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INFLUENCE OF INDIAN POINT UNIT 2
AND OTHER STEAM ELECTRIC GENERATING PLANTS
ON THE HUDSON RIVER ESTUARY
WITH EMPHASIS ON STRIPED BASS AND OTHER FISH POPULATIONS

Submitted to

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January 1977

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FOREWORD

This report presents the conclusions of a seven year ecological study program to determine the impact of Indian Point Unit 2 and other power plants on the aquatic ecosystem of the Hudson River. The study program focused its attention on striped bass, the only species of recreational and commercial significance which was thought to be affected by the plant. A substantial amount of information on other species is also presented.

The results of the program show that all Hudson River power plants including Indian Point Unit 2 have an insignificant effect on the striped bass and other important fish populations of the Hudson River. Long term impacts on the striped bass population based on 1974 and 1975 data were computed by an equilibrium reduction equation method. This showed that the impact of Unit 2 alone, operating as it did in 1974 and 1975, would produce a long term reduction in the Hudson River striped bass population of approximately 1%. The estimated total reduction due to the impact of long term operation of all power plants on the Hudson River built since 1970 (multiplant impact), operating as they did in 1974 and 1975, would be about 2%. This level is considered to be insignificant from an ecological and economic point of view.

Predictions of future impacts over the 40-year life of the plants were also computed by use of a model simulating the life cycle of the striped bass. The input factors to this model are discussed at length in the report. The model shows that the impact of Unit 2 on striped bass after 40 years of operation is approximately a 1% reduction in population based on 1974 and 1975 data. Predictions of multiplant impact on the Hudson River striped bass population after 40 years of operation of all plants on once through cooling systems at planned operating levels are approximately a 4 to 5% reduction in population. Direct estimates of the total numbers of striped bass entrained and killed at Indian Point Unit 2 were 3.19 million eggs and 5.92 million larvae during 1974, and

3.52 million eggs and 16.14 million larvae during 1975.

The impact calculations referred to above for the equilibrium reduction equation and the striped bass life cycle model both take into account the existence of compensation, the natural processes of biological systems which increase survivability with decreasing populations and decrease survivability with increasing populations. The fact that compensatory processes operate in biological communities has been well recognized for many years. The ecological study program provided proof that compensation is occurring in the Hudson River striped bass population and also provided an estimate of the extent of the compensatory reserve.

The program included a determination of the relative contribution of striped bass stocks from various estuaries to the Atlantic coastal striped bass fishery. By the use of a composite of physical characters, a procedure was developed by which the natal estuary of a particular striped bass could be identified. Samples of striped bass were taken from ten strata in the Atlantic coastal fishery extending from Maine to Cape Hatteras. The classification techniques were applied to these fish using procedures of statistical analysis to determine relative contribution to the fishery. The result was an estimate of approximately a 7% contribution from the Hudson River, a 90% contribution from the Chesapeake Bay and a 3% contribution from the Roanoke River.

The program also included investigation of the feasibility of supplying hatchery-reared striped bass to replace potential reductions in population size caused by power plant operations. This program has been successfully concluded. The report indicates that Hudson River striped bass can be successfully reared in a hatchery and that the hatchery-reared fish survive in the estuary at least as well as the wild fish.

A summary of the report's conclusions is set forth in Section 15. Section 1 describes the background of the report in relation to the history of previous hearings. Sections 7-14 contain the analyses, data, and references to data contained in earlier reports which support the conclusions indicated in this Foreword and in Section 15.

ACKNOWLEDGEMENT

This report was prepared under the direction of James T. McFadden, Ph.D. with technical assistance from Texas Instruments Incorporated; Lawler, Matusky and Skelly Engineers, Incorporated; New York University Medical Center, Laboratory for Environmental Studies. Other contractors whose data were incorporated into this report include: Stone and Webster Engineers, Inc.; Ecological Analysts, Inc.; The University of Rhode Island; Alden Research Laboratories, Inc.; and the LaSalle Hydrological Laboratories, Ltd.. Dr. McFadden was responsible for designing the report format and for coordinating and reviewing all technical aspects. The studies which provided the data for this report were jointly financed by Consolidated Edison Company of New York, Inc; the Power Authority of the State of New York; Orange and Rockland Utilities, Inc.; and Central Hudson Gas and Electric Corporation.

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INTRODUCTION

The purpose of this report is to summarize and integrate a number of ecological studies carried out in the Hudson River, principally between 1969 and 1976, and to assess the importance of the impact of power plants using once through cooling on the aquatic ecosystem. Main emphasis is on Indian Point Unit 2 nuclear generating station, but the joint effects of all units at Indian Point plus four fossil-fuel plants located in the central part of the estuary are evaluated also. The striped bass is the species of principal concern because of its value in sport and commercial fishing and its vulnerability to power plant impact. The effects of power plants on populations of white perch, Atlantic tomcod, American shad, blueback herring, and shortnose sturgeon are also examined.

This report is structured in the following way. The history of licensing proceedings for Indian Point Unit 2 with the U.S. Nuclear Regulatory Commission is reviewed and the ecological research program of Consolidated Edison, upon which this report is based, is described as a response to the issues which have arisen in these proceedings (Section 1). The lower Hudson River is described from the dam at Troy, New York which marks the upstream limit of tidal influence and penetration of estuarine fishes, to its mouth at the Battery in Manhattan (Section 2). Water circulation, water chemistry, and temperature are examined in detail as a basis for understanding biological phenomena, and predicting power plant impact. The location and operating characteristics of power plants on the Hudson River are detailed. As further foundation, the ecosystem is described both in general terms (Section 2) and quantitatively from the perspective of energy flow (Section 3). Phytoplankton and zooplankton populations are treated in this part of the report. The benthic invertebrate community is then described (Section 4) and effects of power plants on both benthos and zooplankton are evaluated. A review of the life histories of important fishes and description of the fish community of the lower Hudson (Section 5) completes the foundational part of the report.

The degree to which striped bass and the other five species treated in some detail in this report (white perch, Atlantic tomcod, American shad, blueback herring, and shortnose sturgeon) are exposed to power plant influence through their spatial and temporal distribution in the estuary is evaluated (Section 6) as a first step in impact estimation. This is called vulnerability assessment. It provides an indication of the risk, but not necessarily the actual impact that a species experiences. Factors such as vertical distribution or avoidance capability can ameliorate impact even when vulnerability (exposure) is high.

The ecology of striped bass, the species of primary concern, is then described in detail (Section 7) with special emphasis on those characteristics which relate to power plant impact (distribution, development rate, movement, etc.). The phenomena of entrainment (Section 8) and impingement (Section 9) are examined with particular reference to striped bass. Estimates of numbers entrained and impinged at Indian Point Unit 2 and other power plants on the Hudson River are presented. Phenomena which determine the actual numbers of organisms entrained and killed (e.g., differential spatial distribution of organisms; avoidance capability; mortality during entrainment; recirculation of entrained water) are quantified (Section 8) in a form (f factors and w ratios) useful for later incorporation in impact estimation calculations.

The final step before carrying out these calculations is the establishment of a conceptual basis for the important process of compensation; demonstration of the operation of specific compensatory mechanisms in the Hudson River striped bass population; and estimation of compensatory reserve from empirical data (Section 10). Compensation is the ability of a population to partially offset reductions in numbers caused by natural or man-induced impacts by increases in birth or survival rates. It must be included along with the measured kill of organisms in order to realistically assess the significance of power plant impact.

Calculation of actual impact, measured as the <u>long term</u> average reduction of fish population size, is carried out by two different methods (Section 11 and 12) for striped bass for Indian Point Unit 2 and for the multi-plant case.

Mitigation of power plant impact by stocking hatchery-reared fish and by use of fish diversion devices at water intake screens is evaluated (Section 13).

Entrainment and impingement impact assessment is then carried out for white perch, Atlantic tomcod, American shad, and blueback herring (Section 14). These species have not been studied as intensively as striped bass, so the impact assessments are not based on as large a set of data. In the case of shortnose sturgeon, data are insufficient for an assessment of impact but the effects of power plant operation would not be expected to be severe because of the demersal character of the species.

The results of these studies can be summarized as follows. While power plant thermal effluents produce measureable local increases in water temperatures, they do not pose a problem for aquatic life (Section 1). Chemical discharges are limited to levels which do not cause significant ecological damage (Section 1). Phytoplankton, zooplankton, and benthic invertebrates are not detrimentally affected by power plant operation (Sections 3 and 4). Patterns of energy flow within the ecosystem are not disrupted (Section 3). The principal ecological impacts are caused by entrainment and impingement of small fish.

Entrainment and impingement effects vary among species and require detailed examination because of the physical and biological complexity of the Hudson River ecosystem. Channel form (width, depth, bottom contour, gradient), freshwater flow, and tidal phenomena control a complex and dynamic pattern of estuarine circulation (Section 2) which determines the movement and distribution of non-motile early life stages of striped bass and some other species. The distribution of many organisms, including highly motile forms such as adult fish, is related to salinity patterns, which are a function of the same factors which govern estuarine circulation.

Several indices of relative abundance of striped bass have been developed and can be used to follow year to year changes in numbers of young-of-the-year. Year class strength is subject to at least 4-fold variation (Section 7). Of seven environmental factors tested, a predation index, an egg production index, and the rate of water temperature rise during the first summer of life accounted for 70% of the year to year variation in juvenile striped bass abundance. This analysis, which is equivalent to a pre- vs. post- operational comparison for Indian Point Unit 2, showed no significant relationship between power plant operation and abundance of juvenile striped bass.

Using several lines of evidence, egg production for striped bass was estimated to be about 88 billion in 1974-75 with 5 to 6 million juveniles surviving to late August. When year classes of about this size predominate, the population probably consists of some 240,000 age II females, and an average spawning stock of some 86,000 females (Section 7.8). By contrast with 1974-75, the 1973 year class consisted of about 20 million fish in late August.

Striped bass eggs are concentrated in bottom waters; yolk-sac larvae and post yolk-sac larve are concentrated in deeper waters in daytime but are more evenly distributed in the water column at night (Section 7). As the young develop past the planktonic stages they become increasingly oriented to bottom waters and shoals, then tend to concentrate in the shoreward zone. In late summer and early fall, pronounced downstream movement towards wintering areas begins, although some young remain in all sections of the estuary. These distribution and movement patterns influence susceptibility to entrainment significantly, and they are important quantitative inputs to impact estimates.

A substantial fraction of entrained striped bass survive and are returned to the river in the cooling water discharge. Survival at Indian Point is 51% for eggs; 15% for yolk-sac larvae; 49% for post yolk-sac larvae and 84% for juvenile I fish (Section 8). Different survival estimates have been obtained for the other plants.

Several compensatory mechanisms (e.g., density-dependent growth of juveniles; density-dependent fishing) have been empirically demonstrated to operate in the Hudson River striped bass population, and an estimate of compensatory reserve has been developed from analysis of historical records or fishery yield and effort. The analysis shows that the population possesses a substantial compensatory reserve which will offset in part reductions caused by power plant impact (Section 10).

Calculations of entrainment and impingement impact by Indian Point Unit 2 alone and by the multiplant set of Indian Point Units 2 and 3, Roseton, and Bowline were carried out. The calculations use data on abundance of striped bass ichthyoplankton and juveniles in 1974 and 1975; plant cooling water usage; entrainment and impingement estimates; factors representing spatial distribution of young striped bass, their ability to avoid cooling water intake flows, survival during entrainment, and recirculation of previously entrained water; and compensatory reserve. Two independent methods of calculation were developed: (a) the equilibrium reduction equation (ERE), and (b) the real-time life-cycle model (RTLC). The ERE was used to estimate impact based on 1974 and 1975 plant flow conditions. The RTLC was used to estimate impact based on projected plant operating conditions over the next 40 years. The RTLC has been developed to simulate transport of early stages of striped bass by water mass movements on a real-time basis, representing the river as a two-layered system of surface and bottom waters. Both methods use the same definition of impact, i.e., the percentage by which the average equilibrium level of the striped bass population is reduced as a result of power plant operation. Estimates produced by the two methods agree well (Sections 11 and 12). Impact was estimated by the ERE to be about 1% for Indian Point 2 and about 2% for the multiplant case based on 1974 and 1975 data. Predictions of impact using the RTLC were about 1% for Indian Point 2 and 4-5% for the multiplant case. These impacts are not large enough to be of any ecological significance.

The Hudson River was found to contribute approximately 7% of the Atlantic coastal striped bass fishery, Chesapeake Bay 90%, and the Roanoke River 3%. Therefore, the impacts calculated for the Hudson River stock would have almost no effect on the Atlantic coastal fishery, to which the contribution of the Hudson is small.

Striped bass can be successfully reared under artificial conditions from spawn taken from Hudson River fish, and the hatchery fish when stocked as juveniles survive at least as well as wild fish. Hatchery fish could be propagated in large enough numbers to replace losses in the natural population resulting from power plant operation. Angled screens and louvers have been shown to be potentially effective for reducing impingement losses at Indian Point and other Hudson River power plants.

Direct impact assessments of other species of fish show that white perch is the species most affected. During 1974, the multiplant impact on white perch was 6.3% while the Indian Point impact was 4.6%. Impacts calculated for Atlantic tomcod, American shad, and blueback herring were much lower than those calculated for white perch. These impacts are insignificant from an ecological and economic point of view. At this time, available data do not permit estimation of power plant impact on the shortnose sturgeon population, but such impact would not be expected to be severe because of the demersal character of the species.

SECTION 1

ENVIRONMENTAL QUESTIONS REGARDING OPERATION OF INDIAN POINT UNIT 2 WITH ONCE-THROUGH COOLING AND RESPONSE THROUGH APPLICANT'S ECOLOGICAL RESHEARCH PROGRAM

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SECTION 1

ENVIRONMENTAL QUESTIONS REGARDING OPERATION OF INDIAN POINT UNIT 2 WITH ONCE-THROUGH COOLING AND RESPONSE THROUGH APPLICANT'S ECOLOGICAL RESEARCH PROGRAM

1.1 HISTORY OF LICENSING PROCEEDINGS AND ORIGINAL CONTENTIONS

The history of the Commission's* concern with nonradiological environmental matters commenced with passage of the National Environmental Policy Act of 1969 (NEPA), which became effective January 1, 1970. Before that time, the Commission's regulatory jurisdiction had been limited to radiation safety. The construction permit for Indian Point Unit 2, which authorized construction of the plant with a once-through cooling system, was issued on October 17, 1966.

NEPA directed all federal agencies to include in all major federal actions significantly affecting the environment a detailed statement on specified environmental issues. Pursuant to NEPA, the Commission published proposed rules on June 3, 1970, requesting applicants for licenses to file an environmental report. Con Edison's application for an operating license for Indian Point Unit 2 was then pending, having been filed with the Commission on October 15, 1968. Hearings were to commence on December 1, 1970, and Con Edison was anxious to avoid licensing delay occasioned by the implementation of NEPA. Accordingly, Con Edison filed an Environmental Report with the Commission on August 6, 1970.

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* The regulatory jurisdiction herein was exercised by the Atomic Energy Commission prior to January 19, 1975, and was transferred to the Nuclear Regulatory Commission after that date by the Energy Reorganization Act of 1974 and EO 11834, 40 F.R. 2971 (1975). References to the Commission shall be to the Atomic Energy Commission for events prior to January 19, 1975, and to the Nuclear Regulatory Commission for events subsequent thereto.

The Commission published final regulations implementing NEPA on December 4, 1970. These regulations provided, among other items, that nonradiological environmental issues could not be considered in a hearing if notice of the hearing was published in the Federal Register before March 4, 1971. Accordingly, such issues were excluded from consideration in the Indian Point Unit 2 hearings.

This provision of the Commission's regulations was held invalid by the Circuit Court of Appeals for the District of Columbia on July 23, 1971 (Calvert Cliffs' Coordinating Committee Inc. v. U.S. Atomic Energy Commission et al., 449 F.2d 1109). The court required full environmental reviews in connection with all licensing actions taken after January 1, 1970, and said that environmental costs and benefits must assume their proper place among the other considerations in federal licensing actions. Con Edison thereupon filed an extensive Environmental Report dated September 1971 discussing the environmental impacts of operation of Indian Point Unit 2 in accordance with draft guidelines issued by the Commission in February 1971 for preparation of environmental reports. On the basis of this report and independent investigation by the Commission staff and its consultant, the Commission published a Draft Environmental Statement on April 13, 1972, which concluded that operation of Indian Point Units 1 and 2 (RM 42: km 69) had a potential for long-term environmental impact but that existing information was insufficient to predict the degree of potential damage that would take place. It recommended a detailed study of closed-cycle cooling systems and monitoring of environmental impacts with a view to evaluating results within the second year of operation to determine actions to be imposed on Con Edison to minimize environmental impact.

The NRC staff significantly changed these recommendations in a Final Environmental Statement (FES) dated September 1972. Although the staff still considered the existing information insufficient to predict long-term impacts accurately, it concluded that irreversible damage might be incurred by the time such studies could be completed. It also concluded that operation of Indian Point Unit 2 with once-through cooling should terminate on January 1, 1978, and that a closed-cycle cooling system should be required thereafter.

The Ecological Study Program is an outgrowth of the concerns expressed in the FES. Although the Atomic Safety and Licensing Appeal Board in ALAB-188 (7 AEC 323 [1974]) subsequently criticized certain key portions of the staff's environmental analysis, the Ecological Study Program responded to the concerns expressed in the FES without awaiting the outcome of the subsequent hearing. The Study Program also was modified in some respects to reflect discussions with the NRC Staff and developments in the FPC proceeding involving the Cornwall pumped-storage plant.

The hearings on environmental issues terminated on April 26, 1973. The result was a license condition, required by the Atomic Safety and Licensing Board in its September 25, 1973, decision (6 AEC 751 [1973]) that operation of Indian Point Unit 2 with once-through cooling would be permitted until May 1, 1978, and that a closed-cycle cooling system should be required thereafter. Following the Atomic Safety and Licensing Appeal Board's review of this decision on April 4, 1974 (ALAB-188, 7 AEC 323 [1974]), the requirement was changed to permit operation of the plant with its once-through cooling system during an interim period, the reasonable termination date of which appeared to be May 1,1979. The license included various provisions for changing the requirement. The Atomic Safety and Licensing Board authorized a change of this date to May 1, 1980 by a decision dated December 27, 1976 because of the failure to receive all governmental approvals of a closed-cycle cooling system until not earlier than December 1, 1976. Con Edison has filed on June 6, 1975, an application to extend this date to May 1, 1981. The license also permits an application to eliminate the requirement entirely on the basis of information such as that included in this report. To set the framework for the ecological study program, we must reveiw the FES environmental analysis that led the Commission to conclude that closed-cycle cooling should be required for Indian Point Unit 2 and must briefly outline the disposition of environmental issues in the Indian Point Unit 2 proceeding.

1.1.1 THERMAL EFFECTS. The FES discussed thermal effects in terms of the New York State thermal criteria, concluding that operation of Units 1 and 2 would meet the criterion limiting surface temperature to 90°C (<32°C) but that the thermal discharges might not meet the thermal criteria for cross-sectional area and surface width enclosed within the 4°F Δt isotherm. The FES concluded that the 4°F Δt isotherm would extend for more than two-thirds of the surface width of the river and might even extend across the whole width of the river.

In the operating license hearings, Con Edison disputed these contentions and offered evidence showing that the thermal criteria would be met in all respects. Prior to 1972, the major environmental issue had been thermal discharges, sometimes referred to as thermal pollution. Con Edison had therefore studied this environmental impact to the maximum extent possible in a preoperational mode. A hydraulic model of the Hudson River in the vicinity of Indian Point (RM 42; km 69) which had been constructed at Alden Laboratories, had been used by the firm of Quirk, Lawler and Matusky (now known as Lawler, Matusky and Skelly) to develop a mathematical model of the thermal discharges, which included saline-induced circulation that could not be reflected in the hydraulic model. The hearings reflected differences between the NRC staff and Con Edison in modeling techniques and heat-dispersion calculations. The Atomic Safety and Licensing Board (ASLB) concluded that they found no basis in the evidence for deciding that the criteria would or would not be met. It said, "This must be determined by careful measurements of temperatures under appropriate conditions" (6 AEC at 760).

1.1.2 CHEMICAL EFFLUENTS AND EFFECTS. The FES concluded that most of the chemicals discharged in small quantities, (e.g., phosphate, hydrazine, amines, boric acid, and chromate) were not expected to produce important biological effects. The FES went on to state that chlorination three times per week per unit for a total of 6 h wk^{-1} might result in releasing water containing 0.5 ppm of residual chlorine. This residual and chloramines formed from reactions with the river water might be toxic to aquatic life in the thermal plume and in the immediate vicinity of the outfall. The FES also concluded that dissolved oxygen in the thermal plume might be reduced to levels detrimental to aquatic life, principally in the late summer and early fall.

At the hearing, Con Edison stated that, although 0.5 ppm was a New York State limit on chlorine discharges, actual discharges would be considerably below that level. Con Edison embarked on a program to reduce the frequency of chlorination and, by the end of the hearing, was able to state that it would chlorinate only when the water temperature was $>45^{\circ}F$ ($7^{\circ}C$). By chlorinating only one-half of a condenser section at a time, dilution would be achieved in the outlet of the water box of each section and additional dilution would occur as the water flowed through the discharge canal and into the river, where it would be rapidly absorbed by the chlorine demand of the river. Accordingly, Con Edison stated that there would be no detectable effects in the plume. With respect to dissolved oxygen, Con Edison stated that the potential reduction was based on theoretical concepts, and, in practice, there would be no measurable reduction in dissolved oxygen from plant operations.

The ASLB concluded that Con Edison's procedures to reduce the frequency of chlorination provided assurance that the chlorine concentrations would be below the New York State limit. During the short periods of chlorination, the ASLB said there would be considerable damage to organisms passing through the plant but that concentrations expected in the river would be below harmful levels. The ASLB also concluded that dissolved oxygen should be monitored and the discharge aerated if necessary. The ASLB said it did not expect this to be necessary (6 AEC at 772-73).

1.1.3 ENTRAINMENT OF STRIPED BASS. The impact of entrainment of early life forms of striped bass through Indian Point Unit 2 was one of the most critical issues in the proceeding and formed the principal basis for the NRC staff's recommendation for substitution of a closed-cycle cooling system for the present once-through cooling system. The FES concluded that 30-50% of the striped bass larvae migrating past Indian Point from upstream spawning areas were likely to be killed by entrainment and there was a high probability that the combined effects of entrainment and impingement would result in a similar decrease in recruitment to the adult striped bass in New York, New Jersey, and New England. This conclusion was based on a mathematical model derived from data acquired in the 1960s admittedly for an entirely different purpose than the type of calculation the staff had done. The staff assumed that all entrained organisms would be killed in passage through the plant.

Con Edison presented a different mathematical model employing additional data and computing the impact on adult populations. Con Edison's model indicated a realistic estimate of a 3% reduction of total striped bass after 5 yr of operation and 5% reduction after 10 yr of operation. The most conservative estimate was 5% reduction after 5 yr and 6% after 10 yr.

The Appeal Board in ALAB 188 reviewed these mathematical models in great detail. Its conclusion was that the record supported Con Edison's apparent maximum values of certain key factors called "f factors" (7 AEC 385) relating to the number of organisms actually entrained and killed in the plants and that Con Edison's model "more nearly conforms to reality and is superior to the staff's model" (7 AEC 383).

1.1.4 IMPINGEMENT OF STRIPED BASS AND WHITE PERCH. The most visible environmental problem at Indian Point has been the impingement of fish on the intake screens. Biologists were previously uncertain as to the ecological significance of this impingement. The FES treated the impingement impact as incremental to the more significant entrainment impact.

The FES stated that between 2,000,000 and 5,000,000 fish would be impinged on the intake screens annually. These would be young-of-the-year striped bass and other fishes of about 1 to 2 inches in length. Striped bass was estimated as constituting 4% of the impinged fish (V-30).

The staff estimate had been based on all prior data. Con Edison submitted testimony in the Indian Point Unit 2 hearings that earlier problems had been corrected by changes in the intake system. The Con Edison estimate based on more recent data was that 1,252,000 fish would be impinged annually, of which approximately 3% would be striped bass. The ASLB reviewed this testimony and concluded only that more than 70% of the impinged fish would be white perch and 3 to 5% would be striped bass; it did not attempt to resolve the controversy on numbers, concluding that it could not determine the significance of impingement without data on the size of the Hudson River populations of striped bass and white perch (6 AEC 767-68).

1.1.5 MULTIPLANT IMPACT ON STRIPED BASS. During the course of the Indian Point Unit 2 hearings, the parties submitted testimony on the combined impact on the young-of-the-year striped bass population by all the power plants in the spawning areas of the river. Using its model, the staff indicated a combined impact of 38 to 64% on young-of-the-year striped bass. Con Edison used its model to estimate 5% potential reduction from operation of Indian Point Units 1 and 2 and other new plants on the river (Bowline [RM 39.5; km 64] and Roseton [RM 65.4; km 105.6]. Appeal Board comments on the respective models described above apply to these estimates.

1.1.6 COMPENSATION. Another important issue which arose during the Indian Point Unit 2 hearings was the subject of compensation, a natural process which adjusts the size of animal populations. A compensatory response is one that increases the rate of survival in low populations and decreases the rate of survival in large populations.

The FES contained considerable discussion of this phenomenon because it had been mentioned in earlier documents filed by Con Edison. In the FES, the staff concluded that many Hudson River fish populations may have the ability to compensate for plant-caused increases in mortality; however, available information on shad and striped bass along the Atlantic Coast indicated that compensatory capabilities in these species were not the factors determining population level (V-61). Con Edison introduced considerable testimony on this subject, stating that compensation is a very important factor in assessing the impact of plant operations on an ecosystem. The Con Edison witness said that compensation is a factor that must exist in all animal populations; staff witnesses responded by saying that compensation in early life stages requires saturation of spawning and nursery areas; the Con Edison witness responded with references showing that compensation was found in estuarine and high-seas fish populations.

The Appeal Board reviewed this testimony in detail, concluding that the record supported the Con Edison position. The Appeal Board found that compensation during the entire life cycle of striped bass can be expected to be a factor in offsetting losses incurred by the operation of the Indian Point facility (7 AEC at 387).

1.1.7 CONTRIBUTION OF HUDSON RIVER STRIPED BASS TO MID-ATLANTIC FISHERY. The contribution of Hudson River striped bass to the Mid-Atlantic fishery is a critical issue in a benefit/cost analysis of plant impacts since all parties agree that the Hudson River sport and commercial fishery is very small while the mid-Atlantic sport and commercial fishery for striped bass is highly significant. The staff first discussed this issue in the FES chapter on responses to comments. After considerable discussion in which the staff noted that all prior investigators had said that the Chesapeake Bay region was the major source of mid-Atlantic striped bass, it proposed the admittedly novel hypothesis on the basis of a literature review that the Hudson River was an important source of recruitment to the mid-Atlantic fishery (XII-36). Subsequent testimony put the staff's estimate on this contribution at 80%. The staff also concluded that "increased mortality of larvae and juveniles is very likely to cause proportionally reduced recruitment" to the Atlantic population (V-56). Con Edison rebutted the staff analysis as being scientifically unsound and said that there was no reason to change the conclusions contained in the extensive literature on this subject.

The Appeal Board reviewed this testimony and agreed with the Con Edison testimony. The Appeal Board concluded that it had to reject the staff's claim that the Hudson River was a major source of the mid-Atlantic striped bass fishery and its prediction of damage grounded thereon (7 AEC at 365).

1.1.8 ENTRAINMENT AND IMPINGEMENT IMPACTS ON OTHER SPECIES. Although primary emphasis in the Indian Point proceedings was placed on striped bass and to a somewhat lesser extent on white perch, the FES noted potential for adverse impacts on other species of fish and on aquatic biota other than fish.

With respect to aquatic biota other than fish, the FES said that no important changes would occur in bacterial populations (V-33), significant changes could occur in the phytoplankton community (V-33), detrimental effects on resident benthic organisms would occur over a small portion of the estuary (V-35), and there may be an adverse effect on the zooplankton community, especially *Neomysis* (V-37). With respect to fish, the FES said that the species most likely to be affected by plant operation include tomcod, bay anchovy, blueback herring, alewife, American eel, smelt, American shad, white perch, and striped bass.

In the course of the hearings, Con Edison submitted evidence to show that there would be no substantial impact on bacteria, phytoplankton, and zooplankton; any direct effects would be slight in relation to the total populations of these organisms. With respect to fish species, Con Edison presented testimony that impacts were not substantial in view of the abundance of these species in the estuary. Con Edison also noted the lack of value to society of the species other than striped bass and American shad, noting also that shad impacts were minimal.

The ASLB supported Con Edison's position with respect to organisms other than fish. The ASLB said that it did not consider these impacts to be a major issue in the proceeding and found that no important adverse effects were likely to occur (7 AEC at 772).

With respect to the fish species, the ASLB supported the staff's position. The ASLB said that, to the extent that other species use the river in the vicinity of Indian Point as a spawning and nursery ground, one must expect that the impact of once-through cooling on the populations of those fishes will be similar to the impact on the population of striped bass.

The Appeal Board concurred with the ASLB that the available data did not permit any firm conclusions concerning the impact on the populations of fish species other than striped bass. The Appeal Board interpreted the ASLB's statement "one must expect" (referred to above) as meaning that, if any other species had a life cycle the same as striped bass, the impact on such species would be similar to the impact on striped bass. The Appeal Board noted that the record showed no such species. The Appeal Board concluded that the Licensing Board's decision to require closed-cycle cooling did not rest on the adverse impact which it found might occur to species of fish other than striped bass (7 AEC at 388).

1.1.9 MITIGATION CAPABILITY. The FES, in its discussion of alternatives, referred to a Con Edison statement that it would be willing to replace any loss of fish by replenishment from hatcheries. The staff expressed doubt concerning the effectiveness and real value of a hatchery program and said that a more thorough evaluation was needed to determine if fish-hatchery technology is adequate to rear the specific species of concern (XI-11). The FES concluded that Con Edison might, if it so desired, consider the impact of an effective restocking program (p. viii).

At the hearing, Con Edison presented a witness with extensive experience in operating striped bass hatcheries; he testified there was no biological reason why Hudson River fish could not be reared in a hatchery. The staff calculated reported results of striped bass hatcheries, including early experimental years, and concluded that hatchery survival was less than estimates of natural survival.

The Appeal Board reviewed the testimony on this point and concluded that the staff's calculation was "highly questionable" (7 AEC at 401). The Appeal Board said that the record did not require a conclusion at that time that stocking cannot be a viable alternative for either short-term or long-term impacts; it sought the conclusion of the research program to permit a better assessment of the scope of the rearing and stocking programs that would have to be undertaken and the likelihood of success (7 AEC at 402).

1.2 APPLICANT'S RESEARCH PROGRAM

Research effort developed in response to issues raised in the Indian Point Unit 2 hearings. Some additional earlier data from studies on the lower Hudson by Quirk, Lawler and Matusky (now Lawler, Matusky and Skelly), Boyce Thompson Institute, New York Department of Environmental Conservation, and other investigators have been integrated with the more recent studies developed by Con Edison.

1.2.1 GOALS FORMULATED IN RESPONSE TO INDIAN POINT UNIT 2 HEARINGS.

To resolve the issues raised in the Indian Point Unit 2 hearings, Con Edison developed a comprehensive program of ecological research concentrating on the striped bass but including, with lesser emphasis, a number of additional fish species. Power plant impact was evaluated for Indian Point Unit 2 alone as well as for the joint effect of all power production units activated after 1972. Preliminary field studies were begun in 1972, reached full scale in 1973, and have continued, with appropriate variations through time, to the present. A body of scientific information believed adequate to resolve pending questions about continued operation of Indian Point Unit 2 with once-through cooling has been assembled principally from the work completed during 1973-75. This information will be used also in predicting impact of the proposed Cornwall pumped-storage plant (the licensing proceedings of which are under the jurisdiction of the Federal Power Commission) and for regulatory hearings (conducted by the Environmental Protection Agency) dealing with the various power plants on the lower Hudson River.

The research program has been designed to achieve the following 10 goals:

(1) Basic Ecosystem Studies - Develop an understanding of the phytoplankton, zooplankton, and zoobenthos communities of the Hudson River in order to assess power plant impact on these elements of the ecosystem and to understand sufficiently their relationships to the fish population.

(2) Entrainment - Attempt to estimate the numbers of ichthyoplankton present during the season of vulnerability to power plant intakes, numbers actually entrained, survival during passage through plant cooling systems, and the conditional mortality rate (probability of death) due to plant operation.

(3) Impingement - Estimate the number of fish impinged at each power plant, the standing crop present in the river during the entrainment season, and the conditional mortality rate (probability of death) due to impingement.

(4) Compensation - Review the historical informational base on compensation in fish populations, study compensatory mechanisms in Hudson River striped bass, and analyze historical data from the Hudson River to estimate the compensatory reserve of the striped bass population.

(5) Striped Bass Ecology - Study abundance, development rate, movement, and temperature effects on behavior and physiology for early life stages; analyze movement, growth, age at maturity, fecundity, and age structure for the Hudson River striped bass population; quantify the contribution of the Hudson River to the mid-Atlantic fishery; and study relationships between striped bass and other fish species during the first year of life.

(6) Physical Environment - Measure physical parameters such as dissolved oxygen, salinity, temperature, freshwater flow, turbidity, which may affect the distribution and abundance of fish and study tidally-induced circulation and plant-induced circulation as they affect entrainment and impingement of striped bass.

(7) Power Plant Impact - Integrate data from objectives 1 through 6 to estimate the impact of operation of Indian Point Unit 2 alone and multiplant impact on the striped bass population. Impact is defined as the percentage reduction in the average equilibrium level of the fish population by power plant operation. Using the same empirical data base, impact is estimated by two methods: an equilibrium reduction equation using conditional mortality rates due to plant operation calculated directly from plant operational data and ichthyoplankton abundance estimates; and a real-time life-cycle simulation model including a hydraulic transport function.

(8) Power Plant Effects on Other Species - Assess the vulnerability of white perch, tomcod, blueback herring and alewives, shad, and sturgeon to power plant impact and estimate the impact for white perch and tomcod.

(9) Long-Term Indices of Abundance - Calculate indices of abundance for the most important species of fish affected by power plant operation from the longest available sets of data to monitor changes in abundance through time. This will provide a baseline against which to compare future monitoring data and a direct basis for observing possible changes in abundance in the fish population coinciding with activation of additional power generating units.

(10) Mitigation of Power Plant Impact - Evaluate hatchery production and artificial stocking of striped bass as a means of replacing wild fish killed by power plant operation. Evaluate diversion structures that may be used to guide fish away from cooling-water intakes.

The data required to meet the goals just listed have been collected through a large number of integrated studies, most of which have been carried out by three principal contractors--New York University, Texas Instruments Incorporated, and Lawler, Matusky and Skelly. These programs and a number of additional ones of lesser scope are outlined in the following four sections.

1.2.2 NEW YORK UNIVERSITY (NYU) STUDIES. New York University Medical Center Institute for Environmental Medicine initiated studies at Indian Point in 1971, when Unit 1 was in operation and Units 2 and 3 were under construction. Personnel affiliated with the Institute have been involved in studies on the Hudson River since approximately 1968, those studies relating primarily to pesticide contamination, radionuclide analysis, and fish ecology.

The studies that began in 1971 represented a concentrated effort in a single area of assessment--the accumulation and analysis of data on entrainment of planktonic organisms, including the early life stages of fish at and in the vicinity of Indian Point (RM 43; km 69). Simultaneously, these data contributed to a broad-spectrum assessment by their inclusion in predictive mathematical models of impact.

The New York University Medical Center program has been a combined research/monitoring effort executed in the field and under controlled laboratory conditions. The areas of study included at the outset: physical/chemical parameters; bacteria; phytoplankton; microzooplankton; macrozooplankton; and ichthyoplankton. As data have accumulated and been analyzed, certain study areas have been de-emphasized and other areas added; similarly, the concentration of effort during certain sampling periods has been dictated by plant operations. For example, studies conducted in 1971 and 1972 demonstrated the lack of impact of Indian Point Unit 1 on bacterial populations in the river system; consequently, the analysis of intake and discharge flows for bacteria has ceased. Likewise, the phytoplankton studies were de-emphasized after 1975 since the data demonstrated no effect of the Indian Point station (Units 1 and 2) on phytoplankton populations or on primary production in the Hudson River. Studies of plume entrainment, however, were initiated in 1974 in an effort to determine whether the chlorinated thermal effluent from Indian Point could have an adverse effect on plankton populations that had not passed through the cooling-water system. In 1975, the Con Edison experimental flume was used to assess the effect of sampling gear on ichthyoplankton survival, quite apart from plant operations.

The following documents the research and monitoring efforts related to the Indian Point nuclear plant. Each study's present status (terminated or ongoing), focus (Units 1, 2, or 3), and study objective are indicated.

- Physicochemical Studies

Initiated:	1971
Status:	Ongoing
Focus:	Units 1, 2, 3 - nearfield
Objective:	Document physical/chemical parameters in the estuary in the vicinity of Indian Point as a necessary correlate to biological data for assessing plant impact.
Cognate:	River longitudinal surveys
Initiated:	1973
Status:	Terminated, end of 1975
Focus:	Units 1, 2, 3 - farfield
Objective:	Obtain necessary background data for riverwide assessments. Obtain riverwide perspective on planktonic communities.

- Bacteria

Initiated:	1971
Status:	Terminated, end of 1972
Focus:	Unit 1
Objective:	Determine from samples taken in intake and discharge canal whether passage through the power station affects bacterial populations.
Cognate:	Laboratory tolerance studies
Objective:	Determine if temperatures expected during plant operation would affect bacterial populations.

- Phytoplankton

River Population Studies

Initiated:	1971
Status:	Terminated, end of 1975
Focus:	Units 1, 2 - nearfield
Objective:	Obtain data on river phytoplankton populations in the vicinity of Indian Point to assess whether plant operation affects numbers, diversity, or physiology of phytoplankton communities.
Cognate:	River longitudinal survey
Initiated:	1973
Status:	Terminated, end of 1975
Focus:	Units 1, 2 - farfield
Objective:	Obtain necessary background on riverwide phytoplankton communities for assessment of plant effect.

Entrainment Effects

Initiated: 1971
Status: Terminated end of 1975
Focus: Units 1, 2 - nearfield
Objective: Determine whether plant operations affect phytoplankton populations and/or physiology under controlled conditions of temperature, mechanical stress, and chemical stress.

Cognate: Plume entrainment study
Initiated: 1974
Status: Terminated, end of 1975
Focus: Units 2, 3
Objective: Determine under lab and field conditions whether phytoplankters from the river could be affected by entrainment in the chlorinated thermal plume at Indian Point.

- Microzooplankton

River Population Studies

Initiated: 1971
Status: Ongoing
Focus: Units 1, 2, 3 - nearfield
Objective: Establish characteristics of river populations, distribution, and abundance for analysis of power plant effects on microzooplankton.

Cognate: Longitudinal surveys
Initiated: 1974
Status: Terminated, end of 1975
Focus: Units 1, 2 - farfield
Objective: Characterize riverwide microzooplankton populations for use in nearfield and farfield entrainment effects.

Entrainment Effects

Intake-Discharge Studies

Initiated: 1972
Status: Terminated, end of 1975
Focus: Units 1, 2 - nearfield
Objective: Determine effects of plant passage on survival of key microzooplanktonic organisms during and apart from chlorination.

Cognate: Plume entrainment studies
Initiated: 1974
Status: Terminated, end of 1975
Focus: Units 2, 3
Objective: Determine from controlled experiments in the lab

and in the field whether selected microzooplankton species could be affected by entrainment into the chlorinated thermal plume from Indian Point.

Laboratory Tolerance Studies

Initiated:	1971
Status:	Terminated, end of 1975
Focus:	Units 1, 2, and 3
Objective:	Determine the tolerance of selected microzooplankters to thermal and chemical stresses expected in the Indian Point cooling-water system.

- Macrozooplankton

River Population Studies

Initiated:	1971
Status:	Ongoing
Focus:	Units 1, 2, 3 - nearfield
Objective:	Determine distribution and abundance of macrozooplankton for analysis of power plant effects on the river community, concentrating on major constituents of the macrozooplankton community.

Cognate:	Longitudinal surveys
Initiated:	1974
Status:	Terminated, end of 1975
Focus:	Unit 1, 2 - farfield
Objective:	Determine distribution and abundance of macrozooplankton for use in nearfield and farfield assessments of entrainment effects.

Entrainment Effects

Intake Discharge Studies

Initiated:	1971
Status:	Ongoing
Focus:	Units 1, 2
Objective:	Determine survival rates of major macrozooplankton organisms after plant passage.

Cognate:	Plume entrainment studies
Initiated:	1974
Status:	Terminated, end of 1975
Focus:	Units 2, 3
Objective:	Determine effects of entrainment of river organisms into the chlorinated thermal discharge from Indian Point.

Laboratory Thermal Tolerance Studies

Initiated:	1971
Status:	Terminated, end of 1975
Focus:	Units 1, 2, 3
Objective:	Establish thermal-tolerance limits for key macrozooplankton species.

Cognate: Chlorine tolerance studies
Initiated: 1974
Status: Terminated, end of 1975
Focus: Units 1, 2, 3 - nearfield
Objective: Establish limits of tolerance of key macrozooplankton species to chlorine alone and in combinations with elevated temperatures.

Cognate: Preference-avoidance studies
Initiated: 1975
Status: Terminated, end of 1975
Focus: Units 1, 2, 3 nearfield
Objective: Determine the concentration of chlorine alone and in combination with thermal effluents to which key species of macrozooplankton respond with a definitive behavioral response.

- Ichthyoplankton

River Population Studies
Initiated: 1971
Status: Ongoing
Focus: Units 1, 2, 3 - nearfield
Objective: Determine abundance and distribution of ichthyoplankton in vicinity of Indian Point station.

Cognate: Longitudinal surveys
Initiated: 1974
Status: Terminated, end of 1975
Focus: Units 2, 3 - farfield
Objective: Develop riverwide data base within which the population at Indian Point may be evaluated.

Entrainment Effects

Intake-Discharge Studies
Initiated: 1971
Status: Ongoing
Focus: Units 1, 2, 3
Objective: Determine survival of ichthyoplankton after plant passage.

Cognate: Plume entrainment studies
Initiated: 1974
Status: Terminated, end of 1975
Focus: Units 2, 3
Objective: Determine, under controlled conditions whether entrainment into the discharge plume would affect survival of key estuarine ichthyoplankton such as striped bass.

Laboratory Studies

Thermal Tolerance Studies

Initiated: 1971
Status: Terminated, 1974
Focus: Units 1, 2
Objective: Determine thermal tolerance limits for various life-history stages of striped bass and Atlantic tomcod.

Cognate: Preference-avoidance studies
Initiated: 1975
Status: Terminated, end of 1975
Focus: Units 2, 3, plume
Objective: Determine thermal characteristics necessary to elicit definitive behavioral response in striped bass juveniles.

Chlorine-Tolerance Studies

Initiated: 1975
Status: Terminated, end of 1975
Focus: Units 2, 3, plume
Objective: Determine median tolerance limits for striped bass exposed to solutions of chlorine in Hudson River water.

Cognate: Preference-avoidance studies
Initiated: 1975
Status: Terminated, end of 1975
Focus: Units 2, 3, plume
Objective: Determine concentrations of chlorine in Hudson River water eliciting definitive behavioral response in striped bass juveniles.

Pressure Studies

Initiated: 1973
Status: Terminated, 1976
Focus: Cornwall; Units 1, 2, 3
Objective: Determine whether changes in hydrostatic pressure cause mortality among life-history stages of striped bass.

Alden Flume Studies

Initiated: 1975
Status: Terminated, end of 1975
Focus: Units 1, 2, 3 - nearfield model
Objective: Determine rate of mortality among ichthyoplankton associated with capture by plankton nets.

Cytogenetic Studies

Initiated: 1975
Status: Terminated, 1975
Focus: Striped bass population studies
Objective: Describe karyotype of Hudson River striped bass and assess the potential for using karyotype analysis to differentiate Hudson River striped bass from other populations.

1.2.3 TEXAS INSTRUMENTS (TI) STUDIES. In 1972, Texas Instruments Incorporated began the first of its studies under contract to Con Edison relating to impact of power plants on the Hudson River estuary. The overall objective was to determine the biological significance to the ecosystem of steam electric power plant operation. The early studies dealt with specific sites or plants while the later "multiplant" study has addressed the impact of all operational power plants on populations of key fish species.

1.2.3.1 Indian Point Studies. The studies associated with the Indian Point nuclear generating station (RM 42; km 69) began in early 1972. Specific studies included:

- Fish sampling at standard stations using beach seines, bottom trawls, and surface trawls (TI 1973b, 1974a, 1975e).
- Impingement studies, including daily monitoring at intakes of Units 1, 2, and 3; evaluating collection efficiency at intake screens and survival of impinged fishes; and evaluating fish pumps and air curtains as means of reducing impingement mortality at Indian Point (TI 1973a, 1974b, 1975f).
- Bioassay of simulated cooling-tower blowdown ~~(TI 1974e)~~. (TI 1974d)
- Benthic community studies in vicinity of Indian Point (TI 1976g).
- Thermal-plume mapping (TI 1972, 1973a).

- Investigations of physiological and behavioral effects of temperatures on striped bass and white perch (TI 1976g).

- Determination of age and length composition, age at maturity, fecundity, condition, growth, and food habits of striped bass, white perch, Atlantic tomcod (TI 1973a, 1974a, 1975e).

- Ecological analyses to integrate data from TI studies with those collected earlier (such as by Raytheon) in the Hudson River.

1.2.3.2 Cornwall Study. The proposed Cornwall pumped storage hydroelectric plant (RM 56; km 90) was the subject of studies in 1965-68 (Carlson and McCann 1969) and again in 1973 and 1975 by TI. The TI study program included:

- Beach seine survey of the Hudson River from near George Washington Bridge (RM 12; km 19) to Troy, N.Y. (RM 153; km 246) (TI 1976f).

- Ichthyoplankton survey of the Hudson River with emphasis on occurrence and abundance of striped bass (TI 1976f).

- Implementation of a pilot hatchery to demonstrate feasibility of artificial propagation of striped bass (TI 1974c, 1975k).

- Benthic community study in area of proposed landfill at Cornwall (TI 1975*l*).

- Trawl surveys to determine relative abundance of fishes (TI 1976f).

- Mark/recapture program to estimate movements and population size for striped bass and white perch (TI 1976f).

- Transect studies at Cornwall to provide data on vertical and lateral distribution of striped bass eggs and larvae (TI 1976f).

1.2.3.3 Multiplant Study. The Multiplant Impact Study (TI 1975b, c) of the Hudson River estuary incorporates the ichthyoplankton and beach seine surveys and mark/recapture studies initiated in the Cornwall program and several additional areas of study:

- Assessment of degree of exposure (vulnerability) of various life stages of key fishes to power plant operations.
- Analysis of historical data (commercial landings, licensed effort, etc.) for trends in population abundances.
- Determination of the stock size and stock recruitment relationship for striped bass.
- Determination of impact of plant operations on populations of striped bass, white perch, and other key species of fish.

1.2.3.4 Special Studies. Several studies not conveniently assigned to a specific plant or program have been conducted in connection with the Indian Point, Cornwall, and multiplant studies (e.g., water quality) and sometimes as separate programs (Ossining study):

- Evaluation of the various types of ichthyoplankton sampling gear in use on the Hudson River.
- Relative contribution of the Hudson River striped bass stock to the mid-Atlantic fishery (TI 1975d).
- Preparation of a summary of the physical and chemical factors determining water quality.
- Survey of the fishes of the lower Hudson River estuary including western Long Island Sound, the New York bays, and Jamaica Bay (TI 1975e).
- Study of food habits of bluefish in the Hudson River estuary to determine their potential significance as a predator on striped bass young-of-the-year (TI 1976a).
- Ossining (RM 32.5; km 52) siting study for a proposed generating station (TI 1975k).

1.2.4 LAWLER, MATUSKY AND SKELLY (LMS) STUDIES. The results of several research studies and monitoring programs conducted by LMS during 1973-75 are presented and applied in later sections of this report. The LMS studies fall into two principal categories: mathematical modeling and related data analysis funded by Con Edison and other members of the Inter-Utility Coordinating Committee (IUCC) and field studies performed under contract to Central Hudson Gas and Electric Corp. and Orange and Rockland Utilities.

1.2.4.1 Modeling Studies. Figure 1.2-1 summarizes the models developed by LMS to predict the impact of power plant operations on the Hudson River striped bass population. As suggested by the illustration, the principal emphasis in the modeling studies since the development of the basic life-cycle model has been to refine the estimate of power plant impact by improving the simulation of the longitudinal distribution and movement of the entrainable life stages (eggs, larvae, and early juveniles) of the striped bass. Of particular concern has been the development of an accurate simulation of the effects of the Hudson's tidal action on the distribution of eggs and larvae. The transport model, developed shortly after the life-cycle model, includes a tidal-averaged approximation of the river's hydrodynamics but does not permit a direct simulation of several phenomena that were discussed during the Indian Point Unit 2 hearings held during 1972-73. One of the areas of concern during the hearings was the possible interaction of the vertical migration of larvae and the river's transport mechanisms. Thus, to model this interaction directly and improve the overall accuracy of the simulation, the real-time model was developed.

Development of the real-time model was during 1974-75. This model includes a real-time simulation of the tidal action in the Hudson, as well as the vertical diurnal migration of larvae.

LIFE-CYCLE MODEL (1971-1972)*

- Simulation of striped bass life cycle: eggs through adults
- Prediction of population cropping due to entrainment and impingement
- Density-dependent natural mortality in larval and juvenile stages
- No simulation of spatial effects (e.g., hydrodynamic transport, migration and plant location)

TRANSPORT MODEL (1972-1973)

- Tidal-averaged hydrodynamic transport simulation
- Simulation of longitudinal migration of juveniles
- Effects of each plant simulated separately, including longitudinal location

REAL-TIME MODEL (1974-1975)

- Real-time simulation of tidal effects of hydrodynamic transport
- Vertical effects (velocity and organisms distribution and migration) simulated explicity

*Dates indicate when models were developed. Model capabilities are cumulative from life-cycle model through real-time model.

Figure 1.2-1. Summary of Models Developed by LMS to Predict Impact of Power Plant Operations on Striped Bass

To track the diurnal migration and the heterogeneous distribution of organisms in the vertical dimension, the model is divided into two layers of equal depth, thus providing a direct simulation of the interaction of the tidal action in the upper and lower layers of the river and the vertical migration of larvae. To improve the simulation of the different biological and behavioral characteristics of the young-of-the-year life stages, the yolk-sac and post yolk-sac stages are considered separately so that different mortality, distribution, and migration parameters can be specified for each life stage.

As part of the modeling studies performed for Con Edison and the IUCC, LMS has reduced and analyzed data collected by Texas Instruments Incorporated, New York University, Ecological Analysts, Inc., its own laboratory, and others during 1973, 1974, and 1975 and has used these data to evaluate input parameters for the real-time model. Figure 1.2-2 summarizes the input parameters required by the model and the data sources for each.

1.2.4.2 Field Studies. The field studies conducted by LMS under contract to Orange and Rockland Utilities and Central Hudson Gas and Electric Corp. during 1973, 1974, and 1975 have provided data regarding the nearfield distribution of the early life stages of fish, the density of these early life stages in the intakes and discharges of the power plants, and the rates of impingement of juvenile and adult fish on the debris screens at the intakes. All of these studies have been conducted at or in the vicinity of the Bowline Point (RM 39.5; km 64), Lovett (RM 41; km 66), Roseton (RM 65.4; km 105.6), and Danskammer (RM 66; km 106) generating stations.

The data collected during these studies have been used to evaluate input parameters for the real-time model. Nearfield data collected at transects in the river in front of the power plant intakes are used to calculate the distribution of striped bass eggs and larvae between the upper and

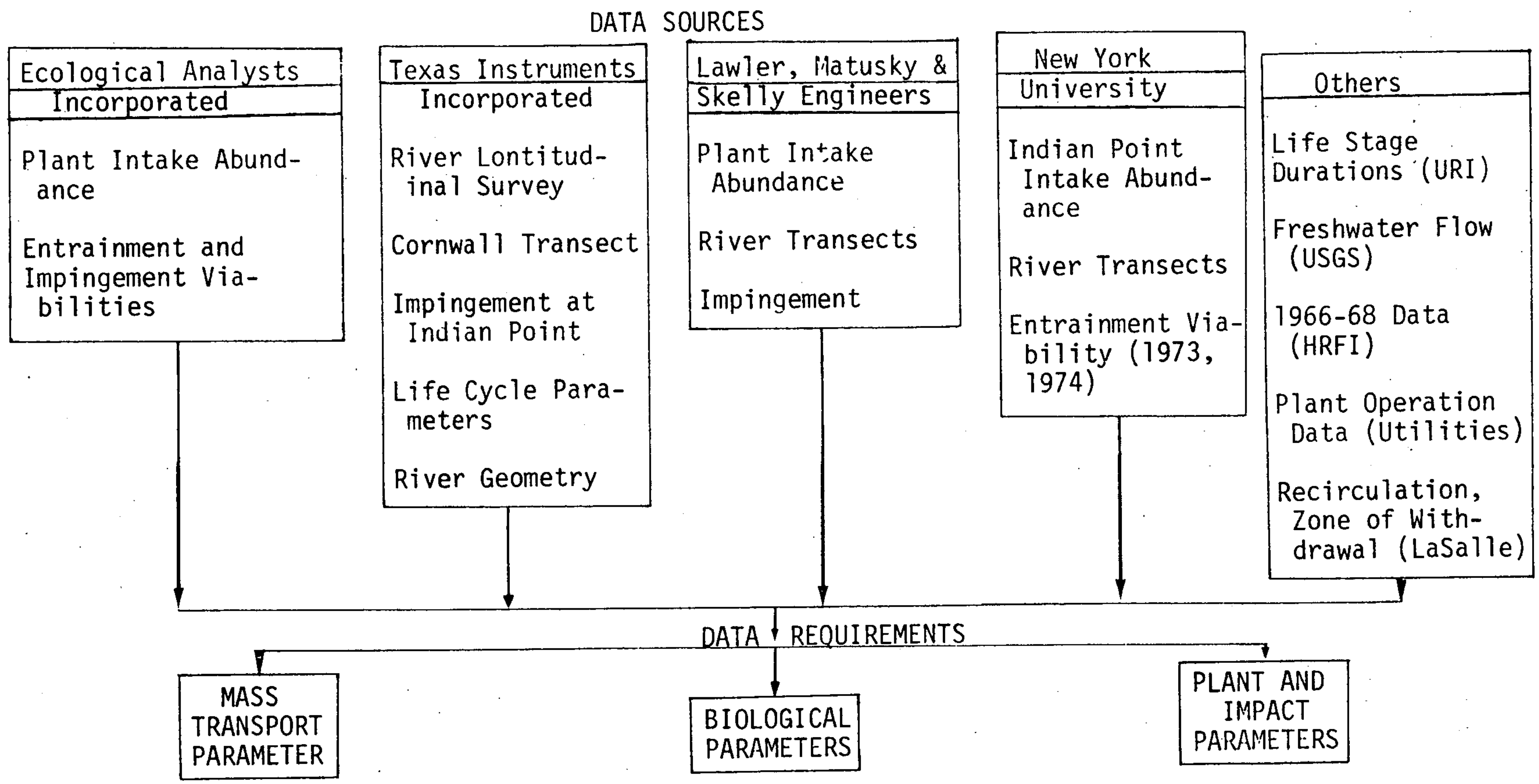

Figure 1.2-2 Hudson River Striped Bass Real-Time Model Data Sources

lower layers, the vertical diurnal migration preferences of larvae, and the average cross-sectional nearfield concentrations of organisms. The average cross-sectional concentrations are used in conjunction with the data collected at the plant intakes and discharges to determine the ratio of the organism concentrations in the plant cooling systems to those in the river.

The impingement rates, determined by collecting fish from the traveling screens, are used in the model to project impingement mortality under different operating conditions.

1.2.5 OTHER STUDIES. The following additional studies have provided data used in evaluation of the impact of Indian Point Unit 2 on the Hudson River fish population:

- Racial Investigation of the Striped Bass Using Critical Scale Analysis, 1975, by E.S. Taub, University of Rhode Island

- Striped Bass Rearing Experiments, 1975, by UMA Engineers, Inc.

- The Rearing of Hudson River Striped Bass at the Edenton National Fish Hatchery, 1975, by the Edenton National Fish Hatchery

- Indian Point Flume Study, Final Report Consolidated Edison Company of New York, Inc., 1976, by Stone and Webster Engineering Corporation

- Indian Point Generating Plants Hydraulic Model Study of Hudson River Flows Around Cooling Water Intakes, 1976, by the LaSalle Hydraulic Laboratories, Ltd.

1.2.6 INTEGRATION OF STUDIES AND DEVELOPMENT OF CONCLUSIONS FROM RESEARCH PROGRAM. The 10 goals of the research program listed in subsection 1.2.2 and the structure of this report reflect the conceptual framework within which data from the various contributing studies are integrated. The many reports produced thus far constitute a valuable basis of detailed biological information, and most interim conclusions have been sustained in the final analyses. However, not until this report has there been a comprehensive synthesis and interpretation of the research data.

The studies performed by the several contractors were necessarily conducted fairly independently of one another during their early stages. The different lines of study gradually, and by design, flowed together. The data from all contractors were pooled through cooperative arrangements within the Inter-Utility Coordinating Committee. In the later stages of the program, major tasks of integration were assigned to different groups of scientists, sometimes drawn from several different contractors, who used all relevant data regardless of which contracting organization had originally collected it. Working groups of scientists from the principal contractors (TI, LMS, and NYU) met periodically to reach technical consensus on ecological questions of special importance. Later, scientists from Ecological Analysts Inc., which is presently carrying on work for Orange and Rockland and Central Hudson, were added to these meetings.

The roles of various contractors and consultants have differed in important ways. A distinction must be made between the function of carrying on the research that produces the basic pool of ecological information and the function of making a scientifically informed expert judgment on power plant impact on the ecosystem.

The role of NYU and TI in the Hudson River program has been mainly in the area of applied ecological research. This research responsibility for TI has included measuring impact on the ecosystem by direct use of data on fish populations and actual power plant operations. LMS has filled a dual role, both carrying on applied field research and, through a fish life-cycle simulation model, entering the area of expert judgment.

Through the simulation model, it is possible to examine power plant impact under operating conditions different from those actually observed, to test the effects of different assumptions about ecological processes and power plant effects, and to simulate long-term performance of the fish population under different levels of plant impact and environmental variability. This final report on the research carried out from 1973 through 1975 and the synthesis of data upon which it is based was designed and coordinated by James T. McFadden, consultant to Con Edison. It was his responsibility to determine the content, work directly with contractor scientists in carrying out the analyses and formulating conclusions, and submit the completed report to Con Edison.

1.3 ENVIRONMENTAL QUESTIONS OF CURRENT IMPORTANCE

1.3.1 ENVIRONMENTAL QUESTIONS BELIEVED RESOLVED TO SATISFACTION OF NRC STAFF. In the Commission staff's re-analysis of the environmental impacts of once-through cooling in the FES for Indian Point Unit 3, a few changes were made from the Indian Point Unit 2 FES, which appeared to indicate that certain issues were no longer in contention.

1.3.1.1 Dissolved Oxygen. The FES concluded that the dissolved oxygen (DO) content of the cooling water changes very little during passage through the plant. However, the staff expressed a new concern about the effect of the DO reduction in the thermal plume, particularly when considered in conjunction with thermal plumes from other power plants (V-111).

1.3.1.2 Planktonic Organisms. The FES for Indian Point Unit 3 concluded that the entrainment of phytoplankton, microzooplankton, and macrozooplankton (except *Neomysis*) would not be expected to have any measurable effect on the aquatic ecosystem in the vicinity of Indian Point (V-214). The staff concluded that the entrainment of *Neomysis* when the salt front is in the vicinity of Indian Point might reduce the standing crop of this crustacean (V-215).

1.3.1.3 <u>Fish Species Not Subject to Significant Impact</u>. In the FES for Indian Point Unit 3, the staff concluded that the species most likely to be affected by plant operation were tomcod, bay anchovy, blueback herring, alewife, white perch, and striped bass. This list indicates that the staff no longer expects the effects on other species named in the Indian Point Unit 2 FES (viz., American eel, smelt, and American shad) to be as significant as was previously indicated (v).

1.3.2 ENVIRONMENTAL QUESTIONS TREATED FURTHER IN THIS REPORT. Based on the development of ecological questions in the original Indian Point Unit 2 hearings, interpretation of the NRC staff's present position, and the applicant's assessment of ecological questions of critical importance, the following emphases are developed in this report:

- Thermal Effects

  The impact of thermal discharges on the water mass is discussed in Section 2.3.2.1, and thermal relations of striped bass are briefly summarized in the life history information presented in Section 7.

- Dissolved Oxygen

  The possibility of decreased oxygen in plant discharge water is treated in Section 2.2.8.1.

- Chlorine

  New data on chlorine levels in plant effluent are presented in Section 2.3.2.2.

- Entrainment of *Neomysis*

  Impact on this organism is treated in Section 4.5.3.

- Entrainment of Striped Bass

  Major emphasis is given to the phenomenon of entrainment in Section 8, and the data are used in Sections 11 and 12 in impact estimation. A major portion of the research effort, producing a very large amount of new data, has been focused on entrainment.

- Impingement of Striped Bass

  Counts of impinged fish have been made on a continuing basis. The data are presented in Section 9 and used, along with estimates of population size from Section 7, in the impact estimation of Sections 11 and 12. A significant amount of new data is presented.

- Multiplant Impact on Striped Bass

  Impact is estimated by several different methods in Sections 11 and 12 both for Indian Point Unit 2 alone and for the multiplant case. The volume and quality of the data and the methods employed represent major advances over those available during the initial Indian Point Unit 2 hearings.

- Compensation

  An expanded review of the process of biological compensation, empirical evidence for its operation in the striped bass population of the Hudson River, and an empirical estimate of compensatory reserve in Hudson River striped bass are presented in Section 10.

- Contribution of the Hudson River to the mid-Atlantic Striped Bass Fishery

  New data that complement those reviewed during earlier hearings and allow the contribution of the Hudson River to the Atlantic coastal fishery to be determined are presented in Section 7.10.

- Entrainment and Impingement Impacts on Other Species of Fish

  Though not treated as intensively as striped bass, a substantial amount of new data on white perch, tomcod, blueback herring, alewife, and shad are included in Section 14. The first four of these are species of concern to the NRC staff. The shad is included because of its importance as a commercial species. The fragmentary data available on shortnose sturgeon are presented also because of the species' status as rare and endangered. The only species of concern to the NRC staff as concluded in Section 1.3.1, which is not included in this report, is the bay anchovy, for which data are extremely difficult to interpret because the species spawns repeatedly during the summer.

- Applicant's Mitigation Capability

  The feasibility of artificially rearing and stocking striped bass has been carefully evaluated. Mechanical devices for guiding fish away from cooling-water intakes have also been investigated. The new information is presented in Section 13.

As can be seen from the table of contents, this report is not structured to parallel the outline of environmental questions extracted from the history of the licensing proceedings. Nevertheless, it is useful to maintain some degree of historical perspective on the research program as it has unfolded since the initial licensing proceedings. The ultimate objective of the research program has been to develop quantitative estimates of power plant impact on striped bass and other fish species. In the original Indian Point Unit 2 proceedings, Con Edison cited 10 assessment cirteria that were believed applicable to striped bass and white perch and were to be used in the then proposed research program (McFadden and Woodbury 1973). This report presents data through which 9 of the 10 criteria proposed in 1973 are applied to impact assessment in the Hudson River; sufficient time has not yet elapsed for the life cycle of the fish to be completed to provide the requisite data for the single unapplied criterion. For one of the 9 criteria successfully applied, no direct measurements were obtained; however, inferences could be drawn from data collected in relation to other criteria. The criteria as quoted from the 1973 proceedings, along with a brief description of data and analyses through which they are applied and reference to the sections of this report containing the data, are presented below for striped bass. Less extensive treatment of other species is contained in Section 14 of this report.

(1) Criterion: "Decline in density of juvenile II, juvenile III, and age group I fish coincident with startup of Unit 2 and not accounted for by changes in egg production by parental stock or by natural environmental fluctuations."

Data: Age group I fish have not been sufficiently accessible to provide useful data. Latent root analysis of juvenile abundance over 10 yr, including 2 yr of Unit 2 operation, tests the significance of increased usage of cooling water while separating out the effects of natural environmental variation (Section 7.9). The simulation model contrasts abundances of young fish with and without power plant effects (Section 12).

(2) Criterion: "Large fraction of the population of eggs, larvaal, or juvenile I fish entrained."

Data: Standing crops of ichthyoplankton (Section 7.7) and numbers entrained (Section 8.3-8.10) are empirically estimated. Withdrawal factors reflecting the susceptibility of organisms in the vicinity of a power plant to entrainment have been measured in the field (Section 8.2). Probability of death due to entrainment is estimated from empirical data (Section 11). Power-plant impact is estimated through a simulation model (Section 12).

(3) Criterion: "High mortality rate of entrained organisms".

Data: Survival of ichthyoplankton during entrainment is measured (Section 8.2).

(4) Criterion: "Substantial reduction in survival rate from egg stage to juvenile II, etc., accounted for by entrainment."

Data: Inferences can be drawn from data in criteria 2 and 3. Data on compensation mechanisms, estimate of compensatory reserve, and demonstration of the small change in natural survival required to offset impact are relevant (Section 10).

(5) Criterion: "Substantial percentage of stock from significant area of estuary impinged on intake screens."

Data: Population size (Section 7.9) and number of fish impinged (Section 9) have been directly measured. A method for assessing population reduction due to impingement has been developed (Section 10) and applied with empirical data (Section 11). Long-term effects of continuing impingement losses are evaluated with the simulation model (Section 12).

(6) Criterion: "Lack of compensatory increase in survival rate among juvenile II and juvenile III fish following fulfillment of criterion 4.

Data: No large impact of the kind postulated in criterion 4 has been observed; hence, full application of criterion 6 is not possible. Data used in criterion 1 provide evidence that impact as postulated in criterion 6 does not occur (Section 7.9 and Section 12). Compensatory mechanisms are shown to operate during these life stages in response to natural fluctuations in numbers and therefore are available to offset impacts (Section 10). Evidence of significant compensatory reserve expressed over entire life cycle indicates that compensation (Section 10) would offset to a considerable degree a reduction as postulated in criterion 4.

(7) Criterion: "Lack of compensatory increase in survival rate among juvenile III to age group I fish following fulfillment of criterion 5."

Data: There has been no large impact of the kind postulated in criterion 5, so full application of criterion 7 is not possible. Density-related migration or mortality demonstrated for juveniles would operate in response to a major impact of the kind postulated in criterion 5 (Section 7.9). Also applying here is information on compensation cited in the data summary for criterion 6 (Section 10).

(8) Criterion: "Increase in growth rate of fish. Note that increased growth rate is both a classical indicator of a substantial decrease in stock density (hence, an indicator of adverse impact) and a compensatory response to reduction in density (hence an indicator of some capability of the fish stock to sustain itself in the face of increased mortality)."

Data: Power-plant operation has not caused sufficient reduction in fish stock to trigger a measurable compensatory response of the kind postulated; however, a compensatory growth response to the larger natural fluctuations in numbers that have occurred has been empirically demonstrated (Section 10) and would undoubtedly operate if power plant operation caused a very large reduction in fish stock.

(9) Criterion: "Attainment of sexual maturity at an earlier average age. The note in criterion 8 identifying the criterion as an indicator of both adverse impact and compensatory capability of the population applies here as well."

Data: The year classes of fish affected by the earlier full operation of Indian Point Unit 2 have not yet reached sexual maturity; hence, data with which to apply this criterion are not yet available. Reductions in fish populations caused by power plant operation are not believed to be large enough to produce a measurable response of the kind postulated, even when data would become available.

