsen 1975)

beach sand, and to avoid shallow nearshore areas where the topography or existence of a surf zone prohibits a shoreline intake structure. Offshore intakes provide more flexibility in intake location than shoreline intakes, but the cost of offshore intakes can be substantially greater than for comparable shoreline structures. The cost is principally determined by how far offshore the intake must be to provide reliable performance, avoid biologically active areas, and avoid thermal recirculation.

Closed-cycle or smaller capacity offshore intakes in rivers and freshwater bodies often incorporate point of withdrawal screening, so additional screening is not required at the pumpwell. When the intake conduit is relatively short, such systems can be superior to shoreline intakes with vertical traveling screens in terms of cost, operating performance, maintenance, and environmental acceptability (Odgaard et al. 1984).

Offshore intake structure location requires consideration of the spatial distribution of aquatic organisms, vertical stratification of water temperature (when it exists), and hydrology. Problems associated with ice, sedimentation, biofouling control, fish removal and return, and obstruction of navigable water must be addressed in the design and location of offshore intakes.

Offshore intakes include an offshore point of water withdrawal, a conduit to convey water to the power plant, and an onshore screenwell. Screen location depends, in part, on whether the system is for once-through or closed-cycle cooling or operates in a marine or freshwater environment. Because of the large water volumes and/or the possibility of biofouling in marine environments, once-through systems and marine systems usually use recessed screening. Many closed-cycle freshwater systems use screening at the point of water withdrawal.

Once-through systems with screens near the pumpwell create a zone of fish entrapment between the offshore entrance to the intake structure and intake screens. Alleviating fish entrapment within the intake relies on preventing entry, and using removal systems to return entrapped fish. Methods to prevent fish entry include velocity caps to reorient the flow pattern into the intake from vertical to horizontal flow. A velocity cap on the offshore intake at El Segundo Power Station reduced the tonnage of fish entering the intake by approximately 95 percent (Weight 1958). Alternative methods of preventing fish entry into large offshore intakes on once-through systems include porous dikes and behavioral response systems. Screens, both stationary and vertical traveling screens, in offshore structures have also been considered.

Closed-cycle systems with offshore intake structures are most frequently constructed in rivers or smaller waterbodies. They often employ screening at the point of water withdrawal. The earliest of these systems employed perforated plate cylindrical screens. More recently these systems have used profile-wire screening. Other screening technologies include infiltration galleries, artificial filter beds or screened intake towers.

Offshore intake designs should:

1. Avoid locating the intake in areas which are highly productive, have high population densities of fish and shellfish, or where intakes are likely to create high productivity or high population densities.
2. Locate the intake to minimize recirculation of cooling water and entrainment of organisms and debris. In some cases, intentional seasonal heated water recirculation minimizes operational problems due to icing.
3. Design intake velocities to accommodate swimming performance and behavioral response of resident and migratory fishes, as well as engineering constraints.
4. Provide for the escape or removal of organisms from the intake structure.
5. Locate the intake where it will not impede navigation.
6. Locate the intake where the likelihood of damage, blockage or destruction of the intake by ice is minimized or avoided.

D.3.3 Approach Channel Intakes

Approach channel intakes (recessed intakes) are used to provide a protected area for intake screens, to separate the intake and discharge locations to minimize thermal recirculation, or for other engineering or economic reasons.

The approach channel conveys water from the shoreline to an intake structure, in an enclosed conduit or an open canal. Fish can become trapped in the conduit or canal and may become stressed or fatigued, and eventually impinged.

Open-approach channels generally have lower water velocities than enclosed conduits. Open channels allow greater behavioral avoidance and reduced entrapment of organisms, so enclosed conduits should be avoided whenever an alternative configuration can be used. The U.S. EPA (1976) favors properly designed shoreline or offshore intakes over open-approach channels.

D.4 Intake Design Parameters

The principal intake design parameters influencing organism losses are (1) intake velocities, (2) intake screen design, screen opening size, and screen material, (3) intake configuration, and (4) fish return system. A brief discussion of intake velocity and intake screen design follows. A discussion of intake configuration is presented in Section D.3. Fish return systems are described in Section D.5.3.

D.4.1 Intake Velocities

Intake velocities at two locations have received the widest biological attention: the approach velocity of water entering the intake (in front of the bar rack structure), and the through-screen velocity. To reduce impingement losses, approach velocities should be based, in part, on the swimming performance of fish species present in the vicinity of the intake. Through-screen velocity should be based, in part, on the relationship between through-screen velocity and survival of impinged organisms.

D.4.1.1 Intake Approach Velocity

Design criteria for intake structures based on swimming performance must consider several factors. First, the fish to be protected differ from one geographical region to another. Second, some species are more susceptible to entrainment and impingement than others, and the susceptibility of a species to entrainment, entrapment, or impingement varies for each life stage. Third, environmental variables such as water temperature, salinity, illumination, and dissolved oxygen concentration may alter the ability of a species to avoid entrapment and impingement. Fourth, predator species may alter the behavioral pattern of individual fish or schools of fish and increase their susceptibility to entrapment (Landry and Strawn 1974).

Studies of swimming performance have been done on a variety of species. It is difficult to correlate the observations and establish a realistic approach velocity design criterion for swimming ability, because of variations, inconsistencies, or omissions in reporting data; pretest conditions; experimental design; physiological conditions; and environmental considerations. In addition, most tests have been performed with uniform approach velocities perpendicular to the screen, with limited provision for fish bypass or for the fish to swim away from the intake field of influence. These escape and field of influence issues are important for offshore submerged intakes, particularly those with point of withdrawal screening.

Approach velocity design criteria typically range from 0.2 to 1.5 fps (6-46 cm/sec) for shoreline intake structures and offshore intakes with point of withdrawal screening, and 1.5 to 2.0 fps (46-61 cm/sec) for offshore uniform velocity cap intake structures. An intake should have a uniform velocity profile across the entrance. In addition to biological considerations, the approach velocity depends on engineering constraints associated with the intake design and configuration, hydrology, and water quality of the source waterbody — all of which must be determined on a site-specific basis.

Dredging to remove sediment deposits from an existing intake structure can reduce approach velocities. Routine maintenance of the bar racks and intake entrance area to remove accumulated debris and obstructions is important to assure satisfactory intake operation.

D.4.1.2 Through-Screen Velocity

The probability of impingement mortality increases with increasing impingement duration and with higher water velocity. Mortality results from respiratory difficulty and abrasion by the screen surface. Biological studies on the survival of impinged fish have been conducted by Bibko et al. (1974), Prentice and Ossiander

(1974), Landry and Strawn (1974), King et al. (1978), and many others (see Oak Ridge National Laboratory and Atomic Industrial Forum, Inc. 1979 for an extensive review). These studies indicate that, in addition to being affected by through-screen velocity, impingement survival depends on the species, size, and life stage of impinged organisms; the season; spraywash pressure; and the duration of impingement. Hemmorahaging, descaling, and mechanical abrasion are important factors contributing to impingement mortality. As a result of the interacting factors influencing impingement mortality, it is difficult to isolate the contribution of through-screen velocity.

Through-screen velocities at intakes of U.S. utilities typically range from 0.5 to 3 fps (15-92 cm/sec) for vertical traveling screens. Through-screen velocities for cylindrical, off-shore, point of withdrawal screens average 0.35 fps (10 cm/sec). Once an intake flow rate and the submerged screen area have been established, decreases in the open area of the screen increase the through-screen velocity.

Fish are impinged on screens as a function of the local velocity, not the average velocity. With the exception of cylindrical, offshore intakes and traveling screens designed for uniform velocity, most intakes demonstrate substantial flow non-uniformity through the screen, with local velocities two or three times greater than the average velocity.

If fish protection depends on the ability of the fish to avoid the screen for a sufficient time enabling it to leave the intake flow field, biological information on swimming ability and endurance can be used to select through-screen and approach velocity design criteria. If fish protection depends on impingement of fish eggs and larvae on fine-mesh intake screens followed by safe transport to a discharge point away from the screen, establishing through-screen velocity and impingement duration can be more complicated. This is true, in part, because the criteria for "safe" impingement of eggs and larvae can be very different from the "safe" velocity and impingement duration for more mature life stages. Fish eggs and larvae are delicate and can be extruded through screens or damaged if through-screen velocities are too high. Juveniles and older fish have better survival rates if they are not fatigued when they become impinged. Since these fish have greater swimming ability than their younger counterparts, higher velocities can facilitate rapid impingement so that they can be washed from the screens and routed to the release trough. For some species the velocities for egg and larvae protection may overlap the velocities for effective collection of juveniles. For other species there may be a significant gap between the best velocities for fish of different life stages. Establishing appropriate through-screen velocity and impingement duration relationships is essential if fine-mesh intake screens are being considered to remove fish eggs and larvae from cooling water to safely return them to the source (Tomljanovich et al. 1978). Data on through-screen velocities needed for impingement survival are not available for most species of fish. The data available on the relationship between impingement survival, duration of impingement, and through-screen velocity are inconclusive and do not provide a reliable basis for design criteria for through-screen velocity for a broad variety of fish species and life stages.

D.4.2 Intake Screen Design, Mesh Size, and Screen Material

A variety of intake screen designs are available for cooling water intakes (see Section D.5.2 for a review of intake screening devices). The major engineering and biological design requirements for intake screens include:

1. The intake screens must provide the necessary coolant flow while maintaining through-screen velocities within design parameter limits.
2. The intake screen must remove debris which might clog the condenser system. This requires a balance between the amount and size of debris removed, screen maintenance requirements and operational reliability, and alternate techniques for maintaining condenser heat transfer efficiency.
3. The intake screen must ensure a reliable and adequate supply of cooling water.
4. The intake screen should minimize mechanical effects resulting in injury or death from abrasion or suffocation during impingement on screen surfaces.

Note that design parameters may conflict. Velocities for active screen avoidance may be lower than the velocity required to push debris against the screen face with sufficient force to ensure effective removal by vertical traveling screens. However, vertical traveling screens with fish return systems and fish troughs on the screen panels can accommodate lower through-screen velocities because the fish troughs also carry debris.

Intake screen design parameters at a specific site require knowledge of the power plant cooling system design, characteristics of the water source (including sediment and debris loads), and the species and size of organisms to be protected. No single intake screen design is best for all sites.

Intake screen mesh openings are often chosen so that the mesh opening is approximately 50 percent of the condenser tube diameter to avoid condenser clogging. As a result of this criterion, most power plant cooling systems with 7/8-in. (22.2-mm) diameter condenser tubes, have 3/8-in. (9.5-mm) square woven-wire mesh intake screens.

NMFS criteria for salmonid fry protection call for a maximum clear opening of 0.14 in. and maximum approach velocity of intake water immediately in front of the screen of 0.5 fps (Swan et al. 1980). A secondary factor has been reducing maintenance requirements by reducing debris loading of condenser tubes or inline filters. To select an intake screen mesh size for biological reasons, it is necessary to:

- Determine the screen opening size/intake screen design combination most likely to combine high system survival rates with reliable water supply.

- Determine if the organisms and life stages in question can withstand impingement stresses more easily than entrainment stresses.

Retention of various species of fish larvae by screen meshes of various sizes is presented in Figure D-10. Screen mesh with 0.02-in. (0.5-mm) openings will retain the majority of egg and larval fish present in most water sources. Tomljanovich et al. (1978) reviewed experimental studies to determine the feasibility of protecting larval fish at water intakes using fine-mesh screening. Additional considerations in selecting a screen mesh size include debris loading and screen clogging, available open area and through-screen velocity, screen reliability under site-specific operating conditions, and the feasibility of safely returning impinged organisms to the source waterbody.

Recently, increased emphasis has been placed on determining screen mesh sizes based on the size of organisms to be eliminated from entrainment. Schneeberger and Jude (1981) established a linear relation between total length and body depth of fish larvae found in Lake Michigan for use in predicting the effectiveness of larval exclusion by fine mesh screens at intakes. Length was related to body depth rather than body width, because mean depth is greater than mean width for most larval fish. Estimates of exclusion can then be made based on the assumption that larvae pass through the screens lengthwise. The possibility of extrusion through the screens can be accommodated by assuming that only larvae with body depths a certain assumed percentage larger than the screen mesh size are excluded. Of course, the question of impingement effects on the excluded organisms must also be addressed. In some cases impingement effects may be so significant that it is preferable to allow the organisms to be entrained and pass through the cooling system. It should further be noted that large larvae have higher natural survival rates, so their losses have greater ecological implications for the population than the loss of newly hatched larvae.

Several models developed to predict the size of fish retained by various intake screen meshes (Turnpenny 1981; Schneeberger and Jude 1981; Fisher et al. 1981) were evaluated using size-specific impingement information from operating cooling water intakes by Hanson and Seltenrich (unpublished). Hanson and Seltenrich (unpublished) found that predictions of screen mesh retention varied considerably, and generally overestimated the length of striped bass actually retained on intake screens at water diversions. Thus, the predictions are conservative in that fish smaller than the predicted size are also successfully excluded. For striped bass, 95 percent of juveniles 36-mm long were excluded by a 9.5-mm (3/8-inch) screen, whereas the predicted lengths for exclusion ranged from 47 to 84 mm.

Screen mesh configurations for vertical traveling screens include square mesh woven-wire, and horizontal slot configurations using woven-wire or welded-wedge wire. For offshore point of withdrawal screening, screen surfaces include horizontal and vertical slot-welded wire, cylindrical and flat screens, and perforated metal plate. Each screen type is available with a broad range of screen opening size and open area ratios. Hydrodynamic and biological investigations are continuing (e.g.

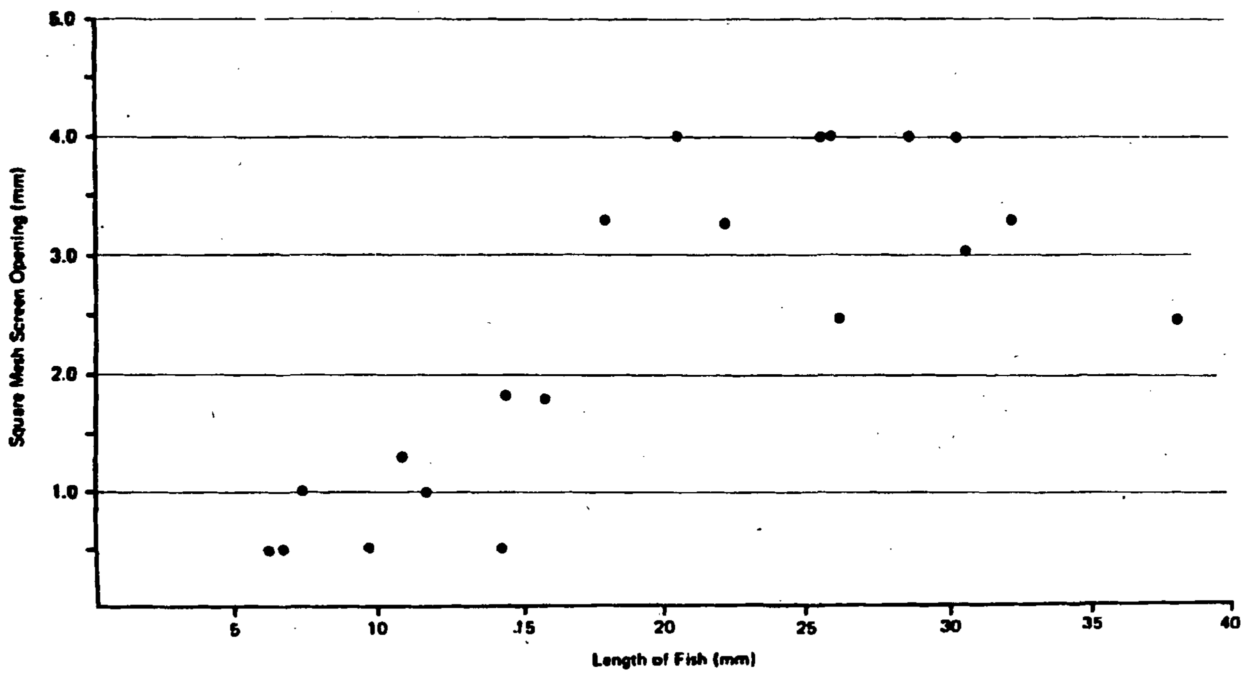


Figure D-10

Relationship between Square Mesh Screen Opening Size Required for 90 Percent Retention and Length for Twelve Species of Fish (Data from Erkkila et al. 1950; Kerr 1953; Clay 1961; Prentice and Ossiander 1974; Fisher 1978; and Tomljanovich et al. 1978)

Cook 1978; Heuer and Tomljanovich 1978; Walker and Kamata 1979) to determine the advantages and disadvantages of various intake mesh configurations. Cook (1987) reviewed the screening characteristics of offshore point-of-withdrawal screens. Available data does not indicate that one intake screen/mesh combination significantly reduces biological losses, debris loading, and hydraulic losses in comparison to other available configurations for all combinations of biological species to be protected, water withdrawal requirements, and other site and project specific factors.

Intake screens are available in polyester, nylon, stainless steel, and Monel. The selection of a screening material depends on screen opening size and configuration and the desired durability of the screen. Polyester and nylon screen is used where a fine-mesh screen (0.02-0.06-in.; 0.5-1.5-mm) is desired and when screen mesh is replaced or altered seasonally. Stainless steel is used where durability over a long period in a corrosive environment (such as saltwater) is needed. Monel is used in fresh and saltwater environments, but requires greater maintenance and more frequent replacement than stainless steel. In addition to durability, capital cost and replacement cost are considered in the selection of screening material.

In surveying fish protection facilities on the Columbia and Snake Rivers, Swan et al. (1980) found that wire mesh screening was the least durable because of rust and corrosion. Monofilament mesh was subject to brittleness and eventual breakdown after prolonged exposure to sun and weather. On the other hand, stainless steel screens heldup well with minimum maintenance.

There is no data to indicate that the type of screen material influences the survival of impinged organisms.

However, it should be noted that studies conducted in 1983 at the Pittsburg Power Plant in California show that the actual survival of striped bass impinged on a fine-mesh traveling screen is substantially lower than impingement survival rates derived from laboratory studies (PG&E 1985).

D.4.3 Other Intake Design Parameters

In the early 1950's PG&E and Bechtel undertook a study in cooperation with the California Department of Fish and Game to minimize intake entrapment and impingement losses (Kerr 1953). As an outgrowth of the study, PG&E established design criteria for all of their subsequent intake structures. A typical shoreline intake is shown in Figure D-8. Besides reducing entrapment and impingement, intakes must meet a number of hydraulic and mechanical criteria. In addition to approach velocity, through-screen velocity and screen design criteria, fish protection criteria identify preferred locations in the waterbody (previously discussed in Section D.3), and provisions for lateral fish escapes between the bar racks and traveling screens.

D.5 Intake Guidance and Diversion Technologies

D.5.1 Behavioral Barriers

Various stimuli such as light, sound, velocity gradients, electric shock, and chemicals, have been tested in attempts to deter fish from entering cooling water intakes. Louvers and velocity caps provide stimuli to guide fish away from intakes. Behavioral barriers rely on the ability of organisms to respond to stimulus, and are of little or no value in protecting planktonic fish eggs and larvae. In addition, the behavioral response of fish to artificial stimuli varies among species and within a species, because of differences in age or physiological state (Sonnichsen 1975). Because of the variability in responses to stimulus, behavioral barriers are most appropriate where a single species of fish of relatively uniform size and age is concerned. EPRI has a continuing evaluation program to investigate various behavioral barriers. Behavioral barriers are usually used in addition to, or in combination with, physical barriers on an intermittent or continuous basis. Qualitative conclusions are presented in Table D-1.

Patrick et al. (1987) in reporting the results of tests of a combined sound, light and air-bubble curtain behavioral barrier on Lake Ontario conclude that "Although behavioral systems such as sound may show promise in controlling fish at specific locations they should not be considered as a separate way of thinking to physical systems in controlling fish."

McKinley and Patrick (1987) studied the effectiveness of strobe lights, pneumatic popper and hammer sound deterrents in diverting downstream migrating sockeye salmon smolts at the Seton Hydroelectric Station in British Columbia. They found that "Percent exclusion was highest for the hammer (75 percent), followed by popper (66 percent) and strobe (56 percent) deterrents." Air-bubble curtains were not effective.

Matousek et al. (1987) report the results of tests of three types of behavioral barriers, separately and in combination, at the Roseton Generating Station on the Hudson River. The barriers tested were:

- air-bubble curtain;
- pneumatic gun sound generator;
- underwater strobe lights.

They state that "The overall effectiveness of the three test devices alone and in combination was generally low." Maximum effectiveness was 62 percent for the strobe plus air curtain, but significant differences in behavioral barrier effectiveness were noted for different taxa and different diel periods. On the basis of these field tests, they conclude that behavioral barriers have limited overall effectiveness at riverine power plant intakes.

TABLE D-1

SUMMARY OF EXPERIENCE WITH BEHAVIORAL BARRIERS FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Reduces Larval Entrainment	Reduces Impingement	Reduces Entrapment	Operationally Reliable	Comments
Light	○	○	○	●	Attracts some species
Sound	○	○	○	●	After initial avoidance, fish acclimate to sound
Velocity gradient	○	○	○	○	Requires relatively high velocities, stable water level
Bubble screen	○	(?)	○	●	Attracts some species at night
Electrical barrier	○	(?)	○	(?)	Applicable to fresh water only; can induce fish mortality
Chemicals	○	○	○	○	Discharge of chemicals into receiving waters; undemonstrated
Magnetic barrier	○	○	○	○	Undemonstrated
Cables and chains	○	○	○	○	Undemonstrated
Louvers	○	◓	○	◓	Lack automatic debris-cleaning capability
Velocity cap	○	●	●	●	Applicable to offshore intakes only

<u>Legend</u>

● Demonstrated effective

◓ Demonstrated somewhat effective

(?) Data inconclusive, conflicting or variable

○ Demonstrated ineffective or no data

D.5.1.1 Light

Intense illumination was characterized by Bibko et al. (1974) as a passive deterrent for striped bass, temporarily deterring fish passage under experimental conditions. Fields (1966) reported that the avoidance response of salmonids to artificial light varied, depending on the light adaptation of the species, water clarity, and flow conditions. Fields found constant light more effective than interrupted or flashing light for guiding young salmon. Adaptation to light intensity substantially decreases the guidance efficiency of light barriers.

Taft et al. (1987) states that "Strobe lights modified behavior of some species and lifestages in the laboratory, but field evaluation to date does not confirm such differences. Mercury lights also modified the behavior of some species and lifestages in the laboratory and field evaluation confirmed this behavior can be exploited to alter fish passage rates. The field attraction to mercury lights did not always produce the desired or expected results in all species or under all test conditions. Therefore test results should be applied with caution and possibly only with additional field verification."

Patrick et al. (1987) tested sonic deterrents, air-bubble curtains and strobe lights at the Pickering Nuclear Generating Station and found that strobe lights were the least effective of the three methods tested.

Available data on the effectiveness of light as a behavioral barrier are contradictory. In some tests, fish are attracted to light, while in others fish are repelled. In addition, light does not provide an effective barrier during the daytime or in highly turbid water. Thus, light barriers are not considered to be an effective method of reducing entrainment or impingement of organisms at intakes.

D.5.1.2 Sound

Sonic barriers to repel fish from industrial water intake structures have been reported by Moore and Newman (1956), Burner and Moore (1962), VanDerwalker (1964), and Trefethen (1968). Moulton and Backus (1955) reviewed the literature regarding the guidance efficiency of sonic barriers.

In general, maximum avoidance response has been observed for low-frequency, high intensity sound, but variation in hearing ability among species and high-level background noise leads to poor repeatability in fish responses to sonic barriers. Burner and Moore (1962) reported response to sound was insufficient to safely guide young salmonids around dams and diversions. Anderson (1987) suggests that salmonids migrating downstream on the Columbia River may be entrained in the turbines at Rocky Reach Dam because they are avoiding low frequency sound generated by the submersible traveling screen intended to divert the fish. The Virginia Electric and Power Company (VEPCO) tried using high-intensity, multi-frequency sound to repel fish from power plant intakes (J. White 1976, personal communication). Although sound was partially effective, sound alone was inadequate for repelling fish from the cooling water intake, because of the diversity of species, and behavioral patterns of the fish encountered.

Schuler and Larson (1975) tested an underwater pneumatic impact device (popper) as a sonic barrier at a power plant intake. They concluded that the effective range of sonic barriers is limited and that fish quickly become accustomed to a sound stimulus and no longer show an avoidance response.

