Diablo Canyon Power Plant

Thermal Effects Monitoring Program Analysis Report

Chapter 1 - Changes in the Marine Environment Resulting from the Diablo Canyon Power Plant Discharge

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Glossary of Terms and Abbreviations

°C	degrees Centigrade (or Celsius)
°F	degrees Fahrenheit
ac	acres
AFAS	Algal-Faunal Association Study
ambient	natural or unaltered (generally referring to seawater not warmed by the power plant)
ANOVA	Analysis of Variance statistical test
BACI	Before-After-Control-Impact statistical analysis
CA	Correspondence Analysis
community	an assemblage of plants and animals living together within an area, linked by interactions
DCPP	Diablo Canyon Power Plant
delta (statistical)	difference in abundance between control and impact; used in BACI analysis
delta T°	difference in temperature (generally between natural seawater and discharge)
FC	Field's Cove
ft	feet
gpm	gallons per minute
ha	hectares (1 hectare = 2.471 acres)
HBT	Horizontal Band Transect
IR	infrared radiation; pertaining primarily to overflight images of sea surface temperature
isobath	line of equal depth
isotherm	line of equal temperature
linear distance	(re: shoreline) - straight-line measurement of shoreline length; does not include coves, inlets, etc.
m	meters
MLLW	mean lower low water; the elevation defined as 0.0 m (ft)
NC	North Control
NDC	North Diablo Cove
NPDES	National Pollutant Discharge Elimination System
p	probability level
PG&E	Pacific Gas and Electric Company
RPC	Random Point Contact method for sampling subtidal algae
SAQ	Subtidal Arc Quadrant method for sampling subtidal invertebrates
SC	South Control
SDC	South Diablo Cove
SDP	South Diablo Point
SFQ	Subtidal Fixed Quadrat method for sampling subtidal invertebrates
shoreline distance	length of shoreline measured by following the mean high water mark; includes coves, inlets, etc.
TEMP	Thermal Effects Monitoring Program
VBT	Vertical Band Transect
WS	withering syndrome disease in abalone

SUMMARY

Purpose

The Thermal Effects Monitoring Program (TEMP) studies were done to fulfill the Central Coast Regional Water Quality Control Board's (Regional Board) monitoring and reporting requirements for the Diablo Canyon Power Plant (DCPP) National Pollutant Discharge Elimination System Permit (NPDES) No. 90-09. The purpose of the TEMP studies was to determine changes in the biological communities resulting from the DCPP cooling water discharge. The greatest effects were expected to be associated with the discharge of heated water from the plant's cooling water system. Changes in the permit in 1995 required PG&E to submit to the Regional Board a comprehensive final assessment of the TEMP studies on the effects of the DCPP discharge on the receiving water communities.

The *Diablo Canyon Power Plant Thermal Effects Monitoring Program Analysis Report, Chapter 1 -- Changes in the Marine Environment Resulting from the Diablo Canyon Power Plant Discharge* (Analysis Report) consists of analyses and descriptions of over 20 years of monitoring data on the DCPP nearshore marine environment. A companion report, *Diablo Canyon Power Plant Thermal Effects Monitoring Program Analysis Report, Chapter 2 -- Assessment of Thermal Effects* (Assessment Report) presents PG&E's assessment of whether the current NPDES discharge temperature limit protects the beneficial uses of the receiving waters, the regulatory standard established by the Regional Board's Basin Plan, and the California Ocean Plan and Thermal Plan for existing discharges.

Organization of Report

The Analysis Report has been designed for readers with a wide range of scientific knowledge and experience. This summary provides background information and presents results without the details of analytical techniques or statistical analyses. The main body of the Analysis Report includes descriptions of techniques and analyses, and presents the details of our findings. The appendices include data and supporting information necessary to allow scientific professionals to critically review our results.

Power Plant Study Location and Description

DCPP is a nuclear-powered steam-turbine power plant with a rated output of 2,200 megawatts of electricity, enough to supply the electrical needs of approximately 2.2 million people. It is owned and operated by Pacific Gas and Electric Company (PG&E). Commercial operation of Unit 1 began in May 1985, and Unit 2 in March 1986. DCPP is located on a coastal terrace midway between the communities of Morro Bay and Avila Beach, on the central California coast (Figure S-1). The local coast is a steep and rugged rocky shoreline that is exposed to heavy wave activity. The study area supports a rich community of marine life that is a biogeographical extension of similar marine communities that extend many hundreds of miles to the north. Except for the DCPP, the coast is largely uninhabited and undeveloped along the 16 km (10 mi) between the cities of Morro Bay and Avila Beach.

The power plant draws in seawater from a constructed intake cove to provide cooling for power plant operations. After passing through the plant's cooling-water system, approximately 2.5 billion gallons per day of heated water is discharged back into Diablo Cove. The discharge is approximately 11°C (20°F)

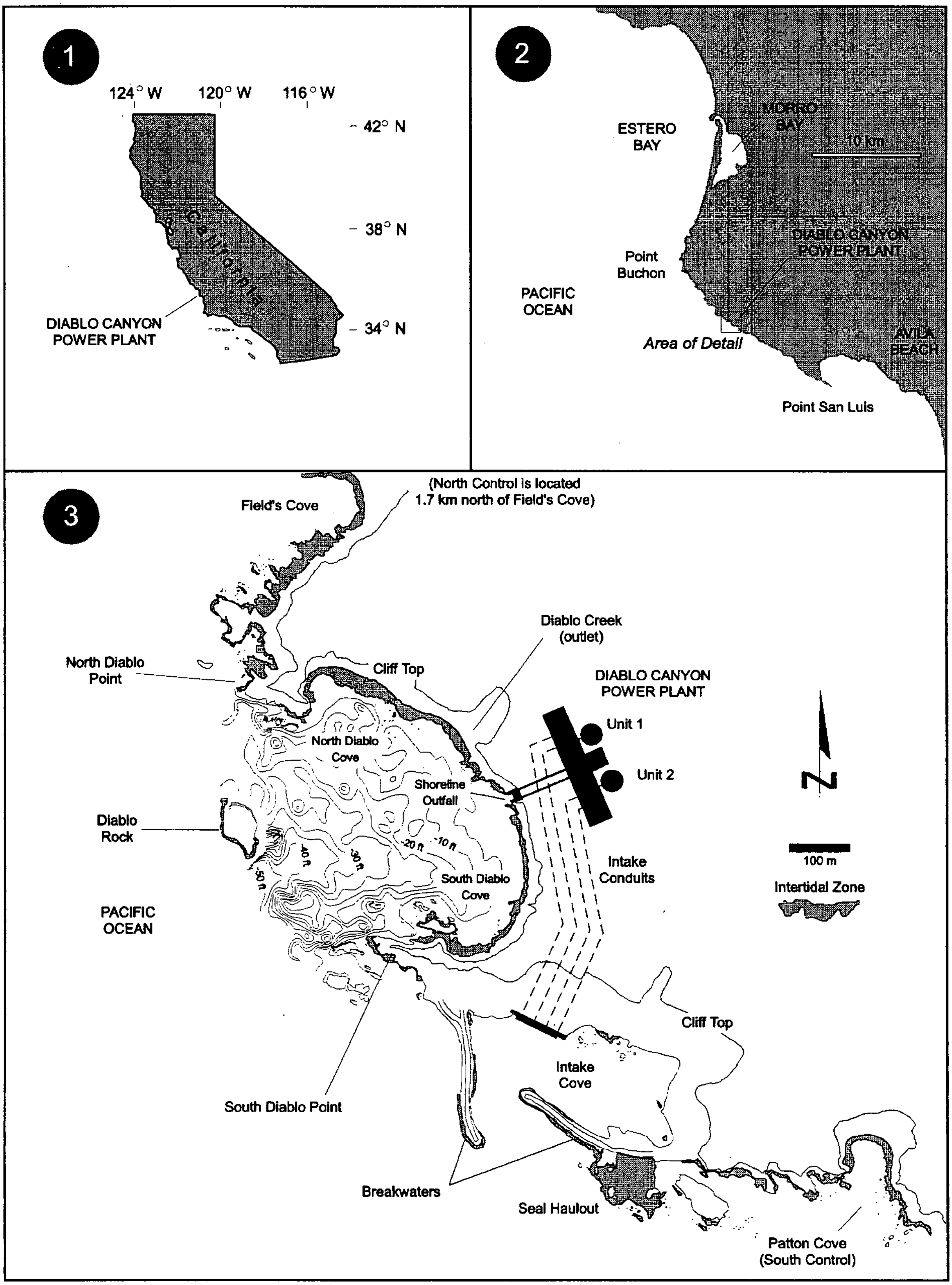


Figure S-1. Location of Diablo Canyon Power Plant.

warmer than ambient ocean waters under normal operating conditions. Even after significant mixing with the ambient receiving water, the discharge produces localized temperatures that are higher than those normally encountered by marine life in the area. Other constituents of the discharge, and potential toxicity of these constituents, are regularly monitored by PG&E for compliance with limits established in the NPDES permit. These constituents of the discharge were not measured in this study, but are included for reference in Appendix I.

Analysis Approach

Definition of 'impact'

Throughout this report we will be discussing impacts, effects and changes attributed to the discharge, and will be using these terms interchangeably. It is important to understand that an impact is any change in the numbers, size, behavior, distribution, or many other aspects of an organism's biology if, based on the study design, the change can be attributed to the effects of the discharge. The determination that an impact has occurred will usually be based on finding a statistically significant difference in the abundance of an organism between areas contacted and not contacted by the discharge, although it can also be based on corroborative results from several studies.

We use the term 'significant' to refer to statistical significance. Statistical significance does not necessarily imply that an effect is ecologically important. For example, we were able to detect changes in abundance in a number of species due to the length of the study and large number of surveys. The magnitude of an effect is also important, and this is considered in the report by comparing the statistical results with the percent change and plots of species abundance through time. The ecological importance of these changes is evaluated in Chapter 2.

The use of these terms in this report differs from their use in the Assessment Report (Chapter 2), where the term *impact* is used in a stricter sense. The Assessment Report evaluates whether the *effects* identified in this report *impact* 'protection of beneficial uses'.

What was studied

This report addresses the effects of the discharge on intertidal and nearshore subtidal plants, invertebrates, and fishes. Several different survey methods were used to sample a particular habitat or group of organisms. For example, algae in the intertidal zone were sampled within permanent quadrats at two tidal elevations using the horizontal band transect (HBT) method, but algae in the subtidal were sampled at permanent stations with the random point contact (RPC) method. Likewise, invertebrates and fish were each sampled with different methods in intertidal and subtidal habitats. The effects on other marine species such as birds, mammals, and plankton were investigated by separate research programs, and the relevant information regarding protection of beneficial uses for these groups is presented in the Assessment Report.

The data collected were primarily measures of the abundance (percent cover or numbers per area) of species. In reporting results we will often discuss 'taxa' as opposed to species. Taxa is a more general term and may refer either to a single species or taxon, or to several taxa grouped together because they are closely related and difficult to distinguish. Taxa may also be grouped together for some analyses because they form a logical group based on sampling methods, such as 'midwater fish', or a functional group, such as 'filter feeders'.

Study sites

Study sites were located in areas contacted by the discharge and in control areas not contacted by the discharge. Areas directly contacted by the discharge were determined by examining patterns of water temperature from studies of the thermal plume and data from field temperature recorders. Over the course of our study, the main temperature changes were within Diablo Cove, Field's Cove, and South Diablo Point. Study sites located in these areas were designated as 'impact' sites for purposes of statistical analysis. To compare effects within these areas to natural conditions outside the impact area, control sites were located further away both north and south along the coast (Figure S-2).

Monitoring and experimental studies

This was a monitoring study designed to detect changes within the study area. It was not an experimental study. Experimental studies are often directed toward explaining processes and are less effective at monitoring a wide range of potential changes. Our conclusions were usually limited to determining that a change did or did not occur, and whether or not it was attributed to the discharge. We were generally unable to provide a detailed explanation of the processes responsible for the change.

Changes in abundances of taxa

Graphs showing changes in abundance over time for the most common taxa sampled during the study (those taxa comprising a cumulative abundance of 99% of the individuals sampled by a particular method) are presented in Appendix E. When abundance estimates for a taxon over time are graphed, the results may illustrate the effects of major environmental events during the study. These environmental events include habitat disruption by storms, El Niño warming, and sea otter predation, in addition to the effects of the DCPP discharge. The graphs illustrate changes over the periods of plant start-up and operation. Statistical analyses were used to determine whether the apparent changes between times or sites as seen in the graphs represent statistically significant changes in the biota caused by the discharge. We used other statistical techniques to combine the many changes recorded for various taxa into integrated estimations of change at the community level.

BACI analysis for individual taxa

The main analytical tool we used to analyze the data is a form of ANOVA (analysis of variance) called a BACI (Before-After-Control-Impact) analysis. The BACI compares impact sites near the discharge with control sites distant from and unaffected by the discharge. In a hypothetical BACI analysis, data are collected from impact and control sites several times before and after power plant start-up (Figure S-3). Differences between the two areas are taken for each survey and a mean difference computed for each period. If impact sites that 'resembled' control sites before the plant began operating began to show changes *relative to* control sites after plant start-up, then those changes should be reflected in a change in the mean difference between periods and could be attributed to the discharge. If control and impact areas change in similar amounts following power plant start-up, the mean differences for each period will be similar and the changes are assumed to be natural. We used BACI analyses to examine the data on abundance of individual species to give an objective measure of whether an observed change in a species' abundance was great enough to be significant. Because of stringent mathematical requirements of the BACI analysis, only our most complete data sets, and those that did not show strong trends of increasing

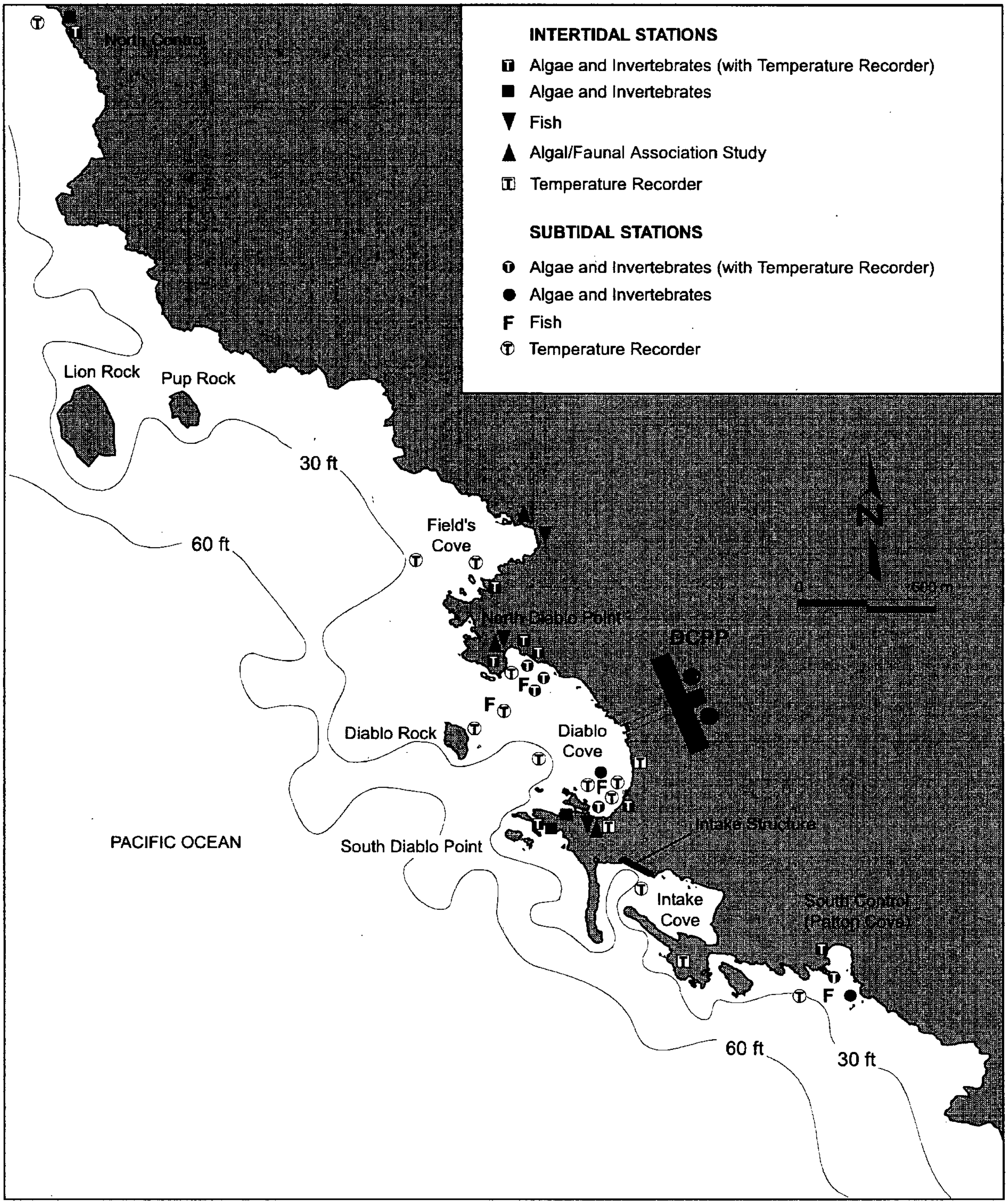


Figure S-2. Locations of biological monitoring stations analyzed statistically, and locations of temperature recorder stations. Bathymetric contours from U.S.G.S. Port San Luis Quadrangle-San Luis Obispo, 7.5 minute series (topographic) scale 1:24,000.

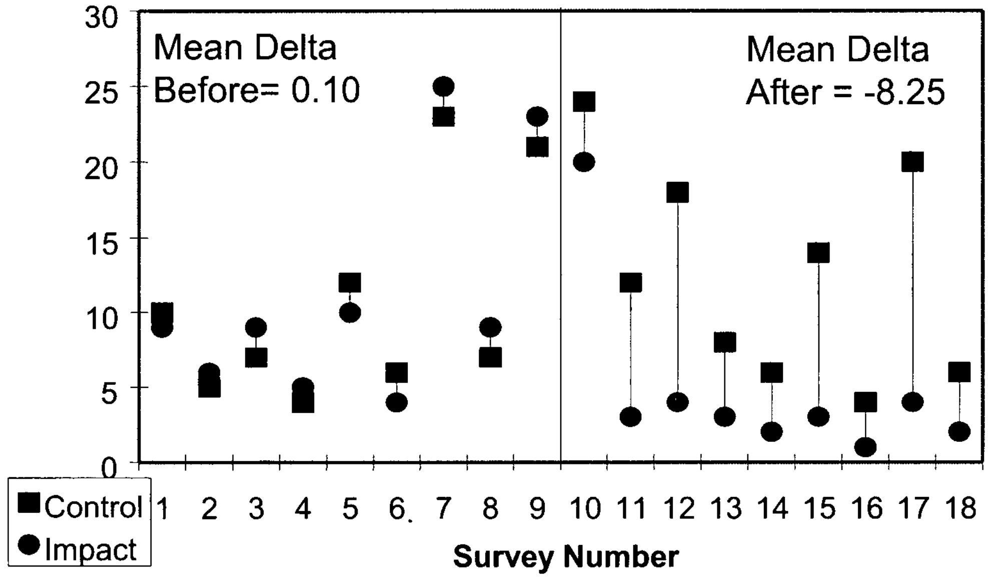


Figure S-3. Hypothetical abundance data over time for a single species at a control and impact site. The mean difference (delta) is computed from the differences for each survey by subtracting the impact abundance from the control abundance. The BACI analysis tests for a significant difference between the mean delta in the 'before' period and the mean delta in the 'after' period. In this example, if the difference between the deltas was significant, it would be due to a decrease in the mean abundance at the impact site in the 'after' period, and be interpreted as an effect of the discharge.

or decreasing relative abundances before the discharge began, could be analyzed with this method. Such trends, if continuing into the operation period, could be incorrectly interpreted as having been caused by the power plant. These requirements resulted in especially powerful statistical tests. Many of the data that did not pass the requirements for the BACI analysis were analyzed using the Fisher's exact test, a statistical method that does not have the same rigorous assumptions of the BACI analysis.

Fisher's exact test

The Fisher's exact test was used in two ways. It was used to analyze the abundance of a particular species or taxon. The changes that occurred in the abundance of the species within the impact area for surveys done after power plant start-up were compared to changes in the overall variability of the species at both impact and control sites and from pre-operation and operation surveys. If the species abundance within the impact area changed more than would be expected, given the overall level of variability for that species following plant start-up, then that change was considered statistically significant and caused by the discharge.

The Fisher's exact test was applied to many species simultaneously, to take a broader look at the overall response of the biological community. The test compares the numbers of species that changed in abundance within the impact areas with the numbers of species that changed in the control areas, and tests whether these numbers are higher or lower than would be expected by chance. An area in which the density of many species changed following the beginning of plant operation is presumed to have been more strongly affected than an area that changed less.

Correspondence analysis of changes through time

Correspondence analysis is a statistical method that describes changes in a biological community over time and among areas. It provides an estimate of similarity, based on species composition and abundance, between communities in different areas, or at different times. In this study, correspondence analysis allowed us to compare sites to each other and to themselves over a sequence of several time periods, often revealing how the biological community gradually changed over time. It is the only analysis, other than graphical procedures, that analyzed species survey abundances over multiple time periods: the other statistical analyses simply compared the period before plant operation to the period of operation through June 1995.

Distance calculations

Shoreline distances were calculated to describe the lengths of coastline affected by the thermal discharge. The basic coastal features from Point Buchon to Point San Luis were digitized from two USGS 7.5 minute series topographic maps (Port San Luis and Morro Bay South quadrangles) at a listed scale of 1:24,000. However, a more detailed resolution map for the coastal segment that included the Intake Cove, Diablo Cove, Field's Cove, and Patton Cove was digitized from engineering survey maps at a scale of approximately 1:9,000. Distances in this report that are referred to as 'shoreline distances' include the contours of the numerous indentations and emergent offshore rocks along the waterline at mean high water and were measured from digitized maps using the ARC/INFO geographic information system (GIS) software. The calculated distances reflect the detail, or resolution, portrayed on the digitized maps (i.e., a highly detailed map yields a longer shoreline distance for a given coastal segment than a less detailed map). For example, the shoreline distance of Diablo Cove was calculated as 0.8 km using the 1:24,000 scale map, and 1.1 km using the 1:9,000 scale map. Calculated distances using these different scales cannot be compared directly. In almost all cases shoreline distances were calculated from the 1:9,000 scale digitized map. The less-detailed 1:24,000 scale map was used to calculate distances over larger coastal segments where the 1:9,000 scale information was not available, and use of the 1:24,000 scale is indicated in the text where appropriate. Simple 'straight-line' distances from larger scale maps are also presented in this report for describing the distance between two geographic points, such as the distance between DCPP and Point Conception.

Findings

Overview of Discharge Plume Patterns

When the warm water discharge leaves DCPP, it flows down a steeply sloping concrete structure and enters the water at the edge of the shore of Diablo Cove. As the discharge reaches the ocean, its temperature is approximately 11°C (20°F) higher than the ambient ocean temperature under normal operating conditions. The ambient temperature of the intake water varies both seasonally and yearly. Since the power plant generally raises the temperature of the cooling water by a consistent 11°C, the temperature of the outflow also varies both seasonally and yearly.

The discharge enters the cove as 'white water', much like rapids on a river. The turbulence produces foam, that can be thick when phytoplankton abundance is especially high in the ocean. The foam has become a persistent feature of the cove, occasionally blanketing the intertidal in the immediate area and areas adjacent to the discharge in the cove.

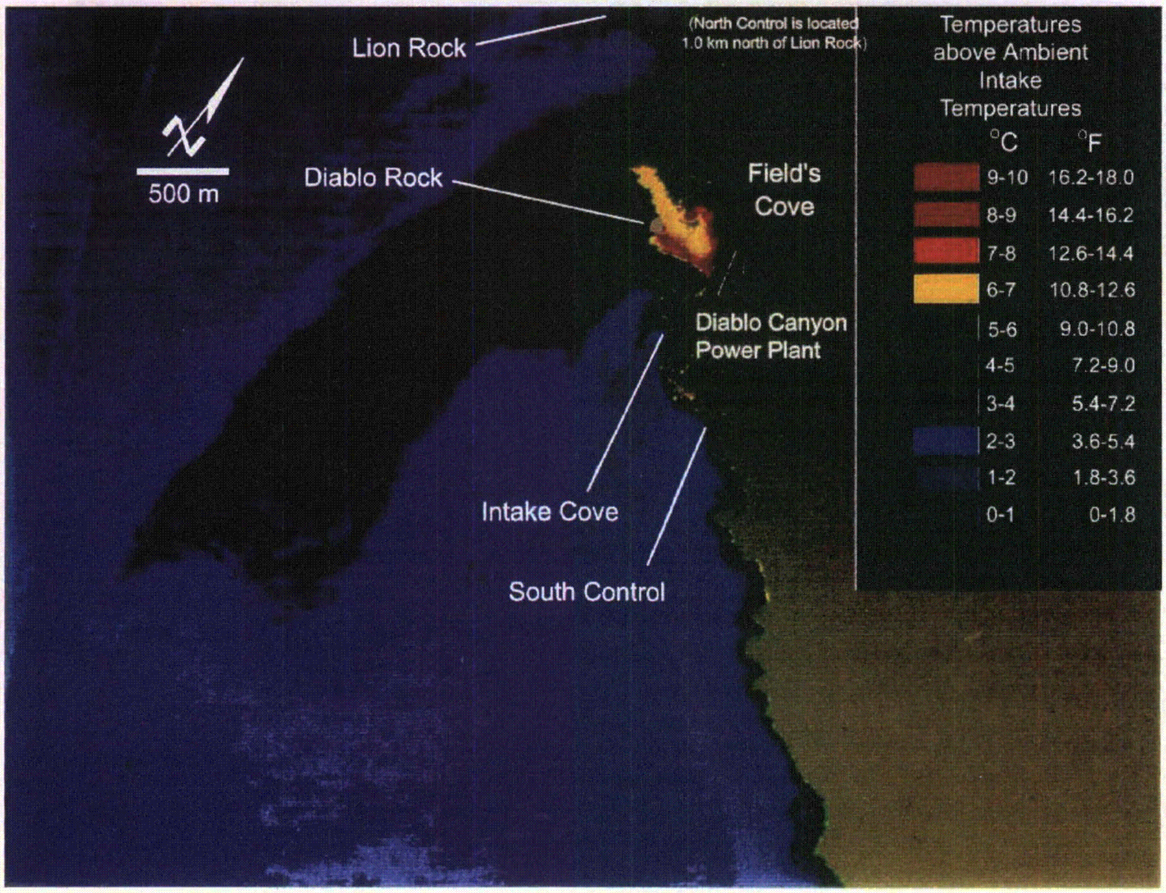
Warm water is less dense than cold water, and the discharge forms a floating plume of warm water that spreads across the surface of Diablo Cove and moves offshore. The fact that the plume tends to float has two effects. The intertidal areas of Diablo Cove and nearby areas are impacted more strongly by the discharge than deeper areas, and the plume travels offshore as a coherent flow, not mixing completely with colder ocean waters while within Diablo Cove. The direction of the plume as it exits Diablo Cove varies with tidal height and wind direction. Ridges in the bottom topography of the cove in front of the discharge structure direct the plume towards Diablo Rock during low tide. The plume bifurcates around Diablo Rock causing some of the warm water to be directed out the north channel of the cove. The volume of flow through the north channel is also influenced by the prevailing northwesterly winds and waves. During high tide the plume passes over the ridges and mainly exits through the south channel. The deeper portions of Diablo Cove (below approximately -8 m (26 ft) MLLW) are typically below the main influence of the plume, and show little or no increase in temperatures.

Data from two aerial infrared surveys of the surface plume were collected while the plant was operating at 100 percent power for Unit 1 and 70 percent power for Unit 2 (Figures S-4 and S-5). The first aerial survey (Figure S-4) was done on June 11, 1986 under mid-tide conditions and shows that, although warm water at the surface is diverted out the north channel, the central plume jet (warmest temperatures) exits the south channel of the cove. The other survey (Figure S-5) was done on June 12, 1986 under low tide conditions and shows the central plume jet shifted towards Diablo Rock. This test was also done in the morning under low wind conditions which allowed the plume to spread out past Field's Cove towards Lion Rock to the north. The June 11 survey was done in the late afternoon during a period with strong northwesterly winds that divert the plume to the south. The plume configuration varies with seasonal and power plant operational conditions. Both of these photos were taken in summer during low swell conditions. During winter, large waves and rougher sea states can create greater mixing with ambient water, resulting in plume configurations likely to be smaller than those present during typical summer conditions. Ambient sea surface temperatures (Figures S-4 and S-5) were always 1-2°C warmer than ambient intake temperatures because intake flows were drawn from a cross-section of cooler sub-surface waters up to -32 ft (10 m) MLLW within the Intake Cove.

Unlike the surface infrared data, Figures S-6 and S-7 are composites of 40 different plume surveys and show the percent of time that surface water temperatures for those 40 plumes were 2.2°C (4°F) and 1.1°C (2°F) warmer than background temperatures under a range of environmental and plant operational conditions. An overlay of all 40 plumes would show that a single plume never assumed the larger configuration shown in Figures S-6 and S-7, and that the boundaries of the greatest extent of the composite representation were single occurrences within the group of 40 plume measurements. The 1.1°C temperature increases occur over a much broader area and during a greater percentage of time than the slightly warmer 2.2°C temperatures. On rare occasions (1-20% of the surveys) the 2.2°C isotherm was present in the area offshore from the south control stations. Although the plume is occasionally present in the area offshore of the north control stations, Lion Rock appears to block the plume's northward movement under most conditions. Shallow nearshore areas were not sampled during these surveys.

Biological Responses to the Discharge

More than 800 taxa were identified during the TEMP studies (Appendix D). Of these, most were observed infrequently and any discharge effects on them could not be statistically analyzed. The most abundant taxa were analyzed using either the BACI or Fisher's exact test to determine if significant changes occurred in their abundance in response to the discharge. The response typically involved decreases in the abundance or disappearance of a species within the impact sites, but also included increases in abundance of many other species at the same impact sites. These findings and other analyses



Test TV-7
Date: June 11, 1986
Time: 18:20 PDT

Unit	Discharge Temp° C	Cooling Water Flow (cfs)	Reactor Power (%)
1	21.4	2000	100
2	19.5	2000	70

Intake Temp: 10.9° C
Tide: 2.8 ft (MLLW)
Wind: 17.5 mph from 313° (true)
Offshore Currents: 19.4 ft/min. from 135°
Sig. Wave Ht.: 92 cm @ 11 sec from 270°
Air Temperature: 15.5° C

Figure S-4. Surface thermal plume isotherms (°C) above ambient intake temperatures measured on June 11, 1986. Ambient intake temperatures (of water drawn from -10 m [-32 ft] MLLW) were 1-2°C cooler than ambient surface temperatures. Therefore, the ambient intake temperature color (0-1°C) does not appear in the plume figure.

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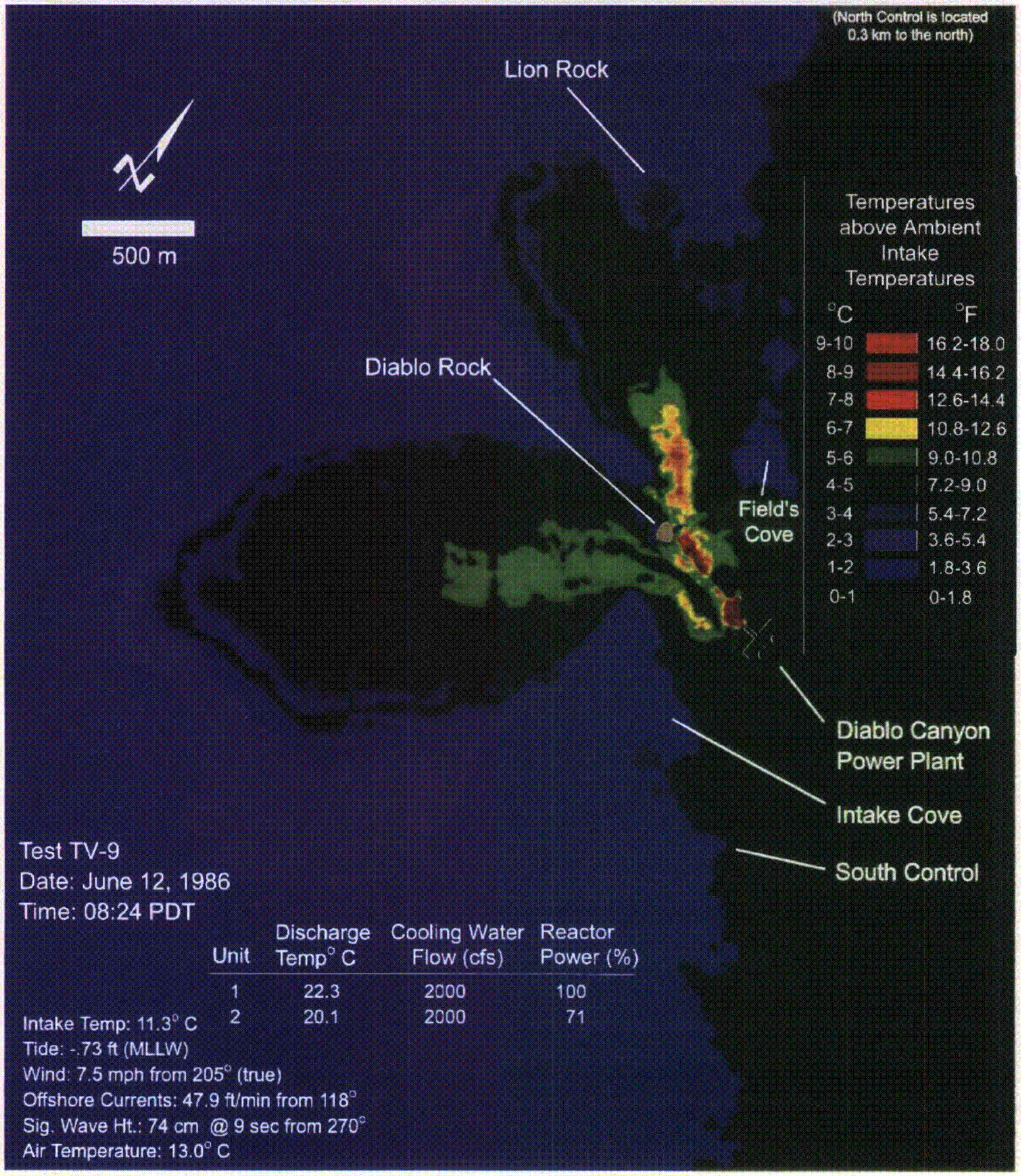

Figure S-5. Surface thermal plume isotherms (°C) above ambient intake temperatures measured on June 12, 1986. Ambient intake temperatures (of water drawn from -10 m [-32 ft] MLLW) were 1-2°C cooler than ambient surface temperatures. Therefore, the ambient intake temperature color (0-1°C) does not appear in the plume figure.

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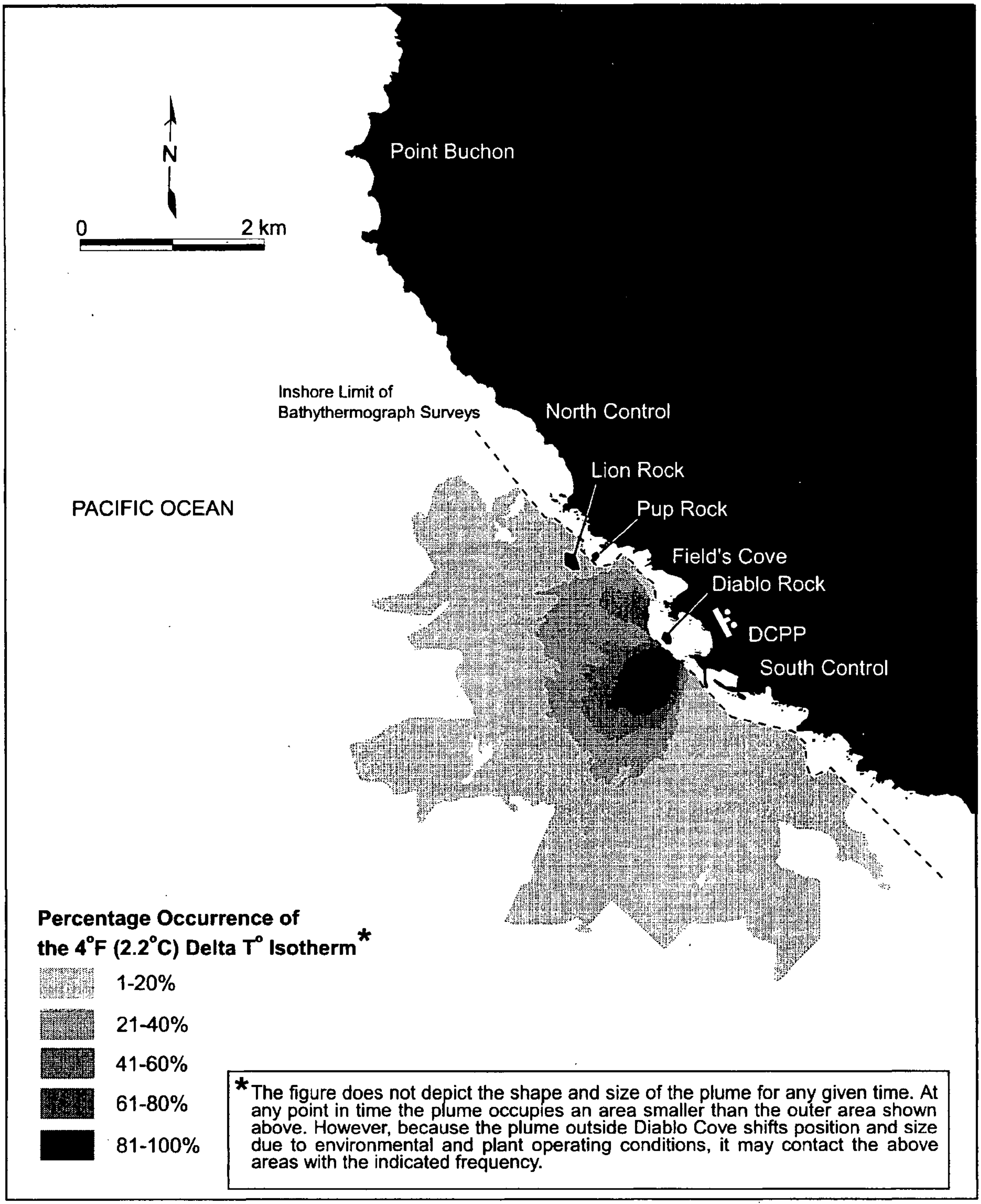


Figure S-6. Composite offshore surface thermal plume map of the DCPP discharge 4°F (2.2°C) delta T° isotherm. Percentage occurrence was calculated from 40 thermal plume maps. Maps were developed from data using a towed bathythermograph. Surveys were conducted from December 1985 to April 1990. Shoreline contact of isotherms not shown, due to the survey areas not including the coastline.

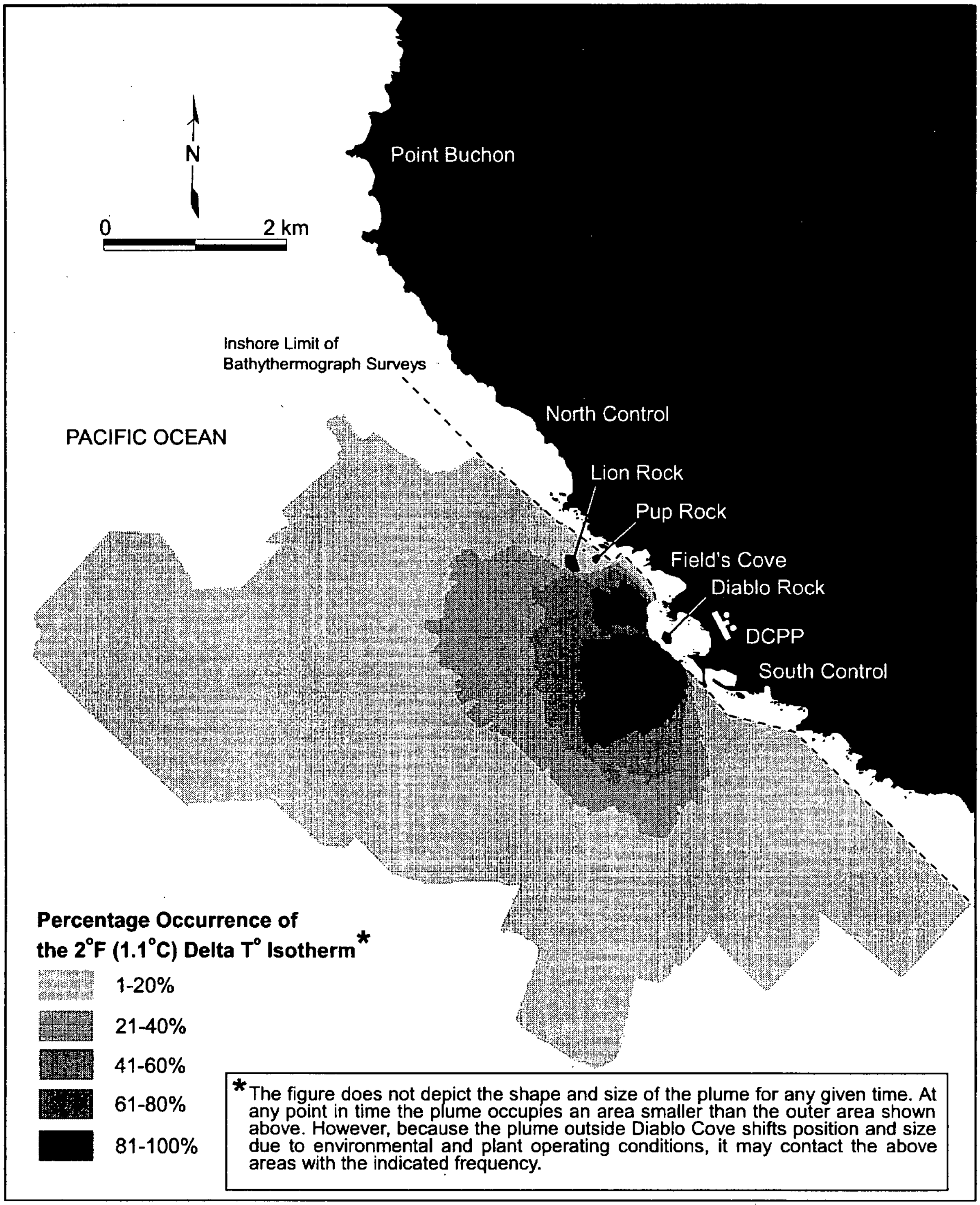


Figure S-7. Composite offshore surface thermal plume map of the DCPP discharge 2°F (1.1°C) delta T° isotherm. Percentage occurrence was calculated from 40 thermal plume maps. Maps were developed from data using a towed bathythermograph. Surveys were conducted from December 1985 to April 1990. Shoreline contact of isotherms not shown, due to the survey areas not including the coastline.

are summarized separately for algae, fishes and invertebrates in the sections below. A summary of effects on major taxa groupings such as algae, invertebrates and fishes are presented in Table S-1. Brief descriptions of several common taxa and how they were affected are presented in Table S-2.

Algae

Intertidally, 119 algal taxa were sampled during the study. Thirty eight of the most abundant algal taxa were analyzed using either the BACI analysis or the Fisher's exact test. Significant increases in abundance at impact stations in Diablo Cove, Field's Cove or at South Diablo Point were detected for 7 of the taxa and significant decreases were detected for 26 taxa (Table S-3). Of the 5 remaining taxa, 2 showed no changes and data were insufficient to detect changes for 3 taxa.

Total algal cover decreased within Diablo Cove, relative to north and south control, by an average of 70% in the high intertidal and 44% in the low intertidal. Declines in the algae primarily occurred in perennial (long-lived) algae that had been abundant prior to plant operation, including *Mazzaella flaccida*, *M. heterocarpa*, *Endocladia muricata*, *Mastocarpus jardinii*, *Fucus gardneri*, and *Pelvetia compressa*. The declines in perennial algae lead to significant increases in bare rock, crustose algal cover, and ephemeral (short-lived) taxa. Although the intertidal algal community changed in response to the discharge, it did not become colonized with warm water tolerant species more common in southern California. Taxa that increased or remained relatively unchanged in Diablo Cove appeared to be the most tolerant to wide temperature fluctuations.

The spatial extent of documented shoreline effects on intertidal algae included all of Diablo Cove, the southern shoreline of Field's Cove and South Diablo Point; a total shoreline distance (includes Diablo Rock intertidal and wash rocks in Diablo Cove) of 3.7 km (2.3 mi) (Figure S-8). Further north and south are areas of reduced plume contact. Effects on intertidal algae in these areas are likely to be less than effects along the south shore of Field's Cove and other areas with reduced observed effects.

From the subtidal sites, 109 algal taxa were identified. Analyses of the subtidal data included 39 algal taxa and measures of algal diversity (an index of the numbers and abundances of taxa in a sample), species richness (the number of taxa in a sample), and total algal percent cover. Significant increases in abundance at impact stations in Diablo Cove were detected in 14 of the taxa and significant decreases were detected in 11 taxa (Table S-4). Of the 14 remaining subtidal algal taxa, 2 showed no changes and data were insufficient to detect changes in 12 taxa.

Changes in the subtidal algal community due to the increased water temperatures were dominated by losses of both subcanopy and surface-canopy kelps. The subcanopy kelps *Pterygophora californica* and *Laminaria setchellii* declined in all areas of Diablo Cove to depths of approximately 7 m (20 ft). *Nereocystis luetkeana* was the predominant surface-canopy kelp species in Diablo Cove prior to power plant start-up. This species is a spring-summer annual. Each year, during plant operation, as the bull kelp grew towards the surface in Diablo Cove it was exposed to the thermal plume and began to senesce before completing its reproductive cycle. Near the end of the study the canopy-forming giant kelp *Macrocystis pyrifera* increased in abundance throughout Diablo Cove.

Changes in understory algae occurred following plant start-up, with increases in temperature tolerant understory species including *Cryptopleura violacea*. A reduction in the coverage of some understory red algae was probably due to light attenuation from the increased *Macrocystis* canopy. Algal diversity, species richness, and percent cover of bare rock all increased within the impact areas during the same period.

Table S-1. Summary of discharge effects on algae, invertebrates and fish. The extent of documented coastline effects for each group was determined by quantitative sampling and analysis, qualitative observations, and the results of ocean temperature monitoring. Most effects occurred within Diablo Cove, with diminishing effects to the north and south. Refer to intertidal and subtidal results for further details on changes to individual species.

Biological Grouping	Contour length of documented shoreline effects (miles)	Area of nearshore zone of documented effects (acres)	Effects on taxa diversity	Effects on numbers of taxa	Effects on coverage (algae only)	Effects on individual taxa (Table numbers appearing in report)	Comments
INTERTIDAL							
Algae	2.3	—[1]	decrease	decrease	decrease	S-3, 3-5, 3-6	Declines in *M. flaccida* delineated extent of main effects.
Macroinvertebrates [2]	2.3	—	n/t [3]	no change	—	S-5, 3-9, 3-10	Increases in algal grazers affected D.C. intertidal areas.
Microinvertebrates [4]	2.3	—	n/t	—	—	S-6	Use of Field's Cove as comparison limited power of analysis.
Endocladia assemblage	—	—	—	decrease	—	3-13, 3-14	Habitat alga (*Endocladia*) declined significantly in D.C.
Gastroclonium assemblage	—	—	—	no change	—	3-14, 3-16	Habitat alga (*Gastroclonium*) did not change in D.C.
Black abalone	7.9	—	n/t	n/t	—	3-19	Withering syndrome disease caused widespread mortality.
Fish	2.3	—	n/t	n/t	—	S-9, 3-23, 3-24	Use of Field's Cove as comparison limited power of analysis.
SUBTIDAL							
Algae	—	19.9 160.9 [5]	increase (-4 m)	decrease (-4 m)	no change	S-4, 4-4, 4-5	Test results for diversity and numbers of species were inconclusive at the -3 m stations. Giant kelp increased, bull kelp decreased in D.C.
Invertebrates	—	40.6	n/t	no change	—	S-7, 4-9, 4-10	Shelled gastropods declined overall in Diablo Cove.
Red abalone	—	40.6	n/t	n/t	—	Figure 4-37	Absolute declines attributed to DCPP effects and sea otters.
Fish	—	>40.6	—	—	—	S-9, 4-13, 4-14	Warm water discharge attracted bat rays and leopard sharks.
Benthic (bottom) transects	—	—	decrease	no change	—	—	Number of taxa increased in north Diablo Cove, but decreased in south Diablo Cove; interpreted overall as 'no change'.
Midwater transects	—	—	no change	increase	—	—	Number of taxa were unchanged on the midwater transects.

[1] Area was not calculated due to variable widths and topography of intertidal zone.
[2] Macroinvertebrates were sampled using the horizontal band transect method.
[3] Not tested; Diversity comparisons were not applicable to invertebrate data with numerous, unrelated taxonomic groupings; diversity changes were also not calculated in the intertidal fish studies and abalone studies due to low numbers of taxa.
[4] Microinvertebrates were sampled using the algal-faunal association study method.
[5] Includes surface canopy cover of bull kelp (*Nereocystis*).

Table S-2. Examples of common taxa affected by the DCPP discharge. These are not necessarily the taxa with the largest changes, and many other taxa increased, decreased, or were unchanged. See Tables S-3 and S-4 (algae); S-5, S-6 and S-7 (invertebrates); and S-8 (fish) for results of additional taxa.

Invertebrates

Increases

Common name	*Scientific name*	Ecological Description
Aggregating Anemone	*Anthopleura elegantissima*	Forms mat-like colonies on shoreline areas near discharge; common subtidally in turbulence zone of discharge feeding on fouling organisms sloughed from cooling system.
Sand-tube Worm	*Phragmatopoma californica*	Individuals or encrusting colonies attach to rocks or kelp holdfasts; filter food particles from water column; occurs in all depth zones.
Volcano Limpet	*Fissurella volcano*	Small grazer on algal and diatom films; common intertidally.
Checkered Periwinkle	*Littorina scutulata*	Small snail of the high shoreline, grazes on microscopic algal films and/or large rockweeds.
Purple Sea Urchin	*Strongylocentrotus purpuratus*	In dense populations, as in north Diablo Cove, this urchin can severely overgraze algae, leaving only crustose forms; firmly attached in rock depressions or aggregated in rock crevices.
Lined Shore Crab	*Pachygrapsus crassipes*	Intertidal shore crab; picks and eats microscopic algae and invertebrates from rock substrate.
Norris' Top Snail	*Norrissia norrisi*	Large snail common in southern California kelp beds; feeds on kelp blades and microscopic algae.
Black Turban Snail	*Tegula funebralis*	Very common intertidal snail; feeds on drift kelp and microscopic algal films; prey for several other predatory snail species.
Giant Gumboot Chiton	*Cryptochiton stelleri*	Large chiton (up to 12 inches in length) grazes on red algae; a northern species which attains high population densities in deeper areas of Diablo Cove.

Decreases

Common name	*Scientific name*	Ecological Description
Black Abalone	*Haliotis cracherodii*	Intertidal abalone; aggregates in crevices and feeds primarily on drift algae; susceptible to withering syndrome disease.
Red Abalone	*Haliotis rufescens*	Subtidal abalone; feeds on drift kelp; adults preyed upon by sea otters.
Brown Turban Snail	*Tegula brunnea*	Common grazing snail on variety of microscopic and macroscopic algae; food item for fishes and other invertebrates.
Six-rayed Sea Star	*Leptasterias hexactis*	Small sea star that broods eggs; common among shoreline and shallow water algae.
Bat Star	*Asterina miniata*	Medium-sized sea star; omnivorous on detrital invertebrate and algal material; susceptible to 'wasting disease' infection under certain warm water conditions.

(table continued)

Table S-2 (continued). Examples of common taxa affected by the DCPP discharge.

Algae and Sea Grass

Increases

Common name	*Scientific name*	Ecological description
Giant Kelp	*Macrocystis pyrifera*	Large canopy-forming kelp provides habitat and food for numerous invertebrates and fishes; can ecologically dominate an area by shading-out smaller algal species.
Hidden-rib Seaweed	*Cryptopleura violacea*	Ribbon-like red alga overgrows other algal species in Diablo Cove.
Agar Seaweed	*Gelidium robustum*	Bushy red alga occurring from low shoreline and into shallow subtidal zone.
Turkish Towel Seaweed	*Chondrocanthus corymbiferus*	Flat-bladed red alga grows on rocks subtidally; grazed upon by gumboot chitons, and small snails.

Decreases

Common name	*Scientific name*	Ecological description
Bull Kelp	*Nereocystis luetkeana*	Large annual canopy-forming kelp with long, narrow stipe and hanging blades forming habitat for fishes and invertebrates.
Oar Kelp	*Laminaria setchelli*	Short-statured kelp can withstand rough conditions.
Feather-boa Kelp	*Egregia menziesii*	A large strap-like kelp common along the shoreline.
Surfgrass	*Phyllospadix* spp.	Two co-occurring species of sea grasses (not algae) that fringe the shoreline; important habitat-formers for variety of invertebrates, fishes and epiphytic algae.
Iridescent Seaweed	*Mazzaella flaccida*	Red alga identified by the presence of an iridescent sheen on the blades; common on rocky shorelines; grazed upon by small snails; coverage protects other algal species from drying at low tide.
Rockweed	*Fucus gardneri*	Brown alga occurring on mid- to high shoreline; habitat for small snails and limpets.

Fish, Sharks and Rays

Increases

Common name	*Scientific name*	Ecological description
Leopard Shark	*Triakis semifasciata*	Omnivorous predator growing to lengths of up to 5 ft; aggregates in loose schools in warm-water discharge; more common in bays than outer coast.
Bat Ray	*Myliobatis californica*	Large ray that feeds on invertebrates buried in sand or mud; may aggregate in midwater schools, females most common around discharge.
Sheephead	*Semicossyphus pulcher*	Medium-sized wrasse preys on a variety of shellfish; more common in southern California, but recruits in central California during El Niño periods.
White Seabass	*Atractoscion nobilis*	Sub-adults form schools, larger individuals (3 ft length) usually solitary; preys mainly on fishes and squid.
Black Surfperch	*Embiotoca jacksoni*	One of several surfperch species common in shallow subtidal zone; prey on a variety of small invertebrates among low-growing algae; bear live young.
Topsmelt	*Atherinops affinis*	Both the topsmelt and the closely related jacksmelt aggregate in loose schools near the surface; can be a prey species for fast-moving predators such as white seabass or leopard shark.

(table continued)

Table S-2 (continued). Examples of common taxa affected by the DCPP discharge.

Fish, Sharks and Rays (continued)

Decreases

Common name	*Scientific name*	Ecological description
Kelp greenling	*Hexagrammos decagrammus*	Medium-sized bottom-dweller eats small crabs and shrimps; mostly northern in distribution.
Black-and-yellow rockfish	*Sebastes chrysomelas*	One of several species of bottom-dwelling rockfishes; eats crabs, octopus, and variety of other invertebrates; young-of-the year use kelp canopies as protective habitat.
Blue rockfish	*Sebastes mystinus*	Common midwater rockfish forms loose schools particularly over high-relief bottoms; eats blades of bull kelp and sea jellies.
Black prickleback	*Xiphister mucosus*	Small eel-like species of the shallow rocky shoreline; may eat algae or small invertebrates.

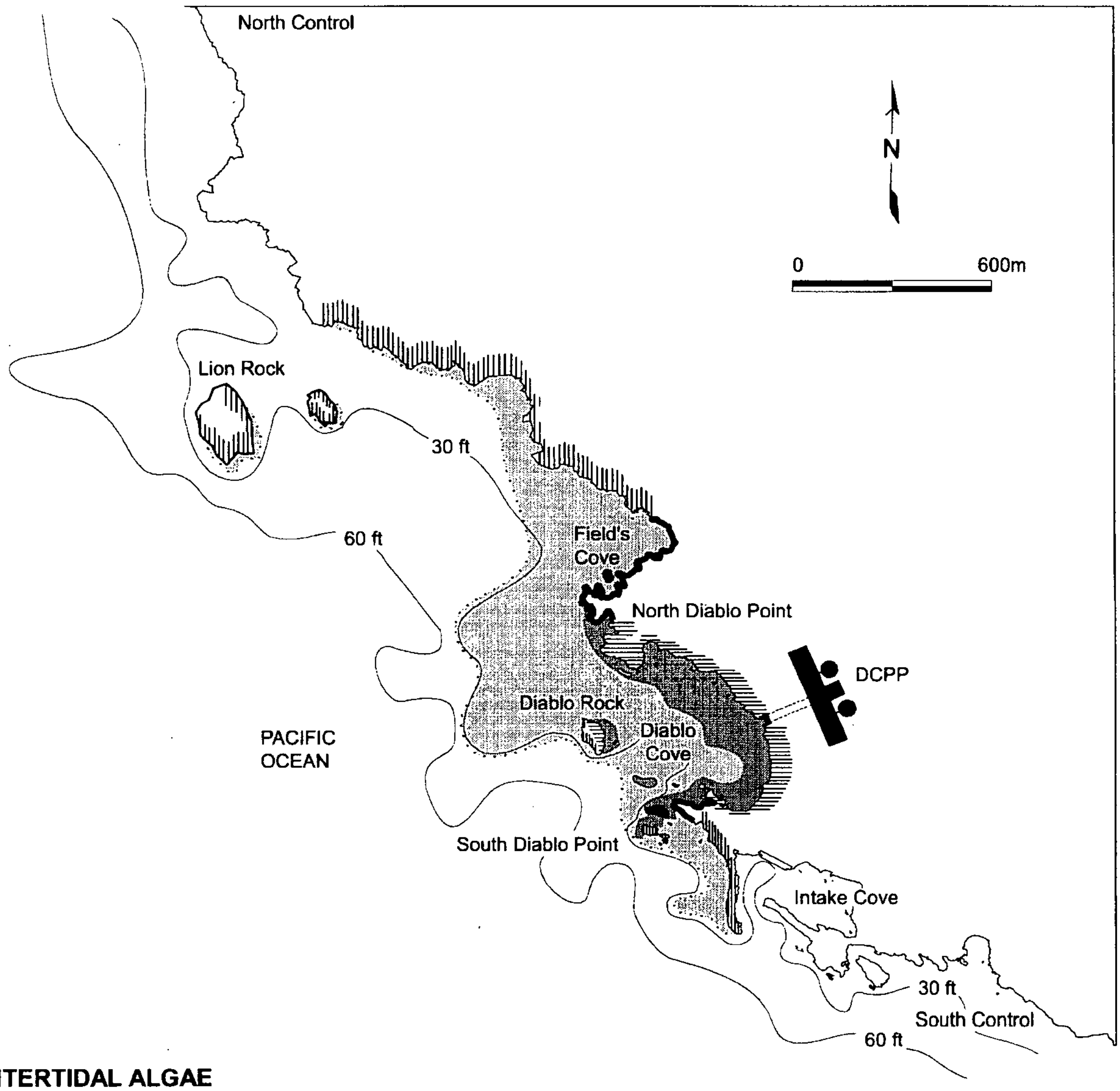
Table S-3. Effects of the DCPP discharge on intertidal algae determined by BACI analysis and Fisher's exact test of Horizontal Band Transect data.

INTERTIDAL ALGAE

(38 of 119 taxa sampled were analyzed statistically[1])

Increases	Decreases	Unchanged	Test Results Inconclusive[2]
7	26	2	3
19%	68%	5%	8%
Red Algae (Rhodophyta)			
Coralline algae (juv. articulated)	*Calliarthron/Bossiella*	Coralline algae (crustose)	*Chondrocanthus corymbiferus*
Filamentous red algae	*Callithamnion/Pleonosporium*	*Osmundea* spp.	*Microcladia borealis*
Gelidium coulteri	*Chondracanthus canaliculatus*		*Spongomorpha/Acrosiphonia*
Gelidium pusillum	*Corallina officinalis*		
Non-coralline algae (crustose)	*Corallina vancouveriensis*		
Prionitis spp.	*Cryptopleura violacea*		
	Cryptosiphonia woodii		
	Endocladia muricata		
	Gastroclonium subarticulatum		
	Mastocarpus jardinii		
	Mastocarpus papillatus		
	Mazzaella affinis		
	Mazzaella flaccida		
	Mazzaella heterocarpa		
	Mazzaella leptorhynchos		
	Mazzaella lilacina		
	Microcladia coulteri		
	Neorhodomela larix		
	Porphyra spp.		
	Smithora naiadum		
Green Algae (Chlorophyta)			
Ulva/Enteromorpha spp.	*Cladophora* spp.		
Brown Algae (Phaeophyta)			
	Egregia menziesii		
	Fucus gardneri		
	Pelvetia compressa		
Sea Grasses (Angiospermata)			
	Phyllospadix spp.		
Benthic Diatoms (Chrysophyta)			
	Chrysophyta unid.		

[1] the remaining 80 taxa either did not meet the minimum abundance criterion for statistical analysis, or did not meet BACI assumptions.
[2] the taxon was too variable for the statistical tests to detect changes in abundance between the pre-operation and operation phases.



INTERTIDAL ALGAE

Area of continuous plume contact with greatest observed effects: (2.2 km; 1.4 miles - based on 1:9,000 scale)

Area of reduced plume contact with reduced observed effects: (1.5 km; 0.9 miles - based on 1:9,000 scale)

Area of reduced plume contact with unknown effects likely to be less than those in areas with reduced observed effects: (3.0 km; 1.8 miles - based on 1:9,000 scale)

SUBTIDAL ALGAE (not including *Nereocystis* and *Macrocystis*)

Area of greatest observed effects: (8.1 hectares; 19.9 acres)

Area of reduced plume contact with unknown effects likely to be less than those observed in affected areas of Diablo Cove: (39.5 hectares; 97.6 acres)

Figure S-8. Approximate areas of discharge effects on the distribution and abundance of intertidal and subtidal algae observed in the study, not including the surface canopy-forming kelps *Nereocystis luetkeana* and *Macrocystis pyrifera*. Shoreline distances account for coastline indentations and islands.

Table S-4. Effects of the DCPP discharge on subtidal algae determined by BACI analysis and Fisher's exact test of subtidal Random Point Contact data and Subtidal Arc Quadrant data.

SUBTIDAL ALGAE

(39 of 109 taxa sampled were analyzed statistically[1])

Increases 14 36%	Decreases 11 28%	Unchanged 2 5%	Test Results Inconclusive[2] 12 31%
	Red Algae (Rhodophyta)		
Ahnfeltiopsis linearis	*Calliarthron/Bossiella* spp.	*Microcladia coulteri*	*Osmundea* spp.
Callophyllis flabellulata	*Callophyllis* spp.	*Rhodymenia* spp.	*Polyneura latissima*
Chondracanthus corymbiferus	*Corallina officinalis*		*Gastroclonium subarticulatum*
C. harveyanus/spinosus	*Cryptopleura ruprechtiana*		*Mazzaella lilacina*
coralline algae (crustose)			*Mazzaella rosea*
Cryptopleura violacea			*Nienburgia andersoniana*
Farlowia/Pikea spp.			*Prionitis australis*
filamentous red algae-complex			*Pterocladia caloglossoides*
Gelidium robustum			
Halymenia/Schizymenia spp.			
non-coralline algae (crustose)			
Prionitis spp.			
Sarcodiotheca gaudichaudii			
	Green Algae (Chlorophyta)		
			Ulva/Enteromorpha spp.
	Brown Algae (Phaeophyta)		
Macrocystis pyrifera	*Cystoseira osmundacea*		*Dictyoneurum californicum*
	Desmarestia spp.		Laminariales (juv.)
	Egregia menziesii		
	Laminaria setchellii		
	Nereocystis luetkeana		
	Pterygophora californica		
	Sea Grasses (Angiospermata)		
	Phyllospadix spp.		
	Benthic Diatoms (Chrysophyta)		
			Chrysophyta unid.

[1] the remaining 70 taxa either did not meet the minimum abundance criterion for statistical analysis, or did not meet BACI assumptions.

[2] the taxon was too variable for the statistical tests to detect changes in abundance between the pre-operation and operation phases.

The spatial extent of documented effects on subtidal understory algae was restricted to the shallower areas of Diablo Cove (less than -3 m to -4 m MLLW), a total area of 8.1 ha (19.9 acres) (Figure S-8). Deeper areas of the cove and subtidal areas in Field's Cove and off South Diablo Point are contacted by the plume less frequently. Effects in these areas are likely to be less than effects observed in Diablo Cove.

During the 1987 El Niño when ambient water temperatures were warmer than normal, effects on bull kelp were observed as far north as Lion Rock, an area of 42.3 ha (104.6 acres) (Figure S-9). Effects during most years were typically restricted to an area of approximately 23.0 ha (56.3 acres) in Diablo Cove and the north Diablo Channel. Effects in areas with reduced plume contact [an area that totals 68.7 ha (169.7 acres)] are likely to be less than areas where effects on bull kelp have been observed regularly (Figure S-9).

Invertebrates

Two hundred forty eight invertebrate taxa were sampled from the intertidal, horizontal band transect study, 238 from the subtidal benthic study, and 314 from the intertidal Algal-Faunal Association Study. Some taxa were common between study methods.

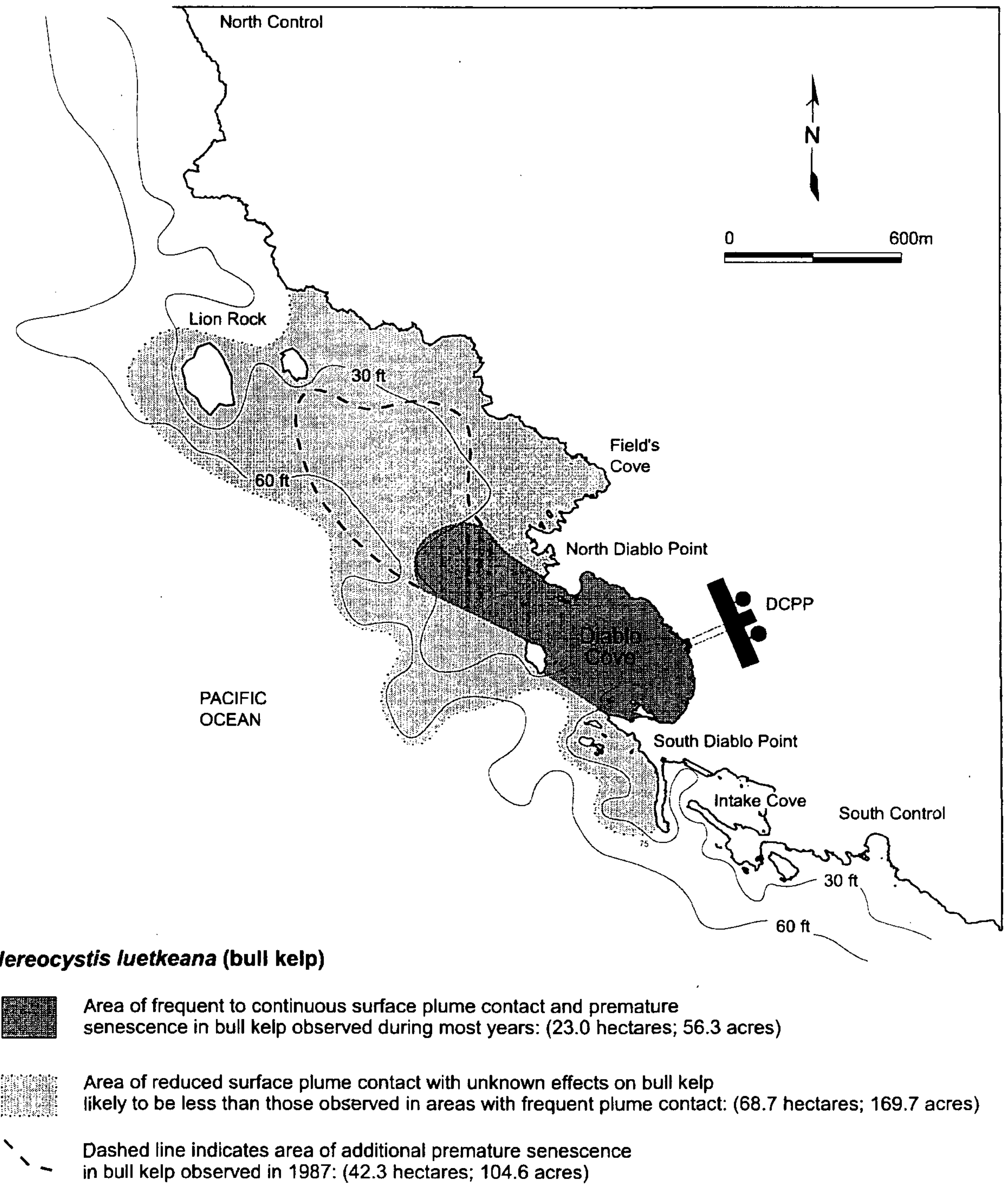
In the intertidal, 39 macroinvertebrate taxa were analyzed. Significant increases in abundance were detected for 16 taxa, while 16 decreased in abundance (Table S-5). Of the 7 remaining taxa, 4 showed no changes and data were insufficient to detect changes for 3 taxa. Large increases were observed in many species of herbivorous limpets, the sand tube worm *Phragmatopoma californica*, and the barnacle *Chthamalus fissus.*

One hundred microinvertebrate taxa were sampled from two abundant intertidal algae (*Endocladia muricata* and *Gastroclonium subarticulatum*) and were analyzed for differences between Diablo Cove and the adjacent Field's Cove reference station. Field's Cove was contacted by the discharge plume less frequently than Diablo Cove, resulting in a mean delta T° of approximately 1°C. Therefore the results of the AFAS may have underestimated microinvertebrate changes using Field's Cove as a reference. Twenty-two taxa increased and 36 taxa decreased significantly between periods. Six taxa did not appear to be affected by the discharge, based on comparisons between Field's Cove and Diablo Cove. Test power was insufficient to determine impacts for the remaining 36 taxa (Table S-6). In general, molluscs responded negatively to the discharge, while crustaceans (primarily amphipods and isopods) responded positively.

The spatial extent of documented shoreline effects on intertidal invertebrates included all of Diablo Cove, the southern shoreline of Field's Cove and South Diablo Point; a total shoreline distance (includes Diablo Rock intertidal and wash rocks in Diablo Cove) of 3.7 km (2.3 mi) (Figure S-10). Further north and south are areas of reduced plume contact with unknown effects on invertebrates that are likely to be less than those seen in areas with reduced observed effects.

In the subtidal studies, 106 taxa were analyzed. Significant increases in abundance at impact stations in Diablo Cove were detected for 28 of the taxa and significant decreases were detected for 32 taxa (Table S-7). Of the 46 remaining taxa, 14 showed no changes and data were insufficient to detect changes for 32 taxa.

Changes in subtidal invertebrates were characterized by decreases in several previously abundant taxonomic groups. Significant decreases were detected in several taxa of shelled gastropods, including brown turban snails *Tegula brunnea*, one of the most common and abundant invertebrates in Diablo Cove prior



***Nereocystis luetkeana* (bull kelp)**

Area of frequent to continuous surface plume contact and premature senescence in bull kelp observed during most years: (23.0 hectares; 56.3 acres)

Area of reduced surface plume contact with unknown effects on bull kelp likely to be less than those observed in areas with frequent plume contact: (68.7 hectares; 169.7 acres)

Dashed line indicates area of additional premature senescence in bull kelp observed in 1987: (42.3 hectares; 104.6 acres)

Figure S-9. Approximate areas of premature senescence in *Nereocystis luetkeana* (bull kelp) observed in the study. Areas of premature senescence during most years and during the 1987 El Niño are shown separately. Outer-most boundary of reduced surface plume contact encompasses areas of rocky bottom within the approximate depth limit of *Nereocystis*.

Table S-5. Effects of the DCPP discharge on intertidal macroinvertebrates determined by BACI analysis and Fisher's exact test of Horizontal Band Transect data. This method mainly enumerated larger taxa and larger size-class invertebrates than the Algal-Faunal Association method (Table S-6).

INTERTIDAL INVERTEBRATES (Horizontal Band Transect Method)

(39 of 248 taxa sampled were analyzed statistically[1])

Increases **16** 41%	**Decreases** **16** 41%	**Unchanged** **4** 10%	**Test Results Inconclusive[2]** **3** 8%
	Sponges (Porifera)		
	Haliclona spp.		
	Porifera unid. (encrusting)		
	Sea anemones (Cnidaria)		
Anthopleura elegantissima	*Epiactis prolifera*		
Anthopleura xanthogrammica			
	Segmented Worms (Polychaeta)		
Phragmatopoma californica	*Pista* spp.		*Dodecaceria fewkesi*
	Spirorbidae		
	Snails, Clams, Nudibranchs, Chitons (Mollusca)		
Cyanoplax spp.	*Haliotis* spp.	*Acanthina* spp.	*Mytilus californianus*
Fissurella volcano	*Mopalia* spp.	*Tectura scutum*	*Serpulorbis squamigerus*
Lotia digitalis	*Nuttallina californica*		
Lottia limatula	*Ocenebra* spp.		
Lottia pelta	*Tegula brunnea*		
Macclintockia scabra			
Tegula funebralis			
	Crabs, Amphipods, Barnacles (Crustacea)		
Chthamalus fissus	*Pugettia* spp.	*Balanus* spp.	
Pachygrapsus crassipes		*Pagurus* spp.	
Pollicipes polymerus			
Tetraclita rubescens			
	Sea Stars, Sea Urchins, Sea Cucumbers (Echinodermata)		
Pisaster ochraceus	*Leptasterias* spp.		
Strongylocentrotus purpuratus			
	Other Groups		
	Bryozoa, unid. (encrusting)		
	Bryozoa, unid. (foliose)		
	Nemertea unid.		
	tunicates, colonial/social		

[1] the remaining 209 taxa either did not meet the minimum abundance criterion for statistical analysis, or did not meet BACI assumptions.

[2] the taxon was too variable for the statistical tests to detect changes in abundance between the pre-operation and operation phases.

Table S-6. Effects of the DCPP discharge on intertidal microinvertebrates determined by BACI analysis and Fisher's exact test of Algal-Faunal Association Study data. This method mainly enumerated smaller taxa and smaller size-class invertebrates than the Horizontal Band Transect method (Table S-5).

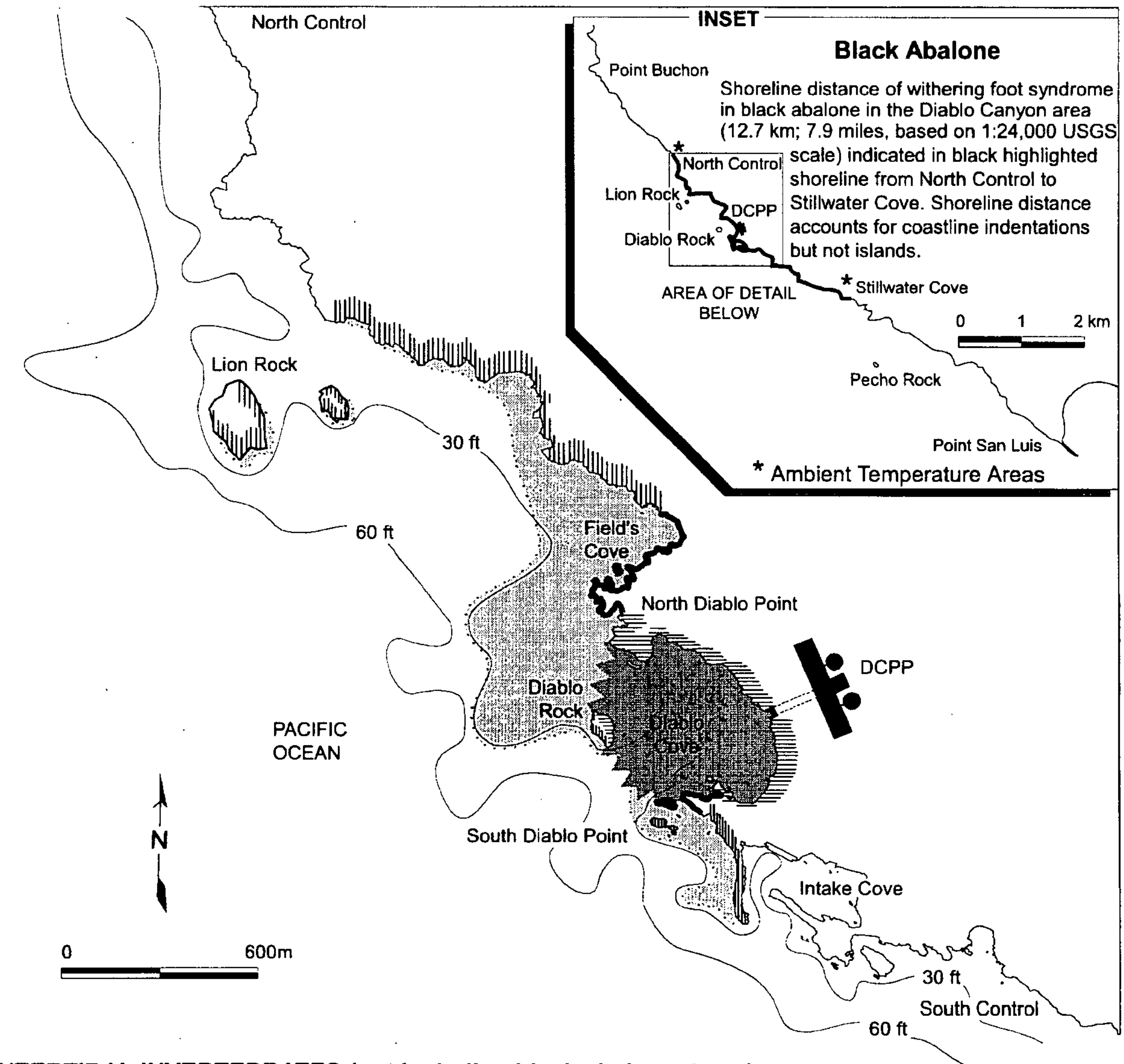
INTERTIDAL INVERTEBRATES (Algal-Faunal Association Study Method)

(100 of 314 taxa sampled were analyzed statistically[1])

Increases **22** 22%	**Decreases** **36** 36%	**Unchanged** **6** 6%	**Test Results Inconclusive**[2] **36** 36%
	Segmented Worms (Polychaeta)		
Phragmatopoma californica	*Nereis grubei*		Cirratulidae unid.
	Lumbrineridae unid.		*Naineris dendritica*
	Maldanidae unid.		*Nereis pelagica neonigripes*
	Syllidae unid.		*Pista elongata*
			Polychaeta unid.
			Spionidae unid.
	Snails, Clams, Nudibranchs, Chitons (Mollusca)		
Hiatella arctica	*Acanthina punctulata*	Acmaeidae	*Alvinia* spp.
Lasaea cistula	*Alia* spp.	*Amphissa* spp.	*Bittium purpureum*
Littorina planaxis	*Barleeia* spp.	*Collisella scabra*	*Bittium* spp.
Littorina scutulata	*Bittium eschrichtii*	*Epitonium tinctum*	*Cooperella subdiaphana*
Modiolus carpenteri	*Calliostoma* spp.		*Epitonium tinctum*
Mytilus spp.	*Crepidula adunca*		*Fissurella volcano*
Odostomia spp.	*Cyanoplax* spp.		*Homalopoma baculum*
Tegula brunnea	*Cymakra* spp.		*Kellia laperousa*
	Cystiscus/Granulina spp.		*Lacuna unifasciata*
	Homalopoma luridum		*Pseudomelatoma torosa*
	Lacuna marmorata		*Stenoplax heathiana*
	Lirularia succinta		
	Musculus pygmaeus		
	Ocenebra circumtexta		
	Ocenebra spp.		
	Tegula funebralis		
	Tricolia pulloides		
	Turbonilla spp.		
	Crabs, Amphipods, Barnacles (Crustacea)		
Elasmopus antennatus	*Ampithoe* spp.	*Cancer* spp.	Caprellidea unid.
Exosphaeroma inornata	*Aoroides columbiae*		*Cirolana harfordi*
Exosphaeroma octoncum	*Dynamanella* spp.		*Exosphaeroma amplicauda*
Exosphaeroma rhomburum	*Idotea* spp.		Grapsidae unid.
Hyale californica	*Oligochinus lighti*		*Hyale frequens*
Jassa falcata	*Pagurus* spp.		*Ianiropsis* spp.
Leptochelia dubia	*Parallorchestes ochotensis*		Jearopsidae unid.
	Paraphoxus spp.		*Lophopanopeus* spp.
	Pugettia producta		megalops unid.
	Pugettia richii		*Nymphopsis spinosissima*
			Pachygrapsus crassipes
			Photis spp.
			Porcellanidae unid.
	Sea Stars, Sea Urchins, Sea Cucumbers (Echinodermata)		
Amphipholis squamata	*Eupentacta quinquesemita*		*Amphiodia occidentalis*
Ophiactis simplex	*Leptasterias* spp.		*Henricia leviuscula*
Strongylocentrotus spp.	*Lissothuria nutriens*		Ophiuroidea unid.
	Other Groups		
Diptera larvae	Nemertea unid.	Tunicata unid.	*Clavelina huntsmani*
Anthozoa unid.			Diptera pupae
Phascolosoma agassizii			Turbellaria unid.

[1] the remaining 214 taxa either did not meet the minimum abundance criterion for statistical analysis, or did not meet BACI assumptions.

[2] the taxon was too variable for the statistical tests to detect changes in abundance between the pre-operation and operation phases.



INTERTIDAL INVERTEBRATES (not including black abalone; inset)

Area of continuous plume contact with greatest observed effects: (2.2 km; 1.4 miles - based on 1:9,000 scale)

Area of reduced plume contact with reduced observed effects: (1.5 km; 0.9 miles - based on 1:9,000 scale)

Area of reduced plume contact with unknown effects likely to be less than those in areas with reduced observed effects: (3.0 km; 1.8 miles - based on 1:9,000 scale)

SUBTIDAL INVERTEBRATES

Area of greatest observed effects: (16.4 hectares; 40.6 acres)

Area of reduced plume contact with unknown effects likely to be less than those observed in affected areas of Diablo Cove: (31.1 hectares; 76.8 acres)

Figure S-10. Approximate areas of discharge effects on the distribution and abundance of intertidal and subtidal invertebrates observed in the study. Black abalone shown in inset. Shoreline distances account for coastline indentations and islands. Subtidal zig-zag boundaries represent unknown transition zones outside Diablo Cove.

Table S-7. Effects of the DCPP discharge on subtidal invertebrates determined by BACI analysis and Fisher's exact test of Subtidal Arc Quadrant data and Subtidal Fixed Quadrat data.

SUBTIDAL INVERTEBRATES

(106 of 238 taxa sampled were analyzed statistically[1])

Increases **28** 26%	**Decreases** **32** 30%	**Unchanged** **14** 13%	**Test Results Inconclusive[2]** **32** 30%
	Sponges (Porifera)		
	Leucandra heathi		*Hymenamphiastra cyanocrypta*
	Porifera unid. encrusting		*Leucilla nuttingi*
	Tethya aurantia		
	Sea anemones and cup coral (Cnidaria)		
Anthopleura elegantissima	*Balonophyllia elegans*		*Anthopleura artemisia*
Anthozoa unid.	*Cactosoma arenaria*		*Halcampa decemtentacula*
	Epiactis prolifera		
	Segmented Worms (Polychaeta)		
Pista spp.	*Dodecaceria fewkesi*	*Diopatra ornata*	*Eudistylia polymorpha*
Chaetopteridae unid.	*Salmacina tribranchiata*	*Phragmatopoma californica*	Nereidae unid.
Cirratulidae/Terrebellidae			Sabellidae unid.
Serpulidae unid.			
Spirorbidae unid.			
	Snails, Clams, Nudibranchs, Chitons (Mollusca)		
Acmaea mitra	*Anisodoris nobilis*	*Alia* spp.	Acmaeidae unid.
Aplysia californica	*Calliostoma ligatum*	*Amphissa* spp.	*Cryptochiton stelleri*
Dendropoma spp.	*Crassodema giganteum*	*Bittium* spp.	*Diodora* spp.
Fissurella volcano	*Crepidula* spp.	*Doriopsilla albopunctata*	*Fusinus luteopictus*
Ischnochitonidae unid.	*Homalopoma* spp.	*Hopkinsia rosacea*	*Haliotis* spp.
Lacuna spp.	*Lottia instabilis*	*Lottia ochraceus*	*Hermissenda crassicornis*
Lithopoma gibberosum	*Pseudomelatoma torosa*	*Mitra idae*	*Hipponix* spp.
Norrisia norrisi	*Serpulorbis squamigerus*	*Ocenebra* spp.	*Lepidizona* spp.
Pelecypoda unid., boring	*Tegula brunnea*	*Tonicella lineata*	*Mopalia* spp.
Phidiana hiltoni	*Tegula montereyi*	*Tricolia* spp.	Pelecypoda unid.
Pododesmus cepio			*Tegula pulligo*
			Triopha maculata
			Williamia peltoides
	Crabs, Amphipods, Barnacles (Crustacea)		
Balanus/Tetraclita spp.	*Balanus* spp.	*Cryptolithodes sitchensi*	*Cancer* spp.
Lophopanopeus spp.	*Pagurus* spp.		
Majidae unid.	*Pugettia* spp.		
Tetraclita rubescens			
	Sea Stars, Sea Urchins, Sea Cucumbers (Echinodermata)		
Lissothuria nutriens	*Cucumaria* spp.	*Asterina miniata*	*Eupentacta quinquesemita*
Ophiothrix spp.	*Henricia leviuscula*		Holothuroidea unid.
Ophiuroidea unid.	*Leptasterias* spp.		*Ophioplocus* spp.
Pisaster giganteus	*Pisaster/Henricia* (juv.)		*Pisaster brevispinus*
Strongylocentrotus purpuratus	*Pycnopodia helianthoides*		
	Other Groups		
Bryozoa, unid. (foliose)	Bryozoa, unid. (encrusting)		*Boltenia villosa*
	Didemnum/Trididemnum spp.		*Clavelina huntsmani*
	Sipuncula unid.		*Clavularia spp.*
	Styela spp.		*Cnemidocarpa finmarkiensis*
	tunicates, colonial/social		*Eurystomella bilabiata*
	tunicates, solitary unid.		*Hymenamphiastra cyanocrypta*
			Pyura haustor

[1] the remaining 132 taxa either did not meet the minimum abundance criterion for statistical analysis, or did not meet BACI assumptions.

[2] the taxon was too variable for the statistical tests to detect changes in abundance between the pre-operation and operation phases.

to power plant operation. *T. brunnea* settlement (planktonic dispersal) still occurs within Diablo Cove based on field observations and results of the intertidal Algal-Faunal Association Study. The lack of large individuals may result from predation by fish that have increased in Diablo Cove since plant operation began. Several invertebrates mainly distributed south of Point Conception have been observed in the Diablo Cove subtidal since operation began, and their occurrences are considered to be directly attributable to the warmer water temperatures in Diablo Cove. These include the southern kelp crab, white urchin, wavy top snail, Solander's cowry, chestnut cowries, Norris's top snail, Kellet's whelk, California black sea hare, and giant keyhole limpet.

The spatial extent of documented effects on subtidal invertebrates were restricted to Diablo Cove, a total area of 16.4 ha (40.6 acres) (Figure S-10). Subtidal areas outside of Diablo Cove are less frequently contacted by the plume and effects in these areas are likely to be less than those observed in Diablo Cove.

In both intertidal and subtidal habitats, the changes in abundances of invertebrates were probably a combination of responses to increased water temperatures from the discharge, and responses to changes in other components of the community (e.g. decreases in algal cover in the intertidal, increases in algal cover in the subtidal, and increased abundances of predatory fish). A number of taxa more commonly found in southern California either increased in abundance or were found for the first time in Diablo Cove after power plant start-up.

Abalone

Prior to 1988 black abalone abundances were unaffected by the discharge (PG&E 1988a). Red abalone in subtidal areas of Diablo Cove were also unaffected by normal power plant operation prior to 1988. However, in October 1987, twenty dead red abalone, and a few individuals of other invertebrate taxa, were observed in the immediate area of the discharge a few days following a heat treatment. Since the late 1980's a disease, termed 'withering syndrome' (WS), caused large declines in abalone populations throughout southern California and as far north as Cayucos, approximately 27 km north of DCPP. Abalone with the disease show dramatic decreases in body mass before dying. WS is thought to have affected all abalone species, but has been especially damaging to populations of black abalone. Since 1988, black abalone in Diablo Cove have decreased dramatically due to WS. The declines observed in Diablo Cove were consistent with declines observed at the southern California Channel Islands beginning in 1986, and at other mainland sites near Point Arguello in 1994 (Altstatt et al. 1996). Surveys of abalone populations in the immediate area of DCPP showed that WS first appeared within Diablo Cove. Abalone in areas immediately outside Diablo Cove did not begin showing symptoms until a year later, with symptoms appearing at nearby sites first and at more distant sites several years later (Table S-8). WS was found as far north as North Control and as far south as Stillwater Cove although neither of these areas were contacted by the thermal plume. The total shoreline distance (computed from a USGS 1:24,000 scale map) where WS has been observed in black abalone was 12.7 km (7.9 mi) (Figure S-10). Red abalone were found with WS in Diablo Cove in 1989. Considering direct observation of WS red abalone in Diablo Cove and shell accumulations under ledges and in crevices at depths of 6 m and less, WS mortality is thought to have contributed significantly to the reduction of red abalone observed there since 1990, especially in the shallower, warmer areas. The area in which red abalone effects have been observed totals 16.4 ha (40.6 acres).

When black abalone in Diablo Cove were first observed with symptoms of WS, the presence of the disease had already been confirmed at several of the Santa Barbara Channel Islands, 160 km (100 miles) south, but had not yet been seen at any more northerly (and colder) mainland sites except Diablo Cove. This pattern of the disease being common in warmer, more southerly waters and in Diablo Cove, is consistent with laboratory experiments done at DCPP. Although the discharge is not the cause of WS in either black or red abalone, our studies indicate that the mortality rate associated with the disease is directly correlated with increased water temperature from the discharge.

Table S-8. Years when withering syndrome disease was first observed in areas surveyed in quantitative black abalone surveys (1988-1994).

Year	Area of Observation / Comments	Distance from Diablo Cove (straight-line)
1988	Diablo Cove	
1989	Diablo Cove - red abalone found with WS	
1989	Postelsia Point (north Diablo Point)	0.1 km north
1990	Field's Cove	0.5 km north
1990/91	Point Arguello; a few abalone (P. Haaker CDF&G pers. comm.)	76.0 km south
1991	Seal Haulout; also found in Diablo Cove juveniles	0.7 km south
1992	Green Rock Cove (inside Lion Rock)	1.6 km north
1993	Suspected WS (empty shells) at North Control and Stillwater Cove	
1994	HBT Station SC-3 (south of Stillwater Cove)	4.7 km south
1994	North Control	2.2 km north

Fish

Studies on fish were conducted both intertidally and subtidally. Of the 82 taxa identified in the subtidal, 37 were analyzed for changes resulting from the power plant. Significant changes due to the discharge were detected for 21 of the 37 taxa (Table S-9). Increases in abundance were detected for 13 of the 22 taxa, decreases for 8 of the 22, 6 taxa showed no changes, and the data were insufficient to draw any conclusions for 10 taxa. Analyses also detected a significant increase in the numbers of fish taxa within Diablo Cove, while fish diversity decreased.

Eleven intertidal fish taxa were analyzed for differences between Diablo Cove and the adjacent Field's Cove reference station. Because Field's Cove was also contacted by the discharge plume, the results of this study may have underestimated the effects of the discharge. No significant increases were detected in any of the taxa tested. Decreases were detected in 4 taxa, 2 taxa were unchanged, and data were insufficient to draw any conclusions for 5 taxa (Table S-9).

The most obvious changes in fish composition during power plant operation occurred near the discharge in Diablo Cove, where certain species appeared to be attracted to the turbulent warm water. These species, rare in the area before plant start-up, include leopard shark, bat ray, round ray, white seabass, opaleye, halfmoon, sheephead and señorita. A similar assemblage occurs where the plume washes against the inshore side of Diablo Rock and extends down to depths of about 7 m (22 ft). The same fishes from the warm area occur sporadically throughout other warm areas of Diablo Cove shallower than 10 m (30 ft). The lower edge of the plume forms an area of mixing of warm and cold waters (a thermocline) that often appears to attract various surfperch species when it is close to the bottom. Below the thermocline, cooler ambient temperatures are normal, and the fish fauna is basically the same as that of control areas outside of Diablo Cove. Ancillary observations in Field's Cove and Lion Rock Cove (north of Diablo Cove), and the Breakwater/Seal Haulout area (south of Diablo Cove), indicate that the fish fauna there appear to have been unaffected by the power plant discharge.

Table S-9. Effects of the DCPP discharge on intertidal and subtidal fish determined by BACI analysis and Fisher's exact test of Vertical Band Transect data and Subtidal Fish Observation data.

FISH

(48 of 96 taxa sampled were analyzed statistically[1])

Increases	Decreases	Unchanged	Test Results Inconclusive[2]
13	**12**	**8**	**15**
27%	25%	17%	31%
		Intertidal Taxa	
(none)	*Gobiesox maeandricus*	*Anoplarchus /Cebidichthys*	Cottidae (juv.)
	Scytalina cerdale	*Xerepes fucorum*	*Gibbonsia* spp.
	Xiphister atropurpureus		*Oligocottus snyderi*
	Xiphister mucosus		Stichaeidae / Pholidae
			Xiphister spp. (juv.)
		Subtidal Taxa	
Atherinidae	*Artedius* spp.	*Cebidichthys violaceus*	*Brachyistius frenatus*
Aulorhynchus flavidus	*Hexagrammos decagrammus*	Cottidae	Embiotocidae
Citharichthys spp.	*Oxyjulis californica*	*Embiotoca jacksoni*	*Engraulis mordax*
Coryphopterus nicholsii	*Oxylebius pictus*	*Embiotoca lateralis*	*Gibbonsia* spp.
Damalichthys vacca	*Scorpaenichthys marmoratus*	*Sebastes chrysomelas/S. carnatus* (yoy)	*Heterostichus rostratus*
Girella nigricans	*Sebastes chrysomelas*	*Sebastes serranoides/S. flavidus* (yoy)	larval / post-larval fish, unid.
Medialuna californiensis	*Sebastes rastrelliger*		*Ophiodon elongatus*
Myliobatis californica	*Sebastes* spp. (yoy[3], unid.)		*Sebastes melanops* (juv.)
Paralabrax clathratus			*Sebastes mystinus* (yoy)
Rhacochilus toxotes			*Sebastes paucispinus* (yoy)
Sebastes mystinus			
Sebastes serranoides			
Semicossyphus pulcher			

[1] the remaining 48 taxa either did not meet the minimum abundance criterion for statistical analysis, or did not meet BACI assumptions.

[2] the taxon was too variable for the statistical tests to detect changes in abundance between the pre-operation and operation phases.

[3] young of the year

The spatial extent of documented shoreline effects on intertidal fishes included all of Diablo Cove, the southern shoreline of Field's Cove and South Diablo Point; a total shoreline distance (includes Diablo Rock intertidal and wash rocks in Diablo Cove) of 3.7 km (2.3 mi) (Figure S-11). The spatial extent of documented effects on subtidal fishes was largely restricted to Diablo Cove, a total area of 16.3 ha (40.3 acres) (Figure S-11). Subtidal areas outside of Diablo Cove are less frequently contacted by the plume and effects in these areas are likely to be reduced from effects observed in Diablo Cove. The presence of the surface plume outside of Diablo Cove may have some unknown effect on midwater fish populations and fishes that feed at the surface.

Summary of Spatial Extent of Effects

Several types of data were used to determine the spatial extent of the discharge effects:

1) Remote sensing and field measurements were used to determine the area affected by the warm water plume.

2) Changes in abundance of taxa were plotted for the different study sites.

3) Divers mapped changes by depth inside and outside of the cove.

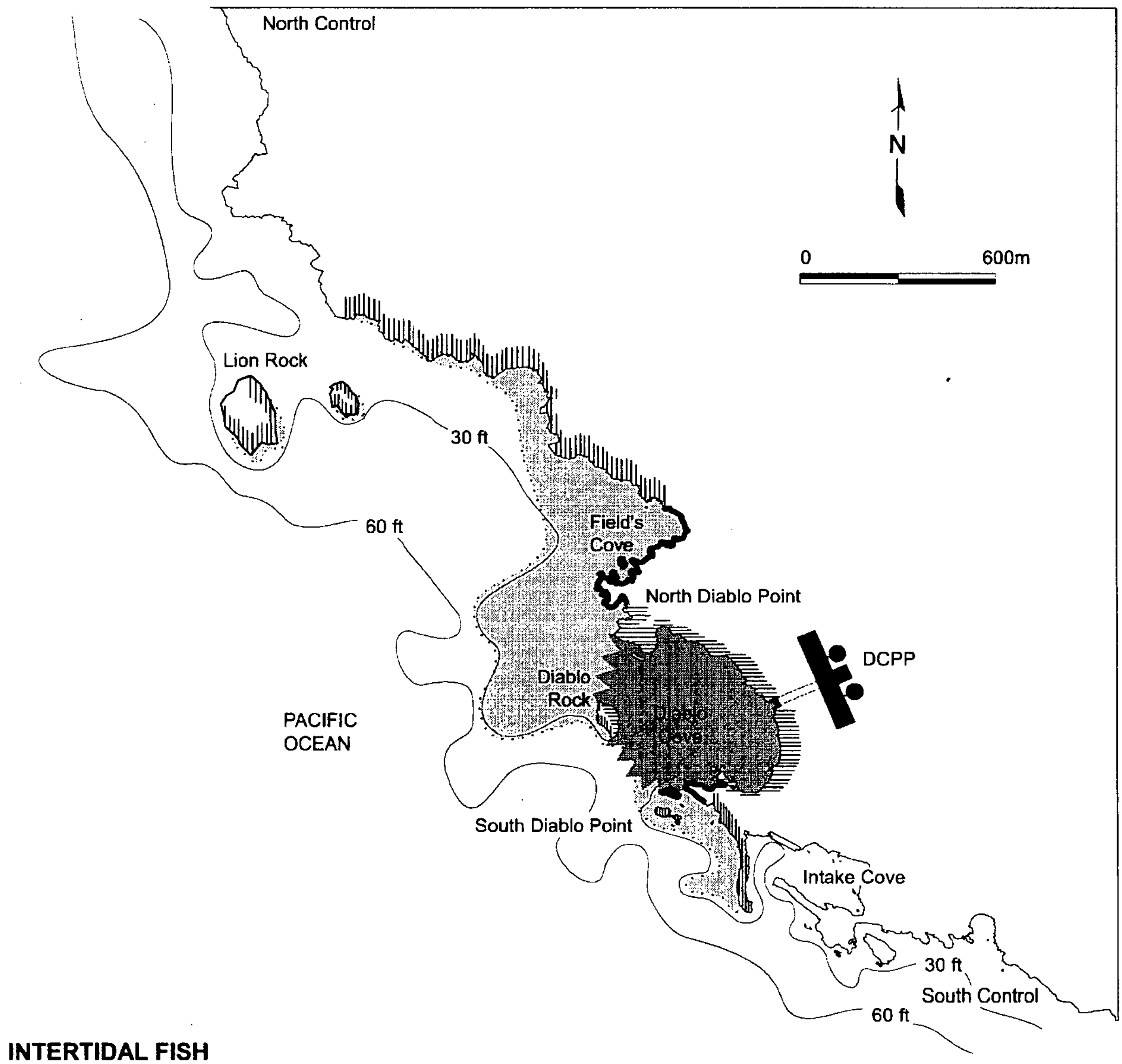
The spatial extent of effects varies somewhat depending on the species or habitat examined.

In the intertidal zone, effects were observed throughout Diablo Cove, and extended north into Field's Cove, south onto South Diablo Point, and along the inshore side of Diablo Rock, a total shoreline distance of approximately 3.7 km (2.3 mi). The magnitude of the effects observed at the two areas outside Diablo Cove was much less than effects within the cove. The intertidal areas further north and south of these areas have reduced frequency of plume contact and would be expected to also show diminishing biological effects, except for the occurrence of WS disease in some black abalone. Impacts were not evident at Seal Haulout 0.7 km (0.4 mi) to the south of Diablo Cove or at the North Control sites, 2.2 km (1.4 mi) north. Within the subtidal benthic habitat, most effects of the discharge were limited to the shallow (<7 m [22 ft]) portions of Diablo Cove, a bottom area of approximately 8.1 ha (19.9 ac).

In the surface waters the extent of the plume can be considerably greater, depending on wind and tide. The only surface-dwelling organisms included in this study are the kelps that have surface canopies. The only noticeable effect was upon bull kelp *Nereocystis luetkeana*. Evidence of this effect, the senescence of surface blades, was mapped by diver surveys, cliff-top observations and boat surveys (Figure S-9). During an unusually warm water period during the fall of 1987, the areas of bull kelp affected included Diablo Cove, Field's Cove and north to near Lion Rock, covering a total surface area of 42.3 ha (104.6 ac). Observations of bull kelp were made each year, and after 1987 the extent of effects never reached as far as Lion Rock and were more typically confined to an area of approximately 23.0 ha (56.3 acres).

Temporal Extent of Effects

The results of the correspondence analyses show that the community within Diablo Cove, relative to communities in control areas, has slowly changed since the warm water discharge began, and continues to change. The change is toward a community with a greater percentage of southerly species in the warm waters of the discharge, and a reduced percentage of more northerly species. Although statistical designs



INTERTIDAL FISH

Area of continuous plume contact with greatest observed effects: (2.2 km; 1.4 miles - based on 1:9,000 scale)

Area of reduced plume contact with reduced observed effects: (1.5 km; 0.9 miles - based on 1:9,000 scale)

Area of reduced plume contact with unknown effects likely to be less than those in areas with reduced observed effects: (3.0 km; 1.8 miles - based on 1:9,000 scale)

SUBTIDAL FISH

Area of greatest observed effects: (16.4 hectares; 40.6 acres)

Area of reduced plume contact with unknown effects likely to be less than those observed in affected areas of Diablo Cove: (31.1 hectares; 76.8 acres)

Figure S-11. Approximate areas of discharge effects on the distribution and abundance of intertidal and subtidal fish observed in the study. Shoreline distances account for coastline indentations and islands. Subtidal zig-zag boundaries represent unknown transition zones outside Diablo Cove.

for impact analysis do not necessarily require long-term data to detect effects, results from DCPP studies show that many of the changes caused by the discharge would have gone undetected in a shorter study. For example, significant increases in giant kelp and losses of black abalone only occurred after several years of plant operation.

Natural events have affected, and will continue to affect, the type of biological changes observed in both impact and control areas. Northerly flowing El Niño currents are a mechanism for the introduction of warm water taxa, larvae and algal spores from southern California. Although the magnitude of the effects of the discharge have been greater than those observed from El Niño, annual differences in oceanographic factors and thermal discharge characteristics will continue to influence biological communities in the DCPP area.

The timing and spatial extent of thermal discharge-related effects varied among affected taxa. Fish generally responded quickly to thermal changes in Diablo Cove by moving to preferred temperature regimes. Subsequent changes in fish abundances involved differences in recruitment success and species interactions within thermally affected areas. The timing of the declines in perennial algal taxa was relatively consistent among stations in the thermal discharge area, whereas increases in limpet and sea urchin grazers, barnacles, and ephemeral algae were more variable in space and time. This variation is undoubtedly due to physical and biological factors that affected species occurrences, including habitat dissimilarities, and spatial and temporal variation in local temperature regimes. Although variation can be expected in most natural populations, the TEMP studies have shown that the nature and magnitude of changes within impacted areas exceed those in control areas.

Conclusions

Twenty years of monitoring the marine communities near the DCPP has shown that the discharge of large volumes of heated water produced by the power plant has had, and continues to have, effects on many species within Diablo Cove and nearby areas. The community found within the cove now includes a number of species that are more commonly found in warmer waters further south, but remain uncommon along the coast outside Diablo Cove. Other species that are still common along the coast north and south of the plant are now infrequent or absent within the cove. In the intertidal, algal cover has decreased while invertebrate abundance has increased. Bull kelp abundance initially decreased in the subtidal area. This change, an increase in giant kelp in Diablo Cove since 1990, and effects of increased temperatures from the discharge, have resulted in changes in the species composition and abundance of understory algae and invertebrates. Numbers of fish taxa have also increased in subtidal areas within Diablo Cove.

The result is an unusual community in the cove formed around a pocket of warm water in the midst of a cool temperate coastline. The floating, warm water plume can extend as a thin surface layer in a radius up to approximately 4 km (2.5 mi) distant from the power plant (for temperatures 2°F above ambient). Based on data presented in this report, effects of the discharge have been documented along a total shoreline distance of approximately 3.7 km (2.3 mi) that includes the shoreline areas of Diablo Cove, the south part of Field's Cove, South Diablo Point, and Diablo Rock. The biological communities within the affected area are continuing to change relative to control areas in response to the DCPP discharge and warmer water temperatures.

1.0 INTRODUCTION

1.1 Purpose

This report is a quantitative and qualitative analysis of the data collected by the Thermal Effects Monitoring Program (TEMP) to determine the effects of the Diablo Canyon Power Plant (DCPP) discharge in Diablo Cove and surrounding coastal areas. DCPP is a 2,200 megawatt, nuclear-fueled power plant operated by the Pacific Gas and Electric Company (PG&E). The plant has operated since 1985 and discharges approximately 2.5 billion gallons of cooling water per day under full two-unit operation. The TEMP studies began in 1976 and have continued as a requirement of the National Pollutant Discharge Elimination System (NPDES) permit. The results have been routinely submitted as annual reports to the California Regional Water Quality Control Board Central Coast Region (the 'Regional Board'). NPDES permit 90-09 (Appendix I), modified by the Regional Board on February 10, 1995, required that a comprehensive final assessment of the TEMP studies on the effects of the DCPP discharge on the receiving water communities be submitted.

The purpose of the TEMP studies was to determine changes in the biological community resulting from the DCPP cooling water discharge. Natural variation in biological communities complicates direct estimates of the effects of the discharge or other types of man-made disturbances. Effects can be determined by estimating the state of the biological populations that exist in the areas affected by the discharge before and after the disturbance, estimating the state that the biological communities would have had without the discharge by comparison with unaffected areas, and determining the uncertainty of these estimates (Osenberg and Schmitt 1996). The results of the TEMP studies provide estimates of the magnitudes and types of changes in the biological communities resulting from the discharge. This information is necessary for regulatory assessment of environmental impacts (Stewart-Oaten 1996a). The findings of this report are used in a companion report that examines the current NPDES discharge temperature limits relative to protection of the beneficial uses of the receiving waters identified in the California Ocean Plan.

1.2 Background

1.2.1 Power Plant Description

DCPP consists of two units, each of which uses a four-loop pressurized-water nuclear reactor as a steam supply system. Although each of the units has an independent seawater cooling system, they share common intake and discharge structures that together draw approximately 2.5 billion gallons per day (bgd) of seawater from a constructed intake cove, and discharge the waste heat from a shoreline discharge into Diablo Cove. The removal of heat from the condensers of both units (15.2×10^9 Btu/hour at full design power) results in point-of-discharge temperature about 11°C warmer than the incoming seawater temperature. The first warm water discharges occurred intermittently in late 1984 with the start-up testing of Unit 1. Nearly continuous thermal discharges began with the commercial operation of units 1 and 2 in May 1985 and March 1986, respectively. In the receiving water, the shoreline discharge is a surface layer of warm, buoyant water, that mixes with the cooler water in Diablo Cove as it flows offshore. Additional details on the operation of the power plant and characteristics of the discharge plume are presented in Section 2.0 - *Power Plant Operation and Thermal Plume Characteristics.*

1.2.2 Environmental Setting

DCPP is situated on a coastal terrace located in central California midway between the coastal communities of Morro Bay and Avila Beach (Figure 1-1). The 20 km (12 mi) (USGS 1:24,000) stretch of continuous rocky shoreline between these two communities consists of wave exposed headlands alternating with semi-protected coves. Diablo Cove has a surface area of approximately 15 hectares (38 acres). Field's Cove is directly north of Diablo Cove. South of Diablo Cove is the breakwater forming the DCPP Intake Cove, after which natural rocky shoreline extends to Avila Beach.

The average depth of Diablo Cove is about 8 m (26 ft) with a maximum depth of approximately 18 m (59 ft). The intertidal and subtidal areas of the cove consist of bedrock, boulder, and cobble fields. Submerged and emergent offshore rock pinnacles are scattered throughout the cove and in areas north and south. There are sandy subtidal areas in the southern portion of the cove. Diablo Creek enters Diablo Cove just north of the DCPP discharge and provides seasonal freshwater inflows. The north portion of the cove's subtidal area has practically no large sandy areas. Diablo Rock, a predominant feature of the cove, is centered at the mouth of the cove. Offshore of the cove, the sea bed continues to slope downward across the narrow continental shelf for approximately 80 km (50 mi) to a depth of over 1 km (0.6 mi).

California rocky nearshore intertidal and subtidal areas are characterized by diverse assemblages of algae, invertebrates, and fish (Ricketts et al. 1985; Foster and Schiel 1985; Foster et al. 1988). The algae are of particular ecological importance as food and shelter for associated animals (Lubchenco 1978; Kitting 1980; Cubit 1984; Foster and Schiel 1985; Geller 1991). The diversity of plants and animals is high, and natural variation in their abundance and distributions within the different nearshore zones results from variations in physical factors (temperature, elevation, wave exposure, open space, substrate type) and biological factors (grazing, predation, space competition, and recruitment episodes) (Dayton 1971; Connell 1972; Lubchenco and Menge 1978; Seapy and Littler 1978; Sousa 1979a; Dayton and Tegner 1984; Dayton et al. 1984; Foster and Schiel 1985; McGuinness 1987; Menge et al. 1994).

The natural ecological setting and species composition in the nearshore area of DCPP area have been previously described by Sparling (1977), Gotshall et al. (1984), PG&E (1988a), and North et al. (1989). It is similar to other central California rocky nearshore habitats north of Point Conception (located 138 km (86 mi) south of DCPP), as described by McLean (1962), Murray et al. (1980), Murray and Littler (1981), and Foster and Schiel (1985). Point Conception is a biogeographic boundary between warm-temperate organisms to the south and cool-temperate organisms to the north (Murray and Littler 1981; Haury et al. 1986; Hobson 1994). The entire area from approximately Monterey Bay south to San Diego is recognized as a biogeographic transition zone between the Oregonian Province north of Point Conception and the Californian Province that extends south to Magdalena Bay in southern Baja California (Morris et al. 1980). Although the area around DCPP is dominated by cool-temperate organisms, the area also has some organisms with primarily warm-temperate distributions (Abbott and North 1971). Abundances of many organisms in central California nearshore communities fluctuate during the year (e.g., Foster et al. 1988; Horn et al. 1983; Kinnetics Laboratories, Inc. 1992; PG&E 1994), particularly in response to winter storm waves, whereas fewer seasonal storm-related changes are seen south of Point Conception (Devinny 1975).

1.2.3 Effects of Thermal Discharges: Overview

A common cause of changes to receiving water communities from power plant operations is increased water temperatures from thermal discharges (Adams 1969; Coutant and Brook 1970; Vadas et al. 1976;

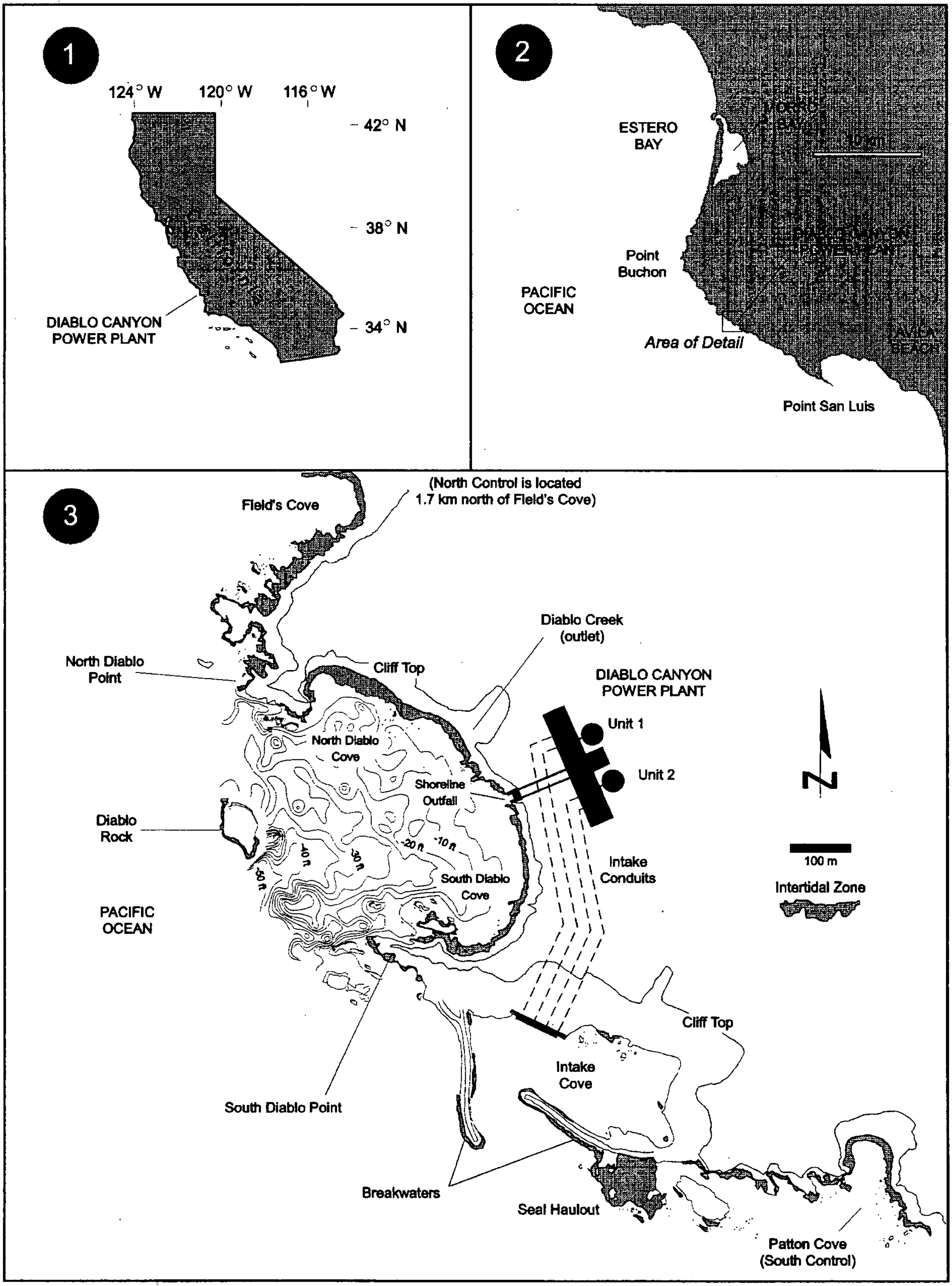


Figure 1-1. Location of Diablo Canyon Power Plant.

Hocutt et al. 1980; Bamber and Spencer 1984). Although considerable information exists in the scientific literature on the relationship between temperature and biological responses, there is relatively little on the actual effects of thermal discharges on rocky coast marine communities. DCPP is the only west coast power plant with a shoreline discharge along a predominantly rocky intertidal and subtidal habitat. Most information on the effects of power plants on the marine environment is in technical reports submitted for regulatory compliance. The Yankee Atomic Electric Company (1982) reviewed thermal effects studies at 16 east and west coast ocean-sited power plants in the United States. The review noted that the abundance of marine algae is often reduced by scouring and thermal effects in immediate discharge areas, but that beyond immediate discharge areas (yet still within the artificially warmed waters) algal abundance can be either unchanged or increased. Other investigations of power plant effects on algae have found localized reductions of brown algae (Arndt 1968; Bader et al. 1972; Vadas et al. 1976), and increases in ephemeral algae characteristic of early successional or disturbed communities (Markowski 1960; Adams 1975; Devinny 1975). Both types of changes were observed during the first seven years following power plant start-up at DCPP (PG&E 1994).

Effects on invertebrates have been less apparent. North (1969) found fewer relationships between temperature and invertebrates than with algae at the PG&E Morro Bay Power Plant in central California, 18 km (11 mi) (straight-line distance) north of DCPP. Similarly, no appreciable negative changes to invertebrate communities were found in the immediate discharge areas of other power plants (Yankee Atomic Electric Company 1982). Most changes were attributed to natural, coast-wide changes in populations. In some cases, invertebrate richness was actually higher in areas closer to thermal discharges. Many of the power plants reviewed by the Yankee Atomic Electric Company (1982) were adjacent to sandy beaches where differences in infaunal composition between locations were largely attributed to differences in sediment grain size. The San Onofre Nuclear Generating Station in southern California has an offshore discharge. No intertidal effects were detected on the predominantly sand or cobble beaches at this site, but declines in certain macroinvertebrates and kelp in the subtidal were attributed to loss of habitat from sedimentation and increased turbidity caused by the discharge, and not temperature (Murdoch et al. 1989).

Increased temperatures from power plant discharges can also result in localized changes in fish assemblages (Adams 1975; Stephens et al. 1994). Fish and other mobile organisms may avoid elevated discharge temperatures and move to thermal transition zones of lower warm water temperatures (Stephens and Zerba 1981). The diversity of fish assemblages was increased by thermal stratification associated with the discharge from a coastal power plant in King Harbor located in southern California (Stephens et al. 1994).

Temperature is recognized as a critical factor affecting species composition, abundance, geographic distribution, and vertical distribution (e.g., Kinne 1963; Norris 1963; Coutant and Brook 1970), and as an important physiological factor (e.g., Meldrim and Gift 1971; Lüning and Neushul 1978). More recently, it has become the subject of extensive review and study as a result of concerns about global environmental change, including atmospheric and ocean warming (e.g., Lubchenco et al. 1991; Dunham 1993; Carpenter et al. 1993; Lubchencho et al. 1993). Barry et al. (1995) suggested that a natural, long-term increase in ocean warming from 1931 to 1994 may have resulted in northern range extensions of some invertebrates, and a decline in some cold-water species at a site in Monterey Bay. These and other recent studies have benefited from extensive work on ecological community dynamics, including disturbance theory, which has been used to construct predictive models of species responses to natural and man-made perturbations (Bender et al. 1984). Direct effects on individual populations from temperature increases occur as a result of changes to reproductive and mortality rates (Ives and Gilchrist 1993). Temperature can also indirectly affect abundances through behavioral changes as a result of temperature avoidance or preference (Allen et al. 1970; Hocutt et al. 1980; Schroeter et al. 1993), and increased risk of disease (Andrews 1976; Vadas 1979; Goff and Glasgow 1980; Lessios et al. 1984; Carpenter 1988; Steinbeck et al. 1992). Although ecological theory has been useful for predicting the effects of temperature variation on direct species interactions, the indirect effects among species in complex food webs can be much less predictable, and potentially of greater importance (Yodzis 1988; Pimm 1991; Wooton 1994). When manipulative field experiments or disturbances occur over long time periods ('press experiments', *sensu* Bender et al. 1984), the dynamics of the indirect interactions in the system can increase with the duration of the perturbation (Schmitz 1997). The results of these studies have raised questions about the time required to reach some new equilibrium following a disturbance, and whether any equilibrium can be attained within a period of time that could reasonably be studied (Schmitz 1997). The duration of the studies at DCPP provided an opportunity to examine the effects of a variable, long-term 'press' perturbation, and the potential complexity of indirect effects that can occur.

1.3 TEMP Study Design

1.3.1 Background

The original study plan for the TEMP studies, the 316(a) Demonstration Work Plan, was submitted to the Regional Board in 1975 (TERA Corp. 1975). The studies from the original Work Plan, including those analyzed in the present report and others that were discontinued before or soon after power plant start-up, are shown in Table 1-1. The sampling schedules and studies comprising the program changed over time based on review and discussion with staff of the Regional Board and the California Department of Fish and Game (CDF&G). CDF&G conducted studies at the plant until 1982 and some of these studies were incorporated under the TEMP. The table identifies studies originally done by other research groups at DCPP that later became part of the TEMP. The Work Plan also called for laboratory thermal tolerance studies of temperature effects on survival, growth, behavior and reproduction of selected fish, invertebrates and algae. The laboratory studies, completed in 1982, investigated the thermal tolerances of 37 indigenous marine organisms (PG&E 1982a). Another component of the Work Plan was physical studies on the dispersion characteristics of the discharge plume. These studies were completed using mathematical and physical modeling and field measurements. The findings from the plume modeling and laboratory thermal effects studies were used to predict warm water discharge effects on select species, and were submitted to the Regional Board in the Thermal Discharge Assessment Report (PG&E 1982b).

1.3.2 Analysis Rationale

The four intertidal and seven subtidal studies analyzed for the present report were selected based on the completeness of their pre-operation and operation data. The data requirements of individual studies for analysis of discharge effects were agreed upon with the Regional Board staff, their consultants and CDF&G. The start of plant operations in 1985 and 1986 for units 1 and 2, respectively, provided nine year pre-operation and nine year operation study periods. Analyses of data from water temperature recorders were used to group stations into 'impact' and 'control' areas, with control areas defined by the absence of temperature increases resulting from power plant operation. The only available comparison data for two of the four intertidal studies were from stations located in Field's Cove, an area affected by the thermal plume. Results from the analyses of these studies were considered to be conservative estimates of the potential effects of the discharge. The amount of temperature increase in an area could be used to approximate the magnitude of changes, but could not be used to predict the types of changes

Table 1-1. Completion of TEMP studies from 1976 to 1995. Dark shaded areas denote studies completed during year, and data presented in this report. Light shaded areas denote studies completed during year, and data not presented in this report. Open boxes denote no data collected.

Intertidal Studies	Method Summary[1]	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Horizontal Band Transects	Algal cover and invertebrate abundances at permanent 0.3 m and 0.9 m MLLW stations. Transects 30 m in length, quadrats 1 m^2. 7 stations in Diablo Cove, 14 sta. outside of D.C.																				
Vertical Band Transects[2]	Intertidal fish counts, algal and invertebrtate presence/absence along vertically oriented transects. 4 stations in Diablo Cove, 1 station in Field's Cove.																				
Algal/Faunal Association[2]	Abundances of small intertidal invertebrates associated with two species of intertidal algae sampled by collecting algae in 0.01 m^2 quadrats. Lab processing and identifications.																				
Black Abalone	Census of abalone in Diablo Cove with a random quadrat method. Abalone also counted in 7 permanent 10 m transects inside and outside of Diablo Cove. Supplements HBT data.																				
Random-Point-Contact	Quantifies algal and sessile invertebrate cover by identifying species contacted at randomly selected points in 0.25 m^2 quadrats. 3 permanent quadrats at each HBT level.																				
Station Photography	Color and color infrared photos taken of random point contact quadrats on horizontal band transects during each biological survey. Concurrent with random point contact sampling.																				
Algal Biomass	Algae scraped in randomly selected 0.0625 m^2 quadrats to determine dry weight biomass of each component species.																				

Subtidal Studies	Method Summary	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Benthic (inverts, 28 m^2 arcs)	Invertebrates counted in permanent 28 m^2 stations inside and outside of Diablo Cove. Includes inverts greater than 2.5 cm and selected inverts of all sizes.																				
Benthic (inverts, ¼ m^2 quads)	Invertebrates counted in permanent 0.25 m^2 circular quadrats on same benthic stations as arc invertebrate counts. No size limitations on species counted.																				
Benthic Stations (algae)	Algal cover by species quantified within same permanent stations censused for invertebrates. Random point contact method (cover) for all species; kelp species counted.																				
Fish Transects	Diver counts of fish along permanent 50 m transects. Benthic and midwater transects surveyed separately. 7 stations in Diablo Cove, 3 in South Control (Patton Cove).																				
Bull Kelp and Giant Kelp[3]	Counts and locations of surface-emergent bull kelp plants in Diablo Cove. Giant kelp surface canopy coverage also mapped. Surveyed once per year in October.																				
Red Abalone	Random 30 m^2 areas surveyed by divers for adult and juvenile red abalone. Stations inside and outside Diablo Cove surveyed in summer of each year.																				
Crab Trapping	Rock crabs sampled using baited traps. Traps set for 24 hr in proximity to benthic sampling stations. Crabs measured, weighed, tagged and released.																				
Colonization Plates	Hard plates simulating bare rock surfaces placed on shallow subtidal benthic stations to measure abundances and cover of fouling organisms.																				
Video Transects	Contiguous subtidal transects videotaped to provide overview of algal assemblages, macroinvertebrates, fish, and substrate characteristics in Diablo Cove.																				
Fish Gut Contents[4]	Surfperch, rockfish and greenling species collected for examination of gut contents. Provided information on prey species and trophic interactions.																				
Fish Trapping	Plexiglas traps baited with mussels or frozen anchovy and deployed adjacent to subtidal benthic stations. Captured fish were measured, weighed, tagged and released.																				
Sedimentation Tubes[4]	Vertically-placed tubes quantified the settlement of particulates on benthic stations. Organic and inorganic fractions separated by combustion; grain size analyzed.																				
Primary Productivity[4]	Measured *in situ* respiration rates of selected subtidal algae by measuring oxygen concentrations in light/dark experimental chambers.																				