(10) Criterion: "Continuing decline in population size or stabilization at an undesirably low level following a period of decline, as predicted by a simulation model of the fish population which integrated the empirical data from the ecological studies."

Data: A real-time life-cycle model of the striped bass population incorporates the empirical data collected in the ecological studies and provides long-term predictions of the pattern of decline and eventual stabilization of the fish population under various intensities of entrainment and impingement impact (Section 12).

SECTION 2

THE HUDSON RIVER AS A RESOURCE SYSTEM

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SECTION 2

THE HUDSON RIVER AS A RESOURCE SYSTEM

2.1 GENERAL DESCRIPTION OF WATERSHED

The chemical and physical characteristics of watershed drainages are determined by factors such as watershed slope, soil and rock composition, meteorological patterns, and vegetative cover of the land. The following sections describe these factors, providing bases for discussing flow-related phenomena (Section 2.2) and materials and energy input to the estuary (Section 3).

2.1.1 GEOGRAPHY. The Mohawk-Hudson watershed is one of five major drainage systems in New York and the only one that includes a major estuary. The Mohawk-Hudson watershed includes portions of four mountain systems: the Adirondacks, the Taconics, the Highlands, and the Catskills. These are primarily within eastern New York (Fig. 2.1-1), although small portions extend into southwestern Vermont, northwestern Massachusetts, and northern New Jersey. The watershed may be conveniently divided into three major sections: the upper Hudson drainage from Mt. Marcy in the Adirondacks to Albany, the Mohawk drainage from Rome to Albany, and the lower Hudson drainage from the confluence above Albany to Manhattan.

The estuarine (tidally influenced) portion of the Hudson River (Fig. 2.1-2) extends from the southern tip of Manhattan Island (Battery Park [RM 0; km 0]) to the Federal Dam near Albany (Troy [RM 153; km 246], New York). The photographic representation (prepared according to Skalfy, Fisher, and Hardy 1977) of a 31 August 1976 LANDSAT multispectral image of the lower Hudson River characterizes the region. The lower Hudson River is essentially upland (magenta) and lowland (brown) vegetation with foci of urban areas (tan) located at either end and at various sites along the river. The high-density urban areas are color-contrasted by a light tan.

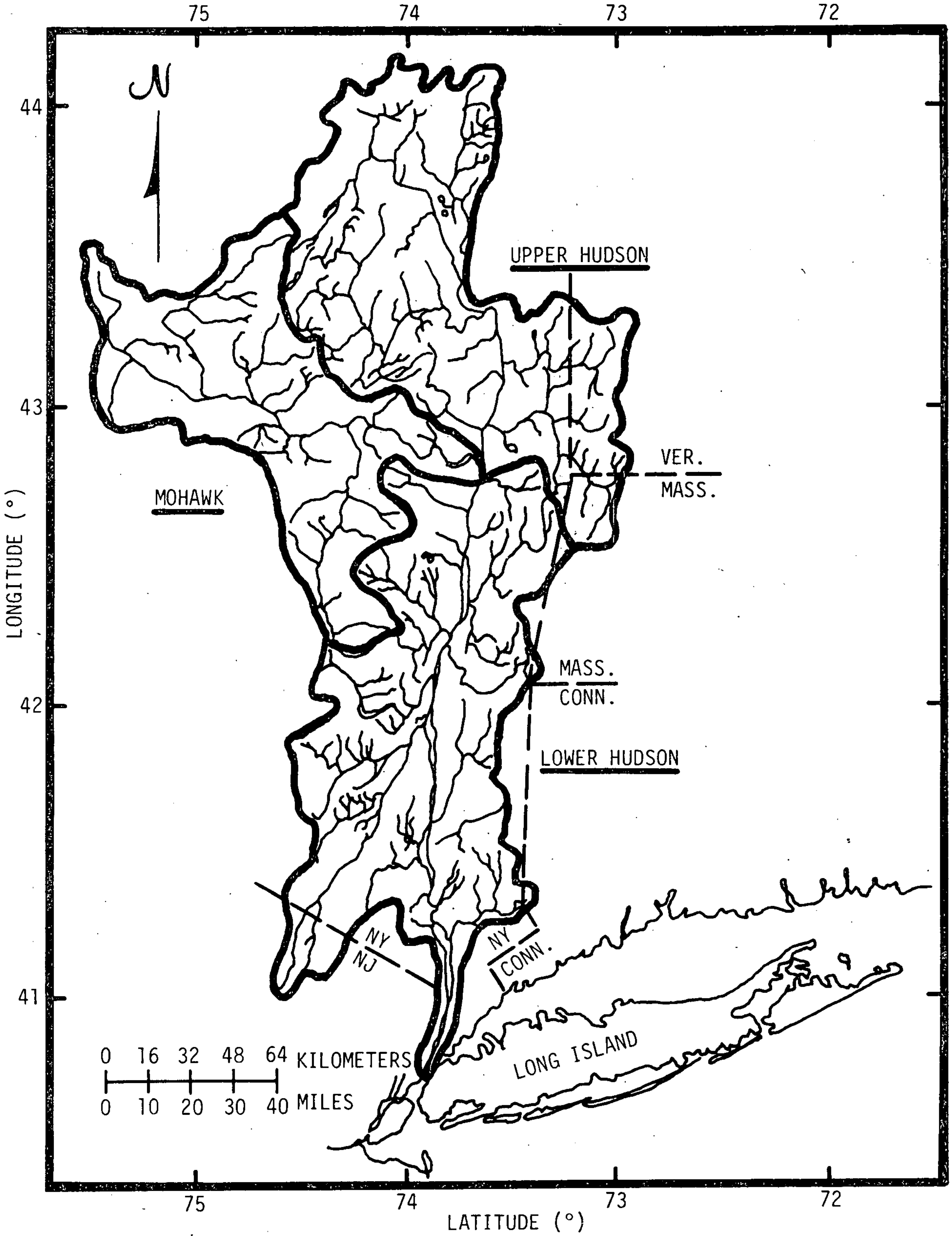


Figure 2.1-1 Watershed and Associated Tributaries of Mohawk-Hudson Drainage ~~System~~ System (after Giese and Barr, 1967)

Figure 2.1-2 Photographic Representation of 16 August 1976 LANDSAT Multispectral Image of the Lower Hudson River

Very few wetland (freshwater-dark brown and saltwater-light magenta) areas are associated with the estuarine portion of the river. The associated watershed extends 19-56 mi (30-90 km) into the Catskills, Highlands, and Taconic ranges. The most extensive tributary to the estuary is the Wallkill-Rondout system, which has headwaters in northern New Jersey.

2.1.2 PHYSIOGRAPHY AND TOPOGRAPHY. The Hudson River watershed includes a diverse group of physiographic features of considerable variation in elevation, slope, and relief. The elevation range exceeds 5000 ft (1500 m), accompanied by general slope extremes ranging from 100 to 200 ft mi^{-1} (19 to 39 m km^{-1}). In certain areas, slopes only a few degrees from vertical occur near water's edge. Maximum relief is approximately 4000 ft (1200 m). Major physiographic regions within the Hudson watershed are the Adirondack, Catskill, and Taconic mountain ranges, the Hudson Highlands, the Hudson and Mohawk valleys, and the Helderberg escarpment to the north of the Catskills (Fig. 2.1-3 and 2.1-4). Each region possesses distinct elevation, slope, and relief characteristics.

The Adirondack Mountains form much of the northeastern portion of New York and include the highest point in the state, Mt. Marcy, 5344 ft (1619 m). Maximum relief in the Hudson watershed, 4000 ft (1200 m), occurs in the southern portions of this range (Hamilton and Essex counties). The slope of the upper Hudson River between Mt. Marcy and Hudson Falls averages approximately 85 ft mi^{-1} (16 m km^{-1}).

The Catskill Mountains contribute drainage components to both Mohawk and lower Hudson watershed systems, but the southern portion of this range contributes predominantly to the Delaware and Chesapeake systems. The southern province seems to grade into the Appalachians, specifically, the Poconos. In other directions, the Catskills merge with the southwestern plateau and, to the north, with the Helderberg escarpment. The eastern side forms a steep front facing the Hudson River Valley.

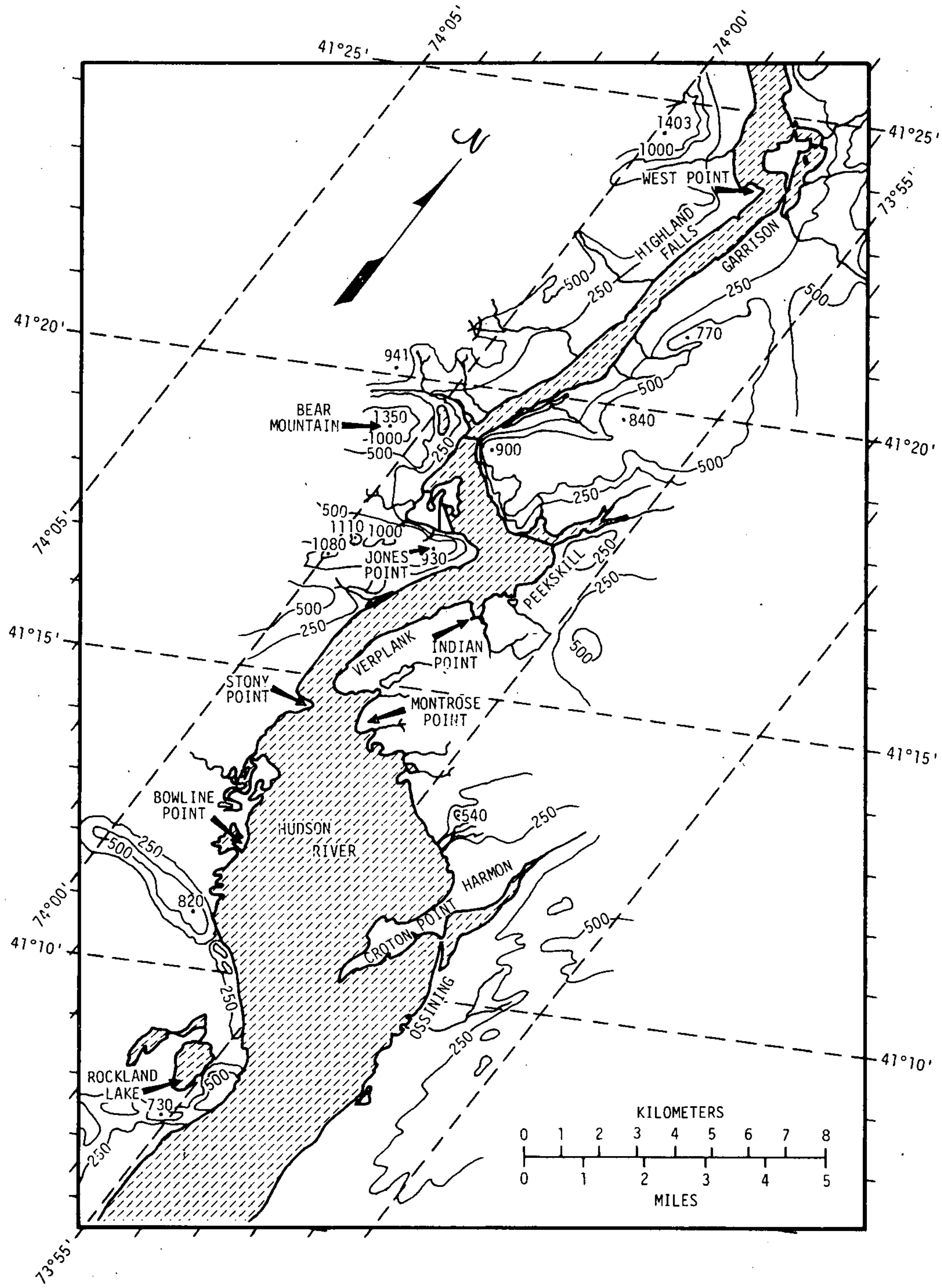


Figure 2.1-3 Hudson River in Vicinity of Indian Point

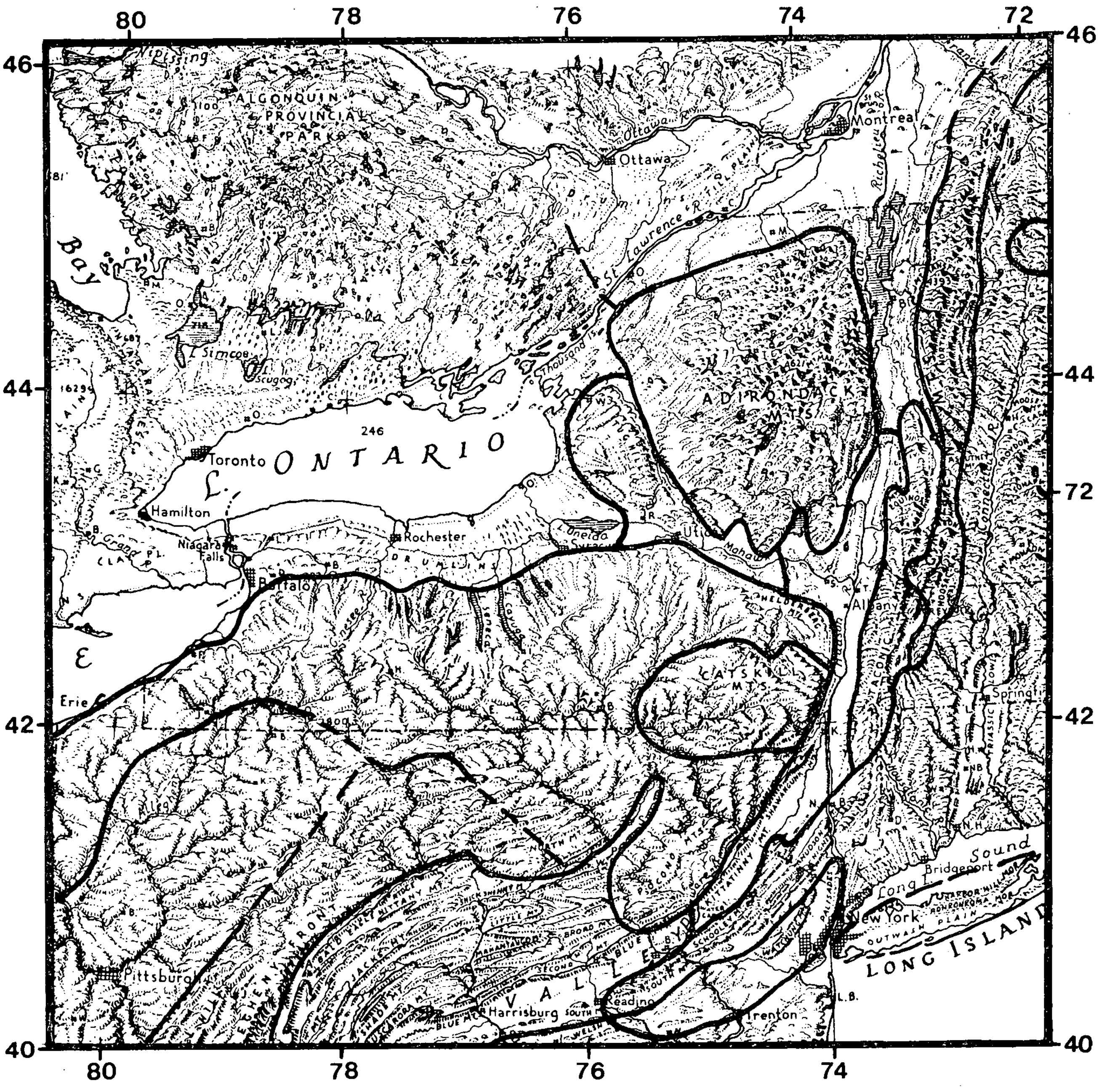


Figure 2.1-4 Major Physiographic Regions within Hudson River Watershed

The Mohawk Valley extends in an east-west direction between Rome and Albany, sharply separating the Catskill-Helderberg system and the Adirondacks. The valley floor is inclined from an elevation of approximately 500 ft (150 m) at Rome to <50 ft (15 m) near Cohoes and Troy. The Tug Hill area above Rome and Utica does not drain into the Mohawk system, although these hills are included in the Mohawk Valley physiographic region.

The Hudson River Valley extends south from Hudson Falls to Kingston and Newburgh and then southwest along the path of the Wallkill River. At the extremes of this valley, the watershed extends slightly into Vermont and Massachusetts to the northeast and into New Jersey to the southwest. Elevations are <500 ft (150 m), with the average slope of the Hudson River channel almost zero. The estuary channel cuts through the Hudson Highlands between Newburgh and Peekskill, New York, producing steep granitic walls bounding a deep, fjord-like passage. Elevations >1200 ft (360 m) occur in close proximity to the river channel. Relief between 500 ft (150 m) and 800 ft (240 m) is common, with even greater relief occurring adjacent to the channel.

Only 10% of the total watershed area drains into the river from Cornwall and Beacon south to Battery Park (Table 2.1-1). The majority of this drainage area lies to the east in the low rolling hills between the Hudson River and the Housatonic watershed (sometimes called the "White Plains"). The Highlands represent only 4% of the total watershed area. The runoff contribution is proportionately small due to a paucity of large tributaries within the Highlands proper. The majority of drainage enters the estuary near Garrison and Peekskill.

The Indian Point generating facility was constructed on a low, rocky prominence (Indian and Verplanck Points) situated at the southern end of the Hudson River passage through the Highlands on the east side of the river near the juncture of two projections of the New England Upland:

the Reading (Highlands) and Manhattan prongs. The Indian-Verplanck Point formation is bracketed by several tributaries: to the north, Annsville Creek, Peekskill Creek, and two small streams around Charles Point (Standard Brands); to the south, tributaries entering Lake Meahagh and Green's Cove.

Table 2.1-1 Drainage Areas of Hudson-Mohawk River System

Watershed	Area mi^2	Area km^2	% of Total
Upper Hudson	4,634	12,002	34.6
Mohawk	3,456	8,951	25.8
Above Green Island	8,090	20,953	60.4
Above Staatsburg	11,629	30,119	86.8
Above Poughkeepsie	11,730	30,381	87.5
Above Beacon	12,000	31,080	89.6
Above Peekskill and Tompkins Cove	12,600	32,634	94.0
Total	13,400	34,706	100.0

2.1.3 SOILS. The soils of the watershed grade from the podsols typical of cool coniferous forests to rock-laden modified glacial till. These soils, especially the podsols, tend to be acidic in nature. Leaching of limestone materials has a neutralizing effect, increasing pH values of runoff beyond 8.0 in some tributaries.

2.1.4 CLIMATOLOGICAL FACTORS. The nature of freshwater flows and their availability to the estuary is dictated by seasonal and long-term patterns of precipitation modified by the freeze-thaw cycle and evapotranspiration. The interaction of these processes can be summarized as follows:

(1) Evapotranspiration and total precipitation interact to produce greatest runoff during the cooler months.

(2) The freeze period (September/November - April/June) causes retention of potential runoff (ice and snow) on the watershed.

(3) The spring thaw period (generally early April-late June) causes the release of "trapped" runoff.

The latter two processes constitute the freeze-thaw cycle.

Mean air temperatures over the Hudson watershed range from 41.5°F (5.3°C) in the Adirondacks to 52.9°F (11.6°C) near the Atlantic Coast (Table 2.1-2). This gradient comprises latitudinal and elevational components, both of which impose reduced average temperatures to the north and northwest. Air temperature varies cyclically from minimum values in late January to maximum values in late July.

Precipitation is evenly distributed over the watershed (Fig. 2.1-5). Average annual levels generally range from 40 in (102 cm) in the upper Hudson to 46 in (117 cm) in the lower Hudson (Giese and Barr 1967:5). However, Esopus Creek, a tributary arising near Slide Mountain in the Catskills, is subjected to mean annual precipitation of 60 in (152 cm) near its headwaters. The annual cycle of total precipitation is similar to the seasonal pattern for temperature. Maximum precipitation occurs in July with minimum values in January and February.

Table 2.1-2 Average Monthly and Annual Air Temperatures at Selected Stations in Three Major Subdivisions of Hudson River Watershed*

Location	Air Temperature (°C) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Upper Hudson													
Tupper Lake	-8.7	-8.3	-3.5	4.1	11.2	16.3	18.6	17.4	13.2	7.4	0.6	-6.9	5.1
Indian Lake	-8.6	-8.4	-3.7	3.5	10.4	15.5	17.8	16.8	12.8	6.9	0.4	-6.9	4.7
Mohawk Valley													
Little Falls	-6.1	-5.7	-0.9	6.7	13.4	18.5	21.2	20.1	15.9	9.9	3.1	-4.2	7.7
Salisbury	-7.6	-7.3	-2.3	5.2	11.8	16.9	19.4	18.3	14.1	8.2	1.7	-5.7	6.1
Lower Hudson													
Poughkeepsie	-2.6	-1.9	2.9	9.7	15.9	20.9	23.7	22.4	18.1	12.2	5.9	-0.8	10.5
West Point	-2.1	-1.5	3.1	9.8	15.9	20.9	23.8	22.8	18.6	12.7	6.2	-0.4	10.8

*Data from NOAA (1960).

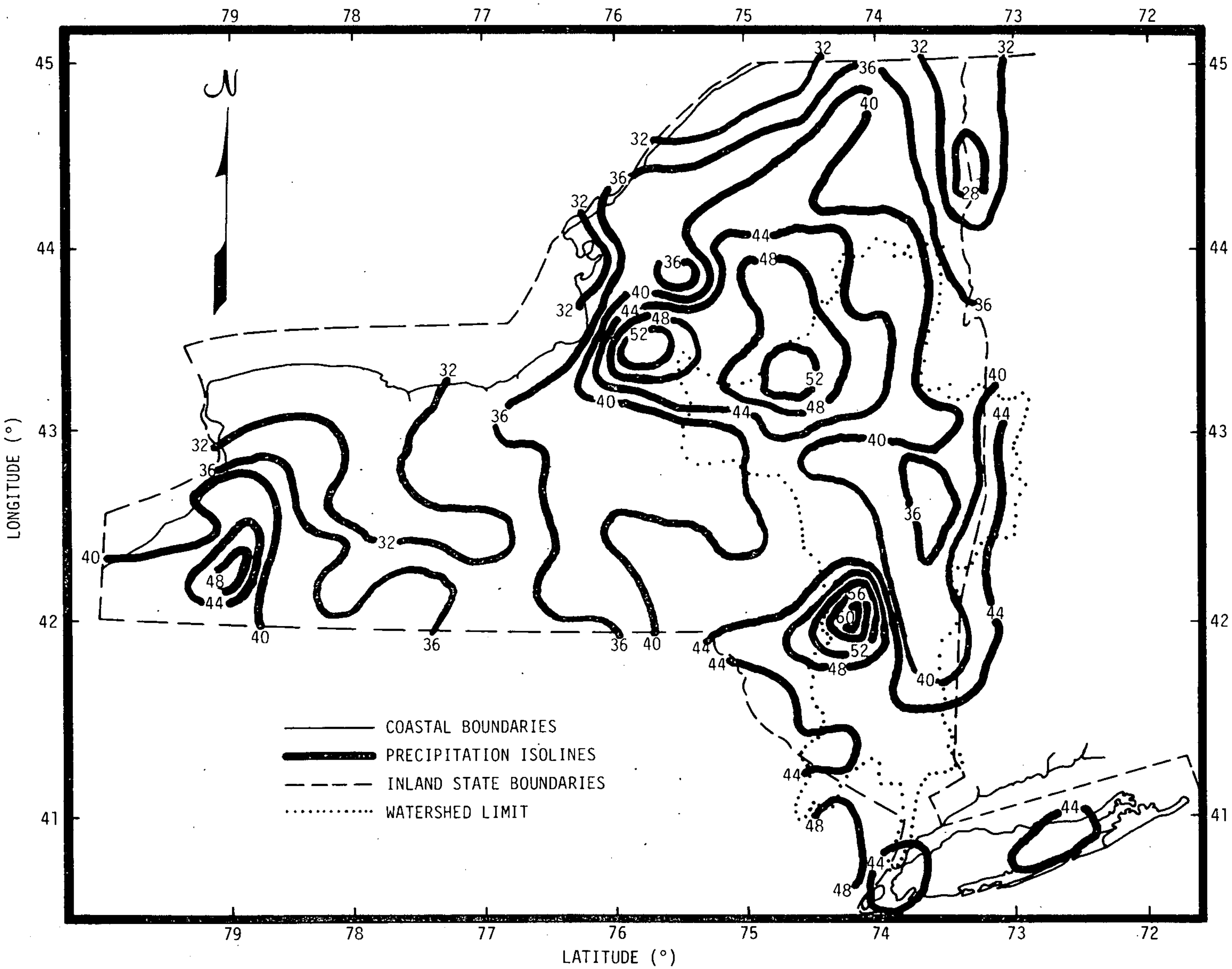


Figure 2.1-5 Mean Annual Precipitation in New York State, 1931-55 (Redrawn from NOAA 1960)

The annual freeze interval expands with increasing altitutde and increasing latitude. Mean seasonal snowfall reaches 100-180 in (254-457 cm) in mountainous areas of the watershed compared to 50-90 in (127-229 cm) in the valleys (Fig. 2.1-6). Consequently, spring thaw-flows from the Adirondacks generally occur later than thaw-flows from the valley provinces. The net effect is a broadening of the peak spring thaw period for the watershed as a whole.

Regular temporal patterns of air temperature and precipitation have been reported, and these patterns are quite similar for both meteorological factors, as shown in Figure 2.1-7. Figure 2.1-6 also includes other precipitation indices (water surface elevations in Lake Erie, Lake Ontario, and the upper pool at Troy, N.Y.). All plots follow the same pattern for the respective periods of data availability; i.e., all precipitation and runoff indices exhibit minimum moisture availability during years near 1965, with amounts increasing regularly into earlier and later years. The progression of 5- and 10-yr mean temperatures also seems to follow a similar pattern. The general upward trend of temperatures since 1880 is characteristic of most areas between latitudes 40°N and 50°N (Fig. 2.1-7).

Frequently, occillating (harmonic) components are attributed to the previously mentioned pattern(s). The most commonly indicated periods (intervals between peaks) are near 21 and 10 yr, corresponding to components of solar activity according to numerous authors (Clayton 1934, 1936, 1938, 1946; Abott 1935, 1944; Stetson 1947:160-177; Willett 1961, 1965, 1967; Cohn and Robinson 1976). However, solid cause-and-effect relationships have not been established.

2.1.5 VEGETATION. The Hudson watershed typically is covered by an oak-hickory-maple overstory system grading to a mixed conifer forest in the Adirondacks and portions of the Catskills. A large number (>12) of oak species (*Quercus* spp.) inhabit the watershed. Hickory (*Carya* spp.) and maple (*Acer* spp.) species are fewer in number; however, localized

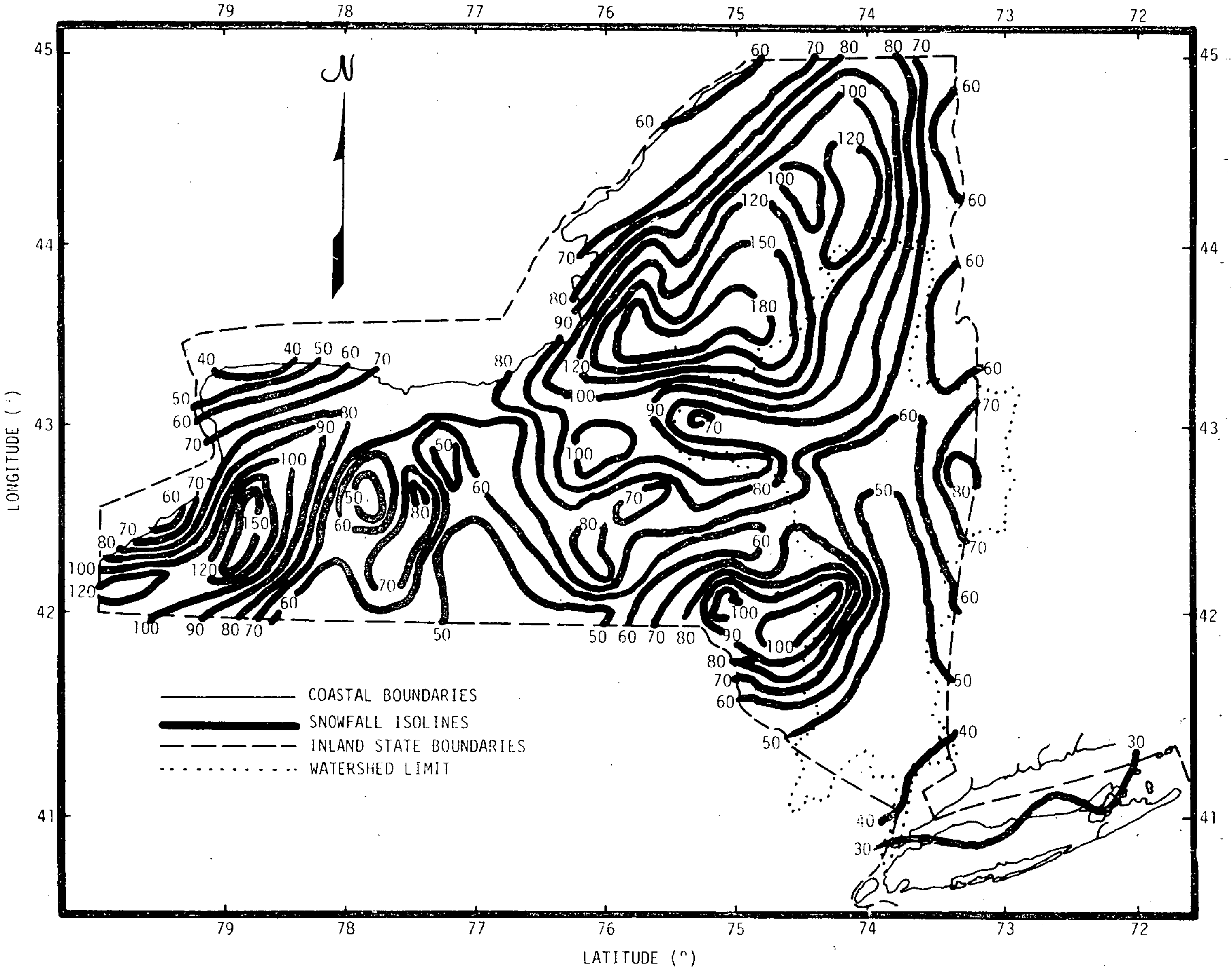


Figure 2.1-6 Mean Seasonal Snowfall in New York State, 1931-68 (Redrawn from NOAA 1960)

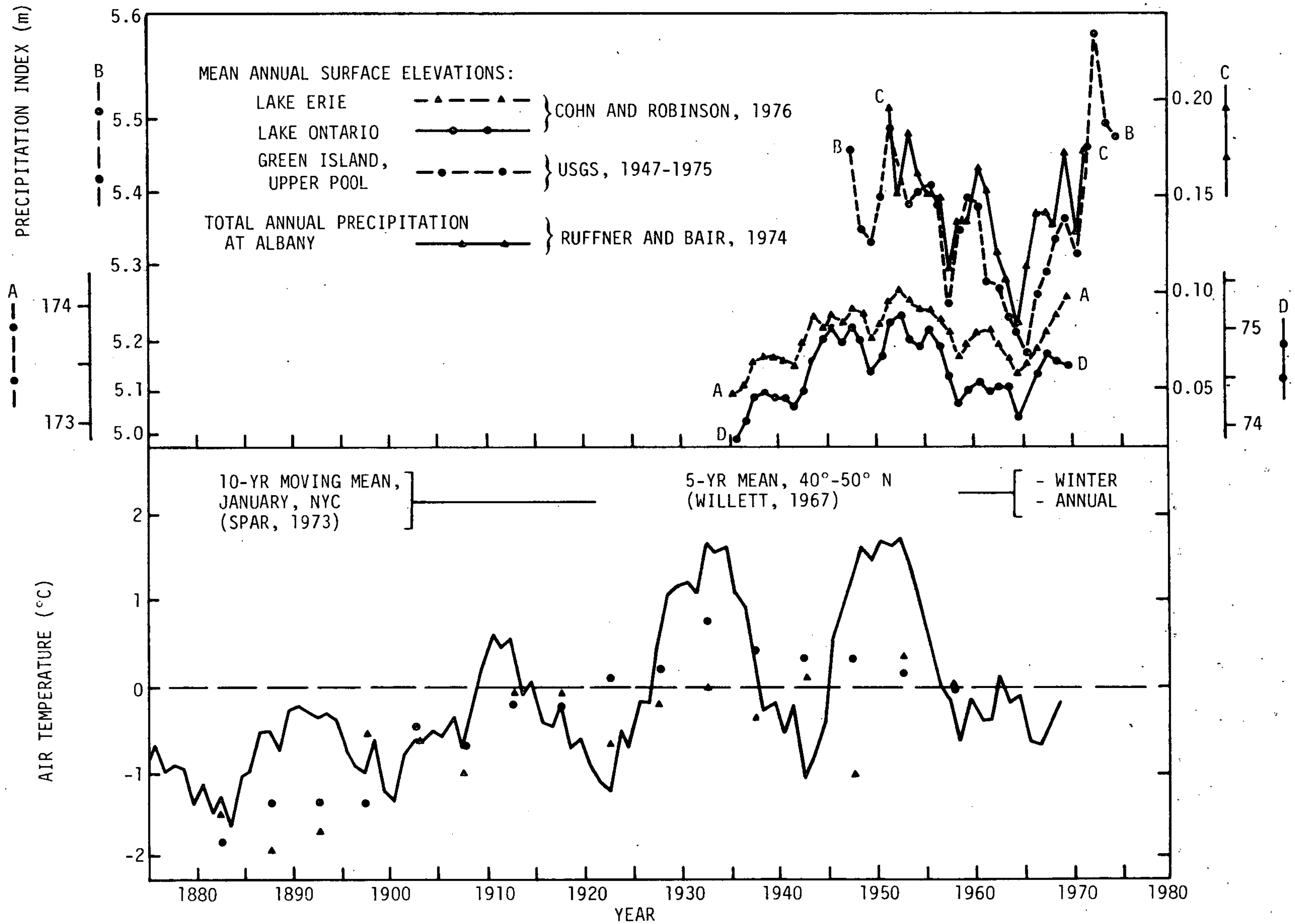


Figure 2.1-7 Long-Term Meteorological Patterns Influencing Hudson River Watershed

high densities of these species occur. The overstory system of New York state is predominantly second-growth replacement of virgin forests. The original forest was composed of an oak-chestnut-hickory climax community; however, extensive logging and shipbuilding activities during the 18th and 19th centuries, followed by the chestnut blight, a fungus introduced in 1940, effectively changed the character of the watershed forests.

2.1.6 CHANGES CAUSED BY HUMAN SETTLEMENT. Human settlement of the Hudson-Mohawk watershed apparently began in 4000 B.C. (Boyle 1969:28). As indicated by early European exploration records, the Indian races (tribes) comprising this settlement tended to inhabit the valley provinces, seldom entering the mountain provinces, especially the Adirondack Mountains.

Between the late 1609 explorations by Henry Hudson and the beginning of the 19th century, settlement of the Hudson river watershed was limited largely to the lower Hudson River. Even as settlement progressed up the Hudson Valley, human population densities remained low due to the establishment of "patroonships" under Dutch settlement; these patroonships, with their attendant "serfdom", were maintained through British rule and into the early 1800s. During this period, the major transportation artery was the Hudson River.

The rugged nature of the Hudson Highlands restricted industrial and agricultural usage to small-scale operations. Tillable soil was and is limited within the Hudson Highlands.

The development of steam-powered travel, canal waterways, and railways in the early 1800s permitted increased settlement in the Mohawk Valley. The Erie (barge) and Champlain canal systems and the Mohawk and Hudson railroad were the initial transportation penetrations beyond Albany. As settlement of the upper reaches of the watershed increased, industrialization increased until the present land-use patterns were established.

Now, land-use patterns abruptly change at the southern border of the Hudson Highlands (the general vicinity of the Indian Point generating plant site). South of the Highlands, human population densities increase downstream to New York City. This portion of the watershed is principally urban or suburban in terms of zoning and use; in fact, cities in an area 20-30 mi (30-50 km) either side of the Hudson River below the Highlands are frequently termed "bedroom communities" in reference to their suburban nature. Within the Hudson Highlands, land use remains rural to suburban, with agricultural interest at a low level. The area is often viewed locally as a parklike bulwark against urban intrusion. A second abrupt change in land-use patterns occurs where the Hudson channel leaves the Highlands and enters the Hudson River Valley. From this point north, agricultural interests increase, especially along the eastern portion of the valley. Generally, this trend continues to the north and west, moderated by the ruggedness of montane systems. The Mohawk Valley and high, rolling portions of the Catskills and Adirondacks are used primarily for agriculture.

The land within a 15 mi (24 km) radius of Indian Point is zoned largely for industrial, suburban residential and recreational-park use. The land immediately adjacent to the Indian Point power plant site is industrial along the waterfront and residential inland, with peak population densities associated with the City of Peekskill, New York.

Major shoreline alterations within recorded history are primarily attributable to construction of railroad rights-of-way along the eastern shoreline. According to Boyle (1969:65), bays near Tivoli and Hudson were open water (non-marshy). Construction of causeways partially blocked tributary inlets, thereby trapping sediment and detritus, producing new marsh areas. Similar filling is apparent in the areas of Constitution Island, Iona Island, Peekskill Bay, and Croton Point. These marshy areas contribute favorably to the habitat diversity of the Hudson River ecosystem.

Periodic dredging enhances the navigability of the Hudson. The dredged portions include a short channel cut through a sill structure south of Stony Point and more extensive dredging between Kingston and Albany. All such channels are maintained at depths of 30-35 ft (9-11 m). In many sections above Kingston, mud flats and islands surround the channel.

The biological resources of the Hudson River that have been utilized by man for the longest period have been fish (and shellfish in the upper and lower bays of the Hudson River estuary). These populations have been important to the interests of private sport fishermen and commercial fisheries; until the recent (March 1976) ban on sales of fish from the Hudson River because of PCB contamination, commercial fishing may have been an important factor affecting some species in the Hudson River, especially striped bass, American shad, and Atlantic sturgeon on which the industry has been based. The history of the striped bass fishery in the Hudson River is reviewed in Section 7.1.

Changes in land-use patterns within the watershed and man's direct addition of effluents have greatly altered the physical and chemical characteristics of the Hudson River. Present water quality is characterized by stress in the Albany and New York areas and generally good water quality in the mid-Hudson region (LMS 1975g). At Albany, this has been reflected in the biological community by occasional fish kills (due to low DO), an impoverished fish fauna, and a benthic fingernail clam (QLM 1971b; LMS 1975g). In the lower Hudson near New York, poor water quality has resulted in loss and/or contamination of shellfish beds and in a benthic fauna dominated by pollution-tolerant polychaete worms (LMS 1975g). However, pollution-abatement efforts have improved water quality in recent years.

Suspended and colloidal solids discharged into the Albany and New York areas have caused high turbidity, sludge deposits and, at times, odors (LMS 1975g). No comprehensive measurements of metals are available in the Albany area. The New York City area, however, violates EPA criteria for several metals, particularly lead. Heavy metals are known to be toxic to fish, invertebrates, and algae; yet, these effects have not been quantified for the Hudson. Pollutional sources in the Hudson are described in Section 3.5.

2.2 DESCRIPTION OF LOWER HUDSON

The lower Hudson River is tidal throughout its length from RM 0 at the Battery to the Troy Dam (RM 153.7; km 247.4) and is brackish approximately one-half the length of its tidal reach (Fig 2.2-1). Throughout most of an "average" year, the salt front (defined as salinity of 0.10 o/oo) is generally restricted to Haverstraw Bay (RM 34-39; km 55-63) and southward during periods of high freshwater runoff, intruding as far north as West Point (RM 52; km 84), and occasionally Newburgh (RM 61; km98) only during low flow. The salt front has occasionally intruded as far upriver as Poughkeepsie (RM 76; km 122) and during the 1964 drought, was observed in the vicinity of Hyde Park (RM 82; km 132).

Two aquatic ecosystems exist in the lower Hudson: one representing a tidal freshwater river and the other a typical mid-Atlantic estuarine system. None of the fixed physical characteristics of the Hudson serve as a point of demarcation between these ecosystems. Within a given year, the apparent boundary between the freshwater and estuarine systems fluctuates as the salt front moves up or downstream.

2.2.1 BASIN MORPHOMETRY. The basic data on the channel geometry (topographical layout and soundings) of the Hudson River estuary are provided by the U.S. Coast and Geodetic Survey (USCGS) Navigational Charts 745, 746, 282, 283, and 284.

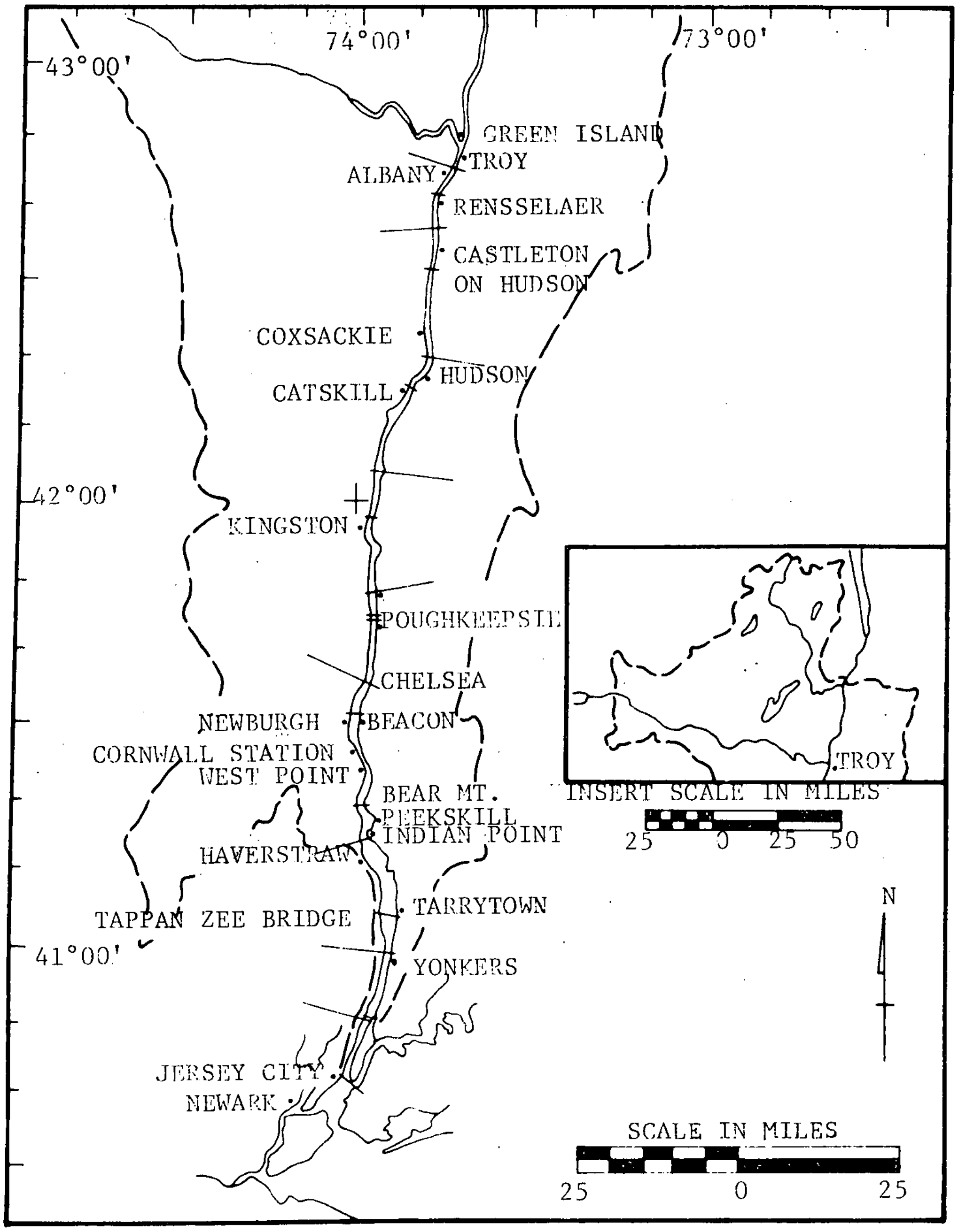


Figure 2.2-1 Hudson River Estuary. (Insert shows upper drainage area)

The Hudson River estuary is a relatively deep and straight channel. Figure 2.2-2 shows the variations in major channel characteristics, i.e., cross-sectional area, surface width, and mean depth, based on the USCGS Navigational Charts. The cross-sectional area of the channel ranges from about 250,000 ft^2 (23,226 m^2) in Haverstraw Bay to <30,000 ft^2 (2787 m^2) in the most upstream reach of the estuary. Surface width varies significantly and somewhat erratically along the longitudinal axis of the estuary. due to the presence of several bays and shoals in the lower Hudson. Locations of two major bays, Haverstraw and Newburgh, are shown in Figure 2.2-2. The widest section of the river occurs at Haverstraw Bay, where the surface width reaches almost 3 mi (5 km). The estuary's mean depth, defined as the cross-sectional area divided by the surface width, generally decreases from about 33 ft to 16 ft (10 m to 4.9 m) from the Battery to the head of Haverstraw Bay. Upstream of Haverstraw Bay, the mean depth abruptly increases, reaching a maximum of approximately 90 ft (27 m) in the vicinity of West Point. Maximum depth values approach 200 ft (61 m).

The geological features described in Section 2.1 differ in their susceptibility to erosion, so the width and depth characteristics of the river change dramatically throughout its lower length. Extensive channelization and stream improvements that maintain the port of Albany (RM 143; km 230) have produced a relatively narrow and deep channel. South of Albany in the vicinity of the I-90 bridge, the soft soils of glacial outwash silt have been eroded extensively. There, the river is wide, but numerous and extensive backwaters and side channels coexist with the maintained shipping channel.

South of Coxsackie (RM 124; km 200), the Hudson River is narrow and deep except in zones widened by glacial activity. In the vicinity of Verplanck (RM 41; km 66), the river begins to widen and has its widest expanse in Haverstraw Bay.

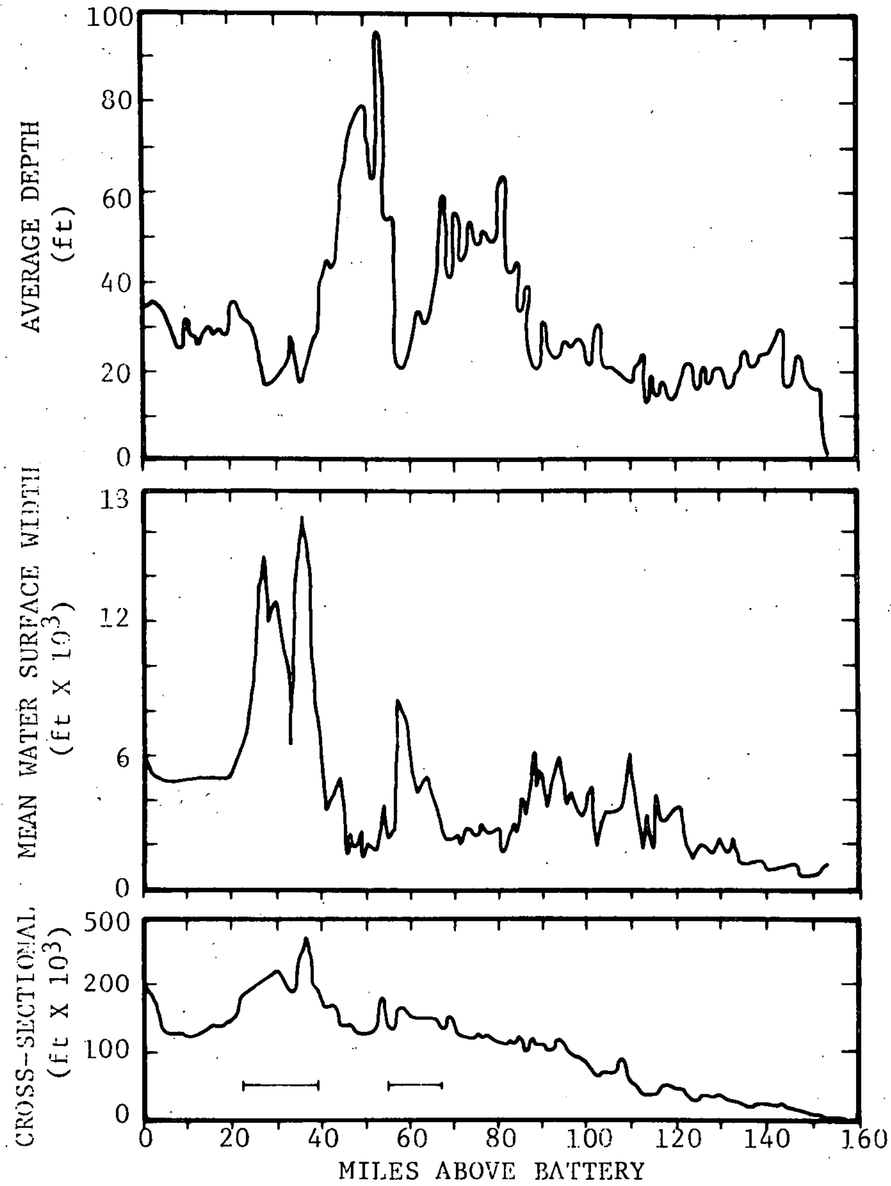


Figure 2.2-2 Hudson River Channel Physical Characteristics

South of Piermont (RM 25; km 40), the river is narrow, confined by the Palisades on the west and by the diking of Yonkers and New York City on the east to prevent erosion of the glacial till on the east side of the river. The lower Hudson then discharges into upper New York Bay and subsequently through the Verrazano Narrows into lower New York Bay, an arm of the Atlantic Ocean.

2.2.2 FRESHWATER FLOW REGIME. Freshwater inflow into the estuary provides a net movement of water in the estuary from its head to its mouth. It flushes pollutants discharged into the estuary and dilutes the saline ocean water that enters the estuary at its mouth.

The major portion of freshwater flow (about 80% under normal summer conditions) enters the estuary at its head at Troy; the remaining portion is contributed by tributaries flowing largely into the upper reach of the estuary. The rates at which fresh water enters the estuary at its head have been recorded by the USGS gaging station at Green Island. Based on observations of Hudson River flows over a period of 57 yr (1918-75), the long-term average freshwater flow at Green Island has been estimated to be 13,268 $ft^{-3}s$ (376 m^{-3}/s^{-1}).

Runoff from only about 50% of the river basin downstream of Green Island is gaged. Since measurement of the freshwater flow in the estuary is not possible because of tidal oscillation, lower Hudson River flow histograms in the tidal portion of the river are usually constructed by measuring Hudson River flows at Green Island (the most downstream USGS gaging station above tidewater) and by utilizing empirically developed flow and travel-time relationships between the tributaries and Green Island. Based on such a relationship developed by Quirk, Lawler and Matusky Engineers, the long-term average (1918-73) freshwater flow in the estuary downstream of Wappinger Creek (RM 67; km 107.8) has been estimated to be 18,600 $ft^{-3}s^{-1}$ (526.8 $m^{-3}s^{-1}$).

Freshwater flow varies over the period of 1 yr, with maximum flows occurring primarily during spring (March, April, and May) and low freshwater flows usually beginning in June and continuing until November. Figure 2.2-3 depicts the variation of long-term monthly average flows in the lower Hudson River (downstream of Wappinger Creek) over a period of 1 yr. In the 1960s, the entire northeastern region of the United States experienced a severe drought characterized by extremely low stream flows. The most severe drought in the Hudson River was observed in 1964 when freshwater flow in the estuary averaged only 3,500 $ft^{-3}s^{-1}$ (99 $m^{-3}s^{-1}$) during the 6- mo period from June through November; at that time, natural freshwater inflow into the estuary was significantly increased by releases of water from the flow regulating reservoirs located in the upper Hudson River and Mohawk River basins. It was estimated that without the flow regulating effect of the reservoirs the freshwater flow in the estuary would have averaged approximately 1,300 ft^{-3} s^{-1}(36.8 $m^{-3}s^{-1}$)(LMS 1975).

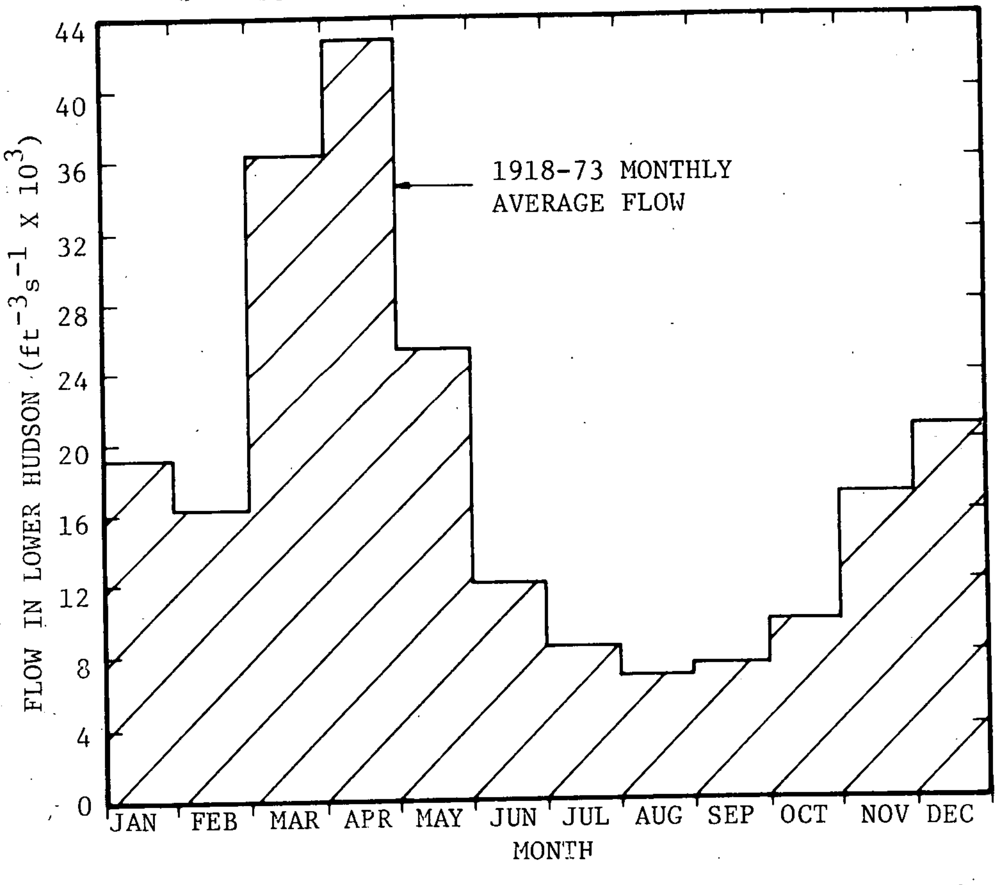


Figure 2.2-3 Lower Hudson River Long-Term Monthly Average Freshwater Flows Downstream of Wappinger Creek, 1918-73

During the past several years, the Hudson River has experienced a wet period, with freshwater flows generally higher than or close to their long-term average counterparts, as indicated in Table 2.2-1.

2.2.3 TIDAL CHARACTERISTICS. The lower Hudson River is classified as a damped, reflected tidal wave regime. Damping occurs by dissipation of tidal energy via channel friction as the oceanic tidal wave progresses upstream. Reflection includes secondary wave propagations caused by channel obstructions. Complete reflection occurs at the federal dam at Troy. Additional wave reflections occur with significant changes in channel width: as widths increase, wave amplitudes tend to decrease, whereas a decrease in channel width causes an increase in wave amplitudes. Tidal behavior at any section is the composite effect of ocean tide, channel friction, and wave reflection. The primary ocean tides are also variable, with maximum amplitude occurring during neap tide. Variations in freshwater discharge and barometric conditions also contribute to changes in amplitude.

The tidal characteristics and relevant field surveys of the Hudson River are described in detail in "Tides and Currents in the Hudson River," Special Publication No. 180 of the U.S. Coast and Geodetic Survey (Schureman 1934). Predictions of tidal heights and currents in the Hudson River are published yearly by the U.S. National Oceanic and Atmospheric Administration in "Tide Tables" and "Tidal Current Tables."

For several reasons, actual tides and tidal currents often differ in both magnitude and time from those predicted. For example, annual predictions are made under the assumption of a freshwater flow of around 6,000 ft $^{-3}$ s^{-1} (170 $m^3 s^{-1}$), however, significantly higher freshwater flows during spring months may deflect the actual tidal characteristics, particularly far upstream, from those presented in prediction tables.

Table 2.2-1 Monthly Average (1971-75) and Long-Term Average (1918-75) Hudson River Freshwater Flow ($ft^{-3}\ s^{-1}$) at Green Island

Month	1971	Water* 1972	1973	1974	1975	Long-Term Average 1918-1975
Oct.	8,186	7,811	7,291	5,650	9,049	7,773
Nov.	9,333	7,291	26,150	8,380	17,180	12,200
Dec.	11,390	17,000	27,010	26,420	19,380	17,771
Jan.	9,002	13,410	26,210	22,010	19,070	12,833
Feb.	12,110	10,930	20,460	18,640	19,370	12,199
Mar.	20,220	26,860	29,410	20,730	23,680	22,190
Apr.	37,270	37,960	30,960	30,170	25,580	31,060
May	35,240	40,520	27,600	22,960	20,000	19,028
Jun	7,334	29,620	13,050	8,791	12,970	9,684
Jul.	6,233	18,380	10,390	11,780	7,464	6,900
Aug.	8,929	7,616	5,591	6,359	8,966	5,446
Sep.	9,315	6,309	4,791	10,390	17,030	6,231
Yearly Average	14,547	18,643	19,077	16,015	16,645	13,268

*Water year begins in October and ends in September of following year; e.g., water year 1972 began on 1 October 1971, and ended on 30 September 1972.

Figure 2.2-4 illustrates the principal tidal characteristics along the stretch of river between the ocean entrance and Troy. The high water and low water lunar intervals, with reference to the transit of the moon over the meridian of Greenwich, are shown on the upper portion of the figure; the lower portion of the figure indicates high and low water above mean low water at Sandy Hook, New Jersey. The half-tide level indicates the average slope in the river; the total fall from Troy to the sea is about 2 ft (0.6 m). In moving upstream, the range of the tide diminishes from about 4.4 ft (1.3 m) at the Battery to a minimum of about 2.6 ft (0.8 m) at a point near Storm King (RM 56; km 90), then increases to its maximum of 4.7 ft (1.4 m) at Troy. The spring tide is characterized by a higher range of high and low water elevations from about 5.3 ft (1.62 m) at the Battery to 3.1 ft (0.9 m) at West Point and about 5.1 ft (1.55 m) at Troy.

Figure 2.2-5 shows the variation of mean sectional tidal velocity along the river. The raw data for the ebb and flood strengths were obtained from 1934, then each was averaged across the river cross-section. Mean absolute velocity over a tidal cycle was obtained by averaging the section-averaged ebb and flood strengths. The Hudson River ebb strength (maximum ebb current) is generally greater than the flood strength in the entire estuary, primarily because the freshwater flow and the ebb flow proceed in the same direction.

The mean tidal flow along the river, also shown in Figure 2.2-5, decreases from a maximum of 425,000 $ft^{-3}s^{-1}$(12,035 $m^{-3}s^{-1}$) at the Battery to zero at the Troy Federal dam (approximately RM 153; km 245). Freshwater flow affects these values, particularly in the upstream reaches of the estuary. The values shown correspond to low summer freshwater flows of about 6,000 $ft^{-3}s^{-1}$(170 m^3s^{-1}). High freshwater flows into the estuary generally decrease tidal flood velocities and flows and increase ebb velocities and flows, an effect which is more pronounced in the upstream reaches than in the intermediate and downstream reaches. In fact, during periods of extremely high freshwater flows, the tidal oscillation may

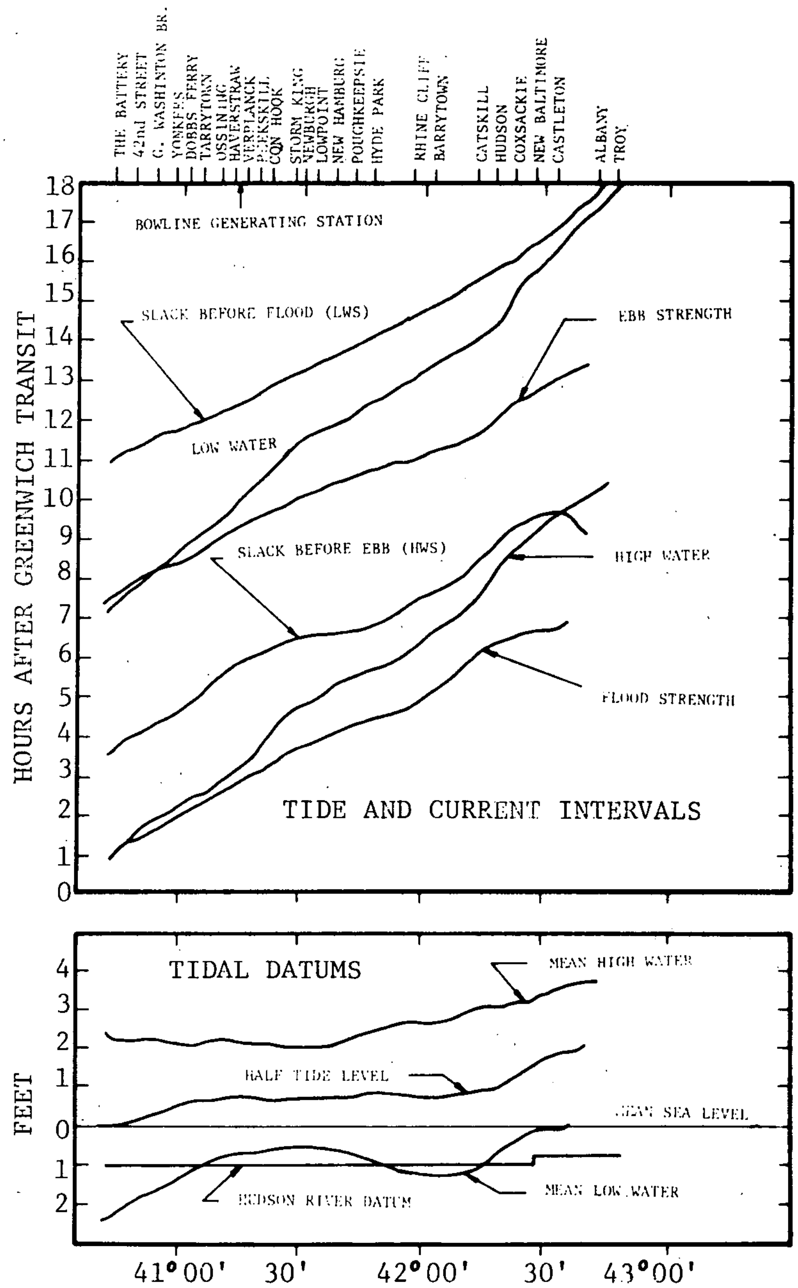


Figure 2.2-4 Hudson River Tidal Characteristics

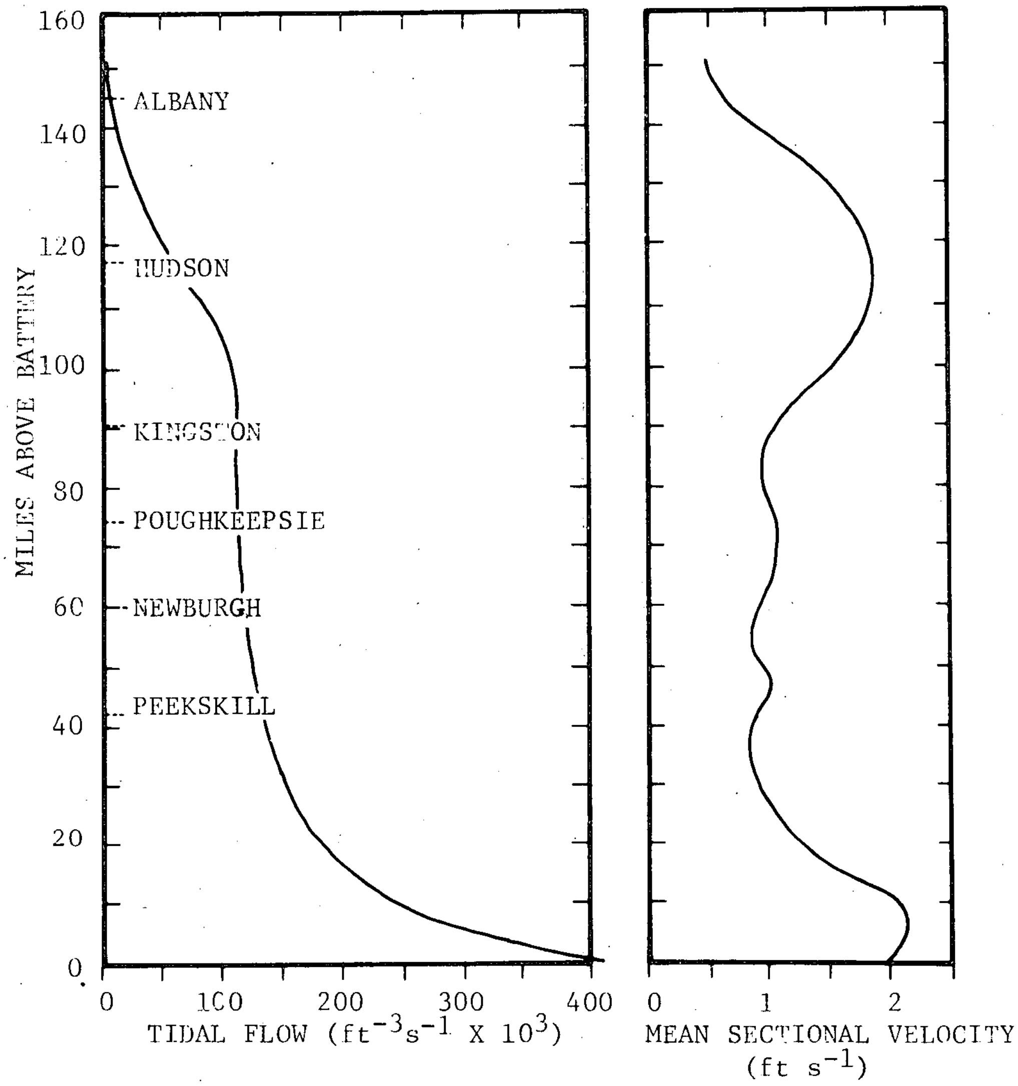


Figure 2.2-5 Hudson River Tidal Flow and Velocity. (Mean values are based on freshwater flow of 6,000 ft^3 s^{-1} [170 m^3 s^{-1}] at Green Island)

be entirely suppressed in the upper portion of the estuary. This was observed, for example, during the storms of March 28, 1913, and March 19, 1936, when freshwater flow discharges of 223,000 $ft^{-3}s^{-1}$ (6315 $m^{-3}s^{-1}$) and 215,000 $ft^{-3}s^{-1}$(6088 $m^{-3}s^{-1}$), respectively, resulted. No tidal oscillation in the uppermost 30 mi (48 km) of the estuary has been observed during the extreme freshwater inflows (Darmer 1971).

2.2.4 TIDALLY INDUCED MIXING. Fresh water generally enters the Hudson River at Troy and flows downstream through the estuary to the ocean; simultaneously, heavier seawater intrudes upstream through the ocean entrance and flows beneath the lighter fresh water. Since the fresh water flows in the downstream direction, it increases the tidal ebb currents and decreases the flood currents. Also, since the fresh water is lighter and flows above the salt water, its influence on ebb duration is maximum at the surface; i.e., at the surface the ebb duration is greater than the flood duration and at the bottom the flood duration exceeds the ebb duration.