Although fish are initially frightened by sound barriers, laboratory and field studies indicate they may become accustomed to sound stimuli, rendering the barrier ineffective. Patrick et al. (1987) discuss preliminary results of tests in Lake Ontario using sonic deterrents with a range of frequencies. They claim some success in controlling the movement of alewife. They also state that alewife did not show habituation to the sound signal, although the test duration was only six hours. However, at this time, sonic deterrents cannot be considered a proven technology for controlling fish movement.

D.5.1.3 Velocity Gradients

Kerr (1953), Clay (1961), Bates (1964), Bates and VanDerwalker (1964), Niggol (1964), and Prentice (1966) discussed flow acceleration or deceleration barriers for guiding or deflecting fish. Flow acceleration barriers increase the approach velocity over a short distance by using wedges in approach channels. Bates and VanDerwalker (1964) reported a 70 percent diversion efficiency for an experimental water-jet deflector at a approach velocity of 2.5 fps (76 cm/sec). High diversion efficiencies (81 percent) were reported by Prentice and Ossiander (1974) for vertical flow accelerators at a 20^{0} deflection angle for channel velocities ranging from 1.2 to 2.4 fps (37-73 cm/sec). Horizontal flow accelerators had an average deflection efficiency of 56 percent for channel velocities from 1.5 to 2.3 fps (46-70 cm/sec) (Prentice and Ossiander 1974). No difference between daytime and nighttime diversion efficiency was observed. Blinded fish, tested by Gerold and Niggol (1964), were guided by flow acceleration barriers with diversion efficiencies comparable to normal fish.

No application of velocity gradients for diverting fish from power plant intakes has been tested. The use of velocity gradients within an intake structure requires a confined approach channel and relatively high approach velocities. This combination is likely to entrain and entrap fish, and requires effective guidance of diverted organisms into a bypass system. Further, this combination may also result in establishment of a resident predator population. Therefore, velocity gradients are not a reliable technique for reducing entrainment or impingement at power plant intakes.

D.5.1.4 Air-Bubble Screens

Air-bubble screens have been unsuccessful at consistently diverting fish (Brett and MacKinnon 1953; Fields 1966; Mayo 1974). However, several cases of partial success have been reported. Bibko et al. (1974) reported that striped bass would not actively pass through an air-bubble screen at 40 or 52 F (4.5 or 11.1 C), but would drift passively through the screens when the water temperature was 33 F (0.8 C). Striped bass passed through an air-bubble screen at all test temperatures if openings 2 in. (5.2 cm) or greater were allowed in the screen. Gizzard shad would not pass through an air-bubble screen at water temperatures of 52 F (11.1 C), but were not deterred at 33 F (0.8 C) (Bibko et al. 1974). Bates and VanDerwalker (1964), studying juvenile migrant salmon, reported that air-bubble screens produced diversion efficiencies up to 95 percent during daylight, but declined to 28 percent at night and were not improved by artificial lighting. Alevras (1974) observed that an air-bubble screen at the Indian Point Power Station on the Hudson River did not repel fish during the daytime, and preliminary data indicated that the air-bubble screen may attract fish at night. Tests performed by Patrick et al. (1987) at the Pickering Nuclear Generating Station on Lake Ontario found that "An air-bubble curtain, used either alone or combined with strobe lights, was not a consistent deterrent." Matousek et al. (1987) also found that the air-bubble curtain, when used alone, was the least effective of the three deterrents (strobe, air curtain and pneumatic gun) tested, although an air curtain combined with a strobe did show some effectiveness at night.

Because of the variability in response among species, poor effectiveness at night and in turbid water, and lack of success in field applications, air-bubble screens are not an effective method of reducing entrainment or impingement.

D.5.1.5 Electric Barriers

Electric barriers have been used to divert fish from small power plants, dams, irrigation canals, and municipal water supply systems with variable success. Holmes (1948) discussed the history, developmental problems, and practical applications of electrical techniques for fish diversion. Applegate et al. (1954) reviewed the literature on electric fish screens.

Pugh (1962), Pugh et al. (1964), and Elliott (1970) reported that pulsed current was most effective in terms of guidance, diversion, and power requirements. The behavioral reaction of fish to an electric field are: (1) avoidance, (2) electrotaxis, and (3) electronarcosis leading to paralysis and eventual death (Applegate et al. 1954; Elliott 1970; Maxwell 1973). The required current density and resulting behavioral response varies among species and sizes of fish (Pugh 1962; Pugh et al. 1964).

Trefethen (1955) reported 68 percent guidance efficiency of electric barriers in large-scale laboratory experiments with fingerling salmon. Efficiency decreases as water velocity exceeds 0.5 fps (15 cm/sec) (Pugh 1962; Pugh et al. 1964). Maxwell (1973) reported variable success of electric barriers used at small freshwater intakes, usually with resident rather than migrating fish species. Because of low electrical resistance, no application of electric fish barriers has been made in salt or brackish waters.

Electric barriers are most effective when impingement of only a few species of relatively uniform size is of concern. At intakes where a variety of species and sizes of fish are encountered, or at intakes in marine or estuarine waters, electric barriers are not effective in minimizing entrainment.

D.5.1.6 Chemicals

A barrier consisting of a fish-repelling chemical, discharged near the intake, may be used to discourage the entry of fish. Fish-repelling chemicals are available, but no large-scale testing has been conducted. Chemical barriers are of little practical value because of the large volumes of cooling water involved and the adverse effect of discharges of fish-repelling chemicals on non-target organisms in the receiving waterbody.

D.5.1.7 Magnetic Barriers

Magnetic fields have been examined as a method of guiding juvenile salmonids past water diversions (Cannon et al. 1979). Salmonids did not respond to changes in magnetic fields under experimental conditions. No tests have been conducted to examine the effectiveness of magnetic barriers at power plant intakes. In the absence of information suggesting the applicability of magnetic fields for reducing entrainment or impingement, further consideration of magnetic barriers is not warranted.

D.5.1.8 Chains and Cables

Chains and cables hung vertically at the entrance to a water intake have been examined as a behavioral barrier. Experiments with juvenile salmonids by Brett and Alderdice (1958) suggest that chain and cable barriers are not effective in consistently diverting fish. In the absence of demonstrated effectiveness, chain and cable barriers are not a reliable technique for reducing entrainment or impingement of fish.

D.5.1.9 Louvers

The application of louvered deflectors for diverting juvenile migrant salmonids and striped bass has been discussed by Bates and Vinsonhaler (1957), Bates and Jewett (1961), and Skinner (1974). Diversion of downstream migrants of anadromous species with louvers has had variable success. Diversion efficiency is influenced by approach velocities and the species and sizes of fish. Louvers depend on the behavioral response of fish, triggered by changes in the magnitude and direction of the local velocity field, for their success. Uniform flow patterns must be established, so fish can sense the flow fields and respond to them. Louvers are a well-developed engineering and biological design concept, requiring minimum handling of fish. However, they do not divert fish eggs and larvae, are vulnerable to biofouling accumulations, and are not self-cleaning.

Skinner (1974) discussed the diversion efficiency of the Delta Fish Protective Facility near Byron, California, which diverts water from the Sacramento – San Joaquin river system primarily for agricultural usage. The facility is a fixed-louver design oriented 15° to the flow, with primary and secondary bypass facilities. Present diversion capacity of the facility is approximately 6,000 cfs (170 m^3/sec). Louver efficiency for white catfish is directly related to fish length. Primary diversion efficiency ranged from 4 percent for white catfish 0.4-0.5 in. (10-12.5 mm) long to 68 percent for those 3.0-3.9 in. (75-100 mm) long. Diversion efficiency for salmonids was related to fish length and water velocity. Velocity greatly influenced diversion efficiency of smaller fish, but as fish increased in size and swimming capabilities, velocity became less critical. Diversion efficiency for salmonids ranged from 65 to 84 percent in 1970 and from 84 to 90 percent in 1971 for salmon 2.0-5.9 in. (50-150 mm) long. Differences in diversion efficiency between the two years was probably related to the operator's ability to attain and maintain test parameters. Based on observations of 1.3 million striped bass 0.2-4.9 in. (5-125 mm) in length, there is an inverse relationship between diversion efficiency and channel approach water velocity. Lower approach velocities were most favorable for striped bass less than 1.2 in. (30 mm) long. The diversion efficiency of the louver system for striped bass was 69 percent.

Schuler (1974) observed the reaction of marine fish to louvers oriented at various angles to the flow, vane spacings, and approach velocities. For marine fish, highest guidance efficiency was observed for louvers oriented 20° and 30° to the flow with vanes 1 in. (2.5 cm) apart. Maximum diversion efficiency occurred at a mean approach velocity of 2 fps (61 cm/sec). Schuler (1974) observed that the guidance component extended 5.9-7.9 in. (15-20 cm) from the louver face and that test species guided better along an array of louvers than along screens.

Louvers have been used effectively for diverting migrating anadromous fish from large agricultural water diversions, but the application to power plant intakes has not been attempted. Louvers do not provide a positive barrier for eliminating entrained planktonic organisms or debris from a cooling water flow. Entrainment could block the condenser tube system, leading to reduced operating reliability and increased maintenance of the cooling water system.

A combined louver/traveling screen intake was operated satisfactorily at the San Onofre Nuclear Generating Station in California. The structure combines the guidance characteristics of louvers with the positive physical barrier of a screen.

D.5.1.10 Velocity Cap

During the early 1950's, offshore intakes would entrap large schools of fish in the intake conduit. The entrances of these offshore intake conduits were unscreened and oriented vertically in the water column to minimize sediment deposition within the intake. The fish entrapped in the intake would eventually impinge on the intake screens and would occasionally force a cooling system shutdown. Based on experiments, it was determined that fish sense and react to vertical flow fields much more slowly than to horizontal flow fields. As a result, a velocity cap (Figure D-11) is placed over the entrance to the offshore intake to reorient the flow patterns from a vertical to a horizontal flow field. Although fish behavior is species and age specific, fish removed from one intake structure decreased from 272 tons the year before installation of the velocity cap to 15 tons the year after installation, a reduction of nearly 95 percent (Weight 1958).

Velocity caps are presently used in offshore intakes in the Pacific Ocean off southern California and in Lake Michigan. A velocity cap functions as a behavioral barrier and is used in combination with onshore intake screens, which provide a physical barrier for those fish that do enter the intake. Approach velocity, the influence of tides and waves, and the ratio of structural height to diameter must be considered when designing velocity caps. Intakes in Lake Michigan and Lake Oak in the Dakotas have placed screens at the circumference of a velocity cap to combine a behavioral barrier and point of withdrawal screening. Because of biofouling problems, this approach is less likely to be successful in a marine environment. Velocity caps are effective behavioral barriers for reducing the numbers of impinged fish in an offshore intake. Velocity caps will not reduce entrainment of planktonic organisms.

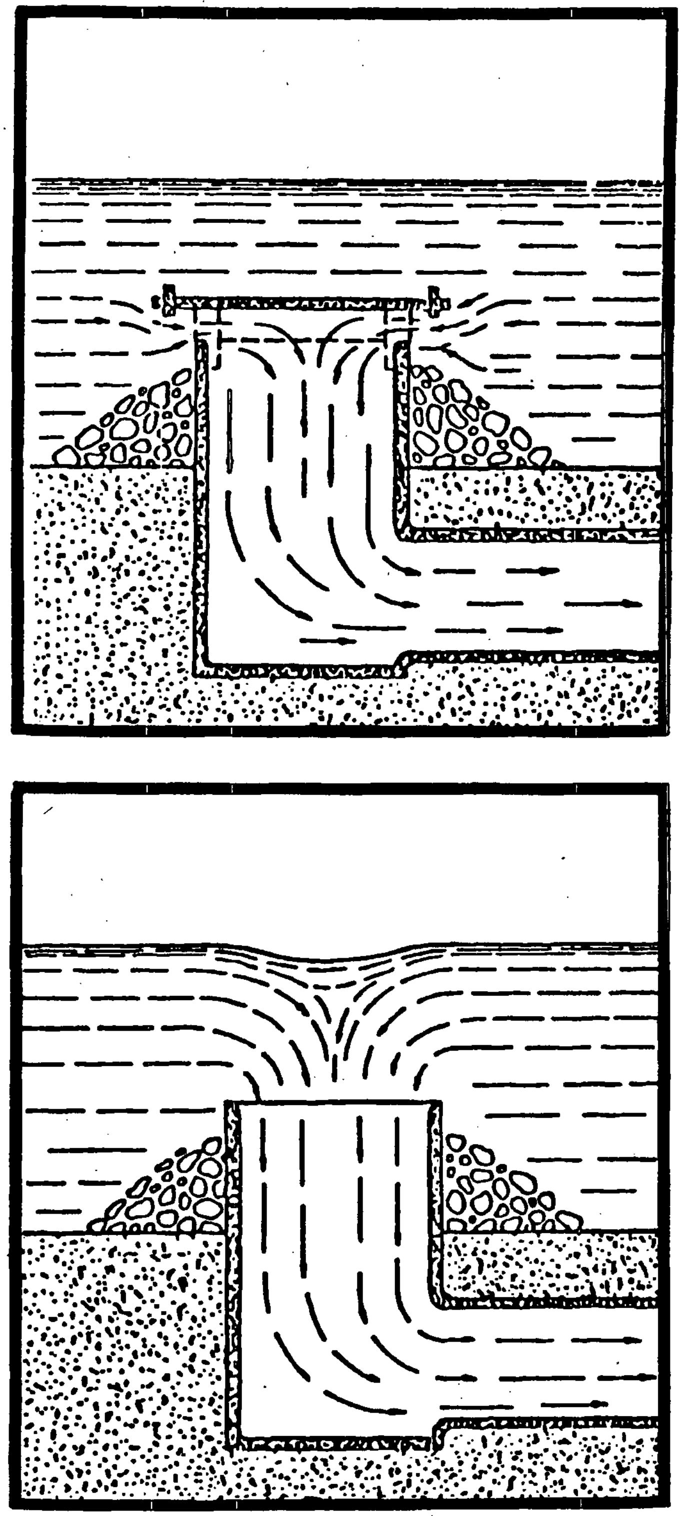
D.5.2 Physical Barriers

Historically, intake screens and other physical barriers have been designed to remove entrained debris from the water prior to passage through the condensers. During recent years, extensive effort has been devoted to designing and modifying physical barriers to exclude fish and invertebrates from the water supply while minimizing mortality from impingement. In addition to excluding debris and organisms from a cooling water supply, an acceptable physical barrier must be mechanically dependable and operate as designed under a variety of conditions.

Some physical barriers impinge organisms for brief periods until they are mechanically transferred to a bypass channel. Recently, many physical barrier systems (e.g., vertical traveling screens and centerflow screens) have been modified on an experimental basis to include fine-mesh (0.02 to 0.1-in., or 0.5 to 2.5-mm) screen material, in an attempt to minimize the numbers of eggs and larval fishes entrained.

In the following sections, biological and engineering considerations associated with the use of various physical barriers at power plant intakes are reviewed. Discussions are based on laboratory studies, prototype field studies, and operating experience at intakes and diversions.

Alternative designs include media filters, infiltration systems, fixed screens and traveling screens. Qualitative conclusions are presented in Table D-2.



Capped Intake
High velocity horizontal flow scares fish

Original Intake
Vertical flow traps fish

Figure D-11

Schematic Representation of an Offshore Intake with Velocity Cap
(From Weight 1958)

TABLE D-2

SUMMARY OF EXPERIENCE WITH PHYSICAL BARRIERS FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Applicable to Once-Through	Applicable to Closed-Cycle	Reduces Entrainment	Reduces Impingement	Operationally Reliable	Comments
Rapid sand filter	○	●	●	●	○	Suitability limited to extremely low flow rates
Porous dike	Ex	Ex	Ex	Ex	Ex	Three-year field training program underway, 1979-81
Radial well collector	○	●	●	●	○	Suitable for low flows; depends on geology, groundwater levels, and water quality
Stationary screen, perforated pipe, and plate	○	●	Ex	Ex	○	Possibly suitable where debris loading is light and biofouling minimal
Drum screen	○	○	○	?	●	Vertical type ineffective for subadult fish
Horizontal traveling screen	○	○	○	?	○	Mechanical performance under sediment load and varying water conditions unsatisfactory
Rotating disc screen	○	○	○	○	○	Limited non-power-plant application
Centerflow traveling screen	●	●	○	?	?	Requires increased screen-to-pump distance; irregular flow patterns
Vertical traveling screen	●	●	○	○	●	Impingement survival depends on design and operation parameters

Legend

● Demonstrated effective

? Inconclusive, conflicting or variable data

Ex Undergoing experimental studies, developmental stage

○ Demonstrated ineffective or no data

D.5.2.1 Rapid Sand Filters

The high-capacity rapid sand filter (infiltration gallery) has the potential to prevent entrainment, entrapment, and impingement of all species and life stages of fish in cooling systems. Free flow across the filter surface and low approach velocity combine to eliminate potential fish kills and the need for handling and disposal of debris. These filter systems, however, are plagued by operational problems, primarily associated with clogging of the filter media. As a result, filters have had limited use at power plant intakes.

The Montour Steam Electric Generating Plant, on the Susquehanna River in Pennsylvania, used a filter bed to provide make-up cooling water at a rate of approximately 33,000 gpm (73 cfs; 2 m^3/sec). Filter operation was unacceptable as a result of filter clogging by algae and fine sediments. Despite several modifications, reliability remained unacceptable, and its use was discontinued. The filter bed was replaced by a perforated pipe intake.

The feasibility of filtration beds in marine environments was examined by Stober et al. (1974) and Strandberg (1974). They concluded that a filter intake is potentially effective for excluding pelagic eggs and larval fish from power plant cooling systems. However, the present technology is not sufficiently developed to allow reliable design and operation of filter intakes.

The low infiltration rates of filters require large surface areas, approximately 10 acres (24.7 hectare) for every 1,000 gpm (2 cfs; 0.07 m^3/sec) of cooling water. This makes their application infeasible at many sites even as a supply of make-up water for closed-cycle cooling systems.

Reliability problems with rapid sand filters result from clogging of filter beds with silt, sediment and organic matter. Fish eggs and larvae can be trapped in the filter bed and killed. In addition, some species seek gravel beds for spawning. If they spawn on the filter bed, direct egg losses will be increased by eggs lost because they never entered the water column.

Operational problems and poor reliability of filter intake systems, as a result of clogging, filtration, and biofouling, make further consideration of the concept for use at power plant intakes unwarranted.

D.5.2.2 Porous Dikes and Leaky Levees

A porous dike or leaky levee uses a filter medium of stone and gravel to exclude organisms from a cooling water system. The porous-dike concept is applicable for both shoreline and offshore intakes, may provide a behavioral and physical barrier for larval and juvenile-adult fish, and eliminates the necessity of a fish return system. A porous dike enclosing a four acre pond has been used as an intake at Wisconsin Electric's Lakeside Power Plant on Lake Michigan for about 65 years (Michaud 1981). A doughnut shaped leaky dam intake has been used at the Point

Beach Nuclear Plant on Lake Michigan for over 15 years (Michaud 1981). The porous dike and leaky dam did not exclude small fish, and icing problems were encountered with the leaky dam. In a marine environment, biofouling problems would be more significant than in a freshwater environment. Operational reliability and maintenance associated with biofouling, clogging, and sediment accumulation are subject to question.

Criteria for the design and use of a porous dike as an intake structure include the following:

1. The dike must be stable and resistant to erosion by currents and wave action.
2. The size and composition of the medium must provide structural integrity, acceptable flow rates, and exclusion of organisms.
3. The hydraulic efficiency must be high and biofouling and sediment accumulation lows.
4. The dike must not require excessive maintenance.

Laboratory hydraulic investigations of flow-through porous/dikes (Roberge 1978) provide a foundation for the design of large-scale porous dikes. The primary biological advantage of a porous dike depends on its effectiveness in excluding larval and juvenile fishes from the cooling system. Schrader and Ketschke (1978) reviewed the biological aspects of porous/dike intake structures and concluded that a porous dike could act as both a behavioral and a physical barrier for larval and adult fishes. Available information is insufficient to determine the exclusion efficiency for various sizes and species of fish eggs and larvae as a function of medium size and approach velocity.

The operation and maintenance, engineering performance, and biological effectiveness of a large-scale prototype porous dike has undergone a year-long test at the Brayton Point Steam Electric Station on Narragansett Bay, Massachusetts. The prototype porous dike consisted of gabions filled with 8 inch stones on the downstream side and 3 inch stones on the upstream face. Exclusion of fish and other organisms down to larval size appeared to be good. One to two feet of head loss developed across the filter during the course of the year due to filter clogging. Furthermore, detritus passed through or produced in the filter built up in the collection well on the downstream side. This detritus problem caused New England Electric to abandon the porous dike in favor of an angled traveling screen. (J. DiVito 1988, personal communication).

Definitive conclusions regarding the engineering feasibility or biological effectiveness of porous-dike intake structures cannot be made at present.

D.5.2.3 Radial Well Collectors

Radial wells are subterranean intakes that withdraw water from aquifers or overlying water sources such as rivers or lakes. Radial wells have been used to supply water for domestic and industrial use, and are planned as intakes for cooling tower make-up water at several power plants. The maximum capacity of a typical radial well collector is approximately 55,500 gpm (124 cfs; 3.5 m^3/sec). This is insufficient to meet the demands of a once-through cooling system. Limitations in aquifer size, sediment permeability, and groundwater hydrology make it technically and economically impractical to build radial wells big enough to provide adequate water volume for once-through cooling.

Radial well collectors rely on induced infiltration through unconsolidated alluvial deposits. They furnish water low in turbidity and concentrations of suspended solids. Because of the large surface area of radial well collectors, the water velocity at the waterbody/sediment interface is extremely low, less than 0.0003 fps (0.01 cm/sec) (Mikels and Bennett 1978). The low velocities and positive physical barrier created by the substrate result in complete exclusion of eggs, larval fish, and microzooplankton. Thus, the radial well is an effective intake for minimizing or eliminating the biological impact associated with entrainment or impingement.

Engineering and operational considerations affecting the suitability of radial wells include the suitability of geological structures and groundwater hydrology of a particular site, sediment deposition, biological fouling, and accumulation of debris. The potential for depleting groundwater storage reserves, particularly during droughts, and the operational reliability of the intake through the life of the power plant must be evaluated.

The use of radial wells is limited to specific sites, because of substrate permeability and aquifer characteristics. They can only meet small water demands, comparable to the make-up water requirements for closed-cycle cooling. The limited capacity and siting constraints significantly limit the applicability of radial well collectors for power plant intakes.

D.5.2.4 Stationary Mesh Screens, Perforated Plates, and Pipes

Stationary screens have long been used in irrigation canals and industrial water intake systems. Debris accumulations on screen surfaces reduce water flow volume and the efficiency of these installations. Blockage of a stationary intake screen by impinged debris results in unacceptable reliability of stationary screens for use in large once-through cooling water intakes.

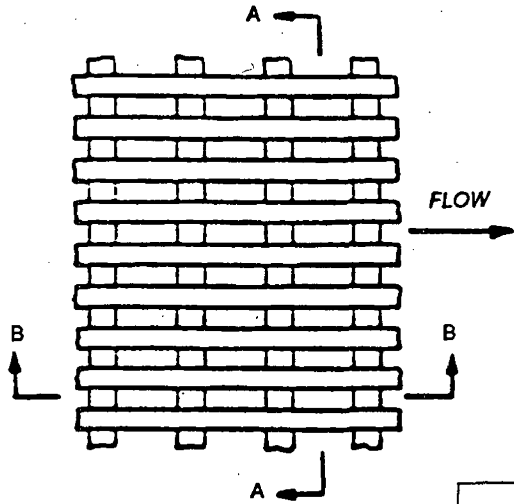
Perforated plates and pipes provide a positive barrier for adult and sub-adult fish and can provide protection for eggs, larvae, and juvenile fish (Maxwell 1973; Richards 1978; Cook 1987). These screens are not self cleaning. Clogging resistance is accomplished by employing low through-screen velocities and using maximum velocity criteria to minimize progressive clogging. Cleaning is by air-burst backwash, water backwash, and/or a continuous air curtain to sweep and lift debris away from the screen surface on a continuous basis. Profile-wire and perforated pipe intake structures are used to supply make-up water at a number of power plants. One large (800MWe) power plant employs point of withdrawal profile-wire screening for once-through cooling in a freshwater environment. Some smaller plants use such screens for once-through cooling, but the water requirements are similar to the water requirements for closed-cycle cooling on a large plant.