(table continued)

Table 1-1 (continued). Completion of TEMP studies from 1976 to 1995.

Other NPDES Data	Method Summary[1]	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Intertidal Temperature[5]	Water and air temperatures recorded every 20 min on biological sampling stations.																				
Subtidal Temperature[5]	Water temperatures recorded every 20 min on selected benthic sampling stations.																				
Kelp Aerial Photography	Color infrared photographs of surface kelp canopies from Pt. San Luis to Pt. Buchon.																				
Subtidal Light	Photosynthetic active radiation (PAR) measured at two benthic stations in Diablo Cove.																				
Current Velocity[6]	Current velocity and direction measured at moored buoy 1 km offshore of Diablo Cove.																				
Wave Height and Period[6]	Wave height and period measured with NOAA/Scripps Wave Rider 0.5 km offshore.																				
Dissolved Oxygen, pH[6]	DO and pH from collected water samples at 6 station/depths inside Diablo Cove.																				

[1] Additional descriptions of methods presented in appropriate report sections and Appendix B.
[2] Study initiated by PG&E independent of TEMP, and later incorporated into TEMP program in 1988.
[3] Study initiated by CDF&G and incorporated into TEMP in 1983.
[4] Short-term studies conducted for testing sampling methodologies.
[5] Partial data collected during 1980 due to changes in instrumentation.
[6] Conducted independent of TEMP; information not included in present report.

which may have occurred. 'Direct' effects of the discharge include impacts on organisms from increased water temperature, current changes, foam, chemical compounds, treated sewage from an onsite treatment facility, and shell debris sloughed from the cooling water system into Diablo Cove. 'Indirect' effects primarily result from ecological factors such as species interactions and interactions with disease. 'Direct' and 'indirect' effects on a species may be inseparable because of interactions between physical and biological effects.

The TEMP and other impact studies with both pre-operation and operation data, and impact and control study sites are defined as "optimal impact study designs" by Green (1979). While there has been little disagreement over what components are required for an optimal design, the best methods for analysis of such a design have been debated in the literature (e.g., Bernstein and Zalinski 1983; Hurlbert 1984; Stewart-Oaten et al. 1986; Underwood 1992; Green 1993; Underwood 1993), including a review volume devoted to the topic (Osenberg and Schmitt 1996). The difficulty in detecting impacts to natural populations results from the necessity of separating changes due to the impact from the co-occurring natural spatial and temporal variation (Stewart-Oaten et al. 1986). Natural spatial variation complicates the interpretation of designs that use direct comparisons of control to impact areas to assess effects, and natural temporal variation affects designs that use a test comparing pre-impact to impact periods. One of the sources of confusion about appropriate methods of analysis results from the fact that these are observational studies without true replication, and not experimental designs with replicated control and treatment groups (Eberhardt and Thomas 1991). Therefore, many analysis designs that rely on strict replication within treatment groups to control variation become confounded by interacting temporal and spatial sources of variation in an impact study. To avoid these problems, a Before-After/Control-Impact (BACI) design has been proposed that uses the differences in values ('deltas') between paired, contemporaneous sampling of impact and control stations to compute and compare deltas before and after an impact has occurred (Stewart-Oaten et al. 1986). If the assumptions of the design are met, the deltas remove the confounding effects of temporal variation from the computation of the difference between control and impact locations.

TEMP abundance data from repeated sampling of macro-algae, invertebrate, and fish assemblages at fixed stations within and beyond the influence of the discharge were analyzed for effects of the discharge using a modified BACI design. (As previously mentioned, the only available comparison data for two of the four intertidal studies were from stations located in Field's Cove, an area contacted by the thermal plume). Other data that did not meet the requirements of an optimal impact study design were analyzed for changes using a less powerful statistical test, the Fisher's exact test. In presenting and discussing the results of the analyses we use the terms 'significant change', 'significant increase' or 'significant decrease', to describe statistically significant changes. A significant change is interpreted as being caused by the discharge. All statistical tests for changes resulting from the discharge used a probability level of 90%, instead of the conventional 95% level. This was done to increase the statistical power of the tests to detect change, with the result that a greater number of significant changes were likely to be detected in the analysis (Winer et al. 1991). This convention was agreed upon with the Regional Board staff, their consultants, and CDF&G. The use of lower probability levels in ecological impact analysis increases the probability that changes resulting from the discharge do not go undetected, and also increases, on average, the likelihood of finding an impact which may not actually exist from 1 in 20 times, to 1 in 10 times. This increase in error rate is recognized as a reasonable tradeoff to ensure that impacts do not go undetected (Mapstone 1995; Peterman 1990).

The data were also analyzed graphically and used to corroborate the results of the statistical hypothesis testing done using the BACI and Fisher's exact test. Generally, at least two summer surveys and two winter surveys were done annually for each study component to encompass seasonal variation. The fixed station sampling design was considered important in the heterogeneous open coast environment of the

Diablo Canyon area where spatial variation can be large between nearby locations. The station locations, and their positions relative to mean lower low water (MLLW), were selected to monitor certain representative habitats and biotic assemblages, and not to monitor all of the organisms potentially exposed to the discharge. Random sampling for intertidal black abalone and subtidal red abalone was used to monitor population changes in areas exposed to the discharge plume. Additional details on sampling methods for individual tasks are presented in the following sections.

1.3.3 Study Limitations

The TEMP field study was originally designed in 1976 as an intensive short-term program that would collect 18 months of pre-operational data and 18 months of operational data. The design included a large number of intertidal and subtidal stations that were generally replicated within areas (Appendix B). For example, the original intertidal horizontal band transect study had multiple stations located in each study area, including north control, Field's Cove, north and south Diablo Cove, South Diablo Point, Seal Haul-out and south control. When initial plant operation was delayed, the original TEMP program was reduced by decreasing the number of stations in the program. These changes to the program over the course of 5-6 years reduced the ability of the study to detect changes in certain locations. Control stations that were retained throughout the study were able to be used in the final analysis of impacts.

The original study and subsequent changes were not designed to define gradients of change or areas of coastline affected by the discharge. All stations used in the original study design were fixed and repeatedly sampled through time. Fixed stations were the logical choice for a short-term study as they tend to reduce spatial variation within an area and increase the ability to detect changes due to plant operation. The fixed design was also a reasonable design choice based on the short duration of the study and the large complement of stations. As stations were eliminated from the program, the areal extent of inference was reduced to comparisons of Diablo Cove to one or two control areas. Statistically, a fixed design does not allow extrapolation across areas, as the area of inference is strictly limited to the sampled area. Another limitation of the fixed sampling, in combination with a reduced list of stations, was the inability to detect spatial gradients of change, either within Diablo Cove, or more importantly outside Diablo Cove. In this report, gradients of change are discussed using a combination of quantitative data and qualitative observations.

The location of stations also became a limitation of the study when it was observed that Field's Cove was impacted by the thermal plume. Early thermal modeling and thermal plume verification studies did not focus on movement of the plume into Field's Cove, but rather on the offshore extent of the plume. It was not realized that temperature increases in Field's Cove were biologically significant until after several years of operation when biological changes became apparent. The lingering changes from the 1982-83 El Niño also made early detection of the changes in Field's Cove more difficult. Temperature monitoring at the biological sampling stations showed increased seawater temperatures in Field's Cove after two-unit operation began. The TEMP monitoring throughout much of the pre-operational period had been limited to a single intertidal station in Field's Cove. Additional intertidal and subtidal stations located in Field's Cove were added to the program in 1990, but these stations had no pre-operational data, and therefore could not be used to detect discharge effects in a BACI design.

Two studies begun by PG&E to supplement the TEMP monitoring used a single control station in Field's Cove. The vertical band transect (VBT) study was designed to sample intertidal fishes and intertidal vertical gradients in algal and invertebrate communities, and the algal-faunal association study (AFAS) was designed to sample invertebrates associated with certain habitat-forming intertidal algae. Both of these programs focused on habitats and communities not studied by TEMP. As a result, these programs that had been started by PG&E in the pre-operational period were added to TEMP in 1990. The analysis of these studies uses the same Before-After-Control-Impact (BACI) design used to analyze effects from other studies. The design differs from others by using Field's Cove as a reference for computing measures of relative change for the Diablo Cove stations. This analysis was done, rather than analyzing for changes before and after plant operation, because of the increased power of the design to detect change. This approach is valid if the effects detected from the analysis were treated as conservative estimates of impact. A probability level of 90%, instead of the conventional 95%, was used in determining impacts for all statistical testing. Consequently, on average, a greater number of significant impacts were likely to be detected by the analyses. Unless effects in Field's Cove were large, this approach should result in detecting impacts that may have been reduced by the use of Field's Cove as a control and impacts that may have gone undetected using a probability level of 95%. Also, qualitative and quantitative observations have shown that effects in Field's Cove are much less than in Diablo Cove.

Some habitats that were potentially affected by the discharge were not studied (e.g., sand and cobble beaches). The program studies focused on benthic hard bottom communities in the intertidal and subtidal, as these were the most common habitats along the stretch of coastline near the power plant. These habitats are also more stable than the cobble or sand communities that are not as common as the hard bottom habitats. The susceptibility of the cobble and sand habitats to natural disturbance by storms, waves and seasonal deposition of substrate made them less desirable for detecting changes due to the power plant. The TEMP program was also largely designed to assess changes in the abundance of larger conspicuous algae, invertebrates and fishes. With the exception of the AFAS study that collected samples of specific habitat forming algae that were sorted in the laboratory for associated small invertebrates, all sampling was non-destructive and all organisms enumerated were observable without the benefit of magnification. Other smaller infaunal organisms, phytoplankton and zooplankton were not studied as part of the program.

Other decisions on areas and habitats studied were dictated by the practicality of sampling certain habitats along an exposed stretch of coastline. Intertidal sampling for the horizontal band transect study was limited to two tidal elevations and did not include elevations below the +0.3 m tidal level. The lower intertidal and shallow subtidal area between +0.3 m and -3.0 m MLLW was not sampled due to the difficulty and hazards of sampling within this zone, primary habitat for surfgrass *Phyllospadix* spp. and feather boa kelp *Egregia menziesii*. These taxa are known to be important habitat formers in the nearshore area. The same rationale was used when deciding not to sample directly within the turbulence zone of the discharge and on wave-exposed headlands, surge channels and offshore rocky areas which are known to be contacted by the plume.

In 1987, following the submittal of the TEMP Final Report (PG&E 1988a), studies on changes in algal biomass, rock crab populations, algal and invertebrate subtidal colonization and subtidal light were discontinued. PG&E, CDF&G and the Regional Board agreed to discontinue these studies and still preserve the core intertidal and subtidal components to address NPDES monitoring requirements. The algal biomass study was never a requirement of the TEMP program. This study used destructive sampling techniques and the total number of available samples was limited. All available samples were collected during the nine years the study was conducted (Table 1-1). The subtidal light study was designed to measure light transmittance through the water column. However, variation in kelp canopy shading and debris covering the light sensors produced highly variable data that could not be used to accurately detect power plant effects. In 1990, the algal-faunal association and vertical band transect studies were added to the TEMP program and the intertidal random-point-contact, station photography, subtidal video transect, and kelp aerial photography studies were discontinued. PG&E, the Regional Board and the California Department of Fish and Game agreed to discontinue the random-point-contact study because it provided the same type of information as the horizontal band transect study. Photographic and videographic documentation were also discontinued because it was determined that they only provided information supplemental to existing studies. These and other changes to the program are shown in Table 1-1.

1.4 Report Format

Sections 1.0 and 2.0 provide background and temperature information relevant to results presented in subsequent sections. Results, methods and discussion of the intertidal and subtidal biological studies are in sections 3.0 and 4.0. Detailed discussion of the methods used for analysis of the data are in Section 3.0, and not repeated in the subtidal section, Section 4.0., Section 5.0 synthesizes information from sections 3.0 and 4.0 on the spatial and temporal extent of the changes resulting from the discharge. Section 6.0 presents the literature cited.

The following appendices are included with the report: a list of the personnel associated with the project (Appendix A), tables illustrating the time periods when each station was completed for a specific study (Appendix B), graphs of temperature over time at all recording stations (Appendix C), a list of current scientific names and taxonomic references for all organisms sampled during the study (Appendix D), graphs of abundance over time for the taxa comprising the top 99% of the total abundance for each study (Appendix E), lists of taxa used in analyses for each study (Appendix F), results from assumption tests, BACI analyses and Fisher's exact test for taxa analyzed (Appendix G), an independent evaluation of the computer programs used in the analysis of the data (Appendix H), and the sections from the NPDES permit listing the limitations for all of the plant's discharges (Appendix I). A separate Data Appendix volume includes tables of survey means for all taxa by sampling method and statistical output tables for BACI ANOVA, Fisher's exact test and correspondence analysis for all studies analyzed in the present report.

Over the course of study, the scientific names of many organisms have changed as a result of taxonomic revisions. The TEMP species lists used in this report were reviewed for accuracy by researchers familiar with the accepted name changes. Additional revisions of species names were obtained from current published references. Appendix D lists the current names and synonyms used in past TEMP annual reports. The results often discuss 'taxa' as opposed to species. Taxa is a more general term and may refer either to a single species, or to several species grouped together. Although the majority of organisms were identified to the species level during the study, the data were grouped into taxa for analysis because they were closely related and difficult to distinguish, or because they formed a logical ecological grouping, such as 'midwater fishes'. The names of the sampling stations used in the present report differ from those used in past TEMP reports. Station names were changed to make their location more descriptive in text, table, and figure reporting. A comparison between the present and previous station names is presented as part of Appendix B.

2.0 POWER PLANT OPERATION and THERMAL PLUME CHARACTERISTICS

2.1 Discharge Description

2.1.1 Power Plant Intake, Condenser Cooling, and Discharge Systems

Diablo Canyon Power Plant (DCPP) units 1 and 2 have independent cooling systems for re-condensing freshwater steam for the turbine power cycle. Each unit has its own system of intake and discharge conduits, but they all share the same intake structure and discharge location (Figures 2-1 and 2-2). During normal operation, seawater is drawn from the Intake Cove through the Unit 1 and Unit 2 conduits and pumped approximately 26 m (85 ft) above sea level to the two condenser systems. The freshwater steam is condensed back to water by transferring heat to the seawater. The warmed seawater for each unit is then discharged back into the ocean at the shoreline of Diablo Cove. The discharge system consists of two parallel conduits (one for each unit) that interact with each other immediately before discharging into Diablo Cove. Cutouts in the center wall that separate the two conduits allow mixing when flows from both units are unequal, but are of less importance when the flows from each unit are equivalent. The velocity of the effluent at the point of discharge into Diablo Cove is relatively high due to the momentum created by the water cascading down the discharge conduits, beginning from an elevation of about 26 m above mean lower low water (MLLW) and ending at the shoreline. The first warm water discharges occurred intermittently in 1984 with start-up testing of Unit 1. Commercial operation of Unit 1 began in May 1985, and Unit 2 in March 1986.

2.1.2 Flow Volumes and Point-of-Discharge Water Temperatures

Each condenser cooling system is served by two main seawater pumps. The pumps produce a combined rated flow for Unit 1 of between 778,000 gpm and 854,000 gpm, and for Unit 2 of between 811,000 gpm and 895,000 gpm (two-unit combined flow is 1,589,000 gpm minimum and 1,749,000 gpm maximum). The removal of heat from the condensers of both units (15.2 x 10^9 Btu/hr at full design power) during normal operation results in a discharge temperature of about 11°C warmer than the incoming seawater temperature, but varies depending on intake temperature, electrical generation heat load, condenser cooling efficiency, and other operating parameters of the power plant.

Changes in discharge flow volumes, intake and discharge temperatures, and differences between intake and discharge temperatures (referred to as delta T°) are portrayed in Figure 2-3. Intake temperatures are measured within the cooling water conduits directly behind the circulating water pumps, and discharge temperatures are measured at a point beyond the condensers where discharge flows mix before cascading through the discharge structure into Diablo Cove. A comparison of intake temperatures and subtidal control temperatures confirmed that intake temperatures are unaffected by thermal discharges. Discharge flows are about 2.5 billion gallons per day at maximum, but the flows become lower when pumps are taken out of operation (e.g., during unit outages) (Figure 2-3a). Refueling outages, lasting about 40 days each, occur at approximately 18 month intervals per unit, and are offset in schedule so that at least one unit is operating at all times. Outages do not necessarily result in lower discharge temperatures unless all four cooling water pumps remain operational (e.g., half the heat load with full cooling water volume).

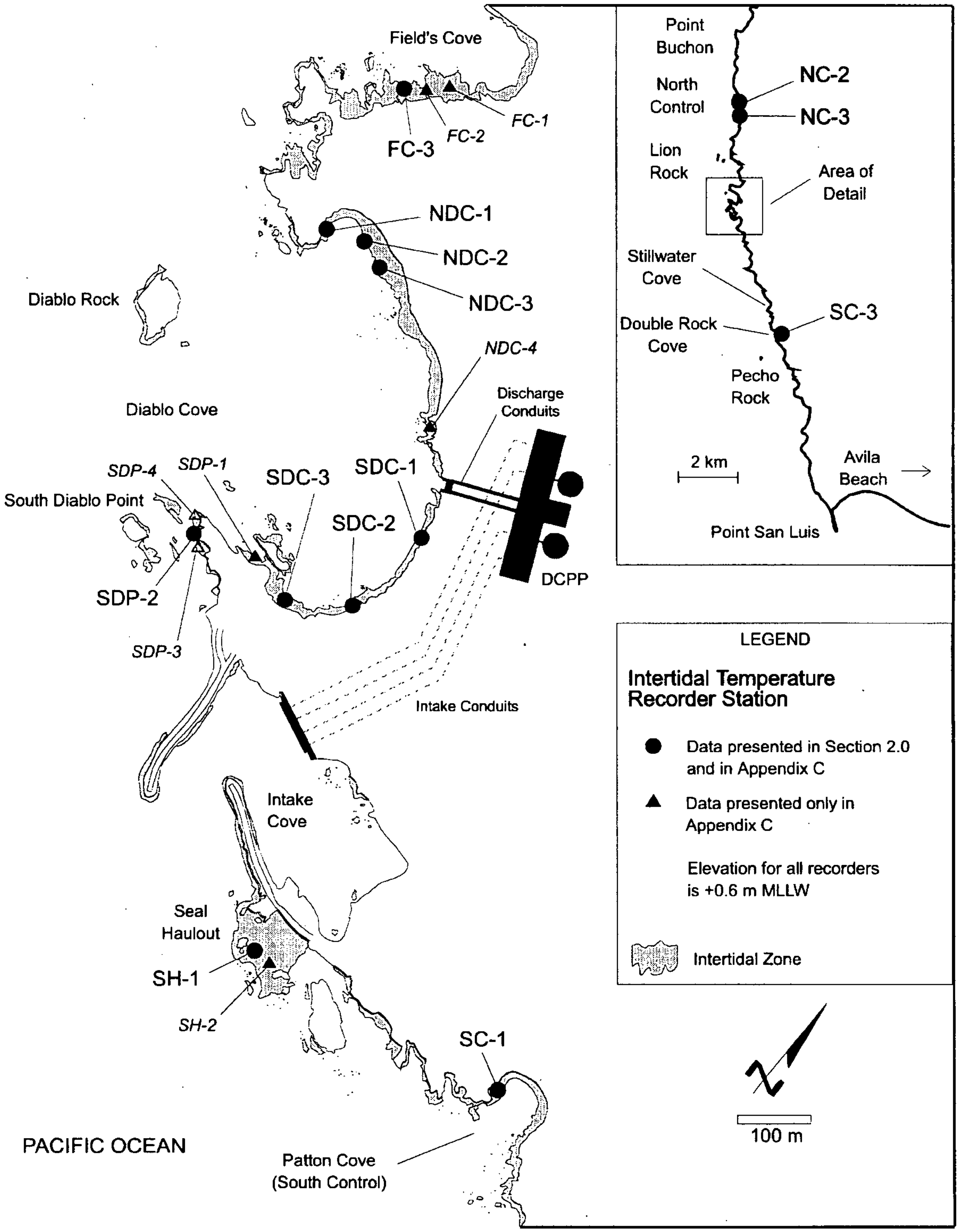


Figure 2-1. Locations of intertidal seawater temperature monitoring stations.

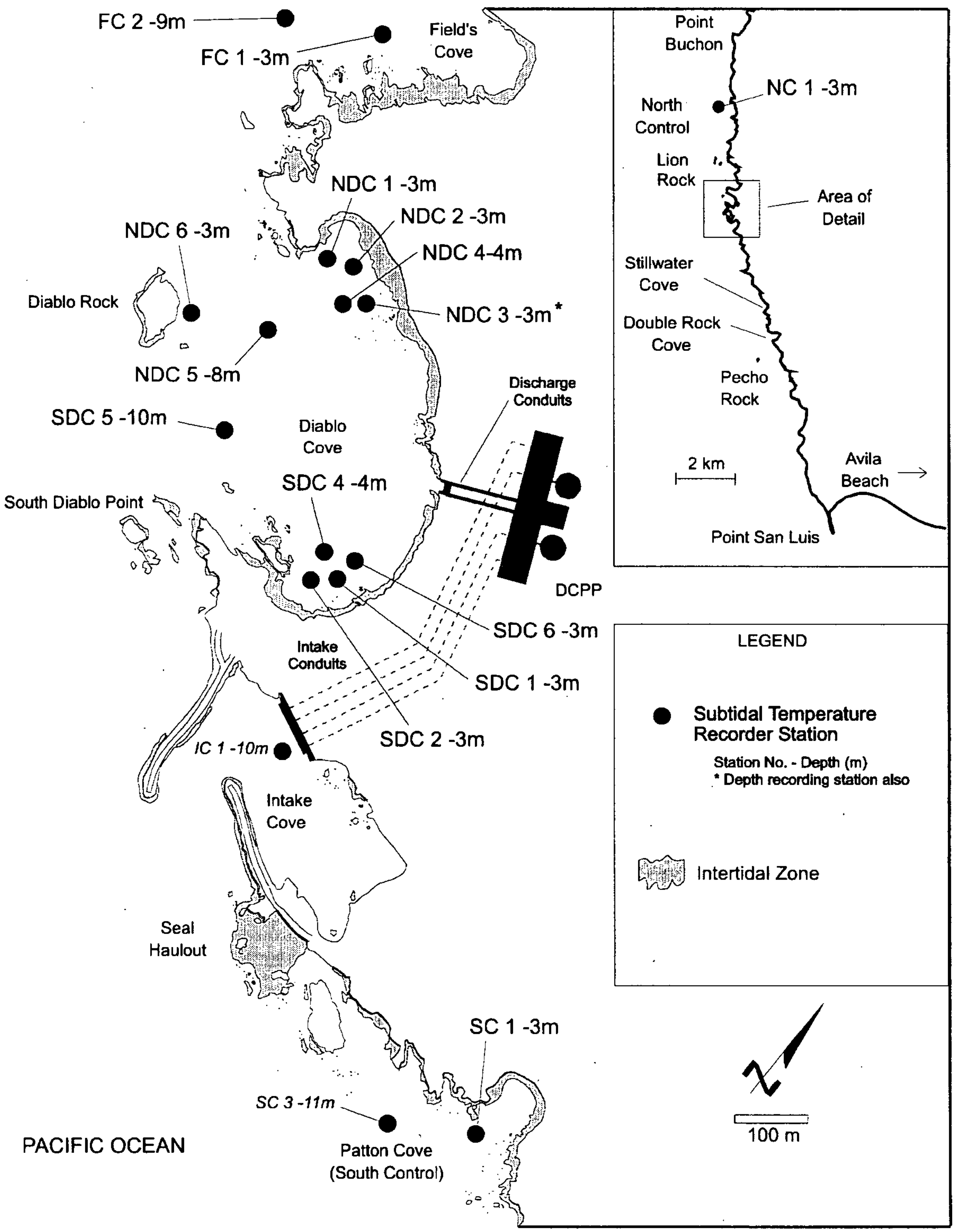


Figure 2-2. Locations of subtidal seawater temperature monitoring stations.

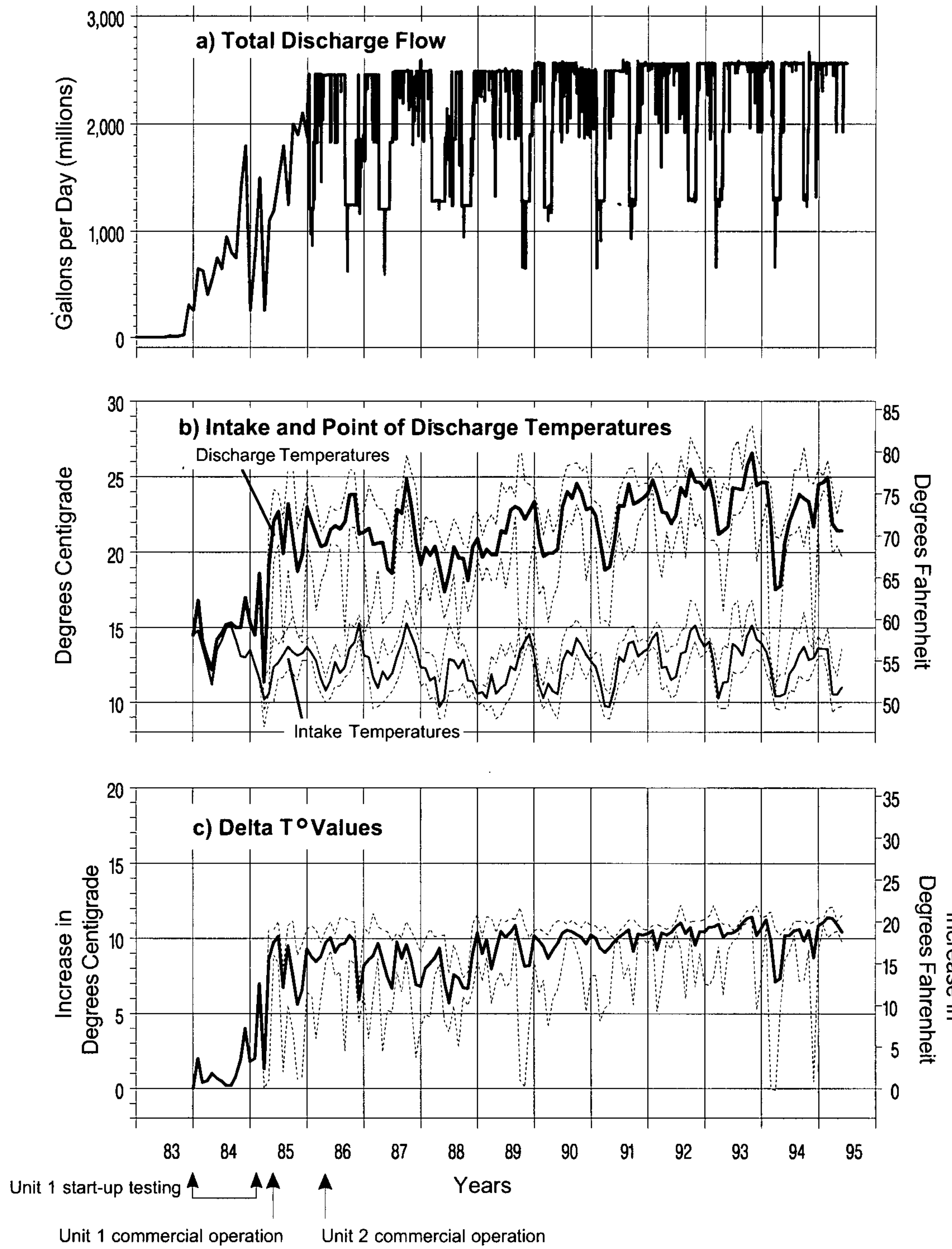


Figure 2-3. Power plant discharge characteristics. (a) Daily discharge flow volumes. (b) Monthly intake and point of discharge temperatures. (c) Monthly differences between intake and discharge temperatures (delta T ° values). Monthly data (b,c) are the averages of daily values. Dotted lines (b,c) are highest and lowest daily values by month. Data were obtained from monthly and annual NPDES reports submitted by PG&E to the RWQCB. Flow data prior to January 1986 and temperature data prior to April 1985 were obtained from PG&E 1988a (Figures 1.1.1-2 and -3, respectively).

Openings connecting the Unit 1 and Unit 2 discharge conduits allow partial mixing for thermal dilution of the two discharge flows at locations upstream from the point where discharge water temperatures are measured. There was a slight increase in recorded discharge flow volumes, beginning in 1990 (Figure 2-3a). The increase is due to changes in the methods of flow measurement and flow computation.

Discharge temperatures also fluctuate due to changes in the temperature of the ambient seawater (Figure 2-3b). Ambient temperatures vary seasonally, and from year to year. Warmest ambient temperatures normally occur in fall (approximately 15°C [59°F]). Lowest ambient temperatures normally occur in spring (approximately 9°C [48°F]). The warmest monthly mean point-of-discharge temperatures of 26-27°C (79-81°F) occurred in 1993. The maximum daily discharge temperatures that year slightly exceeded 28°C (82°F). Lowest monthly mean discharge temperatures occurred in spring 1994 and were about 17.5°C (63.5°F), with the lowest daily discharge temperatures during the same period of about 12°C (54°F).

Overall, from 1984 through 1986, discharge flows, temperatures, and delta T°'s varied with the start-up testing and commercial operation of Unit 1, the start-up testing and commercial operation of Unit 2, and shutdown of Unit 1 for its first refueling outage. Both power plant units were in simultaneous operation in fall 1987 when a minor El Niño condition resulted in discharge temperatures higher than normal. Lowest discharge temperatures occurred in 1988 as a result of unit outages and the end of the 1987 El Niño event (Figure 2-3b). From 1988 to 1994, discharge temperatures gradually increased, and this is reflected in delta T° values (Figure 2-3c). The increasing trend was interrupted in spring 1994, as a result of a unit outage (Figure 2-3b, c). The increase in discharge temperatures was due to increased amounts of rejected waste heat generated by normal wear on power plant components associated with the cooling water system. The increase in rejected waste heat is due in varying amounts to feedwater nozzle fouling, loss of steam between the generator's turbine blades and housing due to erosion, diminished seawater flow through the heat exchangers from plugged condenser tubes, and losses in seawater pump efficiencies due to erosion. Since 1994 the feedwater nozzle fouling problem has been eliminated and the units have been able to run more consistently at higher power through a fuel cycle without producing a continuation of the rise in delta T° values.

2.1.3 Characteristics of the Thermal Plume

The DCPP discharge has momentum from its 26 m drop in elevation and buoyancy from its increased temperature. The thermal discharge plume, when entering the receiving water, pushes aside ambient water at a constant velocity. Downstream the plume expands both laterally and vertically. In this area the mean velocities and temperature levels decrease with distance from the discharge point due to mixing with ambient water. The rate of mixing depends on many factors such as the shear stress induced by velocity differential and turbulence between the plume and the ambient flow. The mixing rates of ambient waters are further compounded by the topography, which limits the lateral mixing due to the semi-enclosed bay at Diablo Cove, and the bathymetry that inhibits the vertical mixing due to the shallowness at different tide stages. At some point along the plume's trajectory, the momentum is diluted to the extent that the force of buoyancy becomes dominant. At this point the plume will detach (or 'lift-off') from the bottom and become a surface phenomenon. The surface plume is subject to buoyant spreading that is an essential process in dissipating waste heat to the atmosphere. In general, the plume can be categorized into two regions in which different physical processes occur: the near-field within Diablo Cove where the plume's inertia is the dominant force; and the far-field beyond the cove where the buoyancy force dominates. Environmental factors such as winds, tides, waves and ambient current interact with each other and the plume dynamics resulting in various configurations for the DCPP thermal plume.

The Diablo Canyon Power Plant discharge system and characteristics of the receiving water body are complex, resulting in highly dynamic thermal plume dispersion patterns in the receiving waters. The immediate receiving water area is shallow with a typical water depth of less than about 3 m (10 ft) MLLW over a distance of 137 m (449 ft) from the outfall. The topography directly in front of the discharge consists of shallow water rock ridges at oblique angles to the plume's trajectory. These bottom features modify the direction and momentum of the discharge plume depending on tide. During low tides the rock ridges act as guidance vanes that deflect the discharge plume northward towards Diablo Rock. The plume at high tide is oriented more in-line with the discharge structure and the south channel of the cove.

Thermal dilution, from cross flow of ambient water into the immediate discharge area, is determined by the volume and velocity of the discharge flow into Diablo Cove. The lower boundary of the thermal plume in Diablo Cove varies between -5 m (-16 ft) and -11 m (-36 ft) MLLW. Maximum plume depths coincide with extreme low tides, high wave action, and strong winds. Minimum depths coincide with extreme high tides, low wave action, and calm winds. Warm water eddies and countercurrents occur at the plume's boundary areas. As discharge velocity decreases, thermal buoyancy becomes dominant and causes the plume to lift-off the bottom to become a surface layer of warm water as it exits Diablo Cove (Figure 2-4).

At the mouth of Diablo Cove a small island, Diablo Rock, obstructs the discharge plume. As the plume bifurcates around Diablo Rock, the plume downwells on the inshore side of the rock, and deeper ambient water upwells on the offshore side (Figure 2-4). The plume's general line of trajectory also shifts back and forth slightly within a day. During low tide, the rock ridges in front of the outfall tend to deflect a larger portion of the plume north towards Diablo Rock, resulting in a portion of the plume exiting from the north channel. The north channel of the cove is shallower than the south channel. This, in combination with prevailing northwesterly winds and currents, slows any warm water that may exit through the north channel of Diablo Cove. During high tide, the plume tends to pass over the near-field ridges without changing its direction and the plume exits Diablo Cove through the south channel between Diablo Rock and South Diablo Point. The topography in this area is more irregular, consisting of wash rocks originating from depths of about 18 m (59 ft). Hydraulics of the discharge plume cause it to entrain cold bottom water and create a subsurface countercurrent into Diablo Cove through the south channel where the smooth topography of the bottom allows uninterrupted current flows into the cove. This subsurface flow is often seen as a discrete thermocline at depths of between 8-10 m (26-33 ft). The amount of the ambient water entrained by the subsurface countercurrent is estimated to be about 50% to 150% of the discharge flow. The subsurface countercurrent provides a large volume of cooler water for mixing with the discharge. Its effects are more prominent in the south portion of the cove, resulting in the cooler water temperatures there.

In the offshore area the shape and size of the plume are affected by winds and currents. The winds and currents can vary rapidly in strength and direction, producing highly dynamic offshore plume dispersion patterns. Prevailing winds and currents from the northwest can deflect the offshore plume movement southward, or winds and currents from the south can move the offshore plume northward, and under certain situations towards Lion Rock and into Field's Cove. Details on variation of offshore plume configurations are given in Section 2.2 - *Receiving Water Temperature Monitoring*.

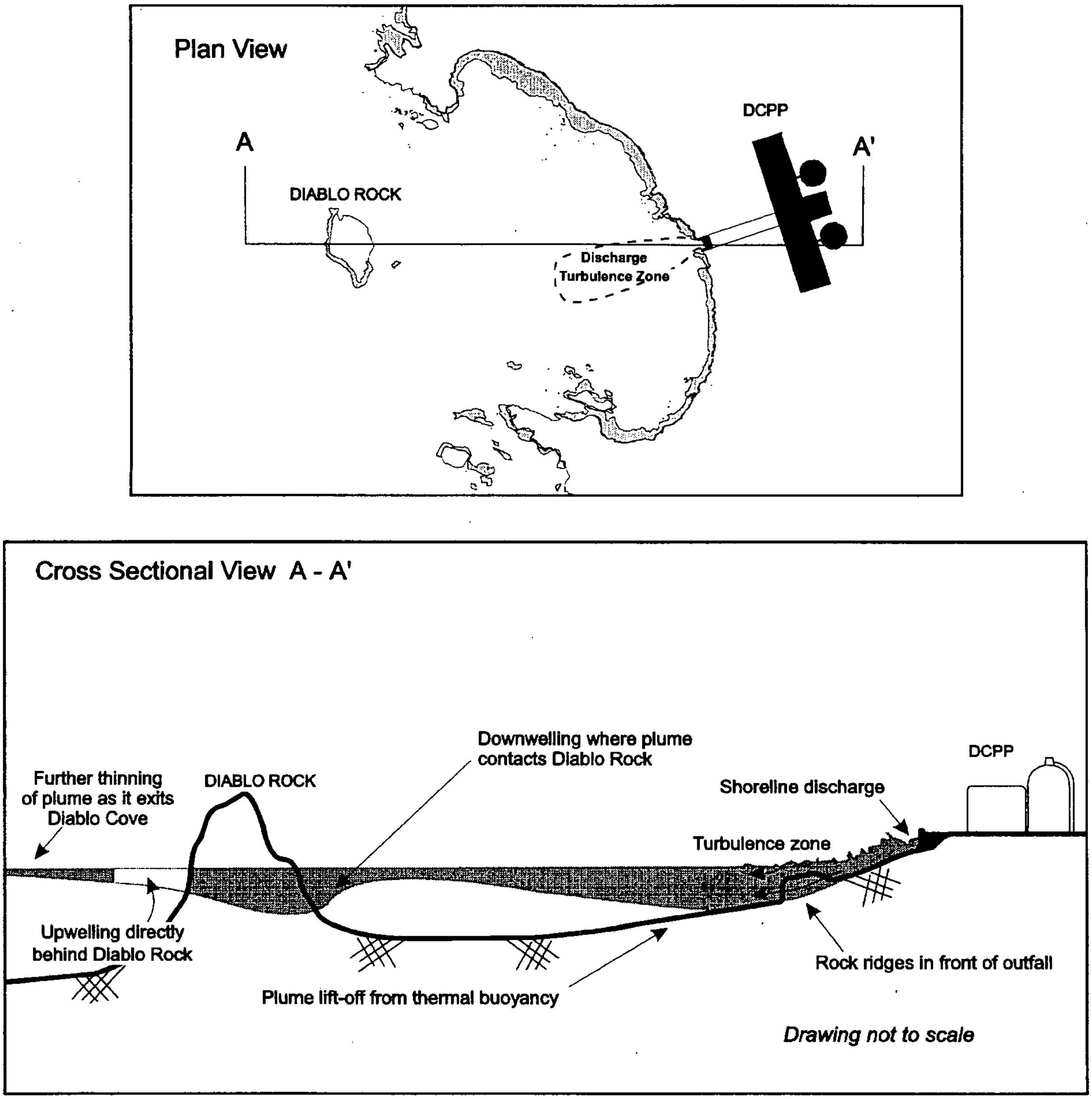


Figure 2-4. Conceptual diagram of a cross sectional view of the thermal plume in the near-field receiving water of Diablo Cove.

2.1.4 Plant Biofouling Control Operations

The plant's cooling water system conduits present an enormous amount of surface area for the settlement and growth of marine fouling organisms. Two types of fouling occur in a power plant. Micro-fouling by small unicellular algae and bacteria is a problem in the plant's condenser tube system, where the resulting surface layer of fouling organisms reduces the efficiency of heat transfer. Macro-fouling, primarily mussels and barnacles, attach and grow on most untreated surfaces that are exposed to the flow of seawater through the plant. These organisms are filter feeders and the continual flow of seawater through the system provides a rich food source for rapid growth. Left uncontrolled, mussels and barnacles eventually break off the conduit walls and plug the plant's condenser tubes, decreasing plant efficiency.

Heat treatment was used as the primary macro-fouling control method from 1985 to January 1989. During this period 13 heat treatments were done to control biofouling within the intake conduits. Heat treatment was done on one unit at a time. During heat treatment the conduit being treated was partially closed off so the discharge flow was only 25% of normal. The remaining water in the system was recirculated until it reached a temperature of 40.5°C (105°F) for about 45 minutes. Discharge temperatures were elevated above normal for this period of time (but still within discharge temperature limits allowed for heat treatments) (PG&E 1988b). Discharge volumes were lowered due to the decreased flow from the unit being treated, resulting in a plume that was different from normal operation. Field and modeling studies found that the thermal plume during heat treatment was as much as 2°C greater at the surface than normal plume surface temperatures, but the plume contacted less bottom area due to greater thermal buoyancy (Leighton 1988). Heat treatments did not cause a detectable rise in temperatures at intertidal or subtidal monitoring stations above those that occurred during normal plant operations.

Organisms killed during heat treatments were not physically removed from the system resulting in condenser tube plugging. In 1989, heat treatment was replaced by manual scraping of biofouling organisms from the conduit walls during 50% power curtailments. During manual scraping all the biofouling material was removed from the system eliminating the animal material in the conduits that could dislodge and plug the condenser tubes. In 1992, an automated chemical injection system for controlling biofouling was installed at the intake. Acti-Brom (Nalco Chemical Co.) is a proprietary sodium bromide solution that is blended with sodium hypochlorite (bleach) to inhibit settlement and growth of biofouling organisms. The solution is injected six times daily, each for 20 minutes, at a rate to maintain compliance with NPDES limits. Concentration of total residual oxidant (TRO) upon release to the receiving water is very low (<20-70 ppb). Chronic toxicological assays of Acti-Brom at these concentrations were negative for larval red abalone (*Haliotis rufescens*). The solution has the additional benefit to plant operation in controlling micro-fouling inside the condenser tubes.

2.2 Receiving Water Temperature Monitoring

2.2.1 *Methods*

Offshore surface thermal plume mapping

The thermal plume's characteristics from the point of discharge were investigated and analyzed in both the near-field and far-field regions of the discharge in three major studies: 1) an extensive field survey series; 2) a 1 to 75 scale physical model; and 3) a far-field numerical model.

Studies of the thermal plume were done during start-up testing of Unit 1 in 1984 and Unit 2 in 1985 (PG&E 1986), during thermal verification studies in June 1986, and during NPDES plume surveys from 1986 to 1990. The results were analyzed as isotherms of excess plume temperature above ambient that were measured or simulated under a variety of oceanographic and power plant operating conditions. Comprehensive analyses of the behavior of the DCPP discharge plume, including the surface and depth distribution of excess temperature, temperature dilution and decay, plume trajectories, velocity drogue vectors, current data, plume isotherms and buoyant spreading area extent, and the geographic locations of shoreline and bottom detachment of the plume are discussed with respect to various environmental factors for the near-field and far-field regions in Leighton et al. (1986) and Tu et al. (1986). Several studies were done to estimate the dilution factor for the thermal discharge plume (Leighton 1988). Plume isotherm maps prepared from these analyses are included along with a listing of the various thermal plume field surveys and reports in Appendix C. The following description of the plume is summarized from findings presented in Leighton et al. (1986), Tu et al. (1986) and Leighton (1988). Other data files and sources of thermal plume information, listed in the Data Appendix, were also reviewed and considered in summarizing thermal plume findings.

The plume data were obtained primarily by a towed electronic bathythermograph unit near the water's surface (<0.3 m depth) with a microwave navigation system for positioning. Additionally, during June 10-12, 1986, aerial infrared (IR) sea surface temperatures were measured to provide a data base for thermal verification testing (TV series). An optical imaging system developed by Battelle-Northwest was used to collect data on the thermal plume. The system had a detector sensitive to IR radiation (8-14 μ) which provided temperature sensitivity to < 0.5°C. Data collected with the system were representative of surface seawater temperatures. A separate IR system on board a boat was used to ground truth the aerial IR data.

Data on sea surface temperatures were also collected approximately bimonthly using a towed electronic bathythermograph. These data and other plume profiling collected during power ascension testing and thermal verification testing are included in Appendix C3. These data were collected to determine the offshore extent of the plume and therefore do not include data from nearshore shallow subtidal areas. Sea surface temperature profiles from 40 of the surveys from December 1985 through April 1990 presented in Appendix C3 were compiled into a composite profile to determine the extent of the plume under a variety of environmental and power plant conditions. Data were generally collected during calm sea conditions. Higher winds and waves can dissipate the plume, reducing it's size. These conditions more commonly occur during winter and spring. The 40 surveys are more representative of summer sea-state conditions. The plant operating conditions from the 40 surveys are representative of plant operation during the years of operation in which the surveys were conducted. The composite figures present the frequency of occurrence for the 1.1°C (2°F) and 2.2°C (4°F) isotherms. Each frequency contour represents an envelope collectively derived from all plume measurements and does not represent the plume extent at any single time. The composite figure shows the 1.1°C plume isotherm extending 2 miles upcoast and 2 miles downcoast from DCPP, a condition that would never occur.

Fixed monitoring stations

Digital temperature recorders were placed inside metal canisters at permanent +0.6 m (2 ft) MLLW intertidal stations and at permanent subtidal stations that ranged in depth from -3 to -11 m (-10 to -36 ft) MLLW (Figures 2-1 and 2-2, respectively). The designation of individual stations reflects their area location and number, followed by elevation or depth relative to MLLW. (e.g., Station NDC 1 -3 m is subtidal station 1 in north Diablo Cove at a depth of -3 m MLLW.) A station may be referred to by its location and number only (e.g. NDC-1), in cases where its elevation or depth is previously mentioned. For example, all intertidal temperature recorders were placed at +0.6 m MLLW. Therefore, the intertidal temperature stations may be referenced using only their area and number.

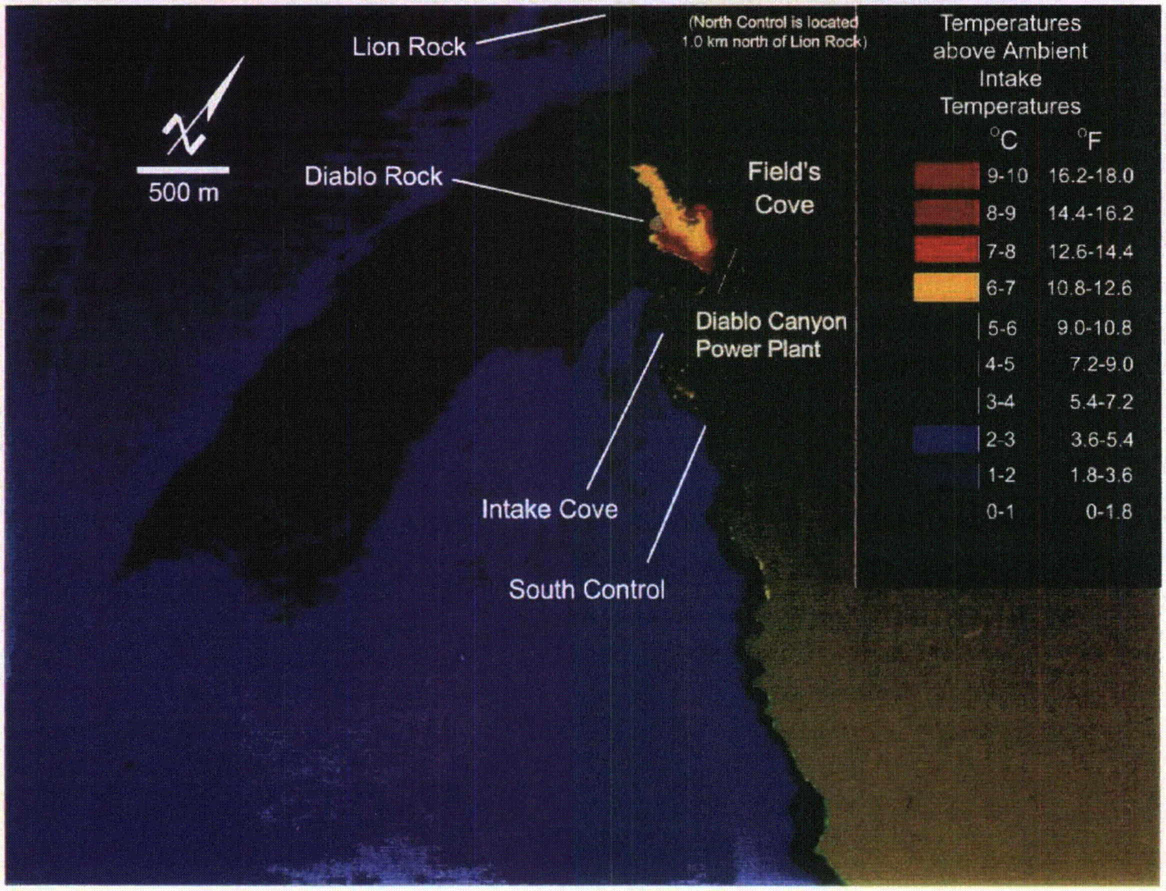
Temperature recorders at the stations synchronously logged water temperatures (or air temperatures during low tide for intertidal recorders) at 20 min intervals. Temperature resolution was 0.02°C, with an accuracy of ±0.2°C. Instruments were exchanged with serviced and calibrated units at approximately 60 day intervals. The data from the recorders were downloaded to a computer for processing into engineering units and transferred to a database for storage and analysis. In 1980, the type of instrument used in recording temperature was replaced by another model and no temperature recording units were deployed in the field.

2.2.2 Overview of Receiving Water Temperature Changes

Offshore surface thermal plume mapping

The aerial IR data present excess surface temperatures as varying colored pixels. The tests used the plant's intake temperature recorder as the ambient value used in computing excess temperatures. Seawater at the intake is withdrawn from a depth of 5-10 m (16-33 ft) and can be lower in temperature than surface water. The IR data of surface temperatures show that the intake temperature (measured at -5 m MLLW) for the thermal verification test on June 11, 1986 (TV-7) was approximately 1.1°C cooler than surface temperatures measured offshore using a towed bathythermograph (Leighton 1988). Therefore, the isotherms presented in the figures represent natural heating and the effect of the discharge plume (Leighton 1988).

Data for two tests were collected while the plant was operating at 100 percent power for Unit 1 and 70 percent power for Unit 2 (Figures 2-5 and 2-6). Test TV-7 (Figure 2-5) was done on June 11, 1986 under mid-tide conditions and shows that, although warm water at the surface is diverted out the north channel, the central plume jet (warmest temperatures) is directed towards the south channel of the cove. The aerial IR representations of the plume only portray temperatures from a thin layer of surface water. They do not portray the three-dimensional dynamics of the plume that result from changes in its mass and momentum, as depicted in Figure 2-4. Test TV-9 (Figure 2-6) was done on June 12, 1986 at low tide and shows the central plume jet shifted towards the north channel. This test was also done in the morning under low wind conditions which allowed the plume to spread out past Field's Cove towards Lion Rock to the north. Test TV-7 was done in the late afternoon during a period with strong northwesterly winds that



Test TV-7
Date: June 11, 1986
Time: 18:20 PDT

Unit	Discharge Temp° C	Cooling Water Flow (cfs)	Reactor Power (%)
1	21.4	2000	100
2	19.5	2000	70

Intake Temp: 10.9° C
Tide: 2.8 ft (MLLW)
Wind: 17.5 mph from 313° (true)
Offshore Currents: 19.4 ft/min. from 135°
Sig. Wave Ht.: 92 cm @ 11 sec from 270°
Air Temperature: 15.5° C

Figure 2-5. Surface thermal plume isotherms (°C) above ambient intake temperatures measured on June 11, 1986. Ambient intake temperatures (of water drawn from -10 m [-32 ft] MLLW) were 1-2°C cooler than ambient surface temperatures. Therefore, the ambient intake temperature color (0-1°C) does not appear in the plume figure.

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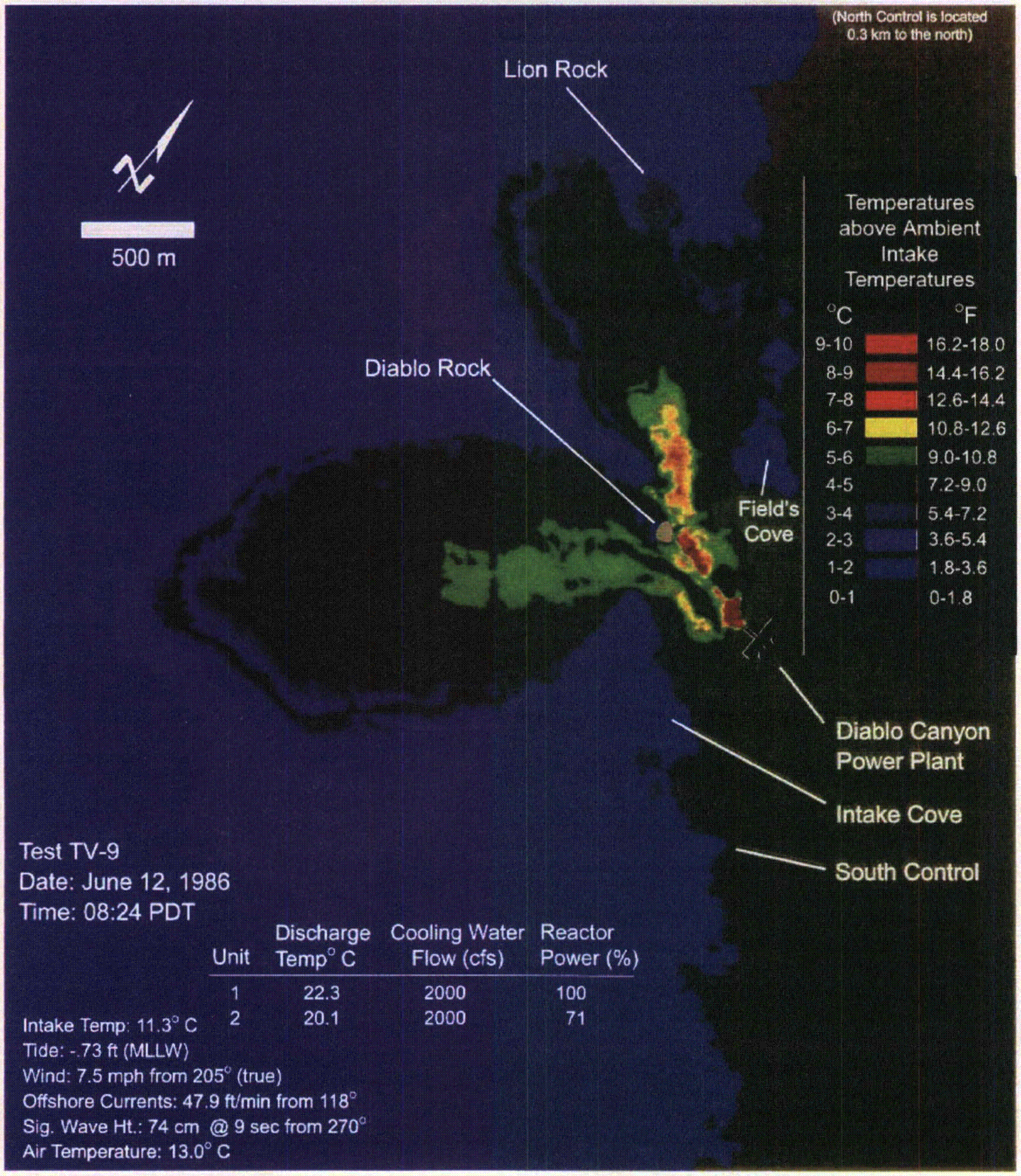

Figure 2-6. Surface thermal plume isotherms (°C) above ambient intake temperatures measured on June 12, 1986. Ambient intake temperatures (of water drawn from -10 m [-32 ft] MLLW) were 1-2°C cooler than ambient surface temperatures. Therefore, the ambient intake temperature color (0-1°C) does not appear in the plume figure.

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divert the plume to the south. The figure also depicts the effect of solar insolation that warms shallow shoreline areas through the day. The two surface plumes (Figures 2-5 and 2-6) represent summer conditions. Under other seasonal conditions the plume characteristics can be different. Stronger winds in spring and large waves in winter can dramatically affect plume characteristics. Ambient sea surface temperatures were always 1-2°C warmer than ambient intake temperatures because intake flows were drawn from a cross-section of cooler sub-surface waters up to -32 ft (-10 m) MLLW within the Intake Cove.

Unlike the surface IR data, composite figures showing the frequency of occurrence for the 1.1°C (2°F) and 2.2°C (4°F) isotherms (Figures 2-7 and 2-8) present the far field configuration of the plume under a wide range of environmental and plant operational conditions (Table 2-1). The shallow nearshore zone was not sampled during these surveys. The plume is occasionally present in the area offshore of the north and south control stations. Lion Rock appears to block the plume's northward movement under most conditions (Figure 2-8). Additional data on individual thermal plume field tests are presented in Appendix C3.

Based on these field surveys, the distance of the offshore 1.1°C (2°F) surface isotherm from Diablo Rock ranges between 0.8-1.2 km (0.5-1.0 mi) on the 41-60% probability level, and on rare occasions (1-20% probability), the longest distance extended 2-6 km (1-4 mi) (Figure 2-8). As noted earlier, Figures 2-7 and 2-8 are composite diagrams showing the collective plume extent and do not represent the area or size of an individual plume during a single point in time. Tu et al. (1986) found that in general, the surface area of the offshore plume (seaward of Diablo Rock) was largest (607-809 ha [1500-2000 ac]) when the tide level was ebbing towards mean sea level (+0.9 m [3 ft] MLLW), and smallest (202-283 ha [500-700 ac]) during low tide conditions. During high tide conditions the plume covered an area of about 283-486 ha (700-1200 ac).

Fixed monitoring stations

Temperatures recorded at intertidal (+0.6 m; +2 ft MLLW) and shallow subtidal (-3 m; -10 ft MLLW) stations in Diablo Cove, Field's Cove, South Diablo Point, and at control stations illustrate the long-term pattern of receiving water temperatures and delta T° values before and during power plant operation (Figures 2-9, -10, and -11). Delta T° values for the figures were computed by subtracting the mean temperature for the pooled control stations computed for each 20 minute reading from the corresponding temperature (or temperature mean for multiple stations) for the impact stations. The data are summarized as monthly means ±99 percentile values. In Figure 2-9 the intertidal temperature data for north Diablo Cove was obtained from NDC-1, -2, and -3, and south Diablo Cove from SDC-1, -2, and -3. The control stations used were NC-2 and -3 and SC-1 and -3. In Figure 2-10 the intertidal temperature data for Field's Cove and South Diablo Point were obtained from FC-3 and SDP-2, respectively. Data were collected at South Diablo Point starting in late 1980. Figure 2-11 depicts temperatures recorded at the -3 m MLLW subtidal stations. The subtidal temperature data for north Diablo Cove were obtained from stations NDC-1, -2, and -3, and south Diablo Cove from SDC-1, -2, and -6. Control data were obtained from subtidal stations NC-1 and SC-1. Temperatures from simultaneous 20-minute recordings among the various intertidal and subtidal station groups were first averaged before computing monthly means and delta T° values. Station-specific temperature patterns are described in Sections 2.2.3 and 2.2.4 *(Intertidal Temperatures and Subtidal Temperatures)*. Data gaps in the figures were caused by temperature recorder malfunctions or damaged recording media that voided the data collected during that period. Temperature data for all intertidal and subtidal monitoring stations are presented in Appendix C.

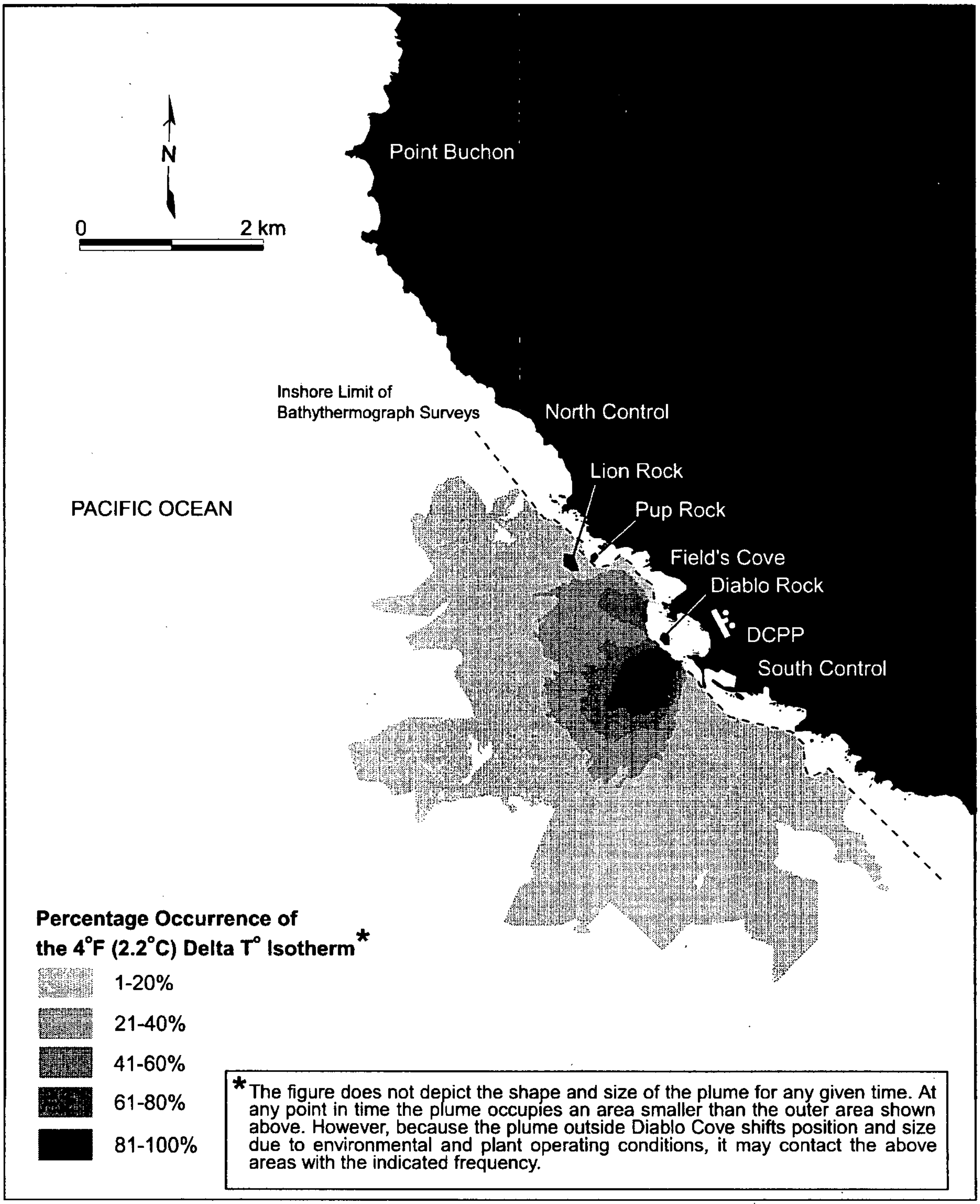


Figure 2-7. Composite offshore surface thermal plume map of the DCPP discharge 4°F (2.2°C) delta T° isotherm. Percentage occurrence was calculated from 40 thermal plume maps. Maps were developed from data using a towed bathythermograph. Surveys were conducted from December 1985 to April 1990. Shoreline contact of isotherms not shown, due to the survey areas not including the coastline.

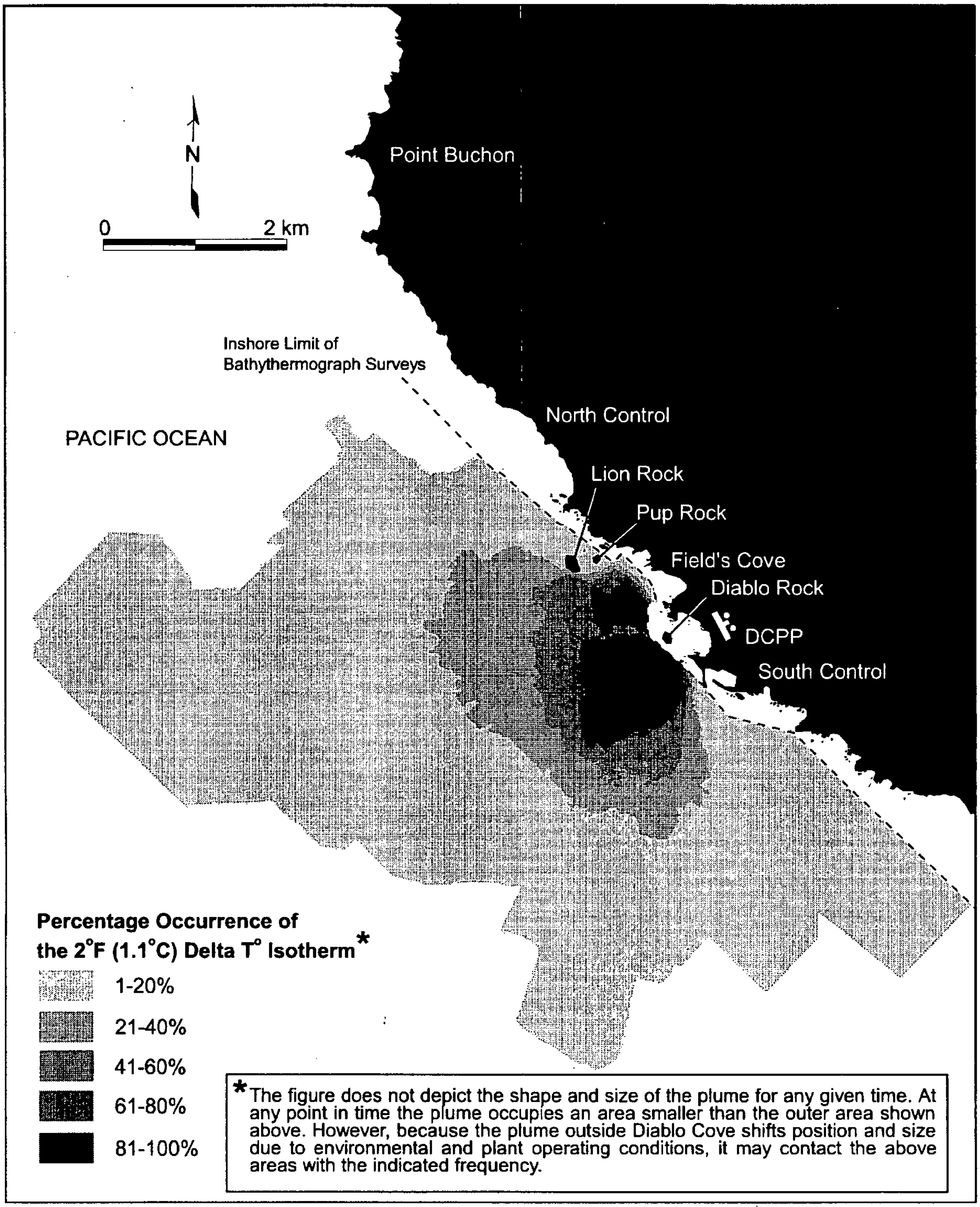


Figure 2-8. Composite offshore surface thermal plume map of the DCPP discharge 2°F (1.1°C) delta T° isotherm. Percentage occurrence was calculated from 40 thermal plume maps. Maps were developed from data using a towed bathythermograph. Surveys were conducted from December 1985 to April 1990. Shoreline contact of isotherms not shown, due to the survey areas not including the coastline.

Table 2-1. Environmental conditions and power plant output levels during tests used to develop 2°F and 4°F composite plume maps (Figures 2-7 and 2-8). nd = no data available.

Test No.	Date	Time	Average Wave Height (ft)	Unit 1 Power (%)	Unit 2 Power (%)	Tide Range (ft MLLW)	Wind Speed (mph)
POWER ASCENSION TESTING DATA							
10-2	11-Dec-85	1528-1643	7.6	100	90	3.2-3.0	6.5
10-3	12-Dec-85	0928-1113	6.6	100	90	7.0-5.2	3.1
10-4	12-Dec-85	1514-1650	7.2	100	90	(-1.2)-(-1.9)	17.9
11-1	8-Jan-86	1229-1436	3.9	100	100	0.9-(-1.5)	3.8
11-2	10-Jan-86	0759-0851	5.9	100	100	6.7-7.1	3.1
11-3	10-Jan-86	1320-1600	6.3	100	100	1.6-(-1.6)	12.7
11-4	11-Jan-86	0710-1000	7.0	100	100	5.5-7.0	3.8
11-5	11-Jan-86	1140-1500	7.0	100	100	5.7-0.3	4.5
12-4	30-Apr-86	1635-1910	4.5	100	100	3.4-3.1	13.0
12-5	1-May-86	0650-1005	3.2	100	100	2.1-(-0.4)	5.6
THERMAL VERIFICATION TESTING DATA							
TV6	11-Jun-86	1125-1400	3.5	100	71	1.9-2.9	11.4
TV7	11-Jun-86	1710-1920	3.0	100	71	2.7-2.9	17.5
TV9	12-Jun-86	0830-1030	2.4	100	71	(-0.4)-0.7	7.5
TV10	12-Jun-86	1300-1515	2.7	100	73	2.5-3.0	21.4
BI-MONTHLY NPDES PLUME DATA							
8-86A	8-Aug-86	0815-0953	2.7	63	100	1.4-3.2	10.5
8-86B	8-Aug-86	1315-1505	2.5	63	100	3.7-2.4	19.9
10-86	10-Oct-86	0955-1110	nd	0	99	3.7-3.8	6.3
12-86	22-Dec-86	1640-1740	5.9	1	100	2.8-3.6	7.5
2-87	5-Feb-87	0807-0953	8.0	100	100	2.0-1.3	4.3
4-87	14-Apr-87	1412-1521	4.3	100	0	2.3-1.4	11.8
6-87	18-Jun-87	0840-1000	4.6	99	0	2.1-0.5	17.8
8-87	7-Aug-87	1010-1121	4.9	100	100	3.9-4.0	4.0
10-87	22-Oct-87	0907-1104	2.4	100	100	5.5-5.8	8.4
12-87	21-Dec-87	1405-1528	4.6	100	100	1.6-(-1.0)	4.8
2-88	4-Feb-88	0946-1135	4.4	83	100	5.4-3.5	5.2
4-88	14-Apr-88	1004-1123	5.2	0	100	4.8-3.5	12.0
6-88	16-Jun-88	0857-1032	2.9	0	100	0.4-1.4	7.6
8-88A	3-Aug-88	0922-1243	2.5	100	0	1.4-4.1	nd
8-88B	4-Aug-88	0819-0955	3.0	100	0	2.0-2.0	7.5
10-88	11-Oct-88	0650-0810	6.9	100	0	3.9-5.3	15.9
12-88	13-Dec-88	0738-0900	5.9	100	51	3.2-4.2	17.5
2-89	8-Feb-89	0748-1006	4.8	100	100	4.4-1.7	nd
4-89	26-Apr-89	0730-0935	4.9	100	100	1.1-0.1	nd
6-89	8-Jun-89	0755-0950	4.9	100	100	(-0.2)-0.8	25.5
8-89A	8-Aug-89	0640-1000	3.0	100	100	2.0-3.0	nd
8-89B	9-Aug-89	0645-0900	4.9	100	100	2.5-2.7	6.5
10-89	4-Oct-89	0620-0810	6.9	100	100	2.8-3.8	4.3
12-89	7-Dec-89	1050-1230	5.2	0	100	1.0-1.3	3.8
2-90	21-Feb-90	0700-0830	4.4	0	100	5.3-4.7	3.0
4-90	11-Apr-90	0708-0900	6.2	100	0	0.2-2.0	17.0
	Average % power level during all tests:			**82.7**	**80.2**		

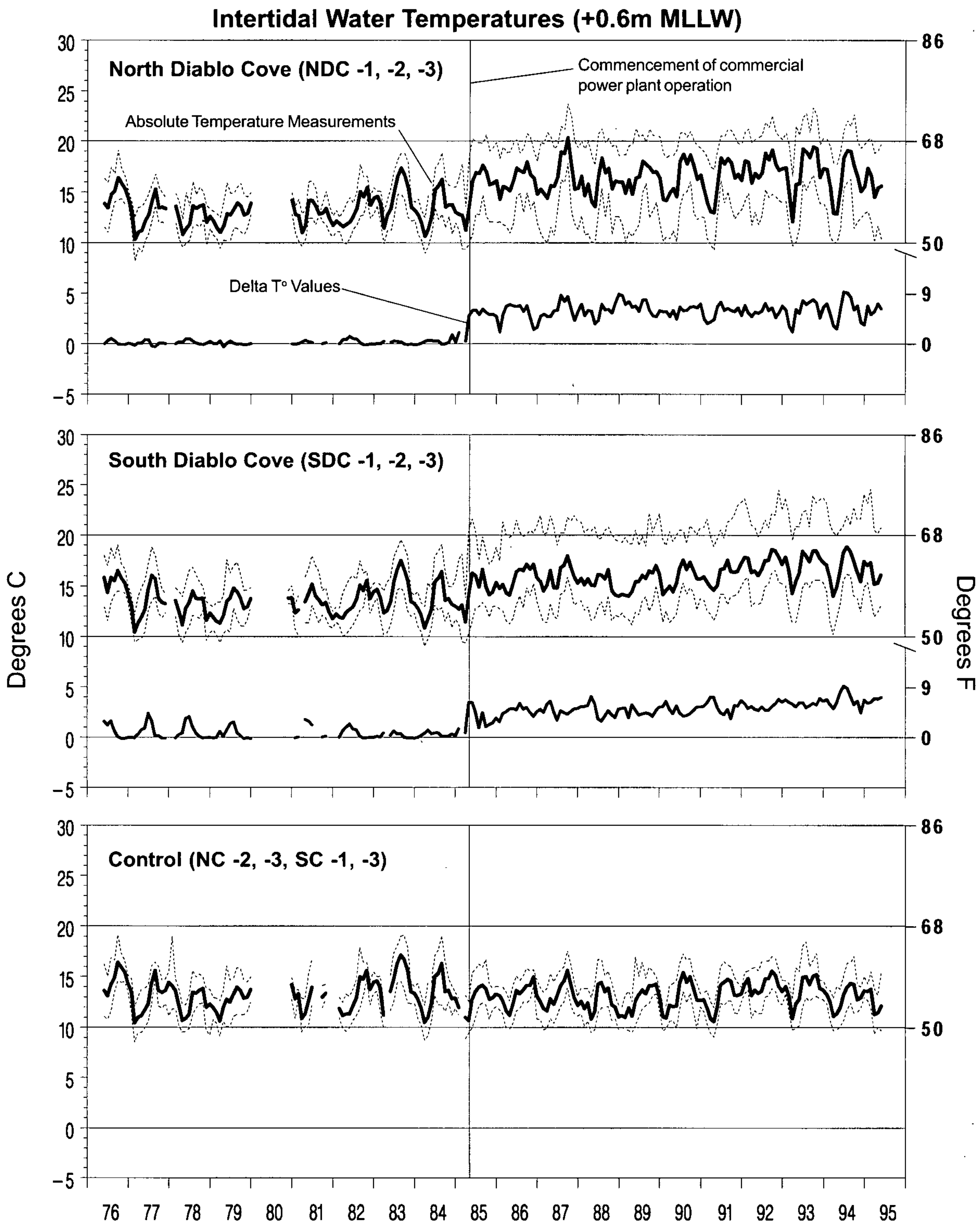


Figure 2-9. Intertidal monthly mean temperatures and delta T ° values for the north and south Diablo Cove and control sampling areas. Dotted lines denote the highest and lowest 99 percentile values of 20-minute recordings that occurred in the month.

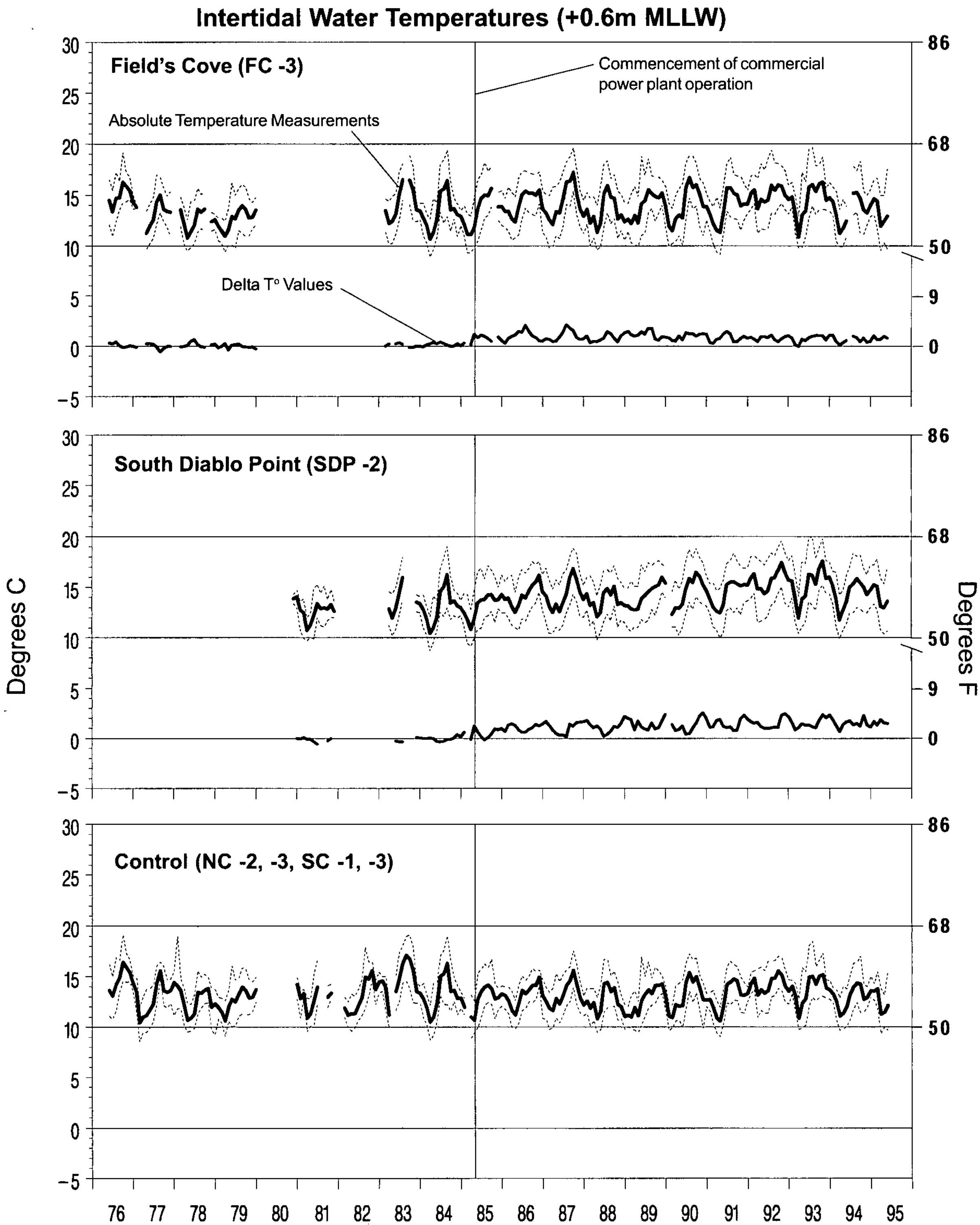


Figure 2-10. Intertidal monthly mean temperatures and delta T ° values for the Field's Cove, South Diablo Point, and control sampling areas. Dotted lines denote the highest and lowest 99 percentile values of 20-minute recordings that occurred in the month.

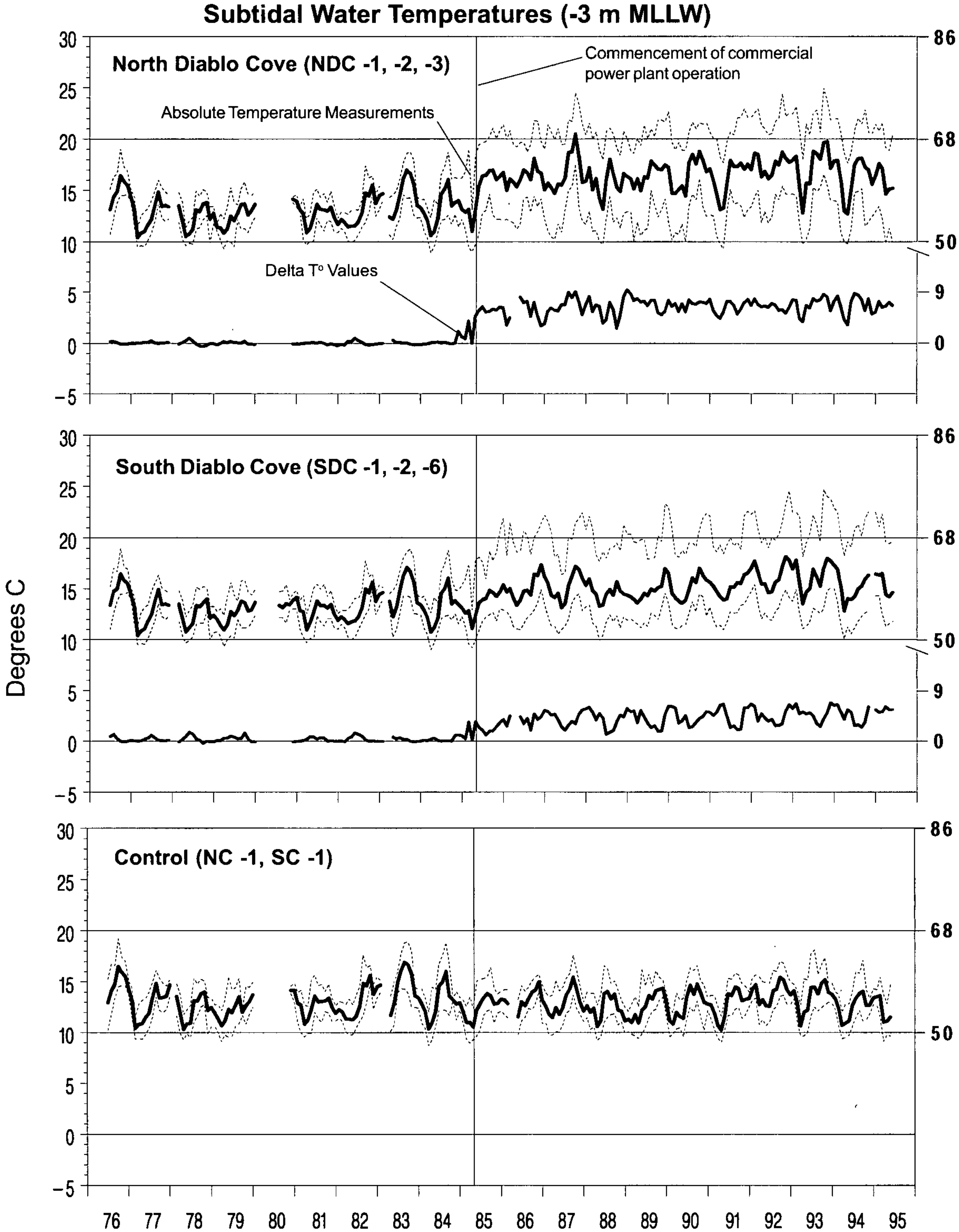


Figure 2-11. Subtidal monthly mean temperatures and delta T ° values for the north and south Diablo Cove and control sampling areas. Dotted lines denote the highest and lowest 99 percentile values of 20-minute recordings that occurred in the month.

Water temperatures among all the intertidal and shallow subtidal stations were similar before power plant start-up (Figures 2-9 to 2-11). Delta T° values for the pre-operation period in south Diablo Cove were seasonally warmer than control areas (Figure 2-9). South Diablo Cove is protected from wind and waves and can be more susceptible to warming through solar insolation during the day. Upon power plant start-up, the initial effects on temperature from power plant commercial operation can be seen as increases in delta T° values (Figures 2-9 to 2-11). Although monthly mean discharge temperatures were as high as 11.2°C above ambient (Figure 2-3c), the highest monthly mean temperatures measured at intertidal and subtidal stations in Diablo Cove never exceeded ambient by more than 7.0°C (Figure 2-12). On average, intertidal and shallow (-3 m) subtidal temperatures in the cove were 1.9-4.5°C above ambient (Figure 2-12).

During the period of plant operation from 1985 through July 1995, El Niño events occurred in 1987, 1992 and 1993. During these periods ambient water temperatures were warmer than normal with monthly means approaching 16°C (61°F) in the fall periods of 1987, 1992 and 1993 (Figure 2-3b). The warmest discharge temperatures occurred during these periods, with maximum temperatures approaching 28°C (82°F) in the fall of 1993 (Figure 2-3b). The 1992 El Niño occurred through spring, which disrupted the normal upwelling conditions resulting in the highest spring water temperatures recorded during operation. The weakened upwelling associated with the El Niño was documented by Lenarz et al. (1995).

The main area of thermal plume contact with the shoreline was within Diablo Cove, and included all intertidal areas and subtidal areas to depths of about -11 m (Tu et al. 1986). Intertidal temperatures were slightly warmer in north Diablo Cove than south Diablo Cove (Figure 2-9), and subtidal temperatures were generally higher in north than in south Diablo Cove (Figure 2-11). Due to the changes in ambient conditions, plant operations and plume dynamics, variation in temperatures increased during power plant operation. A large increase in temperature variation occurred in Diablo Cove and other areas affected by the discharge following plant operation (Figures 2-9 to 2-11). The increasing trend in discharge temperatures from 1987 to 1995, discussed in Section 2.1.2 (*Flow Volumes and Point-of-Discharge Water Temperatures*), caused increases in absolute temperatures and delta T°'s at the Diablo Cove temperature monitoring stations (Figures 2-9 and 2-11).

Delta T° values for Field's Cove and on South Diablo Point show that increased temperatures from the thermal plume extend to intertidal and subtidal areas outside Diablo Cove (Figure 2-12). These areas are less impacted than Diablo Cove. Although no temperature recorders were placed between the Field's Cove and North Control stations, composite plume profiles show that the plume rarely extends into areas immediately offshore from control stations (Figures 2-7 and 2-8).

2.2.3 Intertidal Temperatures

Intertidal temperature units were exposed at low tide, and therefore recorded air temperatures when tidal levels fell below about +0.6 m. The recorded air temperatures were removed during data processing by referencing concurrent tidal height measurements so that only water temperatures were analyzed. Ambient water temperatures were recorded at NC-2 and NC-3 at North Control, SC-1 in Patton Cove, and at SC-3 [4.7 km (2.9 mi) south of the plant]. These stations were used as controls for calculating ambient mean temperatures for generating delta T°s, as they had the most complete temperature records of all stations located furthest from the influence of the discharge. The temperatures among these stations differed by 0.4°C on average.

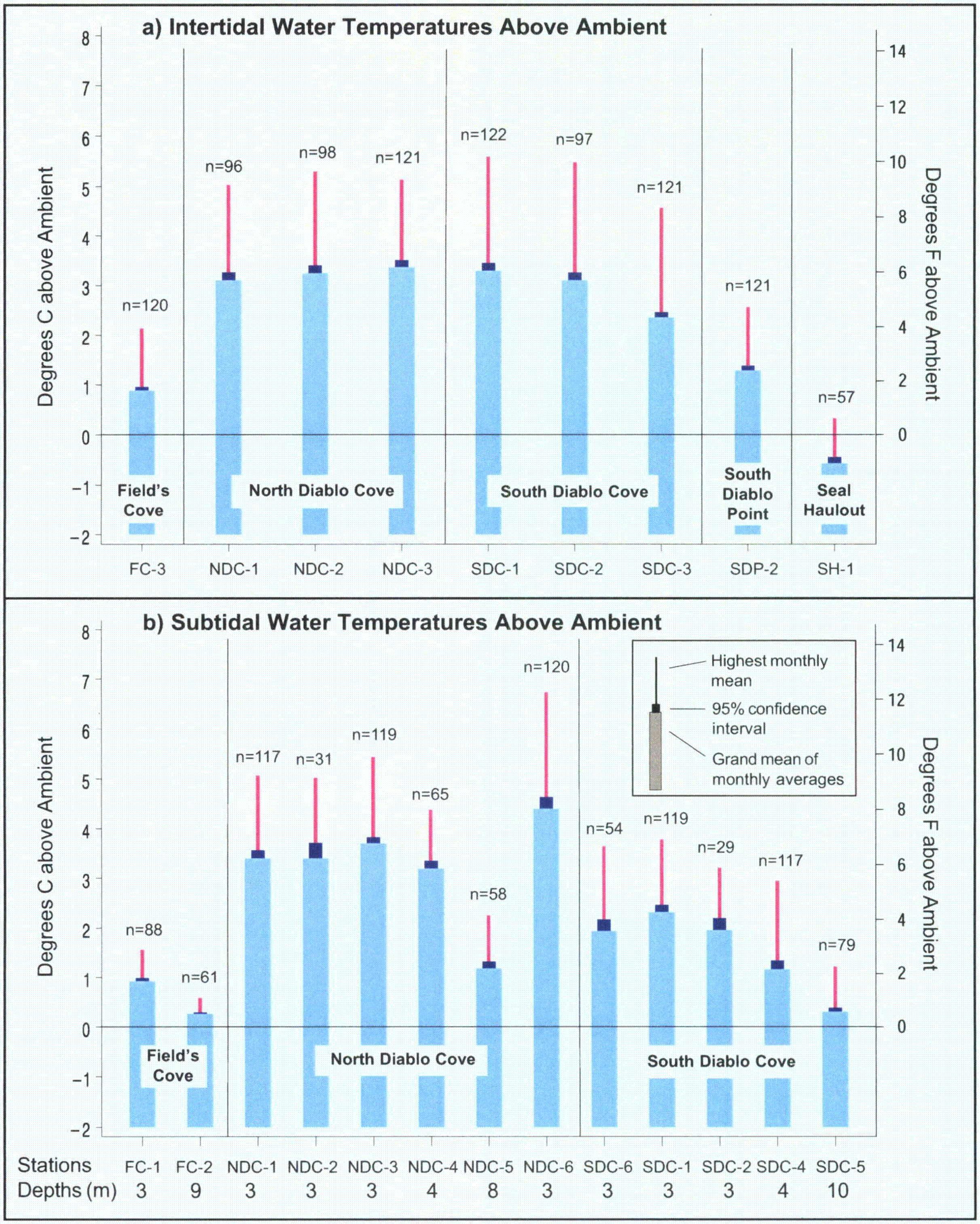


Figure 2-12. Receiving water temperatures above ambient (delta T°) for (a) intertidal and (b) subtidal stations for the period May 1985-June 1995. Delta T° values for each station were determined from control stations of same depth or elevation. See text for pairing. n = number of monthly averages used in computing the grand mean of monthly averages.

Monthly mean temperatures above ambient were recorded at stations in Field's Cove, north Diablo Cove, south Diablo Cove, and South Diablo Point during plant operation (Figure 2-12). The average of the monthly mean temperatures among all these stations ranged between about 2.5° and 3.5°C above ambient with highest monthly mean temperatures between about 5° and 6°C above ambient. Temperatures at South Diablo Point were slightly warmer than Field's Cove to the north. Temperatures recorded at SH-1 on Seal Haulout were, on average, 0.6°C lower than temperatures measured at the control stations. Station SH-1 was located on an exposed rocky bench that drops off steeply into deep water. The low water temperatures at this station were probably due to wave runup and mixing with deep cold water. The North and South Control stations were in areas where the shoreline slopes more gradually, as in Diablo Cove.

2.2.4 Subtidal Temperatures

Subtidal temperatures were recorded at stations 3 m to 11 m depths (Figure 2-2). Delta T° values were calculated using data from control stations of the same or nearest depth. Therefore, stations NC-1 and SC-1 (at -3 m) provided data for calculating deltas for shallow stations in the vicinity of thermal discharge, and stations IC-1 and SC-3 (-10 m and -11 m, respectively) were used for calculating deltas for deeper stations in the vicinity of the thermal discharge. The shallow control stations differed among each other, on average, by 0.3°C and the deeper control stations by 0.2°C.

All subtidal stations in Diablo Cove and Field's Cove had temperatures above ambient (Figure 2-12b). Overall, temperatures in north Diablo Cove were warmer than in south Diablo Cove (Figure 2-12b). Warmest temperatures were recorded at Station NDC 6 -3 m, located at the base of Diablo Rock, where temperatures averaged about 4°C above ambient, but occasionally reached about 6°C above ambient. Subtidal stations NDC-1, -2, and -3, at -3 m MLLW in north Diablo Cove, recorded higher temperatures than stations of the same depth in south Diablo Cove (Stations SDC-1, -2, and -6). Similarly, warmer temperatures were recorded at Station NDC 4 -4 m in north Diablo Cove than at Station SDC 4 -4 m in south Diablo Cove. Temperatures greater than ambient were recorded from the two deepest stations in Diablo Cove, NDC-5 and SDC-5 at -8 m and -10 m, respectively, indicating that the plume penetrated to these depths. Temperatures recorded from the two Field's Cove stations, FC 1 -3 m and FC-2 -9 m, were also increased by power plant discharges, with highest monthly averages at these stations of 1.7°C and 0.5°C above ambient, respectively.

3.0 INTERTIDAL STUDIES

3.1 Introduction

California rocky intertidal areas are characterized by diverse assemblages of algae, invertebrates, and fish (Ricketts et al. 1985; Foster et al. 1991). The majority of intertidal species in the present study are restricted to certain elevations along the shoreline. While species' upper vertical limits are largely determined by the ability to withstand desiccation, other important factors that determine vertical zonation of species are competition, predation, and microhabitat differences. On wave-exposed shores, such as headlands, wave run-up and splash enable species to survive at higher elevations than those normally found in wave-protected areas. In Diablo Cove, there are large differences in the various physical characteristics of the north and south areas of the cove. The north area is composed mainly of bench rock and boulders that create moderately high bathymetric relief, whereas the substrate is largely low-relief rock and cobble in the south. Wave impact is also greater on the north shores than on the south. On the other hand, the south shores are subject to greater scouring by sand, from sand channels in the adjacent subtidal area.

The following description is a general overview of the intertidal habitat that characterized the Diablo Canyon nearshore vicinity before power plant operation and as presently exists in areas outside Diablo Cove. The vertical distribution of conspicuous intertidal organisms in the study area, before power plant operation, is depicted in schematic profile in Figure 3-1. The diversity of algal and invertebrate species tends to increase from high to low elevations. The high intertidal is only occasionally wetted by wave splash and is sparsely covered by taxa such as blue-green algae, *Bangia* spp., and *Enteromorpha* spp. In these areas *Littorina* spp. (periwinkle snail) are found in rock crevices and *Tegula funebralis* (turban snail) and *Pachygrapsus* (shore crab) may be found in the shade of boulders. Occasionally a high intertidal tidepool will contain species more commonly found in lower elevation habitats. The barren appearance of the splash zone disappears lower in the intertidal (+1.3 m MLLW) as algal cover becomes more conspicuous with scattered clumps of *Fucus* and *Pelvetia* (rockweeds) and *Endocladia* (red algae). This more truly intertidal area (the highest regularly submerged) is inhabited by numerous species of limpets, *Chthamalus* spp. (the small acorn barnacle) and encrusting algae. In the next 0.3 m of elevation (+1 m MLLW) many of the higher elevation species of algae increase in cover, joined by lower elevation species such as *Mazzaella flaccida* and *Mastocarpus papillatus*. Beneath the foliose blades of these upright algae are rock-encrusting algae that form layers between patches of barnacles and bare rock. *Pagurus* (hermit crab), *Haliotis cracherodii* (black abalone), other snails, motile and tube-forming worms, encrusting bryozoans, sponges, and tunicates all become more abundant in the lower intertidal regions, where longer tidal submergence enable increased feeding, reproduction and recruitment opportunities. Fish species in the low intertidal, such as *Xiphister* spp. (prickleback), are also relatively common to habitat under cobbles, in pockets of water and dense algal cover. In the remaining +0.3 m above MLLW, algal cover increases, especially red algae, including *M. flaccida, M. papillatus, Gastroclonium subarticulatum,* and *Chondracanthus canaliculatus*. *Phyllospadix* spp. (surfgrass) commonly fringes the shoreline at the lower boundary of the intertidal zone at about the -0.6 m tidal level.

Permanent intertidal sites were monitored to study changes in populations of macro-algae, invertebrates, and fish exposed to elevated discharge temperatures and populations of similar species beyond the plume's influence. Analyses of the changes before and after plant startup and between control and impact areas were performed on the species comprising the top 99% of total cover or the top 99% of total counts. Two additional intertidal studies were conducted to supplement the quantitative field data from

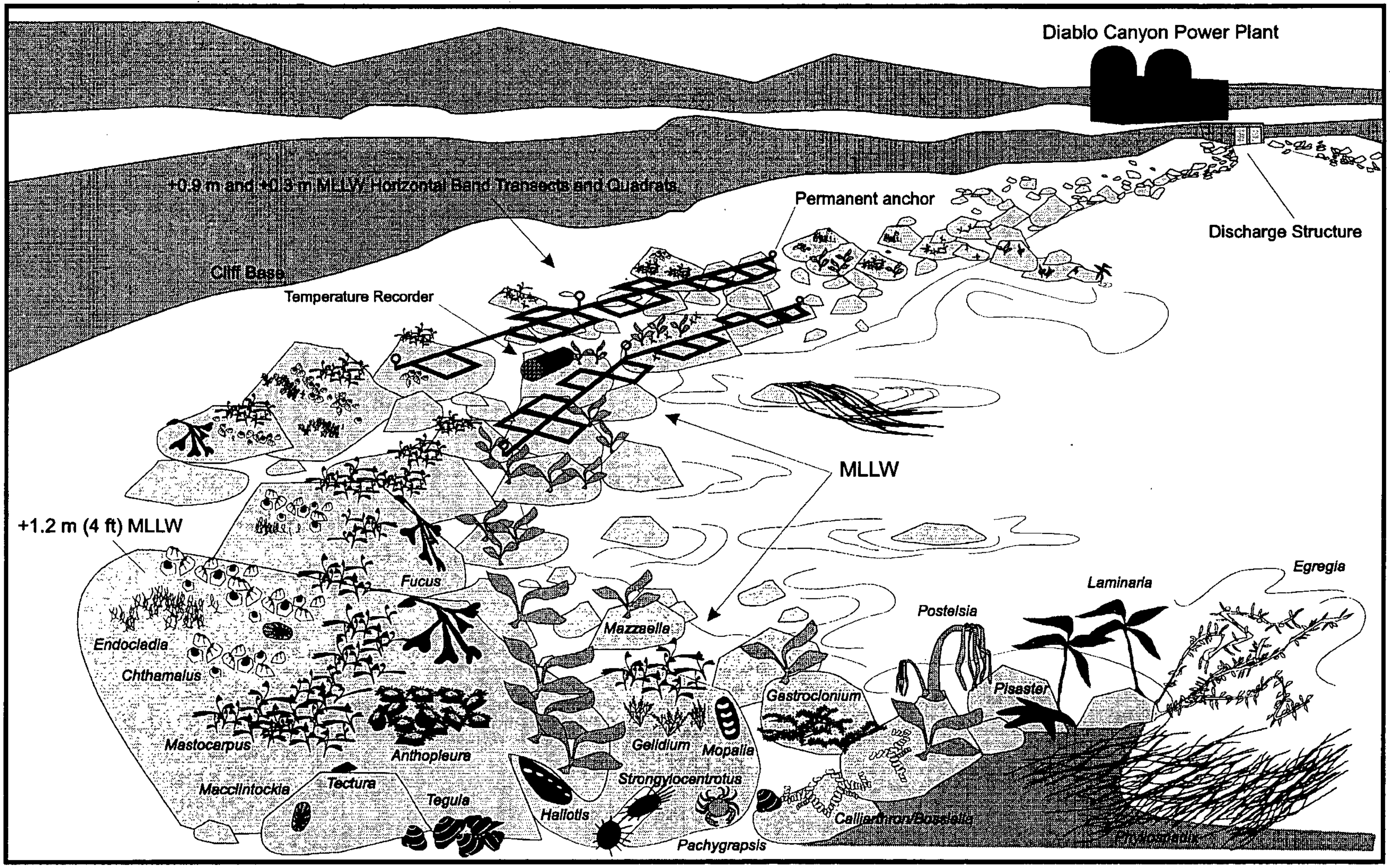


Figure 3-1. Representation of intertidal zonation. Horizontal band transects, sampling quadrats, and fixed temperature recorder in mid-ground.

permanent quadrats. The first focused on microinvertebrates associated with pure stands of *Endocladia muricata* and *Gastroclonium subarticulatum* (Algal-Faunal Association Study). Algal samples were collected and returned to the laboratory where the small associated invertebrates were sorted, identified and counted. A second field intertidal study, a population census of black abalone (*Haliotis cracherodii*) in Diablo Cove and Field's Cove, included individual counts, shell measurements and inspection of animals for withering syndrome (WS). A species list of all of the organisms sampled in the Thermal Effects Monitoring Program (TEMP) appears in Appendix D.

3.2 Methods

Intertidal algae, invertebrates and fish were sampled in the field using several methods. The primary method was counts of motile invertebrates and cover estimates of algae and sessile invertebrates on the horizontal band stations. Vertical band stations were used to count intertidal fish and to record the presence or absence of invertebrate and algal taxa. Small invertebrates associated with two common intertidal algae were counted in samples that were collected in the field and processed in the laboratory. Black abalone were censused in Diablo Cove using a random sampling design, and counted along permanent transects both inside and outside Diablo Cove. In addition, laboratory experiments were done on black abalone to test the effects of temperature on the incidence of withering syndrome disease.

The primary data analysis method was the BACI (Before-After/Control-Impact) analysis of variance design. Data not meeting statistical assumptions necessary for the BACI were analyzed with the Fisher's exact test. Most of the analytical methods were basically the same for the intertidal and subtidal data sets. The BACI and Fisher's exact tests are explained in this section and are referred to when referenced in the subtidal section. Analytical methods specific to each field sampling method are explained in the appropriate sub-sections.

3.2.1 Sampling Methods and Station Locations

Horizontal Band Stations

Shoreline sampling stations were permanently established north and south of the Diablo Canyon Power Plant (DCPP) discharge to monitor changes in intertidal biological communities (Figure 3-2). Frequently sampled stations were used for quantitative analysis of changes, and other supplemental stations, sampled less frequently, were used for qualitative analysis. All were established on substrata consisting of mixed bedrock and boulders with varying amounts of cobble and sand, and were sampled at low tide. Tidepools and surge channels were not sampled because these habitats were always submerged and the organisms could not be accurately sampled while under water. Stations consisted of 10-1 m^2 quadrats located along 'transects' at both the +0.3 m (1 ft) and the +0.9 m (3 ft) tide level. Annual tidal range varied from about -0.8 m to +2.0 m (Ricketts et al. 1985), and thus the quadrats sampled the middle portions of the intertidal zone. Stations on wave-exposed, rock bench headlands consisted of only a +0.9 m transect. One station near the discharge (SDC-1) had a +0.6 m transect instead of a +0.9 m transect due to a lack of suitable rock at the +0.9 m elevation.

Station designations indicated geographical location (NC and SC = North and South control, respectively; FC = Field's Cove; SDP = South Diablo Point; and NDC and SDC = North and South Diablo Cove, respectively). Multiple stations within these geographic areas were identified by a station number and the elevation of the accompanying transect. For example, NDC2 +0.3 m designated the +0.3 m MLLW transect for Station 2 in north Diablo Cove.

Sampling began at low tide by attaching a 30 m line to permanent stainless steel posts that functioned as the transect's origin, middle, and terminus. Ten 1 m^2 permanent quadrat positions were then located and sampled along each transect. Substrate relief in a quadrat varied from none on rock platforms to about 0.5 m, resulting in some quadrats tilting from horizontal. Observers counted organisms or estimated species' cover within the quadrat as viewed perpendicularly to the quadrat frame. Rock underhangs were not sampled, and rocks were not overturned.

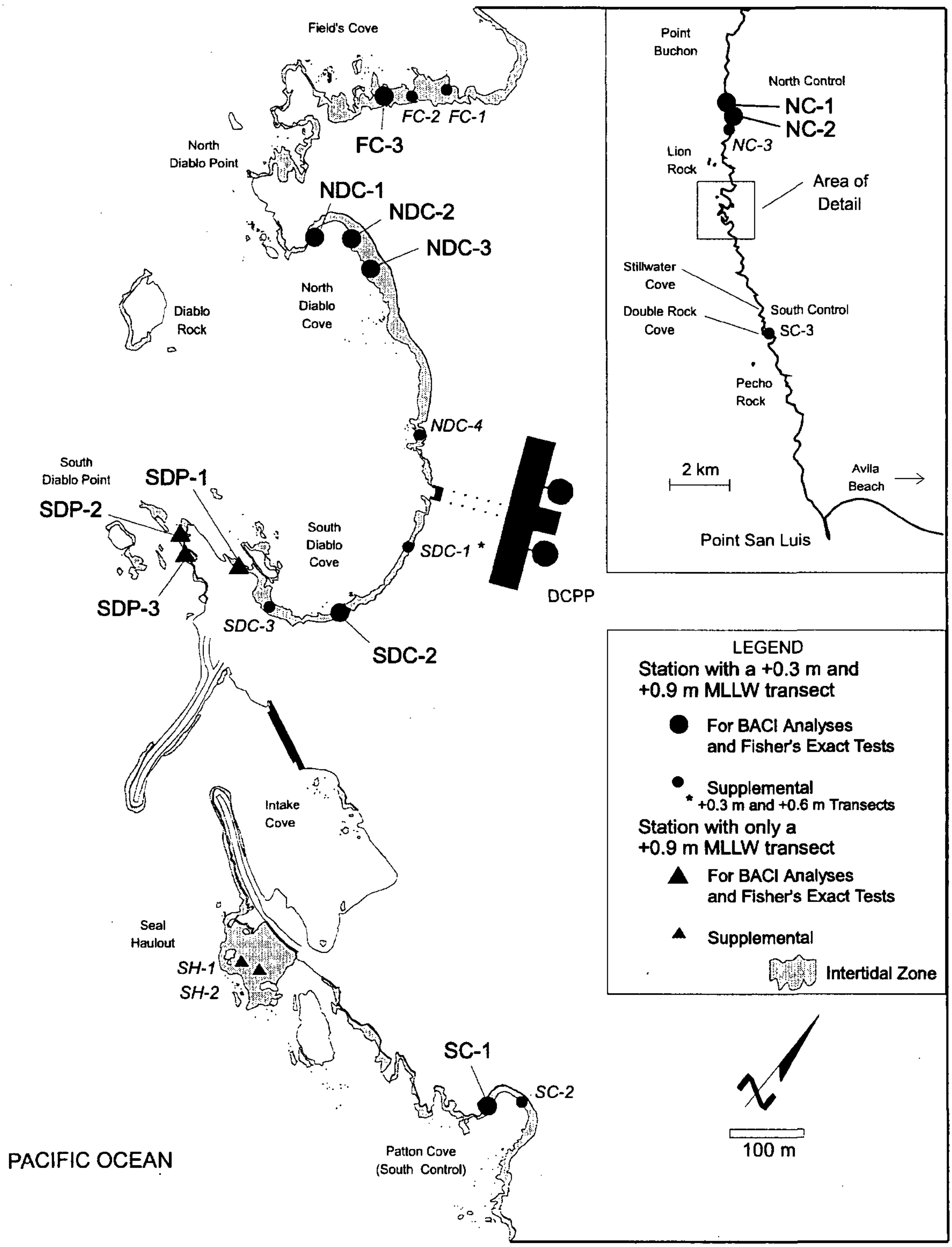


Figure 3-2. Locations of intertidal horizontal band transect stations.

Percent cover was estimated visually for all algal species and bare substrate in each quadrat (Figure 3-2). The quadrat was a 1 m^2 plastic frame subdivided by strings into 16-$^1/_{16}$ m^2 sub-quadrats. Algal coverage was recorded as the number of $^1/_{16}$ m^2 sub-quadrats covered by the species plus the number of 9^{th} sub-units of $^1/_{16}$ m^2 additionally covered (determined by visually separating a $^1/_{16}$ m^2 sub-quadrat into nine sub-units). Species found in less than one 9^{th} sub-unit in each quadrat were recorded as present. Overstory species were estimated first and then moved aside to allow estimates of the understory and crustose species. These data were later converted to percentages for tabulation and analyses. Total algal cover per quadrat often exceeded 100 percent due to the overlayering of multiple taxa.

Frequently it was not practical to count all invertebrates in a 1 m^2 quadrat, so they were sampled using one of two methods. In five of the quadrats all species were recorded as either present or absent, and individuals larger than 2.5 cm in greatest dimension were counted. In the other five quadrats the same method was used, except that certain species of invertebrates were counted regardless of size (Table 3-1). Black abalone were counted in all ten quadrats, regardless of size, and the percent cover of encrusting invertebrates, such as sponges and tunicates, was estimated using the same visual techniques as for the algae.

Abundances of some organisms that were difficult to identify were grouped into broader categories comprised of several species (e.g., crustose coralline algae). Species that could not be identified in the field were collected, if possible, from outside the quadrats and identified in the laboratory. Algae were identified according to Abbott and Hollenberg (1976), Scagel et al. (1989), and Silva (pers. comm.). Invertebrates were identified according to Barnard (1969), Smith and Carlton (1975), McLean (1978), Morris et al. (1980), and Behrens (1991). Over the course of the study, taxonomic revisions resulted in some nomenclature changes. A listing of all species found in the TEMP, including any changes in nomenclature, appears in Appendix D.

From 1977 to 1988, stations were sampled at two month intervals. From 1989 to 1995, sampling was reduced to two summer and two winter surveys per year that assured sampling of annual maximum or minimum abundances. Within a survey, sampling of all stations was normally completed within a 30-day period.

Vertical Band Stations

Vertical band station sampling complemented the horizontal station design by sampling a greater range of tidal elevations and by sampling invertebrates under moveable substrates. Species presence or absence was recorded within quadrats, in contrast to the quantitative abundance estimates used during the horizontal band study. A subset of the vertical band data set was analyzed in the present report because of duplication of information from the horizontal band stations.

At each of five study stations (Figure 3-3), three transects were positioned perpendicularly to the shoreline according to permanent markers. Each transect originated in the high intertidal zone (approximately +1.5 m MLLW) near the cliff base and terminated near the water's edge at low tide (approximately -0.2 m MLLW). Transects within a station were separated by approximately 3 m. Each transect served as a reference line used to position 12-1 m^2 permanent sampling quadrats, for a total of 36-1 m^2 quadrats per station. Station SDC2-V had only 27-1 m^2 quadrats due to a limited shoreline width at that location.

Table 3-1. Invertebrate taxa counted regardless of size in five 1.0 m^2 quadrats at each station-level.

Taxa		Common Name
Anthozoa		
	Anthopleura elegantissima	Aggregating anemone
	Anthopleura xanthogrammica	Solitary anemone
	Epiactis prolifera	Proliferating anemone
Echinodermata		
	Leptasterias hexactis	Six-rayed sea star
	Pisaster ochraceus	Ochre sea star
	Strongylocentrotus purpuratus	Purple sea urchin
Mollusca		
	all Neogastropoda	predatory snail species
	Fissurella volcano	Volcano limpet
	Haliotis cracherodii	Black abalone
	Lottia digitalis	Ribbed limpet
	Lottia limatula	File limpet
	Lottia pelta	Shield limpet
	Macclintockia scabra	Rough limpet
	Mopalia spp.	Chiton
	Notoacmaea scutum	Plate limpet
	Nuttalina californica	Chiton
	Tectura persona	Limpet
	Tegula brunnea	Brown turban snail
	Tegula funebralis	Black turban snail
Crustacea		
	Balanus spp.	Barnacle
	Hemigrapsus nudus	Purple shore crab
	Pachygrapsus crassipes	Lined shore crab
	Pagurus spp.	Hermit crab
	Tetraclita squamosa	Thatched barnacle

The presence or absence of each algal taxon, invertebrate taxon (both on top of rocks and underneath rocks) and substrate type within a quadrat were recorded. Moveable rocks were carefully lifted and replaced in their original position after the organisms underneath were examined. Species were identified in the field to the lowest possible taxon using the same criteria and references as employed in the horizontal band study. Intertidal fish that occurred within algal cover, in tidepools and under moveable rocks were captured in hand nets, identified, measured, tallied and returned to the quadrat. The fishes were identified in the field to the lowest practical taxonomic level using Miller and Lea (1972). The field methods did not allow consistent identification of newly settled juvenile fishes to the species level. These were grouped into composite taxa such as *Anoplarchus/Cebidichthys* or Pholididae/Stichaeidae. The study began in May 1979 and continued through August 1983 (pre-operation period). Following a two-year break in sampling, the study resumed in November 1985 and continued until February 1995.

Algal - Faunal Association Study

This study quantified small invertebrates within pure stands of two abundant intertidal algae (*Endocladia muricata* and *Gastroclonium subarticulatum*). These two algae were sampled because they were prominent at the mid- and lower intertidal elevations, respectively, and both had growth forms that harbored numerous species of small invertebrates. The AFAS was designed to supplement ongoing 316(a) demonstration studies by collecting data on invertebrate abundance and composition within intertidal "habitat-forming" algae, as defined by Kelly and Behrens (1981) and the U.S. Environmental Protection Agency (1977). The study began in October 1979 and continued through December 1982 (pre-operation period). Following a four-year break in sampling, the study resumed in February 1987 and continued until February 1995 (operation period).

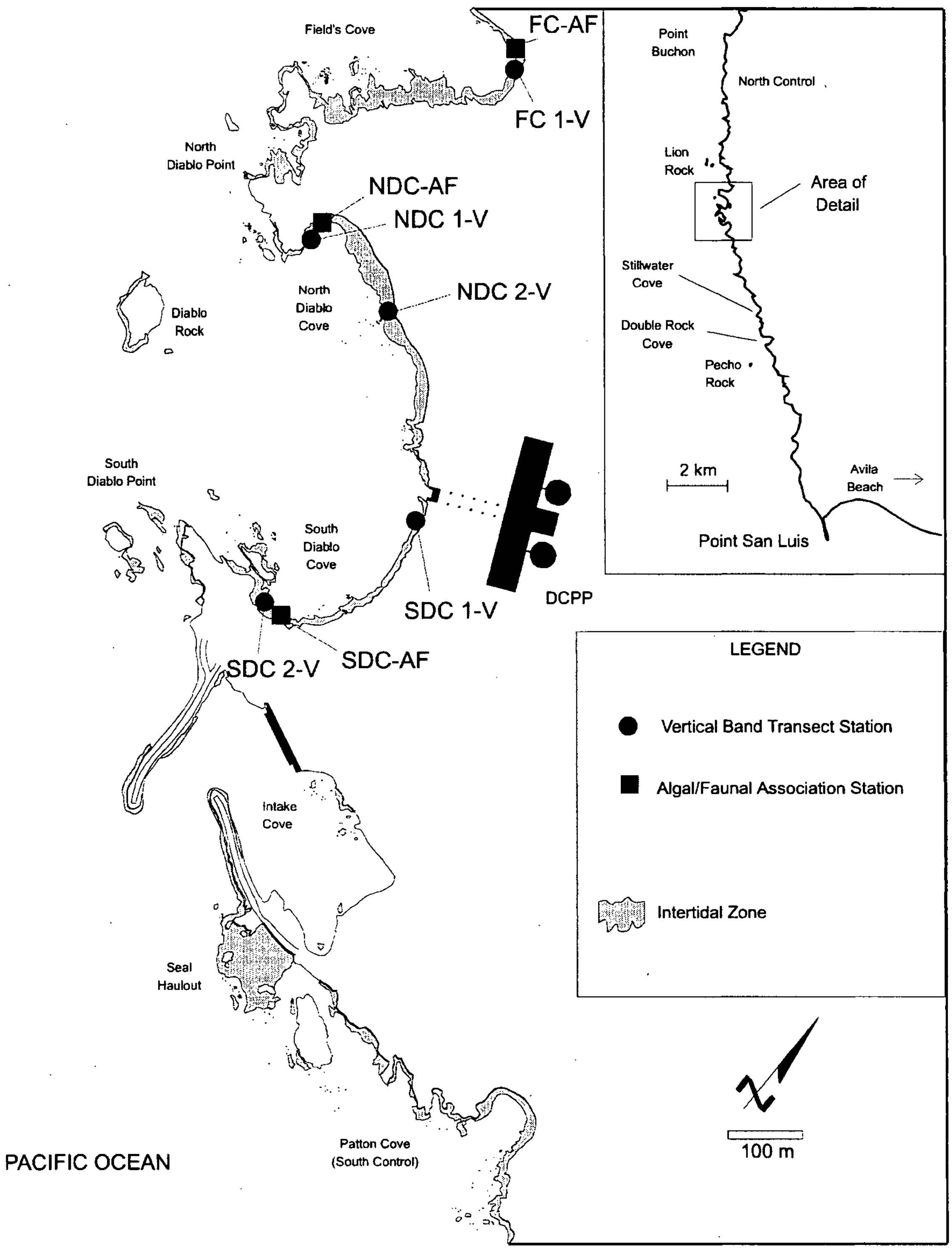


Figure 3-3. Locations of intertidal vertical band transect and algal/faunal association stations.

At three stations (two within Diablo Cove and one in Field's Cove, Figure 3-3), investigators located areas with pure stands of *Endocladia* (approximately +0.9 m MLLW) and *Gastroclonium* (approximately +0.3 m MLLW). Eight 10 x10 cm (.01 m^2) samples of each alga were manually scraped from the substrate, preserved, and returned to the laboratory for enumeration and identification of invertebrates. Quadrats were placed only on flat-aspect substrate (i.e., vertical and sloped substrate was not sampled) and were subjectively located to 'best' sample the extent of the algal patch area. Samples were sieved through a 1 mm screen and the retained invertebrates (>1 mm) were identified to the lowest possible taxon using a dissecting microscope (using references previously cited for the horizontal band study). Target algae were dried and weighed to the nearest 0.1 g. All invertebrate abundance data were reported as no./gram dry target alga. Surveys were conducted four times a year. At the completion of the TEMP studies, the *Endocladia* patch sizes at both Diablo Cove stations where samples were collected were approximately 15 m^2. The Field's Cove *Endocladia* patch size was much larger, covering an area of approximately 3,000 m^2.

Black Abalone

Field Studies

In addition to monitoring abundance of black abalone (*Haliotis cracherodii*) as part of the horizontal band transect method, the distribution, abundance, size and condition of black abalone were determined within Diablo Cove using a stratified random sampling design ('random quadrat surveys'). Approximately 10% of the 15,500 m^2 of Diablo Cove intertidal zone delineated by the upper and lower boundaries of this study area was sampled during each semi-annual survey. Ten adjoining reference lines 100 m in length were aligned along permanent markers in the mid-intertidal zone of Diablo Cove (Figure 3-4). Random distances above and below the lines were then used to locate 1 m^2 quadrats between approximately the +0.3 m and +1.3 m tide levels. Abalone were counted within each quadrat and their shell lengths visually estimated as either small (<50 mm), medium (51-100 mm) or large (>100 mm) from 1981 to 1990. From 1991 to 1995, abalone were measured to the nearest mm, or as accurately as possible, depending on the ability of the investigator to obtain an accurate measurement of abalone concealed in crevices. A juvenile size category (<25 mm) was added in 1991 to better identify recruitment episodes. Flashlights were used to search for cryptic abalone in crevices and under boulders. The study was done in 1981/1982, 1983, 1984/1985, and once or twice per year thereafter. Population density was calculated for each transect using the number of quadrats sampled and the number of black abalone present. An estimate of the total number of abalone present in Diablo Cove during each survey was the product of the unweighted mean of the individual transect densities and the estimated 15,500 m^2 of potential black abalone habitat within the cove.

Abalone withering syndrome (WS) disease was first observed in Diablo Cove in 1988. To monitor the extent and effects of this disease, additional field studies and laboratory experiments were done from 1988 to 1995. In one field study ('10-meter stations') the abundance, size distribution and condition of abalone were monitored within permanent 2x10 m areas at two stations within Diablo Cove and five stations outside the cove (Figure 3-4). Surveys were done approximately semi-annually in winter and summer. In the other field study ('qualitative surveys'), abalone were inspected for signs of WS (abalone 'foot' shrunken to a size smaller than the circumference of its shell margin) within several generally defined areas that were accessible along the approximately 10.0 km (6.2 mi) of coast (straight line distance) between Point Buchon and Stillwater Cove. All accessible abalone encountered during the shorewalk surveys were manipulated by hand to determine how firmly they were attached to the rock surface. Those that could be easily pulled from the rocks were usually unhealthy and were inspected for symptoms of WS. Abalone not accessible for manipulation were examined *in situ* for other signs of WS

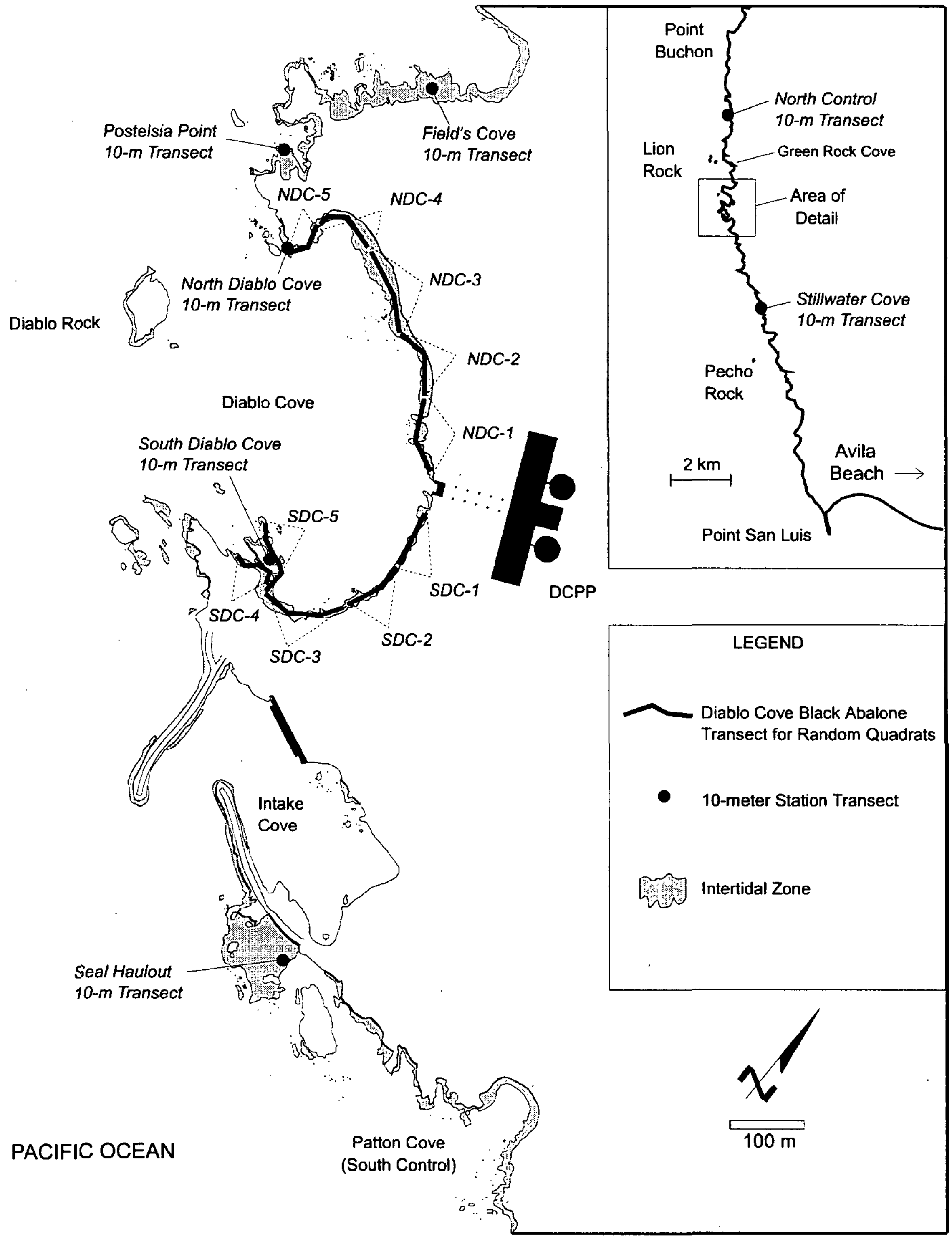


Figure 3-4. Locations of black abalone Diablo Cove transects for random quadrats and locations of fixed 10-meter transects.

including whether the epipodium was visible or not and whether the micro-habitat where it was located was characteristic of a healthy abalone. Abalone not obviously afflicted were considered healthy. The method yielded a conservative estimate of the proportion of healthy to unhealthy abalone within each inspected area.

Effects of Temperature on Abalone in the Laboratory

A laboratory experiment tested the effects of elevated seawater temperatures on the susceptibility of black abalone to WS disease. Black abalone with no visual indications of WS disease were collected from seven areas that ranged from immediately outside Diablo Cove to approximately 5 km north and south. Abalone were individually tagged and shell length and width, total weight, and area of collection recorded before being randomly assigned to the experimental groups. The single experimental variable was the holding water temperature of the abalone. The experimental design called for two treatment groups of 60 abalone each held at a constant temperature of 16°C and 18°C, respectively, and one control group of 40 abalone held at ambient seawater temperature (ca. 11-13°C). This experiment used only one replicate (i.e., tank) for each treatment group and control group. It was assumed, with no evidence which suggested otherwise, that the results of the experiment were not affected by characteristics of the seawater delivery system, boiler delivery system, or holding tanks among the experimental groups.