In addition to magnitude of freshwater flow (Q_f) and tidal currents (Q_T), the mixing processes just described are controlled also by the physical characteristics of the river channel and the effect of the earth's rotation (Coriolis force).

In the Hudson, tidal mixing predominates because of the effects of wide shallow embayments and strong tidal currents. The large horizontal extent of this water body allows development of lateral shear of the tidal current. When averaged over a tidal cycle, this may result in a net landward current in one region of the estuary, balanced by a net seaward flow elsewhere. If the average salinity is higher in the landward flow, a net flux of salt into the estuary is produced.

The Hudson River becomes narrow and deep farther upstream, reducing the cross-channel variation of the tidal currents. Tidal energy in this region may be insufficient to maintain vertical homogeneity, and density effects may accordingly become more important. This transition represents the change from a well-mixed estuary circulation to a partially mixed system. In the latter, seawater, being denser than the water of the river, flows into the estuary as a bottom layer, displacing the lighter, less saline water; the salt gradually mixes upward as it intrudes, modifying the overlying seaward-flowing surface layer. The convective circulation derived from this density flow is known as the gravitational circulation. Clearly, in some parts of the estuary, both salt intrusion mechanisms--tidal mixing and gravitational circulation--are acting simultaneously.

The ratio of the tidal flow (Q_T) to the freshwater flow (Q_f) combines most of the important variables just discussed into a single factor (Q_T/Q_f). This ratio provides an overall picture of the relative state of mixing and circulation in the Hudson estuary. When the tidal currents are relatively strong compared to the freshwater flow, turbulence increases and causes an upward advection of salt water and a downward movement of fresh water into the lower layer. Water bodies of this type are known as partially stratified estuaries. The Hudson River is a typical example. Mean tidal flow decreases from a maximum of 425,000 $ft^{-3}s^{-1}$(12,035 $m^{-3}s^{-1}$) at the ocean entrance (the Battery) to some 140,000 $ft^{-3}s^{-1}$(3,964 $m^{-3}s^{-1}$) at Peekskill and approaches zero at the head (the Federal dam at Troy). These values may be compared with the long-term monthly averages shown in Figure 2.2-3.

Ranges of Q_T and Q_f, as well as the Q_T/Q_f ratio in the Hudson River, appear in Table 2.2-2, which contains values for the reach between the ocean entrance and Hyde Park, New York, some 80 mi (129 km) upstream of the Battery. The Hyde Park location represents the upstream limit of observed salt intrusion under severe drought conditions. The table shows that the computed (Q_T/Q_f) in the lower Hudson River ranges between

Table 2.2-2 Hudson River Vertical Stratification Factor

Parameter	Range of Values		
	Maximum (Spring)	Average (Winter and Fall)	Minimum (Summer)
Monthly average freshwater flow $ft^3\ s^{-1}$ ($m^3\ s^{-1}$)	43,000 (1218)	14,500 (410)	6,000 (170)
Mean tidal flow $ft^3\ s^{-1}$ ($m^3\ s^{-1}$) at			
The Battery (RM 0; km 0)		425,000 (12040)	
Bowline (RM 37.5; km 60.4)		150,000 (4249)	
Indian Point (RM 42; km 69)		140,000 (3966)	
Danskammer (RM 66; km 106)		120,000 (3400)	
Vertical stratification factor (VSF)* Q_T/Q_f at			
The Battery	10	29	70
Bowline	3.5	10	25
Indian Point	3.3	9.6	23
Danskammer	2.8	8.3	20

*Values bounded by broken lines are not indicative of degree of density stratification since, under these flow conditions, indicated locations are outside the salinity intrusion region.

3 and 70. Since the tidal flow is at a maximum at the ocean entrance and decreases with distance upstream, the degree of stratification defined as Q_T/Q_f for a given freshwater flow condition increases in the landward direction. The values bounded by the broken lines are not indicative of the degree of stratification since, under such conditions, the indicated locations are outside of the salt-intruded region. The unbounded values indicate that, under normal conditions, the salt-intruded reach of the lower Hudson generally has a vertical stratification factor (VSF) >10 and can be considered a partially stratified estuary. The kinematic and dynamic characteristics of a partially stratified estuary are detailed in a paper by Abood (1974).

2.2.5 LMS REAL-TIME TRANSPORT MODEL. The history of the models of the Hudson striped bass population developed by Lawler, Matusky and Skelly Engineers was described in Section 1.2.5. For reasons discussed below, the model applied in this study is referred to as the real-time model.

To simulate accurately the effects of hydrodynamic transport in the Hudson River on the spatial and temporal distributions of the early life stages of fish, the following phenomena are included in the real-time model:

- Tidal effects (Section 2.2.3)
- Vertical/diurnal migration of larvae (Section 8.2.5)
- Variations in the vertical and longitudinal distributions of the early life stages (Sections 8.2.5 and 8.2.6)
- Transport effects of the partial stratification of the flows in the Hudson (Section 2.2.4)
- Possible interactions of the vertical/diurnal migration of larvae and the vertical stratification of the flow

Temporal variations in flow due to tidal effects and diurnal migrations of larvae are simulated by evaluating the hydrodynamic function and the distribution of organisms at 3-hr intervals. The dynamic nature of this portion of the simulation is the reason the model is called "real-time."

Dividing the river into 29 segments (Table 2.2-3) and keeping track of the number of organisms in each segment accounts for changes in tidal and freshwater flows and the distributions of organisms along the longitudinal dimension.

To simulate the stratified nature of the flow in the Hudson, the vertical/diurnal migration of fish larvae, and the heterogeneous distribution of eggs and larvae in the vertical dimension, the real-time model is divided into two vertical layers of equal depth. The partially stratified flow in the Hudson is simulated with individual sinusoidal functions for the ebb and flood cycles in the upper and lower layers as shown in Figure 2.2-6. More details regarding these sinusoidal functions are presented in a recent report prepared by LMS (1975e). This report also describes the migration function used to simulate movement of larvae between the upper and lower layers in the model. By directly simulating the tidal nature of the stratified flow in the Hudson and the vertical/diurnal migration of larvae, the model accounts for possible interaction of these phenomena.

The defining equation for the real-time model is derived from an approach presented by Rotenburg (1972) and is similar to equations used in physics and engineering to model transport processes. The defining equation is:

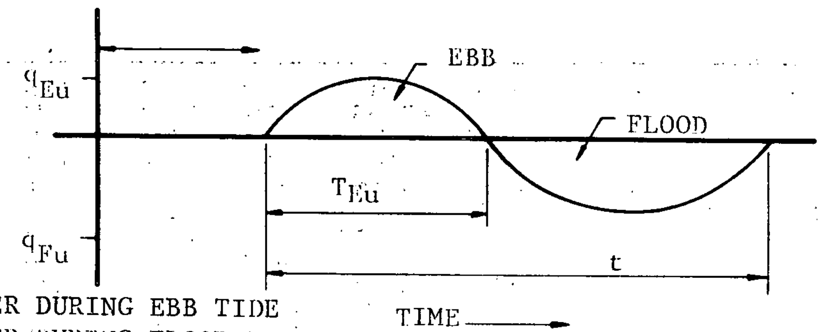
$$\frac{\partial c^k\ (x,a,t)}{\partial t} + \frac{\partial c^k\ (x,a,t)}{\partial a} + \frac{1}{A}\,\frac{\partial c^k\ (x,a,t)\ .\ Q^k(x,t)}{\partial x} =$$

$$\frac{1}{A}\,\frac{\partial}{x}\quad EA\,\frac{\partial c^k(x,a,t)}{\partial x} + M^k(x,a,t,) - E_R^k(x,a,t)\ .\ c^k(x,a,t) \qquad (2.1)$$

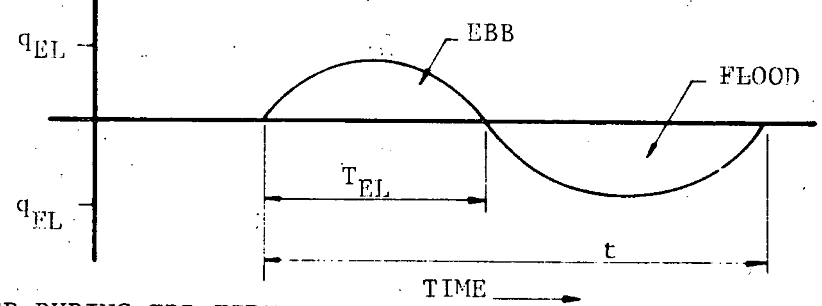
$$-KD(c,a)\ .\ c^k(x,a,t)$$

Table 2.2-3 Schematized Geometry Including Embayments and Local Datum of Hudson River

Segment No.	River Mile km	River Mile mi	Segment Length ΔX km	Segment Length ΔX mi	Total Width m	Total Width ft	Depth m	Depth ft	Core Width m	Core Width ft	Storage Width m	Storage Width ft	Datum m	Datum ft
1	193-209	120-130	16	10	792.5	2600	5.7	18.9	441.7	1449	1.5	5.0	55.6	128.5
2	177-193	110-120	16	10	977.5	3207	4.9	15.9	712.6	2338	1.3	4.3	56.4	184.9
3	161-177	100-110	16	10	1259.7	4133	6.0	19.6	983.0	3225	1.0	3.4	55.2	181.1
4	153-161	95-100	8	5	1232.3	4043	7.0	22.9	1051.6	3450	1.1	3.5	54.2	177.8
5	145-153	96- 95	8	5	1489.9	4888	7.2	23.8	1244.8	4084	2.3	7.6	53.9	176.9
6	137-145	85- 90	8	5	1301.2	4269	9.7	31.9	1102.5	3617	1.7	5.7	51.4	168.8
7	129-137	80- 85	8	5	928.7	3047	11.8	38.6	885.1	2904	1.0	3.1	43.4	162.1
8	121-129	75- 80	8	5	725.4	2380	16.2	53.2	719.0	2359	0.4	1.2	44.9	147.4
9	113-121	70- 75	8	5	772.1	2533	14.2	46.4	754.4	2475	0.7	2.1	47.0	154.2
10	109-113	68- 70	3	2	1042.1	3419	12.1	39.8	1011.6	3319	1.1	3.5	49.0	160.7
11	106-109	66- 68	3	2	1129.3	3705	12.2	39.1	939.1	3081	2.2	7.2	49.0	160.6
12	103-106	64- 66	3	2	1241.2	4072	11.2	36.8	1194.6	3919	0.9	2.8	142.2	163.6
13	100-103	62- 64	3	2	1622.4	5359	9.4	30.7	1518.2	4981	0.9	3.1	51.8	169.9
14	97-100	60- 62	3	2	1755.0	5758	9.3	30.6	1533.4	5031	1.4	4.5	51.8	170.0
15	93- 97	58- 60	3	2	2218.6	7279	7.5	24.8	1987.0	6519	1.4	4.6	53.6	175.8
16	90- 93	56- 58	3	2	1986.4	6517	8.4	27.7	1748.9	5738	1.2	3.8	52.7	172.9
17	85- 90	53- 56	5	3	963.8	3162	17.8	58.5	723.0	2372	1.5	4.9	43.3	142.1
18	80- 85	50- 53	5	3	798.3	2619	27.3	70.0	602.0	1975	1.3	4.3	39.8	130.6
19	76- 80	47- 50	5	3	627.6	2059	23.6	77.6	554.4	1819	0.8	2.6	37.5	123.0
20	71- 76	44- 47	5	3	800.7	2627	22.4	73.8	615.5	2019	0.8	2.8	38.7	126.8
21	68- 71	42- 44	3	2	1609.6	5281	13.2	43.3	1173.5	3850	1.8	5.8	41.9	137.4
22	64- 68	40- 42	3	2	1253.0	4111	13.4	44.0	1112.5	3650	1.8	5.8	47.7	156.5
23	61- 64	38- 40	3	2	3077.3	10096	7.0	22.8	2442.4	8013	1.6	5.1	54.1	177.6
24	58- 61	36- 38	3	2	4842.4	15887	4.7	15.4	4244.9	13963	2.7	9.0	56.4	185.0
25	55- 58	34- 36	3	2	3365.0	11040	5.8	19.2	2880.4	9450	2.8	9.3	55.2	181.2
26	52- 55	32- 34	3	2	1145.7	3759	6.2	20.5	2796.5	9175	2.0	6.6	54.8	179.9
27	48- 52	30- 32	3	2	3408.0	11181	5.4	17.6	3390.9	11125	2.0	6.5	55.6	182.4
28	32- 48	20- 30	16	10	2967.9	9409	6.5	21.2	2551.2	8370	1.3	4.4	54.6	179.2
29	16- 32	10- 20	16	10	1449.6	4756	8.6	28.1	1434.1	4705	0.4	1.4	52.6	172.4



q_{Eu}=MAX FLOW IN UPPER LAYER DURING EBB TIDE
q_{Fu}=MAX FLOW IN UPPER LAYER DURING FLOOD TIDE
T_{Eu}=DURATION OF EBB PHASE IN UPPER LAYER



q_{EL}=MAX FLOW IN LOWER LAYER DURING EBB TIDE
q_{FL}=MAX FLOW IN LOWER LAYER DURING FLOOD TIDE
T_{EL}=DURATION OF EBB PHASE IN LOWER LAYER

Figure 2.2-6 Schematic Flow in Upper and Lower Layers where

$c^k(x,a,t)$ = concentration (number of organisms per volume) at a point in the population space defined by x, longitudinal dimension; a, age; t, time in layer k.

$\frac{\partial c^k}{\partial t}$ = accumulation term

$\frac{\partial c^k}{\partial a}$ = maturation term

$\frac{\partial c^k \cdot Q^k}{\partial x}$ = convection term

$\frac{1}{A}\frac{\partial}{\partial x} \quad EA\frac{\partial c^k}{\partial x}$ = dispersion term

$Q^k(x,t)$ = real-time flow

E = dispersion coefficient obtained from Elder's equation

A = cross-sectional area of river

$M^k(x,a,t)$ = migration rate in vertical or longitudinal direction

$KD(c,a)$ = mortality rate

$E_R^k(s,a,t)$ = entrainment or impingement parameter

With correct specification of the parameter values, Equation 2.1 is applied for the egg and larval stages, where the mass transport effects of the river's hydrodynamics are operative, and for the juvenile stages, during which the behavioral characteristics of the fish determine their longitudinal distribution. During the larval stage, the migration term $M^k(x,a,t)$ is used to simulate the vertical/diurnal migration of the larvae. After the larvae mature into juveniles, their longitudinal distribution is largely determined by migratory preferences. Thus, in the simulation of the juvenile stage, the real-time flow Q and the dispersion coefficient E are set to zero and the migration term is used to determine longitudinal distribution. In both the larval and juvenile stages, the migration rate is calculated directly from field data (Sections 8.2.5 and 8.2.6).

2.2.6 TEMPERATURE REGIME. Ambient temperature is defined as that temperature which exists in a water body without the addition of artificial (manmade) heat. Since power plants with once-through cooling systems use large volumes of cooling water, they contribute artificial heat to water bodies.

Within any given natural water system, ambient temperatures vary both temporally (seasonally and daily) and spatially (over the length, width, and depth of the water body). Such changes are natural phenomena caused by water body geometry, overland runoff, dispersion and circulation, temperatures of the ocean and fresh water, and climatological conditions such as air temperature, wind, and solar radiation. These natural variations make it difficult to determine the effects of artifical heat on a water body's temperature, a problem which becomes even more difficult in the absence of consistent historical records of the natural temperature variations before the addition of artificial heat.

Figure 2.2-7 shows the various sources and sinks of heat input into a typical estuarine system. (Input can be either positive, in which case heat is added, or negative, where the temperature of the water body is decreased.) The sources, which are discussed next, include inputs due to atmospheric conditions, tributaries, ocean and freshwater flow, artificial heat, and river geometry. Equilibrium temperature also is discussed because of its importance in the overall heat transfer through the water surface.

2.2.6.1 Atmospheric Conditions. The major sources of heat input into the body are those related to atmospheric conditions. The five major processes are shown in Figure 2.2-7.

2.2.6.2 Equilibrium Temperature. For specified meteorological conditions and solar radiation, a water surface temperature exists which will yield a zero net heat transfer across the surface; this temperature

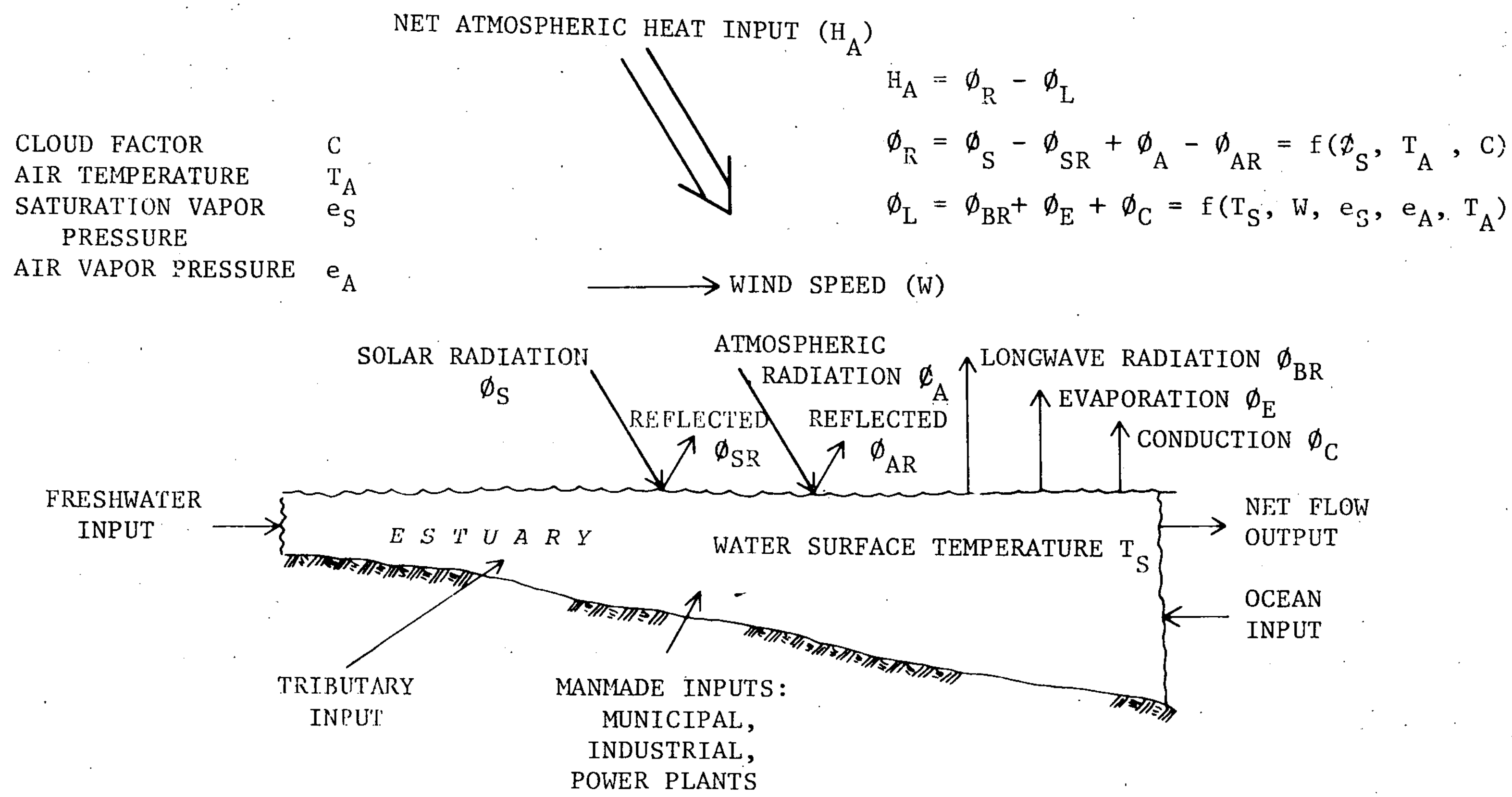


Figure 2.2-7 Sources of Heat Input to Estuary

is called the water surface equilibrium temperature (T_e). This equilibrium temperature and the ambient water surface temperature (T_s) may be used to express the net heat rate, or the rate at which the body of water is cooled or heated. This can be expressed as follows:

$$\Delta H = \overline{K}\ (T_s - T_e) \tag{2.2}$$

where

ΔH = net rate of heat transfer (+ or -) (Btu ft^{-2} day^{-1})

$\overline{K}$ = overall heat transfer coefficient across the water surface (Btu ft^{-2} $^{o}F^{-1}$ day^{-1})

Equation 2.2 indicates that an ambient surface temperature greater than the corresponding equilibrium temperature would result in a net heat loss from the water body through the water surface. An equilibrium temperature less than the ambient surface temperature would mean that the water body was warming; i.e., it would indicate a net heat gain across the water surface.

Both the heat transfer coefficient and the equilibrium temperature are highly dependent on solar radiation, atmospheric radiation, air temperature, relative humidity, air vapor pressure, and wind speed, all of which determine the rate of heat transfer across the water surface.

Figure 2.2-8 shows the relationship between the equilibrium surface temperature and the river ambient temperature near Indian Point on the Hudson River during the period from September 1973 through August 1974. As indicated, the naturally occurring temperature (ambient) lags behind the equilibrium temperature by approximately 1 mo. This shows the water body to be warming from February through July and cooling from August through January. The two periods during which no heat transfer takes place (ΔH=0) are mid- to late February and late July.

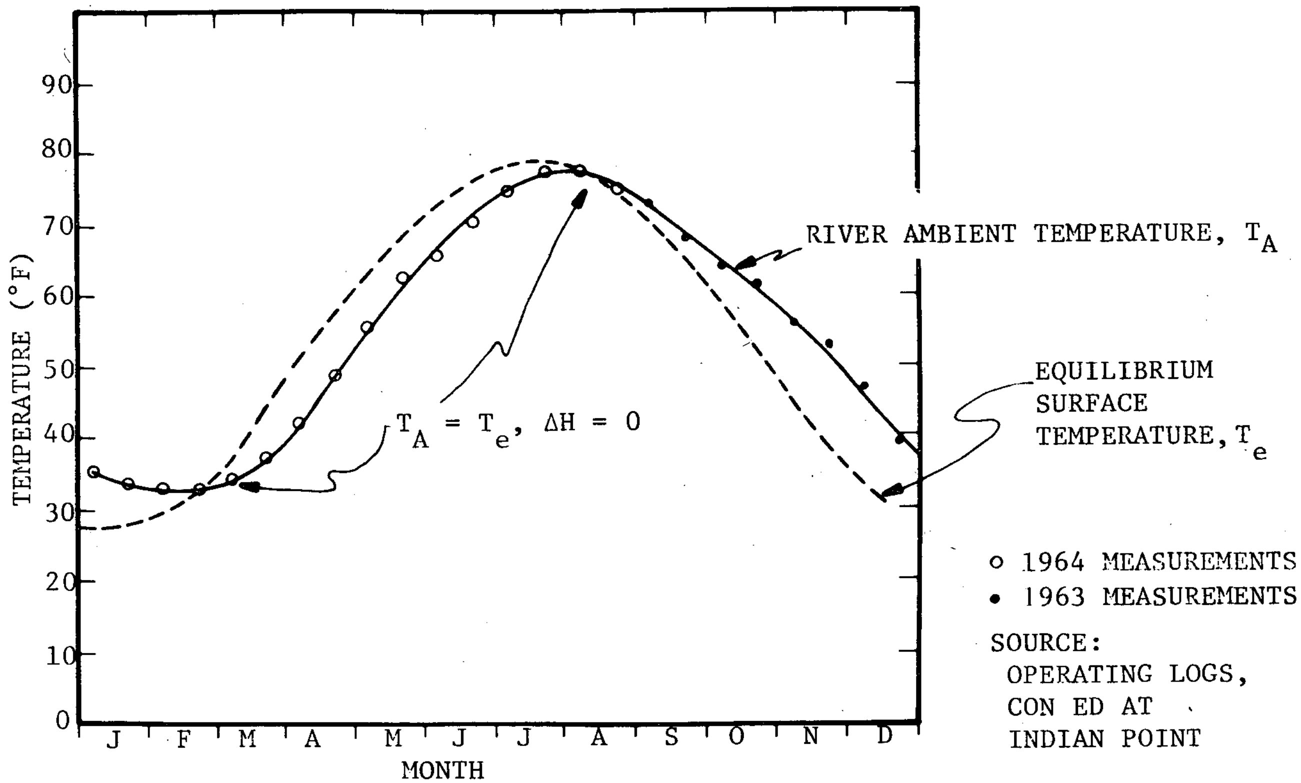


Figure 2.2-8 Hudson River Ambient Temperature Near Indian Point

2.2.6.3 Tributaries. The major tributaries of the lower Hudson River are Kinderhook Creek (RM 125, km 200), Catskill Creek (RM 112, km 180), Roeliff-Jansen Kill (RM 110, km 177), Esopus Creek (RM 101, km 163), Roundout Creek (RM 91, km 146), Walkill River, Wappinger Creek (RM 67, km 108), and the Croton River (RM 34, km 55). North of Troy dam, the river is considered to be a freshwater input into the estuary. The magnitude of this freshwater flow, as well as its associated temperature, has a profound effect on the overall dynamics and temperature of the estuarine portion of the river.

The remaining tributaries are generally smaller in size and experience higher velocities due to their smaller cross-sectional areas. Therefore, heat input into these tributaries is retarded, causing a summer temperature difference of 1-2^{o}F (.58-1.1^{o}C) between the tributaries and the main stem.

Another source of river freshwater flow is groundwater which, because of ground insulation, is usually colder in the summer and warmer in the winter than the ambient temperature of the main water body.

2.2.6.4 Ocean. The ocean's effect on the estuarine temperature and dynamics is similar to that of the freshwater flow at the other end of the estuary. However, the ocean, because of its size and depth, is a more constant water body, cooler than freshwater bodies in the summer and spring because its temperature increases less rapidly and warmer in the winter and fall due to a less rapid decrease.

2.2.6.5 River Geometry. The river geometry, as well as the freshwater flow and tidal currents caused by the ocean, affects the river's temperature and its hydrodynamic dispersive characteristics. The nearer the ocean boundary, the greater the influence of the tidal currents that create a reversal of currents and greater mixing dispersion. In the Hudson River, tidal currents are minimal at the northern reach of the estuary (Albany), where the freshwater flow at times completely masks the tides.

The river's cross-sectional area, surface width, and depth largely determine its hydrodynamics; because of the wide range of these dimensions (Fig. 2.2-1), the river parameters of mixing and temperature vary greatly. An even more important parameter is the surface area because heat transfer to or from the atmosphere, which is one of the largest sinks or sources of heat, occurs at the surface. Large, shallow areas such as Haverstraw Bay have a greater ability to absorb or radiate heat than do deep narrow areas such as West Point, and they create temperature gradients over the longitudinal length of the river.

2.2.6.6 Manmade Inputs. Inputs from human activities include municipal and industrial waste discharges and, more significantly, power plant discharges. Some manmade sources exercise either a heating or a cooling effect on the river. For example, a sewage effluent having a temperature of 65°F (16°C) constitutes a cooling factor in the Hudson during the summer because river ambient temperatures are higher. The greatest percentage of the artificial heat input results from the use of river water for condenser cooling purposes for the electric power industry. All of these factors create significant temperature variations in the Hudson River, so temperatures recorded over past years can be used to indicate the extent of these variations.

The two background temperatures, i.e., those of ocean water and fresh water, follow the same general seasonal pattern although there is a time lag because warming and cooling processes take place in ocean water after they have already occurred in fresh water. This phenomenon occurs because relatively shallow streams discharging fresh water into the estuary warm and cool more rapidly than the deep ocean waters, which never reach the seasonal temperature extremes of the streams and rivers. Since the effect of freshwater temperature is more pronounced in the upper reaches of the estuary while that of ocean-water temperature is felt in the downstream segments of the estuary, longitudinal gradients in estuarine temperatures are often observed. Longitudinal temperature profiles in which temperature decreases from the mouth toward the head of the estuary are typical for late autumn and winter; temperatures that increase from the estuarine mouth toward the head are typical for spring and summer. These trends can be seen in Figure 2.2-9.

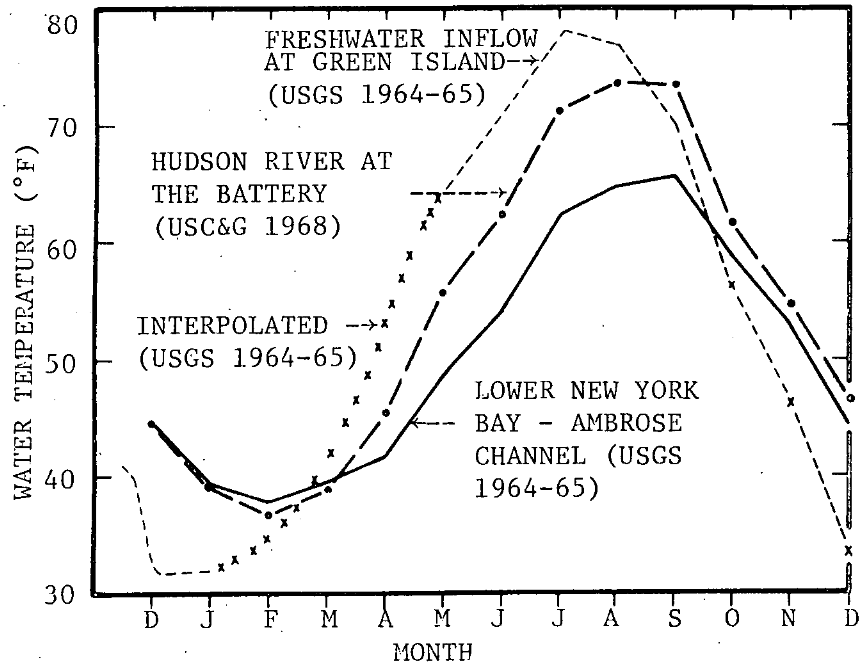


Figure 2.2-9 Comparison of Seasonal Variations in Temperatures of Ocean and Freshwaters Entering Hudson River Estuary, 1964

Hudson River temperatures vary significantly from year to year. For example, the USGS observations at Poughkeepsie, New York (Tables 2.2-4 and 2.2-5), indicate river temperatures $\geq 77^oF$ (25^oC) during all days of August 1970 but only 12% of the time in August 1965. Similarly, the river temperature was $\leq 33^oF$ ($.55^oC$) during 95% of the days in February 1973, but was never $\leq 33^oF$ ($.55^oC$) during February 1970.

Considerable diurnal variation in Hudson River ambient temperatures has also been observed. In August and September 1929, temperatures were recorded as part of a USGS current survey of the Hudson River. Because no significant artificial heat source existed on the Hudson River in

Table 2.2-4 Lower Hudson River at Poughkeepsie† Variations in Water Temperature during July and August, 1964-73

Year	Maximum Observed Temperature During Year (°F)	July % of Days with Temperature Equal to or Greater than Stated Magnitude			August % of Days with Temperature Equal to or Greater than Stated Magnitude		
		77°F	75°F	73°F	77°F	75°F	73°F
1964	78.0	41	89	100	88	100	100
1965	77.0	0	73	89	12	100	100
1966	80.0	79	100	100	96	100	100
1967	7910	39	67	89	90	100	100
1968	78.8	38	57	62	87	100	100
1969	78.1	0	94	100	57	100	100
1970	80.0	*	*	*	100	100	100
1971	78.1	65	100	100	92	92	100
1972	79.0	27	38	50	30	78	100
1973	78.1	16	77	77	56	100	100
Long-Term Average	78.61	34	77	85	70.5	97	100

*Insufficient number of observations.
†Based on Observations by the New York State Department of Environment Conservation

Table 2.2-5 Lower Hudson River at Poughkeepsie† Variations in Water Temperature during January and February 1964-73

Year	January: % of Days with Temperature Equal to or Less than Stated Magnitude 33°F	34°F	36°F	February: % of Days with Temperature Equal to or Less than Stated Magnitude 33°F	34°F	36°F
1964	18	100	100	0	100	100
1965	69	71	88	100	100	100
1966	4	52	100	21	100	100
1967	0	25	100	0	100	100
1968	8	79	81	0	43	86
1969	39	74	100	0	24	100
1970	17	100	100	0	92	100
1971	81	100	100	71	100	100
1972	35	90	100	92	100	100
1973	69	88	100	95	100	100
Long-Term Average	40	80	97	38	86	99

†Based On Observations By The New York State Department of Environment Conservation

1929, these data give a good indication of natural temperature variations. Changes in river temperatures by 3.0°F (1.6°C) within an approximately 8-hr period were recorded during this survey (Fig. 2.2-10).

In addition to diurnal temperature variations, the 1929 survey recorded vertical and latitudinal temperature variations (Fig. 2.2-10); temperature differentials of 1.4°F (.77°C) over depths of 20 ft (6 m) and 3.0°F (1.6°C) across the river width were reported in this survey. Because of the lag between ocean temperature and freshwater temperature, the varying climatic patterns through the lower Hudson, and changes in river geometry, there are pronounced longitudinal temperature patterns in the lower Hudson estuary. The 1929 data in Figure 2.2-11 illustrate that longitudinal temperature differences occurred before the addition of artificial heat. The more recent data of Figures 2.2-12 and 2.2-13 indicate the persistence of a particular temperature pattern during certain months and how distribution changes throughout the year.

The above data indicate the extent and some of the causes of natural temperature variations in the lower Hudson River. Table 2.2-6 summarizes these variations.

Table 2.2-6 Temperature Variation in Lower Hudson River, 1974-75

	Temperature Range (°F)	(°C)
Temporally		
Year to Year	2-4	(1.1-2.2)
Seasonal	33-80	(.55-17)
Diurnal	1-4	(.55-2.2)
Spatially		
Longitudinal	0-15	(0-8.2)
Latitudinal	0-4	(0-2.2)
Vertical	0-4	(0-2.2)

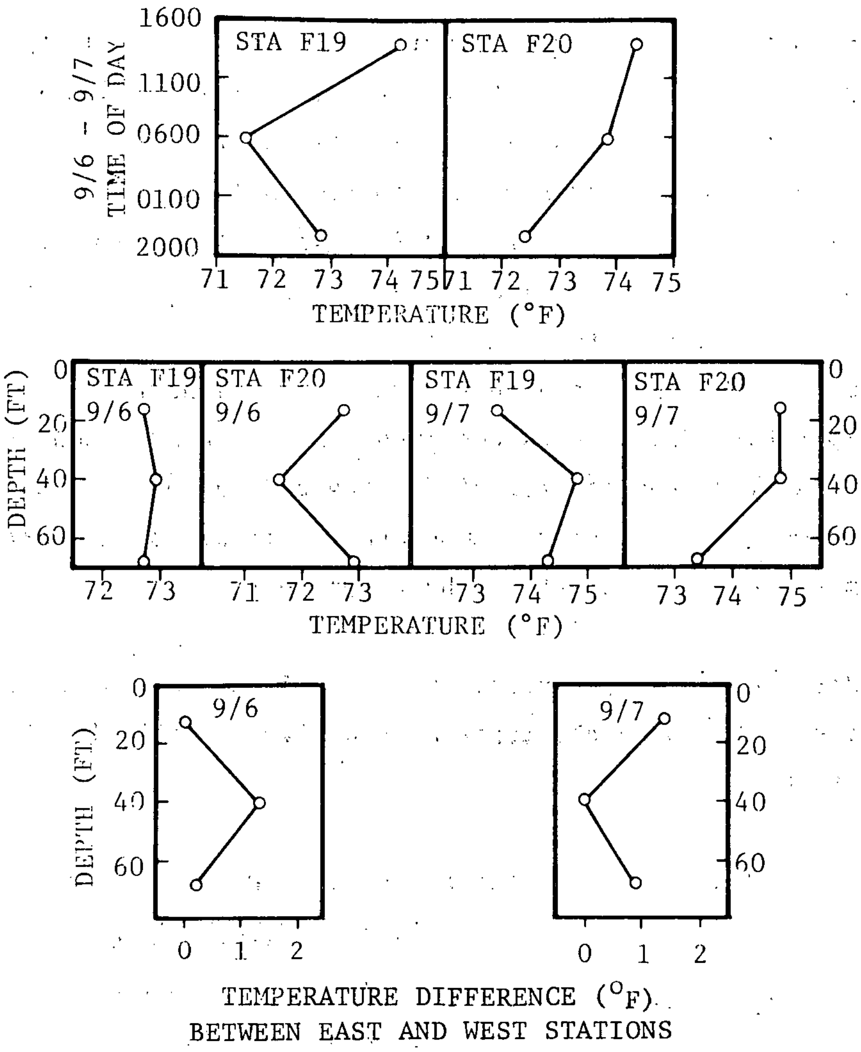


Figure 2.2-10 Diurnal, Vertical, and Lateral Temperature Variations, 1929 at Storm King Mountain (West, Station F19; East, Station F20)

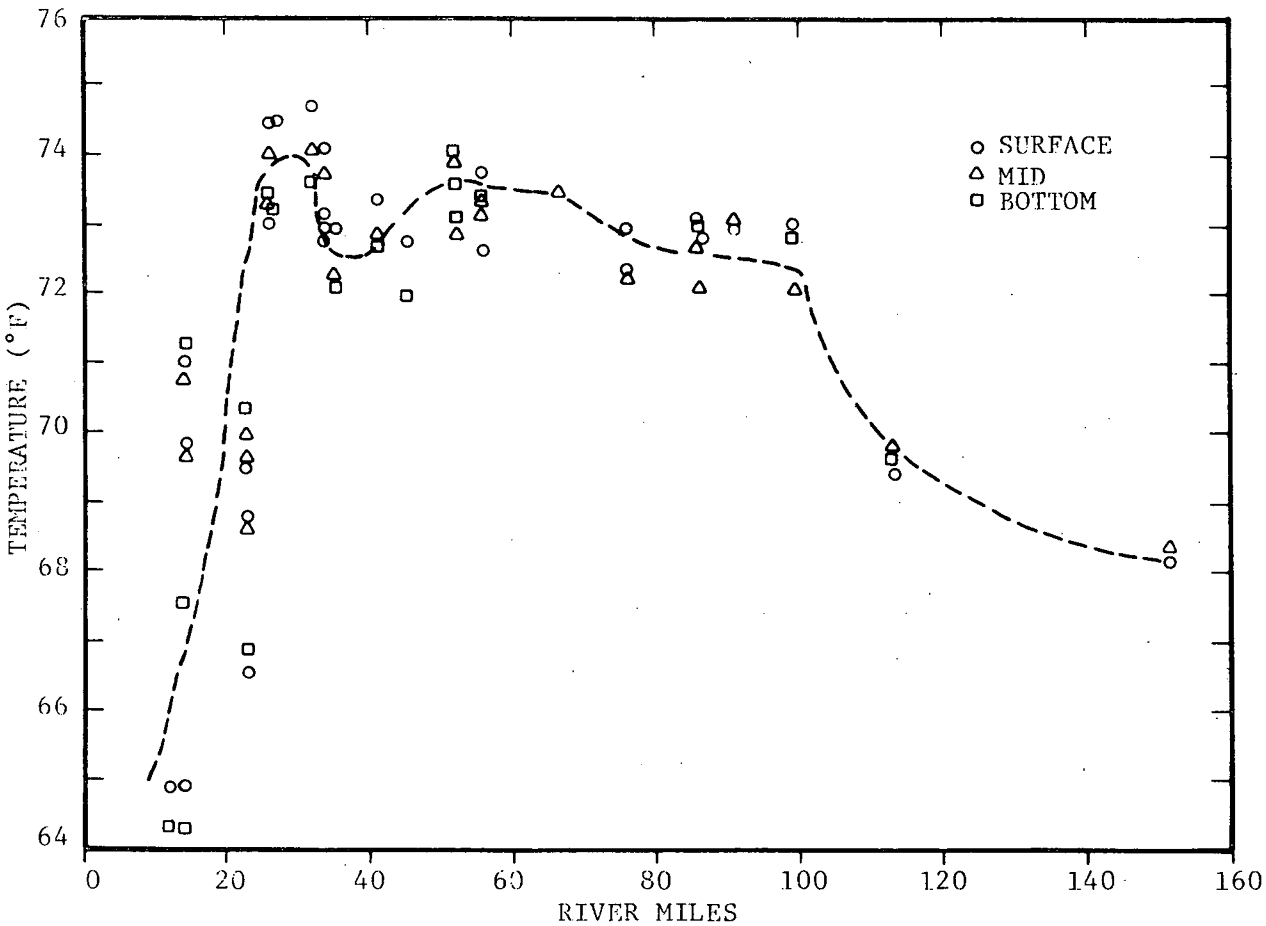


Figure 2.2-11 Hudson River Temperature Readings in 1929

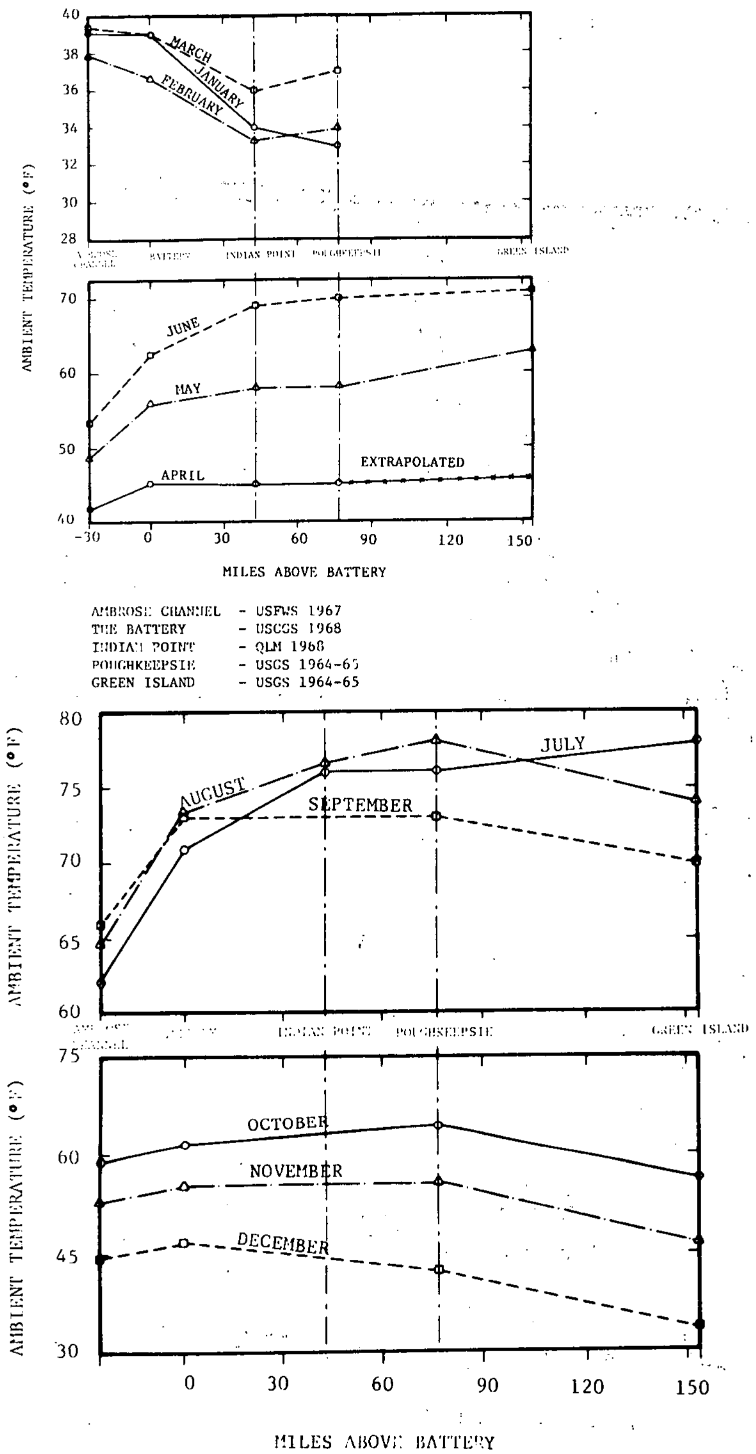


Figure 2.2-12 Longitudinal Profiles of Monthly Average Water Ambient Temperatures in Lower Hudson River

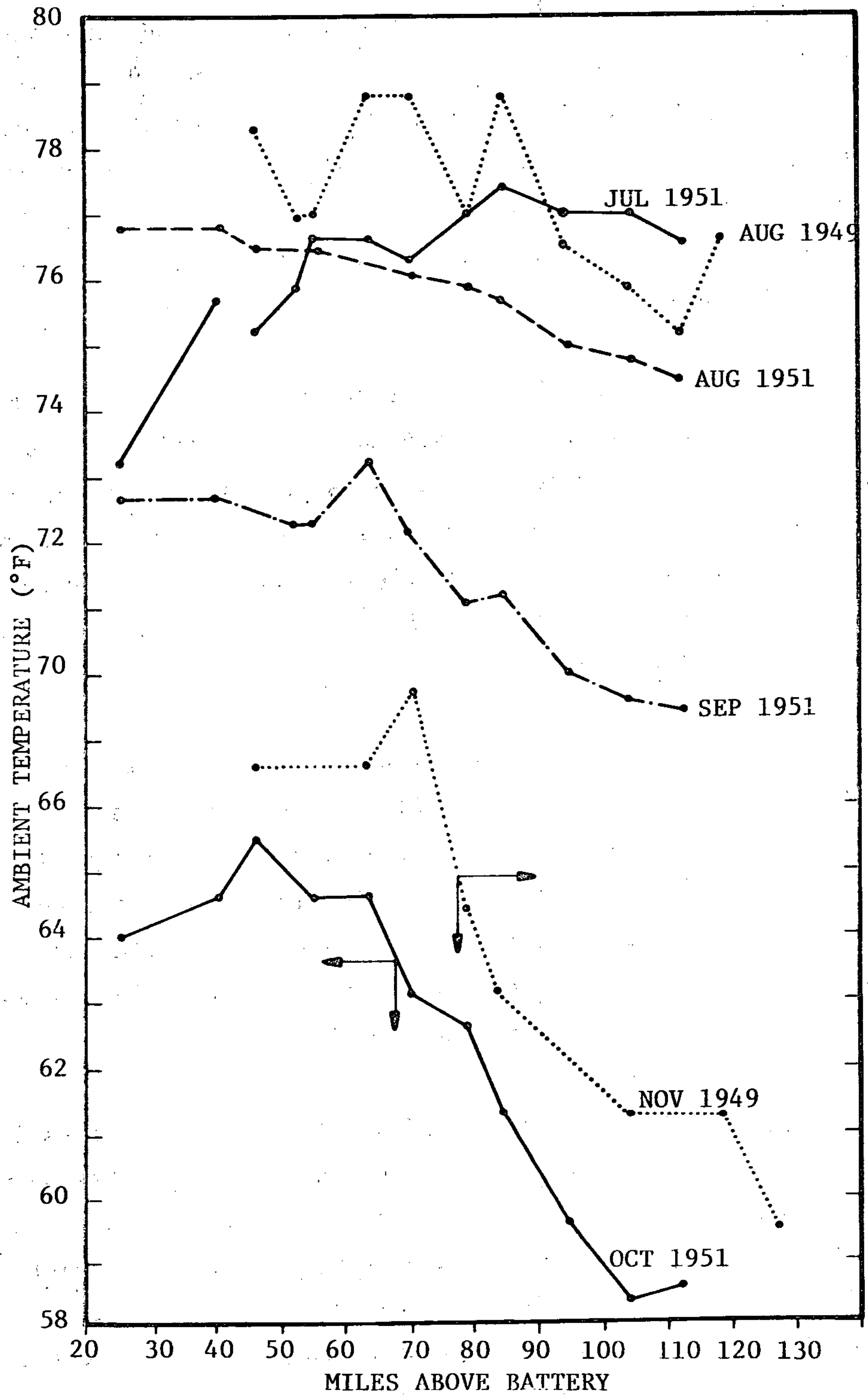


Figure 2.2-13 Hudson River Ambient Temperature Profiles 1947-75

2.2.7 OTHER PHYSICAL PARAMETERS. The quality of Hudson River water is affected by siltation, color imparted by dissolved substances, and transport of suspended solids. The operation of power plants does not significantly affect any natural properties of the water associated with these parameters. Because of their relevance to ecological processes such as photosynthesis and production of benthic animals, they are discussed in Appendix A.

2.2.8 WATER CHEMISTRY. Biological production is limited by the availability of dissolved nutrients and may be affected by the presence of toxic heavy metals. Natural processes as well as activities of man significantly influence these two classes of dissolved substances, although power plant operation has no significant effect. Levels of nutrients and heavy metals in Hudson River water are briefly discussed and summarized in Appendix B.

The two aspects of water chemistry that have received attention in relation to the operation of power plants are dissolved oxygen and salinity. Concern about the former, which is of critical importance to aquatic life, has been based on the possibility that DO levels would be reduced in plant effluents. Salinity is of interest, not because it is affected by plant operation, but because it is important in water circulation phenomena and influences the distribution and movement of fish.

2.2.8.1 Dissolved Oxygen. The ecological significance of dissolved oxygen in the Hudson River is discussed in Appendix B. It has been speculated that the operation of the Indian Point power plant will lower dissolved oxygen in the circulating water (and thus in the river) because of temperature and pressure effects on the saturation value of DO. Earlier analytical and field work indicates that there is no discernible difference in the DO concentration between the intake and discharge due to plant operations and that the thermal plume will not cause significant reduction in the river DO concentration (TI 1973c:IV-44 to IV-56).

In 1974 and 1975, Con Edison conducted a series of DO surveys across the cooling water systems of both Indian Point Units 1 and 2 pursuant to requirements specified in the 401 Certificate issued by DEC for Indian Point Unit 2. Examination of the 1974-75 data that were submitted to NYSDEC and NRC confirms the previous finding that plant operation causes no discernible difference between DO measurements obtained at the intake of Unit 2 and the discharge canal (Con Edison 1974b, 1975a, 1975b). The NYSDEC concurred with this conclusion (reached on the basis of the first and second surveys) and consequently amended the 401 DO survey requirements from 30 days of measurements four times a year (a total of 120 days per year) to 5 days of measurements to be conducted at the time of each thermal survey.

It is apparent from the intake and discharge measurements that elevated temperatures alone do not decrease DO levels. Since the maximum temperature of the cooling water is reached in the discharge canal, the maximum driving force to reduce DO levels (by increased temperature) would be found only in the canal; any impact in the river, where the cooling water is diluted and reduced in temperature, would be substantially less.

2.2.8.2 Salinity. The concentration of dissolved solids of seawater, salinity, is an important water quality parameter for estuarine areas. The concentration of dissolved salts determines the species of aquatic organisms that are able to live there, and salinity also interacts with other variables (e.g., temperature) to determine the solubility of oxygen in water: as salinity increases, the possible dissolved oxygen concentration decreases. Salinity is expressed in parts per thousand (o/oo).

The intrusion of salt from the ocean into the Hudson River is the primary cause of density (salt) induced circulation in the estuary. The net movement of estuarine water resulting from this circulation affects the estuarine transport of energy, mass, and planktonic forms of aquatic life.

2.2.8.2.1 Hudson River Salinity Data. Since 1929, there have been 22 intrusion surveys and continuous fixed location salinity measurements. Some of the recorded salinity data are presented as longitudinal salinity profiles in Figure 2.2-14. Although freshwater flow is the major factor affecting salt intrusion in the estuary, a correlation of available salinity data with corresponding freshwater flow rates is difficult because several other factors also affect the data. These factors are briefly discussed below.

Because of the cyclical variation of the tidal current, the salinity at a given location is a continuous function of time. The intratidal variation in river salinity generally follows a sinusoidal function: maximum concentrations occur at high water slack, whereas minimum concentrations are at low water slack. The differences between slack and mean salinities may represent a significant portion of mean salinity. Therefore, sampling time with respect to tidal phase is an important factor affecting recorded salinity concentrations.

Observations also indicate that salinity concentrations vary significantly with depth, increasing from a minimum at the water surface to a maximum at the river bottom. Thus, sampling depth is another important factor that may significantly influence reported salinity concentrations. Some river salinity surveys mentioned previously have reported only mid-depth values while others have reported cross-sectional average salinity values based on 10 samples taken at different locations across the river and at different depths.

Observations also indicate that the length of salt intrusion and river salinities are influenced, to some extent, by the prevailing tidal range conditions. Maximum concentrations of salt correspond to periods of minimum tidal ranges.

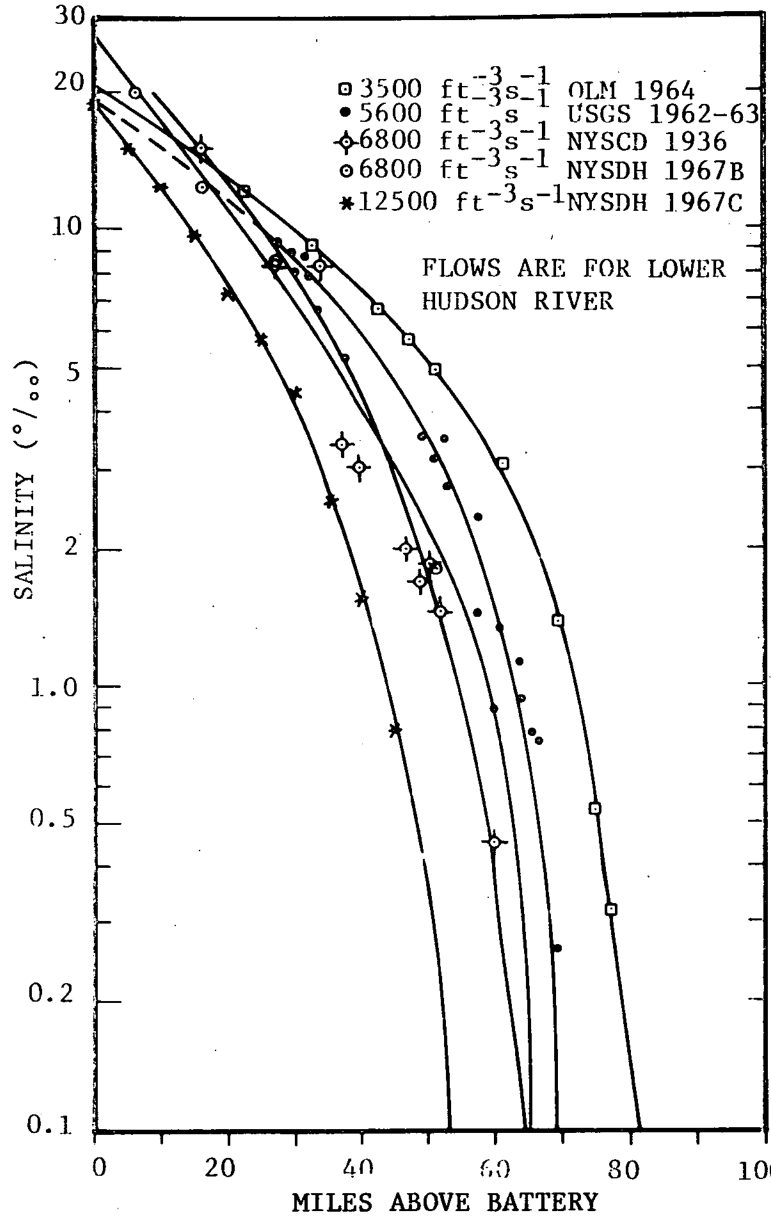


Figure 2.2-14 Hudson River Mean Salinity Intrusion Profiles

Prevailing meteorological conditions during a particular survey also may influence salinity concentrations through changes in sea level, wind speed, direction, and runoff from precipitation.

Freshwater flow has already been identified as the factor having the greatest impact on salt intrusion. However, under variable freshwater flow conditions (unsteady state), a common relationship between freshwater flow and salinity distribution is extremely difficult to establish. Furthermore, accurate determination of total freshwater flow into the estuary under conditions of highly variable freshwater inflow is extremely difficult.

The most complete Hudson River surveys are presented in Table 2.2-7, which also gives the characteristics of an ideal salinity survey for comparison. This table indicates that the 1936, 1962-63, 1964, and 1967 (boat) surveys most closely approximated conditions of the ideal survey.

2.2.8.2.2 Empirically Developed Correlations of Hudson River Salt Intrusion Characteristics and Freshwater Flow. Available Hudson River salinity data has been used to develop an empirical relationship between salt front location (concentration of 0.1%) and freshwater flow and generalized mean salinity profiles. The developed relationship between lower Hudson River freshwater flow and salt front location, depicted in Figure 2.2-15, indicates a strong correlation between these two parameters.

Several parameters influence the shape of steady state longitudinal salinity profiles:

- Freshwater flow
- Intrusion length
- The controlling freshwater flow at which the tidal average salinity reaches a concentration of 0.1% at a given distance from the estuarine mouth
- Mean salinity concentration of the ocean

Table 2.2-7 Hudson River Salinity Survey Evaluation Sheet

Survey	Sampling Time	Location of Sampling Points	Tidal Range Variation	Meteorological Conditions	Freshwater Stability	Field Instruments	Conducted by	Date
Ideal survey	TA	CA	N	N	SS	CT		
1929	TA	M/CA	N	N	SS/US	D	USC&GS	8/29 - 9/14
1936	TA	CA	N	N	SS	CT	NYSCD	6/19 - 9/4
1959	S/TA	M	N	N	SS/US	CT	NYCDH	8/5 - 9/2
1962-1963	S/TA	M/CA	N	N	SS	CT	USGS	Sept. & Oct.
1964	TO	CA	N	N	SS	CT/SAL	QL&M	11/19 - 24
1965	S/TA	M/B	NT	U	US	U	FWPCA	7/19 - 22
1967 (boat)	TA	CA	N	N	SS	CT	NYSDH/QL&M	9/21 - 26
1967 (copter)	TA	MM	N	N	US	CT	NYSDH/QL&M	8/14 - 17
1966	S	M	N/NT	N	US/SS	C/SAL/CT	QL&M	Jan. - May

Key:
- B = Bank location
- C = Conductivity
- CA = Cross-sectional average
- CT = Chemical Titration
- D = Density
- M = Mid-channel
- MM = Mid-channel mid-depth
- N = Normal
- NT = Neap Tide
- SAL = Salinometer
- SS = Steady-state
- TA = Tidal average
- U = Unknown
- US = Unsteady-state

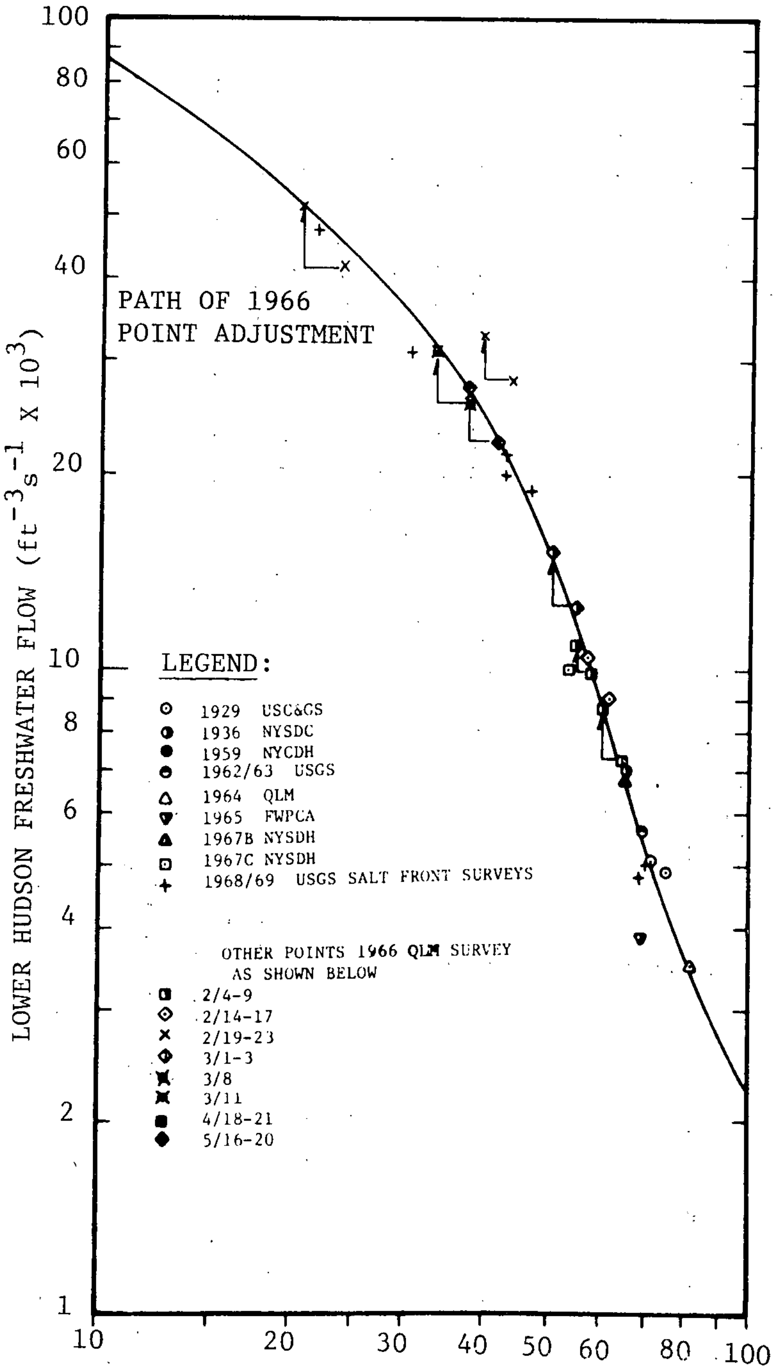


Figure 2.2-15 Hudson River Effect of Freshwater Flow on Equilibrium Length of Mean Salinity Intrusion

These parameters were combined to form the generalized relationship shown in Figure 2.2-16.

It should be stressed that these figures are based on observed normal behavior of the Hudson River salinity intrusion and that, during transient states of freshwater flow, actual salinity concentrations may be significantly different. Flow rates of short duration may not result in the steady state salinity profile indicated in the illustrations since the duration of freshwater flows at a certain rate (or rates) is an important factor in the salinity intrusion process, as is the flow rate itself.

2.2.9 BIOTA OF LOWER HUDSON RIVER. Organisms of the lower Hudson River include species characteristic of both fresh and marine waters, as well as true estuarine forms. The species are distributed along a gradient of increasing salinity from the permanent freshwater areas (Kingston and north) to the higher salinity waters of New York harbor. Therefore, the Hudson River includes more species than are found within the biotic communities of any one geographical area of the lower river.

Primary producers in the Hudson include phytoplankton, periphytic algae, and aquatic vascular plants. Since the Hudson is turbid, lack of light is a major factor limiting plant growth; photosynthesis is generally restricted to a shallow surface zone (the upper 1 m). Vascular plants are restricted to marginal nearshore areas and generally extend <100 yd (91 m) from shore. These plants are consumed directly by some animals but probably make their greatest contribution to the aquatic food web as a detrital component when they die and decompose. In addition, they provide habitat for aquatic invertebrates and are a source of protection and food for juvenile fish.

Submergent and emergent aquatic plant species in six marshes of the Hudson are listed in Tables 2.2-8 and 2.2-9. A major brackish marsh occurs at Piermont, and a number of freshwater marshes are located north of Haverstraw Bay.

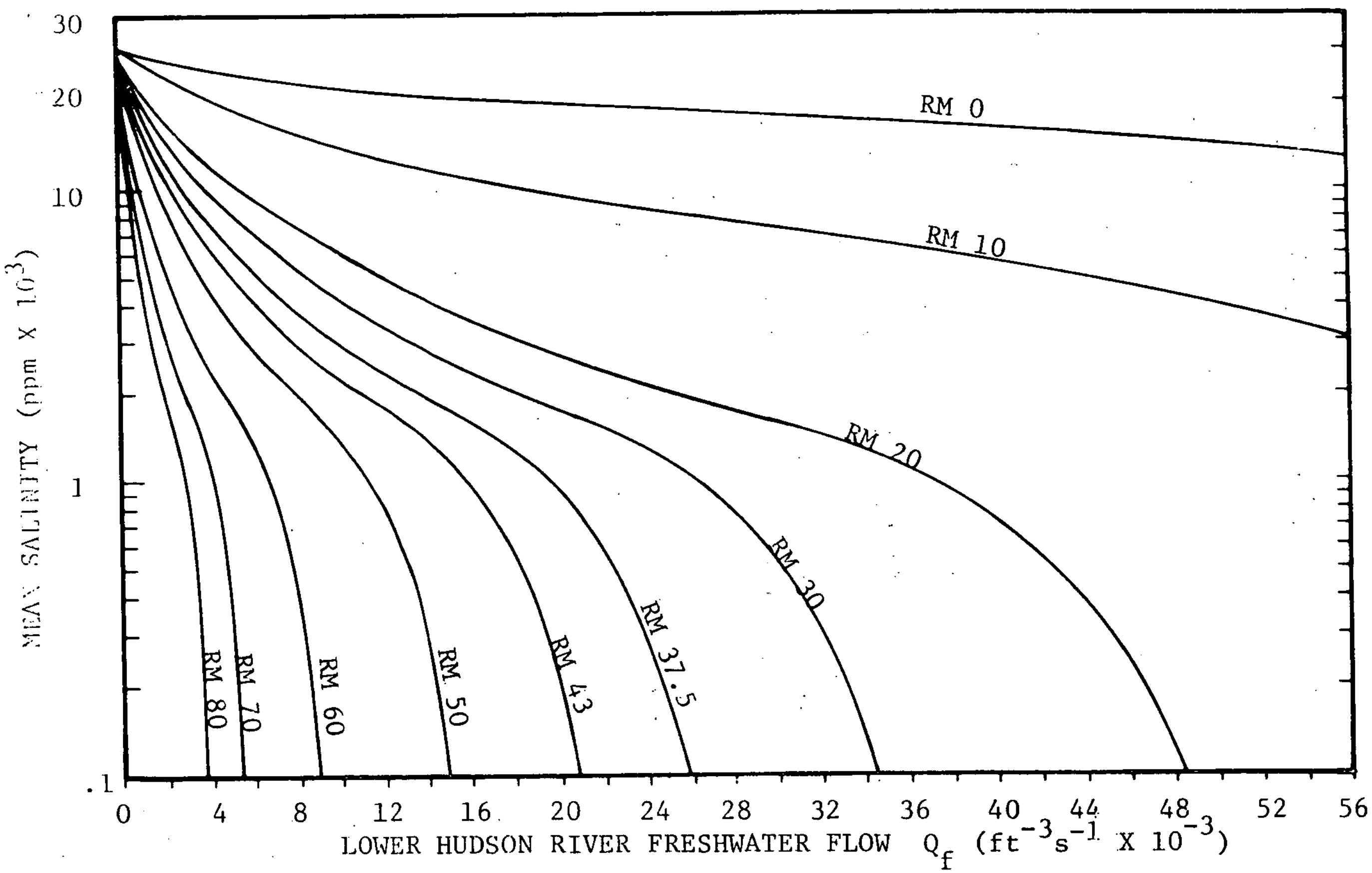


Figure 2.2-16 Hudson River Generalized Mean Salinity Profiles under Steady-State Conditions

Table 2.2-10 lists the dominant phytoplankton of the Hudson. These small plants serve as a direct food source for herbivorous planktonic and benthic invertebrates, but their relative importance in the food web compared with particulate detrital material remains to be quantified. Data indicate that phytoplankton growth in the Hudson is light limited and that potential eutrophication problems such as obnoxious algal blooms are minimal. Seasonal changes in percent composition of the major algal groups are presented in Figure 2.2-17.