Profile-wire screens provide effective and reliable water supply in closed-cycle freshwater systems. Application of the technology to large volume once-through cooling systems requires careful analysis of site conditions. Application of the technology to cooling water systems for estuarine or marine environments has not yet been reliably demonstrated and will require methods to minimize biofouling. Work is underway to develop effective techniques to control or prevent biofouling, but these techniques are not yet commercially available.

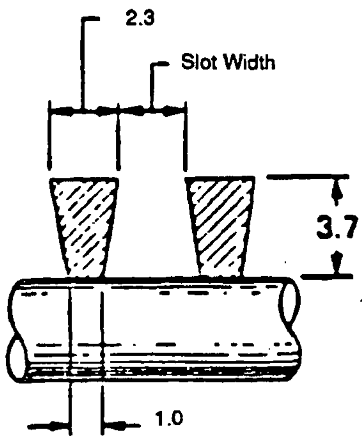
The design of stationary, submerged, cylindrical screens typically includes the use of profile-wire. Profile-wire screen is manufactured by welding triangular wire to a support structure (Figure D-12). Profile-wire screens are constructed with slot widths from 0.02 to 0.25 in. (0.5-6.3 mm) and offer 24-70 percent open area for water passage. The design results in a smooth screen surface and screen openings that widen inward, minimizing screen clogging and facilitating screen cleaning. The screen design creates near uniform flow through the screen surface, increasing the hydraulic efficiency of the screens, and minimizing the screen clogging potential (Cook 1987). The cylindrical screen configuration (which promotes radial flow into the screen), the use of techniques to create near uniform velocities through the screens, and the use of profile-wire screen material reduce screen clogging from impinged organisms and debris.

An intake with stationary, completely submerged, cylindrical screens is shown in Figure D-13. The cylindrical screens can be used individually, in pairs, or in a manifold or multi-screen design to provide the necessary cooling water volume. The fish protection potential of cylindrical profile-wire screens depends on the location of the screens, orientation with respect to ambient water currents, size of the screen openings, and the through-screen velocity. The absence of a confining screenwell (which may entrap organisms), through-screen velocities less than 0.5 fps (15 cm/sec) maximum, and freedom of screen location reduce the numbers of organisms entrained and impinged.

Biological data on the effectiveness of profile-wire cylindrical screens in minimizing entrainment and impingement are discussed in a recent literature review (Cook 1987). Tests to date indicate significant reduction of entrainment of eggs and larvae and no involuntary impingement. In some of the tests, organisms have been found moving over the screen surface to graze on accumulated materials while the screen passed water with no measurable increase in head differential.

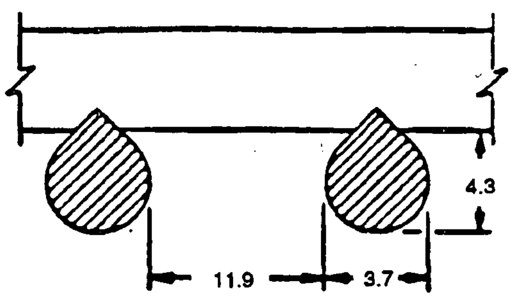


Material:	Stainless Steel
Slot widths:	1.0-2.5 mm
Open area:	22.3-39.5%



Section A-A

Dimensions (mm)



Section B-B

Figure D-12

Characteristics of Flat Wedge-Wire Screen Panels
Used in the TVA Hydraulic Test
(From Cada et al. 1979)

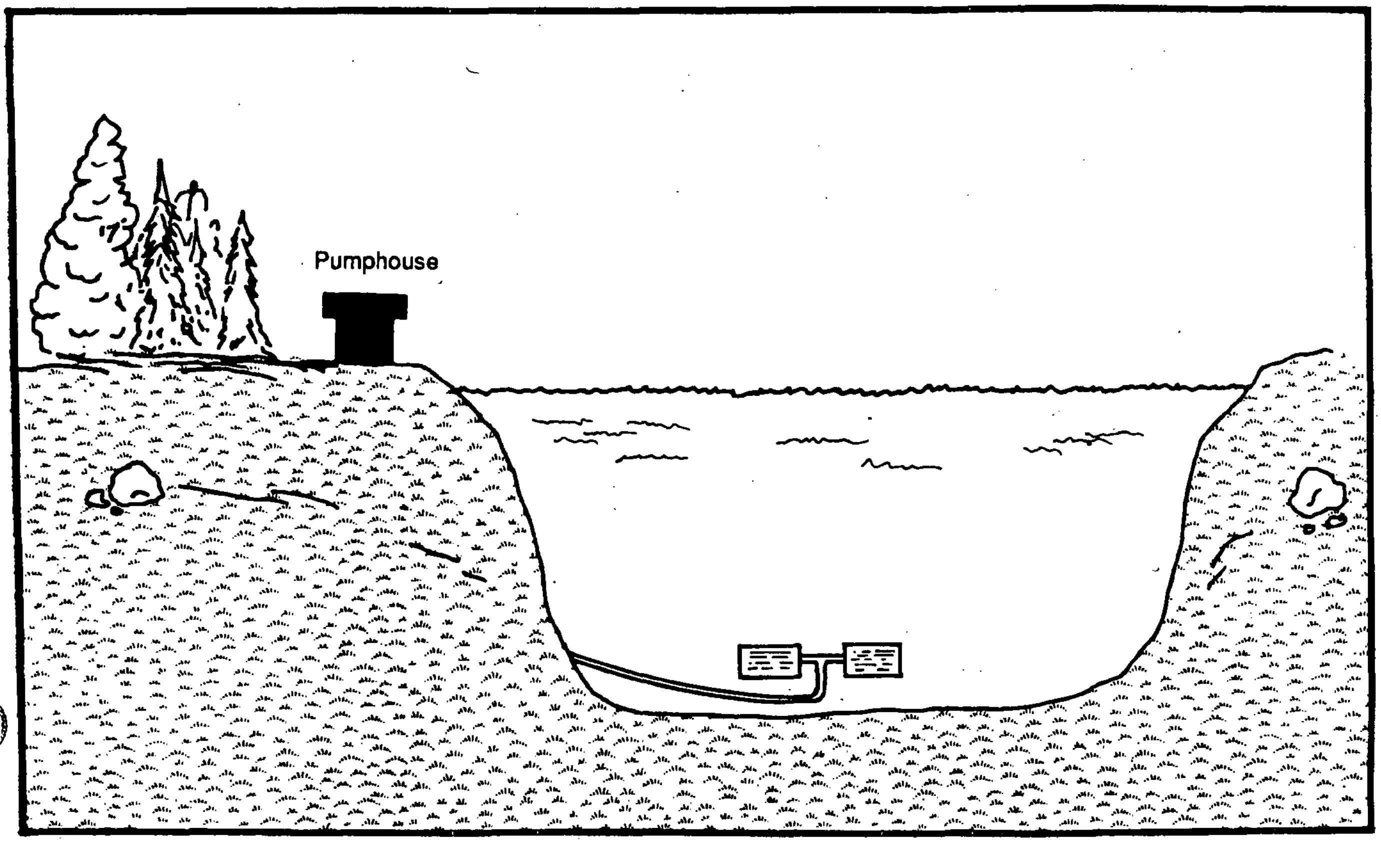


Figure D-13

A Design Concept for Cylindrical Wedge-Wire Screens at Power Plant Cooling Water Intakes (From Cada et al. 1979)

Engineering concerns for cylindrical profile-wire screens focus on location, maintenance, and operational reliability of the intake, which are influenced by the extent and frequency of debris clogging, techniques for debris and biofouling removal, silt and sediment transport in the waterbody, and icing. For marine and estuarine sites where biofouling is likely, the screens must be located so that they can be removed for periodic mechanical removal of growth on the screens. The problem of removing biofouling organisms from screens in brackish or marine environments is described by Key and Miller (1978), Browne et al. (1981), Wiersema et al. (1979), Espey (1981), and Weisberg (1987). Debris removal is accomplished by air burst backwash, water backwash, or continuous air curtain. The screens have been incorporated into closed-cycle intake systems for sites where water withdrawal is difficult. (Ettema and Johnson 1984). An ambient water velocity parallel to the screen axis helps carry debris past the screen, promoting self cleaning. The screens should be shifted away from areas of high biological productivity if possible, and away from areas where debris tends to accumulate, such as dead end canals or embayments where wind driven leaves pile up. If significant sand and sediment transport is characteristic of the source waterbody (moving sand bars, etc.) great care must be exercised in the design of any intake.

Stationary screens such as profile-wire cylindrical screens, have primarily been applied for industrial plants and closed-cycle cooling systems at power plants on rivers and lakes. Field and laboratory testing has established the biological effectiveness of the screens in eliminating impingement and significantly reducing entrainment of eggs and larvae. The testing has also indicated that pump sample testing can severely underestimate the ambient concentration of fish of all life stages in the waterbody. Operational reliability of the screens on the one freshwater once-through power plant cooling system has been satisfactory.

On the other hand, McGroddy et al. (1981) reported on tests of fine-mesh cylindrical wedge-wire screens used as offshore intakes at the Redondo Beach Generating Station in California. Because of the need for frequent cleaning because of biofouling, and the lack of reliable system to accomplish the cleaning in an offshore installation, they recommended against the use of fine-mesh cylindrical screens for offshore marine intakes.

Wert (1987) reports on laboratory tests of the Eicher passive pressure screen fish bypass system. This system designed primarily for use at hydroelectric facilities, consists of angled screens set in the penstocks leading to hydraulic turbines, which pass water through to the turbine while diverting fish to a bypass. Laboratory tests indicated that:

- no scale loss occurred during passage of steelhead trout, coho salmon and chinook salmon
- no delayed mortality occurred
- screens set on an angle of 10.5 degrees to the flow were superior from the standpoint of debris movement than larger angles

- parallel bar wedge-wire screens provided better debris movement than perforated plates

A similar screen system is in use at a hydroelectric plant at Willamette Falls, Oregon. Use of the system in a marine environment, where biofouling might be a problem, has not been reported.

Two seawater treatment plants on the Beaufort Sea in Alaska use angled, horizontally-oriented, fixed wedge-wire screens with 9.5-mm (3/8-in.) slot openings to divert organisms to a fish return system. The screening system at the 104 million gallon/day (mgd) Prudhoe Bay seawater treatment plant has performed satisfactorily (ARCO Alaska Inc. 1985). Debris loading on the primary diverter screens was not a major concern and the screens generally remained clear year-round. Furthermore, no impingement was noted on the diverter screens. On the other hand, severe problems were encountered with detrital loading of the screens at the 28 mgd Kuparuk River seawater treatment plant (ARCO Alaska Inc. 1987). Treatment plant throughput at Kuparuk River achieved only 25 percent of potential maximum during the open-water season from mid-June through mid-October. Throughputs were about 65 percent of potential maximum during the remaining (ice-covered) times of year. This lead ARCO Alaska to begin development of an alternate intake design for use at Kuparuk River during the open water period. In addition, detrital loading of the primary diverter screens at Kuparuk River increased the probability of impingement by creating high flow velocity through those parts of the screen that are clear of detritus. This considerable difference in performance of two very similar systems deployed at two locations highlights the critical importance of local site conditions in determining the effectiveness of any given intake technology.

D.5.2.5 Drum Screens

Vertical drum screens have been used with variable success for fish diversion in irrigation canals, and in British steam electric stations for the protection of salmonids. (Eicher 1974). Vertical drum screens having diameters of approximately 9.8 ft (3 m) are commonly aligned in rows leading to a bypass channel. Screen rotation carries impinged fish toward the bypass and provides self-cleaning of debris. Vertical drum screens provide a positive barrier for adult and sub-adult fish, but do not protect eggs and larval fish. Fluctuations in water depth do not affect the performance of vertical drum screens.

Horizontal drum screens have been used for fish diversion in irrigation facilities, power plants, and hydroelectric projects, as discussed by Maxwell (1973), Eicher (1974), and Mayo (1974). These screens provide a positive barrier for adult and sub-adult fish, but do not protect fish eggs or larvae. The screen surface is cleaned through screen rotation, but screen rotation is detrimental to impinged fish if no bypass facility is provided. Diversion efficiency of horizontal drum screens is sensitive to fluctuating water levels. In addition, screen bypass and sealing problems can become a problem as the screens age and wear occurs.

D.5.2.5.1 Angled Drum Screens

Johnson (1987) has discussed angled drum screens for open channel applications such as irrigation diversion canals. These are horizontal rotating drum screens placed at an angle of 25° or less to the incident flow. Drums rotate with the upstream face rising and the downstream face descending, providing a self cleaning action as the screen rotates. Fish are guided along the face of the screen to bypasses. Johnson states that the water velocity component normal to the screens should not exceed 0.5 ft/sec (0.15 m/sec), while the velocity component parallel to the screen should be at least twice the magnitude of the normal component.

Johnson points out that "The approach channel to the screen should be designed to minimize slack water areas and back eddies. Predatory fish can hold in these areas with low energy expenditure and feed on the target fish." Sedimentation can be a concern with these systems, because construction of an angled drum screen may require enlarging the channel cross-section, reducing velocities and promoting deposition. Entrance and exit channel velocities should be kept as high as possible to minimize sedimentation.

Angled drum screen structures with hydraulic capacities in the range from 100 to 3,200 cfs are in design or construction. An angled drum screen has been in use on the Tehama-Colusa Canal in California for many years. Angled drum screens at Sunnyside and Wapato, Washington have proven effective for the guidance and bypass of fingerling steelhead and salmon.

Drum screens, although acceptable once-through power plant cooling system intakes, offer no biological or engineering advantages over vertical traveling screens. Drum screens have not been used extensively in electric generating stations in the United States, partly because of problems associated with the carry-over of debris into the condensers, which reduces system reliability.

D.5.2.6 Horizontal Traveling Screens

The horizontal traveling screen (Figure D-14) developed by Bates (1969) has been proposed for fish diversion in canals, hydroelectric dams, irrigation intakes, and power plant intakes. Horizontal traveling screens aim to provide (1) a complete physical barrier, (2) high diversion efficiency of juvenile migrant fish, and (3) release of impinged fish into a bypass without passing the air-water interface. Operation of horizontal traveling screens is not affected by fluctuations in water depth. The screen is self-cleaning, minimizing head loss, and is capable of operating under higher approach velocities than possible with other types of screens. Research and development of the horizontal traveling screen has been reported by Bates (1969), Bates et al. (1970), Farr and Prentice (1974), and Prentice and Ossiander (1974).

Prentice and Ossiander (1974), studying 70-mm (2.8-in.) fingerling chinook salmon observed 98 percent diversion efficiency with a traveling screen at an angle of 30° to a flow of 1.5 fps (46 cm/sec) under lighted conditions, and 91 percent diversion

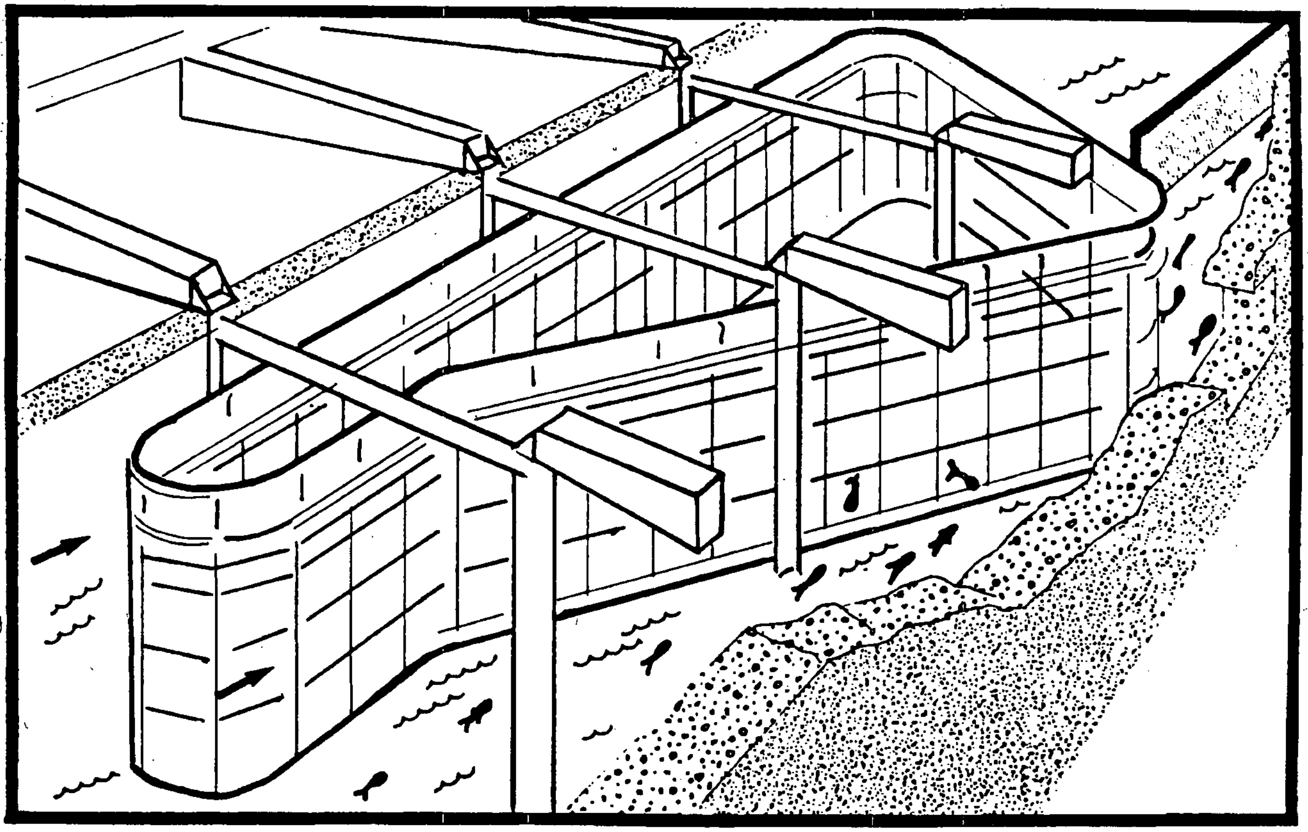


Figure D-14

Horizontal Traveling Screen
(Courtesy of Envirex)

efficiency under dark conditions. Diversion efficiency for 170-mm (6.7-in.) salmonids under similar conditions was 99.6 and 99.8 percent during day and night tests, respectively. No screen impingement was observed and 48-hour post-test survival exceeded 97 percent for all experiments.

Mechanical performance of horizontal traveling screens is not, at present, acceptable for continuous operation at a power plant intake. Prototype tests to examine mechanical operation and assess performance limitations are discussed by Farr and Prentice (1974). Solutions to mechanical problems resulting from suspended sediment and sediment bedload, have yet to be perfected.

Horizontal traveling screens minimize fish impingement but do not reduce the number of organisms entrained into a cooling system. The lack of reliable operation of horizontal traveling screens, however, precludes further consideration of their use in power plant cooling water intakes.

D.5.2.7 Rotating Disc Screens

Rotating disc screens have been used in small irrigation diversions and municipal water supplies. No application of rotating disc screens in power plant intake structures has been reported. Rotating disc screens offer no biological or engineering advantage over vertical traveling screens for use in cooling water intakes.

D.5.2.8 Centerflow Traveling Screens (Single-Entrance, Dual-Exit Traveling Screens)

Centerflow traveling screens have been used extensively in European industrial and electric generating facilities for almost three decades. Centerflow screens (Figure D-15) are oriented parallel to the approaching waterflow. Water enters the center of the screen and exists through both vertical faces. Screen panels on centerflow screens are attached to a continuous drive chain. Unlike conventional vertical traveling screens, each screen panel forms a concave basket, increasing screening surface area. Screen mesh sizes range from 0.02 to 0.4 in. (0.5-9.5 mm), with many units having 0.04 to 0.1 in. (1.0 to 2.5 mm) mesh. Because debris accumulates rapidly on the small mesh commonly used in centerflow screens, they operate with continuous screen rotation.

The hydraulic flow patterns associated with centerflow screens are more complex than those for vertical traveling screens. Water flows into the screen chamber through a keyhole-shaped opening in the front wall of the intake screen structure, turns 90° to flow through the screen mesh, and turns 90° to complete its transit to the circulating water pump. Screening occurs on the ascending and descending sides of centerflow screens, increasing available screen surface area. As a result, the <u>average</u> through-screen velocity of a centerflow screen is less than the approach velocity to the screen. However, through-screen velocities are variable across the screen face because of flow patterns and screen orientation, and velocities increase

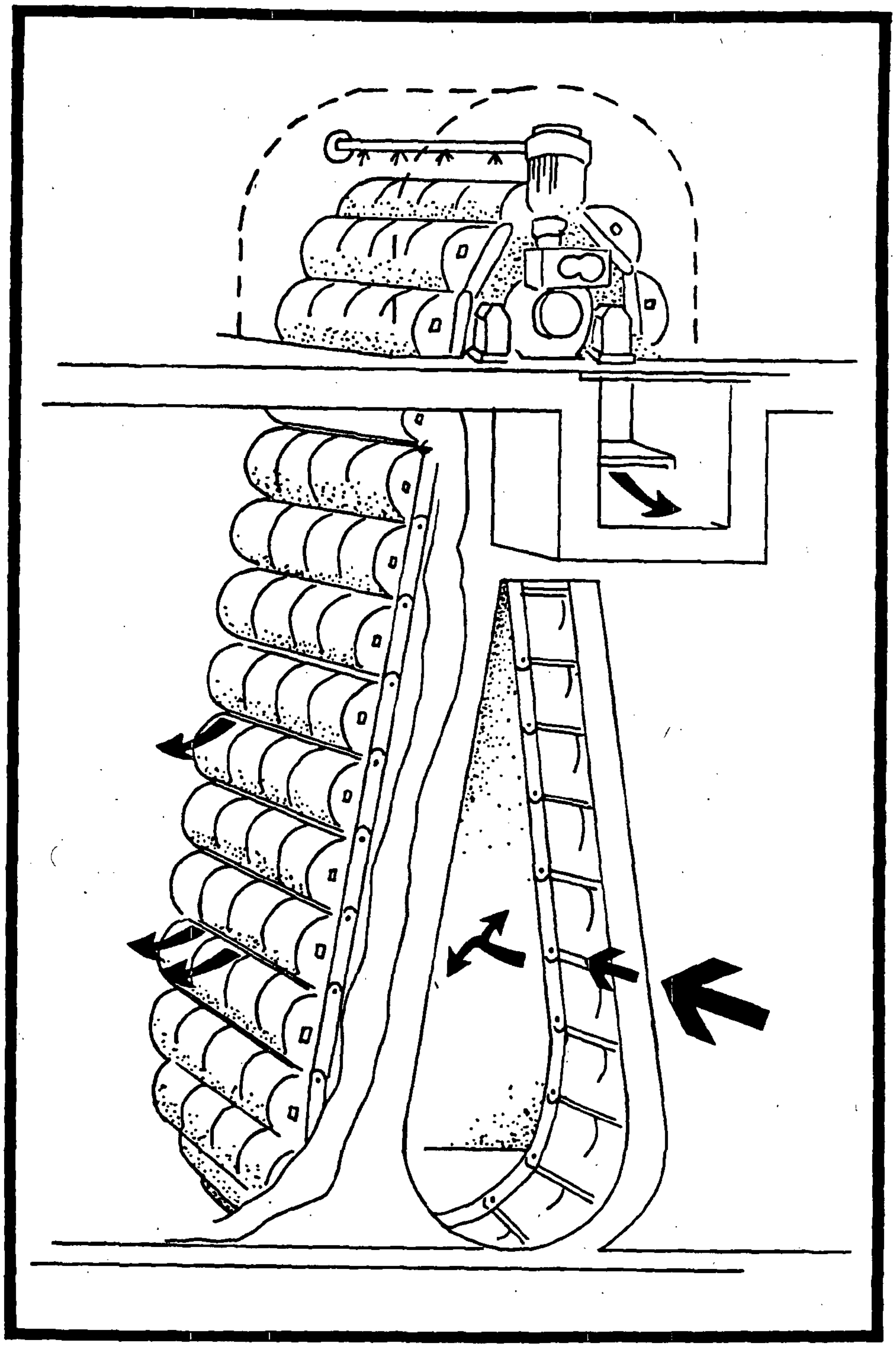


Figure D-15

Centerflow Traveling Screen
(Courtesy of the Passavant Corporation)

with distance downstream from the chamber entrance. Turbulence may negate potential benefits from reduced average through-screen velocities. High velocities at the entrance to the screen may also serve as a behavioral barrier, preventing the escape of fish entrapped within the screen structure.