Each group of abalone was held in a 1.2 x 2.4 m fiberglass tank equipped with flowing seawater that was either heated to the target temperatures or held at ambient seawater temperatures. Abalone were contained within PVC, Vexar® and Plexiglas® cages approximately 1.0 x 0.5 x 0.2 m that allowed unrestricted water flow and non-disruptive observation of the foot muscle of most abalone. Abalone were held in the experimental apparatus at ambient water temperatures for a two-week acclimation period. The experiment was initiated by heating the two treatment tanks to their target temperatures over a 24-hr period. Abalone were fed excess quantities of *Macrocystis*, and occasionally, other brown or red algae. Cages were checked approximately daily for dead or dying abalone, and the postmortem condition of foot muscles was recorded as either withered or unknown. The experiment was run for 496 days.

3.2.2 Data Analyses

Overview

Over the course of the study an extensive database was compiled on the abundances and distributions of several hundred taxa of marine organisms, most of which were identified to the species level. All these data were useful in evaluating natural changes over time and detecting impacts resulting from power plant operation. However, the primary method for objectively recognizing significant change in individual taxa over time (the BACI analysis described below) could only analyze a subset of all the data collected. This analysis requires that data be collected concurrently in control and impact areas both before and after power plant start-up. Data from surveys done during the start-up phases of DCPP units 1 and 2 (1985-1986) were excluded from the analyses in order to clearly separate the pre-operation and operation periods. The taxa included in the BACI or Fisher's analyses were those which comprised 99% of all organisms in a particular data set. Taxa comprising less than 1% of the organisms sampled were not analyzed. A diagram of the decision process and criteria for selecting stations, surveys, and taxa for statistical hypothesis testing is presented in Figure 3-5. The criteria used for determining which data met the requirements of the BACI analysis are discussed in the *Data Analyses* sub-sections for each study.

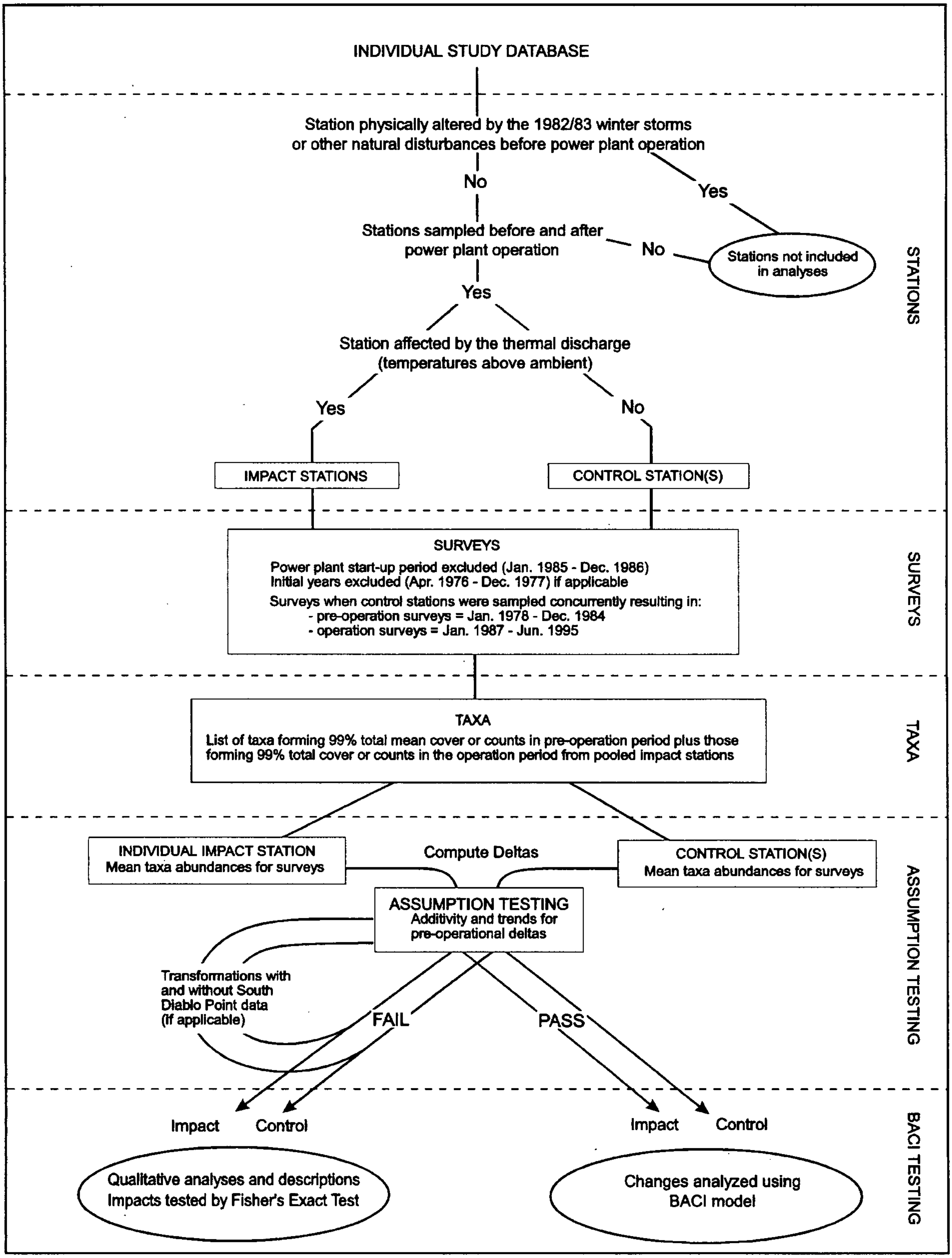


Figure 3-5. Station, survey, and species criteria for BACI analyses.

For multivariate analyses, other criteria were applied to the analyzed data sets, and the rationale for these criteria is discussed in the appropriate sub-sections below. All data are included in graphical presentations of the more abundant taxa. Survey mean abundances for all taxa sampled during TEMP are presented in Appendix E. In addition, a Data Appendix that contains complete output of all analyses has been produced as a separate volume, and has been filed with the Regional Board.

The BACI model and Analysis of Variance Testing

Detecting impacts to natural populations can be difficult if high spatial and temporal variation occurs concurrently with an impact (Stewart-Oaten et al. 1986; Underwood 1992, 1993, 1994; Green 1993; Schroeter et al. 1993; Wiens and Parker 1995). The best approach available for separating spatial and temporal variation from variation resulting from an impact is to use a Before-After/Control-Impact (BACI) design (Stewart-Oaten et al. 1986). This design uses paired, concurrent sampling of impact and control stations, and statistically compares the mean differences in abundance ('deltas') between impact and control stations before and after power plant start-up. The paired sampling events are used as replicate measures of the difference between control and impact areas under natural and disturbed conditions. The original BACI model has been modified to use multiple control stations (Underwood 1992, 1993, 1994), and multiple impact stations (Schroeter et al. 1993). Our analysis combined aspects of both approaches by using multiple control stations when they were available, and testing both individual impact stations and pre-planned combinations of impact stations grouped by area or depth.

Correct use of the analysis methods requires that data conform to certain statistical assumptions. Assumptions for BACI analyses are generally the same as those for analysis of variance (ANOVA), and have been described in detail by Stewart-Oaten et al. (1986), Schroeter et al. (1993), and Stewart-Oaten (1996b). The deltas for the station data were tested for additivity, linear trend, serial correlation and homogeneity of variances. These tests were run on raw data as well as data that were transformed using either log(x), 1/(x), or $\sqrt{(x)}$ for counts, or arcsine(x) for percentage cover. The transformations of counts required that a constant be added to account for observations with values of zero. The value of the constant used can potentially bias the analysis of the data; therefore assumption tests were run with constants of 1.0, 0.1 and .01 and the best combination of constants and transformations was chosen according to the rationale described below.

Application of the BACI model requires that populations in control and impact areas have similar trends in abundance before a disturbance. Absolute abundances need not be equal, but changes in abundance between the two populations must track one another prior to the disturbance. The "one degree of freedom" test for additivity (Tukey 1949) was used to test if deltas among stations in the pre-operation period tracked one another.

If the deltas trended positively or negatively with time in the pre-operation period, with the trend continuing into the operation period, the trend could be incorrectly interpreted as having been caused by the power plant. A test for linear trends in the mean deltas for all stations in the pre-operation period was done by regressing the mean deltas against time. Due to the large sample sizes, it was expected that many of the regressions would be significant. Therefore, the coefficient of determination (R^2) was also calculated to determine the proportion of the variability explained by the regression. If the regression was significant and R^2 was greater than 0.5 (50% of the variance in the data was accounted for by the trend), the BACI analysis for that taxon was not done.

Significant serial correlation of data, which violates the statistical assumption of independence of errors, can occur in sampling designs where surveys are somewhat equally spaced in time. Serial correlation was tested for using a ratio of mean square successive differences to the variance (von Neumann 1942). A Q-value was calculated from the mean delta for all stations for the pre-operation and operation periods, with Q-values close to zero indicating significant serial correlation in the data. All values were tested using a T-distribution approximation for Q developed by Bingham and Nelson (1981). If significant values of Q were present for both periods, or a value of less than 1.0 was found in either period, an autoregressive term was added to the ANOVA model in order to model the autocorrelated error in the data. The data were analyzed using the Proc Mixed procedure in SAS (SAS Institute 1990). This program analyzes mixed-model ANOVAs that include random and fixed factors. The program also provides options for modeling the covariance structure of random factors using a number of heterogeneous variance models, including autoregressive models (Littell et al. 1996). If a data set required an autoregressive error term, the data were run with a single autoregressive error term for the entire data set and separate autoregressive terms for each period. This procedure accounted for potential differences in autocorrelation between periods.

The assumption of homogeneity of variances was tested using Levene's test (Milliken and Johnson 1984). If the test was significant, the option for using Satterthwaite's adjusted degrees of freedom was specified in the Proc Mixed procedure (Milliken and Johnson 1984). If both serial correlation and heterogeneity of variances were present in a data set, only the autoregressive term for modeling the heterogeneous variance structure was added to the model. This followed from the assumption that the heterogeneity was a result of the autocorrelated errors in the data.

A BACI model, similar in design to the models described by Stewart-Oaten et al. (1986) and Schroeter et al. (1993), was used to test for effects of the DCPP discharge on the receiving water community. Stations were assigned to either 'control' or 'impact' groups, based on whether or not temperature measurements at the stations indicated any warming from the discharge plume. For these analyses 'impact' station refers to the stations that were tested for changes compared to the control stations. The terminology does not imply that significant changes actually occurred at the 'impact' stations. The mean abundance from the control stations was used in computing the deltas for the impact stations tested. The number of control stations and impact stations analyzed varied among the different studies (described in detail in the *Data Analysis* section for each study). In order for a given set of impact station surveys to be used, the impact stations and all control stations had to be sampled concurrently. The data were used to calculate deltas using the formula $x_i^C - x_i^I$ (the mean abundance for the three control stations (x_i^C) minus the mean abundance for an impact station (x_i^I) for each survey i). This convention was used in contrast to the formula ($x_i^I - x_i^C$) (Stewart-Oaten et al. 1986) so that the sign (positive or negative) of a delta reflects the actual change in abundance at the impact station relative to the control.

The following ANOVA model was used to test the hypothesis that impact stations were unaffected by the power plant discharge:

$$X_{ijk} = u + S_i + P_j + SP_{ij} + T_{k(j)} + ST_{ik(j)}$$

where X_{ijk} = the delta value for a station (S) for a given survey (T) within the pre-operation or operation period (P) (transformed as appropriate); u = the mean difference across all station, period and survey effects; S_i = the effect of the ith Station; P_j = the effect of the jth Period; SP_{ij} = the effect of the Station x Period interaction; $T_{k(i)}$ = the effect of the kth Survey within the jth Period; and $ST_{ik(j)}$ = the effect of the Station x Survey within Period interaction, which was also the error term for the model. The following insert lists the factors in the model and their interpretation in the ANOVA table:

Source	Degrees of Freedom	Effect tested
Station	$(x_i - 1)$ where x_i = number of impact stations	Mean delta among stations
Period	$(x_j - 1)$ where x_j = number of periods	Mean delta between periods
Station x Period	$(x_i - 1)(x_j - 1)$	Mean delta among station-period combinations

The Station effect in the model tested the hypothesis that there was no significant difference among stations. The test for differences among stations is not relevant to examining discharge effects because of the confounding effects of period in the station means. Results for the test of a Station effect are therefore not presented. The Period effect tested the hypothesis that there was no significant difference in mean deltas between periods. The Station x Period effect, or interaction, tested the hypothesis that the difference in mean deltas between periods was the same for all stations. A significant Period effect indicated significant differences between pre-operation and operation periods that may have been an effect of the discharge. However, in tests that also had a significant interaction, individual paired-comparisons between periods for each station were examined to determine the nature of the Period effect. Pre-planned comparisons between periods for groups of stations were also done on data sets for some studies (described in detail in the *Data Analysis* section for each study). The planned comparison tests were done if the impact stations could be logically grouped by area or depth, and differential impacts for the group of stations were suspected. If results of paired comparisons showed that the significant Period effect was caused by one station with a large change between periods, and this was not evident at other stations, then it was assumed that an alternative hypothesis, other than discharge effects, may have been responsible for the significant Period effect. A discharge effect would be indicated if the paired comparisons showed that the interaction was the result of a general, but variable, change between periods at all stations. In tests with significant interactions, the results were examined to make sure that it was correct to average over the Station effect when comparing the effects of Period (Milliken and Johnson 1984).

All tests were done using a probability level of 90% to determine significance. A level of 90% was chosen over the more commonly used 95% to increase the statistical power of the tests, thereby decreasing the probability of making a Type II error (Winer et al. 1991). This lower probability level increases the likelihood of finding significant changes where none may have occurred (Type I error), but in ecological impact analysis it is important to balance this error against the potentially more serious error of not recognizing a significant change when one has occurred (Type II error) (Mapstone 1995). The power of a test is a measure of the probability of correctly concluding that no change occurred (Winer et al. 1991). In these analyses, power was calculated as the ability of the test to detect a theoretical 50% change in the data using the observed error variance (Schroeter et al. 1993). This provides an indication of whether non-significant results correctly indicate little change in the data, or merely reflect low detection power.

A measure of the amount of change documented for each data set is provided by the calculation of relative percent change. The mean abundances for the pooled control and impact stations for each period were calculated, and the relative percentage change calculated using the ratio of control to impact area mean abundances using the following formula:

$$\text{Relative \% Change} = [(x_{Bc} / x_{Bi}) - (x_{Ac} / x_{Ai})] / (x_{Ac} / x_{Ai})$$

where x_{Bc} = mean abundance before operation at the pooled control sites; x_{Bi} = mean abundance before operation at the pooled impact sites; x_{Ac} = mean abundance after plant start-up at the pooled control sites; and x_{Ai} = mean abundance after plant start-up at the pooled impact sites. For data sets where mean abundances in the control populations were zero for either period, the absolute percentage change at the pooled impact stations is presented. No measure of percent change was calculated for data sets with mean abundances of zero for either period for the pooled impact stations.

The combination of transformations, constants and addition of autoregressive error terms resulted in a large number of potential analyses for each data set. The results of the assumption tests for each data set were examined to determine if a particular set of transformations could be tested. A transformation was not analyzed if the assumptions of additivity or trend were violated. If none of the combinations of transformations passed the additivity or trend tests, a BACI analysis was not done for that data set. All other combinations were analyzed using the BACI model. The results from all the assumption tests and BACI analyses for a data set were ranked based the solely on the power of the analyses to detect a 50% change in the data. If the power was similar for a number of analyses (< .10 difference), the result of the Tukey test for additivity was used to identify the transformation that best met the additive assumption of the model. If the choice of analysis was still not clear, transformations that did not introduce autoregressive error terms or Satterthwaite adjustments to the data were chosen over those that did, and log transformations for count data, or arcsine transformation for percentage cover data, were chosen over other transformations. The probability values for the main effects, or planned comparisons, were not used in choosing the analysis reported in the results. The computer program used in the analysis used an iterative maximum likelihood solution for ANOVA that did not converge on a solution for some data sets due to the combination of terms added to meet assumptions. Results for data sets that were unable to run or did not pass assumption tests were analyzed using the Fisher's exact test (described below).

Data used in the BACI analyses included abundance estimates for individual taxa based on count and percent cover, cover estimates for substrates, species richness (total number of taxa) and species diversity (Shannon-Wiener H'). While diversity indices, including H', are not typically analyzed statistically due to known problems with the statistical distribution of derived variables (Atchley et al. 1976), these problems are overcome in the BACI analysis by using deltas between impact group and control group stations, and not original estimates of H'. Complete results from all studies for assumption tests and BACI analyses are presented in Appendix G.

Fisher's exact test

Taxa that did not pass the tests of assumptions for BACI analysis were analyzed using the two-tailed Fisher's exact test. This non-parametric test requires fewer assumptions than the BACI model, but is also less powerful. It was used to test the hypothesis that the median delta (difference between control and impact) was the same for the pre-operation and operation time periods. The Fisher's exact test uses row and column totals from a 2x2 table to compute a distribution that is used to determine the probability of the observed values occurring by chance (Zar 1984). A probability level of 90% was used to determine significance. The analysis used a pooled survey mean for control and impact areas computed from the same stations used in the BACI analysis. Surveys were excluded if data were not available for all control stations. The surveys used in the analysis were the same ones used in the BACI analyses. Taxa were not included in the analysis if all remaining surveys and stations had values of zero. Differences were computed for each survey as $x_i^I - x_i^C$, where x_i^I is the mean abundance for the pooled Diablo Cove stations for survey i, and x_i^C is the mean abundance for the pooled control stations for survey i. A single median delta was computed for all surveys. The delta for each survey was then categorized as being less than, greater than or exactly equal to the median delta. The 2x2 table was constructed by first building a 2x3 table with a row for each of the two time periods and a column for each of the three 'relative to median' categories. Usually the 'equal to median' column was removed to produce the 2x2 table. In a few cases one of the other columns had no data in either row, and in those cases the 'no-data' column was removed.

For example, when over half of the deltas are equal to zero and the rest are greater than zero, the 'less than median' column has no surveys and was therefore removed.

The two-tailed Fisher's exact test was also used to analyze changes in the percent frequency of taxa occurrences between periods. Each taxon was categorized as having increased or decreased from the pre-operation to the operation period, based on its percent frequency of occurrence for a period. Only taxa that occurred at both control group and impact group stations were used in the analysis, and taxa that did not change between periods were not included. The results were organized into a two-by-two table with a row for each area (Diablo Cove or control), and columns for increases and decreases. Tables were constructed separately for invertebrate and algal taxa. The analysis was used to test the hypothesis that the proportions of increases to decreases of all taxa were independent of period (pre-operation and operation).

Multivariate Analyses

Multivariate statistical methods are useful for characterizing communities and measuring responses of communities to natural and human-induced disturbances (Boesch 1977; Green 1979). Ordination techniques, such as principal components analysis (PCA) and correspondence analysis (CA) provide representations of community structure and dynamics that can be examined for spatial and temporal responses to disturbances or ecological interactions (Agard et al. 1993; Ardisson et al. 1990; Gray et al. 1990; Olsgard and Gray 1995). Although typically used to examine gradients and spatial variation among locations, ordination has also been used to examine temporal gradients of change (Swaine and Greig-Smith 1980).

Correspondence analysis (CA) is an ordination method that has a number of advantages over other techniques that have made it very popular with ecologists. Unlike principal components analysis (PCA) and many other multivariate techniques, CA does not require multivariate normal data, and data not meeting this assumption do not bias the results of the analysis (Gauch 1982). The method of CA is unique in providing a 'double ordination' of both taxa abundances across sampling units (called taxa scores) and sampling unit abundances across taxa (site or survey scores). CA is an extension of direct gradient analysis in which taxa abundances are examined in relation to an environmental gradient (Digby and Kempton 1987; ter Braak 1987). A direct gradient analysis solution for CA would use a known environmental gradient of sites to derive a set of scores for the taxa occurring along the single one-dimensional gradient. The taxa scores would then be used to derive a new set of site scores, and the process would continue iteratively until some convergence criteria between the sets of scores was satisfied (Digby and Kempton 1987). A similar process can be used to derive multidimensional site and taxa scores using PCA by first analyzing a matrix of site correlations or covariances, and then analyzing the same set of data as a matrix of taxa correlations or covariances. Unfortunately, the two sets of results will be scaled differently and are not directly comparable. A number of ordination techniques including principal coordinate analysis and multidimensional scaling do not provide direct measures of the contribution of individual taxa to the results for an analysis. In CA an optimal multidimensional solution for both sets of scores is derived that provides the best correspondence between site and taxa scores (Greenacre 1984). Thus, taxa scores provide a relative measure of changes in taxa abundances across sampling units, while site scores simultaneously provide a relative measure of corresponding sampling unit change across taxa. In this study the data were analyzed across a temporal gradient of change using annual means for taxa groups, and survey and annual means for individual taxa.

Results from CA were presented in two forms. Results of first axis CA survey scores from a single station were plotted to examine relative variation among surveys along the one-dimensional axis of time.

In these presentations the variation explained by the analysis will be attributable to the surveys showing the most change relative to other surveys. The variation may be due to seasonality, disturbance due to storm events, effects due to operation of the power plant or random variation. Results from separate analyses are not directly comparable, but can be used to contrast the major sources of variation present at individual stations or groups of stations. Taxa scores presented for the analyses are useful in interpreting the contribution of individual taxa to the pattern in survey scores. Taxa scores with positive scores would correspond to the pattern observed for positive survey scores and would be interpreted as taxa experiencing some relative change corresponding to those surveys. The second form in which CA results were presented involved plotting out the first and second axis, or first and third axis CA scores in a two-dimensional plot. Results were presented in this format when more than one group of stations was analyzed and allowed examination of scores among the groups which may have extended to multiple dimensions due to contrasting patterns of variation. Taxa scores would be plotted on the same axes to help interpret the relative contribution of taxa to the pattern of survey scores.

Data for the period of power plant 'start-up' testing that may have been excluded from univariate analyses were included in multivariate analyses. This was appropriate, since multivariate analyses were used to examine and describe changes over time at a location, and were not used for statistical hypothesis testing. When annual mean abundances were used in the analysis, data for 1995 were excluded because a full year of data was not collected. Station survey or mean annual scores and taxa scores were plotted to examine contrasting patterns of temporal variation between impact and control stations.

Taxa were also combined into larger groupings representing morphological types for algae and functional feeding types for invertebrates. A multivariate 'meta-analysis' of community disturbance using broad taxonomic categories can sometimes be preferable to taxon-based methods when comparing communities across broad scales (Warwick and Clarke 1993). When combining taxa, data were first transformed using a log transformation to account for different scales of measurements in the combined data sets and individual groups. The results of CA and other ordination techniques are known to be sensitive to effects of rare or relatively rare taxa (Digby and Kempton 1987). All CA analyses used a set of criteria to identify the most abundant taxa and taxa which occurred relatively frequently in the surveys. Only these taxa were included in CA analyses because they would likely be the best indicators of major changes in a community. The criteria for taxa selection for CA analysis for each study are described in the appropriate report sections.

Diversity is a community characteristic that was measured in the present study to describe the number of taxa present at sampling locations during a particular survey, and the relative abundances among those taxa. An index of diversity widely used in community ecological studies is the Shannon-Wiener index (H') (Shannon and Weaver 1949):

$$H' = -\sum p_i \log p_i$$

where p_i = the proportion of the community belonging to the i^{th} taxon. The index was tested as a variate with the BACI design to examine differences in diversity between periods at control and impact stations. The index was applied to both intertidal and subtidal data sets.

Data Codes

Data for a large number of taxa, most of which were identified to the species level, were collected during the TEMP studies. All taxa during the study were assigned unique codes. Each taxon was also assigned an additional code that allowed the grouping of taxa. This procedure combined taxa that may have been difficult to identify in the field due to similarities in morphology, or that were identified by their life history stage or condition in the field. For example, various species of the algae *Farlowia* and *Pikea* identified with individual codes in the field were combined under one code for analysis because of known difficulties in separating these species. Juvenile, sub-adult and adult stages of fishes may have been separately identified in the field, but these were combined under a single code for analysis. The combined codes rather than individual taxa codes were used in all analyses.

Horizontal Band Transects (HBT)

The following sections describe data analysis methods specific to the different intertidal TEMP studies. The stations, surveys and taxa used in statistically testing for effects of the discharge are described in each section. The BACI model used to test for discharge effects varied slightly for each study from the general model described in the previous section of the methods. These differences are described in the sections below. A summary of the data used in the BACI analyses for each study is presented in Table 3-2.

Data Analyzed

Effects of the discharge on taxa abundances were primarily tested using the BACI analysis described previously in the methods section. Data sets that did not pass tests of assumptions for the BACI analysis were tested using a Fisher's exact test. Changes in the intertidal community were analyzed using correspondence analysis of HBT data. All the data for taxa comprising the top 99% cumulative abundance were used in graphical analyses showing changes in abundance over time (Appendix E).

<u>Stations</u> - A BACI analysis requires concurrent sampling of both control and impact stations. Therefore, although a large number of HBT stations were sampled during the TEMP study only a subset of the stations that were sampled consistently before and during plant operation were suitable for analysis. Severe storm waves in March 1983 eroded shoreline cliffs that resulted in the complete burial of Stations SDC-1 and SDC-3 (south Diablo Cove) under rock fragments and sand. Sampling was continued after station burial to document biological recovery during plant operation. However, since algal cover and invertebrate densities were still depressed at these stations when power plant discharges began, they were excluded from analyses for discharge effects. The largest effects of the discharge were expected to occur in Diablo Cove. Increased temperatures were also detected at intertidal stations at Field's Cove and Diablo Point, and thus were also included as impact stations in the model. Using these criteria in combination with water temperature results, three stations (NC-1, NC-2, SC-1) were used as control stations, and seven stations (FC-3, NDC-1, NDC-2, NDC-3, SDC-2, SDP-1, SDP-2, SDP-3) were tested for significant changes against these controls. The South Diablo Point stations (SDP-1, SDP-2, SDP-3) have only a single transect at the +0.9 m tidal level. Due to greater wave exposure on South Diablo Point, the species composition at these stations had closer affinities to the +0.3 m stations from other areas and were therefore analyzed with the +0.3 m data set.

The +0.3 m and the +0.9 m transects at each station were analyzed as separate data sets. The pattern of data was different for the two tidal levels, which limited the analysis of certain combinations of stations, surveys and treatments. Treating elevation as an additional experimental factor in the analysis would have presented difficulties in interpreting statistical tests of significance for the interactions, due to unequal treatment combinations (Milliken and Johnson 1984). It would be expected that the interaction of tidal elevation and wave exposure would be different among locations, which would have ensured significant interactions among transect elevation and station in the TEMP data sets. There were also differences in species composition and abundance between the +0.3 and +0.9 m transects. Combining data from both transect elevations in the analysis would have added data with small or zero abundance for many taxa, which would have affected statistical testing (Stewart-Oaten et al. 1986).

Table 3-2. Summary of intertidal data sets used in BACI analyses.

Study	Taxa Groups	Quads	Total # Stations Sampled	Impact Stations in BACI	Control Stations in BACI	Total # Surveys Sampled	Pre-operation Surveys for BACI	Operation Surveys for BACI	Total # Taxa Sampled	# Taxa Analyzed in BACI
Horizontal Band Transects (+0.9m)	Invertebrates	5	28	7	3	100	31	29	248[1]	35
	Algae	10	28	7	3	100	31	29	119[1]	35[2]
Horizontal Band Transects (+0.3m)	Invertebrates	5	21	5	3	98	34	29	-	22
	Algae	10	21	5	3	98	34	29	-	26[2]
Vertical Band Transects	Fish	36	5	2	1[3]	58	9	31	30	11
Algal-Faunal Association (*Gastroclonium*)	Invertebrates	8	5	2	1[3]	46	12	33	302	91
Algal-Faunal Association (*Endocladia*)	Invertebrates	8	5	2	1[3]	46	12	33	177	38

[1] includes 2 crustose algal taxa groups not included in list of top 99% total abundance.
[2] includes 2 kelp taxa groups not included in list of top 99% total abundance.
[3] study did not have a control station unaffected by thermal discharge; Field's Cove station was used for comparison.

Surveys - The TEMP intertidal study began in April 1976, but the data collected in the surveys through 1977 were not analyzed because of several changes that occurred in the sampling program methods. The remaining surveys were partitioned into pre-operation and operation periods. The pre-operation period was defined as January 1, 1978 to December 31, 1984 (41 surveys). The first thermal discharges occurred intermittently in late 1984 with the start-up testing of Unit 1. Total discharge flow was greatly reduced from operational levels and temperature differences from ambient were intermittent and always less than 4°C. The operation period was defined as January 1, 1987 to June 30, 1995 (36 surveys). Full commercial operation began in May 1985 for Unit 1 and in March 1986 for Unit 2. These periods excluded the two years encompassing most of the start-up testing and initial operation of units 1 and 2. This was done to allow time for taxa abundances to respond to the effects of the discharge, increasing the ability to detect changes between periods. All surveys were used in graphical analyses of individual taxa showing changes in abundance over time.

Surveys were also not included in the BACI analysis if control stations used in the analysis were not all sampled during a survey. This ensured that the estimate of the mean control abundance for a given taxon was the best unbiased predictor available. Although this criterion reduced the sample size for the pre-operation and operation study periods, it had the benefit of reducing the potential for serial correlation among consecutively sampled surveys (Stewart-Oaten et al. 1986). By these criteria, a maximum of 34 surveys in the pre-operation period and 29 surveys in the operation period were used for comparison with impact group station data.

Taxa - Almost 400 intertidal taxa (invertebrates, algae and fish combined) were enumerated during the TEMP, most taxa could not be statistically analyzed for changes because they were encountered too infrequently. The most abundant algal taxa were selected for analysis by compiling taxa lists for the +0.3 m and +0.9 m transects separately because the tidal elevations differed substantially in biotic composition. The lists reflect those taxa comprising 99% of the non-crustose mean algal cover in the pre-operation period (grand mean percentage cover across all impact group stations) merged with the list of taxa using the same criteria from the operation period. Merging taxa lists from the two periods, rather than compiling a single list computed from grand mean abundances across all surveys and stations, ensured that taxa that were rare in one period but abundant in the other were accounted for in the analysis. The list of algae analyzed included 33 algal taxa at the +0.3 m elevation and 24 taxa at the +0.9 m elevation.

The list of invertebrates was developed similarly, but mean abundances were computed from the five quadrats per transect where certain invertebrates were counted regardless of size. Invertebrates that were enumerated as percent cover (e.g., sponges) were compiled separately using data from all ten quadrats. The list of invertebrates for analysis included the taxa comprising the top 99% of the cumulative abundance at the +0.3 m and +0.9 m transect elevations. Many taxa were only recorded as present or absent, or were counted only if greater than 2.5 cm in greatest dimension. Although these taxa were not enumerated consistently, the bias represented by the potential differences was considered to be equal across all stations and therefore, these taxa were analyzed. The list of invertebrates analyzed included 36 invertebrate taxa at the +0.3 m elevation and 22 taxa at the +0.9 m elevation. Other data sets analyzed include percent cover of combined groupings of crustose and non-crustose algae, percent cover of bare rock, species richness of algae and invertebrates, and diversity (Shannon-Wiener H') of algae. Diversity (H') was not tested for invertebrates as a group because the widely dissimilar taxa of invertebrates and varying levels of taxonomic classification in the samples made any ecological interpretation of this index difficult. The list of taxa and data sets analyzed is presented in Appendix F.

BACI Analysis

The BACI model presented in the introduction to this section was used for testing effects of the discharge for the HBT data. Discharge effects were tested by either using the main effect of period, or through planned comparisons between periods for stations and station groups. The data used in computing deltas for the analysis were the mean abundances of algae, invertebrates or substrate measured as counts or percent cover per 1 m^2 at each transect. Abundance per 1 m^2 was calculated based on ten quadrats for algae, substrates, abalone, and invertebrates measured as percent cover. Abundances were computed for all other invertebrates using the five 'count' quadrats at each transect. Delta values used in the BACI analysis were computed by subtracting the mean abundance for an impact group station from the pooled mean abundance for the three control stations for each survey. All data sets were tested for assumptions using the set of transformations and constants discussed previously. The analysis presented in the results was chosen based on the power of a given transformation to detect a 50% change in the data, results of the Tukey test for additivity, and other criteria presented previously. Results for all assumption tests and BACI analyses for all transformations are presented in Appendix G.

The majority of effects from the discharge were expected to occur in Diablo Cove. Stations from Field's Cove and South Diablo Point had a lower potential for impact but were included in the analysis with stations from Diablo Cove. This increased the likelihood that the interaction between station and period effects would be significant. To allow testing for discharge effects in the different areas, a set of *a priori* planned comparisons were used in the analyses. The testing proceeded by first determining if there was a significant Station x Period interaction. If there was no significant interaction among stations between periods then the overall Period effect was used to test the hypothesis that there was no significant difference in mean deltas between periods. If the interaction was significant, it was likely caused by including stations with varying degrees of impact in the analysis. Separate comparisons between periods to test for discharge effects were made for stations at Diablo Cove and Field's Cove for both transects, and an additional comparison between periods was made among the South Diablo Point stations for the

+0.3 m transects. Additional paired comparisons between periods for each station are presented in the BACI results.

Other Analyses

Data sets that did not pass the tests of assumptions for BACI analysis were analyzed using the Fisher's exact test. The analysis was used to test the hypothesis that the proportions of differences categorized as less or greater than the median difference were independent of period (pre-operation and operation). The Fisher's exact test was also used to analyze changes in the percent frequency of taxa occurrences between periods.

The data from the horizontal band transects were used to analyze changes in the community using correspondence analysis. Temporal patterns of variation were examined using survey means for individual taxa and overall survey scores for individual transects. A 'meta-analysis' of these data was also done by log transforming the CA scores to account for different scales of measurements and then combining the data into larger groupings based on the criteria in Table 3-3. Annual means were computed separately for the +0.3 m and +0.9 m transects for two groups: Diablo Cove stations NDC-1, NDC-2, NDC-3, SDC-2, and control stations NC-1, NC-2 and SC-1. Correspondence analysis results were scores for taxa used in the analysis, and annual scores for each of the two locations. The two sets of scores were plotted to examine the contrasting patterns of temporal variation at the two locations.

Vertical Band Transects (VBT)

Overview

Algal and invertebrate data for the vertical band transect study were not analyzed, due to the lack of pre-operation data for algae and invertebrates from the Field's Cove station. Without data from a comparison station outside Diablo Cove, the BACI design could not be used. Although some pre-operation data existed for invertebrates in Field's Cove, they were not analyzed statistically because most of the same taxa were sampled by the horizontal band transect study, which provided a more powerful data set for hypothesis testing. The invertebrate data sets were qualitatively analyzed for change by comparing taxa presence plotted over time against quadrat elevation. The analyses were used to supplement the results from horizontal band transects.

Effects of the discharge on intertidal fish abundances were primarily tested using a BACI analysis. The BACI model for VBT used Field's Cove as the 'control' or 'reference' station for the purposes of computing the deltas used in the analysis, and could be better described as a comparison station. Since results from temperature monitoring showed that Field's Cove had been impacted by the thermal discharge and had mean water temperatures for the operational period that were above ambient, all impacts detected by the BACI model were considered to be conservative estimates of actual impacts. Data sets that did not pass tests of assumptions for the BACI analysis were tested for changes between pre-operation and operation periods using a Fisher's exact test. All the data for taxa making up the top 99% cumulative abundance were used in graphical analyses showing changes in abundance over time (Appendix E).

Table 3-3. Algal and invertebrate ecological categories used in multivariate analyses. Algal categories were based on morphology descriptions modified from Littler and Littler (1984); invertebrate consumer categories were developed from Morris et al. (1980). Category abbreviations in parentheses appear on multivariate plots (Figures 3-51 to 3-54). Categories without abbreviations did not meet abundance criteria for final testing and do not appear on multivariate plots.

CATEGORY	CHARACTERISTICS	EXAMPLE SPECIES
ALGAE		
Perennial Algal Species		
Branched (Branch)	Variable group consisting of stiff or soft, relatively large thalli with large variations in branching patterns, thickness, and shape.	*Mastocarpus papillatus*, *Gastroclonium subarticulatum*
Foliose (ABlade)	Variable group consisting of single or multiple flat, elongate blades; layers over shorter statured algae	*Mazzaella splendens*, *Chondracanthus corymbiferus*
Articulated corallines (ACoral)	Calcified segments.	*Calliarthron/Bossiella* spp.
Saccate	Globose, low growing.	*Halosaccion glandiforme*, *Colpomenia* spp.
Stipitate Kelp; Rockweed (ARckWd)	Thick, leathery, tough.	*Pelvetia compressa*, *Fucus gardneri*, *Laminaria setchellii*
Strap	Elongate, polystromatic, relatively strong tensile strength, layers over shorter statured algae.	*Phyllospadix* spp., *Egregia menziesii*
Ephemeral Algal Species		
Epiphyte; Parasite	Host requirement.	*Microcladia coulteri*
Filamentous Turf (ATurf)	Uniseriate, lightly corticated, soft and delicate.	*Polysiphonia* spp., *Centroceras clavulatum*
Thin Sheet (ASheet)	One to several cells thick, soft and delicate.	*Ulva/Enteromorpha* spp., *Cryptopleura* spp.
Crustose (ACrust)	Prostrate growth forms.	Crustose coralline algae (*Lithothamnion* spp.), non-coralline crustose algae (*Petrocelis, Ralfsia, Cylindrocarpus*)
INVERTEBRATE		
Active Predator (Predtr)	Motile species that actively feed on live sessile and motile animals.	Snails (*Acanthina spirata*, *Ocenebra circumtexta*). large sea stars, cancer crabs, polychaetes, and nemertean worms
Algal Grazer (AlGraz)	Motile species that actively feed on attached or drift plant material.	Limpets, chitons, abalone, kelp crabs and decorator crabs
Animal Grazer	Motile species that actively feed on encrusting animal species (e.g., sponges and bryozoans).	Nudibranchs and some small molluscs (*Trivia californica* and *Epitonium tinctum*)
Detritus, Deposit, Suspension Feeder (DDSusp)	Species that actively or passively feed on detrital or deposited material that is suspended in or settles out of the water or substratum.	*Phragmatopoma californica*, *Pista* spp., and sipunculid worms (*Phascolosoma aggassii*)
Filter Feeder (FlFeed)	Species that actively or passively filter food from the water.	Barnacles, sponges, tunicates
Scavenger (Scavgr)	Non-sessile animals that actively feed on dead or decaying animal or plant material.	Hermit crabs, shore crabs, small molluscs (*Alia* spp., *Tricolia* spp.)

Data Analyzed

Stations - Three of the five stations sampled for intertidal fish abundances (FC1-V, NDC1-V and SDC2-V) were used in the analysis, because the two stations in Diablo Cove were sampled less frequently during the pre-operation period. FC1-V in Field's Cove was used as a comparison station for the purposes of computing deltas for the analysis. The two stations in Diablo Cove were assigned to the impact group for the analysis.

Surveys - The definitions of pre-operation and operation periods used in the HBT analysis were also used for analysis of the VBT data, which excluded the two years encompassing the start-up of units 1 and 2. The station in Field's Cove was only sampled during nine surveys in the pre-operation period from April 1979 through April 1981. These 9 pre-operation surveys and the 31 surveys from the operation period, when all three stations were sampled, were used in the BACI analysis.

Differences between numbers of pre-operation and operation surveys did not impact the computational aspects of the analysis. The calculation of power to detect a 50 percent change in the data was based on the pre-operational data from nine surveys. Therefore, the value presented in the results probably underestimates the true power of the tests when operational surveys were included.

Taxa - Thirty taxa of fish were enumerated during the vertical band transect studies. The BACI analysis was conducted on the taxa comprising the top 99 percent of the cumulative abundance, calculated from the two Diablo Cove impact stations, using the same methods described for the HBT data.

BACI Analysis

The BACI model for testing effects of the discharge for VBT data was similar to the general example described in the introduction to Section 3.2.2 - *Intertidal Data Analysis*. Discharge effects in the model were tested either by using the main effect of period, or through paired comparisons between periods for the two impact stations. The data used in computing the deltas for the analysis were the mean abundance of fish per $1m^2$ for the 36 quadrats at each station. Delta values used in the BACI analysis were computed by subtracting the mean abundance for the Diablo Cove stations (more thermally impacted) from the mean abundance for the Field's Cove station (less thermally impacted). All data sets were tested for assumptions using the set of transformations and constants discussed previously. The analysis presented in the results was chosen based on the criteria previously discussed.

A significant interaction between periods and the two Diablo Cove stations was used to determine if the overall Period effect could be used to test the hypothesis that there was no significant difference in mean deltas between periods. If the interaction was significant, paired comparisons between periods for each station were analyzed to determine the nature of the interaction. Effects detected from the VBT data were interpreted as conservative estimates of impact because of the use of Field's Cove (an area affected by power plant discharge) as the reference station for the analysis.

Algal-Faunal Associations (AFAS)

Overview

A BACI analysis was used as the primary test for effects of the discharge on the abundances of invertebrate taxa. The BACI model for AFAS used Field's Cove as the 'control' or 'reference' station for the purposes of computing the deltas used in the analysis, and could be better described as a comparison station. Since results from temperature monitoring showed that Field's Cove had been impacted by the thermal discharge and had mean water temperatures for the operational period that were above ambient, all impacts detected by the BACI model were considered to be conservative estimates of actual impacts. Data sets that did not pass tests of assumptions for the BACI analysis were tested for changes between pre-operation and operation periods using a Fisher's exact test. Correspondence analysis was used to analyze changes in the invertebrate communities from the collections of the two algae. All the data for taxa making up the top 99 percent cumulative abundance were used in graphical analyses showing changes in abundance over time.

Data Analyzed

Stations - Three of the five AFAS stations (FC-AF, NDC-AF, and SDC-AF) were sampled consistently from 1979 through 1995. *Endocladia* and *Gastroclonium* collections from these three stations were included in the analysis. The two stations in Diablo Cove were assigned to the impact group for the analysis. Station FC-AF in Field's Cove was used as the 'control' or reference station for the purposes of computing deltas for the analysis. Since analysis of temperature data showed that the Field's Cove area was impacted during power plant operation, the analysis may underestimate the effects of the discharge.

Surveys - The definitions of pre-operation and operation periods used in the HBT analysis, which excluded the two years encompassing the start-up of units 1 and 2, were also used for analysis of the AFAS data. During the pre-operation period the study was conducted from October 1979 through December 1982. Twelve pre-operation surveys and 33 operation period surveys were analyzed. The differences between numbers of pre-operation and operation surveys did not impact the computational aspects of the BACI analysis. The calculation of power to detect a 50 percent change in the data was based on only the pre-operational data, and therefore, the value presented in the results probably underestimates the true power of the tests given the large number of operational surveys.

Taxa - With over 300 taxa enumerated during the Algal-Faunal Association Study, most of which were rare, only a fraction of the taxa could be statistically analyzed. Invertebrate counts in each sample were converted to a mean abundance per gram dry weight of algae. For each of the two algae sampled, the BACI analyses used the taxa comprising the top 99 percent of the cumulative abundance, as calculated from the two Diablo Cove impact stations using the same methods described for the HBT data. This resulted in a list of 38 taxa from the *Endocladia* samples and 91 taxa from the *Gastroclonium* samples. Invertebrate species richness was also analyzed.

BACI Analysis

The BACI model for testing effects of the discharge was identical to the example previously described for the VBT study. Discharge effects in the model were tested either by using the main effect of period, or through paired comparisons between periods for the two impact stations in Diablo Cove. The data used in computing the deltas for the analysis were the mean abundance per gram dry weight from the eight 10x10 cm scrape collections at each station. Delta values used in the BACI analysis were computed by subtracting the mean abundance of a taxa for the Diablo Cove stations (more thermally impacted) from the mean abundance of a taxa for the Field's Cove station (less thermally impacted). All data sets were tested for assumptions using the set of transformations and constants discussed previously, and the analysis presented in the results was chosen based on the criteria previously discussed (Appendix G).

A significant interaction between periods and the two Diablo Cove stations was used to determine if the overall Period effect could be used to test the hypothesis that there was no significant difference in mean deltas between periods. If the interaction was significant, paired comparisons between periods for each station are presented to determine the nature of the interaction. The effects detected using the algal scrape data were interpreted as conservative estimates of impact because of the use of Field's Cove as the comparison station in the analysis.

Other Analyses

Data sets that did not pass the tests of assumptions for BACI analysis were analyzed using the Fisher's exact test. The analysis was used to test the hypothesis that the proportions of differences categorized as less or greater than the median difference were independent of period (pre-operation and operation). The Fisher's exact test was also used to analyze changes in the percent frequency of taxa occurrences between periods (see Section *Data Analysis Overview*).

Changes in invertebrate communities represented by data from the *Endocladia* and *Gastroclonium* collections were analyzed using correspondence analysis (see *Data Analysis Overview*). Each alga was analyzed separately. Invertebrate taxa that accounted for 95% of the total abundance and occurred in at least 20% of the surveys were included in the analysis of the *Endocladia* data. Taxa that accounted for 90% of the total abundance and occurred in at least 20% of the surveys were included in the analysis of the *Gastroclonium* data. All data were transformed using log (x+1) prior to analysis to account for differences in scales of abundance among species. Annual means for individual taxa used in the analysis were computed for stations NDC-AF and SDC-AF in Diablo Cove and Station FC-AF from Field's Cove. Annual mean survey and taxa scores from the analysis were plotted to examine and contrast the temporal patterns of variation at the three stations.

Black Abalone

Black abalone were sampled in the horizontal band transects, and those data were statistically analyzed using the methods described for the invertebrates in the HBT study. Black abalone were also sampled using a random design census in Diablo Cove and counts along permanent 10 m transects. The data from these studies were not analyzed statistically for significant changes, due to the absence of pre-operation data and control stations. The data (abundance and size frequency) were analyzed using graphs and tables.

Shoreline Distance Determinations

Shoreline distances were calculated to describe the lengths of coastline affected by the thermal discharge. The basic coastal features from Point Buchon to Point San Luis were digitized from two USGS 7.5 minute series topographic maps (Port San Luis and Morro Bay South quadrangles) at a listed scale of 1:24,000. A more detailed resolution for the area of the Intake Cove, Diablo Cove, Field's Cove and Patton Cove was digitized from engineering survey maps at a scale of approximately 1:9,000. These provided highly detailed shoreline configurations from which distances of various coastal segments were calculated using the ARC/INFO geographic information system (GIS) software. Shoreline distance, in contrast to a simple linear coastline distance, was measured from digitized maps that included the numerous indentations and emergent offshore rocks along the waterline at mean high water. These calculated distances are proportional to the detail, or resolution, portrayed on the digitized maps (i.e., a highly detailed map would yield a longer shoreline distance for a given coastal segment than a less detailed map). The calculated shoreline distances in the report are referred to as 'shoreline distances'. In almost all cases shoreline distances were calculated from the 1:9,000 scale digitized map. The less-detailed 1:24,000 scale map was used to calculate distances over larger coastal segments where the

1:9,000 scale information was not available. Shoreline distances in the present report that were calculated using the 1:24,000 scale map are specified in the text.

3.3 Results

3.3.1 Algae

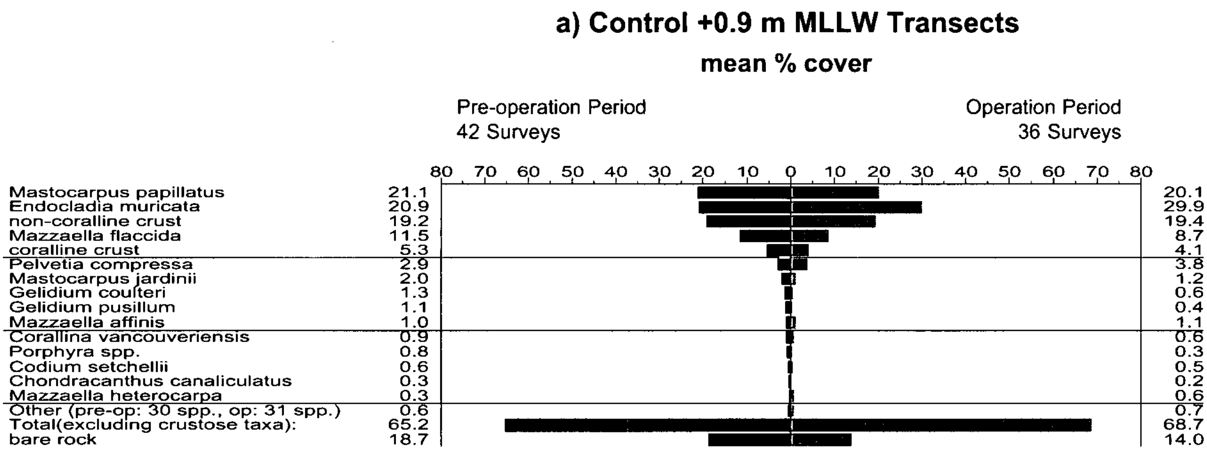
One-hundred and nineteen algal taxa, most of which were identified to the species level, were sampled in the intertidal horizontal band transect study. Surfgrass (*Phyllospadix* spp.) is a flowering plant that is included with the algae as one of the 119 taxa. Figures 3-6 to 3-9 present changes in mean algal abundances between periods for each tidal elevation at control sites, Diablo Cove, Field's Cove, and South Diablo Point stations. The taxa in the figures are those that formed 99 percent of the total algal cover in either the pre-operation or operation study periods. Rankings for each period were based on mean survey abundances pooled across stations. Abundances of crustose coralline algae, crustose non-coralline algae, and bare rock are also shown in the figures. The figures show decreases in algal abundance in a number of taxa at impact stations and fewer changes at control stations. These abundance changes between periods at the impact stations were analyzed statistically for impacts resulting from the discharge against control station abundances using a BACI or Fisher's exact test. Thirty-eight taxa were analyzed at one or both sampling elevations. Algal diversity (Shannon-Weiner H'), total algal cover, numbers of taxa (species richness), and bare rock cover were also analyzed for each sampling elevation. Table 3-4 summarizes the main discharge effects on intertidal algae, with more detailed analyses following.

Table 3-4. Summary of discharge effects on intertidal algae sampled in the horizontal band transect study.

Category	+0.9 m MLLW	+0.3 m MLLW	Notes
Length of shoreline with greatest observed effects	2.2 km	2.2 km	Mainly Diablo Cove and Diablo Rock.
Length of shoreline with reduced observed effects	1.4 km	1.4 km	Mainly Field's Cove and South Diablo Point.
Effects on algal diversity (H')	decrease	decrease	BACI results.
Effects on overall numbers of algal taxa	decrease	decrease	BACI results.
Effects on algal coverage	decrease	decrease	Crustose taxa were not included.
Number (%) of taxa increases	1 (4%)	7 (20%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa decreases	19 (72%)	20 (57%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa unchanged	2 (8%)	3 (9%)	Includes BACI only.
Number (%) of taxa with inconclusive test results	4 (16%)	5 (14%)	Includes both BACI and Fisher's exact test.
Number of taxa analyzed statistically	26	35	Taxa comprising top 99% cumulative abundance.
Number of taxa sampled during study	119		Includes both levels combined; also includes some species that were grouped into combination taxa for analysis.

Analysis of Changes

Assumption testing necessary for the BACI analysis was completed for each data set using transformed and untransformed data (Appendix G). BACI results were categorized as statistically significant increases, statistically significant decreases, no significant change, and test results inconclusive relative to



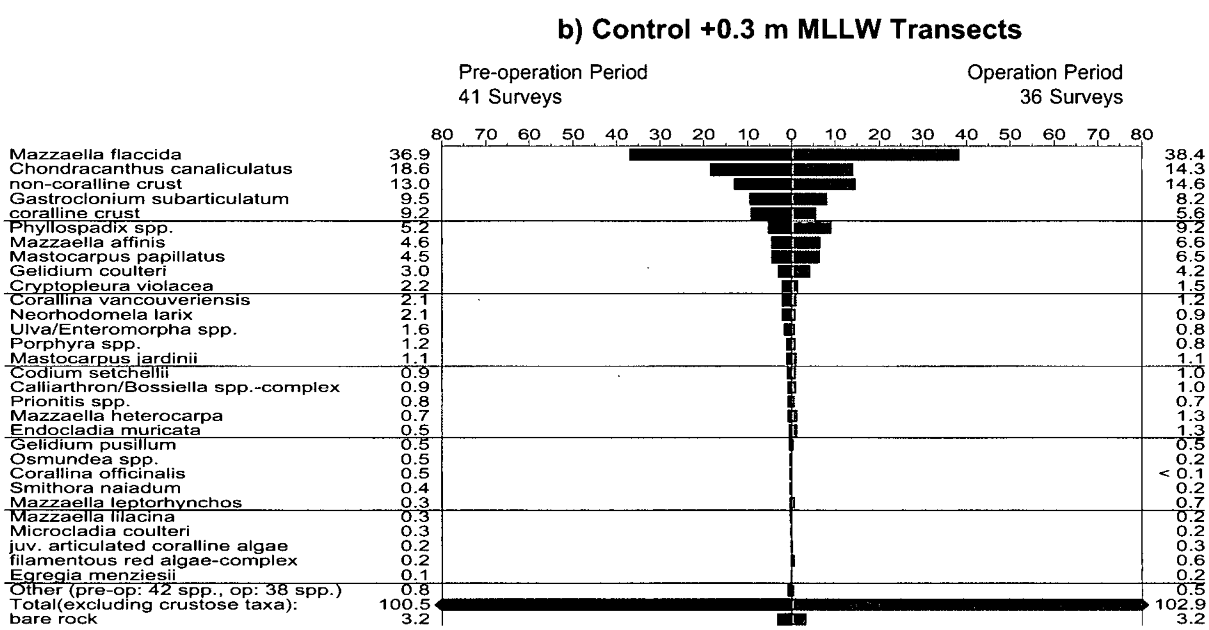
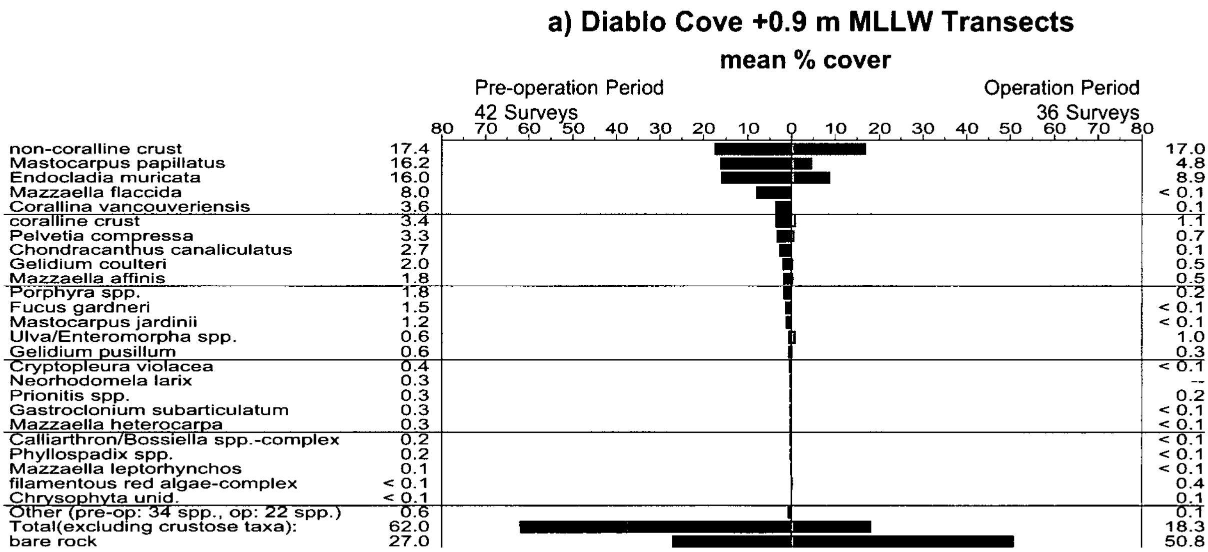


Figure 3-6. Intertidal algal abundances at the control (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from NC-1, -2, and SC-1. For each sampling elevation, the list of taxa are those that formed 99% of the total algal cover in the pre-operation period combined with the list that formed 99% of the total algal cover in the operation period (not including bare rock and crustose taxa, which were added separately). Data collected in 1976-77 and 1984-86 were not included.



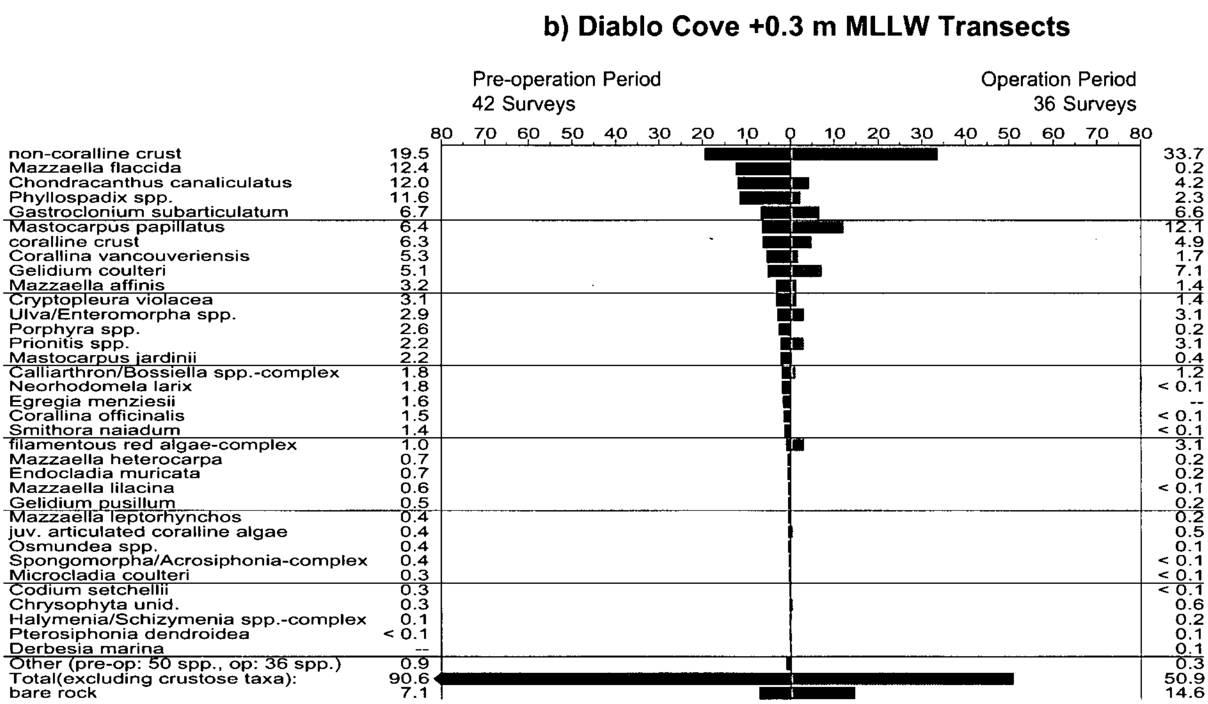
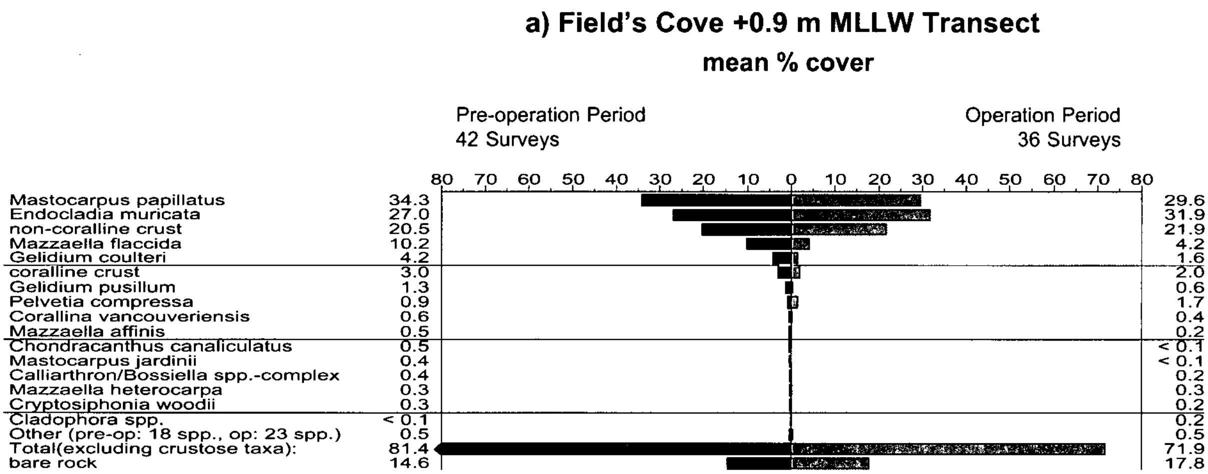


Figure 3-7. Intertidal algal abundances at the Diablo Cove (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from NDC-1, -2, -3 and SDC-2. For each sampling elevation, the list of taxa are those that formed 99% of the total algal cover in the pre-operation period combined with the list that formed 99% of the total algal cover in the operation period (not including bare rock and crustose taxa, which were added separately). Data collected in 1976-77 and 1984-86 were not included.



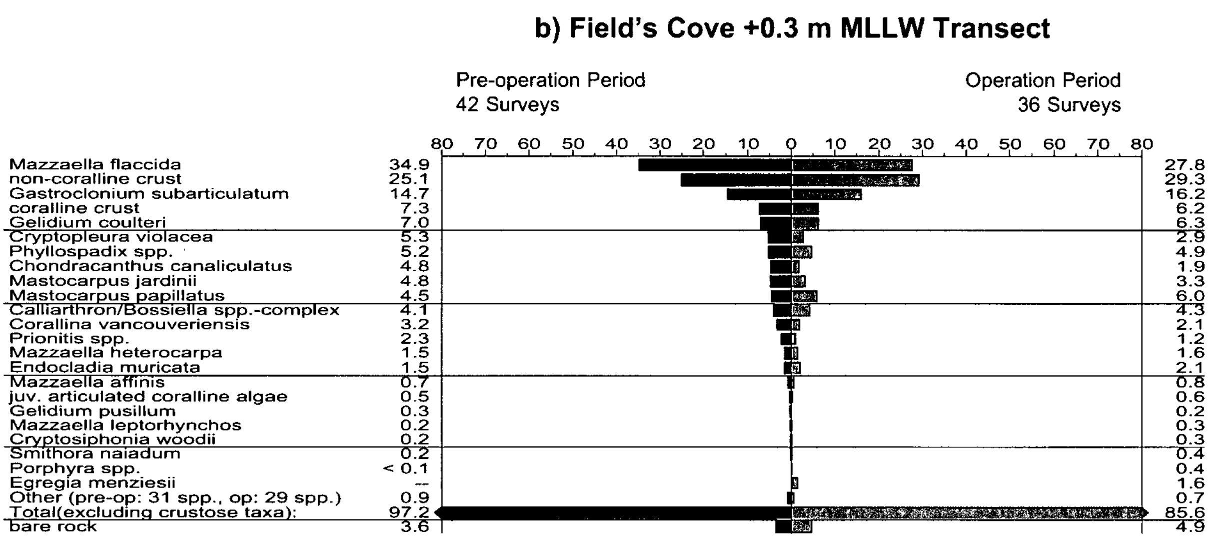


Figure 3-8. Summary of intertidal algal abundances at the Field's Cove (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from FC-3. The list of taxa are those that formed 99% of the total algal cover in the pre-operation period combined with the list that formed 99% of the total algal cover in the operation period (not including bare rock and crustose taxa, which were added separately). Data collected in 1976-77 and 1984-86 were not included.

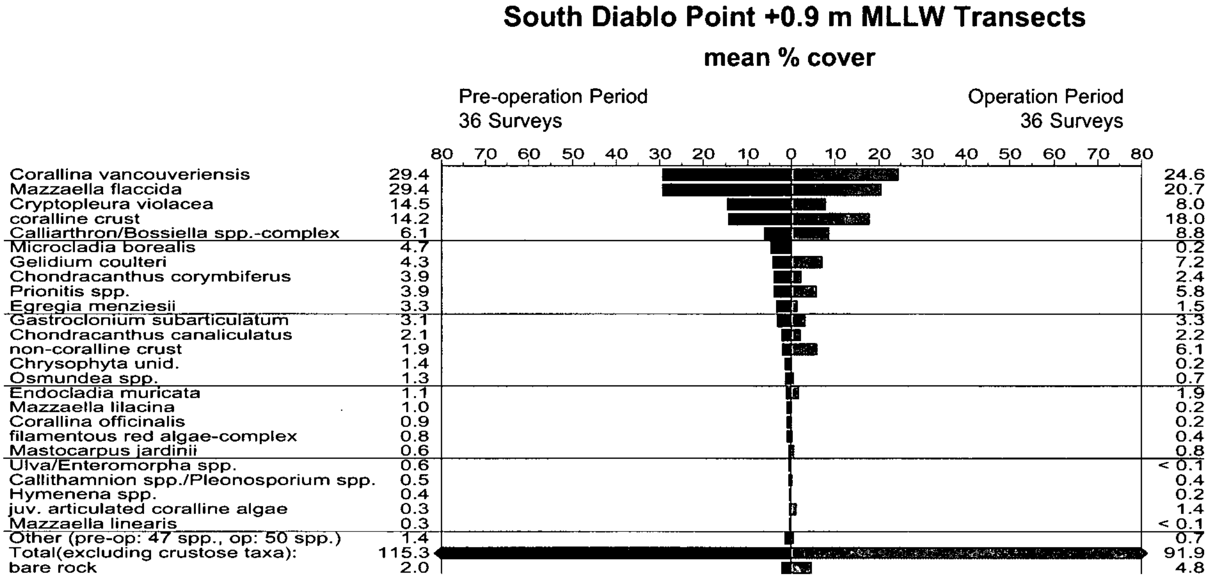


Figure 3-9. Summary of intertidal algal abundances at the South Diablo Point +0.9 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from SDP-3, -2, and -3. The list of taxa are those that formed 99% of the total algal cover in the pre-operation period combined with the list that formed 99% of the total algal cover in the operation period (not including bare rock and crustose taxa, which were added separately). Data collected in 1976-77 and 1984-86 were not included.

controls, based on resulting p-values for period and interaction effects, and planned comparisons between periods for Diablo Cove, South Diablo Point, and Field's Cove station groups (Table 3-5).

Data sets that did not pass assumption testing at either elevation were analyzed for changes with the Fisher's exact test (Table 3-6). The results were grouped into three categories: significant increases; significant decreases; and test results inconclusive. Taxa that occurred infrequently in the study, generally at only one station or in one survey, were not analyzed by the BACI model or Fisher's exact test. However, they were included in analysis of diversity (H'), numbers of taxa, and total algal cover, analyzed by the BACI analysis. Results of assumption testing and complete BACI analysis results and Fisher's exact test results are presented in Appendix G.

Graphs depicting changes in abundance over time for each taxon examined in the BACI model and Fisher's exact test appear in Appendix E. Some of these graphs appear in the present section to illustrate the various types of changes observed in the study.

Significant Increases

Statistically significant increases in abundance relative to control abundances were detected in seven taxa at Diablo Cove, South Diablo Point, or Field's Cove (Table 3-5). No significant increases were detected with the Fisher's exact test (Table 3-6). Non-coralline crustose algae was the most abundant taxon that increased in the lower elevation transects in Diablo Cove (Figure 3-7). Statistically significant increases were detected in filamentous red algae complex and *Ulva/Enteromorpha* spp., two ephemeral algal taxa groups. Increases were also detected for three perennial taxa, *Prionitis* spp., *Gelidium coulteri* and *G. pusillum*, relative to controls.

Increases among the seven taxa were generally inconsistent among stations, and included decreases for some of the same taxa at some stations, relative to controls (Table 3-4). Although significant increases were detected for crustose coralline algae and *Gelidium coulteri* at the lower elevation transects, significant decreases were detected at the upper sampling elevation (see following). *G. coulteri* became very abundant at station SDC-1, located 100 m from the outfall (Figure 3-10). Algal coverage at this station had been reduced to zero when it became buried under sand during the 1982/83 winter storms.

Significant Decreases

A greater number of significant decreases than increases were detected in algal abundance using either the BACI or Fisher's exact test. Decreases occurred in 26 taxa (Tables 3-5 and 3-6). Although crustose coralline algae decreased significantly at the upper elevation, the decrease was small, and was offset by a small relative increase at the lower elevation. The decrease in *G. coulteri* was also small at the upper elevation, but the large increase in this species at the lower elevation resulted in this species being better categorized as having significantly increased overall. Taxa that decreased formed most of the non-crustose intertidal algal cover prior to plant operation.

Mazzaella flaccida (iridescent seaweed) was one of the most abundant algae during the pre-operation period, but declined to absence at both sampling elevations in Diablo Cove during the operation period

Table 3-5. Results of BACI ANOVA for intertidal algae from horizontal band transects. Negative values indicate decreases between periods for individual stations and positive values indicate increases. Statistically significant results (p<0.10) are in **bold** type.

	% Change Between Periods Relative to Controls				Power to Detect a 50% Change	Interaction	Pairwise Comparisons by Station or Area (p value) [mean temperature increases above ambient listed in °C]									
	All Impact	Diablo Cove	Period		Between	Between	Diablo	South	FC - 3	NDC - 1	NDC - 2	NDC - 3	SDC - 2	SDP - 1	SDP - 2	SDP - 3
Taxon	Stations	Stations only	F-Value	P	Periods	Per. and Sta.	Cove	Diablo Pt	[0.9°]	[3.1°]	[3.3°]	[3.4°]	[3.1°]	[1.7°]	[1.3°]	[1.3°]
Level +.3 m MLLW																
Significant Increase																
coralline algae (articulated, juv.)	+88	+3	14.5	<.01	.98	<.01	.63	<.01	.20	-.09	.65	<.01	-.72	<.01	<.01	<.01
coralline algae (crustose)[1]	+71	+22	3.4	.07	1.00	<.01	.11	—	.05	-<.01	.04	<.01	<.01	—	—	—
Gelidium coulteri[1]	-1	-4	2.8	<.10	1.00	<.01	.26	.01	-.08	.97	-.29	<.01	.16	<.01	.49	.53
Non-coralline algae (crustose)	+38	+62	54.1	<.01	1.00	<.01	<.01	.02	.04	<.01	-<.01	<.01	<.01	<.01	.73	-.83
Prionitis spp.	+31	+29	15.6	<.01	1.00	<.01	<.01	—	-.01	-.89	.14	<.01	<.01	—	—	—
red algae (filamentous)	-44	-17	12.4	<.01	1.00	<.01	.14	-<.01	-.03	.70	.05	<.01	-.01	-<.01	-<.01	-<.01
Ulva / Enteromorpha	+79	+126	.3	.62	.98	<.01	.09	-.13	.08	.14	-.17	<.01	-.91	-<.01	.51	.72
bare rock substrate	+116	+123	26.2	<.01	1.00	<.01	<.01	<.01	.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Significant Decrease																
Calliarthron / Bossiella	+16	-42	14.3	<.01	1.00	<.01	-<.01	—	.45	-.02	-<.01	-.01	-<.01	—	—	—
Callithamnion / Pleonosporium	+521	-92	3.4	.07	1.00	<.01	-.06	-.07	.14	.78	-.43	-<.01	.12	-<.01	.60	.71
Chondracanthus canaliculatus	-51	-51	6.6	.01	1.00	<.01	-<.01	—	-.44	-.67	-.09	-<.01	-.09	—	—	—
Corallina officinalis	-50	-84	32.4	<.01	1.00	<.01	-<.01	-<.01	.03	-.80	-<.01	-<.01	-<.01	-<.01	-.74	-<.01
Egregia menziesii	-82	*no calc*[2]	70.3	<.01	1.00	<.01	-<.01	-<.01	<.01	-.32	-<.01	-<.01	-<.10	-.09	-<.01	-<.01
Endocladia muricata	-29	-79	19.5	<.01	1.00	<.01	-<.01	-<.01	-.12	-<.01	-<.01	-<.01	-<.01	-<.01	-.01	-.01
Mastocarpus jardinii	-52	-78	22.1	<.01	1.00	<.01	-<.01	-.57	-.01	-<.01	-<.01	-<.01	-<.01	-<.01	.13	.42
Mazzaella affinis	-61	-58	6.7	.01	.93	<.01	-<.01	-.18	-.09	-.11	-<.01	-.58	-<.01	-.30	-.11	-.30
Mazzaella flaccida	-55	-98	74.6	<.01	1.00	<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-.02	-.01	-<.01
Mazzaella heterocarpa	-78	-86	118.0	<.01	1.00	<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-.01	-<.01	-<.01
Mazzaella leptorhynchos	-61	-57	3.1	.08	.68	<.01	-<.10	-.18	-.03	.25	-.02	-.30	-<.01	-.58	-.03	-.51
Mazzaella lilacina	-81	-99	12.9	<.01	.97	<.01	-<.01	—	.25	.15	-<.01	-<.01	-<.01	—	—	—
Microcladia coulteri	-50	-84	.6	.46	.68	<.01	-.03	.26	-.71	.62	-<.01	-<.01	-.09	.13	.75	.53
Neorhodomela larix	-97	-97	5.7	.02	.68	<.01	.54	<.01	<.01	<.01	<.01	<.01	-<.01	<.01	<.01	<.01
Porphyra spp.	-80	-89	.4	.51	.78	<.01	-<.01	.04	.08	-.18	-<.01	-.08	-<.01	.04	.64	.02
Algal Cover	-32	-44	14.8	<.01	1.00	<.01	-<.01	-<.01	-.22	-<.01	-<.01	-<.01	-.01	-.01	-.07	-<.01
Algal Diversity	-21	-30	17.1	<.01	1.00	<.01	-<.01	—	.97	-<.01	-.07	-.01	-<.01	—	—	—
Algal Species Richness	-27	-34	78.3	<.01	1.00	<.01	-<.01	-<.01	-.91	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-.05
No Change[3]																
Cryptopleura violacea	-21	-38	1.7	.19	1.00	<.01	-.24	-.22	-.12	-.08	.58	-<.01	.01	.13	-.01	-.02
Mastocarpus papillatus	+48	+87	1.4	.24	1.00	<.01	.93	-.02	-.07	.64	.25	-.25	-.78	-.06	-.04	-.08
Osmundea spp.	-35	-49	.9	.34	1.00	<.01	-.82	-.07	-.44	.89	.02	-<.01	.32	.58	-.02	-<.01
Test Results Inconclusive[4]																
Spongomorpha / Acrosiphonia	-3	-95	.2	.69	.39	<.01	-.19	.13	.15	.23	-.57	-.32	-<.01	.27	.59	.24

(table continued)

Table 3-5 (continued). Results of BACI ANOVA for intertidal algae from horizontal band transects.

Taxon	% Change Between Periods Relative to Controls: All Impact Stations	Diablo Cove Stations only	Period F-Value	P	Power to Detect a 50% Change Between Periods	Interaction Between Per. and Sta.	Pairwise Comparisons by Station or Area (p value) [mean temperature increases above ambient listed in °C]: Diablo Cove	South Diablo Pt	FC - 3 [0.9°]	NDC - 1 [3.1°]	NDC - 2 [3.3°]	NDC - 3 [3.4°]	SDC - 2 [3.1°]	SDP - 1 [1.7°]	SDP - 2 [1.3°]	SDP - 3 [1.3°]
Level +.9 m MLLW																
Significant Increase																
Gelidium pusillum	+54	+71	5.4	.02	1.00	<.01	.01	—	.46	.84	<.01	.61	.01	—	—	—
bare rock substrate	+111	+116	231.1	<.01	1.00	<.01	<.01	—	<.01	<.01	<.01	<.01	<.01	—	—	—
Significant Decrease																
Calliarthron / Bossiella	-88	-92	33.8	<.01	1.00	.31	-<.01	—	-<.01	-.02	-<.01	-<.01	-<.01	—	—	—
Chondracanthus canaliculatus	-90	-91	98.1	<.01	1.00	<.01	-<.01	—	-.04	-<.01	-<.01	-<.01	.58	—	—	—
coralline algae (crustose)[1]	-42	-49	20.3	<.01	1.00	<.01	-<.01	—	.76	-<.01	-<.01	-<.01	.07	—	—	—
Endocladia muricata	-49	-63	344.2	<.01	1.00	<.01	-<.01	—	-.02	-<.01	-<.01	-<.01	-<.01	—	—	—
Gastroclonium subarticulatum	-99	-99	33.0	<.01	.96	<.01	-<.01	—	-.02	-<.01	-.06	-<.01	-.01	—	—	—
Gelidium coulteri[1]	-36	-39	33.1	<.01	1.00	<.01	-<.01	—	-<.01	-<.01	-<.01	-<.01	.42	—	—	—
Mastocarpus papillatus	-47	-65	26.3	<.01	1.00	<.01	-<.01	—	-.52	-<.01	-<.01	-<.01	-.09	—	—	—
Mazzaella affinis	-66	-67	34.7	<.01	1.00	<.01	-<.01	—	-.01	-<.01	-<.01	-.02	-.45	—	—	—
Mazzaella flaccida	-86	-100	20.0	<.01	1.00	<.01	-<.01	—	-.06	-<.01	-.04	-<.01	<.01	—	—	—
Mazzaella heterocarpa	-87	-98	161.3	<.01	1.00	<.01	-<.01	—	-<.01	-<.01	-<.01	-<.01	-<.01	—	—	—
Pelvetia compressa	-77	-86	7.4	.01	.96	<.01	-<.01	—	.29	.49	-<.01	-<.01	-.81	—	—	—
Algal Cover	-57	-70	97.4	<.01	1.00	<.01	-<.01	—	-.03	-<.01	-<.01	-<.01	-.01	—	—	—
Algal Diversity	-32	-37	163.9	<.01	1.00	<.01	-<.01	—	-.04	-<.01	-<.01	-<.01	-<.01	—	—	—
Algal Species Richness	-41	-49	93.0	<.01	1.00	<.01	-<.01	—	.85	-<.01	-<.01	-<.01	-<.01	—	—	—
No Change[3]																
Mazzaella leptorhynchos	-17	-27	1.2	.29	.72	<.01	.45	—	.04	.04	.59	.43	-.37	—	—	—
Non-coralline algae (crustose)	+11	+11	.5	.47	1.00	<.01	.85	—	.10	<.01	-<.01	.02	.13	—	—	—
Test Results Inconclusive[4]																
red algae (filamentous)	*no calc*	+928	.8	.37	.18	<.01	.30	—	.77	-.90	.36	<.01	.96	—	—	—

[1] taxon had differing significant effects between elevations.

[2] percent change could not be calculated because mean control abundance was zero during one or both periods.

[3] there was no significant difference between period means, and the power of the test to detect a 50% change in abundance between periods was greater than .70.

[4] there was no significant difference between period means, and the power of the test to detect a 50% change in abundance between periods was less than .70.

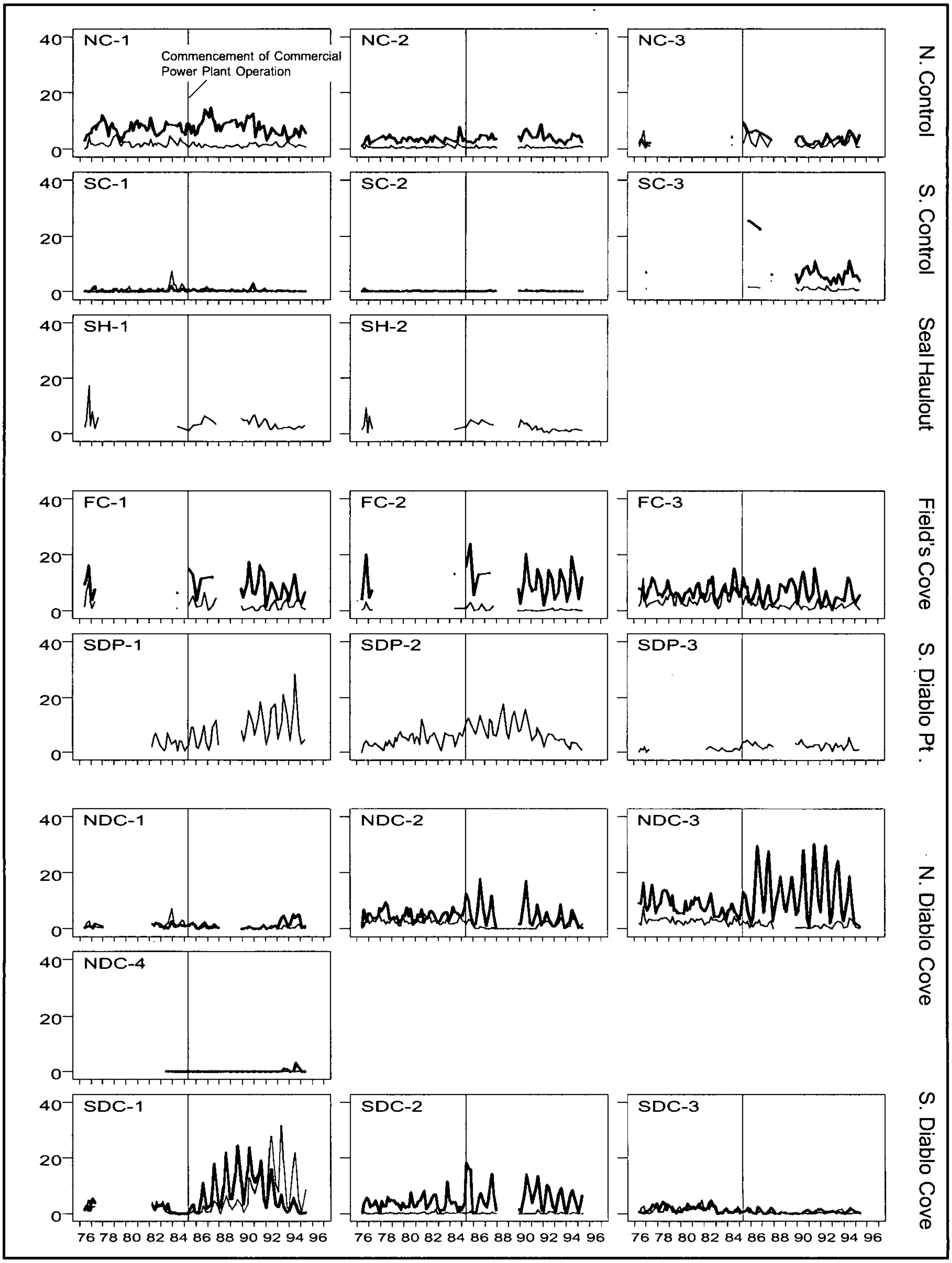


Figure 3-10. *Gelidium coulteri*: changes in cover at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

Table 3-6. Results of Fisher's exact test for intertidal algae not tested in BACI analysis. Statistically significant results (p<0.10) are in **bold** type.

Taxon	Diablo Cove P	Field's Cove P	Diablo Point P
Level +.3 m MLLW			
Significant Increase			
None	—	—	—
Significant Decrease			
Chrysophyta unid.	**.04**	.12	.48
Corallina vancouveriensis	**<.01**	.65	**<.10**
Cryptosiphonia woodii	**<.01**	.64	1.00
Phyllospadix spp.	**<.01**	**<.01**	**<.01**
Smithora naiadum	**<.01**	1.00	.81
Test Results Inconclusive			
Chondracanthus corymbiferus	1.00	.16	**<.01** (decr)
Gastroclonium subarticulatum	.17	.17	.81
Gelidium pusillum	1.00	.65	1.00
Microcladia borealis	1.00	1.00	**<.01** (decr)
Level +.9 m MLLW			
Significant Increase			
None			
Significant Decrease			
Cladophora spp.	**<.01**	.82	—
Corallina vancouveriensis	**<.01**	.50	—
Cryptopleura violacea	**<.01**	.21	—
Cryptosiphonia woodii	**<.01**	.50	—
Fucus gardneri	**<.01**	1.00	—
Mastocarpus jardinii	**.04**	.11	—
Phyllospadix spp.	**<.01**	**<.01**	—
Porphyra spp.	**<.01**	**.01**	—
Test Results Inconclusive			
Chrysophyta unid.	.40	.55	—
Prionitis spp.	.11	**.04** (decr)	—
Ulva / Enteromorpha	.11	**<.01** (incr)	—

(Figure 3-11). The 1982/83 winter storms and El Niño caused a temporary, coast-wide reduction in the abundance of this species. Control populations recovered from the El Niño, while the population in Diablo Cove continued to decline following power plant start-up. Qualitative shorewalk surveys showed that *M. flaccida* had become nearly absent throughout Diablo Cove. Smaller but statistically significant declines, relative to controls, were also detected during the operation period in Field's Cove and on South Diablo Point. Similar patterns of decline occurred at stations FC-1 and FC-2 in Field's Cove, which are not included in the BACI analysis (Figure 3-11).

Chondracanthus canaliculatus is another species that declined after power plant start-up at both the upper and lower sampling elevations in Diablo Cove (Figure 3-12). Although it declined to some extent at all stations (including controls), greater declines occurred at the impact stations. Beginning in 1990, the decline reversed, and increases in abundance occurred. The increase at some stations in Diablo Cove resulted in abundances greater than pre-operation levels (e.g., SDC-1, Figure 3-12), but the overall statistical test on *C. canaliculatus* still resulted in a significant decline in the species compared to the pre-operation levels.

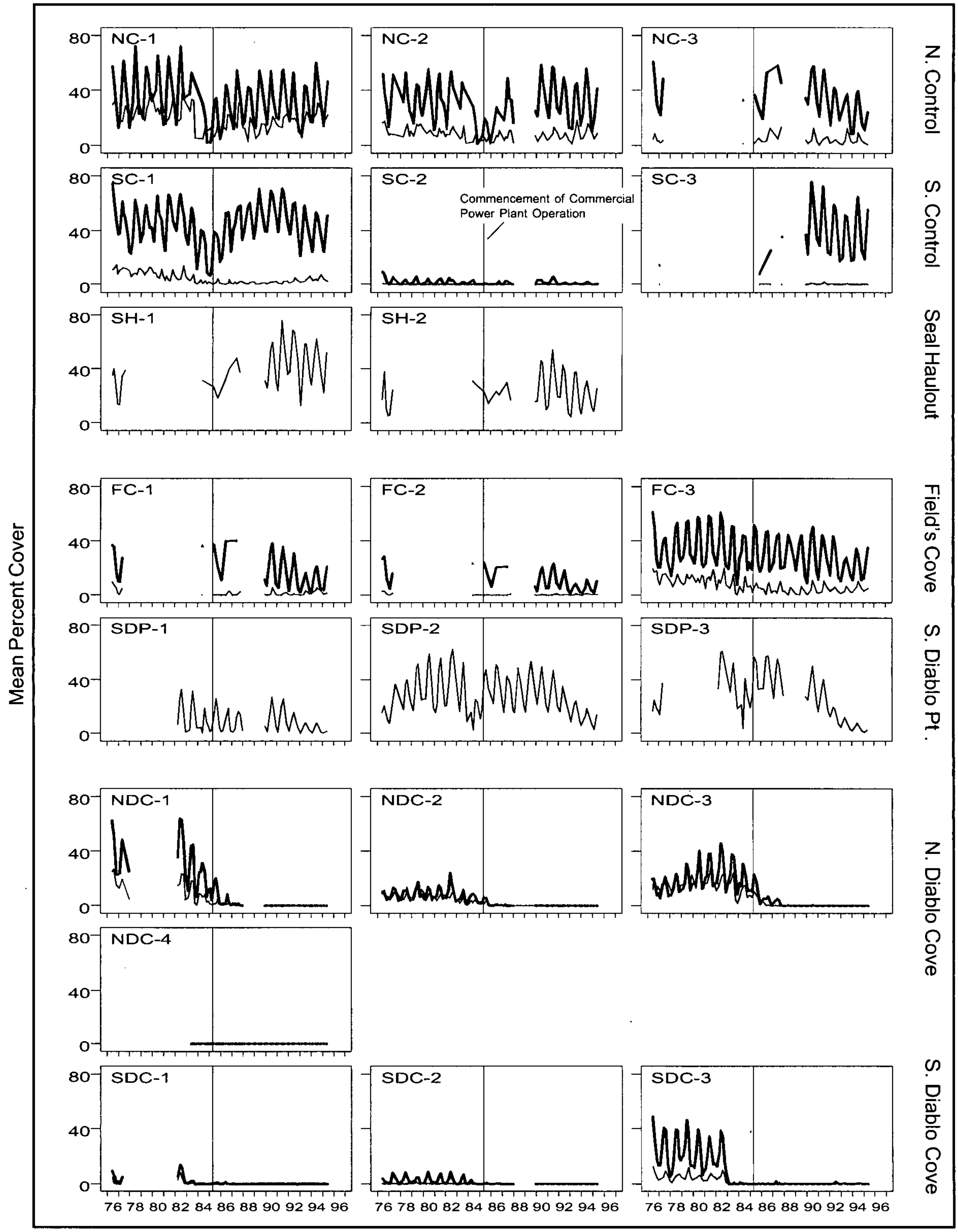


Figure 3-11. *Mazzaella flaccida*: changes in cover at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

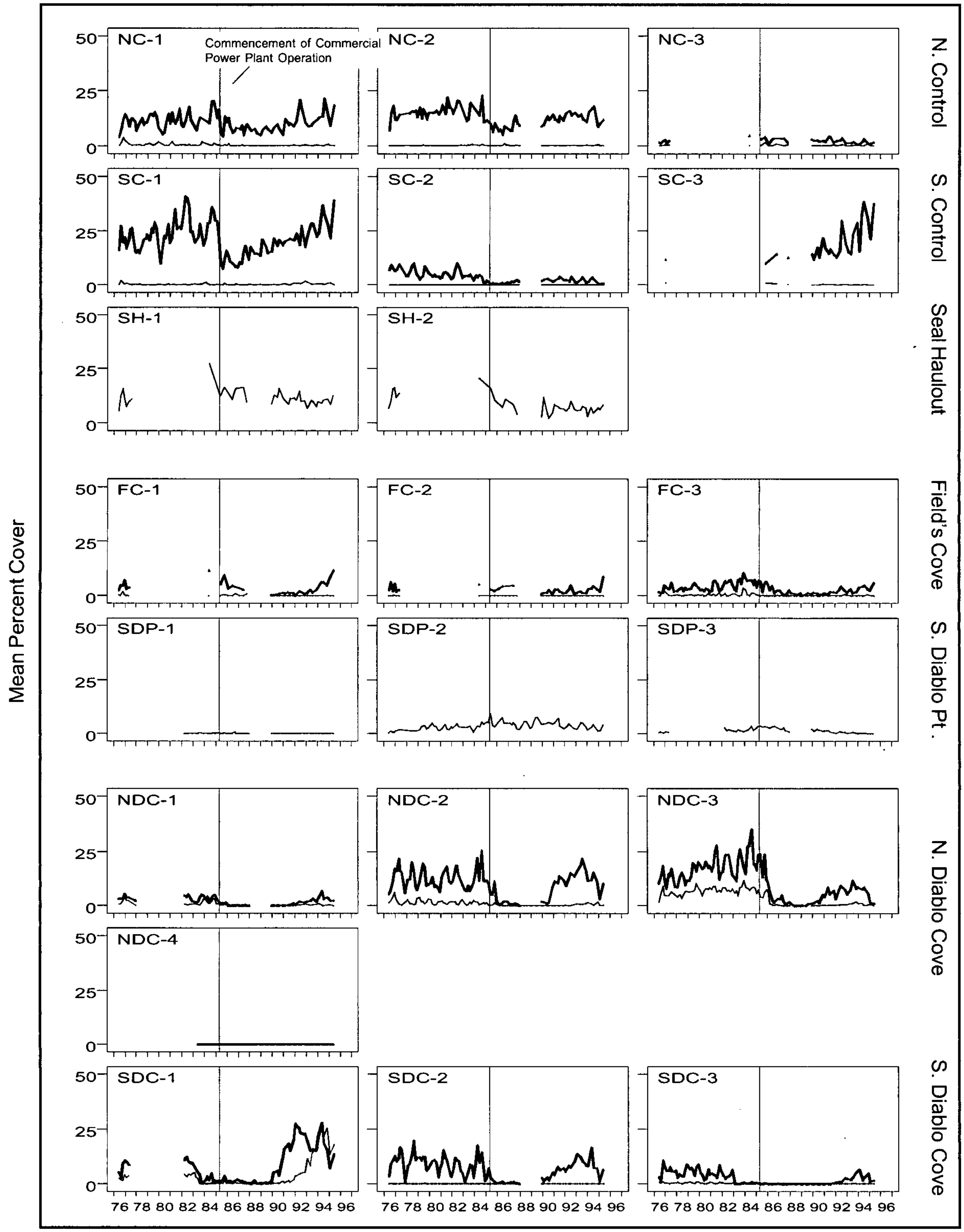


Figure 3-12. *Chondracanthus canaliculatus*: changes in cover at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

Mastocarpus papillatus and *Gastroclonium subarticulatum* significantly declined in abundance relative to control stations at only the upper sampling elevation (Table 3-5). Although the abundance of *M. papillatus* had increased at the lower elevation in Diablo Cove (Figure 3-7), no significant change was detected because of similar increases at control stations (Figure 3-6). *G. subarticulatum* was too variable in abundance over time at lower elevation transects to detect whether it had changed significantly relative to control stations (Table 3-6). Increases in the abundance of *G. subarticulatum* were observed at some of the low intertidal transects beginning in about 1990, including large increases at station SDC-1 near the outfall (Appendix E). *G. subarticulatum* also increased in abundance below intertidal transects in areas previously occupied by *Phyllospadix* spp. (based on qualitative observations).

Pelvetia compressa and *Fucus gardneri* (rockweeds) and *Endocladia muricata* are algal taxa that occur primarily in the high intertidal. Statistically significant declines were detected in all three algae using either the BACI or Fisher's exact test. (Tables 3-5 and 3-6). *Phyllospadix* spp., a common taxon found mainly in the low intertidal, was analyzed using the Fisher's exact test. Significant declines were detected at both sampling elevations (Table 3-6). *Smithora naiadum*, an obligate algal epiphyte on *Phyllospadix* spp. also declined (Table 3-6). *Phyllospadix* spp. was most abundant in Diablo Cove at station NDC-2 but was reduced in abundance during the 1982/83 storms and associated El Niño. Further declines occurred in Diablo Cove during power plant operation, while control populations increased (Figure 3-13). Significant decreases were also detected using the Fisher's exact test in *Corallina vancouveriensis*, an articulated coralline that was a large component of the understory in the pre-operation period (Table 3-6).

No Significant Change

It was determined that no change occurred due to the discharge if an analysis had sufficient power (>.70) to detect change. No change was detected for *Osmundea* spp. (Table 3-5). Other taxa in this category had significant results at either the upper or lower elevation. Crustose coralline algae increased at the lower elevation but decreased at the upper elevation, effects that were interpreted as no change overall for this taxa.

Test Results Inconclusive

Except for *Spongomorpha/Acrosiphonia* spp., *Chondracanthus corymbiferus*, and *Microcladia borealis*, most taxa listed in this category in Tables 3-5 and 3-6 had significant results at one or the other sampling elevation, as previously referenced.

Analysis of Community Changes

Significant decreases in total algal cover were detected at both sampling elevations. Total algal cover (not including crustose forms) in Diablo Cove at both sampling elevations decreased approximately 40% between the pre-operation and operation study periods (Figure 3-7). Based on increases in total algal cover at the control stations (Figure 3-6), the declines in the cove represented a 70% decrease at the upper elevation transects and a 44% decrease at the lower elevation transects), relative to controls (Table 3-5). Smaller declines in total algal cover occurred in Field's Cove and at South Diablo Point (Figures 3-8 and 3-9, respectively). A significant decline was also detected in numbers of taxa in Diablo Cove, relative to controls. The statistically significant decline in Diablo Cove of total algal cover and number of taxa accounts for the significant decrease detected in diversity (H'). In contrast, bare rock significantly increased as a result of reductions in algal cover (Table 3-5).

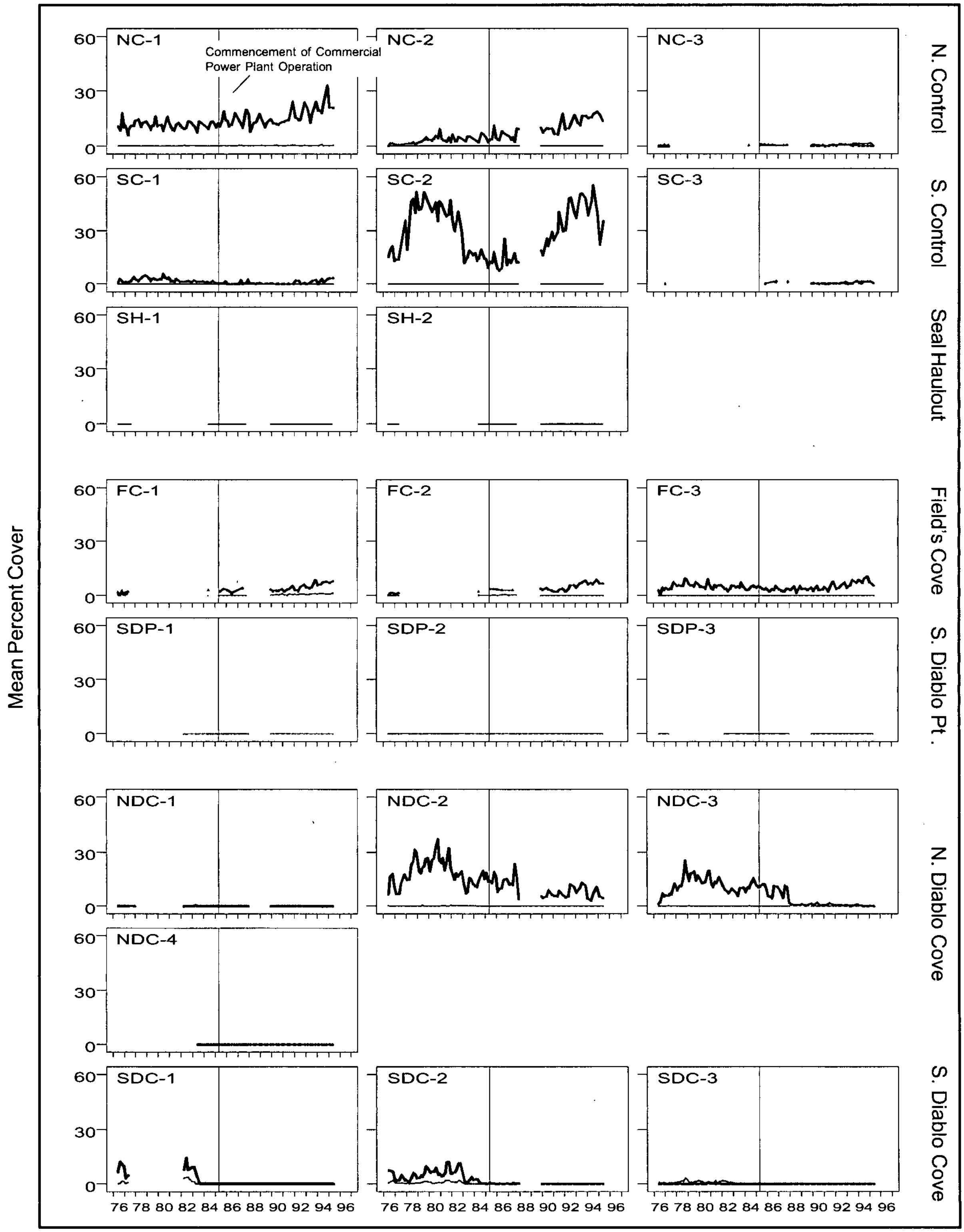


Figure 3-13. *Phyllospadix* spp.: changes in cover at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

The Fisher's exact test was used to examine changes relative to controls in taxa occurrences before and after power plant start-up, separately for Diablo Cove, Field's Cove, and South Diablo Point (Table 3-7). The analysis for Diablo Cove detected significant differences between areas for both elevations, corroborating the results that show significant decreases in number of taxa. No significant changes in the ratio of decreases to increases were detected for Field's Cove and South Diablo Point.

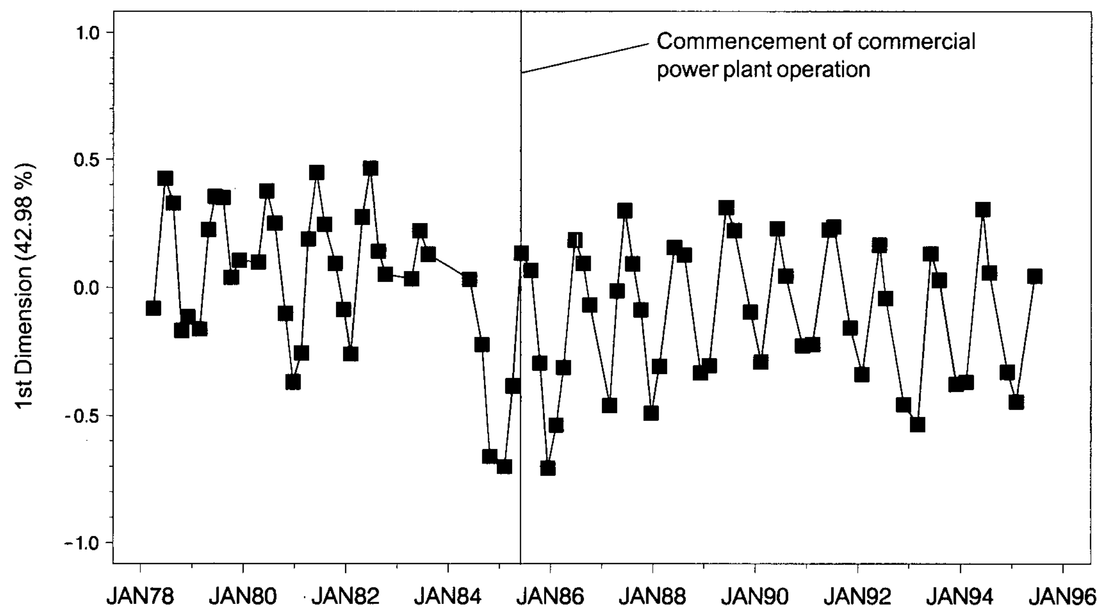
Table 3-7. Results of Fisher's exact test for intertidal algae: a) Diablo Cove, b) Field's Cove, and c) South Diablo Point. Data were number of species changes at the Diablo Cove and control stations between pre-operation and operation periods. Statistically significant results ($p<0.10$) are in **bold** type.

a) Diablo Cove	**+0.3 m MLLW**		**+0.9 m MLLW**	
	Decreases	Increases	Decreases	Increases
Diablo Cove	46	10	31	3
Control	26	30	19	15
	p = **<0.01**		p = **0.02**	

b) Field's Cove	**+0.3 m MLLW**		**+0.9 m MLLW**	
	Decreases	Increases	Decreases	Increases
Field's Cove	23	17	16	10
Control	21	19	13	13
	p = 0.82		p = 0.58	

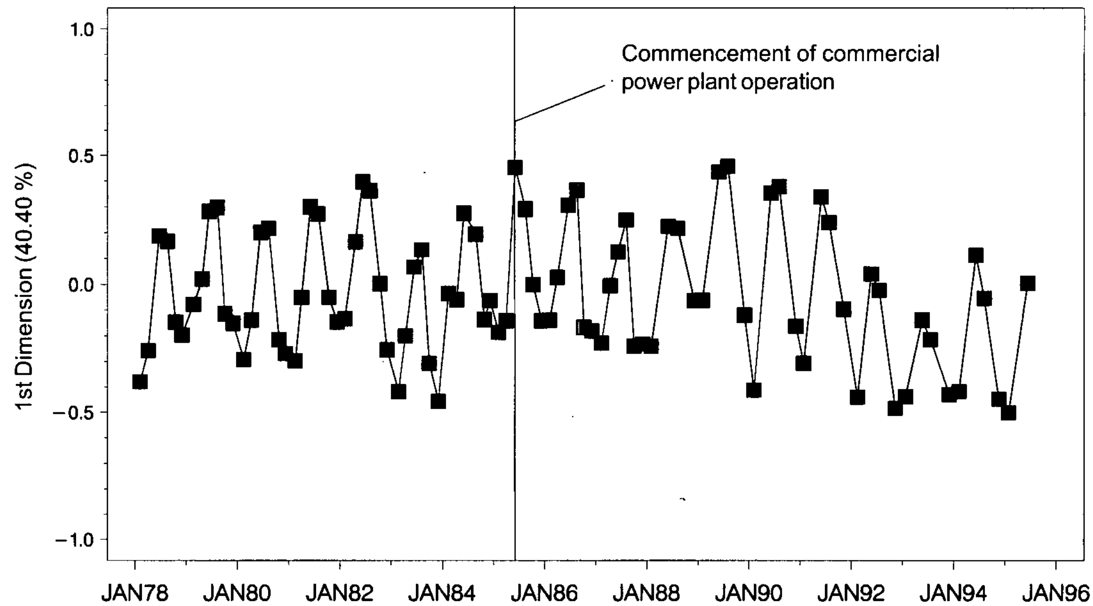
c) South Diablo Point	**+0.3 m MLLW**		**+0.9 m MLLW**	
	Decreases	Increases	Decreases	Increases
Diablo Point	*(no stations at this level)*		35	16
Control			26	25
			p = 0.11	

Correspondence analysis (CA) was used to analyze the major factors accounting for variation in the intertidal algal community data sets for control and impact stations (Figures 3-14 to 3-16). The data consisted of survey means for the taxa that formed 95% of the total cumulative abundance across all surveys and which occurred in at least 20% of the surveys. Survey scores from the first correspondence analysis axis show patterns of variation over time, which explained approximately 40% of the total variation for each data set. First axis taxa scores are presented in the figures to identify the relative contribution of each taxon to the patterns observed in the survey scores. Survey scores for the control area (Figure 3-14) show that seasonal variation was the largest component of variation. The large positive taxa score for *Mazzaella flaccida,* an abundant alga that fluctuates seasonally in cover, indicates that the positive survey scores over time represent summer periods when algal cover is at its maximum.



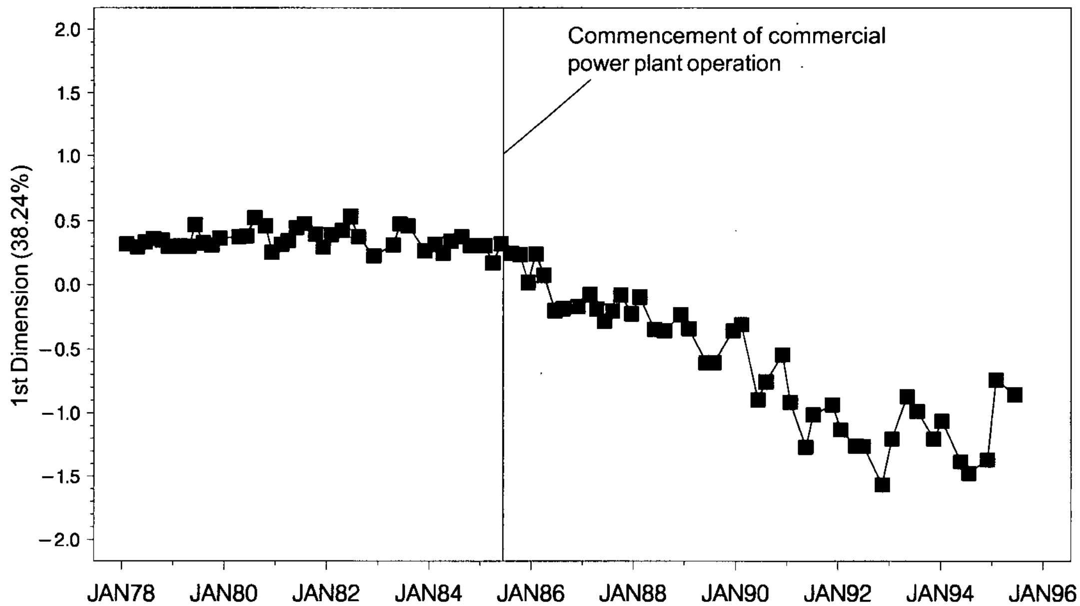
Score	Taxa
0.360	*Mazzaella flaccida*
0.072	*Mastocarpus papillatus*
0.031	*Cryptopleura violacea*
-0.051	*Mazzaella leptorhynchos*
-0.113	*Mazzaella affinis*
-0.128	*Gelidium coulteri*
-0.164	*Endocladia muricata*
-0.165	*Chondracanthus canaliculatus*
-0.275	*Phyllospadix* spp.
-0.293	*Codium setchellii*
-0.307	*Calliarthron/Bossiella* spp.-complex
-0.327	*Gastroclonium subarticulatum*
-0.618	*Corallina vancouveriensis*

Figure 3-14. Intertidal algal survey scores from the first correspondence analysis axis plotted over time for the control +0.3 m MLLW transects. Species scores are listed below the graph. The axis accounts for 42.98% of the total variation of the data set. Stations used were NC-1, -2, and SC-1.



Score	Taxa
0.257	*Mazzaella flaccida*
0.179	*Mastocarpus papillatus*
0.152	*Gelidium coulteri*
-0.013	*Mastocarpus jardinii*
-0.051	*Endocladia muricata*
-0.082	*Chondracanthus canaliculatus*
-0.198	*Cryptopleura violacea*
-0.281	*Gastroclonium subarticulatum*
-0.304	*Phyllospadix* spp.
-0.311	*Prionitis spp.*
-0.322	*Calliarthron/Bossiella* spp.-complex
-0.458	*Corallina vancouveriensis*

Figure 3-15. Intertidal algal survey scores from the first correspondence analysis axis plotted over time for Station FC 3+.3m. Species scores are listed below the graph. The axis accounts for 40.40% of the total variation of the data set.



Score	Taxa
0.625	*Egregia menziesii*
0.615	*Mazzaella flaccida*
0.483	*Corallina officinalis*
0.434	*Phyllospadix* spp.
0.372	*Cryptopleura violacea*
0.360	*Mastocarpus jardinii*
0.241	*Chondracanthus canaliculatus*
0.240	*Corallina vancouveriensis*
-0.002	*Gastroclonium subarticulatum*
-0.446	*Prionitis* spp.
-0.448	*Gelidium coulteri*
-0.523	*Mastocarpus papillatus*
-0.527	*Mazzaella affinis*
-0.588	*Calliarthron/Bossiella* spp.-complex
-0.655	juv. articulated coralline algae
-1.514	*Ulva/Enteromorpha* spp.
-1.789	filamentous red algae-complex

Figure 3-16. Intertidal algal survey scores from the first correspondence analysis axis plotted over time for Station NDC 3+.3m. Species scores are listed below the graph. The axis accounts for 38.24% of the total variation of the data set.

However, effects from the 1982/83 winter storms and 1983 El Niño temporarily interrupted this pattern. The decrease in survey scores from the storm and El Niño effects indicates less contribution of *M. flaccida*, presumably due to decreases in abundance of this and other foliose algae. Negative taxa scores for understory articulated coralline algae correspond to winter periods when overstory algae were less abundant.

Survey scores for Field's Cove station FC 3+.3m (Figure 3-15) also show that over the course of study seasonality accounts for the largest source of variation in the data set. Survey scores also show temporary effects from the 1982/83 winter storms and 1983 El Niño, as seen for the control stations, and recovery following. However, unlike the pattern at the control stations, the scores for FC 3+.3m show a change beginning in 1992 that is similar to the El Niño period pattern. The lower taxa scores after 1992 are associated with the same foliose algal taxa that accounted for the lower El Niño pattern of scores. Plots of taxa abundance over time show that these lowered survey scores were due to decreases in the abundance of these taxa. However, they could have also resulted from relative shifts in the composition of taxa with positive scores to ones with negative scores.

Results of CA for Diablo Cove station NDC 3+.3m show a different pattern of variation on the first axis (Figure 3-16). Survey scores show that independent of other sources of variation, including seasonality, the major source of variation for this station contrasts pre-operation surveys with plant operation surveys. The lack of variation in the pre-operation scores is contrasted with the decreasing trend of survey scores in the operation period. Positive taxa scores correspond to the pre-operational community and the decreasing survey scores represent a relative shift to a community dominated by the taxa with negative taxa scores. The lowest taxa scores were assigned to the ephemerals *Ulva/Enteromorpha* spp. and filamentous red algae, which became abundant in the last few years of the study.

Ancillary Observations

Ancillary observations in areas not sampled by the horizontal band transects were made over the course of study. Two areas affected by the discharge that were examined were the natural rock bench adjoining the outfall structure and the intertidal region from Diablo Creek north to NDC-3. Prior to power plant start-up, the discharge bench supported a diverse algal assemblage. After start-up, algal cover and diversity were reduced in the area and it became colonized with patches of mussels, barnacles, and sea anemones. Near the end of the study, the region from Diablo Creek north to NDC-3 became heavily populated with grazing sea urchins (primarily *Strongylocentrotus purpuratus*) creating 'urchin barrens'.

Isolated stands of *Postelsia palmaeformis* (palm kelp) occurred on the headlands at South Diablo Point and North Diablo Point (Postelsia Point) prior to power plant operation. It is presently listed as a species of special concern by CDF&G. The two headlands represented its known southern range limit. Although this is an annual kelp species, it was eliminated during the 1983 El Niño and never re-colonized these areas. The nearest population of *P. palmaeformis* to DCPP now occurs approximately 6 km north, at Montaña de Oro State Park.

Spatial Extent of Effects

The length of shoreline discharge effects on the intertidal algae is best exemplified by the declines in cover of *Mazzaella flaccida* (Figure 3-11). South Diablo Point was the southern most location where significant declines were detected (Table 3-5). Decreases in cover at that station were less than decreases in Diablo Cove, suggesting that *M. flaccida* was only marginally impacted at South Diablo Point, and that impacts would continue to decrease in magnitude further south. Only a small amount of pre-operation data were collected at Seal Haulout stations SH-1 and -2, located 0.6 km south of South Diablo Point, and therefore these stations were not analyzed in the BACI analysis. *M. flaccida* remained abundant at these stations during power plant operation, indicating no impacts (Figure 3-11). Field's Cove (stations FC 3+.3m and FC 3+.9m) was the most northern location where significant declines in cover were detected in *M. flaccida* (Table 3-5), but similar to South Diablo Point, *M. flaccida* did not decline to the low levels observed in Diablo Cove, suggesting that this species was also only marginally impacted in Field's Cove, and that impacts would continue to decrease in magnitude further north. Similar declines in cover also occurred at neighboring stations FC 1+.3m and FC 2+.3m in Field's Cove (Figure 3-11), but those stations were not analyzed. Significant declines at FC 3+.3m and FC 3+.9m, and similar declines observed at neighboring low elevation stations, indicate that the discharge affected *M. flaccida* cover along the entire southern shoreline of Field's Cove. At our sampled stations and along the entire shoreline of Diablo Cove, *M. flaccida* declined to absence (Figure 3-11). No quantitative or qualitative observations were made to determine whether impacts extended north between Field's Cove and North Control.

Considering the findings for *M. flaccida*, the discharge affected approximately 3.7 km (2.3 mi) of the shoreline (from the head of Field's Cove to South Diablo Point) (Figure 3-17). This figure includes the inshore portion of Diablo Rock and accounts for shoreline indentations. Effects along the south shore of Field's Cove and South Diablo Point have been observed to be less than those observed in Diablo Cove. The discharge plume can under some conditions contact shoreline areas north to Lion Rock, which typically blocks the plume from migrating further north (*see* Section 2.0 - *Power Plant Operation and Thermal Plume Characteristics*). South of the power plant, the discharge plume separates from the shoreline at South Diablo Point. The shoreline distance with reduced plume contact is approximately 3.0 km (1.8 mi) where effects may occur that are likely to be less than effects seen in areas with reduced observed effects.

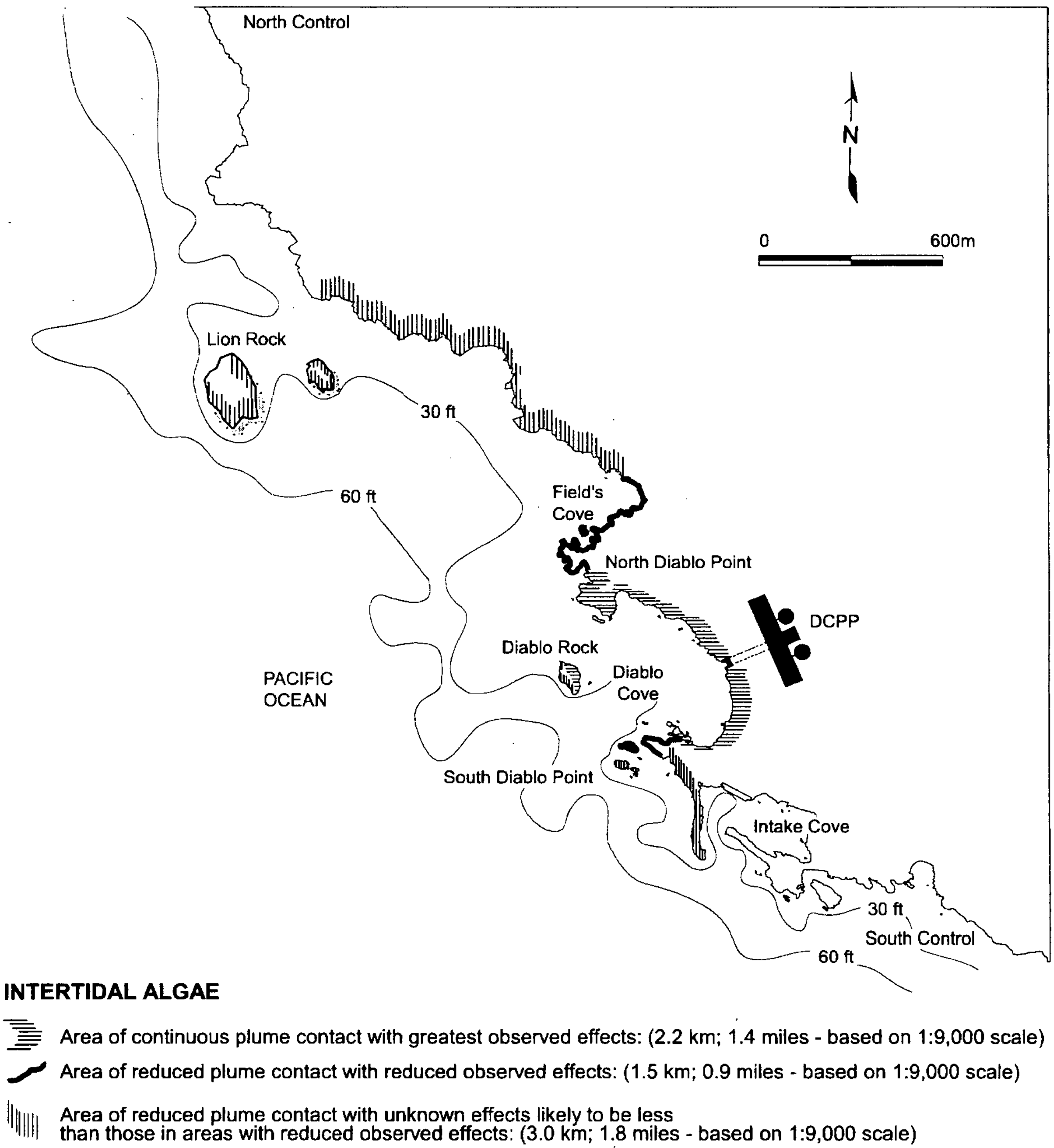


Figure 3-17. Approximate shoreline areas of discharge effects on intertidal algae observed in the study. Shoreline distances account for coastline indentations and islands. Map of effects was developed from horizontal band transect station sampling and qualitative shorewalk observations.

3.3.2 Invertebrates (Horizontal Band Transect Study)

Two hundred forty eight invertebrate taxa were sampled from 1978 to 1995 during the horizontal band transect (HBT) study. Those invertebrate taxa comprising 99% of individuals sampled are compared between the pre-operation and operation periods for counted taxa (Figure 3-18), and sessile taxa enumerated as percent cover (Figure 3-19). Similar comparisons are presented for Field's Cove (Figures 3-20 and 3-21), South Diablo Point (Figures 3-22 and 3-23), and combined control stations (Figures 3-24 and 3-25). Results of assumption testing and complete BACI and Fisher's exact test results are presented in Appendix G. Table 3-8 summarizes the main discharge effects on intertidal invertebrates, with more detailed analyses following.

Table 3-8. Summary of discharge effects on intertidal invertebrates sampled in the horizontal band transect study.

Category	+0.9 m MLLW	+0.3 m MLLW	Notes
Length of shoreline with greatest observed effects	2.2 km	2.2 km	Mainly Diablo Cove and Diablo Rock.
Length of shoreline with reduced observed effects	1.4 km	1.4 km	Mainly Field's Cove and South Diablo Point.
Effects on overall numbers of taxa	increase	no change	BACI results
Number (%) of taxa increases	10 (45%)	11 (33%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa decreases	5 (23%)	14 (39%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa unchanged	7 (32%)	6 (17%)	Includes BACI only.
Number (%) of taxa with inconclusive test results	0 (0%)	4 (11%)	Includes both BACI and Fisher's exact test.
Number of taxa analyzed statistically	22	35	Taxa comprising top 99% cumulative abundance.
Number of taxa sampled during study	248		Includes both levels combined; also includes some species that were grouped into combination taxa for analysis.

Analysis of Species Changes

Species composition and abundance at both elevations of the control stations were relatively unchanged between periods. (Declines in *Haliotis* spp. abundance at all stations are addressed in greater detail in Section 3.3.4). Stations adjacent to Diablo Cove (Field's Cove and South Diablo Point) showed differences in species composition and abundance between periods, though these were generally of less magnitude than those of Diablo Cove.

Thirty-nine taxa from the Diablo Cove stations (+0.3 m and +0.9 m elevations combined) were analyzed using either the BACI or the Fisher's exact test (Table 3-9 and Table 3-10). Presentation of the results is organized by tidal level. Some taxa changed significantly at both levels, while others were only affected at one level with no detectable effects at the other.

Of the taxa tested, 16 increased significantly and 16 decreased significantly between periods. Discharge-related effects were not detected for seven taxa. Most taxa tested produced significant Station x Period interaction terms, indicating that the differences between periods were not similar at all stations. In these cases, paired station comparisons were examined to assist in categorizing taxa into the appropriate response groups. Graphs of abundance versus time for all taxa comprising the 99% abundance list appear in Appendix E.

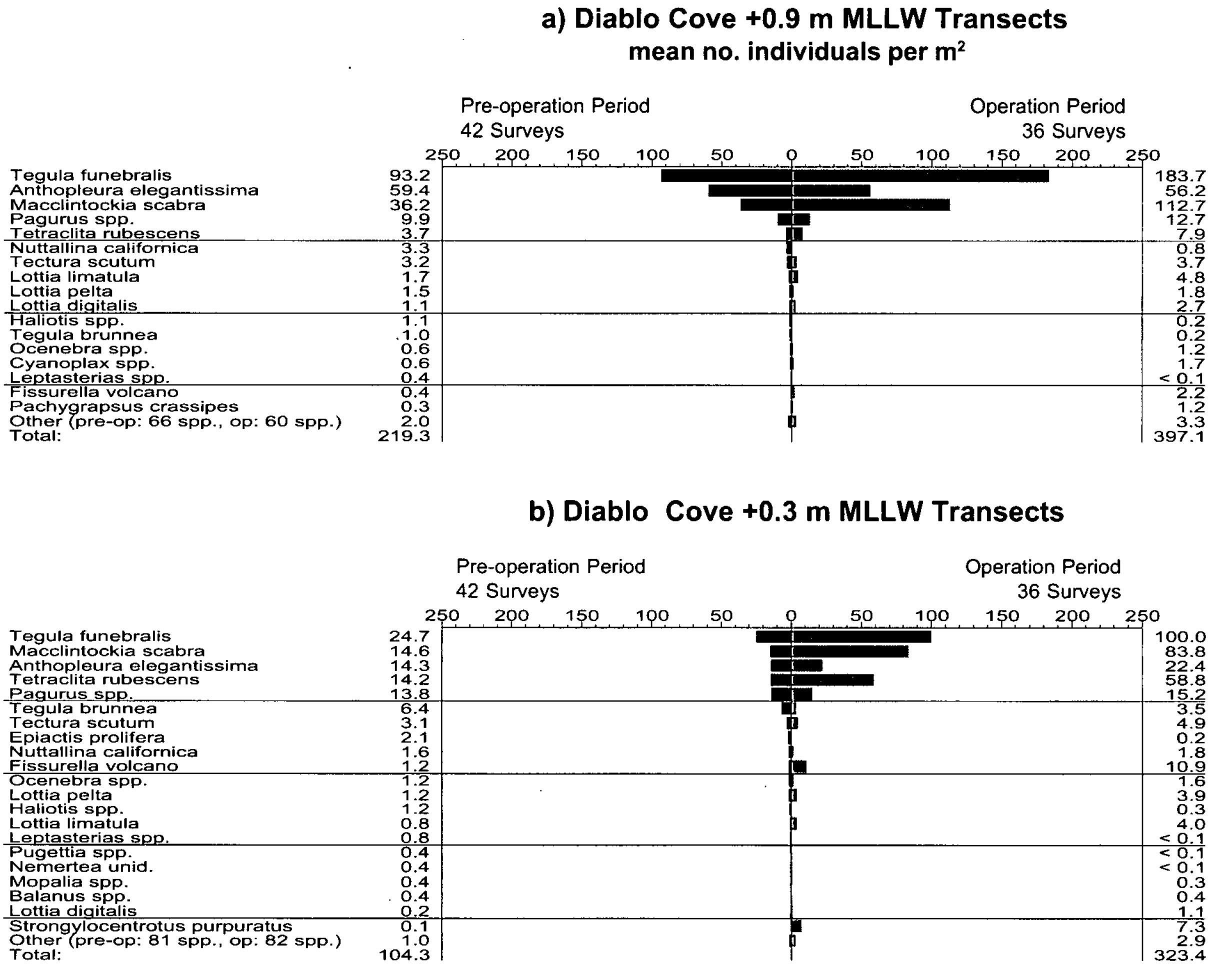


Figure 3-18. Intertidal invertebrate densities at the Diablo Cove (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the five 'count' quadrats per transect at NDC-1, -2, -3 and SDC-2. For each sampling elevation, the list of taxa are those that formed 99% of the total counts in the pre-operation period combined with the list that formed 99% of the total counts in the operation period. Data collected in 1976-77 and 1984-86 were not included.