Table 2.2-8 The Distribution of Submergent Aquatic Plants in the Hudson River

Plant Species	Kingston*	Haverstraw Bay**	Nyack Area***
Potamogeton perfoliatus	X	X	X
P. pectinatus	X	X	
P. crispus	X	X	
P. epihydrus	X		
Vallisneria americana	X	X	X
Myriophyllum spicatum	X	X	
Trapa natans	X		
Najas minor	X		
Zannichellia palustris			X
Heteranthera dubia	X		

X = plant species observed
* = QLM, 1973
** = LMS, 1975
*** = Menzie, unpublished

Table 2.2-9 Distribution and Relative Abundance of Some High Aquatic Plants in 6 Hudson River Marshes, 1972*

Taxon	Piermont	Croton	Haverstraw	Iona	Manitou	Consitution
PTERIDOPHYTES (Ferns)						
Thelypteris palustris	xx	x	xx	xxx	xxx	xxx
Onoclea sensibilis	?	x	xx	xx	xx	xx
Osmunda regalis	?	-	x	xx	xx	xx
MONOCOTYLEDONOUS PLANTS						
Graminae (Grasses)						
Phragmites communis	xxx	xx	xx	xx	x	xx
Spartina alterniflora	xxx	xx	x	-	-	-
S. cynosuroides	xxx	x	x	-	-	-
S. patens	xxx	xx	-	-	-	-
S. pectinata	x	-	x	-	-	-
Distichlis spicata	xxx	xx	-	-	-	-
Zizania aquatica	-	x	xx	x	-	xxx
Echinochloa walteri	?	xx	xx	xx	?	xx
Leersia oryzoides	?	xx	xx	-	-	-
Cyperaceae (Sedges)						
Scirpus robustus	xx	x	-	-	-	-
S. americanus	xx	xx	xx	x	x	x
S. fluviatilis	xx	x	x	-	-	-
S. olneyi	x	xx	x	xxx	xx	xx
S. validus	xx	x	x	x	-	xx
Cyperus odoratus	?	xx	xx	?	?	?
Eleocharis calva	?	xx	?	?	?	?
Eleocharis parvula	?	xx	?	?	-	-
Juncaceae (Rushes)						
Juncus gerardi	xx	x?	-	-	-	-
Other Monocots						
Typha augustifolia	xxx	xxx	xxx	xxx	xxx	xxx
T. Latifolia	x	-	x	x	xxx	x
Peltandra virginica	xx	xx	xxx	xxx	xxx	xxx
Pondederia cordata	?	x	x	xx	?	xx-xxx
DICOTYLEDONOUS PLANTS						
Broadleaf						
Lilaepsis lineatae	xx	xx	?	?	?	?
Iva frutescens	xx	-	-	-	-	-
Solidago sempervirens	xxx	-	-	-	-	-
Atriplex patula	x	x?	-	-	-	-
Ptilimnium capillaceum	x	xx	-	-	-	-
Lythrum salicaria	xx	xx	xx	xx	xx	xx
Rosa palustris	?	x	x	x	x	xx
Cornus amomum	?	x	x	x	x	xx
Hibiscus palustris	xx	xx	x	x	?	xx
Impatiens biflora	x	x	xx	xx	x	xx
Cephalanthus occidentalis	-	x	x	x	x	x
Rhus vernix	-	-	-	xx	x	-
Pluchea purpurascens	xx	xx	x	?	-	xx
Polygonum arifolium	x	?	xx	xx	x	xx
P. punctatum	xx	xx	xx	xx	-	xx

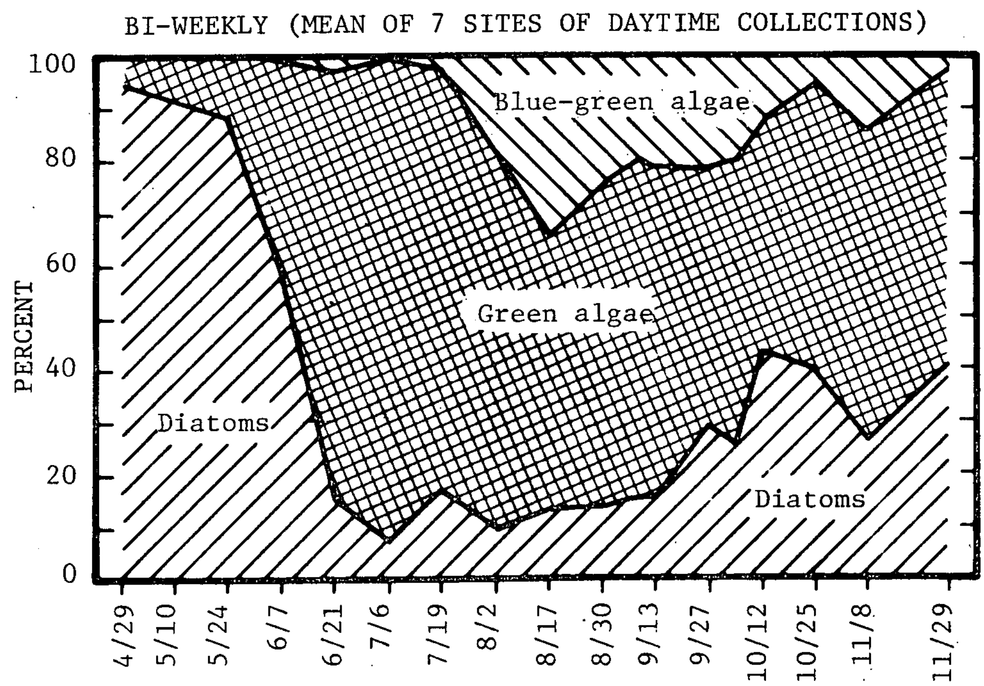
Key: x = incidental
xx = occasional to common
xxx = very common or large clones
\- = not present
? = questionable identification

* Boyce Thompson Institute 1974 cited in LMS 1975

Table 2.2-10 Distribution of Dominant Phytoplankton in the Hudson River (1971-1974)*

TAXON	KINGSTON	NEWBURGH	HAVERSTRAW BAY
Diatoms			
Asterionella sp.		X	X
Coscinodiscus sp.	X	X	
Cyclotella sp.	X	X	X
Melosira spp.	X	X	X
Navicula sp.		X	X
Skeletonema costatum			X
Green Algea			
Actinastrum sp.	X	X	
Ankistrodesmus	X	X	
Chlamydomonas sp.			X
Coelastrum sp.		X	
Dictyosphaerium sp.	X		X
Echallocystis sp.			X
Eudorina sp.		X	
Micractinium sp.	X	X	
Mougeotia sp.		X	
Pandorina spp.	X	X	
Pediastrum sp.	X	X	X
Scenedesmus sp.	X	X	X
Stichicoccus sp.			X
Tetradesmus sp.		X	
Tetrastrum sp.	X	X	
Ulothrix sp.			X
U. subtillissima			X
Blue Green Algae			
Anabeana sp.		X	
Anacystis sp.	X		X
Aphanocapsa sp.	X		
Aphanizomenon flos-aquae	X	X	
Coelosphaerium sp.	X		
Gomphosphaeria sp.	X		
Lyngbya sp.		X	
Merisimopedia sp.		X	
Microcystis aeruginosa	X	X	
Oscillatoria sp.	X	X	X
Other			
Euglena sp.		X	

*Data from LMS Hudson River studies



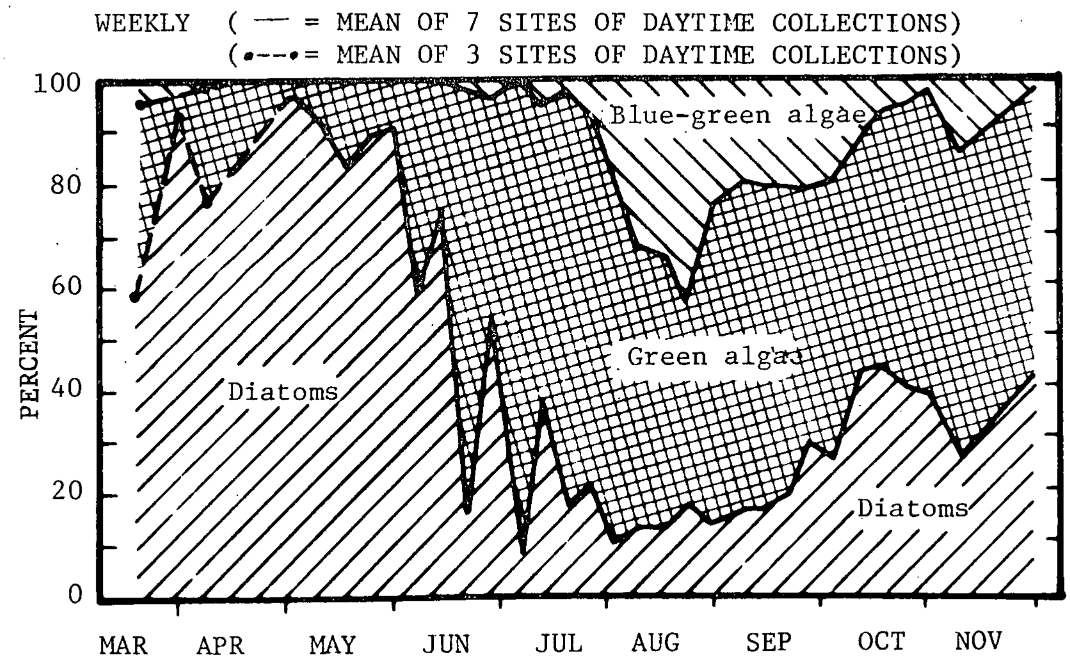


Figure 2.2-17 Percentage Composition of Hudson River Phytoplankton by Major Taxonomic Groups Based on 1971 Data (Heffner 1973)

In Table 2.2-11 the dominant zooplankton of the Hudson are listed. Zooplankton feed on both algae and detrital particulates and, in turn, are eaten by other invertebrate zooplankton (e.g., the cladoceran *Leptodora* and the rotifer *Asplanchna*), ichthyoplankton, and planktivorous fish such as alewife. Thus, zooplankton serve as a middle link in the transfer of energy and materials through the Hudson River food web.

Benthic invertebrates (those found in or on bottom sediments) are predominantly detritivores. Tubificid oligochaetes and chironomid insect larvae are dominant throughout the oligohaline-freshwater stretch of the Hudson (Table 2.2-12 and Fig. 2.2-18), and polychaetes become abundant with increasing salinity. The abundance of benthic organisms in the Hudson (Section 4) is greater than reported for many inland freshwater lakes and rivers, but this can be correlated with the high organic input to the sediments (Section 3.4). Much of this input is derived from sources outside the Hudson estuarine system and includes terrestrial runoff and municipal wastes.

Fish populations within the Hudson River have been studied more intensively than any other group of organisms. Forty-two freshwater, 28 marine migrant, 7 estuarine, 10 anadromous, and (since 1969) 1 catadromous fish species have been recorded in the Hudson. The greatest concern has been expressed for populations of anadromous species such as striped bass and American shad, which have been commercially fished, and in the case of striped bass, are recreationally important. These species move up the river during the spring months to spawn, and the larval and juvenile fish utilize the estuary as a feeding and nursery ground for varying lengths of time before migrating to the sea.

2.3 UTILIZATION OF LOWER HUDSON FOR POWER PRODUCTION

2.3.1 HISTORY OF PLANT OPERATION. The availability of large quantities of water and the advantages of water transportation have led to extensive urban, industrial, and commercial developments in the area

Table 2.2-11 Distribution of Dominant Zooplankton in Hudson River, 1971-74, LMS 1974a, b; 1975b, c, d; 1976b. (Data have not been completely analyzed and listed organisms may be found to be abundant at these locations upon more detailed analysis.)

	Kingston	Newburgh	Haverstraw Bay
Rotifera			
Asplanchna sp.			x
Brachionus sp.			x
Kellicottia sp.			x
Keratella sp.	x	x	x
Nothulca sp.		x	x
Ploesoma sp.	x	x	
Polyarthra sp.	x	x	x
Testuidinella sp.		x	
Cladocera			
Bosmina sp.	x	x	x
Daphnia sp.		x	x
Leptodora sp.		x	
Noina sp.			
Copepoda			
Acartia tonsa			x
Copepod nauplii	x	x	x
Ectocyclops			x
Eurytemora affinis			x
Halicyclops			x
Paracyclops			x
Temoridae			x
Others			
Cirripedia nauplii			x
Epistylus (protozoan)			x
Gastropoda			x
Polychaete larvae			x
Amphipoda			
Gammarus		x	x
Monoculoides			x
Diptera			
Chaoborus larvae		x	x
Dipteran pupae		x	x
Isopoda		x	x
Caldocera			
Daphnia			x
Leptodora kindtii	x	x	x
Others			
Mysid			x
Decapoda			x

Table 2.2-12 Benthic Invertebrate Fauna of Hudson River

COELENTERATA
- *Cordylophora lucustris*
- *Hydra* sp.

PLATYHELMINTHES
- Turbellaria

NEMERTEA

ASCHELMINTHES
- Nematoda

BRYOZOAN

ANNELIDA
- Hirudinea (Leeches)
  - *Erpobdella punctata*
  - *Helobdella elongata*
  - *H. stagnalis*
  - *Pisicola punctata*
- Oligochaeta
  - Naidae
    - *Nais pseudobtusa*
    - *Paranais frici*
    - *Stylaria fossularis*
    - *Vejdovskyella intermedia*
    - *V. comata*
  - Tubificidae
    - *Aulodrilus plusriseta*
    - *A. pigueti*
    - *A. americanus*
    - *Homochaeta naiclina*
    - *Ilodrilus templetoni*
    - *Limnodrilus profundicola*
    - *L. udekemianus*
    - *L. hoffmeisteri*
    - *Peloscolex benedeni*
    - *P. ferox*
    - *P. freyi*
    - *P. multisetosus*
    - *Potamothrix hammoniensis*
    - *P. vejdovskyi*

  - Tubificidae (continued)
    - *Rhyacodrilus coccineus*
    - *Tubifex tubifex*
    - *T. newaenis*
    - *T. (kessleri) americanus*
- Polychaeta
  - *Baccardiu bumatu*
  - *Hypaniolo grayi*
  - *Manayunkia* sp.
  - *Nereis succinea*
  - *Polydora* sp.
  - *Scolecolepides viridis*

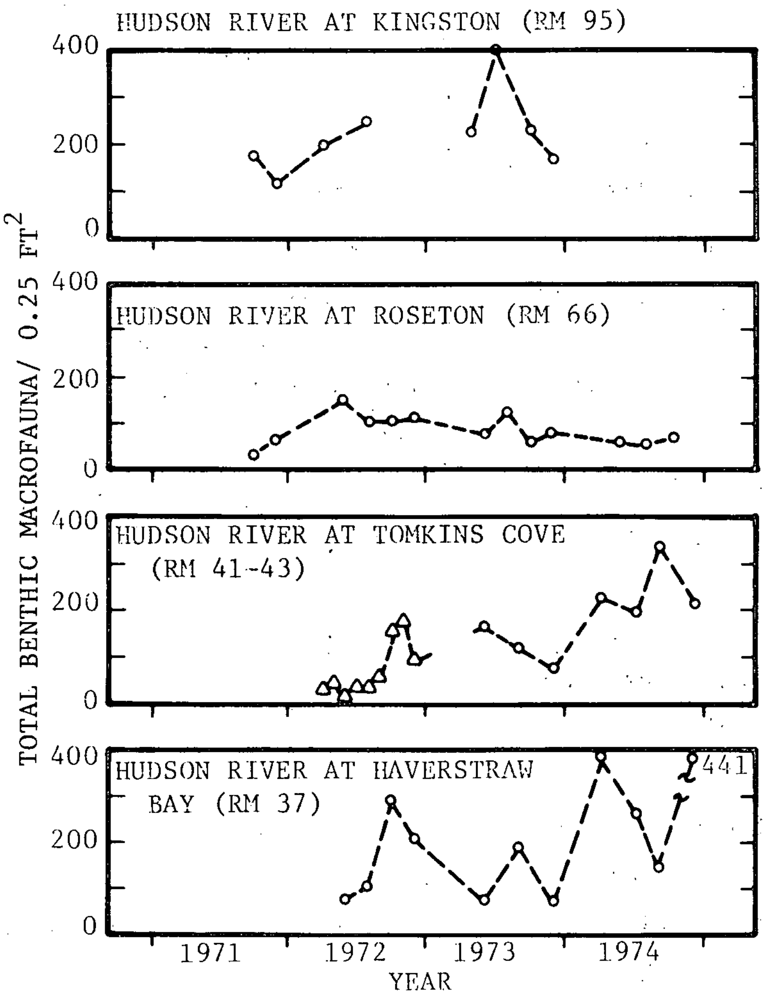
MOLLUSCA
- Pelecypoda
  - *Congeria leucophaeta*
  - *Elliptio* sp.
  - *Macoma balthica*
  - *Mullinia lateralis*
  - *Mya arenaria*
  - *Pisidium* sp.
  - *Sphaerium* sp.
- Gastropoda
  - *Amnicola limosa*
  - *Bithinia tentaculata*
  - *Nassarius vibex*
  - *Viviparus* sp.

ARTHROPODA
- Insecta
  - Diptera
    - Ceratopogonidae
      - *Bezzia* sp.
      - *Palypomyia* sp.
    - Culicidae
      - *Chaoborus* sp.
    - Chironomidae
      - *Brillia* sp.
      - *Chironomus (=Tendipes)* sp.
      - *Coelotanypus* sp.
      - *Cricotopus* sp.
      - *Cryptochironomus* sp.
      - *Dicrotendipus* sp.
      - *Eukieferiella* sp.

Table 2.2-12 (Cont'd)

Chironomidae (Continued)
Harnischia sp.
Orthocladius sp.
Polypedilum sp.
Procladius sp.
Rheotanytarsus sp.
Paracladopelma sp.
Phaenosectra sp.
Paralanterborniella sp.
Stenochironomus sp.
Psectrocladius sp.
Tanytarsus (=Calospectra) sp.
Odonata
Collembola
Istomurus palustris
Coleoptera
Hydrophilidae
Tricoptera
Agraylea costello
Anthrispsodes dilutus
Oecetis inconspicua
O. cinerascens
Oxyethira sp.
Arachnida
Acarina sp.
Unicola sp.
Crustacea
Amphipoda
Corophium lacustre
C. simile
C. volutador
Gammarus fasciatus
G. daiberi
G. daiberi-tigrinus (complex)
G. tigrinus
Hyalella sp.
Leptochierus plumulosus
L. pinguis
Monoculoides edwardsi

Isopoda
Asellus sp.
Chiridotea almyra
Cyathura polita
Edotea Montosa
Idotea sp.
Mysidacea
Neomysis americana
Cumacea
Alyracuma proximoculi
Decapoda
Callinectes sapidus
Crangon septemspinosa
Cancer irroratus
Neopanope (texana) sayi
Palaemonetes pugio
*Penaeus (*Melicertus*) aztecus azecus*
*Penaeus (*Litopenaeus*) setiferus*
Orconectes limnosus
Rhithropanopeus harrisii
Uca minax
Copepoda
Harpactocoida



o = data from LMS studies
Δ = data from Williams et al. 1973 (copepods were not included)

Figure 2.2-18 Densities of Benthic Macrofauna at Various Locations Along Hudson River, 1971-74 bordering the Hudson River estuary and have resulted in different demands for water use. Among the industrial users of these estuarine waters, the power industry is the most extensive. Currently, seven thermal power plants having a total rated generating capacity of 5,988 MWe* are located on the Hudson River estuary. Table 2.3-1 lists these plants, indicating their locations and basic operational parameters. In addition to the thermal power plants listed, Con Edison plans to construct at Cornwall (RM 56; km 90) a pumped-storage hydro-electric plant with an initial peak output of approximately 2,000 MWe. This plant was licensed by the Federal Power Commission in 1970 after six years of litigation. Construction commenced early in 1974 and was suspended in July 1974 as a result of further legal proceedings requiring additional consideration of fishery issues by the Federal Power Commission. Figure 2.3-1 depicts the approximate locations of power plants on the Hudson River.

Hudson River waters were initially used as a cooling water source for electric generating stations in 1918, when Con Edison's 59th Street plant became operational. An increase in per capita energy demands in the years following 1950 (Fig. 2.3-2) mandated the construction of new electric generating stations. By 1960, an additional 10 units were in operation at three other locations--Albany (RM 142;km 229), Danskammer Point (RM 66; km 106), and Lovett (RM 41; km 66), and a permit had been issued (1956) by the Atomic Energy Commission to Con Edison for construction of a nuclear station at Indian Point (RM 42; km 69). Between 1960 and 1970, permits for constructing Indian Point Units 2 and 3 had been issued to Con Edison, with additional power being generated by units constructed at Lovett and Danskammer Point. The total megawatt capabilities of generating stations located on the Hudson River then approached 1,750 MWe. Since 1970, electric power generation capabilities have increased 187% to 5,023 MWe. This does not include Indian Point Unit 3 but does include the 257 MWe that could be generated if Indian Point Unit 1 were on line.

*Includes Indian Point Unit 3.

Table 2.3-1 Characteristics of Hudson River Power Plants

POWER PLANT (Owner)	TYPE OF POWER PLANT	LOCATION (River Mile)	GENERATING UNIT NO.	GROSS RATED CAPACITY (MWe)	COOLING WATER FLOW (gal min^{-1})	PLANT TEMPERATURE RISE (°F)	WASTE HEAT (BB day^{-1})	TYPE OF DISCHARGE STRUCTURAL	DATE OF COMMERCIAL OPERATION
Albany Steam Station	Fossil	142.0	1	100	88000	10.3	10.9	Surface discharge	11/16/52
(Niagara Mohawk	Fuel	West Bank	2	100	88000	10.3	10.9	common to all	12/14/52
Power Corp.)			3	100	88000	10.3	10.9	generating units	10/1/53
			4	100	88000	10.3	10.9		9/10/54
			TOTAL	400	352000	10.3	43.6		
Danskammer Point	Fossil	66.0	1	66	42000	17.0	8.6		12/31/51
(Central Hudson Gas	Fuel	West Bank	2	66	42000	17.0	8.6	Surface discharge	9/14/54
and Electric Corp.)			3	118	82000	17.0	16.7		10/15/59
			4	229	150000	17.0	30.6		9/15/67
			TOTAL	482*	316000*	17.0	64.5		
Roseton	Fossil	65.4	1	600	320500	17.8	68.6	Submerged diffuser	12/74
(Central Hudson Gas	Fuel	West Bank	2	600	320500	17.8	68.6	common to both	9/74
and Electric Corp.)Δ			TOTAL	1200*	641000**	17.6	137.2	units	
Indian Point	Nuclear∇	43.0							
(Consolidated Edison		East Bank	1	265	318000†	12.0	47	Submerged near-	9/30/62
Company of New York,			2	873	870000†	14.6	153	surface discharge	10/73
Inc.)			3	1033	870000†	16.0	167	common to all units	6/75
			TOTAL	2171	2058000†	14.8	367		(Scheduled)
Lovett	Fossil	41.0	1	19	25200			Surface discharge	2/6/49
(Orange and Rockland	Fuel	West Bank	2	20	25200	13.2	14.7	common to Units 1-3	7/12/51
Utilities, Inc.)*			3	68	42000				3/1/55
			4	187	104000	17.0	21.3	Submerged near-surface	5/15/66
			5	202	120000	14.0	20.2	Submerged near-surface	4/27/69
			TOTAL	496	316000	NA	57.0‡		
Bowline Point	Fossil	37.5	1	600	384000†	Δt=14.9	62.0	Submerged diffuser	9/8/72
(Orange and Rockland	Fuel	West Bank	2	600	384000†	Δt=14.9	62.0	Submerged diffuser	5/13/74
			TOTAL	1200	768000†	NA	124.0		
59TH Street	Fossil	5.0	Total of	132	168000	6.7‡	8.3‡	Surface discharge	1918
(Consolidated Edison	Fuel	East Bank	7 Units						
Company of New York,									
Inc.)									

†Including service water.
‡Some units at 59th Street supply steam to Manhattan. According to this supply, the heat load and plant temperature rise may vary.
∇Indian Point 1 requires both fossil and nuclear fuels
NA - Not applicable

‡Including waste heat in service water (7000 gpm).
ΔRoseton power plant is also partially owned by Con Edison and Niagara Mohawk.
*Bowline Point power plant is also partially owned by Con Edison.
**All pumps operating

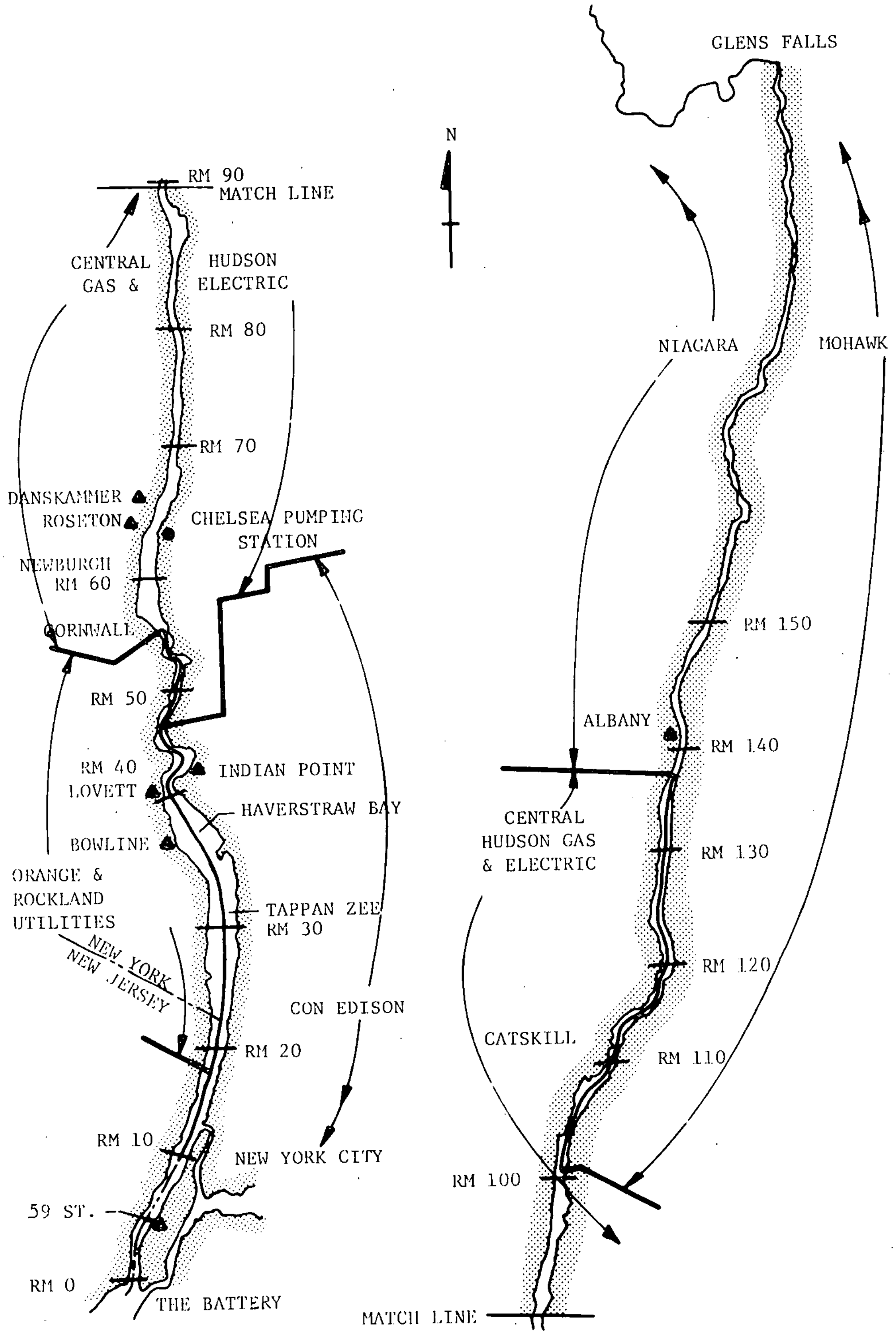
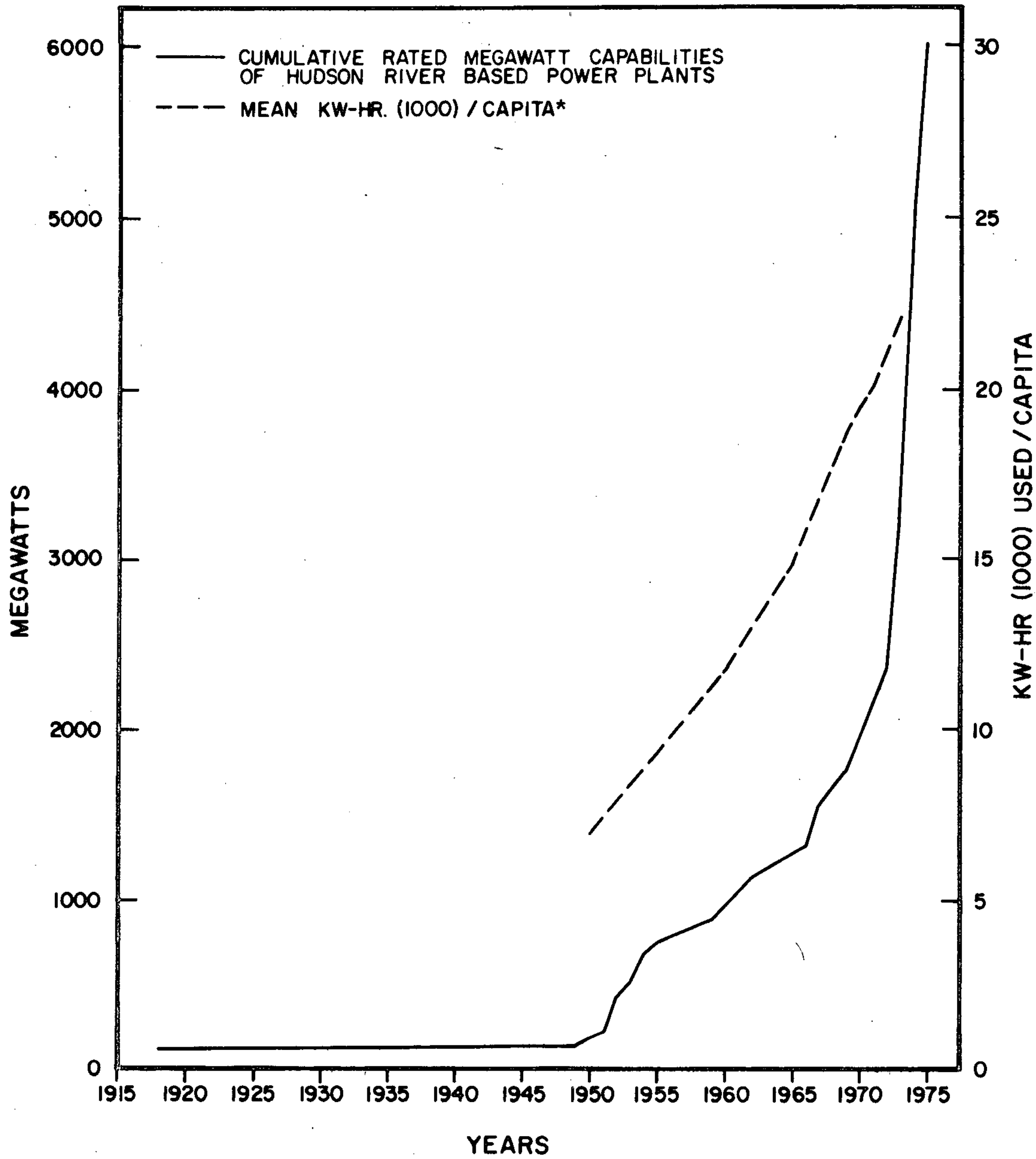


Figure 2.3-1 Hudson River Generating Stations



*Mean of all states (U.S. Dept. of Commerce, 1974).

Figure 2.3-2 Cumulative Power Generation and Average per Capita Consumption Along Hudson River

2.3.2 INTERACTION OF POWER PLANTS WITH ECOSYSTEM. This section describes the important ways in which aquatic organisms may be affected by the operation of power plants. Some of the problems do not occur to a significant degree in the Hudson River. Entrainment and impingement are the major concerns. Only a few species of fish are believed to be vulnerable; phytoplankton and invertebrates are not seriously threatened. Aquatic organisms may interact with and be affected by a power plant in several ways:

- Organisms may actually come into contact with the facility itself, primarily by being drawn into the plant's cooling water system. Smaller organisms, primarily plankton, pass through the plant but are subjected during passage to mechanical, pressure, thermal, and chemical stresses. This is known as pump entrainment. Larger organisms such as fish are forced against the plant intake screens designed to remove them from the cooling water flow and this is known as impingement.

- Organisms not drawn into the plant may be affected by contact with effluents from the generating station. The primary considerations here are the effects of the elevated temperature of such discharges on organisms in the receiving water body, the effects of chemical and radiological pollutants, and physical alterations caused by the currents. In addition, a power plant may alter the ecological complexity of the community through a variety of processes including changes in species composition or relative abundance; changes in the behavior of migratory fish species; the addition of energy (heat) into the system; and changes in the abundance and distribution of species at any trophic level, which may be transmitted to organisms at other levels of the food web.

2.3.2.1 <u>Thermal Plumes and Nearfield Thermal Effects</u>. Temperature elevation is the most prominent aspect of power plant discharges. The ecological effects of the discharge will depend, in part, on the degree and distribution of heat input to the environment. These effects are described in general terms in Appendix C. Dissipation of heat (decrease in volume or surface area within the warmer isotherms) occurs in the nearfield mainly as a result of the momentum of the discharge and dilution with the ambient current flow and in the farfield from heat exchange with the atmosphere. The final sink for artificial heat discharged to the river is the atmosphere.

The two methods commonly used to discharge heated effluents into a receiving water body are a low velocity surface discharge and a high velocity submerged discharge. The surface discharge offers:

- More rapid transfer of heat to the overlying atmosphere
- Stratification of the upper layer of the receiving water body so that the bottom region remains relatively free of heat and bottom scour
- Low level of induced turbulence due to low discharge momentum
- Low construction costs

The submerged diffuser has the advantages of:

- High nearfield dilution due to the high initial momentum of the discharge flow, resulting in more uniform temperature distribution, with a significantly lower maximum temperature rise above ambient, and smaller percentages of the surface area within the warmer isotherms than a surface discharge
- Dispersion of waste heat farther from shore, resulting in lower temperature rises at the shore and less recirculation of heated discharge water

The calculated maximum effects of individual power plants on Hudson River temperature distributions that are summarized in Table 2.3-2 are based on extensive studies by the power companies. These results are the summary of field, mathematical model, and hydraulic model studies that have been

Table 2.3-2 Maximum Extents of Effects of Power Plants on Hudson River Temperatures and Comparison of Plant-Induced Temperature Rises with Observed Variations in Ambient River Temperatures

Survey Series* Date	MWe**	MAXIMUM TIDAL PHASE*** Excess Temp. (°F)	% River Width† (Tidal Phase)	% Cross-Sectional‡ Area (Tidal Phase)	TIDAL AVERAGE Excess Temp. (°F)	% River† Width	% Cross-‡ Sectional Area
5/31/74	1075	3.2	46 (LWS)	19 (LWS)	3.4	27	8
6/13/74	975	3.9	36 (LWS)	16 (LWS)	3.6	28	12
7/17/74	810	3.8	40 (EBB)	15 (FLOOD)	3.2	28	12
8/20-24/74	1140	3.8	33 (HWS)	14 (HWS)	3.7	24	11
9/24/74	1135	4.0	35 (LWS)	20 (LWS)	3.5	26	16
10/22-25/74	1160	3.9	53 (LWS)	18 (LWS)	3.6	30	13
11/20/74	700	4.0	49 (LWS)	18 (LWS)	3.4	30	11
4/23/75	900	4.0	18 (HWS)	6 (FLOOD)	3.8	14	4.3
5/13-15/75	900	4.0	16 (LWS)	5 (LWS)	3.4	11	4

*For consecutive daily surveys during August and October 1974 and May 1975, data represent the most severe thermal impacts of those surveys which were taken on August 23 and October 23, 1976, and May 13, 1975.
**Total MWe from Units 1 and 2 with Indian Point Unit 2 operational since November 1974.
***Maximum tidal phase is designated as the tidal phase at which the most severe thermal impacts occur.
†Percentage of river surface width contained within the 4°F excess temperature isotherm.
‡Percentage of the river cross sectional area contained within the 4°F excess temperature isotherm.

performed at each power plant through 1975; more comprehensive descriptions of the temperature distribution caused by each power plant can be found in the individual studies done for each plant. This table also compares the evaluated plant induced temperature rises with the observed variations in ambient river temperatures.

Figure 2.3-3 shows the longitudinal distribution of tidal average, cross-sectional average river temperature rises induced by simultaneous maximum operation of all Hudson River power plants (excluding Indian Point Unit 3). This figure was constructed using results of LMS's 28-segment model applied to the Danskammer Point (RM 66; km 106), Roseton (RM 65.4; km 105.3), Lovett (RM 41; km 66), and Bowline Point (RM 37.5; km 60.4) thermal discharges. The river temperature rises induced by the Albany steam station (RM 142; km 229) and 59th Street power plant (RM 5; km 8) were estimated using LMS's constant parameter single-discharge model. Although temperatures outside the range of tolerance may result in death or marked physiological or behavioral changes, organisms can, within limits, respond to changes in their thermal environment. To maintain survival and reproduction, the Environmental Protection Agency has established thermal guidelines for discharges into various types of waterbodies. Since Indian Point Unit 2 meets the EPA thermal discharge requirements applicable to the Hudson River (as described in Section 1.1.1), no significant detrimental impacts to Hudson River life are anticipated as the result of thermal discharges from this facility.

The nearfield thermal effects of Indian Point Unit 2 have been evaluated in relation to questions raised in the licensing proceedings through 11 routine or intensive thermal surveys conducted since the beginning of plant operation in 1974. A "routine" thermal survey comprises measurements of the intensity and extent of the Indian Point plume over five successive tidal phases--maximum ebb, low water slack, maximum flood, high water slack, and minimum ebb. An intensive thermal survey consists of similar measurements conducted over four or five successive tidal cycles for

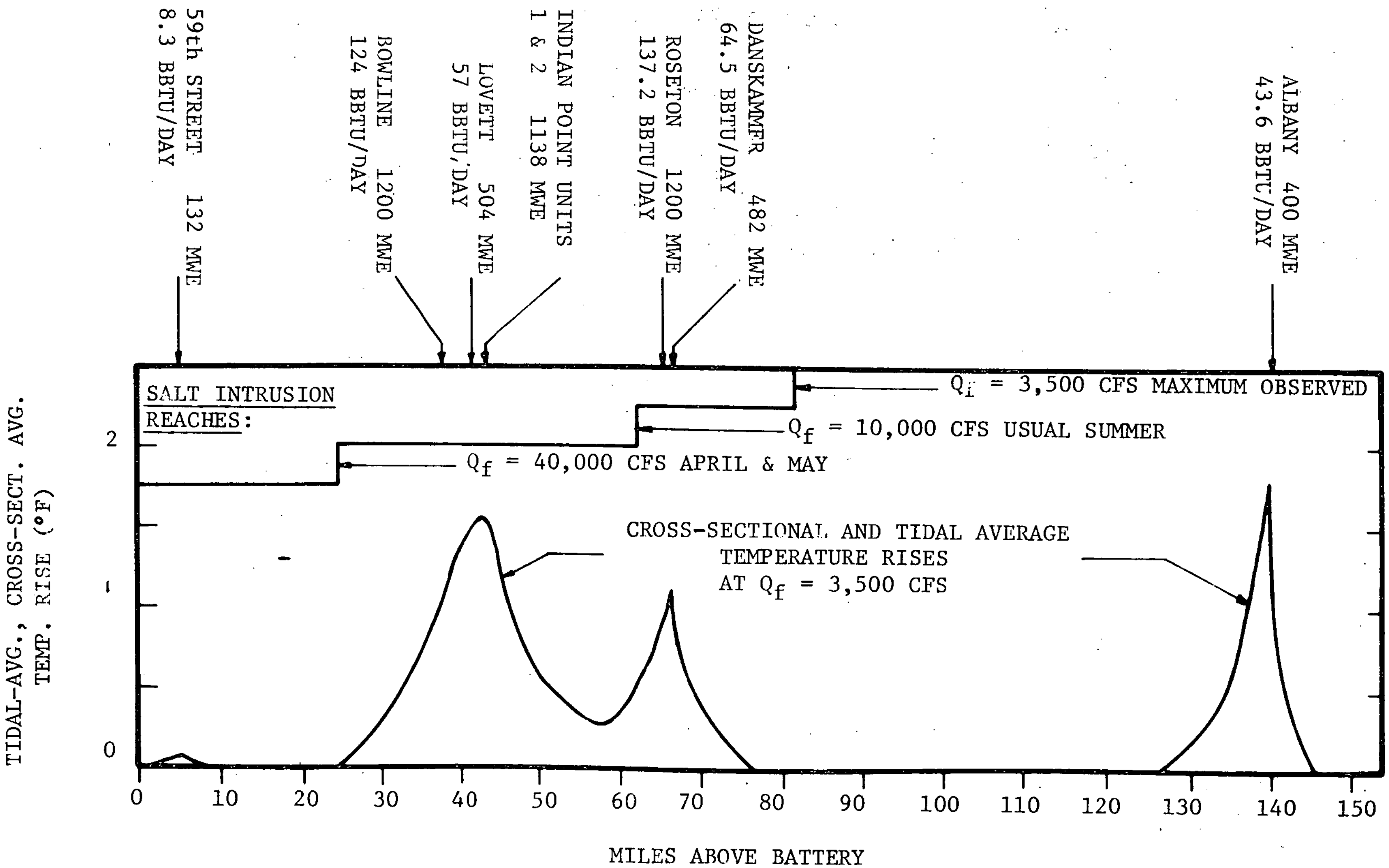


Figure 2.3-3 Effect of Simultaneous Operation of Hudson River Power Plants on River Temperature

3 or 4 days and acquires more detailed measurements of auxiliary hydrological and meteorological parameters such as salinity. These surveys constitute a comprehensive field monitoring program formulated to ascertain characteristics of the thermal plume of the Indian Point station and consequently to permit comparison of the magnitude of the plume with the New York State thermal criteria, as well as to provide field data for assessing the predictive capabilities of the physical and mathematical models. The scope of the Indian Point Unit 2 thermal monitoring program is described in detail in the Indian Point Unit 2 Environmental Technical Specification Requirements (ETSR) set by the United States Nuclear Regulatory Commission.

Eight surveys were completed in 1974, two in 1975, and one in 1976. The 1974 and 1975 surveys were conducted with either or both Indian Point Units 1 and 2 in operation. (Indian Point Unit 1 has been out of service since November 1974 due to regulatory requirements.) The October 1976 survey was conducted with both Indian Point Unit 2 and 3 in operation. The results of the field surveys with respect to the New York State thermal criteria are summarized in Table 2.3-3.

According to New York State thermal criteria, operation of the Indian Point station was found to be well within the limits on width and cross-sectional area occupied by the plume. (Details of the first nine surveys have already been reported to NRC. Reports for the last two surveys are expected to be completed in January 1977).

The August and October 1974 surveys were specifically designed to yield information necessary for model-prototype comparison. The results of those comparisons, which were submitted to NRC in March 1976, indicated that both the Alden Research Laboratories' (ARL) physical model and the LMS mathematical model were conservative in predicting Indian Point's thermal effluent behavior.

Table 2.3-3 Indian Point Thermal Survey Summary

Power Plant	Extent of 4°F Temperature Rise or 83°F Temperature: Surface Width	Cross-Sectional Area	Maximum Surface Temp. °F	River Cross-Sectional Average Temperature Rise: Near Plane of Discharge °F	1 Mi Below Plant °F	One Tidal Excursion Below Plant °F	Two Tidal Excursions Below Plant °F	Linear Extents of Surface Isotherms: Length 4°F 10^3 ft	Length 6°F 10^3 ft	Length 8°F 10^3 ft	Width 4°F 10^3 ft	Width 6°F 10^3 ft	Width 8°F 10^3 ft	Volumes of Water Enclosed by Given Isotherm, 10^6 Cubic Ft (% of River Vol.) in One Tidal Excursion: 4°F	6°F	8°F
Albany Steam Station	100	46	93	1.0	ND	ND	ND	4.6	ND	ND	0.73	ND	ND	ND	ND	ND
Roseton and Danskammer Combined*	60.9	16.8	86†	1.8	1.3	0.5	0	7.1†	4.3†	2.0†	0.77†	0.41†	0.44	63.9 (0.8)	7.8 (0.09)	3.5 (0.04)
Indian Point Units 1 & 2**	33‡	14.3	91.6	1.5‡	1.1‡	0.0‡	0‡	3.15	0.7	0.2	1.42	0.85	0.56	14.4	6.6	1.5
Lovett	35ǂ	4ǂ	92ǂ	1.45ǂ	1.25ǂ	1.0ǂ	0.55ǂ	8.8	2.5	1.3	1.0	0.5	0.25	43.2 (0.61)	6.3 (0.09)	2.0 (0.03)
Bowline	31	7	88.5	1.0	0.8	0.51	0.19	12.0	(5°F) 1.8	(>7°F) 0	2.4	(5°F) 1.2	(>7°F) 0	144.0 (1.56)	7.2 (0.07)	0
59th Street	5.0	1.0	81.0	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Observed Variations in Ambient River Temperatures (River Channel)††

Power Plant	May: Within Any Hour	May: Within Any Day	May: Monthly Avg. Yr to Yr	July: Within Any Hour	July: Within Any Day	July: Monthly Avg. Yr to Yr	September: Within Any Hour	September: Within Any Day	September: Monthly Avg. Yr to Yr	November: Within Any Hour	November: Within Any Day	November: Monthly Avg. Yr to Yr
Roseton and Danskammer Combined	IS	IS	3.0	IS	0.8	6.0	IS	0.5	3.0	IS	IS	6.0
Indian Point Units 1 & 2	0.4	0.9	3.0	0	6.0	6.0	0.8	1.8	3.0	IS	1.7	6.0
Lovett	0.4	0.9	3.0	0	6.0	6.0	0.8	1.8	3.0	IS	1.7	6.0
Bowline	0	1.0	3.0	1.6	4.5	6.0	IS	7.7	3.0	IS	0.8	6.0

†Expected in the vicinity of the Roseton discharge, based on field data and ambient temperature of 80°F. Surface temperatures in the vicinity of Danskammer discharge have exceeded 90°F, however future load requirements indicate that surface temperatures will rarely exceed 90°F.

‡Based on maximum measured surface area and average plume shapes.

ǂMultiplant effects of Danskammer Units 1-4, Roseton Units 1 & 2, Indian Point Units 1 & 2, Lovett Units 1-5 and Bowline Units 1 & 2.

††Maximum temperature - minimum temperature.

IS = insuficient data; ND = not determined.

* Based on 1975 field observations and supersedes earlier estimates.

**Data representing worst cases occurring during the August 1974 survey.

In March 1976, Con Edison presented to NRC a multi-dimensional time-dependent mathematical model to supplement the existing physical and simple mathematical models for assessing Indian Point's thermal effluent behavior. Initial model prototype comparison indicated that this complex hydrothermal model was capable of evaluating actual temperature distributions in a transient manner and, in Con Edison's opinion, can supplement if not totally replace the thermal survey monitoring program just described.

2.3.2.2 Chemical Effluents and Their Biological Effects. Appendix D discusses the biological effects of chemical effluents and summarizes bioassay work on chemical effects on Hudson River organisms.

Indian Point Unit 2's discharge of chemical wastes into the Hudson River is regulated by the "Environmental Technical Specification Requirements" (ETSR) set forth by the United States Nuclear Regulatory Commission, the National Pollutant Discharge Elimination System (NPDES) permit issued by the United States Environmental Protection Agency, and the certificate issued by the New York State Department of Environmental Conservation pursuant to Section 401 (a) (1) of the Federal Water Pollution Control Act. Specifically, the three documents not only specify the limits of various chemical discharges but mandate a continuous monitoring program to assure that chemical discharges do not exceed the established limits. Results of the 1975 chemical monitoring program which were submitted to the NRC in March 1976, clearly indicate that actual chemical discharges are much less than maxima specified by ETSR. Similar findings are reported for the first 6 mo of 1976. Thus, chemical effluents from Indian Point are not believed to present any danger to the biota of the Hudson River.

In response to specific concern about chlorine toxicity expressed in the Indian Point Unit 2 FES, Con Edison modified its original chlorination procedures. The results are believed to have eliminated any basis for concern about ecological damage. For most of the year, the residual chlorine in the effluent from Indian Point is practically undetectable (<0.05 ppm whereas the accuracy of a residual chlorine analysis is +0.05 ppm). The low residual chlorine values are solely attributable to the company's chlorination procedure adopted since 1975 to minimize chlorination frequency. The new procedure calls for physical examination of the condensers in order to determine whether chlorination is necessary. The Indian Point Unit 2 cooling water system was chlorinated only 16 times in 1974 and 14 times in 1975. This actual chlorination frequency is much less than the maximum possible yearly frequency of chlorination as specified in ETSR (assuming that chlorination would be required from mid-April through early December and the frequency of chlorination would be three times per week, the total number of chlorination treatments would be about 100 times per year).

2.3.2.3 Entrainment. Power plant cooling water intakes are usually equipped with intake screens to prevent debris from entering and clogging the condenser cooling system. However, along with the cooling water, organisms smaller than the screen openings (usually 0.95 cm^2; 3/8 in^2) can be drawn into the cooling system, a process called pump entrainment. Planktonic organisms (phytoplankton, microzooplankton, macrozooplankton, and ichthyoplankton) are susceptible to this entrainment because their limited swimming ability prevents escape from the entrained water mass. Once within the cooling system, the organisms are subjected to temperature pressure, and velocity changes, shear exposure, and mechanical abrasion.

Lauer et al (1974) described the magnitude, sequence, and duration of entrainment effects for the Indian Point nuclear power station. Table 2.3-4 indicates temperature rises and passage times under full flow and reduced flow for single and simultaneous operation. Total passage time ranges from 5.91 min through Unit 3 during full flow simultaneous operation to 55.54 min through Unit 1 during reduced flow single unit operation. The temperature rise in the condenser ranges from 7.0°C (44.6°F) in Unit 1 during full flow conditions to 15°C (59°F) in Unit 3 during reduced

Table 2.3-4 Average Transit Times and ΔT for Cooling Water during Full and Reduced (60%) Flow Operation of Indian Point Units 1, 2, and 3

	Individual units single operation			Individual units simultaneous operation			
	1	2	3	1	2	3	Mean
Full Flow							
Time (min)							
Intake to condenser	1.16	1.52	1.52	1.16	1.52	1.52	1.51
Condenser transit	0.08	0.14	0.14	0.08	0.14	0.14	0.13
Condenser to effluent	32.08	13.52	7.05	6.12	7.90	4.25	6.07
Total	33.32	15.17	8.71	7.36	9.55	5.91	7.71
Temperature rise (ΔT deg. C)							
Condenser rise	7.0	8.3	9.0	7.0	8.3	9.0	8.4
Condenser and service water	6.7	8.1	8.9				8.2
Reduced Flow							
Time (min)							
Intake to condenser	1.93	2.53	2.53	1.93	2.53	2.53	2.52
Condenser transit	0.14	0.23	0.23	0.14	0.23	0.23	0.22
Condenser to effluent	53.47	22.53	11.75	10.18	13.17	7.08	10.12
Total	55.54	25.30	14.52	12.25	14.93	9.84	12.86
Temperature rise (ΔT deg. C)							
Condenser rise	11.7	13.8	15.0	11.7	13.8	15.0	14.0
Condenser and service water	10.3	13.2	14.7				13.2

*Lauer et al. (1974)

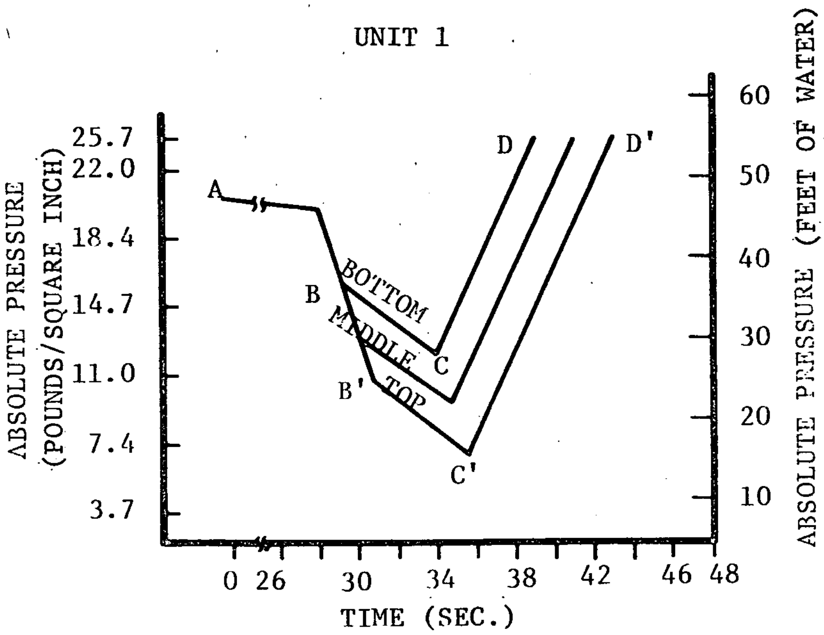
flow conditions. Obviously, the time/temperature exposure to which an organism will be subjected depends on the unit into which it is entrained and the plant's operational conditions. Organisms entrained in a cooling system also will be exposed to rapid changes in hydrostatic pressure: a pressure drop entering the condenser, followed by a pressure increase as the cooling water leaves the condenser system. Lauer et al (1974) also illustrated the upper, lower, and average pressure changes that organisms will experience during passage through Indian Point Units 1 and 2 (Fig. 2.3-4).

Pump-entrained organisms also will be exposed to rapid changes in velocity, and stressful conditions may exist at velocity interfaces. Velocities within the Indian Point condenser system range from 1.68 to 2.47 m s^{-1} for Unit 1 and 1.82 to 2.47 m s^{-1} for Unit 2; cooling water is discharged back into the river at a velocity of 3 m s^{-1}. The degree of mechanical buffeting and abrasion during passage through the Indian Point cooling system has not been quantified.

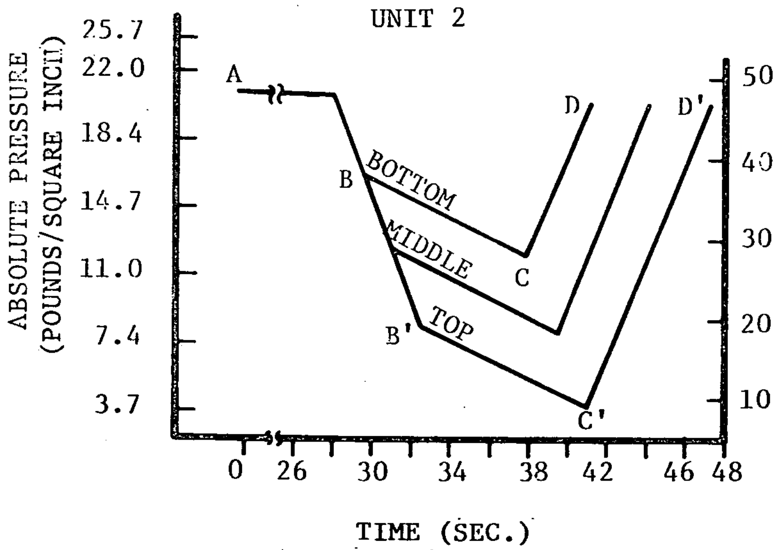
Assessing entrainment impact on an aquatic community requires the study and quantification of at least three biological parameters:

- Size, distribution, and resiliency of parent populations
- Numbers and species of organisms entrained
- These organisms' viability after passage through the power plant

The impact by entrainment on phytoplankton and zooplankton populations in the Hudson River is not sufficient to be of concern (Section 1.1.8), but these two components of the ecosystem are treated in Section 3 of this report from the perspective of the ecological energy budget. More serious is pump entrainment of the planktonic life stages of fish, especially striped bass, so estimates of entrainment impact are developed in Sections 8, 11, 12, and 14 of this report.



A-B = PIPE FROM CIRCULATING PUMP TO CONDENSER
B-B' = INLET WATER BOX
B-B' TO C-C' = CONDENSER
C-C' TO D-D' = EXIT WATER BOX TO DISCHARGE TUNNEL



A-B = PIPE FROM CIRCULATING PUMP TO CONDENSER
B-B' = INLET WATER BOX
B-B' TO C-C' = CONDENSER
C-C' TO D-D' = EXIT WATER BOX TO DISCHARGE TUNNEL

Figure 2.3-4 Absolute Pressure in Relation to Time from Circulator to Discharge Pipe of Indian Point Units 1 and 2 (Lauer et al. 1974)

2.3.2.4 Impingement. Power plants with once-through condenser cooling systems utilize traveling screens at the intake to keep cooling water free of debris. The mesh aperture of these screens is usually .95 cm^2 (3/8 in^2). As the water passes through these screens, it presses (impinges) organisms larger than the mesh openings, including juveniles and adults of many species, against the screens. Various screenwash systems are employed for periodically removing impinged fish from the screens and either disposing of them or returning them to the water body from which they were withdrawn.

2.3.2.4.1 Impingement Mortality. A certain percentage of fish subjected to the stresses of impingement die, either immediately (short-term mortality) or within some time period (latent or long-term mortality); this phenomenon is one aspect of the public concern over the ecological consequences of power generation. The actual cause of mortality in impinged fish is primarily the physical stress imposed by the process itself, i.e., loss of protective scales and mucous membranes and bodily injury from contact with screens, high pressure screenwash systems, and bypass structures. Fish viability after impingement (i.e., that proportion of fish which survive the process) depends on several plant-related factors such as intake velocity, plant structures, and operating conditions.

To a large degree, impingement survival is species-specific; also it varies with season. Soft-bodied fish such as alewives, which possess easily lost, cycloid scales, generally suffer higher impingement mortality than do hardier fish such as white perch, which have ctenoid scales. Other fish species such as the Atlantic tomcod, suffer little short-term mortality from impingement prior to spawning but demonstrated low survival when they are impinged following spawning (LMS 1974b, 1975c).

2.3.2.4.2 Causal Factors in Impingement. The abundance of fish in the water body and the location and design of the cooling water intake structure are major factors determining the numbers of fish impinged. Also, impingement is a species-specific phenomenon. For example, fish species that move fairly widely about the estuary are more likely to be impinged than are those that remain in discrete areas.

The location of the intake in the water body is a critical factor. Withdrawing cooling water from a sheltered littoral area that serves as a fish spawning or nursery ground would be likely to subject large numbers of spawning adults or juvenile fish to impingement. Species which undertake diurnal movements into nearshore zones to feed would also be more susceptible to being drawn into intake structures located in shore areas. Situating an intake structure near the mouth of a river or stream used by populations for spawning might cause the impingement of many fish during their seasonal spawning migrations.

Other factors considered important include intake current velocities and direction of flow, water temperature, and light and sound associated with the plant. As the interaction of these factors has become better understood, impingement mitigating measures have been proposed to decrease the number of fish impinged by individual power plants. The testing and evaluation of various mitigating measures has been reviewed by Jensen (1974) for the Second Entrainment and Intake Screening Workshop and by Stone and Webster (1975, 1976a, 1976b, 1976c). Mechanisms for decreasing the number of fish drawn into a power plant include louvers, stationary and traveling screens, electric currents, chemical or sound repellents, air-bubble screens, water-jet curtains, and hanging chain barriers. In general, methods that depend on fish avoiding particular environmental conditions (e.g., repellents, air-bubble screens, hanging-chain curtains) have been only partially effective in reducing impingement at existing plants; however, Stone and Webster (1976b) has found that air-bubble screens, water-jet curtains, and hanging-chain barriers can be effective in reducing impingement.

2.3.2.4.3 Significance of Impingement. The importance of fish impingement must be viewed in the light of numbers actually killed in relation to the size and resiliency of the natural population. The impact of impingement can be initially evaluated by quantifying the number of fish impinged and estimating the percent loss to the fish population. This percent loss can be put in perspective by being compared to losses resulting from other cropping factors. The impact of impingement on Hudson River striped bass and other fish species is analyzed in Sections 9, 11, and 12.

2.3.3 DESCRIPTIONS OF PRESENT POWER PLANTS

2.3.3.1 General Physical Features of Each Plant. Each plant's physical characteristics that are important in relation to impact on the Hudson (plant size, location on the river, and nature of intake and discharge) are briefly described in this section:

- 59th Street Generating Station - a 132-MWe unit fossil-fueled power plant (see note c on Table 2.3-1) located 5 mi (8 km) north of the Battery on the east shore of the Hudson. It has a shoreline intake and a shoreline surface-level discharge. The 59th Street Station is not included in this report's development of impact estimates for the five plants located in the central part of the estuary (RM 37-66). Riverwide surveys showed few striped bass larvae as far south as the George Washington Bridge, so entrainment at this plant would not be significant.

- Bowline Point Generating Station - a 1,200-MWe 2-unit fossil-fueled power plant 37.5 mi (60.4 km) north of the Battery on the west shore of the Hudson. It has a once-through cooling system with an intake in a small embayment (Bowline Pond) and a multiport diffuser discharge 1,400 ft (427 m) offshore at a depth of approximately 20 ft (6 m).

- The Lovett Power Plant - a 504-MWe 5-unit fossil-fueled power plant 41 mi (66 km) north of the Battery on the west shore of the Hudson. It has a once-through cooling system. Units

1 and 2 have common intake canal, whereas the other three units have shoreline intakes. The effluents from Units 1, 2, and 3 are combined to form a common surface discharge south of the plant. Unit 4 has a single port submerged discharge; its outlet is near the Units 1-3 discharge. Unit 5 has a skimmer wall and discharges north of the plant.

- Indian Point Nuclear Power Plant - a 2,171 MWe 3-unit nuclear power plant located 42 mi (67 km) north of the Battery on the east shore of the Hudson. It has a once-through cooling system with a shoreline intake at a depth of 25 ft (8.0 m) at Unit 1 and 26 ft (8.3 m) at Units 2 and 3. Discharge water flows through a single discharge canal and is returned to the river through a series of submerged discharge ports in a 800 ft (244 m) length of the canal wall at the downstream end of the canal.

- Roseton Generating Station - a 1,200 MWe 2-unit fossil-fueled plant located 65 mi (105 km) north of the Battery on the west shore of the Hudson. It has once-through cooling with a shoreline intake at a depth of 26 ft (8 m) and a submerged multiport diffuser discharge at a depth of 29 ft(9 m) located 250 ft (36 m) offshore approximately 500 ft (152 m) downstream from the intake.

- Danskammer Point Generating Station - a 482 MWe 4-unit fossil-fueled plant located 66 mi (106 km) north of the Battery on the west shore of the Hudson River. It has a once-through cooling system with an intake canal north of the plant and a surface level discharge into a cove south of the plant.

- Albany Steam Electric Generating Station - a 400-MWe 4-unit fossil-fueled plant 142 mi (229 km) north of the Battery on the west shore of the Hudson River. It has a once-through cooling system with a shoreline intake just below surface extending to a depth of 35 ft (11 m) and a shoreline surface level discharge. In developing impact estimates in this report, the Albany steam station is not included with the five plants located in the central part of the estuary (RM 37-66), except in the presentation of impingement data in Section 9.

2.3.3.2 Operational Characteristics. The operational characteristics of the power plants currently operating along the Hudson River estuary are presented in Table 2.3-1.

2.3.3.3 Intake Structures. The following paragraphs describe in detail the structures for cooling water intake at each power generating station on the Hudson River.

2.3.3.3.1 Indian Point Nuclear Plant. The Indian Point nuclear plant has three nuclear reactors (Units 1, 2, and 3), each with its own cooling water intake system. Except for the Unit 1 intake, which has a wharf projecting from the shoreline into the river, all three intakes are flush with the shoreline (Fig. 2.3-5).

The Unit 1 intake has four forebays, each about 11 ft (3 m) wide and 25 ft (8.0 m) deep at the mean low water level. Behind the wharf, a concrete skimmer wall extends across the front of each intake from above the water level to approximately 5 ft (1.5 m) below the water surface (Fig. 2.3-6). Fixed vertical screens of fine (0.375 in^2; 2.42 cm^2) wire mesh are installed in front of the skimmer wall to remove debris. These fixed screens are lifted periodically so that the accumulated debris can be washed off. At the bottom and upstream of the fixed screens, air bubblers are in operation. Behind the vertical fixed screens are trash racks consisting of 0.5 x 3 in (1.3 x 8 cm) vertical steel bars set on 3.4 in (8.6 cm) centers. The vertical traveling screens, consisting of panels with 0.375 in^2 (2.42 cm^2) wire mesh, are installed behind the trash racks and about 31 ft (9.4 m) downstream of the vertical fixed screens. The vertical traveling screens rotate continuously, and the debris or fish remaining on the screens are sprayed off by high pressure (40-100 psi) water jets into the sluice, which carries them away.