Screenwash mechanisms are similar for centerflow and front-entry vertical traveling screens. Spraywash pressures range from 50 to 100 psi. Some screen assemblies have a low pressure spraywash for organism removal prior to the higher pressure debris removal sprays. Debris and impinged organisms dislodged from the screens are carried away in a single sluiceway, or separate sluiceways for fish and debris return to the waterbody. Additional fish protection systems for centerflow screens involve watertight holding troughs at the base of each screen panel.

Murray and Jinnette (1978) examined the initial survival of organisms impinged on continuously rotating centerflow screens at the Barney M. Davis Steam Power Plant, Corpus Christi, Texas. Initial impingement survival for 15 species of invertebrates and 37 species of fish was estimated at 86 percent (10,406 individuals alive; 1,654 individuals dead) during the 12-month study. Impingement survival varied among species and among months of the year. Lowest initial mortality for the dominant species by month occurred in February, when menhaden (mean standard length = 21 mm; 0.8 in.) experienced a 5 percent initial impingement mortality. Highest initial mortality for a dominant species by month occurred in June, when bay anchovy (mean standard length = 25 mm; 1.0 in.) experienced a 98 percent initial impingement mortality. No studies were performed to examine long-term survival of organisms impinged on centerflow screens, or the effectiveness of the return system. Predator birds were observed feeding vigorously from the return trough.

Fine-mesh centerflow screens have been investigated in laboratory studies to determine their effectiveness for protecting larval fish at power plant intakes (Magliente et al. 1978). Field and laboratory studies are required to evaluate initial and long-term survival of fish eggs and larvae impinged on fine-mesh centerflow screens. Insufficient data preclude a detailed comparison of the potential survival of fish eggs and larvae impinged on modified vertical traveling screens (fine-mesh screen material, fish buckets, low-pressure spraywash, continuous rotation) and centerflow screens (fine-mesh screen material, continuous rotation).

Centerflow screens require increased screen-to-pump distance over vertical traveling screens. This may make retrofit of an existing intake infeasible because of space limitations. Irregular velocity patterns, turbulence, and attendant head losses are inherent with the waterflow patterns for the centerflow screen. Highest water velocities occur in the entrance area of centerflow screens and could contribute to fish entrapment. Within the screen chamber, velocity varies irregularly as it changes direction, resulting in non-uniform flow through the screening surface. Use of average approach and through-screen velocities for centerflow screens is inappropriate and misleading. The turbulence associated with centerflow screens was examined by Alden Research Laboratory (1974), who found that circulating water pump performance was adversely affected by flow irregularities if screen-to-pump distances were too short or baffling was inadequate.

Operating and maintenance experience with centerflow screens in the United States is limited to one installation, the Barney M. Davis Steam Power Plant, where centerflow screens have been in use since 1974. Originally a 0.02-in. (0.5-mm) polyester mesh was used. However, the polyester screen failed during operation. It was replaced with a nylon mesh with 0.04-in. (1.0-mm) openings which give satisfactory performance. Routine maintenance has been described as nominal (P. Benes 1978, personal communication).

Several alternative design configurations for centerflow screens have been proposed to minimize the probability of organisms becoming entrapped within the screen structure. In addition to the single-entrance/dual-exit design in Figure D-15, there is a double-entry/single-exit design in which water enters the screen from two sides and passes out one end. This design can be located within a screenwell or supported from a platform with no confining concrete housing (Figure D-16). A double-entry/double-exit screen design has also been proposed. Biological and engineering data are not available to compare the relative effectiveness of these alternative screen configurations.

Centerflow screens are an acceptable intake screening technology for new units based on engineering performance, operational reliability, and maintenance. Retrofit installation of centerflow screens into an existing intake structure may require extensive modification of the intake, and might adversely affect performance and reliability of circulating water pumps. Centerflow screens do not offer major biological advantages over conventional vertical traveling screens. Significantly increased impingement survival has not been satisfactorily demonstrated for these systems.

D.5.2.9 Vertical Traveling Screens

The vertical traveling screen (VTS), the most commonly used intake screen at power plants in the United States, is available from a number of manufacturers in a wide range of lengths, widths, and materials. It consists of screen panels attached to a chain drive, mounted vertically in a concrete structure which normally functions as the screenwell and circulating pumpwell (Figure D-17). A design proposed (but not constructed) by Western LNG Associates (California Public Utilities Commission 1978) locates the vertical traveling screens, but not the circulating water pumps, in an offshore intake caisson. Although in recent years modifications have been made to enhance the fish protection capabilities of the screens, their primary function is to prevent clogging of condenser tubes. The screens are designed to remove particles whose diameters are more than one-half that of a condenser tube. In most situations, 3/8-in. (9.5-mm) mesh is used. The screens rotate intermittently, either at regular intervals of several hours or when debris buildup causes a predetermined pressure differential across the screen. Most screens are not equipped to rotate continuously for extended periods of time. During rotation, debris is removed by a

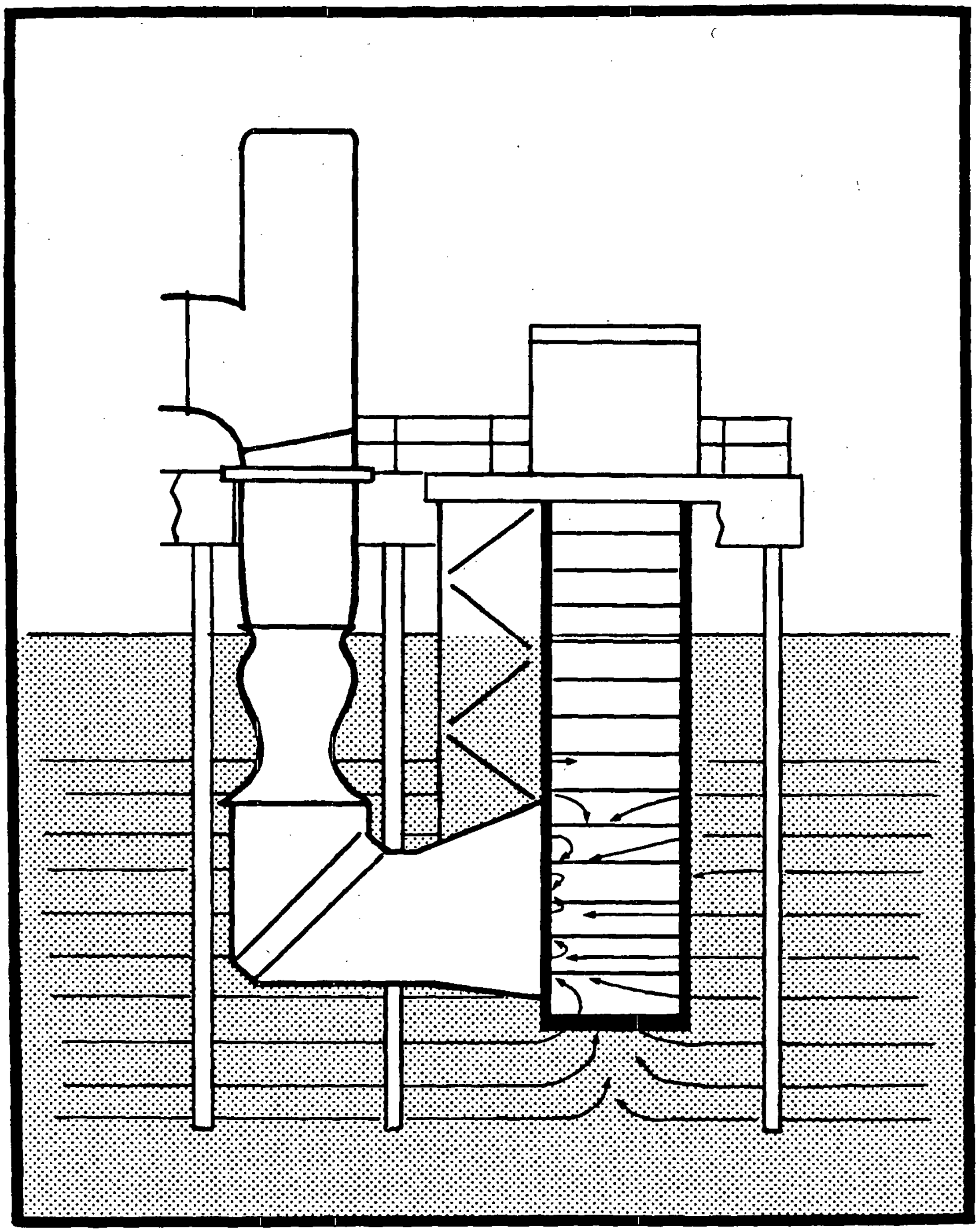


Figure D-16

Double-Entry/Single-Exit Screen
(Courtesy of FMC Corporation)

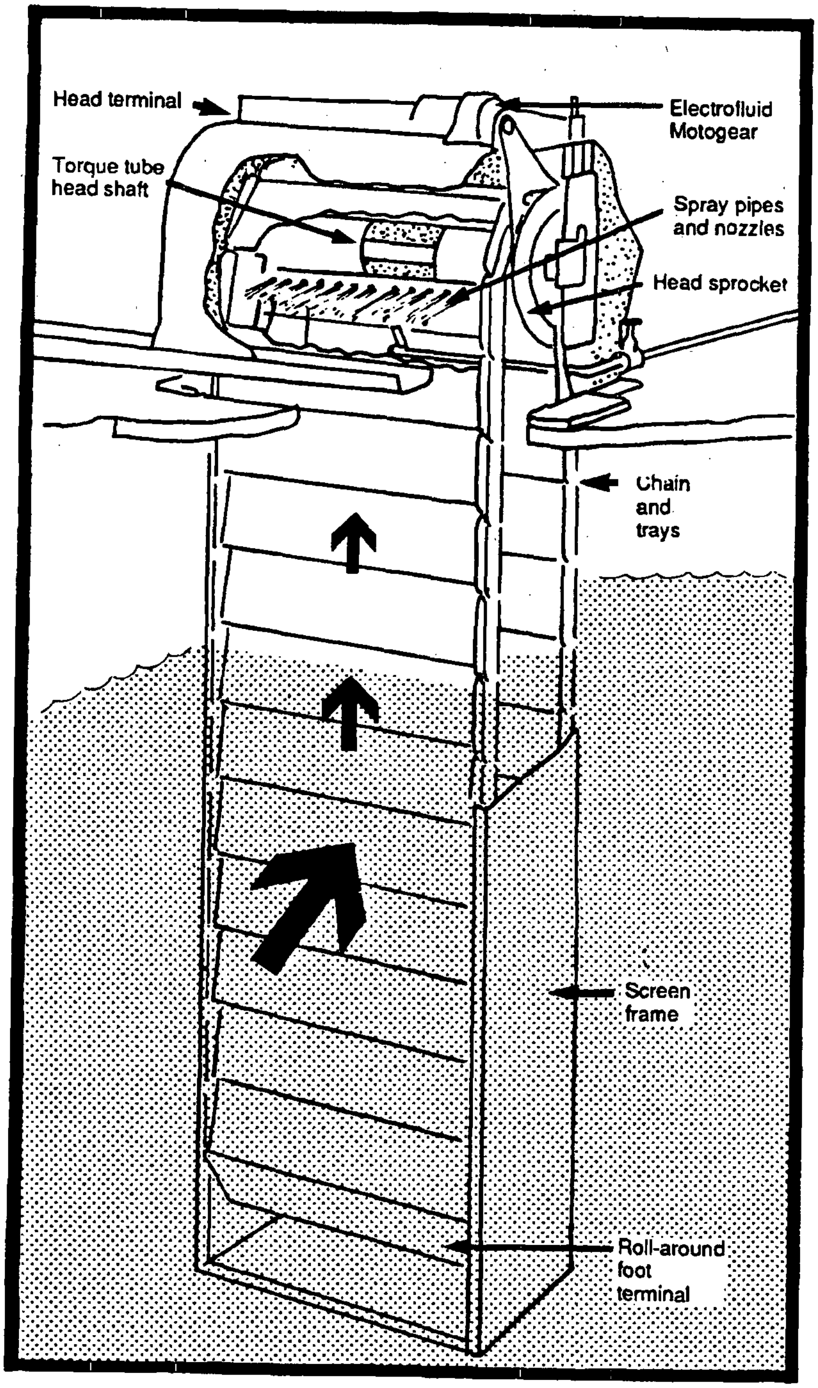


Figure D-17

Conventional Vertical Traveling Screen
(Courtesy of Envirex)

high-pressure (50-100 psi) spraywash and either returned to the source waterbody or transferred to trash bins for disposal. This technology will be discussed in greater detail in Section D.5.3.1.

D.5.2.10 Angled Vertical Traveling Screens

The most promising alternative intake design concept is vertical traveling screens oriented at an angle to the intake flow and leading to a bypass. Under laboratory conditions, this design concept was 100 percent effective in diverting alewife into a bypass (Taft and Mussalli 1978). Davis et al. (1987) conducted a study of the angled screen intake at the Brayton Point Power Station on Narragansett Bay, Massachusetts. They found a diversion efficiency of 76 percent. They found that, although the angled intake screen was deemed effective, there was considerable variation of survival by species. A "sensitive" group composed of a few numerically dominant taxa (mostly bay anchovy and Atlantic silversides) exhibited survival below 25 percent, whereas a "hardy" group of mixed taxa dominated by winter flounder and northern pipefish had survival values greater than 65 percent. However, fish survival may have been adversely affected by collection and handling of fish taken from the bypass flow for study.

D.5.2.11 Other Physical Barriers

A wide variety of physical barriers, in addition to those previously discussed, have been examined for their application to power plant intakes. Many of these alternative designs originated as intake structures for industrial or municipal water supplies, at irrigation water diversions, or in association with hydroelectric dams. There is a continuing effort to identify, design, and test the potential effectiveness of intake design concepts under laboratory conditions.

Barrier nets have been used successfully in power plant intakes where velocities are low (about 0.2 to 0.3 fps), and debris loading and fouling are light (Musalli 1984). The netting enclosing the intake area forms a behavioral and physical barrier for fish. Problems potentially associated with barrier nets include debris accumulation, hazards to navigation, and maintaining the integrity of the net during storms or in areas with irregular bottom topography.

Barrier nets solved two problems at the Pulliam Generating Station in Green Bay, Wisconsin. Yellow perch and other game fish were impinged in significant numbers at the intakes, and alewife passed through the traveling screens and fouled the condensers. At the peak of the alewife population, one of the six generating units had to be shut down in turn each night to clean the condensers (E. Newman 1988, personal communication). Air-bubble curtains were tested with no evidence of reduced impingement. Then, nylon nets with 0.64-cm stretch mesh were installed. Two nets were used at each intake to allow cleaning and repair of each net while maintaining protection. The nets are deployed when water temperature exceeds 4 C (approximately April 1 to December 1). The nets have been very successful, reducing impingement 90 percent or more.

Consumers Power uses nets to screen the intakes at their Whiting and Karn stations on Lake Erie. The key species of concern are gizzard shad and yellow perch, and maintenance intervals range from once a month to once a week, depending on the season. At the Whiting plant, a pair of 300-ft long, 24-ft deep, 3/8-in. mesh nylon nets have been in place for more than five years. They have reduced impingement by 90 percent at an annual maintenance cost of about $50,000. At the Karn plant, the nets are 1,500-ft long and 24-ft deep, with 1/2-in. mesh. There has been an 80 percent reduction in yellow perch impingement, based on mark/recapture studies. Furthermore, the nets have prevented the plant shutdowns that formerly resulted from large runs of gizzard shad. (J. Gulvas 1988, personal communication).

On the other hand, a net with 1/2-in. (30-mm) mesh installed in 1982 and 1983 at Chalk Point Generating Station on the Patuxent River (Taft 1986) reduced impingement of menhaden (by 86 percent), blue crab (by 80 percent) and hogchoker (by 50 percent), but increased impingement of white perch by (800 percent) and silverside (by 350 percent). In another case, a net was placed across the intake canal at Detroit Edison's Monroe Plant on Lake Erie, to exclude yellow perch, gizzard shad and other fish. However, intake velocities exceeded 1.3 fps (0.4 m/sec) and the net clogged with fish and collapsed (Taft 1986).

Variations of intake designs previously discussed include offshore louvers, a caisson offshore intake surrounded by vertical traveling screens, inclined traveling screens (conveyor screen), and "hump-back" screens. Sonnichsen (1975) discusses many of these alternative designs. Few of these alternatives are generally applicable to power plant intake screening, but may have site-specific applicability depending on the biological characteristics and engineering requirements at the site.

D.5.3 Fish Collection, Removal, and Conveyance Systems

There are three basic approaches to fish return systems for cooling water intakes. The first excludes organisms from the cooling system by an intake that minimizes or eliminates impingement and entrapment (e.g., radial wells, sand filters, porous dikes, submerged stationary cylindrical screens, perforated pipes), and requires no fish return system. The second, fish conveyance systems, impinges organisms for brief periods until they are mechanically transferred to a screenwash sluiceway and returned to the receiving waterbody. The third, fish removal systems, concentrate entrapped organisms within an intake structure and removes them by pumps, elevator baskets, or bypass channels.

The following sections review the design, effectiveness, and application of fish conveyance and fish removal systems at power plant intakes. Intake structures relying on exclusion of organisms rather than return systems were discussed in Section D.5.2. Qualitative conclusions are presented in Table D-3.

TABLE D-3

SUMMARY OF EXPERIENCE WITH FISH COLLECTION, REMOVAL, AND CONVEYANCE SYSTEMS FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Enhances Impingement Survival	Reduces Impingement	Reduces Entrainment	Reduces Entrapment	Operationally Reliable	Comments
Vertical traveling screen, fish buckets, and accessories	●	○	○	○	●	Some larvae are subject to increased mortality through physical handling; debris-fish-larvae separation undeveloped
Fish pump	○	●	○	●	●	
Fish bypasses or escapes	○	●	○	●	●	Lateral fish escapes are an outgrowth of the Kerr (1953) studies
Fish basket collector	○	○	○	Ex	Ex	Possible application when fish pumps are not
Sluiceway and pipeline return	?	○	○	○	?	Design parameters difficult to identify for biological effectiveness

Legend

● Demonstrated effective

? Inconclusive, conflicting, or variable data

Ex Undergoing experimental studies, developmental stage

○ Demonstrated ineffective or no data

D.5.3.1 Vertical Traveling Screen With Fish Buckets and Accessories

Impingement survival of aquatic organisms depends on the species, life stage, size, impingement duration, stress, fatigue, hydraulic parameters, and debris loading.

Impingement survival for some species has been improved by incorporating watertight collection buckets along the base of each screen panel to prevent repeated impingement of organisms and provide a holding area for organisms during screen rotation (Figure 6-3). In addition, a low-pressure wash system has been installed to remove impinged organisms from the screen and reduce stress and abrasion from exposure to the high-pressure debris removal spraywash. A separate fish-return sluiceway transports organisms back to the receiving waterbody. Continuous screen rotation also reduces stress on impinged organisms.

Modifying existing vertical traveling screens to incorporate some of these features requires analysis of the specific intake structure and its performance. Potential problems include (1) altering the hydraulic characteristics of the intake structure, affecting performance and reliability of circulating water pumps; (2) requirements for additional screen area to maintain acceptable approach velocities while providing adequate cooling water volumes; and (3) increased maintenance resulting from screen clogging and reduced reliability of drive motors from continuous operation.

A dual spraywash system requires separate sluiceways for fish and debris, additional pumps, control mechanisms, piping, and increased maintenance costs. Installation of watertight buckets on screen panels or fine-mesh screen material requires reinforced structural supports to support the screen under increased static and dynamic loads. In the absence of extensive operating information for modified screens, especially those equipped with fine-mesh screen, predictions of operation and maintenance problems influencing reliability cannot be made with certainty.

King et al. (1978) compared the effects of different screen rotation frequencies and screenwash pressures on the survival of fish impinged on vertical traveling screens at three power plants on the Hudson River (Table D-4). Continuous screen rotation resulted in better impingement survival of young-of-the-year white perch than screenwash at either 2- or 4-hour intervals (Figure D-18). Low pressure screenwash sprays (50 psi) resulted in better initial and long-term (84-hour) survival of impinged white perch on several occasions, but the results of screenwash pressure studies were generally inconclusive.

White and Brehmer (1976) evaluated initial survival of fish impinged on a modified vertical traveling screen similar to the one shown in Figure 6-3, which has been in operation since 1974 at the Surry Power Station, James River, Virginia. Average initial survival for 58 species of impinged fish was 93.3 percent. Survival of impinged fish beyond the 15-minute holding and observation period was not determined.

TABLE D-4

INITIAL SURVIVAL OF JUVENILE WHITE PERCH UNDER VARIOUS CONVENTIONAL VERTICAL TRAVELING SCREEN OPERATIONAL MODES AND SCREENWASH PRESSURES AT THREE HUDSON RIVER POWER PLANTS DURING NOVEMBER AND DECEMBER 1976

Power Plant	Screen Operational Mode	Washwater Pressure (psi)	Survival % Initial	Survival % Long-Term [(a)]
Roseton	Continuous	50	98	44
	Continuous	100	79	6
	2-hr intermittent	50	96	8
	2-hr intermittent	100	92	5
	4-hr intermittent	50	96	17
		100	71	0
Danskammer Point	Continuous	55-65	82	29
	2-hr intermittent	55-65	62	15
Bowline Point	Continuous	10-20	98	56
	Continuous	30-50	96	55
	2-hr intermittent	10-20	90	26
	2-hr intermittent	30-50	90	32
	4-hr intermittent	10-20	75	19
	4-hr intermittent	30-50	69	19

(a) Long-term survival at Roseton and Danskammer Point determined 84 hours after impingement; at Bowline Point, 96 hours after impingement.

Source: King et al. 1978.

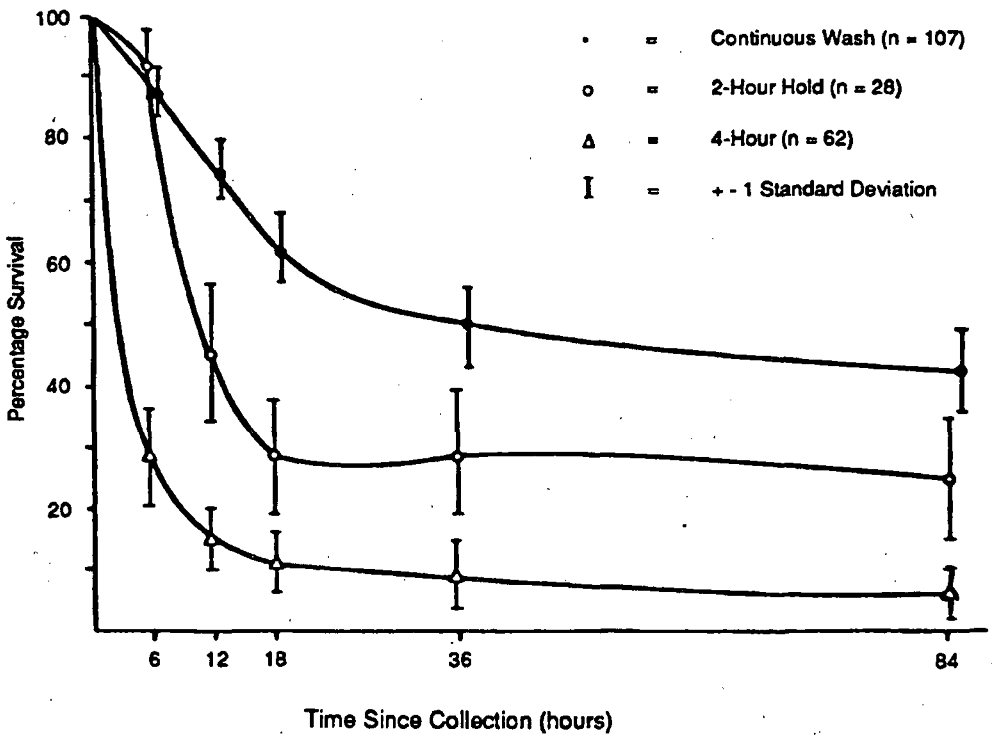


Figure D–18

Probability of Surviving Impingement for
Young-of-the-Year White Perch and Adult Atlantic Tomcod
Collected at Danskammer Point Plant (from King et al. 1978)

The effectiveness of low-pressure spraywash systems in removing impinged fish from a modified vertical traveling screen was examined by Public Service Electric and Gas Company (1977, cited in Cannon et al. 1979) on modified screens installed at Salem Nuclear Generating Station. The number of impinged fish washed into a fish return sluiceway by a low-pressure spraywash (15 psi) and those washed into a debris sluiceway by a high-pressure spraywash (100 psi) was determined. A total of 3,770 fish were collected, of which only 23.3 percent were removed from the modified screens by the low-pressure spraywash. These results indicate that low-pressure spraywash systems may be ineffective in removing impinged fish from an intake screen. Additional development and evaluation of low-pressure spraywash systems is required, especially when intake screens are subjected to high detrital loading or when large fish may be impinged.