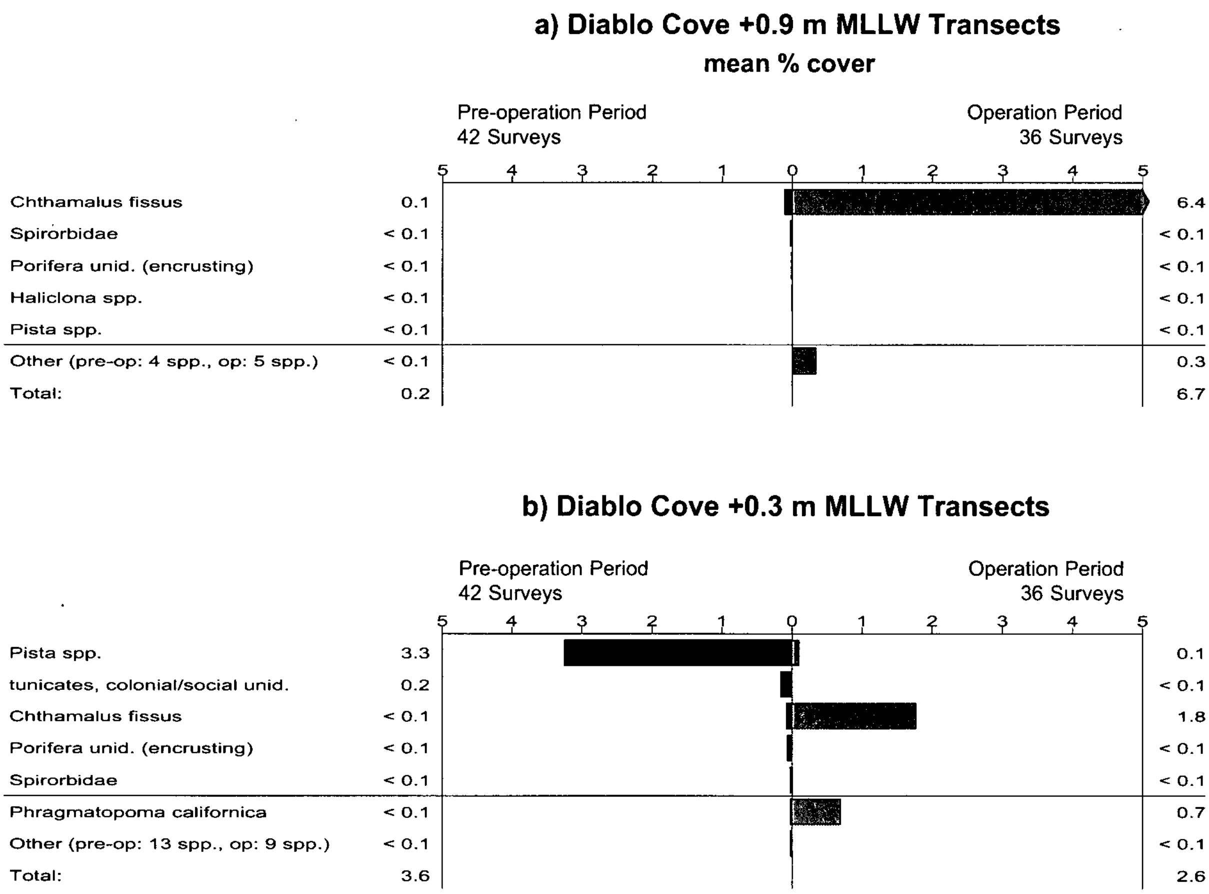


Figure 3-19. Intertidal invertebrate coverage abundances at the Diablo Cove (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the 10 quadrats per sampling elevation at NDC-1, -2, -3 and SDC-2. Data collected in 1976-77 and 1984-86 were not included.

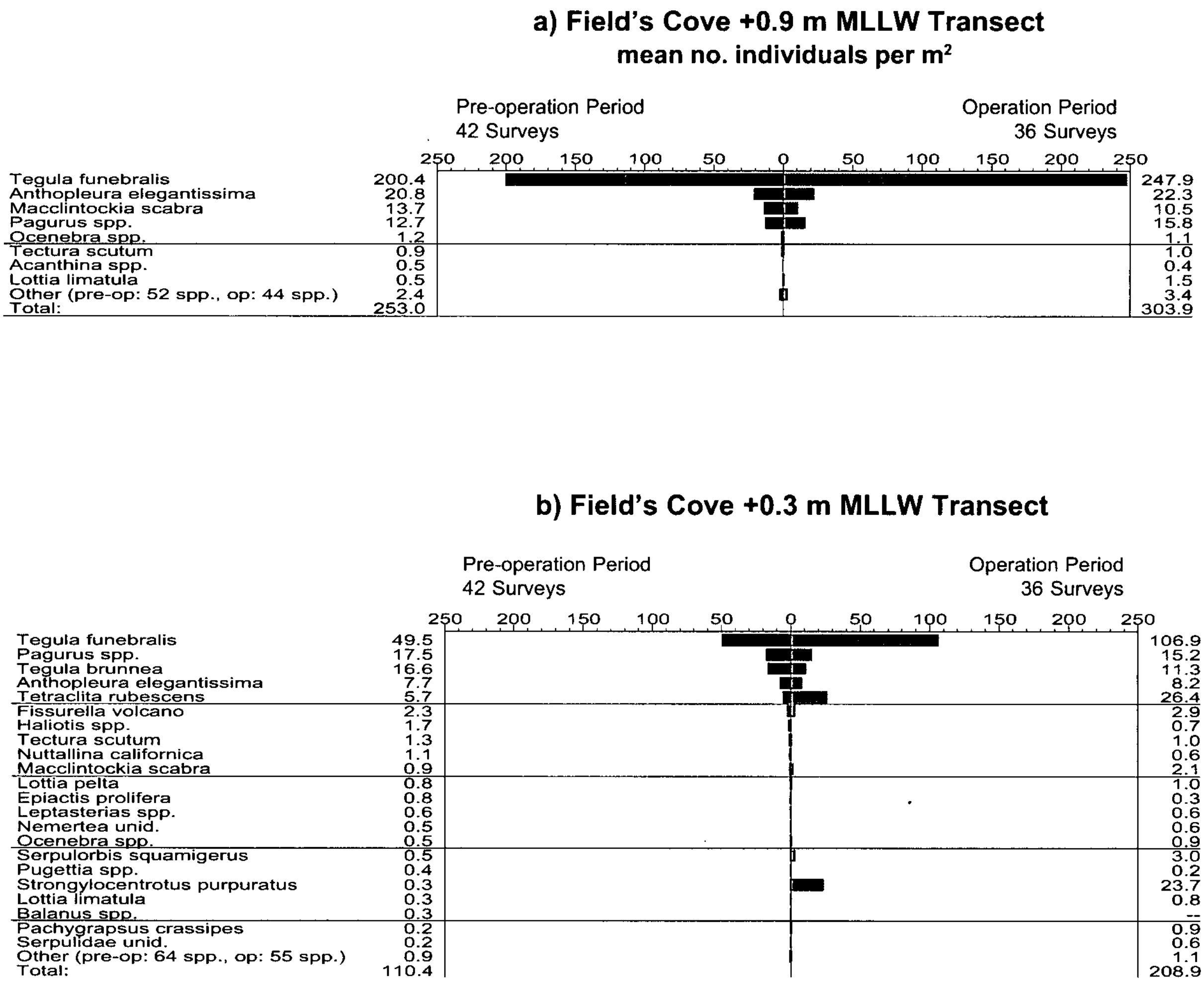


Figure 3-20. Intertidal invertebrate densities at the Field's Cove (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the five 'count' quadrats per transect at FC-3. For each sampling elevation, the list of taxa are those that formed 99% of the total counts in the pre-operation period combined with the list that formed 99% of the total counts in the operation period. Data collected in 1976-77 and 1984-86 were not included.

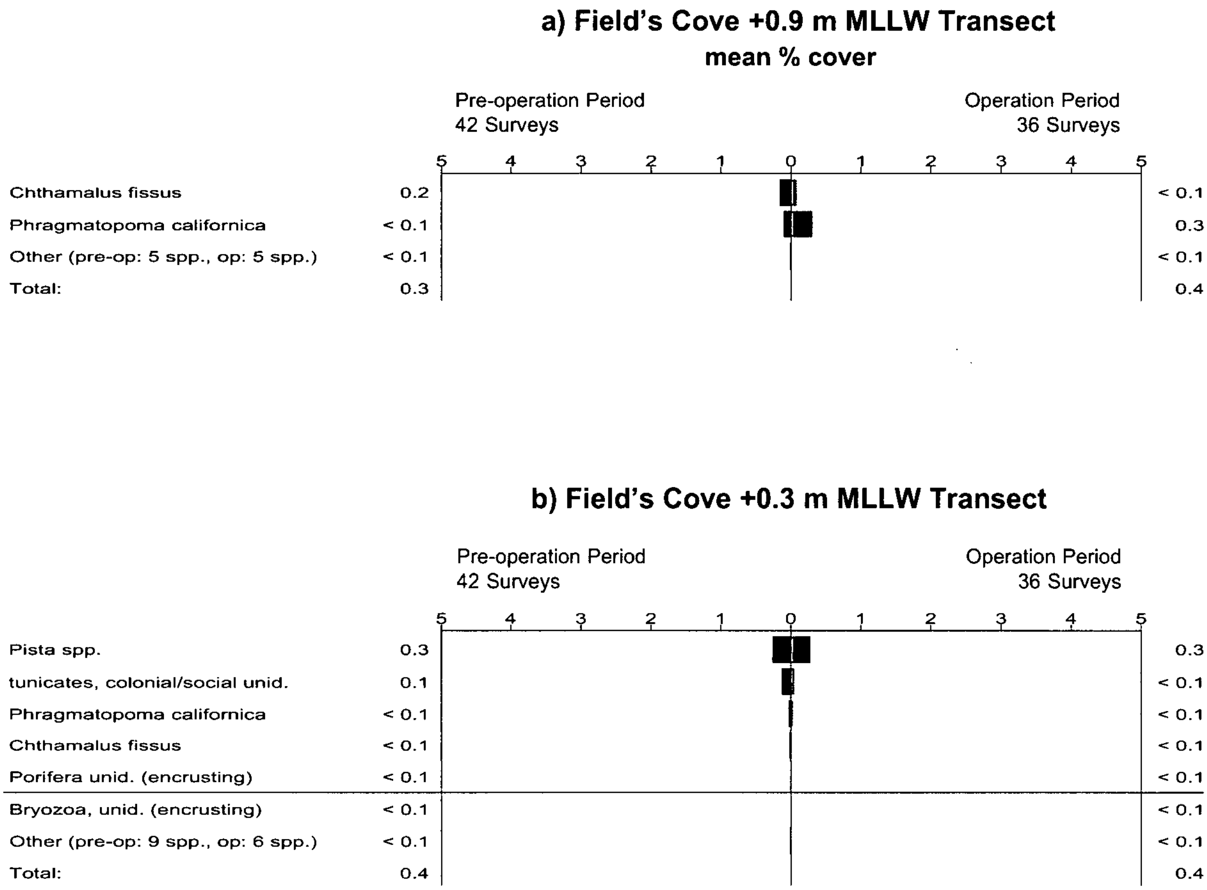


Figure 3-21. Intertidal invertebrate coverage abundances at the Field's Cove (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the 10 quadrats per transect at FC-3. Data collected in 1976-77 and 1984-86 were not included.

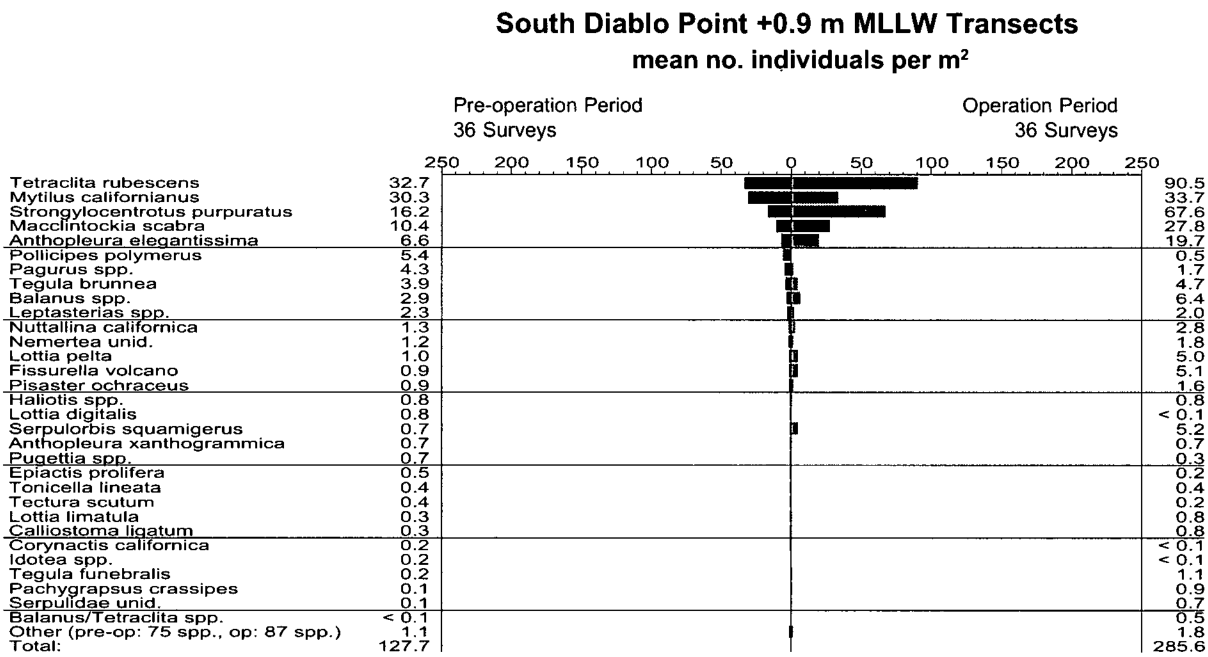


Figure 3-22. Intertidal invertebrate densities at the South Diablo Point +0.9 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the five 'count' quadrats per transect at SDP-1, -2, and -3. For each sampling elevation, the list of taxa are those that formed 99% of the total counts in the pre-operation period combined with the list that formed 99% of the total counts in the operation period. Data collected in 1976-77 and 1984-86 were not included.

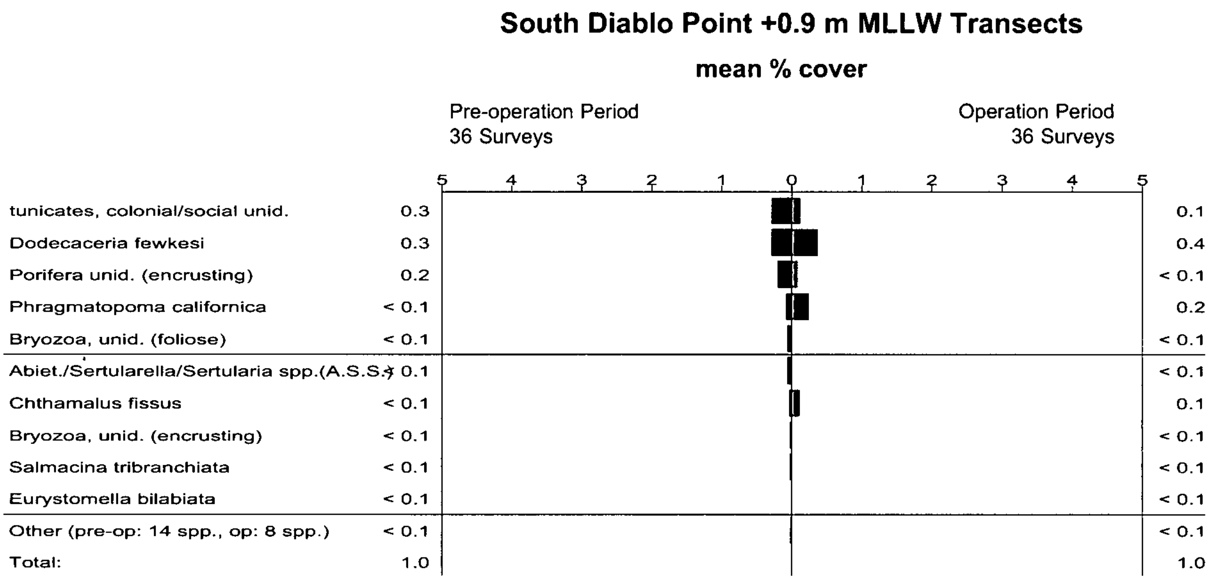


Figure 3-23. Intertidal invertebrate coverage abundances at the South Diablo Point +0.9 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the 10 quadrats per transect at SDP-1, -2, and -3. Data collected in 1976-77 and 1984-86 were not included.

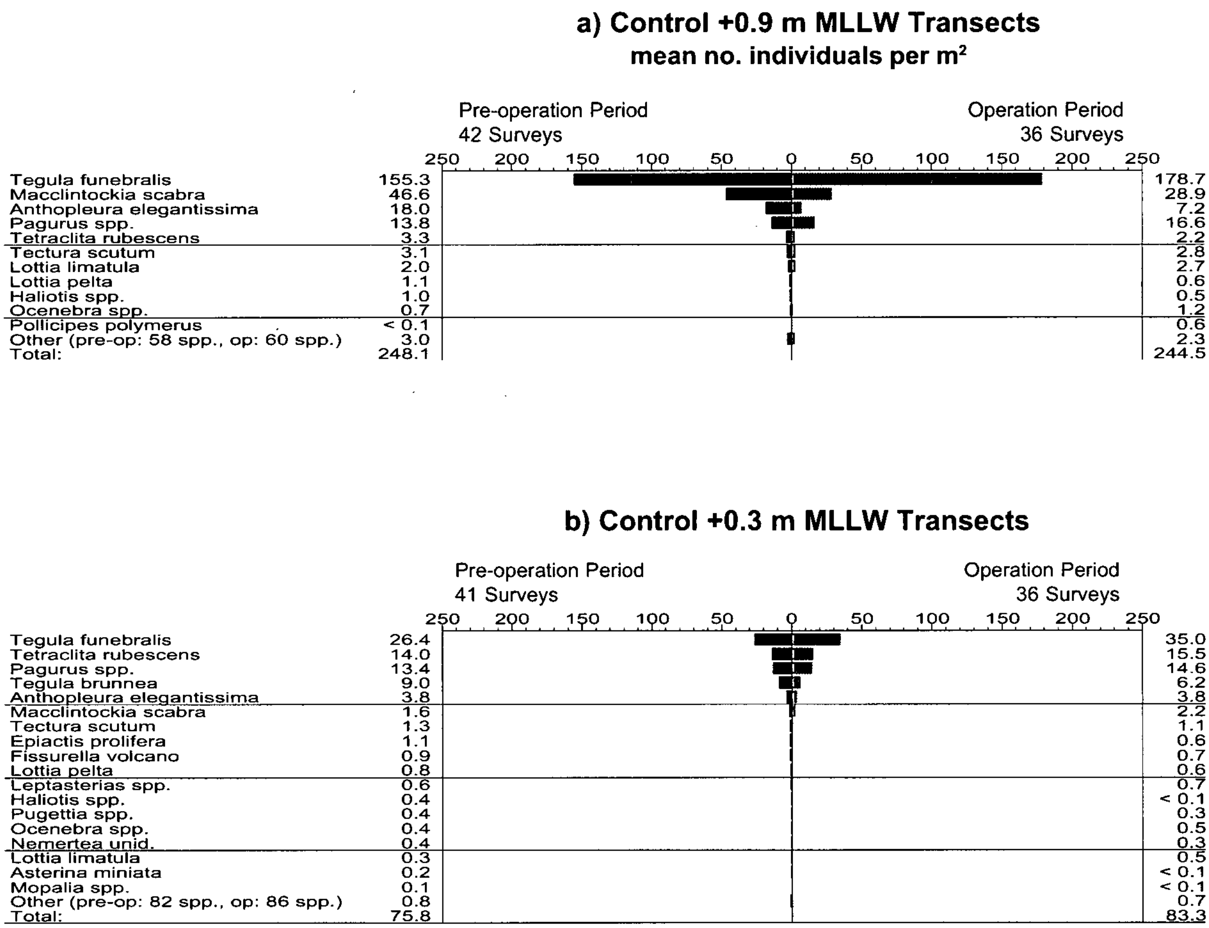


Figure 3-24. Intertidal invertebrate densities at the control (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the five 'count' quadrats per transect at NC-1, -2 and SC-1. For each sampling elevation, the list of taxa are those that formed 99% of the total counts in the pre-operation period combined with the list that formed 99% of the total counts in the operation period. Data collected in 1976-77 and 1984-86 were not included.

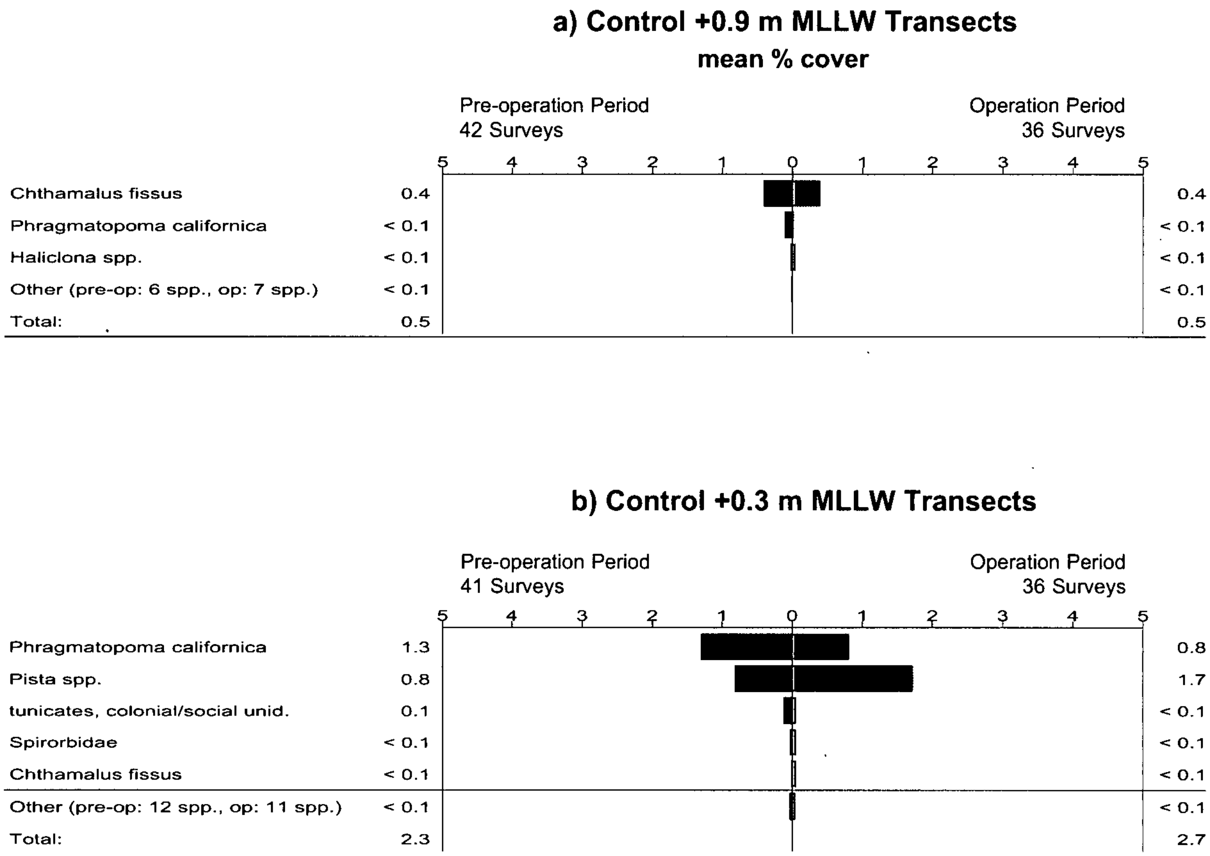


Figure 3-25. Intertidal invertebrate coverage abundances at the control (a) +0.9 m and (b) +0.3 m MLLW horizontal band transects for the pre-operation and operation periods. Period means were calculated from pooled survey means from the 10 quadrats per transect at NC-1, -2, and SC-3. Data collected in 1976-77 and 1984-86 were not included.

Table 3-9. Results of BACI ANOVA for intertidal invertebrates from horizontal band transects. Negative values indicate decreases between periods for individual stations. Statistically significant results (p<0.10) are in **bold** type.

	% Change Between Periods Relative to Controls				Power to Detect a 50% Change	Interaction	Pairwise Comparisons by Station or Area (p value) [mean temperature increases above ambient listed in °C]									
	All Impact	Diablo Cove	Period		Between	Between	Diablo	South	FC - 3	NDC - 1	NDC - 2	NDC - 3	SDC - 2	SDP - 1	SDP - 2	SDP - 3
Taxon	Stations	Stations only	F-Value	P	Periods	Per. and Sta.	Cove	Diablo Pt	[0.9°]	[3.1°]	[3.3°]	[3.4°]	[3.1°]	[1.7°]	[1.3°]	[1.3°]
Level +.3 m MLLW																
Significant Increase																
Anthopleura elegantissima	+135	+115	5.7	**.02**	1.00	**<.01**	**<.01**	**.02**	.98	**<.01**	**<.01**	.44	**<.01**	**<.10**	.23	**<.01**
Anthopleura xanthogrammica	+1593	+1718	5.0	**.03**	.93	**<.01**	**.06**	**.04**	**.01**	**.09**	-.20	**.01**	**<.01**	**.03**	.18	.13
Chthamalus fissus	+225	+325	1.8	.18	.30	**<.01**	**<.01**	-.23	-.24	**<.01**	**<.01**	**.03**	.44	-.55	-.15	-.32
Fissurella volcano	+447	+742	23.7	**<.01**	1.00	**<.01**	**<.01**	**<.01**	-1.00	**.01**	**<.01**	**<.01**	**.08**	.49	**<.01**	**<.01**
Lottia limatula	+110	+138	8.6	**.01**	.98	**<.01**	**<.01**	-.92	**.09**	.15	.27	**<.01**	**<.01**	-.59	-.37	.33
Lottia pelta	+516	+390	16.3	**<.01**	.99	**<.01**	**<.01**	**<.01**	**-.02**	.53	**<.01**	**<.01**	.86	**.01**	**<.01**	**<.01**
Macclintockia scabra	+356	+424	4.8	**.03**	.93	**<.01**	**<.01**	-.52	-.62	**.04**	**<.01**	**<.01**	**-.04**	.35	**-<.01**	.61
Pachygrapsus crassipes	+30	+120	26.6	**<.01**	.60	**<.01**	**<.01**	**.01**	**<.01**	**.04**	**<.01**	**<.01**	**.01**	.87	**.02**	**<.01**
Pisaster ochraceus	+322	+887	5.4	**.02**	.96	**<.01**	**.01**	**.01**	-.81	**.01**	.45	**<.01**	**.05**	**<.01**	**.07**	.14
Strongylocentrotus purpuratus	+283	+3315	9.4	**<.01**	.21	**<.01**	**<.01**	**-.03**	**<.01**	**<.01**	**<.01**	**<.01**	**.03**	**-.07**	-.27	**-.06**
Significant Decrease																
Bryozoa, unid. (encrusting)	-90	-99	2.9	**<.10**	.22	.28	**-.07**	-.14	-.90	-.81	**-.08**	**-.06**	**-.07**	-.88	-.54	**-.02**
Epiactis prolifera	-73	-86	4.5	**.04**	1.00	**<.01**	**-<.01**	-.78	-.58	.46	-.12	**-.02**	**-<.01**	.43	-.75	-.26
Haliotis spp.	+893	+235	5.0	**.03**	1.00	**<.01**	**-<.01**	-.49	-.15	-.14	**-<.01**	**-<.01**	.15	.90	**.02**	**-<.01**
Leptasterias spp.	-42	-98	41.0	**<.01**	1.00	**<.01**	**-<.01**	**-.02**	-.46	**-<.01**	**-<.01**	**-<.01**	**-<.01**	**-<.01**	-.53	-.43
Mopalia spp.	-25	-41	0.8	.38	.97	**<.01**	**-<.01**	**.07**	-.68	-.11	**-.02**	**-.07**	**-<.01**	.38	**.06**	.20
Nemertea unid.	+27	-91	2.6	.11	1.00	**<.01**	**-<.01**	.35	.56	-.12	**-.01**	**-<.01**	-.36	-.90	**<.01**	-.75
Ocenebra spp.	-24	-22	9.6	**<.01**	.99	**<.01**	**-<.01**	-.42	.45	**-<.01**	**-.02**	-.85	**-<.01**	.45	-.13	-.21
Pugettia spp.	-57	-62	6.1	**.02**	.99	.18	**-.07**	**-.01**	-.15	.55	**-.02**	**-.01**	-.13	-.29	**-<.10**	**-.01**
Spirorbidae	-72	-63	5.3	**.02**	.11	.78	**-.05**	**-.05**	**-.04**	.93	**-.04**	**-.01**	**-.05**	-.19	**-.05**	-.19
Tegula brunnea	+6	-14	0.3	.59	1.00	**<.01**	**-.03**	.34	.38	.14	**-.05**	**-<.01**	-.53	-.25	**<.01**	.36
tunicates, colonial/social	-67	*no calc*[1]	10.0	**<.01**	1.00	**<.01**	**-<.01**	**-.01**	-.62	.87	**-<.01**	**-<.01**	.54	.36	**-<.01**	**-<.01**
No Change[2]																
Balanus spp.	+1176	+244	0.0	.92	.91	.50	.86	.85	-.66	.61	-.22	.48	.81	-.28	.57	.31
Nuttallina californica	+27	-40	1.4	.24	1.00	**<.01**	.99	**.01**	.99	**.04**	**-.03**	.89	-.70	.21	**.09**	**<.01**
Pagurus spp.	-15	+11	4.4	**.04**	1.00	**<.01**	.58	**-<.01**	-.11	**.02**	-.15	**-<.01**	.18	**-.07**	**-<.01**	-.16
Tectura scutum	+57	+82	0.6	.45	1.00	**<.01**	.70	.31	-.65	**-.02**	.22	**<.01**	-.14	-.73	.52	.12
Tegula funebralis	+128	+305	0.3	.60	1.00	**<.01**	.20	-.75	-.94	-.72	.81	.22	**<.01**	.60	-.47	-.51
Tetraclita rubescens	+244	+365	0.0	.92	.99	**<.01**	.57	.25	.63	**-<.10**	-.94	**.01**	.16	.59	**-<.01**	-.48
Invertebrate Species Richness	+7	-2	0.1	.71	1.00	**<.01**	-.43	—	.29	-.41	-.14	**<.01**	**-<.01**	—	—	—
Test Results Inconclusive[3]																
Lottia digitalis	+692	+2711	0.0	.96	.10	**<.01**	.13	**-<.10**	-.73	.17	**<.01**	.32	**-.06**	-.25	**-.03**	-.71
Serpulorbis squamigerus	-26	+821	0.3	.60	.10	**<.01**	-.92	-.17	.48	**-.08**	**-.04**	-.59	**<.01**	-.42	-.18	-.20

(table continued)

Table 3-9 (continued). Results of BACI ANOVA for intertidal invertebrates from horizontal band transects .

	% Change Between Periods Relative to Controls		Period		Power to Detect a 50% Change	Interaction	Pairwise Comparisons by Station or Area (p value) [mean temperature increases above ambient listed in °C]									
Taxon	All Impact Stations	Diablo Cove Stations only	F-Value	P	Between Periods	Between Per. and Sta.	Diablo Cove	South Diablo Pt	FC - 3 [0.9°]	NDC - 1 [3.1°]	NDC - 2 [3.3°]	NDC - 3 [3.4°]	SDC - 2 [3.1°]	SDP - 1 [1.7°]	SDP - 2 [1.3°]	SDP - 3 [1.3°]
Level +.9 m MLLW																
Significant Increase																
Chthamalus fissus	+5561	+7399	2.4	.13	.10	<.01	.05	—	-.88	.12	.15	<.01	.74	—	—	—
Cyanoplax spp.	+58	+34	17.5	<.01	.93	<.01	<.01	—	<.01	.01	<.01	<.01	-.01	—	—	—
Fissurella volcano	+464	+456	7.5	.01	.91	<.01	<.01	—	-.52	.16	.01	<.01	-.42	—	—	—
Lottia digitalis	+2434	+2323	21.8	<.01	.82	<.01	<.01	—	.01	.15	<.01	<.01	-.66	—	—	—
Lottia limatula	+137	+128	44.6	<.01	1.00	<.01	<.01	—	.01	<.01	<.01	<.01	<.01	—	—	—
Macclintockia scabra	+389	+409	17.6	<.01	1.00	<.01	<.01	—	.58	<.01	<.01	<.01	-.54	—	—	—
Pachygrapsus crassipes	+164	+190	51.6	<.01	1.00	<.01	<.01	—	.05	.04	<.01	<.01	.41	—	—	—
Phragmatopoma californica	+3194	+49018	115.2	<.01	.32	<.01	<.01	—	<.01	.19	<.01	<.01	<.01	—	—	—
Tegula funebralis	+54	+79	24.5	<.01	1.00	.03	<.01	—	.06	.01	.06	<.01	<.01	—	—	—
Tetraclita rubescens	+349	+347	2.0	.16	.75	<.01	.06	—	-.54	-.59	-.60	.14	<.01	—	—	—
Invertebrate Species Richness	+10	+9	25.0	<.01	1.00	.04	<.01	—	<.01	.02	<.01	<.01	.57	—	—	—
Significant Decrease																
Nuttallina californica	-89	-90	17.1	<.01	.73	<.01	-<.01	—	-.03	-.01	-<.01	-<.01	-.08	—	—	—
Tegula brunnea	-64	-66	21.9	<.01	1.00	<.01	-<.01	—	.65	-.03	.71	-<.01	.63	—	—	—
No Change[2]																
Acanthina spp.	-2	+12	0.1	.71	.75	.02	.86	—	-.42	.30	.62	.82	-.01	—	—	—
Anthopleura elegantissima	+134	+125	0.7	.40	.99	<.01	.40	—	.50	-.50	.52	.72	.01	—	—	—
Lottia pelta	+79	+66	3.2	.08	1.00	.01	.16	—	.01	.06	.76	-.89	.02	—	—	—
Haliotis spp.	+87	-58	0.0	.97	.94	<.01	-.44	—	<.01	-.18	-.26	-.03	.03	—	—	—
Ocenebra spp.	0	+22	1.2	.28	1.00	<.01	.69	—	-.01	.70	-.91	.03	-<.01	—	—	—
Pagurus spp.	+12	+13	0.3	.60	1.00	.02	.70	—	.39	-.89	-.57	.02	-.79	—	—	—
Tectura scutum	+32	+32	0.6	.44	1.00	.27	.84	—	-.06	-.39	.63	.54	-.66	—	—	—

[1] percent change could not be calculated because mean control abundance was zero during one or both periods.
[2] there was no significant difference between period means, and the power of the test to detect a 50% change in abundance between periods was greater than .70.
[3] there was no significant difference between period means, and the power of the test to detect a 50% change in abundance between periods was less than .70.

Significant Increases

Significant relative increases in abundance between periods were detected in 16 taxa from Diablo Cove, Field's Cove and Diablo Point (Tables 3-9 and 3-10). The greatest percent increases between periods in Diablo Cove were seen in *Phragmatopoma californica* (sand tube worm), *Chthamalus fissus* (acorn barnacle), *Strongylocentrotus purpuratus* (purple sea urchin), and *Lottia digitalis* (limpet). *Tegula funebralis* (black turban snail) was an abundant species at both intertidal levels (Figure 3-26). It increased significantly at the higher elevations in Diablo Cove, but was unchanged at the lower elevation (Table 3-9). Although the absolute increases in *P. californica* appeared to be small during plant operation (Figure 3-27), the percent increases relative to the control were large (Table 3-9). *Pachygrapsus crassipes* (lined shore crab) increased significantly at both elevations (Table 3-9). This highly motile crab was also sampled in the vertical band transect (VBT) method that encompassed a wider range of elevations than the HBT. *P. crassipes* was chosen as an example of a species that generally increased in frequency of occurrence on all VBT stations during the operation period compared to the pre-operation period. Inspection of the VBT distribution data indicated that the crabs increased at all tidal levels surveyed (Figure 3-28).

Significant Decreases

Significant decreases between periods were detected in 16 taxa from Diablo Cove, Field's Cove and Diablo Point (Tables 3-9 and 3-10). Most notable among these were declines in encrusting Bryozoa (-99%), *Leptasterias* spp. (-98%, Figure 3-29), *Nuttalina californica* (-90%), and *Epiactis prolifera* (-86%, Figure 3-30). Most declines (% change) were larger within Diablo Cove, compared to the complete set of impact stations (Table 3-9). Increases in the percent change (+235) between periods for *Haliotis cracherodii* (black abalone) were contrary to its categorical decrease at the 0.3 m level (Table 3-9). Absolute abundances of this taxon declined within Diablo Cove, but larger declines at the control resulted in a relative increase in Diablo Cove (for additional data see Section 3.3.4 - *Black Abalone*)

Table 3-10. Results of Fisher's exact test for HBT intertidal invertebrate taxa not tested in BACI analysis. (*) indicates taxon was analyzed for +0.9 m elevation. All other taxa were analyzed for +0.3 m elevation. Statistically significant results (p<0.10) are in **bold** type.

Taxon	Diablo Cove p	Diablo Point p	Field's Cove p
Significant Increase			
Pollicipes polymerus	**<.01**	**.01** (decrease)	1.00
Significant Decrease			
Bryozoa, unid. (foliose)	**.07**	**.03**	.70
Pista spp.	**<.01**	.81	**.01**
Spirorbidae*	**<.01**		**<.01**
Haliclona spp.*	**.04**		**.03**
Porifera unid. (encrusting)	**<.01**	**.01**	.35
Porifera unid. (encrusting)*	**<.01**		.15
Test Results Inconclusive			
Dodecaceria fewkesi	1.00	.24	**.03** (increase)
Mytilus californianus	.14	.48	1.00

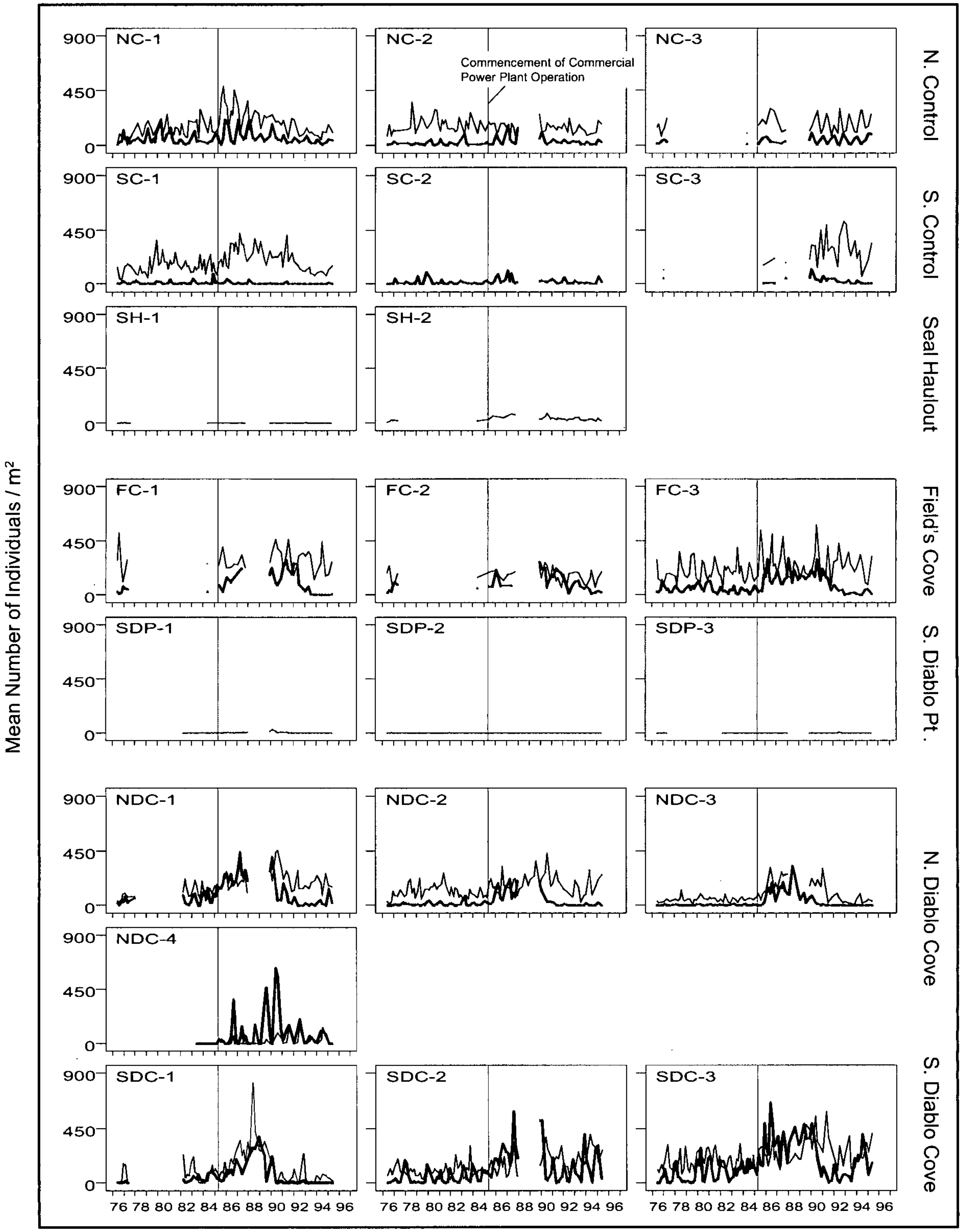


Figure 3-26. *Tegula funebralis*: changes in density at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

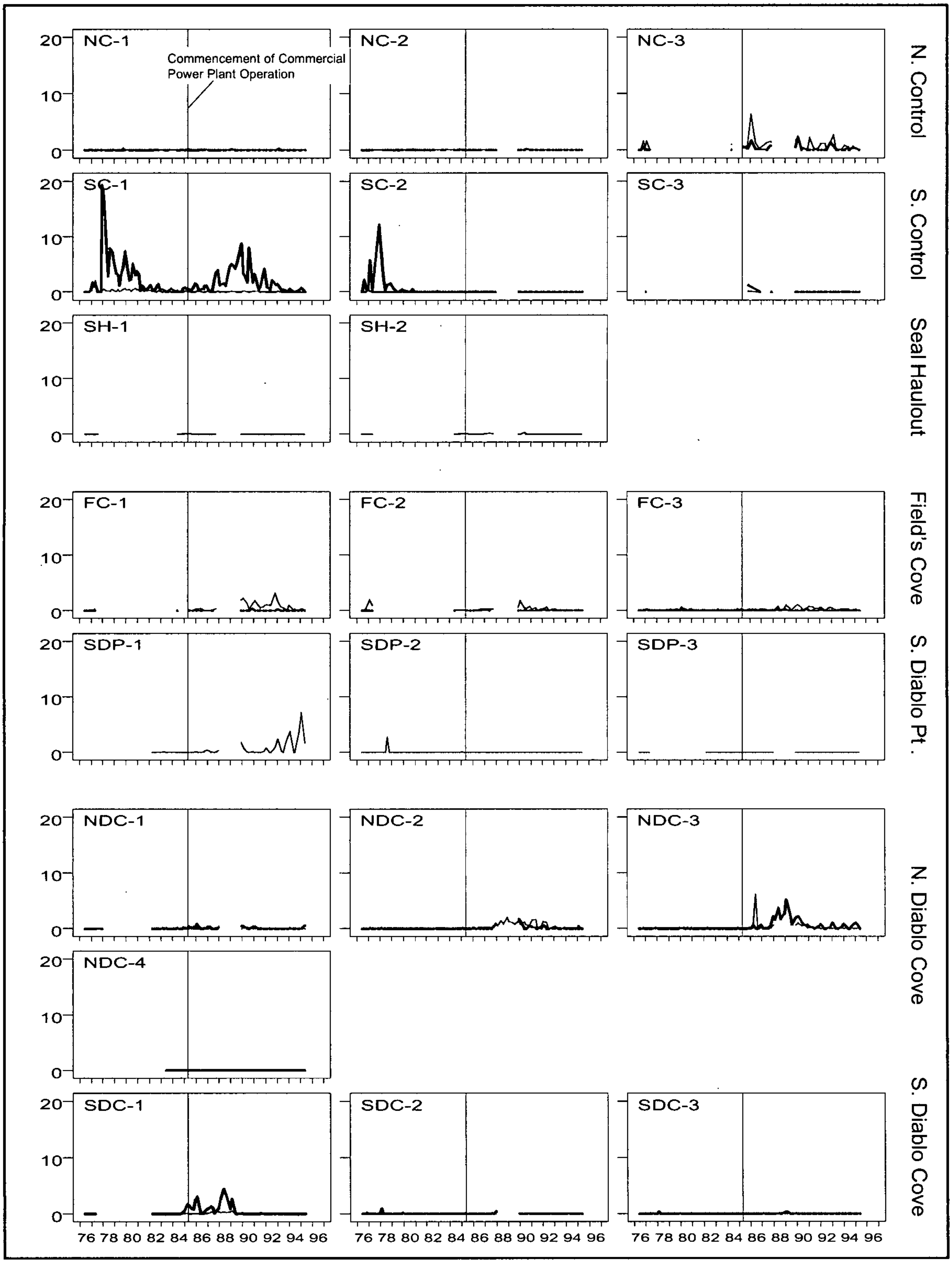


Figure 3-27. *Phragmatopoma californica*: changes in cover at the horizontal band transect stations. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

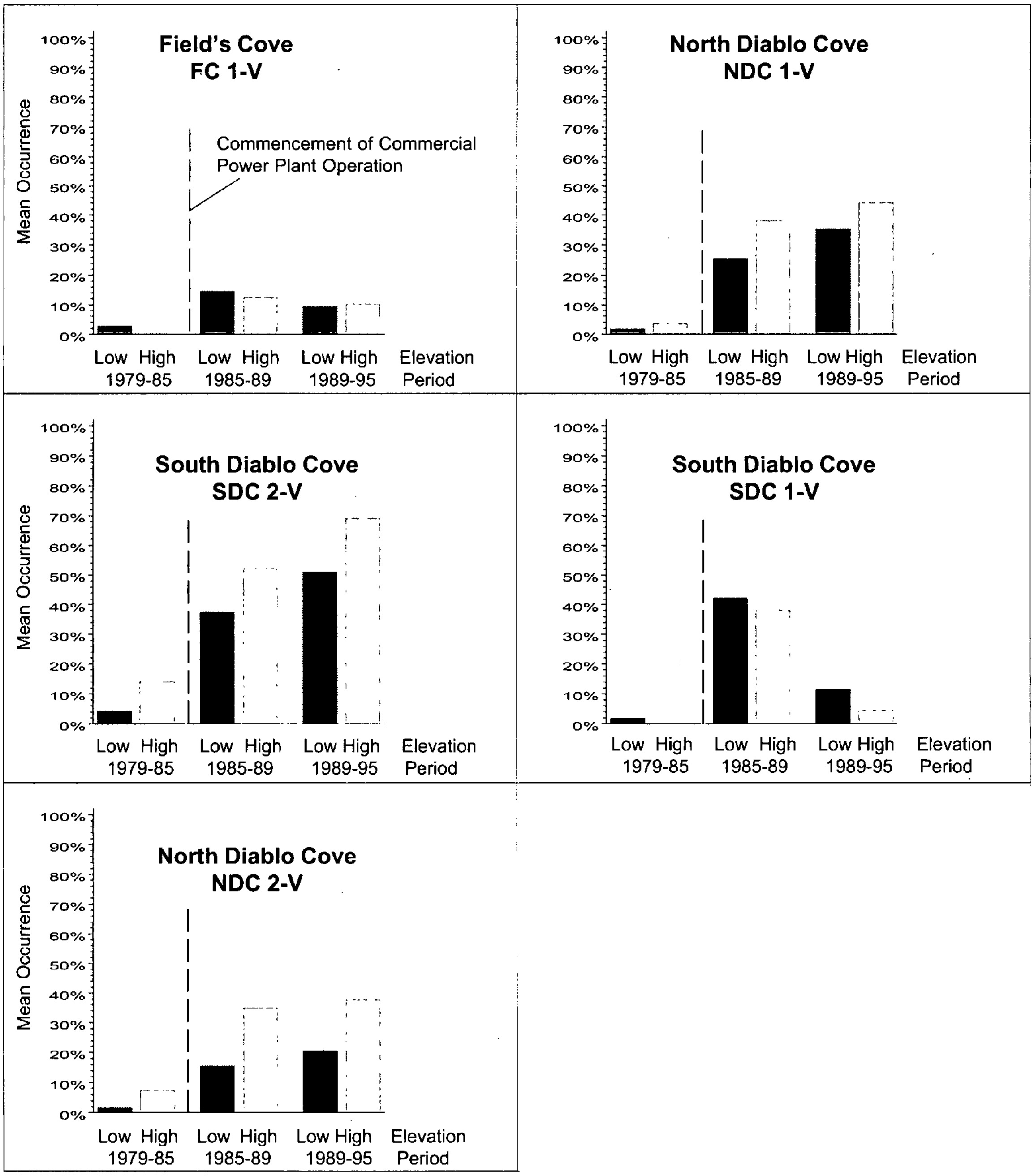


Figure 3-28. *Pachygrapsus crassipes* elevational distribution by time period from vertical band transect data. Values are mean percent occurrence of 36 quadrats sampled over time. High versus low elevation quadrats separated at +0.43 m MLLW.

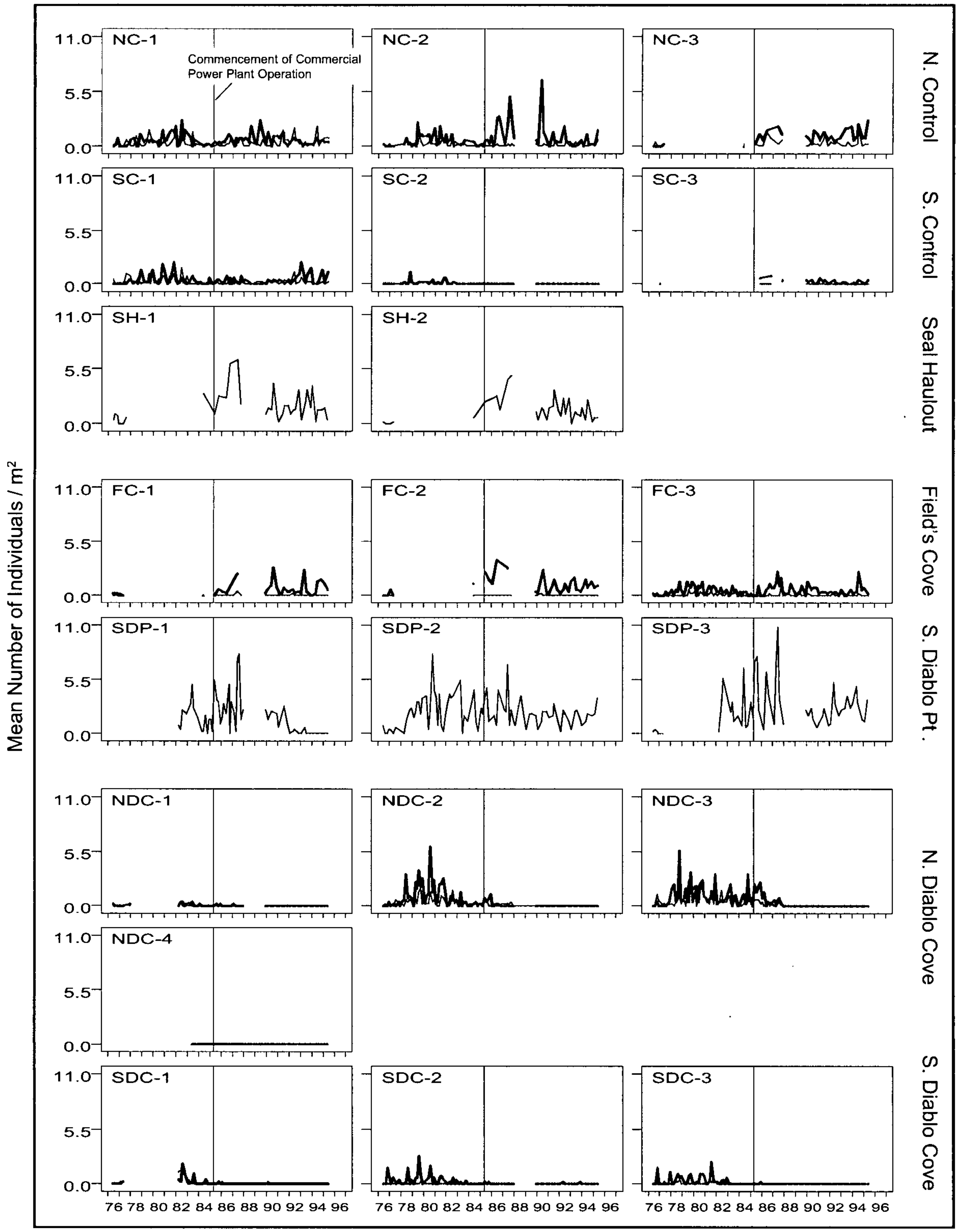


Figure 3-29. *Leptasterias* spp.: changes in density at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

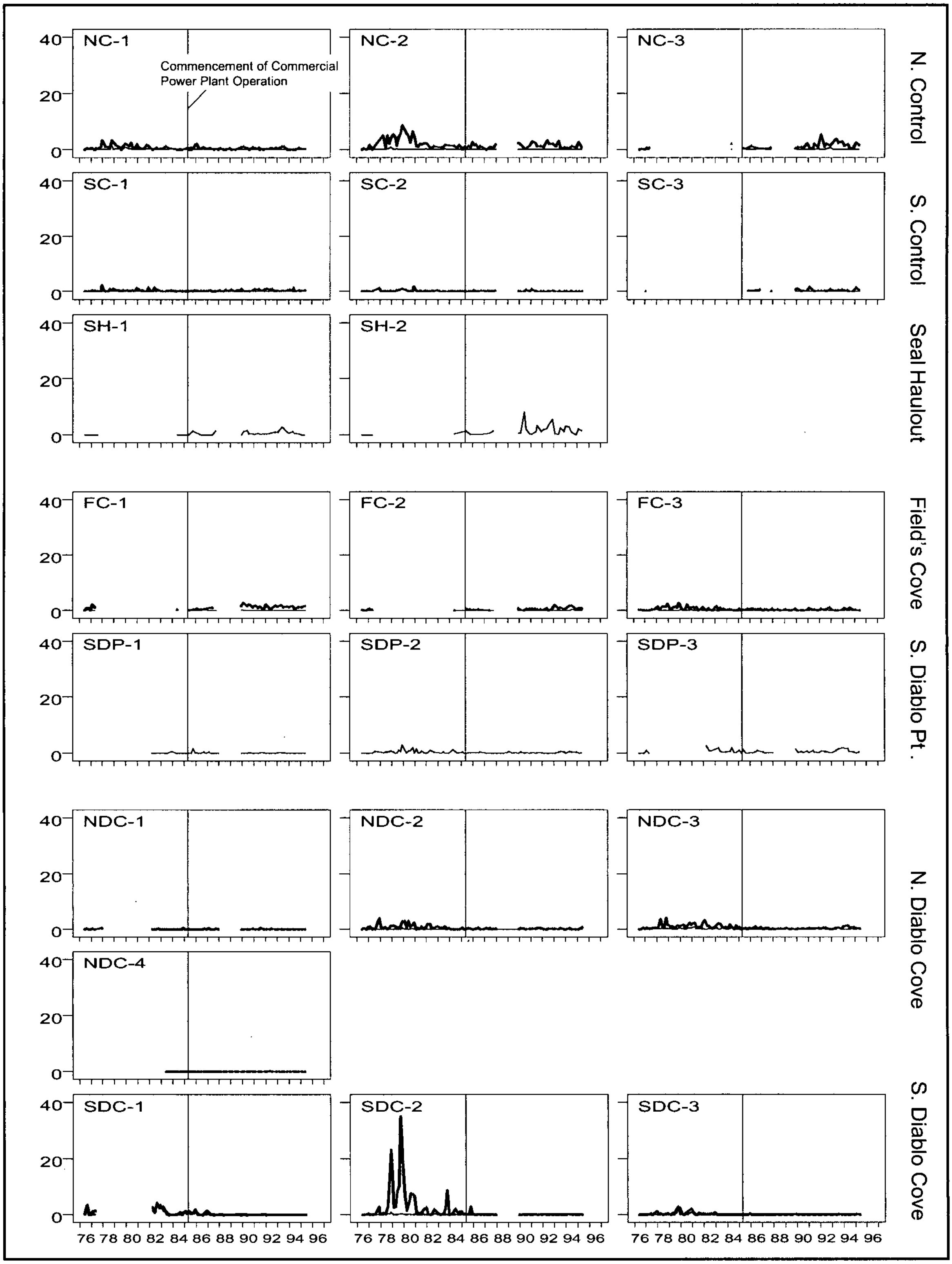


Figure 3-30. *Epiactis prolifica*: changes in density at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

Hemigrapsus nudus (purple shore crab) generally occur beneath rocks on sand substrate, and as such, were not effectively sampled in the HBT method. For this reason, they did not contribute to the HBT 99% abundance list presented in Figure 3-18. However, the VBT method, allowing the turning of rocks, documented a decrease in frequency of occurrence at all Diablo Cove stations between periods (Figure 3-31). No change in their frequency of occurrence was evident at FC-1V.

No Change

Test power was sufficiently high (>.70) to conclude that the discharge did not appear to affect 4 taxa at both elevations (Table 3-9). Seven taxa that were identified in Table 3-9 as having no changes at one elevation did show significant changes at the other elevation, and were classified as having increased or decreased accordingly. For example, although no significant changes were detected for *Ocenebra* spp. (rock snails) at the upper elevation, this taxon declined significantly at the lower elevation and was therefore classified as having decreased overall. These types of classifications resulted in a conservative assessment of overall discharge effects on a taxon.

Test Results Inconclusive

The analyses could not detect between-period effects in the abundance of the molluscs *Lottia digitalis* (+0.3 m only), *Serpulorbis squamigerus*, and *Mytilus californianus*, and the polychaete *Dodecaceria fewkesi* (Tables 3-9 and 3-10). Although *L. digitalis* showed a very large (+2,711%) change between periods in Diablo Cove, this taxon is not commonly found in the low intertidal region. The significant increase noted for *L. digitalis* at the +0.9 m level is more representative of its true interperiod discharge response.

Analysis of Community Changes

Community composition and abundances of select taxa changed at all station groups between periods, though larger changes occurred in Diablo Cove. Invertebrate faunal changes (absolute) within Diablo Cove were mainly characterized by large declines between periods in *Nuttalina californica*, *Tegula brunnea*, *Haliotis* spp., *Leptasterias* spp., *Epiactis prolifera*, *Pugettia* spp. and nemertean worms, and corresponding increases in *Fissurella volcano*, *Pachygrapsus crassipes*, *Strongylocentrotus purpuratus*, *Lottia digitalis*, and *Chthamalus fissus* (Figures 3-18 and 3-19). Absolute increases occurred at Field's Cove in *Tegula funebralis, Tetraclita rubescens, S. purpuratus* (Figures 3-20) and *Phragmatopoma californica* (Figure 3-21), and at South Diablo Point in *T. rubescens*, *Macclintockia scabra*, *Anthopleura elegantissima* (Figures 3-22) and *P. californica* (Figure 3-23). Most taxa at the lower elevation (+0.3 m) control transects changed little in abundance between periods (Figure 3-24b). In contrast, several of the most abundant taxa at lower elevation transects in Diablo Cove increased substantially after plant start-up (Figure 3-18b).

Numbers of invertebrate taxa increased significantly between periods at the +0.9 m level (considering all impact stations together), but did not change at the +0.3 m level, relative to the control (Table 3-9). Proportionately, more species declined in their frequency of occurrence between periods at both Diablo Cove elevations, relative to the control (Table 3-11). No significant differences were detected in this proportion at either the South Diablo Point or Field's Cove impact areas.

Correspondence analysis (CA) describing community-level changes at control and impact stations used the group of taxa that formed 95% of the combined period cumulative abundance and occurred in at least 20% of the surveys. Analysis of the pooled survey means from the combined control was conducted

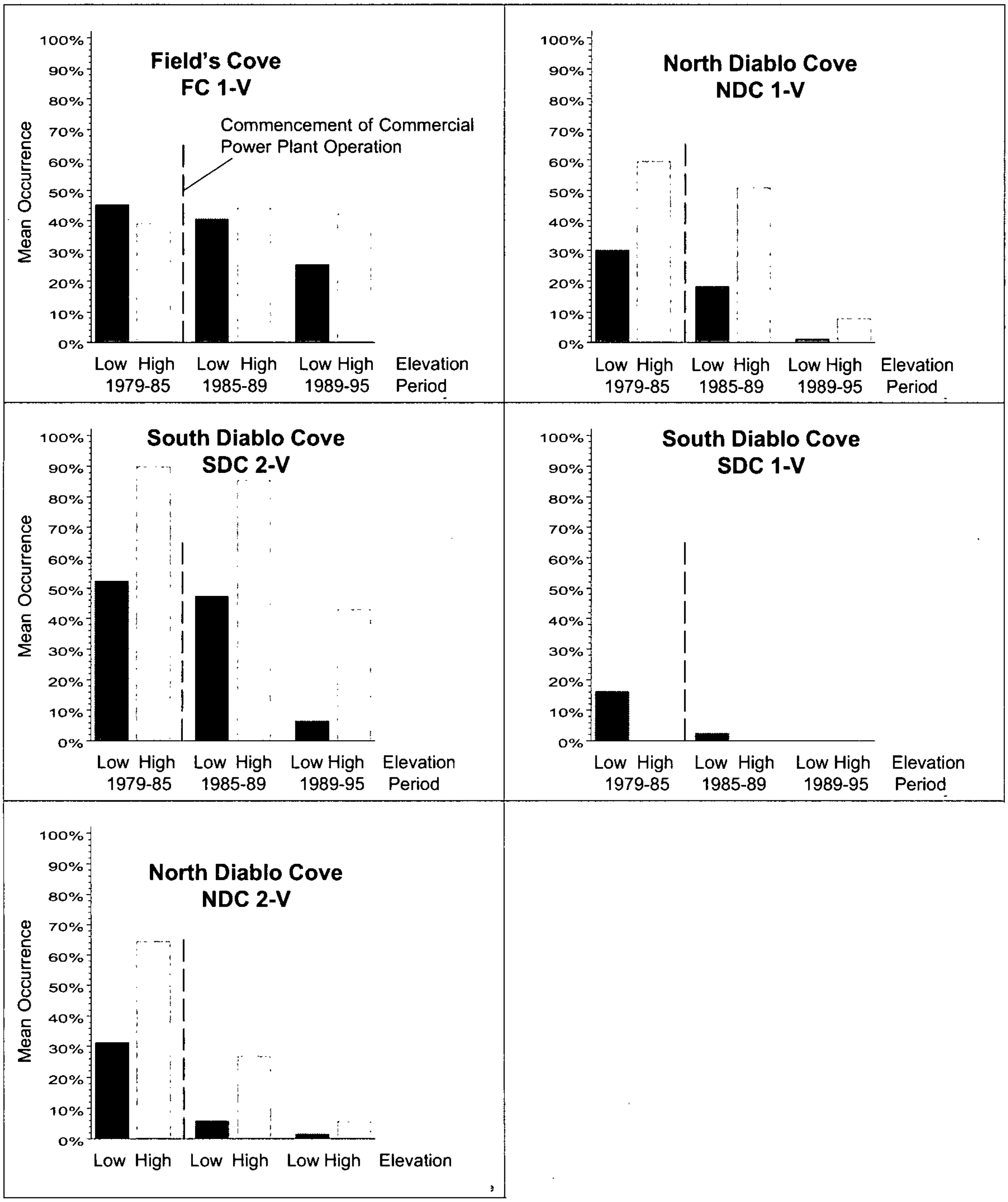


Figure 3-31. *Hemigrapsus nudus* elevational distribution by time period from vertical band transect data. Values are mean percent occurrence of 36 quadrats sampled over time. High versus low elevation quadrats separated at +0.43 m MLLW.

using 16 taxa. Survey scores from the first correspondence analysis axis explained 38.8% of the total variation for the data set (Figure 3-32). Survey scores for the control area show that the largest component of variation in the data set is associated with changes following the 1982-83 El Niño period. The strong pattern of variation following El Niño shown on the first axis probably delegated any seasonal pattern of variation to a subsequent independent axis of variation. Positive species scores for several limpets and the barnacle *Tetraclita rubescens* are associated with these survey scores, and results from plots of abundance over time for these taxa show the pattern is due to relative increases in the abundance of these taxa during this period. Survey scores returned to pre-1983 community patterns of variation by 1988.

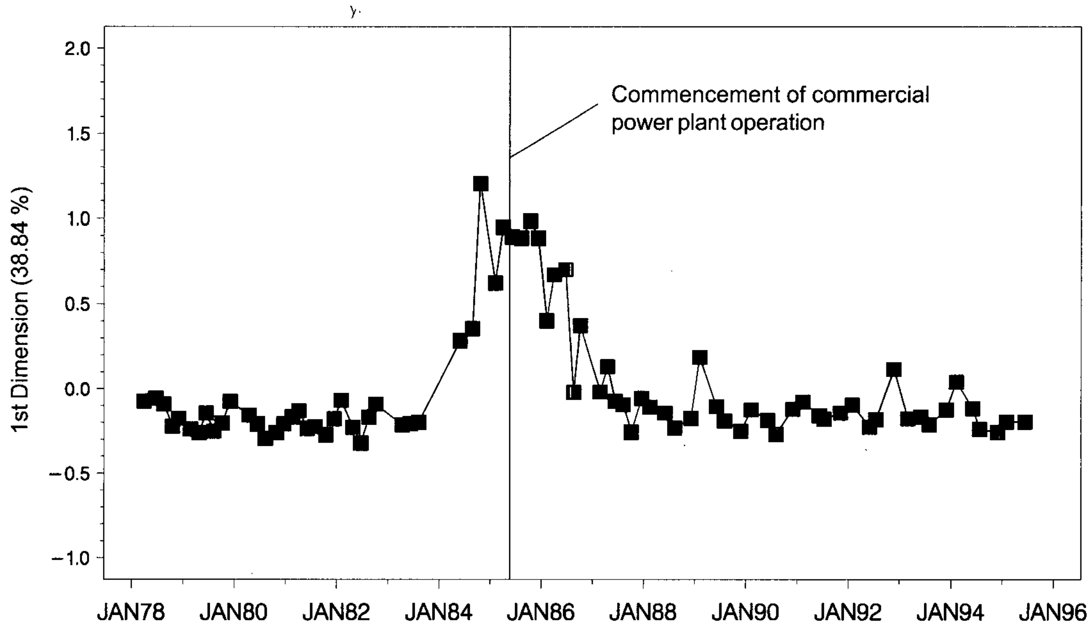
Table 3-11. Results of Fisher's exact test for intertidal invertebrates: a) Diablo Cove, b) Field's Cove, and c) South Diablo Point. Data were number of species changes at the Diablo Cove and control stations between pre-operation and operation periods. Statistically significant results ($p<0.10$) are in **bold** type.

a) Diablo Cove	**+0.3 m MLLW**		**+0.9 m MLLW**	
	Decreases	Increases	Decreases	Increases
Diablo Cove	71	39	52	28
Control	53	57	40	40
	p = **<0.02**		p = **0.08**	

b) Field's Cove	**+0.3 m MLLW**		**+0.9 m MLLW**	
	Decreases	Increases	Decreases	Increases
Field's Cove	47	21	25	21
Control	42	26	28	18
	p = 0.47		p = 0.67	

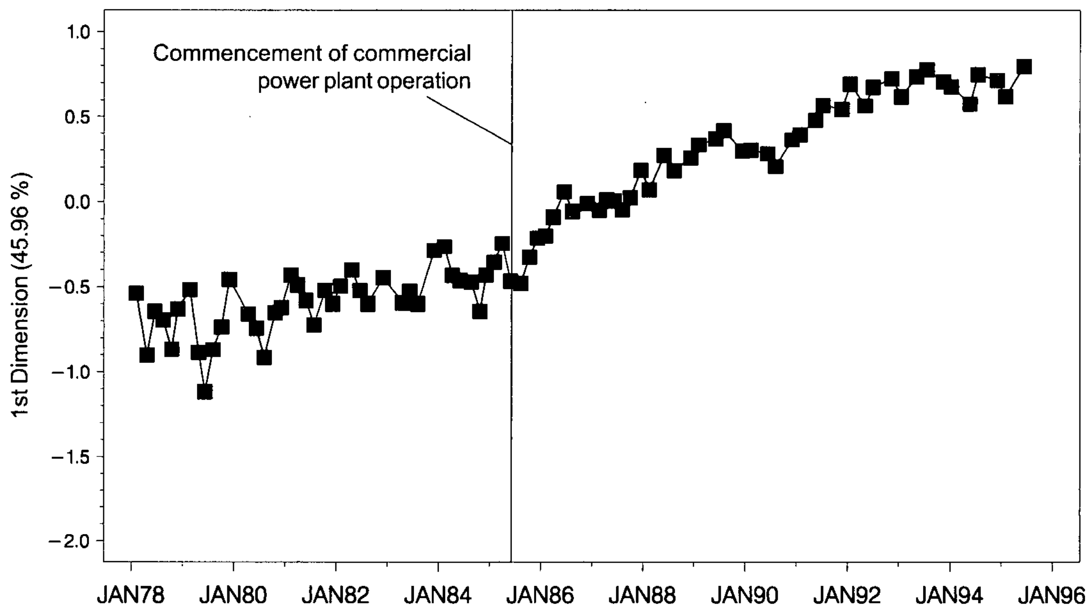
c) South Diablo Point	**+0.3 m MLLW**		**+0.9 m MLLW**	
	Decreases	Increases	Decreases	Increases
Diablo Point	*(no stations at this level)*		42	34
Control			41	35
			p = 1.00	

First axis CA survey scores for Diablo Cove Station NDC 3+.3m show a different pattern of variation than results for control stations (Figure 3-33). This pattern of variation accounts for almost 46% of the variation in the data set and contrasts pre-operational surveys with operational period surveys. Seventeen taxa were included in the analysis that resulted in this pattern of variation. Results show a stronger pattern of seasonal variation prior to the 1982-83 El Niño than is observed in the results for the control



Score	Taxa
-0.293	*Tegula brunnea*
-0.234	*Leptasterias* spp.
-0.232	*Crepidula* spp.
-0.191	tunicates, colonial/social unid.
-0.185	*Epiactis prolifera*
-0.177	*Alia* spp.
-0.090	*Pista* spp.
-0.083	*Pagurus* spp.
-0.064	*Lacuna* spp.
-0.016	*Tegula funebralis*
-0.016	Spirorbidae
0.001	*Anthopleura elegantissima*
0.246	*Tetraclita rubescens*
0.268	Acmaeidae unid.
0.596	*Tectura scutum*
1.869	*Macclintockia scabra*

Figure 3-32. Intertidal invertebrate survey scores from the first correspondence analysis axis plotted over time for the control +0.3 m MLLW transects. Species scores are listed below the graph. The axis accounts for 38.84% of the total variation of the data set. Stations used were NC-1, -2, and SC-1.



Score	Taxa
1.037	*Strongylocentrotus purpuratus*
0.588	*Macclintockia scabra*
0.513	*Lottia limatula*
0.431	*Lottia pelta*
0.364	*Chthamalus fissus*
0.272	*Fissurella volcano*
0.237	*Phragmatopoma californica*
0.175	*Tetraclita rubescens*
0.005	*Tectura scutum*
-0.117	*Ocenebra* spp.
-0.152	*Tegula funebralis*
-0.369	*Nuttallina californica*
-0.459	*Pagurus* spp.
-0.663	*Epiactis prolifera*
-0.754	*Haliotis* spp.
-0.766	*Tegula brunnea*
-1.104	*Leptasterias* spp.

Figure 3-33. Intertidal invertebrate survey scores from the first correspondence analysis axis plotted over time for Station NDC 3+.3m. Species scores are listed below the graph. The axis accounts for 45.96% of the total variation of the data set.

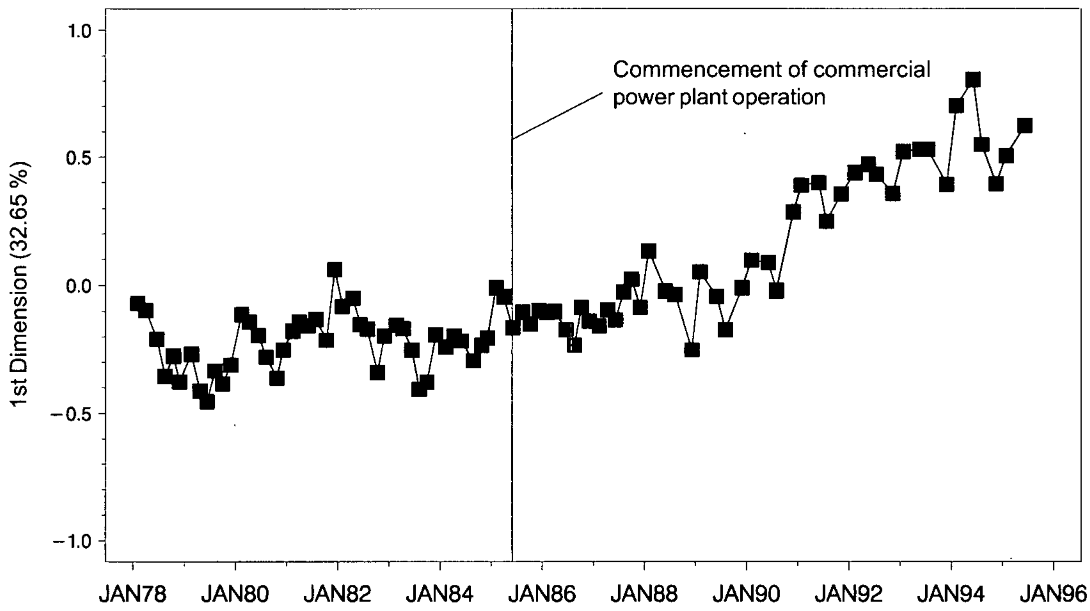
stations. This pattern is interrupted during the El Niño period, but unlike the control stations, survey scores for the Diablo Cove station show continued change following the post El Niño period that is coincident with plant operation. Species scores show that changes in survey scores are related to the same relative increases in limpets observed in the results for the control stations. Unlike the control results, relative abundances in these taxa did not decline but continued to remain high relative to pre-operational levels, and several other taxa appear to contribute to continued changes including the purple urchin *Strongylocentrotus purpuratus* and the acorn barnacle *Chthamalus fissus*. Negative species scores are associated with taxa that are associated with negative survey scores during the pre-operational period, and have declined relative to taxa with positive taxa scores during the operational period. These taxa include *Leptasterias* spp., *Tegula brunnea* and *Haliotis* spp., all of which have declined in abundance during plant operation.

CA of Field's Cove Station FC 1+.3m (Figure 3-34) shows a pattern of variation that is similar to results for the Diablo Cove station. This pattern of variation accounts for less variation (32.65%) than the Diablo Cove station results but shows the same contrast between pre-operational surveys and operational period surveys. The lower percent of variation explained by the first axis for this analysis may result from the larger number of taxa (19) that were included in the analysis. Larger numbers of taxa in an analysis introduce more patterns of variation that are less able to be explained by a single independent pattern of variation. The change in survey scores does not occur until approximately 1990 in contrast to the stronger trend that began following the El Niño period for Diablo Cove, and this may also explain the lower percent of variation explained by the first axis. The pattern of species scores that is related to changes in survey scores is similar to the pattern of species scores for the Diablo Cove analysis. These include positive scores for *S. purpuratus* and *T. rubescens*, and negative scores for *Haliotis* spp.. The results show that the taxa responsible for operational changes at this Field's Cove station are somewhat different from the taxa changes in Diablo Cove.

Ancillary Observations

The worms *Pista elongata* and *Pista pacifica* are particle feeders that construct fibrous tubes. These worms were locally abundant on the stations of the Diablo Canyon study area before power plant start-up, particularly at the lowest tidal elevations, but they generally occurred as scattered groups or isolated individuals. Beginning in the early 1990's, large colonies of these worms were observed on the discharge bench (SDC-1). Large numbers of *Pista spp.* were not observed at stations outside Diablo Cove during the same period. Similarly, large aggregations of *Phragmatopoma californica* (sand tube worm) have formed in Diablo Cove during the operation period. Often, *P. californica* is associated with intertidal *Gastroclonium subarticulatum* (see Section 3.3.3 - *Algal-Faunal Association Study*).

Two species of sea urchins are common in the Diablo Canyon study area. *Strongylocentrotus purpuratus* (purple urchin) is much more abundant than the larger *S. franciscanus* (red urchin) in both the subtidal and intertidal study areas. Prior to 1987-88, urchin abundance was highly variable among the stations in the Diablo Canyon study area. The abundance of purple urchins increased in 1987-88 (PG&E 1989) in many areas of the Diablo Canyon study area, and by 1991 they were very abundant in the low intertidal area between Diablo Creek and HBT station NDC-3. At this station the main body of urchins occurred below the 0.4 m level. From 1991 to 1993, this area developed into an urchin barrens with measured densities of over 500 *S. purpuratus* per m^2. In June, 1995 the mean density of urchins in this area (a linear shoreline distance of approximately 150 m), was $140/m^2$ (n=108 random m^2 quadrats sampled) with a range from 0 to $485/m^2$. The urchins were not in depressions, or otherwise sheltered. Rather, they were exposed and actively grazing. The grazing caused an associated reduction of fleshy algae and



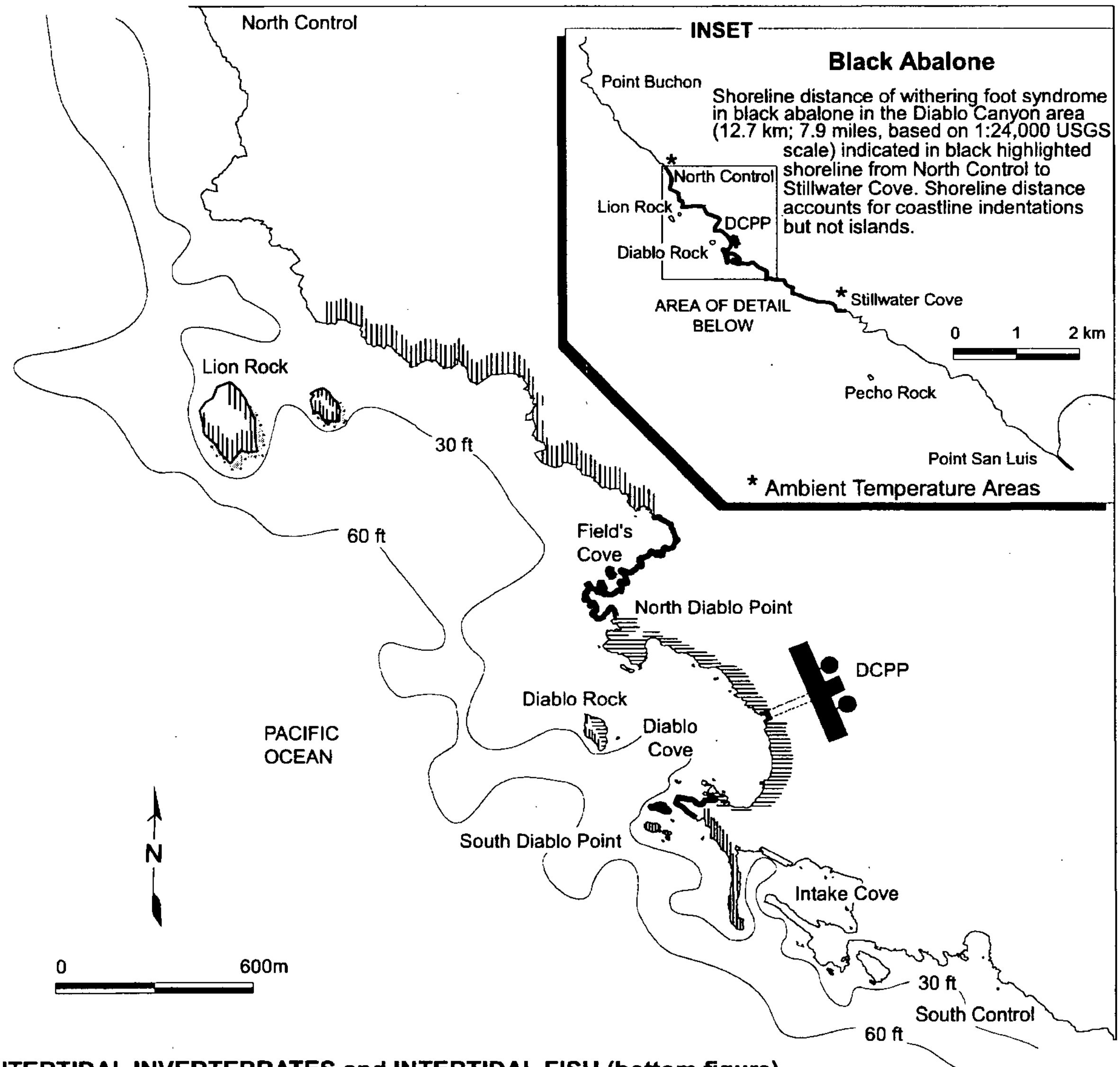
Score	Taxa
-0.313	*Haliotis* spp.
-0.292	*Nuttallina californica*
-0.273	*Chthamalus fissus*
-0.268	*Tectura scutum*
-0.203	*Leptasterias* spp.
-0.158	*Tegula funebralis*
-0.117	*Pagurus* spp.
-0.106	*Tegula brunnea*
-0.098	*Anthopleura elegantissima*
-0.026	*Ocenebra* spp.
-0.018	*Fissurella volcano*
0.006	*Phragmatopoma californica*
0.024	*Pista* spp.
0.034	*Macclintockia scabra*
0.036	*Lottia pelta*
0.218	Serpulidae unid.
0.381	*Serpulorbis squamigerus*
0.479	*Tetraclita rubescens*
0.990	*Strongylocentrotus purpuratus*

Figure 3-34. Intertidal invertebrate survey scores from the first correspondence analysis axis plotted over time for Station FC 3+.3m. Species scores are listed below the graph. The axis accounts for 32.65% of the total variation of the data set.

increase of crustose and articulated coralline algae in these areas. This barrens area expanded until 1995, at which time urchin abundances began to decline. Despite a general increase in sea urchin abundance within the Diablo Canyon study area, the only barrens area observed was in north Diablo Cove. In the other areas where urchins increased (e.g., FC 3+.3m and NC 3+.3m), they were almost entirely restricted to home depressions.

Spatial Extent of Effects

Results from the HBT invertebrate study showed that the greatest changes occurred in Diablo Cove. Significant effects also occurred at South Diablo Point and Field's Cove stations. The magnitudes of the changes at these stations were less than effects on the same taxa in Diablo Cove. Based on HBT invertebrate study results, changes in intertidal algal assemblages, intertidal temperature data (Section 2.2.3), and qualitative observations, effects on intertidal invertebrates extended along a shoreline distance of approximately 3.7 km (2.3 mi), the distance from south Field's Cove to South Diablo Point (Figure 3-35). However, plume thermography (Figures 2-5 and 2-6) showed reduced plume contact along the shoreline beyond these areas northward to Lion Rock, and southward to the west intake cove breakwater, a shoreline distance of approximately 6.7 km (4.2 mi) (Figure 3-35). Any effects on intertidal invertebrates in these areas are likely to be less than those observed in areas with reduced effects.



INTERTIDAL INVERTEBRATES and INTERTIDAL FISH (bottom figure)

Area of continuous plume contact with greatest observed effects: (2.2 km; 1.4 miles - based on 1:9,000 scale)

Area of reduced plume contact with reduced observed effects: (1.5 km; 0.9 miles - based on 1:9,000 scale)

Area of reduced plume contact with unknown effects likely to be less than those in areas with reduced observed effects: (3.0 km; 1.8 miles - based on 1:9,000 scale)

Figure 3-35. Approximate shoreline areas of discharge effects on intertidal invertebrates and fish observed in the study. Bottom figure excludes black abalone. Inset shows range of withering foot syndrome in black abalone in the vicinity of DCPP. Shoreline distances account for coastline indentations and islands. Map of effects was developed from horizontal band transect station sampling, Diablo Cove random quadrat sampling, 10-meter station sampling, algal/faunal association sampling, and qualitative shorewalk observations.

3.3.3 *Invertebrates (Algal-Faunal Association Study)*

The intertidal Algal-Faunal Association Study (AFAS) sampled 314 invertebrate taxa. Analysis results are presented for 100 taxa, organized by each alga sampled: *Endocladia muricata* and *Gastroclonium subarticulatum*. Twenty-nine taxa were common to both algae and were analyzed separately. Select individual species plots are presented in text for taxa displaying representative or unique abundance over time patterns. Individual species plots for taxa comprising the 99% abundance lists, for both algae, are presented in Appendix E. Although the Field's Cove algal scrape station was originally established as a control, data from temperature recorders showed that this location is potentially contacted by the thermal discharge, with a mean annual delta T of approximately 1°C at nearby (≈160 m) intertidal station FC-3 (Figure 2-10). Results presented in this section therefore should be viewed as underestimates of actual effects. Using this approach to determine discharge-related impacts, the BACI analysis is appropriate. Table 3-12 summarizes the effects of the DCPP discharge on intertidal invertebrates, as sampled by the AFAS. A narrative presentation of these results by alga follows. All statistical results presented represent changes within Diablo Cove between periods, relative to Field's Cove (Appendix G).

Table 3-12. Summary of discharge effects on invertebrates associated with two intertidal algal species from Algal-Faunal Association Study data.

Category	Habitat Alga: *Endocladia*	Habitat Alga: *Gastroclonium*	Notes
Total length of shoreline with observed effects	3.7 km	3.7 km	Shoreline distance of effects determined from HBT invertebrate results. Use of Field's Cove as comparison area (also contacted by thermal discharges), limited ability of analysis to delineate the extent of effects.
Changes in coverage of habitat algae in Diablo Cove relative to Field's Cove	63% decline at 0.9 m	Not detectable at 0.3 m	Changes determined by BACI analysis of HBT algae data.
Effects on overall numbers of taxa	decrease	unchanged	Refer to 'species richness' in BACI tables.
Number of taxa increases	7	17	Represents 42% of taxa analyzed for *Endocladia*, 25% for *Gastroclonium*.
Number of taxa decreases	16	23	Represents 42% of taxa analyzed for *Endocladia*, 25% for *Gastroclonium*.
Number of taxa unchanged	3	8	Represents 8% of taxa analyzed for *Endocladia*, 9% for *Gastroclonium*.
Number of taxa with inconclusive test results	12	43	Represents 32% of taxa analyzed for *Endocladia*, 47% for *Gastroclonium*.
Number of taxa analyzed statistically	38	91	Represents those taxa contributing to the 99% cumulative abundance. Represented 21% of taxa sampled for *Endocladia*, 30% for *Gastroclonium*.
Number of taxa sampled during study	177	302	314 taxa total after accounting for duplication between algae. 251 discrete species were categorized into 177 taxa for *Endocladia*, and 439 discrete species were categorized into 302 taxa for *Gastroclonium*.

Analysis of Species Changes - *Endocladia muricata* Assemblage

Thirty-eight taxa contributed to the top 99% cumulative abundance list for *Endocladia muricata*. Changes in invertebrate community composition and species abundance were evident at both Diablo Cove (Figure 3-36a) and Field's Cove (Figure 3-36b) though magnitudes of these changes were greater at Diablo Cove. Of the 38 taxa, 35 were analyzed using the BACI model, and the remaining three were analyzed using Fisher's exact test. Results of these analyses showed that 23 taxa changed significantly in Diablo Cove between periods, relative to Field's Cove: seven taxa increased and 16 taxa decreased. No significant changes were detected in the remaining 15 taxa.

Significant Increases

Significant relative increases between periods were detected for the molluscs *Littorina scutulata*, *Littorina keenae (= Littorina planaxis)*, *Lasaea cistula*, and *Mytilus* spp., and the isopod *Exosphaeroma inornata* and dipteran (kelp fly) larvae (Table 3-13). These taxa, except diptera larvae, all had absolute increases in abundance within Diablo Cove (e.g., *E. inornata*, Figure 3-37a) with no corresponding increases at station FC-AF. A significant increase between periods was also detected for the amphipod *Hyale californica* (Table 3-14). *H. californica* increased during the operation period at all stations but increases were larger at the Diablo Cove stations, resulting in a significant relative increase (Figure 3-37b). Increases in abundance of *H. californica* were not observed at FC-AF until 1990, almost six years after DCPP started commercial operation.

Significant Decreases

Significant relative decreases in abundance were detected between periods for nemertean worms (largely *Paranemertes peregrina* and *Amphiporus imparvispinosus*), seven mollusc, six crustacean, and two polychaete taxa (Table 3-13). Most of these taxa displayed absolute declines within Diablo Cove, with no decreases in abundance at FC-AF (for example, the amphipod *Oligochinus lighti*, Figure 3-37c). In contrast, the abundance of *Barleeia spp.* and *Tegula funebralis* (Figure 3-37d) increased at all stations between periods, with the largest increases occurring at FC-AF resulting in significant relative declines in Diablo Cove.

No Change

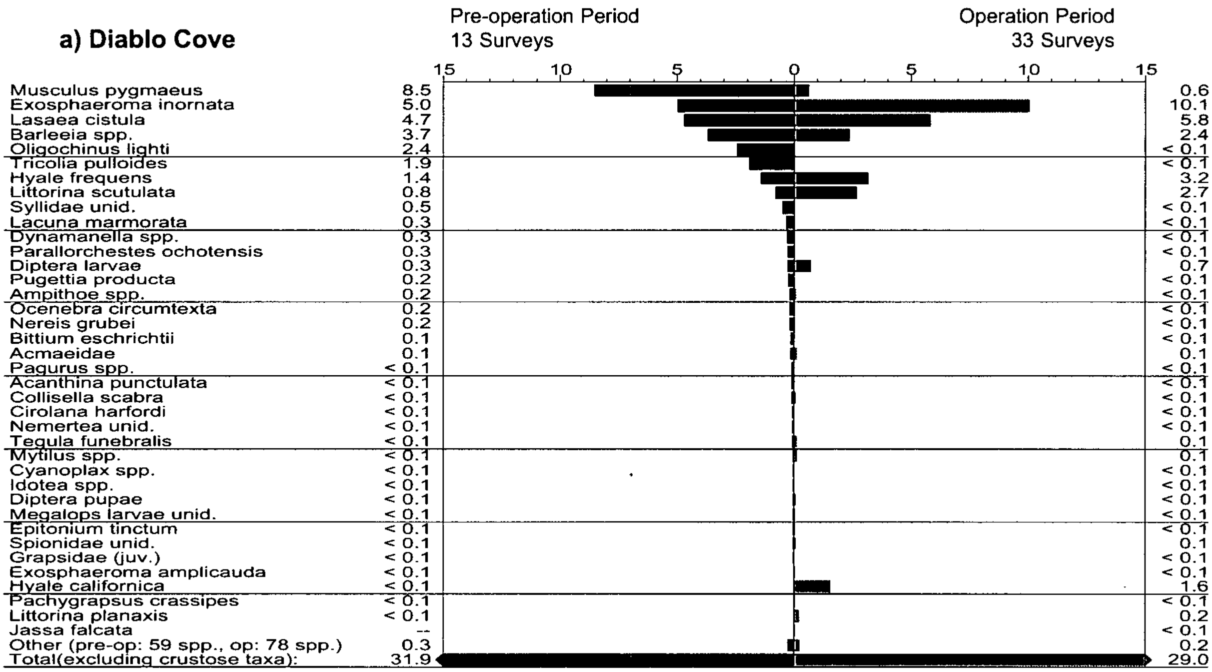
Test power was sufficiently high (> .70) to conclude that the discharge did not appear to affect juvenile Acmaeidae, *Macclintockia scabra (= Collisella scabra)*, and *Bittium eschrichtii* (Table 3-13).

Test Results Inconclusive

Ten taxa were tested with insufficient power (≤ .70) using the BACI analysis to conclusively detect any changes related to the discharge (Table 3-13). In addition, effects were not detectable in the crustaceans *Jassa falcata* and *Exosphaeroma amplicauda* as analyzed by the Fisher's exact test (Table 3-14).

Analysis of Community Changes - *Endocladia muricata* Assemblage

Community composition and individual species (taxa) abundance in Diablo Cove (Figure 3-36a) and Field's Cove (Figure 3-36b) changed between periods. Changes were greater in Diablo Cove, however, due largely to declines in *Oligochinus lighti* and the molluscs *Musculus pygmaeus* and *Tricolia pulloides*. Changes at FC-AF between periods were largely due to a smaller decline in *M. pygmaeus* and a large



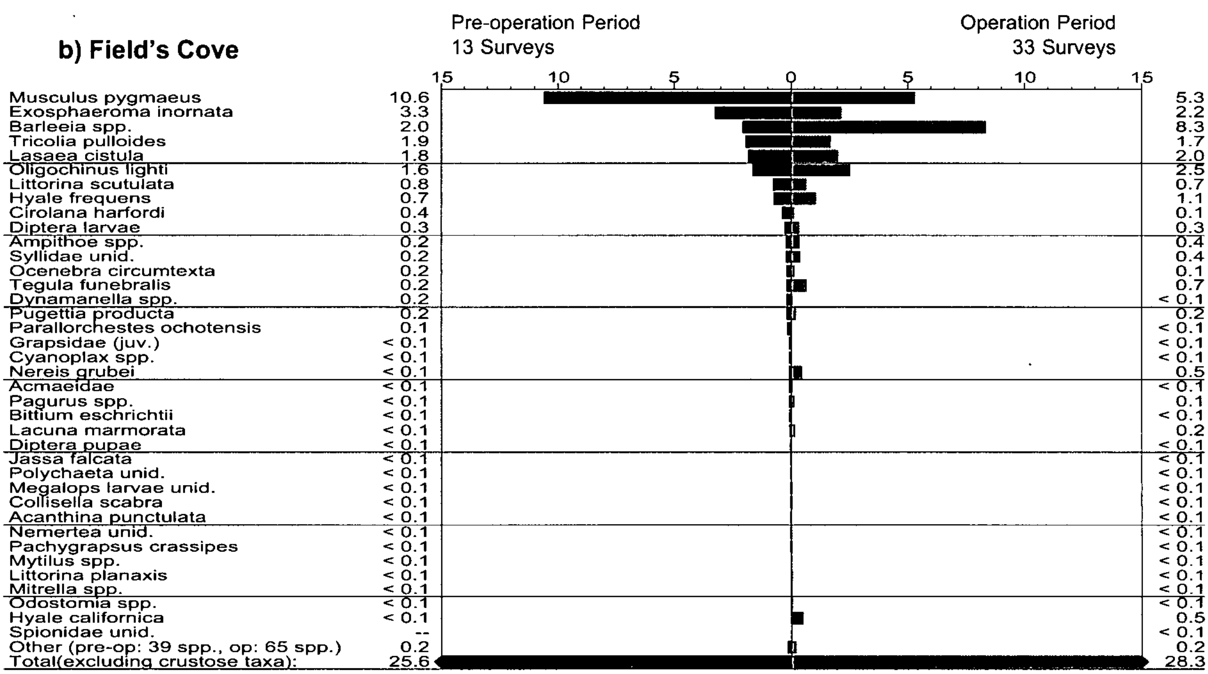


Figure 3-36. Pre-operation and operation invertebrate abundances from samples of *Endocladia muricata* from a) Diablo Cove stations (NDC-AF and SDC-AF) and b) the Field's Cove station (FC-AF). Values represent the grand mean number of individuals per gram dry weight of *Endocladia* habitat for each period.

increase in the abundance of the molluscs *Barleeia* spp.. Numbers of taxa in Diablo Cove declined (-17%) significantly (Table 3-13) between periods, relative to Field's Cove, as did the frequency of observed occurrences of taxa between periods (Table 3-15).

Table 3-13. Results of BACI ANOVA for *Endocladia* invertebrate assemblage from AFAS. Negative values indicate decreases between periods for individual stations. Statistically significant results (p<0.10) are in **bold** type.

Species Name	Relative % Change Between Periods	Period F-Value	Period P	Power to Detect 50% Change	Interaction Area*Period	Pairwise Comparison SDC-AF	Pairwise Comparison NDC-AF
Significant Increase							
Diptera larvae	+97	21.5	**<.01**	.98	**.02**	**.03**	**<.01**
Exosphaeroma inornata	+184	7.8	**.01**	.87	.37	**.01**	.13
Lasaea cistula	+20	4.3	**.05**	.84	**<.01**	-.72	**<.01**
Littorina planaxis	+1569	8.4	**.01**	.10	**.04**	.51	**<.01**
Littorina scutulata	+314	23.0	**<.01**	.43	**<.01**	**.01**	**<.01**
Mytilus spp.	+34	5.4	**.03**	.91	.28	**.02**	.38
Significant Decrease							
Acanthina punctulata	-85	23.4	**<.01**	1.00	.54	**-<.01**	**-<.01**
Ampithoe spp.	-60	6.1	**.02**	.51	**<.01**	**-<.01**	-.97
Barleeia spp.	-83	23.8	**<.01**	.48	.67	**-<.01**	**-<.01**
Dynamanella spp.	-84	3.3	**.08**	.71	**<.01**	**-<.01**	.14
Idotea spp.	-55	13.8	**<.01**	.95	.81	**-<.01**	**-.01**
Lacuna marmorata	-94	3.1	**.08**	.34	**.08**	-.65	**-.02**
Musculus pygmaeus	-87	29.4	**<.01**	.43	**<.01**	**-<.01**	**-<.01**
Nemertea unid.	-83	8.1	**.01**	.39	**<.01**	-.51	**-<.01**
Nereis grubei	-94	12.7	**<.01**	.31	**.05**	**-.02**	**-<.01**
Ocenebra circumtexta	-66	3.0	**.09**	.57	.31	**-.05**	-.23
Oligochinus lighti	-99	37.1	**<.01**	.54	.94	**-<.01**	**-<.01**
Pagurus spp.	-89	6.0	**.02**	.20	.53	**-.02**	**-.05**
Pugettia producta	-94	6.1	**.02**	.30	**.01**	-.39	**-<.01**
Syllidae unid.	-95	17.9	**<.01**	.46	.12	**-<.01**	**-<.01**
Tegula funebralis	-40	4.2	**.05**	.57	**.01**	-.74	**-<.01**
Tricolia pulloides	-99	4.7	**.04**	.61	.18	-.29	**-.01**
Species Richness	-17	3.4	**.07**	1.00	.33	-.21	**-.04**
No Change[1]							
Acmaeidae	+78	1.1	.30	.80	**.06**	**.06**	-.82
Bittium eschrichtii	-81	2.1	.16	1.00	**.01**	**-<.01**	.38
Collisella scabra	-46	0.1	.82	.81	.91	-.91	-.80
Test Results Inconclusive[2]							
Cirolana harfordi	+6	0.7	.42	.13	.29	-.21	-.90
Cyanoplax spp.	+12	0.2	.67	.27	.83	.63	.78
Dipteran pupae	+173	2.4	.13	.16	.49	**<.10**	.37
Epitonium tinctum	+5	0.0	.97	.36	.37	.59	-.56
Grapsidae (juv)	+1375	2.3	.14	.12	.22	.31	**.08**
Hyale frequens	+76	0.1	.70	.33	**.07**	-.59	.23
Brachyuran megalopae	-16	0.1	.74	.25	**<.01**	**-.06**	.19
Pachygrapsus crassipes	+179	0.5	.48	.13	.60	.74	.38
Parallorchestes ochotensis	-99	0.5	.49	.28	**<.01**	.14	**-.01**
Spionidae unid.	*no calc*[3]	0.3	.60	.11	.61	-.48	-.82

[1] no significant difference between Field's Cove and Diablo Cove period means, and power of the test to detect a 50% change between periods was greater than .70.

[2] no significant difference between Field's Cove and Diablo Cove period means, and power of the test to detect a 50% change between periods was less than .70.

[3] percent change could not be calculated because mean control abundance was zero during one or both periods.

Results for the second axis largely represent variation between the two Diablo Cove stations during the operation period, although the survey score for 1993 for Station NDC-AF does not match the pattern of the other scores (Figure 3-38a). Pre-operational survey scores (1980-1982) for the two stations show less

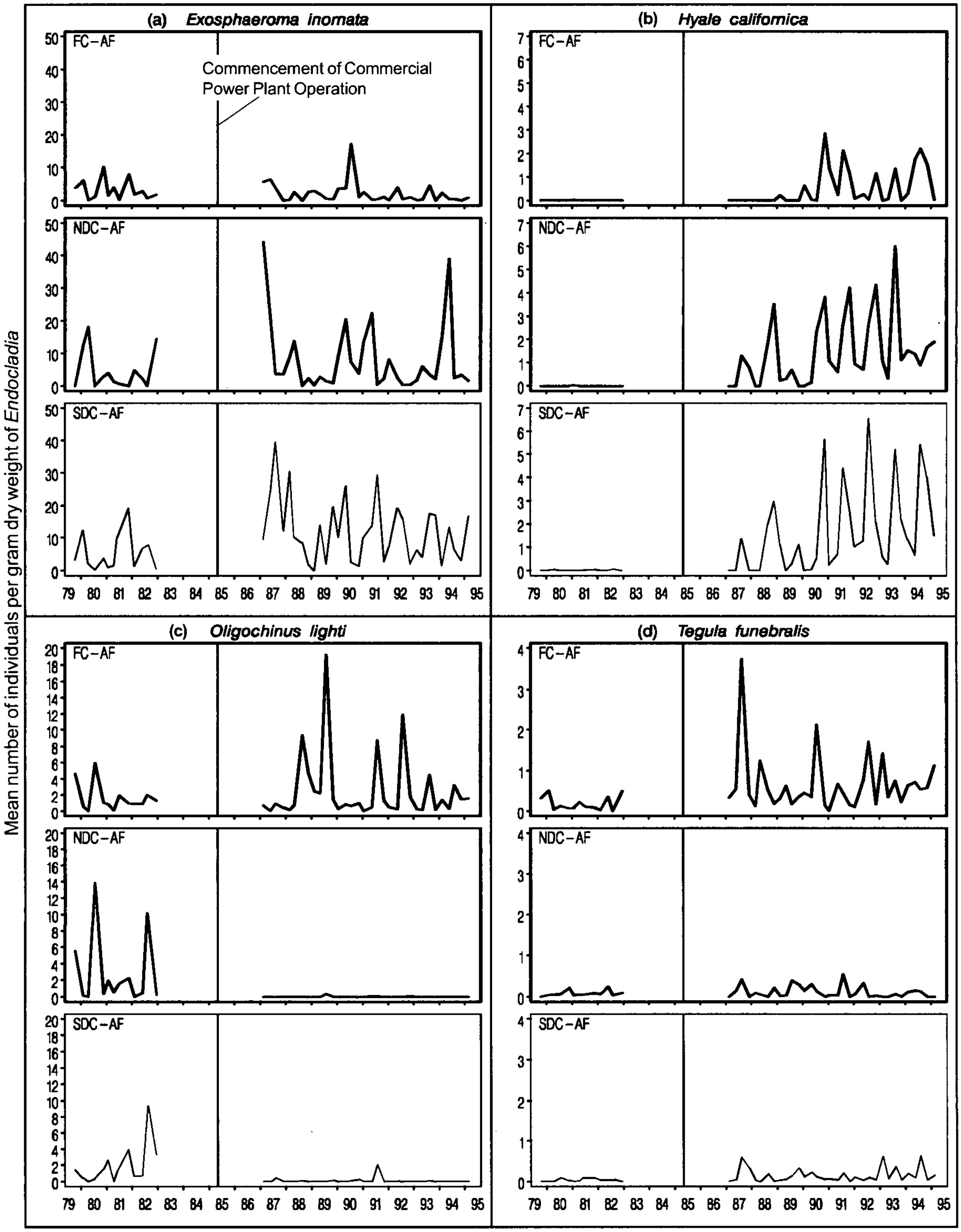


Figure 3-37. Abundance versus time for select invertebrates from *Endocladia muricata* samples. (a) *Exosphaeroma inornata*, (b) *Hyale californica*, (c) *Oligochinus lighti*, and (d) *Tegula funebralis*. Note that Y-axes abundance units differ between species.

variation than scores for the operational period (1987-1994). Unlike survey scores for Field's Cove that are relatively closely clustered along the second axis, plant operation appears to have increased variation at individual stations within Diablo Cove and accentuated the differences between those stations. The increased variation at Station NDC-AF would explain the low survey score for 1993 at that station. Taxa scores show that differences between Diablo Cove stations within the operation period were due to relatively large increases in the abundance of *L. cistula* and *L. scutulata* at SDC-AF, and relatively larger increases in the abundance of *H. frequens* at NDC-AF (Figure 3-38b). A decrease in the abundance of *H. frequens* in 1993 at NDC-AF (Appendix E) resulted in the low survey score for 1993 (Figure 3-38a).

Table 3-14. Results of Fisher's exact test for AFAS intertidal invertebrate taxa not tested in BACI analyses. Statistically significant results (p<.10) are in **bold** type.

Assemblage	Taxon	Diablo Cove P
Endocladia muricata		
Significant Increase		
	Hyale californica	**<.01**
Test Results Inconclusive		
	Exosphaeroma amplicauda	1.00
	Jassa falcata	.48
Gastroclonium subarticulatum		
Significant Increase		
	Elasmopus antennatus	**.05**
	Hiatella arctica	**<.01**
	Jassa falcata	**<.01**
	Leptochelia dubis	**.02**
	Ophiactis simplex	**<.01**
	Strongylocentrotus spp.	**<.05**
Test Results Inconclusive		
	Caprellidea unid.	1.00
	Cirolana harfordi	.51
	Cooperella subdiaphiana	.30
	Hyale californica	.40
	Jearopsidae unid.	1.00
	Kellia laperousa	.19
	Naineris dendritica	1.00
	Ophiuroidea unid.	1.00
	Porcellanidae unid.	1.00
	Tricolia pulloides	.51

Results for the third axis are presented along with first axis results to maintain the groupings of pre-operational and operational scores represented on the first axis (Figure 3-39a). Plotting the results against the first axis helps to clarify the pattern represented by the third axis that contrasts variation between periods for Station FC-AF. All pre-operational survey scores (1980-1982) in the cluster of scores representing reference or pre-operational conditions are negative, and all survey scores for the operational period at FC-AF are positive. These results corroborate temperature data from Field's Cove that indicate that Station FC-AF was impacted by the discharge. Taxa scores show less clear separation on the third axis than was seen in results for the first and second axis (Figure 3-39b). This may indicate that community changes at FC-AF during operation have involved smaller relative shifts in taxa composition rather than large changes in abundance of several taxa.

Analysis of Species Changes - *Gastroclonium subarticulatum* Assemblage

Ninety-one taxa contributed to the top 99% cumulative abundance list for *Gastroclonium subarticulatum*. As in *Endocladia*, changes in invertebrate community composition and individual species abundances between periods were evident at both Diablo Cove (Figure 3-40) and Field's Cove (Figure 3-41), with the magnitudes of these changes being greater in Diablo Cove. Of the 91 taxa, 75 were analyzed using the BACI model, and the remaining 16 taxa were analyzed using Fisher's exact test (Tables 3-16 and 3-14). Results of these analyses showed that 40 taxa changed significantly between periods, relative to Field's Cove: 17 taxa increased and 23 taxa decreased. The analyses did not detect changes in 18 taxa, and test results were inconclusive for the remaining 33 taxa.

Table 3-15. Results of Fisher's exact test for AFAS invertebrates. Data were number of species changes within *Endocladia* algae between pre-operation and operation periods. Statistically significant results ($p<0.10$) are in **bold** type.

Endocladia invertebrates		
	Decreases	Increases
Diablo Cove	50	47
Field's Cove	35	62
	p = **0.04**	

Significant Increases

Significant relative increases between periods were detected for unidentified anemones, the sipunculid worm *Phascolosoma agassizii*, the polychaete worm *Phragmatopoma californica*, six mollusc taxa, five crustacean taxa, and three echinoderm taxa within *Gastroclonium* using the BACI model or Fisher's exact test (Tables 3-14 and 3-16). *P. californica* (Figure 3-42a) and *Lasaea cistula* (bivalve mollusc) did not occur in large numbers during the early years of the operation period, but both taxa showed large abundance increases beginning in 1990 (Appendix E). Absolute abundances of the isopod *Exosphaeroma octoncum*, although low in both periods, showed a large relative percent increase (Table 3-16). Increases for *Ophiactis simplex* (brittlestar), *P. agassizii*, and *Odostomia* spp. (gastropod) were also not evident until well after power plant start-up, generally beginning within the period 1990-92. The amphipod crustacean *Jassa falcata* (Figure 3-42b) increased at all sampled stations through time, though increases were much larger at Diablo Cove stations.

Significant Decreases

Significant relative decreases between periods were detected for twelve mollusc, five crustacean, three echinoderm, and three polychaete taxa in Diablo Cove (Table 3-16). Most of these taxa declined in abundance at Diablo Cove stations, while remaining generally unchanged at FC-AF (Appendix E). In contrast, the gammarids *Aoroides columbiae* (Figure 3-42c) and *Ampithoe* spp. (largely *A. pollex*) both declined (-93% and -41% declines, respectively, [Table 3-16]) at Diablo Cove stations, while the Field's Cove population increased. The polychaete *Nereis grubei* (Figure 3-42d), and the gastropods *Tegula funebralis* and *Alia* spp. (mostly *A. carinata [= Mitrella carinata]*) increased in abundance within Diablo Cove, but increased to a greater extent at Field's Cove, resulting in relative declines.

No Changes

Eight taxa that showed no significant abundance changes between periods were tested with sufficient power (>.70) to conclude that they were unaffected by the discharge (Table 3-16).

Test Results Inconclusive

The analysis was unable to detect changes in the remaining 43 taxa using the BACI analysis or Fisher's exact test (Tables 3-14 and 3-16).

Analysis of Community Changes - *Gastroclonium subarticulatum* Assemblage

Similar invertebrate communities existed within *Gastroclonium* during the pre-operation period in Diablo Cove and Field's Cove. Gastropods (*Tricolia pulloides, Bittium eschrichtii, Alia* spp. [= *Mitrella* spp.]) and juvenile hermit crabs (*Pagurus* spp.) were common in all areas prior to plant operation. Community composition changed between periods at both Diablo Cove (Figure 3-40) and Field's Cove (Figure 3-41) stations. Neither species richness ($p=0.11$, Table 3-16) nor the proportion of frequencies of taxa increases and decreases (Table 3-17) changed significantly between periods.

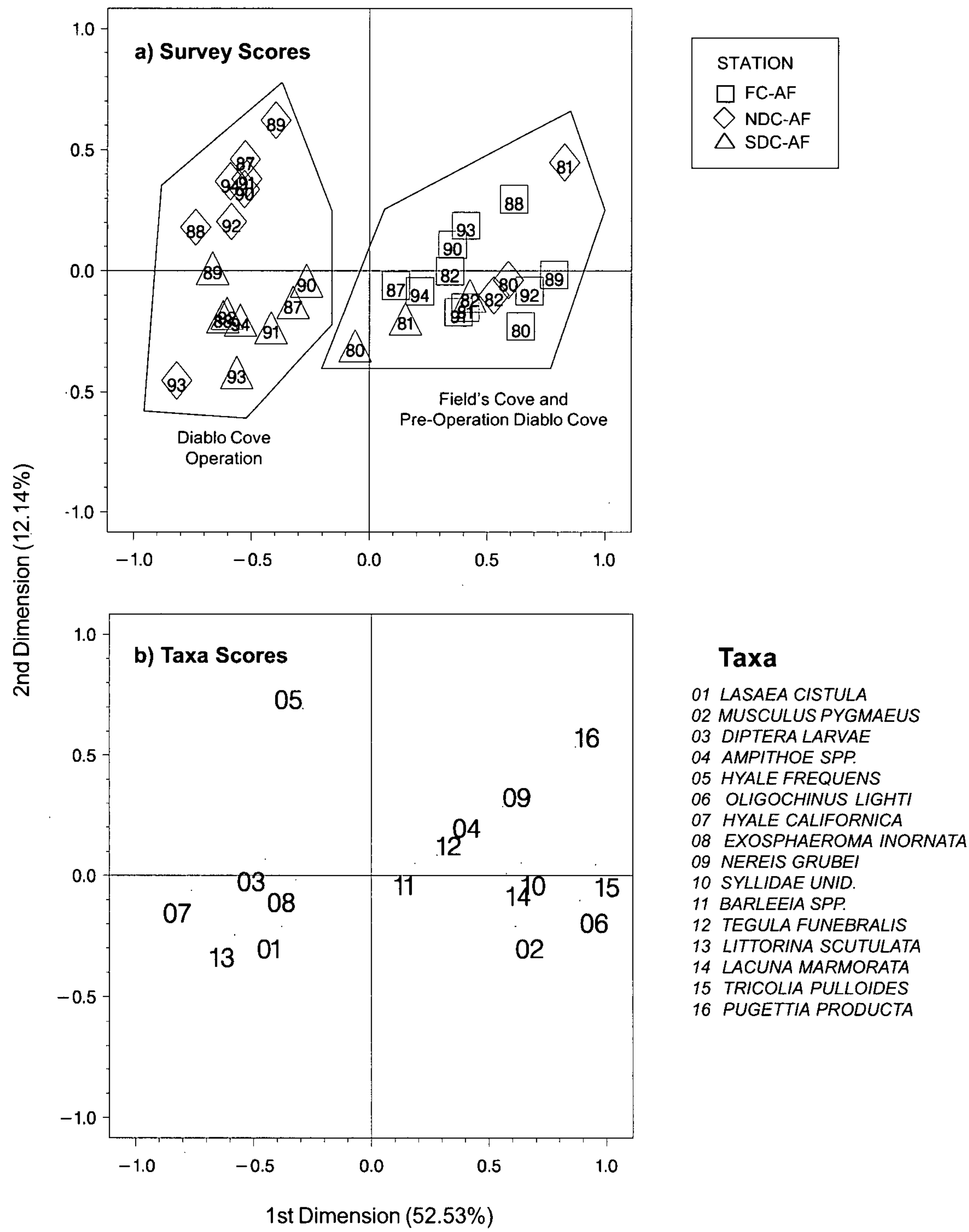


Figure 3-38. First and second dimension scores from correspondence analysis of invertebrate data obtained from *Endocladia muricata* habitat. (a) Annual survey scores. (b) Taxa scores. Numbers inside of symbols are years. Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Percentages in parentheses denote amount of variation explained by corresponding dimension.

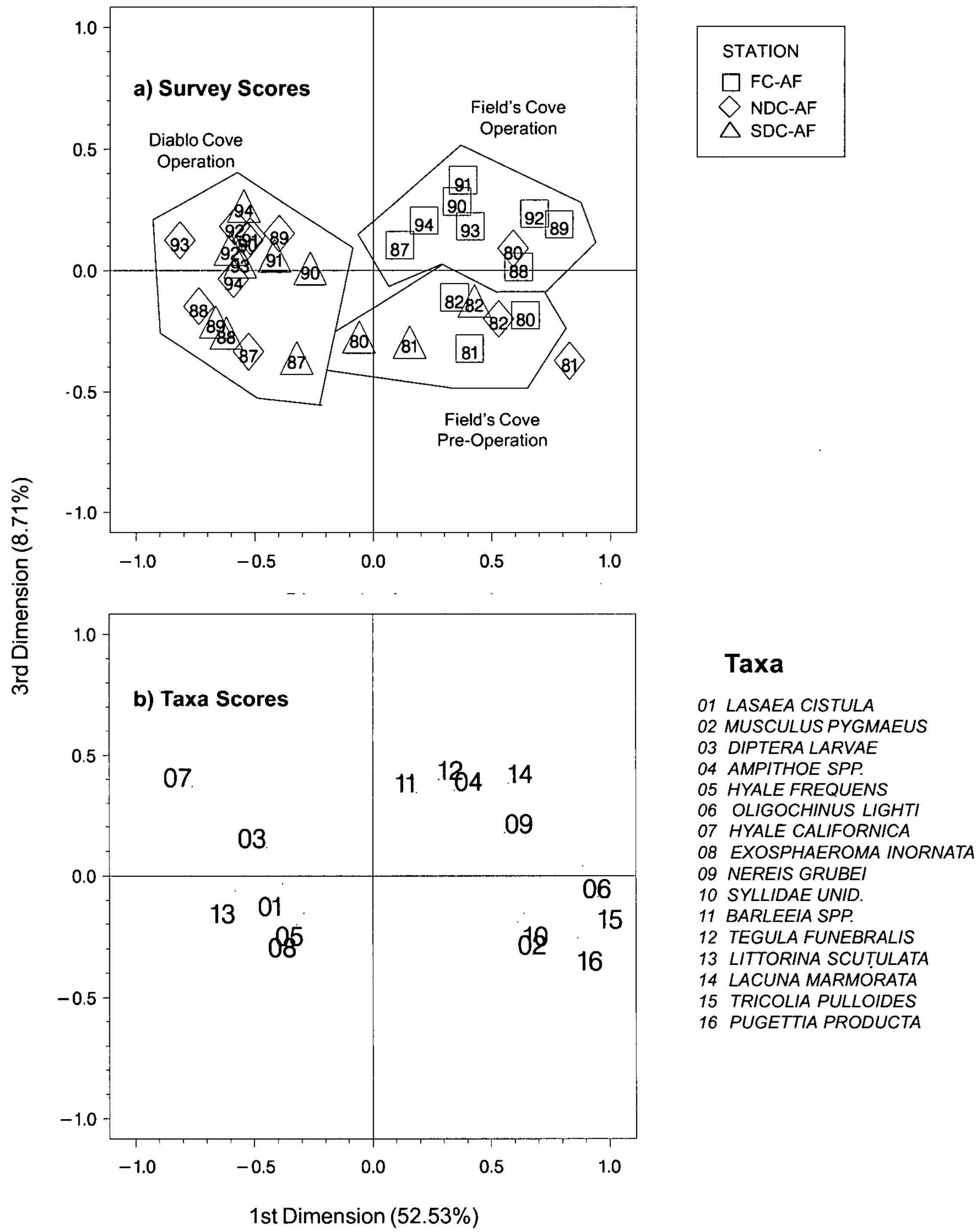


Figure 3-39. First and third dimension scores from correspondence analysis of invertebrate data obtained from *Endocladia muricata* habitat. (a) Annual survey scores. (b) Taxa scores. Numbers inside of symbols are years. Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Percentages in parentheses denote amount of variation explained by corresponding dimension.

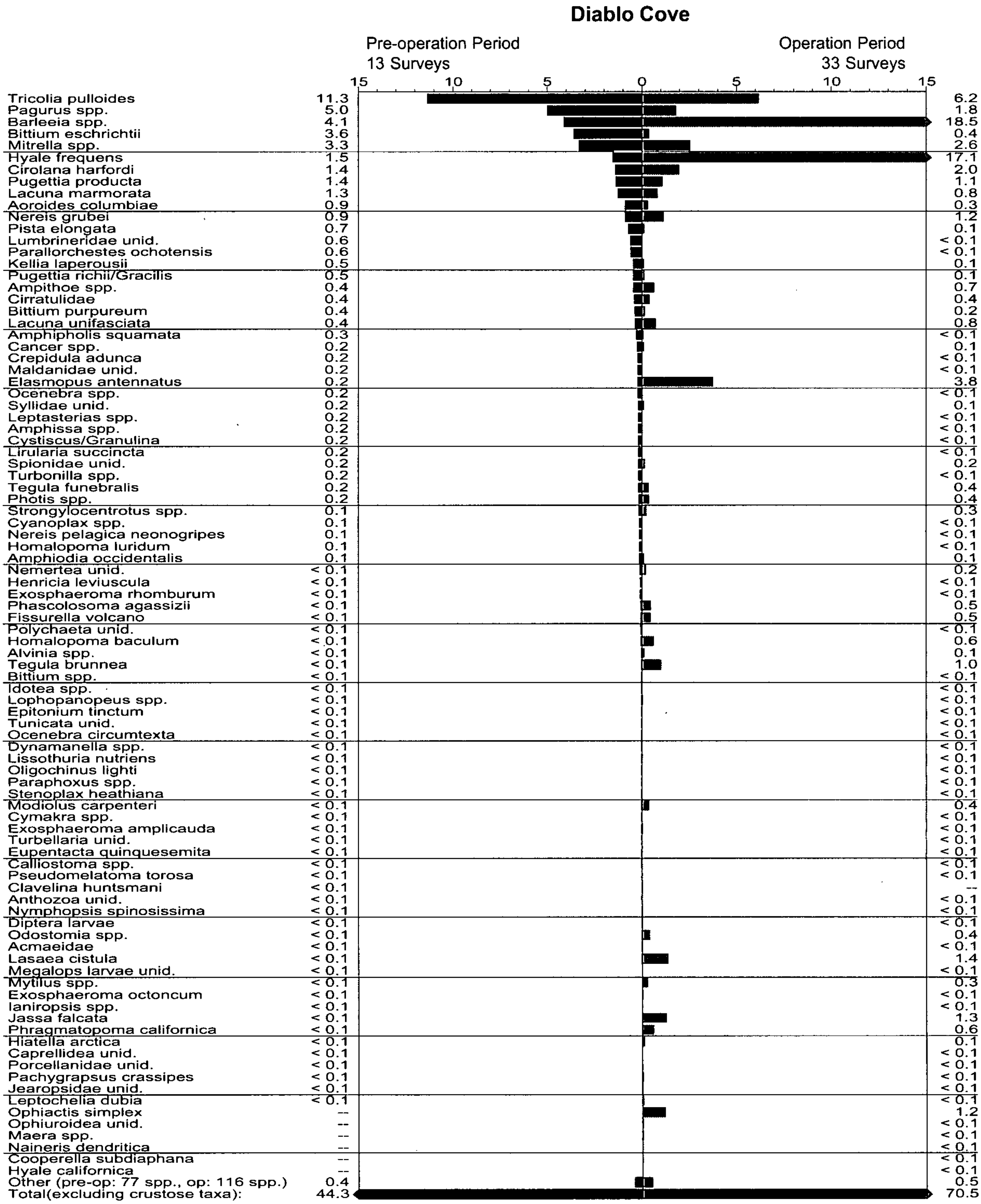


Figure 3-40. Pre-operation and operation invertebrate abundances from samples of *Gastroclonium subarticulatum* from Diablo Cove stations (NDC-AF and SDC-AF). Values represent the grand mean number of individuals per gram dry weight of *Gastroclonium* habitat for each period.