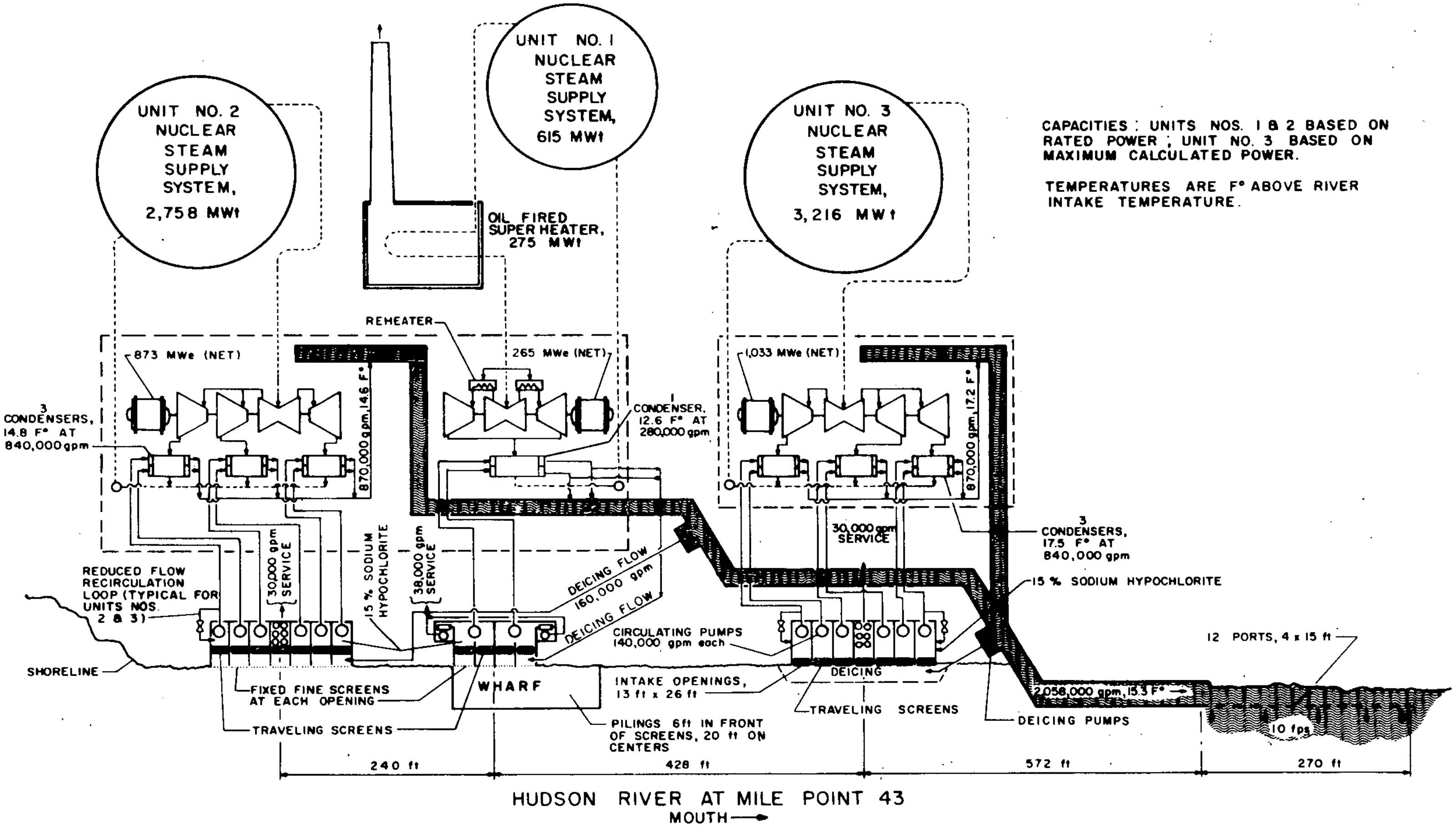
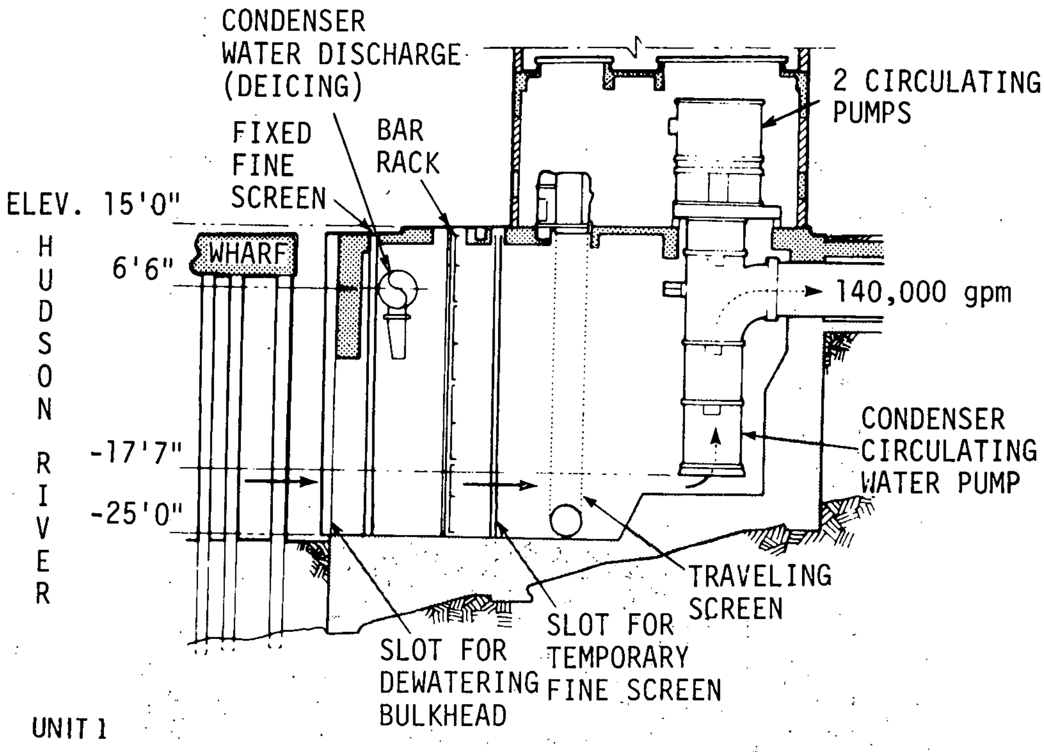


Figure 2.3-5 Indian Point Plant Layout



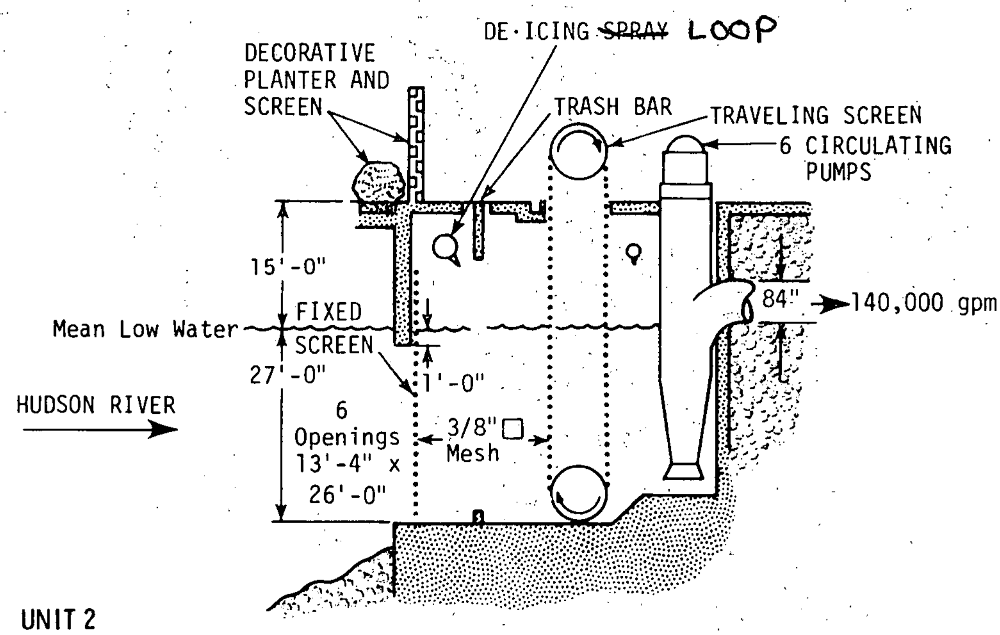


Figure 2.3-6 Cross-Sections of Unit 1 and 2 Intakes at Indian Point Nuclear Power Generating Station

The Unit 2 intake has six forebays. Unlike the Unit 1 intake, which has two circulating water pumps, each withdrawing water from two forebays, each of the six circulating water pumps at Unit 2 withdraws water from one forebay, which is about 13 ft (4 m) wide and 27 ft (8 m) deep at the mean low water level. Except for this, the Unit 2 intake is equipped like the Unit 1 intake with air bubblers, skimmer wall, vertical fixed screens, trash racks, and vertical traveling screens (Fig. 2.3-6); in addition, however, Unit 2 also has an intake structure for six service water pumps, each with a 5,000 gal min^{-1} capacity (18,927 litre m^{-1}) (Fig. 2.3-5).

The Unit 3 intake structure, shown in Figure 2.3-7, is identical to that at Unit 2, except that it has no air bubblers or vertical fixed screens and its traveling screens are at the river face of the intake structure so that there are no forebays that may permit trapped fish to escape impingement. In addition, the Unit 3 intake is equipped with "stoplogs" that can be inserted into the vertical guides during maintenance operations to prevent entry of river water into the pump bay.

2.3.3.3.2 Roseton Generating Station. The intake structure at the Roseton generating station is on the shoreline of the Hudson River about 65 mi (105 km) above Battery Park. There are four circulating water pumps with a total capacity of 641,000 gal min^{-1} (2,426,449 litre min^{-1}) supplying cooling water to two fossil-fueled generating units (1 and 2). Each pump withdraws water from two bays, each of which is about 10 ft (3.1 m) wide and about 25 ft (7.6 m) deep at the mean low water level (Fig. 2.3-8 and 2.3-9). A vertical traveling screen with 0.375 in^2 (2.42 cm^2) wire mesh in installed in each bay. The face of each traveling screen is flush with the shoreline so that fish entering the intake structure may escape impingement on the traveling screens.

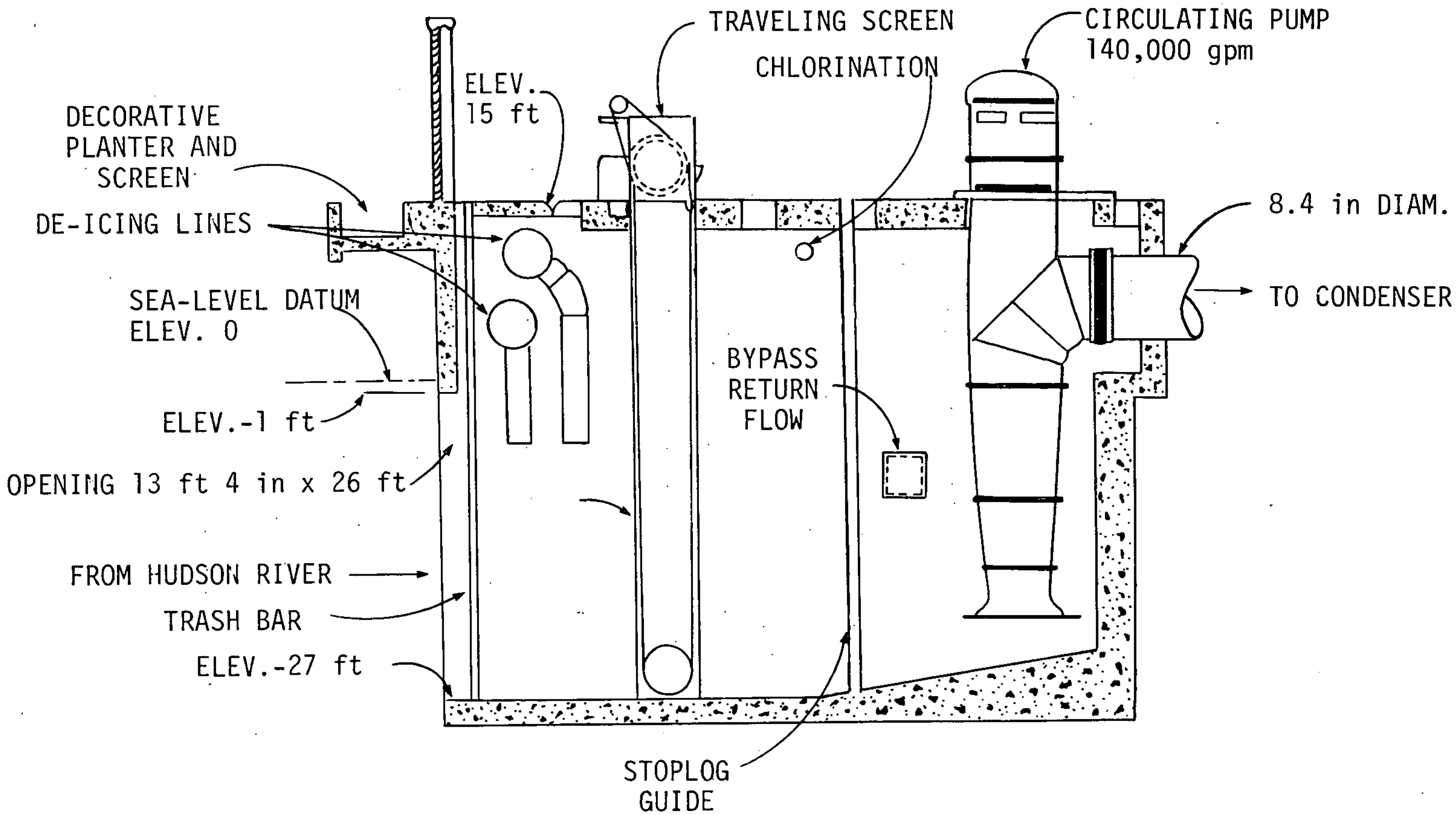
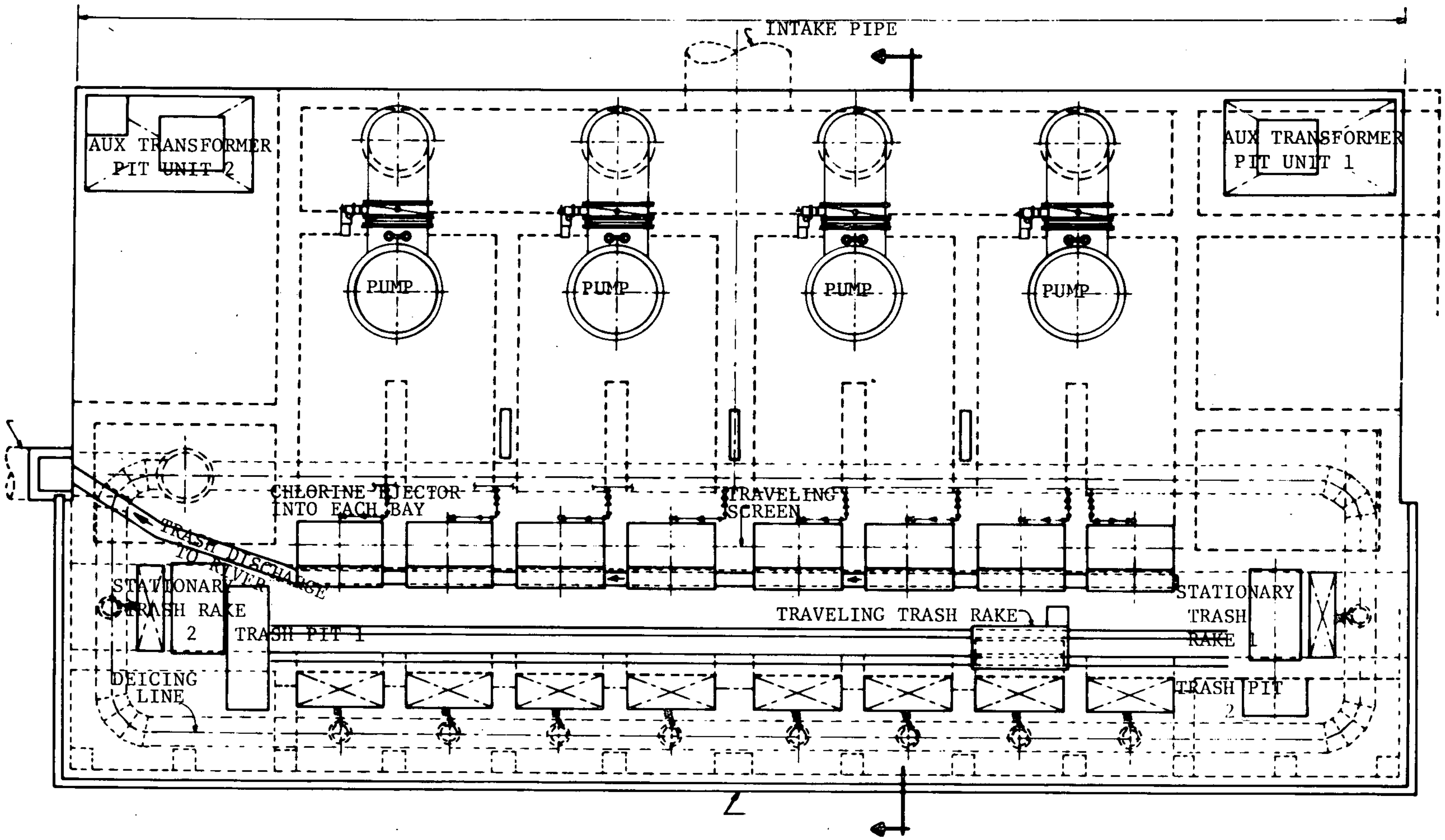
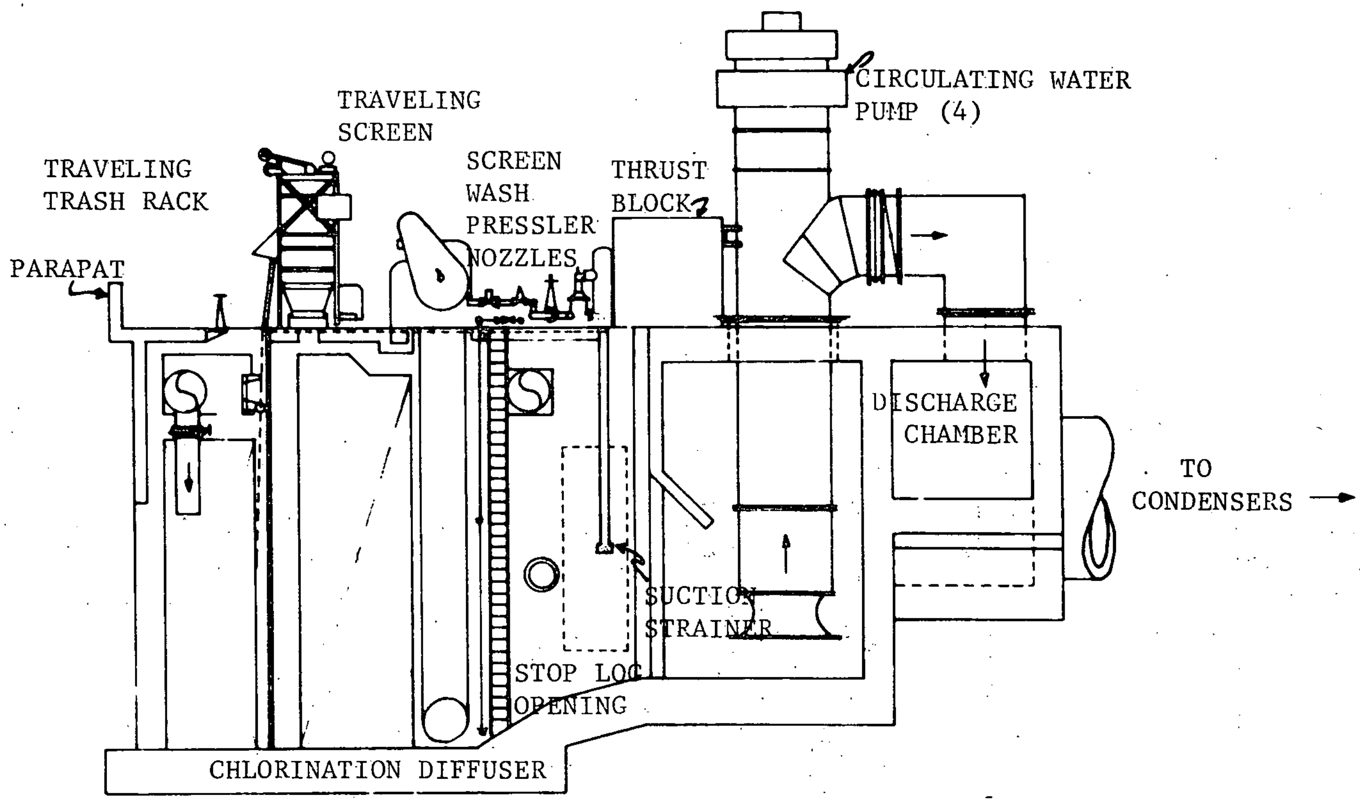


Figure 2.3-7 Diagrammatic Section through Condensing Water Intake Structure (Total of 6 for Indian Point Unit 3)



PLAN

Figure 2.3-8 Roseton Generating Station Cooling Water Intake Layout



SECTION A A THRU INTAKE STRUCTURE

Figure 2.3-9 Diagrammatic Section of Roseton Generating Station Cooling Water Intake

The intake structure is 153 ft 10 in (46.9 m) wide and has 10 trash racks, 8 on the front of the structure and one on each side (Fig. 2.3-8). The trash racks consist of 0.5 x 3 in (8 cm) vertical steel bars spaced approximately 3.5 in (8.9 cm) apart. The water passes through these trash racks and then, via a common chamber, enters the traveling screens; it is then pumped at the end of intake bays by four circulating pumps and discharged into a common 12-ft (4 m) diameter intake pipe that subsequently divides into two pipes, each leading to one of the tow condenser housing units. In front of the trash racks, a skimmer wall extends from the top of the structure to about 3 ft (1 m) below the normal low water level and across the entire face of the intake structure. This prevents blockage of the water intake by ice and/or large debris. In addition, de-icing lines tap heated water from the discharge. Near the traveling screens are 2 in (5.1 cm) chlorinators that can be operated intermittently to control the formation of slime throughout the cooling system. Figure 2.3-10 is a detailed schematic of the arrangement of this intake structure's various devices.

2.3.3.3.3 Bowline Point Generating Station. The Bowline site is on the west bank of the Hudson River about 38 river miles (61 km) north of the Battery. The oil fired steam electric generating plant withdraws condenser cooling water from Bowline Pond, which draws water from the Hudson River via a pond inlet approximately 219 ft (67 m) wide at the water surface and 16.5 ft (5 m) deep at the mean low water level. Figure 2.3-11 illustrates the relative locations of the plant, pond, intake structure, discharge pipes, and the Hudson River.

The condenser cooling water intake is a reinforced-concrete structure 140 ft (43 m) wide and about 27 ft (8 m) deep at mean water level (Fig 2.3-12 and 2.3-13). The structure is divided into six bays, three for each of the two generating units. Each bay is about 16 ft (5 m) wide and is equipped with a trash bar rack at the entrance, a de-icing bubbler, a traveling screen and screen wash pump, a chlorine solution diffuser,

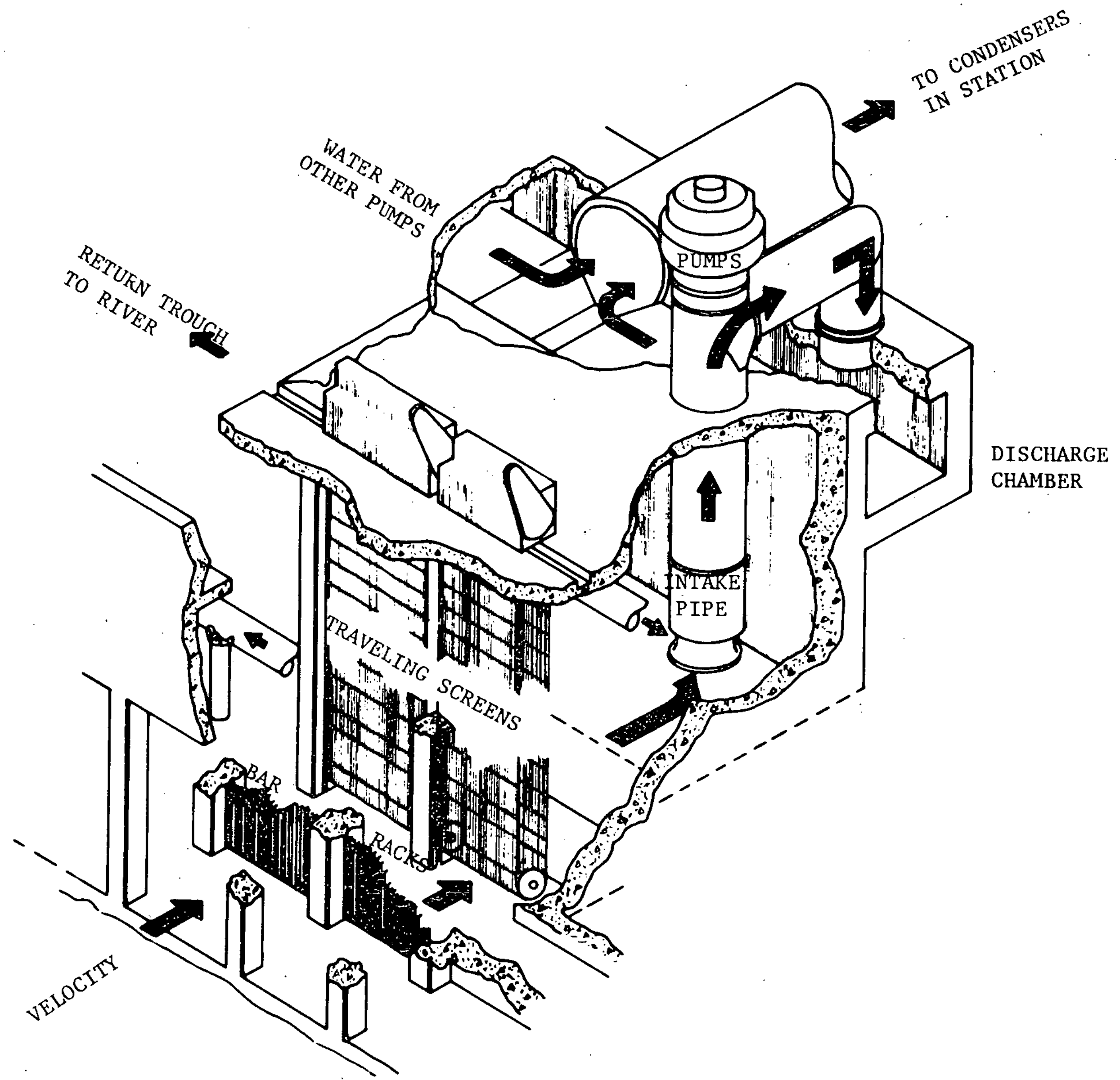


Figure 2.3-10 Detailed Schematic of Roseton Generating Station Intake Profile

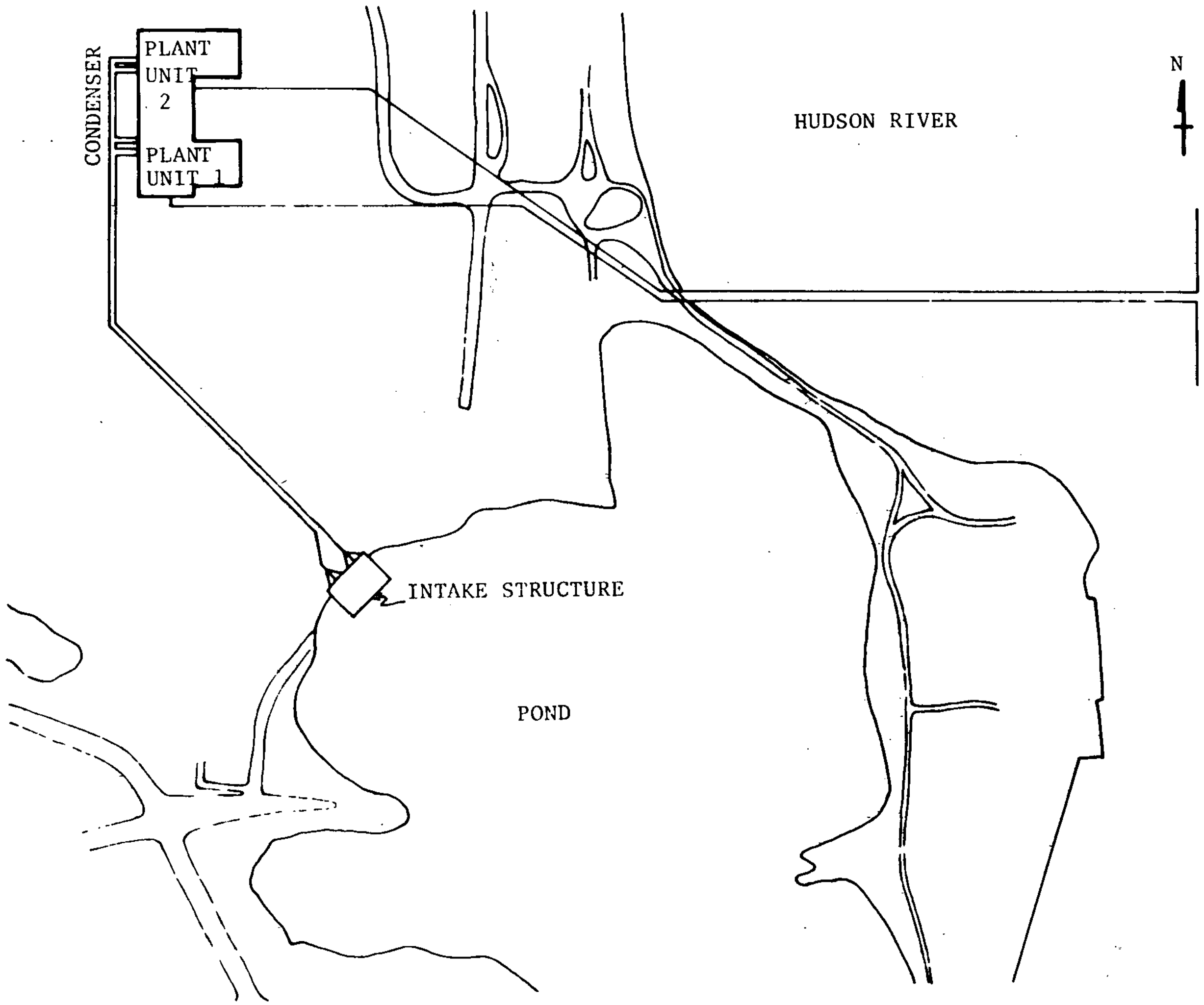


Figure 2.3-11 General Plan of Bowline Point Generating Station Circulating Water System

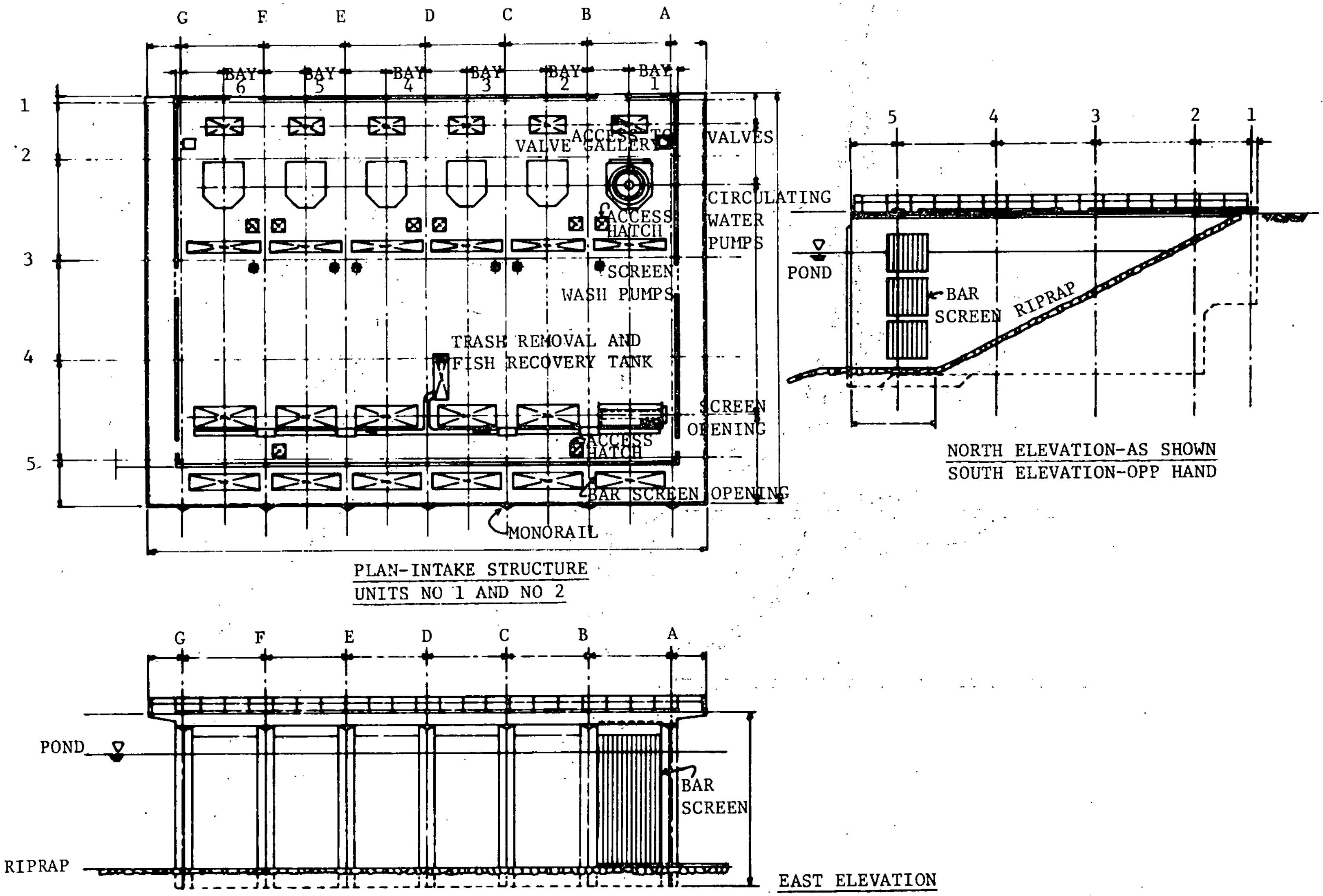


Figure 2.3-12 Plan and Elevations of Intake Structures of Bowline Point Generating Station Units 1 and 2

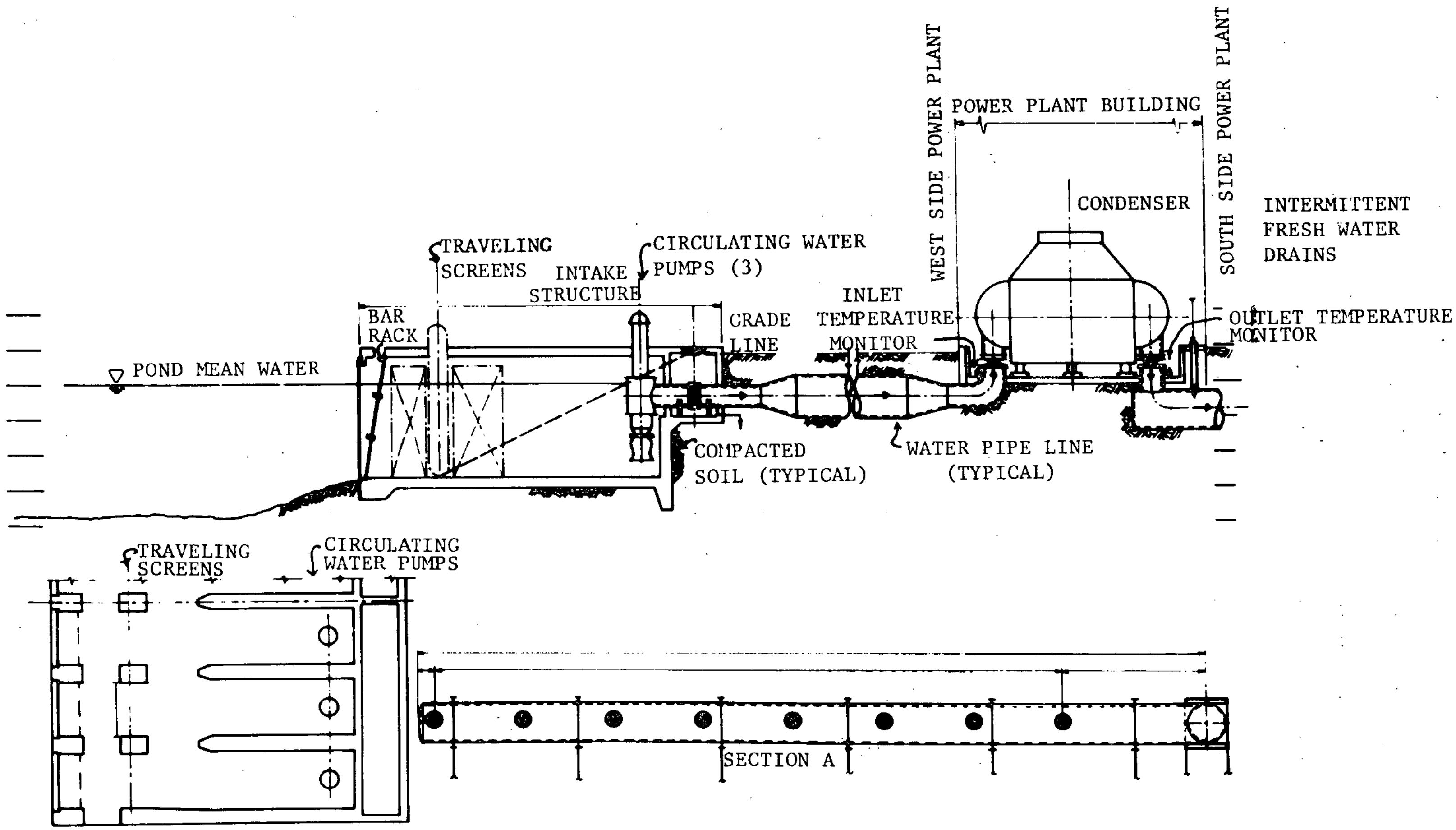


Figure 2.3-13 Sections and Profiles of Bowline Point Generating Station Circulating Water System

and an 85,000 gal min^{-1} (700,301 litre min^{-1}) circulating water pump. The bays are interconnected downstream of the traveling screens to minimize waterflow velocity where fewer than three circulating water pumps are operating. This may reduce fish impingement potential. In addition, trash racks on the sides of the structure as well as those on the front of the structure provide fish that enter the intake with an additional opportunity to escape impingement on the traveling screens.

2.3.3.3.4 Lovett Generating Station. The Lovett steam electric generating plant, which is on the west bank of the Hudson River about 42 river miles (68 km) north of the Battery consists of five fossil-fueled generating units. As shown in Figure 2.3-14, Units 1 and 2 have a common intake channel, whereas all others have individual intakes. All the intakes have standard trash bar racks located on the shoreline of the Hudson River. The intake channel for Units 1 and 2 is about 10 ft (3 m) wide and 15 ft (5 m) deep and is divided into two bays at the entrance to the generating building, each equipped with a 0.375 in^2 wire mesh traveling screen to remove debris. At the Unit 3 intake, three circulating water pumps withdraw water from a common intake channel that divides into three bays, each having a vertical traveling screen with 0.375 in^2 (2.42 cm^2) wire mesh to remove debris.

Both Units 4 and 5 have two circulating water pumps with two associated vertical traveling screen installations. Figures 2.3-15 and 2.3-16 illustrate diagrammatically the plan and profile of the Units 4 and 5 intakes. The trash racks are flush with the shoreline. Each intake is divided into two bays, each with its trash racks, a skimmer wall extending 2 ft 3 in (0.69 m) below the mean low water level, and a circulating water pump. Water in the bay is about 13 ft (4 m) deep at the mean low water.

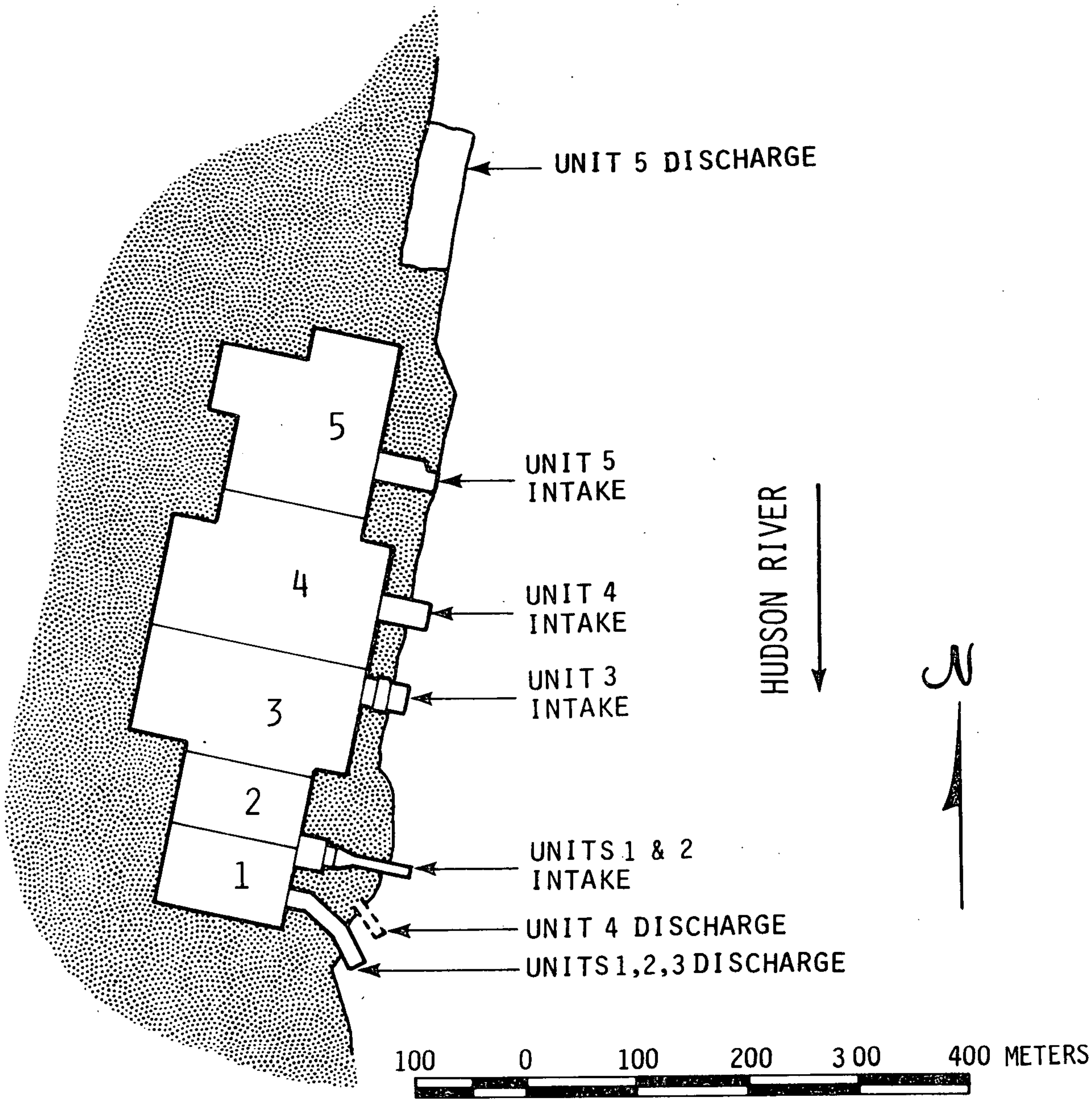


Figure 2.3-14 Lovett Generating Station Plant Diagram

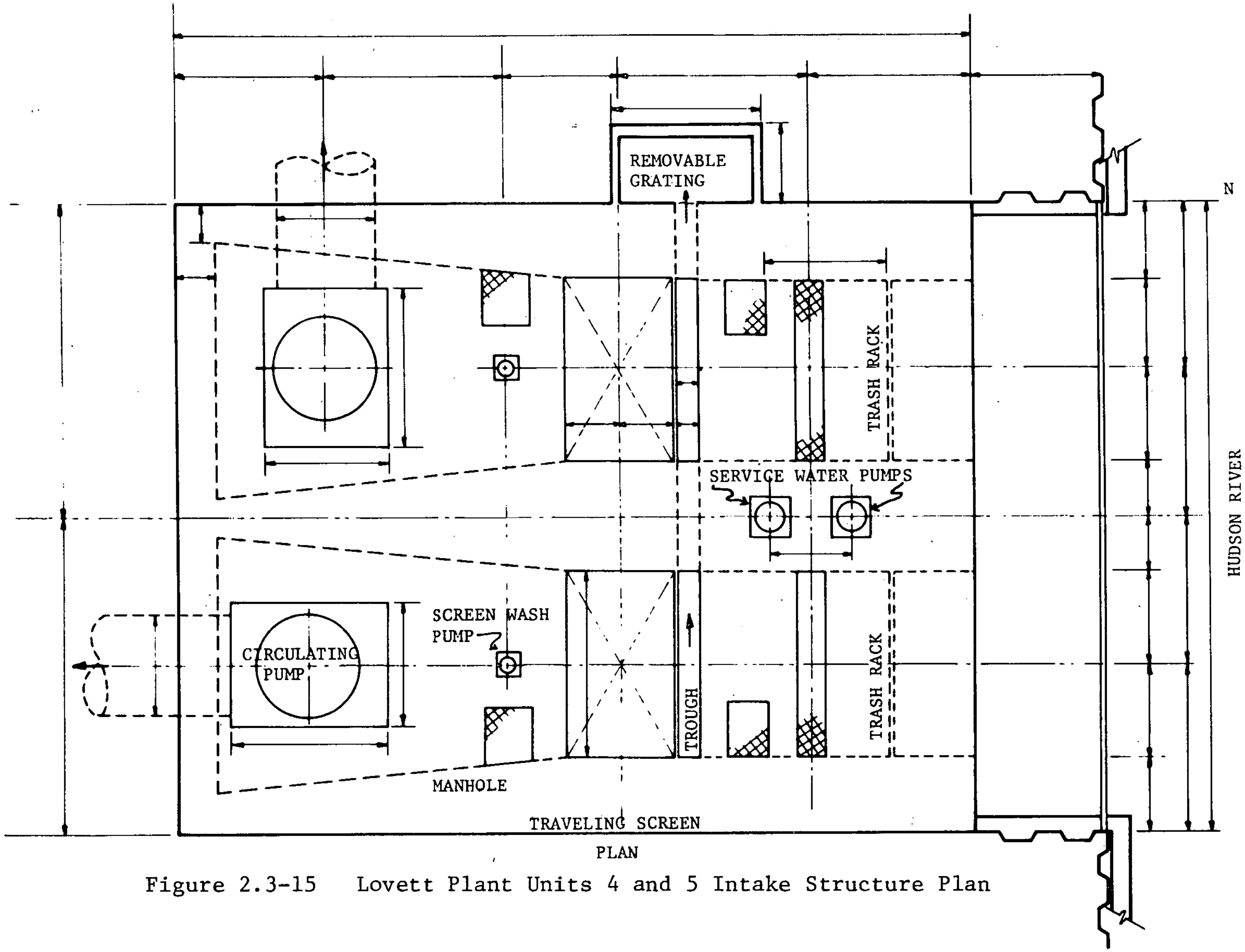


Figure 2.3-15 Lovett Plant Units 4 and 5 Intake Structure Plan

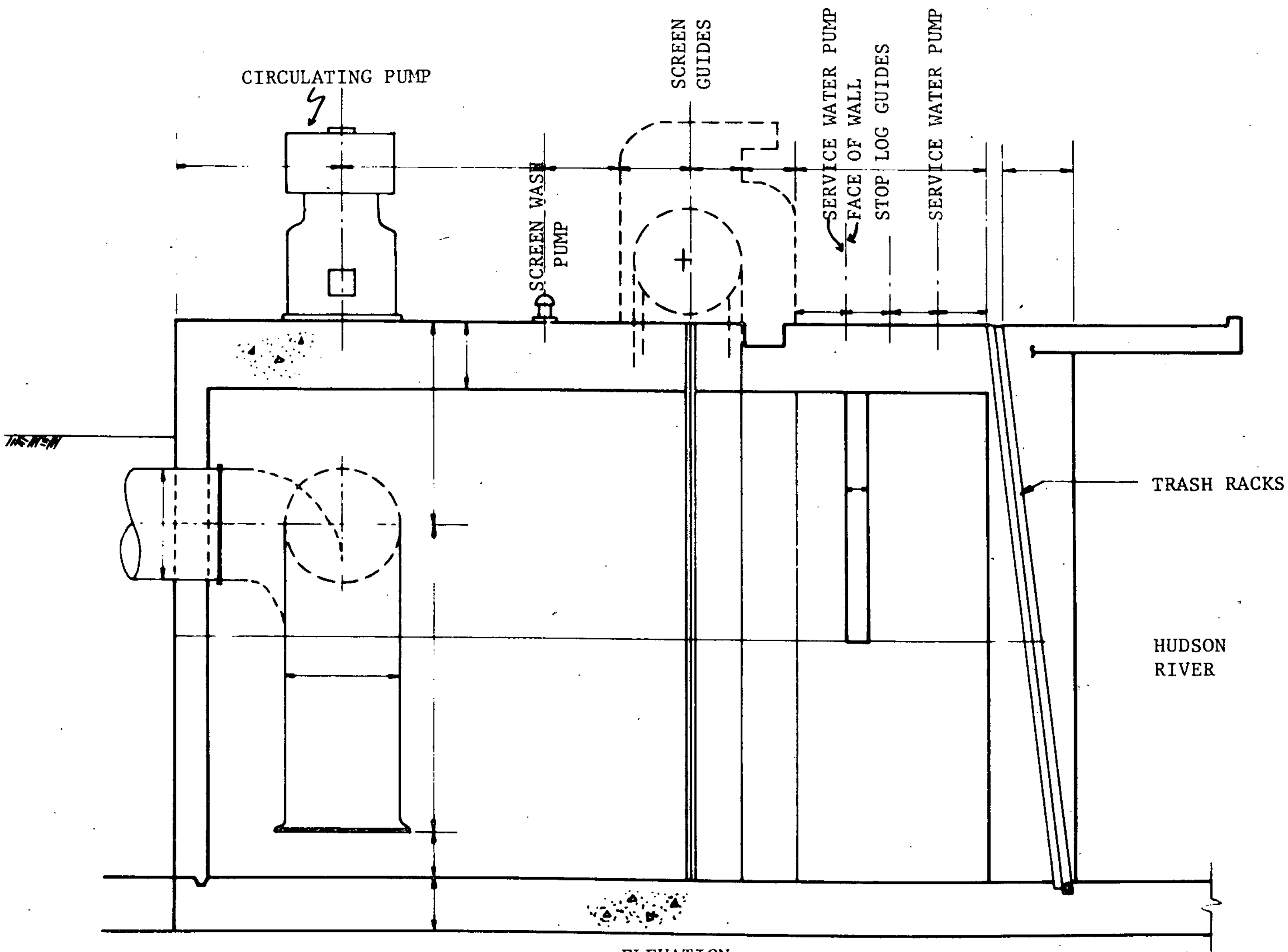


Figure 2.3-16 Lovett Plant Units 4 and 5 Intake Structure Profile

2.3.3.3.5 Danskammer Point Generating Station. The fossil-fueled Danskammer plant has four generating units. As shown in Figure 2.3-17, the cooling water intake at the Danskammer plant consists of trash bar racks located at the river shoreline, an intake channel, and a common intake bay from which river water is diverted into various cooling systems through a series of vertical traveling screens. The trash rack is about 34 ft (10 m) wide; depending on water levels, the gross cross-sectional area may vary from 348 to 433 ft^2 (32.4 to 40.3 m^2) at the mean low water and high water levels, respectively. The intake channel is about 450 ft (137 m) long, 34 ft (10 m) wide, and approximately 11 ft (3 m) deep. When all units are operating, the average water velocity in the channel is about 1.94 ft s^{-1} (0.59 m s^{-1}).

There are two circulating water pumps, each having three vertical traveling screens, at both Units 1 and 2. Units 3 and 4 share a common intake. There are six traveling screens at this intake, three each for Units 3 and 4. Unit 3 has two circulating water pumps that draw water from the intake channel and deliver it to the Unit 3 condenser system via a 102 in (259 cm) diameter pipe. Unit 4 has two circulating water pumps situated behind their respective traveling screens.

2.3.3.4 Nearfield River Morphology. The general morphologic characteristics of the Hudson River are discussed in Section 2.2.1. Specific river morphometric characteristics in the vicinity of the discharge of each power plant appear in Figure 2.3-18 and Table 2.2-3.

2.3.3.5 Nearfield Circulation Detail. If plankton were uniformly distributed and either did not swim or swam only weakly, the numbers entrained could be calculated simply from the rate of withdrawal of cooling water. However, many planktonic species spend different parts of the day near the top and bottom of the water column; thus, to calculate their entrainment, it is necessary to know from what part of the body of water the cooling water is withdrawn. This requires a detailed description of the nearfield flow characteristics around inlets.

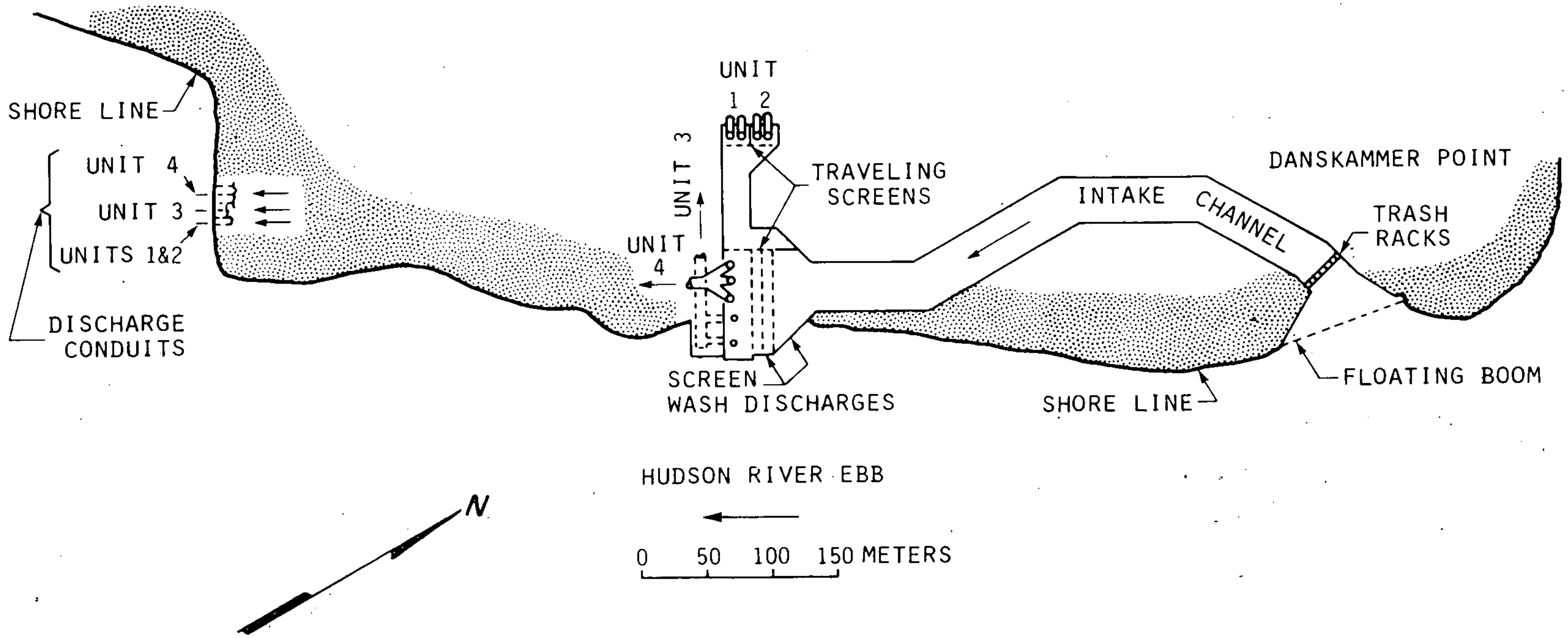
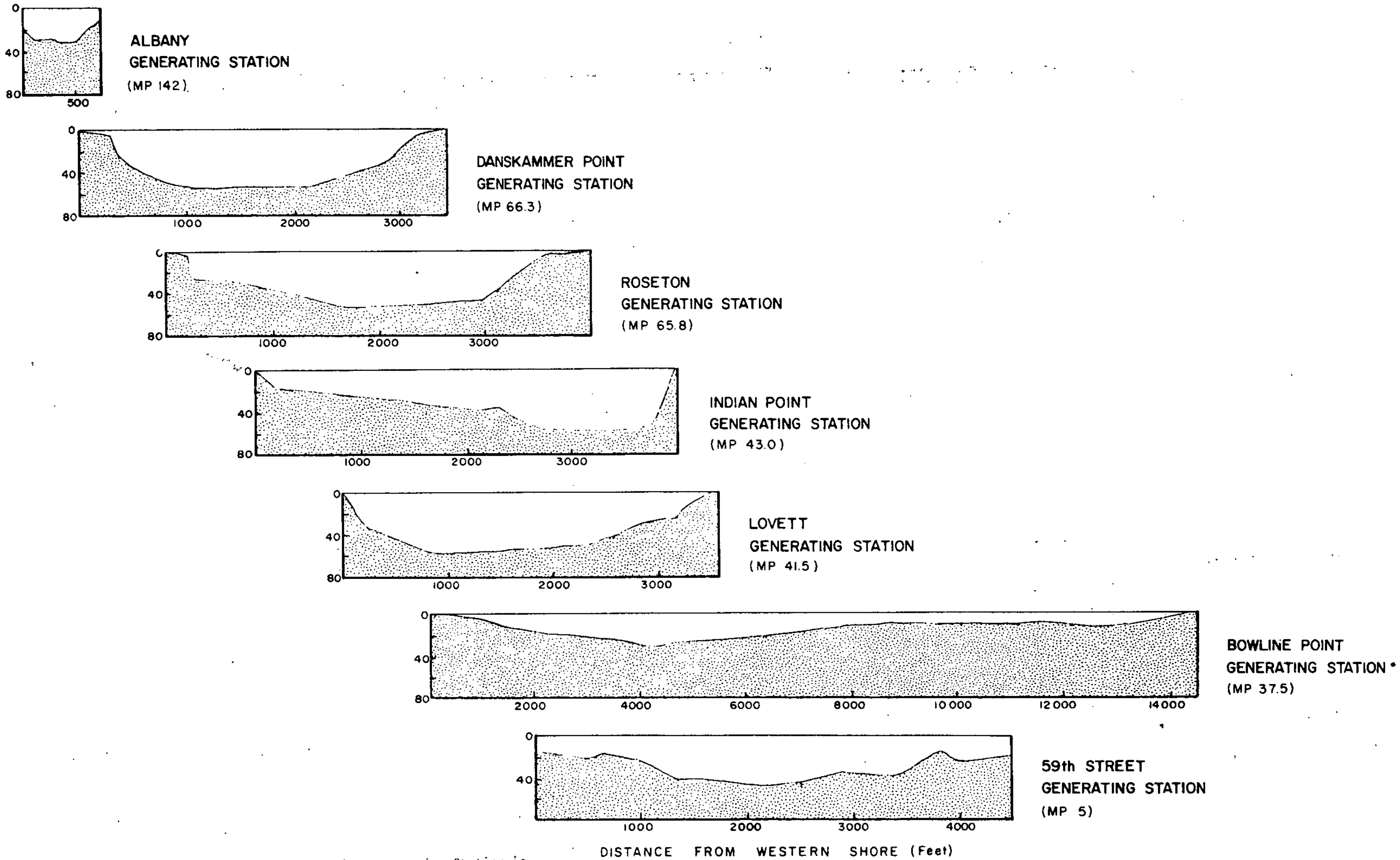


Figure 2.3-17 Danskammer Point Generating Station Intake Structure



*The horizontal axis of the Bowline Point Generating Station is drawn at twice the scale of the other channel cross sections.

Figure 2.3-18 Channel Cross Sections at Hudson River Power Plant Discharges

The amount of water withdrawn from any position on the cross section may vary, depending on the location of the circulating water pump, the configuration of the intake structure, the frictional drag at the bottom, and the rise and fall of the tides. The river may be sufficiently stratified in cross section so that it is hydrologically possible that some of the water mass in the vicinity of the plant will never go through the cooling plant whereas other water masses may go through twice. LMS is using two mathematical models to analyze this type of behavior for the Roseton and Danskammer Point plants and the Bowline Point generating station: one describes fluid velocity profiles near the immediate vicinity of the water pump under simplified conditions; the other is an analytical, transient, 3 dimensional model to provide intake flow behavior beyond some 400 ft (122 m) in front of the plant. Data from these studies are presented in Table 2.3-5. Preliminary studies have shown that most of the water withdrawn and pumped through the plant during slack tide conditions comes from a radius of approximately 1600 ft (488 m) from the discharge. During ebb and flood tide, the influence of pumping is not normally detected beyond 400 ft (122 m) from shore. Hydraulic model studies performed at Alden Research Laboratories and Lasalle Hydraulic Laboratory show that water comes to the Indian Point intakes from a band about 200-350 ft (61-107 m) wide along the east shore of the river during the ebb and flood stages (Table 2.3-5). The remainder of the time, the water drawn into the intakes comes from the local area just in front of the plant or from the upstream direction due to the effluent discharge cutting off downstream flow. The studies also show that plant induced change in river velocities is very small, which means that any organisms not subjected to natural river transport are not disturbed by plant operation. In conclusion, the studies show that only a small percentage of organisms located beyond a short distance from the front of the intakes are normally subjected to plant withdrawal.

Table 2.3-5 Extent of Lateral Zone during Various Tidal Phases

	Maximum Lateral Extent (ft)		
	Max. Flood	Max. Ebb	Aver. Slack
Indian Point*	200-300	200-300	1600
Roseton**	300	400	1400
Danskammer**	300	400	1400
Bowline***	210	350	630

*Hydraulic model results, Alden and LaSalle
**Mathematical model results, LMS
***Field survey and mathematical results

SECTION 3

ENERGY BUDGET OF THE LOWER HUDSON RIVER

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SECTION 3

ENERGY BUDGET OF THE LOWER HUDSON RIVER

3.1 INTRODUCTION

Energy dynamics of the lower Hudson River ecosystem integrate the energy available from marine, human, and terrestrial systems surrounding the river with primary production within the river. While sunlight ultimately regulates energy production in systems, overall system function reflects the energy available to biological components, interactions among biological components (e.g., predation, competition), interaction with adjacent systems (e.g., migration, material import or export), and effects of physical forces (e.g., tide, wind, currents). In this section, energy inputs to the Hudson River and their principal interactions are estimated and organized in an energy model of the lower Hudson ecosystem. Some estimates are adopted from other aquatic systems where Hudson River data are not available; some parameters are estimated with no better than order of magnitude precision. Nevertheless, it has been possible to reach ~~important~~ general conclusions about power plant impacts on the ~~ecosystem.~~ energy budget of the Hudson River.

3.2 BENTHIC PLANTS

Benthic plants growing in shallow water contribute to net production in the Hudson. Studies by Quirk, Lawler and Matusky (LMS 1975d) and Kiviat (1973) provide descriptions and identifications of rooted aquatic plants, but neither presents quantitative data on biomass or respiration from which energy fixation can be calculated. Since the species composition of Hudson River marsh communities (Kiviat 1973) is similar to those described by Whigham and Simpson (1975:27-31; 1976:176) for the Delaware River, plant production reported from the latter has been used as an estimate of plant production in the Hudson.

North of Peekskill, emergent vegetation in freshwater marshes of the tidal Hudson River is dominated by loosestrife (*Lythrum*), arrow arum (*Peltandra*), cattail (*Typha*), and pond lily or spatterdock (*Nuphar*). Submergent plants include eelgrass (*Vallisneria*), water milfoil (*Myriophyllum*), and pondweed (*Potamogeton*). Cordgrass (*Spartina*) is restricted to marshes south of Peekskill, which are periodically covered by brackish water (LMS 1974:VI-39 to VI-40). As estimated from navigational charts (USCGS 282, NOAA 12347 and 12348), there are approximately 2400 acres (970 ha) of marshes in the Hudson River between the George Washington Bridge at New York City and the Federal Dam at Troy (RM 12-153; km 19-246).

Net production values for various marsh plants and communities have been listed by Keefe (1972) and Whigham and Simpson (1976:178-179). Estimates range from 300 g $m^{-2} yr^{-1}$ (*Spartina* saltmarsh, New Jersey) to 2104 g $m^{-2} yr^{-1}$ (*Lythrum* freshwater marsh, New Jersey); their average was 1000 g $m^{-2} yr^{-1}$, the value used here as the approximate net production in marshes. The caloric content of aquatic seed plants is assumed to be 4.1 kcal g^{-1} dry weight (Cummins and Wuycheck 1971:17). Hence, the total approximate net production is 40×10^9 kcal yr^{-1}.

3.3 PHYTOPLANKTON

New York University has been assessing the effects of power plant entrainment on algae in the area of Indian Point for 5 yr, analyzing algal assemblages for species composition and species abundance. However, phytoplankton abundance among years is not directly comparable from the Indian Point data since studies in 1971 and 1972 used net sampling procedures, while studies in 1974 and 1975 used whole-water sampling, a procedure that permitted analysis of the "nannoplankton" (that portion of the algal community composed of organisms <18 μ in diameter). Trends in abundance were similar in 1972, 1974, and 1975. In May of 1974 and 1975, peaks throughout the region were similar, with abundances of approximately 10^7 cells litre^{-1}. Except for a peak in July 1975, total phytoplankton numbers at all stations were approximately 10^6 cells litre^{-1} for all years.

Algal species composition in the area of Indian Point (RM 43; km 69) exhibited an expected seasonal variation. Throughout all years of comparable examination (1972, 1974, and 1975), green algae and diatoms dominated, diatoms being abundant in early spring but replaced in June and July by green algae, which peaked in late summer and early fall. Diminishing abundance of green algae in the winter was balanced by the growth of the diatom population at that time. Average chlorophyll-a concentration at the seven river stations varied significantly among dates; peaks occurred during spring and fall, coinciding with peak densities of phytoplankton observed at those times.

Primary production in the Hudson River estuary has been estimated from oxygen evolution data, ^{14}C uptake, and extrapolation from chlorophyll-a values. Estimates derived by NYU (1976a) and Ecological Analysts (1976a, b) generally agree on carbon fixation. Assuming that all photosynthesis occurred in the upper 3.3 ft (1.0 m) in the Indian Point area, production values (carbon fixation) ranged from as low as 0.024 g m^{-2}day^{-1} in December 1974 (NYU 1976a:74-75, 83-87) and 0.060 g m^{-2} day^{-1} at Bowline in November 1975 (EA 1976a:5-6 to 5-7) to as high as 1.2 g m^{-2} day^{-1} at Indian Point in May 1974. Mean values for the Bowline area in 1975 were 0.5, 0.6, and 0.06 g m^{-2} day^{-1} in June, August, and November, respectively (NYU 1976a:74-75, 83-87).

Production is lowest during the colder months (December-April) and increases rapidly during the spring diatom bloom. Thereafter, variable production is related to nutrient availability, consumption by animals (zooplankton), and turbidity. A gradual decline in production usually occurs in late summer and fall, although diatom blooms may result in transient peaks during October and November.

Annual production in aquatic ecosystems is best estimated by the time-weighted average of monthly observations rather than by a simple arithmetic mean (Flemer 1970:126) because the arithmetic mean (0.42 g m^{-2} day^{-1}) of the above observations may be two to three times higher than the actual annual primary productivity. Consequently, time-weighted production (carbon fixation) in the Hudson River is probably close to 0.2 gm^{-2} ~~mg~~ day^{-1} during the year, the value reported by Flemer (1970:126) for the upper area of Chesapeake Bay. Therefore, production in the Hudson River estuary is on the order of 20 x 10^9 g carbon yr^{-1}, or 200 x 10^9 kcal yr^{-1}.

3.4 DETRITAL AND DISSOLVED INPUTS FROM UPSTREAM

All dissolved and particulate organic material entering the tidal Hudson River from the upper watershed comes through or over the dam at Troy, New York. Water flow and physical and chemical characteristics of the water are monitored at Green Island by the U.S. Geological Survey. During 1974 and 1975, total organic carbon averaged 5.2 g m^{-3} (USGS 1975:93; 1976:401). Using this average, the input of organic materials (as carbon) from the upper Hudson-Mohawk River watershed is 6.2 x 10^7 kg yr^{-1} or 620 x 10^9 kcal yr^{-1}.

3.5 NATURAL TERRESTRIAL INPUTS FROM LOWER HUDSON WATERSHED

Energy as organic material enters the Hudson estuary from the watershed and via primary production (photosynthesis) in the lower Hudson River. Organic materials may be imported in particulate form or in solution; the dissolved fraction may be much larger than the particulate fraction (Birge and Juday 1934:467-468). Transport of dissolved organics and particulate organics (detritus) of terrestrial origin is highly seasonal and closely follows the runoff-streamflow patterns of the watershed. Import from the watershed below the federal dam at Troy is considered in this section. Estimates of terrestrial inputs were developed from the scientific literature, i.e., studies conducted in a northern hardwood forest in which species composition is very similar to that of the hardwood forest of the Hudson Valley.

Dissolved organic substances enter the water from many biological sources. Living plants and animals produce many compounds (e.g., amino acids, carbohydrates, and soluble proteins), which are washed from living and dead organisms by rain. Plant litter (leaves, twigs, bark, fruits, roots, etc.) loses soluble organics by leaching into surface runoff or ground water. In areas abundant with bogs, tannins, humic acid, and other organic materials flow into ponds or streams from the deposits of long-dead plant materials. Living plants lose organics through stemflow (water flowing down the stem) and via through-fall (rain falling through the foliage), guttation, and root exudation. Animal products contribute some soluble organics to surface and ground waters via excrements (urine, feces), and decay (dead animals, including soil invertebrates as well as vertebrates). Fisher and Likens (1972:35) reported export of energy in dissolved organic materials from a small watershed covered by northern hardwood forest to be about 2800 kcal m^{-2} yr^{-1}. Assuming this value to be representative of the lower Hudson watershed (~~8544~~ 5310 mi^2; 13,750 km^2), the total unadjusted energy contribution of dissolved organic substances of terrestrial origin would be ~~385~~ 38500 x 10^9 kcal yr^{-1}.