Impingement survival of juvenile chinook salmon on modified vertical traveling screens on the Columbia River was reported by Page et al. (1976, 1978). Initial survival was 95.6 and 97.2 percent in 1976 and 1977, respectively. Long-term (96-hour) survival of impinged chinook salmon in 1976 was 94.8 percent. Long-term survival was not reported for 1977. Page et al. (1978) estimated initial impingement survival of yellow perch fry at 92 percent.

Fletcher et al. (1987) performed laboratory studies on various designs of vertical traveling screen panels. They found that juvenile fish "survived impingement without significant harm for extended periods at water speeds to 45 cm/sec, except for random descaling of sensitive species by crimped-or welded-wire mesh screens." Smooth-woven mesh imposed no detectable descaling. Discussing continuous traveling screens with duration of impingement on the order of minutes they state that "impingement alone could not account for the high mortalities observed in our field tests on a machine fitted with smooth-woven mesh." After analysis of motion pictures taken in the laboratory, they attribute the major impingement related injuries to buffeting of fish within the fish troughs. Dye studies of flow through the screens showed that water in the fish collection troughs "was shear driven by the main flow, which produced a longitudinal trough vortex of such strength that captive fish were swirled about and consequently injured by repeated collisions with the screen structure at the rear of the trough." They also found that filamentous algae could be held against the screen mesh by the water flow, and that "fish entangled in this algal matrix were carried past the fish removal apparatus and into the high-pressure debris spray where they were usually killed."

As a result of their studies, Fletcher et al. (1987) tested a modified vertical traveling screen at Consolidated Edison's Indian Point plant that included the following features:

- Smooth-woven screen mesh to prevent descaling
- A fish trough with an elevated, reshaped leading edge, to deflect the main flow and create a sheltered region of low turbulence within the trough, and installation of low auxiliary screens at the leading edge of each fish trough

to prevent fish from escaping from the trough as the trough breaks through the surface of the water

- A high pressure debris removal spray that acts before fish removal, with a shield to protect the fish trough from debris as the trough passes through the high pressure spray.

In comparing a standard Ristroph traveling screen machine with their modified version, Fletcher et al. (1987) report their results as follows: "observed injuries and mortalities to striped bass were reduced from 53 percent to 9 percent, from 75 percent to 32 percent in the case of Atlantic tomcod, from 64 percent to 14 percent in the case of white perch, and from 47 percent to 1 percent in the case of pumpkinseed. Striped bass losses to the debris removal system were reduced from 23 percent to zero, tomcod losses from 20 percent to 0.3 percent and white perch losses from 33 percent to 1.3 percent."

Studies by the Grant County Public Utility District in Washington using profile-bar screens resulted in similar survival rates with a greater proportion of fish and flow interception than with vertical traveling screens. Approach velocities in the tests ranged from 3 to 5 fps. Screen openings were 1/8 in. and open area was about 60 percent.

Ecological Analysts (1979) studied fine-mesh screens (0.1-in. (2.5-mm) nylon mesh) in a vertical traveling screen under field conditions, in an effort to reduce larval fish entrainment in a power plant cooling system. It was concluded that early life stages of striped bass could not withstand the stress of impingement and collection. For larval striped bass (0.6-in. (15-mm) mean length), 96-hour survival was estimated at 60 percent. For juvenile striped bass (0.8-in. (19-mm) or greater in length) survival exceeded 75 percent.

The survival of entrained striped bass passing through the Indian Point Power Plant cooling system was compared with survival of striped bass impinged on the 0.1-in. (2.5-mm) screen at the Indian Point cooling water intake (Ecological Analysts 1979). It was concluded, based on the low retention and survival of eggs and smaller larvae impinged on the fine-mesh traveling screen, that fine-mesh screens would not reduce entrainment losses for these life stages. In addition, since survival of larger larvae and juveniles following entrainment was comparable to that following impingement of the fine-mesh screens, selectively diverting these fish at the intake would not appreciably affect their survival.

Texas Instruments, Inc. (1977) examined survival of young-of-the-year and yearling fish impinged on a modified vertical traveling screen (low-pressure spraywash, dual screenwash sluiceways, fish buckets) equipped with 0.1-in. (2.5-mm) nylon screen mesh. The vertical traveling screen was rotated continuously during the studies. Most of the 3,616 fish collected were bay anchovy, blueback herring, and white perch. Mean initial survival of all species was 41 percent, and mean survival of each species is presented in Table D-5. Species-specific survival patterns are apparent,

TABLE D-5

INITIAL AND LONG-TERM IMPINGEMENT SURVIVAL OF YOUNG-OF-THE-YEAR AND YEARLING FISH IMPINGED ON A CONTINUOUSLY ROTATING FINE-MESH (2.5-MM) MODIFIED VERTICAL TRAVELING SCREEN

Taxon: Common Name	Taxon: Scientific Name	Age[a] Class	Number Collected	Survival (%): Initial	Survival (%): 84-hour
Striped bass	*Morone saxatilis*	1	13	85	75
White perch	*Morone americana*	1	223	45	26
White perch	*Morone americana*	2	37	41	18
Atlantic tomcod	*Microgadus tomcod*	1	78	92	58
Atlantic tomcod	*Microgadus tomcod*	2	2	100	100
Blueback herring	*Alosa aestivalis*	1	509	93	19
Blueback herring	*Alosa aestivalis*	2	1	100	0
Bay anchovy	*Anchoa mitchilli*	1	2,415	25	1
Bay anchovy	*Anchoa mitchilli*	2	65	55	13
Alewife	*Alosa pseudoharengus*	1	107	69	6
American shad	*Alosa sapidissima*	1	4	100	0
Hogchoker	*Trinectes maculatus*	1	4	100	100
Amercian eel	*Anguilla rostrata*	2	4	100	100
Banded killifish	*Fundulus diaphanus*	1	1	100	-
White catfish	*Ictalurus catus*	1	27	100	100
Spottail shiner	*Notropis hudsonius*	1	2	100	100
Sea lamprey	*Petromyzon marinus*	1	1	100	100
Largemouth bass	*Micropterus salmoides*	1	1	100	100
Yellow perch	*Perca flavescens*	1	1	100	100
Weakfish	*Cynoscion regalis*	1	3	67	67
Bluefish	*Pomatomus saltatrix*	1	4	100	0
Rainbow smelt	*Osmerus mordax*	1	20	10	0
Rainbow smelt	*Osmerus mordax*	2	4	25	0
Menhaden	*Brevoortia* spp.	1	1	100	-
Gizzard shad	*Dorosoma cepedianus*	2	5	100	0
Unid. clupeids	Clupeidae	1	80	51	-
Centrachids	Centrachidae	1	5	100	100
Northern pipefish	*Syngnathus fuscus*	1	1	0	-

with high long-term survival for white catfish, white perch, and Atlantic tomcod and low survival for bay anchovy and rainbow smelt.

Tomljanovich et al. (1978) conducted laboratory studies to examine factors influencing retention and post impingement survival of larval fish impinged on fine-mesh screen material. Four square-mesh screen sizes ranging from 0.02- 0.1 in. (0.5-2.5-mm) were tested. Only the 0.02-in. (0.5-mm) screen provided 100 percent retention of the larval fish tested. Post-impingement survival of larval fish was inversely related to duration of impingement. Survival depended on the species and sizes of fish tested and, to a lesser extent, on water velocity. Survival of larval fish 48 hours after 16 minutes of impingement ranged from less than 1 percent for striped bass to 96 percent for bluegill and smallmouth bass.

Available data suggests that entrainment of larval fish can be virtually eliminated by 0.02-in. (0.5-mm) intake screen mesh. But survival of larval fish passing through a cooling water system may be relatively high (Cada et al. 1979), and survival on a fine-mesh screen operated in an intermittent screenwash mode or subject to high detrital loads may be extremely low (Tomljanovich et al. 1977). As a result, if entrainment survival is higher than impingement survival for key organisms and these organisms do not cause condenser clogging, it is preferable not to screen them out of the cooling system.

Brueggemeyer et al. (1987) report on the performance of fine-mesh (0.5-mm) vertical traveling screens with fish buckets and spraywashes at the Tampa Electric Company (TEC) Big Bend Station. Big Bend Station located on Tampa Bay, has four coal-fired generating units in the 400 MWe range. Each unit draws about 540 cfs of bay water from a single intake canal through a once-through condenser cooling system with a single discharge canal. Marine growth, particularly barnacles and oysters, was the main cause of screen mesh and seal failures, and of spray line and nozzle clogging. Noting that toxin releasing paint applications have been virtually banned by the environmental agencies, Brueggemeyer et al. (1987) state that TEC is considering the use of non-toxic low surface energy paints to control this biofouling, instead of the labor and cost intensive mechanical measures presently in use. Screening efficiencies (impingement) for the fine-mesh vertical traveling screen averaged 95 percent for fish eggs, 86 percent for larvae and 100 percent for macroinvertebrates. Brueggemeyer et al. (1987) stress the importance of adequate operation and maintenance procedures in achieving these high efficiencies.

Tsou and Mussalli (1987) surveyed vertical traveling screens at 16 power plants under EPRI Project RP 1689-9 to develop guidelines for reliable designs. They point out that vertical traveling screens are subject to mechanical, control and structural failures caused by such things as: stress from continual operation, misalignment, inadequate chain tension control, corrosion, electrical control failures and inadequate guide motor power. They indicate that upgrading screens is likely to be more costly than purchasing new screens. Among their recommendations are the following:

- To reduce mechanical wear of rotating components, screens should operate at the lowest speeds compatible with adequate control of debris loading.
- Where fish removal and handling is required, a low-pressure spray should be used to remove fish, followed by a high pressure spray to remove debris.
- Because finer mesh impinges more organisms and requires frequent screen operation, mesh size should be between 1/8 and 3/8-in. unless site-specific conditions dictate otherwise.

Vertical traveling screens are an acceptable intake screening technology. The vertical traveling screen has demonstrated performance capability and an extensive and impressive history of operational reliability. Two types of modifications have been proposed for vertical traveling screens: (1) "fish buckets," a system of troughs and low-pressure sprays to minimize damage to impinged fish, and (2) fine-mesh screens, which impinge ichthyoplankton instead of entraining them. The merits of these modifications depend on the biological and engineering conditions at the particular plant where they are to be installed.

D.5.3.2 Fish Return Conveyance Systems

Fish return conveyance systems, used in association with vertical traveling screens, are open or enclosed troughs which return organisms and debris removed from the intake screens to the receiving waterbody. The sluiceway troughs are typically concrete or steel, using gravity flow or a pumping system. Conveyance systems have not been standardized or extensively studied, so they vary widely from one intake to the next. The limited data on the relationship between conveyance design and survival of organisms returned to the receiving waterbody make it difficult to quantify the effects of various design parameters on the biological effectiveness of conveyance systems. The difficulty in generalizing from one site to another is particularly important in designing fish return conveyance systems for use with fine-mesh intake screens for removing egg and larval fish from the intake.

Recommendations by Cada et al. (1979) concerning fish return conveyances include:

1. Maintain sufficient water levels and velocities to expedite return.
2. Avoid turbulence in the conveyance.
3. Prevent ice formation in the conveyance.
4. Maintain smooth surfaces in the conveyance.
5. Enclose the conveyance to minimize avian predation.
6. Use multiple release locations to minimize predation at the outfall.
7. Prevent re-entrapment.
8. Avoid thermal shock.

9. Separate debris sluiceways from fish sluiceways.

D.5.3.3 Fish Pump Systems

Fish pumps have been developed for entrapment problems where fish are concentrated in a confined area of the intake structure and can be removed by a pump system. The first fish pump at a power plant intake was installed at the Contra Costa Power Plant (Kerr 1953). Prior to installing the fish pump, the behavioral responses of fish to various pump collector (intake) designs were tested in various velocity gradients. Based on observations and tests, a zone of fish concentration was identified within the intake structure between the vertical traveling intake screen and a curtain wall. Placing a large intake collector (similar in design to the inlet of a vacuum cleaner) in the fish concentration zone, resulted in high diversion efficiency and high survival of all species removed from the intake structure. Kerr (1953) estimated the survival of fish following passage through the fish pump at greater than 98 percent. More recent studies of the Contra Costa fish pump (PG&E 1981) indicate that the number of fish impinged on the power plant intake screens is reduced approximately 80-98 percent by the fish pump removal system. Following passage through the fish pump, initial and latent (96-hour) survival of juvenile striped bass were approximately 100 percent and 85-95 percent, respectively (PG&E 1981). Fish pumps at the Contra Costa Power Plant reduce the numbers of fish impinged while maintaining high survival of fish returned to the receiving waterbody. However, some problems have been encountered with maintenance and with loss of pump prime at very low tides.

Other fish pumps have had mixed success. Studies at the Monroe Nuclear Generating Station estimate removal efficiencies of 52-99 percent and gizzard shad survival of 10-99 percent (Cannon et al. 1979). Southern California Edison reports a lack of success at its Huntington Beach and El Segundo generating stations (Stipanov 1976). The effectiveness of fish pumps in reducing impingement losses varies between species. The configuration, operation, and hydraulic characteristics of an intake in addition to the design, location, and operation of the fish pump system have a significant effect on diversion efficiency of a fish pump system.

Mussalli and Taft (1977, cited in Cannon et al. 1979) investigated jet pumps as an alternative to centrifugal pumps in fish removal systems. Based on laboratory testing, a peripheral-type jet pump fish return has been designed for the intakes of two plants on Lake Ontario, Nine Mile Point Nuclear Station Unit 2 and Oswego Steam Station Unit 6. Jet pumps have also been used successfully in fish return systems for several water diversion facilities located in the Arctic (ARCO 1985, 1987); however, the high water flow rates required may make them too costly for many applications.

Fish pump return systems may substantially reduce entrapment and impingement of fish at cooling water intake structures. Data are insufficient to evaluate conflicts in the findings. Additional research is needed on behavioral responses of fish (which can be used to concentrate organisms within a confined area of an intake structure), and the design parameters for a fish pump system to minimize fish mortality during removal from an intake.

D.5.3.4 Fish Basket Collectors

Fish basket collectors were developed for intakes where fish pumps had not been effective. Fish basket collectors allow fish to congregate over the collection basket, which is then raised to capture and return the entrapped fish to the receiving waterbody.

Testing of fish basket collectors has been conducted at the Alden Laboratory (Stone & Webster Engineering Corporation 1975) and at the Redondo Beach test facility of the Southern California Electric Company (Schuler and Larson 1975). In both tests, fish basket collectors provided acceptable fish removal. A full-scale fish basket collector has been developed for the San Onofre Nuclear Generating Station, based in part on modeling conducted at the Redondo Beach test facility, and has demonstrated satisfactory performance (J. Palmer 1988, personal communication).

Fish basket collectors are not expected to be effective for all species and sizes of fish. In addition, the hydraulic conditions within an intake structure, debris loading, and the configuration and design of an intake influence the effectiveness of fish basket collectors for removing entrapped fish. Fish basket collector systems are not generally applicable to shoreline intake structures.

D.5.3.5 Fish Bypasses and Escape Channels

Some intake structures provide bypasses or escape channels to minimize entrapment within the intake. A shoreline intake structure currently in use at several power plants, including the Diablo Canyon, Pittsburg, and Contra Costa power plants, uses vertical traveling intake screens located flush with the shoreline. Concrete dividing walls between forebays have been eliminated and bar racks enclose the front and sides of the intake. This allows lateral flow of water across the face of the intake screens, tending to guide entrapped fish away from the intake screens and out of the intake structure.

A second intake structure uses vertical traveling screens at an angle to the inflow of water (Section D.5.2.10). The angled intake screens divert entrapped fish across the face of the screen and into a bypass channel. This approach combines the advantages of intake screening with the diversion capability of louvers. Results of prototype tests (Taft and Mussalli 1978) indicated that high diversion efficiencies and survival rates for fish diverted by angled screens are possible. As noted previously in Section D.5.2.10, angled vertical traveling screens have been successfully used at the Brayton Point Power Station on Narragansett Bay in Massachusetts, achieving a diversion efficiency of 76 percent (Davis et al. 1987). Angled traveling screens have been used with similar success at the San Onofre Nuclear Generating Station in California (J. Palmer 1988, personal communication).

Concentrating fish in a bypass channel requires non-turbulent flow to guide fish into the bypass. Backflows, eddies, and rapid water velocity changes approaching a bypass will stimulate avoidance responses in fish, interfering with their transit past the intake screens and into the bypass. A gradual acceleration of flow in the direction of the bypass provides optimal hydraulic conditions for fish diversion (Taft et al. 1976).

The shoreline intake structure with fish escape channels has demonstrated acceptable performance at power plant intakes sited on lakes, rivers, and open coastal environments. The angled-screen diversion approach has also demonstrated acceptable performance in diverting fish at the San Onofre and Brayton Point plants. The use of fine-mesh screens on angled-screen diversions may be effective in diverting larval fish, but no data are currently available. Angled-screen diversions are applicable to offshore intakes with a fish return system, or shoreline intakes.

D.6 Intake Maintenance and Operation

Operational modifications of power plant cooling systems to reduce entrainment and impingement focus on reducing exposure of organisms to physical, chemical, and thermal stresses.

Physical stress results when organisms are impinged on intake screens or exposed to shear and pressure forces, or mechanical abrasion, during cooling system transit. Physical stress can be reduced by maintenance dredging in front of the intake to keep approach velocities low, or by reducing the volume of cooling water used. Cooling water volume reduction can be achieved by limiting the operation of circulating water pumps or by complete curtailment of cooling system operation and thus, also, electric generation.

Chemical stress on entrained organisms results primarily from exposure to biocides used to control biological fouling in cooling systems. Operational modifications to reduce chemical stress on entrained organisms focus primarily on minimizing the frequency, duration, and concentration of chemicals used for biofouling control.

Thermal stresses on entrained organisms result from exposure to elevated temperatures in the condensers and cooling water discharge. Operational modifications to minimize thermal stresses on entrained organisms focus on minimizing the temperature rise (ΔT) and time of exposure during cooling system transit.

Qualitative conclusions are presented in Table D-6.

D.6.1 Dredging

Sediment transport, sediment deposition, and littoral drift are frequently encountered near intakes. Such deposition increases approach velocities. Dredging is the simplest and most cost-effective means of minimizing physical stresses on

TABLE D-6

SUMMARY OF EXPERIENCE WITH MAINTENANCE AND OPERATIONAL MEASURES FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Reduces Physical Stress	Reduces Chemical Stress	Reduces Thermal Stress	Operationally Reliable	Requires Outage Time to Implement	Comments
Dredging in front of intake	◐	○	○	●	NO	
Reducing circulating water flows	◐	○	⊗	○	YES	Increases (Δ T)
Curtailing plant operation	◐	●	●	⊗	YES	Produces no electricity
Establishing biofouling procedures	○	●	○	●	NO	
Modifying circulating water system	◐	○	○	○	YES	No mechanical data
Lowering the temperature differential	○	○	●	○	YES	Retrofit of major plant systems (Section C.2.3)

Legend

● Demonstrated or expected improvement

○ No change or unknown

⊗ Demonstrated or expected deterioration aquatic organisms by ensuring the design velocities and uniform velocity gradients are maintained.

D.6.2 Reducing Circulating Water Flows

Reducing the number of circulating water pumps in operation is one operating strategy for reducing cooling water volume and intake approach velocities, thus reducing the rate of entrainment and impingement. Reducing cooling water flow rate during full-load generation reduces generating capacity and thermal transfer efficiency, with more significant losses at higher ambient inlet water temperatures. Changes in condenser backpressure, (reducing turbine cycle thermal efficiency, and increasing temperature differential through the condensers (ΔT), occur when cooling water flow rates are reduced during generation. Although a reduction in cooling water volume decreases entrainment, the associated increase in ΔT may substantially reduce the survival of the organisms entrained. Furthermore, this allowable temperature rise through the cooling system is sometimes specified in the National Pollutant Discharge Elimination System (NPDES) permit for a power plant.

Variable-speed motor drives for circulating water pumps can be used to match circulating water flow rates to generating unit power levels. This allows a reduction in cooling water flow during periods of low power generation, with an accompanying reduction in entrainment and impingement losses. Variable-speed operation can be accomplished by variable frequency controls that modify the frequency of the alternating current used to run the motors, allowing normal single-speed motors to operate at variable speeds. At present, the only variable frequency controls available for loads below 800 horsepower operate at 480 volts. If variable frequency controls are used, condenser air evacuation pumps must be installed to ensure proper priming of the system, maintaining water level and flow in the highest condenser tubes at all times. Otherwise, reduced pressure heads could result in air accumulating in the condenser water boxes. If this air were not removed by the air evacuation pumps, it would restrict flow through the upper condenser tube rows, reducing the effective condenser cooling surface area and baking dirt into the condenser tubes.

Another method of matching circulating water flow rates to power generation levels involves installation of magnetic (eddy current) couplings between the drive motors and the circulating water pumps. However, the reliability of magnetic couplings is questionable, and installation of these devices imposes a significant risk of forced outages. In any case, the use of magnetic couplings would also require the use of condenser air evacuation pumps.

Assessing the biological effectiveness of reducing entrainment and impingement losses by reducing the volume of cooling water withdrawn depends on quantitative information on the relative contribution of physical stresses and thermal stress for each species and life stage considered. Insufficient data are available to determine an appropriate balance between cooling water volume and ΔT for most power plants and fish species.

Regulation of cooling system volume and ΔT becomes increasingly complex when a diverse array of species and life stages, each with different tolerances to physical and thermal stress, are involved. During those periods when the ΔT and absolute discharge water temperature exceed the upper lethal limit for a species, it may be desirable to increase the cooling water volume, decreasing the discharge water temperature below a lethal limit. The alternative approach of reducing cooling water volume to a minimum and increasing ΔT above the thermal tolerance of a species may increase the total number lost to the population.

The biological complexities of cooling system operational modifications are compounded by engineering constraints. Many multiple circulating water pumps cannot be throttled or regulated. In addition, reducing cooling water volume reduces the thermal efficiency of the cooling system, resulting in decreased generating capacity. Therefore, reduced generation must be considered in perspective with electrical demand on a site-specific basis for a specific period of time.

Eliminating the use of multiple circulating water pumps when a unit is removed from service may not only reduce biological losses, but may also reduce the cost required to operate one or more circulating water pumps.

D.6.3 Curtailing Plant Operation

Entrainment and impingement of aquatic organisms at a power plant can be entirely eliminated by shutting down the system. Cooling system curtailment results in curtailment of electrical generation, and hence involves cost implications and reduced system-wide capability for meeting electrical demand.

Cooling system curtailment may be feasible if the seasonal period of maximum abundance of a critical species is short and coincides with a period when electrical generating capacity exceeds demand. The cost implications from loss of generation, electrical transmission from alternative sources, and availability of alternative sources of electricity (e.g., hydroelectric), must be evaluated on a site-specific basis. Coordinating plant activities, such as scheduled outages for maintenance or refueling, with periods of high organism densities can also be considered.

Coordinating cooling system curtailment with periods of highest abundance of a critical species requires a continuing biological monitoring program at the site to identify the period of maximum abundance. Coordinating scheduled outages with the temporal distribution of a particular species is difficult because outages require precise scheduling months in advance, while the precise temporal pattern of species abundance may not be predictable.

The feasibility of utilizing cooling system curtailment and scheduled maintenance outages to minimize biological losses must be examined on a site-specific and species-specific basis.