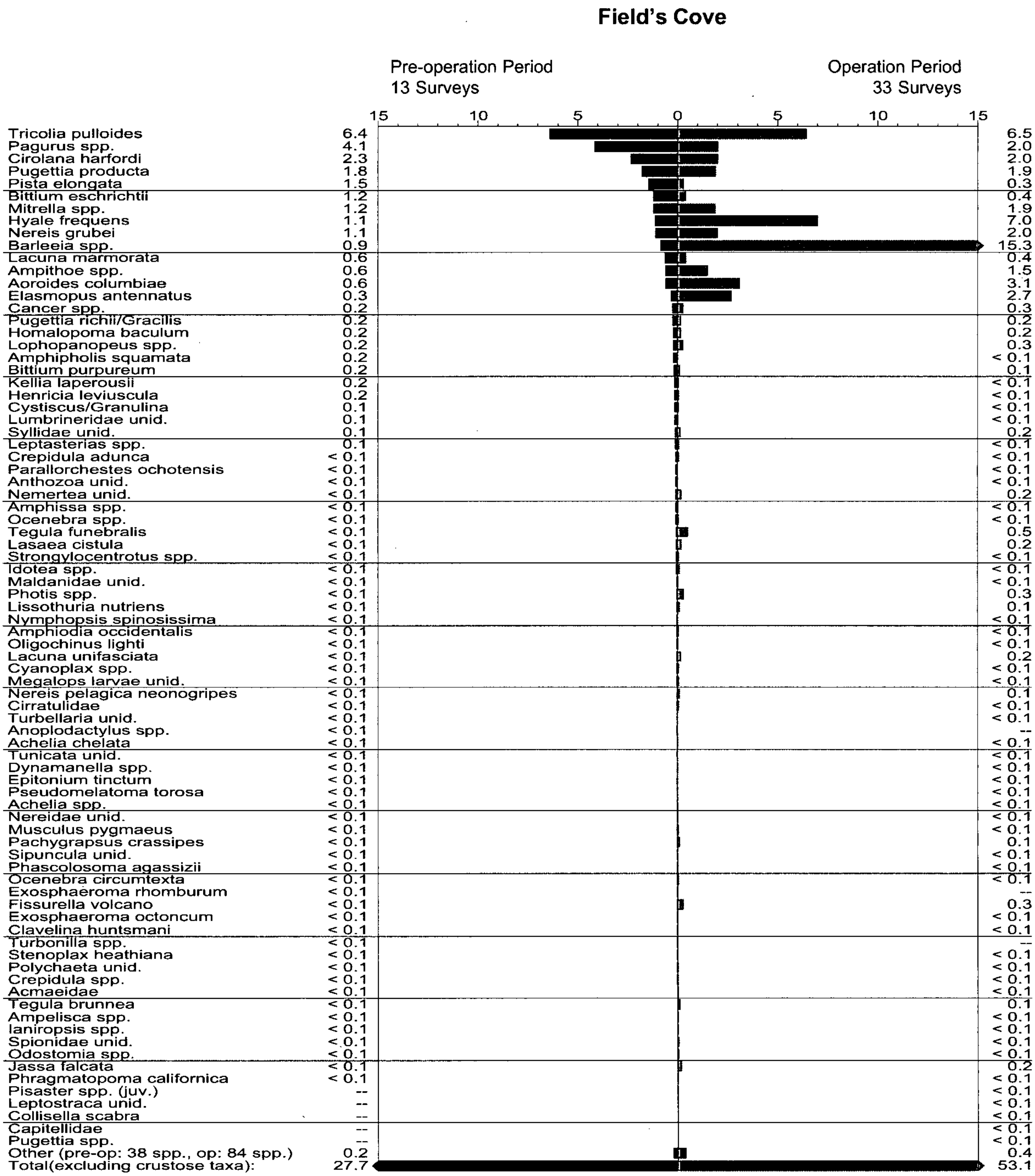


Figure 3-41. Pre-operation and operation invertebrate abundances from samples of *Gastroclonium subarticulatum* from the Field's Cove station (FC-AF). Values represent the grand mean number of individuals per gram dry weight of *Gastroclonium* habitat for each period.

Table 3-16. Results of BACI ANOVA for *Gastroclonium* invertebrate assemblage in AFAS. Negative values indicate decreases between periods for stations. Statistically significant results (p<0.10) are in **bold** type.

Taxon	% Change Between Periods Relative to Field's Cove	Period F-Value	Period P	Power to Detect 50% Change	Interaction Area*Period	Pairwise Comparison SDC-AF	Pairwise Comparison NDC-AF
Significant Increase							
Amphipholis squamata	+262	2.9	**.09**	.82	.14	.46	**.03**
Anthozoa unid.	+286	8.9	**.01**	.15	.71	**.01**	**.01**
Exosphaeroma octoncum	+4137	13.6	**<.01**	.11	.35	**<.01**	**.03**
Exosphaeroma rhomburum	*no calc*[1]	9.6	**<.01**	.62	**<.01**	.10	**-<.01**
Lasaea cistula	+6295	16.4	**<.01**	.12	.94	**<.01**	**<.01**
Modiolus carpenteri	*no calc*	20.7	**<.01**	.19	**.08**	**<.01**	**<.01**
Mytilus spp.	*no calc*	26.1	**<.01**	.10	.31	**<.01**	**<.01**
Odostomia spp.	+74	4.7	**.04**	.13	.94	**.06**	**.05**
Phascolosoma agassizii	+217	8.2	**.01**	.36	.78	**.04**	**.02**
Phragmatopoma californica	+2702	11.3	**<.01**	.10	.75	**.01**	**<.01**
Tegula brunnea	*no calc*	5.6	**.02**	.16	**.02**	**<.01**	.28
Significant Decrease							
Alia spp.	-51	4.4	**.04**	.84	.99	-.13	-.14
Ampithoe spp.	-41	5.7	**.02**	.56	.79	-.10	**-.05**
Aoroides columbiae	-93	33.2	**<.01**	.28	.79	**-<.01**	**-<.01**
Bittium eschrichtii	-70	23.3	**<.01**	.93	**.01**	**-.01**	**-<.01**
Calliostoma spp.	-100	3.4	**.07**	.64	.80	-.20	-.12
Crepidula adunca	-84	16.8	**<.01**	.86	**<.01**	**-<.01**	**-.02**
Cyanoplax spp.	-83	11.3	**<.01**	.78	.39	**-<.01**	**-.01**
Cymakra spp.	*no calc*	3.8	**.06**	.83	.96	-.11	**-<.10**
Cystiscus/Granulina spp.	-99	7.6	**<.01**	.77	**.01**	**-<.01**	**-<.10**
Eupentacta quinquesemita	-83	3.4	**.07**	.37	**<.01**	-.76	**-<.01**
Homalopoma luridum	-100	13.4	**<.01**	.99	.44	**-.03**	**-<.01**
Leptasterias spp.	-99	11.0	**<.01**	.66	**<.01**	**-<.01**	-.89
Lirularia succincta	*no calc*	15.2	**<.01**	.99	**.02**	-.18	**-<.01**
Lissothuria nutriens	-38	2.9	**<.10**	.20	.78	-.19	-.11
Lumbrineridae unid.	-96	6.6	**.01**	.38	.17	**-.09**	**-.01**
Maldanidae unid.	-93	26.8	**<.01**	.99	.23	**-<.01**	**-<.01**
Nereis grubei	-24	5.0	**.03**	1.00	**.02**	-.83	**-<.01**
Ocenebra spp.	-76	25.4	**<.01**	.96	**.05**	**-<.01**	**-<.01**
Parallorchestes ochotensis	-97	29.7	**<.01**	.90	**<.01**	**-<.01**	**-.02**
Paraphoxus spp.	-96	7.6	**.01**	.57	.27	**-.03**	**-.01**
Pugettia richii	-56	10.8	**<.01**	1.00	**.05**	-.18	**-<.01**
Tegula funebralis	-70.0	7.5	**.01**	.33	.76	**-.03**	**-.01**
Turbonilla spp.	*no calc*	25.6	**<.01**	1.00	.22	**-<.01**	**-<.01**
No Change[2]							
Amphissa spp.	-9.0	1.1	.31	.77	.16	-.12	-.78
Barleeia spp.	-74.0	0.2	.65	.99	**.01**	-.23	**.05**
Cancer spp.	-59.0	1.4	.24	.72	.60	-.20	-.46
Epitonium tinctum	+667	0.1	.79	.90	**.07**	.34	-.17
Lacuna marmorata	-4.0	0.1	.81	.76	.43	-.51	.79
Pagurus spp.	-24.0	2.4	.13	1.00	**.01**	**-.01**	.94
Pugettia producta	-29.0	1.0	.32	.99	.71	-.52	-.30
Tunicata unid.	-49.0	2.3	.14	.84	.12	-.66	**-.04**
Species Richness	-6.0	2.7	.11	1.00	.24	-.36	**-.05**

(table continued)

Table 3-16 (continued). Results of BACI ANOVA for *Gastroclonium* invertebrate assemblage.

Taxon	% Change Between Periods	Period F-Value	Period P	Power to Detect 50% Change	Interaction Area*Period	Pairwise Comparison SDC-AF	Pairwise Comparison NDC-AF
Test Results Inconclusive[3]							
Acmaeidae	-10.0	0.0	.93	.12	.59	.75	-.88
Alvinia spp.	+2	0.7	.39	.49	**<.01**	**.01**	-.22
Amphiodia occidentalis	-35.0	1.2	.28	.39	.51	-.51	-.21
Bittium purpureum	-29.0	0.1	.80	.50	**<.01**	**-.01**	**.03**
Bittium spp.	*no calc*	0.6	.44	*no calc*	.11	-.56	**<.10**
Cirratulidae	-60.0	0.1	.72	.32	.68	-.64	-.83
Clavelina huntsmani	*no calc*	0.0	.90	.11	**.03**	-.50	.66
Diptera larvae	-15.0	0.1	.73	.21	.32	-.40	.80
Dynamanella spp.	-13.0	0.0	.91	.43	.53	.78	-.65
Exosphaeroma amplicauda	+91	0.2	.67	.14	.88	.81	.67
Fissurella volcano	-57.0	1.5	.23	.29	.13	**-.08**	-.77
Henricia leviuscula	-84.0	0.0	.89	.31	**.02**	.44	-.61
Homalopoma baculum	+1147	0.3	.58	.13	.80	.54	.70
Hyale frequens	+104	2.7	.11	.67	.61	.19	**.09**
Ianiropsis spp.	0	0.1	.75	.10	.33	-.95	.51
Idotea spp.	-65.0	1.3	.27	.18	.80	-.26	-.35
Lacuna unifasciata	-72.0	2.5	.12	.35	**.07**	**.02**	.83
Lophopanopeus spp.	+53	0.1	.73	.30	.86	.82	.70
Megalops larvae	+68	0.0	.86	.13	.48	.85	-.62
Nemertea unid.	-1.0	0.0	.84	.31	.21	-.64	.42
Nereis pelagica neonigripes	-68.0	0.3	.57	.18	.14	-.23	-.83
Nymphopsis spinosissimma	-24.0	2.3	.13	.19	.78	.18	.13
Ocenebra circumtexta	-69.0	2.2	.15	.24	.32	**-.08**	-.46
Oligochinus lighti	-49.0	0.8	.36	.18	.91	-.40	-.46
Pachygrapsus crassipes	+604	0.0	.98	.10	.68	.83	-.86
Photis spp.	-62.0	2.7	.11	.37	.58	-.25	**-.09**
Pista elongata	-15.0	2.0	.16	.43	.32	**.09**	.44
Polychaeta unid.	-76.0	1.0	.33	.13	**.06**	.93	**-.08**
Pseudomelatoma torosa	-80.0	0.4	.55	.40	**<.01**	**-.03**	.23
Spionidae unid.	-95.0	1.1	.29	.23	.54	-.23	-.45
Stenoplax heathiana	-68.0	1.6	.21	.24	.69	-.35	-.20
Syllidae unid.	-49.0	2.6	.11	.63	.12	**-.03**	-.70
Turbellaria unid.	-18.0	1.1	.31	.11	.12	.84	.11

[1] percent change could not be calculated because mean control abundance was zero during one or both periods.
[2] no significant difference between Field's Cove and Diablo Cove period means, and power of the test to detect a 50% change between periods was greater than .70.
[3] no significant difference between Field's Cove and Diablo Cove period means, and power of the test to detect a 50% change between periods was less than .70.

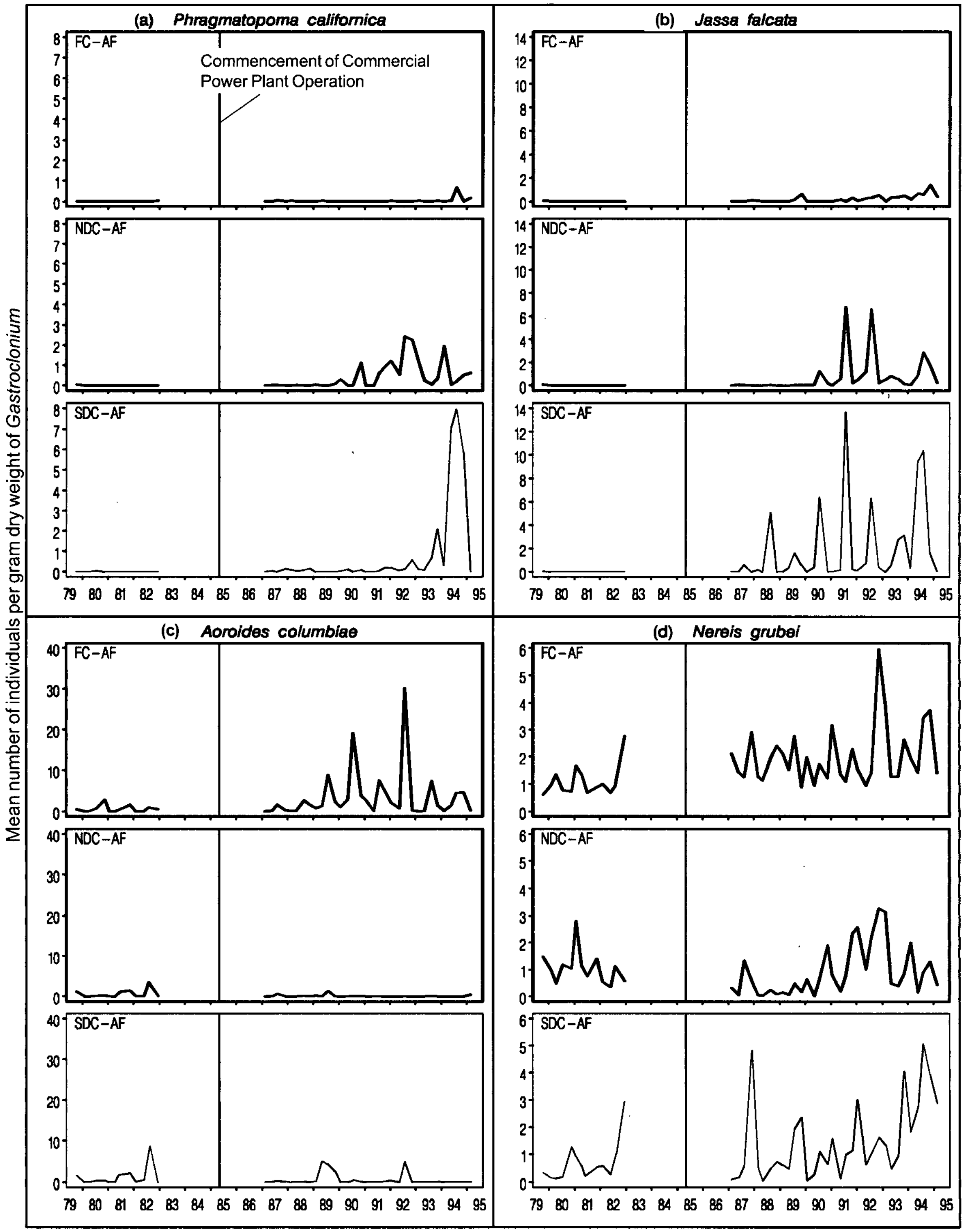


Figure 3-42. Abundance versus time for select invertebrates from *Gastroclonium subarticulatum* samples. (a) *Phragmatopoma californica*, (b) *Jassa falcata*, (c) *Aoroides columbiae*, and (d) *Nereis grubei*. Note that Y-axes abundance units differ between species.

Results of correspondence analysis of annual means for 23 taxa are presented for the first two independent axes of variation that accounted for 39.2% and 15.6%, respectively, of the total variation within the data set (Figure 3-43a and b). The pattern of survey scores along the first axis indicates that the greatest amount of variation was due to operational period scores at Diablo Cove stations diverging from the clustered pre-operational period scores at Diablo Cove stations and Field's Cove during both periods (Figure 3-43a). Considering the range of scores, Station FC-AF generally shows less variation along the first axis than either of the Diablo Cove stations. Variation was greatest for Station NDC-AF. There is some overlap of survey scores between the Field's Cove station and Diablo Cove stations. Most of the overlap occurs among survey scores for early operational years within Diablo Cove and later operational years for Field's Cove. The overlap among survey scores corroborate temperature data from Field's Cove that indicate that Station FC-AF was impacted by the discharge. The overlap may also indicate that community changes in Field's Cove late in the study are similar to some of the changes that occurred in Diablo Cove earlier during the operational period. Taxa scores reveal that differences between periods were due primarily to increases in the abundance of the brittlestar *Ophiactis simplex*, the bivalve *Lasaea cistula*, the amphipod *Jassa falcata*, and the polychaete *Phragmatopoma californica*, and declines in the abundance of the polychaete *Pista elongata* and the gastropod *Bittium eschrichtii* (Figure 3-43b).

Table 3-17. Results of Fisher's exact test for AFAS invertebrates. Data were number of species changes within *Gastroclonium* algae between pre-operation and operation periods. Results were statistically significant if $p<0.10$.

Gastroclonium invertebrates	Decreases	Increases
Diablo Cove	77	92
Field's Cove	63	106
	$p = 0.15$	

The second dimension, accounting for over 15% of residual variation among survey scores separates pre-operational survey scores in Field's Cove from operational period scores, and operational period scores for Field's Cove from later operational period scores for the two Diablo Cove station (Figure 3-43a). This second independent pattern of variation shows a similar but contrasting pattern to the survey scores for the first axis, and also indicates power plant impacts on the Field's Cove community.

Supplementary Observations - Species Range Extensions

Potential range extensions were recorded for seven invertebrate species sampled in the AFAS (Table 3-18). The first five species listed are molluscs. *Odostomia oregonensis, Pycnogonum rickettsii* (sea spider), and *Musculus pygmaeus* are northern species, and the remaining four are considered southern species. Only two *P. rickettsii* were recorded in the AFAS, one during each period. *Norrisia norrisi* and *Odostomia* spp. were only sampled in the AFAS during the operation period. *Turbonilla kelseyi*, a southern species, was much more abundant within Diablo Cove AFAS samples during the pre-operation period versus the operation period (Table 3-18). The southern distribution of this species indicates a warm water preference, and suggests that factors other than temperature were primarily responsible for its decline in Diablo Cove. *Musculus pygmaeus* is a narrowly distributed bivalve that was a numerically important component of intertidal *Endocladia* during the pre-operation period at all stations. Based on the reported range of this taxon (Monterey Bay south to Cayucos, San Luis Obispo County), it appears that warm water temperatures within Diablo Cove, and potentially within Field's Cove, may be unsuitable for continued survivorship. *Ophiactis simplex* has flourished in Diablo Cove during the operation period, and was the most abundant brittle star sampled in the AFAS. This taxon ranges from Santa

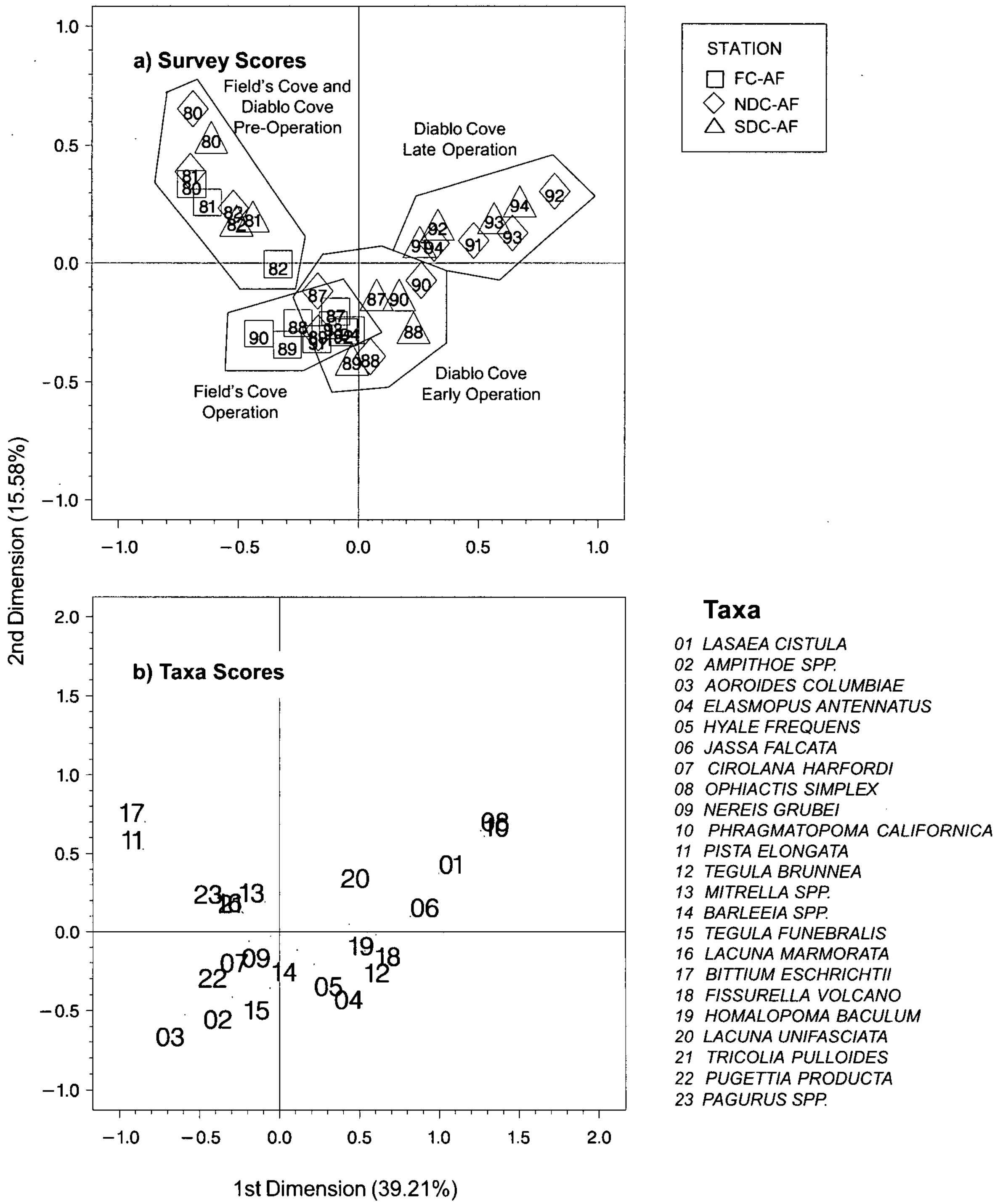


Figure 3-43. First and second dimension scores from correspondence analysis of invertebrate data obtained from *Gastroclonium coulteri* habitat. (a) Annual survey scores. (b) Taxa scores. Numbers inside of symbols are years. Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Percentages in parentheses denote amount of variation explained by corresponding dimension.

Cruz Island (Channel Islands) south to Panama and the Galapagos Islands (Morris et al. 1980). *O. simplex* reproduces both sexually via planktonic larvae and asexually through fragmentation and regeneration. Qualitative subtidal observations indicate that *O. simplex* may now be the most abundant brittle star in Diablo Cove.

Table 3-18. Potential range extensions for invertebrates sampled in the AFAS. Numbers in parentheses are individuals/survey. Pre-operation n=13 surveys, Operation n=33 surveys. References for reported ranges from Morris et al. (1980), McLean (1978) and Abbott (1974).

		Total # individuals in study			
		Diablo Cove		Field's Cove	
Species	Range	pre-op	op	pre-op	op
Norrisia norrisi	Point Conception to Baja Calif.	0	5	0	0
Odostomia eucosmia	Palos Verdes to Baja Calif.	0	11	0	8
Odostomia oregonensis	B.C. Canada to central Calif.	0	376	0	69
Turbonilla kelseyi	Santa Barbara to Baja Calif.	49 (3.8)	14 (0.4)	2	0
Musculus pygmaeus	Monterey to Cayucos	6874 (529)	1324 (40)	5030 (387)	7913 (240)
Ophiactis simplex	Santa Cruz Is. to Panama	0	1806	0	4
Pycnogonum rickettsii	Friday Harbor (WA) to Monterey	1	1	0	0

Spatial Extent of Effects

Results of temperature monitoring data and plume thermography have shown that the AFAS station located in Field's Cove was contacted by the discharge. Mean annual delta T°'s (water temperature difference from ambient) during the operation period were approximately +3°C at Diablo Cove intertidal stations, and +1°C at Field's Cove intertidal stations. In the AFAS BACI analysis this station was used as a reference station for computing deltas, but results were interpreted as probably representing a minimum estimate of effects. Results of community analyses also suggest discharge effects at the AFAS Field's Cove station. Observations on microinvertebrates associated with *Endocladia* and *Gastroclonium* were not conducted outside the study areas and therefore, the spatial extent of effects on these taxa were made using HBT invertebrate study results, intertidal temperature data (Section 2.2.3), and qualitative observations. Using these data, impacts to invertebrates extended a shoreline distance of approximately 3.7 km (2.3 mi) from Field's Cove to South Diablo Point (Figure 3-35). However, plume thermography (Figures 2-5 and 2-6), shows areas with reduced plume contact extending along a shoreline distance of approximately 3.0 km (1.8 mi). Effects in these areas were not known, but were likely to be less than effects in areas with reduced observed effects (Figure 3-35).

3.3.4 *Black Abalone*

Introduction

The following section presents results from black abalone studies designed to supplement horizontal band transect (HBT) surveys. The need for focused studies was due to the black abalone's status as a species of special concern because of its fishery value. The focused studies were also important for tracking changes in Diablo Cove black abalone with the appearance of withering syndrome (WS) disease beginning in 1988. Overall, the studies documented WS-related declines in Diablo Cove populations of black abalone and the spread of effects to areas adjacent to Diablo Cove. Information specific to black abalone from the HBT data set is summarized first, followed by data from the focused studies.

Horizontal Band Transect Surveys

Results of the BACI analysis of HBT data (Table 3-9) showed a significant decrease in black abalone in Diablo Cove between periods at the +0.3 m level, and no change at the +0.9 m level. Plots of abalone abundance through time at each HBT transect (Figure 3-44) show that, with the exceptions of NC-1 +0.9 m and NDC-3 +0.9 m, black abalone abundances on all TEMP stations declined prior to 1985. These reductions have been attributed to a combination of factors including predation by sea otters, human harvesting and mortality incurred during extreme storm conditions such as occurred during winter 1982-83 (PG&E 1988a). Black abalone abundances on the HBT stations remained relatively stable following 1982-83 until 1988 when WS was observed among black abalone in Diablo Cove. Reductions in abalone abundance due to WS disease were evident at NDC-3 +0.9 m in 1988 and at stations farther away from Diablo Cove after 1991 (e.g., Stations SDP-3, SH-1, and NC-3). Some black abalone recruitment was observed on Stations NDC-2 and NDC-3 after 1991 when the number of black abalone on the permanent stations was the lowest recorded since 1976.

Random Quadrat Surveys in Diablo Cove

Eighteen surveys were conducted in Diablo Cove from 1981 to 1995. The number of randomly sampled quadrats per survey varied from 1,159 to 1,571. The estimated total number of individuals in the Diablo Cove population ranged from 1,485 to 17,355 (Table 3-19). Prior to 1991, estimates of total number of black abalone in Diablo Cove generally included those individuals greater than about 2.5 cm shell length although in 1988 in south Diablo Cove, over 100 individuals with shell length smaller than 2.5 cm were found in the sampled quadrats. From 1991 through 1995, the estimates of total number of abalone were for all individuals with shell length greater than about 0.8 cm.

On occasion, some quadrats could not be accurately sampled or were not sampled during a survey due to excessive amounts of drift algae, foam or, due to a high degree of substratum irregularity, water. This affected subsequent population estimates. For example, transects NDC1 and SDC5 (Figure 3-4) were areas with good abalone habitat that were not sampled during the 1983 survey, and this likely resulted in an underestimate of Diablo Cove black abalone population in that year.

From 1988 to 1991, the abalone population in Diablo Cove declined by almost 90% (Figure 3-45). Recruitment of juvenile abalone resulted in an increase in estimated abalone densities during summer 1991 and began a pattern of summer increases followed by winter decreases which persisted from 1991 to 1994. In each of these years, recruitment events resulted in newly settled juvenile abalone in Diablo

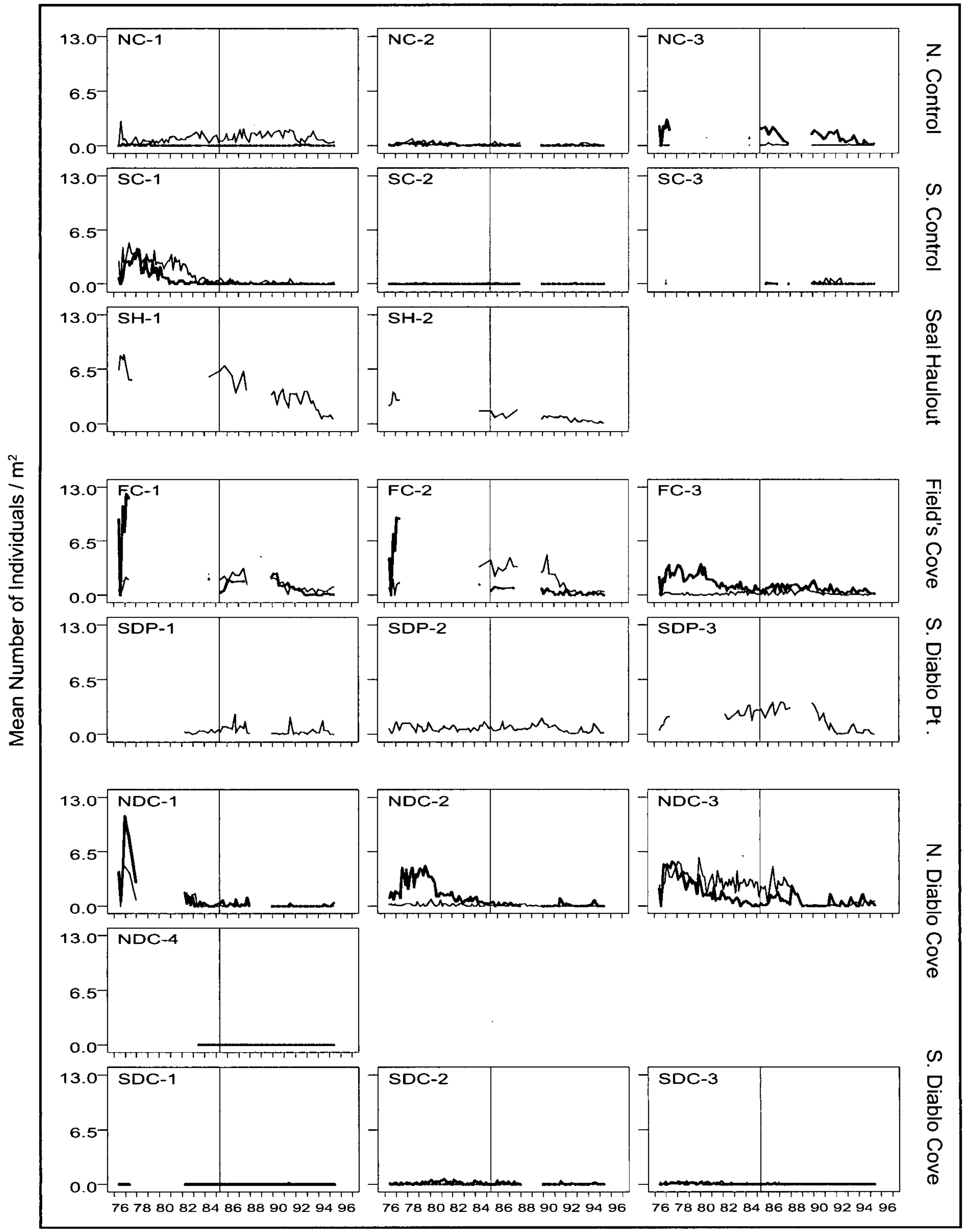


Figure 3-44. *Haliotis cracherodii*: changes in density at the horizontal band transects. Wide and thin lines represent +0.3 m and +0.9 m MLLW transect data, respectively.

Table 3-19. Mean number of abalone per m^2, number of quadrats sampled per transect, and Diablo Cove population estimates for Diablo Cove random surveys from 1981 to June 1995. Surveys from 1981-1985 extended throughout the spring and summer months of each year.

	Survey Month/Year																	
Transect	81	83	85	10/88	1/89	7/89	1/90	7/90	1/91	7/91	1/92	7/92	1/93	6/93	2/94	6/94	2/95	6/95
Number of quadrats sampled per transect																		
S1	190	181	153	172	167	174	158	138	159	156	168	170	166	161	172	171	166	180
S2	114	124	110	128	122	123	127	n/s	130	111	130	124	128	134	132	131	138	124
S3	182	199	125	205	201	195	195	n/s	195	186	195	n/s	195	205	195	202	204	198
S4	83	90	86	89	93	90	89	96	102	89	93	93	95	96	96	94	96	91
S5	82	n/s	86	79	87	81	74	89	93	77	86	90	90	88	90	90	82	88
N1	125	n/s	136	148	157	197	208	170	207	156	105	191	n/s	185	n/s	170	210	200
N2	184	190	227	225	234	224	228	228	228	230	228	231	231	223	232	231	230	224
N3	193	226	230	217	225	215	224	230	231	233	n/s	233	233	229	223	234	232	228
N4	151	154	157	153	161	156	157	158	161	170	158	158	161	157	160	159	160	160
N5	47	51	50	50	55	48	60	50	55	52	54	52	54	55	57	53	53	55
Total quadrats	1351	1215	1360	1466	1502	1503	1520	1159	1561	1460	1217	1342	1353	1533	1357	1535	1571	1548
Transect	**Mean number of abalone per m^2**																	
S1	.08	.01	.01	.00	.01	.00	.00	.00	.00	.04	.00	.02	.00	.00	.00	.01	.00	.00
S2	.25	.23	.25	.24	.14	.05	.01	n/s	.01	.09	.02	.02	.01	.07	.08	.11	.01	.02
S3	.21	.08	.08	.08	.02	.01	.02	n/s	.02	.02	.04	n/s	.00	.00	.00	.00	.01	.04
S4	2.27	.83	1.76	1.92	1.23	.68	1.38	.45	.48	.42	.74	.41	.12	.21	.04	.34	.10	.08
S5	.63	n/s	.85	3.00	1.72	1.59	1.58	.38	.40	1.74	.51	1.06	.47	.68	.13	.81	.24	.05
N1	.64	n/s	.19	.14	.00	.00	.00	.00	.00	.10	.00	.02	n/s	.03	n/s	.00	.04	.06
N2	1.19	.26	.78	.21	.09	.10	.03	.07	.03	.87	.17	.19	.07	.35	.21	.36	.40	.25
N3	1.01	.86	.83	.86	.36	.05	.03	.01	.03	.58	n/s	.33	.19	.90	.17	1.59	.60	.54
N4	.73	.30	.58	.15	.11	.01	.03	.01	.00	.11	.11	.22	.06	.44	.15	.30	.28	.09
N5	4.19	1.55	1.12	2.26	.07	.33	.18	.18	.00	1.15	.39	.27	.11	.82	.18	1.00	.42	.45
Mean density	1.12	.51	.64	.89	.37	.28	.33	.14	.10	.51	.22	.28	.11	.35	.11	.45	.21	.16
Total number sampled	1122	490	805	847	409	246	272	107	103	619	200	309	131	495	145	676	341	251
Diablo Cove Population Estimate	17355	7982	9985	13747	5803	4354	5045	2139	1485	7928	3409	4334	1767	5437	1634	7001	3265	2439

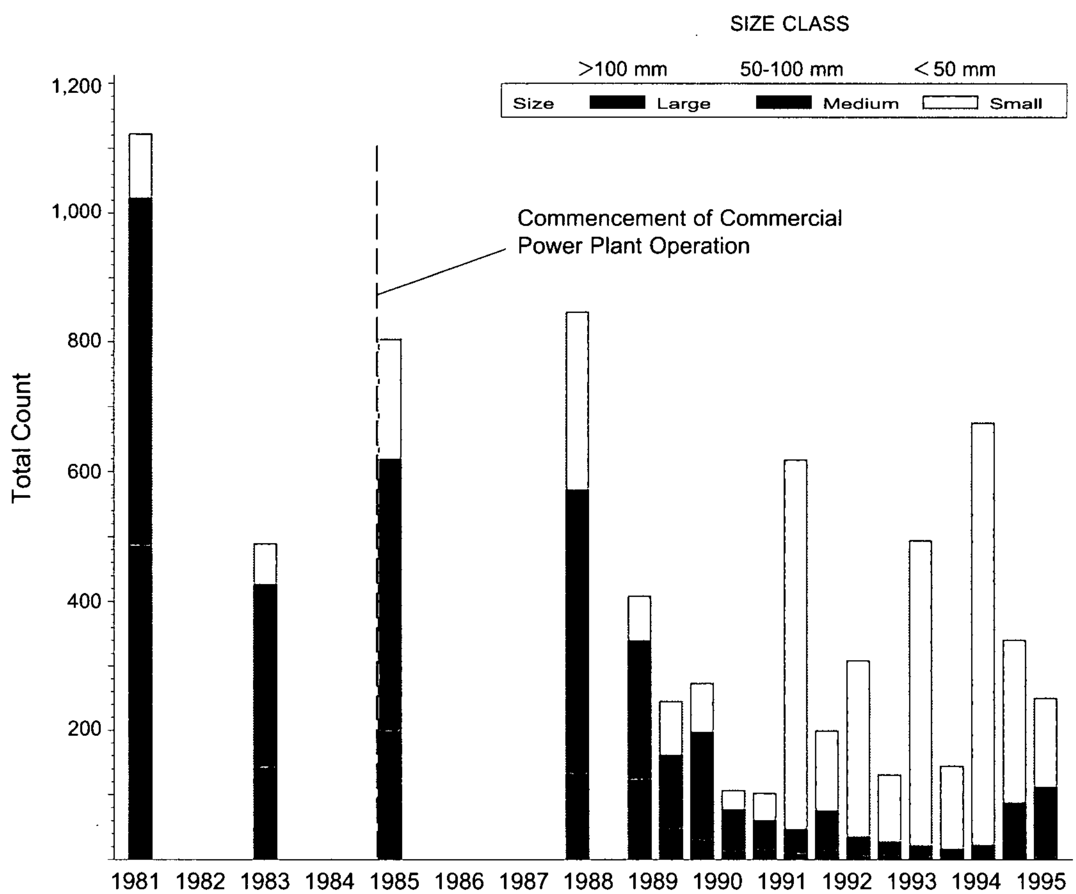


Figure 3-45. Black abalone, *Haliotis cracherodii*, total counts by size class in Diablo Cove from the random quadrat surveys.

Cove, followed by a decline in density estimates from the fall survey, due to the added effect of WS on the naturally high juvenile mortality rates. Increased WS mortality during the fall and early winter periods were also observed among black abalone in the southern California Channel Islands (Tissot 1991).

The combined effects of annual recruitment and presence of WS in the local population effectively changed the size distribution of black abalone in Diablo Cove. Prior to 1989, the distribution of sizes was weighted toward large and medium length individuals (Figure 3-45). Mortalities related to WS occurred among all size classes in the Diablo Cove population; and, from 1991 to 1994, very few of the medium-sized (75-100 mm) and large-sized individuals (>100 mm shell length) were found (Table 3-20). Large black abalone, which were still below the legal size of 127 mm when there was a sport and commercial fishery for them, have rarely been seen in Diablo Cove since 1993. Enough of the newly recruited juvenile abalone observed from 1991 to 1994 probably survived each year to produce small increases in the number of medium abalone recorded in the 1995 surveys.

10-meter Transects

The observation of a rapid decline in a population of over 100 abalone in north Diablo Cove in 1988 resulted in increased monitoring of similar assemblages at increasing distances from the cove. Black abalone generally declined from 1988 to 1995 in 10-meter transect surveys (Figure 3-46), but the dates of onset and rates of decline differed substantially among transects (Figure 3-46, Figure 3-47 and Data Appendix). Abalone density in those transects located inside Diablo Cove or adjacent to Diablo Cove (i.e., Postelsia Point, and Field's Cove) declined at a faster rate and declines began earlier than on transects farther away from Diablo Cove (i.e., Seal Haulout, North Control and Stillwater Cove).

The largest declines, as of June 1995, occurred in north Diablo Cove (100% reduction) beginning in 1988, and were followed by declines on transects in south Diablo Cove (88%) and Postelsia Point (86%) beginning in mid-1989 (Figure 3-47). The Postelsia Point station was located approximately 150 m (straight-line distance) from the north Diablo Cove station. The decline in abundance at Field's Cove, which began in 1990 and eventually resulted in a 59% reduction, occurred at a slower rate than declines observed in Diablo Cove and at Postelsia Point. Declines at the remaining three stations, which were from 2.2 km north of Diablo Cove (North Control - 73%) to 0.7 km south (Seal Haulout - 77% reduction) and 4.7 km south (Stillwater Cove - 57%, respectively), did not begin until mid-1991 and their rates of decline were slower than those observed on transects closer to Diablo Cove.

Qualitative Surveys and Observations

Abalone with symptoms of WS were first seen in Diablo Cove in 1988 and in areas outside Diablo Cove in subsequent years (Table 3-21). The extent of WS effects on black abalone extended from at least North Control to Stillwater Cove, a coastline length of 12.7 km (7.9 mi) (USGS 1:24,000) (Figure 3-35 [inset]). This information was compiled from qualitative shorewalk surveys and other observations, and represents a conservative estimate of the onset of WS in each area. In some cases, recent mortality from WS was suspected to have occurred in an area before these dates, by the discovery of clean unchipped shells, although direct evidence (alive or dead individuals with obvious foot reductions) was lacking. In areas where the incidence of WS among abalone was high, such as in north Diablo Cove, Postelsia Point and Field's Cove, empty shells were abundant and individuals with WS were common.

Table 3-20. Abundance of black abalone by size class (1981 to January 1991) or size range (July 1991 to June 1995) for all Diablo Cove random surveys.

Size Range	Size	Survey Date																	
(mm)	class[1]	81	83	85	88	1/89	7/89	1/90	7/90	1/91	7/91	1/92	7/92	1/93	6/93	2/94	6/94	2/95	6/95
1 - 10											12	0	26	13	16	9	26	0	0
11 - 15	Juv[2]	—	—	—	—	—	—	—	—	8	81	8	78	26	87	20	103	1	5
16 - 20											171	8	65	20	128	15	217	8	10
21 - 25											203	28	43	15	124	14	195	11	6
Total juvenile		—	—	—	—	—	—	—	—	**8**	**467**	**44**	**212**	**74**	**355**	**58**	**541**	**20**	**21**
% of total abalone										*7.8*	*75.4*	*22.0*	*68.6*	*56.5*	*71.7*	*40.0*	*80.0*	*5.9*	*8.4*
26 - 30											44	22	13	12	58	16	50	34	10
31 - 35											5	18	15	4	34	21	28	44	23
36 - 40	Sm	98	63	185	274	69	84	76	29	34	49	19	11	2	11	11	7	70	27
41 - 45											6	11	11	4	13	10	13	55	36
46 - 50											1	10	11	7	2	12	14	30	22
Total small		**98**	**63**	**185**	**274**	**69**	**84**	**76**	**29**	**34**	**105**	**80**	**61**	**29**	**118**	**70**	**112**	**233**	**118**
% of total abalone		*8.7*	*12.9*	*23.0*	*32.3*	*16.9*	*34.1*	*27.7*	*27.1*	*33.0*	*17.0*	*40.0*	*19.7*	*22.1*	*23.8*	*48.3*	*16.6*	*68.3*	*47.0*
51 - 60											5	7	15	7	4	11	12	32	79
61 - 70											1	22	4	5	4	0	5	27	17
71 - 80	Md	538	285	421	441	217	115	168	66	46	27	13	3	3	6	3	1	24	9
81 - 90											5	8	4	6	4	0	3	4	3
91 - 100											0	13	5	1	1	1	1	1	2
Total medium		**538**	**285**	**421**	**441**	**217**	**115**	**168**	**66**	**46**	**38**	**63**	**31**	**22**	**19**	**15**	**22**	**88**	**110**
% of total abalone		*48.0*	*58.2*	*52.3*	*52.1*	*53.1*	*46.7*	*61.3*	*61.7*	*44.7*	*6.1*	*31.5*	*10.0*	*16.8*	*3.8*	*10.3*	*3.3*	*25.8*	*43.8*
101 - 110											9	7	4	4	2	0	0	0	1
111 - 120	Lg	486	142	199	132	123	47	30	12	15	0	0	1	0	1	1	1	0	1
>120											0	6	0	2	0	1	0	0	0
Total large		**486**	**142**	**199**	**132**	**123**	**47**	**30**	**12**	**15**	**9**	**13**	**5**	**6**	**3**	**2**	**1**	**0**	**2**
% of total abalone		*43.3*	*29.0*	*24.7*	*15.6*	*30.1*	*19.1*	*10.9*	*11.2*	*14.6*	*1.5*	*6.5*	*1.6*	*4.6*	*0.6*	*1.4*	*0.1*	*0.0*	*0.8*
Total abalone		**1122**	**490**	**805**	**847**	**409**	**246**	**274**	**107**	**103**	**619**	**200**	**309**	**131**	**495**	**145**	**676**	**341**	**251**

[1] From 1981-1990 abalone were classified into broad size classes. The total numbers within these size classes are listed with the median size range for that class.

[2] Juveniles were included in counts of small abalone from 1981-90.

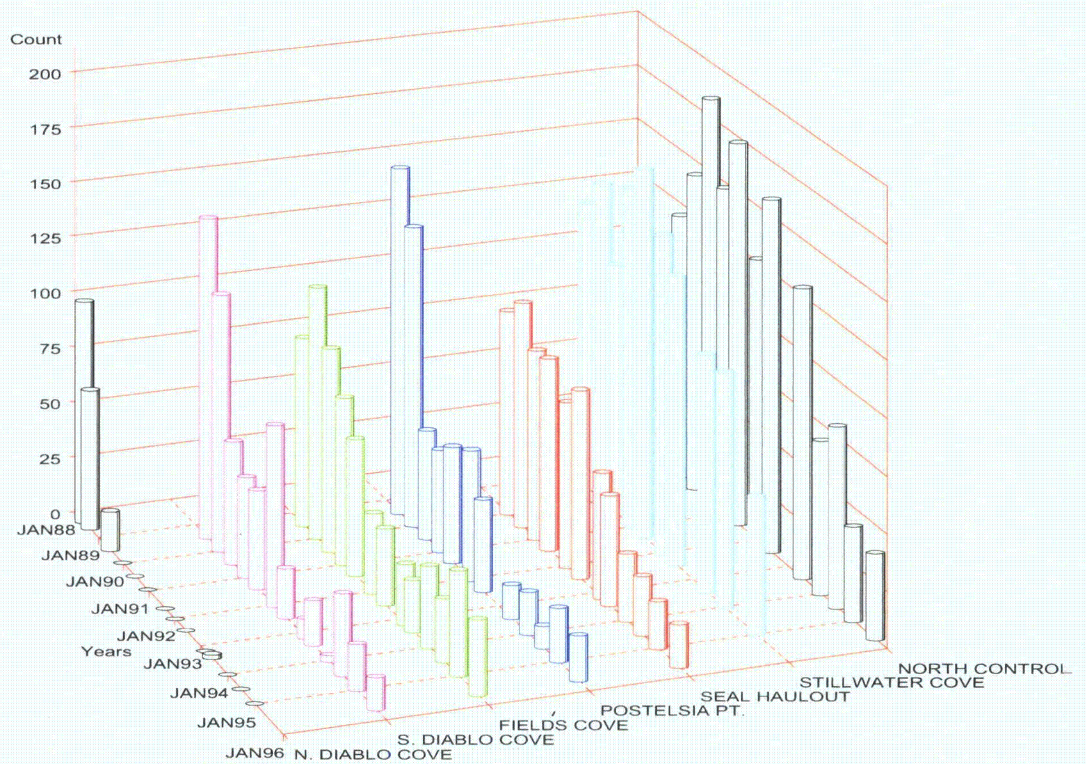


Figure 3-46. Black abalone, *Haliotis cracherodii*, total counts over time on the 10-meter stations. All surveys were completed after commencement of commercial power plant operation.

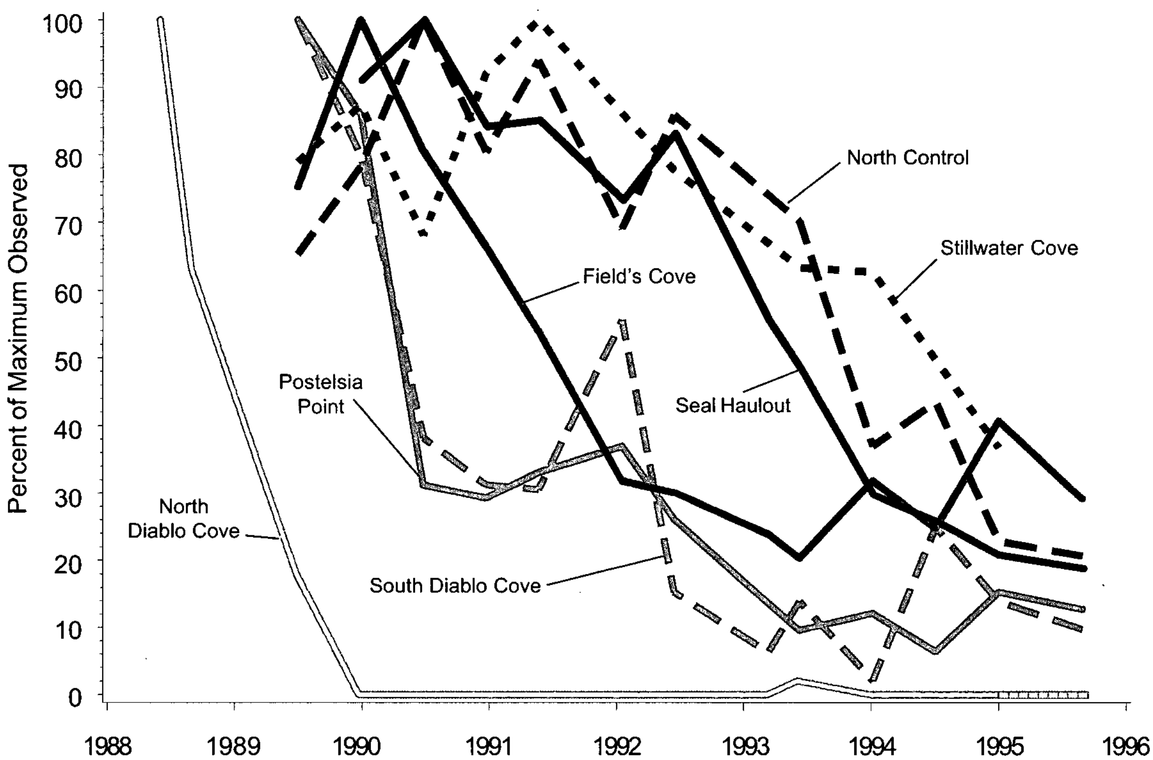


Figure 3-47. Black abalone, *Haliotis cracherodii*, changes in the abundance on 10-meter stations after commencement of commercial power plant operation, expressed as percentage of maximum number observed at a station during any single survey.

Table 3-21. Years when withering syndrome disease was first observed among abalone in the area surveyed in quantitative black abalone surveys (1988-1994).

Year	Area of Observation / Comments	Distance from Diablo Cove (straight-line)
1988	Diablo Cove	
1989	Diablo Cove - red abalone found with WS	
1989	Postelsia Point (north Diablo Point)	0.1 km north
1990	Field's Cove	0.5 km north
1990/91	Point Arguello; a few abalone (P. Haaker CDF&G pers. comm.)	76.0 km south
1991	Seal Haulout; also found in Diablo Cove juveniles	0.7 km south
1992	Green Rock Cove (inside Lion Rock)	1.6 km north
1993	Suspected WS (empty shells) at North Control and Stillwater Cove	
1994	HBT Station SC-3 (south of Stillwater Cove)	4.7 km south
1994	North Control	2.2 km north

Temperature Effects on Development of Withering Syndrome in Black Abalone

Experiments were conducted to investigate the relationship between water temperature and the incidence and progression of WS in black abalone collected from the DCPP study area. The shell lengths of abalone used in the experiment ranged from 25-134 mm with a mean size of 82.8 mm. Temperatures in the two treatment tanks (16.0°C and 18.0°C) remained within about 0.2°C of the target temperatures during the experiment, except for isolated incidents when malfunctions caused temporary loss of fresh seawater or shutdown of the water heating system. During these occasions, which lasted from 12 to 48 hours, the temperature in the heated tanks either dropped several degrees C to the ambient seawater temperature, or increased several degrees C toward ambient laboratory room temperature (ca. 20°C) when seawater inflows ceased. Seawater temperature in the ambient temperature tank ranged from 10-15°C (average 12.8°C) during the experiment.

At the start of the experiment in December 1988, 42 abalone were in the control group and 60 abalone were in each of the two temperature treatments. The composition of abalone in the experimental groups was the result of random assignment of abalone collected from the seven areas to the cages and the cages then randomly assigned to a treatment or the control group. Seven live abalone from the control group and nine abalone from each treatment group were removed in June 1989 and sacrificed for histological examination as part of an investigation into the role of kidney infection by parasitic coccidian protozoans as a potential causative agent in WS (Steinbeck et al. 1992). The greatest incidence of infection was found in specimens from the control group (100%) and the lowest incidence of infection was from the 18°C treatment (25%). The 16°C treatment had an intermediate proportion of infection (63%). Later work found that the disease was likely caused by another protozoan (Gardner et al. 1995), and explains the results showing a negative correlation between coccidean infection level and mortality rates in the three temperature treatments.

Final shell and foot measurements were made in December 1989, but the experiment was extended through March 1990 to track continuing development of WS. During this four month period, WS-related mortalities were recorded for two additional abalone at the 16°C treatment, and the first WS-related mortality occurred in the ambient treatment group. At the conclusion of the experiment, percent mortality related to WS was 86% at 18°C, 28% at 16°C and 3% for the control after 496 days (Table 3-22). Six other deaths in the experiment were attributed to causes other than WS based on the *post mortem* observation that their foot muscle was not obviously atrophied. When the experimental results were expressed as percent survival (the inverse of percent mortality) over time by treatment, it was evident that a greater proportion of abalone survived at cooler temperatures (Figure 3-48).

Table 3-22. Summary of laboratory experiments on survivorship of black abalone held at three temperatures for 496 days.

Treatment	Number of abalone alive in experimental treatment on date				Number (%) and cause of deaths	
	11/15/88	# removed for histological exam. (6/26/89 & 8/7/89)	12/30/89	3/25/90	WS	not known
18°C	60	9	4	4	44 (86.3)	3 (5.8)
16°C	60	9	38	36	14 (27.5)	2 (3.9)
ambient (avg. 12.8°C)	42	7	35	33	1 (3.0)	1 (3.0)

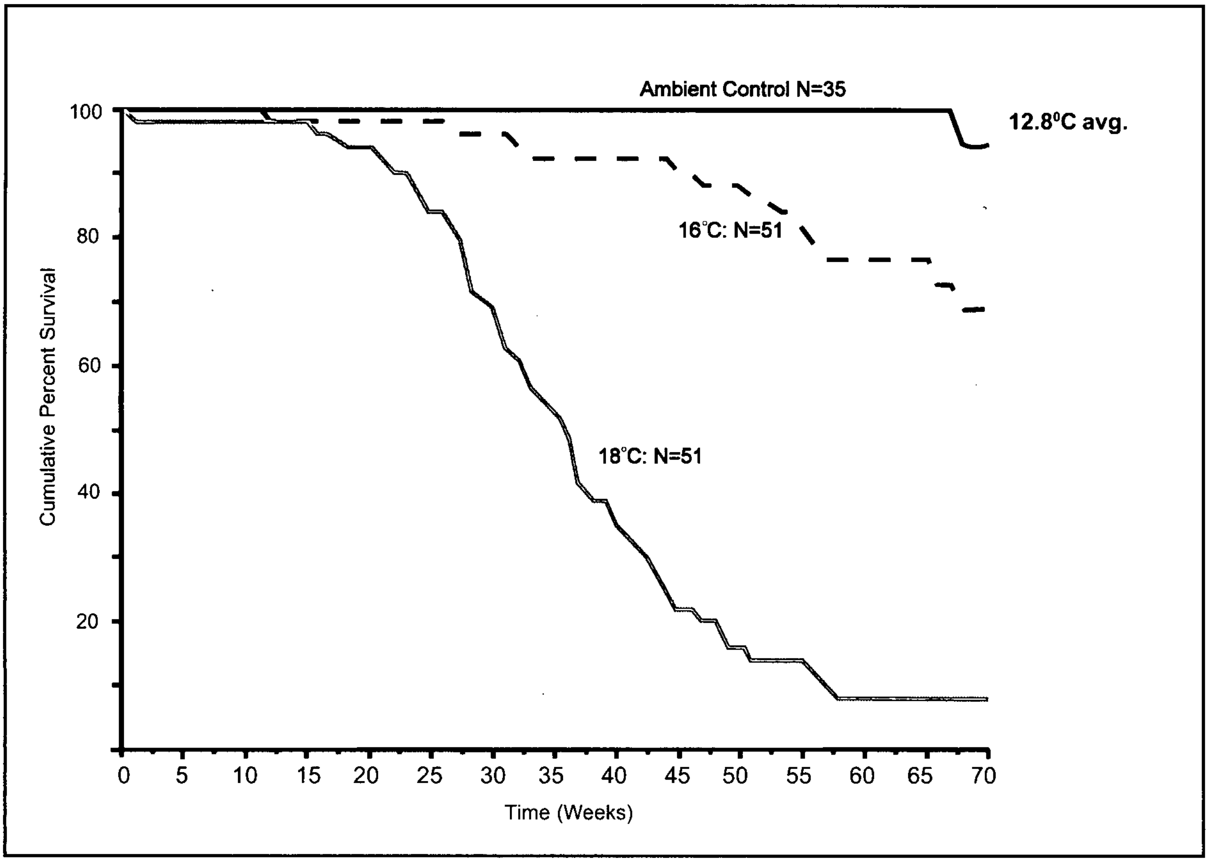


Figure 3-48. Black abalone, *Haliotis cracherodii*, survival versus time in laboratory test tanks held at ambient and two test temperatures. (N = number of abalone tested at each treatment temperature).

3.3.5 *Intertidal Fish*

Twenty-eight intertidal fish taxa were sampled in 199 vertical band transect (VBT) surveys during the period 1979 to 1995. Nine of the taxa were found only in Diablo Cove and two were found only in Field's Cove (Figure 3-49). Six taxa comprised over 90% of the individuals sampled during both periods. Most of these were small eel-like fishes of the families Stichaeidae and Pholididae.

Species Abundance

Of the 28 fish taxa recorded during the study, 11 (37%) comprised the top 99% by abundance. Eight of these 11 taxa conformed to ANOVA assumptions necessary for BACI analysis (Appendix G). The three remaining taxa were analyzed using Fisher's exact test. Abundance plots for all taxa tested are presented in Appendix E.

Significant Increases

Only one taxon (9% of those tested) increased significantly (Table 3-23). *Anoplarchus/Cebidichthys* showed a variable response to the discharge, increasing in south Diablo Cove but decreasing in north Diablo Cove. This discrepancy may be attributed to combining two species in the analysis, each responding differently to intertidal conditions after power plant start-up. Use of the complex taxon combining *Anoplarchus/Cebidichthys* (high cockscomb/monkeyface-eel) was because of similarities in the field appearance in juveniles of the two species. Adults of the two species could be easily separated in the field. None of the abundances of the three species tested with Fisher's exact test instead of BACI analysis showed significant increases (Table 3-24).

Significant Decreases

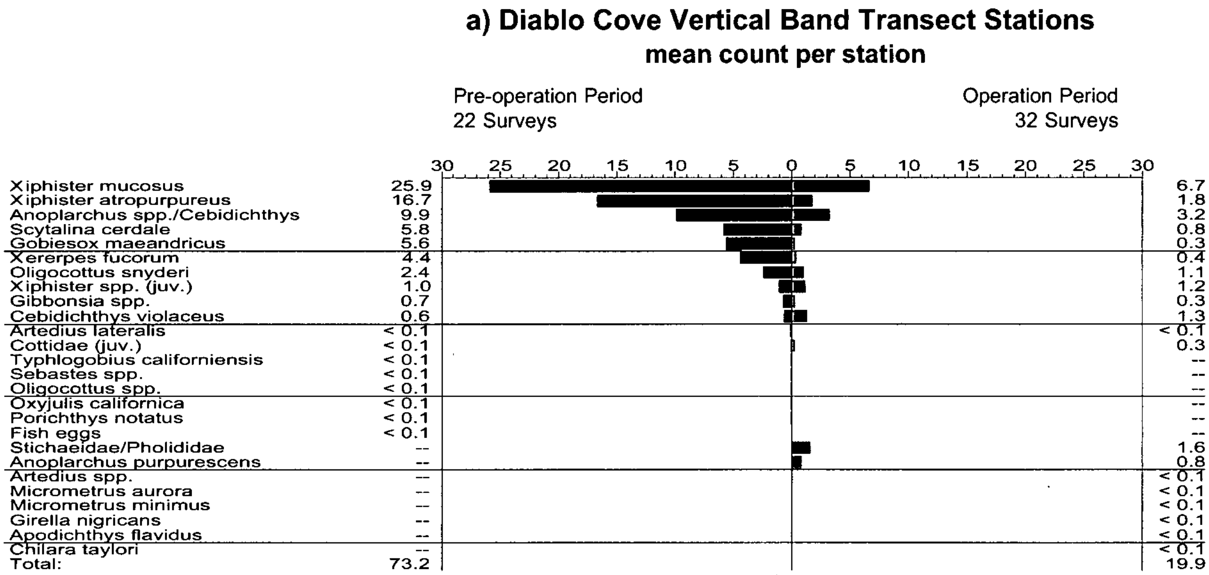
Five of the 11 taxa tested (45%) decreased significantly between periods (Tables 3-23 and 3-24). These were *Anoplarchus/Cebidichthys* (see above), *Xiphister atropurpureus* (black prickleback), *X. mucosus* (rock prickleback), *Gobiesox maeandricus* (clingfish), and *Scytalina cerdale* (graveldiver). For those taxa tested using the BACI analysis, all but *Gobiesox* decreased significantly at NDC, and only *X. atropurpureus* decreased significantly at both NDC and SDC.

No Change

Only one taxon (13% of those tested) did not change after plant start-up. This was the gunnel *Xerepes fucorum*, an eel-like fish commonly associated with various algal species.

Test Results Inconclusive

Neither BACI analysis nor Fisher's exact tests were able to detect any statistically significant changes in the abundances of five taxa (45% of those tested). Low power of the tests to detect a 50% change in abundance between periods (Table 3-23) indicated that the taxa were too variable to determine whether or not they were significantly affected by discharge temperatures.



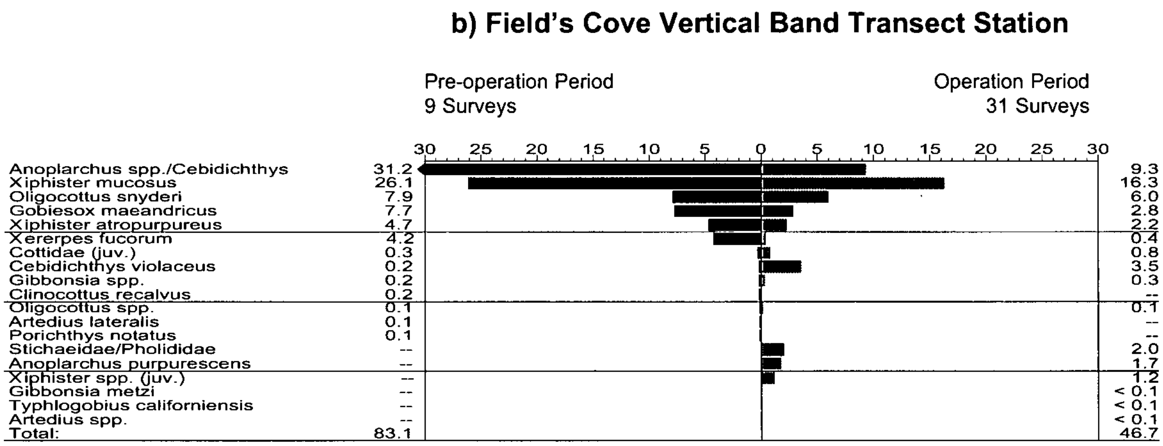


Figure 3-49. Intertidal fish abundances for the pre-operation and operation periods at (a) Diablo Cove and (b) Field's Cove vertical band transect stations. Diablo Cove stations = NDC V-1 and SDC V-1. Field's Cove station = FC V-1. Data collected in 1986 was not included.

Table 3-23. Results of BACI ANOVA for intertidal fish from VBT fish counts. Negative values indicate decreases between periods for individual stations. Statistically significant results (p<0.10) are in **bold** type.

Taxon	% Change Between Periods Relative to Field's Cove	Period F	Period P	Power to Detect 50% Change	Area x Period Interaction P	Area SDC P	Area NDC P
Significant Increase							
Anoplarchus /Cebidichthys [1]	+7	.1	.78	.98	**<.01**	**.01**	**-.02**
Significant Decrease							
Anoplarchus /Cebidichthys [1]	+7	.1	.78	.98	**<.01**	**.01**	**-.02**
Gobiesox maeandricus	-86	1.3	.27	.44	**<.01**	**-.06**	-.81
Xiphister atropurpureus	-72	30.1	**<.01**	1.00	.78	**-<.01**	**-<.01**
Xiphister mucosus	-52	6.6	**.01**	.44	**.01**	-.27	**-<.01**
No change [2]							
Xererpes fucorum	+1	.7	.40	.75	**.05**	-.97	-.13
Test Results Inconclusive [3]							
Cottidae (juv.)	-58	<.01	.97	.10	.13	.55	-.51
Gibbonsia spp.	+33	<.01	.88	.10	.65	-.99	.76
Oligocottus snyderi	-55	<.01	.95	.12	.10	-.90	.80

[1] taxa listed twice because of differing significant effects between areas.
[2] no significant difference between period means; power of test to detect a 50% change was greater than .70.
[3] no significant difference between period means; power of test to detect a 50% change was less than .70.

Community changes

In comparing mean abundances of the intertidal fish assemblage for Field's Cove between the pre-operation and operation study periods (Figure 3-49), abundances of almost all taxa decreased and taxa composition shifted somewhat.

Declines in taxa abundances also occurred in Diablo Cove between study periods (Figure 3-49). Eight taxa were present during the operation period that were not found during the pre-operation period. In Field's Cove, six taxa were present during the operation period that were not present before operation. Results from the Fisher's exact test did not detect any significant differences in the relative proportions of increasing vs. decreasing taxa between periods (p=0.49) (Table 3-25).

Table 3-24. Results of Fisher's exact test for VBT intertidal fish taxa not tested in BACI analysis. Statistically significant results (p<0.10) are in **bold** type.

Taxon	Diablo Cove p
Significant Increase	
none	—
Significant Decrease	
Scytalina cerdale	**<.01**
Test Results Inconclusive	
Xiphister spp. (juv.)	1.00
Stichaeidae/Pholididae unid.	1.00

Extent of Effects

The extent of discharge effects on intertidal fish could not be directly determined from the array of sampling stations because all stations were affected by the thermal discharge to varying degrees. Therefore, it was assumed that the probable extent of effects was the same as that identified for intertidal invertebrates (Figure 3-35). This encompassed a shoreline distance of 3.7 km (2.3 mi) of observed effects, and a shoreline distance of 3.0 km (1.8 mi) of unknown effects which are likely to be less than those seen in areas with reduced observed effects. Effects on intertidal fishes were probably greater in Diablo Cove than in Field's Cove because of warmer delta T°s (Figure 2-12) and greater losses of algal cover (Appendix E, Figure E1-1).

Table 3-25. Results of Fisher's exact test for VBT intertidal fish taxa. Data were number of species changes between pre-operation and operation periods. Results were statistically significant if $p<0.10$.

	Decreases	Increases
Diablo Cove	11	6
Field's Cove	8	9
	p = 0.49	

3.3.6 Community-Level Analysis

From a functional group perspective, grazers of algae (e.g., *Tegula funebralis*, sea urchins, and limpets) proliferated in areas contacted by the discharge (Figure 3-50). Increases at control stations were observed following the El Niño period, but returned to pre-El Niño levels by 1992. In contrast, grazers remained in high abundance at Diablo Cove +0.9 m transects, and showed large fluctuations in abundance at the +0.3 m transects.

After power plant start-up, decreases in algal cover in Diablo Cove were observed that were coincident with increases in grazer abundance (Figure 3-50). There was little variation in grazer abundance and algal cover at the control +0.3 m transects, and changes in grazers appeared to have little effect on algal cover at the +0.9 m transect level. Changes in grazer abundance in Diablo Cove show a strong negative correlation with algal cover. The increase in algal cover from 1990 through 1992 at the +0.3 m transects in Diablo Cove can be attributed to increases in ephemeral forms which began to colonize the area during that period. The decline and subsequent increase in grazers from 1992 through 1996 may be a response to changes in the algal assemblage.

Algal and invertebrate ecological groupings (see Table 3-3) were analyzed separately for the +0.3 m and +0.9 m transects using correspondence analysis (CA). To help compensate for different scales of measurements used for the taxa within a group, the data were first log transformed (log x+0.0625). Data used in the analyses were pooled annual means computed for each group for control and Diablo Cove stations using the control stations NC-1, -2 and SC-1 and the Diablo Cove stations NDC-1, -2, and -3 plus SDC-2 (Diablo Point and Field's Cove data excluded). The results for the first three CA axes for survey and taxa scores for the +0.3 m transects are presented in Figures 3-51 and 3-52 and account for the three largest independent patterns of variation in the data set. These first three axes for the analyses explained a total of 91% of variation in the data.

Results for the first dimension annual survey scores represent differences between operational years at Diablo Cove (negative annual survey scores) and all other survey scores, which include both pre-operational years for Diablo Cove and survey scores for the control group (positive scores) (Figure 3-51).

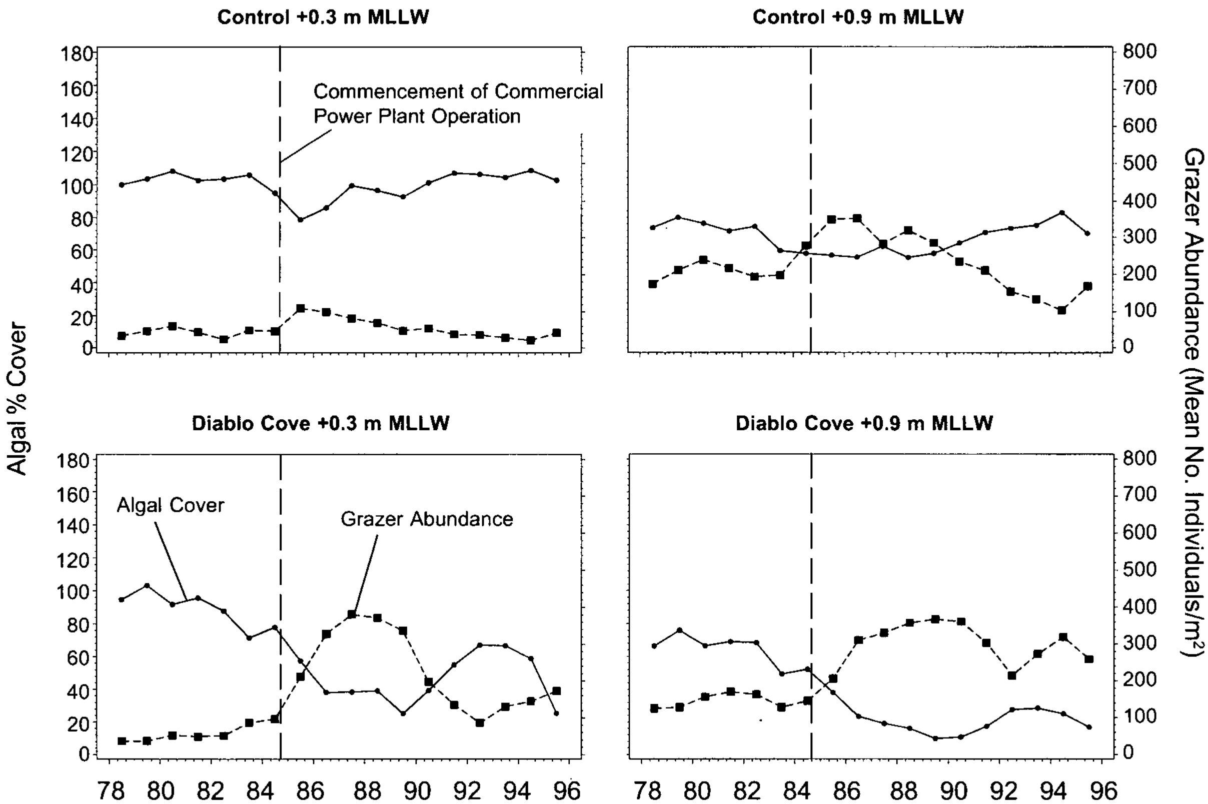


Figure 3-50. Algal cover and grazer abundance versus time at control and Diablo Cove sampling elevations. Control stations = NC-1, -2, and SC-1: Diablo Cove stations = NDC-1, -2, -3, and SDC-2. Data are from the five 'count' quadrats per station-elevation.

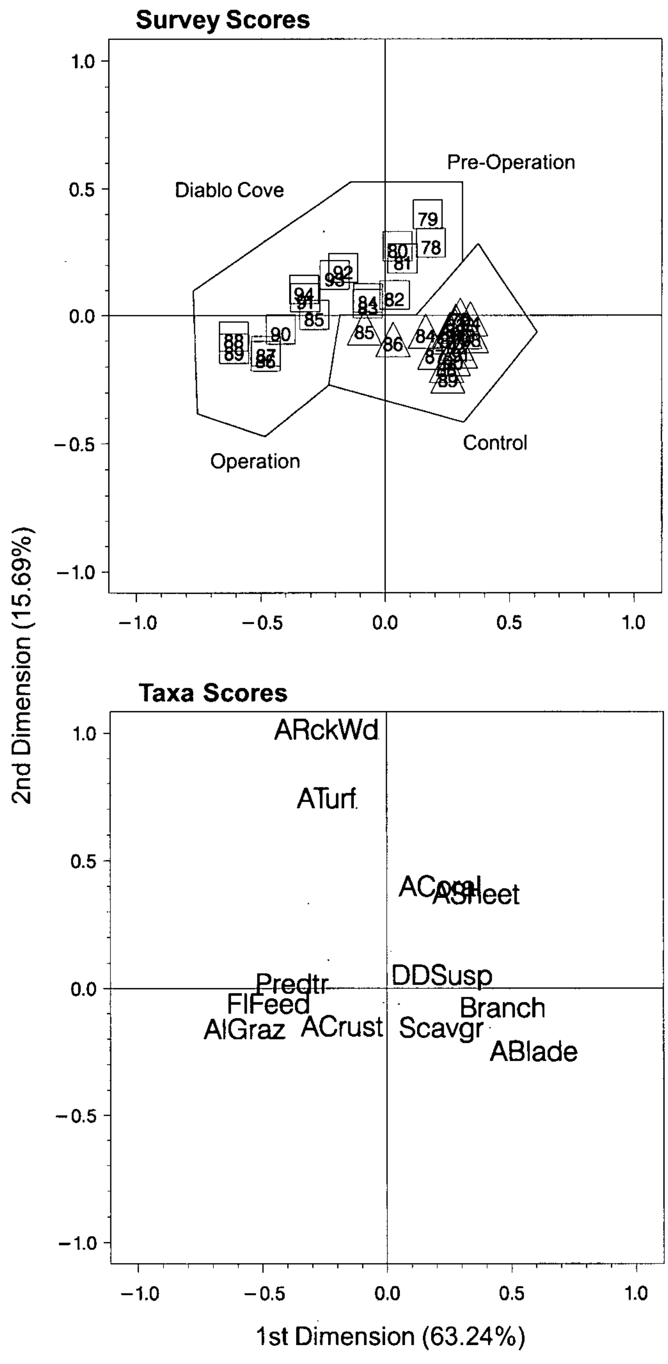


Figure 3-51. Annual survey scores for algal forms and invertebrate trophic groups from the first and second correspondence analysis axes for the Diablo Cove and Control +0.3 m MLLW transects. Triangles represent control stations (NC-1, -2, and SC-1). Squares represent Diablo Cove stations (NDC-1, -2, -3, and SDC-1). Numbers inside of triangles and squares are years from 1978 to 1994. Data for 1995 were excluded due to the year being partially sampled (study ended in June). Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Refer to Table 3-3 for complete names of abbreviated categories. The data were transformed using log (x +0.0625) prior to combining into ecological categories.

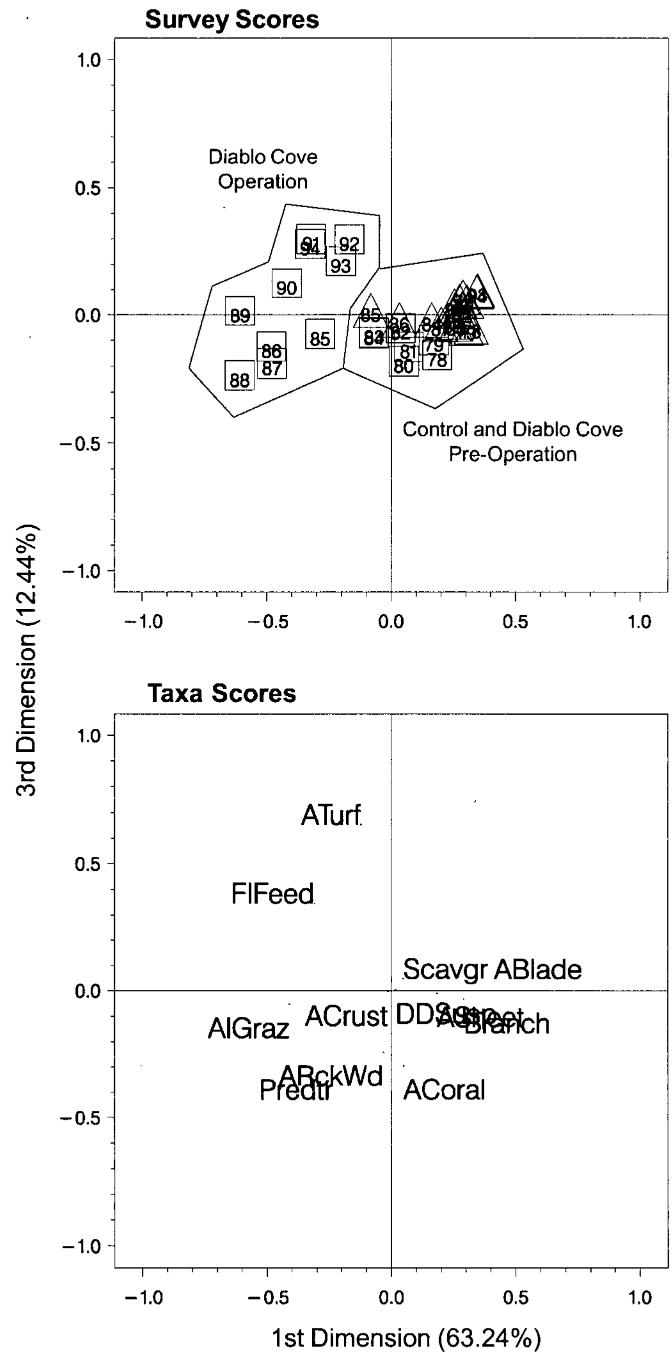


Figure 3-52. Annual survey scores for algal forms and invertebrate trophic groups from the first and third correspondence analysis axes for the Diablo Cove and Control +0.3 m MLLW transects. Triangles represent control stations (NC-1, -2, and SC-1). Squares represent Diablo Cove stations (NDC-1, -2, -3, and SDC-1). Numbers inside of triangles and squares are years from 1978 to 1994. Data for 1995 were excluded due to the year being partially sampled (study ended in June). Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Refer to Table 3-3 for complete names of abbreviated categories. The data were transformed using log (x +0.0625) prior to combining into ecological categories.

The survey scores for the control stations show little variation among years, except during the post-El Niño period of 1984-1986. The effects of the El Niño are shown by the negative survey score for 1985 that shows the greatest departure from other scores. Although the effects of El Niño obviously caused some divergence from normal control station conditions, the 1986 and 1987 scores for the control stations indicate recovery to pre-El Niño conditions. The El Niño period scores resulted from relative decreases in branched and bladed forms of algae, and relative increases in algal crust and filamentous turf. The configuration of survey scores prior to the El Niño for the Diablo Cove stations shows the same relatively stable community pattern seen at control stations, but the scores for Diablo Cove show greater effects from the El Niño, possibly facilitated by the start-up of Unit 1. The recovery to pre-El Niño conditions did not occur inside Diablo Cove, and the continued divergence of survey scores from any stable configuration indicate continued change in the community with the onset of power plant operation in 1985. Taxa scores for the first axis indicate that changes during operation were due to relative increases in invertebrate grazers, predators, and filter feeders, shown by the negative taxa scores, and relative decreases in algal blades, shown by the positive taxa scores.

The second axis describes variation related to pre-operational differences between Diablo Cove and control areas (Figures 3-51). Taxa scores show that algal rockweeds and turf (positive scores) were more important components of the community in Diablo Cove than algal blades, algal crusts, and grazers that were associated with control areas (negative scores). Negative survey scores from 1986-1990 for Diablo Cove result from increases in grazers and algal crust associated with early years of operation. The third axis explains patterns of variation associated with the plant operation period in Diablo Cove. While the second axis taxa scores showed increases in algal grazers associated with early years of operation within Diablo Cove, the third axis shows increases in filter feeders relative to grazers occurred in later years of operation. The results also show that algal rockweeds declined in Diablo Cove relative to algal turfs that increased in later years of operation. The range of variation in survey scores for Diablo Cove on both axes is much larger than the range of variation for the control group, and both axes show distinct trajectories of change from year-to-year. The results show that algal and invertebrate assemblages in Diablo Cove continued to shift in relative importance after power plant start-up.

The results for the first three CA axes for station and species scores for the +0.9 m transects are presented in Figures 3-53 and 3-54. The results and interpretations of each axis are similar to those described for the lower elevation transects. Results for the first dimension annual survey scores represent differences between operational years at Diablo Cove (negative annual survey scores) and all other survey scores, which include both pre-operational years for Diablo Cove and survey scores for the control group (positive scores) (Figure 3-53). Annual survey scores for the control group shows little variation among years, except during the post-El Niño period of 1984-1986. In contrast to the results from the lower elevation, annual survey scores for control areas did not return to pre-El Niño conditions as rapidly, indicating that recovery was slower at the higher elevation. Similar to the lower elevation, second axis results contrast pre-operational surveys in Diablo Cove with control survey scores, although taxa scores show that different algal groups were representative of pre-operational conditions in Diablo Cove at the higher elevation transects. Results show that sheet-like algae were more abundant in Diablo Cove relative to algal blades and rockweeds associated with control areas. Third axis results also present patterns of variation associated with the plant operation period in Diablo Cove. These results show the same distinct trajectories of change from year-to-year seen in the results for the lower elevation. These results corroborate lower elevation results that show continuing change in Diablo Cove during power plant start-up.

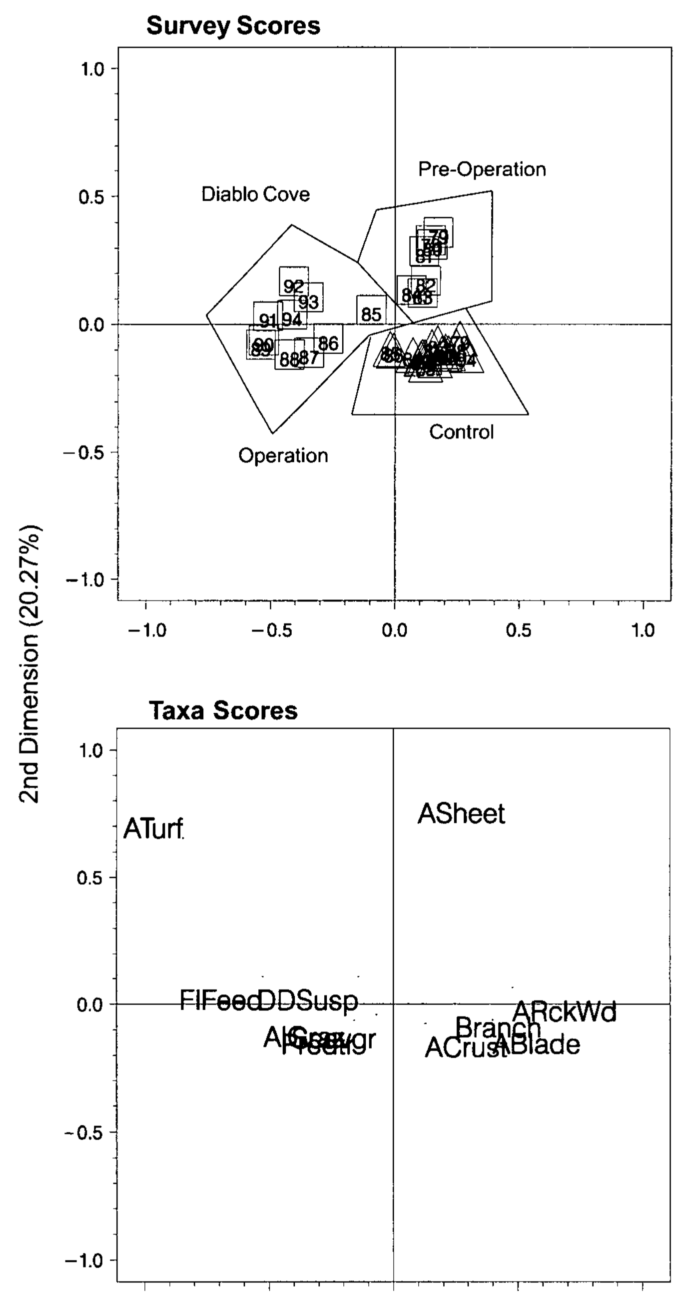


Figure 3-53. Annual survey scores for algal forms and invertebrate trophic groups from the first and second correspondence analysis axes for the Diablo Cove and Control +0.9 m MLLW transects. Triangles represent control stations (NC-1, -2, and SC-1). Squares represent Diablo Cove stations (NDC-1, -2, -3, and SDC-1). Numbers inside of triangles and squares are years from 1978 to 1994. Data for 1995 were excluded due to the year being partially sampled (study ended in June). Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Refer to Table 3-3 for complete names of abbreviated categories. Percentages in parentheses denote amount of variation explained by corresponding dimension. The data were transformed using log (x +0.0625) prior to combining into ecological categories.

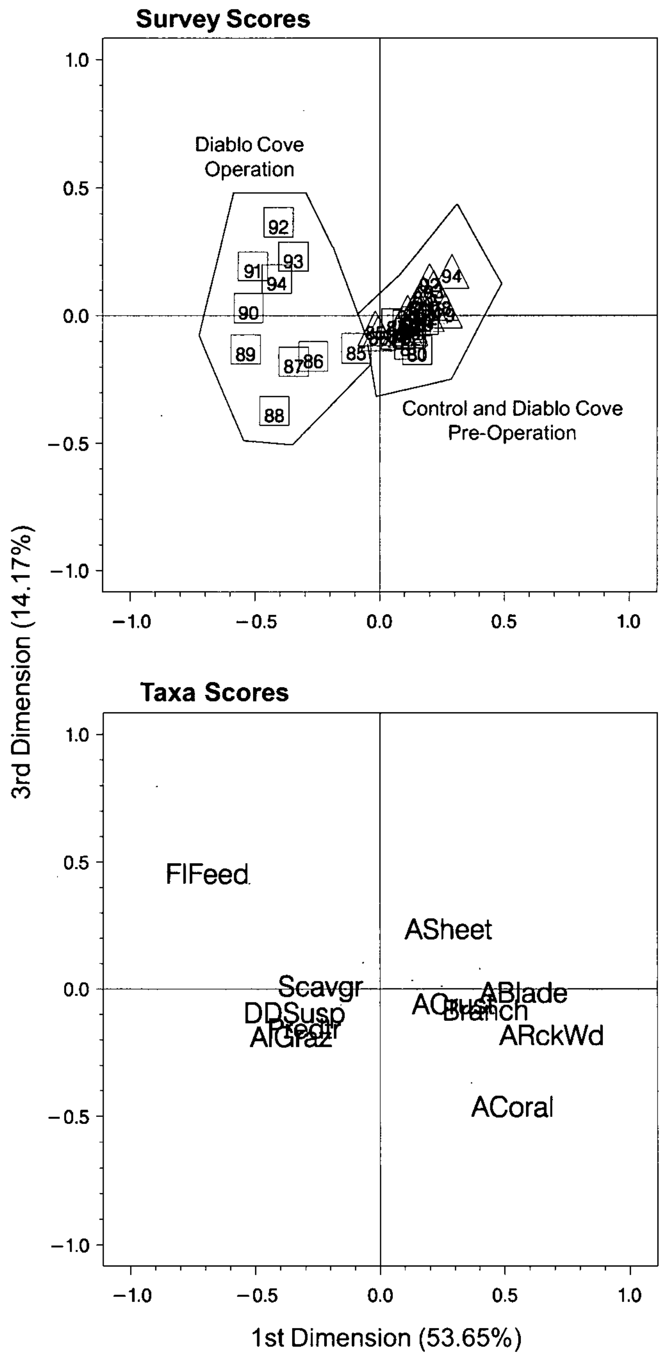


Figure 3-54. Annual survey scores for algal forms and invertebrate trophic groups from the first and third correspondence analysis axes for the Diablo Cove and Control +0.9 m MLLW transects. Triangles represent control stations (NC-1, -2, and SC-1). Squares represent Diablo Cove stations (NDC-1, -2, -3, and SDC-1). Numbers inside of triangles and squares are years from 1978 to 1994. Data for 1995 were excluded due to the year being partially sampled (study ended in June). Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Refer to Table 3-3 for complete names of abbreviated categories. Percentages in parentheses denote amount of variation explained by corresponding dimension. The data were transformed using log (x +0.0625) prior to combining into ecological categories.

3.4 Discussion

3.4.1 Algae

The composition and abundance of algae have been used to describe the effects of physical perturbations in the environment (Connell and Slayter 1977; Littler et al. 1983). Because algae are sessile and relatively easy to sample, they have been used to characterize the 'health' or 'ecological importance' of areas in terms of productivity, habitat suitability, and biological diversity (Widdowson 1971; Borowitzka 1972; Littler and Murray 1975; Zimmerman and Livingston 1976; May 1981; Shubert 1984). Studies of succession on ephemeral and perennial life history 'types' have also been used (Sousa 1979a, 1979b, 1980, 1984; Dayton 1971; Littler and Littler 1980; Turner 1983; Clayton 1990; Kinnetic Laboratories, Inc. 1992). Changes in algal abundance have also been shown to cause secondary changes in intertidal systems (Connell 1972; Dayton 1975, 1984; Taylor and Littler 1982; Paine 1986).

The effects of the DCPP discharge on the intertidal algal community included statistically significant decreases in algal diversity, total algal cover, and number of taxa primarily within Diablo Cove. Of the 38 intertidal algal taxa tested, significant declines were detected in 68% of the taxa, increases were detected in 19% of the taxa, and no changes or inconclusive results were found in 13% of the taxa. The length of shoreline affected was based on observations from *M. flaccida* (Table 3-5). This species was one of the most abundant foliose algae along the coast, occurring as an almost continuous band along the shoreline, but declined to very low levels in Diablo Cove due to the discharge. In Field's Cove to the north and South Diablo Point to the south, significant declines in *M. flaccida*, relative to controls, were also detected. Decreases in cover in these areas were less, which was consistent with the lower plume temperatures in these areas. On this basis, Field's Cove and South Diablo Point were used to represent the minimum range of impacts to the intertidal algae (Figure 3-17). However, reduced impacts may have extended over greater distances, where plume contact is also reduced. The northernmost location of potential impacts was Lion Rock. The discharge plume does not appear to contact the shoreline north of Lion Rock (*see* Section 2.0 - *Power Plant Operation and Thermal Plume Characteristics*). The southernmost location where the discharge separates from the shore is probably at or immediately south of South Diablo Point. Therefore, the maximum distance of shoreline impacts (between Lion Rock and South Diablo Point) was estimated to be 6.7 km (4.2 miles). This distance accounts for shoreline indentations and portions of Lion Rock and Diablo Rock. Results of correspondence analysis revealed that changes in the Diablo Cove algal community were continuing through 1995.

Declines in the algae were manifested in three basic patterns related to the magnitude of effects on different taxa, involving perennial algae that had been abundant prior to plant operation. The first pattern was a decline (after power plant start-up) to localized absence or near-absence. These included *M. flaccida*, *M. heterocarpa*, *Endocladia muricata*, *Mastocarpus jardinii*, *Egregia menziesii*, *Fucus gardneri*, and *Pelvetia compressa*. The declines in the latter four kelp taxa were consistent with declines from increased water temperature observed in brown algae, in general, from other studies (Arndt 1968; Turner and Strachan 1969; Devinny 1975; Vadas et al. 1976; and Gunnill 1985). A second pattern of decline was a reduction in abundance at only the upper sampling elevation, with no change or an increase occurring at the lower elevation. This occurred in *Mastocarpus papillatus, Gelidium coulteri,* and *Gastroclonium subarticulatum*. A third pattern of change was a reduction in cover, followed by recovery, then reduction again, as seen mainly in *Chondracanthus canaliculatus*.

The declines in perennial algae were concomitant with a significant increase in bare rock and expansion of crustose algal cover. Later in the study, short-lived (ephemeral) taxa (such as *Ulva/Enteromorpha* spp.

and filamentous red algae) colonized available open bare rock space. Typically, these algae appear following a disturbance (Rossler 1971; Kinnetic Laboratories 1992). The increases in cover of ephemeral taxa did not offset the losses in cover of perennials, resulting in an overall decrease in algal diversity and cover. The increases in *Mastocarpus papillatus* and non-coralline crustose algae in the low intertidal sampling elevation in Diablo Cove were likely associated (Slocum 1980; Littler and Littler 1980) because *Petrocelis middendorfii* was the most abundant species of the crustose group of algae, and is the alternate life stage of *M. papillatus* (Polanshek and West 1975, 1977; West 1972). The increase in *P. middendorfii* was possibly facilitated by gastropod grazing, as crustose taxa tend to predominate in areas of high grazing activity (Nicroti 1977; Branch and Branch 1980; Kitting 1980; Underwood and Jernakoff 1981; Dethier 1994).

Although the intertidal algal community changed in response to the discharge, it did not become colonized with southern California algal taxa, although *Rosenvingia floridiana*, a warm water red algal species, was found during a survey following plant start-up. Geographic ranges have been used to categorize taxa as warm-water tolerant taxa (Abbott and North 1971; Abbott and Hollenberg 1976). Many of these taxa decreased in abundance during plant operation perhaps because local populations may have different optimum temperatures for growth than southern California populations (North et al. 1989). Taxa that increased or remained relatively unchanged in Diablo Cove had to have been the most eurythermal (wide temperature range) forms, since the range of temperature fluctuations in the cove increased considerably after power plant start-up (*see* Section 2.0 - *Power Plant Operation and Thermal Plume Characteristics*).

North and Anderson (1973) predicted that temperature exposures of as little as 2°C (3.6°F) above ambient would likely affect the more sensitive stenothermal (narrow temperature range) organisms at DCPP, and that conditions where temperatures reached 4-5°C (7.2-9°F) above ambient would favor eurythermal groups. Intertidal water temperatures in north Diablo Cove increased 3-5°C on average (see Section 2.2.3 - *Intertidal Temperatures*), and the range of temperatures increased mainly due to variations in power plant discharges. The combination of warmer and wider-ranging temperatures may have tended to favor the most eurythermal algae. Conversely, the lack of establishment of a predominantly southern California algal community in Diablo Cove may have been partially due to the wide variation in temperatures, in particular the occasional cool ambient temperatures occurring during power plant outages.

The recovery patterns of algae at SDC-3, which in March 1983 was completely buried under cobble from a collapsed cliff, involved a unique case of algal recolonization in the presence of the discharge. *Mastocarpus papillatus* became numerically dominant at SDC-3, perhaps due to remnant patches of *P. middendorfii* that expanded and provided spores for the growth of *M. papillatus*, its alternate life history stage. The absence at SDC-3 of ephemerals and other taxa that increased in other affected areas may have been due to the periodic accumulation on the shore of foam generated by the turbulent mixing of the discharge. Foam was extensive at times during the study (Kenzler 1987). The accumulations in south Diablo Cove may have interfered with spore settlement processes and reduced available light for growth. Accumulations of foam in south Diablo Cove and on SDC-3 actually hindered sampling on many occasions.

The intertidal zone of Diablo Rock was contacted by the thermal plume but it comprised a relatively small area that was not accessible from the shoreline and was not surveyed in the TEMP studies. However, the same types of biological changes probably occurred there as in other areas studied in the cove. North et al. (1989) sampled the intertidal zone of Diablo Rock and noted declines in intertidal *Egregia menziesii*, *Mazzaella flaccida*, *Laminaria setchellii*, *Endocladia muricata*, and *Mastocarpus papillatus* that were attributed to power plant operation. Near the end of the study, the low intertidal region in Diablo Cove between Diablo Creek and NDC-3 became heavily populated with grazing sea urchins (primarily *Strongylocentrotus purpuratus*). The dense aggregations of sea urchins created 'urchin barrens' (areas devoid of foliose algal cover). The principal algae that remained were crustose coralline algae. Other areas in relatively close proximity to the outfall but not quantitatively sampled were the wave-exposed North Diablo Point and portions of South Diablo Point. These areas were not visited at sufficient intervals to assess biological changes.

Changes in *Mazzaella flaccida* probably provide the clearest evidence of discharge temperature effects. *M. flaccida* was one of the most abundant and widely distributed intertidal algae in Diablo Cove before power plant start-up, but was nearly eliminated shortly after power plant start-up. While the initial growth phases and reproductive phases of *M. flaccida* are important forage items for several taxa of small gastropods (Gaines 1985, Dayton 1971, Nicroti 1977), grazing alone could not have affected this species over such a broad area for such a long period. Foster (1982) found *M. flaccida* to be a successful colonizer in areas subjected to grazing pressure. Significant declines also occurred in Field's Cove and at South Diablo Point. Greatest losses in *M. flaccida* were found closest to the outfall, suggesting that effects on *M. flaccida* occurred along a thermal gradient. The results suggest that *M. flaccida* may be used as an indicator of the areal extent of thermal effects on intertidal algae.

The kelps *Egregia menziesii*, *Fucus gardneri*, *Pelvetia compressa*, and *Postelsia palmaeformis* were not as widely distributed or as abundant as *M. flaccida*. Changes in these brown algae are consistent with observations on the effects of increased water temperature in other brown algae (Arndt 1968; Devinny 1975, Vadas et al. 1976). *P. palmaeformis* (listed for protection by CDF&G) is a cool-temperate, annual brown kelp specific to wave exposed headlands (Abbott and Hollenberg 1976). Prior to power plant operation, its southern range limit was South Diablo Point. The demise of this species at both North and South Diablo Point may have been due to a combination of the warm water of the 1983 El Niño, limited spores for recruitment, and the area possibly remaining too warm during power plant operation to allow recovery. The nearest populations of *P. palmaeformis* now occur approximately 6 km north, at Montaña de Oro State Park.

Mechanisms that would explain the patterns of change in *Chondracanthus canaliculatus* are unclear. The species declined significantly in Diablo Cove, although it also declined at the control stations following plant start-up. Because the reductions in Diablo Cove were temporary, its recovery may represent the establishment of a warm-water tolerant strain of this alga. Reciprocal transplant experiments would be needed to test if the Diablo Cove and control populations were different strains of the same species.

The significant decreases detected in algal abundances near their upper intertidal range suggest that water temperature may be of importance in determining vertical distribution. However, the increase in grazer densities and barnacle cover in the high intertidal could also account for the observed declines (see Section 3.3.6 - *Intertidal Community-Level Analysis*). Another potential mechanism that might account for the decreases was the loss of *Mazzaella flaccida* as canopy cover that offered shorter-statured understory taxa (e.g., *Mazzaella affinis*) some protection from desiccation during low-tide.

Secondary discharge effects on algal abundances include changes brought about by other ecological interactions, including grazing and competition. Declines in algal diversity closely corresponded to increases in grazer abundance. In another study at DCPP, North et al. (1989) were uncertain whether the changes they observed were caused directly by the discharge, or resulted from secondary causes from the discharge. They also observed declines in warm-water tolerant taxa (e.g., *Endocladia muricata*). The temperature tolerance of *E. muricata* is not well understood, but its occurrence in high intertidal zones and in southern California demonstrates its ability to survive warm conditions. Grazer abundance and barnacle cover increased in the intertidal zone occupied by *E. muricata*, and the decline in the cover of

E. muricata may have been related to increased grazing on the algal sporelings for recruitment and decreased recruitment space from the large settlements of barnacles. Conversely, the decline in *E. muricata* may have resulted in increased space for barnacle and grazer settlement.

Phyllospadix spp. provides important low-intertidal/shallow-subtidal habitat for fish and invertebrates (Stewart et al. 1978). Prior to plant operation, *Phyllospadix* spp. cover was reduced due to the 1982/83 winter storms. This occurred in the sampling transects and in some areas immediately offshore of the transects (based on qualitative observations). The algae *G. subarticulatum* colonized some of the areas formerly occupied by *Phyllospadix* spp. This switch was not observed in control areas. In other studies, Hodgson (1980) and Turner (1985) found that *Phyllospadix* spp. was slow to recover in areas where it had been removed, especially in areas successfully colonized with *G. subarticulatum.* The lack of recovery in *Phyllospadix* spp. in Diablo Cove may have been related to competition with *G. subarticulatum.* Although *Phyllospadix* spp. significantly declined at the transects in Diablo Cove after power plant start-up, healthy patches of the surfgrass did remain in some lower intertidal areas during the operation period.

Power plant discharge effects changed the relative abundance between grazers and algae in Diablo Cove. For example, declines in *M. flaccida* represented the loss of a species that is not preferred by grazers, as the outermost tissue layer in healthy, non-reproductive blades is thought to have an important role as an anti-herbivore defense (Gerwick and Lang 1977). There was a concurrent increase in non-coralline crustose algae, ephemeral algae, and benthic diatoms, taxa that are all known to be palatable to grazers (Lubchenco 1978; Watson and Norton 1985; Hay 1986). These conditions may have facilitated an overall increase in grazer populations in the Diablo Cove intertidal zone.

3.4.2 Invertebrates (Horizontal Band Transect Data)

Community-level Changes

The effects of the discharge on the intertidal invertebrates at Diablo Cove HBT stations included a significant increase in numbers of invertebrate taxa in Diablo Cove at the +0.9 m elevation, and declines in species' frequencies of occurrence at both elevations, relative to the control. Smaller changes, though not statistically significant, were also detected at stations located to the north (Field's Cove) and south (South Diablo Point) of Diablo Cove. Correspondence analysis of survey scores demonstrated that the largest community changes within Diablo Cove were coincident with power plant start-up, and that considerable inter- and intra-annual community variation was still occurring in 1995.

An important effect of power plant operation on the intertidal invertebrate community in Diablo Cove was a decrease in algal cover and a corresponding increase in open space. Algal cover decreased as a direct result of increased water temperatures and also indirectly from biological factors such as increased grazing pressure from herbivores. Once the standing stock of algae was reduced, algal grazers, particularly limpets and snails, were likely able to maintain the open space. Field studies have documented increases in algal abundance following the removal of grazers from intertidal areas (e.g., Dayton 1971).

Changes in algal species composition and abundance could have affected the abundance of intertidal invertebrates in two ways: increasing food resources (non-coralline crustose algae), and increasing open space for sessile colonizers. Crustose films are a primary food resource for many limpet species and for *Tegula funebralis* (black turban snail) (Wara and Wright 1964; Morris et al. 1980), and probably facilitated increases in the abundance of these grazers. The creation of patchy, open space may also contribute to successful recruitment of gastropod algal grazers (Sousa 1979a), which is consistent with the findings in this study.

Increases of the barnacle *Chthamalus fissus* in Diablo Cove at both station levels (see Section 3.3.2 - *Intertidal Invertebrate Results*) were enhanced by the loss of algal cover and the consequent increase in space available for settlement. *C. fissus* larvae are thought to recruit more heavily in open areas where space is limited (patchy open space), compared to areas of expansive open space (Pineda 1994). There is also an abundant *C. fissus* broodstock in the main cooling water system that potentially provided an abundant larval supply into Diablo Cove (D. Sommerville, PG&E, pers. comm.). The increase in the abundance of the shorecrab, *Pachygrapsus crassipes*, within Diablo Cove may be also be related to increases in the abundance of *C. fissus*. Pineda (1994) noted that *P. crassipes* feeds heavily on *C. fissus* cyprid larvae.

Losses of surfgrass (*Phyllospadix* spp.) in Diablo Cove affected associated invertebrates by reducing available habitat in the low intertidal zone. In a southern California study, Stewart et al. (1978) found, excluding four species of invertebrates exclusively associated with *Phyllospadix*, similar invertebrate species occurred in surfgrass beds and in adjacent areas of mixed algal cover. They concluded that surfgrass beds enhanced invertebrate populations by extending and concentrating environments favorable to many species, thereby greatly increasing invertebrate abundance in the region as a whole.

Measurement of ecological stability or persistence is a complex problem (Connell and Sousa 1983). While it is probably not possible to measure the ecological stability of the intertidal invertebrate community in Diablo Cove following power plant operation, a reasonable approach would be to compare one set of indices between periods for the control and impact groups of stations, and evaluate the relative persistence of species in the two groups. Two assumptions of the Fisher's exact test were: 1) the control stations represented the natural community and were therefore in 'equilibrium', and 2) the number of increases should approximate the number of decreases in an unaffected population. The analysis demonstrated that the ratio of increases and decreases differed significantly between the two areas. This was largely due to invertebrate species in Diablo Cove occurring less frequently than expected by the test during the operation period. Species richness actually increased significantly at the +0.9 m transects during operation, although many species declined in abundance.

Direct effects of power plant operation on the invertebrate community included temperature, an increase in water velocity, and temporary burial under foam or shell debris. It is generally not possible to determine with certainty the effect of these factors without studies designed to evaluate their role separate from other effects. Some organisms may be tolerant of one type of perturbation but susceptible to another, while others may be generally tolerant. *A. elegantissima* is apparently tolerant of all these factors. In Diablo Cove, *A. elegantissima* formed dense aggregations at the discharge structure, the area with the highest water temperatures, the greatest frequency of foam accumulation, and highest water velocities. This taxon also occurs in the thermal discharge canal of the Morro Bay Power Plant, 18 km north of DCPP (North 1969). In the lower intertidal, *A. elegantissima*, *Pagurus* spp., and *T. funebralis*, were the most abundant invertebrates observed directly in the discharge during full operation (PG&E 1988a), indicating a tolerance to increased water temperatures and high water velocities.

Species-level Changes

In general, the effect of power plant operation on intertidal invertebrate taxa was characterized by their relative shifts in operation period abundances, rather than the appearance or disappearance of specific taxa. Among these relative shifts, and in contrast to abundance declines observed in the algae (see Section 3.3.1 - *Intertidal Algae Results*), the most obvious macroinvertebrate responses to the discharge included abundance increases of motile algal grazers (e.g., limpets, urchins, black turban snails), barnacles, and anemones. Motile species, however, may have moved into the permanent stations from adjacent tidal levels or areas, and the results must therefore be interpreted with caution. Taxa that decreased in abundance between periods generally were long-lived, sedentary grazers such as chitons and black abalone, brooding sea stars, and encrusting forms such as colonial /social tunicates and sponges.

Although temperature is one of many factors regulating the distribution and abundance of species, it would be speculative, lacking detailed experimental studies, to describe potential mechanisms of indirect power plant effects to explain a change in the abundance or behavior of a particular invertebrate in Diablo Cove. For example, after power plant start-up, sea urchins became more numerous and formed overgrazing areas ('barrens') in north Diablo Cove, but not in control areas. The causes of urchin overgrazing behavior are complex and not well understood (Foster and Schiel 1985; Elner and Vadas 1990). Possible mechanisms include a response to decreased predation (Leighton et al. 1966, Estes and Palmisano 1974), changing oceanographic conditions that enhance urchin recruitment (Rowley 1989), and intensified food searching behavior resulting from declines in the availability of drift algae (Dean et al. 1984). Some combination of these factors, together with an altered thermal regime, may have contributed to the formation of these urchin overgrazing areas in Diablo Cove.

3.4.3 Invertebrates (Algal-Faunal Association Study)

Overview

Results of the Algal-Faunal Association Study (AFAS) demonstrated discharge-related changes to associated invertebrates within samples of *Endocladia muricata* and *Gastroclonium subarticulatum* from Diablo Cove. Inspection of individual species plots from Field's Cove, comparing pre- versus operation period data, suggest that discharge-related changes also occurred within Field's Cove, though this observation was not tested statistically. These, however, involved fewer taxa and were smaller in magnitude than the changes detected in Diablo Cove.

The AFAS method provided quantitative data on invertebrate taxa abundances per standardized weight of two habitat algae, *E. muricata* and *G. subarticulatum*. Because algal sampling locations were not randomly selected, but chosen to sample pure stands of the target algae, invertebrate abundances in the samples did not measure abundance changes in the invertebrate populations within the cove. That is, the AFAS only sampled changes in invertebrate abundances *within available target algae*. Because the HBT study showed that both algae decreased within Diablo Cove between periods (see Section 3.3 - *Intertidal Results*), reported results, particularly in taxa where no effects were detectable, likely underestimated actual population impacts. This would be especially true for invertebrates that appeared to have obligate associations with specific algae (e.g., *Musculus pygmaeus* and *Oligochinus lighti* associated with *Endocladia*). Similarly, invertebrates that showed significant increases between periods may have, when habitat algae decreases are considered, truly declined as a Diablo Cove population. A randomized sampling design within, or among available intertidal algae would be necessary to accurately document invertebrate population changes. Glynn (1965) noted that *E. muricata* provided an important refuge for associated invertebrate taxa that enabled them to withstand warm air temperatures and desiccation during exposure at low tide. Glynn also found that the invertebrate community associated with *E. muricata* was relatively stable, varying little in composition between years. This contrasts to the large variation in *E. muricata* community composition during the operation period in the present AFAS study.

Community-level Changes

Correspondence analysis (CA) showed that invertebrate community structure changed between periods for both algae sampled. However, changes in species richness were only significant in the assemblage associated with *Endocladia*, where it declined (Table 3-13). CA also showed that community changes were continuing through 1994 at all three stations, evidenced by the continued and increasing divergence of survey scores, by station, from their pre-operation pattern. The changes were greatest at NDC-AF, and may have been related to warmer water temperatures and greater water temperature variability in north Diablo Cove as compared to south Diablo Cove (see Section 2.2.3 - *Intertidal Temperatures*). Discharge-related changes in the abundance of invertebrates associated with other intertidal algal taxa were not studied, but an earlier analysis of the AFAS documented differences in composition and numbers of taxa among four intertidal algae *(E. muricata, G. subarticulatum, Chondracanthus canaliculatus,* and *Corallina vancouveriensis*) before power plant operation (Dearn 1988).

There were no apparent patterns of effects across taxonomic groupings between periods. For example, although some gastropod, amphipod, and polychaete taxa increased significantly, others decreased significantly. There were also no apparent patterns of effects between consumer groups (e.g., algal grazers and filter feeders).

Species-level Changes

There was no consistent pattern in the distribution of taxa that declined significantly between periods. Several species in the study were the northernmost cases of their reported distributions (i.e., *Norrisia norrisi*, *Odostomia eucosmia*, and *Turbonilla kelseyi* [Table 3-18]). These species all have planktonic larval forms (Morris et al. 1980). Glynn (1988) discussed the northward transport of larvae during El Niño events, and the presence of these taxa in the Diablo Cove region was likely due to this transport process. Following their initial settlement, these species were then able to successfully rear, grow, and reproduce within the warmer water environment of Diablo Cove.

The AFAS method sampled small invertebrates that were 0.1-1 cm in greatest dimension, although larger specimens were occasionally present in the samples. Most of the invertebrates were adult forms that were not quantified in the HBT method because they could not be differentiated to the species level in the field. These small taxa, primarily gastropod genera, were listed as only present or absent in the HBT sampling. Some taxa in AFAS samples were juveniles of larger adult forms that were quantified in the HBT. For these taxa, responses to the discharge noted in the AFAS results paralleled results of the HBT study, with few exceptions. *Tegula brunnea* (brown turban snails) increased within Diablo Cove *Gastroclonium* AFAS samples after plant start-up, but significantly decreased at Diablo Cove HBT stations. Conversely, a significant decline in the abundance of *Tegula funebralis* (black turban snail) was observed within Diablo Cove *Endocladia* and *Gastroclonium* AFAS samples, while significant increases were observed at Diablo Cove HBT stations, at both elevations. These results are potentially related to the different sampling methodologies and the different size-classes of organisms sampled in the two methods. The HBT method accurately sampled larger organisms within fixed quadrats, whereas the AFAS method accurately sampled small organisms in selected stands of algae. Specifically, these results indicate that *T. brunnea* could and did settle in Diablo Cove, evidenced by the presence of small individuals in the AFAS. The decline of large individuals noted in the HBT therefore suggests differential mortality of larger individuals (see Section 4.4.2 - *Subtidal Invertebrate Discussion*). Conversely, the increase of adult *T. funebralis* noted in the HBT, and the decline of juveniles in the AFAS, suggests emigration from intertidal *Endocladia* and *Gastroclonium* habitats, rather than discharge-related mortality.

3.4.4 Black Abalone

Declines in Diablo Cove populations of *Haliotis cracherodii* in Diablo Cove following power plant start-up were the result of withering syndrome (WS) caused mortality, exacerbated by elevated discharge temperatures. In the absence of WS, discharge water temperatures would not be expected to cause abalone mortalities. Adult *H. cracherodii* tested in on-site laboratory experiments were unaffected by temperatures below 24°C, showed optimum growth at 17.9°C and could tolerate temperatures from 27°C to 29°C, depending upon acclimation temperatures (Hines et al. 1980). During power plant operation, black abalone in north Diablo Cove intertidal areas were exposed to seawater temperatures of up to 22°C during high tides over several tidal cycles (Figure 2-7). Typical intertidal temperature regimes in north Diablo Cove during fall would have exposed abalone to water temperatures in the 18-20°C range, alternating with air temperatures during low tides. Considering 96hr-ET_{50} results, these water temperatures would not have caused mortality due to thermal stress.

In a laboratory experiment done in 1979, black abalone were held at temperatures from 18-24°C and survived for several months with few mortalities and no symptoms of withering syndrome (PG&E 1982a). In contrast, the results of the 1988 laboratory experiment, reported in Steinbeck et al. (1992), showed that temperatures of 18°C caused mortalities among abalone with WS symptoms within a few months, with 86% mortality after 496 days. The increased mortality in the 1988 experiment was attributed to WS. One explanation of these results is that black abalone used in the experiment, and by extrapolation black abalone in those areas (all outside of Diablo Cove) where they were collected, were carriers of the WS pathogen. The incidence of WS, or at least obvious visual symptoms, among the abalone was a function of time and temperature. At low (ambient) temperatures more time was required for symptoms to show and the incidence was lowest. As temperature was increased above ambient, the abalone displayed WS symptoms at a rate directly proportional to the temperature increase and the incidence of the disease was highest at the highest temperature.

The decrease in black abalone abundance in Diablo Cove, observed in 1988, was coincident with the onset of WS mortalities. The high mortality rate from WS in Diablo Cove was apparently caused by chronic exposure to increased water temperatures from DCPP. This conclusion is supported by three lines of evidence: 1) WS mortality was most acute in north Diablo Cove, an area of high abalone abundance, and one of the warmest intertidal areas of the cove; 2) laboratory experiments demonstrating a relationship between increased water temperatures and increased rates of black abalone mortality from WS; and 3) the rate of decreases in abalone along 10-meter transect surveys declining with increasing distance from Diablo Cove (Table 3-20).

Withering syndrome in black abalone was first described from the southern California Channel Islands in 1986 (Haaker et al. 1992; Tissot 1988). WS was observed at Point Arguello in 1989, but occurred in such low frequency that abundances did not decline noticeably until 1994 (Altstatt et al. 1996). The disease was reported from Diablo Cove in June 1988 (PG&E 1989) and was still affecting abalone in 1995, even though the population numbers partially recovered from 1991 to 1995, probably as a result of juvenile recruitment. Recent work has identified a protozoan that infects the digestive system of black abalone and is the likely cause of WS (Gardner et al. 1995). Although the pathogen that causes WS may have infected black abalone from southern California through San Luis Obispo County, the absence of symptoms in some populations throughout this range suggests that the pathogen can be either dormant or less virulent under normal conditions. It appears that the WS pathogen was present in the abalone at all times and became active only when the body resistance was lowered rather than being absent and highly virulent only when it entered the body of the abalone.

Black abalone grow slowly, requiring decades to attain maximum size (Blecha et al. 1992). WS disease effectively shifted the size composition of the remaining black abalone population to one composed mostly of small individuals. Their relatively slow growth implies that even with individuals resistant to the disease, local populations of large abalone could not significantly increase for many years.

Although adults declined in response to WS, juvenile recruitment continued. The reduction of fleshy algae and the corresponding increase in open space and coralline crust in the barrens area may have contributed to the relatively high recruitment of juvenile black abalone in north Diablo Cove from 1991 to 1994. The strongest juvenile recruitment events were observed in 1991 and 1994 with weaker events in 1992 and 1993: the total number of juveniles per year ranged between 256 and 599 during this time. A very weak recruitment occurred in 1995 with an annual total of only 41 juveniles observed. Of the many factors which contribute to the success of juvenile abalone recruitment (Slattery 1992), three are especially relevant in the present case: an area of favorable habitat; the presence of individuals of the same species; and the chemical compound GABA (gamma aminobutyric acid) which occurs naturally in crustose coralline algae (Morse et al. 1979). Although juvenile black abalone were observed in all areas of Diablo Cove from 1991 to 1994, over 50% of the juveniles abalone observed in random quadrat surveys occurred in the area of the urchin barrens. Juveniles were commonly observed in association with purple urchins, often under their spine canopy. Results also indicate a high mortality rate in newly recruited juvenile abalone between these years.

Sea otters have been observed to feed occasionally on black abalone in the Diablo Canyon study area (Gotshall et al. 1984, 1986; Benech 1995). Following initial declines in black abalone abundance in 1974-75 attributed to sea otter predation (Gotshall et al. 1984, 1986), abundances in Diablo Cove remained relatively stable, although variable, from 1975-1982. Results of the Diablo Cove random surveys from 1984-1988 showed no obvious trends in a stable black abalone abundance and size structure. The sharp decline in abundance in 1989-1991 in Diablo Cove could have been the result of otter foraging activities, but this possibility is not supported by evidence of either direct observation of increased foraging activities (S. Benech, pers. comm.) or an increase in the number of black abalone shells with indications of otter predation (J. Blecha, pers. obs.). Otter predation would first cause a reduction in the preferred larger abalone, followed by declines in smaller less preferred sizes (Benech 1995). A pattern of size-specific declines was not observed in the data; decreases occurred among all size classes. Lastly, sea otters in the Diablo Canyon study area have been observed feeding on black abalone and other intertidal organisms more frequently than during past years (S. Benech, pers. com.). At the same time, the abalone from these shallower feeding areas are larger than those observed several years ago. In this respect, the otter's prey selection of black abalone appears to parallel prey selection of purple urchins. The largest individuals are selected from deep water areas first, and urchin and abalone in shallow water are not preyed upon until prey in deep water are depleted (Benech 1995).

Humans could also affect the number of black abalone present within Diablo Cove by selective harvesting. Black abalone are usually harvested from shore during low tides rather than by divers during high tides. While diver harvesting is possible, it has not been observed nor is it likely to have occurred often since surge conditions in these shallow subtidal areas are seldom suitable for diving. Human harvesting of black abalone, if it did occur, would be expected to impact only the largest individuals and not all size classes as observed. Sport diving activities in Diablo Cove have been observed both directly and indirectly (bar chipped shells) to involve harvesting of the larger, more preferred red abalone (J. Blecha, pers. obs.).

3.4.5 Intertidal Fish

The intertidal fish community in Diablo Cove and Field's Cove prior to power plant operation was similar to that described in other central California rocky coast habitats (Horn et al. 1983; Yoshiyama et al. 1987). Discharge effects were manifested as decreases in abundances of the common species with little change in the rankings of species. In the BACI analysis, four intertidal fish taxa declined significantly after power plant start-up. Comparisons used Field's Cove station FC1-V as a 'control' in the analysis, but FC1-V was contacted by power plant discharges and was a 'transitional' impact station, not a true control.

Xiphister mucosus, one of the more common taxa, has a cool-temperate distribution from Alaska to Point Conception (Miller and Lea 1972) which suggests that it would be susceptible to warm water discharge effects. Analysis of the field data detected significant declines, possibly reflecting its preference for cooler temperatures. Periodic recruitment of juveniles in Diablo Cove indicated that intertidal areas of the cove still provided viable habitat for the species during the operation period. Because fish are motile animals, their ability to avoid deleterious temperatures in a thermal field reduces their susceptibility to mortality from direct temperature effects.

Several intertidal fishes either use algae directly as a food source (Horn et al. 1982) or feed on associated invertebrates only as juveniles (Setran and Behrens 1993). Indirect effects from the significant losses of algal cover in Diablo Cove after power plant start-up (see Section 3.3.1 - *Intertidal Algae Results*) may, in part, have accounted for changes in the abundance and distribution of some taxa.

The population structure of intertidal fish found in Diablo Cove and Field's Cove was characterized by seasonal pulses of stichaeid recruitment (Kelly and Behrens 1985). No concurrent studies were performed to determine the effect of the discharge on stichaeid recruitment in shallow subtidal habitats, although Setran and Behrens (1993) noted differences in optimal intertidal refuge requirements among juvenile *Cebidichthys violaceus* (part of the *Anoplarchus/Cebidichthys* complex in the present analysis) and *X. mucosus* in Diablo Cove. It would therefore be reasonable to conclude that reductions in Diablo Cove and Field's Cove juvenile recruitment seen during the operation period also affected the abundances of both intertidal and subtidal adult stichaeids.

4.0 SUBTIDAL STUDIES

4.1 Introduction

The subtidal zone of Diablo Cove and the surrounding area share many of the same biological and physical attributes of other central California subtidal areas. Foster and Schiel (1985) provide an extensive overview of subtidal kelp forest ecology pertaining to central California, and McLean (1962) and Breda (1982) provide descriptive accounts of species composition and distributions in select kelp forests.

The following description is a general overview of the subtidal habitat that characterized the Diablo Canyon nearshore vicinity before power plant operation and that presently exists in areas outside the influence of the discharge. In the transition zone between the low intertidal and shallow subtidal, surfgrass *Phyllospadix* spp. fringes the shoreline to depths of about -2 m MLLW. Beyond the -2 m depth contour to depths of about -15 m, the subtidal algal assemblage is characterized by scattered dense kelp forests. *Nereocystis luetkeana* (bull kelp) is a common surface canopy forming kelp along the coast in this area. *Macrocystis pyrifera* (giant kelp) occurs with *N. luetkeana* in semi-exposed areas, but tends to be more abundant in calmer water. A third surface canopy-forming species, *Cystoseira osmundacea*, also occurs with these two kelps, generally in areas shallower than about -10 m. The canopies of all three kelp species develop in the spring and become most luxuriant during summer-fall.

Pterygophora californica and *Laminaria setchellii* are one-meter tall kelp plants that provide subcanopy structure throughout the year. The lower-growing algal understory is composed of foliose, branched, filamentous, and crustose species, which is most abundant at depths less than about 10 m. Mats of articulated coralline algae are common in the algal understory, and provide habitat for numerous species of small snails and crustaceans. *Tegula brunnea* (brown turban snails), *Cancer antennarius* (rock crabs), and a variety of sea stars are common kelp forest inhabitants. Sponges, tunicates, bryozoans, and tube-dwelling worms encrust the vertical surfaces of rocks where algal growth is not as prevalent. Crevices and boulder interstices provide shelter for many animals, such as *Haliotis rufescens* (red abalone) and benthic rockfishes (*Sebastes* spp.). Other fish, including *Sebastes* spp., occur in association with the kelp canopies and irregularities over the ocean floor. The kelp canopies provide habitat for fishes, particularly juveniles, which associate with the kelp for protection from predation, while other species, such as *Oxyjulis californica* (señoritas), and Embiotocids (surfperches), swim more freely in the kelp forests. Numerous species of bottom-associated fishes inhabit the area as well, many of which (e.g., lingcod, cabezon, rockfish) are targeted in sport and commercial fisheries.

Similar to intertidal areas, rock relief and wave exposure in the Diablo Cove subtidal are greater in the north versus south portion of the cove. The spatial variation in these physical features influence local species distributions, and can result in natural differences in species abundances between the two sides of the cove.