Particulate organic materials are derived principally from plant litter fall, although some may be eroded from deposits of long-dead plant materials. The entry of plant litter into aquatic ecosystems is seasonal, coinciding with leaf fall in the autumn in deciduous forests such as the Hudson River Valley and with peak runoff from precipitation (either rainfall or snow melt). Some litter enters streams directly from the source plant; wind sweeps in other litter from surrounding areas. Plant debris may be placed in water directly by animals (beavers, muskrats) or in animal feces. Similarly, particles (insect bodies or parts, hair, feathers, etc.) derived from animals enter aquatic systems. Particulate organic material becomes available as usable energy as it decomposes.

Animal fragments (especially soft parts) are rapidly decomposed to soluble forms and are used by detritivores or bacteria. Soft plant parts (e.g., fruits, leaf parenchyma) are consumed or fragmented soon after their entry into the water. Older and consequently tougher leaves, such as those dropped in the fall, are slowly fragmented and may accumulate with other woody plant parts, their fragmentation and decomposition requiring months or years. Fisher and Likens (1972:35) found that the energy export from a northern hardwood forest as particulates was about 1200 kcal m^{-2} yr^{-1}. Leaves entering a water body in the northeastern U.S. may contribute 3500 kcal m^{-1} of shoreline (approximately 350 g C m^{-1}) (Jordan and Likens 1975:1000). Assuming this to be applicable to the lower Hudson River, total annual input (unadjusted for land-use variations) as particulate organics would be about 16500 ~~167~~ x 10^9 kcal. Using the unmodified values for northern hardwood forest (Fisher and Likens 1972: 35; Jordan and Likens 1975:1000), the total input of energy from the watershed would be on the order of ~~552~~ 55000 x 10^9 kcal yr^{-1}.

Factors that may influence the natural terrestrial input are urbanization of the watershed and agriculture with the accompanying loss of forested land. The output of organic material from old fields, pastures, croplands, and urbanized areas is about 2.5 times greater than from forested land (Yu et al. 1971; Loehr 1974:~~1895)~~ 1865. The lower Hudson River watershed contains about 30% urban and agricultural land (Omernik 1976:18); adjusting for this development, total input is approximately ~~800~~ 80,000 x 10^9 kcal yr^{-1}.

Additional energy is derived from sewage and other wastes (Section 3.5) and, to a lesser extent, from the coastal marine ecosystem (Section 3.6).

3.6 POLLUTIONAL INPUTS

Pollutional inputs to the lower Hudson River can be classified as originating from point and nonpoint sources. The major point-source discharges to the Hudson River consist of municipal sanitary and combined sanitary storm sewers and industrial effluents, which may be subdivided into process and cooling water discharges. Nonpoint-source discharges are functions of land use and consist primarily of the materials washed off the surface of the earth during rainfall. For the lower Hudson, these discharges can consist of agricultural runoff, storm-water runoff, and combined sewer-system overflows. In 1973, municipal point sources between RM 0 and 153.7 (km 0 and 247.4) discharged 96% of the total BOD (biochemical oxygen demand) of the river, or 0.82×10^6 kg day^{-1} (1.8×10^6 lb day^{-1}); the industrial BOD point-source contribution was 32,930 kg day^{-1} (72,600 lb day^{-1}). The nitrogen oxygen demand (NOD) of the municipal point-source discharges was 96% of the total, or 0.45×10^6 kg day^{-1} (1.0×10^6 lb day^{-1}) compared with 22,000 kg day^{-1} (48,500 lb day^{-1}) from industrial sources.

The 1973 municipal and industrial point sources are shown in Tables 3.6-1 and 3.6-2, respectively. Some of the former and many of the latter may have been eliminated or reduced since enforcement of the 1972 Federal Water Pollution Control Act Amendments (since 1973). Based on a conversion factor of 3.42×10^3 kcal kg^{-1} 0_2 (Warren 1971:146), total BOD is approximately 1100×10^9 kcal yr^{-1}.

Energy input in the lower Hudson River from such nonpoint sources of pollution as sewer overflows, street-storm runoff, and dairy-herd manure cannot be estimated. As treatment levels of municipal effluents increase, the proportional energy contribution from nonpoint sources will increase.

Table 3.6-1 Municipal Waste Loads Discharge into Lower Hudson River during 1973

MUNICIPALITY	RIVER MILEPOINT	TREATMENT	BOD ~~NOD~~ KG/DAY	BOD ~~NOD~~ LB/DAY	NOB ~~BOD~~ KG/DAY	NOB ~~BOD~~ LB/DAY
Green Island	153.0	NONE	382	841	241	530
Troy	152.0	NONE	7293	16044	4290	9438
Watervliet	152.0	NONE	1438	3163	846	1861
Menands	149.0	NONE	400	879	235	517
Colonie-Latham	146.5	NONE	2128	4482	1252	2754
Rensselaer	146.0	NONE	1238	2723	728	1602
Albany	146.0	NONE	13420	29524	7894	17367
East Greenbush	145.4	NONE	1238	2723	728	1602
Bethleham	142.5	Primary-34%	580	1276	859	1890
Castleton-on-Hudson	137.5	Secondary-84%	32	70	59	130
Revana-Coeymans	133.5	Secondary-87%	57	126	130	285
Coxsackie	125.0	Secondary-85%	42	92	82	180
Athens	118.0	Secondary-84%	31	68*	59	129
Hudson	118.0	Primary-35%	1255	2760*	610	1341
Catskill	114.0	Secondary-90%	62	136	181	399
Cementon	107.0	Secondary-90%	9	20	24	53
Saugerties	103.0	Primary-31%	334	734	143	314
Tivoli	102.0	Secondary-90%	9	19	25	56
Kingston	92.0	Primary-29%	2073	4560	1742	3832
Highland	77.0	Primary-30%	177	390	75	164
Poughkeepsie	76.0	Primary-30%	2599	5717	2184	4804
Arlington	76.0	Secondary-85%	190	417	382	840
Wappingers Falls	68.5	Primary-35%	422	928	382	840
Newburg	61.0	Secondary-91%	273	600	89	195
Beacon	61.0	Secondary-83%	256	563	452	994
Cornwall	57.0	Secondary-90%	170	375	106	233
Cold Springs	54.5	Secondary-90%	57	125	71	156
West Point	52.0	Secondary-90%	94	207	341	750
Highland Falls	51.0	Primary-30%	628	1381	316	696
Bear Mountain	46.0	Secondary-90%	2	5	8	17
Peekskill	44.0	Primary-35%	1416	3115	1403	3086
Camp Smith	43.5	Primary-35%	55	120	82	180
VA Hospital	38.7	Primary-35%	111	245	191	420

Table 3.6-1 (Contd)

MUNICIPALITY	RIVER MILEPOINT	TREATMENT	~~NOD~~ BOD		~~BOD~~ NOD	
			KG/DAY	LB/DAY	KG/DAY	LB/DAY
Stony Point	39.5	Secondary-85%	144	316	282	620
Haverstraw Town	37.0	Secondary-85%	337	714	660	1453
Village of Haverstraw	37.0	Primary-35%	546	1201	556	1224
Croton	37.0	Primary-35%	554	1218	334	735
Ossining	33.0	Primary-30%	1037	2281	1477	3249
Upper Nyack	29.0	Primary-20%	136	300	72	158
Briarcliff and N. Tarrytown	28.0	Primary-30%	726	1597	1343	610
Nyack	28.0	Primary-35%	665	1463	450	990
S. Nyack	27.5	Primary-22%	83	182	234	515
Tarrytown	27.5	Primary-20%	1030	2265	757	1665
Orangeburg	25.0	Secondary-85%	956	2104	1875	4125
Irvington	25.0	Primary-20%	909	2000	401	882
Yonkers - South	18.0	Primary-36%	32758	72068	34411	75705
Rockland Co	24.8	Secondary-85%	2209	4860	4824	10613
Manhattan	0-13.0	NONE	11524	25352	7145	15720
Manhattan	0-13.0	NONE	22087	48592	13695	30130
Manhattan	0-13.0	NONE	37132	81690	23023	50650
Manhattan	0-13.0	NONE	32650	71830	20245	44540
Manhattan	0-13.0	NONE	26250	57750	16273	35800
Manhattan	0-13.0	NONE	26168	44370	12505	27510
Manhattan	0-13.0	NONE	2017	4437	12505	27510
Manhattan	0-13.0	NONE	12228	26900	7582	16680
Riverdale	14.0	NONE	5123	11270	3177	6990
Edgewater	10.0	Primary-20%	2273	5000	1705	3750
Passaic Valley	2.5	Primary-30%	463636	1020000	203636	448000
Jersey City East	0.8	Primary-30%	25064	55140	18495	40690
Staten Island	3.5	NONE	5273	11600	3136	6900
Owl's Head	3.5	Secondary-50%	36818	81000	32409	71300
Hoboken	2.8	Primary-30%	18727	41200	13773	30300
West New York	5.7	Primary-30%	6000	13200	4418	9720
N. Bergen	6.4	Primary-30%	575	1264	422	929
Edgewater	7.5	Primary-30%	1850	4070	1359	2990

Table 3.6-2 Industrial Waste Loads Discharged into Hudson River during 1973

COMPANY	RIVER MILEPOINT	~~NOD~~ BOD		~~BOD~~ NOD	
		KG/DAY	LB/DAY	KG/DAY	LB/DAY
The Bendix Corp.	153.5	324	712	6	14
Manning Paper Co.	153.0	2648	5826	356	784
Allegheny Ludlum Ind.	150.4	52	114	14	31
Albany Felt	148.3	136	300	31	68
Huyck Felt Co.	145.4	392	863	–	–
GAF	145.4	5505	12110	507	1116
Winthrop Lab.	144.4	7240	15927	1218	2679
Brown Co.	138.0	909	2000	50	109
The Columbia Corp.	126.0	158	348	59	130
Hudson Valley Apple Prod. Co., Inc.	72.7	155	342	–	–
Stauffer Chemical Co.	61.0	373	821	–	–
Majestic Wearing Co., Inc.	57.8	1307	2875	391	860
Standard Brands, Inc.	43.5	2291	5040	1915	4212
Kay-Fries Chemical, Inc.	38.8	321	706	2667	5890
Elk Piece Dye Works, Inc.	37.0	177	390	84	185
G E Norgl Prods.	35.9	114	251	–	–
Clevepack Corp.	24.9	824	1812	34	75
Spencer Killog Div. of Textron, Inc.	7.1	69	151	–	–
Wilson Pharmaceutical	6.0	771	1697	–	–
Colgate-Palmolive Co.	0.8	51	113	–	–
I.E. duPont de Nemours & Comp.	0.0	1165	2563	11551	25413
Vulcan Material Co.	0.0	2570	5655	54	119
A. Gross & Co.	0.0	2674	5883	2280	5016
NACP-US Div.	0.3	300	660	19	41
Federal Building	-1.0	48	106	24	52
Baker Castor Oil Co.	-2.0	116	255	183	402
Sucrest Corp.	-2.0	1644	3617	45	98
Howard Smith, Inc.	-13.0	57	126	144	316
Int'l Flowers & Fragrance, Inc.	-16.0	594	1306	410	903

3.7 MARINE INPUT TO HUDSON RIVER ESTUARY

Organic compounds in dissolved or particulate form, living plankton organisms, and larger animals such as fishes and crabs enter the Hudson River estuary from the coastal ecosystem of the New York-New Jersey area. Plankton and nonliving organic material remain in the saline water mass as it moves into the estuary (Ruttner 1963:61), whereas fishes and larger invertebrates may move into the freshwater reaches of the estuary to feed or reproduce.

Tidal flow brings dissolved and particulate matter and plankton into the lower Hudson River. These materials may be trapped temporarily in the estuary when adsorbed onto sediment particles or consumed by organisms residing in the estuary. The dilution of seawater and the net seaward flow in the estuary confine direct input to the lower 62 mi (100 km) of the estuary in summer and the lower 25 mi (40 km) during late winter and spring when freshwater flow is highest. Garside et al. (1976:284, 287) reports that a large portion of the nitrogen in sewage effluents entering the lower estuary is transported out of the estuary by the net seaward flow of water. Consequently, the net input of plankton and nonliving organic material from the coastal ecosystem is probably near zero.

Larger animals entering the Hudson River estuary from the coastal regions of New York and New Jersey may contribute energy to the estuarine ecosystem. Anadromous fishes such as the striped bass and various herrings (family Clupeidae, genus *Alosa*) migrate from the sea to spawn in the freshwater reaches of estuaries. Striped bass spawn large quantities of eggs developed from food sources outside the estuary. The herrings contribute eggs as well. Since eggs and yolk-sac larvae experience a high mortality rate, a large proportion of the energy contained in the eggs is added to the energy budget of the estuary. Mortality of adult striped bass and blue crabs entering the Hudson River is probably of little significance to the ecosystem energy budget. Emigration and harvest of these organisms are routes of export from the aquatic ecosystem (Section 3.8).

Fish eggs input energy to the Hudson River ecosystem depending on the number of fish spawning, proportion of eggs developed outside the estuary, and energy lost due to cellular respiration and development of eggs into larvae. If 88×10^9 eggs (1.5×10^6 kg^{-1}) were spawned by striped bass (Section 7.8), nearly 130,073 lb (59,000 kg) of eggs would be deposited in the estuary. Eggs or yolk-sac larvae that do not develop further because of predation or other causes of mortality enter the energy web as both dissolved and particulate organic material; this accounts for about 97% of all eggs spawned. At 1500 kcal kg^{-1} wet weight (Cummins and Wuycheck 1971:27), this represents about 0.085×10^9 kcal yr^{-1} for striped bass. If similar values are assumed for the energy imported by anadromous herring, the total marine input is about 0.170×10^9 kcal yr^{-1}. Even if this energy import is two orders of magnitude greater than developed here, it is still <1% of the total energy budget.

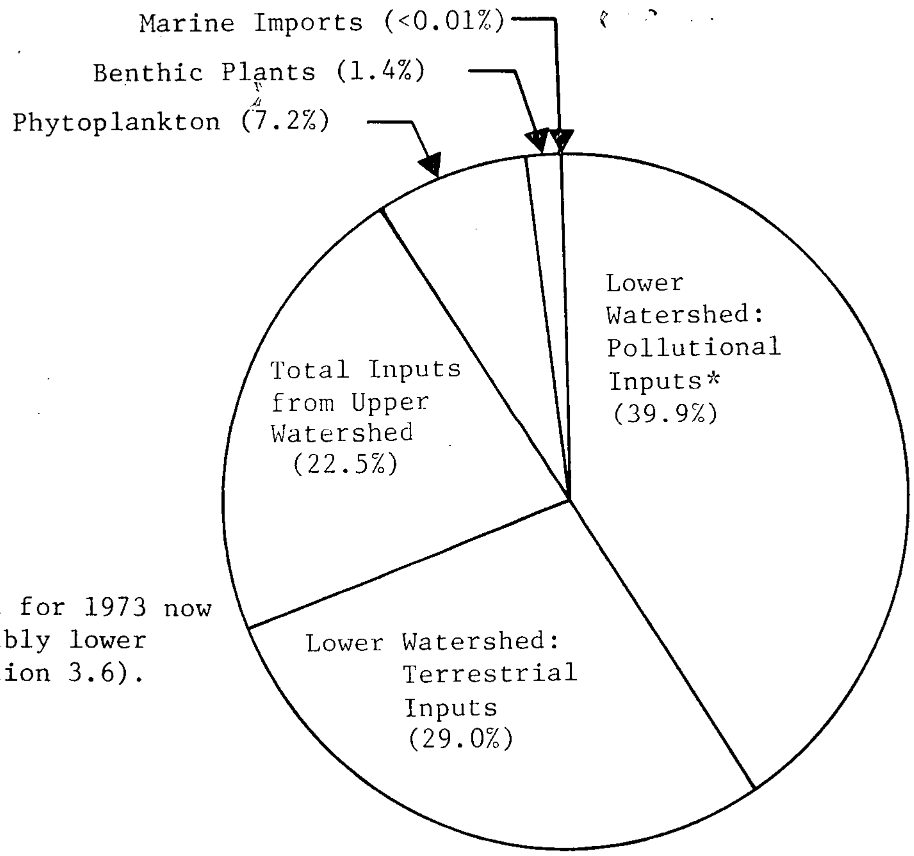
3.8 SUMMARY OF POWER PLANT IMPACTS ON BIOLOGICAL ENERGY BUDGET

Power plant-energy budget interactions involve thermal loading, chemical effluents, and direct organism contact (entrainment and impingement). A summary energy budget for the lower Hudson River is discussed relative to operations of Indian Point and other electric power generating facilities.

3.8.1 ENERGY INPUTS. Energy as organic materials is introduced into the Hudson River from both natural and human systems. Table 3.8-1 lists the various sources and kilocalorie estimates of their respective energy inputs (Sections 3.1 through 3.7). Figure 3.8-1 presents the proportional inputs of energy sources.

Table 3.8-1 Energy Inputs into Hudson River

Source		kcal yr^{-1} x 10^9	% of Total
Benthic plants	Primary Production	40	~~1.4~~ 0.05
Phytoplankton		200	~~7.2~~ 0.24
Upstream watershed		620	~~22.5~~ 0.76
Lower watershed		~~800~~ 80,000	~~29.0~~ 97.61
Human effluents		1,100	~~39.9~~ 1.34
Marine		0.17	<0.01
Total		~~2,760.17~~ 81,960.17	100.0%



Note: Value for 1973 now probably lower (Section 3.6).

Figure 3.8-1 Proportional Contributions to Annual Energy Budget of Lower Hudson River

The Hudson River is a detritus-based system deriving about 40% of its energy from human-system effluents and approximately 60% from the Mohawk and Hudson watersheds and primary production. Marine inputs are insignificant.

3.8.2 ENERGY OUTPUTS. Energy outputs from the Hudson River occur in water outflow and organism migration and harvest. Assuming that 4,000,000 young-of-the-year striped bass (Section 7.9) migrate from the Hudson each fall as well as an average dry weight for each fish of 2.5 g (0.25 x wet weight: Davis and Warren 1965:852) and a caloric content of 4.7 kcal g^{-1} dry wt (value for Centrarchidae: Cummins and Wuycheck 1971:27), striped bass migration will have removed 0.047×10^9 kcal yr^{-1} from the Hudson. Assuming an equal value for the anadromous herrings, there would be a total estimate of 0.094×10^9 kcal output as fish migration. During 1973-75, harvest of year-round residents (primarily white perch) from the river resulted in an average energy output of ~~0.0066~~ 0.00043 $\times 10^9$ kcal yr^{-1} (see commercial catch statistics in Section 5.4). These combined outputs, $< 0.10 \times 10^9$ kcal, are insignificant compared with total available energy in the system. Although some detritus undoubtedly becomes entrapped in river-channel sediments, the outflow of water containing detritus and dissolved organics represents a net export of energy from the Hudson River estuary. Trapped detritus may be excavated later by turbulent currents or removed from the system by dredging operations.

3.8.3 POWER PLANT-ENERGY BUDGET INTERACTIONS. Thermal loading of the water column can kill organisms or modify ecosystem function, the latter through altered production and/or respiration rates. Operating temperatures at Indian Point Unit 2 and those proposed for Unit 3 (USNRC 1975b:V-8) will not adversely affect phytoplankton and zooplankton (NYU 1973:xxvi-xxxi) or benthic communities (TI 1976g:IV-53). Nor is the Indian Point thermal plume likely to affect fish populations since fish avoid critical temperatures (TI 1976a:V-69). Also, since a ~~10%~~ 10°C drop from maximum plume temperatures to winter ambient at Indian Point has been shown not to kill white perch and striped bass (TI 1976g:V-69), cold shock mortality resulting from power plant shutdown is not expected. Other power generating plants of the mid-Hudson (Danskammer, Roseton, Bowline, and Lovett) are also unlikely to have thermal effects on fish populations. These plants have plume temperature regimes similar to or lower than those at Indian Point; their combined waste heat discharge is approximately equal to that of Indian Point Units 2 and 3 (Section 2.3).

Biological effects from power plant chemical effluents are unlikely since concentrations of various toxicants are within limits established for power generating facilities. Chlorine (as sodium hypochlorite) will be the major effluent of interest during normal operation, with concentrations expected to be <0.1 ppm at Indian Point (Con Edison 1972:10-5). Brungs (1973:2188) reported that most fishes tolerate intermittent chlorine concentrations of 0.2 ppm, and Hughes (~~1974~~ 1973:6, 10) found that striped bass larvae and fingerlings were not affected after 96 h in water having calcium hypochlorite concentrations of 0.2 ppm. At Bowline and Lovett, chlorine concentrations at discharge are also <0.1 ppm. Danskammer and Roseton do not employ chlorination during plant operation.

New Paragraphs

Entrainment and impingement of organisms (including ichthyoplankton) results in some mortality, i.e., production of detritus from what were viable organisms. The net energy thus made available in the ecosystem can be calculated as that proportion of the spawn (marine input) killed by power plants which would not have died otherwise. The conditional power plant mortality (m) is the proportion by which the final population (the population at the end of a set interval, e.g., one month, one year) is reduced by power plant operation. In terms of reducing viable organisms to detritus, m is the proportion of the final population which was killed that would not have died from natural causes. Natural mortality from the time of the spawn until striped bass are one year old is very high, >99.995% (Section 13.11.3); survival then is one minus natural mortality or <0.005%. Therefore, energy returned to the system as detritus by entrainment and impingement can be estimated as m x 0.005% of the marine input (0.17×10^9 kcal). Combined entrainment and impingement conditional mortality in 1974 for Indian Point Unit 2 and multiplant case were 6.43% and 11.98% respectively. Therefore, energy returned to the system in 1974 as detritus by Indian Point Unit 2 and multiplant case were 0.55×10^3 kcal and 1.02×10^3 kcal respectively. Collections of impinged fish at Indian Point are disposed of rather than returned to the river. In 1974, 1200 kg (2640 lb) dry weight of fish representing 5.7×10^6 kcal were removed from the ecosystem as impingement collections. Phytoplankton and zooplankton do not appear to be killed in significant quantities by entrainment. Combined entrainment and impingement inputs to the energy budget are negligible in comparison with the total available energy in the system. Figure 3.8-2 reflects this approach in estimating power plant operation effects on the energy budget of the Hudson River.

~~the river as detritus. Conversion of these values to caloric content represented a removal of 0.0057 x 10^9 kcal from the river as impingement collections and a return of 0.025 x 10^9 kcal to the Hudson as uncollected impinged fish. Impingement at the other power plants, 3448 kg (7586 lb) dry weight, returned 0.016 x 10^9 kcal as detritus to the Hudson. Combined power plant impingement returned 0.041 x 10^9 kcal to the Hudson River as detritus and removed 0.0057 x 10^9 kcal from the system.~~

Sunlight and nutrient availability (as a function of water circulation) control primary production in aquatic ecosystems. Stratification in water bodies can limit primary production once nutrients in the photic layer are bound in phytoplankton. Physical circulation of water obviates stratification; hence, primary production is not limited by nutrient depletion. The Hudson River is well mixed (i.e., not stratified) in the area of Indian Point: there is little decrease in dissolved oxygen with increased depth (TI 1972:G-1 to G-3). Total water circulation in the Hudson estuary results from tidal flow, freshwater flow, and power plant pumping. Water circulation at power plant sites attributable to the natural mixing factors and power plant pumping are presented in Table 3.8-2. From the percentages of water circulation attributable to each factor, it is obvious that mixing from pumping will have no effect on primary production at the

Table 3.8-2 Water Circulation at Power Plant Locations in Hudson River Attributable to Tidal Flow, Freshwater Flow, and Power Plant Pumping

		Flow in 10^6 m^3 day^{-1}		
Power Plant	Tidal (%)	Freshwater (%)	Pumping (%)	Total
Danskammer	293.6 (85.5)	47.9 (14.0)	1.8 (0.5)	343.3
Roseton	293.6 (85.0)	47.9 (13.9)	3.6 (1.1)	345.1
Indian Point (2 and 3)	342.5 (85.1) ~~(85.2)~~	50.3 (12.5)	9.5 (2.4) ~~9.3~~ (2.0)	402.3 ~~402.1~~
Lovett	342.5 (86.8)	50.3 (12.8)	1.7 (0.4)	394.5
Bowline	367.0 ~~370.0~~ (87.0)	50.9 (12.0)	4.2 (1.0)	422.1 ~~425.1~~

power plants. Summing or integrating water circulation within the Hudson River attributable to tidal flow, freshwater flow, and power plant pumping results in estimates of 70.1 x 10^{12} m^3 day^{-1}, 1.1×10^{12} ~~10.1 x 10^{12}~~ m^3 day^{-1}, and 20.8×10^6 ~~20.6 x 10^6~~ m^3 day^{-1} respectively; power plant pumping contributes <0.0001% to the total water circulation in the Hudson River. Primary production in the Hudson River will not be affected by increased water circulation from power plant pumping.

Figure 3.8-2 summarizes the energy dynamics of the Hudson River estuary. This diagrammatic energy model presents population compartments, energy sources, and pathways of energy transfer for a generalized estuary influenced by a human system. Detritus entering the river from the watershed may be immediately mineralized by bacteria, entrapped in sediments and mineralized slowly, transported out of the system with the net flow of water, or consumed by detritivores (e.g.,

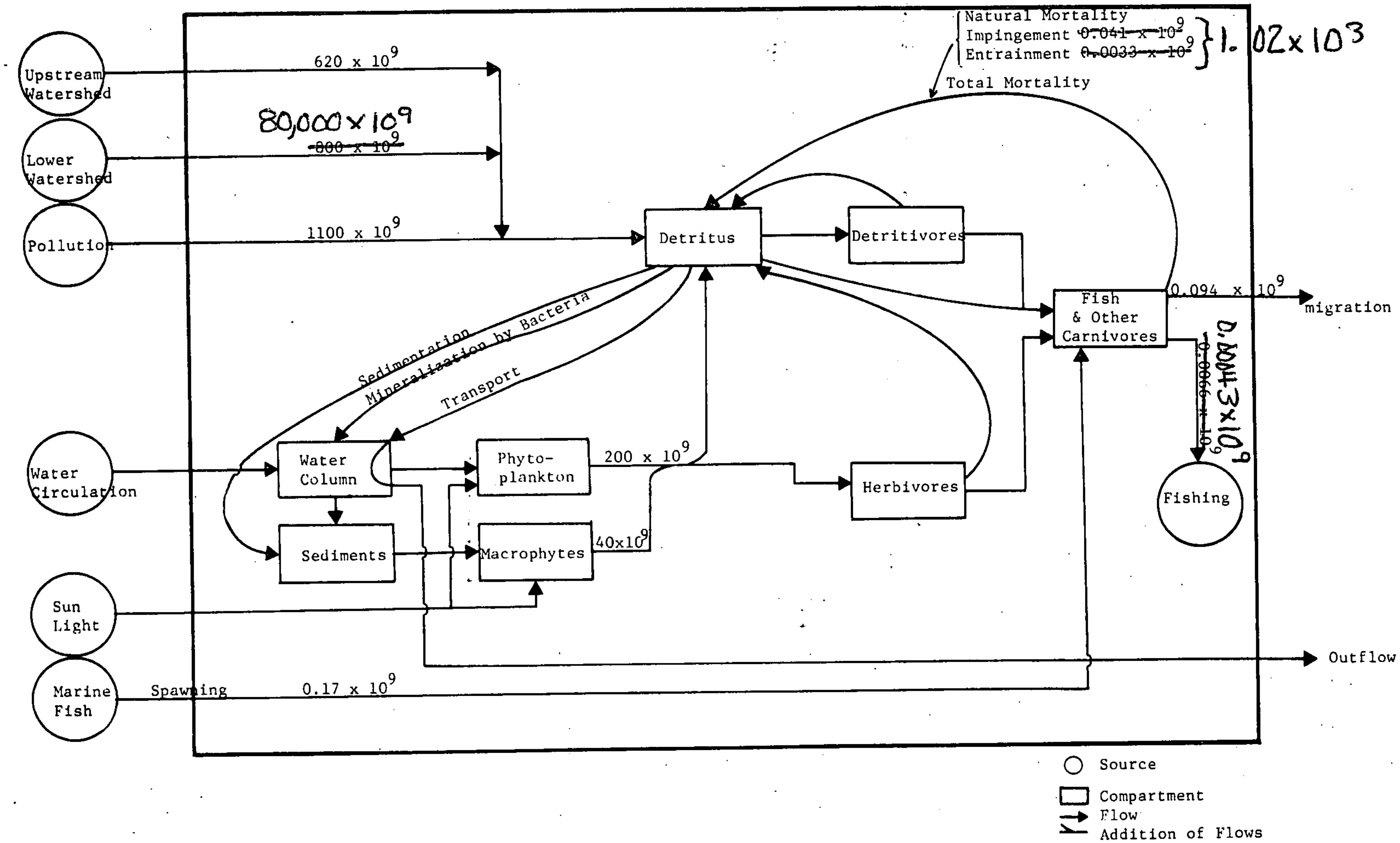


Figure 3.8-2. Energy Model of Hudson River with Multiplant Operation Included (Values are in kilocalories per year)

worms, crabs, carp). Much energy is degraded through respiration to heat during mineralization. Plants assimilate the minerals during photosynthesis (primary production). Plant biomass produced within the system is consumed by herbivores or enters the detritus compartment. Even in production, however, energy is lost from the system through plant respiration. Herbivores and detritivores are eaten by full-time resident fishes such as white perch (*Morone americana*) and by part-time residents such as striped bass (*Morone saxatilis*) and American shad (*Alosa sapidissima*). The latter two species migrate from the sea to utilize the Hudson as spawning and nursery areas. Spawned eggs are a net energy input, as they develop while the fish are in the ocean and only a small percentage survive to migrate back to the sea. White perch spend their entire lives in the Hudson and are harvested commercially. Thus, energy as fish biomass can cycle within the system or be transported into or out of the system, and it is also degraded through respiration to heat.

Figure 3.8-3 presents in symbolic energy circuit language (Odum 1972;140-211) the processes of energy transfer and conversion just discussed. Compartments are defined by their intrinsic functions in the system. Interactions of transfers of energy and minerals are presented as they affect the functions of the compartments. The Hudson River and its lower watershed are presented as self-maintenance systems whose primary productions are regulated by sunlight and nutrients in either soil or water and sediments. Loss of energy through respiration is represented as heat sink. Again, detritus is the major energy compartment in the Hudson, with inputs from the same sources as the previous model--the upstream and lower watersheds, the sea, human systems, and primary production. Bacterial mineralization converts organics to elemental nutrients, and their availability to phytoplankton is regulated by water circulation (i.e., mixing). Natural mortality of animals and their mortality in cooling water intakes at power plants recycle energy as organic material through the detritus compartment.

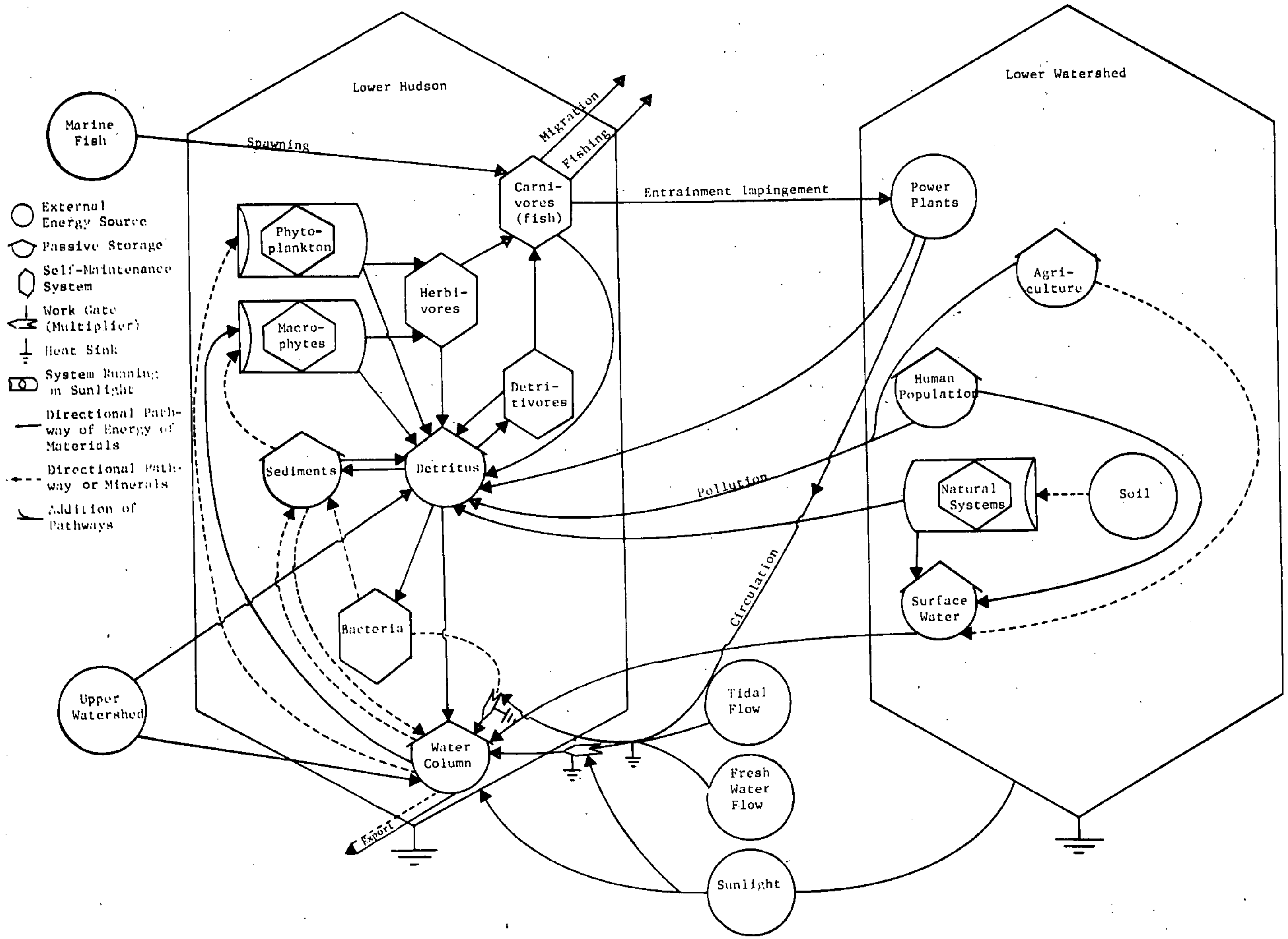


Figure 3.8-3. Energy Circuit Language of Energy Flux and Physical Circulation in Lower Hudson River

Other animals (e.g., fish) may migrate from the system or be harvested through fishing. Transport of detritus in the net outflow of water represents a flow of energy through this open-ended ecosystem. Most energy of the lower Hudson River is input to the system 99.71% ~~(91.4%)~~ rather than produced in the system (0.29%) ~~(8.6%)~~ (see Table 3.8-1). Energy may be cycled within the system and temporarily stored as living biota but eventually is exported from the system or lost as respiratory heat.

In conclusion, operation of power generating facilities will have negligible effect on the energy budget of the Hudson River. Contribution to the energy budget by detrital production (entrainment and impingement) is negligible compared with other energy contributions, and thermal loadings and/or water mixing will not increase primary productivity.

SECTION 4

INVERTEBRATE COMMUNITIES OF HUDSON RIVER ESTUARY

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SECTION 4

INVERTEBRATE COMMUNITIES OF HUDSON RIVER ESTUARY

4.1 HISTORY OF STUDIES

The invertebrates include an immense variety of animals ranging from single-celled protozoans to worms, clams, shrimp, water fleas, and insects. The influence of the Indian Point plant on these populations of organisms was discussed during licensing proceedings for Unit 2 and in the FES for Unit 3. The NRC has concluded that, with the possible exception of the mysid *Neomysis americana*, invertebrates are no longer of concern relative to impacts from power plant operations. Invertebrates are discussed in this report because they are an important component of the aquatic food web and, as such, are essential support for the fish population of the Hudson River.

The invertebrate communities within the Hudson River estuary have been studied in detail since 1968. These study efforts were largely the result of concern about the potential impacts of power generation along the river. Initial concerns pertained to the effect of thermal discharges on the populations of zooplankton and benthic organisms, as well as possible effects on other components of the estuarine food web. Invertebrate population studies have been conducted in the vicinity of Bowline Point, Lovett, Indian Point, Roseton, and Danskammer as well as the proposed plant sites on Haverstraw Bay, at Cornwall, and at Kingston. Combined, these studies provide a substantial knowledge of the invertebrate communities throughout the tidal portion of the Hudson, including the zone of transition from the saline water communities in the lower estuary to the freshwater communities in the upper estuary.

Lawler, Matusky and Skelly Engineers (LMS), New York University (NYU), Texas Instruments Incorporated (TI), and the Raytheon Company have served as the principal investigators. LMS studies related to Bowline Point, Lovett, Roseton, and Danskammer as well as a proposed power plant site near Kingston, New York. Raytheon's survey was in the vicinity of Indian Point. NYU's study principally covered the plankton communities in the vicinity of Indian Point and the effects of passage of plankton through the Indian Point plant; NYU also surveyed zooplankton for the entire tidal Hudson River (RM 0-153; km 0-247). TI studied the benthic communities near Indian Point and at proposed plant sites on Haverstraw Bay (TI 1975m) and lower Newburgh Bay (TI 1975*l*).

4.2 INVERTEBRATE COMMUNITIES

The invertebrates can be divided into major groups and subgroups as follows:

- Benthos
  - Infauna: organisms existing below the surface of the substrata (examples in the freshwater region: *Tubifex* and *Sphaerium*)
  - Epifauna: organisms living on the surface of the substrata (examples: *Cyathura*, *Amnicola*, and *Balanus*)
- Zooplankton
  - Microzooplankton: organisms small enough generally to pass through 571-μ mesh nets (examples: *Keratella*, *Bosmina*, and *Acartia*)
  - Macrozooplankton: organisms that can be captured by 571-μ mesh nets (examples: *Gammarus*, *Monoculodes*, and *Neomysis*)

The invertebrate communities in the Hudson River vary from one dominated by marine organisms in the lower estuary (generally that portion downstream of Stony Point at RM 40 [km 65]) to communities comprising solely freshwater forms in the upper estuary north of Wappinger Creek (RM 68; km 110). Between Stony Point and Wappinger Creek, the invertebrates are exposed to highly variable salinity regimes and the communities there can be thought of as transitional between marine and freshwater. These three communities comprise many species but tend to be dominated in both numbers and biomass by a relatively small group of species. Tables 4.2-1, 4.2-2, and 4.2-3 illustrate the variation in species composition between the lower, middle, and upper sections of the Hudson River estuary. In addition to salinity effects, community composition is influenced also by the nature of the substrate, which varies from soft silty deposits in regions of slow currents to hard rocky substratas where currents are swift.

During periods when river flows at the Troy Dam are >23,000 ft^3s^{-1} (650 m^3s^{-1}), the salt front (defined as 0.1 o/oo salinity) is usually below RM 40 (km 64.5) (Section 2.2.8); consequently, freshwater dominates the middle estuary regions, so invertebrate populations are freshwater forms. When freshwater flows are very low as during summer drought, the salt front is quite often found farther upstream, occasionally reaching as far as RM 80 (km 129); then, brackish-water invertebrates become more common in the middle estuary. Two organisms that demonstrate this point are *Gammarus* and *Neomysis*: *Gammarus* spp. are primarily freshwater macrozooplankton and are generally found upstream of the salt front; *Neomysis*, however, are saltwater organisms and are found most commonly below the salt front. Figure 4.2-1 illustrates this relationship with the salinity of the Hudson River estuary.

Table 4.2-1 Dominant Benthic Invertebrate Taxa at Specific Points in Hudson River Estuary

	Lower Estuary		Middle Estuary		Upper Estuary	
	Tappan Zee (RM 33) (TI 1975m)	Bowline Pt. (RM 38) (LMS 1976b)	I.P. (RM 42) (TI 1975e)	Cornwall (RM 56) (TI 1975l)	Danskammer* (RM 66) (LMS 1975d)	Kingston* (RM 95) (LMS 1975b)
Annelida	*Peloscolex* *Scolecolepides*	*Peloscolex* *Limnodrilus* *Hypaniola*	*Scolecolepides* *Limnodrilus* *Boccardia*	*Limnodrilus* *Scolecolepides*	*Scolecolepides*	Oligochaeta
Crustacea	Harpacticoida *Cyathura* *Balanus* *Leptocheirus*	Harpacticoida *Cyathura* *Leptocheirus*	*Balanus* *Cyathura* *Leptocheirus* *Gammarus*	Harpacticoida *Cyathura* *Gammarus*	*Cyathura* *Gammarus*	*Cyathura*
Insecta		Tendipedidae	Tendipedidae	Tendipedidae	Diptera**	Diptera**
Mollusca	*Amnicola* *Congeria*	*Amnicola*	*Amnicola* *Congeria*	*Sphaerium*	*Sphaerium* *Lampsilis*	†
Other	Nematoda	Bryozoa Chaetognatha	Bryozoa	Nematoda Bryozoa		

*From taxon list and text discussion
**Includes Tendipedidae
†Molluscs a major component, subdivisions not specified

Table 4.2-2 Dominant Microzooplankton Taxa at Specific Points in Hudson River Estuary

	Lower Estuary		Middle Estuary		Upper Estuary	
	Tappan Zee (Rm 33) (TI 1975m)	Bowline Pt. (RM 38) (LMS 1976b)	I.P. (RM 42) (TI 1975e)	Cornwall* (RM 56) (TI 1975l)	Danskammer (RM 66) (LMS 1975d)	Kingston (RM 95) (LMS 1975b)
Rotifera	Present**	*Synchaeta* *Nothulca* *Keratella* *Brachionus*	*Brachionus* *Nothulca*		*Keratella* *Nothulca* *Ploesoma* *Polyarthra*	*Brachionus* *Elosa* *Filinia* *Kellekotia* *Keratella*
Micro-crustacea	*Ectinosoma* *Canuella* *Eurytemora* *Microauthridino* *Cyclops* *Acartia*	*Halicyclops* *Ectocyclops* *Paracyclops* *Eurytemora* *Acartia*	*Eurytemora* *Acartia* *Bosmina* *Diaphanosoma*		*Bosmina* *Daphnia* *Leptodora*	*Bosmina* *Daphnia* *Leptodora* *Pleuroxus* Copepods**
Protozoa	†	†	*Centropyxis* *Difflugia*		†	†

*Comparable data not available
**Species not given
†Protozoa present but data not collected

Table 4.2-3 Dominant Macrozooplankton Taxa at Specific Points in Hudson River Estuary

	Lower Estuary		Middle Estuary		Upper Estuary	
	Tappan Zee (RM 33) (TI 1975m)	Bowline Pt. (RM 38) (LMS 1976b)	I.P. (RM 42) (TI 1975e)	Cornwall* (RM 56) (TI 1975*l*)	Danskammer (RM 66) (LMS 1975d)	Kingston (RM 95) (LMS 1975b)
	Neomysis	*Daphnia*	*Gammarus*	*Gammarus*	*Cyathura*	*Leptodora*
Crustacea	*Gammarus*	*Leptodora*	*Monoculodes*	*Daphnia*	*Leptodora*	Amphipoda**
	Monoculodes	*Neomysis*	*Neomysis*	*Leptodora*	*Gammarus*	*Chiridotea*
	Leptocheirus	*Gammarus*	*Diaphanosoma*†		*Chiridotea*	*Cyathura*
		Chiridotea				
Insecta	‡	‡	*Chaoborus*	*Chaoborus*	*Chaoborus*	Ceratipogonidae
			Tendipedidae	other Diptera	Tendipedidae	Tendipedidae
						Chaoborus

*500μ mesh net, all others in 571μ netting
**Lower taxa not given
†Lovett Plant area, LMS (1975)
‡ Present, species not given

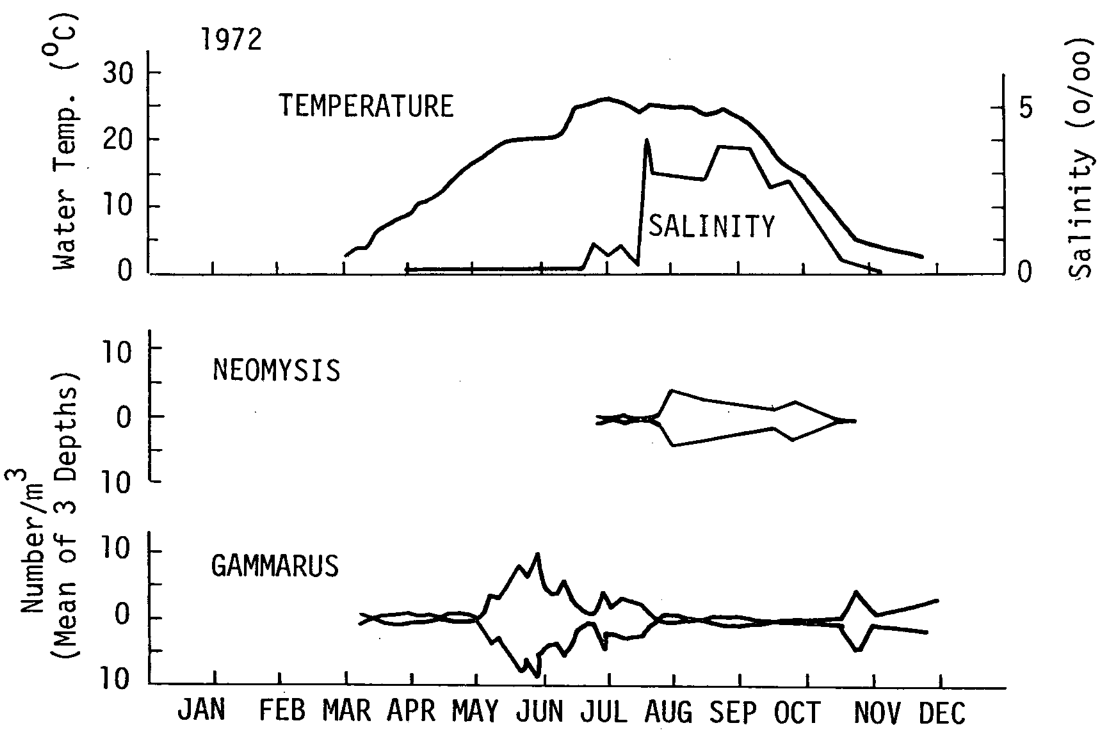
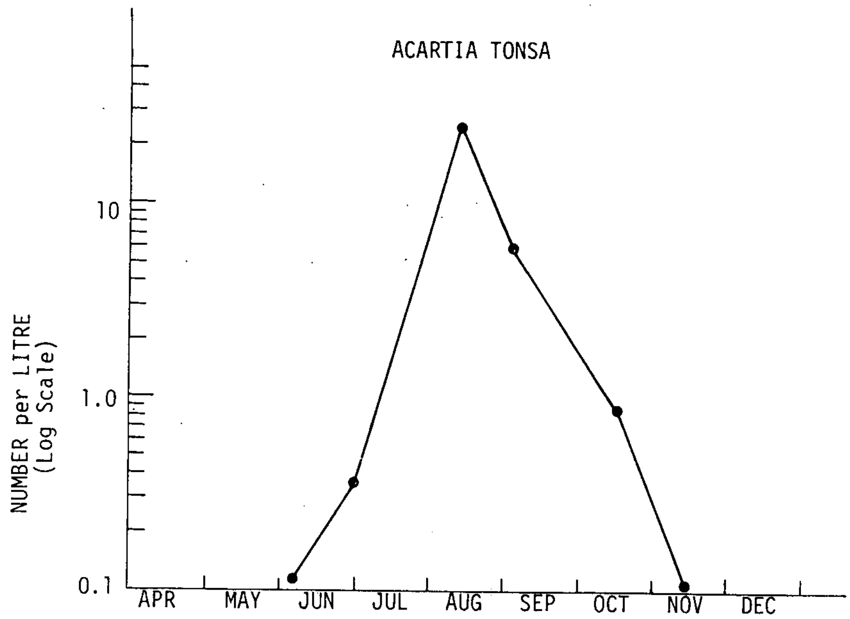


Figure 4.2-1 Seasonal Abundance of *Neomysis americana* and *Gammarus* sp. in Hudson River at Indian Point in Relation to Water Temperature and Salinity in 1972 (NYU 1973). (Abundances represented by vertical distance between graph lines; i.e., values above and below zero line should be added)

The benthic community in the vicinity of Indian Point is dominated by *Amnicola*, *Limnodrilus*, and *Scolecolepides*. These species have varied in abundance from year to year, primarily as a function of the duration of saline water at the site (TI 1976g). Many of the species exhibit large seasonal variations in abundance, some being virtually absent at certain times but present in vast quantities during other seasons. Figure 4.2-2 illustrates examples of variations in seasonal abundance of the microzooplankton *Acartia* and *Eurytemora*, and Figure 4.2-3 shows those for the macrozooplankton *Gammarus* and *Neomysis*.

The invertebrates form important links in the flow of energy through the aquatic ecosystem. Many of the benthic organisms, both the infauna and the epifauna, feed primarily on detritus (particles of dead material from plants and other animals), with the result that nutrients are recycled. Benthic organisms feed on living organisms, microzooplankton, phytoplankton and bacteria gleaned from the water or the substrate; in turn, these benthic organisms may be eaten directly or will die and become part of the detritus food chain. Zooplankton function much in the same manner as the benthos, consuming plants, bacteria, and other zooplankton and recycling nutrients. These invertebrates represent the primary and secondary consumers in the aquatic food web and, in turn, become the food for higher trophic levels such as those composed of fish; those, in turn, may become food for still higher levels comprising aquatic birds, various aquatic mammals, and even man.

The importance of the populations of certain groups of invertebrates has been demonstrated by the food habits of striped bass and white perch in the Hudson River estuary (TI 1976i). Striped bass, when <150 mm in length, feed extensively on *Gammarus* and copepods; white perch exhibit similar food habits in that they feed principally on *Gammarus* and copepods and only occasionally eat fish. White perch more often utilize invertebrates such as insect larvae and small crabs than do striped bass. Figure 4.2-4 generalizes the food web, illustrating relationships among the various invertebrate community compartments in the aquatic food web.



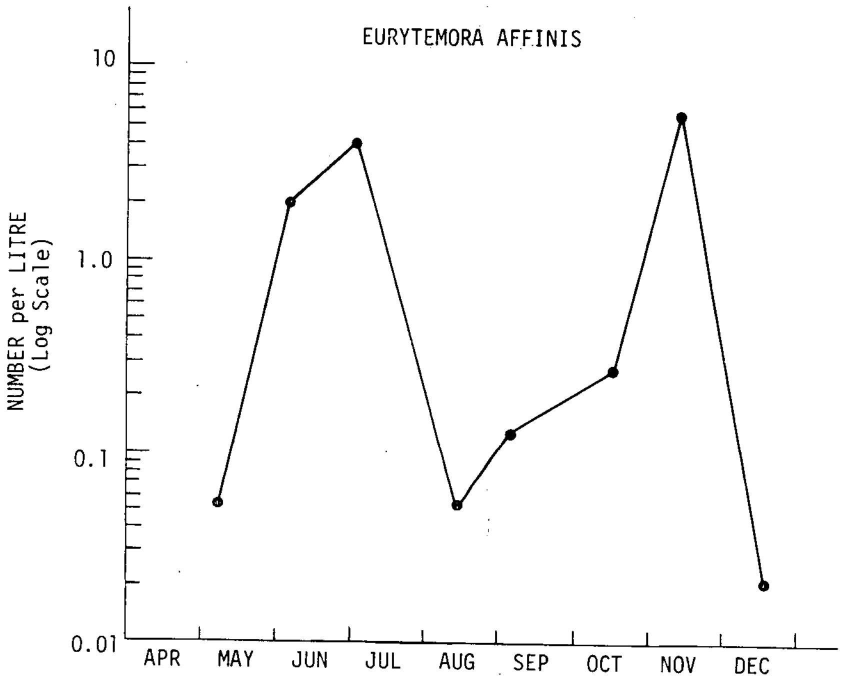


Figure 4.2-2 Seasonal Abundance of Microzooplankton *Acartia tonsa* and *Eurytemora affinis* by Month Based on Nighttime Sampling (NYU 1974)

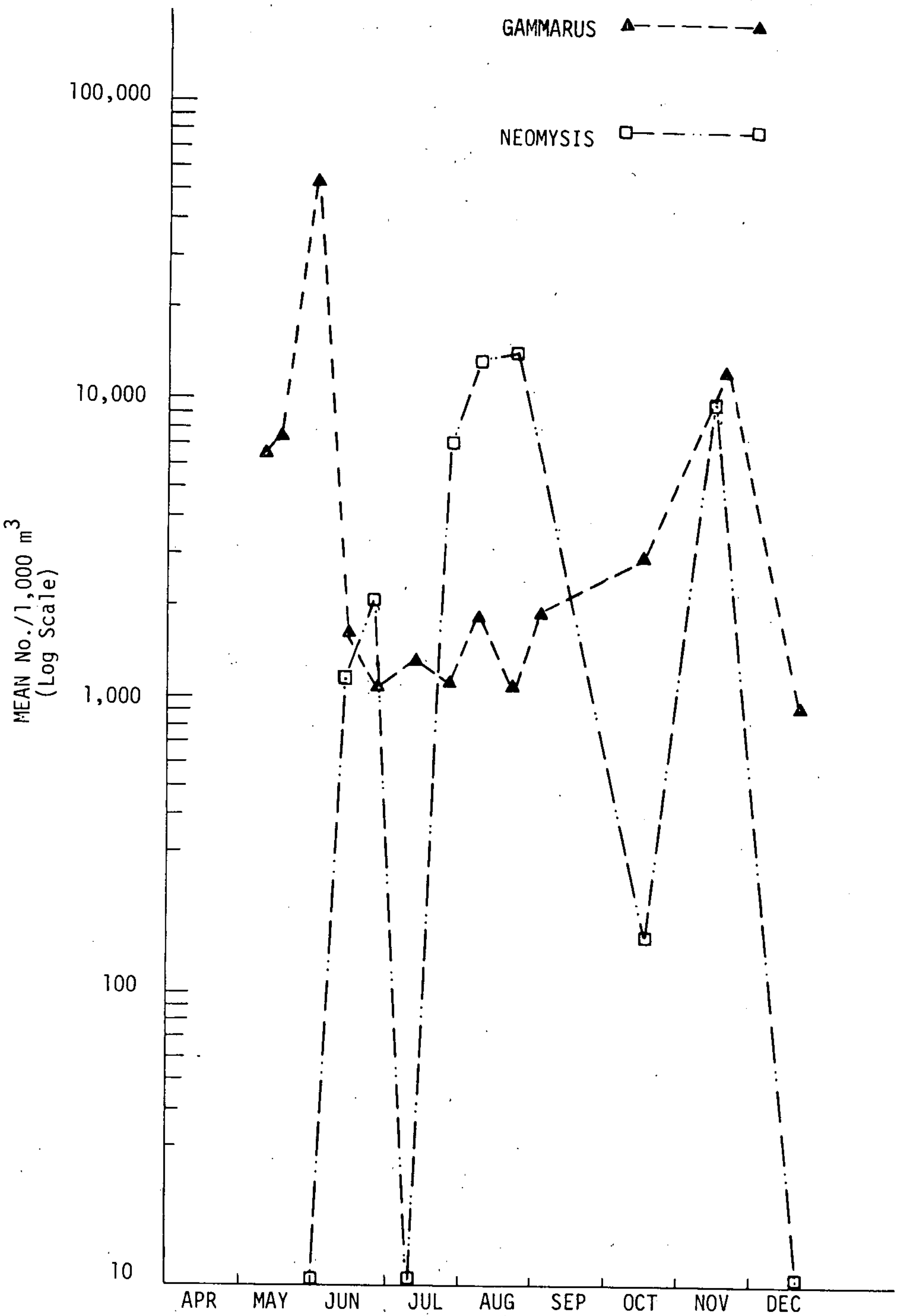


Figure 4.2-3 Seasonal Abundance of the Macrozooplankton *Gammarus* and *Neomysis* by Month Based on Nighttime Sampling (NYU 1974)

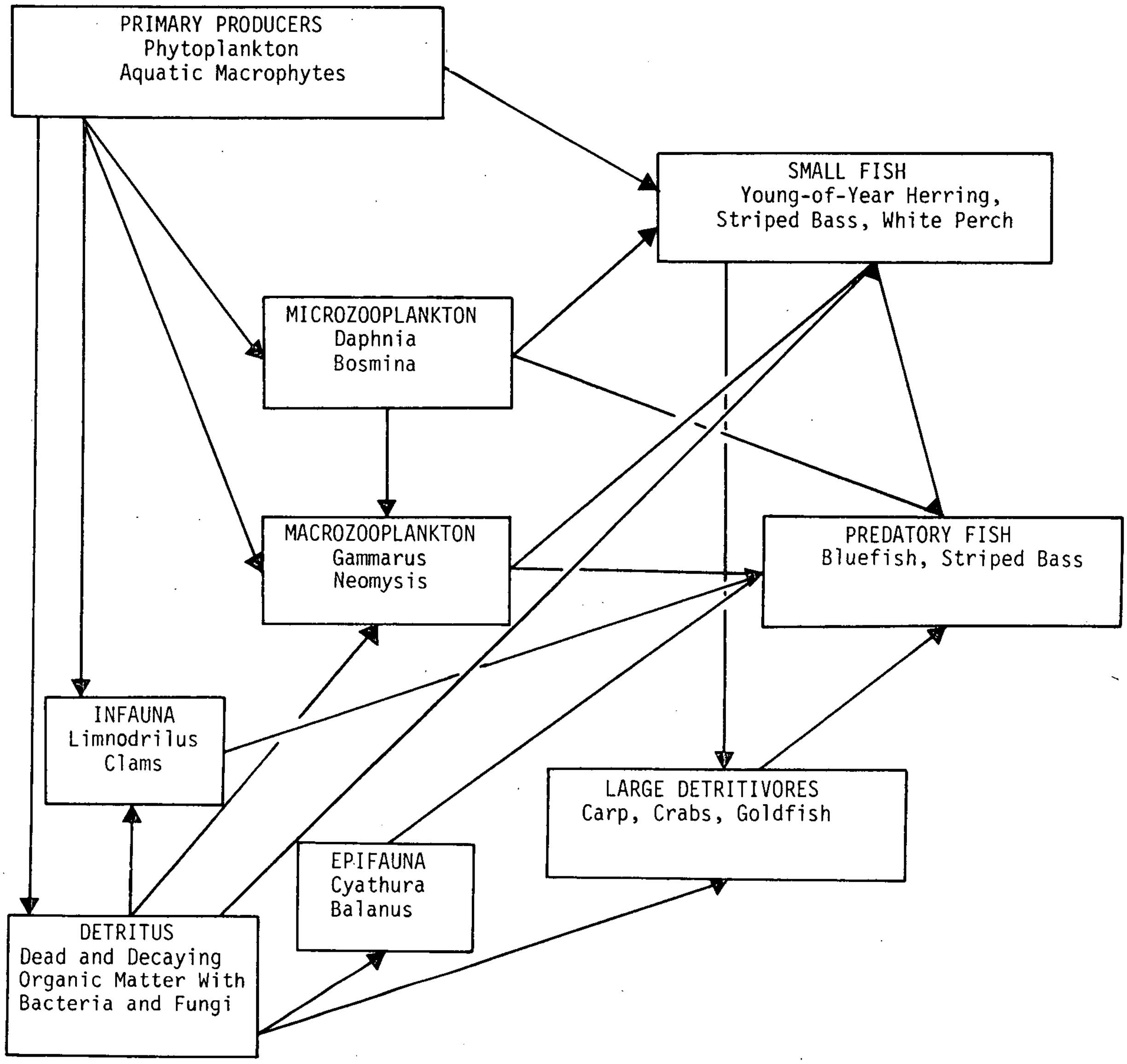


Figure 4.2-4 Diagrammatic Food Web Involving Hudson River Invertebrate Communities

4.3 VULNERABILITY TO INDIAN POINT STATION OPERATIONS

The principal means by which power plant operations may affect invertebrate populations is by entrainment in water flows and chemical discharges or by scouring action on substrates. Entrainment may occur in two ways: withdrawal with water into the cooling system of the plant (pump entrainment) and mixing with the thermal discharge from the plant (plume entrainment). Pump entrainment exposes organisms to (1) mechanical stresses such as shear forces in turbulent flow and contact with plant piping, (2) pressure changes occurring as the water enters and leaves pump impellers and, piping of various diameters and is released to the natural environment, (3) chemical discharges such as chlorine that is used as an antifoulant, and (4) rapidly elevated temperatures. Plume entrainment exposes organisms to (1) shear forces, (2) moderate pressure changes, (3) diluted chemical releases, and (4) elevated temperature regimes. The degree of scouring of substrates by power plant discharges is a function of (1) the angle of discharge relative to the substrate, (2) the proximity of the discharge jet to the substrate, and (3) the velocity of the discharge jet; for the most part, scouring is of nominal significance in its effect on benthic organisms.

The vulnerability of invertebrate communities to either type of entrainment is a function of the dynamics of the dominant species within the population. Benthic infauna and epifauna, because of their generally continuous contact with the substrate, are rarely entrained in either the intake structure or in the plume; they are susceptible to entrainment only during life stages (e.g., the veliger stages of some molluscs) in which they are planktonic in character. Benthic species may be subjected to thermal increases in their habitat if the discharge plume is continuously in contact or close proximity to the substrate; then, shifts in species composition may occur or areas short distances away from the plume may be void of benthos.

These conditions, however, are generally very limited in area as rapid mixing and dilution reduce the temperature increases of the substrates to nominal levels well within normal seasonal temperature ranges. Studies in the vicinity of the Indian Point discharge structure found no evidence of adverse effects of the discharge of heated water or chemical release on the benthic communities (Table 4.3-1). Analyses of the data detected no significant differences in density of important organisms between test and control areas (TI 1976g). In addition, temperature data (Table 4.3-2) indicated no influence of substrate temperature by the discharge plume (TI 1976g).

Zooplankton are more vulnerable to entrainment at power plants than are benthos. Although mobile, zooplankton in most cases tend to drift with water masses and thus are subject to varying degrees of entrainment, depending on the zone of withdrawal by the plants and on the diel habits of the species in the community. Microzooplankton species such as *Acartia, Bosmina,* and *Eurytemora*, which are seasonally abundant in the vicinity of Indian Point, generally exhibit no significant vertical diel movements and hence generally remain equally vulnerable to entrainment during day and night. This is in contrast to certain macrozooplankton species that are also seasonally abundant at Indian Point; *Neomysis*, for example shows marked decreases in abundance in the upper strata of the water column during the day compared with abundance at night (Table 4.3-3). The potential for daytime entrainment is reduced when these organisms are closer to the substrate with which they can orient and lesser volumes of water are being withdrawn from the bottom strata by the power plants.

Microzooplankton species most commonly and abundantly found in the vicinity of Indian Point are *Eurytemora* and *Acartia*; they become entrained, but the effects, as will be described later, are variable. The macrozooplankton species most commonly and abundantly found in the

Table 4.3-1 Comparison of Relative Abundance of Dominant Benthic Taxa in the Vicinity of Indian Point Thermal Plume during August-December 1969, 1972, 1973, and 1974 (TI 1976g: IV-34)

Taxon	Mean No./m^2					
	1969*	1972	1973		1974	
			Test	Control	Test	Control
Congeria leucophaeta	56	192	124	64	521	134
Gammarus sp.	104	72	320	137	189	76
Cyathura polita	160	192	280	138	555	654
Leptocheirus sp.	384	2	3	<1	24	10
Balanus improvisus	1480	227	86	197	1803	1486
Monoculodes sp.	0	<1	<1	3	9	7
Nemertea	16	<1	<1	2	6	44
Rhithropanopeus harrisi	0	8	9	<1	31	22
Corophium sp.	0	27	94	48	236	285
Edotea sp.	16	5	11	45	23	58

*From Raytheon, 1971

Table 4.3-2 Mean *In Situ* Water and Sediment Temperature (^{o}C) for Test and Control Areas in the Vicinity of the Indian Point Thermal Plume (TI 1976g) during 1974

		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
Test	Sediment	4.2	12.8	18.8	26.0	25.0	24.0	18.8	11.9	6.8	16.48
	Water										
	2.5 cm	3.5	12.3	17.8	24.0	24.5	24.0	18.7	11.6	6.3	15.86
	30 cm	3.5	12.0	17.8	24.0	24.0	24.0	18.5	11.5	6.3	15.73
Control	Sediment	5.2	12.7	20.0	25.3	24.8	24.5	17.0	14.0	4.8	16.48
	Water										
	2.5 cm	4.2	12.0	19.0	24.3	24.3	24.2	17.1	13.7	4.3	15.90
	30 cm	4.2	12.0	19.0	24.3	24.0	26.0	16.8	13.3	4.3	15.99

Table 4.3-3 Day/Night Variations in Density (No. $m^{-3} \times 10^{3}$) of Selected Invertebrates Taken in Plankton Nets from Hudson River at Indian Point (Adapted from NYU 1974). Asterisks Indicate Organisms which Are Epibenthic/Planktonic.

Scientific Name	Common Name	Day	Night
Gammarus sp.*	Scud	4430.0	18480.0
Monoculodes sp.*	Scud	207.9	363.6
Corophium sp.	Scud	3.6	2.8
Edotea sp.	Aquatic sowbug	3.0	8.4
Cyathura polita	Aquatic sowbug	4.0	25.1
Chiridotea alymyra	Aquatic sowbug	22.5	168.4
*Neomysis americana**	Opossum shrimp	818.5	2192.5
*Crangon septemspinosa**	Pistol shrimp	1.4	9.4
Chaoborus sp.*	Phantom midge	16.5	70.1
Tendipedidae*	Midges	6.8	6.4
Insect pupae (Pre-emergent)*		36.8	191.3
Hydracarina*	Water mites	3.4	5.4
Oligochaeta	Aquatic earthworms	13.1	19.3
Polychaeta	Segmented marine worms	1.9	3.6
Total		5569.4	21546.3

vicinity of Indian Point, depending on salinity and season, are *Gammarus* and *Neomysis*. When saline water is present at Indian Point, *Neomysis* may be regularly entrained; as the salt front recedes below Indian Point, however, *Neomysis* populations also leave the area so their vulnerability to entrainment at Indian Point diminishes. *Gammarus*, on the other hand, become more abundant as the salt front recedes and hence become more vulnerable to entrainment at Indian Point (Figure 4.2-1).

The following section discusses the entrainment effects on various species of invertebrates and the significance of the effects relative to the distribution and abundance of the species in the Hudson River estuary.

4.4 ECOLOGICAL SIGNIFICANCE OF ENTRAINMENT OF INVERTEBRATES AT INDIAN POINT

Microzooplankton entrainment studies at Indian Point showed significant seasonal variation in the abundance of organisms in the cooling water. Microzooplankton were most abundant during June-September and least abundant in winter and early Spring (January-March) (Table 4.4-1). Patterns of abundance in the intakes at Indian Point closely followed abundance patterns for the same species in the river, with June being the month of peak abundance. The groups of microzooplankton most commonly found in the intake cooling water were copepods and cladocerans, with copepods generally being the more abundant of the two. The cyclopoid copepod *Diacyclops bicuspidatus* was the dominant microcrustacean during fall, winter, and early spring, but *Halicyclops fosteri* was the most abundant cyclopoid copepod during summer. The calanoid copepod *Eurytemora affinis* was consistently present between May and November and was the most abundant calanoid copepod during August. *Acartia tonsa* was present in July and abundant in August.

Table 4.4-1 Plant Abundances (No. litre^{-1}) of Total Microzooplankton, 1975. (II-1, II-2 = Unit 2 intakes, replicates 1 and 2)

Date	II-1	II-2
1/14	3.7	5.9
2/11	83.2	70.3
3/27	14.7	19.2
4/21	21.7	20.4
5/08	60.7	107.1
5/27	114.6	84.0
6/03	561.0	1063.8
6/10	87.6	55.7
6/17	*	*
7/08	145.4	181.0
8/19	428.5	268.9
9/11	242.4	210.3
10/14	27.1	39.2
11/18	15.0	14.0
12/16	91.0	63.5

* Indicates missing samples

The cyclopoid copepods generally demonstrated 90-100% survival during pump entrainment. The calanoid copepods, however, were more sensitive to entrainment and experienced some mortalities upon passage through the plant (Table 4.4-2).