D.6.4 Biofouling Procedures

Schubel and Marcy (1978) recommend the following to minimize mortality associated with chemical stress (most commonly from chlorination to control biofouling) during entrainment:

1. Chlorinate intermittently;
2. Minimize free chlorine concentration to the lowest possible level;
3. Minimize transit time through the cooling system to limit exposure to the biocide; and
4. Maximize the rate of dilution of the discharge water. The rate of dilution is important because of the time-dose response of organisms to heat stress.

Alternative biocidal agents do not appear to be effective in minimizing mortality of non-target entrained organisms. Mechanical fouling control techniques have not proven completely effective in controlling fouling in power plant cooling systems. Fouling control using tributyl tin biocides has not been successful.

Furthermore, the use of biocidal agents such as tributyl tin as a means of fouling control raises the important question of downstream effects. Any chemical agent that is sufficiently toxic to prevent biofouling will undoubtedly have marked effects in the waterbody that receives the cooling water discharge, and is likely to be subject to restriction on its use.

D.6.5 Modifying Cooling Water System Components

Structural modification of cooling system components to reduce mortality of entrained organisms is not effective at present. Insufficient quantitative data are available to isolate specific sources of mortality within a cooling water system. Design parameters specifying pressure regimes, circulating water pump design and operation (e.g., rpm and impeller design), tolerable shear stresses, and cooling system designs to minimize mechanical abrasion have not been developed.

Structural modifications have focused on design and operation of intake structures, with particular emphasis on intake screening systems, to reduce stress on impinged organisms (Section D.5.2). Greater effort has been devoted to methods for excluding fish eggs and larvae from cooling systems than on developing specific criteria for structural modifications to reduce stress on entrained organisms.

D.6.6 Regulation of Thermal Elevations (ΔT)

To minimize mortality of entrained organisms from thermal stress in a once-through cooling system, Schubel and Marcy (1978) recommend:

1. Use the minimum ΔT technologically practicable, based on cooling system design and load.
2. Minimize transit time through the cooling system.
3. Discharge cooling water in a way that promotes rapid mixing and dilution.

Regulating thermal elevation requires integrating information on:

- Plant generating loads and ΔT.
- Species- and size-specific thermal tolerances to evaluate the effectiveness of various cooling system operating modes for reducing entrainment losses.

The temperature rise ΔT through a once-through cooling system is commonly controlled both for engineering reasons and as a means of minimizing a broad spectrum of environmental impacts. For some key species, however, there may be a threshold temperature, below which temperature rise causes no apparent damage. In such situations, the maximum temperature to which organisms are exposed is the controlling variable, rather than the temperature rise ΔT.

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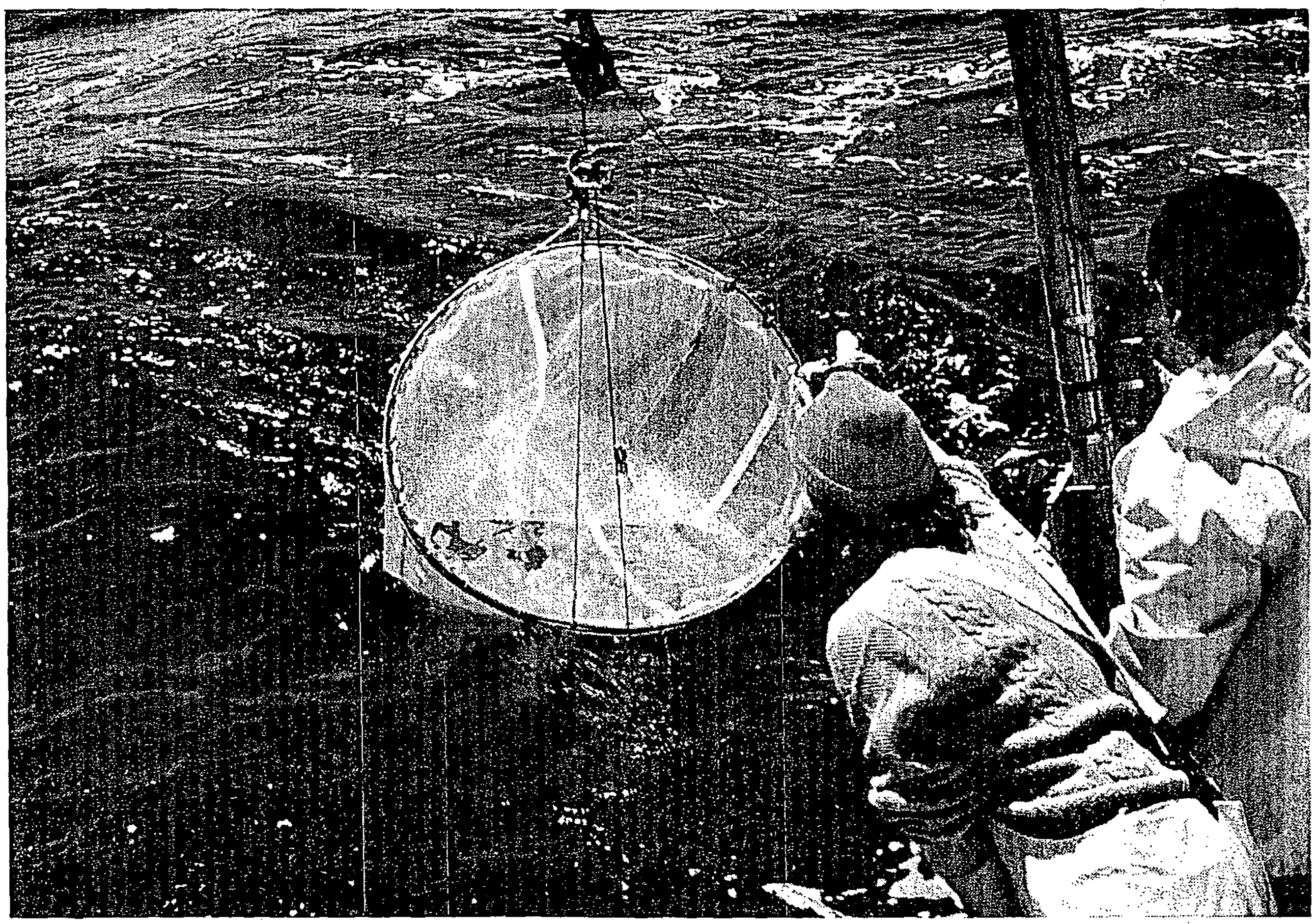
Enclosure 3

Seasonal Distribution of Plankton in the Nearshore Marine Environment of Diablo Canyon Nuclear Power Plant, 1977

Seasonal Distribution of Plankton in the Nearshore Marine Environment of Diablo Canyon Nuclear Power Plant

by J. W. Icanberry and J. W. Warrick



Researchers Sampling Plankton and Larval Fish off Diablo Canyon

Report Issued: APR 13 1977

Report 7846.13-76

PACIFIC GAS AND ELECTRIC COMPANY
DEPARTMENT OF ENGINEERING RESEARCH

SEASONAL DISTRIBUTION OF PLANKTON IN THE NEARSHORE MARINE ENVIRONMENT OF DIABLO CANYON NUCLEAR POWER PLANT

Prepared By:

J. W. Icanberry

J. W. ICANBERRY, BIOLOGIST

J. W. Warrick

J. W. WARRICK, BIOLOGIST

Approved By:

B. F. Waters

B. F. WATERS, SR. BIOLOGIST

J. R. Adams

J. R. ADAMS, SUPV. BIOLOGIST

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ABSTRACT

A 15-month study was conducted to describe the seasonal distribution trends of total zooplankton and phytoplankton densities, dry weight and ash-free dry weight densities (organisms > 150 μm), and ATP (adenosine triphosphate) concentrations (representative of live biomass $\leq$ 150 μm).

Samples were collected at two stations, designated Inshore and Offshore, located 300 m and 1500 m southwest of the seaward perimeter of Diablo Cove, respectively. A 150 μm mesh 30 cm D net was hauled obliquely through the upper mixed layer. Three replicate hauls were made at each station at approximately biweekly intervals.

Statistical comparisons of total zooplankton and phytoplankton densities and ATP concentrations between the Inshore and Offshore Stations found in no significant differences. Thus, the data were combined to describe the nearshore seasonal distributions.

During the study, 168 hauls were taken and 94 zooplankton and 46 phytoplankton taxa were indentified. Five zooplankton taxa comprised 75.0 percent of the total zooplankton density and six phytoplankton taxa comprised 83.4 percent of the total phytoplankton density.

Seasonally, the greatest zooplankton densities occurred in June and July 1974. The average zooplankton density was 9,580 $(m^3)^{-1}$ for the study period. Dry weights and ash-free dry weights peaked twice during the study period, March 1974 to July 1974, and January 1975 to April 1975. The average dry weight density was 92.27 μg l^{-1}, approximately the same as the average (104.02 μg l^{-1}) reported in an earlier zooplankton study of Diablo Cove. The average ash-free dry weight was 29.75 μg l^{-1}.

The seasonal ATP distribution revealed two major peaks. The first one, April 1974 to July 1974, correlated with peak zooplankton densities and probably represents predominant zooplankton $\leq$ 150 μm. The second peak, September 1974 to February 1975, correlated with the period of peak phytoplankton densities and inversely correlated with dry weight and ash-free dry weight peak abundance periods. Thus, the second peak probably represents the increased phytoplankton density present from October 1974 to February 1975.

INTRODUCTION

To assess potential impacts on zooplankton and phytoplankton populations from Diablo Canyon Nuclear Power Plant operations, a study was conducted to determine the seasonal distribution trends of total zooplankton and phytoplankton densities, densities by species, and species composition in the nearshore marine environment of Diablo Cove. Additionally, zooplankton dry and ash-free weights and live biomass estimates were measured. Diablo Cove is located at 35°14' north latitude and 120°51' west longitude (Figure 1).

Waters (1969) conducted vertical net tows of zooplankton from 228 m to 4480 m offshore from the mouth of Diablo Cove on one date, December 5, 1967. Icanberry (1974) reported the seasonal distribution of zooplankton from Intake Cove at Diablo Canyon. There are no other known plankton studies from the immediate vicinity of Diablo Canyon. Monthly zooplankton densities were reported for Morro Bay, 19 km north of Diablo Canyon (Icanberry 1974).

METHODS

Two sampling stations, designated Inshore and Offshore, were established at 300 m and 1500 m southwest of the seaward perimeter of Diablo Cove, respectively.

Zooplankton was collected using a 30 cm, 150 μm mesh net (Kramer et al. 1972). A calibrated flowmeter (General Oceanic Model 2030) was used to quantify the water volume filtered. Three replicate hauls were made approximately biweekly at each station.

For each station occupied, surface temperature, salinity, and dissolved oxygen were measured in the surface layer (1 m). Methodology for these procedures was previously described (Icanberry and Adams 1974). Larval fish

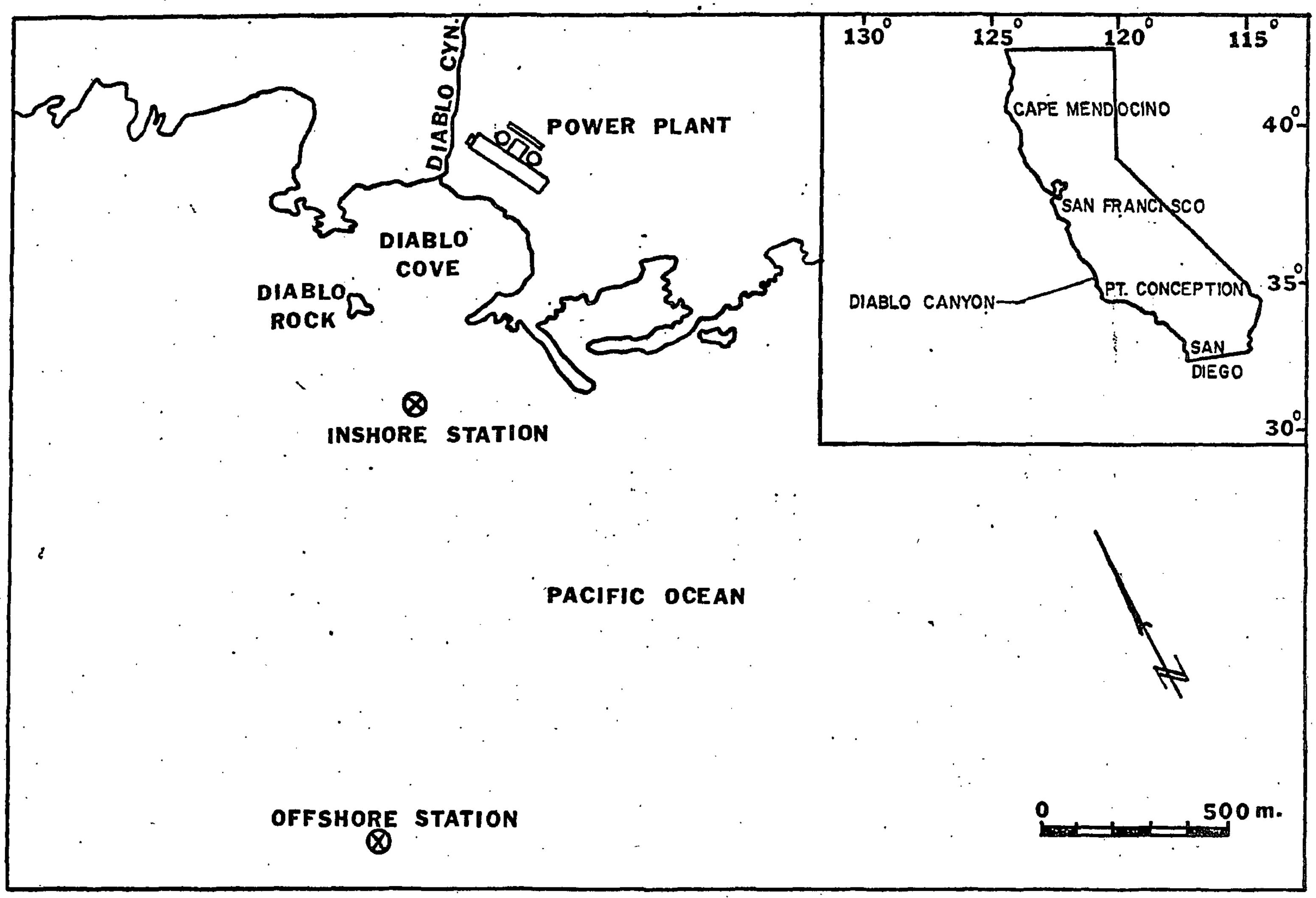

Figure 1 Diablo Canyon area showing locations of the Inshore and Offshore Stations

and fish eggs were simultaneously sampled in oblique hauls. The results of that study have been described by Icanberry and Warrick (1976).

The criteria for establishing net haul depths were maximum existing Inshore and Offshore Station depths, the annual range of the thermocline depth at both stations, and the need to standardize as nearly as possible the sampling depths at both stations. The depths of the Inshore and Offshore Stations were approximately 20 m and 60 m, respectively. The depth of the upper mixed layer down to the thermocline within the sampling area varies seasonally, approximately 5-25 m (Doyle 1974). The net was fished obliquely through the upper mixed layer from average depths of 17 m and 25 m at the Inshore and Offshore Stations, respectively, to the surface, insuring adequate sampling above the thermocline throughout the study.

Towing speeds were 1.6 m $(sec)^{-1}$ or slower. The net was attached to a towing cable about 4 m above a 6.8 kg wire depressor. The net was lowered to its fishing depth in about one minute. During each haul, while the net was fishing at depth, an inclinometer was used to measure the angle-of-stray of the tow wire from the vertical. The maximum depth of the haul was estimated as the product of the amount of tow wire out and the cosine of the angle-of-stray. The net was fished at depth for one minute and hauled to the surface at a slow but constant rate. After washing down the net contents from the outside, the samples were placed in plastic containers, labelled, and preserved in a 10.0 percent formalin solution of seawater.

In the laboratory, zooplankton samples were split with a Folsom Plankton Splitter. One half of the sample was taxonomically identified* and quantitatively enumerated. The remaining sample half was processed to determine dry

*Consultant taxonomist, Sylvia A. Murray, T.V.A., Muscle Shoals, Alabama.

weight and ash-free dry weight (Soeder and Tolling 1971). During this procedure the amount of the half sample filtered was adjusted as a fraction of the sample half and reported as μg l^{-1} for both dry weights and ash-free dry weights. The half samples were filtered through an 8.0 μm nucleopore membrane filter.

At the time of sampling, one liter of unfiltered seawater was collected from ≤ 1.0 m below the surface at each station and preserved with Lugol's solution. In the laboratory, phytoplankton cells were concentrated by allowing them to settle in fabricated glass settling chambers. The cells were then identified and enumerated.

Live biomass (organisms < 150 μm) was determined by ATP (adenosine triphosphate) analysis. At each station, three replicate 1.0 l samples were collected from ≤ 1.0 m below the surface, initially filtered through a 150 μm mesh nylon net , and then through a 8.0 μm nucleopore membrane filter. The filtrate was then placed into test tubes containing 5.0 ml of boiling Tris buffer solution, thus fixing the ATP into solution. After heating for 5.0 min at 100°C, the test tubes were cooled and frozen at -20°C until analyzed. The ATP content was measured with a JRB-ATP photometer (Holm-Hansen and Booth 1966).

A grouped t-test for independent samples was used to test for differences in total zooplankton and phytoplankton densities, densities of zooplankton and phytoplankton species, and biomass, between the Inshore and Offshore Stations.

RESULTS AND DISCUSSION

General

During the 15-month study period, 168 hauls were taken, 94 taxonomic and life stage zooplankton categories and 46 phytoplankton genera were identified.

The average haul time (total time net was fishing) was 3.29 min at the Inshore Station and 3.75 min at the Offshore Station. The average volume of water sampled in each haul was 8.4 m^3, (S.D. = 3.01) at the Inshore Station and 9.0 m^3, (S.D. = 3.01) at the Offshore Station.

Physical and Chemical Data

Upwelling indices indicated two peaks during the study period, April to June 1974 and March to May 1975 (Figure 2). Since there were no apparent differences between Inshore and Offshore Station physical and chemical measurements, the data from both stations for each parameter were combined and averaged (Figure 3). High salinities and low temperatures correlated closely with periods of upwelling (April 1974 to August 1974 and March 1975 to May 1975). Dissolved oxygen concentrations were too variable to evaluate relative to upwelling (Figure 3). The variability associated with dissolved oxygen probably resulted from the natural mixing at the surface interface, thus masking expected lower dissolved oxygen concentrations normally associated with upwelled waters.

Zooplankton Species Composition and Occurrence

Percent composition and occurrence of all zooplankton taxa identified in this study are shown in Table 1. Table 2 shows those taxa comprising 75.0 percent of the total zooplankton numbers. All of the most abundant species in this study, except Oikopleura spp., were reported as comprising 96.8 percent of the total zooplankton numbers in a previous study at Diablo Canyon (Icanberry 1974). Sixty-six additional zooplankton taxa were identified, thus expanding Icanberry's (1974) nearshore Diablo Canyon taxonomic list by 70.2 percent.

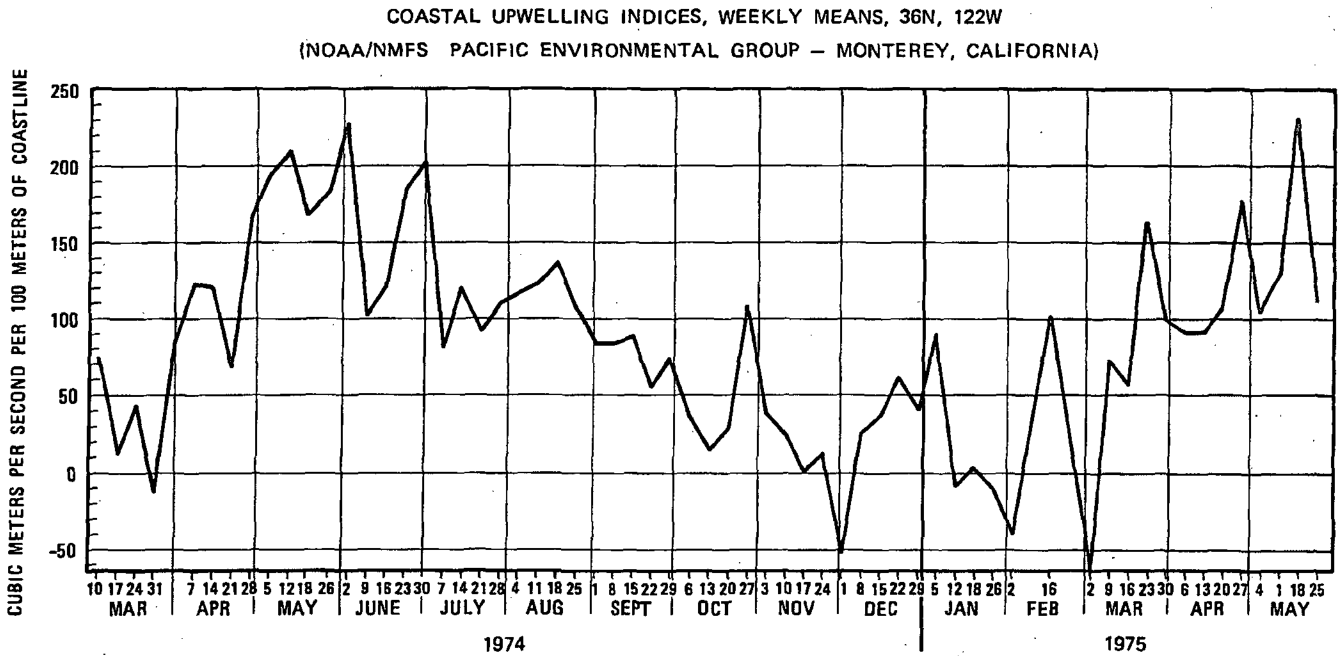

Figure 2 Weekly means of coastal upwelling values derived from the Coastal Upwelling Indices for 36 N lat. and 122 W long., as recorded by NOAA/NMFS Pacific Environmental Group, Monterey, California.

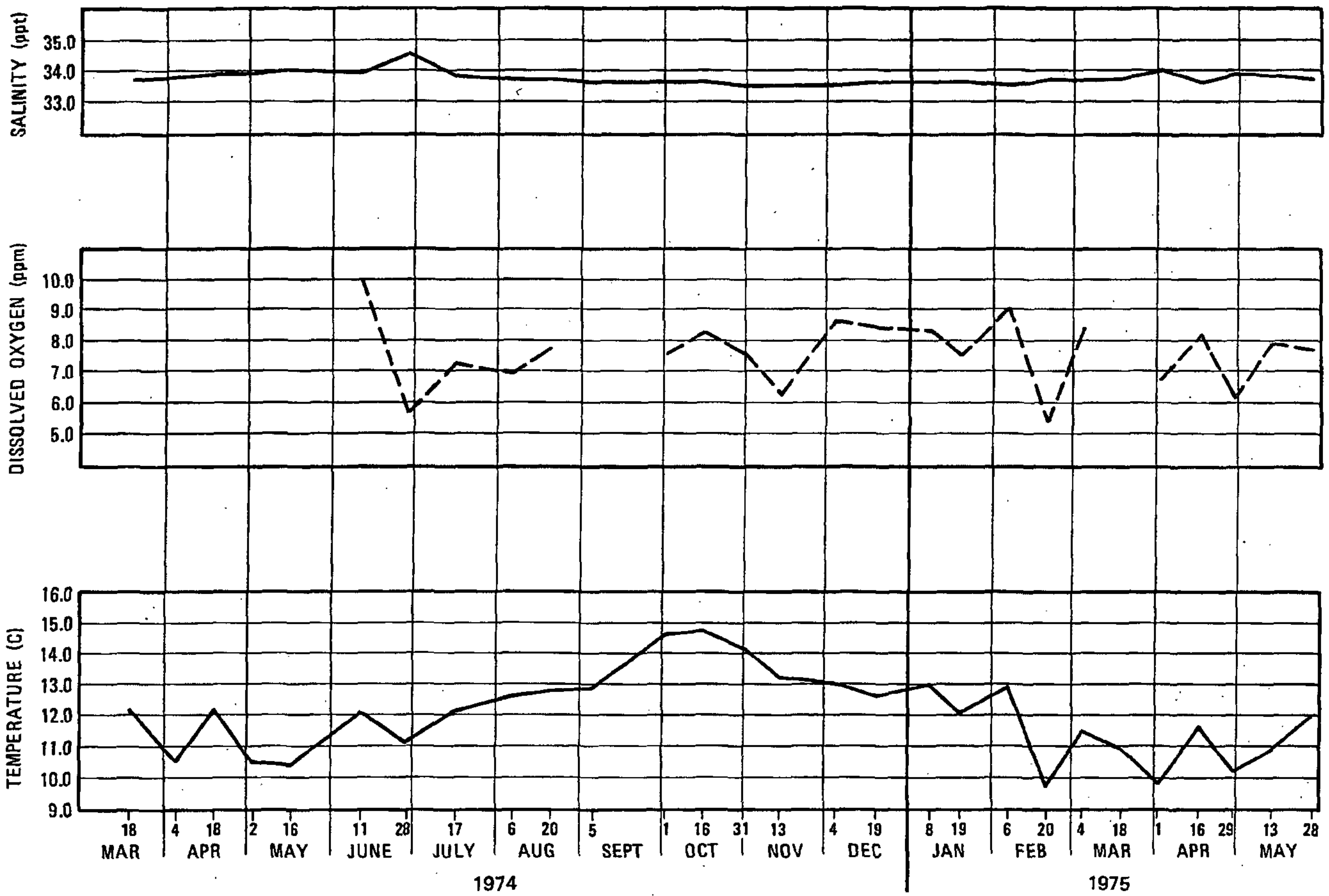

Figure 3 Distribution of mean Inshore and Offshore Station salinites, dissolved oxygens, and temperature values recorded at Diablo Canyon, California.