Species Studied in the TEMP Subtidal Surveys

The TEMP subtidal studies sampled algae, invertebrates, and fish at permanent stations at various depths within and outside of Diablo Cove (Section 4.2 - *Subtidal Methods*). Sampling of *N. luetkeana* and *M. pyrifera* in Diablo Cove was done by counting and mapping the distribution of plants observed from permanent cliff-top stations. The population of *Haliotis rufescens* (red abalone) was also sampled in a random station sampling design that included shell measurements and inspection of animals for withering syndrome. A listing of all species found appears in Appendix D.

4.2 Methods

4.2.1 Sampling Methods and Station Locations

In order to measure abundances of algae, invertebrates and fish, permanent subtidal sampling stations were established in Diablo Cove and north and south from the DCPP discharge. 'Benthic' or bottom stations were sampled for algae and invertebrates. Fish were counted along other permanent transects originating at selected benthic stations. Although counted in the benthic sampling, additional surveys of red abalone, rock crab, and canopy-forming kelps were done using methods specifically designed to sample those particular species. Sampling frequency was approximately quarterly for most subtidal tasks, but varied over the duration of the program. A description of the generalized benthic station layout and sampling procedure is followed by a specific description of each of subtidal sampling method.

The primary subtidal benthic stations were located in areas adjacent to the intertidal stations, approximately 3 per area (Figure 4-1). Three complementary sampling methods were performed by three divers at each station: 1) Random point contact (RPC) for algae and sessile invertebrates; 2) counts of macroinvertebrates and kelps in subtidal 7 m^2 arc quadrants (SAQ); and 3) counts of all invertebrates, regardless of size or growth form in subtidal fixed 0.25 m^2 quadrats (SFQ). All stations were established on substrata of mixed bedrock and boulders with varying amounts of cobble and sand. Depths ranged from -3 m to -10 m MLLW.

Each permanent subtidal station was circular, with a radius 3.1 m and a sampling area of 28 m^2 (Figure 4-2). The central 4 m^2 area occupied by the mooring wheel, and a marginal buffer zone, were not sampled in order to avoid the unnatural algal and invertebrate growths associated with the artificial substrate of the mooring. Each station was divided into four equal sections, or 'arc quadrants', 7 m^2 in area.

Random Point Contact (RPC)

The RPC method quantified the percent area covered by sessile invertebrates, algae, and substrates. Divers used a weighted line attached to the center of the station. To locate sampling loci, the line had 10 points positioned at increasing intervals toward the station perimeter. Fifty points within each of four arc quadrants were randomly selected (using a random number table) before sampling, yielding a total of 200 points per station during each survey. A unique set of random sampling loci were used for each survey. The diver rotated the line counter clockwise to sequentially sample organisms contacting the pre-selected points. The presence of all taxa observed directly under the loci were recorded.

Subtidal Arc Quadrant (SAQ)

The purpose of the SAQ method was to determine the abundance of the more conspicuous macroinvertebrates and kelp species at each station. The invertebrate taxa included a short list of common species that were counted regardless of size (Table 4-1), and all taxa greater than 2.5 cm in largest dimension. A few common species that occurred in numbers too high to efficiently count (noted in Table 4-1) were sampled only in the first one-third of each arc (2.33 m^2). The algal species counted were *Cystoseira osmundacea, Egregia menziesii, Laminaria setchelli, Macrocystis pyrifera, Nereocystis luetkeana, Pterygophora californica,* and *Sargassum muticum. Cystoseira osmundacea* was further differentiated into those plants consisting of only a small basal portion, and larger plants with floating reproductive thalli.

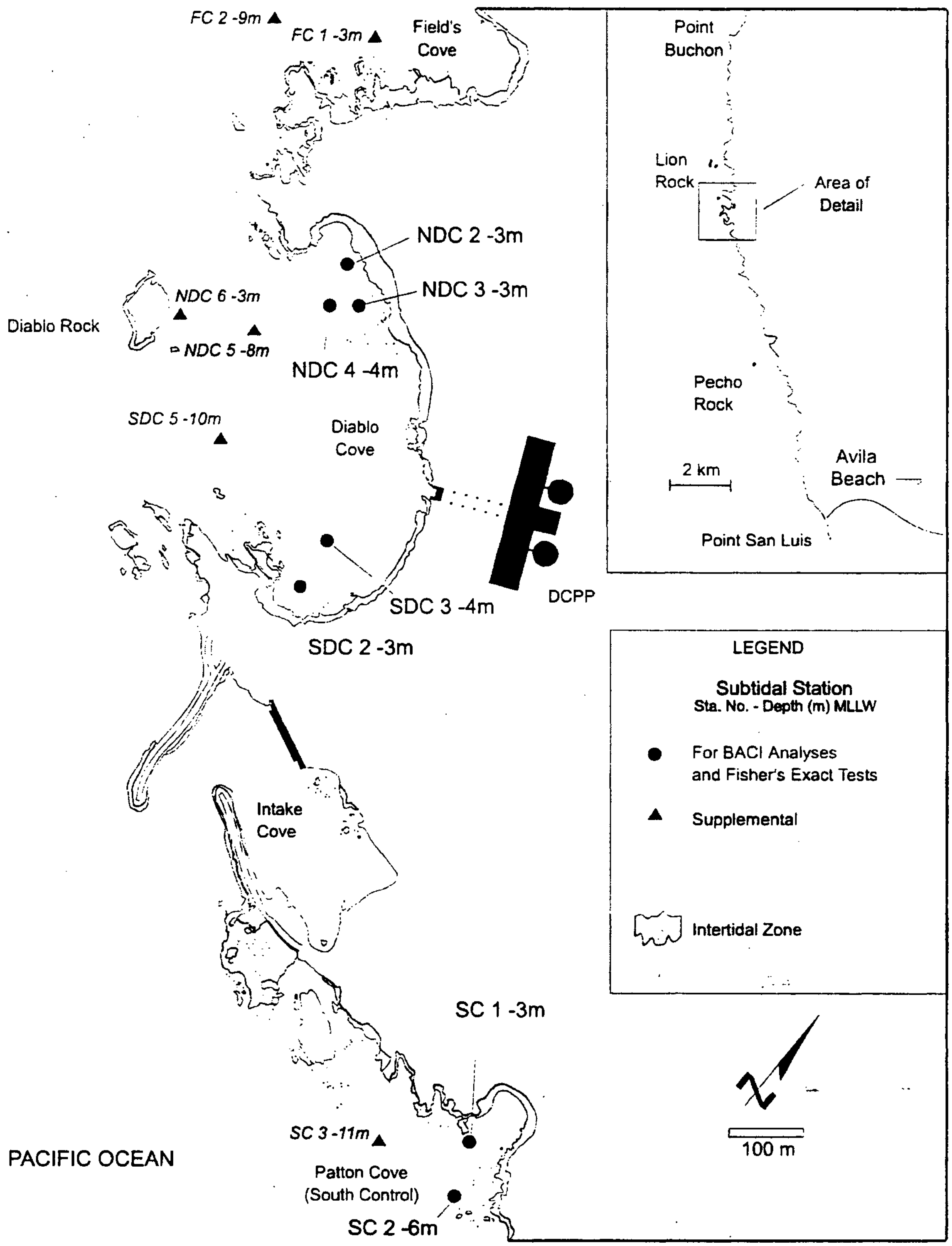


Figure 4-1. Locations of subtidal benthic stations.

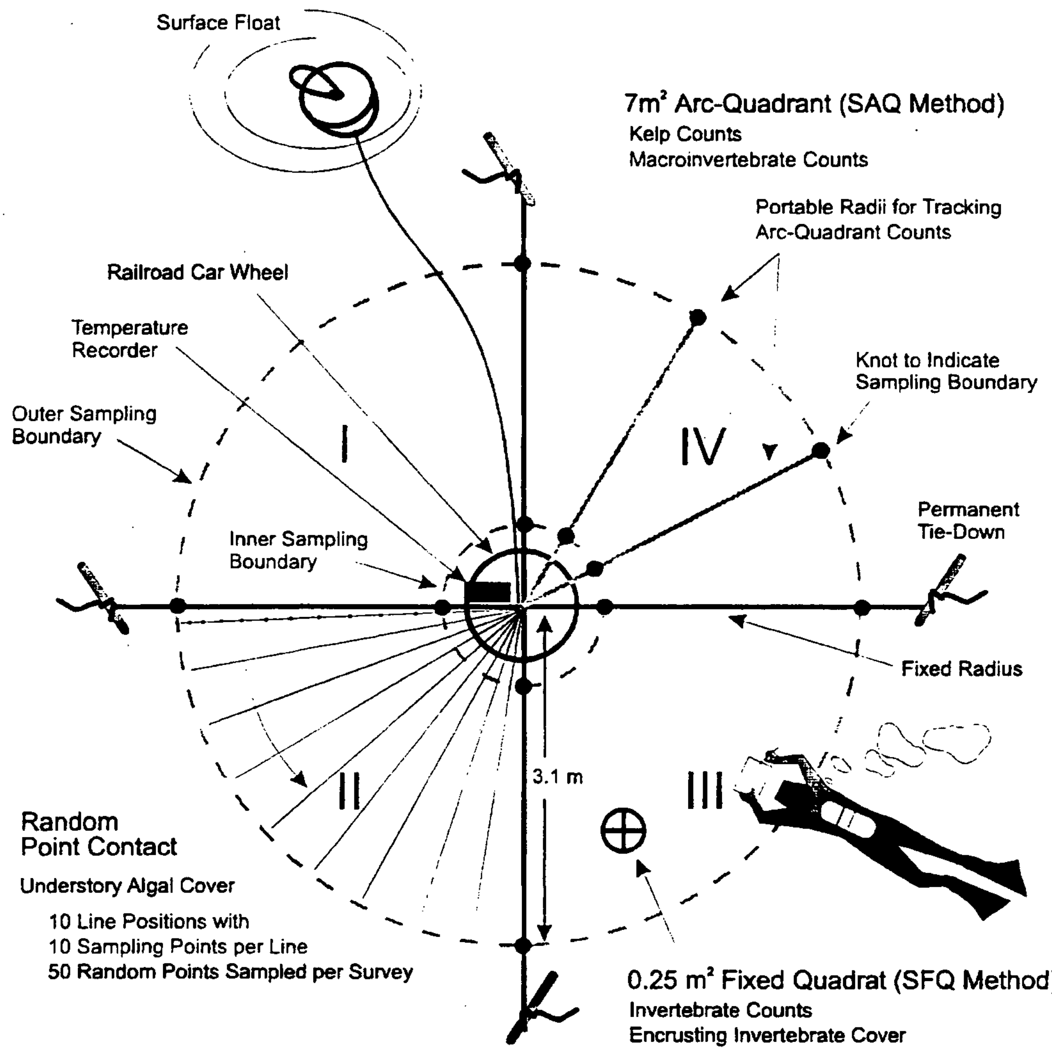


Figure 4-2. Diagram of $28m^2$ subtidal benthic station illustrating the three sampling methods. Each of the three methods is used in each $7m^2$ quadrant.

Table 4-1. Invertebrate taxa counted regardless of size in subtidal arc quadrants. Mollusca marked with an asterisk (*) were only counted in first one-third of each quadrant due to typically high abundances. Total numbers of these taxa per station were calculated accordingly.

Taxon	Common Name
Porifera	
Tethya aurantia	Orange puffball sponge
Anthozoa	
Anthopleura elegantissima	Aggregating anemone
Tealia crassicornis	anemone
Tealia lofotensis	White-spotted rose anemone
Echinodermata	
Asterina miniata	Bat star
Leptasterias hexactis	Six-rayed sea star
Pycnopodia helianthoides	Sunflower star
Parastichopus spp.	Sea cucumber
Pisaster giganteus	Giant spined sea star
Pisaster ochraceus	Ochre sea star
Strongylocentrotus franciscanus	Red sea urchin
Polychaeta	
Diopatra ornata	Tube worm
Eudystylia polymorpha	Feather duster worm
Mollusca	
*Acmaea mitra**	Dunce cap limpet
Anisodoris nobilis	Sea lemon nudibranch
*Calliostoma ligatum**	Topsnail
*Tegula brunnea**	Brown turban snail
*Tegula montereyi**	Monterey turban snail
Lithopoma gibberosum	Wavy top snail
*Tonicella lineata**	Lined chiton
Crustacea	
Cancer antennarius	Rock crab
Pagurus spp.	Hermit crab
Urochordata	
Styela montereyensis	Stalked tunicate

The observer started sampling by positioning two 3.5 m moveable reference lines to divide the arc (one-quarter of the station) into thirds (Figure 4-2). The moveable lines and fixed station lines were all marked to clearly delineate the sampling area boundaries. Organisms were counted within the 7 m^2 arc according to the preceding criteria, and the observer then proceeded in a counter-clockwise direction around the station, eventually sampling all four arcs. Although rocks were not overturned during the search effort, the search effort did include rock crevices and underhangs.

Subtidal Fixed Quadrats (SFQ)

Four circular quadrats with an area of 0.25 m^2 were monitored at fixed locations within each subtidal station to determine the species composition and abundance of smaller, more cryptic subtidal invertebrates, especially those not accurately quantified by the SAQ or RPC methods. Quadrats were established on bedrock or boulder substrate and marked with a small brass eyelet.

To begin sampling, the observer attached the center of the circular quadrat (crossed by two thin stainless steel rods) to the permanent eyelet. Abundances of organisms were recorded on a pre-printed plastic data sheet, as in other subtidal methods. There were no minimum or maximum size limits for the invertebrates in these quadrats. Encrusting forms were quantified by the number of square inches of cover (determined by reference marks on the quadrat), and individuals of all other taxa were counted.

Bull Kelp and Giant Kelp Cliff-top Counts

To determine the changes in kelp canopy through time, surveys were done from cliff-top vantage points above north and south Diablo Cove (Figure 4-3). In these surveys, the total number of surface-emergent bull kelp (*Nereocystis luetkeana*) plants within Diablo Cove were counted and giant kelp (*Macrocystis pyrifera*) surface canopy cover was mapped. Cliff-top kelp surveys were conducted once per year in October, and were done from 1971 to 1994 (surveys from 1971 to 1982 were done by CDF&G). By conducting surveys in October, almost all of the bull kelp plants had reached the surface in their annual growth cycle and could be counted prior to kelp break-up during winter storms. Sub-surface plants could not be counted using this method, but they were counted in the SAQ method described previously.

Two observers per vantage point counted bull kelp plants and mapped the general extent of kelp canopies independently on a pre-printed map of Diablo Cove. Binoculars (7x35) were used to help distinguish individual plants. Notes were also taken on the occurrence of bull kelp plants with bare bulbs, a condition indicative of early blade senescence in plants chronically exposed to warm temperatures.

A final annual census total was developed by summing the maximum plant counts within each area of Diablo Cove, and a composite map depicting the locations of bull kelp and giant kelp was developed from the data of all four observers.

Kelp Overflight Photographic Surveys and Mapping

Aerial photograph surveys were completed one to four times yearly during the period of 1969-1990 to document the extent of kelp beds (*Nereocystis luetkeana* and *Macrocystis pyrifera*) in the vicinity of the power plant. In each survey, infrared (IR) photographs were taken sequentially along a predetermined flight path spanning the region between Point Buchon and Point San Luis (Figure 4-1). All photographs were taken using a Wild RC-8 camera with Kodak Ektachrome IR aero film (Type 2443). The overflights ranged in altitude between of 1,371 and 1,828 m (4,500 to 6,000 ft), and occurred during days of no fog and relatively calm seas. The tide level during the surveys ranged between MLLW and +2 m (6 ft) MLLW.

Red Abalone

Although data on red abalone (*Haliotis rufescens*) abundances were collected using the SAQ method, a supplementary study was designed to provide better estimates of distribution, abundance, and size structure of the subtidal red abalone population in the study area. Compared to the SAQ method, the red abalone study sampled a broader area, wider range of depths, allowed detailed searching for juvenile abalone beneath cobbles, and required the use of underwater flashlights to examine deep crevices for the presence of well-hidden abalone. Red abalone surveys were conducted in 1984, 1986, 1987, and twice annually after 1990.

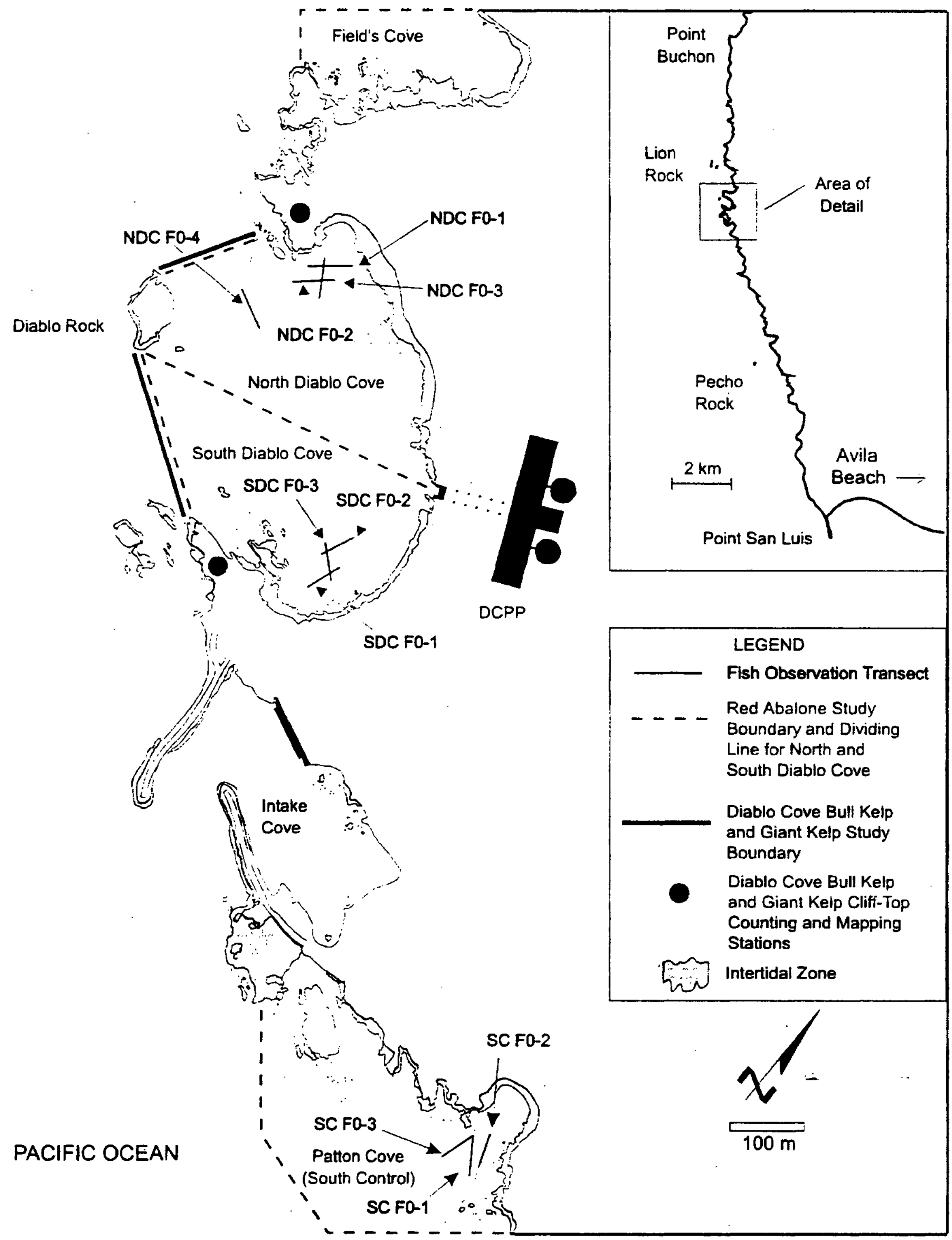


Figure 4-3. Locations of subtidal fish observation transects and red abalone, bull kelp, and giant kelp study areas.

Potential sample sites were the numbered intersections of a 15 m x 15 m grid inscribed on a 1:1,600 scale bathymetric chart of Diablo Cove. The cove was divided into northern and southern halves by a line running from the discharge structure to the eastern edge of Diablo Rock. A similar number of sites, which ranged from 14 to 34 per year, were selected randomly within the northern and southern halves of the cove. Between 70-80% of the approximately 13.8 ha (34 ac) of surface area of Diablo Cove is at a depth of -6 m or less, and the number of selected sites was adjusted by depths to approximate this distribution. Ten sites in Field's Cove (north of DCPP) and ten sites in Patton Cove area (south of DCPP) were also sampled at the same time beginning in 1991. At the time of selection, both areas were considered controls although it was known that the temperature in Field's Cove was slightly above that in Patton Cove. Extensive areas of shallow subtidal depths similar to that in Diablo Cove are not common in the study area. Therefore, selection of the sampling sites in these areas was not strictly random but based on depth, with the range of sampled depths similar to those sampled in Diablo Cove.

Chart and landmark bearings were used to locate sampling sites in the field. After marking the site with a temporary buoy, two divers descended the buoy line to the bottom, then deployed four lines 4 m long that were attached to a central weight, and positioned at 90 degree angles to each other. A knot and flagging on each line 3.1 m from the central weight marked the distal boundary of a circular 30 m^2 area inside the knots to be sampled. The depth of the central weight was the reference depth of the site, and maximum and minimum depths were also recorded. Other physical data recorded were proportions of substrata types (bedrock, boulder, cobble, sand), and bottom relief.

Between a team of two divers, each diver searched two of the four pie-shaped quadrants for all abalone, using hand lights to search all cracks and crevices. Abalone were counted in four size classes: < 25 mm; 25-50 mm; 51-178 mm; and >178 mm shell length. Abalone were either measured in place, or lengths were estimated if abalone were visible but inaccessible. Since 1991, the abundance of several taxa of larger invertebrates and kelps were estimated on the sites sampled. Data for these taxa of special interest were used to supplement data from the subtidal fixed station samples to provide an indication of the areal extent of impacts in areas of Diablo Cove not regularly sampled by other methods.

Fish

Visual counts of fish within fixed subtidal stations were done bimonthly or quarterly from 1976 to 1995. Sampling locations are in Figure 4-3. Each fish observation station consisted of a permanent midwater and benthic transect, in which midwater and benthic fishes were counted separately. A station was delineated by deploying a weighted 50 m transect line from a boat, beginning at a permanent marker buoy and extending along a pre-determined compass course away from the buoy. The benthic sampling area was two meters to either side of the line (4 m width) and 1 m above the bottom. The midwater transect sampling area was a cylinder 4 m in diameter, centered 3 m above the benthic transect. Some transects crossed each other because some sampled along depth contours, and others in the same area sampled across depth contours (Figure 4-3). The area common to both transects in these cases was 2%. It was thought that the overlap did not affect the analysis because numbers of fish counted were totaled by area, and the mobility of most fish added to the independence of transects.

A survey team consisted of two divers, each counting fish along the benthic and midwater portions of a transect independently, but in opposite directions. This sampling technique allowed a more thorough inspection of possible fish habitats from all angles of view than would have been possible by a single diver progressing along a transect in only one direction. Fish were identified to species if possible, but juveniles of some species with similar appearance were combined into broader categories. The resulting survey data was the combined species counts of both divers, divided by two. This yielded an average count for each taxa per 50 m benthic or midwater transect. During each survey, the stations were sampled a second time within one to two weeks of the initial sampling effort. This provided two replicate fish counts within a particular survey for each station.

4.2.2 Data Analyses

The following sections describe data analysis methods specific to the subtidal TEMP studies. The stations, surveys and taxa used in statistically testing for effects of the discharge are described in each section. The BACI model used to test for discharge effects for each study varied slightly from the general model described in the introduction to the intertidal studies (Section 3.2.2 - *Intertidal Data Analyses*). These differences are described in the sections below. A summary of the data used in the statistical analysis for each study is presented in Table 4-2.

Random Point Contact (RPC)

Overview

Effects of the discharge on RPC algal cover were primarily tested using a BACI analysis. Data sets that did not pass tests of assumptions for the BACI analysis were tested using a Fisher's exact test. Correspondence analysis of the TEMP subtidal algal data was used to examine changes in algal communities. All the data for taxa making up the top 99% cumulative abundance were used in graphical analyses showing changes in abundance over time (Appendix E).

Table 4-2. Summary of subtidal data sets used in BACI analyses.

Study	Taxa Groups	Quads	Total # Stations Sampled	Impact Stations in BACI	Control Stations in BACI	Total # Surveys Sampled	Pre-operation Surveys for BACI	Operation Surveys for BACI	Total # Taxa Sampled	# Taxa Analyzed in BACI
Random Point Contact	Algae	4	31	5	2	91	20	22	109	36[1]
Subtidal Arc Quadrant	Invertebrates	4	31	5	2	91	20	22	168	49
	Kelp	4	31	5	2	91	20	22	8	7[2]
Subtidal Fixed Quadrat	Invertebrates	4	31	5	2	91	20	22	231	99
Subtidal Fish	Benthic Fish	-	14	7	3	71	24	29	82[3]	37
	Midwater Fish	-	15	7	3	71	24	29	82[3]	20
Rock Crab Trapping	Rock Crabs	-	49	25	24	66	44	14		

[1] includes 2 crustose algal taxa groups not included in list of top 99% total abundance
[2] includes 2 kelp taxa groups not included in list of top 99% total abundance
[3] taxa totals combined for midwater and benthic transects

Data Analyzed

Stations - A large number of benthic stations were sampled during the TEMP study, but only those stations that were sampled consistently before and during plant operation were used in the BACI analyses. Two stations (SC1-3m and SC2 -6m) both located in Patton Cove, south of Diablo Canyon, were used as reference stations. These were the only two control stations consistently sampled throughout the study. One of the stations is located at a depth of -3 m, and the other at -6 m. Although differences between the stations due to depth, substrate type, and substrate relief may have increased the variability of our estimate of the control mean abundance for some taxa, it was decided that the two stations gave a better estimate than would have been obtained from a single station. Data from five stations (NDC1 -3m, NDC2 -3m, NDC2 -4m, SDC1 -3m, SDC3 -4m) , all in Diablo Cove, were tested for significant changes against the mean abundance from the reference stations.

Surveys - The definitions of pre-operation and operation periods used in the intertidal analyses, which excluded the early years of the study through 1977, and the two years encompassing the start-up of units 1 and 2, were also used for analysis of the RPC data. Surveys were not used in the BACI analysis if both control stations were not sampled during a survey. This resulted in a maximum of 20 surveys in the pre-operation period and 22 surveys in the operation period.

Taxa - Although 109 different algal taxa were identified during the RPC study, most taxa could not be statistically analyzed for changes because they were encountered so infrequently. The 34 taxa analyzed, comprised the top 99 percent abundance in the pre-operation period merged with the list of taxa using the same criteria for the operation period (Appendix F). The mean percentage abundance for each period was calculated for the taxa from the five impact stations used in the analysis. Other data sets analyzed included percent cover of bare substrate, percent cover of crustose and non-crustose algae, species richness of non-crustose algae, and diversity (Shannon-Wiener H') of non-crustose algae.

BACI Analysis

The BACI model for testing effects of the discharge for subtidal RPC data was similar to the model used for intertidal HBT data sets described in Section 3.2.2 - *Intertidal Data Analyses*. The data used in computing deltas for analysis were the mean percentage cover of algae and substrates per 7 m^2, calculated from the four 7 m^2 quadrants at each station. All data sets were tested for assumptions using the set of transformations and constants discussed previously. The analysis presented in the results was chosen based on the power of a given transformation to detect a 50% change in the data, results of the Tukey test for additivity, and other criteria presented previously. Results for all assumption tests and BACI analyses for all transformations are presented in Appendix G.

Unlike the intertidal horizontal band transect study that analyzed the two transect levels separately, the -3 m and the -4 m subtidal stations were analyzed together, because there were no large differences in species composition and abundances between the two depths prior to plant operation. Differences between the depths occurred in the operation period as a result of the varying impacts of the thermal plume at the two depths. To test this hypothesis a set of *a priori* planned comparisons were used in the analyses. The testing proceeded by first determining if there was a significant Station x Period interaction. If there was no significant interaction among stations between periods then the overall Period effect was used to test the hypothesis that there was no significant difference in mean deltas between periods. If the interaction was significant, the interaction was decomposed into two parts to test the hypothesis that there was no difference in the Station x Period effect between depths. If this comparison was not significant, the differences between Periods among Stations were likely the result of a factor other than depth. If the test was significant, differences between Periods were tested separately for the two depths.

Other Analyses

Data sets that did not pass the tests of assumptions for BACI analysis were analyzed using the Fisher's exact test. The analysis was used to test the hypothesis that the proportions of differences categorized as less than or greater than the median difference were independent of period (pre-operation and operation).

The Fisher's exact test was also used to analyze changes in the percentage frequency of taxa occurrences between periods (see Section 3.2.2 - *Intertidal Data Analyses*).

Correspondence analysis was used to describe natural changes and changes caused by the discharge on subtidal algal communities represented by the TEMP RPC data. Correspondence analysis was described in detail in Section 3.2.2 - *Intertidal Data Analyses*. Included in the analysis were data on understory algal cover from the RPC study and data for upright kelp taxa from the subtidal arc quadrant (SAQ) study. Algal taxa that accounted for 95% of the total algal cover and occurred in at least 20% of the surveys were included in the analysis. Kelp taxa that accounted for 99% of the total number of upright kelp taxa and occurred in at least 20% of the surveys were also included in the analysis. The analysis used the same stations analyzed in the BACI analysis. Data were log transformed (log[x+1]) prior to analysis to help remove scale effects caused by combining percentage contact data from the RPC study with count data from the SAQ (Greenacre 1984). Annual mean abundances for individual taxa used in the analysis were computed for Diablo Cove and reference areas from survey means for the stations in those two areas. Annual mean survey and taxa scores from the analysis were plotted to examine and contrast temporal patterns of variation in the two areas.

Subtidal Arc Quadrants (SAQ)

Overview

Effects of the discharge on invertebrate abundance from SAQ data were primarily tested using a BACI analysis. Data sets that did not pass tests of assumptions for the BACI analysis were tested using a Fisher's exact test. Changes in invertebrate communities represented by the SAQ data were analyzed using correspondence analysis. All data for taxa making up the top 99% cumulative abundance were used in graphical analyses showing changes in abundance over time (Appendix E).

Data Analyzed

Stations - The same set of stations used in the subtidal RPC study were used in the BACI analyses for the SAQ data. Two stations (SC1 -3m and SC2 -6m) were used as control stations and five stations (NDC1 -3m, NDC2 -3m, NDC2 -4m, SDC1 -3m, SDC3 -4m) were tested for significant changes against the controls.

Surveys - The same surveys used in the subtidal RPC study were used in the BACI analyses for the SAQ data. Twenty surveys were included in the pre-operation period and 22 surveys in the operation period.

Taxa - Eight algal taxa and 168 invertebrate taxa were identified, most to the species level, during the SAQ study. Most of these taxa could not be statistically analyzed for changes because they occurred so infrequently and their data sets were comprised mostly of zeroes. Invertebrate and algal taxa were each ranked according to abundance using the same methods described for other studies to identify the taxa comprising the top 99 percent of the total cumulative abundance. The kelp taxa comprising the top 99 percent included only 5 taxa. Two additional taxa *Egregia menziesii* and *Nereocystis luetkeana* were also analyzed. The process resulted in 49 invertebrate taxa and 7 algal taxa for analysis (Appendix F). Invertebrate species richness was also analyzed.

BACI Analysis

The BACI model used for analysis of the SAQ data was the same model previously described for the RPC method. The model analyzed -3 m and the -4 m subtidal stations within Diablo Cove as a single group and used a set of comparisons on the interaction term to determine if differences between periods at the two depths should be analyzed separately. The data used in computing deltas for the analysis were the mean abundances of macroinvertebrates and kelp per 7 m^2, calculated from the four 7 m^2 quadrants at each station. All data sets were tested for assumptions using the set of transformations and constants previously presented, and the analysis presented in the results was chosen based on the same criteria used for other studies.

Other Analyses

Data sets that did not pass the tests of assumptions for BACI analysis were analyzed using the Fisher's exact test. The analysis was used to test the hypothesis that the proportions of differences categorized as less than or greater than the median difference were independent of period (pre-operation and operation). The Fisher's exact test was also used to analyze changes in the percentage frequency of taxa occurrences between periods.

Correspondence analysis was used to describe natural changes and changes caused by the discharge on subtidal invertebrate communities represented by the SAQ data. Taxa which accounted for 95% of the total invertebrate abundance and occurred in at least 20% of the surveys were included in the analysis. The analysis used the same stations as the BACI analysis to group the data into two areas. Annual means for individual taxa used in the analysis were computed for Diablo Cove and control areas from survey means for these stations. Data were log transformed (log[x+1]) prior to analysis to compensate for the large scale differences in counts among taxa. Annual mean survey and taxa scores from the analysis were plotted to examine and contrast the temporal patterns of variation at the two areas.

Subtidal Fixed Quadrats (SFQ)

Overview

Effects of the discharge on invertebrate abundance from SFQ data were primarily tested using a BACI analysis. Data sets that did not pass tests of assumptions for the BACI analysis were tested using a Fisher's exact test. Changes in invertebrate communities represented by the SFQ data were analyzed using correspondence analysis. All data for taxa making up the top 99% cumulative abundance were used in graphical analyses showing changes in abundance over time (Appendix E).

Data Analyzed

<u>Stations</u> - The same set of stations used in the subtidal RPC study were used in the BACI analyses for the SFQ data. Two stations (SC1 -3m and SC2 -6m) were used as control stations and five stations (NDC1 -3m, NDC2 -3m, NDC2 -4m, SDC1 -3m, SDC3 -4m) were tested for significant changes against the controls.

<u>Surveys</u> - The same surveys used in the subtidal RPC study were used in the BACI analyses for the SFQ data. Twenty surveys were included in the pre-operation period and 22 surveys in the operation period.

Taxa - Two hundred and thirty-eight invertebrate taxa were identified during the SFQ study. Invertebrate taxa were ranked according to abundance using the same methods described for other studies to identify the taxa comprising the top 99 percent of the total cumulative abundance. The process resulted in the selection of 99 invertebrate taxa for analysis. Invertebrate species richness was also analyzed.

BACI Analysis

The BACI model used for analysis of the SFQ data was the same model previously described for the RPC method. The model analyzed -3 m and the -4 m subtidal stations within Diablo Cove as a single group and used a set of comparisons on the interaction term to determine if differences between periods at the two depths should be analyzed separately. The data used in computing deltas were the mean abundances of invertebrates per 0.25 m^2 calculated from the four quadrats at each station. All data sets were tested for assumptions using the set of transformations and constants previously presented, and the analysis presented in the results was chosen based on the same criteria used for other studies.

Other Analysis

Data sets that did not pass the tests of assumptions for BACI analysis were analyzed using the Fisher's exact test. The analysis was used to test the hypothesis that the proportions of differences categorized as less than or greater than the median difference were independent of period (pre-operation and operation). The Fisher's exact test was also used to analyze changes in the percentage frequency of taxa occurrences between periods.

Subtidal Fish Observations (SFO)

Overview

Effects of the discharge on fish abundance from SFO data were primarily tested using a BACI analysis. Data sets that did not pass tests of assumptions for the BACI analysis were tested using a Fisher's exact test. Changes in fish communities represented by the SFO data were analyzed using correspondence analysis. All the data for fish taxa making up the top 99% cumulative abundance were used in graphical analyses showing changes in abundance over time (Appendix E).

Data Analyzed

Stations - The stations used in the BACI analyses included stations NDC-1, NDC-2 and NDC-3 from north Diablo Cove, stations SDC-1, SDC-2 and SDC-3 from south Diablo Cove, and stations SC-1, SC-2 and SC-3 (South Control). Midwater and benthic transects from each station were analyzed separately. Data from the three stations in an area were combined into area means for each survey for analysis.

Surveys - As for all previous BACI analyses the time periods analyzed were the same pre-operation and operation periods used in the intertidal analyses. The analyses included 24 surveys in the pre-operation period and 29 surveys in the operation period.

Taxa - The same methods used for the other studies to identify the taxa comprising the top 99 percent of the total abundance was also done for the SFO data. The process resulted in the selection of 20 taxa from the midwater stations and 37 taxa from the benthic stations (Appendix F). Species richness and diversity were also analyzed.

BACI Analysis

The BACI model used for analysis of the subtidal fish data was similar to the model used for the intertidal algal-faunal association study where two impact areas were tested against a single control location. Benthic and midwater transects were analyzed separately. Mean fish abundances within an area were calculated for each survey using the data from the three station transects. Deltas used in the analyses were calculated by subtracting the mean survey abundance for each of the two impact areas from the mean abundance for the control area. All data sets were tested for assumptions using the set of transformations and constants previously presented, and the analysis presented in the results was chosen based on the same criteria used for other studies.

Other Analyses

Data sets that did not pass the tests of assumptions for BACI analysis were analyzed using the Fisher's exact test. The analysis was used to test the hypothesis that the proportions of differences categorized as less than or greater than the median difference were independent of period (pre-operation and operation). The Fisher's exact test was also used to analyze changes in the percentage frequency of taxa occurrences between periods.

Correspondence analysis was used to examine natural changes and changes resulting from the discharge on fish communities represented by the SFO data. Only the data from the benthic transects were analyzed. An analysis was done to identify the taxa that accounted for 95% of the total abundance and occurred in at least 20% of the surveys. This list, excluding all young-of-year (YOY) and juvenile fishes, was analyzed. The analysis included the same stations used in the BACI analysis. Annual means for individual taxa used in the analysis were computed for Diablo Cove and reference areas from survey means for these stations. Data were log transformed (log[x+1]) prior to analysis to compensate for the large scale differences in counts among taxa. Annual mean survey and taxa scores from the analysis were plotted to examine and contrast the temporal patterns of variation at the two areas.

Bull Kelp and Giant Kelp Cliff-top Counts

The data from this study were not analyzed statistically for effects of the discharge, due to the absence of control data from outside of Diablo Cove. The results are presented as annual counts of plants, and the distribution of surface canopy coverage in Diablo Cove.

Kelp Overflight Photographic Surveys and Mapping

Kelp maps portraying the distribution and patch sizes of kelp along the Diablo Canyon coast for the period 1969-1977 were constructed from aerial photographs by PG&E (1979). The analysis of those images, detailed in PG&E (1979), consisted of scanning the photographs into digitized images, and then projecting the images onto a computer screen. The kelp images were then traced on the screen using a light pencil, and kelp enumerated for area cover by counting the 'picture points' representing kelp. The present study used ARC/INFO and ArcView Geographic Information System (GIS) software database applications for mapping and determining kelp cover of more recent photographic surveys (October 1981, October 1985, July 1987, and June 1989). Positive IR transparencies were scanned for digitized computer input. Land segments and offshore areas with no kelp were masked to reduce computer file size. Color bands from the images were separated and enhanced to aid in distinguishing kelp from foam, waves, sun reflections, and land. Surface and subsurface kelp color bands were selected and extracted from the images using Adobe PhotoShop software. *M. pyrifera* and *N. luetkeana* could not be distinguished in the photographs and maps. The GIS system was used for orienting and scaling the resultant images of kelp coverage to a digital, geo-referenced model of the coastline. After reconciliation of image overlap, the resulting shapefile polygons were used to calculate the areal extent of kelp in selected zones within the study area.

Digital maps were developed to measure the approximate areal extent of discharge effects in Diablo Cove, Field's Cove and adjacent areas. The areas of these polygons were determined by tracing the polygon outlines as a layer onto the geographic information system (GIS) basemap and then deriving the areas, converted to hectares, using the ARC/INFO GIS system. Only four surveys were completed and included in this report. This limited our ability to use the kelp mapping data in the analysis of discharge effects.

Red Abalone

Data for red abalone from the SAQ and SFQ data sets were analyzed using a BACI model and the methods described for SAQ and SFQ studies. Data from the random red abalone stations were summarized and presented in graphical or tabular form. Trends in abundance and size distribution data were derived from these summaries.

4.3 Subtidal Results

4.3.1 Algae

One-hundred and nine algal taxa (101 understory and 8 kelp taxa) were sampled in the subtidal study. *Phyllospadix* spp. (surfgrass) is a flowering plant that is included with the algae in the present report, due to similarities in ecological function. Figure 4-4 summarizes the changes in abundance between periods for understory algal cover (not including crustose forms) and kelp counts in Diablo Cove. The taxa comprising the top 99% of the total abundance for the combined Diablo Cove stations were analyzed for changes against control abundances (Figure 4-5). The list included 34 taxa from the RPC study and 7 kelp taxa from the SAQ study. Several kelp taxa that were counted in the SAQ study were also abundant according to percent cover by the RPC method, providing a total of 39 taxa analyzed for the two studies. Seventy other taxa (inclusive of those listed in Figure 4-4a as 'other taxa') were not specifically analyzed for individual changes, but were included in computations for diversity (H'), species richness (numbers of taxa), and total algal cover.

Prior to analyses, assumption tests required for the BACI analysis were completed using transformed and untransformed data for each of the 39 taxa and for other subtidal algal data sets including diversity (H'), total algal cover, species richness, bare rock, and sand cover (Appendix G). Table 4-3 summarizes the main discharge effects on subtidal algae, with more detailed analyses following.

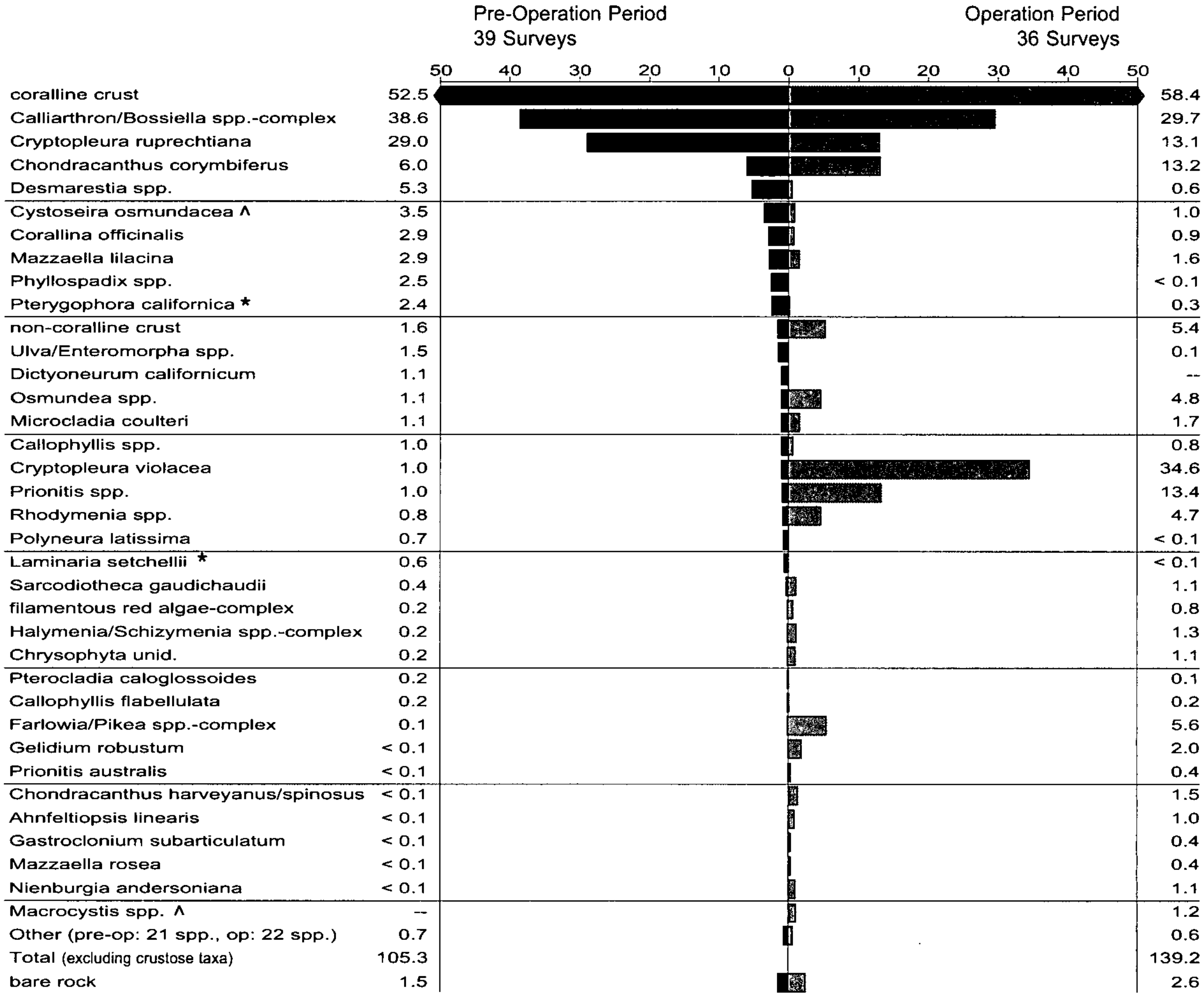
Table 4-3. Summary of discharge effects on subtidal algae sampled using the random point contact and arc quadrant sampling methods.

Category	-3 m MLLW and -4 m MLLW levels combined	Comments
Total area of bottom with observed effects.	8.1 ha (19.9 ac)	Most effects were in Diablo Cove at depths shallower than -7 m MLLW.
Effects on algal diversity (H')	increase	BACI result; significant increase at 4 m depth.
Effects on overall numbers of algal taxa	decrease	BACI result; significant decreases at 4 m depth.
Effects on algal cover	no change	BACI result; crustose taxa were not included.
Number (%) of taxa increases	14 (36%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa decreases	11 (28%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa unchanged	2 (5%)	BACI results only.
Number (%) of taxa with inconclusive test results	12 (31%)	Includes both BACI and Fisher's exact test.
Number of taxa analyzed statistically	39	Taxa comprising top 99% cumulative abundance.
Number of taxa sampled during study	109	Includes all Diablo Cove stations combined; also includes some species that were grouped into combination taxa for analysis.

Analysis of Taxa Changes

Twenty algal taxa passed the tests of assumptions and were analyzed for changes using the BACI model (Table 4-4). The other taxa were analyzed using the Fisher's exact test (Table 4-5). Taxa were categorized as statistically significant increases, statistically significant decreases, no significant changes, and

a) Diablo Cove - Understory Algae: mean percent cover



^ = basal frond cover for *Cystoseira* and sporophyll and holdfast cover for *Macrocystis*

* = holdfast cover for *Pterygophora* and *Laminaria*

b) Diablo Cove - Kelps: mean no. individuals per 7m²

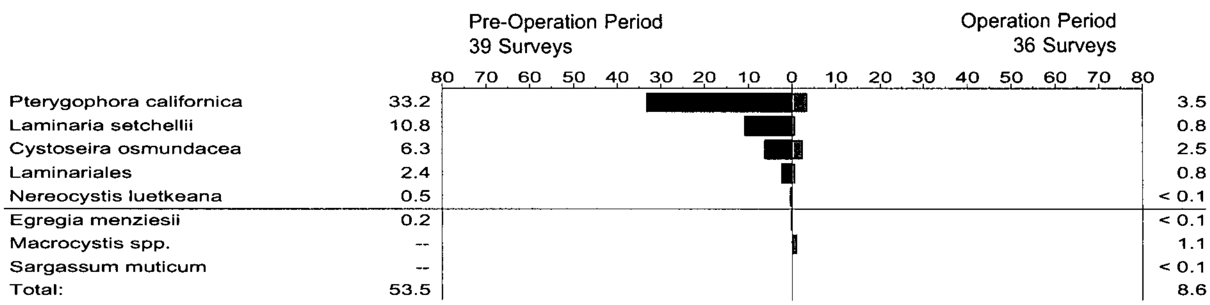


Figure 4-4. Algal abundances at the Diablo Cove subtidal benthic stations. (a) Understory algae mean percent cover sampled by the SLC method. (b) Kelp mean counts/$7m^2$ sampled by the SAQ method.

a) South Control - Understory Algae: mean percent Cover

	Pre-Operation Period 24 Surveys	Operation Period 29 Surveys
coralline crust	61.5	52.5
Calliarthron/Bossiella spp.-complex	46.4	42.5
Cryptopleura ruprechtiana	25.5	37.3
Chondracanthus corymbiferus	24.2	20.3
Callophyllis spp.	4.2	5.9
Ulva/Enteromorpha spp.	3.7	0.6
Polyneura latissima	3.4	2.1
Mazzaella lilacina	3.1	1.4
Laminaria setchellii	2.4	3.1
Cystoseira osmundacea^	2.4	2.7
Desmarestia spp.	2.4	2.9
Pterygophora californica*	1.4	4.6
filamentous red algae-complex	1.4	< 0.1
Dictyoneurum californicum	1.2	--
Microcladia coulteri	1.2	0.7
Halymenia/Schizymenia spp.-complex	1.1	0.2
Osmundea spp.	1.0	2.4
Prionitis spp.	1.0	1.6
Callophyllis flabellulata	0.9	0.6
Corallina officinalis	0.8	0.8
Rhodymenia spp.	0.7	7.9
non-coralline crust	0.7	1.1
Erythrophyllum delesserioides	0.6	0.2
Sarcodiotheca gaudichaudii	0.6	0.2
Phyllospadix spp.	0.4	< 0.1
Cryptopleura violacea	0.4	0.4
Delesseriaceae (juv.)	0.3	--
Farlowia/Pikea spp.-complex	0.3	0.1
Pterosiphonia dendroidea	0.2	--
Gelidium robustum	0.1	0.4
Other (pre-op: 22 spp., op: 16 spp.)	1.5	0.8
Total (excluding crustose taxa)	132.8	140.0
bare rock	2.5	1.6

^ = basal frond cover for *Cystoseira*, * = holdfast cover for *Pterygophora* and *Laminaria*

b) South Control - Kelps: mean no. individuals per 7m²

	Pre-Operation Period 24 Surveys	Operation Period 29 Surveys
Pterygophora californica	48.4	79.5
Laminaria setchellii	36.3	45.7
Laminariales	16.4	28.6
Cystoseira osmundacea	4.1	4.7
Nereocystis luetkeana	1.1	2.1
Egregia menziesii	< 0.1	< 0.1
Total:	106.4	160.6

Figure 4-5. Algal abundances at the South Control subtidal benthic stations. (a) Understory algae mean percent cover sampled by the SLC method. (b) Kelp mean counts/7m² sampled by the SAQ method.

Table 4-4. Results of BACI ANOVA for subtidal algae and surfgrass. Negative values indicate decreases between periods for individual stations. Statistically significant results (p<0.10) are in **bold** type. Analysis was based on percent cover as measure of abundance, except where noted.

	% Change in Diablo Cove Relative to Controls	Period F	Period P	Power to detect 50% Change	Sta*Per Interaction P	Depth*Per Interaction P	Period -3m P	Period -4m P	Pairwise Comparisons by Station (p) [mean temperature above ambient in °C] NDC 2-3m [3.4°]	NDC 3-3m [3.8°]	NDC 4-4m [3.4°]	SDC 2-3m [2.0°]	SDC 3-4m [1.2°]
Significant increase													
Cove-wide (Both Depths)													
Bare rock substrate	+163	5.1	.03	.97	.58	.31	.01	.24	.39	.02	.26	.05	.46
Cryptopleura violacea	+3044	113.8	<.01	.29	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.01
Filamentous red algae	+12369	5.9	.02	.16	<.01	.16	.01	.03	.01	<.01	.01	.10	.12
Prionitis spp.	+1423	17.6	<.01	.21	<.01	<.01	<.01	.02	<.01	<.01	<.01	<.01	.83
Sarcodiotheca gaudichaudii	+478	6.5	.02	.56	<.01	.21	.03	.01	<.01	-.51	.01	<.01	.01
Depth-specific (-3 m stations only)													
Coralline algae (crustose)	+24	17.0	<.01	1.00	<.01	<.01	<.01	.34	<.01	<.01	-.58	<.01	.04
Depth-specific (-4 m stations only)													
Chondracanthus corymbiferus	+85	6.5	.02	1.00	<.01	<.01	.11	<.01	.57	-.84	.06	<.01	<.01
Phyllospadix spp.[1]	-96	25.0	<.01	1.00	<.01	<.01	-<.01	.05	-<.01	-<.01	.07	-<.01	.06
Diversity (H')	+16	4.5	.04	1.00	<.01	<.01	.29	<.01	.69	.86	.13	.02	<.01
Significant decrease													
Cove-wide (Both Depths)													
Calliarthron/Bossiella spp.	-22	10.0	<.01	1.00	<.01	.02	-<.01	-.06	-.02	-<.01	.59	-.12	-<.01
Callophyllis spp.	-65	6.3	.02	.71	<.01	<.01	-.04	-<.01	-.04	-.02	-<.01	-.14	-.38
Cystoseira osmundacea[2]	-63	35.1	<.01	1.00	<.01	.86	-<.01	-<.01	-<.01	-<.01	-<.01	-.12	-.21
Laminaria setchellii[2]	-91	945.6	<.01	1.00	<.01	<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-.05
Depth-specific (-3 m stations only)													
Corallina officinalis	-58	18.5	<.01	1.00	<.01	<.01	-<.01	.22	-<.01	-<.01	.21	-<.01	.42
Desmarestia spp.	-79	16.4	<.01	1.00	<.01	<.01	-<.01	-.22	.38	-.52	.89	-<.01	-.04
Phyllospadix spp.[1]	-96	25.0	<.01	1.00	<.01	<.01	-<.01	.05	-<.01	-<.01	.07	-<.01	.06
Sand, gravel, shell debris	-16	0.3	.60	1.00	<.01	<.01	-.07	.16	.70	.81	<.01	<.01	-.47
Nereocystis luetkeana[2]	-97	1.7	.20	.45	.02	.01	-.06	-.75	-.24	-.09	-.30	-.03	.66
Egregia menziesii[2]	-83	6.8	.01	1.00	<.01	.02	-<.01	-.65	-<.01	-.23	-.69	-.74	-.76
Depth-specific (-4 m stations only)													
Algal Species Richness	-11	8.1	.01	1.00	<.01	<.01	-.23	-<.01	-.72	.89	-.20	-.01	-<.01
No change[3]													
Microcladia coulteri	+166	<.01	.92	.71	.41	.12	-.70	.45	-.79	-.37	.68	.82	.36
Rhodymenia spp.	-30	1.5	.23	.73	.01	.73	-.28	-.21	-.01	-.54	-.57	.77	-.09
Algal Cover	+8	0.5	.50	1.00	.03	.05	.71	.27	.60	-.73	.49	.37	.16
Test Results Inconclusive[4]													
Osmundea spp.	+96	0.2	.67	.38	<.01	.14	.73	.58	.50	-.91	.61	.65	.57
Polyneura latissima	-83	0.5	.49	.24	<.01	<.01	.15	-.65	.16	.15	-.85	.18	-.49
Laminariales juv. unid.[2]	-69	0.3	.59	.18	<.01	<.01	-.33	.91	-.59	-.30	-.66	-.19	.51

[1] taxon listed twice because of differing significant effects between depths.
[2] analysis based on counts of individual plants.
[3] no significant difference between period means, and power of the test to detect a 50% change between periods was greater than .70.
[4] no significant difference between period means, and power of the test to detect a 50% change between periods was less than .70.

Table 4-5. Results of Fisher's exact test for subtidal algae not tested in BACI analysis. Statistically significant results (p<0.10) are in **bold** type.

Taxon	Fisher's P
Significant Increase	
Ahnfeltiopsis linearis	**<.01**
Callophyllis flabellulata	**.09**
Chondracanthus harveyanus/spinosus	**<.01**
Farlowia spp./*Pikea* spp.	**<.01**
Gelidium robustum	**<.01**
Halymenia spp./*Schizymenia* spp.	**<.01**
Macrocystis pyrifera	**<.01**
Non-coralline algae (crustose)	**<.01**
Significant Decrease	
Cryptopleura ruprechtiana	**<.01**
Pterygophora californica	**<.01**
Test Results Inconclusive	
Chrysophyta unid.	.19
Dictyoneurum californicum	.14
Gastroclonium subarticulatum	.28
Mazzaella lilacina	.78
Mazzaella rosea	.58
Nienburgia andersoniana	.13
Prionitis australis	.51
Pterocladia caloglossoides	.26
Ulva spp./*Enteromorpha* spp.	.78

test results inconclusive. Graphs depicting changes in abundance over time for each taxon in Figure 4-4 appear in Appendix E.

Significant Increases

Significant increases, relative to controls, were detected in 14 of the 39 algal taxa analyzed using the BACI analysis (Table 4-4) and Fisher's exact test (Table 4-5). All were understory algae, except *Macrocystis pyrifera*. There were two general patterns of increase: 1) increases beginning soon after power plant start-up; and 2) increases beginning several years after start-up. *Cryptopleura violacea* is an example of the first pattern, in which the increase began approximately one year after power plant start-up (Figure 4-6). *Gelidium robustum* exemplified the second response pattern, responding more slowly to the changed conditions in Diablo Cove and increasing gradually over time (Figure 4-7). There were also some anomalies in the analysis results, specifically the significant increase identified in *Phyllospadix* spp. at the -4 m stations (Table 4-4). This taxon declined during the pre-operation period at Diablo Cove stations and there was also a pre-operation decline in the control population (Figure 4-8). Eventually, *Phyllospadix* spp. became absent at all stations. The different magnitudes of change before and after power plant start-up between the Diablo Cove stations and the control population resulted in the analysis incorrectly identifying the change as a significant increase in *Phyllospadix* spp. at the -4 m stations, relative to the control population.

Macrocystis pyrifera was the only species of kelp that increased significantly in Diablo Cove after power plant start-up (Figure 4-9). Changes in the coverage of its surface canopy throughout Diablo Cove were also mapped, along with counts and mapping of surface-occurring *Nereocystis luetkeana* (see following - *Kelp Mapping*).

Significant Decreases

Eleven algal taxa significantly declined at the impact stations, relative to controls, based on results of the BACI analysis (Table 4-4) and Fisher's exact tests (Table 4-5). These included the kelps *Nereocystis luetkeana*, *Laminaria setchelli*, *Pterygophora californica*, and *Egregia menziesii*. *Cystoseira osmundacea* (Fucales) also significantly declined in abundance, and is included as a kelp for the present discussion. *N. luetkeana* was irregular in occurrence at the stations during the pre-operation study period, but plants no longer occurred during power plant operation at the impact stations tested in the BACI analysis (Figure 4-10). The changes in this kelp species over the entire Diablo Cove area were noted from cliff-top stations by counting floating pneumatocysts (bulbs) and mapping their occurrences (see following - *Spatial Extent of Impacts*).

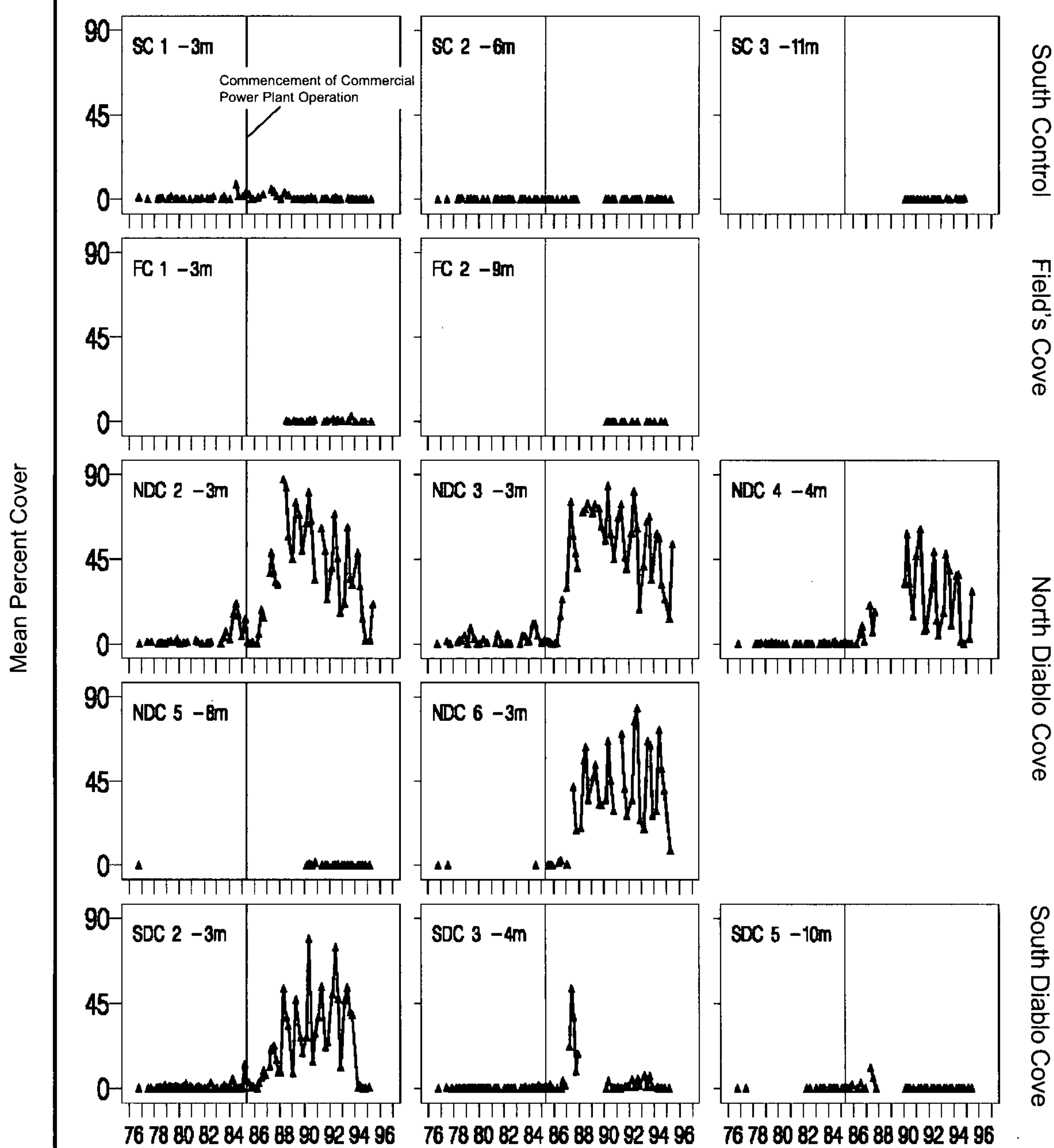


Figure 4-6. *Cryptopleura violacea*: changes in cover at subtidal benthic stations.

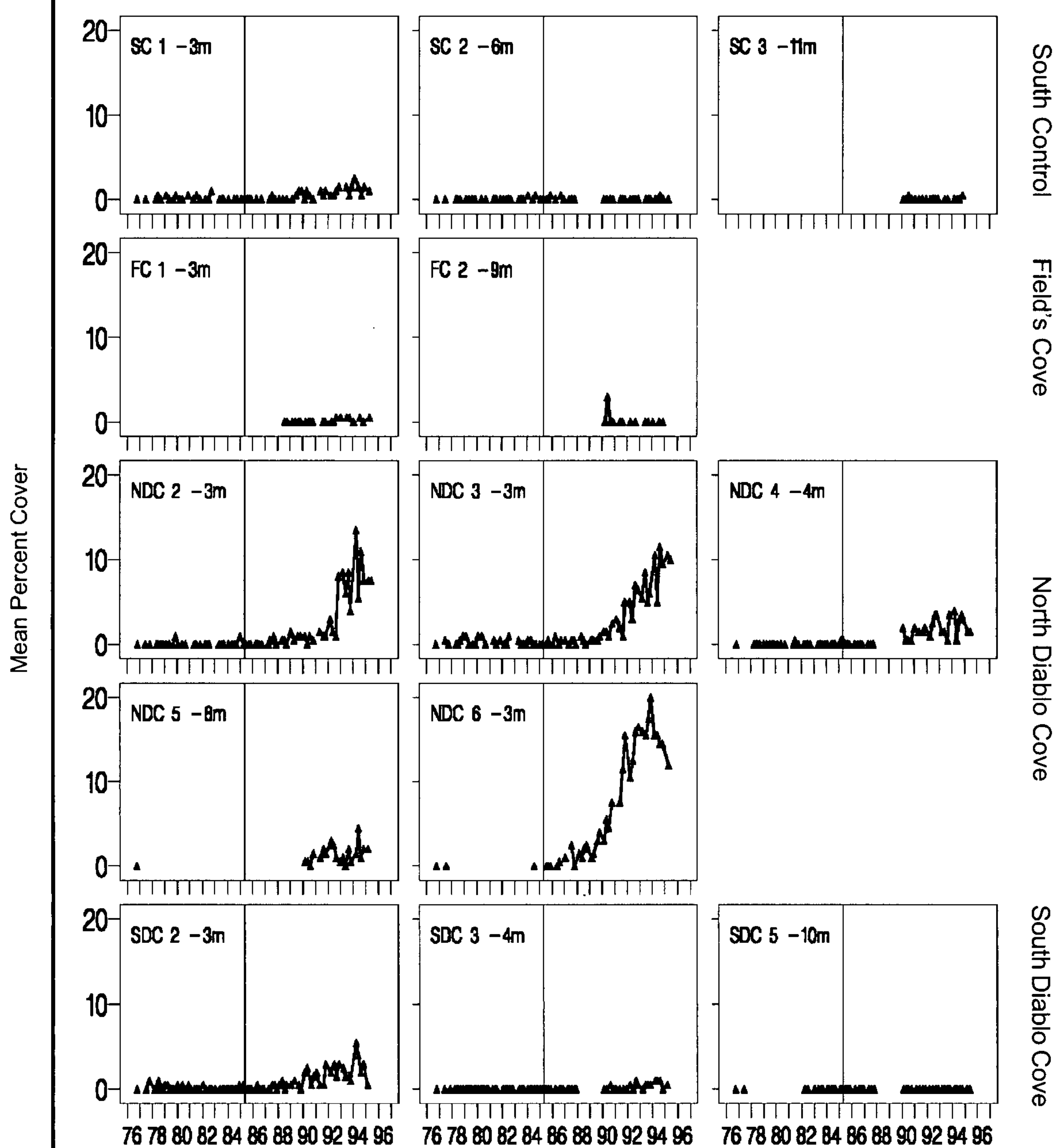


Figure 4-7. *Gelidium robustum*: changes in cover at subtidal benthic stations.

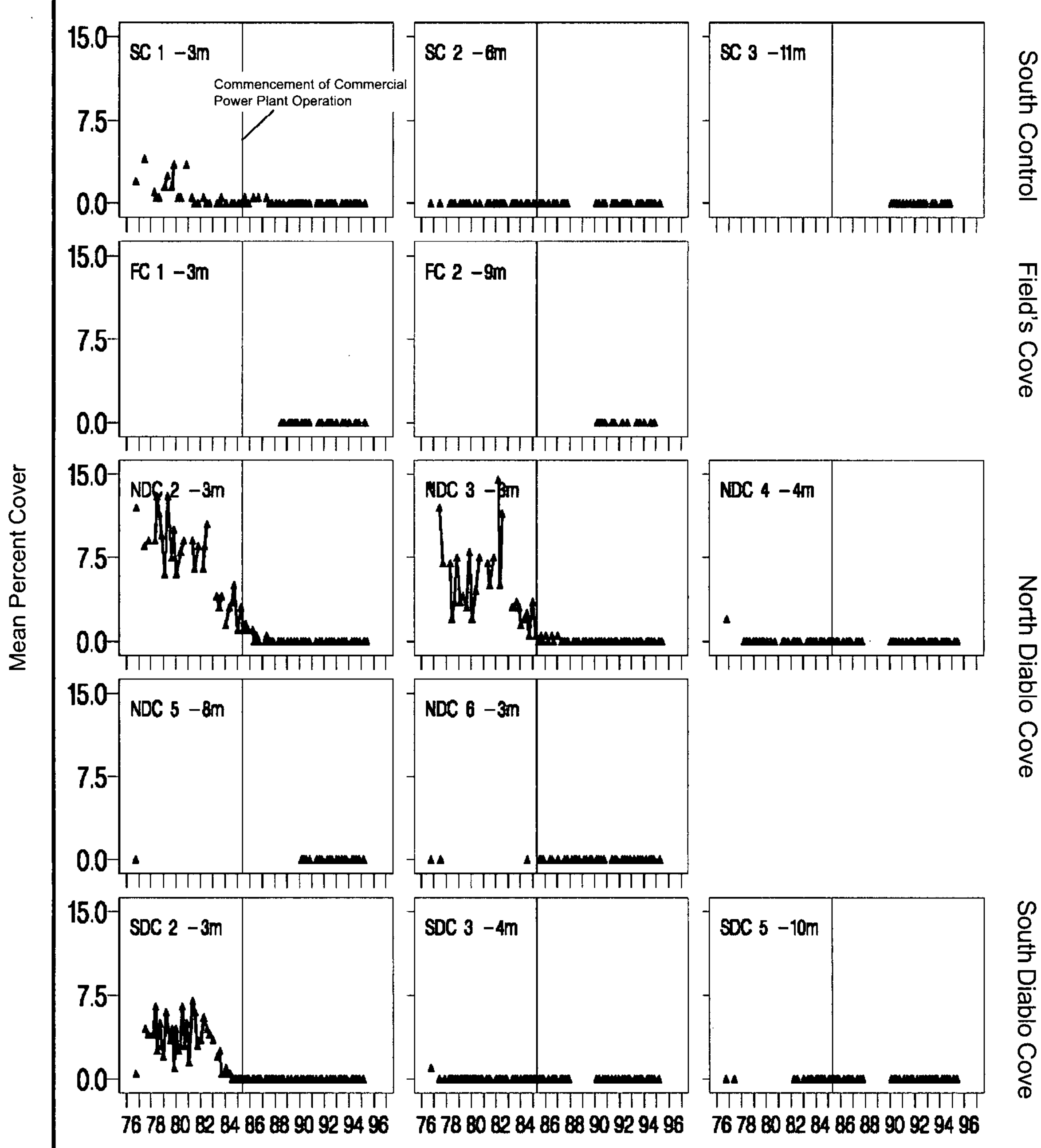


Figure 4-8. *Phyllospadix* spp.: changes in cover at subtidal benthic stations.

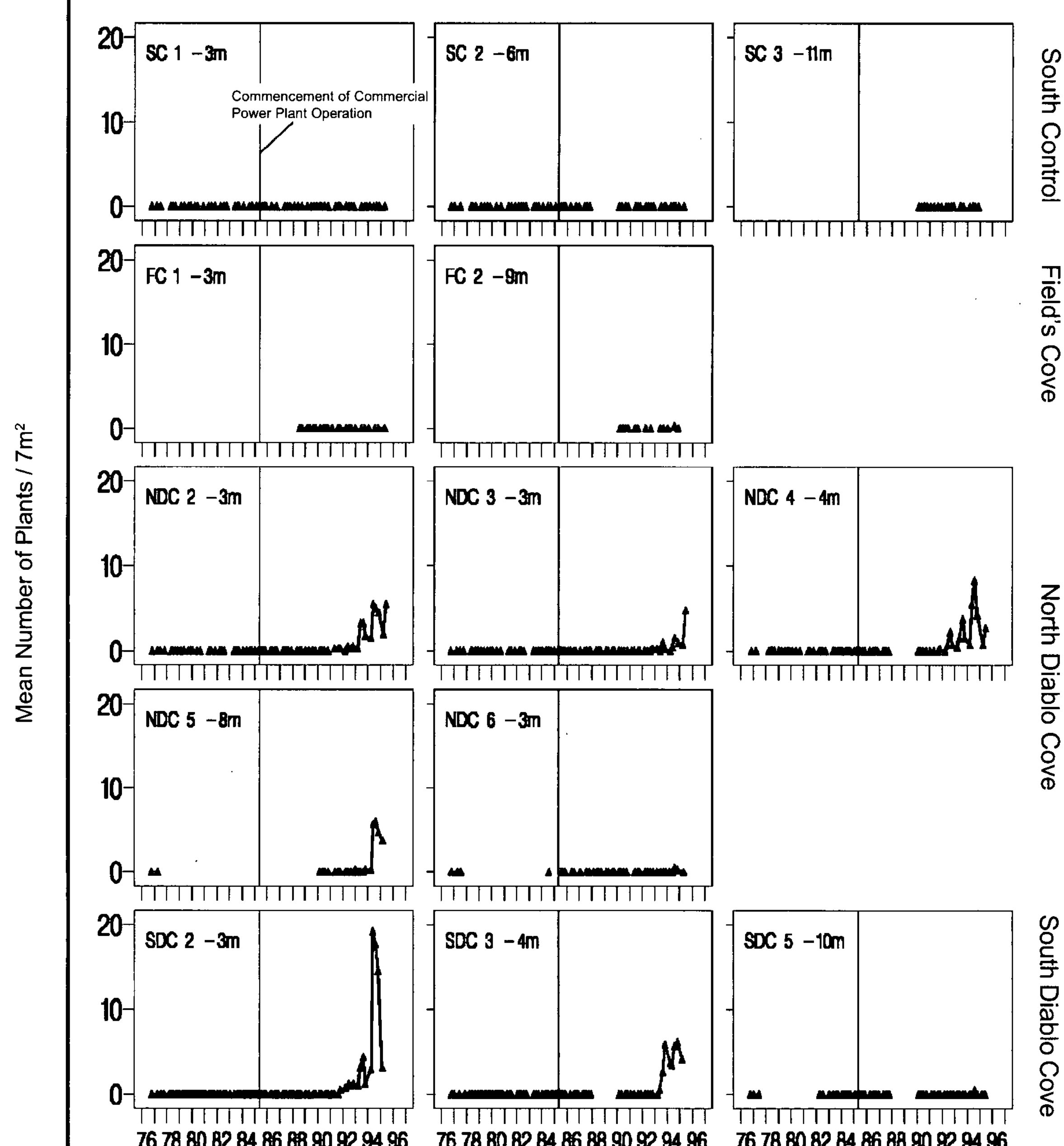


Figure 4-9. *Macrocystis pyrifera*: changes in density at subtidal benthic stations.

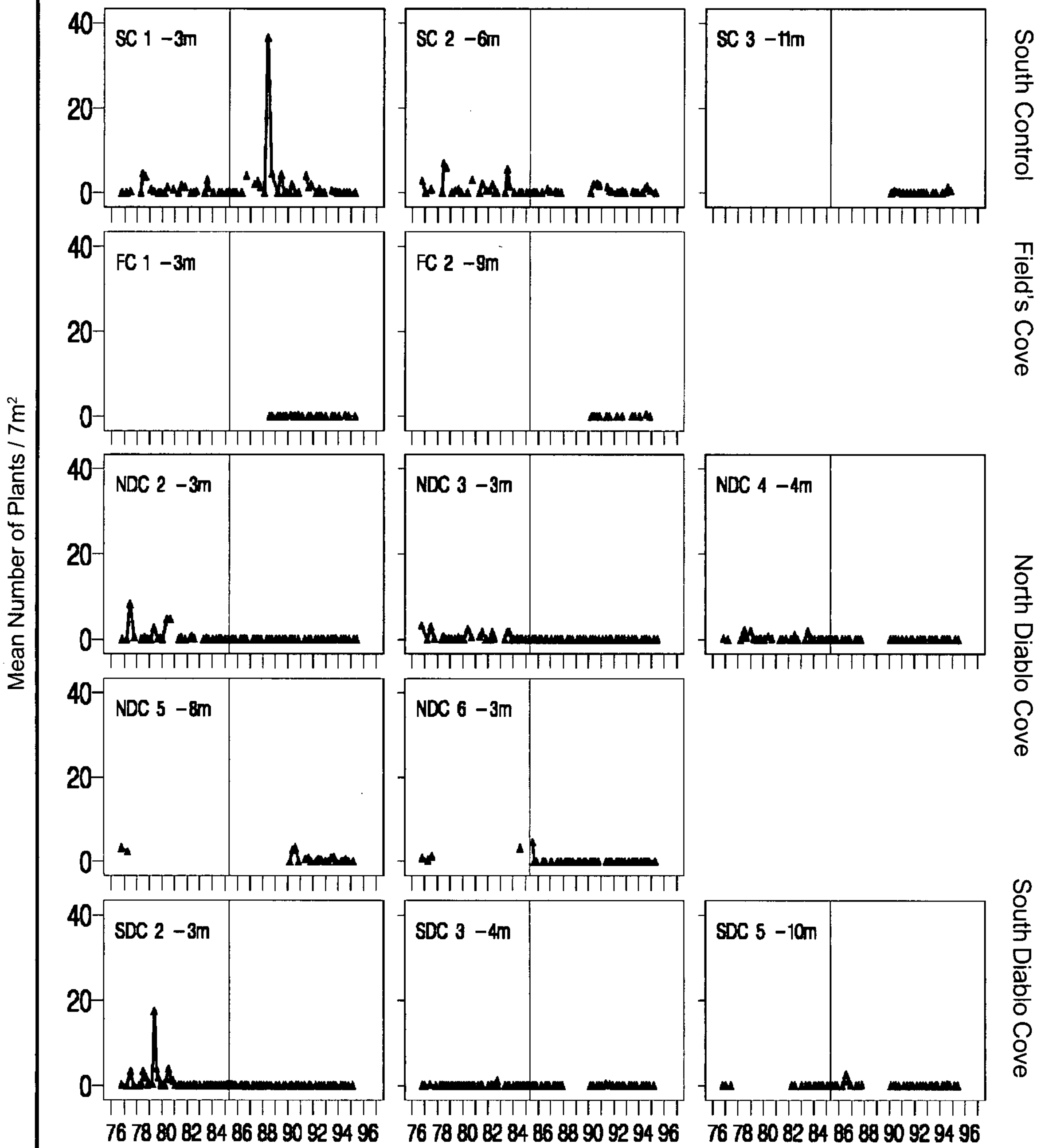


Figure 4-10. *Nereocystis luetkeana*: changes in density at subtidal benthic stations.

Changes in *Cystoseira osmundacea* were variable among the sampling stations (Figure 4-11). Overall however, this kelp significantly declined in abundance (Table 4-4). Beginning in 1991, *C. osmundacea* recovered at some stations where it had formerly declined.

The changes in the subcanopy kelps *Laminaria setchellii* (Figure 4-12) and *Pterygophora californica* were similar. Both were declining in Diablo Cove before power plant start-up, but were still relatively abundant when the power plant began commercial operation. After power plant start-up, these kelps became absent from the shallow (-3 m and -4 m depth) stations in Diablo Cove, except at SDC 3 -4m. The greatest declines observed during power plant operation occurred at NDC 6 -3m, a station not analyzed statistically because of the small number of pre-operation surveys. Both kelps remained common at deeper stations in Diablo Cove, at control stations, and at stations in Field's Cove.

Six of the 10 taxa that decreased were understory algae. *Cryptopleura ruprechtiana* was one of the most abundant understory foliose algae in Diablo Cove before plant operation, with a mean abundance of 29 percent cover (Figure 4-4). After power plant start-up it declined to near-absence at most shallow stations in Diablo Cove, while abundances at control stations remained high (Figure 4-13). The increase at SDC 3 -4m prior to power plant start-up was unique. Declines during power plant operation also occurred in deeper water in Diablo Cove (at NDC 5 -8m). Declines occurred in other taxa in Diablo Cove but were not as large as in *C. ruprechtiana* (e.g., *Calliarthron/Bossiella* spp.; Figure 4-14).

Phyllospadix spp. was abundant at only a few stations in the pre-operation study period (Figure 4-8). The BACI analysis was ambiguous in detecting impacts in this taxon. The analysis detected that it significantly increased at -4 m and significantly decreased at -3 m, relative to the control population (Table 4-4). However, *Phyllospadix* spp. eventually declined to zero abundance at all stations in both the control and impact areas. The changes at NDC 2 -3m and NDC 3 -3m show a large decline in cover during the period of the 1982/83 winter storms and 1983 El Niño, then a decline to zero abundance shortly after power plant start-up. *Phyllospadix* spp. was abundant at only one control station (SC 1 -3m, Figure 4-8) where it declined before 1982/83. The remaining population at the control station also declined to zero abundance shortly after power plant start-up. Similar declines occurred in intertidal *Phyllospadix* spp. in Diablo Cove, but not at intertidal control stations (Section 3.3.1 - *Intertidal Algae*).

No Significant Changes and Test Results Inconclusive

The power to detect a 50% change for the BACI tests was sufficiently high to conclude that no significant change occurred for *Microcladia coulteri* and *Rhodymenia* spp. (Table 4-4). Test results were inconclusive to detect impacts for 12 other taxa using either the BACI or Fisher's exact tests (Tables 4-4 and 4-5, respectively). Some were absent or rare throughout the study, except beginning in 1990-91 when they increased in abundance in Diablo Cove (e.g., *Nienburgia andersoniana*; Appendix E).

Analysis of Community Changes

Algal diversity (H') increased significantly at the -4 m level, although the number of algal species declined significantly at the same level (Table 4-4). Bare rock and sand cover were other categories tested in the BACI analysis. Bare rock increased significantly at both depths tested, while sand cover significantly decreased at the -3 m level (Table 4-4). Total algal cover did not change between periods at either level. The Fisher's exact test revealed no significant differences in the ratio of increases to decreases in survey occurrences among taxa between the control and Diablo Cove locations (Table 4-6).

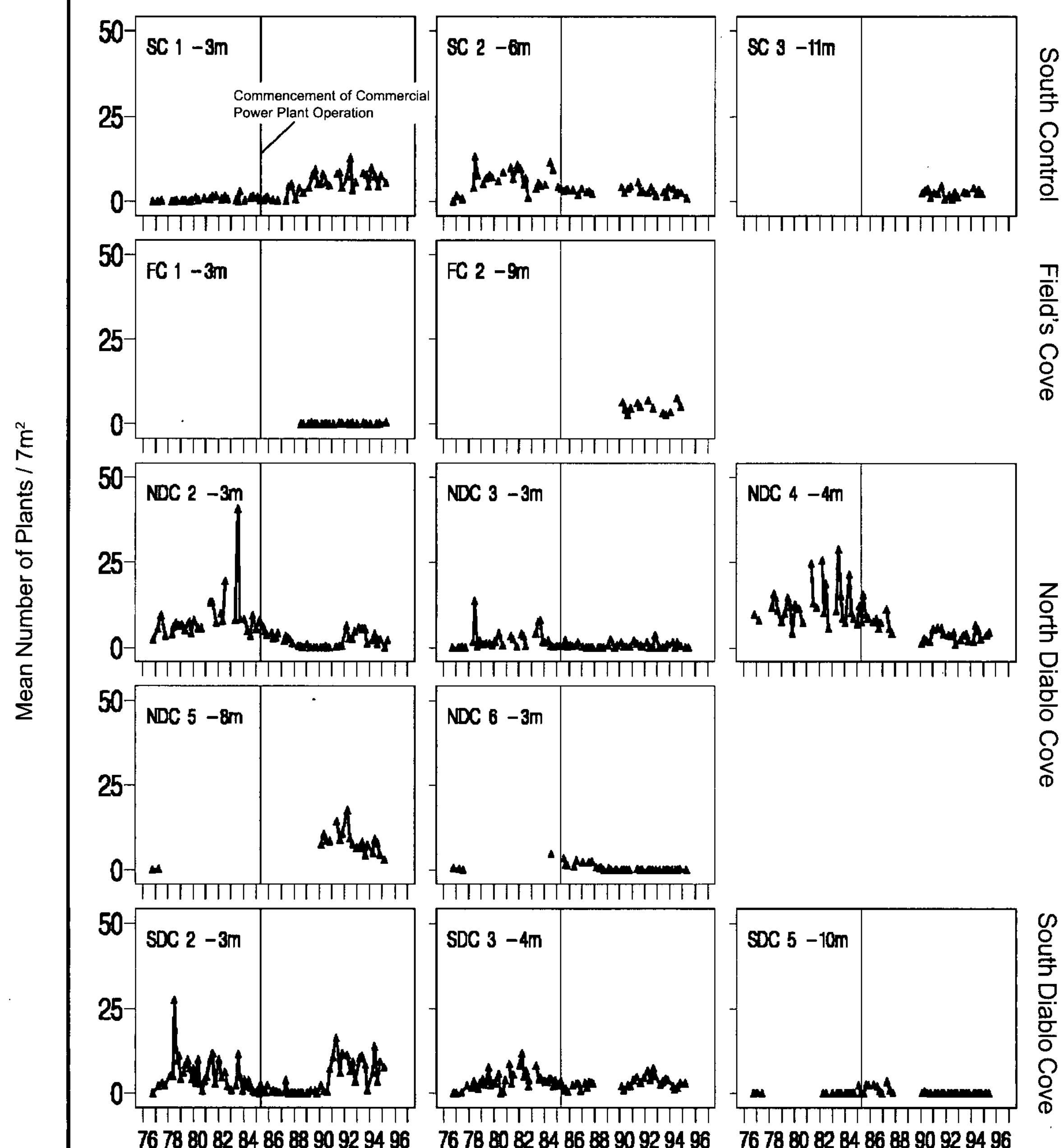


Figure 4-11. *Cystoseira osmundacea*: changes in density at subtidal benthic stations.

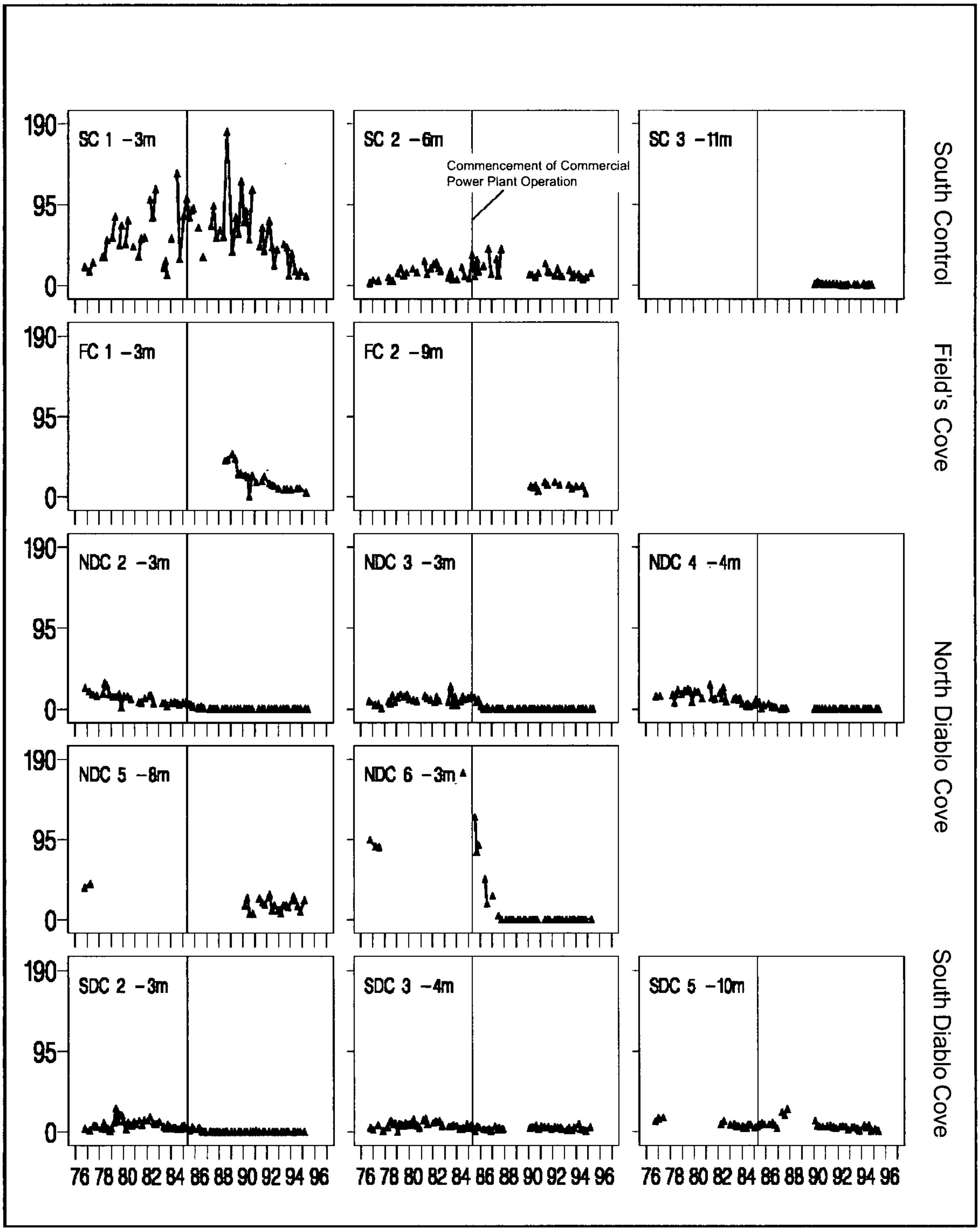


Figure 4-12. *Laminaria setchellii*: changes in density at subtidal benthic stations.

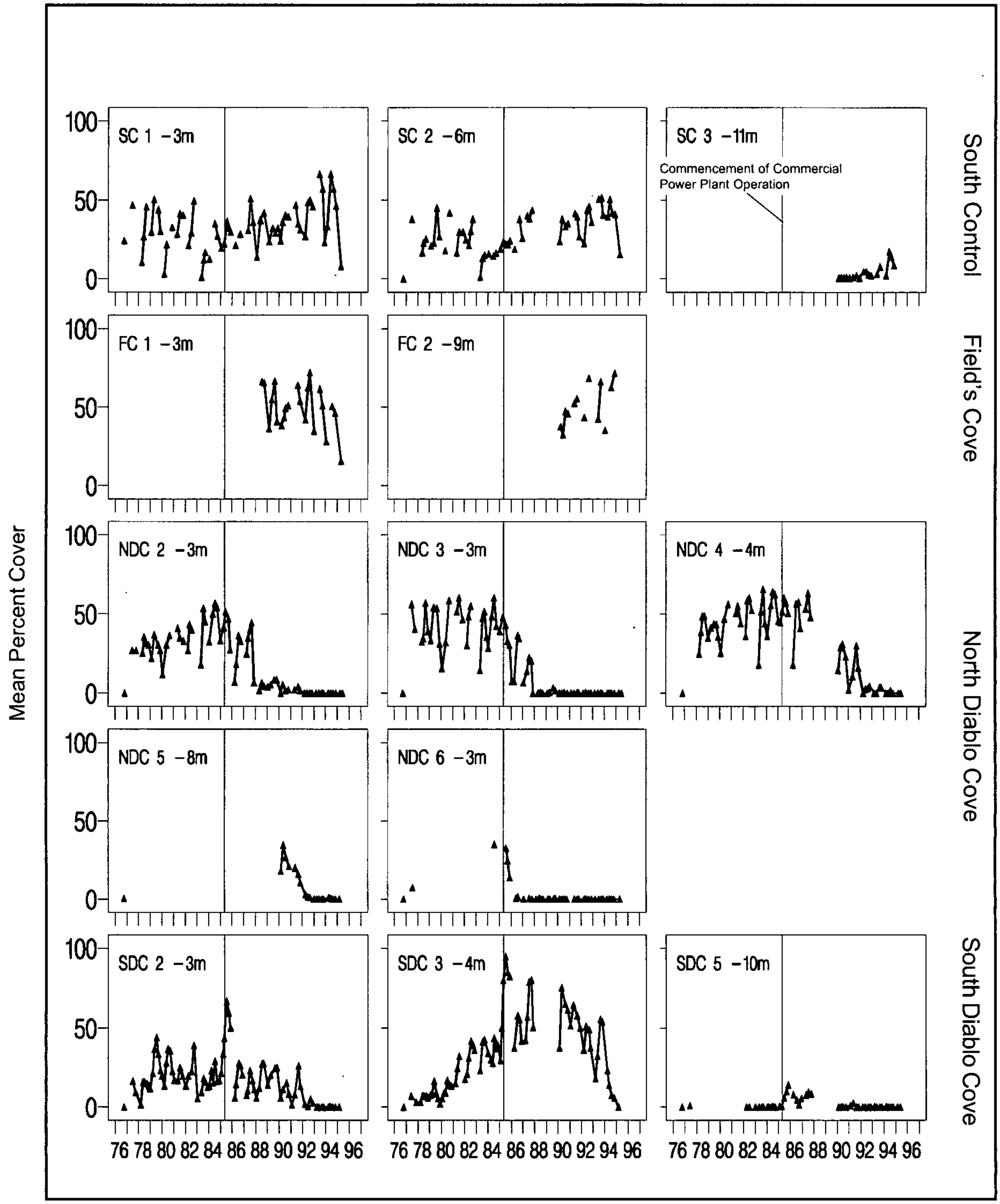


Figure 4-13. *Cryptopleura ruprechtiana*: changes in cover at subtidal benthic stations.

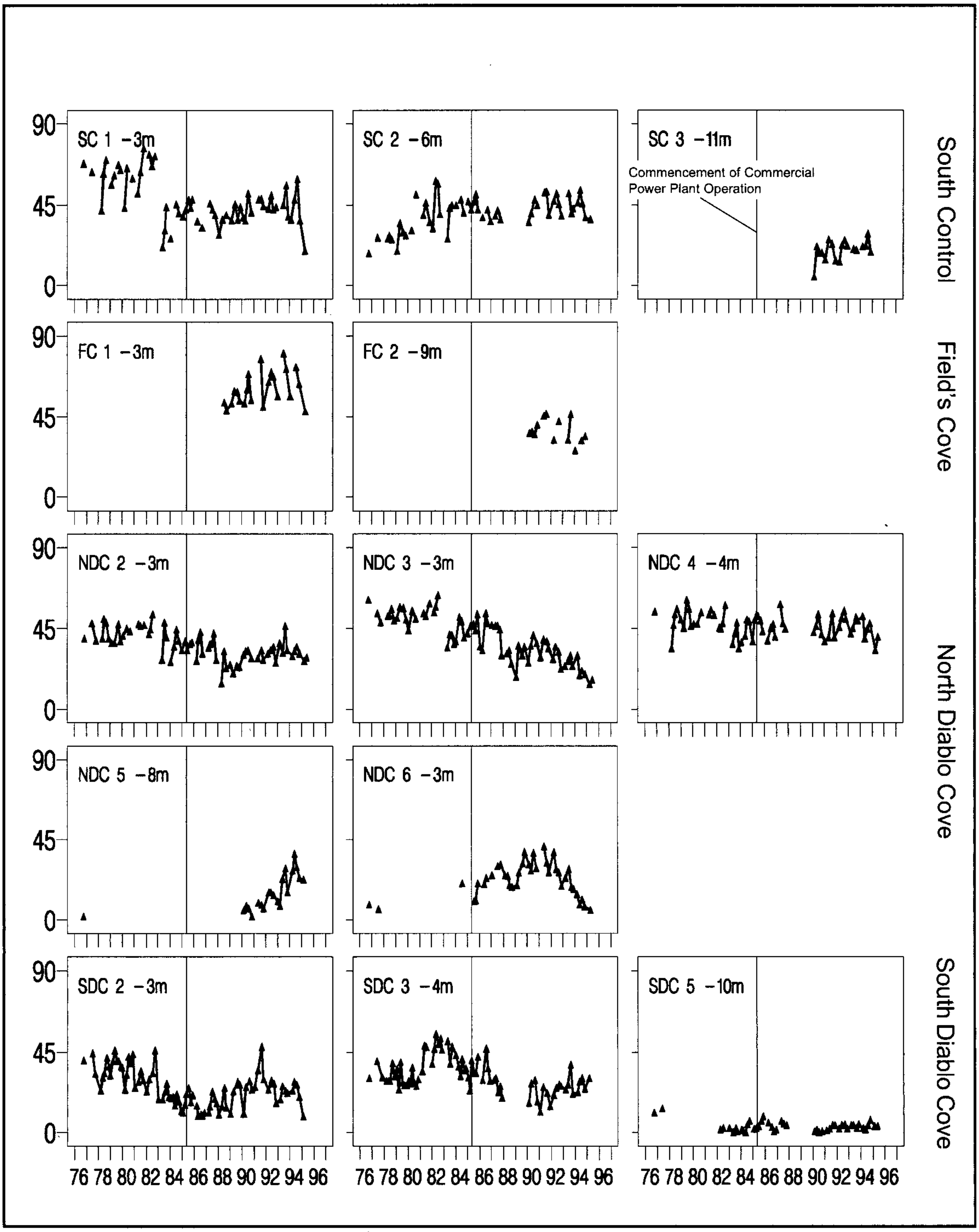


Figure 4-14. *Calliarthron/Bossiella* spp.: changes in cover at subtidal benthic stations.

Table 4-6. Results of Fisher's exact test for subtidal algae: a) RPC understory taxa, and b) SAQ kelp taxa. Data were number of species changes at the Diablo Cove and control stations between pre-operation and operation periods. Results were statistically significant if $p<0.10$.

a) RPC Understory Algal Taxa

	Decreases	Increases
Diablo Cove	47	45
Control	33	32
	p = 1.00	

b) SAQ Kelp Taxa

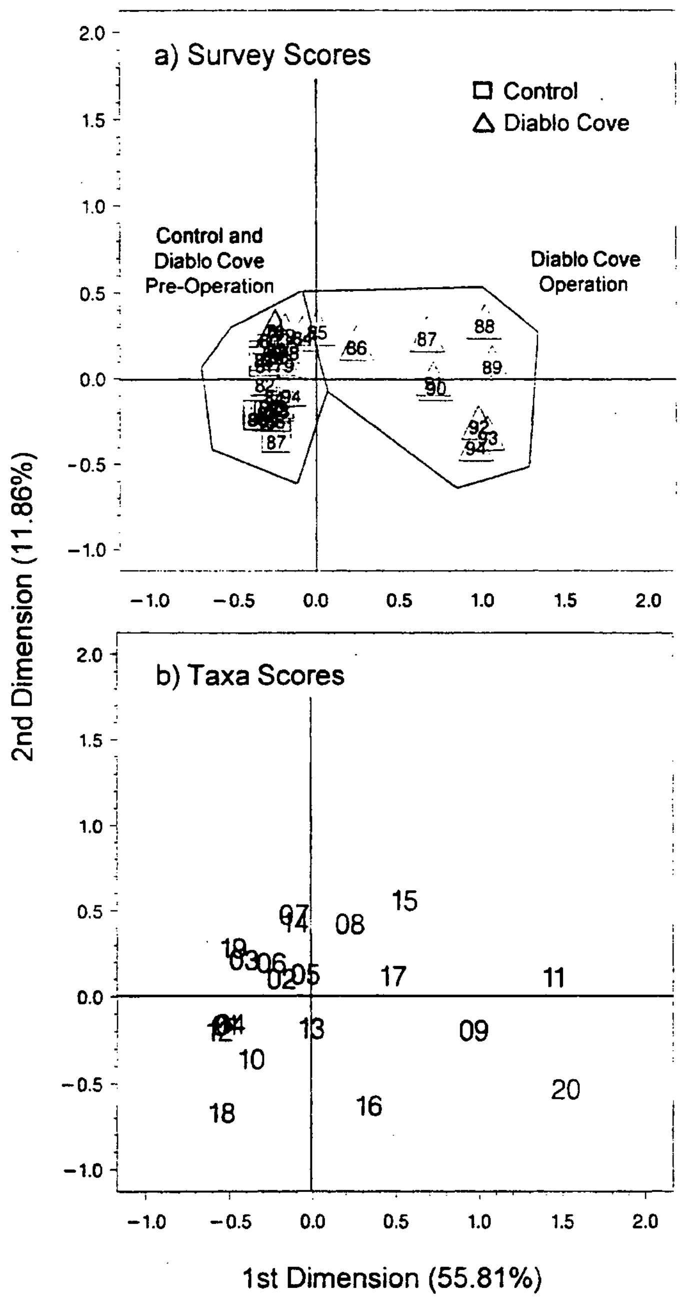
	Decreases	Increases
Diablo Cove	6	2
Control	1	4
	p = 0.13	

Correspondence analysis (CA) was used to analyze algal community variation at Diablo Cove and control locations. Data included in the analyses consisted of annual means for the taxa that formed 95% of the total cumulative abundance across all surveys and occurred in at least 20% of the surveys. This resulted in an analysis of 20 taxa. The first two CA axes (dimensions) explained 68% of the total variation in the data set and represented the two largest independent sources of variation (Figure 4-15a and b). Variation along the first dimension separated operation survey scores for Diablo Cove (positive scores) from all other scores, including pre-operation survey scores from Diablo Cove, and all survey scores from the control area (negative scores). The first axis shows little variation among control area scores. Most of the variation is attributable to variation in Diablo Cove following plant operation, especially during the period from 1985 through 1988. The taxa scores for the first axis reflect some of the changes occurring in the subtidal algal community during this period (Figure 4-15b). Large negative scores occurred for kelp taxa including, *Laminaria setchellii, Pterygophora californica*, and Laminariales, and understory taxa such as *Polyneura latissima* and *Callophyllis* spp., all which declined in abundance immediately following plant start-up. Positive taxa scores on the first axis represent relative increases for several taxa including *Farlowia/Pikea* spp., *Cryptopleura violacea*, and *Prionitis* spp.

The second axis shows additional interannual variation in Diablo Cove that occurred later in the operation period and at the control location from El Niño effects (Figure 4-15a). Variation along this axis represents only 11.86% of the variation within the data set. The taxa scores show that the pattern of variation in Diablo Cove during power plant operation was due to changes in the relative abundance of several understory taxa (Figure 4-15b). Taxa with relative increases on this axis included *Farlowia/Pikea* spp. and *Rhodymenia* spp. (negative scores) and taxa with relative decreases included *Halymenia/Schizymenia* spp., *Microcladia coulteri*, *Mazzaella lilicina* and *Corallina officinalis* (positive scores).

Ancillary Observations

Within the first two years of power plant operation, TEMP divers observed physical changes in *Laminaria setchellii* and *Pterygophora californica* plants that led to complete loss of both populations in shallow



Taxa

01 *Laminaria setchellii*
02 *Cystoseira osmundacea*
03 *Desmarestia* spp.
04 *Pterygophora californica*
05 *Calliarthron/Bossiella* spp.-complex
06 *Cryptopleura ruprechtiana*
07 *Corallina officinalis*
08 *Microcladia coulteri*
09 *Prionitis* spp.
10 *Callophyllis* spp.
11 *Cryptopleura violacea*
12 *Polyneura latissima*
13 *Chondracanthus corymbiferus*
14 *Mazzaella lilacina*
15 *Halymenia/Schizymenia* spp.-complex
16 *Rhodymenia* spp.
17 *Osmundea* spp.
18 *Laminariales*
19 *Ulva/Enteromorpha* spp.
20 *Farlowia/Pikea* spp.-complex

Figure 4-15. First and second dimension scores from correspondence analysis of subtidal kelp and understory algal data. (a) Annual survey scores. (b) Taxa scores. Numbers inside of symbols are years. Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Percentages in parentheses denote amount of variation explained by corresponding dimension.

(<-7 m) regions of Diablo Cove. In both species, tissue degeneration began in the blades and progressed to the stipes. Turban snails (*Tegula* spp.) were often observed clustered on the stipe tips consuming the remaining plant tissues. The degenerative process leading to complete loss of plants took approximately two years beginning with *L. setchellii* during the first year of power plant operation and *P. californica* the following year. The change in both kelps progressed from the warmest to the coolest areas of Diablo Cove, beginning inshore of Diablo Rock, then north Diablo Cove, followed by south Diablo Cove. The depth of effect was also related to temperature; the deepest was inshore of Diablo Rock, to -7 m where the surface thermal plume downwells slightly (see Section 2.0 - *Power Plant Operation and Thermal Plume Characteristics*). The effect extended to -4 m in north Diablo Cove and to -3 m in south Diablo Cove. No deterioration was observed in plants deeper than -7 m in Diablo Cove, or at any depths in Field's Cove and South Control.

Cystoseira osmundacea was affected by a power plant-related incident that occurred just before start-up testing of Unit 1. In summer 1984, a 'subtidal algal bleaching' incident occurred in south Diablo Cove when the power plant's circulating pumps were in operation and discharging water without heat (PG&E 1985). The effect was seen as degeneration and collapse of the *C. osmundacea* canopy during its normal summer period of luxuriant growth. Bleaching was also observed in the articulated coralline algae *Calliarthron/Bossiella* spp.-complex. The bleaching was followed by large increases in benthic diatoms and *Ulva* spp.. These changes were not found in north Diablo Cove or in areas outside Diablo Cove. Because thermal discharges had not begun, increased water temperatures could not explain the observations. An investigation and analysis of power plant discharge constituents was completed and submitted to the Regional Water Quality Control Board (PG&E 1985). No unusual releases were found in the NPDES discharge records, and consequently, the cause(s) of the changes in the algae were unexplained. In late-summer 1984 with discharges continuing (without heat), new tissue growth from damaged portions of *C. osmundacea* canopy fronds was observed, indicating recovery from the incident. One year later, when the power plant began commercial operation, the affected algae in south Diablo Cove appeared normal and the diatom and *Ulva* spp. cover was reduced (PG&E 1985).

Periodically, foam up to 0.5 m thick generated by the discharge tended to accumulate on the water surface in south Diablo Cove. The layers of foam occasionally obscured the *Macrocystis pyrifera* surface canopy. The canopy did not appear to be affected by the foam, as surface fronds appeared normal and healthy.

Kelp Mapping

Changes in the densities of *Nereocystis luetkeana* and *Macrocystis pyrifera* were recorded at the benthic stations, while kelp maps from cliff-top counts and aerial surveys were developed to portray their changes in abundance over broader spatial scales (Diablo Cove and the coastline). Results from the cliff-top surveys show *N. luetkeana* (versus *M. pyrifera*) was the predominant kelp in Diablo Cove before power plant start-up (Figure 4-16). However, from 1979 to 1982, *N. luetkeana* abundance declined in the central, deeper portions of Diablo Cove, but remained abundant around the perimeter of the cove. During this same time span, several small *M. pyrifera* surface canopies (formed by only a few plants) were observed in Diablo Cove, but then disappeared during the 1982/83 winter storms. The storms created open space on the shallow reefs resulting in increased *N. luetkeana* recruitment that year. However, later in the year, the expanded population was affected by warm water associated with the 1983 El Niño event. Although plants were abundant, qualitative observations made from boat and diving surveys found that the entire population in the vicinity of the power plant, including Diablo Cove, had rapidly senesced.

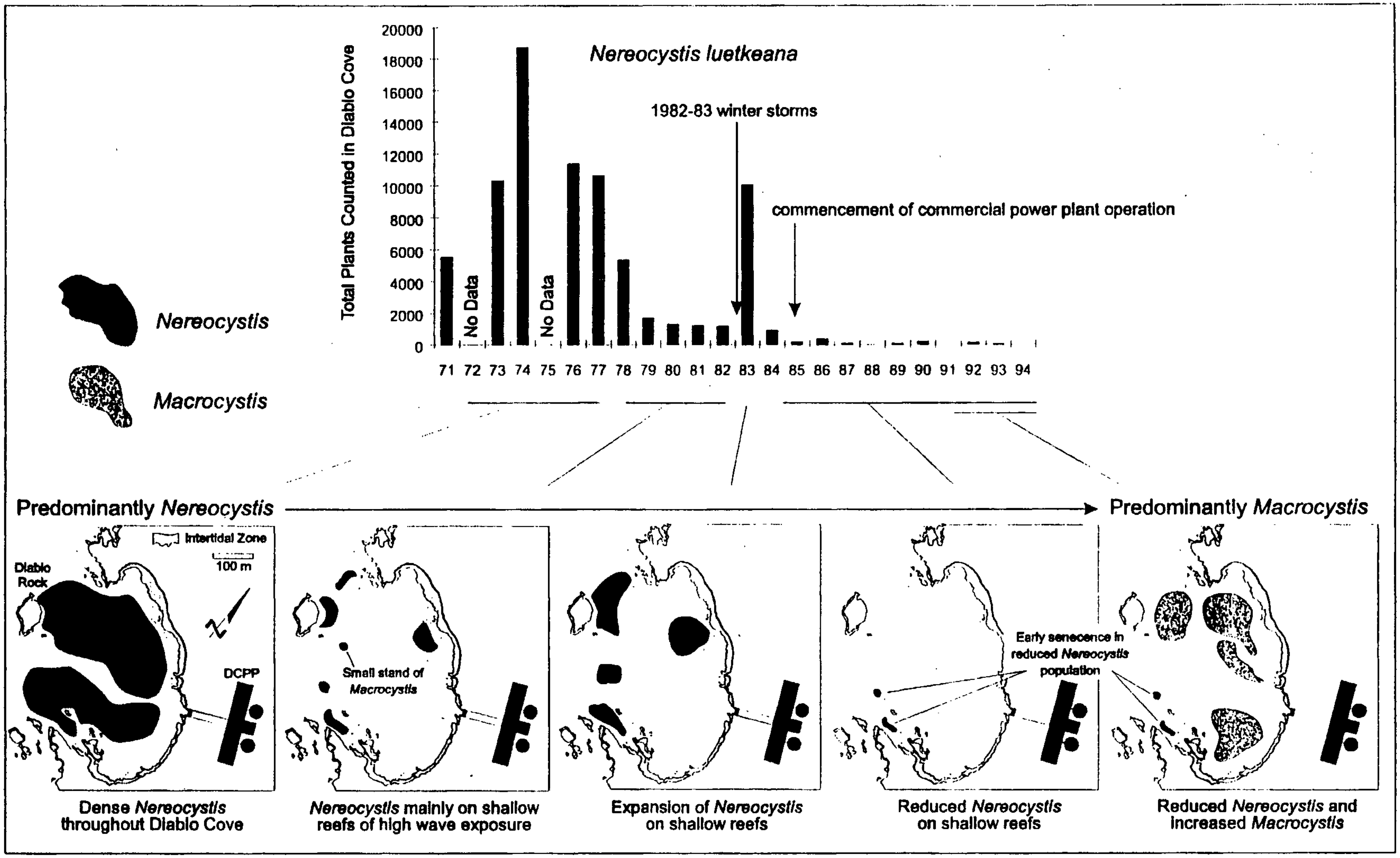


Figure 4-16. Changes in the abundance of *Nereocystis luetkeana* and *Macrocystis pyrifera* in Diablo Cove. Top graph shows counts of *N. luetkeana* obtained from cliff-top stations during October of each year. Bottom maps portray general areas of surface canopies formed by *N. luetkeana* and *M. pyrifera* in Diablo Cove during representative years.

Senescence was characterized by blades having degenerated and sloughed from the plants and the pneumatocysts and stipes becoming pale and soft.

The number of surface *N. luetkeana* counted in 1984 was similar to the numbers counted in 1979-1982. After power plant start-up, the timing of annual recruitment in *N. luetkeana* was normal, but each year's population in Diablo Cove experienced a fate similar to the 1983 population, senescing early by about three months. The sequence of development in *N. luetkeana* observed in control and impact areas is illustrated in Figure 4-17. Qualitative dive observations revealed that small healthy plants developing beneath the thermal plume died once they grew up into the plume. The blades first shortened from tissue degeneration at the distal ends. Further degeneration of blades left only stipes and bare pneumatocysts. The impact resulted in the loss of most plants before they reached reproductive maturity. A gradient of early senescence was observed each year in the Diablo Cove cliff-top surveys. Plants along the southern shoreline of the cove had tattered blades, while plants in the more interior portions of Diablo Cove and in north Diablo Cove had only stipes with bare pneumatocysts.

A boat survey in October 1987 was conducted to determine the areal extent of early senescence in *N. luetkeana* outside Diablo Cove. The survey was conducted because ambient water temperatures were warmer than normal, due to a minor El Niño, and both power plant units were operating simultaneously at full capacity for the first time. Prematurely senescent plants were observed near Lion Rock, approximately 800 m northwest of Diablo Cove (Figure 4-18). Plants elsewhere in Field's Cove and south of the power plant appeared unaffected by the warmer ambient conditions.

M. pyrifera remained absent from the time of the 1982/83 winter storms up until 1991 when large numbers of this kelp recruited in north and south Diablo Cove (Figure 4-16). The plants grew and matured, and, with continued recruitment, the population expanded into other areas of Diablo Cove resulting in densities up to 20 plants/7m^2 on the benthic stations (Figure 4-9).

Aerial photographic surveys were completed from 1969 to 1991 to document the occurrence of kelp along the Diablo Canyon coast between Point Buchon and Point San Luis. The photographs were the only source of information for changes outside Diablo Cove. However, statistical analysis of the data was not done because only data from three maps from the operation study period were available at the time this report was prepared. In addition, the kelp maps were constructed using two different methods. Kelp maps for 1969-1977 were made from hand tracings, with the images digitized to derive kelp cover by computer analysis of colored 'pixels' (PG&E 1979). Kelp maps for 1981, 1985, 1987, and 1989 were created using GIS analysis, with kelp cover delineated and determined by color band selection from aerial photographs (Figure 4-19). All maps and coverage data are for *N. luetkeana* and *M. pyrifera* combined, since the two species are indistinguishable in the photographs.

Data from the kelp aerial surveys were subjectively examined for power plant effects. The area examined for impacts was the reach from Diablo Cove to Lion Rock (Figure 4-19). Amounts of kelp within the impact area versus areas to the north and south were computed from the maps (Table 4-7). Because the coverage data was obtained using two different methods, kelp cover for each year (summer-fall) was standardized by computing the percentage of kelp in the impact area to the total coverage of kelp along the coast (inset graph in Table 4-7). The percentage of kelp in the impact area to the total kelp cover along the coast (9.8% to 26.4%) for the summer-fall of 1985, 1987, and 1989 (after power plant start-up) remained within the range noted for the same seasonal period before power plant start-up (0.5% to 30.2%). Although it appears from the inset graph that the percentage of kelp in the impact area increased after power plant start- up, the highest value (26.4% for 1989) may be an over-estimate, because large portions of the north control area were not mapped (Figure 4-19). Most of the kelp data for the impact

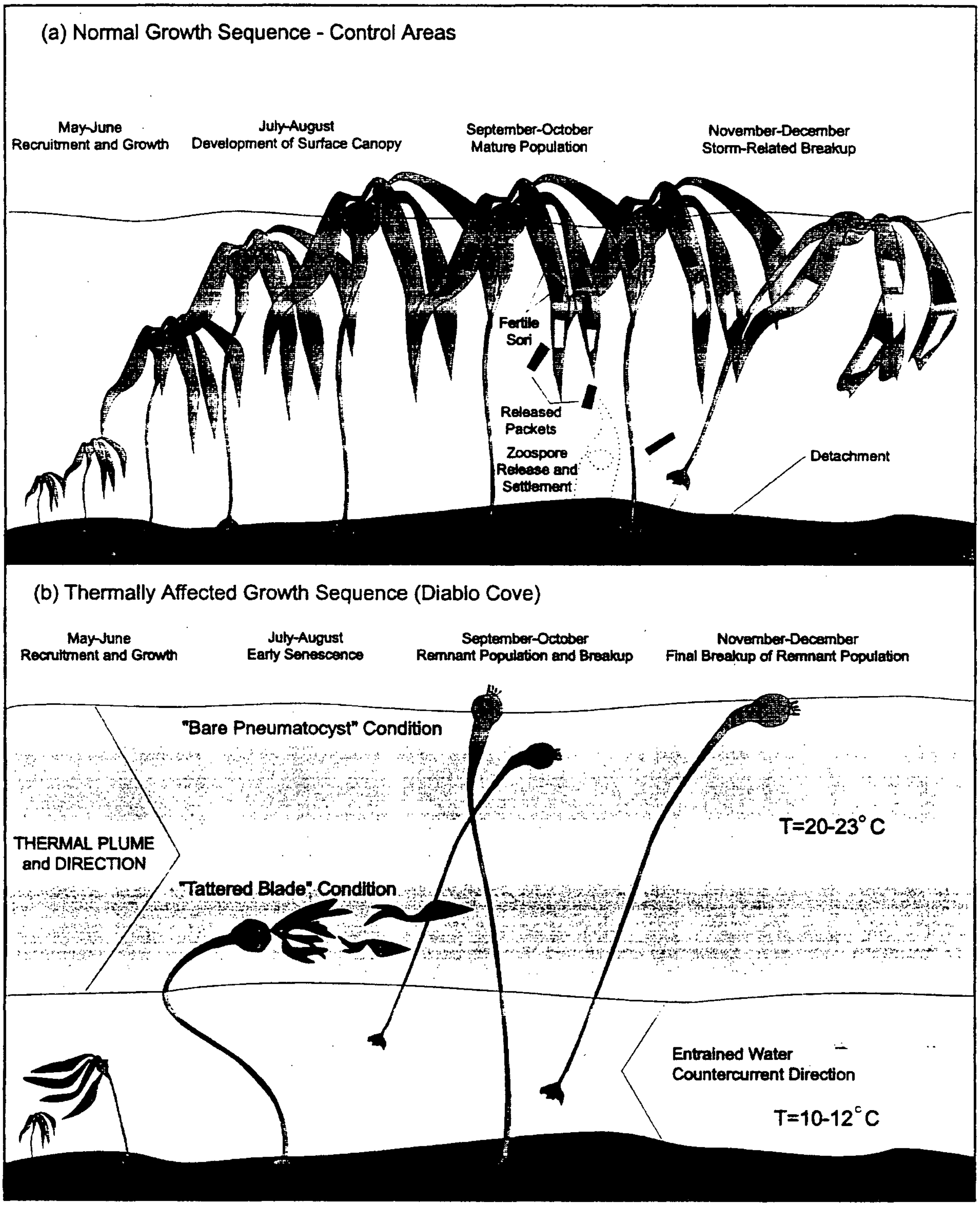
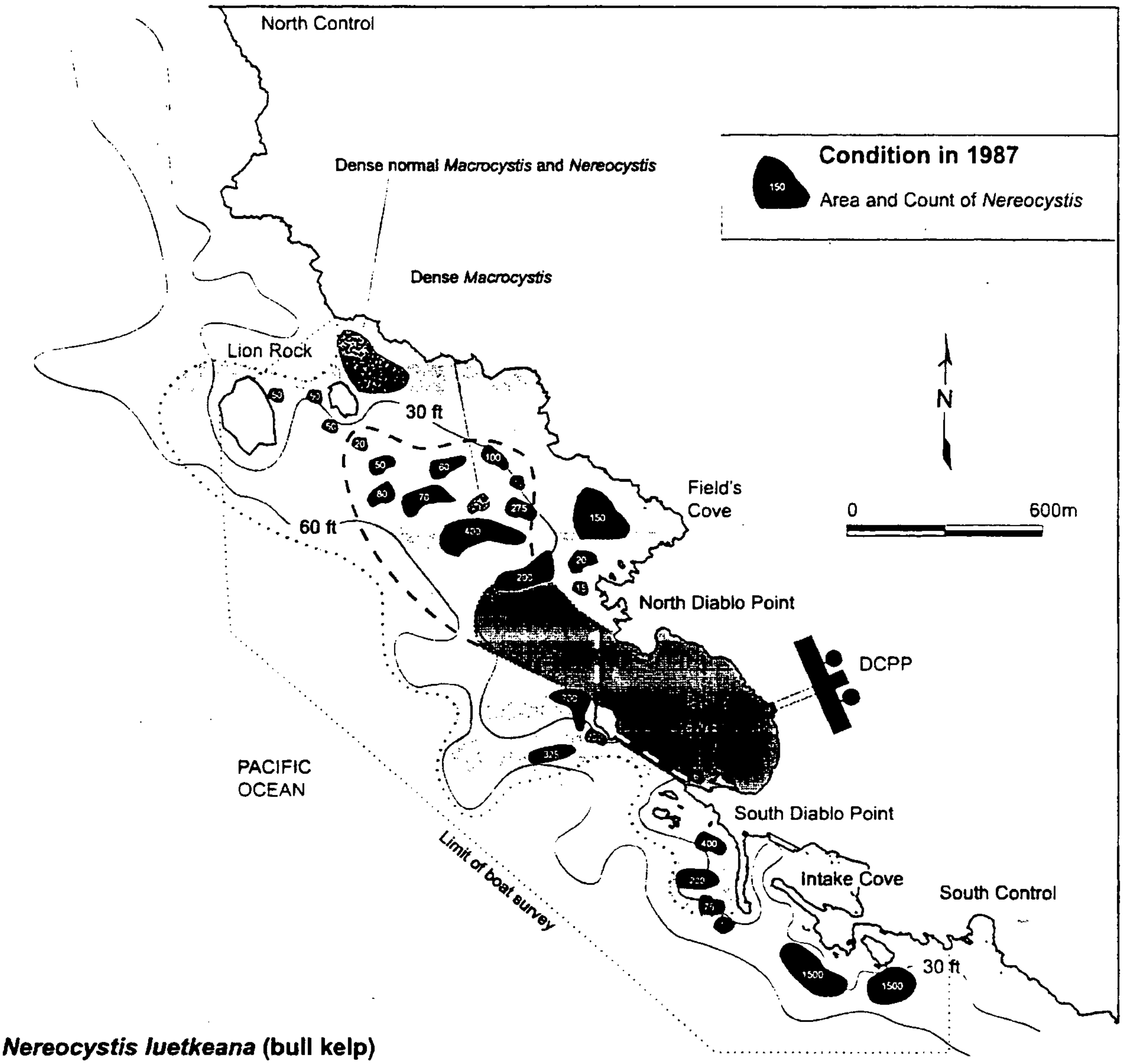


Figure 4-17. Annual development of *Nereocystis luetkeana* in (a) control areas and (b) affected areas. (a) Full surface canopy development occurs in summer-fall. (b) Juveniles develop normally beneath the plume until growth places tissues in contact with the surface plume. Senescence then occurs prematurely, by approximately three months, compared to unaffected plants.



***Nereocystis luetkeana* (bull kelp)**

Area of frequent to continuous surface plume contact and premature senescence in bull kelp observed during most years: (23.0 hectares; 56.3 acres)

Area of reduced surface plume contact with unknown effects on bull kelp likely to be less than those observed in areas with frequent plume contact: (68.7 hectares; 169.7 acres)

Black dashed line indicates area of additional premature senescence in bull kelp observed in 1987: (42.3 hectares; 104.6 acres)

***Macrocystis* (1991-1995)**

Macrocystis increased in Diablo Cove (white dashed line) from 1991 to 1995: (17.5 hectares; 43.2 acres).

Figure 4-18. Approximate areas of premature senescence in *Nereocystis luetkeana* (bull kelp) and increases in *Macrocystis pyrifera* (giant kelp). Areas of premature senescence in *Nereocystis* during most years and during the 1987 El Niño are shown separately. Outer-most boundary of reduced surface plume contact on *Nereocystis* encompasses areas of rocky bottom within the approximate depth limit of this species. *Macrocystis* increased in Diablo Cove from 1991 to 1995. Map of effects was developed from cliff-top observations and a boat survey conducted in 1987.

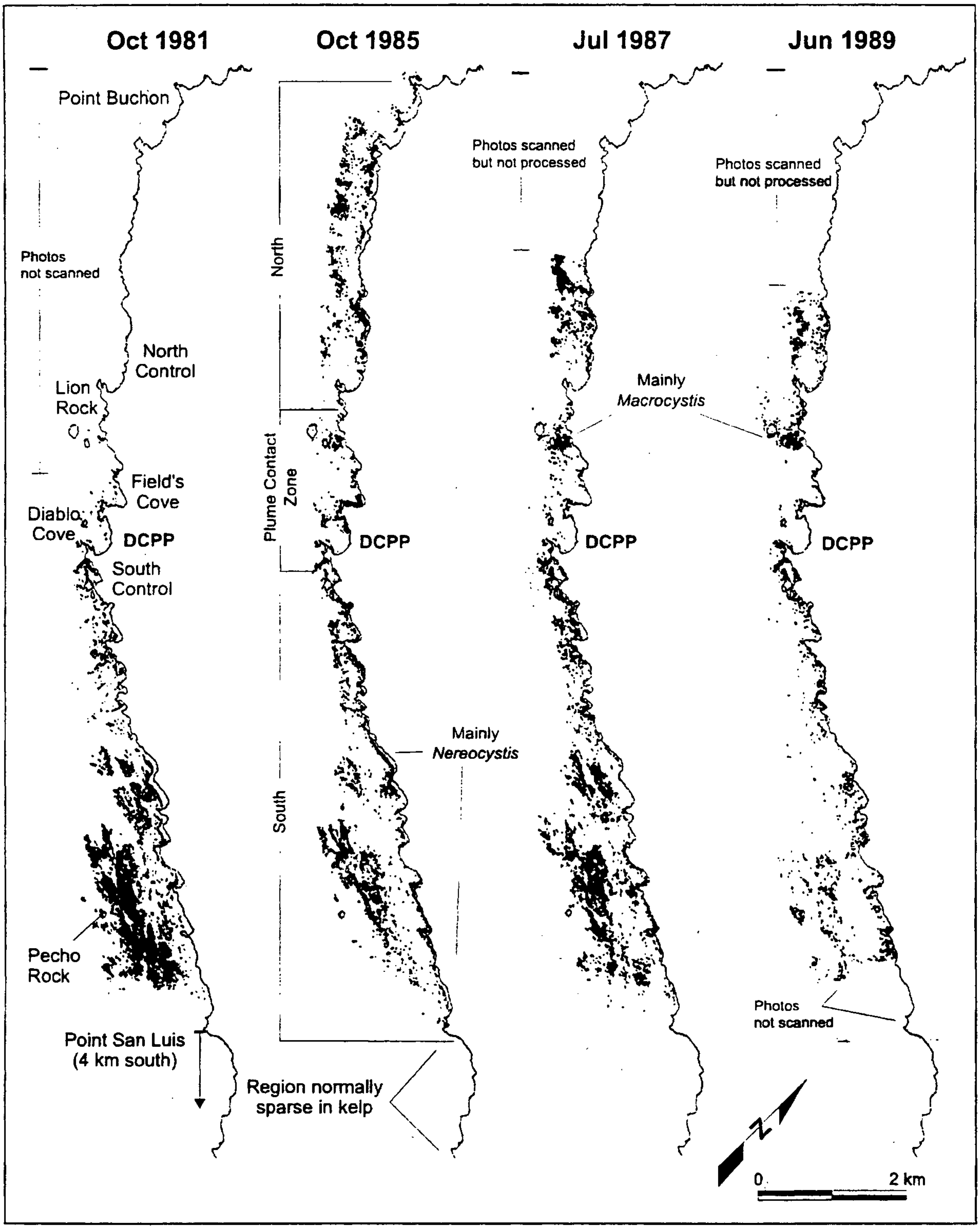
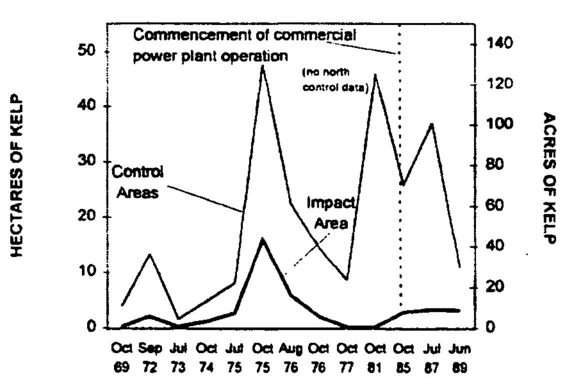


Figure 4-19. Results of GIS kelp mapping for four different aerial surveys. Black areas denote extent of *Nereocystis luetkeana* and *Macrocystis pyrifera* surface canopies combined. Note that the entire coast in 1985 was mapped for kelp cover. Data were unavailable for portions of the coast for all other years. Kelp cover was computed for three different areas shown for 1985.