Upon examination, the latent mortality of entrained microzooplankton, the copepods *Acartia* and *Eurytemora* and rotifers, was found to be generally low (Table 4.4-3). Higher mortality after >24 h was probably due more to culture technique than to temperature effects. Although some entrainment mortality has occurred in some groups of microzooplankton at Indian Point, studies of the species composition and abundance of microzooplankton populations in the river in the vicinity of the plant as well as away from the plant have demonstrated that the operation of Indian Point Unit 2 has had no measurable effects on these organisms.

Table 4.4-2 Mean Percent Survival of Entrained Calanoid and Cyclopoid Copepods at Indian Point Intake (I) and Discharge (D1 and D2), 1974 (NYU 1975)

	Mean % Survival ~~I S.E.~~ ±S.E.	
Month & Station	Calanoid Copepods	Cyclopoid Copepods
March		
I	N.P.	75.0 ± 35.4
D1	N.P.	50.0 ± 50.0
D2	N.S.	N.S.
April		
I	97.5 ± 1.6	94.9 ± 2.8
D1	57.1 ± 60.6	90.6 ± 9.4
D2	N.S.	N.S.
May		
I	63.5 ± 26.6	100.0
D1	57.0 ± 2.6	100.0
D2	N.S.	N.S.
DP	48.8 ± 5.5	100.0
June		
I	100.0	100.0
D1	100.0	100.0
D2	N.S.	N.S.
July		
I	97.4 ± 2.5	100.0
D1	100.0	100.0
D2	89.1 ± 5.4	99.2 ± 0.8
August		
I	96.9 ± 1.0	100.0
D1	73.3 ± 2.9	100.0
D2	87.5 ± 2.3	N.P.
September		
I	100.0	100.0
D1	85.7 ± 6.6	100.0
D2	85.7 ± 9.3	100.0
D1 CH*	100.0	100.0
D2 CH	93.3 ± 4.6	0.0
October		
I	85.4 ± 7.6	98.2 ± 1.7
D1	86.7 ± 13.4	89.1 ± 11.0
D2	81.3 ± 13.8	95.2 ± 4.8
D1 CH	80.0 ± 14.2	96.0 ± 1.7
D2 CH	76.2 ± 9.0	100.0
November		
I	N.P.	100.0
D1	100.0	100.0
D2	95.5 ± 4.6	100.0
December		
I	100.0	78.6 ± 21.5
D1	60.0 ± 1.6	55.9 ± 22.6
D2	0.0	78.6 ± 21.5

*CH = Chlorine present

Table 4.4-3 Latent Mortality of Selected Microzooplankton at Indian Point Held for 24, 36, and 168 Hr Following Entrainment (NYU 1975)

	Date	Intake, °C	Discharge, °C	ΔT, °C	Station	n	% Survival ± S.E. 24 Hr	36 Hr	168 Hr
Eurytemora affinis	5/29/74	16.5	23.3	6.8	I	13	100	92.3 ±7.7	13.1 ±8.2
					D1	10	89.6 ±10.0	89.6 ±10.0	20.0 ±13.3
					D2	10	100	100	12.5 ±12.5
Acartia tonsa	7/16/74	25	36.5	11.5	I	10	80.0 ±13.3	--	--
					D1	10	80.0 ±13.3	--	--
					D2	10	100.0 --	--	--
	7/30/74	25	28.75	3.8	I	26	92.3 ±7.7	--	--
					D1	21	92.9 ±5.2	--	--
	8/20/74	25.2	33.5	8.3	I	16	56.2 ±12.8	--	--
					D1	16	46.7 ±12.5	--	--
					D2	15	46.7 ±27.4	--	--
Rotifers	5/29/74	16.5	23.3	6.8	I	10	100.0	100.0	0.0
					D1	10	100.0	95.0 ±5.0	0.0
					D2	11	100.0	30.3 ±11.2	9.1 ±9.0

Gammarus spp., *Monoculodes edwardsi*, and *Neomysis americana* are the most abundant macrozooplankton entrained at Indian Point (Table 4.3-3). The effects of entrainment on these species are a function of the temperature increase experienced, the ambient water temperature, the duration of exposure to the elevated temperature, and the operating mode of the chlorination system. *Gammarus* can tolerate exposure to 8.3°C temperature increases above summer ambient temperatures for up to 60 min, a period longer than normal transit times for water through the plant, with no significant immediate or latent mortality. Latent mortality after 10 days was insignificant (NYU 1974:168). Field studies also have demonstrated that most *Gammarus* survive entrainment at Indian Point (Tables 4.4-4 and 4.4-5). *Gammarus* entrained during chlorination also have shown substantial survival rates (Table 4.4-6) (Ginn et al. 1974, 1976). *Gammarus*, initially surviving passage through the plant in good condition, experience low latent mortalities (Table 4.4-7).

Field studies have showed that *Gammarus* are abundant in the vicinity of Indian Point and that variation in abundance cannot be related to plant operations. These study results, coupled with data on entrainment survival, indicate that Indian Point Unit 2 has no adverse influence on the population of *Gammarus* in the Hudson River.

Monoculodes edwardsi experienced survival rates similar to those of *Gammarus* (Table 4.4-8) and experienced no significant latent mortalities during 5-day survival tests following entrainment (NYU 1975).

Neomysis americana is the most sensitive of the three major taxa of macrozooplankton entrained at Indian Point; this species has temperature tolerances below those of *Gammarus* and *Monoculodes*. Consequently, those individuals entrained experience significant mortality when ambient temperatures are 26°C (78.8°F) or higher and the ΔT is at least 8.3°C (14.9°F), but these conditions occur only during the summer (Table 4.4-9). For individuals that do survive entrainment, latent

Table 4.4-4 Viability of *Gammarus* spp. Collected at the Indian Point Intake and Discharge Stations during Periods of May 7-30 and October 10-November 12, 1974 (Ambient Temperatures = 13.0-17.5°C, ΔT = 7.0-10.1°C) (NYU 1975)

	Percentage and 95% Confidence Interval		
	Alive	Stunned	Dead
Intake	96.5 95.3-97.7	1.1 0.6-1.6	2.4 1.3-3.5
D-1	94.5 91.6-97.5	2.6 0- 5.3	2.8 0.8-4.9
D-2	95.6 94.1-97.1	1.2 0.4-1.9	3.2 2.0-4.4

Table 4.4-5 Viability of *Gammarus* spp. Collected at the Indian Point Intake and Discharge Stations during the Period of June 13-September 17, 1974 (Ambient Temperatures = 20.5-24.9°C, ΔT = 5.4-8.7°C) (NYU 1975)

	Percentage and 95% Confidence Interval		
	Alive	Stunned	Dead
Intake	94.7 92.2-97.2	1.5 0.5-2.5	3.8 1.7-5.9
D-1	93.5 90.9-96.0	2.4 1.0-3.8	4.2 2.5-5.9
D-2	94.4 92.6-96.2	1.2 0.3-2.1	4.4 3.0-5.8

Table 4.4-6 Viability of *Gammarus* spp. Collected at the Indian Point Intake and Discharge Stations during Condenser Chlorination on August 17 and September 19, 1974 (Ambient temperature = 24.0-26.0°C, ΔT = 6.9-7.0°C)(NYU 1975)

	Percentage and 95% Confidence Interval		
	Alive	Stunned	Dead
Intake	96.0 91.7-100.0	1.6 0 - 3.8	2.4 0.6-5.4
D-1	66.1 57.1 -75.1	19.9 9.4-30.5	13.9 6.7-21.1
D-2	71.2 65.1 -77.2	12.6 5.7-19.5	16.2 6.9-25.6

Table 4.4-7 Latent Survival of *Gammarus* spp. Collected at Indian Point during Condenser Chlorination, 1974 (NYU 1975)

Station	Viability Classification	n	Percent Viable initial	1 Day	5 Day
Intake	Alive	99	100	94.9	85.9
D-1	Alive	100	100	97.0	91.0
D-2	Alive	60	100	100.0	91.7
D-P	Alive	100	100	98.0	89.0
D-1, D-2 & D-P	Stunned	130	100	50.8	40.0

Table 4.4-8 Viability of *Monoculodes edwardsi* Collected at the Indian Point Intake and Discharge Stations during the Period June 13-November 12, 1974 (Ambient Temperature = 13.0-24.9°C, ΔT = 5.4-10.1°C) (NYU 1975)

	Percentage and 95% Confidence Interval		
	Alive	Stunned	Dead
Intake	92.2 88.3-96.1	1.5 0-3.1	6.3 2.4-10.2
D-1	91.0 87.3-94.7	2.0 0.8-3.3	6.9 3.3-10.5
D-2	88.8 80.4-97.2	1.9 0-4.2	9.3 12-17.4

Table 4.4-9 Viability of *Neomysis americana* Collected at the Indian Point Intake and Discharge Stations during the Period June 18-November 11, 1974 (Ambient Temperature = 13.0-25.9°C, ΔT = 5.4-10.1°C) (NYU 1975)

	Percentage and 95% Confidence Interval		
	Alive	Stunned	Dead
Intake	82.0 72.0-92.0	2.2 0.6-3.8	15.8 6.2-25.3
D-1	44.3 31.4-57.2	15.1 7.2-23.0	40.5 28.5-52.6
D-2	46.1 25.6-66.6	10.4 1.3-19.6	43.4 20.7-66.2

mortality is generally low (Table 4.4-10). The mortality rate of *Neomysis* during chlorination is nearly 100%. Although *Neomysis* do experience considerable mortalities upon entrainment at Indian Point, no differences in population distribution and abundance of this species have been found in nearfield sampling at Indian Point. Furthermore, the species is present at Indian Point only when the salt front is at or upstream of the station, which occurs during only 2-3 months per year; *Neomysis* is a saline-water invertebrate and consequently is at the limit of its range at the salt front. Plant-induced impacts on this species in the Hudson River are not significant to the Hudson River ecosystem.

Table 4.4-10 Latent Survival of *Neomysis americana* Collected at the Indian Point Intake and Discharge Stations on August 20 and November 11, 1974 (NYU 1975)

Station	Classification	n	Initial	1 Day	5 Days
Intake	Alive	102	100	92.2	75.5
D-1	Alive	98	100	91.8	80.6
D-2	Alive	79	100	87.3	70.9
D-1	Stunned	65	100	53.8	23.1
D-2	Stunned	32	100	34.4	15.6

4.5 SUMMARY

Operation of the Indian Point power plant's Units 1 and 2 over the past 5 yr has had no significant effect on the invertebrate communities in the Hudson River. Benthos are exposed to plant effects only in very restricted areas--and even there, no reductions in populations have been observed. Microzooplankton are entrained in large numbers, but survival of entrained organisms is high. Population studies from 1971 to the present indicate no major changes in seasonal patterns of abundance of microzooplankton in the vicinity of Indian Point. No new species have appeared in large numbers at any of the sampling stations, nor have any disappeared from any of the stations during the past years' studies.

Analyses of entrained *Gammarus* spp. at Indian Point during 1972, 1974, and 1975 indicate that this abundant amphipod experiences no significant mortalities during normal plant passage. Although a significant reduction in discharge canal survival was noted at Unit 1 in 1972 (summer only), the overall difference between intake and discharge survival was only about 8%. Entrainment studies at Unit 2 reveal no differences between intake and discharge survival of *Gammarus*.

Studies conducted during condenser chlorination indicate that total mortalities of *Gammarus* may approximate 40-50% of the organisms entrained during chlorine injection. However, chlorine concentrations occurring in the discharge plume appear to be well below the lethal limits for *Gammarus* spp.

Mortalities of *Gammarus* from condenser chlorination represent a minimal percentage of the total numbers entrained at Indian Point because:

- The total time of chlorine injection is a small fraction of the total operating time.
- Chlorination is conducted during daylight hours when *Gammarus* abundance in the cooling water flow is low.

Neomysis americana appear to be the most sensitive to Indian Point discharge temperatures. Observed in-plant mortalities correlate well with temperature tolerances determined in the laboratory. At summer ambient temperatures of about 26°C (78.8°F), and a ΔT of 8.3°C (14.9°F), approximately 50% of the entrained *Neomysis americana* will die. During chlorination at maximum discharge temperatures, mortalities of entrained *Neomysis americana* may approach 100%; however, only a very small fraction of the total *Neomysis* population is exposed to entrainment at Indian Point because those organisms at that location in the Hudson are on the fringe of the total population's distribution. At Indian Point *Neomysis americana* is abundant only on limited occasions; generally abundances peak as a function of salt intrusion (NYU 1974). Thus, mortalities resulting from entrainment would not adversely affect Hudson River populations of *Neomysis americana*. The other major macrozooplankton species, *Chaoborus* sp. and *Monoculodes edwardsi*, display no increased initial or latent mortalities resulting from entrainment at Indian Point. Although they would most likely be adversely affected during chlorination, the overall effects are believed to be minimal. The reasons for this are as given earlier relating to *Gammarus*.

SECTION 5

THE FISH COMMUNITY OF THE HUDSON RIVER ESTUARY

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SECTION 5

THE FISH COMMUNITY OF THE HUDSON RIVER ESTUARY

5.1 INTRODUCTION

Sections 3 and 4 of this report have described the plant and invertebrate animal communities and discussed their vulnerability to power plant operations. This section focuses on the fish community of the estuary by describing the taxonomy, anatomy, life history, distribution, trophic relationships, ecological importance and relationships to man of the striped bass, white perch, Atlantic tomcod, American shad, blueback herring, and shortnose sturgeon. Emphasis is placed on biological characteristics which are related to a species' sensitivity to power plant impact. For example, anatomical features such as mouth structure are adaptations to feeding on particular types of prey and hence may restrict the range of habitats occupied by a fish. This in turn may influence the degree of exposure to power plant intake structures. A case in point would be the sturgeons, whose mouths are highly specialized for bottom feeding and whose consequent demersal habits reduce the probability of their being impinged. Reproductive and early developmental characteristics are especially important in relation to entrainment. Some fish eggs are buoyant and hence maximally exposed to entrainment; others are demersal and adhesive, tending to adhere to bottom materials and thereby escaping exposure to entrainment. The duration of the vulnerable larval stages, which is temperature dependent, is a major factor determining the numbers of young fish entrained. The choice of river reach in which spawning is concentrated varies importantly from species to species. The herring spawn far upstream and their eggs and larvae are little exposed to the power plants, which are located in and below the middle portion of the estuary. Striped bass, by contrast, spawn in the very sections of the river where the power plants are sited. The introductory material on the fish community of the Hudson River presented in this section is followed by a much more detailed treatment of striped bass in Sections 6 through 13, and of the other species in Sections 6 and 14.

5.2 STRIPED BASS

The striped bass (*Morone saxatilis* Walbaum) (Fig. 5.2-1), a member of Percichthyidae (temperate basses), is one of approximately 8,000 spiny-finned fishes (Marshall 1966:369-370). Percichthyids occur in warm and temperate coastal zones of the ocean where they are highly successful in occupying many diverse habitats including estuaries; many species, including other *Morone*, live entirely in fresh water. South of New Jersey, the striped bass is commonly known as the rock or rockfish.

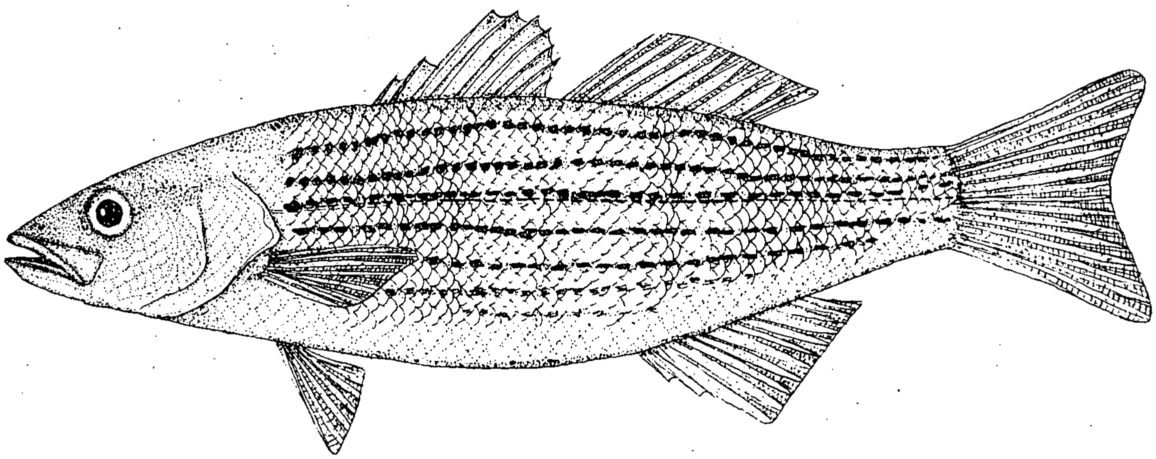


Figure 5.2-1 Side View of Adult Striped Bass (*Morone saxatilis*)

5.2.1 ANATOMY. The anatomy of the striped bass is typical of the Perichthyidae. The adult length is 3.5 to 4 times greater than its depth. There are two separate dorsal fins, two sets of paired fins (pectoral and pelvic), an anal fin, and a caudal fin that provides the thrust for rapid propulsion (Fig. 5.2-2). The first dorsal, pelvic, and anal fins are stiffened by one or more spines and act in concert with the pectoral fins to maintain balance and to provide quick braking or changes in direction, the precise movements needed to catch prey (Marshall 1966:370). The striped bass has a long head, moderately pointed snout, and projecting lower jaw (Scott and Crossman 1973:693). The enlarged mouth cavity and teeth are adapted for capturing and swallowing sizeable prey. The striped bass has a closed or physoclistous gas bladder (i.e., no connection between gas bladder and esophogus) to regulate buoyancy (Fig. 5.2-2).

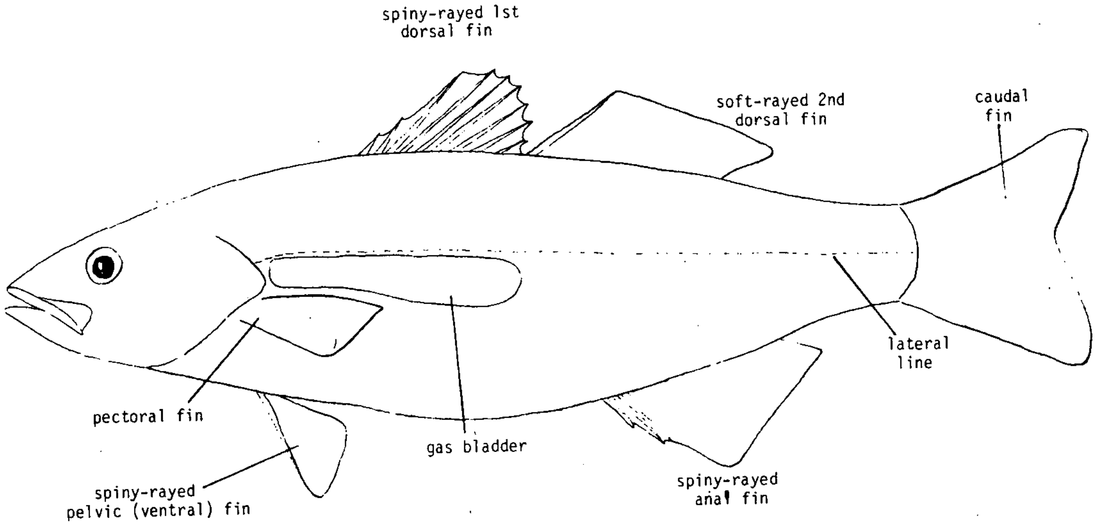


Figure 5.2-2 Basic Anatomical Features of Striped Bass

The striped bass is generally dark olive green to steel blue or black on the back, silvery on the sides, and white on the belly. The sides of older fish have seven to eight dark longitudinal stripes along the scale rows: three to four above the lateral line, one on it, and three below. The upper stripes are longest, reaching from the gill cover to the base of the caudal fin (Fig. 5.2-1). Young fish (< 150 mm) often lack stripes or have a mottled olive green pattern. The scales are ctenoid, i.e., have a serrated outer margin (Fig. 5.2-3).

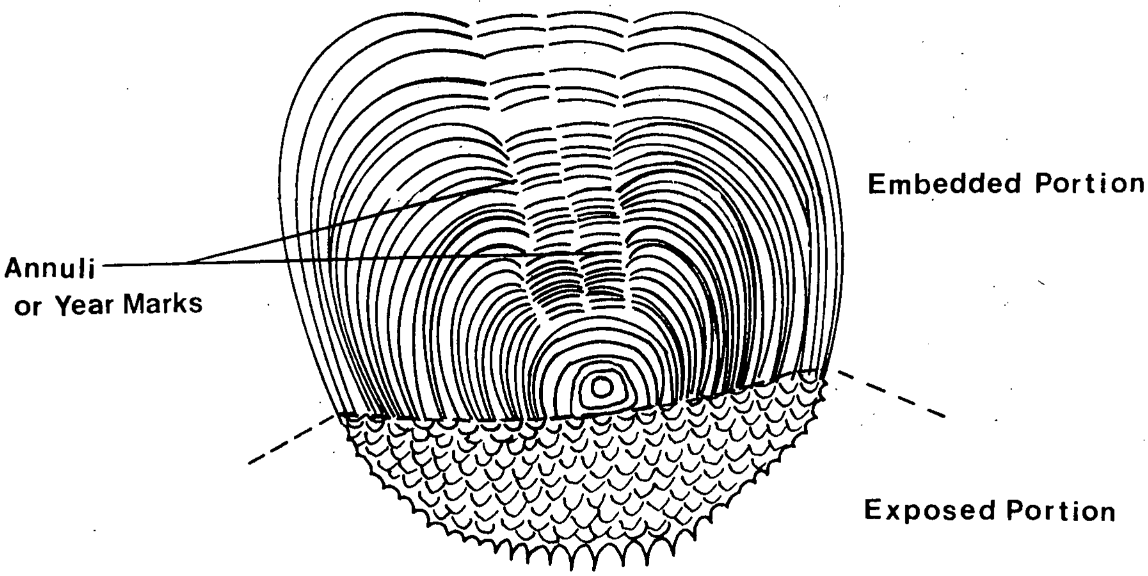


Figure 5.2-3 Typical Ctenoid Scale

5.2.2 DISTRIBUTION. The striped bass is native to North America and ranges along the Atlantic Coast from the St. Lawrence River in Canada to the St. Johns River in northern Florida and from western Florida to Louisiana along the coast of the Gulf of Mexico (Fig. 5.2-4). In 1879 and 1882, striped bass were introduced to the Pacific coast in the Sacramento-San Joaquin River system of California. They flourished and are now found from the Columbia River in Oregon to southern California (Talbot 1966). Striped bass have also been extensively and successfully introduced into the inland waters of at least 24 states (Parsons 1974:2,5). Principal East Coast spawning rivers and bays of residence are: the Hudson River; Delaware Bay and Delaware River; Chesapeake Bay and tributaries (James, York, Elk, Susquehanna, Potomac, Rappahannock, Patuxent, Choptank, and Nanticoke Rivers); the Roanoke and Chowan Rivers and Albermarle Sound, North Carolina; the Santee River, South Carolina; and St. Johns River, Florida (Raney 1952, 1954) (Fig. 5.2-5).

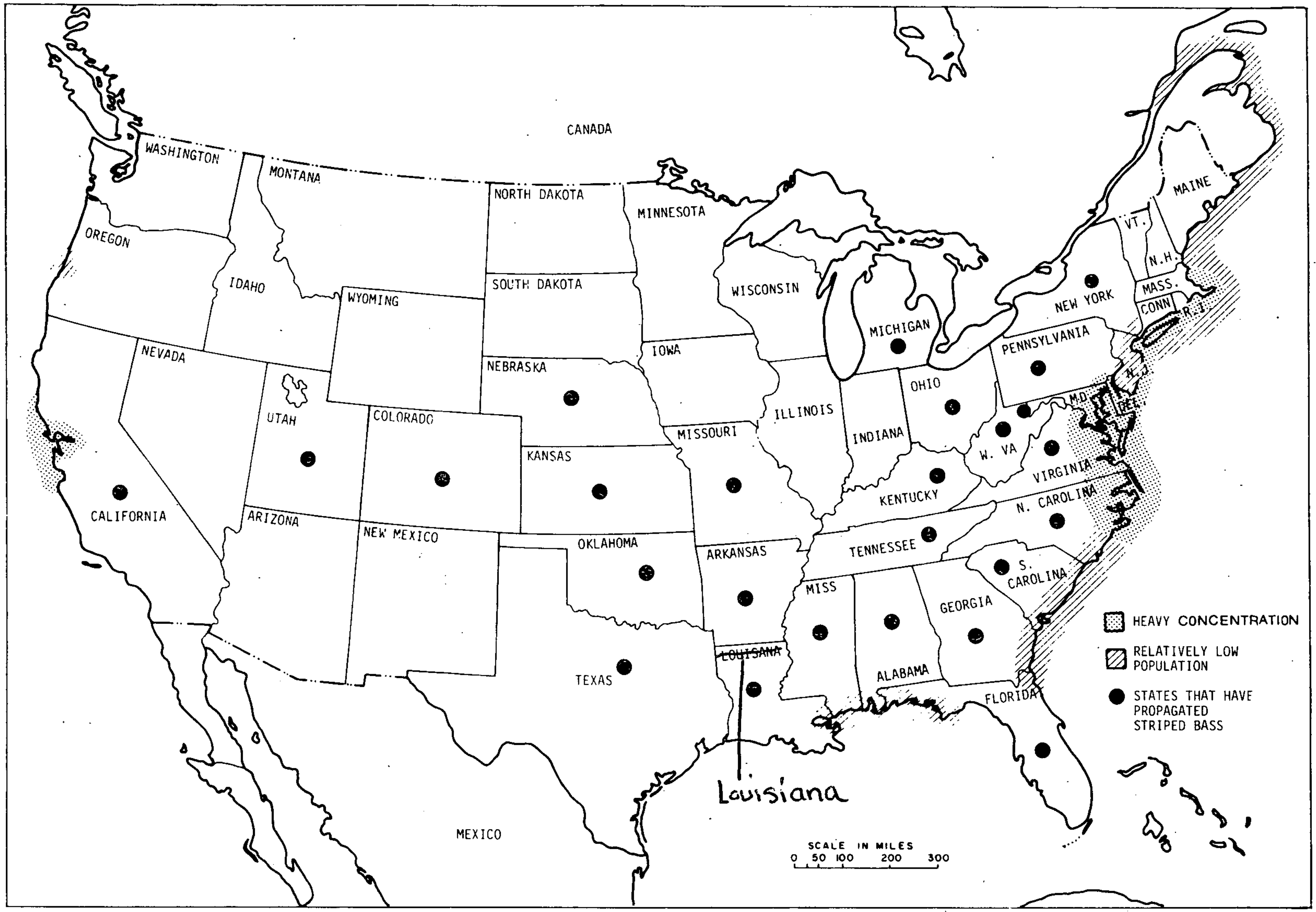


Figure 5.2-4 Distribution of Striped Bass in North American as of 1973 (Parsons 1974)

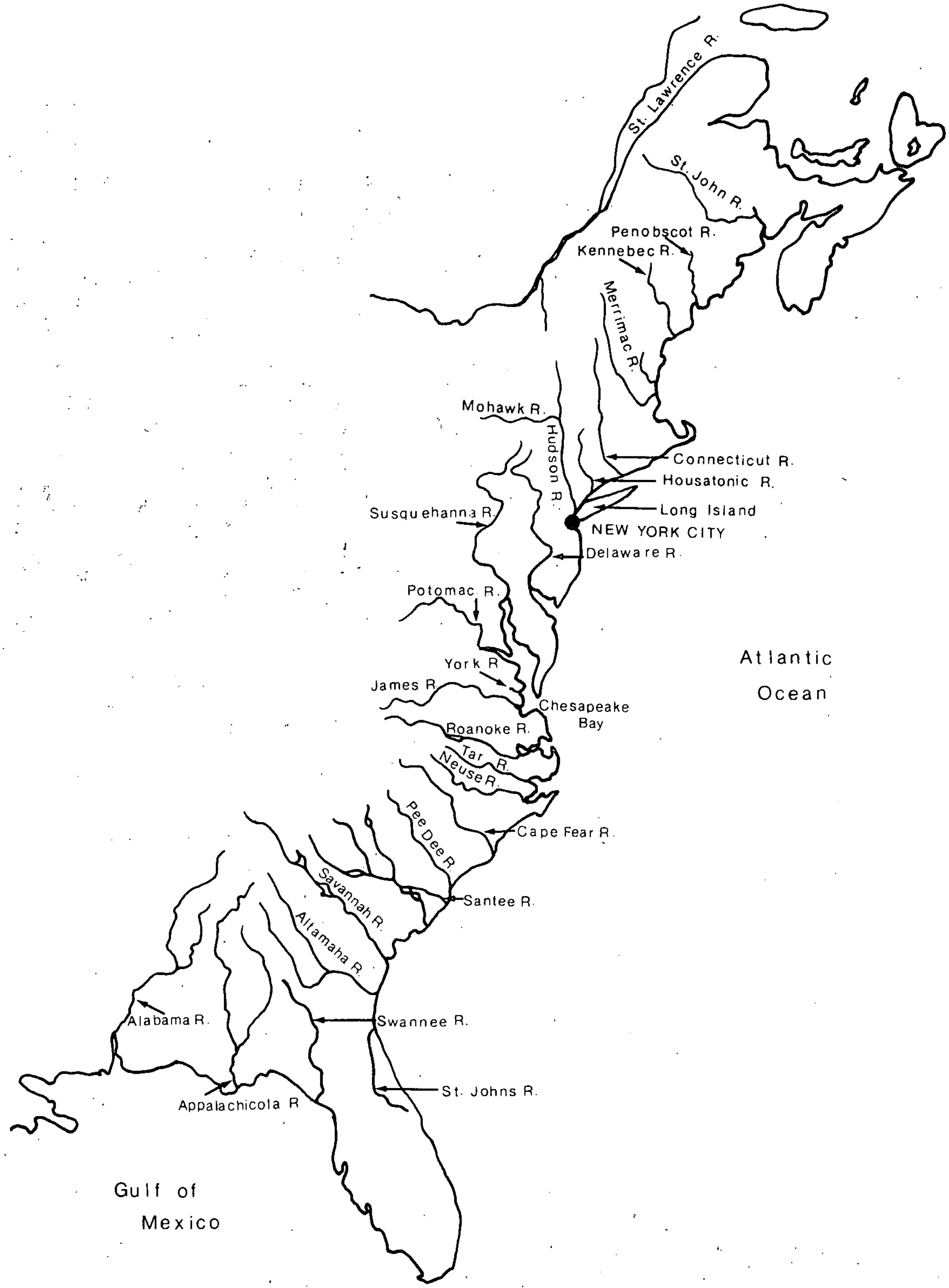


Figure 5.2-5 Major Eastern North American Coastal Rivers

Striped bass apparently do not reproduce successfully north of the Hudson River in the eastern United States (Neville 1939) since most of the northern rivers are blocked by dams. Small spawning populations occur in eastern Canada in the St. Lawrence River of Quebec, Grand Lake and Shubenacadie River and Lake in Nova Scotia, and the St. John and Mirimichi Rivers and Bay of Fundy in New Brunswick (Leim and Scott 1966) (Fig. 5.2-5). In the St. Lawrence River, striped bass have been reported as far upstream as Quebec City and Montreal (Goode 1884).

Limited sport fisheries for striped bass occur in the Appalachicola River and its estuary in western Florida and in the Pascagoula River in Mississippi, all of which are tributaries to the Gulf of Mexico (Fig. 5.2-5). The fish taken in these fisheries are fairly large -- from 3 to 15 kg (McIllwain 1968). Striped bass are also found in the Suwannee and Perdido Rivers in Florida (Barkuloo 1967); the Tangipahoa River in Mississippi; Lake Ponchartrain and the Tchefuncta River in Louisiana (McIllwain 1968); the Savannah, Ogeechee, and Altamaha Rivers of Georgia (Smith 1968, 1970); and the Alabama, Coosa, and Tallapoosa Rivers of Alabama (Smith-Vaniz 1968) (Fig. 5.2-5).

On the West Coast, striped bass range from Morro Bay, California, to Puget Sound, Washington, but most are produced and remain within the Sacramento-San Joaquin River delta and in the adjacent areas of San Francisco Bay, California (Chadwick 1967). Few fish migrate farther than 40 mi (64 km) along the coast from the bay area (Raney 1954). Smaller populations occur in the Coos River estuary in Oregon, but striped bass are rarely found in other areas of the West Coast (Chadwick 1968).

5.2.3 LIFE CYCLE. The reproductive portion of the life cycle of striped bass is typical of an anadromous species: the adults migrate from the ocean to coastal rivers to spawn, usually from April to June (depending on specific location), then move back to the ocean to feed (Fig. 5.2-6). Spawning occurs in freshwater areas where there are moderate to swift currents, narrow widths, and greater-than-average depths

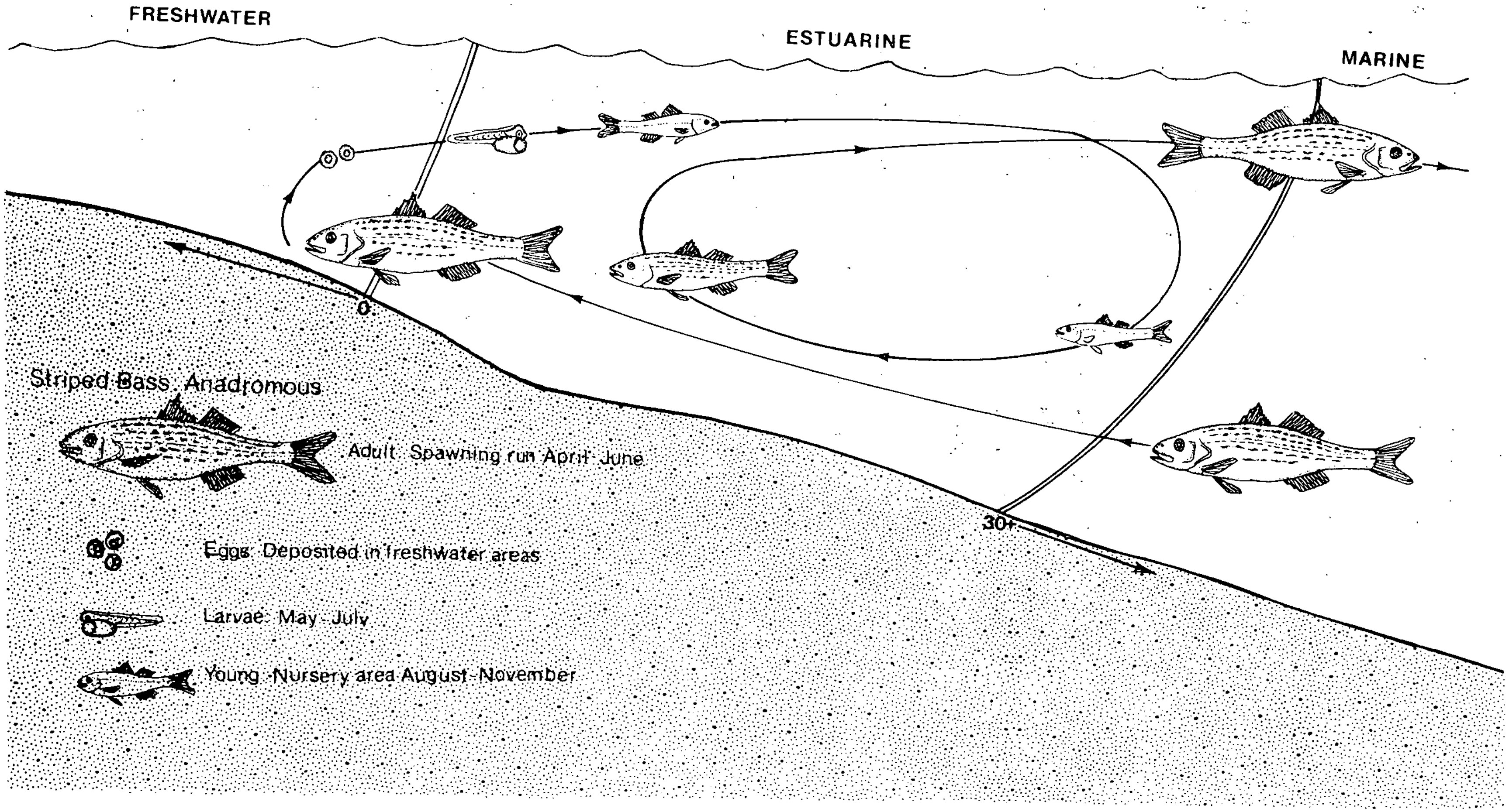


Figure 5.2-6 Generalized Life Cycle of Striped Bass in Hudson River Estuary (Adapted from Cronin and Mansueti 1971:32-35) The numbers 0 and 30+ represent salinities in parts per thousand.

(Pearson 1938, Mansueti 1958, Albrecht 1964). Other major factors that have been shown to affect the site of spawning and the survival of eggs and larvae in several estuarine systems are bottom type (Albrecht 1964, Scruggs 1957, Mansueti 1958, Bayless 1968), water temperature (Shannon and Smith 1967, Raney 1954, Barry 1958), and turbidity (May and Fuller 1965, Tresselt 1952). Female striped bass lay from 150,000 to several million semibuoyant eggs, depending on age and size (Section 7.8). The larvae hatch in 38-74 h, with development most rapid at higher temperatures (Section 7.2).

Larval distribution changes with developmental stage (Fig. 5.2-6). In July, for example, post yolk-sac larvae in the Hudson River estuary move shoreward from the main channel to shoal and beach areas (TI 1974a); in late July, juveniles begin to move downstream to areas of higher salinity (TI 1974a). During September and October, many juveniles migrate out of the estuary; some however, overwinter in the lower estuary (Section 7.5) before proceeding to the ocean, while others are found in Long Island Sound or off the south shores of Long Island. (For a detailed discussion of life stage characteristics, distributions, and movements, refer to Sections 6.2, 7.2, 7.5, 7.6, and 7.8).

5.2.4 TROPHIC RELATIONSHIPS. The trophic (feeding) level of striped bass can be characterized by their prey and predators. Striped bass larvae and early juveniles feed principally on the copepods *Diaptomus* and *Cyclops* and on the amphipod *Gammarus* (Bigelow and Schroeder 1953). Larger juveniles (> 60 mm) eat insect larvae (principally midges), worms, opposum shrimp (*Mysis*), crabs, and small fish (Scott and Crossman 1973: 693-695). The proportion of fish increases in yearling diets, and individuals age II and older feed almost exclusively on fish, primarily herring, shad, menhaden, and anchovies, but occasionally feed on shrimp, lobsters, crabs, squids, and clams, as well (Scott and Crossman 1973: 693-695); one study (Hollis 1952) found 26 species of fish in the diet. Age II and older striped bass in the ocean feed in schools; and individuals from the same school often contain the same kinds of food in the same stage of rapid digestion. Their fast digestion rates, about 6 hr at 70°F (Heubech et al 1963), are characteristic of intermittent feeders (Merriman 1941). For a few weeks before and during spawning, striped bass usually do not eat (Trent and Hassler 1966).

In the Hudson River, striped bass 150-300 mm in total length feed on *Gammarus*, copepods, and insect larvae (TI 1972, 1973b, 1976f), with *Gammarus* being the primary food of juvenile (<150 mm) striped bass. White perch and alewives have been found in stomachs of larger striped bass. Many other species of small fish occurring in the Hudson River (e.g., herring, menhaden, smelt, alewife, shad, silverside, and mummichog) have been reported in striped bass diets in other estuaries (Bigelow and Schroeder 1953) and thus might be expected to be part of the diet of Hudson River striped bass. Striped bass may therefore take advantage of whatever fish are abundant. Adult striped bass are predators at the top of the food chain and have few natural enemies other than man, but small striped bass may be the prey of Atlantic tomcod, Atlantic cod, silver hake, bluefish and larger striped bass (Scott and Crossman 1973:693-695).

5.2.5 MIGRATIONS AND HOMING. Large individuals travel long distances along the coast while foraging but rarely go farther than 10 mi (15 km) from shore (Raney 1954). Smaller fish (<3 kg) are relatively non-migratory and inhabit enclosed bays, estuaries, river mouths, and coastal areas; larger individuals generally inhabit the more offshore areas, except when spawning or in winter (Bigelow and Schroeder 1953).

Striped bass >3 kg leave Atlantic Coast estuaries and generally migrate northward during spring and summer and southward during fall (Section 7.8.7). They winter in the deep waters of bays, estuaries, or coastal rivers (Chapoton and Sykes 1961, Talbot 1966).

A question related to migration is whether striped bass "home", i.e., return to the natal stream to spawn. Evidence of striped bass homing is substantial but largely indirect. Morphometric characters have been used to distinguish striped bass populations from specific areas (Raney and deSylva 1953, Raney et al 1954, Raney 1957, Lewis 1957, Lund 1957, TI 1975d). The studies, taken together, suggest five distinct populations in Chesapeake Bay: James, York, Rappahannock, and Potomac Rivers; and upper Chesapeake Bay. The latter population can be further separated into four subpopulations (Elk, Choptank, Nanticoke, and Patuxent-Potomac Rivers) (Morgan et al 1973). The Hudson River and Roanoke River stocks of striped bass are separable from Chesapeake stocks on the basis of meristic and morphometric characters (Section 7.10). A plausible mechanism that could lead to the genetic segregation of these identifiable populations is homing. Further supporting the homing hypothesis is the recovery of tagged striped bass during successive years on the same spawning grounds (Hollis and Davis 1955, Mansueti 1961c, Nichols and Miller 1967). While those studies do not verify that the recovered fish ever left the spawning area, recent studies (Section 7.8) show that spawning fish do return to the ocean: 46% of the recaptured fish that were tagged and released in the Hudson River during the 1973-75 spawning seasons were recaptured outside the Hudson and its tributaries, including one large fish that moved to Boston Harbor, Massachusetts.

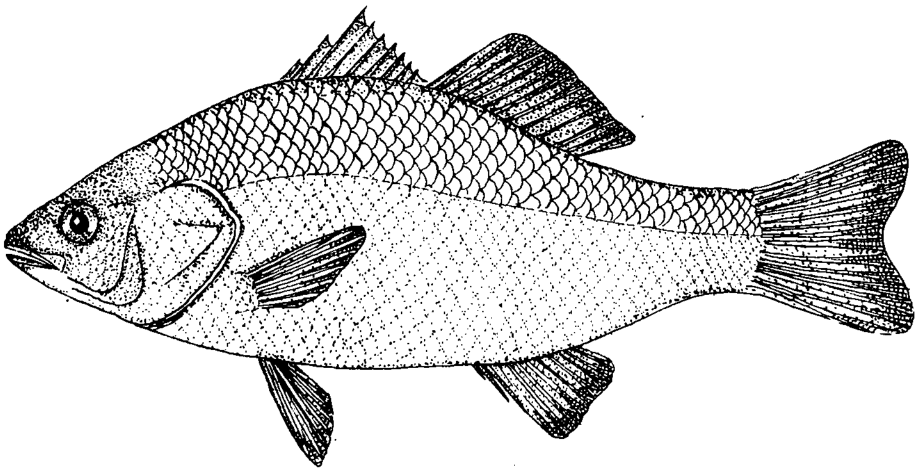
Additional information on age at maturity, growth rates, fecundity, and migration of Hudson River striped bass is presented in Section 7.8.

5.2.6 ANNOTATED BIBLIOGRAPHY. The following references contain much of the current information on Hudson River striped bass. Several of the classical works on other East Coast striped bass populations are included for background.

Alperin, 1966a,b	:	Details on occurrence and movements of yearling and older fish in Great South Bay and along the southern shore of Long Island.
Clark, 1968	:	Seasonal movements of striped bass in Long Island Sound and the New York Bight and possible "contingents".
Koo, 1970	:	Studies on the striped bass commercial fishery of the Atlantic Coast, including records and seasonal patterns of commercial landings.
Mansueti, 1961a	:	Some aspects of population dynamics of striped bass of Chesapeake Bay.
Merriman, 1941	:	Account of life history, population dynamics, and migrations of striped bass of the Atlantic Coast.
Raney, 1952	:	Monograph on the life history of striped bass (principally in Chesapeake Bay).
Raney et al, 1954	:	Studies on the racial structure of Hudson River and other striped bass.
Rathjen and Miller, 1957	:	Studies of striped bass in the Hudson River estuary.
Schaefer, 1968	:	Size, age composition, and migration of striped bass off Long Island.
Texas Instruments, 1974a, 1975b,d,e	:	Studies on striped bass in the Hudson River estuary.
Vladykov and Wallace, 1952	:	Studies on migration routes of striped bass tagged in the Chesapeake Bay region.

5.3 WHITE PERCH, ATLANTIC TOMCOD, AMERICAN SHAD, BLUEBACK HERRING, AND SHORTNOSE STURGEON

5.3.1 WHITE PERCH



As a member of the order Perciformes, the white perch (*Morone americana* [Gmelin]) is part of a large and diverse group of spiny-finned fishes considered to be advanced in the evolution of bony fishes (Marshall 1966: 369-370). The common name is actually a misnomer since this species is not a true perch (of the family Percidae) but rather a close relative of the striped bass and other members of the temperate bass family (Percichthyidae).

5.3.1.1 Anatomy. The white perch resembles the striped bass in general form and structure (Section 5.2) but is deeper-bodied and more laterally compressed, has a more convex dorsal outline and stouter anal spines, and usually lacks permanent longitudinal stripes. Adult white perch are much smaller than adult striped bass, averaging $<$ 250 mm in total length and 450 g in weight. Coloration ranges from dark olive to dark grey on the dorsal surface, shading to silvery white on the belly. Large individuals often have a bluish luster on areas of the head, particularly the chin. The anatomy and general biology of the white perch is detailed by Hildebrand and Schroeder (1928:244-247), Bigelow and Schroeder (1953:405-407), Hubbs and Lagler (1958:100), Thomson et al. (1971:109-110), and Scott and Crossman (1973:684-689).

5.3.1.2 Distribution. The natural range of the white perch extends along the Atlantic coast of North America from the southern Maritime Provinces of Canada and the St. Lawrence River to South Carolina in brackish and freshwater areas near the coast (Fig. 5.3-1).

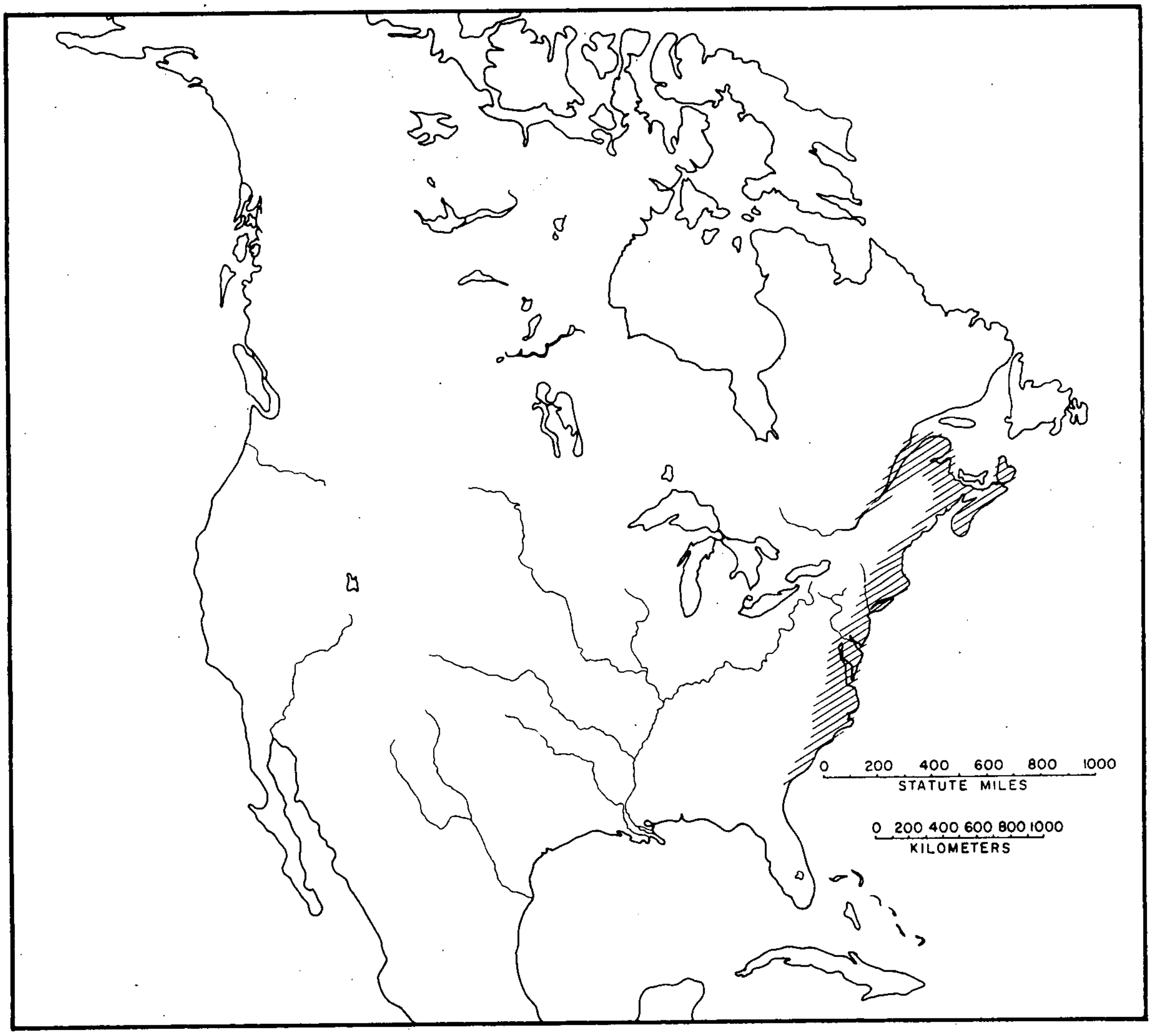


Figure 5.3-1 North American Natural Range of White Perch (*Morone americana*)

The white perch is essentially estuarine, but landlocked populations exist in fresh water throughout its range (Mansueti 1964:4). Freshwater populations predominate in the northern part of the range and white perch are uncommon in salt water north of Cape Cod (Rounsefell 1975:49). Probably as a result of dispersal through canals, they are now found in Lakes Ontario and Erie (Hubbs and Lagler 1958:100; Scott and Crossman 1973:685). Hergenrader and Bliss (1971:734-738) reported the accidental introduction of white perch into Nebraska, where a population became established in a reservoir that drains into a tributary of the Missouri River.

In the Hudson River, the white perch is common below Albany (RM 125; km 200) (Scott and Crossman 1973:685). Except during upriver spawning migrations in late spring, concentrations of adults are greatest south of Indian Point (RM 42; km 68)(TI 1976f:V-36,38). A tagging program (TI 1975b:VI-83) demonstrated extensive spring and early summer movement of adults, suggesting a single population or substantial intermixing of any subpopulations that may exist. The distributions of eggs, larvae, young-of-the-year and yearlings are discussed in Section 6.3.

5.3.1.3 Life Cycle. In the Hudson River estuary, some white perch of both sexes become sexually mature at age II; all males and females are mature by ages IV and V, respectively. In the Patuxent River of Maryland, white perch mature earlier; males at age II and all females by age IV (Mansueti 1961b:182-183). Mansueti (1961b:182-183) also notes that faster-growing white perch mature earlier than do the smaller fish.

Estuarine populations of white perch spawn during spring and early summer in shallow water following upstream migrations to areas of fresh or slightly brackish waters (Fig. 5.3-2). In the Hudson River estuary, spawning occurs during May-July, primarily north of Croton Bay (RM 38; km 61). After spawning, many adults move downriver to areas of higher salinity in Haverstraw Bay and Tappan Zee (TI 1976f:V-38).

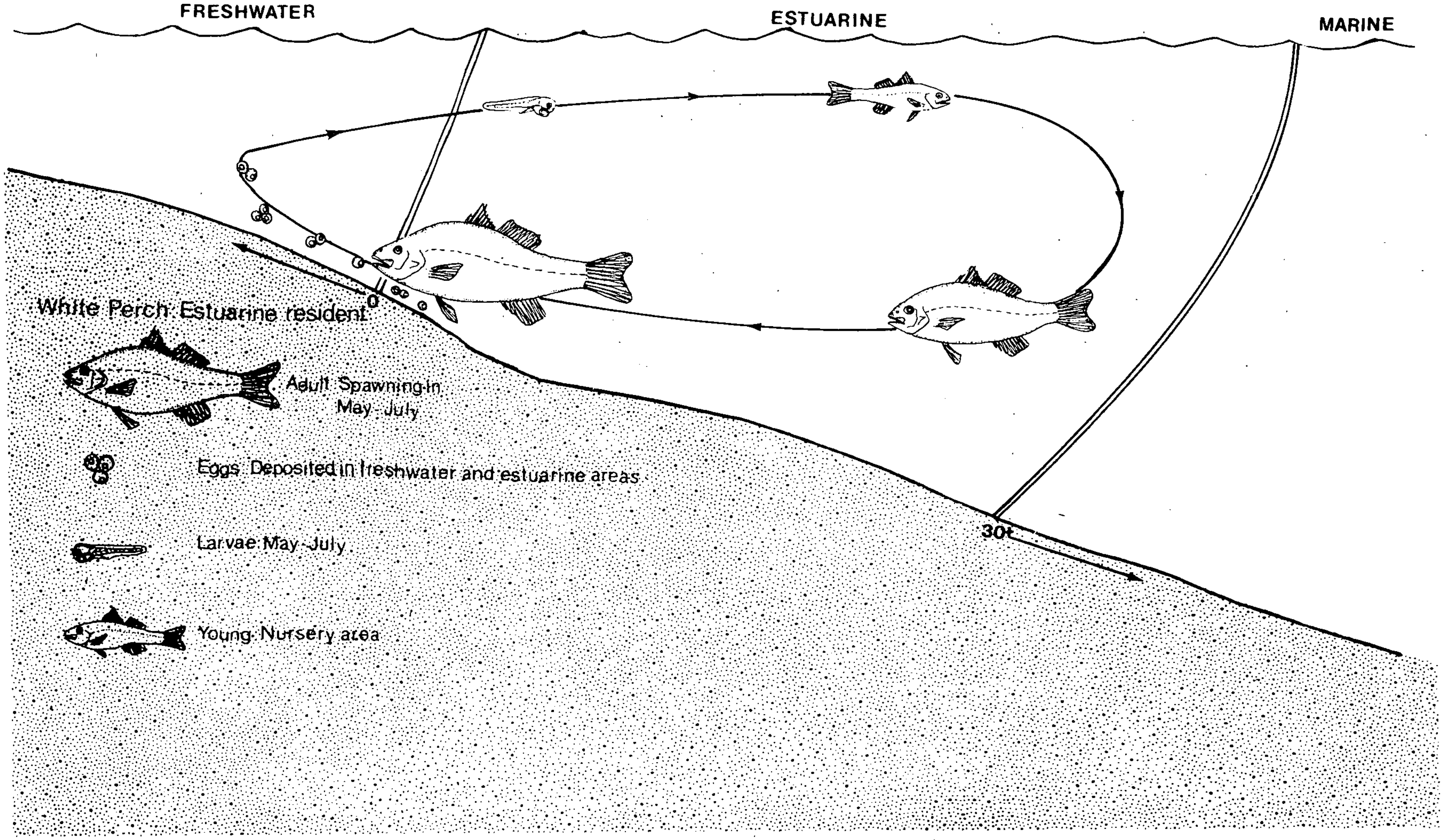


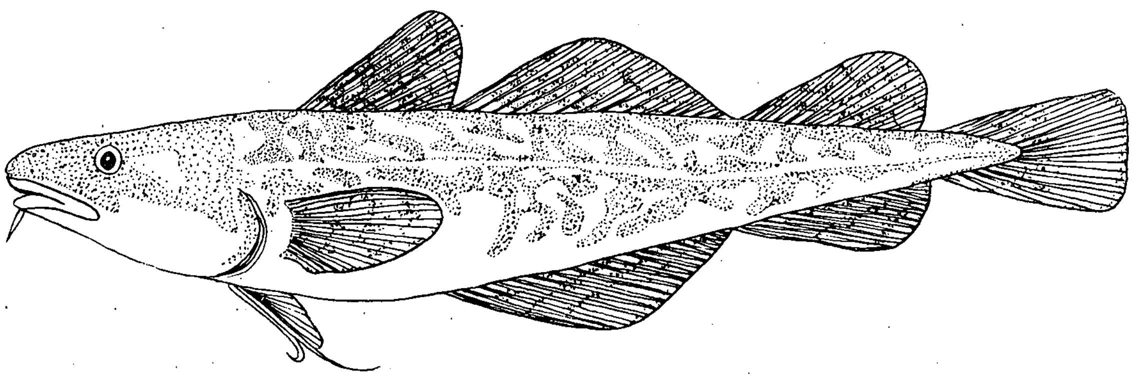
Figure 5.3-2 Generalized Life Cycle of White Perch in Hudson River Estuary (Adapted from Cronin and Mansueti:32-35) The numbers 0 and 30+ represent salinities in parts per thousand.

Egg production in the Hudson River is 10,000-70,000 (0.8-1.1 mm in diameter, water-hardened) per female, the number increasing with fish size. White perch eggs sink to the bottom and, because they are very adhesive, stick to each other and to any substrate that they contact (Mansueti 1964:9). Hatching occurs in 1.5 to 6 days, with development occurring faster at higher temperatures. Newly hatched yolk-sac larvae are 1.7 to 3 mm long (Mansueti 1964:14). During the yolk-sac stage (3 to 5 days), larvae remain on or near the bottom (Mansueti 1964:21). The yolk-sac is completely absorbed when the larvae are 3.5 to 4.0 mm long (Mansueti 1964:15). The juvenile stage (young-of-the-year) begins when young white perch develop the adult fin complement at about 20 mm total length approximately 1 mo after hatching (TI 1975b:VI-24, 40; 1976f: V-45, 49). Juveniles are 70 to 80 mm long (TI 1976f:V-51) by the end of their first summer.

5.3.1.4 Trophic (Feeding) Relationships. The white perch has been described as a "well-adapted predaceous species" (Scott and Crossman 1973:687) preying on a large variety of invertebrates as well as fish and their eggs. In the Hudson River estuary, white perch feed primarily on copepods, midge larvae, and the amphipod (scud) *Gammarus*; the latter two items become more important as the fish grow. Other common food includes cladocerans for juveniles and amphipods (other than *Gammarus*) and polychaetes (marine worms) for adults. Clupeid (herring family) eggs are a major dietary item in the spring. Many studies have shown that fish are important prey for large white perch, but this has not been observed for Hudson River white perch.

Juvenile white perch are prey for larger predators (including adult white perch) but apparently are not preferred in most areas (Scott and Crossman 1973:688). In the Hudson River estuary, yearling and older striped bass prey on juvenile white perch.

5.3.2 ATLANTIC TOMCOD



The Atlantic tomcod (*Microgadus tomcod* [Walbaum]) belong to the predominantly marine codfish family Gadidae, perhaps best known for the Atlantic cod (*Gadus morhua*). From an evolutionary standpoint, codfishes are relatively advanced bony fishes--but along lines different from striped bass and white perch.

5.3.2.1 Anatomy. The body of the Atlantic tomcod is elongate, only slightly compressed, and covered with small cycloid rather than the ctenoid scales of white perch and striped bass (Section 5.2). The three dorsal, two anal, and paired pelvic and pectoral fins are soft-rayed; there are no stiff spines as on spiny-finned fishes (Section 5.2). On the underside of the lower jaw, a slender barbel (fleshy projection) containing taste receptors adapts the tomcod for bottom feeding. The dorsal surface is brown or olive brown with yellow or green tinges and mottled with irregular dark blotches; the belly is greyish or yellowish white. The swim bladder, like that of the striped bass (Section 5.2) and white perch, is closed (physoclistous). Although closely resembling the Atlantic cod in form, the tomcod is much smaller, growing to only

30-38 cm in total length and seldom weighing more than 454 g. The Atlantic tomcod anatomy and general biology have been detailed by Bigelow and Schroeder (1953:96-99), Thomson et al. (1971:74-75), and Scott and Crossman (1973:646-649).

5.3.2.2 Distribution. The Atlantic tomcod is an inshore marine and estuarine species, which ranges from southern Labrador to Virginia along the Atlantic coast of North America and occurs in salt, brackish, and fresh waters (Fig. 5.3-3). In Canada, the Atlantic tomcod occurs in the mid to lower Saint Lawrence River and is landlocked in at least two freshwater lakes (Scott and Crossman 1973:646-647).

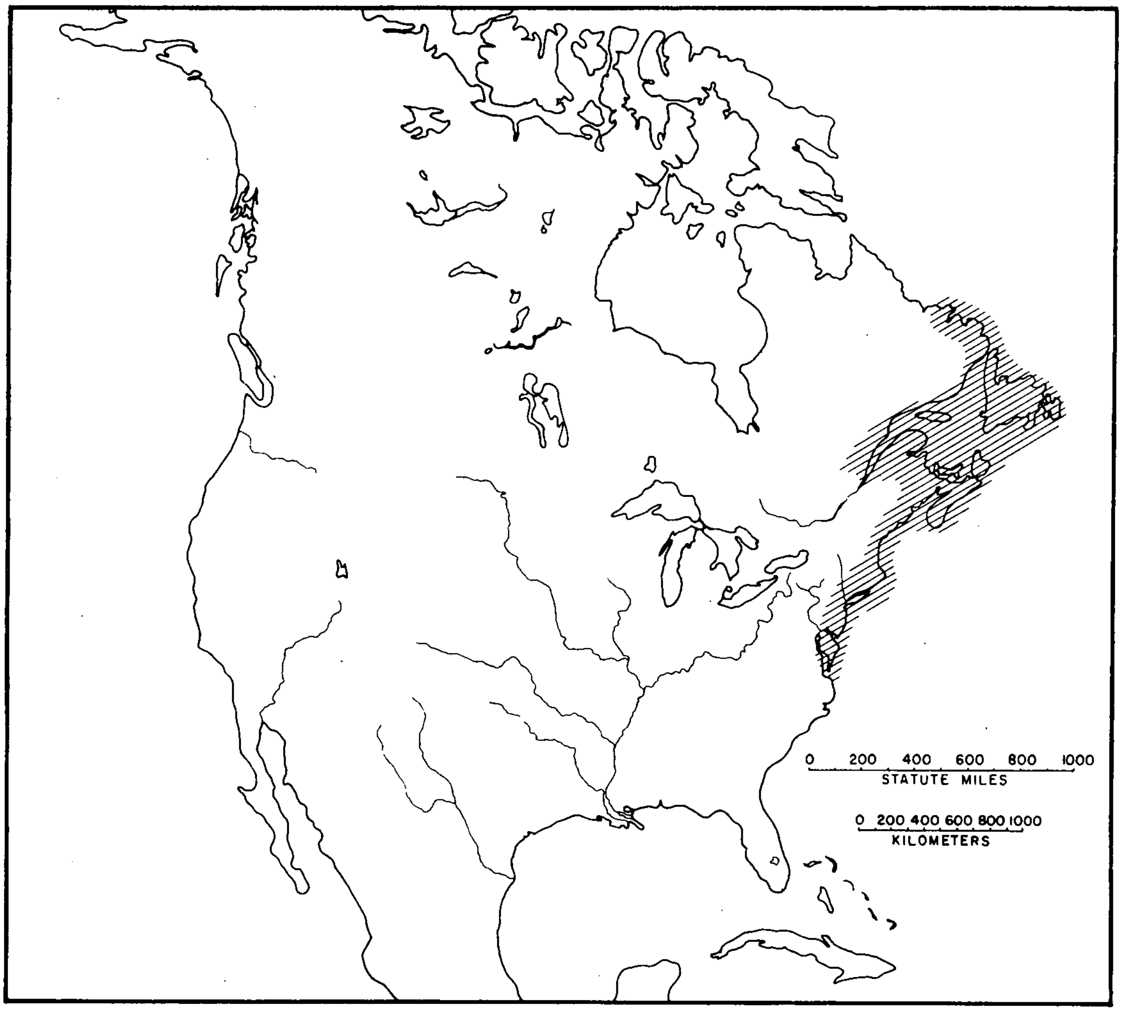


Figure 5.3.3 North American Distribution of Atlantic Tomcod (*Microgadus tomcod*)

In the Hudson River estuary, adult Atlantic tomcod occur at least as far north as Saugerties (RM 94; km 150) during midwinter spawning runs; the largest concentrations, however, are found between Haverstraw Bay (RM 38; km 61) and the Newburgh bridge (RM 61; km 98)(TI 1976f:V-131-132). In the spring, adults appear in deeper waters of the lower estuary, particularly south of West Point (TI 1976f:V-131). The distributions of eggs, larvae, young-of-the-year, and adults are discussed in Section 6.3.

5.3.2.3 Life Cycle. The usually anadromous Atlantic tomcod enters coastal estuaries and rivers to spawn in shallow fresh or brackish water during midwinter (Fig. 5.3-4) (Scott and Crossman 1973:647). Adults may spawn in salt water (Scott and Crossman 1973:647), but Booth (1967:16) found that sperm motility and thus fertility were greatest in brackish or fresh water.

In the Hudson River estuary, spawning populations are composed almost entirely of 11- to 13-mo-old fish. During the winter of 1973-74, estimated fecundities ranged from 3,860 to 55,700 eggs per female (TI 1975e:VII-35). In Massachusetts waters, Schaner and Sherman (1960:348) reported a range of 6,000 to 30,000 eggs per female. Scott and Crossman (1973:647) noted that Atlantic tomcod eggs are spherical, about 1.5 mm in diameter, and adhesive. Low water temperatures during the spawning season cause incubation to be comparatively long, with hatching occurring in about 30 and 24 days at water temperatures of 4.4^{o} and 6.1^{o}C., respectively (Scott and Crossman 1973:648). In the Hudson River estuary, egg duration is probably about 30 days.