Table 1. Taxonomic category, percent composition and percent occurrence of zooplankton collected March 18, 1974 to May 28, 1975 at Diablo Canyon.

Taxonomic Category	Percent Composition	Percent Occurrence
Sagoscena spp.	0.0*	4.8
Sagosphaera spp.	0.0	5.4
Hydromedusa	0.1	33.3
Obelia spp.	0.1	22.0
Leptomedusa	0.0	0.6
Siphonophora	0.2	37.5
Ctenophora	0.0	9.5
Platyhelminthes	0.0	10.1
Pilidium larvae	0.0	6.0
Keratella spp.	0.0	1.8
Nematoda	0.0	3.0
Polychaeta (larvae)	1.2	82.1
Tomopteris spp.	0.0	0.6
Trochophore larvae	0.2	49.4
Veliger larvae (mollusca)	0.0	2.4
Podon spp.	0.7	12.5
Evadne spp.	1.7	53.0
Ostracoda	0.0	5.4
Calanoida nauplii	35.4	94.6
Unknown parasitic calanoida	0.0	3.6
Calanoida copepodites	22.3	97.6
Calanus spp.	0.0	1.8
Calanus finmarchicus	0.5	52.4
Eucalanus spp.	0.0	12.5
Euchaeta spp.	0.0	4.2
Eucalanus bungii bungii	0.0	6.0
Rhincalanus spp.	0.0	5.4

Table 1 - contd.

Taxonomic Category	Percent Composition	Percent Occurrence
Rhincalanus nasutus	0.0	8.9
Para-, *Pseudocalanus* spp. copepodites	0.0	4.2
Pseudocalanus minutus	0.2	18.5
Metridia pacifica	0.0	13.1
Clausocalanus spp.	0.0	1.2
Pleuromamma spp.	0.0	3.0
Centropages spp.	0.0	6.5
Labidocera spp.	0.0	1.8
Acartia spp. copepodites	0.0	0.6
Acartia clausi	1.0	25.0
Acartia tonsa	2.4	54.2
Acartia longiremis	1.6	44.6
Tortanus discaudatus	0.0	13.1
Harpacticoida	0.2	33.3
Copilia spp.	0.0	1.2
Unknown cyclopoida copepods	2.8	47.6
Cyclops spp.	0.0	3.0
Microsetella spp.	0.3	63.1
Macrosetella spp.	0.2	44.0
Euterpina spp.	1.5	57.1
Oithona spp.	0.0	1.8
Oithona similis	1.8	64.9
Oithona spinerostrus	0.3	56.0
Corycaeus spp.	1.6	76.8
Clytemnestra spp.	0.0	0.6
Cyclop-, Harpacticoida copepodites	4.5	95.2
Microcyclops spp.	0.0	9.5
Cirripedia nauplii	6.9	92.9
Mysidae	0.0	1.2
Cumacea	0.0	0.6

Table 1 - contd.

Taxonomic Category	Percent Composition	Percent Occurrence
Isopoda	0.0	9.5
Amphipoda	0.0	1.8
Caprellidae	0.0	0.6
Euphausia spp. zoea	0.0	7.1
Euphausia spp. nauplii	0.1	17.3
Euphausia spp. calyptopis	2.6	51.2
Euphausia spp. furcilia	0.7	13.7
Unknown anomuran larvae	0.0	0.6
Emerita spp. zoea	0.0	0.6
Paguridae zoea	0.0	2.4
Solenocera spp. zoea	0.0	0.6
Sergestes spp. zoea	0.0	1.2
Crangon spp. zoea	0.0	8.3
Spirontocaris spp. zoea	0.0	8.9
Hippolyte spp. zoea	0.0	3.6
Callianassa spp. zoea	0.0	15.5
Munida spp. zoea	0.0	3.0
Blepharipoda spp. zoea	0.0	0.6
Lithodes spp. zoea	0.0	0.6
Cancer spp. zoea	0.6	39.3
Cancer spp. megalopa	0.0	1.2
Porcellanidae zoea	0.0	8.9
Pinnotheridae zoea	0.0	7.1
Pinnixa spp. zoea	0.3	31.5
Hemigrapsus spp. zoea	0.0	8.9
Xanthidae zoea	0.0	1.8
Caridean zoea	0.0	17.3
Pontophilis spp.	0.0	0.6

Table 1 - contd.

Taxonomic Category	Percent Composition	Percent Occurrence
Unknown crustacean larvae	0.0	1.8
Phoronis spp. (larvae)	0.0	11.9
Tunicate larvae	0.0	3.6
Appendicularia	0.0	9.5
Doliolum	0.1	20.2
Salpa spp.	0.0	5.4
Oikopleura spp.	5.9	70.8
Fritillaria spp.	1.1	48.8
Chaetognatha	0.4	63.1

* Zero values indicate percent composition to be <0.1 percent.

Table 2. Percent composition and percent occurrence of taxa comprising 75.0% of the zooplankton densities from hauls conducted March 18, 1974 to May 28, 1975, at Diablo Canyon.

Taxon	Percent Composition	Percent Occurrence
Calanoida nauplii	35.4	94.6
Calanoida copepodites	22.3	97.6
Cirripedia nauplii	6.9	92.9
Oikopleura spp.	5.9	70.8
Cyclopoida and Harpacticoida Copepodites	4.5	95.2

Seasonal Zooplankton Distribution

There were no statistically significant differences at the 95 percent confidence level between Inshore and Offshore Station densities of total zooplankton, individual zooplankton species, dry weights, and ash-free dry weights (Table 3).

The seasonal distribution of total zooplankton densities is shown in Figure 4. The peak zooplankton densities correlated with peak upwelling periods (Figures 2 and 4). The peak density, 127,662 $(m^3)^{-1}$, occurred June 11, 1974, and densities remained high from June 11, 1974, to July 16, 1974. Not enough samples were taken to verify the period of peak zooplankton densities in 1975. The seasonal period of peak abundance (June 11, 1974) coincided with that of 1973 reported by Icanberry (1974) to have been on June 6, 1973 (62,000 $(m^3)^{-1}$). The mean total zooplankton concentration during the study was 9,881 $(m^3)^{-1}$, S.D. 23,865 $(m^3)^{-1}$ or 2.6 times that of 3,794 $(m^3)^{-1}$, the 13-month mean total zooplankton density reported by Icanberry (1974) from zooplankton collections taken at the Intake Cove of Diablo Canyon. This 2.6 times greater difference found in the present study may be explained by: (1) low zooplankton populations existing in the relatively quiet, noncirculating waters of the Intake Cove (Icanberry 1974); (2) avoidance by zooplankters of the pump sampling device used by Icanberry (1974) as compared with the more efficient 30 cm D towed net used in the present study; or (3) zooplankton numbers were possibly lower in 1972-73 than in 1974-75. Since no towed net samples were taken during the Icanberry (1974) study, we cannot verify any of these possible explanations.

Table 3. Statistical comparisons of inshore and offshore concentrations of taxa comprising 75.0% of the zooplankton densities from samples collected March 18, 1974 to May 28, 1975 at Diablo Canyon.

Taxon	d.f.	t-Value*	Calculated Two-Tailed Probability	Probability 0.05	0.01(α)
Calanoida nauplii	30	0.71	0.485	NS	
Calanoida copepodites	54	0.16	0.875	NS	
Cirripedia nauplii	32	2.16	0.038	S	NS
Oikopleura spp.	50	0.15	0.882	NS	
Cyclopoida and Harpacticoida copepodites	54	0.12	0.904	NS	
Total zooplankton	54	0.64	0.525	NS	
Dry weights	54	-0.81	0.420	NS	
Ash-free dry weights	54	-0.05	0.960	NS	

*Positive t-values indicate that greater densities occurred at the Inshore Station; negative t-values indicate the opposite.

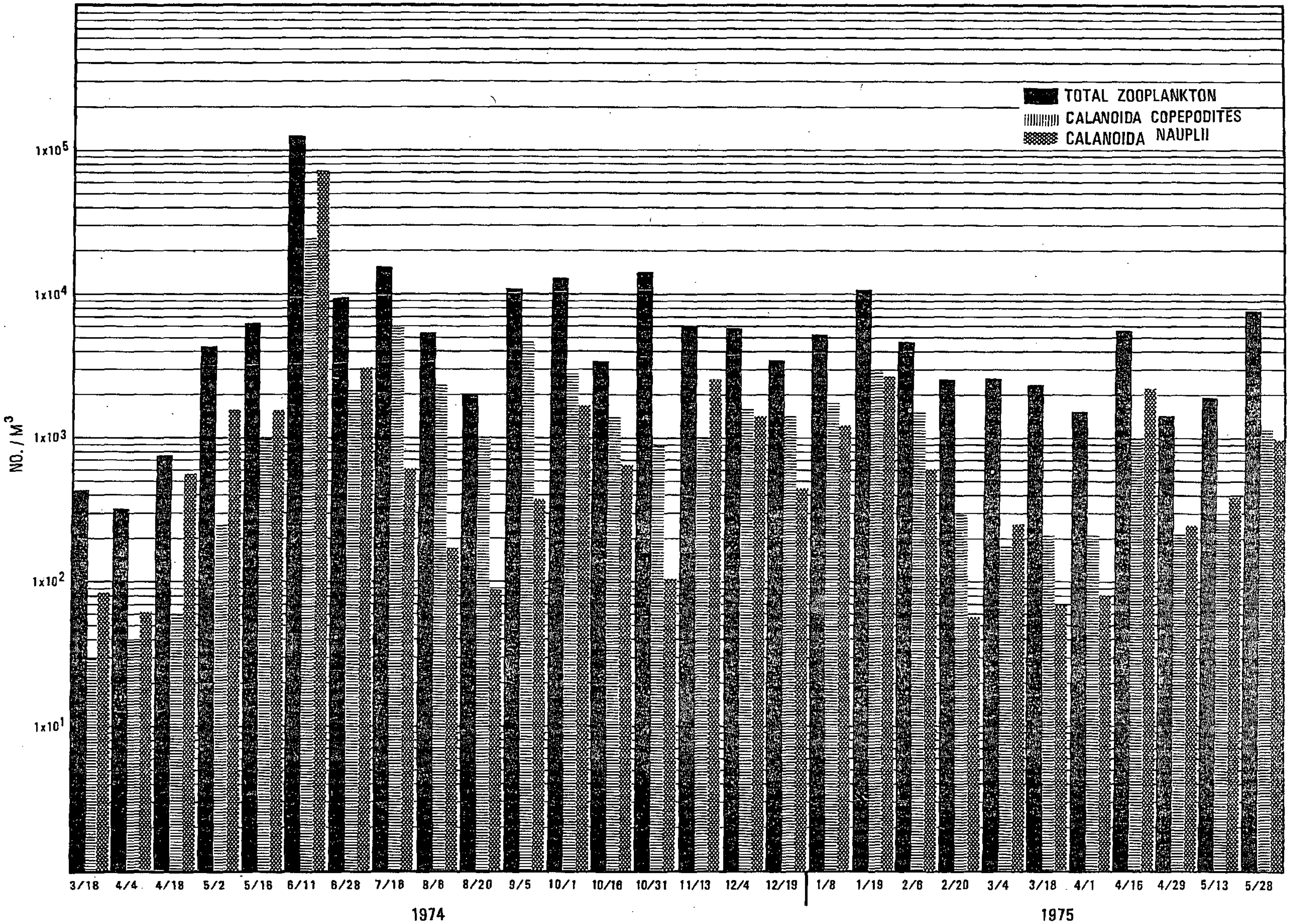

Figure 4 Seasonal distribution of total zooplankton, calanoida copepodites and calanoida nauplii represented as means of combined Inshore and Offshore sample densities for each biweekly sampling effort.

Calanoida nauplii were present throughout the study period (Table 2, Figure 4) and represented 35.4 percent of the total zooplankton density. Their period of greatest abundance coincided with that of total zooplankton, May 2, 1974 to June 28, 1974. During this period, calanoida nauplii constituted 53.9 percent of the total density. As a general distributional trend, they were most abundant during the Upwelling season, then declined and maintained variable populations throughout the Oceanic and Davidson Current seasons.

Calanoida copepodites were present throughout the study period (Table 2, Figure 4) and represented 22.3 percent of the total zooplankton density. Their period of greatest abundance coincided with that of total zooplankton, and they paralleled the seasonal distribution of calanoida nauplii. The copepodites, expectedly, showed less variability than the nauplii because, as the densities of nauplii stages declined in the samples, they essentially grew into the more advanced copepodite stages and declined through natural mortality.

Cirripedia nauplii showed significantly greater densities throughout the study at the Inshore Station (Table 3, Figure 5). Their peak density at the Inshore Station occurred March 4, 1975. Cirripedia nauplii comprised 6.9 percent of the total density but occurred in 92.9 percent of the samples (Table 2).

Oikopleura spp. densities peaked on June 11, 1974 (Upwelling season) and September 5, 1974 (Oceanic season). They comprised only 5.9 percent of the total density but occurred in 70.8 percent of the samples (Table 2).

Cyclopoida and harpacticoida copepodites reached their period of greatest abundance from April 18, 1974, to August 6, 1974, the Upwelling period (Figure 6). Their densities peaked June 11, 1974. Although they comprised only 4.5 percent of the total zooplankton density, they occurred in 95.2 percent of the samples.

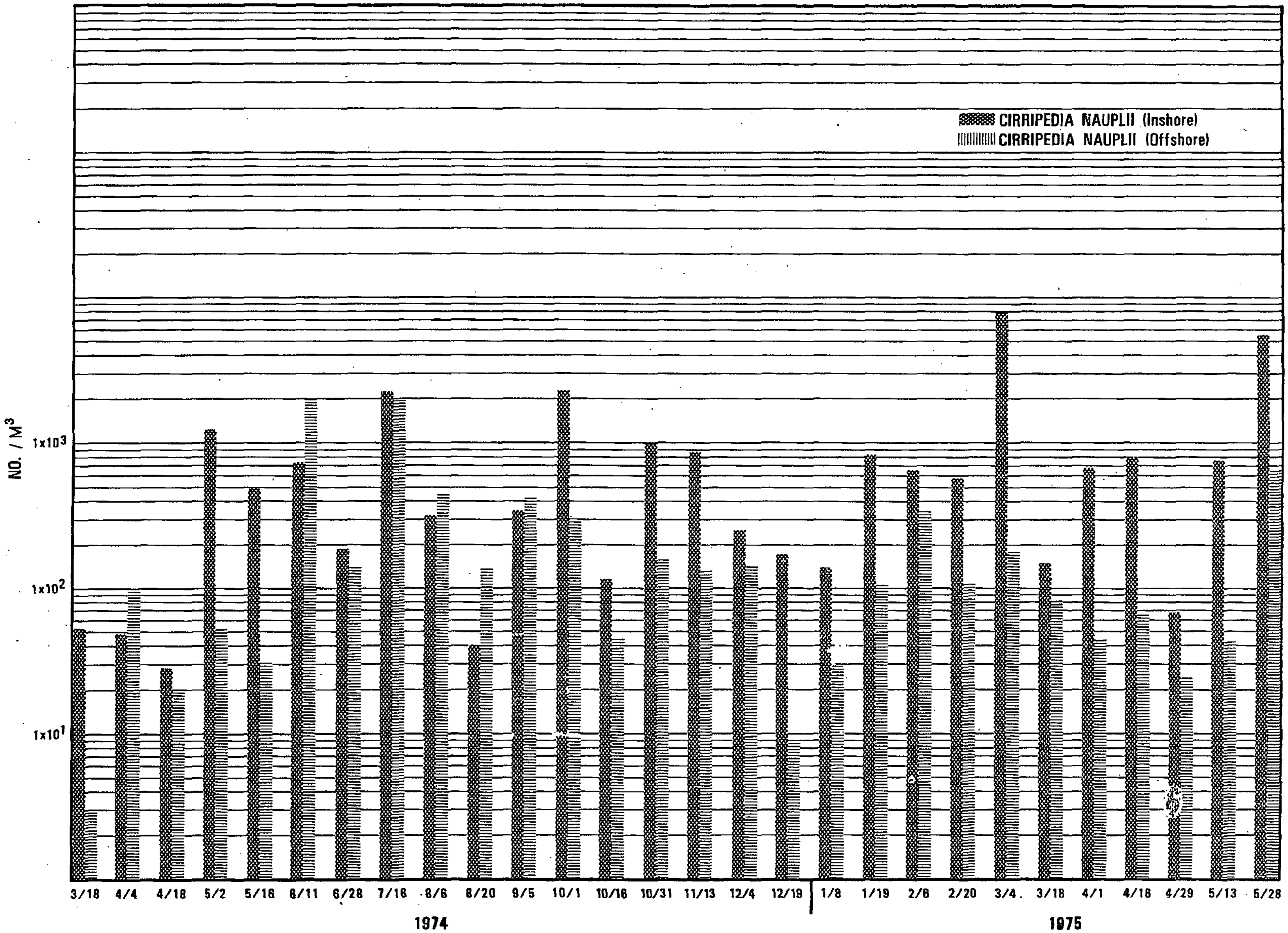

Figure 5 Quantitative seasonal distribution of the mean biweekly densities of Cirripedia nauplii at the Inshore and Offshore Stations collected for each biweekly sampling effort.

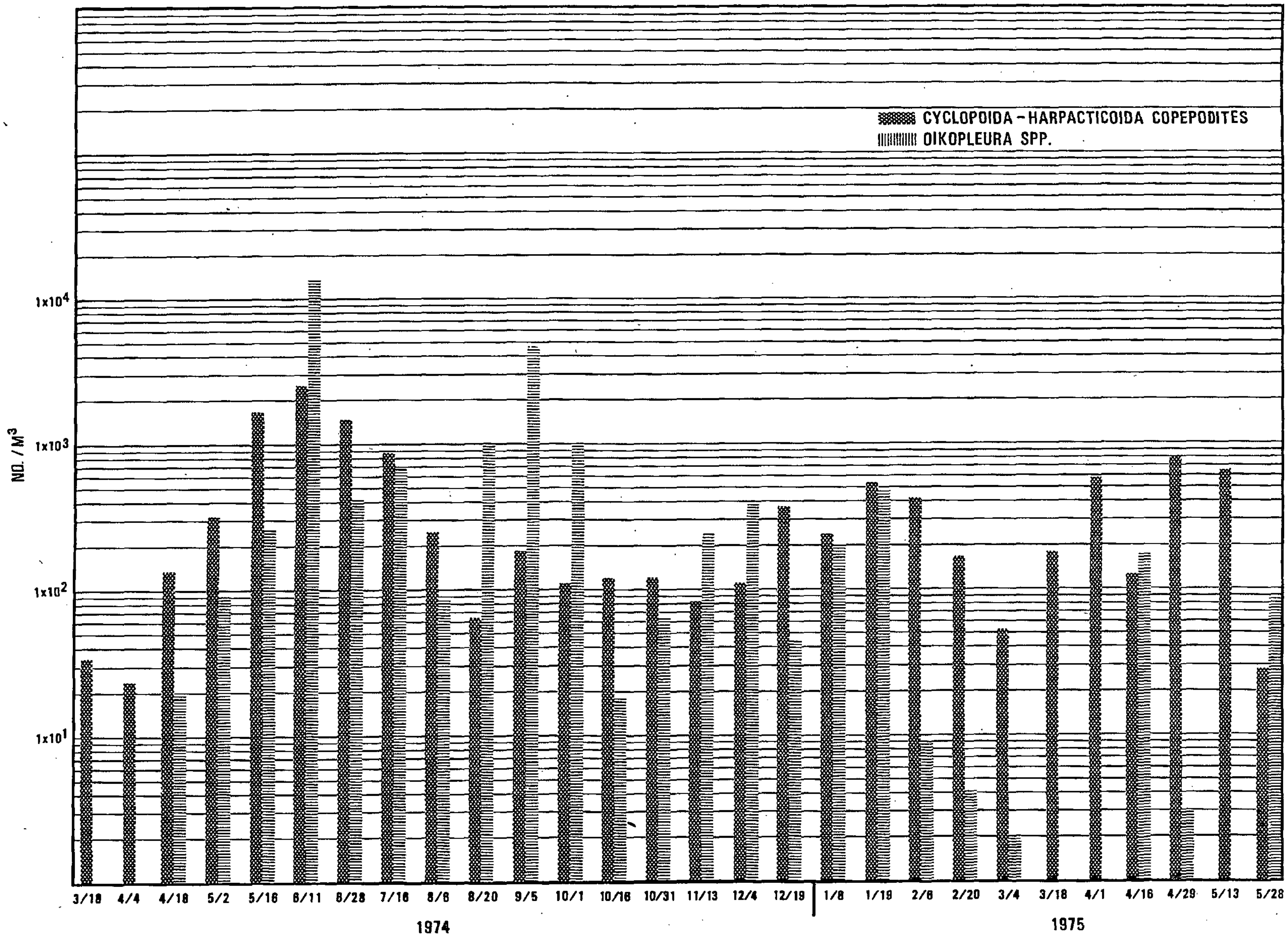

Figure 6 Seasonal distribution of Cyclopoida-Harpacticoida copepodites and <u>Oikopleura</u> spp. represented as means of combined Inshore and Offshore sample densities for each biweekly sampling effort.

Seasonal Distribution of Dry Weight Biomass

The seasonal distribution of dry weight biomass measurements is shown in Figure 7. The peak biomass 607.4 $\mu g\ l^{-1}$, occurred June 11, 1974. The highest concentrations occurred from May 2, 1974 to July 16, 1974. A second peak began January 19, 1975 and extended through April 16, 1975 (peak biomass: 368.54 $\mu g\ l^{-1}$). These periods of peak biomass correlated with the two periods of upwelling documented during the 15-month study (Figure 2). The first peak period, May 2, 1974 to July 16, 1974, correlated with that of total zooplankton (Figure 4). The second biomass peak (February 6, 1975) occurred at the beginning of the second period of upwelling and probably represented a response to the increased volumes of phytoplankton present seasonally at that time (Figure 8).

The average dry-weight biomass during the study period was 92.29 $\mu g\ l^{-1}$, S.D. 126.09 $\mu g\ l^{-1}$, approximately the same as the yearlong average, 104.02 $\mu g\ l^{-1}$, reported by Icanberry (1974).

Seasonal Distribution of Ash-Free Dry Weight Biomass

The seasonal distribution of ash-free dry weights (weight of organic matter) is shown in Figure 7. The distribution parallels that of the dry weight estimates in the same figure, but the values are generally an order of magnitude lower, reflecting the smaller fraction of organic content. The average ash-free dry weight was 29.75 $\mu g\ l^{-1}$, S.D. 54.31 $\mu g\ l^{-1}$. This average is 18.86 percent, S.D. 3.04 percent, of the total dry weights. Peak biomass occurred April 4, 1974 to July 16, 1974 (peak biomass: 91.35 $\mu g\ l^{-1}$) and February 6, 1975 to April 16, 1975 (peak biomass: 280.18 $\mu g\ l^{-1}$).