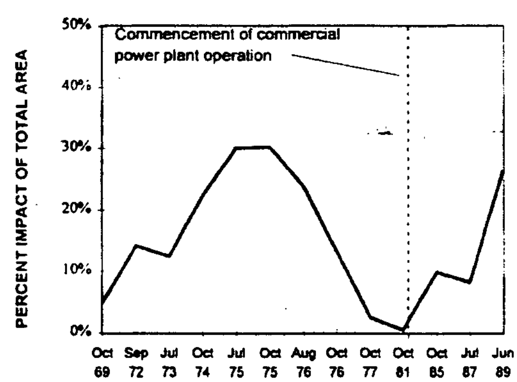
Table 4-7. Coverage of kelp (*Nereocystis luetkeana* and *Macrocystis pyrifera*) in three zones (Point Buchon to Pecho Rock) measured from aerial photographs. Summer-Fall seasons of maximum areal extent are graphed from subsets of the data.

					KELP COVERAGE (hectares)					
YEAR	Date Photo Taken	Time of Aerial Flight	Mean Altitiude (ft)	Tide Ht. Feet (MLLW)	NORTH PT. BUCHON - LION ROCK	Plume Contact LION ROCK - DCPP	SOUTH DCPP - PECHO ROCK	NORTH & SOUTH SUBTOTAL	TOTAL PT. BUCHON - PECHO ROCK	PERCENT Plume Contact of TOTAL AREA
PG&E 1979 METHOD										
1969	30 Oct	12:35	5869		0.10	0.20	3.94	4.04	4.25	4.8%
1970	3 Mar		6234		0.12	0.05	1.03	1.15	1.19	4.2%
1971	29 Nov		6053		3.07	1.21	18.87	21.94	23.16	5.2%
1972	23 Sep		6161		6.61	2.08	5.97	12.58	14.72	14.1%
1973	23 Jul		6198		0.26	0.22	1.28	1.53	1.75	12.4%
1974	11 Oct	14:02	4608		1.65	1.18	2.46	4.10	5.28	22.3%
1975	23 Feb		5939		0.75	0.18	0.58	1.33	1.52	12.1%
	30 Jul		4858		2.72	2.67	3.49	6.22	8.89	30.1%
	16 Oct	14:18	5833		21.77	15.90	14.95	36.72	52.62	30.2%
	19 Nov		4323		0.29	1.35	1.98	2.27	3.62	37.3%
1976	20 Feb		4456		3.14	0.71	0.82	3.96	4.68	15.2%
	25 Aug		5243		10.65	5.93	8.25	18.90	24.83	23.9%
	3 Oct	10:37	4701	3.2	6.98	2.11	6.96	13.93	16.04	13.2%
1977	17 Oct	14:24	4780	5.2	2.46	0.24	6.78	9.24	9.48	2.5%
GIS ANALYSIS (* Not analyzed)										
1978	12 Oct	8:28		5.1	*	*	*	*	*	*
1979	5 Oct	15:38		0.2	*	*	*	*	*	*
1980	28 Oct	12:15		5.7	*	*	*	*	*	*
1981	9 Oct	10:50		3.2	*	0.24	50.39	50.39	50.63	0.5%
1982	20 Sep	9:40		4.9	*	*	*	*	*	*
1983	18 Oct	11:35		3.1	*	*	*	*	*	*
1984	4 Aug	12:15		3.7	*	*	*	*	*	*
1985	23 Oct	9:57		3.9	9.06	2.80	16.58	25.64	28.44	9.8%
1986	(1986 data not available)				*	*	*	*	*	*
1987	31 Jul	3:15		3.1	7.43	3.33	30.10	37.54	40.87	8.1%
1988	15 Oct	10:05		5.5	*	*	*	*	*	*
1989	29 Jun	9:30		3.1	2.51	3.17	6.32	8.83	12.00	26.4%
1990	9 Apr	9:46		4.6	*	*	*	*	*	*

Comparison of kelp abundance in plume contact zone versus control areas for same seasons (summer-fall 1969 to 1989).



Percent of kelp abundance in plume contact zone to total coast kelp abundance for same seasons (summer-fall 1969 to 1989).



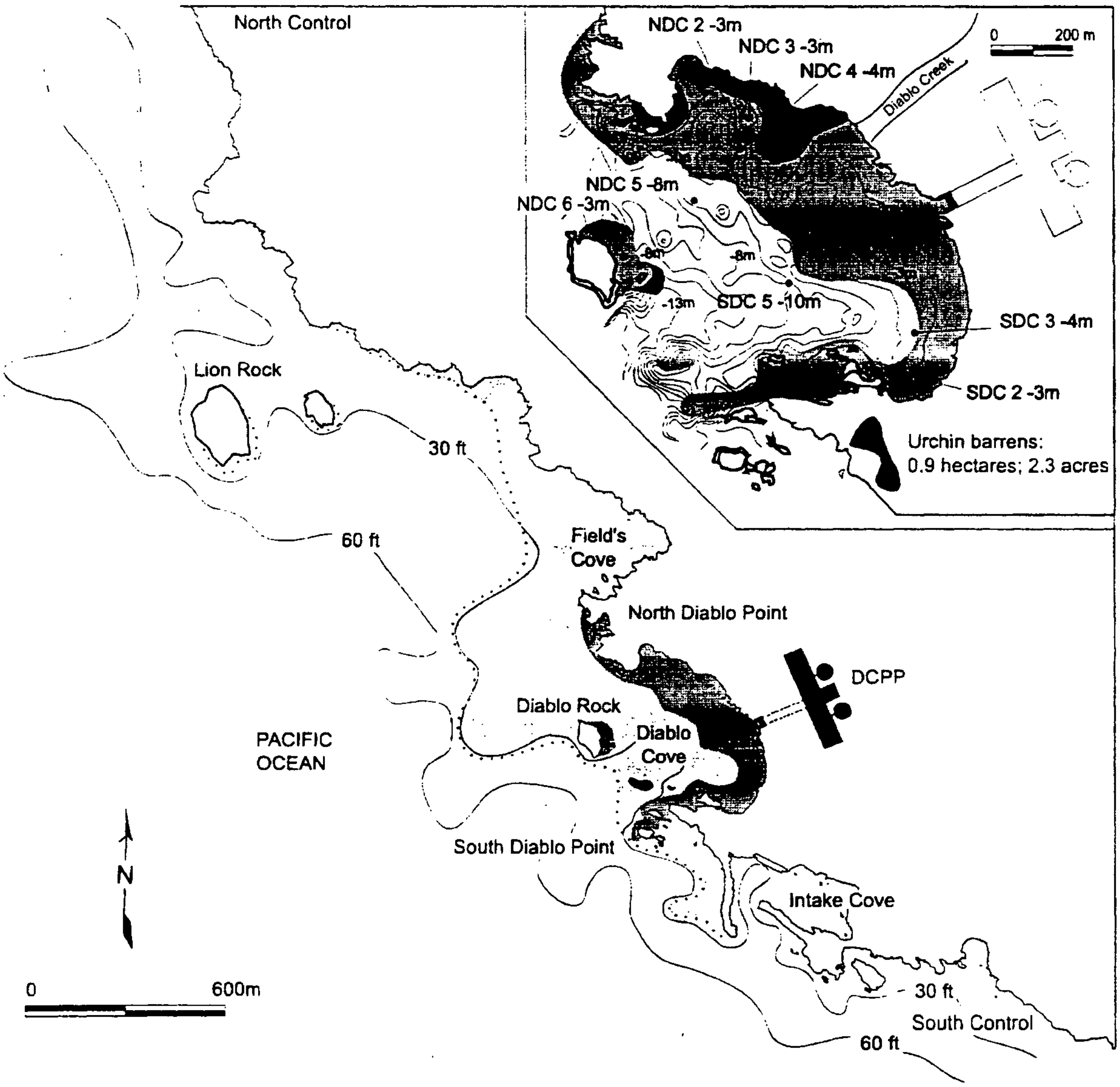
area represents *N. luetkeana*, although the data includes a large stand of *M. pyrifera* that has persisted inshore of Lion Rock. Also, the data does not include the more recent increases in *M. pyrifera* in Diablo Cove after 1991.

Overall, the maps that were examined did not provide sufficient information to draw conclusions on the effects of the DCPP discharge on kelp abundance outside Diablo Cove. The surveys show large variation in kelp canopy cover over time that may be related to the season when the photographs were taken, as well as differences in environmental conditions. *N. luetkeana* tends to peak in abundance during fall, while *M. pyrifera* tends to peak in abundance during summer. Environmental conditions that may have been different between surveys include tides, wind, waves, and currents. High tides and strong wind, waves, and currents, can 'pull' plants beneath the surface, resulting in an under-estimate of kelp abundance. While the surveys were scheduled during relatively calm sea conditions, tidal height and current conditions were not constant between surveys. These differences are not important when examining the difference between control and impact areas over time, but are important when examining changes in kelp cover for specific coastal segments.

Spatial Extent of Effects

Spatial extent of effects on algae occurred in two zones: 1) seafloor areas of effects on benthic algal assemblages; and 2) sea surface areas of effects on kelps that form floating canopies. The approximate boundaries of change along the seafloor were mapped by quantitative and qualitative dive surveys conducted periodically over the course of study (Figure 4-20). The field criteria used to define the areas of change were: absence (or low abundance) of *Pterygophora californica*, *Laminaria setchellii*, and *Cryptopleura ruprechtiana*, combined with relatively high abundances of *Cryptopleura violacea*, *Farlowia/Pikea* spp.-complex, and/or *Gelidium robustum*. The areas of change in each of these taxa closely matched one another at the benthic stations in Diablo Cove. The extent of effects, based on these criteria, extended from the high intertidal to approximately the -4 m depth contour in north Diablo Cove, and slightly shallower in south Diablo Cove. Deeper areas (to -7 m) were affected on the inshore side of Diablo Rock. Portions of the north and south headlands of the cove were also affected. No effects on the benthic algae were observed in other areas of Diablo Cove or outside Diablo Cove. The regions of change to seafloor areas in Diablo Cove (including its headlands) represent an area of 8.1 ha (19.9 ac). Unknown effects in deeper areas of Diablo Cove and areas outside the cove with reduced plume contact are likely to be less than those seen in areas of the cove with observed effects.

Prematurely senescent plants of *N. luetkeana* seen in 1987 during an El Niño period when ambient temperatures were above normal were used to estimate the maximum boundaries of surface plume effects outside Diablo Cove (Figure 4-18). The boundaries observed in 1987 are approximate, however, as plants outside the observed boundaries could have senesced and detached earlier, or healthy plants that were present beyond the observed boundary of effects could have become affected later. The areas affected by the plume could not be determined from the overflight photographs because senescent and normal kelp were indistinguishable in the photographs. Thus, an area of potential effects was appended to the area of documented changes (Figure 4-20). The area of potential effects corresponds to depth regimes where *N. luetkeana* can grow and where the surface plume occurs, but is diminished in temperature and thickness. The total of the documented and potential impact areas represents 111 ha (274.2 ac). Other years (excluding 1987) when ambient temperatures were lower, premature senescence in *N. luetkeana* did not extend as far outside Diablo Cove (Figure 4-18). The area of effects for most years is approximately 23.0 ha (56.3 ac).



SUBTIDAL ALGAE IN BOTTOM FIGURE (not including *Nereocystis* and *Macrocystis*)

Area of continuous plume contact with greatest observed effects; includes urchin barrens: (8.1 hectares; 19.9 acres)

Area of reduced plume contact with unknown effects likely to be less than those observed in affected areas of Diablo Cove: (39.5 hectares; 97.6 acres)

Figure 4-20. Approximate bottom areas of discharge effects in subtidal algae observed in the study. Inset shows the affected areas in Diablo Cove and its headlands in grey shading: to about -4 m MLLW in portions of north Diablo Cove, and to about -3 m MLLW in south Diablo Cove. Effects were deepest (about -7 m MLLW) inshore of Diablo Rock. Areas of urchin barrens (in inset) shown in black. Map of effects was developed from station sampling, qualitative dive observations, boat surveys, shore observations, and North et al. (1989).

While the kelp maps from the aerial surveys cannot be used to determine the spatial extent of effects to kelp, the maps provide a means to estimate amounts of kelp that can occur in the plume contact area, based on kelp abundance mapped during the pre-operation surveys. The area of kelp surface canopy in the plume contact area ranged from 15.9 ha (39.3) in October 1975 to less than 0.1 ha in March 1970.

4.3.2 Invertebrates

The subtidal benthic habitat of Diablo Cove was sampled for invertebrates using both SAQ and SFQ methods. Two hundred thirty-eight taxa were identified from the two methods, most to the species level. The taxa comprising the top 99% of the total abundance for the pooled Diablo Cove stations (Figures 4-21 and 4-22) were analyzed for changes relative to the control areas (Figure 4-23 and 4-24). The list included 49 taxa from the SAQ study and 99 taxa from the SFQ study. A total of 106 separate taxa was analyzed as a number of taxa were common to lists from both methods. A determination was made for taxa that occurred on the lists for both methods as to which method better sampled a particular taxon, and only the results for that method were reported. For example, large (>1 cm), motile taxa (e.g., *Pisaster* spp.) were better sampled using the relatively extensive SAQ method, while small (<1 cm) or encrusting taxa (e.g., *Lacuna* spp. and *Metandrocarpa taylori*, respectively) were better sampled using the relatively intensive SFQ method.

Prior to the analyses, assumption tests required for the BACI analysis were completed using transformed and untransformed data for each taxon and for the number of taxa (species richness) from both the SAQ and SFQ data sets (Appendix G). Table 4-8 summarizes the main discharge effects on subtidal invertebrates, with more detailed analyses following.

Table 4-8. Summary of discharge effects on subtidal invertebrates sampled using the arc-quadrant counts and 0.25 m^2 fixed quadrat method.

Category	-3 m MLLW and -4 m MLLW levels combined	Notes
Total area of bottom with observed effects	8.1 ha 19.9 ac	Based mainly on area of bottom contacted by thermal plume. Most effects were in Diablo Cove.
Effects on overall numbers of invertebrate taxa	decrease	BACI result; significant decreases at 4 m depth
Number (%) of taxa increases	28 (26%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa decreases	32 (30%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa unchanged	14 (13%)	Includes *Alia, Asterina*, and *Phragmatopoma*, which had mixed responses by depth.
Number (%) of taxa with inconclusive test results	32 (31%)	Includes both BACI and Fisher's exact test.
Number of taxa analyzed statistically	106	Taxa comprising top 99% cumulative abundance.
Number of taxa sampled during study	238	Includes all Diablo Cove stations combined; also includes some species that were grouped into combination taxa for analysis.

Analysis of Species Changes

Eighty-one taxa passed the tests of assumptions and were analyzed for changes using the BACI model (Table 4-9). The other taxa were analyzed using the Fisher's exact test (Table 4-10). Taxa were categorized as statistically significant increases, statistically significant decreases, or effects not detected, based

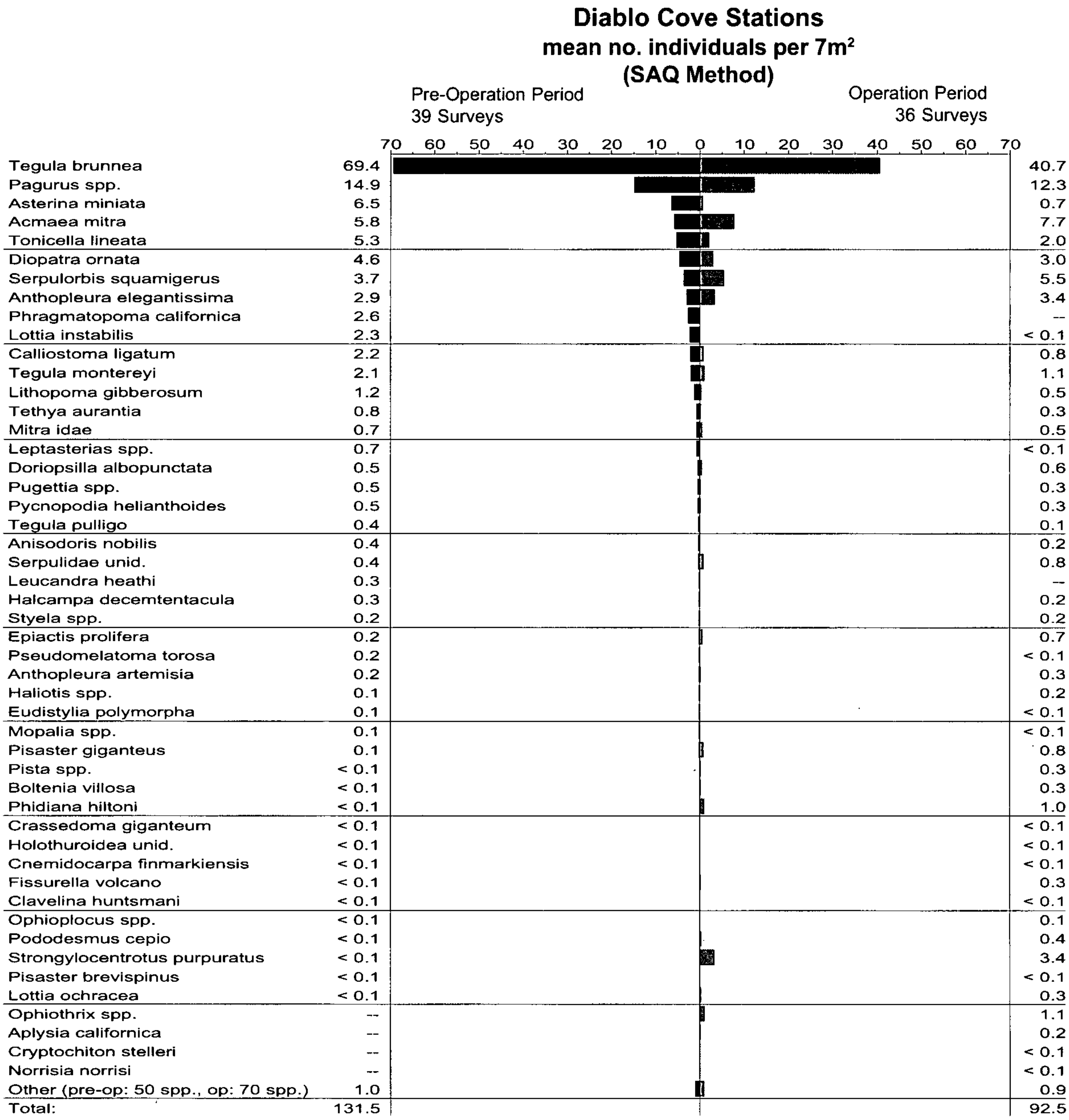
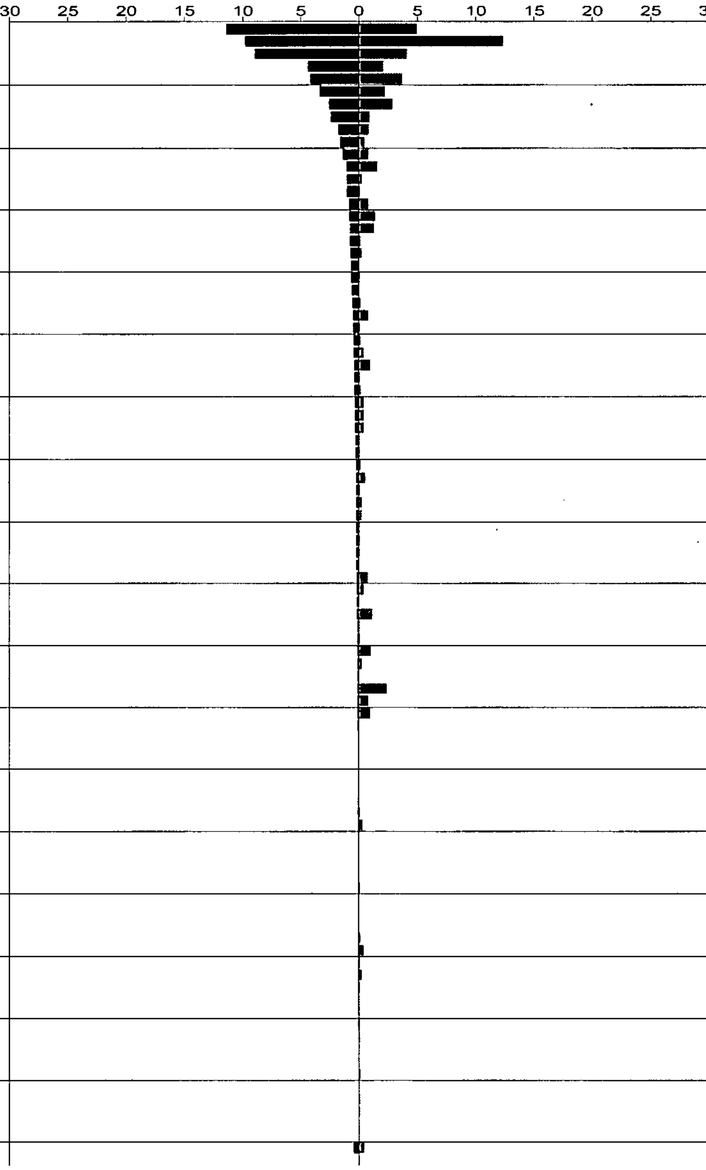


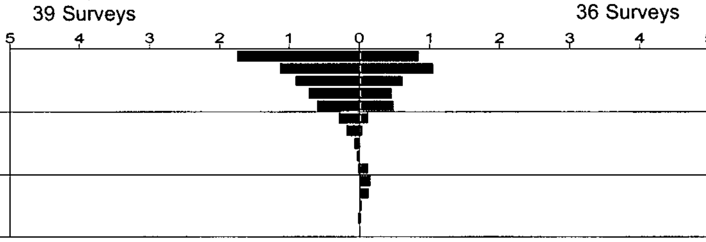
Figure 4-21. Invertebrate densities at the Diablo Cove subtidal benthic stations (SAQ method).

a) Diablo Cove: mean no. individuals per 0.25m²



	Pre-Operation Period 39 Surveys	Operation Period 36 Surveys
Phragmatopoma californica	11.4	5.0
Pelecypoda unid. boring	9.7	12.4
Pagurus spp.	8.9	4.1
Dendropoma spp.	4.3	2.1
Tegula brunnea	4.1	3.7
Alia spp.	3.3	2.2
Chaetopteridae	2.5	2.9
Homalopoma spp.	2.4	0.9
Pugettia spp.	1.7	0.8
Balanophyllia elegans	1.6	0.5
Sipuncula unid.	1.4	0.8
Acmaea mitra	1.0	1.6
Epiactis prolifera	1.0	0.3
Cactosoma arenaria	1.0	< 0.1
Amphissa spp.	0.8	0.8
Lottia ochracea	0.8	1.4
Serpulidae unid.	0.7	1.3
Crepidula spp.	0.7	0.2
Pseudomelatoma torosa	0.7	0.2
Pisaster/Henricia (juv.)	0.6	< 0.1
Leptasterias spp.	0.6	< 0.1
Lottia instabilis	0.6	< 0.1
Anthozoa unid.	0.5	0.2
Pista spp.	0.5	0.8
Leucandra heathi	0.5	< 0.1
Leucilla nuttingi	0.4	0.1
Tonicella lineata	0.4	0.4
Serpulorbis squamigerus	0.3	1.0
Cucumaria spp.	0.3	< 0.1
Ocenebra spp.	0.3	0.2
Bittium spp.	0.3	0.4
Tricolia spp.	0.3	0.4
Clavularia spp.	0.3	0.4
Lophopanopeus spp.	0.3	< 0.1
Asterina miniata	0.2	< 0.1
Diopatra ornata	0.2	0.2
Lacuna spp.	0.2	0.6
Lithopoma gibberosum	0.2	0.1
Anthopleura elegantissima	0.2	0.3
Ischnochitonidae	0.2	0.3
Calliostoma ligatum	0.2	< 0.1
Mitra idae	0.2	0.1
Pyura haustor	0.2	< 0.1
Majidae	0.1	< 0.1
Lissothuria nutriens	0.1	0.8
Pododesmus cepio	0.1	0.5
Cryptolithodes sitchensis	0.1	< 0.1
Strongylocentrotus purpuratus	0.1	1.2
Tegula montereyi	< 0.1	< 0.1
Doriopsilla albopunctata	< 0.1	0.1
Ophiothrix spp.	< 0.1	1.1
Sabellidae	< 0.1	0.3
Henricia leviuscula	< 0.1	--
Balanus/Tetraclita spp.	< 0.1	2.4
Fissurella volcano	< 0.1	0.8
Tetraclita rubescens	< 0.1	1.0
Halcampa decemtentacula	< 0.1	< 0.1
Tegula pulligo	< 0.1	< 0.1
Pycnopodia helianthoides	< 0.1	< 0.1
Hopkinsia rosacea	< 0.1	< 0.1
Cancer spp.	< 0.1	< 0.1
Hipponix spp.	< 0.1	< 0.1
Styela spp.	< 0.1	< 0.1
Mopalia spp.	< 0.1	< 0.1
Clavelina huntsmani	< 0.1	0.3
Ophioplocus spp.	< 0.1	< 0.1
Conus californicus	< 0.1	< 0.1
Haliotis spp.	< 0.1	< 0.1
Anthopleura artemisia	< 0.1	< 0.1
Cirratulidae/Terebellidae unid.	< 0.1	< 0.1
Eupentacta quinquesemita	< 0.1	< 0.1
Hermissenda crassicornis	< 0.1	< 0.1
Pelecypoda unid.	< 0.1	< 0.1
tunicate, solitary unid.	< 0.1	0.1
Balanus spp.	< 0.1	0.4
Ophiuroidea unid.	< 0.1	< 0.1
Phidiana hiltoni	< 0.1	0.3
Boltenia villosa	< 0.1	< 0.1
Lepidozona spp.	< 0.1	< 0.1
Triopha maculata	< 0.1	< 0.1
Eudistylia polymorpha	< 0.1	< 0.1
Diodora spp.	< 0.1	< 0.1
Nereididae unid.	< 0.1	< 0.1
Tethya aurantia	< 0.1	< 0.1
Fusinus luteopictus	< 0.1	0.1
Crassedoma giganteum	< 0.1	< 0.1
Acmaeidae unid.	--	< 0.1
Williamia peltoides	--	< 0.1
Pisaster giganteus	--	< 0.1
Aplysia californica egg mass	--	< 0.1
Other (pre-op: 44 spp., op: 66 spp.)	0.4	0.5
Total:	68.3	58.8

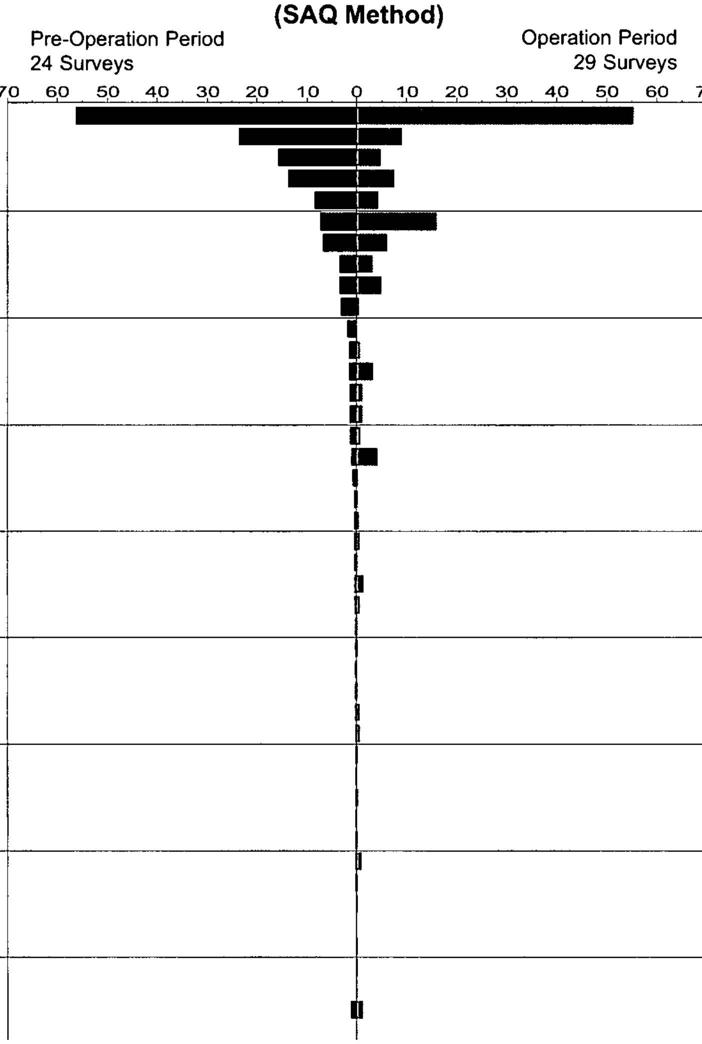
b) Diablo Cove: mean no. 2.5 cm² units cover per 0.25m²



	Pre-Operation Period 39 Surveys	Operation Period 36 Surveys
tunicates, colonial/social unid.	1.7	0.9
Bryozoa, unid. (encrusting)	1.1	1.1
Porifera unid. (encrusting)	0.9	0.6
Didemnum/Trididemnum spp.	0.7	0.5
Spirorbidae	0.6	0.5
Salmacina tribranchiata	0.3	0.1
Dodecaceria fewkesi	0.2	< 0.1
Bryozoa, unid. (foliose)	< 0.1	< 0.1
Hydroida	< 0.1	< 0.1
Eurystomella bilabiata	< 0.1	0.1
Metandrocarpa taylori	--	0.2
Hymenamphiastra cyanocrypta	--	0.1
Chthamalus fissus	--	< 0.1
Other (pre-op: 5 spp., op: 5 spp.)	< 0.1	< 0.1
Total:	5.7	4.1

Figure 4-22. Invertebrate abundances at the Diablo Cove subtidal benthic stations (SFQ method). (a) Counts of individuals. (b) Cover of encrusting forms.

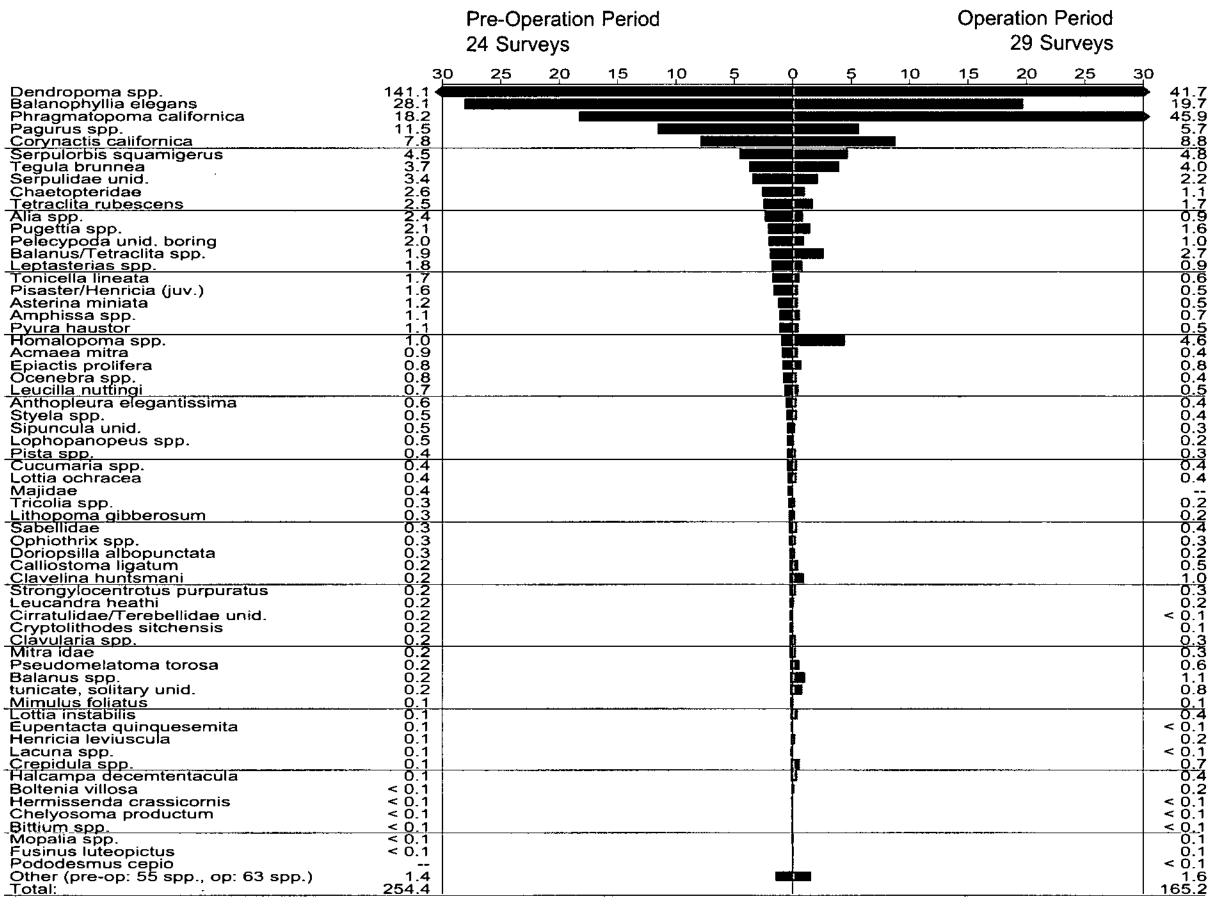
South Control Sations
mean no. individuals per 7m²
(SAQ Method)



Species	Pre-Operation Period (24 Surveys)	Operation Period (29 Surveys)
Tegula brunnea	56.3	55.4
Asterina miniata	23.5	9.0
Tonicella lineata	15.7	4.8
Pagurus spp.	13.6	7.5
Acmaea mitra	8.4	4.2
Serpulorbis squamigerus	7.3	16.0
Anthopleura elegantissima	6.8	6.1
Diopatra ornata	3.4	3.2
Styela spp.	3.4	5.0
Lithopoma gibberosum	3.1	0.4
Phragmatopoma californica	1.9	--
Leptasterias spp.	1.5	0.7
Calliostoma ligatum	1.5	3.3
Serpulidae unid.	1.4	1.1
Tegula montereyi	1.3	1.2
Mitra idae	1.2	0.7
Lottia instabilis	1.1	4.2
Eudistylia polymorpha	0.8	0.4
Pugettia spp.	0.5	0.3
Pycnopodia helianthoides	0.5	0.5
Pisaster giganteus	0.5	0.6
Tegula pulligo	0.4	0.2
Halcampa decemtentacula	0.4	1.3
Doriopsilla albopunctata	0.4	0.7
Pista spp.	0.3	0.2
Anthopleura artemisia	0.3	0.3
Strongylocentrotus purpuratus	0.3	0.1
Haliotis spp.	0.3	0.2
Pyura haustor	0.2	0.5
Boltenia villosa	0.2	0.7
Tethya aurantia	0.2	0.3
Pisaster ochraceus	0.2	< 0.1
Henricia leviuscula	0.2	0.4
Urticina spp.	0.2	< 0.1
Mopalia spp.	0.2	0.2
Epiactis prolifera	0.2	0.9
Anisodoris nobilis	0.2	0.2
Pseudomelatoma torosa	0.1	0.2
Hermissenda crassicornis	< 0.1	0.1
Cnemidocarpa finmarkiensis	< 0.1	0.2
Ophiothrix spp.	< 0.1	0.2
Phidiana hiltoni	< 0.1	0.1
Other (pre-op: 34 spp., op: 50 spp.)	1.1	1.3
Total:	159.0	132.8

Figure 4-23. Invertebrate densities at the South Control subtidal benthic stations (SAQ method).

a) South Control: mean no. individuals per 0.25m²



b) South Control: mean no. 2.5 cm² units cover per 0.25m²

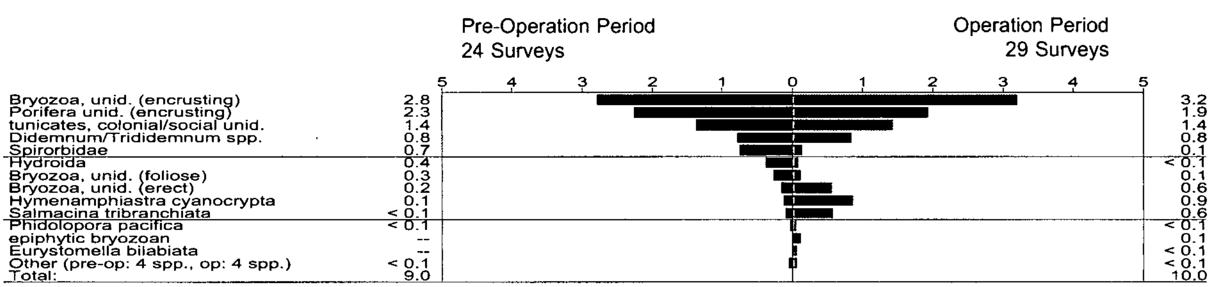


Figure 4-24. Invertebrate abundances at the South Control subtidal benthic stations (SFQ method). (a) Counts of individuals. (b) Cover of encrusting forms.

Table 4-9. Results of BACI ANOVA for subtidal invertebrates. Negative values indicate decreases between periods for individual stations. Statistically significant results (p<0.10) are in **bold** type.

	% Change in Diablo Cove Relative to Controls	Period F	Period P	Power to detect 50% Change between periods	Sta*Per Interaction P	Depth*Per Interaction P	Period -3m P	Period -4m P	Pairwise Comparisons by Station (p) [mean temperature above ambient in °C]: NDC 2 -3m [3.4°]	NDC 3 -3m [3.8°]	NDC 4 -4m [3.4°]	SDC 2 -3m [2.0°]	SDC 3 -4m [1.2°]
Significant Increases													
-3m and -4m MLLW stations													
Acmaea mitra	+238	54.1	<.01	1.00	.08	.64	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Anthopleura elegantissima	+101	28.2	<.01	1.00	<.01	.13	<.01	<.01	<.01	<.01	<.01	.19	.73
Cirratulidae/Terebellidae	+1266	19.8	<.01	.16	.66	.84	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Dendropoma spp.	+155	22.3	<.01	.84	.14	.02	<.01	.10	<.01	.01	.09	.50	<.01
Fissurella volcano	+256	7.6	.01	.41	<.01	.01	<.01	.08	<.01	<.01	<.01	-.43	.93
Ischnochitonidae	+243	4.1	.05	.99	.13	.16	.28	.02	.84	.23	<.01	.62	.42
Lacuna spp.	+120	6.2	.02	.34	.95	.83	.02	.04	.03	.14	.15	.06	.07
Lissothuria nutriens	+216	22.7	<.01	.74	<.01	.10	<.01	.01	<.01	<.01	<.01	-.85	.13
Lithopoma gibberosum	+63	22.5	<.01	.97	<.01	<.01	<.01	.01	<.01	<.01	<.01	.95	<.01
Majidae	*no calc* [1]	4.6	.04	.39	.15	.02	.18	.01	.14	.34	.03	<.01	.34
Ophiothrix spp.	+727	40.8	<.01	.48	<.01	.03	<.01	<.01	.20	<.01	<.01	<.01	<.01
Ophiuroidea unid.	*no calc*	4.0	.05	.12	.97	.60	.05	.27	.35	.12	.42	.40	.18
Pelecypoda unid. boring	+192	24.8	<.01	1.00	<.01	<.01	<.01	.06	<.01	<.01	.06	.22	<.01
Phidiana hiltoni	+101	10.3	<.01	.11	.05	.45	<.01	.02	<.01	<.01	<.01	.43	.30
Pisaster giganteus	+572	27.1	<.01	.30	.21	.78	<.01	<.01	<.01	<.01	<.01	.01	<.01
Pista spp.	+190	7.6	.01	.88	<.01	.77	.02	.01	<.01	.80	.49	<.01	.05
Pododesmus cepio	+4534	9.8	<.01	.10	<.01	<.01	.06	<.01	.81	<.01	<.01	<.01	.11
Serpulidae unid.	+161	64.9	<.01	.87	<.01	<.01	<.01	<.01	<.01	<.01	<.01	-.08	<.01
Spirorbidae	+346	29.5	<.01	1.00	.31	.88	<.01	<.01	<.01	<.01	.08	<.01	<.01
Strongylocentrotus purpuratus	+45678	36.3	<.01	.10	.16	.75	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Tetraclita rubescens	+844	3.8	.06	.10	<.01	.33	.04	.13	.30	<.01	.03	.53	.23
-3m MLLW stations only													
Asterina miniata [2]	-71	1.2	.27	1.00	<.01	<.01	<.01	-.05	.01	.01	-.80	-<.01	<.01
Balanus/Tetraclita spp.	+1666	5.2	.03	.12	.06	.02	.01	.26	.01	.01	.06	.91	.03
Chaetopteridae	+95	6.8	.01	.59	<.01	<.01	<.01	.75	<.01	<.01	.67	.91	.06
Phragmatopoma californica [2]	-78	0.0	.92	1.00	<.01	<.01	<.01	-<.01	<.01	-.75	-<.01	-.01	.02
-4m MLLW stations only													
Alia spp. [1]	+51	0.0	.96	1.00	<.01	<.01	-.05	.01	-<.01	-.01	.07	.01	.05
Anthozoa unid.	+41	3.7	.06	.78	<.01	<.01	.96	<.01	.42	.32	.02	<.01	-.09
Lophopanopeus spp.	+18	2.2	.15	.81	.17	.04	.41	.03	.65	.83	.04	.09	.15

(table continued)

Table 4-9 (continued). Results of BACI ANOVA for subtidal invertebrates.

	% Change in Diablo Cove Relative to Controls	Period F	Period P	Power to detect 50% Change between periods	Sta*Per Interaction P	Depth*Per Interaction P	Period -3m P	Period -4m P	Pairwise Comparisons by Station (p) [mean temperature above ambient in °C] NDC 2 -3m [3.4°]	NDC 3 -3m [3.8°]	NDC 4 -4m [3.4°]	SDC 2 -3m [2.0°]	SDC 3 -4m [1.2°]
Significant Decreases													
-3m and -4m MLLW stations													
Anisodoris nobilis	-60	4.6	.04	.72	.64	.21	-.11	-.01	-.18	-.28	-.01	-<.10	-.14
Balanophyllia elegans	-43	30.2	<.01	1.00	<.01	.75	-<.01	-<.01	.90	.25	-<.01	-.05	-<.01
Balanus spp.	+545	12.2	<.01	.10	.07	1.00	-<.01	-<.01	-<.01	-.02	-.02	-<.01	-.05
Cactosoma arenaria	*no calc*	77.7	<.01	1.00	<.01	<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	.67
Calliostoma ligatum	-94	58.4	<.01	.96	<.01	<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01
Crassedoma giganteum	-93	4.5	.04	.10	.59	.27	-.02	-.18	-.02	-.23	-.36	-.17	-.04
Crepidula spp.	-97	69.4	<.01	1.00	<.01	.12	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01
Epiactis prolifera	-82	51.4	<.01	1.00	<.01	.31	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-.05
Henricia leviuscula	*no calc*	11.6	<.01	.40	<.01	<.01	-.01	-<.01	-<.01	-.03	-<.01	-.03	-.12
Lottia instabilis	-98	80.6	<.01	.99	.02	.48	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01	-<.01
Pisaster/Henricia spp. (juv.)	-92	15.3	<.01	.62	<.01	<.01	-<.01	-.08	-<.01	-<.01	-<.01	.73	.87
Pseudomelatoma torosa	-83	12.5	<.01	.25	.01	.13	-<.01	-<.01	-<.01	-.05	-.05	-<.01	-.01
Pugettia spp.	-45	15.6	<.01	1.00	.03	.06	-<.01	-.05	-<.01	-<.01	-.05	-.25	-.14
Pycnopodia helianthoides	-44	4.6	.04	1.00	.67	.92	-.06	-.07	-.17	-.11	-.54	-.02	-.20
Sipuncula unid.	-31	7.8	.01	1.00	<.01	.11	-<.01	-.07	-.08	-.03	-<.01	.99	-<.01
Tegula brunnea	-71	7.6	.01	1.00	.14	.39	-.01	-.01	-<.01	-.02	-.01	-.02	-.02
Tegula montereyi	-83	10.8	<.01	.90	.40	.21	-.01	-<.01	-.02	-.17	-.01	-<.01	-.01
tunicates, solitary unid.	+18	15.2	<.01	.11	.47	.22	-<.01	-<.01	-<.01	-<.01	-.02	-<.01	-.01
tunicates, colonial/social unid.	-53	10.9	<.01	1.00	<.01	.21	-<.01	-<.01	-.55	-.04	-.01	-<.01	-<.01
-3m MLLW stations only													
Alia spp.[2]	+51	0.0	.96	1.00	<.01	<.01	-.05	.01	-<.01	-.01	.07	.01	.05
Bryozoa unid. (encrusting)	-42	12.1	<.01	1.00	<.01	<.01	-<.01	-.56	-<.01	-.04	-.59	-.67	-<.01
Leptasterias spp.	-92	6.3	.02	1.00	<.01	<.01	-<.01	-.86	-<.01	-<.01	-.02	.04	.78
Pagurus spp.	-38	5.5	.02	1.00	<.01	<.01	-<.01	-.78	-<.01	-.03	-.37	.66	-.75
Porifera unid. (encrusting)	-27	3.9	.06	1.00	.04	.01	-.01	-.77	-.09	-.04	.76	-.42	<.01
-4m MLLW stations only													
Asterina miniata[2]	-71	1.2	.27	1.00	<.01	<.01	<.01	-.05	.01	.01	-.80	-<.01	<.01
Cucumaria spp.	-73	0.7	.41	.35	<.01	<.01	.76	-.02	.68	.94	-.21	-<.01	.74
Didemnum/Trididemnum spp.	-63	13.3	<.01	1.00	<.01	<.01	.80	-<.01	-.07	.16	-<.01	-<.01	.35
Leucandra heathi	-66	1.8	.19	.45	<.01	<.01	-.83	-.01	.96	.70	-.44	-<.01	-.33
Phragmatopoma californica[2]	-78	0.0	.92	1.00	<.01	<.01	<.01	-<.01	<.01	-.75	-<.01	-.01	.02
Serpulorbis squamigerus	-62	5.7	.02	1.00	.04	.07	-.19	-<.01	-.03	.87	-.17	-<.01	-.44

(table continued)

Table 4-9 (continued). Results of BACI ANOVA for subtidal invertebrates.

	% Change in Diablo Cove Relative to Controls	Period		Power to detect 50% Change between periods	Sta*Per Interaction	Depth*Per Interaction	Period		Pairwise Comparisons by Station (p) [mean temperature above ambient in °C]				
		F	P		P	P	-3m P	-4m P	NDC 2-3m [3.4°]	NDC 3-3m [3.8°]	NDC 4-4m [3.4°]	SDC 2-3m [2.0°]	SDC 3-4m [1.2°]
Significant Decreases (continued)													
-4m MLLW stations only													
Styela spp.	-62	0.4	.51	.12	.11	.05	.62	-.07	.89	.79	-.01	-.89	.57
Tethya aurantia	-57	4.3	.05	1.00	<.01	<.01	-.36	-<.01	-.71	-.55	-<.01	-.47	-.19
No Change[3]													
Amphissa spp.	+23	0.0	.91	.98	<.01	.11	-.77	.50	-.11	-.14	-.70	.11	.02
Bittium spp.	+19	0.2	.68	.89	.01	.81	.81	.64	-.11	-.45	.30	-.73	<.01
Cryptolithodes sitchensi	-75	0.6	.44	.83	.02	.04	-.20	.95	-.08	-.18	-.40	.34	-.81
Diopatra ornata	+42	0.1	.72	.76	<.01	.01	.37	-.67	-.85	.30	-.27	.75	.11
Doriopsilla albopunctata	-51.	2.3	.14	.74	.01	.36	-.29	-.08	-.63	-.25	.65	-<.01	-.39
Hopkinsia rosacea	*no calc*	0.0	.83	.93	.44	.75	-.98	.70	.48	.48	.48	-.86	-.14
Lottia ochracea	+101	0.4	.51	.99	.01	.96	.51	.53	.12	.73	.13	-.74	-.95
Mitra idae	-29	1.2	.28	.96	.74	.20	-.61	-.11	-.62	-.90	-.26	-.13	-.58
Ocenebra spp.	-8	0.1	.78	.84	.01	.21	-.52	.78	-.24	-.31	-.21	.08	.57
Tonicella lineata	-26	0.1	.81	1.00	<.01	.66	.87	.73	-.42	-.79	-.52	.19	.13
Tricolia spp.	+113	2.5	.12	.76	.33	.80	.13	.26	.06	-.83	.73	.15	.11
Species Richness (SAQ method)	-7	2.6	.11	1.00	.41	.18	-.04	-.67	-.02	-.56	-.89	-.60	-.20
Species Richness (SFQ method)	-5	0.9	.34	1.00	.16	.24	-.73	-.14	-.87	-.27	-.96	-.02	.60
Test Results Inconclusive[4]													
Boltenia villosa	+99	0.9	.34	.11	<.01	.03	.67	.10	-.53	-.58	.51	.02	.02
Cancer spp.	0	0.0	.96	.58	.29	.06	-.41	.23	.89	-.50	.30	.39	-.22
Clavularia spp.	-10	0.2	.62	.12	.45	.34	.78	.44	.68	-.99	.90	.19	.73
Diodora spp.	+10	0.4	.51	.11	.01	.28	-.38	-.78	.68	-.20	.57	-.28	-.13
Eudistylia polymorpha	-36	1.2	.28	.22	.22	.17	.17	.57	.31	.30	.23	-.88	.11
Eupentacta quinquesemita	-6	0.0	.91	.23	.69	.76	-.85	1.00	-.63	-.62	.76	-.76	.64
Halcampa decemtentacula	-60	0.6	.44	.14	.62	.95	-.44	-.47	-.91	-.49	-.55	-.46	-.20
Hermissenda crassicornis	+167	1.2	.27	.18	.29	.12	.59	.09	.86	.93	.04	.40	.30
Leucilla nuttingi	-58	0.3	.60	.34	<.01	<.01	.35	-.92	.42	.29	.44	-.33	.40
Mopalia spp.	-36	1.0	.33	.37	.32	.83	-.41	-.34	-.88	-.07	-.83	-.17	.95
Pelecypoda unid.	+900	1.0	.31	.10	.43	.23	.53	.16	.59	.59	.05	.59	.60
Pyura haustor	+19	0.0	.91	.22	.73	.19	-.99	-.79	.94	-.98	-.78	-.80	-.94
Triopha maculata	+111	2.5	.12	.10	.22	.47	-.15	-.09	-.15	-.08	-.03	-.27	-.41

[1] percent change could not be calculated because mean control abundance was zero during one or both periods.
[2] taxa listed twice because of differing significant effects between depths.
[3] no significant difference between period means, and power of the test to detect a 50% change between periods was greater than .70.
[4] no significant difference between period means, and power of the test to detect a 50% change between periods was less than .70.

on the results of the analyses. Power analysis allowed the latter category (effects not detected) to be further partitioned and interpreted as either no changes (power >0.70) or test results inconclusive (power ≤0.70). Graphs depicting changes in abundance over time for all 106 taxa appear in Appendix E.

Changes in invertebrate species composition and abundance were evident at both Diablo Cove and the control between periods (Figures 4-21 through 4-24). Of the 106 taxa analyzed for differences in abundance between periods, approximately equal numbers were categorized as significant increases, significant decreases, and effects not detected. Most of the taxa with large abundance changes between periods observed within Diablo Cove did not show similar changes at the control, indicating discharge-related factors were primarily responsible. Several taxa were observed during the operation period that were not present during pre-operation, including *Aplysia californica*, *Cryptochiton stelleri*, and *Norrisia norrisi*.

Of the 81 taxa analyzed with the BACI model, significant increases between periods relative to the controls were detected in 28 taxa, and significant decreases were detected in 32 taxa. Three of these taxa displayed different responses between the two depths tested, and therefore appear twice in the BACI results. Significant changes were not detected in 24 taxa, accounting for the 84 taxa presented in Table 4-9. Twenty-five taxa were analyzed using the Fisher's exact test, three of which increased significantly and three of which declined significantly (Table 4-10).

Table 4-10. Results of Fisher's exact test for subtidal invertebrate taxa not tested in BACI analysis. Statistically significant results ($p<0.10$) are in **bold** type.

Taxon	Fisher's P
Significant Increase	
Aplysia californica	**<.01**
Bryozoa unid. (foliose)	**<.10**
Norrisia norrisi	**<.01**
Significant Decrease	
Dodecaceria fewkesi	**.09**
Homalopoma spp.	**<.01**
Salmacina tribranchiata	**<.01**
Test Results Inconclusive	
Acmaeidae unid.	1.00
Anthopleura artemisia	1.00
Clavelina huntsmani	1.00
Cnemidocarpa finmarkiensis	1.00
Cryptochiton stelleri	1.00
Eurystomella bilabiata	.48
Fusinus luteopictus	.63
Haliotis spp.	1.00
Hipponix spp.	.24
Holothuroidea unid.	.58
Hymenamphiastra cyanocrypta	1.00
Lepidozona spp.	.26
Metandrocarpa taylori	1.00
Nereidae unid.	1.00
Ophioplocus spp.	1.00
Pisaster brevispinus	.26
Sabellidae unid.	1.00
Tegula pulligo	.19
Williamia peltoides	.12

Significant Increases, Both Depths

Significant increases at both depths were detected in 24 taxa from Diablo Cove stations. Among these, the largest increases (% change) in abundance were observed in cirratulid and terebellid polychaete worms, *Ophiothrix* spp., *Pisaster giganteus*, *Pododesmus cepio*, *Strongylocentrotus purpuratus*, and *Tetraclita rubescens*. Large increases in *P. giganteus* were first detected in 1988, nearly three years after commercial operation of DCPP began. Abundances at all impact stations appeared to peak near 1992, and have declined since that time (Figure 4-25). The gastropods *Norrisia norrisi* (Figure 4-26) and *Aplysia californica* (Figure 4-27) also increased significantly in Diablo Cove during the operation period.

Lithopoma gibberosum, red turban snails, showed a significant relative increase between periods in Diablo Cove (Table 4-9). However, this taxon declined notably in Diablo Cove within the period 1988-

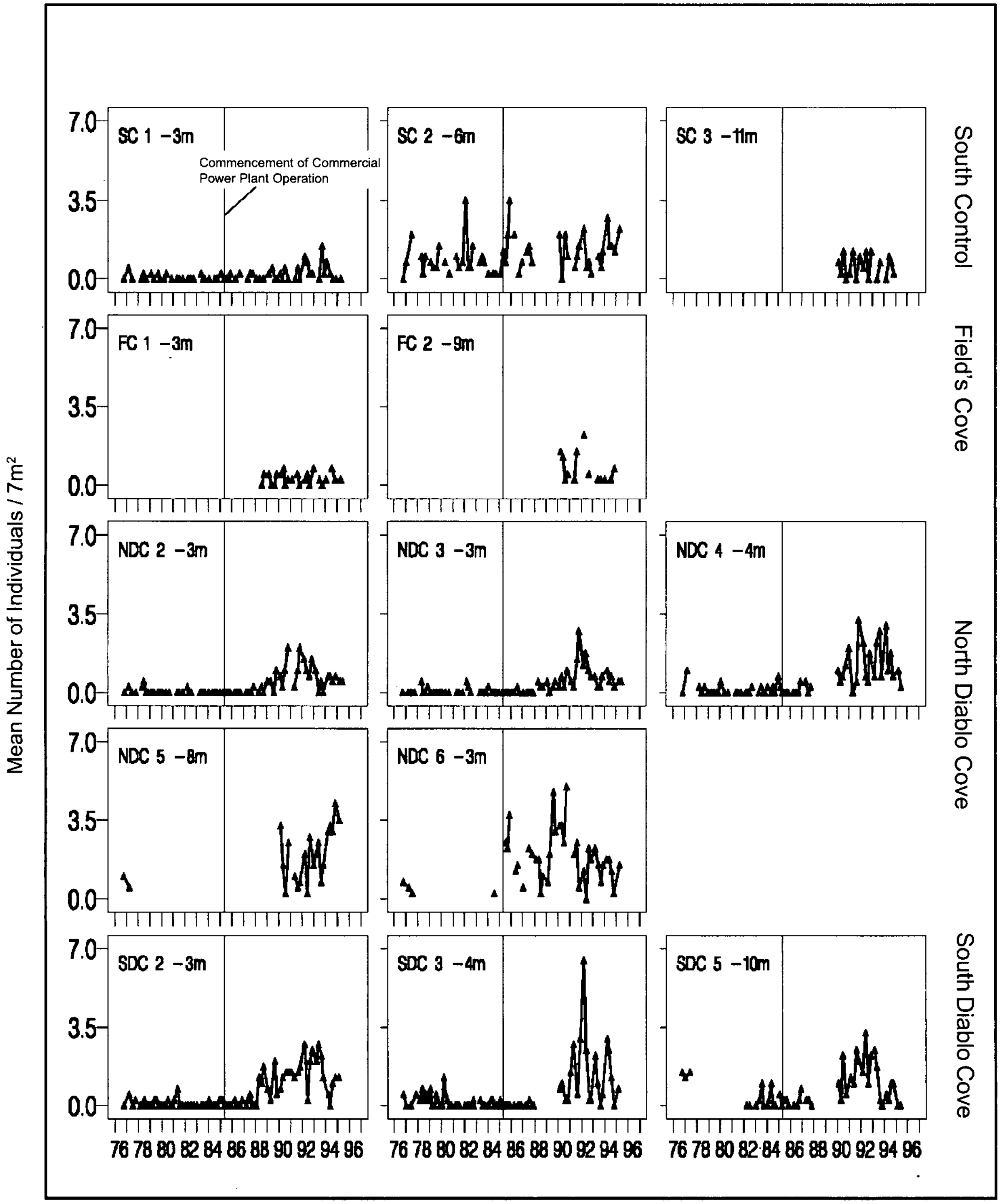


Figure 4-25. *Pisaster giganteus*: changes in density at subtidal benthic stations (SAQ method).

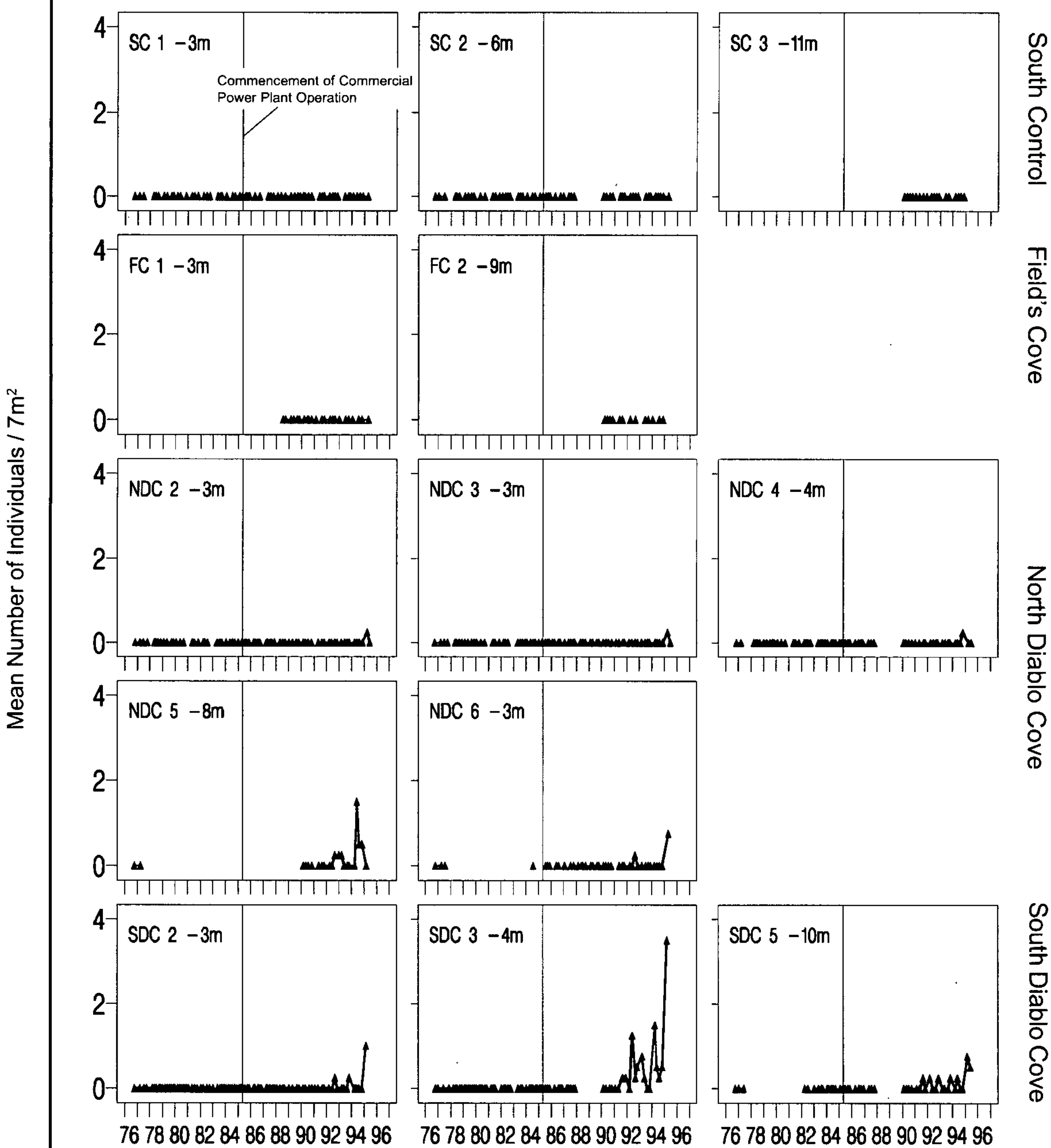


Figure 4-26. *Norrisia norrisi*: changes in density at subtidal benthic stations (SAQ method).

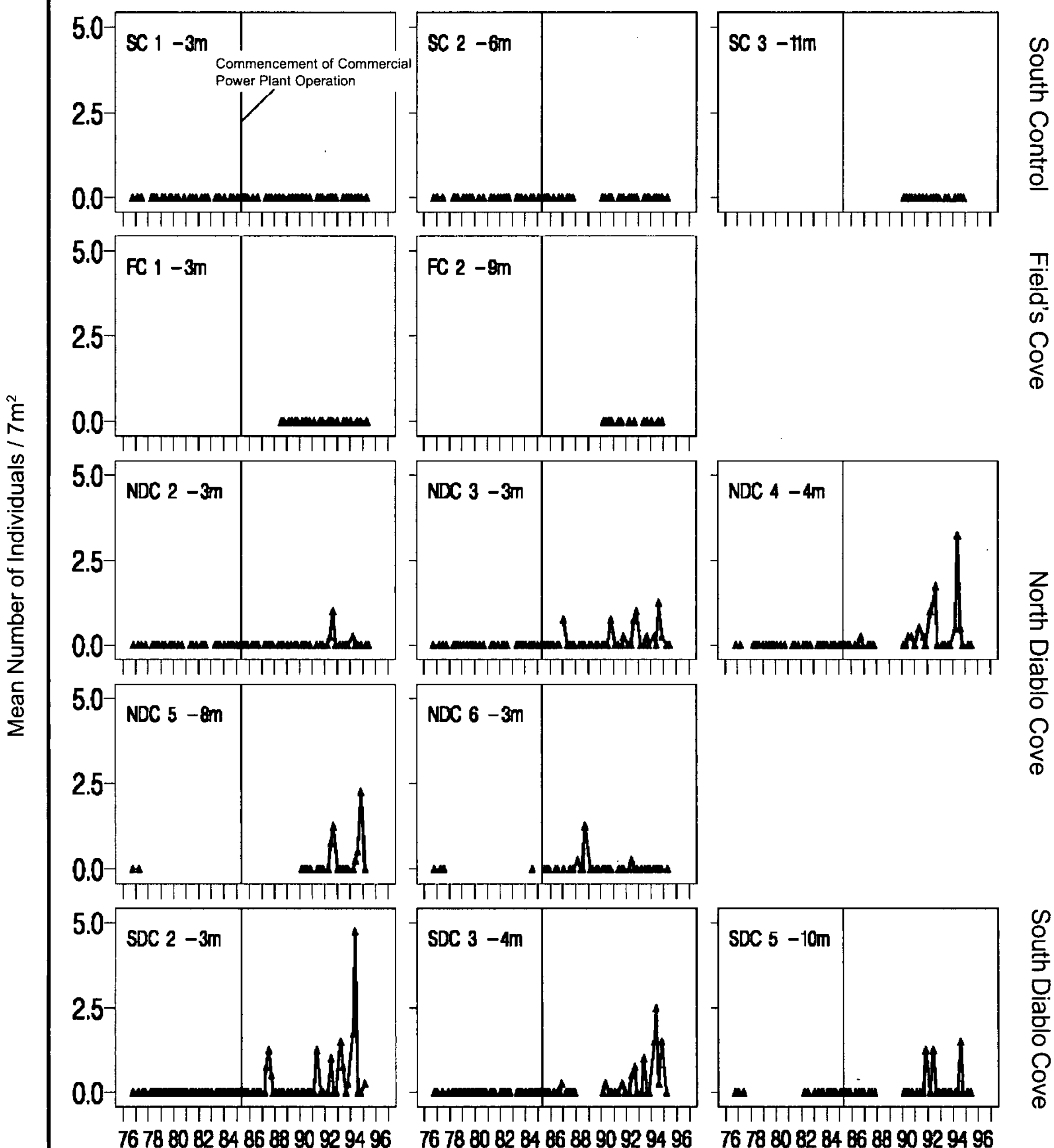


Figure 4-27. *Aplysia californica*: changes in density at subtidal benthic stations (SAQ method).

1990 (Appendix E, Figure E5-80), and were uncommonly observed on the stations sampled from 1990 through the conclusion of the TEMP. Although *L. gibberosum* also declined at the control between periods (resulting in the relative increase in Diablo Cove), they were still observed in moderate abundance through the completion of the TEMP (Appendix E, Figure E5-80).

Significant Increases, Depth-Specific

Results from the tests of the two interaction terms determined that tests between periods needed to be conducted separately at each of the two depths for seven taxa. The largest depth-specific increase was detected in the barnacle group *Balanus/Tetraclita* spp. (a category for unidentified juveniles) at the -3 m level. Similar to the pattern for *P. giganteus*, large increases in *Balanus/Tetraclita* spp. were detected in 1988, peaked in 1990-92, and declined through 1995 (Figure 4-28). Large settlement events for barnacles were evident through time at all stations sampled. A significant increase in *Alia* spp. (largely *A. carinata*), a small snail, was detected at the -4 m stations, with an associated significant decline at the -3 m level.

Asterina miniata (bat stars) showed a relative increase between periods in Diablo Cove at the -3 m depth and a relative decline at the -4 m depth (Table 4-9). Declines in the abundance of *A. miniata* were observed throughout the study area in 1983, but subsequent recoveries evident at the control did not occur in Diablo Cove. *A. miniata* were uncommonly observed at Diablo Cove shallow (-3 to -4 m) stations at the completion of the TEMP (Appendix E, Figure E5-17).

Significant Decreases, Both Depths

Significant decreases at both depths were detected in 22 taxa, including three taxa analyzed in the Fisher's exact test. The largest percent declines were observed in molluscs, including *Calliostoma ligatum*, *Crassedoma giganteum*, *Crepidula* spp., *Lottia instabilis*, *Pseudomelatoma torosa*, and *Tegula brunnea* and *T. montereyi*. The 98% decline between periods in *L. instabilis* (Figure 4-29) was related to the corresponding decline of *Pterygophora californica* and *Laminaria setchellii* from shallower areas of Diablo Cove. This limpet occurs almost exclusively on the stipes of these kelps. The snail *Homalopoma* spp. (primarily *H. luridum*) (Figure 4-30) was an example of a small gastropod that declined significantly in Diablo Cove after plant start-up, though these declines at sampled stations were not evident until 1990.

Percent change increases in *Balanus* spp. (+545%) and solitary tunicates (+18%) shown in Table 4-9 are relative to pre-operation abundance. The absolute abundance of these taxa increased at both impact and control areas between periods, but the increase was greater at the control, resulting in a relative decline at the impact.

Significant Decreases, Depth-Specific

Results from the tests of the two interaction terms determined that tests between periods needed to be done separately at each depth for thirteen additional taxa. The largest decline in this group (92% decrease) occurred in the brooding seastar *Leptasterias* spp. (primarily *L. hexactis*). *Leptasterias* spp. have not been observed commonly in the Diablo Cove subtidal since 1988 (Figure 4-31). Significant declines in *Asterina miniata* (-71%) and *Phragmatopoma californica* (-78%) were restricted to the -4 m level, as these taxa increased significantly at the -3 m level (Table 4-9).

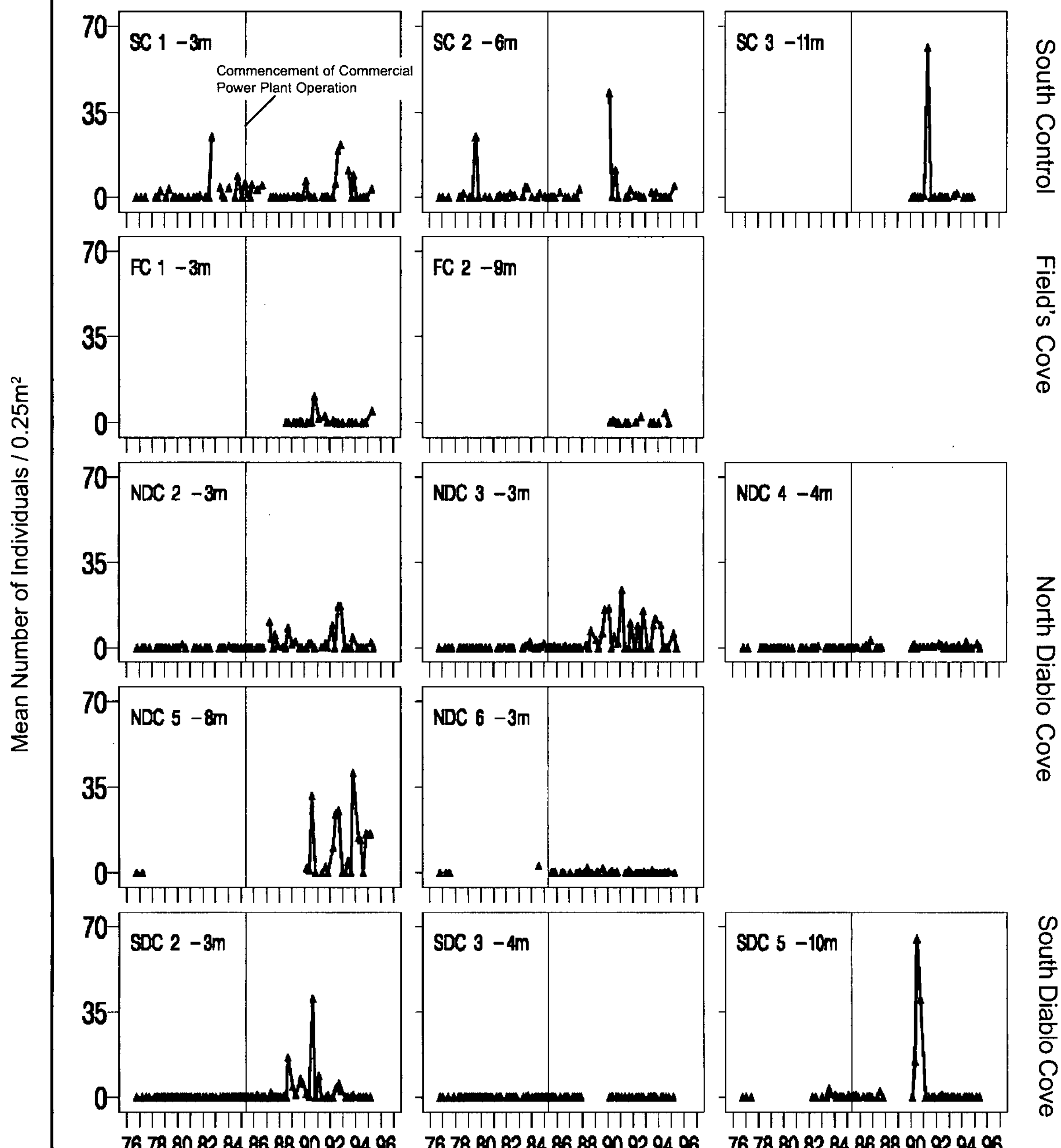


Figure 4-28. *Balanus/Tetraclita*: changes in density at subtidal benthic stations (SFQ method).

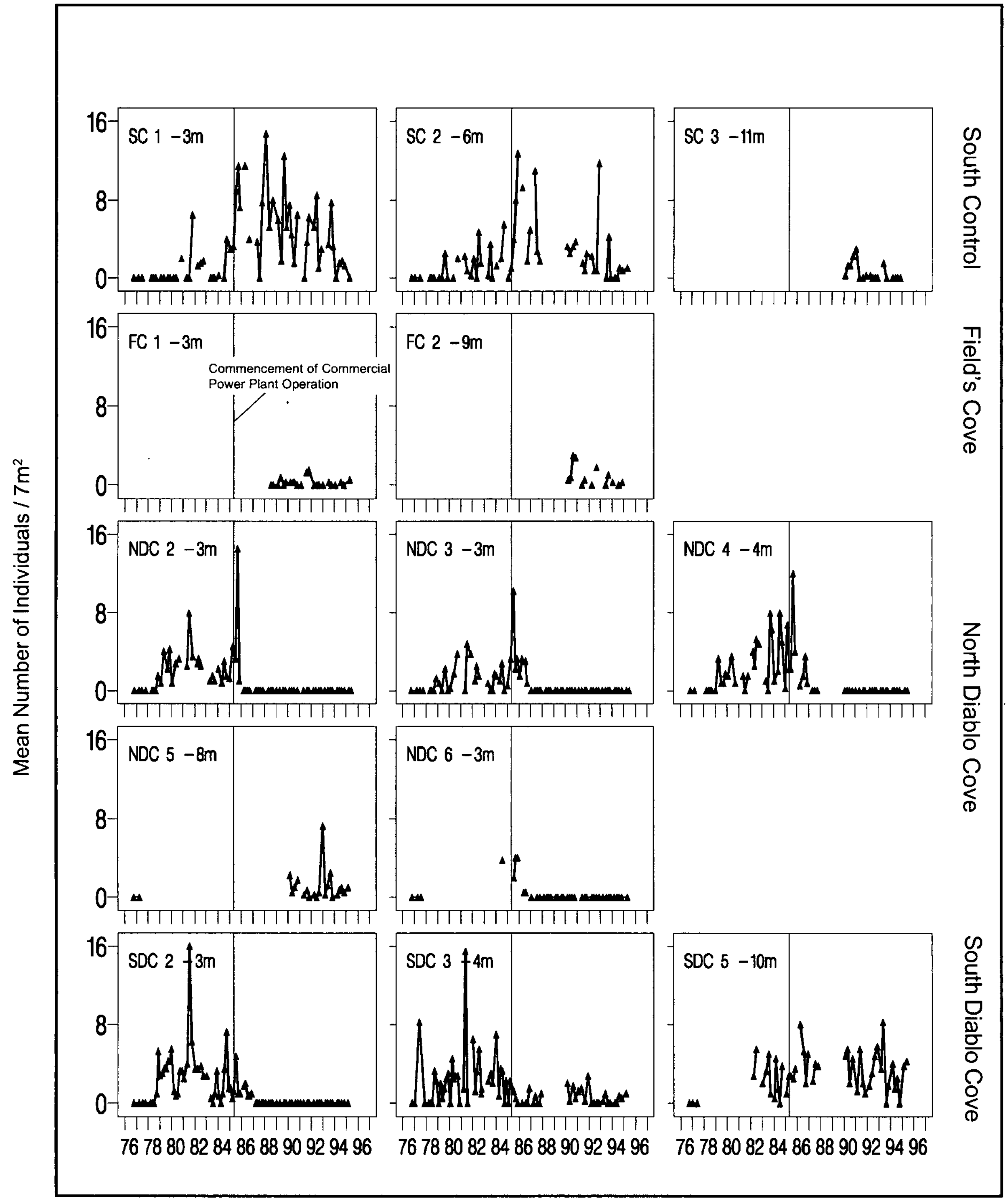


Figure 4-29. *Lottia instabilis*: changes in density at subtidal benthic stations (SAQ method).

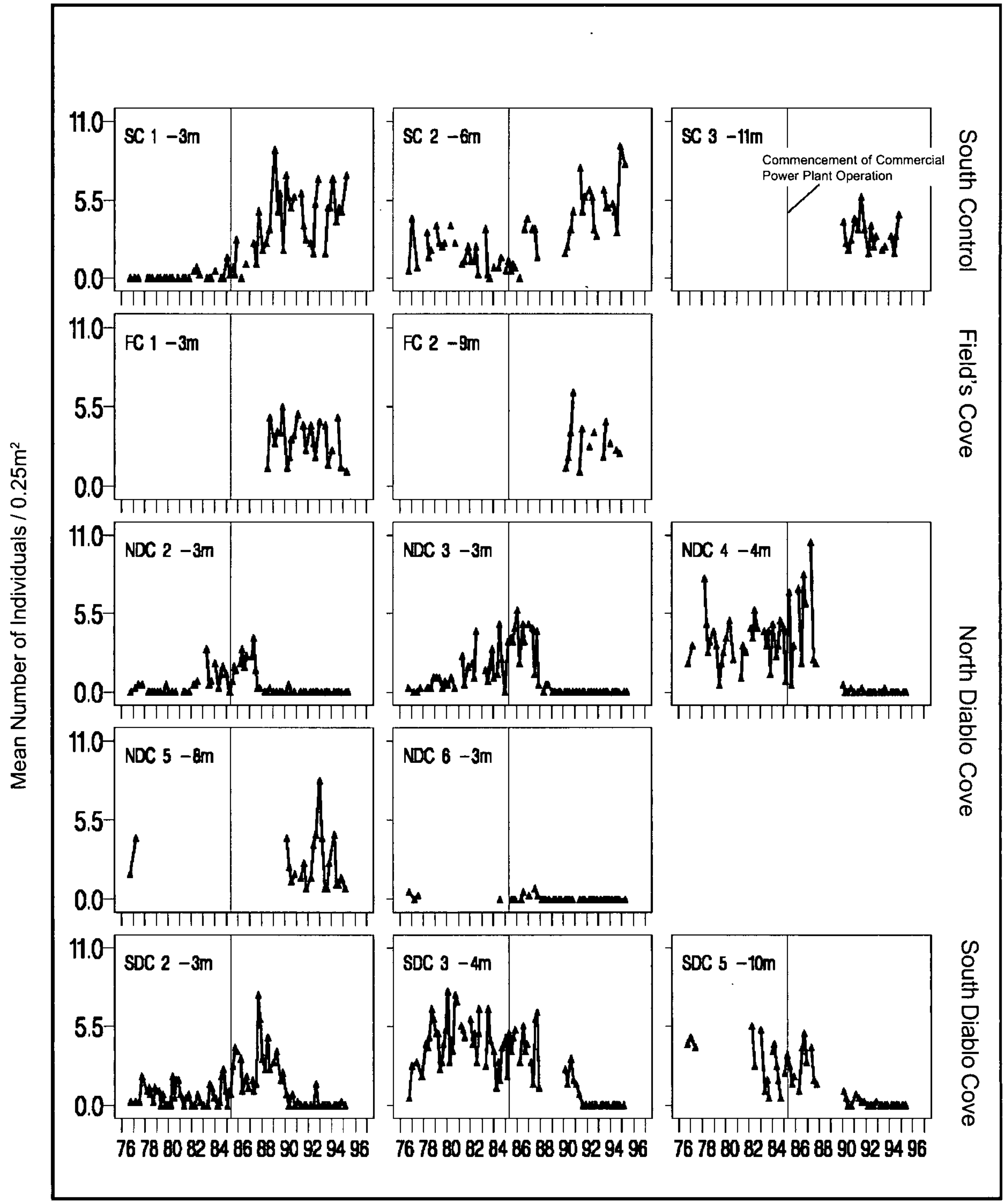


Figure 4-30. *Homolopoma* spp.: changes in density at subtidal benthic stations (SFQ method).

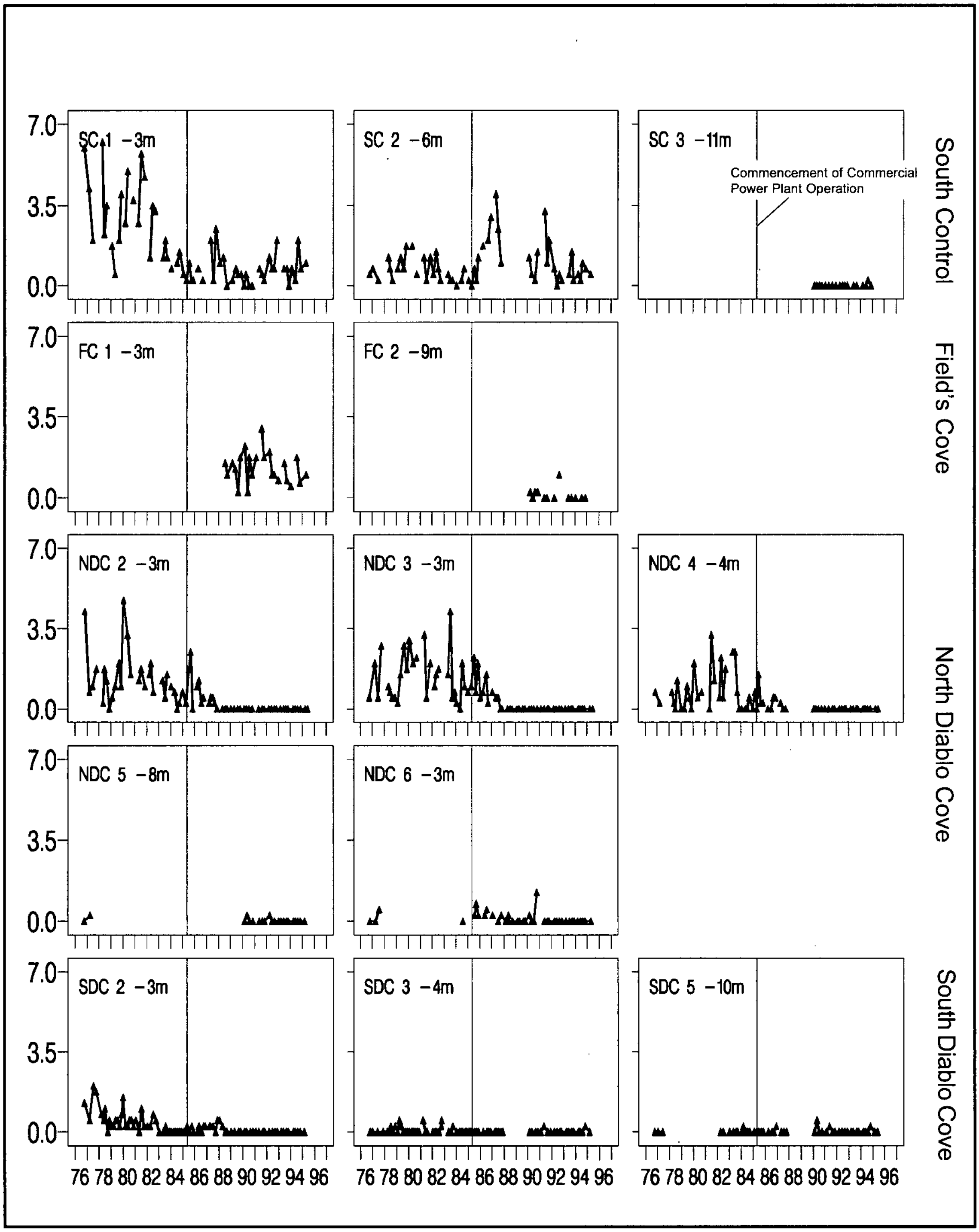


Figure 4-31. *Leptasterias* spp.: changes in density at subtidal benthic stations (SFQ method).

No Significant Changes

The power of the test was sufficiently high (>.70) to conclude that there were no significant changes in 11 taxa (Table 4-9).

Test Results Inconclusive

There was insufficient test power (≤ .70) to detect effects of the discharge in 32 of the taxa tested, even if effects had occurred.

Analysis of Community Changes

Community composition and species abundances changed between periods at both Diablo Cove and control stations (Figures 4-21 through 4-24), though changes in Diablo Cove were generally of greater magnitude. Between-period changes within Diablo Cove were due largely to: (1) occurrences of new species (e.g., *Ophiothrix* spp., *Aplysia californica*, *Cryptochiton stelleri,* and *Norrisia norrisi),* and (2) changes in the abundance of dominant taxa. Interperiod changes at the control were largely restricted to changes in abundance. Despite these changes in Diablo Cove, the between-period frequency of survey occurrences for species did not differ significantly from the control for either the SAQ or SFQ sampling methods (Table 4-11).

Table 4-11. Results of Fisher's exact test for subtidal invertebrates: a) SAQ taxa, and b) SFQ taxa. Data represent number of species changes between pre-operation and operation periods. Results were statistically significant if p<0.10.

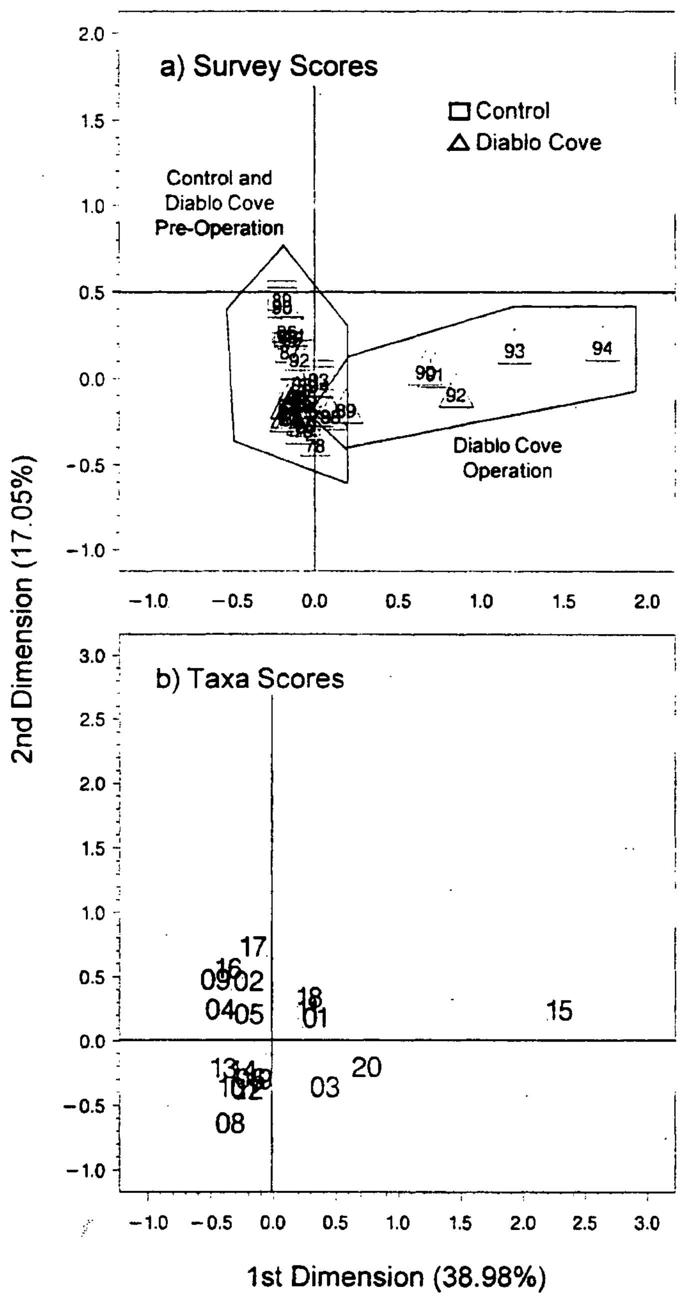
a) SAQ Taxa

	Decreases	Increases
Diablo Cove	52	71
Control	36	61
	p = 0.68	

b) SFQ Taxa

	Decreases	Increases
Diablo Cove	77	114
Control	63	92
	p = 1.00	

Correspondence analysis (CA) was used to analyze invertebrate community variation at Diablo Cove and control locations using data from the SAQ method. Data included in the analyses consisted of annual means for the taxa that formed 95% of the total cumulative abundance across all surveys and occurred in at least 20% of the surveys. This resulted in an analysis of 20 taxa. The first two CA axes explained 56% of the total variation in the data set and represent the two largest independent sources of variation (Figure 4-32 a and b). Variation along the first dimension separates operational period survey scores for Diablo Cove (positive scores) from all other scores including pre-operational period survey scores from Diablo Cove, and all survey scores from the control area (negative scores). The first axis shows little variation



Taxa

01 *Anthopleura elegantissima*
02 *Epiactis prolifera*
03 *Acmaea mitra*
04 *Calliostoma ligatum*
05 *Serpulorbis squamigerus*
06 *Tegula brunnea*
07 *Tonicella lineata*
08 *Lithopoma gibberosum*
09 *Lottia instabilis*
10 *Tegula montereyi*
11 *Diopatra ornata*
12 *Pagurus* spp.
13 *Leptasterias* spp.
14 *Asterina miniata*
15 *Strongylocentrotus purpuratus*
16 *Styela* spp.
17 *Halcampa decemtentacula*
18 *Doriopsilla albopunctata*
19 *Mitra idae*
20 *Serpulidae* unid.

Figure 4-32. First and second dimension scores from correspondence analysis of subtidal invertebrate data from the arc-quadrant study. (a) Annual survey scores. (b) Taxa scores. Numbers inside of symbols are years. Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Percentages in parentheses denote amount of variation explained by corresponding dimension.

among control area scores. Most of the variation is attributable to variation in Diablo Cove following plant operation, especially during the period from 1989 through 1994. Community structure continued to change during this period, evident by the increasing scores, and was still diverging from the control in 1994. Results of taxa scores for the first axis reflect some of the changes occurring in the subtidal invertebrate community during this period. Individual taxa scores show that most of this variation is due to relative increases during this period in the abundance of *Strongylocentrotus purpuratus*, Serpulid worms, the limpet *Acmaea mitra*, the nudibranch *Doriopsilla albopunctata*, and the tube worm *Diopatra ornata* (Figure 4-32b). All these taxa have positive scores and would be contrasted with taxa with negative scores that were associated with pre-operational or control conditions and experienced relative declines during plant operation. These include the limpet *Lottia instabilis*, the turban snail *Calliostoma ligatum* and the six-armed seastar *Leptasterias* spp.

The second axis describes the next largest independent source of variation (17%), and illustrates variation among the survey years at the control following the El Niño storm period (Figure 4-32a). Although variation among the scores continued to occur through 1993 the control community returned to reflect its pre-1985 structure in 1993. This can be contrasted with the Diablo Cove survey scores which showed continued divergence from pre-operational conditions.

Supplementary Observations

A number of taxa observed in Diablo Cove during subtidal survey work in the course of the TEMP study are known primarily as warm-temperate species. These included the southern kelp crab (*Taliepus nuttallii*), the white urchin (*Lytechinus anamesus*), chestnut cowries (*Cypraea spadicea*), the brittle star (*Ophiactis simplex*), Solander's cowry (*Trivia solandri*), Norris' top snail (*Norrisia norrisi*), spiny lobster (*Panulirus interruptus*), Kellett's whelk (*Kelletia kelletii*), wavy top snail (*Lithopoma undosum*), giant keyhole limpets (*Megathura crenulata*), and the black sea hare (*Aplysia vaccaria*). Of these, *O. simplex*, *N. norrisi*, *M. crenulata*, and *A. vaccaria* appear to be firmly established in Diablo Cove, and can be numerous at some cove locations.

Significant declines in *Asterina miniata* abundance were only detected at the -4 m depth using the BACI analysis, although *A. miniata* declined at all Diablo Cove stations (Table 4-9). The random station method used for red abalone supplemented these results, demonstrating cove-wide decreases in this sea star at depths of <4 m, but also showing that these declines generally did not extend below -4 m during the operation period (Figure 4-33). A notable decline in this species occurred in 1993, eight years after power plant start-up. The pattern of decline appeared to be similar at both north and south Diablo Cove. The abundance of *A. miniata* did not change at the control during the same period.

The random sampling also showed that increases in *Strongylocentrotus purpuratus* were largely restricted to the shallow (<3 m) north Diablo Cove region, and that the largest operation period increase occurred in 1993 (Table 4-12). Although not statistically significant, *Cryptochiton stelleri* (giant gumboot chiton) increased within Diablo Cove following power plant operation, with the largest increases at depths below -6 m, primarily within the south Diablo Cove area. Small increases in *C. stelleri* were also noted at the control during the same time period (Appendix E, Figure E5-40).

In 1993 and 1994 urchin barrens were present offshore of Diablo Creek on the top of a rock ridge that is exposed during low tides. This barren area extended into the shallow subtidal to a depth of about 2.0 m MLLW. Separating this ridge from the intertidal urchin barren area, located immediately inshore, was a channel approximately 3 m in depth with a thick cover of the red algae *Cryptopleura violacea* and few urchins. One random red abalone survey station in this subtidal barrens area in 1993 had urchin densities of over $300/m^2$.

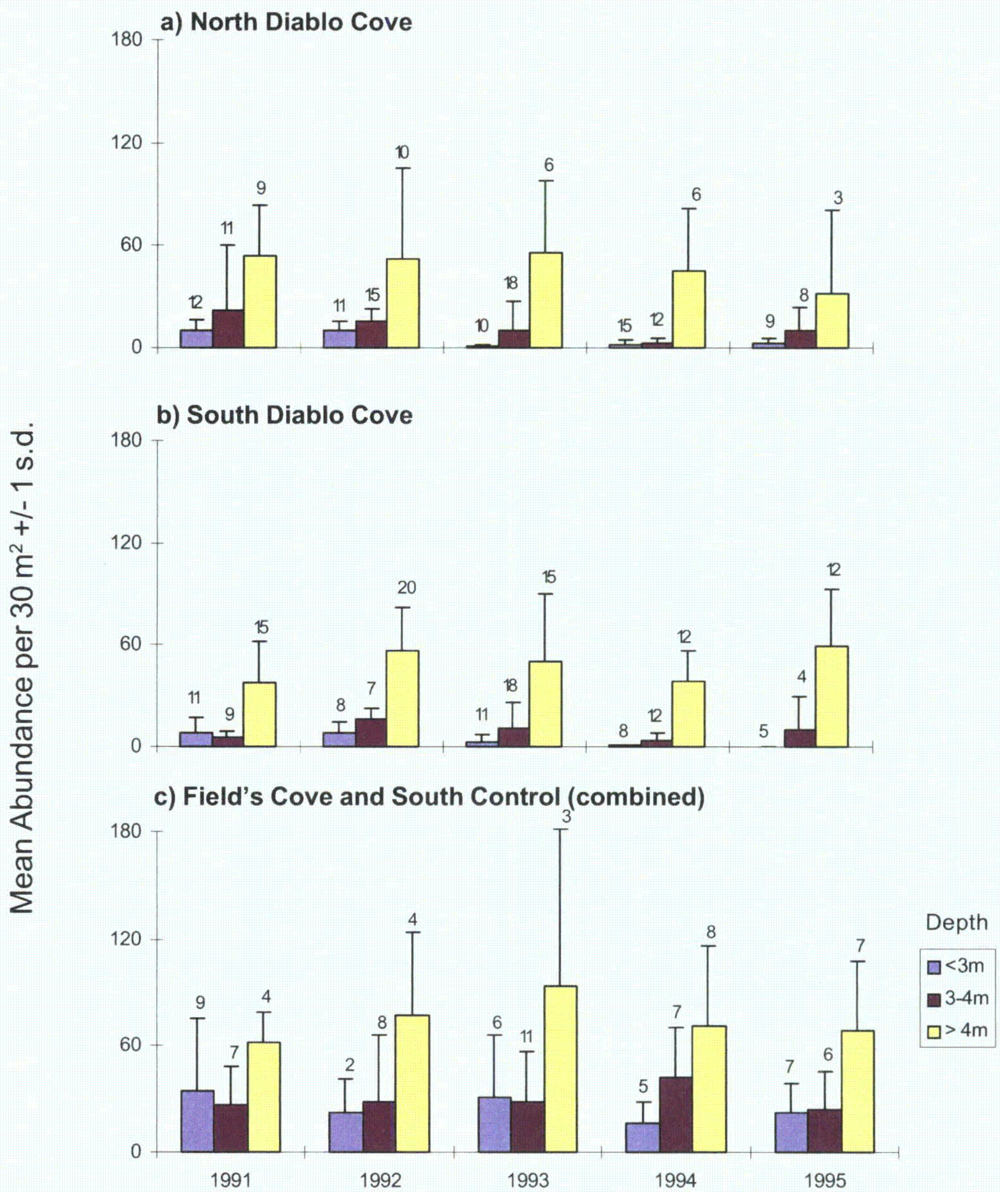


Figure 4-33. *Asterina miniata* abundance sampled in random 30 m^2 stations at three depth regimes after commencement of commercial power plant operation in (a) north Diablo Cove, (b) south Diablo Cove, and Field's Cove and South Control (combined). Number of stations sampled (n) shown above each column. (s.d. = standard deviation)

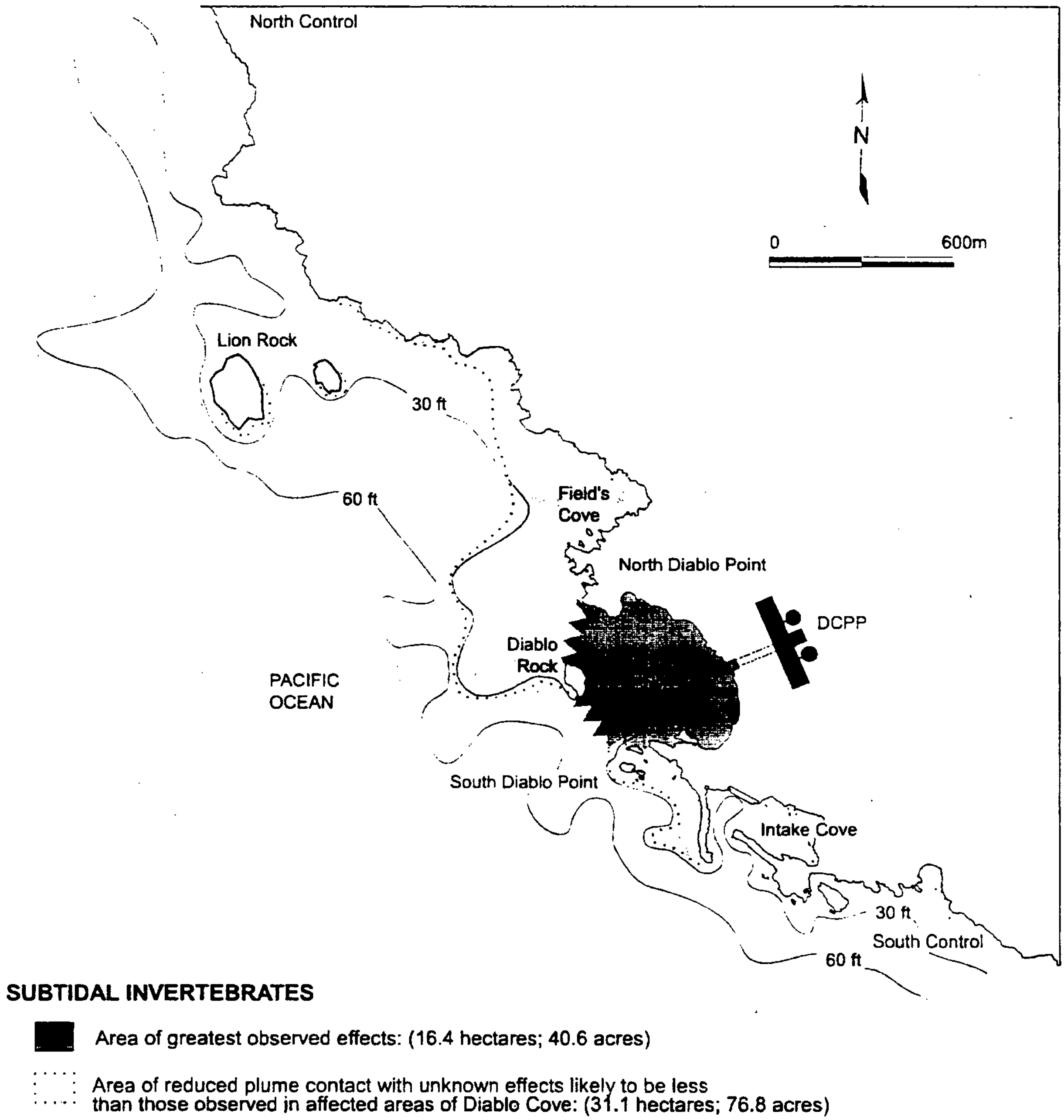


Figure 4-34. Approximate area of discharge effects on the distribution and abundance of subtidal invertebrates observed in the study. Subtidal zig-zag boundaries represent unknown transition zones outside Diablo Cove. Map of effects was developed from benthic station sampling, red abalone surveys, and qualitative observations.

Spatial Extent of Effects

Results from benthic stations, temperature data, red abalone random sampling, and qualitative observations indicate that impacts to subtidal invertebrates were largely limited to Diablo Cove, an area of approximately 16.4 ha (40.6 ac) (Figure 4-34). Thermal plume mapping (Figures 2-5 and 2-6) shows that the thermal plume can contact shallow subtidal areas northward to Lion Rock and southward to the Intake Cove west breakwater. Effects are unknown in these areas that total 31.1 ha (76.8 ac), but, due to reduced plume contact, are likely to be less than those seen in areas of the cove with observed effects.

Near the end of the study, dense populations of purple sea urchins (*Strongylocentrotus purpuratus*) developed in Diablo Cove. The dense populations overgrazed shallow areas in north Diablo Cove (less than -3 m) reducing coverage of kelps and understory algae. Subtidal surveys to accurately delineate this zone were not conducted, but the general area of the subtidal urchin barrens in Diablo Cove, based on qualitative observations is shown in Figure 4-20. The urchin barrens affected approximately 0.9 ha (2.3 ac) in Diablo Cove. Urchin barrens areas were not observed outside Diablo Cove (in Field's Cove or South Control).

Table 4-12. Mean densities per 30 m^2 (and 95% confidence limits) of purple urchins, *Strongylocentrotus purpuratus*, at three depth strata in north Diablo Cove, south Diablo Cove, Field's Cove and South Control (combined). Data are from stratified random sampling of red abalone survey plots from 1991-1995.

			North Diablo Cove		
depth (m)	1991	1992	1993	1994	1995
<3	86.8 ± 73.4	129 ± 198	394 ± 588	214 ± 323	282 ± 316
3-6	49.8 ± 50.1	34.8 ± 33.6	32.1 ± 83.8	38.4 ± 44.0	35.3 ± 21.7
>6	36.4 ± 24.5	12.4 ± 12.4	9.0 ± 6.4	2.5 ± 2.1	1.7 ± 1.5
			South Diablo Cove		
	1991	**1992**	**1993**	**1994**	**1995**
<3	2.1 ± 3.2	5.6 ± 7.1	7.5 ± 16.1	34.0 ± 59.7	32.2 ± 36.2
3-6	5.9 ± 8.0	1.8 ± 1.9	5.5 ± 9.4	34.0 ± 84.6	9.0 ± 18.0
>6	9.6 ± 12.3	3.9 ± 5.2	2.8 ± 6.7	13.7 ± 30.0	5.9 ± 12.6
			Field's Cove and South Control (combined)		
	1991	**1992**	**1993**	**1994**	**1995**
<3	4.9 ± 5.7	1.7 ± 1.5	3.0 ± 1.4	9.2 ± 12.2	4.1 ± 5.1
3-6	4.4 ± 6.6	2.3 ± 4.3	4.1 ± 3.9	3.9 ± 4.8	2.8 ± 3.5
>6	3.3 ± 4.7	1.2 ± 1.6	0.0	4.6 ± 5.7	8.3 ± 11.2

4.3.3 Red Abalone

Abundance data for abalone from the subtidal fixed stations did not meet the assumptions for testing by the BACI analysis and were not abundant enough for other statistical analyses, therefore data are presented graphically. Abalone were generally rare and variable at the fixed stations (Figure 4-35). However, on the shallow Diablo Cove stations (NDC 2, NDC 3 and NDC 4) they were relatively more abundant prior to 1990 than afterwards. Since 1990, abalone at the Diablo Cove stations have remained in low abundance. Abundances at shallow stations in the south control area (SC 1 and SC 2) were variable, but did show periodic increases after 1990. Although there was limited pre-operational data from NDC 5 in Diablo Cove for comparison, it appeared that abalone abundances did not decline substantially in deeper parts of Diablo Cove after 1990. This was also confirmed by qualitative observations on abalone distributions in the deeper portions of Diablo Cove.

Juvenile red abalone (<25 mm) were best estimated using the SFQ method and were observed on all subtidal stations except deep ones in areas with large amounts of sand (SC 3, FC 2 and SDC 5) (Figure 4-36). Abundances of juvenile red abalone are extremely variable due to the seasonal and episodic nature of recruitment. They were frequently observed at stations NDC 2, NDC 4, and NDC 5 (Figure 4-36).

Red abalone abundances in Diablo Cove estimated from the random surveys decreased between 1987 and 1990 at all depths (Figure 4-37). Prior to 1990, abalone were most abundant at depths shallower than 6 m, with mean densities for the 3-6 m depth class as high as 14 per 30 m^2. Mean densities decreased between 1987 and 1990, with the largest declines occurring at depths less than -6 m. As a result, after 1991, red abalone were most abundant at depths greater than 6 m in Diablo Cove, although their absolute abundance at this depth was reduced by about 50 percent from that measured in surveys prior to 1990. Abalone abundance in the Field's Cove and south control areas was variable from 1990 to 1995, but the shallowest stations appeared to be the least variable. The mean abundance at depths less than 3 m was fairly constant at about four abalone per station, and was greater than the mean abundance in Diablo Cove during the same period.

The size class distribution of abalone in Diablo Cove during the 1984-1987 surveys showed considerable variability in numbers of small and medium-sized individuals and lower variability in the numbers of large individuals (Figure 4-38a). Large abalone were present at all depths in roughly equal abundance. A large increase in small abalone was observed in 1986 and 1987; they occurred in greater numbers at the shallower stations. The 1986 small size class individuals may have contributed to the increase in the medium size class for 1987 observed primarily at the deeper stations.

Survey data from 1990 to 1995 show a different pattern of abalone abundance in Diablo Cove. These data show a decrease in all size classes of abalone, but a disproportionately greater decrease in the number of large and medium sized individuals (Figure 4-38a). The sharp increase in juvenile abalone abundance in 1995 was not the result of a widespread, general increase but occurred on only 1 of the 41 stations sampled with 27 of the 46 juveniles seen that year. From 1990 to 1995, the number of abalone in the large size class decreased throughout Diablo Cove, but became very uncommon at depths less than -6 m. Small and medium-sized abalone, although reduced from their pre-1987 abundance, comprised a larger proportion of the total abalone present from 1991 through 1995. The distribution of abalone shifted from being most abundant at depths of less than -6 m in Diablo Cove before 1990 to being most abundant at depths greater than -6 m in Diablo Cove. In contrast, data from the control areas from 1990 to 1995 show no pattern of decrease in abundance at any depths, and in general, individuals of all size classes occurred on the stations (Figure 4-38b). The spatial extent of discharge effects on red abalone was not differentiated from that of other subtidal invertebrates (Figure 4-34).

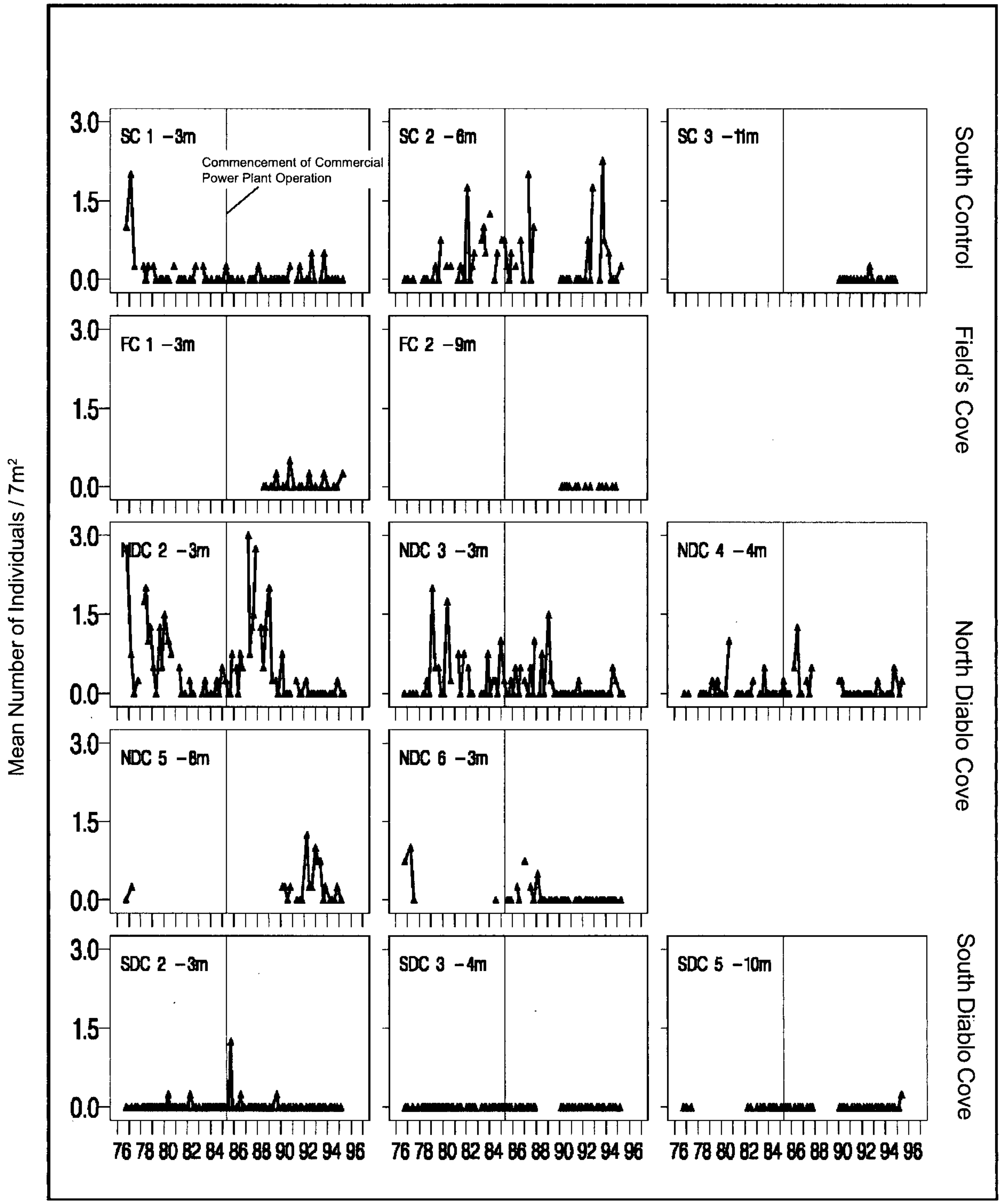


Figure 4-35. Changes in *Haliotis rufescens* density at subtidal benthic stations (SAQ method). This sampling method mainly enumerated larger abalone (50-100 mm length) than the SFQ method.

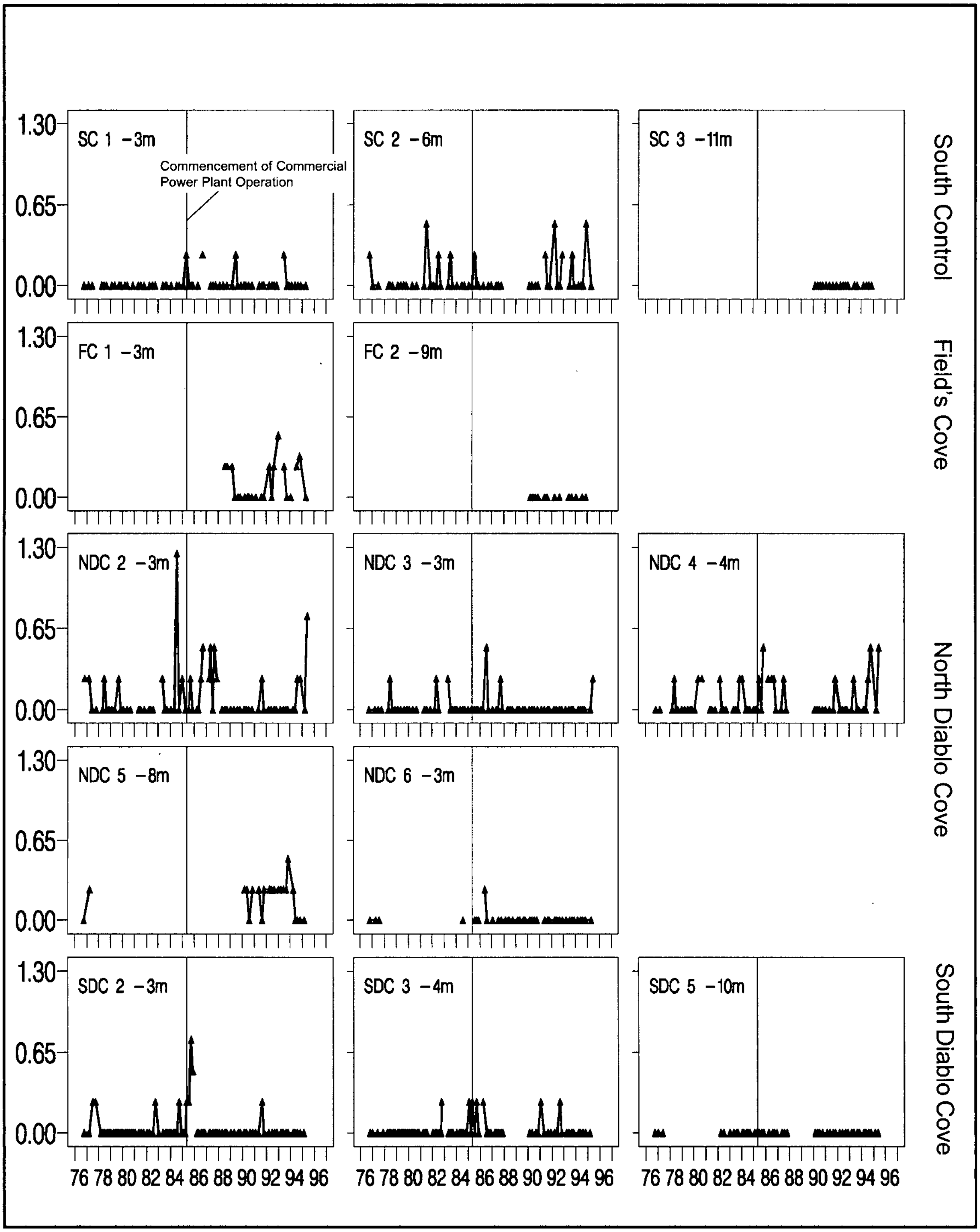


Figure 4-36. Changes in *Haliotis rufescens* density at subtidal benthic stations (SFQ method). This sampling method mainly enumerated smaller abalone (<25 mm length) than the SAQ method.

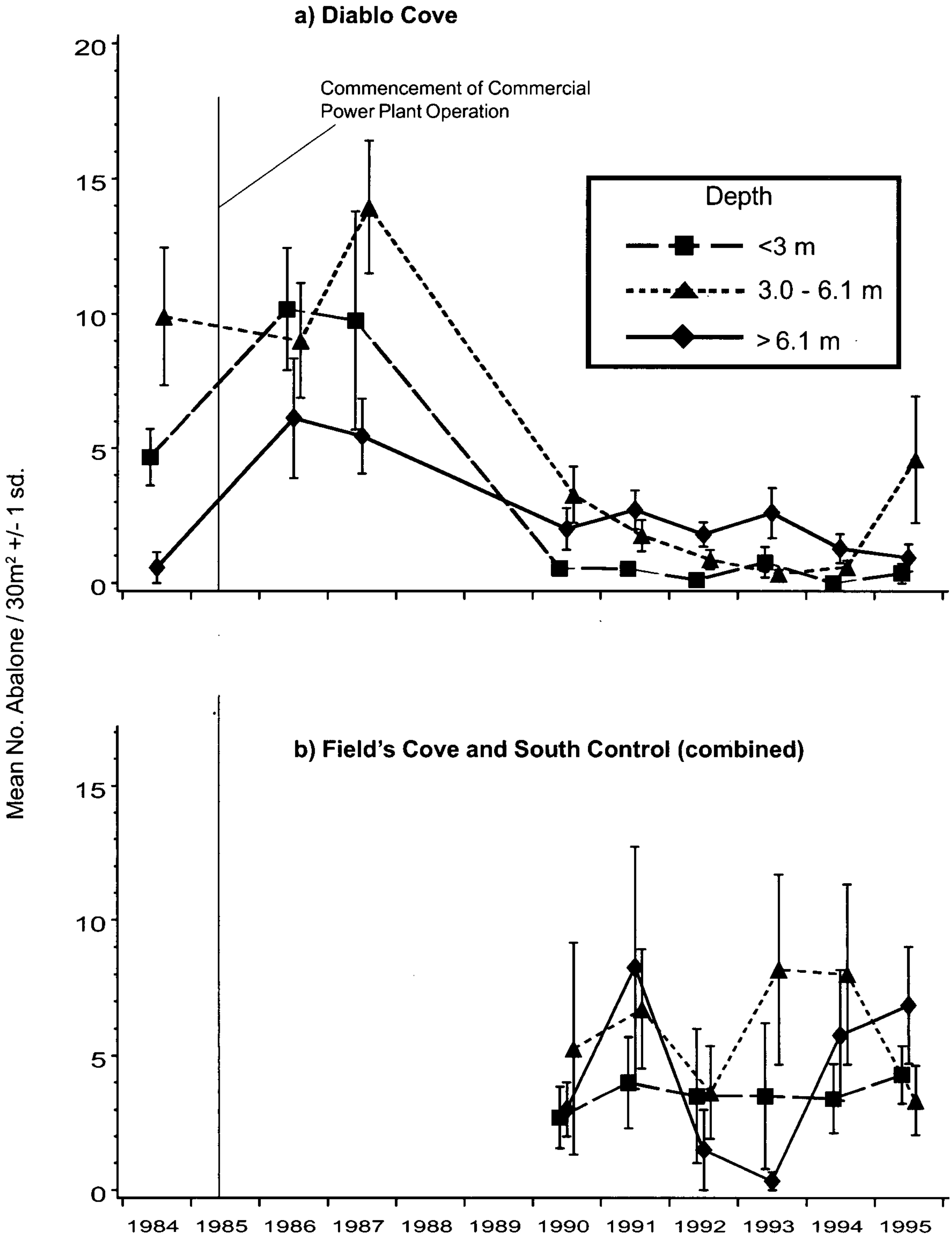


Figure 4-37. Red abalone, *Haliotis rufescens*, changes over time by depth regime in (a) Diablo Cove; (b) Field's Cove and South Control combined. Data are from random station sampling.

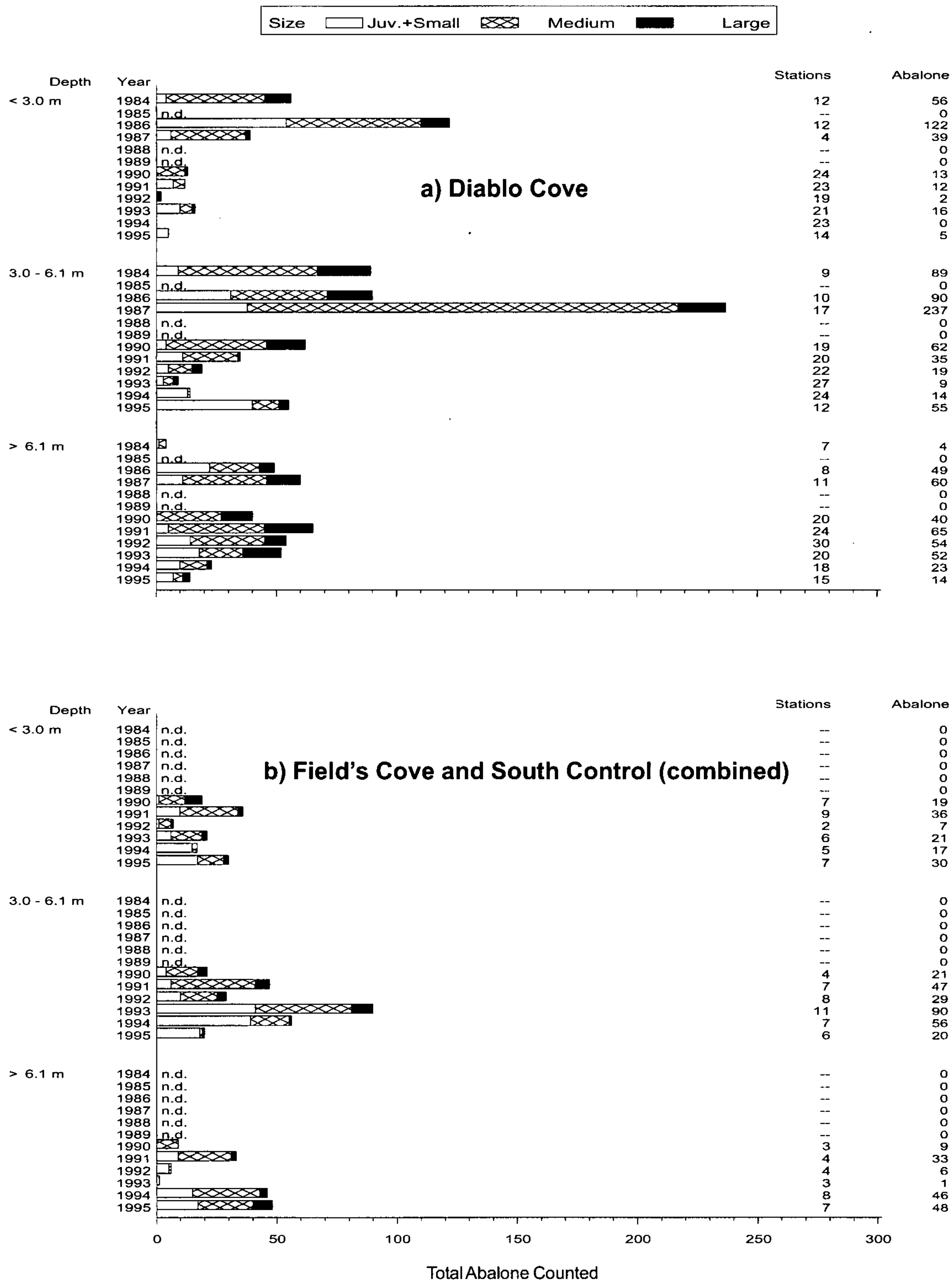


Figure 4-38. Red abalone, *Haliotis rufescens*, size class distribution and total numbers by depth regime in (a) Diablo Cove and (b) Field's Cove and South Control combined. Data are from random station sampling. (n.d. = no data collected)

4.3.4 Fish

In the period from 1976 to 1995, 216,617 fish representing approximately 82 taxa and 29 families were counted in 71 underwater visual surveys of permanent benthic and midwater transects. The majority of taxa were identified to species level, but other taxa were represented by categories combining two or more species for the purposes of field identification. Some taxa were also subdivided into life stage categories (adult, juvenile, and young-of-the-year) to better track seasonal recruitment. Most taxa were observed only on benthic transects (within 1 m of the bottom), but some occurred on both benthic and midwater transects, or on midwater transects only. Common and scientific names of all fish species sampled during the study are presented in Appendix D. Table 4-13 summarizes the main discharge effects on subtidal fish, with more detailed analyses following.

Table 4-13. Summary of discharge effects on subtidal fish sampled by visual counts on permanent benthic and midwater transects.

Category	Benthic transects	Midwater transects	Notes
Total area of habitat with observed effects	16.4 ha (40.6 ac)	16.4 ha (40.6 ac)	Main changes in fish abundance were in Diablo Cove; transition zones outside of D.C. were not identified.
Effects on fish diversity (H')	decrease	no change	BACI result.
Effects on overall numbers of fish taxa	no change	increase	Numbers of taxa increased in north Diablo Cove, but decreased in south Diablo Cove; interpreted overall as 'no change'.
Effects on total count	increase	no change	Benthic increase significant in north Diablo Cove.
Number (%) of taxa increases	9 (36%)	4 (33%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa decreases	6 (24%)	2 (17%)	Includes both BACI and Fisher's exact test.
Number (%) of taxa unchanged	4 (16%)	2 (17%)	BACI result; mixed response of *E. jacksoni* on benthic transects between areas was interpreted as 'no change'.
Number (%) of taxa with inconclusive test results	6 (24%)	4 (33%)	Includes both BACI and Fisher's exact test.
Number of taxa analyzed statistically	25	12	Comprising top 99% cumulative abundance.
Number of taxa sampled during study	82		Includes all Diablo Cove stations combined; also includes some species that were grouped into combination taxa for analysis.

Analysis of Species Changes

Thirty-seven taxa comprised the top 99% of fish counted in Diablo Cove on benthic and midwater transects, with lists compiled separately for the benthic and midwater transects (Figure 4-39a, b). The fish assemblage in Diablo Cove before plant operation was mainly composed of cool-temperate species in the families Scorpaenidae (rockfishes), Embiotocidae (surfperches), Cottidae (sculpins), and Hexagrammidae (greenlings). After plant start-up several species that had not previously been observed became resident in Diablo Cove (e.g., *Semicossyphus pulcher* [sheephead], *Girella nigricans* [opaleye]). Other species that had been common before plant start-up were nearly absent in Diablo Cove after plant start-up (e.g., *Hexagrammos decagrammus* [kelp greenling]). Similar changes did not happen in the control area.

a) Diablo Cove - Midwater Fish Abundance: mean no. individuals per transect

Species	Pre-Operation Period 27 Surveys	Operation Period 31 Surveys
Oxyjulis californica	16.1	16.6
Sebastes serranoides/S. flavidus (juv.)	5.7	4.5
Sebastes chrysomelas/S. carnatus (juv.)	4.4	1.4
Sebastes paucispinus (juv.)	2.8	< 0.1
Aulorhynchus flavidus	1.8	0.2
Sebastes mystinus (juv.)	1.5	0.3
Sebastes mystinus	0.7	0.1
Sebastes spp.	0.6	< 0.1
Atherinidae unid.	0.4	2.6
Sebastes serranoides	0.4	< 0.1
Chromis punctipinnis	0.3	< 0.1
Embiotoca lateralis	0.3	< 0.1
Paralabrax clathratus	0.2	< 0.1
Damalichthys vacca	0.2	1.3
Embiotocidae	0.2	6.4
Brachyistius frenatus	0.1	0.4
Myliobatis californica	< 0.1	0.1
Engraulis mordax	< 0.1	6.1
Girella nigricans	< 0.1	< 0.1
larval/post-larval fish, unid.	--	3.4
Semicossyphus pulcher	--	0.1
Other (pre-op: 7 spp., op: 9 spp.)	< 0.1	0.3
Total:	35.9	44.1

b) Diablo Cove - Benthic Fish Abundance: mean no. individuals per transect

Species	Pre-Operation Period 27 Surveys	Operation Period 31 Surveys
Oxyjulis californica	21.5	36.6
Sebastes serranoides/S. flavidus (juv.)	8.1	2.6
Sebastes chrysomelas/S. carnatus (juv.)	5.4	2.7
Sebastes mystinus (juv.)	3.5	1.1
Sebastes paucispinus (juv.)	2.5	0.2
Embiotoca lateralis	2.2	1.3
Sebastes chrysomelas	2.1	1.1
Oxylebius pictus	2.1	1.4
Aulorhynchus flavidus	1.7	2.2
Embiotoca jacksoni	1.2	2.4
Sebastes mystinus	1.1	0.4
Sebastes spp.	0.9	0.3
Gibbonsia spp.	0.8	0.7
Scorpaenichthys marmoratus	0.7	0.4
Damalichthys vacca	0.6	3.7
Paralabrax clathratus	0.6	0.1
Hexagrammos decagrammus	0.5	< 0.1
Sebastes rastrelliger	0.5	0.6
Cottidae unid.	0.5	0.1
Brachyistius frenatus	0.4	0.3
Citharichthys spp.	0.3	1.5
Embiotocidae	0.3	4.2
Engraulis mordax	0.2	1.0
Artedius spp.	0.2	0.1
Cebidichthys violaceus	0.2	0.2
Ophiodon elongatus	0.1	< 0.1
Orthonopias triacis	0.1	< 0.1
Sebastes atrovirens	0.1	0.2
Heterostichus rostratus	< 0.1	< 0.1
Coryphopterus nicholsii	< 0.1	2.1
Sebastes serranoides	< 0.1	0.2
Rhacochilus toxotes	< 0.1	0.5
Atherinidae unid.	< 0.1	0.2
Hypsurus caryi	< 0.1	0.2
Myliobatis californica	< 0.1	0.4
Semicossyphus pulcher	--	1.4
Girella nigricans	--	0.8
Sebastes melanops (juv.)	--	0.3
larval/post-larval fish, unid.	--	0.3
Medialuna californiensis	--	0.1
Other (pre-op: 25 spp., op: 24 spp.)	0.3	0.2
Total:	59.1	72.3

Figure 4-39. Fish abundances at Diablo Cove (a) midwater and (b) benthic subtidal transects.

Thirty-three taxa comprised the top 99% of fish counted in the south control area on benthic and midwater transects (Figure 4-40a,b). Species composition remained relatively unchanged between pre-operation and operation periods, although mean abundances declined for many taxa (except *Oxyjulis californica* [señorita]). Seasonal pulses of juvenile rockfishes recruited into kelp canopies and numerically dominated midwater counts during some years.

Of the 37 most abundant taxa counted in Diablo Cove, 28 were analyzed for power plant effects with the BACI model and 9 were analyzed with the Fisher's exact test. Only those taxa passing assumption testing could be analyzed using the BACI model. Results of the assumption tests are presented in Appendix G. Several species which were not present before operation, and increased after plant start-up, were among those that could not be analyzed with the BACI model (e.g., *Girella nigricans, Semicossyphus pulcher,* and *Myliobatis californica* [bat ray]). These species were analyzed with the Fisher's exact test. Forty-five taxa (55% of all taxa observed) were not analyzed because they fell below the minimum abundance threshold set for analysis.

The BACI results for 28 taxa, as well as species richness, diversity, and total counts are presented in Table 4-14. Fisher's exact test results for nine taxa are presented in Table 4-15. Most taxa were tested as both juveniles and adults combined, but two *Sebastes* groupings and three *Sebastes* species were tested separately as juveniles (young-of-the-year [YOY]) because they were prominent seasonal components of the fish assemblage. For taxa represented by both a midwater and a benthic data set, the data set which better characterized a species' typical habitat was presented in the analysis. For example, *Damalichthys vacca* (pile perch) were occasionally recorded on midwater transects, but the species is mainly bottom-associated and the benthic counts provided better estimates of their abundance. Graphs of all benthic and midwater data sets comprising the 99% cumulative abundance criteria are presented in Appendix E.

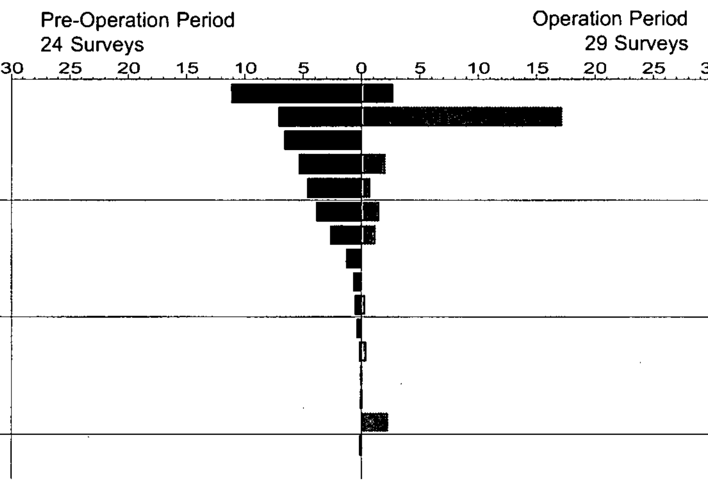
In the BACI analysis, taxa were categorized as having increased, decreased or not changed between periods. In addition, power plant effects on several taxa could not be determined because the test results were not significant and the power of the test to detect a 50% change in abundance between periods was low (<.70). North and south Diablo Cove were determined to be sufficiently different in habitat and species composition *a priori*, and were therefore tested separately. Significant effects on a taxon in only one area were interpreted as a significant overall discharge effect on that taxon. Fisher's exact test was unable to determine that a taxon was unchanged between periods because the power of the test could not be calculated.

Significant Increases

Thirteen of the 37 taxa tested (35%) increased in Diablo Cove after start-up (Tables 4-13 and 4-14). There were variable discharge effects between north and south Diablo Cove, as indicated by significant Area x Period interactions for many of the data sets tested using the BACI model. Of those taxa tested, six of the eight significant increases occurred only in north Diablo Cove. *Embiotoca jacksoni* (black surfperch) was unusual in that it increased in north Diablo Cove but decreased in south Diablo Cove, reflecting a shift in distribution of the local population. Because there were different results for this species between areas, it appears twice in Table 4-14 and was considered unchanged in overall abundance.

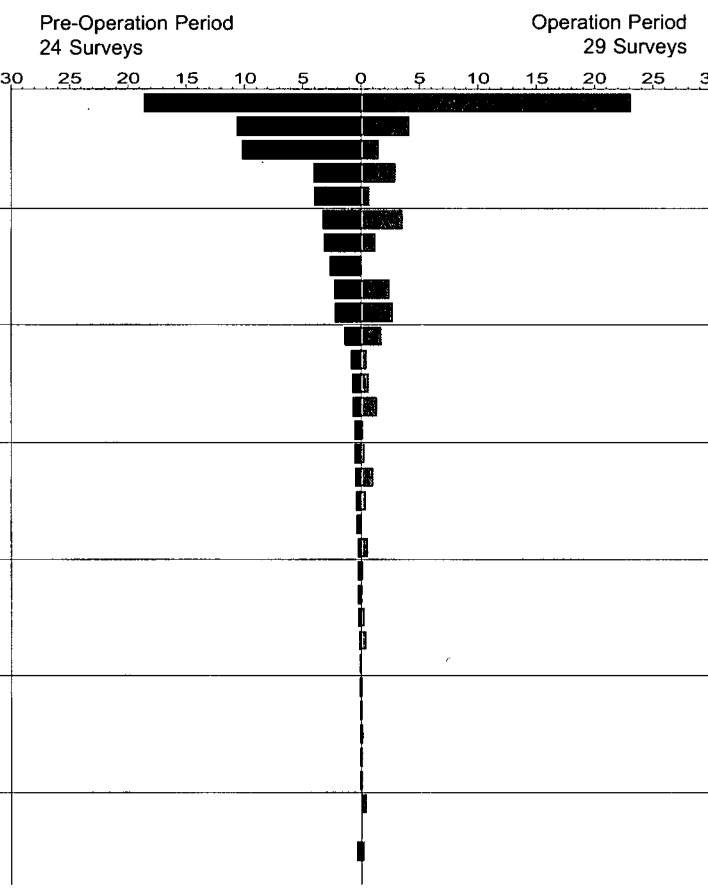
Notable among the species that increased were several that are more typical of warm water environments (e.g., *Paralabrax clathratus* [kelp bass], *Medialuna californiensis* [halfmoon], and *Semicossyphus pulcher* [sheephead]). *S. pulcher* became resident in north Diablo Cove after power plant start-up (Figure 4-41). The slow attrition in numbers from 1989 to 1995 was probably due to maturation and mortality in a strong cohort of juveniles that initially recruited into the area during 1985 and 1986.

a) South Control - Midwater Fish Abundance: mean no. individuals per transect



Species	Pre-Operation Period (24 Surveys)	Operation Period (29 Surveys)
Aulorhynchus flavidus	11.1	2.7
Oxyjulis californica	7.1	17.2
Sebastes paucispinus (juv.)	6.6	< 0.1
Sebastes chrysomelas/S. carnatus (juv.)	5.4	2.1
Sebastes serranoides/S. flavidus (juv.)	4.6	0.8
Sebastes mystinus (juv.)	3.8	1.6
Sebastes mystinus	2.7	1.2
Sebastes serranoides	1.3	< 0.1
Atherinidae unid.	0.7	--
Engraulis mordax	0.5	0.3
Embiotoca lateralis	0.4	< 0.1
Damalichthys vacca	0.1	0.5
Brachyistius frenatus	< 0.1	0.1
Sebastes spp.	< 0.1	0.2
larval/post-larval fish, unid.	--	2.3
Other (pre-op: 12 spp., op: 6 spp.)	0.1	0.1
Total:	44.6	29.3

b) South Control - Benthic Fish Abundance: mean no. individuals per transect



Species	Pre-Operation Period (24 Surveys)	Operation Period (29 Surveys)
Oxyjulis californica	18.6	23.1
Sebastes mystinus (juv.)	10.7	4.2
Sebastes serranoides/S. flavidus (juv.)	10.2	1.5
Embiotoca lateralis	4.1	3.0
Aulorhynchus flavidus	4.0	0.7
Oxylebius pictus	3.3	3.6
Sebastes mystinus	3.2	1.2
Sebastes paucispinus (juv.)	2.7	< 0.1
Sebastes chrysomelas	2.3	2.4
Sebastes chrysomelas/S. carnatus (juv.)	2.2	2.7
Embiotoca jacksoni	1.4	1.8
Hexagrammos decagrammus	0.8	0.5
Scorpaenichthys marmoratus	0.8	0.7
Damalichthys vacca	0.7	1.4
Cottidae unid.	0.5	0.2
Brachyistius frenatus	0.5	0.3
Coryphopterus nicholsii	0.5	1.1
Gibbonsia spp.	0.4	0.4
Sebastes spp.	0.4	< 0.1
Sebastes rastrelliger	0.3	0.6
Sebastes serranoides	0.3	0.2
Ophiodon elongatus	0.3	0.1
Orthonopias triacis	0.2	0.3
Sebastes atrovirens	0.2	0.4
Cephaloscyllium ventriosum	0.1	< 0.1
Hypsurus caryi	0.1	0.1
Rhacochilus toxotes	< 0.1	0.1
Embiotocidae	< 0.1	0.2
Artedius spp.	< 0.1	0.1
Cebidichthys violaceus	< 0.1	0.2
Sebastes melanops (juv.)	< 0.1	0.5
Semicossyphus pulcher	--	< 0.1
Other (pre-op: 12 spp., op: 19 spp.)	0.4	0.3
Total:	69.5	52.2

Figure 4-40. Fish abundances at the South Control (a) midwater and (b) benthic transects.

Table 4-14. Results of BACI ANOVA for subtidal fish from benthic and midwater fish counts. Negative values indicate decreases between periods for individual areas. Statistically significant results ($p<0.10$) are in **bold** type. (yoy) = young-of-the-year.

		% Change Between Periods			Power to	Area*Period	Area	
	Sampling	Relative	Period		Detect	Interaction	NDC	SDC
Taxon	Method	to Control	F	P	50% Change	P	P	P
Significant Increase								
Area-specific (North Diablo)								
Atherinidae unid.	Midwater	*no calc*[1]	7.7	**.01**	.10	**.02**	**<.01**	.41
Coryphopterus nicholsii	Benthic	+1282	10.2	**<.01**	.10	**<.01**	**<.01**	-.72
Damalichthys vacca[2]	Benthic	+196	5.3	**.03**	.73	**<.01**	**<.01**	.86
Embiotoca jacksoni[3]	Benthic	+64	5.6	**.02**	1.00	**<.01**	**<.01**	-.09
Rhacochilus toxotes	Benthic	+482	.3	.60	.19	**.02**	**.08**	-.37
Sebastes serranoides[2]	Midwater	+144	1.0	.32	.14	**.01**	**.05**	-.81
Total Count	Benthic	+70	13.5	**<.01**	1.00	**.01**	**<.01**	.15
Species Richness[3]	Benthic	-1	<.1	.84	1.00	**<.01**	**.04**	-.02
Species Richness	Midwater	+23	4.4	**.04**	1.00	**<.01**	**<.01**	.74
Area-specific (South Diablo)								
Aulorhynchus flavidus[2]	Benthic	+619	4.3	**.04**	.23	.26	.23	**.02**
Sebastes mystinus[2]	Midwater	-67	.7	.40	.10	**.01**	-.67	**.06**
Significant Decrease								
Cove-wide (North and South Diablo)								
Hexagrammos decagrammus	Benthic	-89	34.9	**<.01**	1.00	.26	**-<.01**	**-<.01**
Oxylebius pictus	Benthic	-41	17.1	**<.01**	1.00	**<.01**	**-.09**	**-<.01**
Sebastes chrysomelas	Benthic	-57	22.6	**<.01**	1.00	**.04**	**-<.01**	-.01
Sebastes spp. unid. (yoy)[2]	Midwater	-99	5.7	**.02**	.14	.48	**-.07**	**-.02**
Area-specific (North Diablo)								
Scorpaenichthys marmoratus	Benthic	-39	4.1	**.05**	1.00	**<.01**	**-<.01**	-.80
Area-specific (South Diablo)								
Artedius spp.	Benthic	-61	3.4	**.07**	.48	**.04**	-.48	-.01
Embiotoca jacksoni[3]	Benthic	+64	5.6	**.02**	1.00	**<.01**	**<.01**	-.09
Oxyjulis californica	Midwater	-56	3.4	**.07**	.76	**.07**	-.50	-.01
Sebastes rastrelliger	Benthic	-39	1.2	.28	.97	**<.01**	.32	-.01
Diversity	Benthic	-17	6.0	**.02**	1.00	**.03**	-.25	**-<.01**
Species Richness[3]	Benthic	-1	<.1	.84	1.00	**<.01**	**.04**	-.02
No change[4]								
Cebidichthys violaceus	Benthic	-60	2.6	.11	.93	.35	**-.07**	-.48
Cottidae unid.	Benthic	-38	.9	.34	1.00	.53	-.26	-.59
Embiotoca lateralis[2]	Benthic	-26	.3	.61	.99	.46	-.88	-.43
Sebastes chrysomelas/S. carnatus (yoy)[1]	Midwater	-18	<.1	.91	.77	.70	-.76	.91
Sebastes serranoides/S. flavidus (yoy)[1]	Midwater	+27	<.1	.95	1.00	.10	.24	-.28
Total Count	Midwater	+73	1.0	.32	.91	.58	.26	.53
Diversity	Midwater	+4	.2	.62	1.00	**.02**	.17	-.63
Test Results Inconclusive[5]								
Brachyistius frenatus[2]	Midwater	+109	.3	.58	.15	**.04**	.32	.94
Embiotocidae unid.[2]	Benthic	+486	2.4	.13	.12	.51	**<.09**	.25
Engraulis mordax	Midwater	*no calc*	1.1	.31	.10	.31	.96	.15
Gibbonsia spp.	Benthic	-2	.3	.58	.11	.36	-.48	-.70
Ophiodon elongatus	Benthic	-58	.1	.80	.46	.35	.87	-.53
Sebastes mystinus (yoy)[2]	Midwater	-66	<.1	.93	.34	**.03**	-.32	.41
Sebastes paucispinus (yoy)[2]	Midwater	+195	1.9	.17	.20	.32	.12	.25

[1] percent change could not be calculated because mean control abundance was zero during one or both periods.
[2] taxon also analyzed for other sampling method (midwater or benthic); results are presented for more appropriate method.
[3] taxon listed twice because of differing significant effects between areas.
[4] no significant difference between period means; power of test to detect a 50% change was greater than .70.
[5] no significant difference between period means; power of test to detect a 50% change was less than .70.

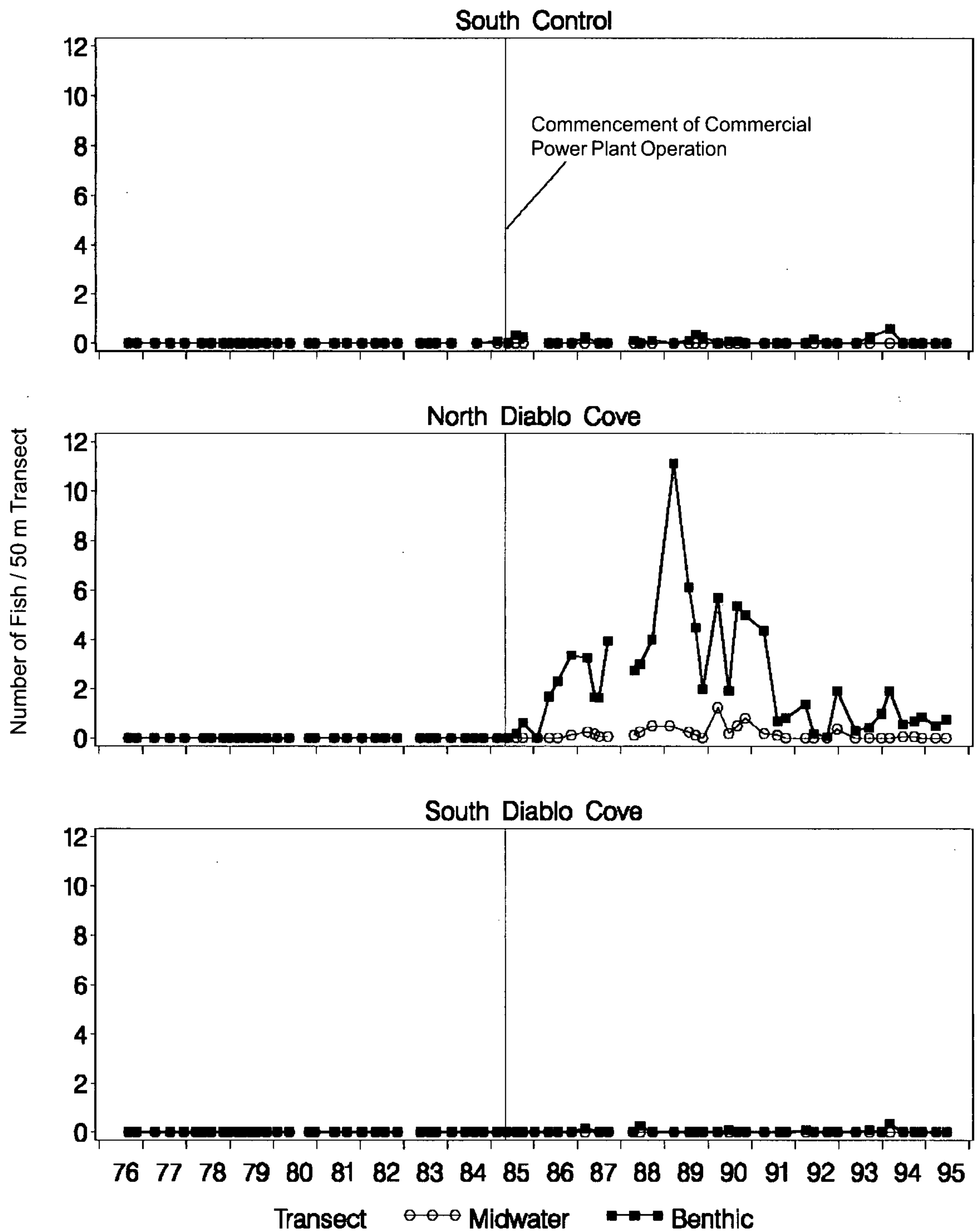


Figure 4-41. *Semicossyphus pulcher* (sheephead): changes in abundance on subtidal transects.

Atherinidae (topsmelt and jacksmelt) is an example of a midwater fish taxon that increased significantly in north Diablo Cove after power plant start-up. Atherinids form schools that, because of continual movement, are unpredictably observed within a study area. The data reflected this variation, showing periodic occurrences of large schools, rather than consistent distributions over time. Because of this type of variability in schooling fishes, discharge effects were often not statistically detectable in the midwater data sets. An example of increases in a species with a strictly benthic habitat was *Coryphopterus nicholsii* (blackeye goby) (Figure 4-42). Gobies were present in north Diablo Cove during all surveys from 1987 to 1995, in contrast to the large variation between surveys seen in topsmelt occurrences (Appendix E, Figure E6-2).

Table 4-15. Results of Fisher's exact test for subtidal benthic and midwater fish taxa not tested in BACI analysis. Statistically significant results ($p<0.10$) are in **bold** type.

Taxon	Method	Fisher's p
Significant Increase		
Myliobatis californica	Midwater	**>.01**
Girella nigricans	Benthic	**>.01**
Citharichthys spp.	Benthic	**.01**
Paralabrax clathratus	Benthic	**.01**
Medialuna californiensis	Benthic	**>.01**
Semicossyphus pulcher	Benthic	**>.01**
Test Results Inconclusive		
Heterostichus rostratus	Benthic	.56
Sebastes melanops (yoy)	Benthic	1.00
larval / post-larval fish, unid.	Benthic	1.00

The analysis detected a significant increase for *Sebastes mystinus* (blue rockfish) in south Diablo Cove, but this was an artifact of the analysis. Blue rockfish abundance in south Diablo Cove was nearly zero throughout the study while the control area abundance declined slightly. The BACI analysis interpreted this as an increase in south Diablo Cove relative to the control.

Significant Decreases

Eight of the 37 taxa tested (22%) decreased in Diablo Cove after start-up (Table 4-14). Four taxa, *Hexagrammos decagrammus* (kelp greenling), *Oxylebius pictus* (painted greenling), *Sebastes chrysomelas* (black and yellow rockfish), and *Sebastes* spp. (unidentified YOY rockfish) decreased significantly in both areas of Diablo Cove after plant start-up. All the taxa that decreased except *Sebastes* spp. and *Oxyjulis californica* (señorita) occupied benthic habitats and were not recorded on the midwater transects. *H. decagrammus* was consistently present on all benthic transects before plant start-up, but was infrequently observed inside Diablo Cove after plant start-up (Figure 4-43).

Four taxa declined significantly only in south Diablo Cove, and one taxon declined only in north Diablo Cove (Table 4-14). Although *Embiotoca jacksoni* declined in north Diablo Cove, it increased in south Diablo Cove and was unchanged overall. Four of the eight taxa that decreased, relative to control populations, were species that are also caught in local sport and commercial fisheries: *Sebastes rastrelliger* (grass rockfish), *S. chrysomelas*, *Scorpaenichthys marmoratus* (cabezon), and *H. decagrammus*.

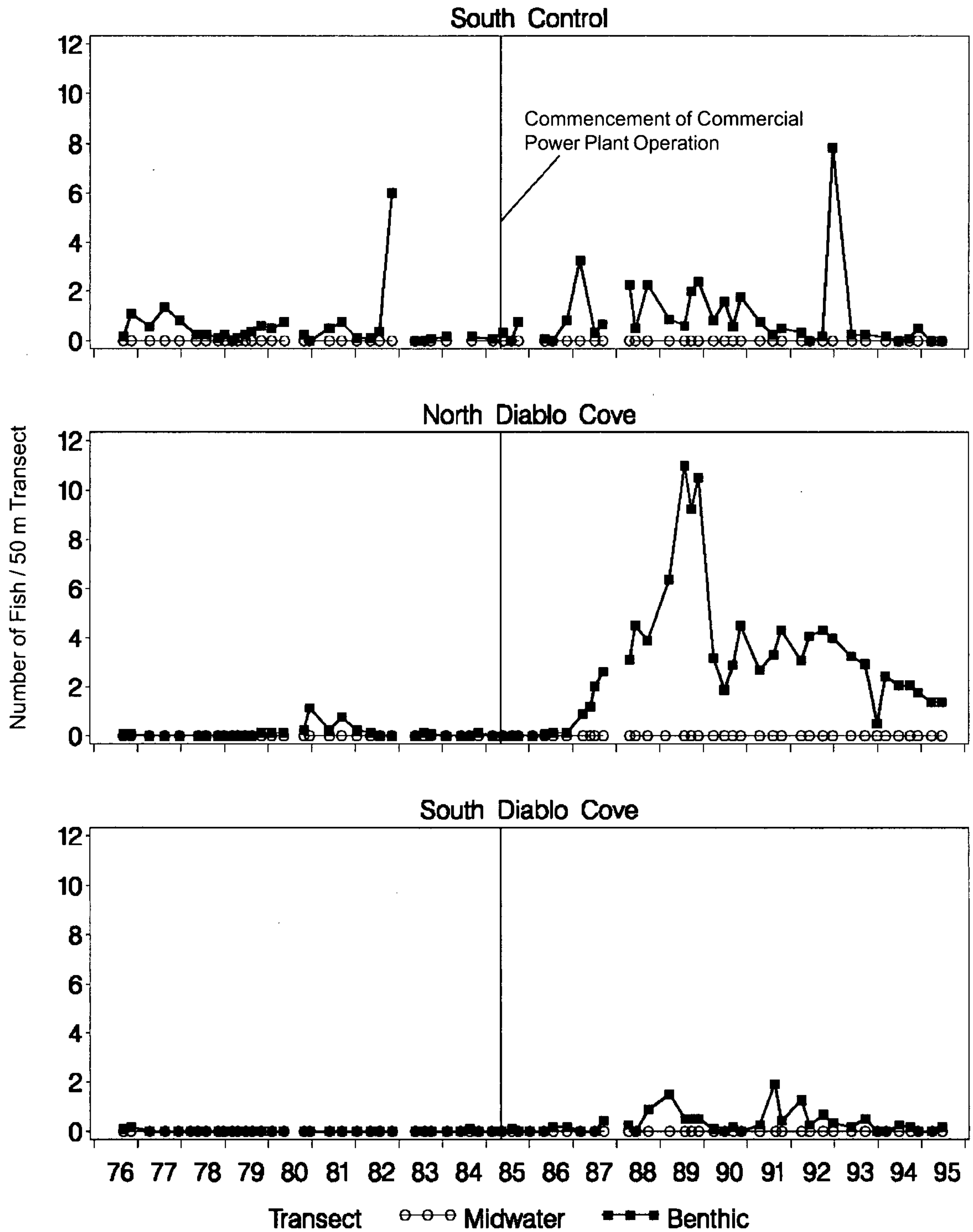


Figure 4-42. *Coryphopterus nicholsii* (blackeye goby): changes in abundance on subtidal transects.

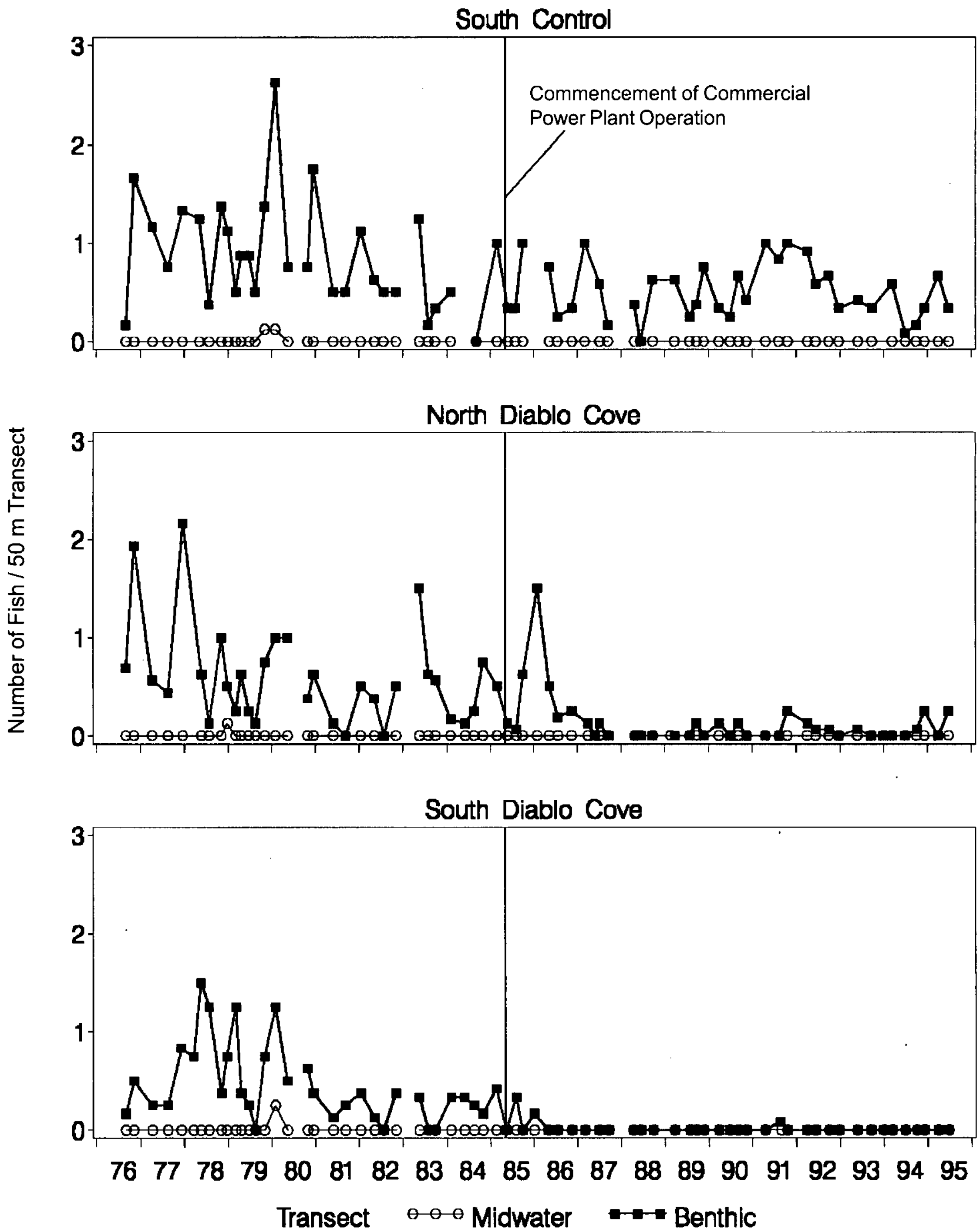


Figure 4-43. *Hexagrammos decagrammus* (kelp greenling): changes in abundance on subtidal transects.

Incidental observations indicated that there was not a disproportionately greater commercial or recreational fishing effort in Diablo Cove as compared to other nearshore areas that would have explained these differences.

No Changes

Six of the taxa tested (16%) were apparently unaffected by the discharge, as evidenced by no significant differences in abundance between periods and relatively high power of the tests to detect changes (Table 4-14). *Embiotoca lateralis* (striped surfperch) was the most consistently abundant species in this category, and was recorded mainly on the benthic transects (Figure 4-44). *Embiotoca jacksoni* (black surfperch) increased in north Diablo Cove but decreased in south Diablo Cove, and was therefore considered unchanged in overall abundance.

Test Results Inconclusive

In ten taxa (27% of the total tested, Tables 4-13 and 4-14), the analysis lacked sufficient power to detect any significant changes in abundance between periods. *Ophiodon elongatus* (lingcod) is a species of interest because of its value to commercial and recreational fisheries. It was not abundant enough in any of the study areas, either before or after operation, to determine if it was affected by the discharge. Many of the species enumerated using the midwater counting method were too variable to detect changes.

Analysis of Community Changes

The gains and losses of species did not significantly change fish diversity (Shannon-Weiner H') on the midwater transects of Diablo Cove, or on benthic transects of north Diablo Cove, but diversity decreased on the benthic transects of south Diablo Cove (Table 4-14). Species richness (total number of species recorded during the period) increased on both midwater and benthic transects in north Diablo Cove after plant start-up. This increase largely resulted from the addition of warm water tolerant species to the assemblage.

Species persistence within areas was measured by comparing the number of surveys during which a species was present in the pre-operation and operation periods. The Fisher's exact test was used to analyze these increases and decreases in frequency of occurrence between fish assemblages in the control area and in Diablo Cove (Table 4-16). The ratio of decreases to increases was significantly different between locations for the midwater transects ($p<.01$), indicating that there were more changes in species occurrences in Diablo Cove than would be expected by chance alone. No significant differences in species persistence were detected for the benthic transects. In the benthic data sets, the number of species that increased matched the number that decreased, resulting in a turnover of species that was balanced between periods.

Correspondence analysis (CA) was used to analyze fish community variation at a control location and two Diablo Cove locations. Data included in the analyses consisted of annual means for the taxa that formed 95% of the total cumulative abundance across all surveys and occurred in at least 20% of the surveys. This resulted in an analysis of 16 taxa. The first two CA axes explained 69.05% of the total variation in the data set and represent the two largest independent sources of variation (Figure 4-45a). Variation along the first dimension separates south Diablo Cove from all other areas regardless of period. Annual survey scores for pre-operational years are generally more similar to scores for the control area that are tightly clustered and show little variation along these two axes. The positive taxa scores for the first axis separate fishes associated with the sand habitats that are more common in south Diablo Cove and that have shown relative increases during the operation period (Figure 4-45b). Taxa that have shown relative increases at this location during operation include *Citharichthys stigmaeus* (speckled sanddab) and *Aulorhynchus flavidus* (tubesnout).

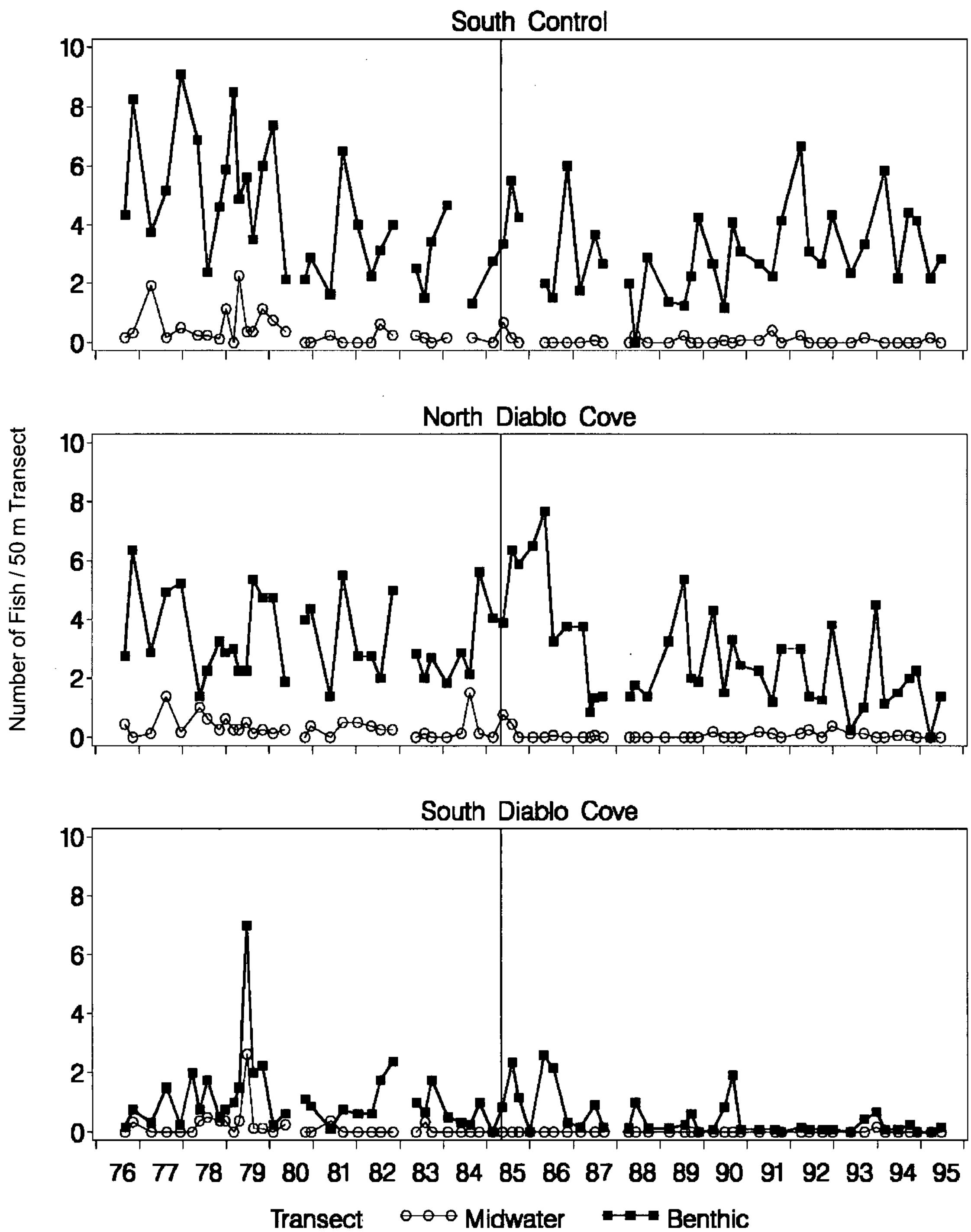


Figure 4-44. *Embiotoca lateralis* (striped surfperch): changes in abundance on subtidal transects.

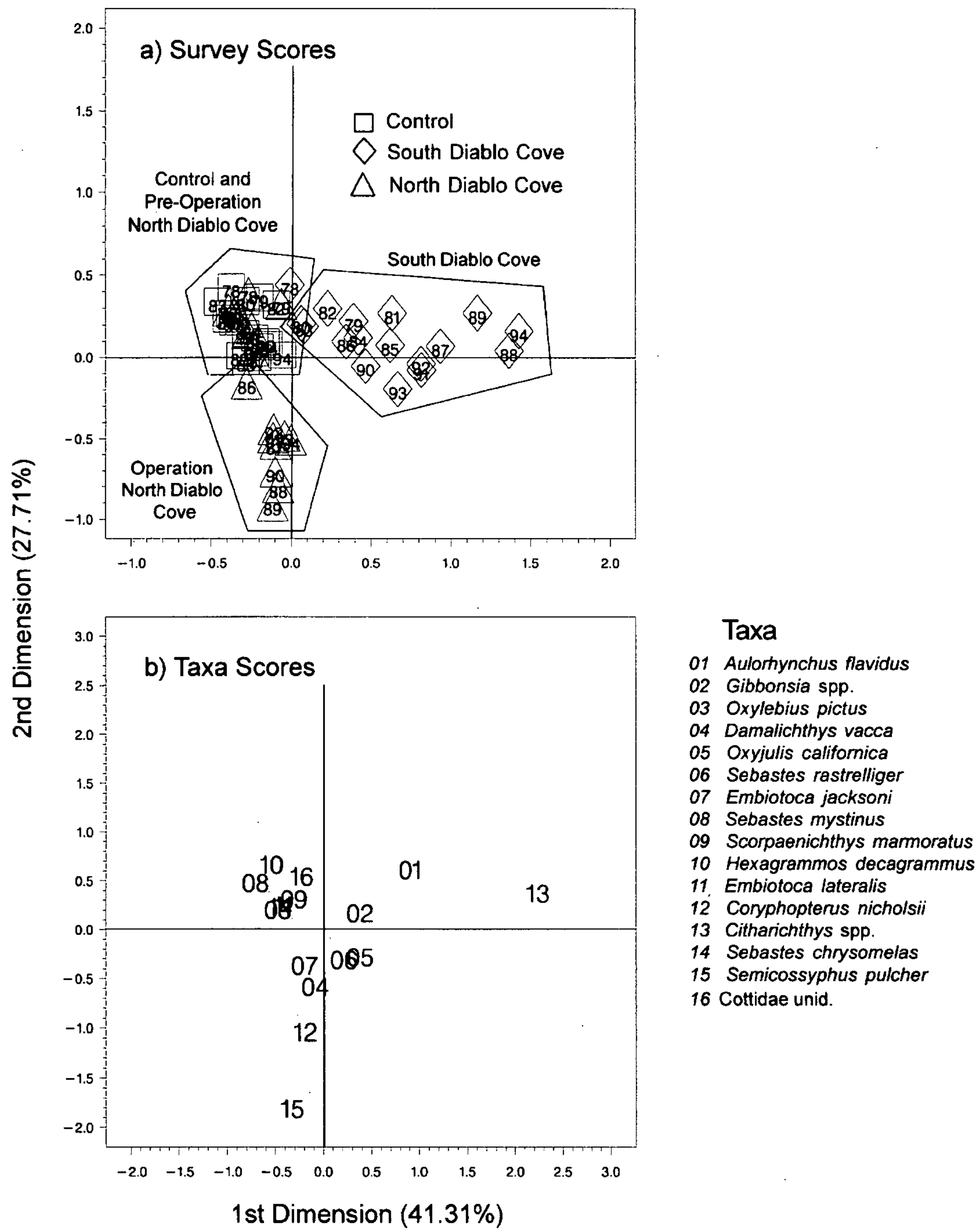


Figure 4-45. First and second dimension scores from correspondence analysis of subtidal fish transect data. (a) Annual survey scores. (b) Taxa scores. Numbers inside of symbols are years. Outlined areas represent clusters or patterns of scores corresponding to major sources of variation. Percentages in parentheses denote amount of variation explained by corresponding dimension.

The second axis which accounted for 27.71% of the total variation in the data set explains variation due to changes in north Diablo Cove during plant operation (Figure 4-45a). Pre-operational annual survey scores are tightly clustered with the control group, but begin to diverge from the control group in 1986, the first year of full commercial operation. Negative taxa scores along the second axis for *S. pulcher* (sheephead) and *C. nicholsii* (black-eyed goby) represent taxa that have shown relative increases during plant operation in north Diablo Cove (Figure 4-45b).

Table 4-16. Results of Fisher's exact test for subtidal fish observations: a) midwater transects, and b) benthic transects. Data were number of species changes between pre-operation and operation periods. Statistically significant results ($p<0.10$) are in **bold** type.

a) Midwater Transects

	Decreases	Increases
Diablo Cove	9	23
Control	20	10
	p = **<.01**	

b) Benthic Transects

	Decreases	Increases
Diablo Cove	36	37
Control	27	28
	p = 1.00	

Ancillary Observations

Fishes in the turbulence zone of the discharge (extending approximately 100 m offshore from the shoreline point-of-discharge [Figure 2-4]) were not studied quantitatively because of the difficulty of making observations in the fast-moving, poor visibility waters of the plume. However, under occasional conditions of high tide and good water clarity, fishes in this zone could be observed. Water temperatures were essentially the same as discharge temperatures, approximately 11°C above ambient (Figure 2-3). Almost all of the species typical of this zone were members of families with affinities for temperate water, and included species that had not been recorded in other parts of Diablo Cove or control areas (Table 4-17).

Triakis semifaciata (leopard shark), *Myliobatis californica* (bat ray), and *Atractoscion nobilis* (white sea bass) were consistently abundant, but because they were mainly associated with the areas of warmest and most turbulent water they were relatively infrequent on the fish observation transects. *M. californica* was observed in large numbers (200-300) schooling in the south Diablo Cove channel east of Diablo Rock where the discharge plume exited Diablo Cove. Aggregations, composed mostly of females, typically swam into the current, maintaining static position near the surface of the water column. These aggregations were observed throughout the year, but seemed to be more abundant in the fall.

Spatial Extent of Effects

Quantitative data clearly demonstrated effects of the discharge on fishes in north and south Diablo Cove, and qualitative observations also revealed changes relative to control areas throughout Diablo Cove

(Figure 4-46). The greatest differences in taxa composition occurred in the warm water of the discharge turbulence zone, with changes generally diminishing with depth. Because the surface plume spread beyond the boundaries of Diablo Cove, midwater fishes such as topsmelt and anchovy may have been attracted to the warmer water as they were in other areas within Diablo Cove. The total area of benthic and midwater habitats known to be affected within Diablo Cove was approximately 16.3 ha (40.3 ac), with potential effects on midwater areas extending outside Diablo Cove. Effects on surface kelp canopies (Figures 4-16 and 4-20) would also have corresponding effects on associated fish taxa. These would primarily include YOY *Sebastes* spp., YOY *Oxyjulis californica*, adult *S. atrovirens* and all life stages of *Brachyistius frenatus*.

Table 4-17. Fish species observed in Diablo Cove thermal discharge (turbulence) zone, and relative abundance on fish transects inside and outside Diablo Cove. Species list and abundances are based on qualitative and quantitative diver observations from 1985-1995.

Scientific name	Common Name	Relative abundance in discharge zone[1]:	Relative abundance on fish transects in Diablo Cove	Relative abundance on fish transects in South Control
Atherinidae	Topsmelt / Jacksmelt	****	***	**
Atractoscion nobilis[2]	White seabass	***	*	—
Chromis punctipinnis[2]	Blacksmith	**	*	*
Clupea pallasii	Pacific herring	**	*	—
Cymatogaster aggregata	Shiner surfperch	**	**	**
Engraulis mordax	Northern anchovy	***	**	**
Embiotoca jacksoni	Black surfperch	****	****	****
Girella nigricans[2]	Opaleye	***	**	—
Halichoeres semicinctus[3]	Rock wrasse	*	—	—
Hermosilla azurea[2]	Zebraperch	*	—	—
Heterostichus rostratus[2]	Giant kelpfish	*	*	*
Medialuna californiensis[2]	Halfmoon	***	*	—
Morone saxatilis	Striped bass	**	—	—
Myliobatis californica	Bat ray	*****	***	—
Oxyjulis californica	Señorita	*****	*****	*****
Paralabrax clathratus[2]	Kelp bass	***	**	*
Paralabrax nebulifer	Sand bass	*	—	—
Phanerodon furcatus	White surfperch	**	*	*
Rhinobatos productus	Shovelnose guitarfish	*	—	—
Sardinops sagax	Sardine	*	*	*
Scorpaena guttata[2]	California scorpionfish	*	—	—
Semicossyphus pulcher[2]	Sheephead	****	****	**
Seriola lalandi[2]	Yellowtail	*	—	—
Sphyraena argentea[2]	California barracuda	*	—	—
Trachurus symmetricus	Jack-mackerel	**	*	*
Triakis semifasciata	Leopard shark	*****	***	*
Urolophus halleri	Round stingray	****	**	*

[1] relative abundance based on qualitative observations; (*****= most abundant, *= least abundant, — = not present)
[2] warm-temperate species with primary distribution south of Point Conception
[3] northern range extension based on available distribution data for this species (Love et al. 1996)

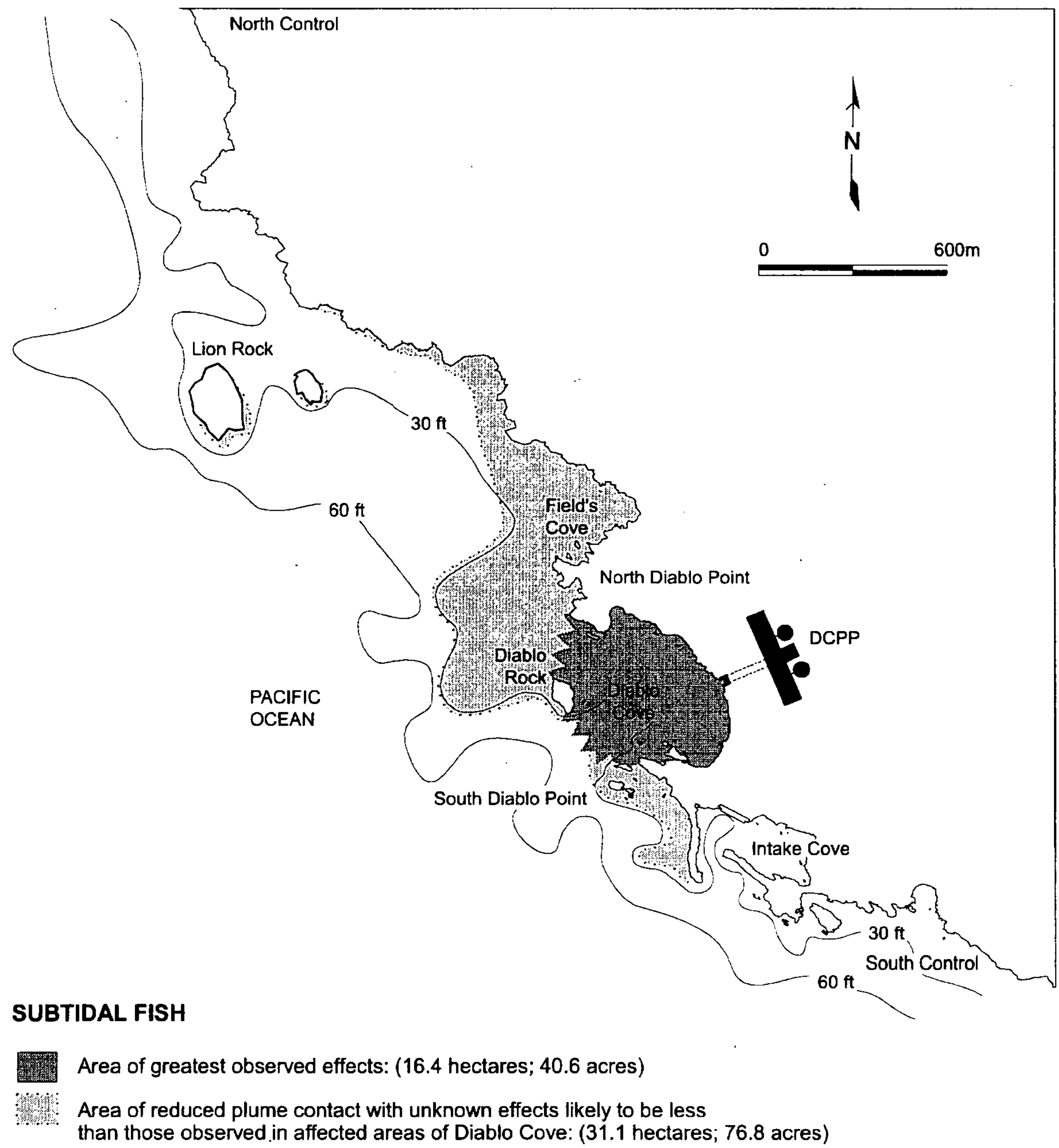


Figure 4-46. Approximate area of discharge effects on the distribution and abundance of subtidal fish observed in the study. Subtidal zig-zag boundaries represent unknown transition zones outside Diablo Cove. Map of effects was developed from fish observation surveys and qualitative observations.

4.4 Discussion

4.4.1 Algae

The results from the TEMP subtidal study show that over the 10 years of power plant operation the discharge caused significant changes in the algal assemblage in Diablo Cove. Correspondence analysis identified shifts in the Diablo Cove community (resulting from changes in the abundance of important individual taxa), which are supported by BACI results of significant changes detected in many of the same taxa, including diversity and species richness. After power plant start-up, subcanopy kelp species that were formerly abundant declined in shallow water, and the lower-growing algal understory shifted in composition and abundance. Some understory species that were abundant before power plant start-up declined, while less abundant species became more common. The changes resulted in an overall significant decline in diversity but a significant increase in the number of taxa. Near the end of the study, giant kelp, *Macrocystis pyrifera*, increased in density, and there was a reduction in the coverage of some understory algae that had formerly increased, probably due to light attenuation from canopy shading (Gerard 1984; Kimura and Foster 1984; Foster and Schiel 1985; Santelices and Ojeda 1984).

None of the above changes were observed outside Diablo Cove. The changes in Diablo Cove's subcanopy kelps and lower-growing algal understory were mainly confined to an area of approximately 8.1 ha (19.9 ac). Effects extended to a maximum depth of about -7 m below MLLW in the area inshore of Diablo Rock. In north Diablo Cove, the effects extended to depths of at least -4 m. In south Diablo Cove, effects were confined to slightly shallower areas. *Nereocystis luetkeana*, was the only alga observed to be affected by the thermal discharge in all areas of Diablo Cove and in areas adjacent to the cove, since it grows to the sea surface and is exposed to the discharge over broader areas than benthic algae. A survey conducted in 1987 during an El Niño period with warmer than normal ambient temperatures estimated the total geographic area of effects on surface-occurring *N. luetkeana* at approximately 42 ha (105 ac).

M. pyrifera expanded in all areas of the cove, except near the headlands and in areas scoured by the discharge. The amount of bare rock cover in Diablo Cove also significantly increased. Some of the increase could have been related to the significant decrease in sand cover, resulting in more bare rock becoming exposed. Although there were changes in Diablo Cove in response to the discharge, the algal assemblage did not shift to one composed mainly of species typical of warm-temperate areas south of Point Conception. Rather, changes occurred as losses in subcanopy kelp species and shifts in the relative abundances of surface canopy-forming kelps and low-growing understory species.

Nereocystis luetkeana was the predominant surface-canopy kelp species in Diablo Cove prior to power plant start-up. This species is an annual (Foreman 1970; Nicholson 1970) which recruits (sporophyte generation) along the coastline during spring-summer. By late fall plants have matured and released spores necessary for development of the intermediate gametophyte generation (a microscopic stage). The first large storms of fall-winter detach most plants, leaving the gametophytes to generate the following year's population. Open space is necessary for spore settlement, germination, and growth, and therefore *N. luetkeana* tends to occur in areas of high wave energy (Foreman 1970).

N. luetkeana in the vicinity of the power plant was affected by the discharge. Qualitative observations showed that each year's population senesced prematurely (Figure 4-19). It was anticipated that *N. luetkeana* would be affected by the discharge from increased temperatures (PG&E 1982b). This kelp does not occur south of Point Conception (Abbott and Hollenberg 1976), suggesting that water temperature may be important in determining this species' southern boundary (Vadas 1972). In Diablo

Cove, deeper reefs below the surface thermal plume became repopulated with *N. luetkeana* during each year of power plant operation. The small plants developed normally, but eventually senesced once they grew upwards into the thermal plume. The October cliff-top surveys enumerated only senescent plants, and a less dense population than was present earlier in the season, as large numbers of plants had already detached and drifted away. Healthy plants were not present when the surveys were conducted. Reduced gametophyte densities for recruitment could also explain the low numbers each year. Since power plant start-up, most of the *N. luetkeana* in Diablo Cove senesced before becoming reproductively mature, which could have reduced the amount of zoospores and gametophytes for regenerating the following year's population. Also, no recruitment was observed on shallow reefs in Diablo Cove that were exposed to the warmest temperatures, indicating effects to the microscopic stages of growth. However, no information on spore dispersal or gametophyte densities was obtained in the study.

N. luetkeana was studied outside Diablo Cove during a single survey in fall 1987 (Figure 4-20). Dense stands of prematurely senescent plants were identified between Diablo Cove and Lion Rock, a distance of approximately 800 m outside the cove. Ambient temperatures during this period were relatively high (16°C), in comparison to other years, and both power plant units were in full operation together for the first time (*see* Section 2.0 - *Power Plant Operation and Thermal Plume Characteristics*). The ambient temperatures of 16°C were probably near the lethal limit for *N. luetkeana* (Vadas 1972), and the additional heat load from the discharge probably caused temperatures over broad areas to exceed the thermal tolerance for this kelp. Point-of-discharge temperatures during fall 1987 were occasionally over 25°C and temperatures in north Diablo Cove were occasionally over 20°C (Section 2.0). When discharge and receiving water temperatures were lower, premature senescence in *N. luetkeana* probably did not extend as far outside Diablo Cove. Analysis of kelp maps from aerial photographic surveys for changes in *N. luetkeana* resulting from the discharge was inconclusive due to insufficient data for the power plant operation study period.

The subcanopy kelps *Pterygophora californica* and *Laminaria setchellii* experienced deterioration of thalli. In a study separate from the TEMP, North et al. (1989) noted that stress in *P. californica* and *L. setchellii* in Diablo Cove after power plant start-up was first indicated as blade lesions caused by the endophytic brown alga *Streblonema evagatum*. North et al. (1989) and the TEMP study observed that the affected areas on the seafloor (Figure 4-21) corresponded to the areas of greatest temperature increases (*see* Section 2.0 - *Power Plant Operation and Thermal Plume Characteristics*). North et al. (1989) also observed the decline of these two kelps along the headlands outside Diablo Cove. Their studies lasted through 1987.

North et al. (1989) noted that because *P. californica* commonly occurs in southern California and *L. setchellii* does not, *L. setchelli* is assumed to be the more temperature sensitive species. The decline of Diablo Cove *L. setchellii* prior to the decline in *P. californica* supports this conclusion. Also, recruitment in both kelp species was not observed in the warmest areas of Diablo Cove where adults declined. Lüning and Neushul (1978) found that temperature exposures of 17°C began to inhibit gametophyte reproductive maturity in central California *L. setchellii*. These temperatures have occurred in Diablo Cove more regularly since power plant start-up. No studies on temperature sensitivity have been conducted on central California *P. californica* gametophytes.

Deterioration in kelps can also be caused by low nutrient concentrations that can be associated with warm water (Jackson 1977; Zimmerman and Robertson 1985; Dean and Jacobsen 1986). In southern California, *M. pyrifera* canopy deterioration occurs when water temperatures become greater than 20°C, particularly during El Niño events, but the process has been linked to inadequate nutrient concentrations associated with the warmer water (Gerard 1982; Zimmerman and Kremer 1984; Dayton and Tegner 1984; Dean and Jacobsen 1986; North et al. 1986). The lowered nutrient regimes, during El Niños in particular, stem from the lack of upwelling that replenishes nutrients into the nearshore waters. Consequently, nutrient concentrations would not be expected to become depleted by the warm water discharge. Furthermore, *M. pyrifera* has increased in the warmest areas of Diablo Cove, including areas where temperatures have approached or exceeded 20°C, the warm water discharge probably has not affected nutrient concentrations.

The relative changes in the understory algae *Cryptopleura ruprechtiana* and *Cryptopleura violacea* were closely associated with one another and with patterns of temperature in the warmest areas of Diablo Cove. *C. violacea* increased and *C. ruprechtiana* decreased (both to large extents) at NDC 6 -3m (the warmest station in Diablo Cove) soon after power plant start-up. Water temperatures at the north Diablo Cove stations were not as warm, and the change following power plant start-up was not as dramatic at NDC 6 -m. SDC 3 -4m was the coolest shallow station in Diablo Cove where *C. violacea* remained sparse in cover and *C. ruprechtiana* remained more common, except during 1987, when *C. violacea* temporarily increased during a natural warming period and *C. ruprechtiana* decreased. The coverage of both species reversed the following year when temperatures declined.

Macrocystis pyrifera increased in abundance during power plant operation. Before power plant operation, *M. pyrifera* was not abundant in Diablo Cove, but dense *Macrocystis* forests occurred 1-6 km north of the power plant, in the region of Lion Rock and Point Buchon (TEMP, unpublished observations). In 1977, several plants became established in Diablo Cove (Gotshall et al. 1984), but the population did not expand. In 1991, large numbers of *M. pyrifera* began appearing in north Diablo Cove, in areas that were formerly occupied by dense stands of *P. californica* and *L. setchellii*. The cause for earlier low numbers of *M. pyrifera* may have been from shading by these subcanopy kelps (Reed and Foster 1984).

One mechanism for the increase in *M. pyrifera* is the transport of spores liberated from the dense *M. pyrifera* population in the DCPP intake cove via the intake-discharge conduits during refueling outages. Another source of spores is the Lion Rock population (next nearest *M. pyrifera* forest 100 km to the north). Although spore dispersal and settlement tend to be most concentrated (within meters) around parent plants (Anderson and North 1966), storm conditions and strong currents may resuspend spores for transport over longer distances (Reed et al 1988). While floating drift kelp probably rarely enters Diablo Cove, due to the outward surface flow of discharge water, spores occurring close to the bottom may become entrained into the cove from countercurrents created by the outward flow of surface discharge water. Near the end of the study, it was apparent that the *M. pyrifera* population in Diablo Cove was self-sustaining. Although mortality was observed, as evidenced by the occurrence of remnant holdfasts, adult plants commonly bore fertile sporophylls, and large numbers of recruits were observed growing interspersed among the adult plants.

During spring-summer, foam generated by the discharge tended to accumulate on the water surface in south Diablo Cove (PG&E 1976, Kenzler 1987), and this (with the *M. pyrifera* surface canopy) may have contributed to reduced underwater light levels. Algal growth beneath dense *M. pyrifera* canopies can be maintained by "sunflecks" through canopy openings created by wave swells (Gerard 1984). The layers of foam in south Diablo Cove occasionally became so thick and extensive that the *M. pyrifera* surface canopy could not be seen from the surface. Thus, the foam may have further reduced the amount of light reaching the bottom, by occluding openings through the *M. pyrifera* surface canopies. The foam itself did not appear to have an effect on *M. pyrifera* canopy tissues.

Declines in understory algae near the end of the study may have resulted from shading effects of *Macrocystis pyrifera* surface canopies and the periodic accumulation of surface foam. This effect was most apparent in south Diablo Cove where foam has tended to become most accumulated. At SDC 2 -3m the primary understory species that declined was *Cryptopleura violacea*. Also, at SDC 3 -4m and at NDC 5 -8m in Diablo Cove, the closely related species, *Cryptopleura ruprechtiana*, remained abundant until a dense *M. pyrifera* canopy formed over the station.

The abundance of *Cystoseira osmundacea* was variable among stations over time in Diablo Cove. The significant decline detected in the BACI analysis may have been related to the 'bleaching incident', which caused collapse of the *C. osmundacea* canopy and mortality in plants just before power plant start-up and lower abundances during power plant operation. While declines continued after power plant start-up in the warmest areas of Diablo Cove (areas less than -4 m deep), healthy plants remained in deeper water and formed normal surface canopies in summer each year of power plant operation (PG&E 1994). Some areas, such as at NDC 6 -3m, may be too warm for recruitment and persistence of *C. osmundacea*. *C. osmundacea* was relatively common at NDC 6 -3m, but no plants have been observed there since power plant start-up, suggesting that temperatures there may be above this species' thermal tolerance for settlement and juvenile growth. North et al. (1989) considered *C. osmundacea* tolerant of warm water, based on its occurrence in southern California, and they anticipated that *C. osmundacea* would not be affected by the thermal discharge. However, they also observed declines in this species in areas of warmest water. They noted that the decline may have been related to increased grazing from gastropods, and suspected that the abundant grazers (e.g., *Tegula* spp.) that fed on *P. californica* and *L. setchellii* switched to grazing on *C. osmundacea* after the former two kelps declined. Occasional recruitment and small plants of *C. osmundacea* have been observed in some areas where the kelp was previously abundant, but large canopy forming plants were more abundant before power plant start-up than after. Articulated coralline algae (*Calliarthron/Bossiella* spp.-complex) were also affected by the 'bleaching incident'.

Phyllospadix spp. is an important low-intertidal/shallow-subtidal habitat and nursery area for fish and invertebrates (Stewart et al. 1978). The -3 m subtidal benthic stations sampled the lower boundary of this surfgrass. Similar to the results for intertidal *Phyllospadix* spp., subtidal *Phyllospadix* spp. was significantly reduced in coverage by the 1982/83 winter storms, and then became absent during power plant operation at both control and Diablo Cove stations. The BACI analysis detected a significant change in surfgrass relative to controls because of the more rapid decline in Diablo Cove.

Ecological Overview

Prior to the TEMP, Diablo Cove was studied by North (1969), North et al. (1989), Burge and Schultz (1973), Colson (1975), and Gotshall et al. (1984, 1986). The results of these studies, in combination with the TEMP findings, provide a continuum of observations in Diablo Cove from 1966 to 1995. The early studies documented an important ecological shift in subtidal community composition in Diablo Cove, beginning in 1974 when the southern front of *Enhydra lutris nereis* (southern sea otter) expansion reached the study area (Gotshall et al. 1984). Over 100 foraging sea otters occupied the area between Point Buchon and Pecho Rock, and over 30 sea otters occupied Diablo Cove (Colson 1975). Previously, North (1969) and Burge and Schultz (1973) described Diablo Cove with large areas overgrazed of algal cover by dense aggregations of *Strongylocentrotus franciscanus* (red sea urchins). Aggregations of 5-50 urchins per square meter formed two distinct areas of deep and shallow-water 'urchin barrens'. Dense kelp forests bordered the urchin barrens (Figure 4-47).

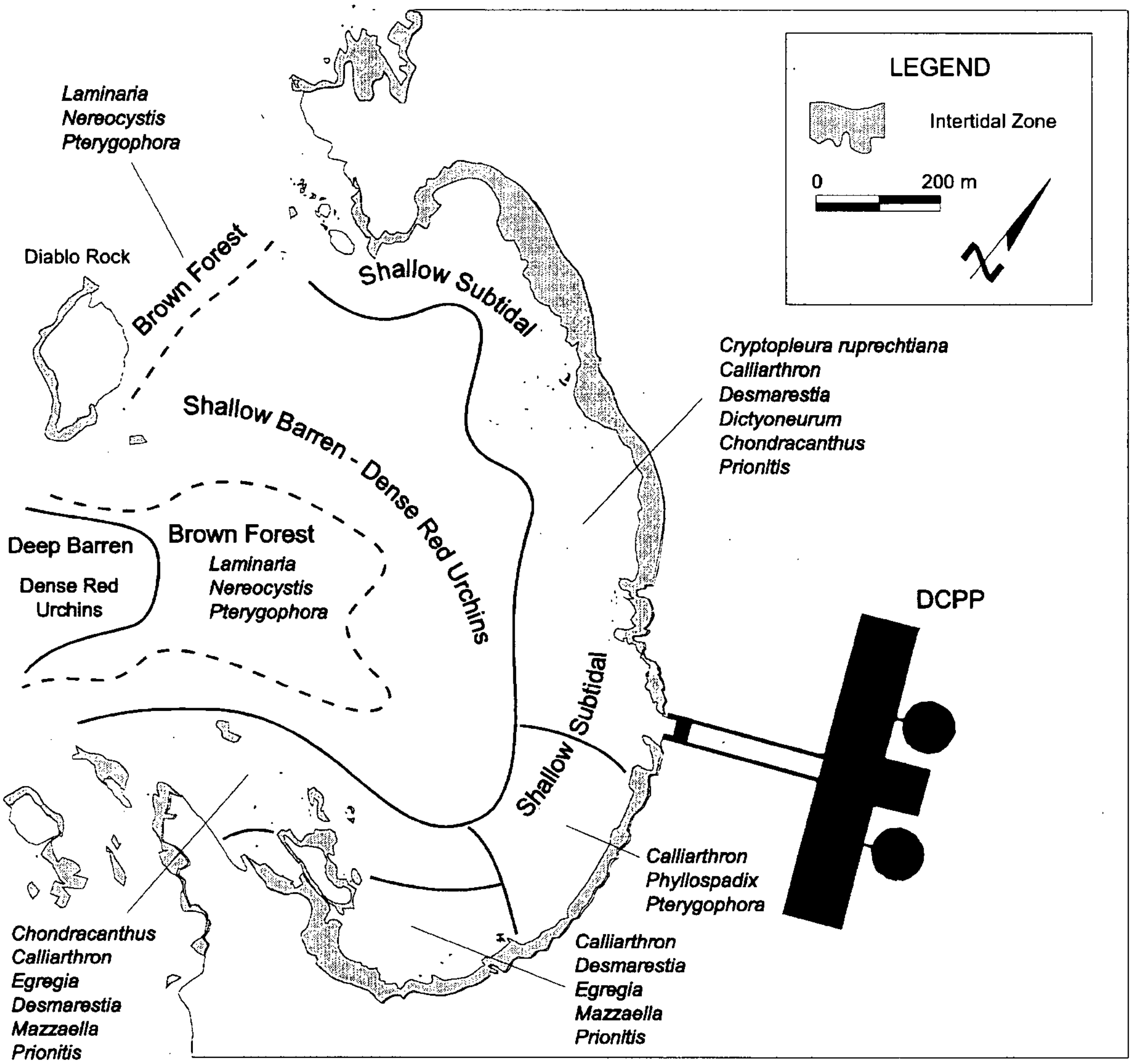


Figure 4-47. Major biological characteristics observed in Diablo Cove in 1966, 19 years before power plant commercial operation and before the arrival of sea otters. Map redrawn from North (1969).

The maintenance of areas low in algal cover caused by grazing sea urchins has been documented worldwide (Lawrence 1975; Pearse and Hines 1979; Dean et al. 1984; Johnson and Mann 1988; Tegner and Dayton 1991), and sea otter foraging on urchins can have important implications in algal growth and species composition in kelp forests (Paine and Vadas 1969; Estes et al. 1978; and Duggins 1980). The relationship of urchin densities and kelp abundance in Diablo Cove from 1974 to 1982, following the arrival of the sea otters, appears in Figure 4-48. The data are results from subtidal random station sampling by the California Department of Fish and Game (CDF&G), compiled from Gotshall et al. (1984, 1986). Once sea otters became established in Diablo Cove, their foraging on *S. franciscanus* reduced grazing pressures on subtidal algae. In response, *Nereocystis luetkeana*, *Pterygophora californica*, and *Laminaria setchellii* increased in density. Eventually, *N. luetkeana* declined while the latter two kelps remained abundant. Annual cliff-top observations of *N. luetkeana* by Gotshall et al. (1984, 1986) noted that the major area of decline occurred in the central, deeper portion of Diablo Cove. The decline is partially explained by the persistence of *P. californica* and *L. setchellii*, both of which are perennial, as compared to the annual life history of *N. luetkeana*, which has to relinquish space each year. The ability of *P. californica* and *L. setchellii* to maintain space from one year to the next possibly facilitated their increase in density, which in turn caused an overall decline in annual recruitment and growth of *N. luetkeana* in Diablo Cove. However, while *N. luetkeana* was reduced in abundance in central, deeper portions of Diablo Cove, it continued to repopulate the most wave exposed, shallow areas of the cove where *P. californica* and *L. setchellii* were less capable of surviving (Figure 4-16). An identical sequence of change among these kelp species occurred on a newly constructed artificial reef 3.9 km south of DCPP where the development of subcanopy kelps eventually replaced *N. luetkeana* (Danner et al. 1994).

The TEMP studies began in 1976, after the subtidal algal assemblage in Diablo Cove had changed in response to the reduction of algal grazers by sea otters. An illustration summarizing the changes observed over the nine year period before power plant start-up and the following 10 years appears in Figure 4-49. At the beginning of the study, dense stands of *Pterygophora californica* and *Laminaria setchellii* occurred in north and south Diablo Cove. In south Diablo Cove both kelps formed a nearly continuous subcanopy over the low-relief bottom, and a lush understory was absent. Canopy shading effects have been found to limit understory algal abundance (Reed and Foster 1984; Santelices and Ojeda 1984; Kennelly 1987), and the low abundance of understory algae in south Diablo Cove probably resulted from shading by the kelps, which formed a relatively flat subcanopy about one meter over the bottom. In contrast, subcanopy kelps and a lush understory co-occurred in north Diablo Cove. There higher bathymetric relief and higher water motion prevented monopolization by the subcanopy kelps. The kelp species tended to occur at the base of rocky outcroppings where water motion was less, while dense understory algal assemblages covered the tops of the outcroppings (above the heights of the kelp subcanopies).

After power plant start-up, subcanopy kelps and some understory algae (e.g., *Cryptopleura ruprechtiana*) declined to near-absence at the sampling stations. With the decline of subcanopy kelps and the presence of warmer water, several understory algae became more abundant (e.g., *Cryptopleura violacea*, *Farlowia/Pikea* spp.-complex, and *Gelidium robustum*). The new assemblage was used as biological criteria to map the areas of discharge effects outside the sampling stations (Figure 4-20). At the end of the study *Macrocystis pyrifera* became the dominant kelp in Diablo Cove and the shading effects from the increased canopy caused reductions in the cover of some warm water tolerant understory species. Therefore, future surveys to delineate the spatial extent of discharge effects to algal assemblages may not be able to use previous biological criteria because of changes in algal composition, abundance, and distribution that may result from the effects of *M. pyrifera*.

Based on qualitative observations, the spatial extent of discharge effects on the benthic algae was confined to mainly shallow areas of Diablo Cove and its headlands, representing an area of 8.1 ha (19.9 ac)

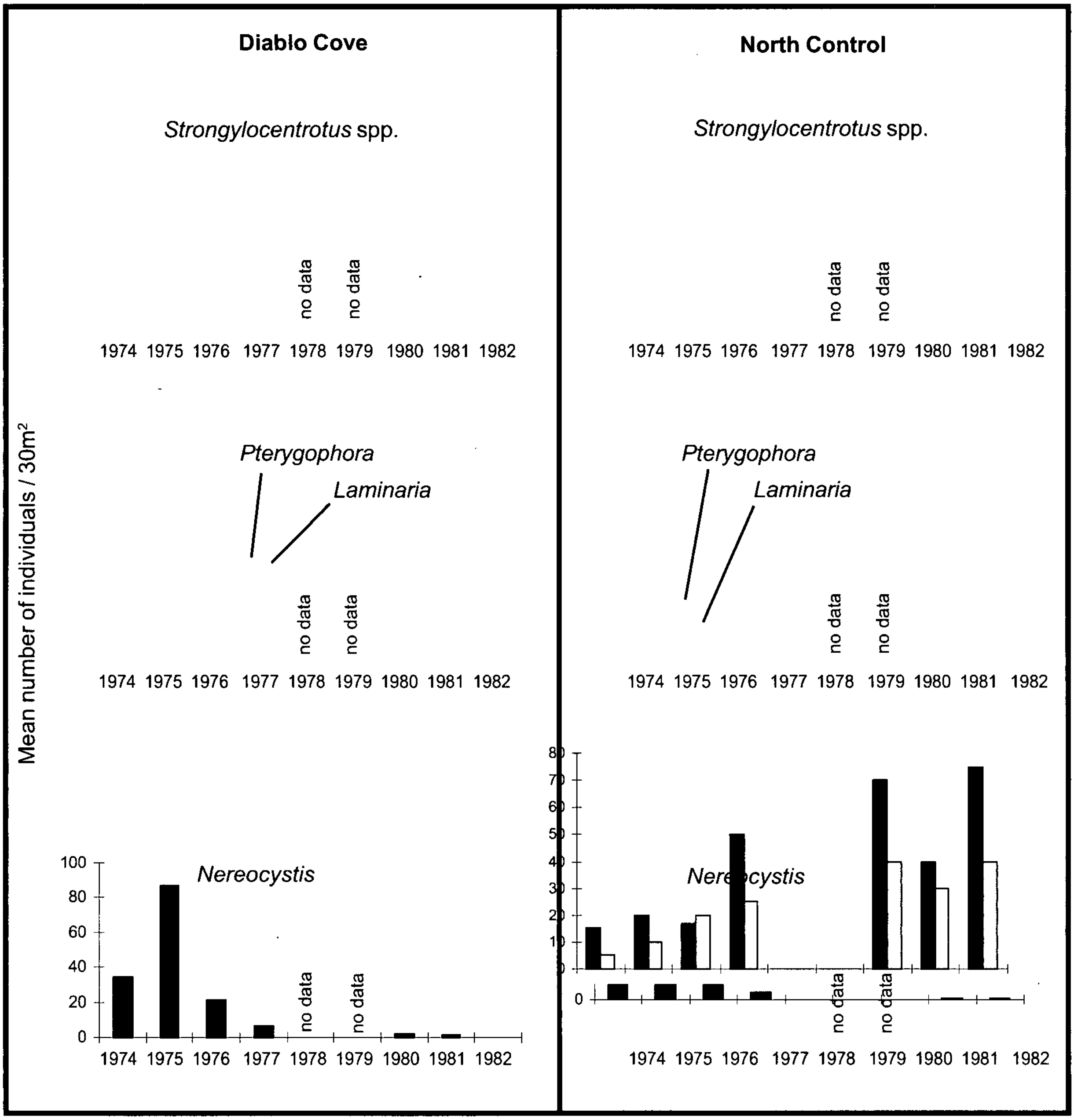


Figure 4-48. Changes in densities of subtidal urchins (*Strongylocentrotus* spp.) and kelp (*Laminaria* and *Pterygophora*) from random 30m² station sampling in Diablo Cove and North Control before commencement of commercial power plant operation. Data compiled from Gotshall et al. (1984, 1986). 'n' per data point = 12-24 stations. Note that Y-axes differ in levels of abundance between species and areas.

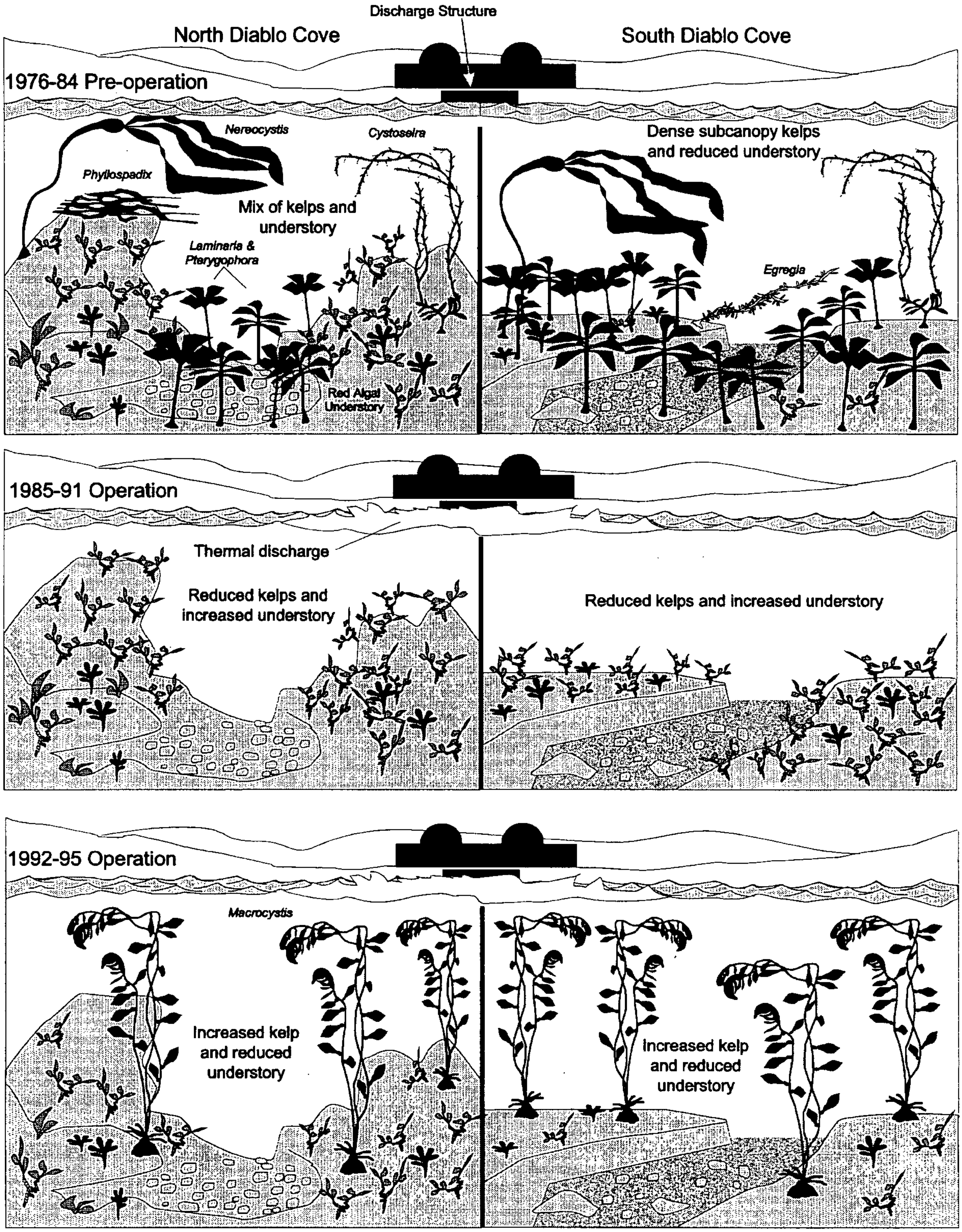


Figure 4-49. Schematic representation of major changes in subtidal algal assemblages at the -3 to -4 m MLLW depth stations in north and south Diablo Cove. Top figure is before power plant start-up. Middle figure shows losses in stipitate kelps and increases in understory red algae from 1985 to 1991. Bottom figure shows increase in *Macrocystis* and declines in understory red algae from 1992 to 1995.

(Figure 4-20). Deeper areas of the cove appeared unaffected where increased water temperatures were measured. Outside Diablo Cove to the north, the temperatures and thickness of discharge plume further diminish as the plume extends into Field's Cove towards Lion Rock. South of the power plant, the plume separates from the shore at South Diablo Point near the intake cove breakwater. The areas contacted by the discharge plume outside Diablo Cove with unknown effects on benthic algae represent an area of approximately 39.5 ha (97.6 ac).

Effects were spread over a larger area in the surface canopy-forming kelps *Nereocystis luetkeana* and *Macrocystis pyrifera*. The area within which effects were documented to these species was 42.3 ha (104.6 ac), although the canopy cover of kelp within this area was considerably less. The amount of kelp within the area immediately north of Lion Rock to south Diablo Point has generally represented less than about 30 percent of the total amount of kelp along the coast from Point Buchon to Point San Luis, based on data developed from aerial photographs (Table 4-7). No data were available to statistically conclude if impacts to *N. luetkeana* have resulted in fewer *N. luetkeana* plants in the impact area outside Diablo Cove.

4.4.2 Invertebrates

Invertebrate Community Changes

The shallow subtidal invertebrate community in Diablo Cove changed following power plant start-up in contrast to control areas where few changes occurred. Most of the changes were manifested as shifts in the relative abundances of the more common and abundant taxa, not a complete replacement of one taxon by another. To a lesser degree, several taxa more typical of the warm water areas of southern California became established in Diablo Cove during the operational period. Although the number of taxa occurrences did not change significantly between periods, the richness of the macroinvertebrate fauna (as measured by the SAQ method) decreased.

Results from the present study and earlier descriptions of Diablo Cove by Gotshall et al. (1984) showed that numerically important invertebrates during the pre-operational period included red urchins (*Strongylocentrotus franciscanus*), seastars (*Asterina miniata*, *Pisaster giganteus*, *Pycnopodia helianthoides*, and *Henricia leviuscula*), anemones (*Anthopleura xanthogrammica* and *Epiactis prolifera*), and cup corals (*Balanophyllia elegans*). Other common taxa included the sponge *Tethya aurantia*, the tunicate *Styela monteryensis*, the rock crab *Cancer antennarius*, and the gastropods *Acmaea mitra*, *Lithopoma gibberosum*, *Doriopsilla albopunctata*, *Haliotis rufescens*, *Homalopoma luridum*, *Serpulorbis squamigerus*, *Tegula brunnea*, and *Tonicella lineata*. Although all of these species were still present in Diablo Cove after power plant operation, significant decreases in abundance were detected in a large number of them.

Toward the end of the present study, *Strongylocentrotus purpuratus* became one of the most abundant taxa in shallow areas of north Diablo Cove, aggregating in densities of over 300 urchins/m^2. Brittle stars, primarily *Ophiothrix spiculata* and *Ophiactis simplex* (a species common in southern California) were abundant within rock fissures and beneath cobbles. Large motile gastropods such as *Tegula* spp. and *Calliostoma* spp. were uncommon, and the balance of macroinvertebrates generally included the nudibranch *Phidiana hiltoni* and the anemone *Anthopleura elegantissima*. Giant gumboot chitons, *Cryptochiton*, which occurred infrequently on permanent stations in the study areas during the pre-operation period, were abundant on the bottom of Diablo Cove at depths below about -6 m. None of these invertebrate species were listed in Gotshall et al. (1984) or North et al. (1989) as common to the pre-operation community fauna in Diablo Cove.

Changes in the relative abundance of taxa can have important consequences, including the alteration of the intensity of interactions among ecologically important (Paine 1974) or numerically abundant species, thereby affecting biological processes such as competition, grazing and predation. For example, Schiel (1981, cited in Foster and Schiel 1985) showed a direct relationship between the density of gastropod grazers and the magnitude of their resultant impact on algal assemblages. Shifts in these processes can affect the structure and stability of the invertebrate community. While changes in abundance of organisms occur naturally, the number and magnitude of the changes in Diablo Cove were greater relative to control sites. For example, substantial reductions of a large number of these taxa occurred within one or two years, between 1989-1990, on most Diablo Cove stations (Appendix E).

With the exception of *S. purpuratus* (which feed primarily on drift algae [Harrold and Reed, 1985]), many areas within Diablo Cove are now dominated by deposit and detritus feeders, rather than algal grazers such as *Tegula brunnea*, *L. gibberosum*, and *S. franciscanus*, present before plant operation. These changes represent a shift of the primary invertebrate algal grazer in Diablo Cove from *Tegula,* and several other taxa of larger, shelled gastropods, to *S. purpuratus*. This replacement of grazers was probably not due to direct competition between the species. The rapid changes in abundances suggest that they resulted from processes acting independently on each taxon. For example, an increase in predation by sheephead (*Semicossyphus pulcher* (Feder et al. 1974) may have caused a decline in *Tegula,* while enhanced larval recruitment or enhanced juvenile survivorship may have led to an increase in *S. purpuratus*. These processes appeared to be related to power plant operation because of the localized effects within Diablo Cove.

Although any changes within Diablo Cove, relative to the control, were by definition related to power plant operation, some changes were no doubt directly related to warmer temperatures. Several invertebrates mainly distributed south of Point Conception have been observed in Diablo Cove since operation began, and their occurrences are considered to be directly attributable to dispersal during El Niño events and the warmer water temperatures in Diablo Cove. Examples of these taxa are California spiny lobster, southern kelp crab, white urchin, wavy top snail, Solander's cowry, chestnut cowries, Norris's top snail, Kellet's whelk, California black sea hare, and giant keyhole limpet. Several of these occurred in the Diablo Canyon vicinity (Point Buchon to Point San Luis) prior to plant operation. However, white urchins, Solander's cowry, wavy top snails and southern kelp crabs were first seen in the study area during the plant operation period. *Norrisia norrisi* was reported to have occurred in Diablo Cove prior to 1970 (North et al. 1989) but was not seen there again until 1991. Although it is possible that many of these invertebrates could have been present in Diablo Cove during the pre-operation period but were overlooked, this seems unlikely, especially for the larger sized species. The level of sampling effort and frequency of observations for the period 1976-1987 were similar to 1987-1995.

A sharp decline in the abundance of several invertebrate species was observed during the operation period at subtidal station NDC6 -3 m, near Diablo Rock (Figure 4-50). A characteristic of heat related mortality, and of some diseases capable of causing mass mortalities is that all or most of the individuals of the species will be affected at the same time (Pearse et al. 1977). The species depicted in Figure 4-50 were selected to show these declines. These declines may be related to chronic heat stress, or possibly disease induced by heat stress. This station is contacted almost constantly by the thermal plume, exposing the fauna to chronically elevated temperatures. Direct thermal mortality to red abalone was observed during a heat treatment in 1987, and this event is discussed as part of the red abalone studies.

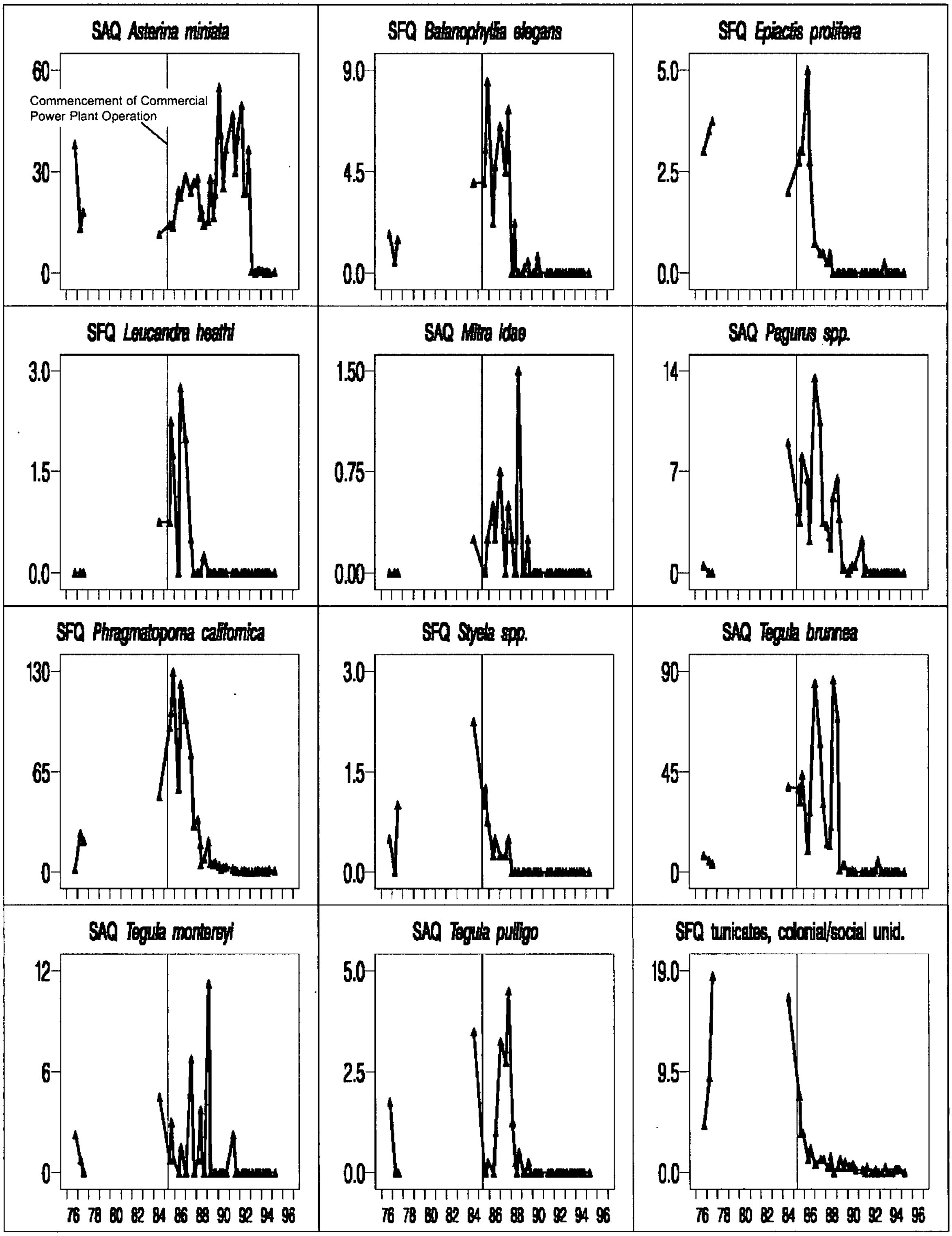


Figure 4-50. Abundance of subtidal invertebrates at NDC 6 -3m inshore of Diablo Rock. Measure of abundance for SAQ invertebrates is mean number of individuals per $7m^2$; SFQ invertebrates is mean number of individuals per $0.25m^2$, except for *Leucandra heathi*, *Phragmatopoma californica*, and tunicates, which were enumerated as number of $2.5cm^2$ units cover per $0.25m^2$.

A condition specific to echinoderms termed 'wasting disease', because the animals rapidly disintegrate over a period of several days, apparently affected *Asterina miniata* and *Pisaster giganteus* twice in the Diablo Canyon study area, once in 1984 and again in 1993. This disease was described as occurring in southern California during years when the water was abnormally warm. Affected *Asterina* that lost their hold on shallow rocks and fell into deeper, colder water, apparently recovered and survived (Foster and Schiel 1985). Losses of *Asterina* throughout the Diablo Canyon study area in 1984 attributed to this disease were coincident with increased water temperatures from El Niño (PG&E 1985). *Asterina* slowly recovered in the control areas through 1995, but generally did not recover in most shallow areas of Diablo Cove, suggesting a power plant effect. However, *Asterina* did appear to recover at subtidal station NDC6 -3 m near Diablo Rock, but again declined sharply in 1993, another El Niño period (Figure 4-50). *Asterina*, and to a lesser extent *Pisaster giganteus,* were both affected throughout shallow areas of Diablo Cove in 1993 (PG&E 1994). The increased water temperatures from El Niño may not have been enough to induce the disease in control areas. The recurrence of wasting disease, only in Diablo Cove and not control areas, suggests a relationship to temperature, although the mechanisms of infection and transmittal are not known.

Based on several lines of evidence, the mortality rate associated with withering syndrome (WS) among subtidal red abalone in Diablo Cove was probably related to elevated temperatures. Changes to red abalone populations are discussed in greater detail in the Section 4.4.3 (*Red Abalone*).

Significant decreases were detected in several taxa of shelled gastropods. Brown turban snails, *Tegula brunnea*, were one of the most common and abundant invertebrates in Diablo Cove prior to power plant operation. Their abundance decreased at most shallow Diablo Cove stations in 1989. Since that time, *T. brunnea* at these stations were mostly small (<1 cm) individuals, in contrast to the large (2-2.5 cm) individuals that were formerly abundant. Toward the end of the study in 1995, most *T. brunnea* occurred among and under cobbles, rather than on the substratum or algae as before.

T. brunnea settlement (planktonic dispersal) still occurs within Diablo Cove based on field observations and results of the intertidal Algal-Faunal Association study. The lack of large individuals may therefore reflect intolerance to chronic thermal exposure, or some other mechanism. TEMP researchers have observed sheephead (*Semicossyphus pulcher*) picking, cracking, and consuming large (2-3 cm) *T. brunnea*. Bat rays, which have been attracted to Diablo Cove in large numbers since plant operation have been known to feed on shellfish, including *Tegula* and *Lithopoma* (Feder et al. 1974). Sea otters are also known to feed on *Tegula* (S. Benech, pers. comm.). The lack of large *T. brunnea*, along with the lack of vacant or large *T. brunnea* shells, and the cryptic habitats of the juveniles, suggests that selective predation is a plausible explanation for the observed declines.

4.4.3 Red Abalone

Statistical analysis for discharge effects was not done on red abalone because of low abalone abundance on the fixed benthic stations. The abalone that were observed from the benthic station arc quadrants tended to be larger (shell lengths generally >100 mm) than those which occured in the fixed quadrats (shell length 4 to 25 mm). A consistent pattern for all Diablo Cove subtidal stations, with the exception of NDC 5- 8m, was a decrease in the number of abalone of all sizes between 1987 and 1990. This decrease was not restricted to Diablo Cove, but was also observed on Patton Cove station SC 2 -6m. However, a recovery of abalone on this station beginning in 1992 was not observed at any Diablo Cove stations. Small abalone recorded from the fixed quadrat benthic data increased on two north Diablo Cove stations, and two non-cove stations, beginning in 1992. An increase in small abalone is generally indicative of juvenile recruitment. Small abalone were consistently observed on station SC 2 -6m from 1991 through 1995 and, with time, their growth may have resulted in the recovery of larger sized individuals. However, the juveniles present on the stations in north Diablo Cove during the same time period either did not survive, emigrated from the area, or were not sampled for a long enough period following the recruitment events to follow their growth into larger size classes.

Results from the random red abalone surveys in Diablo Cove agree with results from the permanent subtidal stations and show a substantial reduction in abalone between 1987 and 1990. Random stations in Field's Cove and Patton Cove were not sampled before 1990, and it is not known whether these areas experienced similar declines before 1990.

Data from the random red abalone surveys between 1984 and 1987 indicate a dynamic, viable population of red abalone in Diablo Cove. Red abalone populations appeared unaffected by power plant operation with the exception of two events that resulted in acute mortalities. In 1974 initial pump testing at the plant using copper condenser tubing resulted in a large number of abalone mortalities (Martin et al. 1977). An acute mortality was also observed in 1987 directly in front of the discharge structure (PG&E 1988a). In October 1987, 20 dead red abalone were found in the shallow subtidal in the immediate area of the discharge structure. Between August 8, 1987 and October 25, 1987 there were three heat treatments. A heat treatment had been completed four days before the dead abalone were discovered. The cause of death was almost certainly heat stress associated with high fall ambient water temperatures, elevated discharge temperatures from two-unit operation and the heat treatment that resulted in temperatures that exceeded 30°C. Similar localized mortalities have not been observed since 1987, and heat treatments for biofouling control were not done after 1989.

Decreases in subtidal abalone abundance in Diablo Cove after 1987 were greatest in the shallow subtidal perimeter of the cove and at all depths in north Diablo Cove, the areas with the warmest water temperatures and greatest abalone abundance. As a result the area of highest red abalone abundance shifted from less than -6 m in north Diablo Cove to deeper than -6 m in south Diablo Cove after 1987.

Mechanisms that may have contributed to the reduction in abalone abundance include foraging activities of sea otters, and predation by other abalone predators including humans. Increased focus on abalone as a target species for sea otters, and other predators, would almost certainly result in a generalized decline in abundance throughout the study area at all depths. These mechanisms would not explain the pattern of declines that appear to be closely correlated with the shallow areas of Diablo Cove with the warmest discharge temperatures (see Section 3.4.4 for further discussion of sea otter and human predation). One mechanism that explains the declines in abundance in areas with the greatest temperatures is mortality associated with withering syndrome (WS). Between 1989 and 1990 six red abalone with WS were collected from Diablo Cove (PG&E 1991). WS was also observed in southern California in red, pink, and green abalone during this period (Davis et al. 1992). An unusually large number of fresh red abalone shells lacking obvious signs of predatory activity (holes or chipped margins) were also observed, particularly in north Diablo Cove. Crevices were commonly observed which contained an accumulation of abalone shells, a situation similar to that observed in the intertidal areas with black abalone shells that had died as a result of WS. Subtidal red abalone with WS have not been observed in study areas outside of Diablo Cove.

The decrease observed in the subtidal red abalone population was similar to the WS related decrease of intertidal black abalone in Diablo Cove in several respects. Declines in both populations occurred between 1988 and 1990. Recruitment in red abalone after 1990 was not as strong as those observed for black abalone during the same time period, but presence of newly recruited juveniles each year indicated that conditions were acceptable for larval abalone settlement and survival in Diablo Cove. Unlike black abalone, however, which showed a trend of growth into the larger size classes, there was no indication that juvenile red abalone survived to contribute to the larger size classes. It is likely, however, that at least some juveniles grew into larger size classes since small and medium sized abalone were present in all surveys after 1990. No red abalone with obvious signs of WS have been found in the study area since 1991. However, subtidal sampling is infrequent and there is only a small chance of finding dead abalone or of observing live abalone with symptoms of WS, as they quickly become subject to predation.

4.4.4 Fish

Community Changes

Fish species richness increased in north Diablo Cove during the operation period, but decreased in south Diablo Cove. The reasons for this difference in discharge effects are not certain, but generally warmer water conditions in north Diablo Cove and a broader depth gradient of temperatures there seemed to attract several species such as sheephead, opaleye, halfmoon, and kelp bass that were absent prior to plant start-up. The thermal gradients characteristic of power plant discharge areas can enhance fish species richness by attracting warm water tolerant species that would otherwise be absent (Stephens et al. 1994). Species preferring cooler conditions can still persist below the thermocline, or in fringe areas where cool and warm waters mix.

Several factors other than temperature may have affected fish community composition and distribution in Diablo Cove. These include changes in algal community structure, food availability, and substrate characteristics.

Substrate characteristics did not change substantially during plant operation, except that small areas directly in front of the discharge accumulated shell debris sloughed from the discharge conduits, and this provided some foraging habitat for round rays and bat rays. No feeding studies were performed during the operation period, and it is not known specifically how changes in prey population patterns within Diablo Cove affected foraging behavior of fishes, but fishes specializing on invertebrate prey may have been affected by this accumulation of shell debris (see Section 4.3.2 - *Subtidal Results Invertebrates*). The effects of algal community structure on fish populations and certain fish species are discussed in the following section.

Earlier fish studies in the Diablo Canyon area were done by CDF&G (Burge and Schultz 1973; Gotshall et al. 1984). These studies used a variety of fish census techniques, including visual underwater counts on permanent transects (similar to the present study), baited fish stations, and poisonings. Burge and Schultz reported 9 families of fishes, representing 15 genera and 24 species from visual censuses in Diablo Cove, and 24 families of fishes representing 47 genera and 77 species using the poisoning method. The studies provided a scientifically useful inventory of fishes in the cove, but are of limited value for impact analysis unless the exact methods were replicated, with controls, after power plant start-up. Similar numbers of species were recorded in both the TEMP and CDF&G studies. The use of poison in sampling by CDF&G substantially increased the number of cryptic species identified.

Temperature is widely recognized as a controlling factor in the life history and behavior of fishes (Raney and Menzel 1969; Beltz et al. 1974; Coutant 1974; Crawshaw 1977; Stauffer 1980). Effects due to elevated temperatures are usually non-lethal if fish can avoid warm temperatures by re-locating into a transitional habitat with cooler temperatures, although temperature shocks (quick changes) may be difficult to avoid. Most species present in Diablo Cove prior to power plant operation should have been capable of selecting preferred temperatures during the slow process of power plant start-up. Initially, resident species probably responded to the discharge by altering their distributions in Diablo Cove, based on preferred temperatures. After a thermal gradient had been established, temperature preference or avoidance by newly recruiting fish resulted in new patterns of species distributions in Diablo Cove. In the few instances when both power plant units were non-operational, bat rays and leopard sharks, which were typically attracted to the thermal discharge zone tended to disperse, but returned when the power plant resumed normal operations.

Allen et al. (1970) studied the distribution of fishes around a power plant thermal discharge in northern California. *Hyperprosopon argenteum* (walleye surfperch) was consistently attracted to the outfall area, as were *Phanerodon furcatus* (white surfperch), *Damalichthys vacca* (pile perch), *Embiotoca lateralis* (striped surfperch), and *Atherinopsis affinis* (jacksmelt). The warm water discharge area of the Morro Bay Power Plant, 18 km north of Diablo Canyon, also has several fish species in common with the discharge area at DCPP (J. Tupen, Tenera Environmental, pers. comm.). Exceptions are a greater number of species associated with sand substrate in the Morro Bay area, including *Amphisticus argenteus* (barred surfperch), *Urolophus halleri* (round stingray), and *Platyrhinoidis triseriata* (thornback).

Fish distribution is a complex phenomenon, and temperature preference tests done in the laboratory do not accurately predict behavior of fishes in the field. In a study on temperature selection in southern California fishes, Shrode et al. (1982) found that four of the six species tested selected similar temperatures in laboratory experimental gradients and in field gradients. However, they found in their experiments that two surfperch species, *Embiotoca jacksoni* and *Micrometrus minimus*, preferred temperatures significantly lower than their field temperatures, leading to the conclusion that field distributions were determined by factors other than temperature. Subordinating factors may include competitive displacement by other fish species (Stephens and Zerba 1981), food availability, or habitat preference. As an example, *Sebastes chrysomelas,* a territorial species that is dependent upon rock crevices or holes for habitat (Larson 1972), maintained position when contacted directly by the discharge plume until rising temperatures during power plant start-up caused mortality.

Changes in algal community structure can alter the distributions and abundance of some temperate reef fishes. Experimental manipulations of kelp density (Carr 1989) and comparison of natural reefs with differing algal communities (Holbrook et al. 1990a, 1990b) have shown that *Macrocystis* forests enhance the abundance of some fish species and reduce the abundance of others. In both studies, recently settled recruits of several fish species used kelp fronds as shelter from fish predation. This was also observed with YOY rockfish in Diablo Cove during the present study. Reductions in benthic algae, due to shading effects by giant kelp, negatively affected other benthic fish species in Carr's study. Juvenile surfperches have also been found to require kelp for shelter from predators (Ebeling and Laur 1985). The habitat-forming kelps *Nereocystis*, *Cystoseira*, *Pterygophora*, and *Laminaria* declined in Diablo Cove after plant start-up, but *Macrocystis* increased. The net result on fish habitat was a canopy structure that exhibited less seasonality than the pre-operation kelp community, and effectively fulfilled the habitat requirements for the annual recruitment of rockfishes, surfperches and other fish taxa.

The type and structure of habitat-forming algae are also known to affect the abundance of surfperch species based on their differing foraging habits (Hixon 1980; Schmitt and Holbrook 1990). *Embiotoca lateralis* specializes on picking invertebrates from foliose algae, *E. jacksoni* picks out invertebrates from turf algae, and *D. vacca* tends to pick food items from open substrate. Although some foliose algal species significantly decreased in abundance in north Diablo Cove after plant start-up (e.g., *Cryptopleura ruprechtiana*) and some increased (e.g., *Cryptopleura violacea*), there was no net change in foliose algal cover which may have indirectly affected surfperch abundance.

Some of the changes in fish abundance observed in Diablo Cove after plant start-up were linked to coastwide oceanographic processes affecting larval fish supply. *Semicossyphus pulcher* (sheephead) is an example of a fish species that is common in warmer waters of southern California. It rarely recruits into areas north of Point Conception except during periods when currents flow in a predominantly northern direction, as during El Niño episodes (Cowen 1985). The periodic recruitment pulses of *S. pulcher* in Diablo Cove reflect these episodic patterns. Recruitment was also observed in the control area, but the warmer water conditions present in Diablo Cove apparently provided a more preferable thermal regime for this species. When present in relatively high densities, *S. pulcher* can significantly affect prey populations, and even impose indirect effects on subtidal community structure (Cowen 1986). As predators on a variety of macroinvertebrates, including urchins, crustaceans, and gastropods, *S. pulcher* residing in Diablo Cove may have disproportionately reduced the abundances of some of these forage items, based on evidence from direct feeding observations and long-term decreases in preferred prey items such as *Tegula brunnea* (see Section 4.3.2 - *Subtidal Results Invertebrates*).

5.0 INTEGRATED DISCUSSION

Studies on the effects of human disturbance on the environment need to provide evidence of statistically significant responses among exposed organisms, as well as, 1) consistent, related patterns of change among many organisms; 2) reasonable explanations for the changes, and; 3) investigations of alternative mechanisms or explanations (Schroeter et al. 1993). The Thermal Effects Monitoring Program (TEMP) studies were focused on documenting patterns of change in biological communities and not the underlying processes. Analysis of both the TEMP intertidal and subtidal data documented significant changes after plant start-up in populations of marine algae, invertebrates, and fish in Diablo Cove and Field's Cove when compared to local populations beyond the power plant's influence. The gradient of biological changes in Diablo Cove and adjoining areas was consistent with some of the changes predicted by the results of laboratory tests of acute temperature tolerance of select taxa (PG&E 1982b). Other biological changes that were the result of chronic exposures to elevated temperature could not be tested in the laboratory, or predicted, because of uncertainties associated with chronic exposures to elevated temperature, long-term population variation, complex interactions among taxa, and effects from other components of the discharge. Generally the long-term changes in population and species interactions from chronic discharge exposures, which accounted for most of the changes observed by the TEMP studies of the Diablo Canyon Power Plant (DCPP) discharge effects, cannot be predicted from laboratory studies. Standard mariculture techniques did not enable long-term laboratory holding and testing of many of the study area's marine algae and invertebrates, certainly not for a period of time necessary to simulate the 10-year period of operation and complex species interactions observed during the TEMP studies. Natural events (sea otter population expansion into the area, severe storms and El Niño ocean warming) occurred during the study and caused coastwide changes that affected all of the TEMP sampling stations, but the studies could not separate natural changes from discharge effects in most cases. When localized natural disturbances occurred that severely impacted a specific study site, the site was not analyzed. For example, intertidal stations in south Diablo Cove were not included in the analysis, because they were buried under cobble from a landslide that occurred during the 1983 winter storms. Changes detected in the analyses could be confused with other natural disturbances if these stations had been included.

The TEMP studies used systematic observations of changes in populations of macroalgae, macroinvertebrates, and fishes to measure effects of the DCPP discharge within the study area's rocky intertidal and subtidal habitats. These organisms and habitats were studied because they were conspicuous, accessible and likely to be affected by power plant discharge. They also provided the most reliable numerical results for statistically detecting change. For example, phytoplankton and zooplankton may have been locally affected by contact with the discharge, but they were not studied due to the low probability of potential impacts at the population level, and the difficulty of detecting changes in these transient and rapidly reproducing organisms.

5.1 Spatial Extent of Changes

Biological changes resulting from the discharge were detected throughout the intertidal and subtidal areas of Diablo Cove. Effects were also detected in intertidal areas of Field's Cove and South Diablo Point. Effects on bull kelp, *Nereocystis luetkeana*, have also been detected outside Diablo Cove, and in fall 1987 during an unusually warm-water period, effects were observed as far north as Lion Rock. In general, observed discharge effects diminished along a gradient of increasing distance and depth from the discharge. Distinguishing discharge effects from natural variation becomes more difficult as the size of the effect decreases for a specific taxon.

The fixed sampling locations used in the TEMP study were not necessarily situated to allow a gradient analysis of discharge effects, but were located in representative areas that were repeatedly sampled, thereby increasing the power of the data to detect change at these specific locations. Delineation of the spatial extent of change is therefore limited by the fixed station sampling, but data from stations not analyzed and qualitative observations were used in establishing general bounds on discharge effects. The low intertidal and shallow subtidal, between mean lower low water (MLLW) and approximately -3 m MLLW, was not quantitatively sampled by any of the intertidal or subtidal study methods, although most taxa in this zone were recorded by one or both of the methods due to their wide depth distribution. *Phyllospadix* spp. (surfgrass) and *Egregia menziesii* (feather boa kelp) are important habitat-formers in this zone.

Intertidal temperature recorders in Field's Cove, Diablo Cove, and South Diablo Point measured temperatures warmer than ambient, indicating that warmer water from the discharge affects these areas (see Section 2.2 - *Receiving Water Temperature Monitoring*). Based on temperatures recorded from these stations and thermal plume mapping (Tu et al. 1986), the surface area of the thermal plume extends throughout Diablo Cove, and spreads into Field's Cove to the north and around South Diablo Point to the south. Beyond these areas of shoreline contact, the discharge plume spreads as a surface layer into deeper water offshore and dissipates to the atmosphere (Figures 2-5 and 2-6). Temperature increases at Field's Cove averaged approximately 1°C above ambient after power plant start-up (Figures 2-12). No temperature or biological monitoring stations were located in areas between Field's Cove and North Control, or between South Diablo Point and Seal Haulout. Average temperatures measured at Seal Haulout were consistently below ambient (Figures 2-12). Based on available thermal plume mapping and temperature recorder data, the northern extent of the discharge plume is the shoreline area beyond Field's Cove and south of North Control (north of Lion Rock), and its southern extent is on the northwest Intake Cove breakwater.

5.1.1 Algae

The extent of thermal effects from the discharge are best exemplified in the intertidal area by iridescent seaweed, *Mazzaella flaccida*. It was abundant throughout the study area prior to plant start-up. It was also shown to be sensitive to warmer seawater temperatures in laboratory experiments (PG&E 1982a). After power plant start-up, *M. flaccida* became nearly absent from Diablo Cove. Outside Diablo Cove, the southern extent of declines in abundance was South Diablo Point. At Seal Haulout (0.6 km further south) *M. flaccida* remained abundant during power plant operation (Figure 3-11). The northward extent of declines in *M. flaccida* probably occurred between Field's Cove and North Control stations. Significant decreases in *M. flaccida* at stations in Field's Cove, suggested that the discharge affected *M. flaccida* abundance along the entire southern shoreline of the cove. Declines were also observed in other intertidal algae, although it is not known whether increased temperatures were the most probable explanation for the declines, as in *M. flaccida*.

Spatial effects of the discharge by depth occur subtidally as impacts on surface canopy kelps and benthic algae. The extent of effects on benthic algae was characterized by the absence or reduction of the subcanopy kelps *Pterygophora californica* and *Laminaria setchellii*, and the understory alga *Cryptopleura ruprechtiana* after power plant start-up. Declines in the abundance of the two kelp taxa were predicted from results of thermal tolerance laboratory studies (PG&E 1982a). Including the declines in the above kelps, areas affected by the discharge were generally characterized by a greater abundance of understory red algae, and occurred from the high intertidal to approximately the -4 m depth contour in north Diablo Cove, and slightly shallower in south Diablo Cove. Deeper areas (to -8 m) were affected on the inshore side of Diablo Rock due to downwelling of the thermal plume. Declines in *P. californica* and

L. setchellii were also observed outside Diablo Cove, along the north and south headlands of the cove, but not in Field's Cove.

The spatial extent of the surface plume was best measured by changes in *Nereocystis luetkeana.* This species was expected to decline in areas contacted by the thermal plume (Ebert 1966; North 1969; and PG&E 1982b). Because this species forms a surface canopy, it was also expected that it would be at risk over a broader area than benthic algae growing beneath the surface thermal plume. Early senescence occurred in *N. luetkeana* each year of power plant operation. The area most affected was Diablo Cove. The extent of effects outside Diablo Cove varied annually, according to the combined effects of ambient water temperature regimes and plant operation, although this was only quantified during fall 1987, when both power plant units operated together for the first time during a period of seasonally high ambient water temperatures. The maximum area of effects were observed in 1987 and extended to near Lion Rock, approximately 800 m (0.5 mi) north of Diablo Cove (Figure 4-18). The operation regime, combined with unusually warm ambient temperatures resulted in the highest discharge temperatures recorded in the study during the fall of that year (see Section 2.2 - *Receiving Water Temperature Monitoring*). In other years, discharge and receiving water temperatures tended to be less, and qualitative observations indicated that premature senescence in *N. luetkeana* did not extend as far. The loss of understory kelps *P. californica* and *L. setchellii*, and overstory bull kelp provided opportunities for the settlement and expansion of giant kelp *Macrocystis pyrifera* in Diablo Cove. This kelp provides both understory and overstory canopy and has expanded in abundance in Diablo Cove to the level where it is affecting the growth of previously abundant understory red algae due to shading effects.

5.1.2 Invertebrates

Effects of the discharge on invertebrate taxa can be generally characterized as increases in abundance of intertidal taxa, and decreases in subtidal taxa, although many species either increased or decreased in both the intertidal and subtidal. Effects probably resulted from a combination of responses to increased temperatures and responses to changes in other components of the community such as algal cover in the intertidal, and algal cover and fish abundance in the subtidal. However, the mechanisms responsible for the many changes in invertebrate taxa were not studied.

Changes in invertebrates also extended beyond areas directly warmed by the plume due to the mobility of many invertebrate taxa. The gumboot chiton, *Cryptochiton stelleri*, increased in subtidal areas below the plume in Diablo Cove following plant operation, but remained uncommon in control areas. This species is more generally found in cooler temperate waters, but has increased in abundance in Diablo Cove. Increased occurrences of warm-water taxa introduced after plant start-up also occurred in areas throughout Diablo Cove (e.g., *Norrisia norrisi*).

Mortalities due to withering syndrome (WS) were observed in black and red abalone. The condition was seen in the southern California Channel Islands in 1986 and observed in black abalone in Diablo Cove in spring 1988. Mortalities from the disease eventually resulted in an approximately 90% population decline in black abalone in Diablo Cove. Although recruitment contributed to increases in the Diablo Cove population in 1991 and 1992, abundances outside Diablo Cove also began decreasing during this same period. By 1994, black abalone populations along a shoreline distance of 12.7 km had declined from WS. Increased mortality rates for black abalone in Diablo Cove were correlated with the increased seawater temperatures from the discharge. Declines in red abalone populations have been limited to areas within Diablo Cove contacted by the discharge plume. Red abalone populations in Diablo Cove below approximately 6-7 m (ca. 20 ft) depth and in control areas have not declined.

5.1.3 Fish

The mobility of most fishes enables them to select preferred temperatures. The most obvious changes in fish composition during power plant operation have occurred near the discharge plume in Diablo Cove, where certain taxa are attracted by the plume's turbulence and warm water. These species, considered rare in the area before plant start-up, include leopard shark, bat ray, round ray, white seabass, opaleye, halfmoon, sheephead and señorita. A similar assemblage occurs on the inshore side of Diablo Rock to depths of about -6 m. These same species are also seen sporadically throughout Diablo Cove at depths shallower than -10 m. The temperature transition zone, or thermocline, often attracts various surfperch species when it is situated close to benthic habitat. Below this depth, cool ambient temperatures are the norm, and the fish fauna is similar to that of control areas outside Diablo Cove. Concurrent with the increases in warm-tolerant species in Diablo Cove were decreases in the occurrence of cool water species such as greenlings and some rockfishes. Ancillary observations in Field's Cove and Lion Rock Cove (north of Diablo Cove), and the Breakwater / Seal Haulout area (south of Diablo Cove), indicate that the fish fauna at these locations has been unaffected by the power plant discharge.

5.2 Temporal Extent of Changes

Bender et al. (1984) categorized manipulative field experiments or perturbations as "press" or "pulse" experiments. They also described the types of species interactions that might be expected under either "press" or "pulse" conditions. Pulse experiments are short-term manipulations or perturbations in which the abundance of one or more species is altered and then allowed to return to some state of equilibrium. Press experiments are long-term perturbations or disturbances that theoretically should result in a new state of equilibrium. In press experiments the strength of species interactions are dependent on the difference between initial community densities, and densities under press conditions (Bender et al. 1984). Studies of press perturbations have shown that indirect species interactions can outnumber and outweigh any direct effects of a disturbance, and this has increased the uncertainty of the results of these studies (Yodzis 1988, Pimm 1991, Wooton 1994). It has also been shown that the number and strength of indirect interactions in the system can increase with the duration of the perturbation, and that states of alternate equilibrium may never be reached (Schmitz 1997).

The DCPP discharge can be categorized as a variable "press" disturbance. The continuing changes in the discharge community underscore the importance of complex interactions between physical conditions, species' physiological responses to changing conditions, and species' interactions. Other evaluations of the effects of press disturbances have been difficult due to the time it takes to reach some new equilibrium, and more importantly, whether such conditions actually exist (Schmitz 1997). Although the TEMP studies on the effects of the DCPP discharge cannot be directly compared to the results of other controlled field experiments, the possible indirect effects of the discharge, the results from press perturbation studies, and the predictions of ecological theory would all indicate that unpredictable biological change under the influence of the discharge will continue.

Natural events have affected, and will continue to affect, the type of biological changes observed in both impact and control areas. Reversal in nearshore currents by northerly flowing El Niño currents are a mechanism for the introduction of warm water taxa, larvae and algal spores from southern California. The effects and recovery patterns of biological communities from El Niño events observed during the TEMP study differed among stations depending on the intensity of the El Niño and associated storm events and whether areas were affected by the discharge. Localized variations in biological responses from El Niño events in other Pacific coast intertidal communities have similarly been observed (Gunnill 1985; Paine 1986). Although the magnitude of the effects of the discharge have been greater than those observed from El Niño, annual differences in oceanographic factors and thermal discharge characteristics will continue to influence biological communities, and can be expected to contribute to their continuing change.

The timing and spatial extent of thermal discharge-related effects varied among affected taxa. The timing of the declines in perennial algal taxa was relatively consistent among stations in the thermal discharge area, whereas increases in limpet and sea urchin grazers, barnacles, and ephemeral algae were more variable in space and time. This variation is undoubtedly due to physical and biological factors that affected species occurrences, including habitat dissimilarities, and spatial and temporal variation in local temperature regimes. Kinnetics (1992), in their multi-site intertidal disturbance study, found that recovery responses could be generalized for only a few species.

The duration of the TEMP study has identified a number of biological effects from the discharge that would have gone undetected in a shorter study. North et al. (1989) completed their DCPP thermal effects study after two years of power plant operation. In general, they found algae as a group had decreased in abundance, while invertebrates as a group had increased in abundance, similar to the findings of the TEMP studies at that time (PG&E 1988a). North et al. (1989) categorized select taxa as "encouraged" or "discouraged" by the discharge. However, later results from the TEMP studies found that in some cases, taxa that decreased in the two years following power plant start-up, later increased. For example, North et al. (1989) categorized *Chondracanthus canaliculatus* as having been "discouraged" by the thermal discharge. The TEMP studies noted the same early decline, but also a general trend of recovery near the end of the study. North et al. (1989) also categorized *Gelidium coulteri* as unaffected by the thermal discharge, but later TEMP studies observed increases in the abundance of this species. Connell and Sousa (1983) and Dayton and Tegner (1984) point out that impact studies need to be sufficiently long in duration to account for population turnover in the longer-lived taxa in the study area. Although statistical designs for impact analysis do not necessarily require long-term data to detect effects, results from DCPP studies show that many of the changes caused by the discharge would have gone undetected in a shorter study, including the recovery of several taxa.

Variation is a normal component of ecological communities, and the variable patterns of responses in the TEMP study area populations over time and space corroborate the statements of Connell and Sousa (1983) that "... only rarely has it been demonstrated that communities can be viewed as being stable in terms of constancy in numbers of organisms and limits of temporal changes and seasonal cycles." Although variation can be expected in most natural populations, the TEMP studies have shown that the nature and magnitude of changes within impacted areas exceed those in control areas. The results also indicate that changes in biological communities resulting from the DCPP discharge will continue.

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