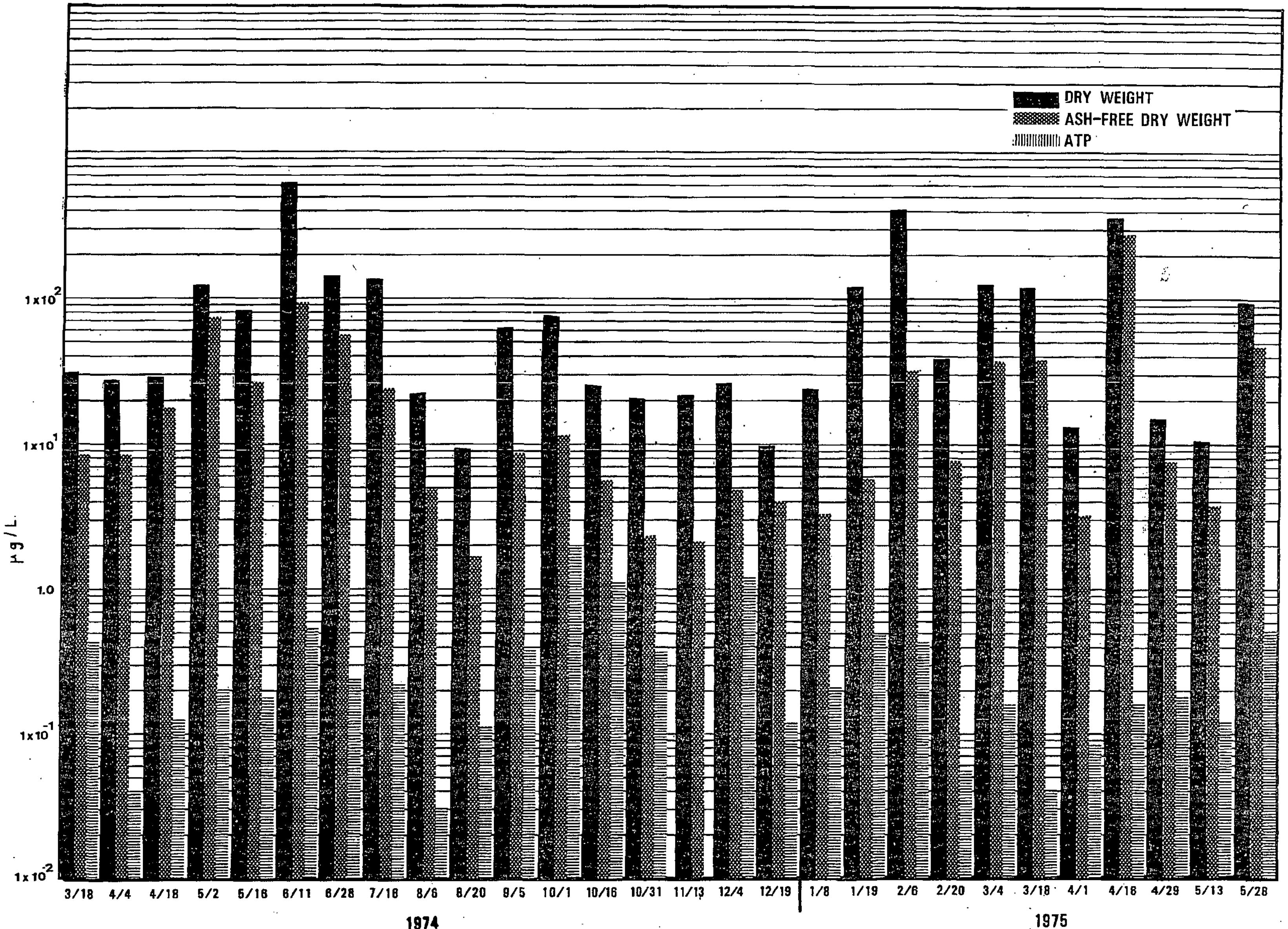

Figure 7 Seasonal distribution of dry weights, ash-free dry weights, and ATP concentrations represented as means of combined Inshore and Offshore sample biomass for each biweekly sampling effort.

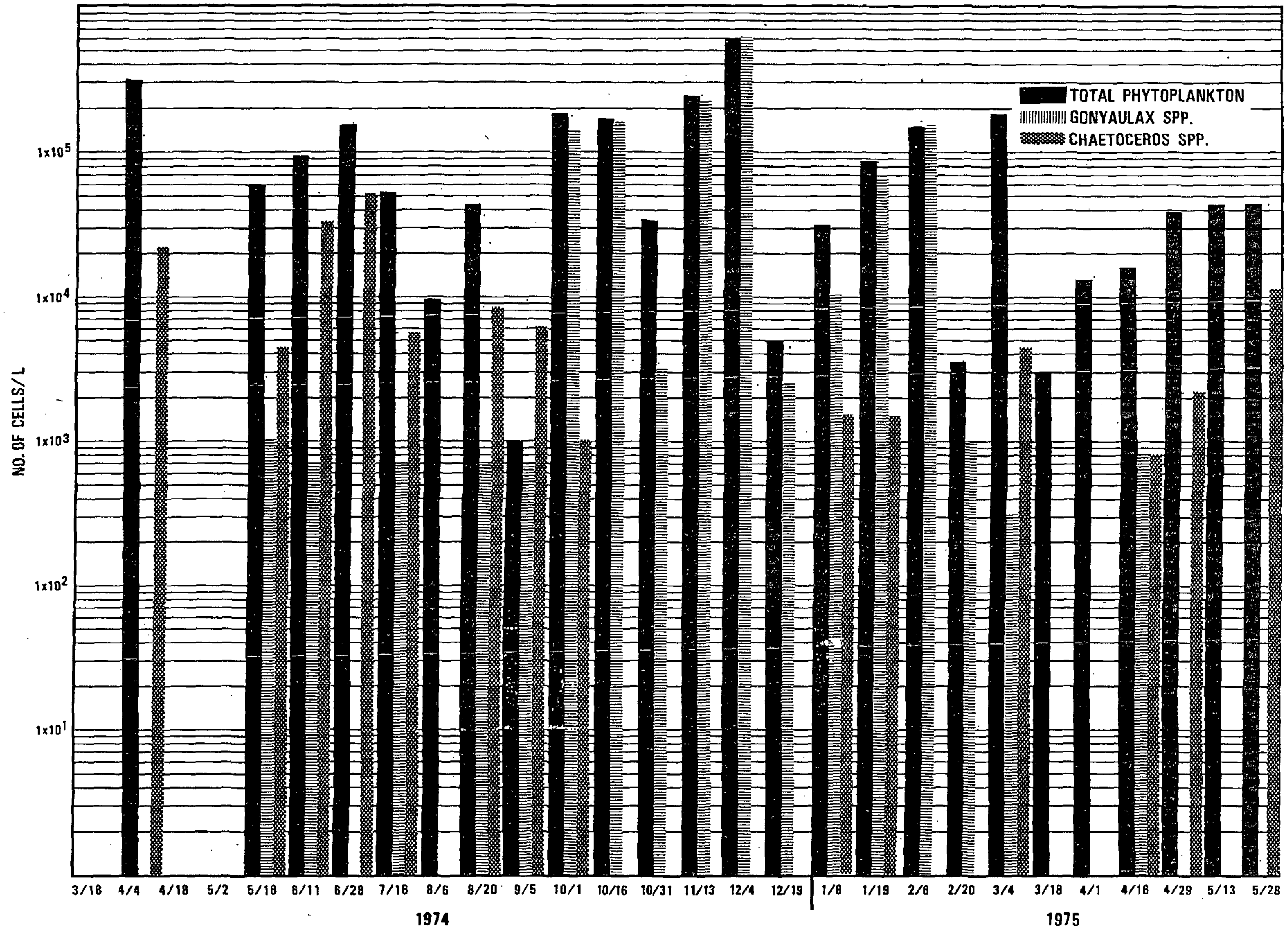

Figure 8 Seasonal distribution of total phytoplankton, Gonyaulax spp. and Chaetoceros spp. represented as means of combined Inshore and Offshore sample densities for each biweekly sampling effort. (Data for 3/18, 4/18, and 5/2 are missing.)

Phytoplankton Species Composition and Occurrence

Percent composition and occurrence of all phytoplankton taxa identified in this study are shown in Table 4. Table 5 shows those taxa comprising 83.4 percent of the total phytoplankton numbers. Dinoflagellata comprised 65.1 percent of the total biomass during the study. Of this total, Gonyaulax spp. comprised 60.6 percent. Bacillariaceae (diatoms) was the second most abundant taxonomic group, comprising 32.9 percent. Mastigophora comprised 4.2 percent, and Foraminifera, of which only one species was identified, showed insignificant numbers.

There are no phytoplankton studies for the Diablo Canyon vicinity reported in the literature.

Seasonal Phytoplankton Distribution

There were no statistically significant differences at the 95 percent confidence level between Inshore and Offshore Station densities of total phytoplankton and individual phytoplankton species; ATP values of organisms $\leq$ 150 μm in size showed no significant differences between the Inshore and Offshore Stations (Table 6).

The seasonal distribution of total phytoplankton densities is shown in Figure 8. The densities remained relatively high from October 16, 1974 through February 6, 1975, exhibiting wide fluctuations (4,500 - 594,500 cells l^{-1}). The peak density, 594,500 cells l^{-1}, occurred December 4, 1974. This peak abundance period was inversely correlated with maximum upwelling and maximum peak zooplankton abundance periods (Figures 2 and 4). Not enough samples were taken to verify the period of peak phytoplankton densities in 1975. The mean total phytoplankton concentration for the study period was 90,820 cells l^{-1}, S.D. 128,313 cells l^{-1}.

Table 4. Taxonomic category, percent composition and percent occurrence of phytoplankton species collected April 4, 1976 to May 28, 1976 at Diablo Canyon.

Taxonomic Category	Percent Composition	Percent Occurrence
BACILLARIACEAE		
Rhizosolenia spp.	3.3	19.7
Rhizosolenia alata	0.1	2.8
Rhizosolenia styliformis	0.0*	0.7
Coscinodiscus spp.	1.9	25.4
Coscinodiscus marginatus	0.5	11.3
Chaetoceros spp.	6.4	40.1
Biddulphia spp.	0.2	3.5
Skeletonema costatum	0.9	9.9
Thalassiosira spp.	2.8	21.8
Eucampia spp.	0.0	0.7
Eucampia zoodiacus	1.2	12.0
Eucampia cornuta	0.0	0.7
Lauderia spp.	0.1	0.7
Melosira spp.	0.1	4.2
Ditylum brightwellii	0.2	4.2
Stephanodiscus spp.	0.1	2.8
Nitzschia spp.	6.0	36.6
Nitzschia closterium	0.1	4.9
Nitzschia seriata	0.1	2.8
Nitzschia longissima	0.1	5.6
Navicula spp.	4.3	51.4
Pleurosigma spp.	0.3	4.9
Licmorpha spp.	0.5	3.5
Synedra spp.	0.3	1.4
Striatella spp.	0.6	2.8
Fragillaria spp.	1.3	14.8
Asterionella japonica	1.0	9.9
Thalassiothrix spp.	0.5	12.0

Table 4 - contd.

Taxonomic Category	Percent Composition	Percent Occurrence
MASTIGOPHORA		
Distephanus spp.	0.2	5.6
Dichtyocha spp.	0.1	5.6
Phacus spp.	0.4	12.0
Trachelomonas spp.	0.0	0.7
Euglena spp.	1.1	16.9
DINOFLAGELLATA		
Prorocentrum spp.	1.2	19.0
Haplodinium spp.	0.0	0.7
Noctiluca scintillans	0.0	1.4
Dinophysis spp.	0.0	0.7
Gonyaulax spp.	60.6	44.4
Ceratium spp.	0.1	2.8
Ceratium hirundinella	2.1	21.8
Ceratium tricips	0.0	0.7
Peridinium spp.	0.9	23.9
Polykrikos spp.	0.1	2.8
Gymnodinium spp.	0.1	2.8
Pyrocystis spp.	0.0	0.7
FORAMINIFERA		
Globigerina bulloides	0.0	0.7

* Zero values indicate percent composition to be <0.1 percent.

Table 5. Percent composition and percent occurrence of taxa comprising 83.4% of the phytoplankton densities from samples collected April 4, 1976 to May 28, 1975, at Diablo Canyon.

Taxon	Percent Composition	Percent Occurrence
Gonyaulax spp.	60.6	44.4
Chaetoceros spp.	6.4	40.1
Nitzschia spp.	6.0	36.6
Navicula spp.	4.3	51.4
Rhizosolenia spp.	3.3	19.7
Thalassiosira spp.	2.8	21.8

Table 6. Statistical comparisons of inshore and offshore concentrations of taxa comprising 75.0% of the phytoplankton densities from samples collected March 18, 1974 to May 28, 1975 at Diablo Canyon.

Taxon	d.f.	t-Value*	Calculated Two-Tailed Probability	Probability (α) 0.05	0.01
Gonyaulax spp.	46	-0.61	0.543	NS	
Chaetoceros spp.	48	-0.72	0.474	NS	
Nitzschia spp.	46	0.49	0.623	NS	
Navicula spp.	46	0.41	0.682	NS	
Rhizosolenia spp.	42	-0.04	0.965	NS	
Thalassiosira spp.	42	-0.79	0.432	NS	
Total Phytoplankton	46	-0.04	0.965	NS	
ATP Values	51	-0.38	0.704	NS	

*Positive t-values indicate that greater densities occurred yearlong at the Inshore Station; negative t-values indicate the opposite.

Gonyaulax spp. were present throughout the study period (Table 5, Figure 8), and represented 60.6 percent of the total phytoplankton density. Their period of greatest abundance, expectedly, coincided with that of total phytoplankton cell numbers, November 11, 1974 to December 12, 1974, with an additional peak January 8, 1975 to February 6, 1975. As a general distributional trend, they were most abundant during the Oceanic and Davidson Current seasons and least abundant during the Upwelling.

Chaetoceros spp. were present intermittently throughout the study period, absent only during late October through December 1974 and, generally, scarce in the early spring of 1974 and 1975 (Table 5, Figure 8). They comprised 6.4 percent of the total density.

Nitzschia spp. were present throughout the study period (Table 5, Figure 8) and represented 6.0 percent of the total phytoplankton density. Their greatest density occurred in June 1974.

Navicula spp. were present throughout the study period (Table 5, Figure 9) and represented 4.3 percent of the total phytoplankton density. Their densities peaked sporadically throughout the year, July 1974, January, April, and May 1975.

Rhizosolenia spp. comprised 3.3 percent of the total phytoplankton density and were present throughout the study period, but in only 19.7 percent of the total samples (Table 5, Figure 10).

Thalassiothrix spp., the sixth most abundant phytoplankton genus, comprised only 2.8 percent of the total phytoplankton density (Table 5). They were sporadically distributed throughout the study period (Figure 10) and reached their greatest densities in May and June 1974.

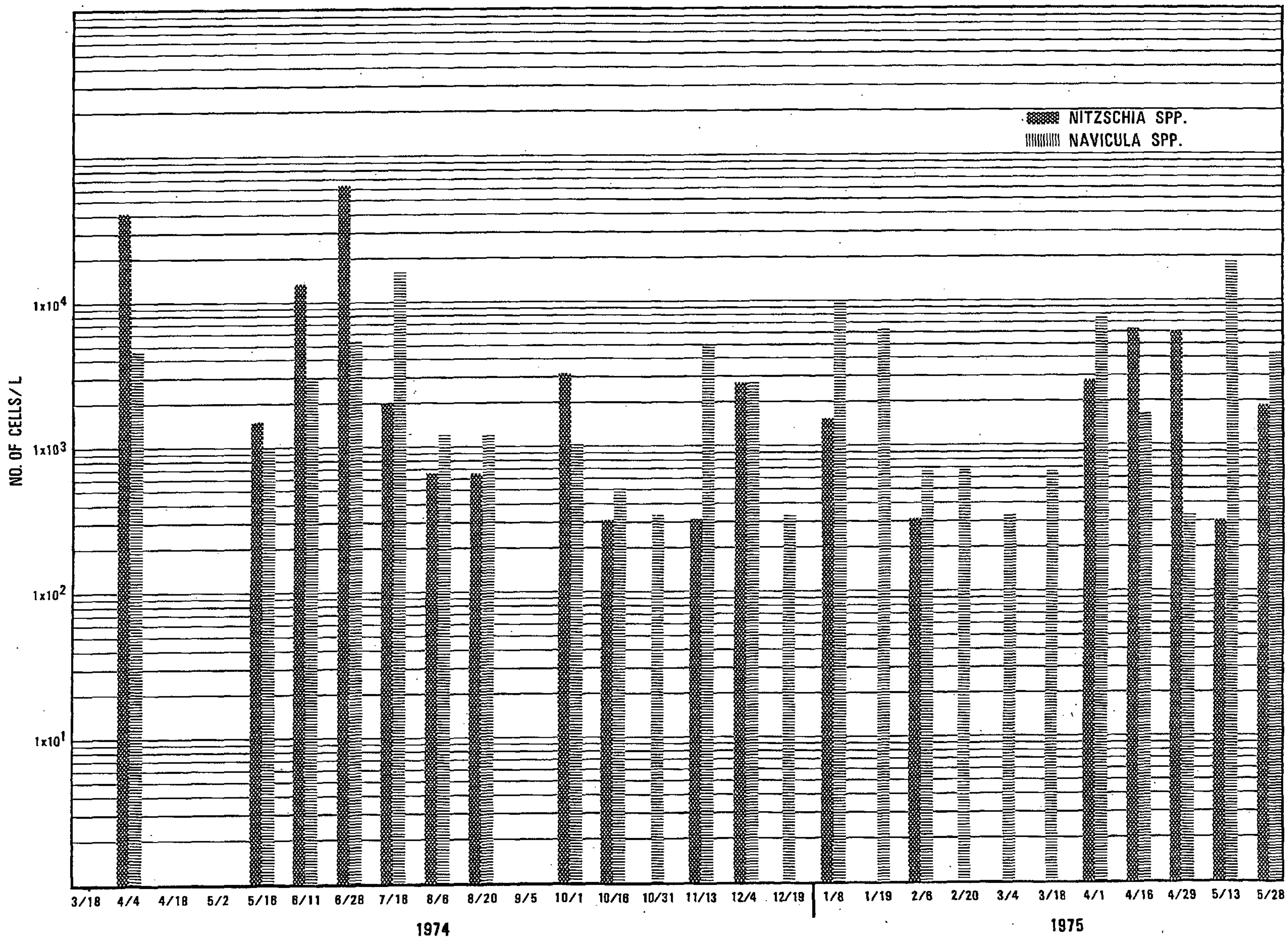

Figure 9 Seasonal distribution of Nitzschia spp. and Navicula spp. represented as means of combined Inshore and Offshore sample densities for each biweekly sampling effort. (Data for 3/18, 4/18 and 5/2 are missing.

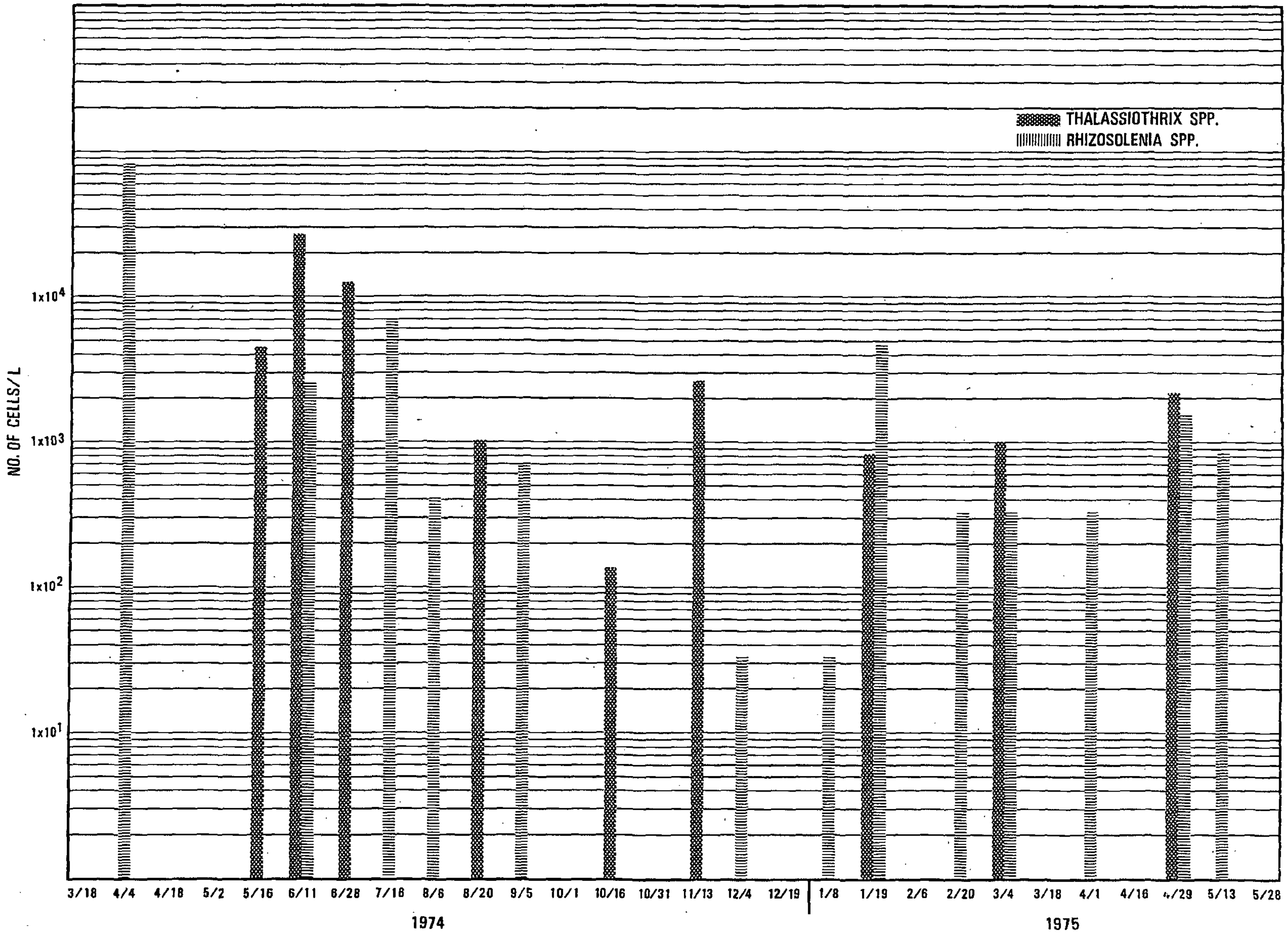

Figure 10 Seasonal distribution of Thalassiothrix spp. and Rhizosolenia spp. represented as means of combined Inshore and Offshore sample densities for each biweekly sampling period. (Data for 3/18, 4/18 and 5/2 are missing.)

Seasonal Distribution of ATP Biomass

The seasonal distribution of ATP (adenosine triphosphate) concentrations is depicted in Figure 7. The results show large fluctuations between biweekly samples. Generally, there were two major peak periods of ATP (live biomass) indentified: (1) April 18, 1974 to July 16, 1974 with ATP concentrations ranging from 0.139 to 0.532 $\mu g\ l^{-1}$; and (2) September 5, 1974 to February 6, 1975 with ATP concentrations ranging from 0.119 to 1.89 $\mu g\ l^{-1}$.

The mean ATP live biomass concentration for the study period was 0.359 $\mu g\ l^{-1}$, S.D. 0.416 $\mu g\ l^{-1}$.

The initial peak period of ATP concentrations (April 18, 1974 to July 16, 1974) correlated with the first upwelling period (April 1974 to August 1974) (Figure 2), the period of peak zooplankton densities (June 1974 to July 1974) (Figure 4), and the first of two peak periods of dry weights and ash-free dry weights (May 1974 to July 1974) (Figure 7). Thus, the initial ATP peak probably represents zooplankton sizes less than 150 μm.

The second peak period of ATP (September 1974 to February 1975) (Figure 7) is directly correlated with the period of peak phytoplankton densities (October 1974 to Feburary 1975) (Figure 8) and inversely correlated with dry weight and ash-free dry weight peak periods (March 1974 to July 1974 and January 1975 to April 1975) (Figure 7). Thus, the second peak period of ATP biomass probably represents the increased phytoplankton density present from October 1974 to February 1975 (Figure 8).

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