Young Atlantic tomcod undergo early development in late winter, when most other Hudson River fishes are relatively inactive. Larvae are 5 mm long at hatching (Nichols and Breder 1927:116). In the Hudson River, complete absorption of the yolk sac probably takes about 1 mo. The juvenile stage begins in early spring; by the beginning of the summer, juvenile Hudson River Atlantic tomcod are approximately 74 mm in total

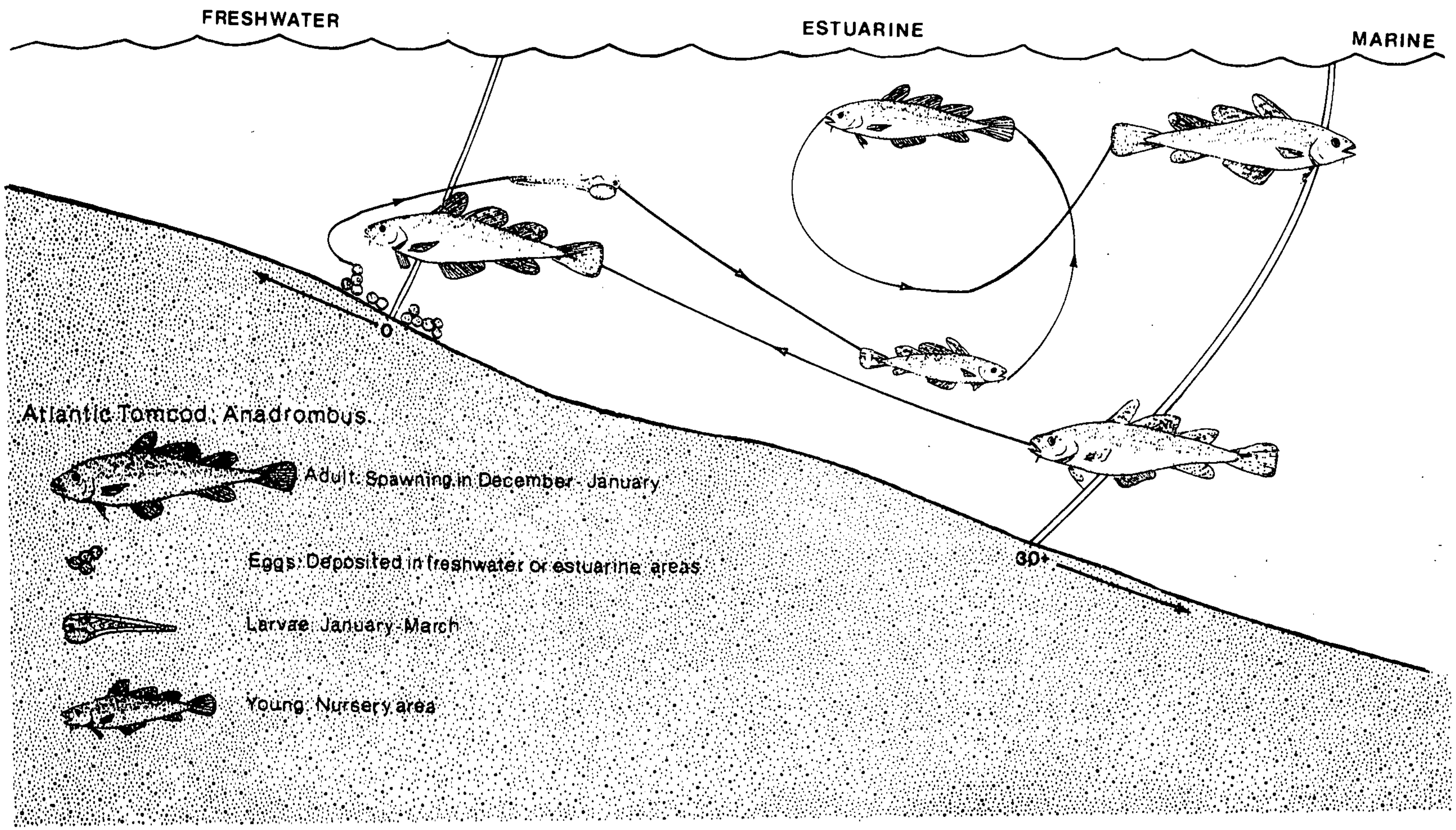


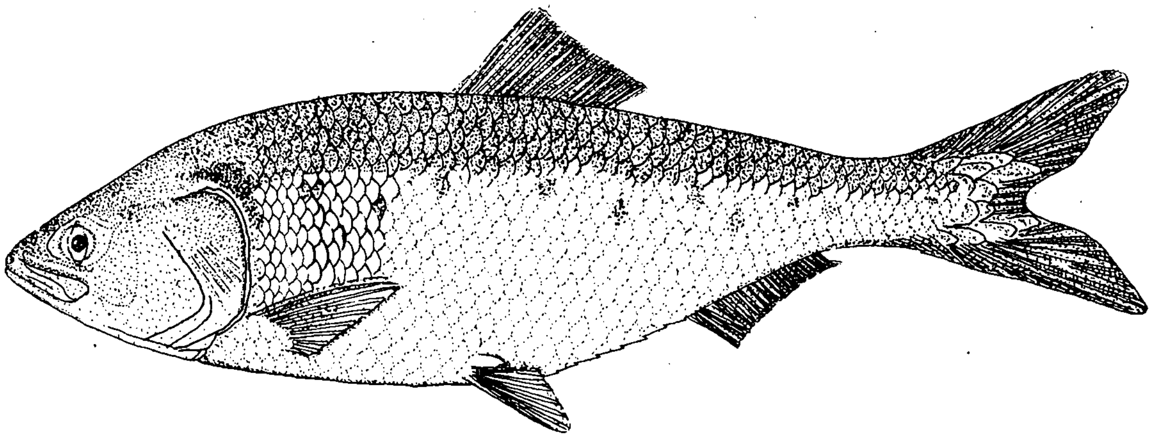
Figure 5.3-4 Generalized Life Cycle of Atlantic Tomcod in Hudson River Estuary (Adapted from Cronin and Mansueti 1971:32-35)
The numbers 0 and 30+ represent salinities in parts per thousand.

length (TI 1975e:VII-31). Little or no growth occurs during the summer, apparently because the Atlantic tomcod is a cold-adapted species (TI 1975e:VII-32). The seasonal pattern of activity and growth is exactly opposite that of most other Hudson River fishes. Juvenile growth resumes in the fall when water temperatures decline, and the young approximately double their summer length by December. The mean total length of young Atlantic tomcod in the Hudson River estuary in December 1974 was 153 mm (TI 1975e:VII-32). Most Hudson River Atlantic tomcod are sexually mature at the end of their first year (TI 1975e: VII-34).

5.3.2.4 Trophic Relationships. Atlantic tomcod feed on small crustaceans (especially shrimp and amphipods), marine worms, small molluscs, and juvenile fish. Adults in the Hudson River estuary primarily eat *Gammarus* and *Neomysis* polychaetes, isopods, other amphipods, shrimp, midge larvae, fish, and tomcod eggs. Juveniles most frequently consume copepods and *Gammarus*.

Juveniles are probably eaten by many larger predators. Boyle (1969:219) reported finding Atlantic tomcod in the stomachs of striped bass caught in the lower Hudson River estuary. Juvenile bluefish (*Pomatomus saltatrix*) consume young tomcod in the lower Hudson River estuary during summer months (TI 1976a:II-4).

5.3.3 AMERICAN SHAD



The herring family Clupeidae is a relatively primitive family of bony fishes, although it has flourished in modern times. The American shad (*Alosa sapidissima* [Wilson]) has close relatives in the Hudson River estuary: the alewife (*A. pseudoharengus*), blueback herring (*A. aestivalis*), and hickory shad (*A. mediocris*).

5.3.3.1 Anatomy. The American shad is long, deep-bodied, and laterally compressed. Adults average about 60 cm in total length and 2.7 kg in weight. The body is covered by large cycloid scales, which are easily lost. The belly has a series of sharp keel-like scales (scutes), which are characteristic of herrings and give the ventral profile a sawtooth appearance. The coloration is bright silver with a bluish cast on the dorsal surface; a series of dark spots extends back from the eye on the side. The single dorsal and anal fins and paired pelvic and pectoral fins are soft-rayed. The swim bladder, like that of all herrings, is physostomous, i.e., connected to the gut as well as the inner ear (Marshall 1966:365), permitting rapid adjustment to changes in pressure and presumably improving hearing. A large mouth, many fine gill rakers, and numerous pyloric ceca (fingerlike projections from the gut) make the shad well adapted for feeding on plankton. The anatomy and general biology of the American shad have been detailed by Leim (1924:3-124), Hildebrand and Schroeder (1928:93-101), Bigelow and Schroeder (1953:108-112), Hildebrand (1963:295-307), Thomson et al. (1971:53-55), and Scott and Crossman (1973:128-132).

5.3.3.2 Distribution. The anadromous American shad ranges from Newfoundland to northern Florida on the Atlantic coast of North America and from southern Alaska to southern California on the Pacific coast, where it was introduced in 1871 (Fig. 5.3-5). Adults are found in the Hudson River estuary only during the spring spawning run but they may range as far north as the federal dam at Troy (RM 153; km 245). Juvenile shad occur throughout the Hudson from Troy southward during the summer (Greeley 1935:90, 1937:91; TI 1976f:V-58). Yearling shad are infrequently collected in the lower estuary (TI 1976f:V-65). Section 6.3 discusses the distributions of eggs, larvae, and young-of-the-year.

5.3.3.3 Life Cycle. American shad usually become sexually mature after 3 to 6 yr at sea (Leggett 1973:92), although some males (buck shad) may mature within 2 yr. Most females (roe shad) mature by their fourth or fifth year (Medeiros 1974:4). In the Hudson River estuary, Greeley (1937:58) collected ripe males and females ranging from age III to VIII.

American shad are capable of annual spawning. Adults first enter the Hudson River estuary in late March or early April (Fig. 5.3-6), depending on water temperature, and spawn through June (Medeiros 1974:4, TI 1976f: V-53-54). Principal spawning areas are between Hyde Park (RM 77; km 123) and Catskill (RM 107; km 171)(TI 1976f:V-55). After spawning, the adults return to the ocean.

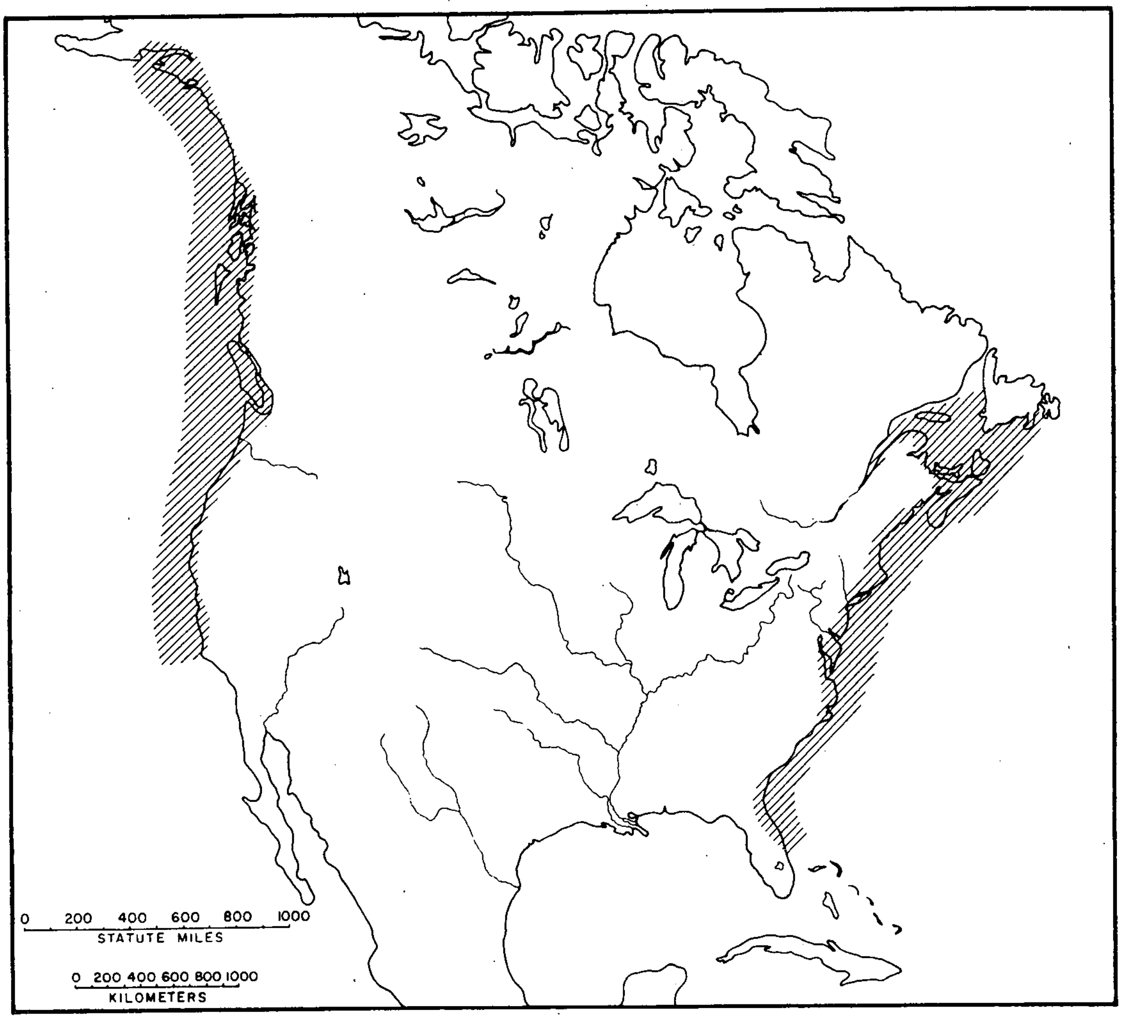


Figure 5.3-5 North American Distribution of American Shad (*Alosa sapidissima*)

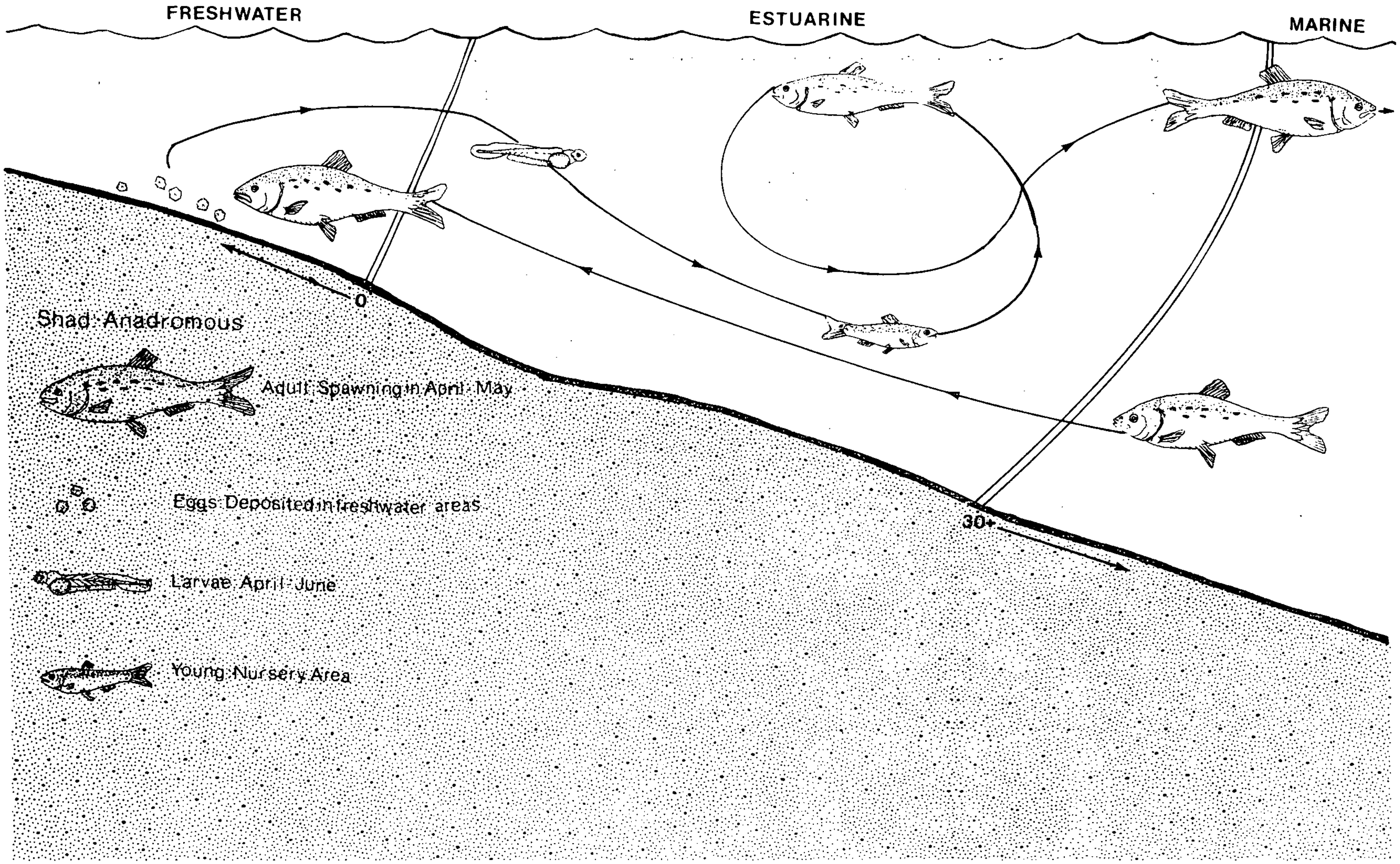


Figure 5.3-6 Generalized Life Cycle of American Shad in Hudson River Estuary (Adapted from Cronin and Mansueti 1971:32-35)
The numbers 0 and 30+ represent salinities in parts per thousand.

A roe shad in the Hudson River estuary may produce 116,000 to 468,000 eggs (Medeiros 1974:5), although Davis (1957:3) reported a narrower range of 209,000 to 307,000 eggs and also noted that Hudson River shad had smaller and fewer numbers of eggs than did shad from more southerly rivers. The eggs are semibuoyant and nonadhesive and hatch in 4 to 7 days, depending on water temperature (Leim 1924:31; Hildebrand 1963:297, Medeiros 1974:5).

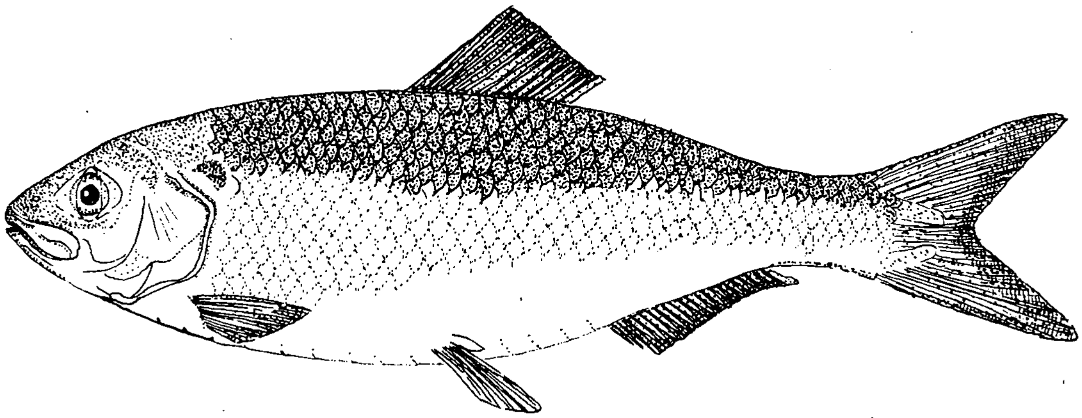
Newly hatched yolk-sac larvae (about 7-10 mm) grow rapidly and absorb the yolk-sac within a week. Within a month, young shad have assumed adult characteristics and reached a length of approximately 25 mm (Leim 1924:42, Hildebrand 1963:297, Medeiros 1974:5); in the Hudson River estuary, juveniles reach this size in late June to mid-July (TI 1976f:V-64).

Juveniles migrate seaward in the early fall when water temperatures decline. By mid-November, most juvenile shad have left the Hudson River estuary at an average total length of about 90 mm (TI 1976f:V-65).

5.3.3.4 Trophic Relationships. Juvenile shad in estuarine nurseries feed on small zooplankton, principally copepods (Leim 1924:56). As juvenile shad grow, they consume increasing numbers of aquatic insects, ostracods, and amphipods (Hildebrand 1963:302-303). Adults and yearlings at sea feed on a variety of zooplankton, small fish, fish eggs, planktonic larvae of molluscs and crustaceans, and some algae (Hildebrand 1963:302-303). Migrating adults do not feed until after spawning is completed (Medeiros 1974:5).

Young shad are prey for larger fish, particularly in the nursery areas (Hildebrand 1963:303). In the Hudson River estuary, young shad are consumed by young-of-the-year bluefish (TI 1976a) and probably other predators including striped bass. Adults probably have few important predators other than man.

5.3.4 BLUEBACK HERRING



The blueback herring (*Alosa aestivalis* [Mitchill]) is a close relative of the American shad (Section 5.2.3) and other herrings that occur in the Hudson River estuary (the alewife and hickory shad).

5.3.4.1 Anatomy. The blueback herring is similar in general form to the American shad but is smaller and not as deep-bodied when adult. The mouth also is smaller and more upturned. Adult blueback herring are usually < 30 cm in total length and 227 g in weight. Body color is dark bluish dorsally and silvery below. Characteristics such as the ventral scutes and numerous fine gill rakers are typical of herrings such as the American shad which was previously described. Externally, the blueback herring so closely resembles the alewife that the two species are separated most reliably by the color of the peritoneum (blackish for blueback herring, pearly grey for alewife) and the comparative shapes of the otoliths (auditory bones). The anatomy and general biology of the blueback herring have been detailed by Hildebrand and Schroeder (1928:85-89), Bigelow and Schroeder (1953:106-107), Hildebrand (1963:325-331), Thomson et al. (1971: 59-60), and Scott and Crossman (1973:119-120).

5.3.4.2 Distribution. The blueback herring is also an anadromous species, ranging along the eastern North American coast from southern New Brunswick and Nova Scotia (where it is uncommon) southward to northern Florida (Fig. 5.3-7). Adults appear throughout the Hudson River estuary northward to Troy (RM 153; km 245) in late spring and early summer during their annual spawning run and a few yearlings are found in the lower estuary during the fall (TI 1976f:V-72). Section 6.3 discusses the distributions of eggs, larvae, and young-of-the-year.

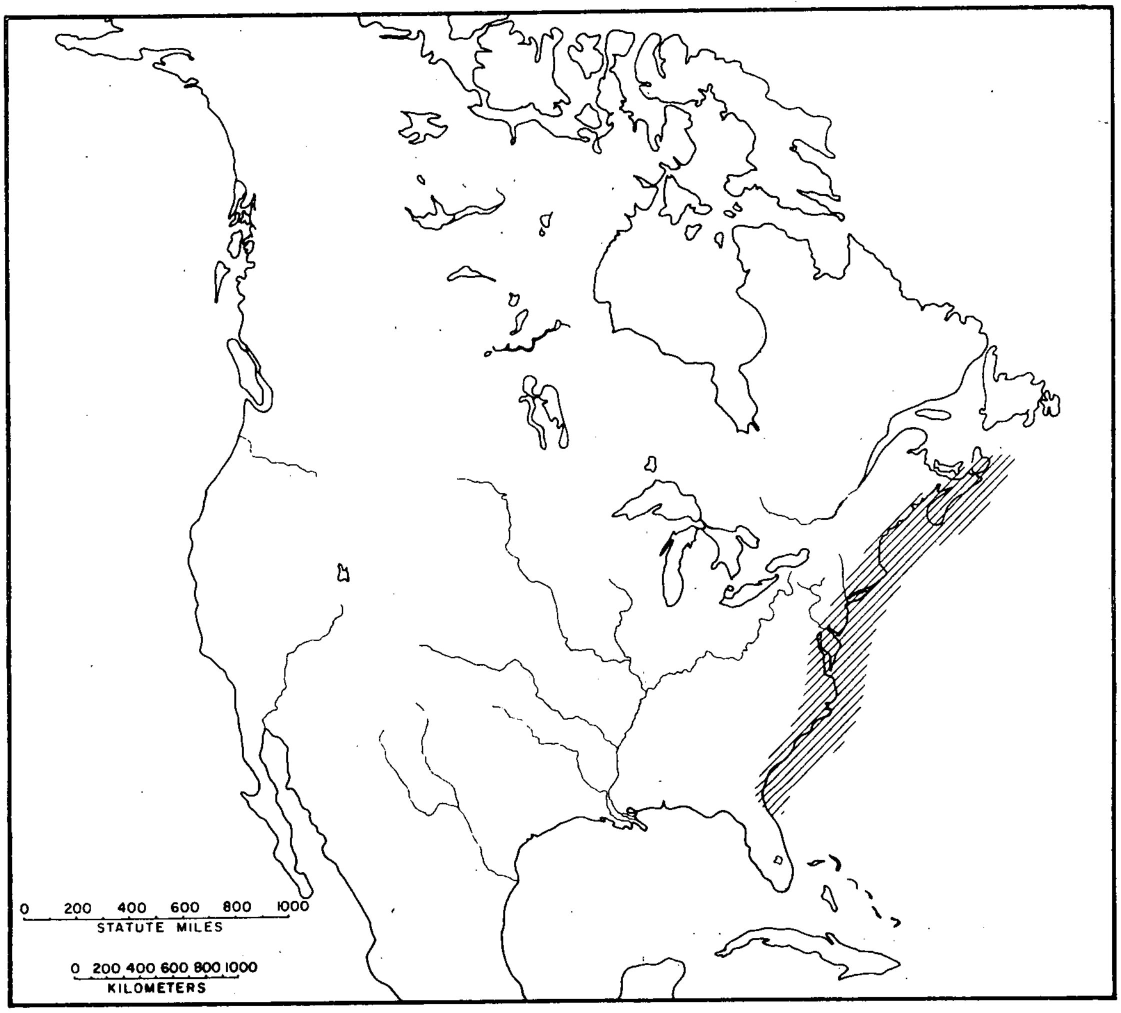


Figure 5.3-7 North American Distribution of Blueback Herring (*Alosa aestivalis*)

5.3.4.3 Life Cycle. Of the three anadromous herring species that spawn in the Hudson River estuary, adult blueback herring are the last to begin their spring spawning run, preferring warmer water than the American shad and alewife. Spawning blueback herring do not ascend coastal streams and rivers as far as alewives. In Connecticut waters, male blueback herring spawned for the first time at age III or IV and females at age IV or V (Marcy 1969:624). During 1973, concentrations of adults in the Hudson River estuary (Fig. 5.3-8) peaked in late May and June (TI 1976f:V-72).

The adhesive blueback herring eggs are found near the bottom and are approximately 1 mm in diameter. Since blueback herring spawn in relatively warm water, incubation proceeds rapidly; hatching occurs in 2 to 3 days at water temperatures ranging from 22 to 24°C. Newly-hatched larvae are slender and approximately 3.1 to 4.2 mm in total length (Lippson and Moran 1974:40). The yolk-sac is absorbed in about 4 days, when the larvae are about 5 mm long (Hildebrand 1963:326). Approximately 1 mo after hatching, blueback herring measure 30 to 50 mm (Scott and Crossman 1973:120). Chittenden (1972:125) found juvenile blueback herring to be highly tolerant of different salinities, enabling them to utilize fresh and saltwater nurseries.

Seaward migration of juveniles from the Hudson River estuary occurs in the fall (October-November) and is essentially complete by December, when the young blueback herring have grown to approximately 70 mm in total length (TI 1976f:V-74, 80).

5.3.4.4 Trophic Relationships. Blueback herring, like other herrings, are primarily plankton feeders and consume copepods, shrimp, larval and early juvenile fish, and fish eggs (Bigelow and Schroeder 1953:107, Hildebrand 1963:329, Thomson et al. 1971:60, Scott and Crossman 1973:120). They are undoubtedly preyed upon extensively by larger fish, particularly as juveniles (Hildebrand 1963:329).

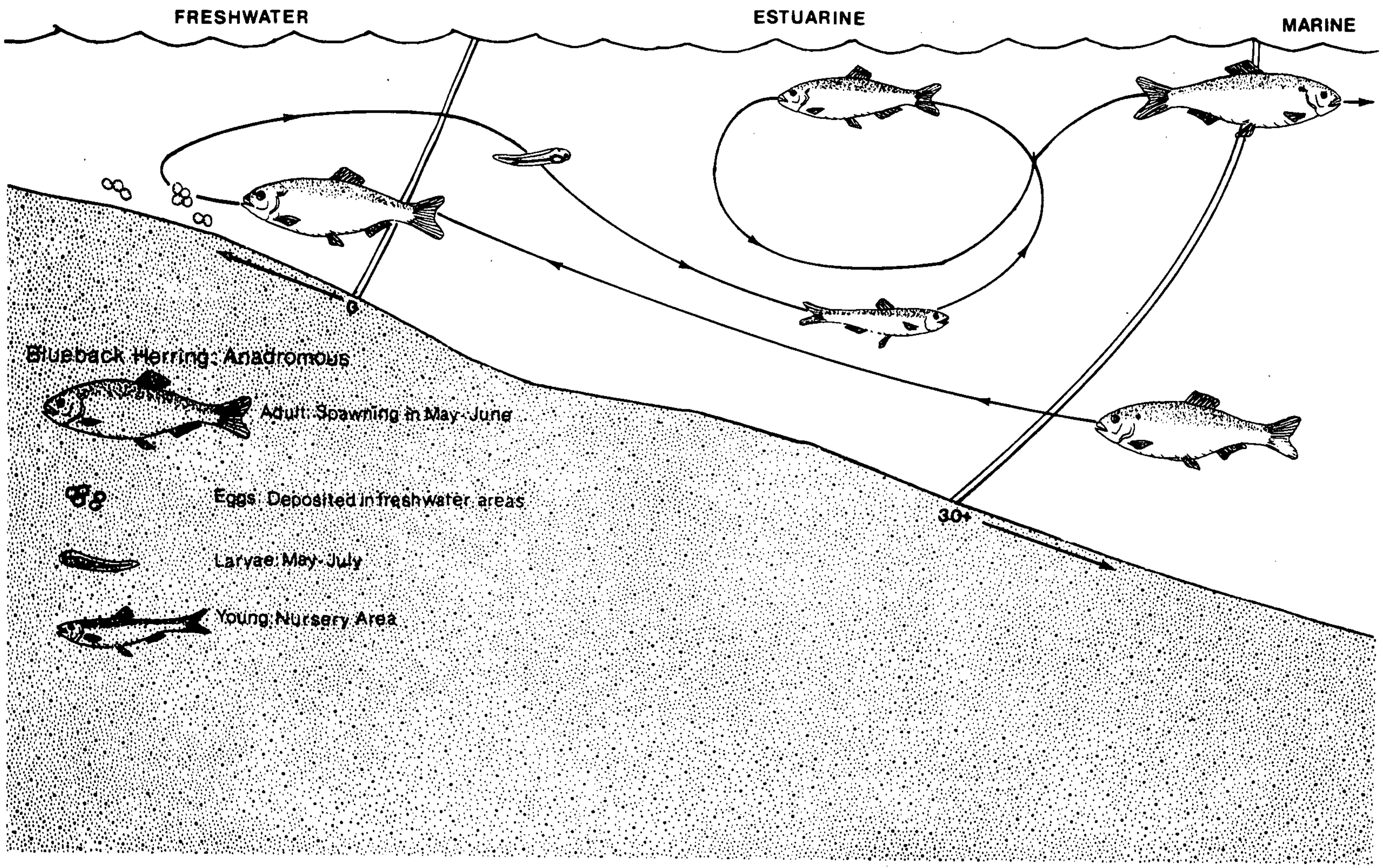
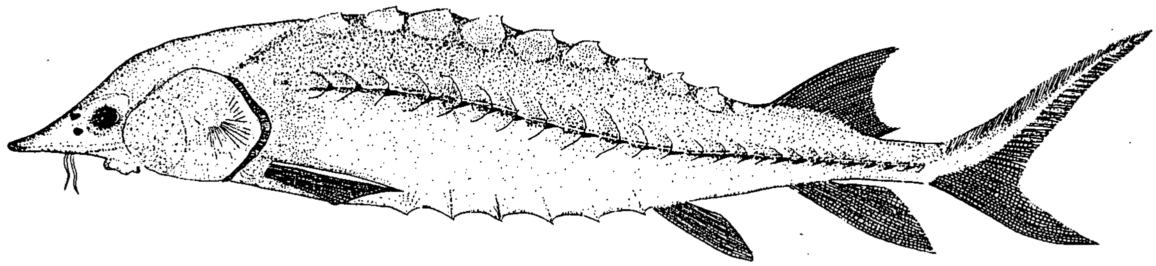


Figure 5.3-8 Generalized Life Cycle of Blueback Herring in Hudson River Estuary (Adapted from Cronin and Mansueti 1971:32-35) The numbers 0 and 30+ represent salinities in parts per thousand.

5.3.5 SHORTNOSE STURGEON



Sturgeons represent one of the most primitive families of bony fishes; they are one of the few surviving members of a group that was dominant in ancient geologic times but has been reduced to relatively few species in modern times (Hubbs and Lagler 1958:38, Marshall 1966:360). The shortnose sturgeon (*Acipenser brevirostrum* Lesueur), as well as Atlantic sturgeon (*Acipenser oxyrhynchus*), occurs in the Hudson River estuary.

5.3.5.1 Anatomy. The shortnose sturgeon is among the smallest members of the sturgeon family, rarely exceeding a total length of 90 cm and a weight of 3.6 kg (Vladykov and Greeley 1963:38, Scott and Crossman 1973:81).

In outward appearance, sturgeons are unmistakable. The skin is scaleless, except for a few ganoid scales on the tail, and is covered with patches of minute tooth-like denticles and armored with five rows of bony plates called bucklers or scutes. The toothless, protrusible mouth is located behind four sensory barbels on the lower surface of the snout. Unlike the other species discussed in Section 5, the sturgeon's tail is asymmetrical (heterocercal). The dorsal surface is dark brown, with some black on the head, while the belly is white. Details on the anatomy and general biology of the shortnose sturgeon have been given by Jordan and Evermann (1896:106), Hildebrand and Schroeder (1928:76-77), Bigelow and Schroeder (1953:84-85), Vladykov and Greeley (1963:36-41), and Scott and Crossman (1973:80-82).

Internally, sturgeons exhibit many primitive characteristics (Romer 1964: 49, 165, 329, 347, Marshall 1966:360). The skeleton is composed mainly of cartilage, although this condition represents a degeneration from ancestral sturgeon stock in which the skeleton was very bony. The short intestine has a spiral valve similar to that found in sharks. A notochord, replaced in more advanced fishes by the vertebral column, is persistent in sturgeons. As with the American shad and blueback herring, the swim bladder is physostomous (i.e., connected to the gut via a duct).

5.3.5.2 Distribution. The shortnose sturgeon is restricted to the Atlantic coast of North America from the Saint John River in New Brunswick to the Saint Johns River in Florida (Fig. 5.3-9). It inhabits fresh, brackish, and salt water but is most common in the lower reaches of large tidal rivers (Vladykov and Greeley 1963:39-40, Scott and Crossman 1973:80). In the Hudson River estuary, it has been collected as far north as Kingston (RM 86; km 137) (Greeley 1937:90, Section 6.2). Dadswell (1975:32) described the shortnose sturgeon as sometimes anadromous in the Saint John River, New Brunswick, although Greeley (1937:78) stated that it was probably a permanent freshwater resident in the Hudson River estuary. Shortnose sturgeon distribution is discussed further in Section 6.3.

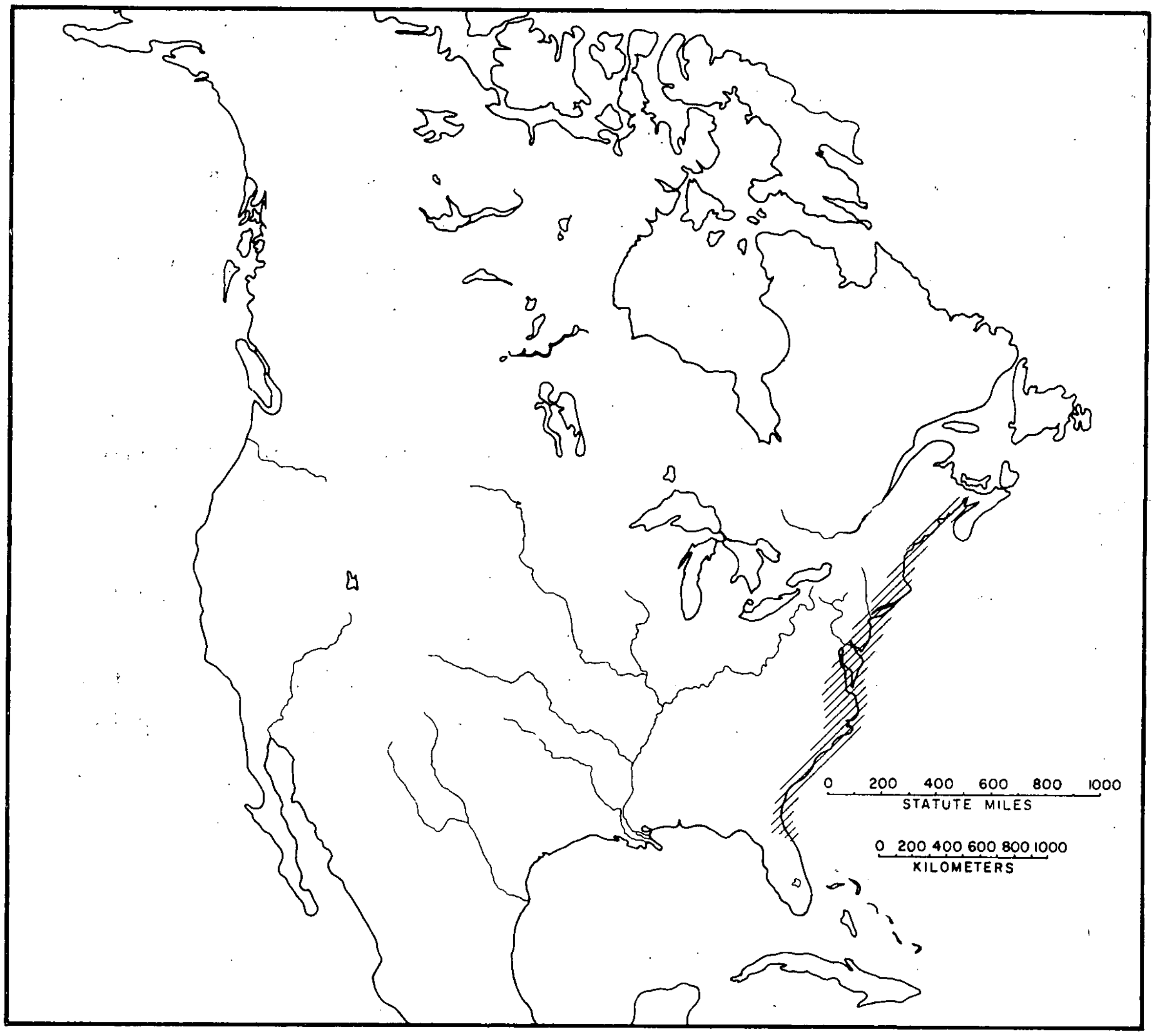


Figure 5.3-9 North American Distribution of Shortnose Sturgeon (*Acipenser brevirostrum*)

5.3.5.3 Life Cycle. Only fragmentary data on the life cycle of the shortnose sturgeon (Fig. 5.3-10) are available.

Growth is very slow. Males mature at perhaps ages III-V at a total length of approximately 50 cm and females mature at possibly ages V-VII at a total length of approximately 60 cm (Vladykov and Greeley 1963:38-39, Scott and Crossman 1973:81). Spawning occurs in freshwater or estuarine portions of coastal rivers during the spring. Females in the

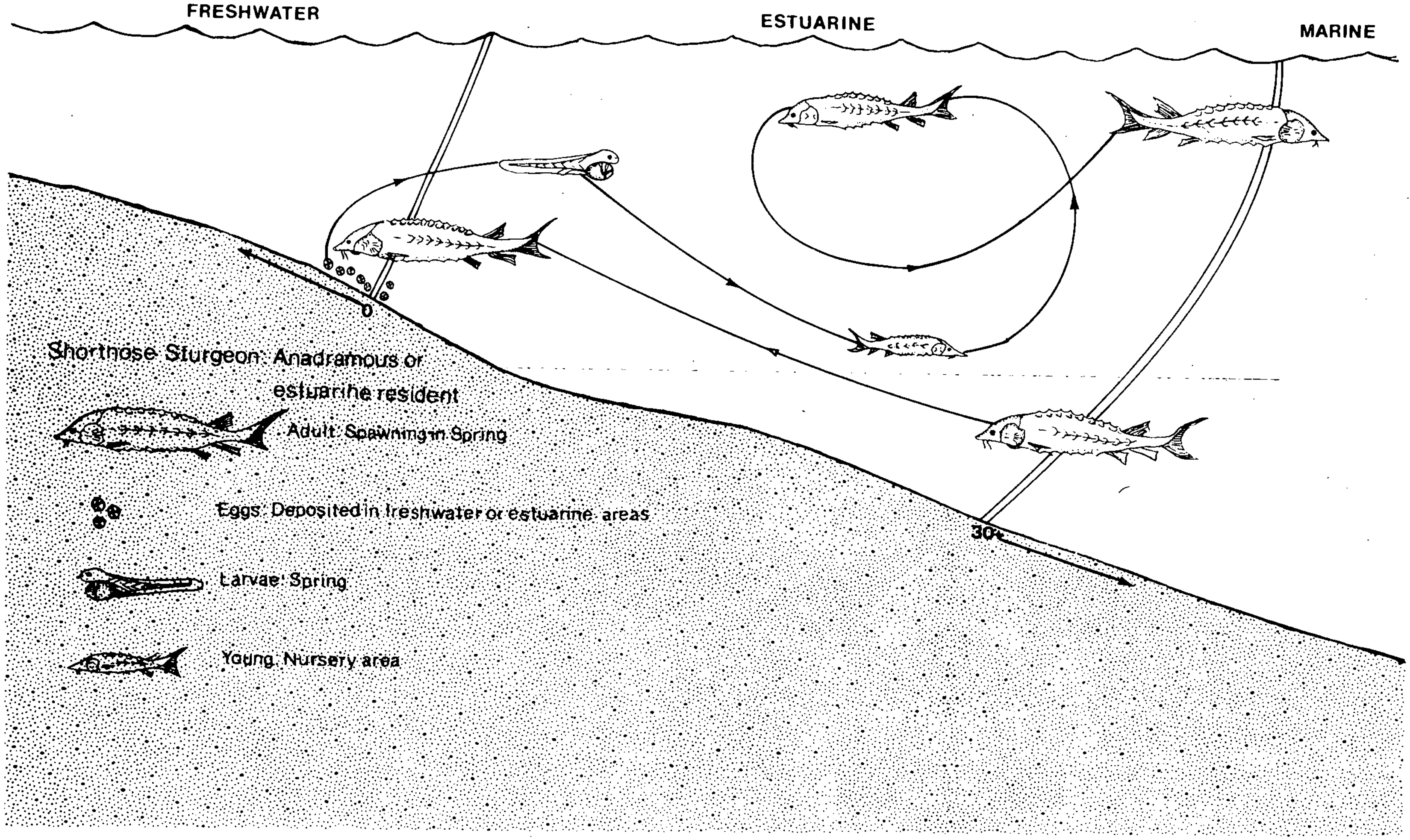


Figure 5.3-10 Generalized Life Cycle of Shortnose Sturgeon in Hudson River Estuary (Adapted from Cronin and Mansueti 1971:32-35) The numbers 0 and 30+ represent salinities in parts per thousand.

Saint John River spawn only once every 3 yr (Dadswell 1975:32). The number of eggs produced by spawning females is unreported. Shortnose sturgeon eggs are smaller than those produced by other sturgeon (Vladykov and Greeley 1963:39).

No studies on larval development and growth of shortnose sturgeon have been published. Since there is no known way to easily separate the larvae of shortnose and Atlantic sturgeons, shortnose sturgeon larvae are virtually impossible to study when the two species occur together as they do in the Hudson River estuary.

Full adult characteristics are not acquired until the fish are about 60 cm in total length (Scott and Crossman 1973:81). Shortnose sturgeon may live $\geq$ 34 yr in Canadian waters (Dadswell 1975:32), but the oldest specimen reported for the Hudson River estuary was 14 yr old (Greeley 1937:70).

5.3.5.4 Trophic Relationships. The protrusible, tube-like mouth of sturgeons (Section 5.5.5) is an adaptation for feeding on bottom organisms (Scott and Crossman 1973:81). Shortnose sturgeon in the Hudson River estuary have been reported to eat marine worms, midge larvae, small crustaceans, and plant material (Greeley 1937:141, Vladykov and Greeley 1963:39). Although man is the only known predator of the shortnose sturgeon (Scott and Crossman 1973:82), the young are probably somewhat vulnerable to predation by larger fishes.

5.3.6 SUMMARY. Points of similarity and difference among the life histories of the species discussed in this section are summarized in Table 5.3-1.

5.4 ECOLOGICAL IMPORTANCE AND RELATIONSHIP TO MAN OF STRIPED BASS

The striped bass, a component of many estuarine and nearshore coastal communities at various stages of its life history, is an important commercial and recreational fish along the Atlantic coast between Cape Hatteras and Cape Cod. Changes in its population size or structure may have direct economic effects on those fisheries or may produce changes in the structure and function of those communities of which it is a member. At the present time, water pollution and dam construction considerably reduce the number of Atlantic coastal rivers suitable for striped bass spawning (Saila and Pratt 1971:6.66). The Hudson River supports a spawning stock, which contributes to the fishery of Long Island and to a lesser extent to the fishery from the coast of Massachusetts to New Jersey (see Section 7.10).

The ecological importance of a species may best be assessed on the basis of its influence on community productivity. Among species interactions which influence productivity in any community are those related to the food web. Because of the general complexity of, and seasonal changes in, the composition of estuarine and coastal communities, interspecific feeding relationships are transitory and difficult to quantify (Tyler 1971, Dahlberg 1972). Feeding relationships of striped bass change with life stage and prey availability, although the species is apparently an opportunistic predator. During their first year of life in the estuary (Section 5.2), striped bass consume a variety of zooplankton and benthic invertebrates that are the same prey organisms important in the diet of many other estuarine fishes, both the young of other anadromous species and the young and older of resident species (Section 5.3). Thus, although estuarine productivity is typically high (Odum 1971:357), interspecific competition at this trophic level may be intense. There is evidence in the Hudson River estuary of high dietary overlap between young-of-the-year white perch and striped bass (TI 1974a:IV-52). Growth of juvenile striped bass within the estuary appears to be inversely related to their density (TI 1975b:VIII-8-VIII-12). This reduction in growth with increasing density presumably reflects intraspecific competition for food, but interspecific competition may also affect growth of juvenile striped bass as well as that of competing species.

Yearling striped bass gradually increase the proportion of fish in their diets, and adults in the estuary and coastal waters consume primarily fish and feed at or near the top of the trophic pyramid. Prey availability strongly influences the relative importance of individual species in their diet (Raney 1952:45-56). No information is available on the effects of interspecific or intraspecific competition on growth of older striped bass; however, it is known that other predators such as the bluefish utilize similar food resources and presumably introduce competition.

Striped bass and other predators may affect populations of other fishes in estuarine and coastal waters. Dovel (1968:317-318) suggested that striped bass predation may have been responsible for reducing populations of croaker, menhaden, and spot in Chesapeake Bay. Opportunistic predators such as the striped bass, which consume prey as a function of their availability, may serve to maintain balance of numbers among prey species and to make resources available to less abundant or rare species. Because of the variety of predators and prey that share most trophic levels in estuarine and coastal waters and the resulting complexity of the food web, it is unlikely that a change in numbers of striped bass would have other than a transitory effect on community organization. Many of the more important species of fishes, including the striped bass, are subject to natural fluctuations in abundance (Saila and Pratt 1971: 6-70) with no apparent long-term effect on community structure.

The striped bass is commercially important and contributes to the commercial fishery along the Atlantic coast. During 1975, preliminary data indicated that 7,450,000 lb of striped bass valued at $3,517,000 were landed along the Atlantic coast from Maine to Florida; this was approximately 50% of the 1973 total (14,739,000 lb), which was the highest total ever recorded (Koo 1970:76, Table 5.4-1).

Table 5.4-1 Commercial Landings (Thousands of Pounds) and Value to Fishermen (Thousands of Dollars) of Striped Bass Reported along Atlantic Coast since 1965

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River†											
Pounds	36.7	44.3	54.6	60.8	77.2	45.9	24.7	17.9	67.0	30.3	46.2
Dollars	4.0	5.3	4.4	11.6	12.3	7.8	4.5	5.0	24.0	12.1	24.9
New York‡											
Pounds	740	1,050	1,630	1,551	1,535	1,338	1,184	836	1,741	1,409	1,183
Dollars	140	193	306	350	369	363	329	269	654	535	639
Mid-Atlantic ‡											
Pounds	1,533	1,429	2,023	2,059	1,888	1,615	1,513	1,457	3,093	2,262	1,715
Dollars	308	282	392	488	453	423	424	447	1,020	748	890
New England ‡											
Pounds	531	843	802	987	1,182	1,442	895	1,499	2,024	484	381
Dollars	97	137	145	191	282	378	242	476	736	181	192
Chesapeake ‡											
Pounds	5,162	6,150	5,827	6,146	7,759	4,702	3,964	5,888	7,864	6,131	4,051
Dollars	975	1,130	935	1,215	1,427	1,029	1,150	1,498	2,324	1,561	1,805
So. Atlantic‡											
Pounds	486	654	1,817	1,913	1,569	2,320	1,451	1,266	1,758	1,016	1,303
Dollars	77	100	253	385	325	479	314	359	594	393	630
TOTAL											
Pounds	7,712	9,076	10,469	11,105	12,398	10,079	7,823	10,110	14,739	9,893	7,450
Dollars	1,457	1,649	1,725	2,279	2,487	2,309	2,130	2,780	4,674	2,883	3,517

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries
** From USNOAA, 1976; Current Fisheries Statistics (preliminary)
† Provided by Fred Blossum (NMFS)
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States

Landings are reported by states grouped into four commercial districts along the Atlantic Coast for reporting purposes by NMFS. During 1975, the Chesapeake district (Virginia and Maryland) reported 54% of the total commercial poundage from the Atlantic coast while the Middle Atlantic district (New York, New Jersey, and Delaware) contributed 23%. The New England district (Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut) and the South Atlantic district (North and South Carolina, Georgia, and the Atlantic coast of Florida) contributed 5 and 18% respectively (Table 5.4-1). From 1930 through 1966, the Chesapeake district typically contributed more than 66% of the total catch (Koo 1970:76-77); since 1965, landings from the Chesapeake district have ranged from ~~4,051,000~~ 3,964,000 lb ~~(1975)~~ (1971) to 7,864,000 lb (1973) and represented from 47 to 68% of the total catch. Landings from the Middle Atlantic district have ranged from 1,429,000 lb (1966) to 3,093,000 lb (1973) and represented from 14 to 23% of the total. In 1973, the last year for which final records were available, commercial landings of striped bass in the Middle Atlantic district (3,093,000 lb) ranked fifth in value ($1,020,000) among finfish (Table 5.4-2).

New York State landings of striped bass in 1975, including all landings from the Hudson River (New Jersey has no commercial striped bass fishery on the Hudson River) were 1,183,000 lb ($639,000), representing approximately 16% of the Atlantic coast poundage (Table 5.4-1). The Hudson River contribution was 46,200 lb valued at $24,900, representing approximately 4% of the New York State total and <1% of the total Atlantic coast catch. Since 1965, Hudson River landings have ranged from 17,900 lb (1972) to 77,200 lb (1969) (Table 5.4-1). The average price paid to Hudson River fishermen has increased from $0.11 lb^{-1} in 1965 to $0.54 lb^{-1} in 1975.

Striped bass also contribute to an extensive sport fishery, although data with which to evaluate the magnitude of this fishery are sketchy. The most recent comprehensive statistics available on catches from marine waters by sport fishermen have been compiled for the year 1970

Table 5.4-2 Landings (Thousands of Pounds) and Value (Thousands of Dollars) of Top 20 Commercial Fishes (in Order of Decreasing Value) in Middle Atlantic Region during 1973*

	Species	Landings	Value
1	Menhaden	156,250	3,992
2	Flounder	12,379	3,048
3	Porgy	5,873	1,808
4	Whiting	8,383	1,079
5	Striped Bass	3,093	1,020
6	Weakfish	4,165	646
7	Butterfish	1,698	390
8	Black Sea Bass	878	337
9	Bluefish	2,303	294
10	Tuna	1,272	271
11	Tilefish	718	235
12	Atlantic Mackerel	1,478	144
13	Common Eel	406	124
14	Red Hake	1,454	116
15	Cod	417	106
16	American Shad	308	79
17	White Perch	268	66
18	Silversides	91	22
19	White Hake	64	12
20	Carp	141	11
	Sturgeon	22	4
	Alewife	30	>1
	TOTAL**	202,386	13,863

* From USNOAA, 1975; Current Fisheries Statistics No. 6816
** Includes species in addition to those listed.

by the National Marine Fisheries Service using household questionnaires and interviews (Deuel 1973). Atlantic coast sport landings were estimated for three districts, which differ from the four used to report commercial landings (Table 5.4-3) ~~(Table 5.4-2)~~. The 1970 sport catch of striped bass along the entire Atlantic coast was estimated to be 73,295,000 lb (Table 5.4-3). Sport landings of striped bass in the North Atlantic district, which includes those states constituting the New England commercial district plus the state of New York, were estimated to be 45,844,000 lb. In both cases, striped bass catch ranked second behind that of bluefish (Table 5.4-4). These figures suggest that the sport catch exceeded the commercial catch along the entire Atlantic coast by a factor of 7.3 and in the North Atlantic district by a factor of 16.5 in 1970.

The survey technique used to estimate the sport catch probably resulted in frequent overestimation because of memory errors and a tendency for reporting fishermen to exaggerate catches (Deuel 1973: 27). Comparing estimates from this survey with party boat logs maintained for the same period in the state of California revealed a twofold to threefold overestimation in survey values (Deuel 1973:34). The contention that Deuel's estimates of striped bass catch are too high, particularly in the North Atlantic district, is further supported by preliminary results of tagging studies conducted by the New York Department of Environmental Conservation (NYDEC) which indicate approximately equal returns from the commercial and sport fisheries of striped bass tagged on ocean beaches of Long Island during 1973, 1974, and 1975 and recaptured from Maine to Virginia (Young 1976:8-10).

If error of the magnitude suspected to exist in California landings is assumed to exist in estimates made for other regions, more realistic values may be produced by reducing survey estimates to approximately one-half of reported levels. The resulting estimate of the striped bass catch along the entire coast is approximately 37,000,000 lb; for the North Atlantic district, 23,000,000 lb. Therefore, sport landings may have exceeded commercial landings by a factor of 3.7 along the entire coast

Table 5.4-3 Estimated Sport Landings and Numbers of Sport Fishermen Fishing for Striped Bass, White Perch, and American Shad along Atlantic Coast of United States during 1970*

	Species					
	Striped Bass		White Perch***		American Shad	
Region**	Lb (1000s)	Fishermen (1000s)	Lb (1000s)	Fishermen (1000s)	Lb (1000s)	Fishermen (1000s)
North Atlantic	45,844	368	32	5	625	17
Middle Atlantic	27,262	415	12,592	363	4,231	52
South Atlantic	189	10	-	-	-	-
Total	73,295	793	12,624	368	4,856	69

* From 1970 Salt Water Angling Survey (Deuel 1973)

** North Atlantic region - Atlantic coast from Maine southward through New York
Middle Atlantic region - Atlantic coast from New Jersey to Cape Hatteras
South Atlantic region - Atlantic coast from Cape Hateras to Florida Keys

*** May include small proportion of other perches; perches reported from South Atlantic region not included because high proportion of silver perch included

Table 5.4-4 Ranking of Fish Landed (Thousands of Pounds) by Sport Fishermen in North Atlantic Sport Fishery Region*

Rank	Species	Landings
1	Bluefish	50,161
2	Striped bass	45,844
3	Atlantic mackerel	41,482
4	Flounder	36,295
5	Cod	35,688
6	Tautog	15,629
7	Puffer	7,899
8	Pollack	5,584
9	Shark	4,795
10	Tuna	3,711
11	Kingfish	3,457
12	Searobin	2,343
13	Porgy	2,296
14	Cunner	1,914
15	Weakfish	1,645

* 1970 Salt-Water Angling Survey (Deuel 1973)

and by a factor of 8.3 along the New England and New York coast. Schaefer (1968:46) suggested that sport landings of striped bass from Maine to Cape Hatteras exceeded commercial landings by a factor of 4 as early as 1960 and were increasing in importance. If it is assumed that the sport catches of striped bass exceeded the commercial catch in 1975 by factors of 3.7 and 8.3 for the Atlantic coast and the North Atlantic district respectively, then the sport catch for these two regions can be estimated to be 27,565,000 lb and 12,981,000 lb.

Information on the sport catch of striped bass in New York is limited. A partial creel survey of boat and surf fishermen in the vicinity of Montauk Point at the extreme eastern end of Long Island from May 1 through November 30 in 1973, 1974, and 1975 (Young 1976:40) respectively produced catch estimates of approximately 390,000, 443,000, and 254,000 lb. There is no estimate as to what proportion of the total New York sport catch this might represent. No records exist as to sport catch of striped bass from the Hudson River.

To assess the value of the Hudson River striped bass stocks, it is necessary to know to what extent striped bass of Hudson River origin contribute to the fisheries along the Atlantic coast. This has long been a point of controversy. The USNRC regulatory staff has defined "inner" and "outer" zones along the Atlantic coast to which the Hudson River is expected to contribute to greater and lesser extents respectively. The inner zone is composed of the Hudson River, the western half of Long Island Sound, and the New York Bight (USNRC 1975b:V-169); the outer zone extends from Maine to Cape May County, New Jersey, less the area included in the inner zone. Estimates (iterative) of 16% and 3% have been developed for the Hudson River contribution to the inner and outer zones respectively (Section 7.10). Application of these values to preliminary records of 1975 commercial landings for the areas included within the inner and outer zones produces an estimate of Hudson River contribution to the inner zone of approximately 113,500 lb valued at

$61,400 and to the outer zone of approximately 43,000 lb valued at $22,600 (Table 5.4-5). Since the contribution of Hudson River stocks to other fisheries is negligible, the total contribution of the Hudson River to the Atlantic coast commercial fishery in 1975 was approximately 156,500 lb valued at $84,000.

The future of the Hudson River fishery resources will be strongly influenced by other demands made upon the water resource. Wastes discharged into the river have long influenced the fishery, with demand for Hudson River fish being limited because of pollution-related off-taste (Medeiros 1974:29-34). Early in March 1976, the New York Department of Environmental Conservation restricted both commercial and sport fishing in the Hudson River because polychlorinated biphenyl (PCB) levels in fish exceeded the 5 ppm maximum imposed by the United States Food and Drug Administration (6 NYC RR§12.19 [Feb 26, 1976]). Results of PCB analyses conducted on fish taken from the Hudson River during 1976 revealed that 57% of the striped bass and 25% of the American shad had PCB levels exceeding 5 ppm. All sport and commercial fishing was prohibited from Fort Edward, New York, to the federal dam at Troy. Commercial fishing for all species except American shad, Atlantic sturgeon, and goldfish was further prohibited from the Troy dam to the Battery. Sport fishing in the lower Hudson River and Long Island Sound was not prohibited, but observations by NYDEC indicated a sharp reduction in fishing effort; many individuals apparently did not fish because of adverse publicity. Restrictions on the taking of baitfishes from the river below the Troy dam were rescinded in July 1976, but other restrictions remain in effect and are expected to continue at least through 1977 (Larry Skinner, NYDEC, personal communication). Information with which to determine the time required for dissipation of PCB levels in the river is not available.

Table 5.4-5 Commercial Landings (Pounds) and Value (Dollars) of Striped Bass Landed in Inner and Outer Zones of Hudson River Contribution as Defined by USNRC (1975)

Zone	Total* Landings lb	Hudson River Contribution lb (%)	Total* Value $	Hudson River Contribution $
Inner				
New York	310,400	49,600 (16%)	167,000	26,700 (16%)
New Jersey	110,400	17,700 (16%)	61,500	9,800 (16%)
Hudson River	46,200	46,200 (100%)	24,900	24,900 (100%)
Subtotal	467,000	113,500	253,400	61,400
Outer				
New York	826,700	24,801 (3%)	446,600	13,400 (3%)
New Jersey	225,000	6,750 (3%)	113,500	3,405 (3%)
Rhode Island	301,000	9,030 (3%)	151,800	4,554 (3%)
Massachusetts	55,000	1,650 (3%)	28,000	840 (3%)
Maine	500	15 (3%)	200	6 (3%)
New Hampshire	25,000	750 (3%)	12,000	360 (3%)
Subtotal	1,433,200	43,000	752,100	22,600
Total	1,900,200	156,500	1,005,500	84,000

* Landings and values taken from USNOAA 1976 Current Fisheries Statistics except those for the Hudson River which were supplied by Fred Blossum (NMFS).

5.5. ECOLOGICAL IMPORTANCE AND RELATIONSHIP TO MAN OF WHITE PERCH, AMERICAN SHAD, ATLANTIC TOMCOD, BLUEBACK HERRING, AND SHORTNOSE STURGEON

5.5.1 WHITE PERCH. Interactions of white perch with other species in the Hudson River estuary and Long Island Sound are not completely known. Juveniles appear to occupy a position in the food web similar to that of striped bass and the young of other fishes, so competition probably occurs (Sections 5.3 and 5.4). In inland waters, white perch frequently produce large populations, which compete with more desirable species (Scott and Crossman 1973:688-689; Watson 1965:13); the intense intraspecific competition within these large populations results in slow growth and the production of individuals too small to be of fishing value. Reduced growth rates with increasing density have been reported from the Patuxent (Mansueti 1961b:190) ~~(Mansueti 1961:190)~~ and Connecticut Rivers (Marcy 1976a:71-72), but there is no evidence of density-dependent growth in the Hudson River (TI 1975e:VIII-12). Young white perch are occasionally utilized as forage by predators but appear not to be widely utilized in the presence of alternate prey (Scott and Crossman 1973:688; Watson 1965:13).

White perch are sometimes used as a food fish. Preliminary 1975 landing records indicate that 1,283,000 lb of white perch valued at $264,000 were landed along the Atlantic coast (Table 5.5-1); since 1965, total landings have ranged from 3,112,000 lb (1969) to 1,283,000 lb (1975). During that period, the Chesapeake district contributed from 54 to 79% of the total. In 1975, the Middle Atlantic district reported 207,000 lb ($50,000); New York contributed 83,000 lb, of which only 700 lb ($100) came from the Hudson River (Table 5.5-1). Since 1965, Hudson River landings have ranged from no reported landings (1972) to 3,600 lb (1965). The white perch ranked 17th in value among commercial finfishes landed in the Middle Atlantic district in 1973 (Table 5.4-2).

Table 5.5-1 Commercial Landings (Thousands of Pounds) and Value to Fishermen (Thousands of Dollars) of White Perch Reported along Atlantic Coast since 1965

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River †											
Pounds	3.6	1.1	1.5	1.7	2.6	1.4	0.2	0.0	0.8	0.8	0.7
Dollars	0.5	0.1	0.2	0.3	0.6	0.4	0.1	0.0	0.1	0.2	0.1
New York ‡											
Pounds	37	61	82	88	67	166	107	55	103	136	83
Dollars	6	9	14	18	14	31	16	14	27	31	20
Mid-Atlantic ‡											
Pounds	156	256	223	262	166	259	212	179	268	256	207
Dollars	23	40	38	50	30	48	38	40	66	58	50
New England ‡											
Pounds	46	28	12	13	35	50	64	81	91	88	38
Dollars	7	3	2	2	6	10	13	22	27	27	11
Chesapeake ‡											
Pounds	1,759	2,389	1,692	2,196	2,704	1,925	1,969	1,420	1,014	673	789
Dollars	220	246	225	292	427	303	303	248	214	128	151
So. Atlantic ‡											
Pounds	261	402	384	299	207	211	367	202	145	309	289
Dollars	27	24	46	31	24	30	45	27	22	57	52
TOTAL											
Pounds	2,222	3,075	2,311	2,770	3,112	2,445	2,612	1,882	1,518	1,326	1,283
Dollars	277	313	311	375	487	391	399	337	329	270	264

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries
** From USNOAA, 1976; Current Fisheries Statistics

† Provided by Fred Blossum (NMFS)
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States

The white perch varies from an important sport fish to a nuisance in various portions of its range (Scott and Crossman 1973:688; Watson 1965:13; Marcy 1976a:102-113). Deuel (1973:18), in a 1970 saltwater angling survey, estimated that 5,000 anglers caught 32,000 lb of white perch in the North Atlantic sport fishery district, which includes New York and New England (Table 5.4-3) ~~(Table 5.4-2)~~. A much greater catch (12,592,000 lb) was estimated for the Middle Atlantic district, which includes Chesapeake Bay. However, the survey technique upon which these estimates were based was biased and may have resulted in a twofold to threefold exaggeration (Deuel 1973:34); they must be viewed accordingly. Catch statistics specific to the Hudson River or New York State are not available.

5.5.2 AMERICAN SHAD. The anadromous American shad is a component of both estuarine and marine communities. Juvenile shad share, in part, a position in the food web with numerous other fishes that consume zooplankton within the Hudson River estuary (Section 5.3). The intensity of competition in the Hudson River is uncertain, although Marcy (1976b: 153) indicated that juvenile shad in the lower Connecticut River grew more slowly than those in the upper river, partly in response to competition with juvenile alewives and blueback herring; in addition, growth of shad was reduced in the Connecticut river in years of high juvenile density (Marcy 1976b:154-155). Young shad serve as forage for bluefish and other predators within the estuary; older shad presumably compete with other plankton-eating fishes in marine waters but apparently are subject to few predators (Section 5.3).

The American shad is a highly desirable food fish and contributes heavily to the Atlantic coast commercial fishery. However, annual landings fluctuate widely and currently are far below the approximately 45,000,000 lb typically landed near the turn of the century (Saila and Pratt 1971: 6-82). In 1975, a total of 2,567,000 lb of shad valued at $853,000 was reported along the Atlantic coast (Table 5.5-2). During 1965-1975, the Chesapeake district annually produced > 50% of the total catch; the 1973

Table 5.5-2 Commercial Landings (Thousands of Pounds) and Value to Fishermen (Thousands of Dollars) of American Shad Reported along Atlantic Coast since 1965

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River †											
Pounds	238	116	176	254	243	232	171	289	252	232	233
Dollars	36	15	29	46	32	33	33	58	83	63	93
New York ‡											
Pounds	133	81	113	126	136	106	73	103	157	164	197
Dollars	22	11	18	22	20	13	16	19	51	42	79
Mid-Atlantic ‡											
Pounds	635	379	387	379	342	314	222	375	308	293	338
Dollars	78	42	54	59	44	41	43	54	79	69	111
New England ‡											
Pounds	380	279	754	218	201	186	283	264	261	258	206
Dollars	76	54	52	62	59	55	68	76	73	78	62
Chesapeake ‡											
Pounds	4,298	3,564	3,005	3,508	3,540	5,134	2,473	3,014	3,033	1,790	1,318
Dollars	457	351	311	267	291	421	259	343	471	276	352
So. Atlantic ‡											
Pounds	2,379	1,736	1,562	2,052	1,904	1,851	1,452	1,091	685	817	705
Dollars	484	371	283	384	439	415	340	296	215	267	328
TOTAL											
Pounds	7,692	5,958	5,708	6,157	5,987	7,485	4,430	4,744	4,287	3,158	2,567
Dollars	1,095	818	700	772	833	932	710	769	838	690	853

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries
** From USNOAA, 1976; Current Fisheries Statistics

† Provided by Fred Blossum (NMFS)
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States

Chesapeake catch represented nearly 71% of that year's total. The Middle Atlantic district produced < 10% of the total Atlantic coast catch during 1965-74. In 1975, the Middle Atlantic catch represented approximately 13% of the total Atlantic coast catch because of the greatly decreased catch in the Chesapeake district.

The Hudson River was once among the most important contributors to the shad fishery, with annual landings in the late 1800s and early 1900s averaging several million pounds. Between 1904 and 1931, the catch averaged only several hundred thousand pounds but increased to nearly 4,000,000 lb in 1944 (Medeiros 1974:2). Overfishing during and immediately after World War II contributed to the decline occurring during the late 1940s. Since 1965, the catch has not exceeded 300,000 lb; the 1975 catch of 233,000 lb was valued at $93,000. Present demand for shad from the Hudson River is reduced because of the availability of an increased variety of fish products, an influx of shad to the northeastern markets from more southerly rivers where runs occur earlier, and the reputation of Hudson River fish for pollution-related off-tastes. Consequently, fishing effort has been reduced; the number of fishermen holding special shad licenses declined from 349 in 1958 to 40 in 1973; virtually all present license-holders are part-time fishermen (Medeiros 1974:29-33).

The American shad is the object of an intensive sport fishery in some rivers along the Atlantic coast. Deuel (1973:18) estimated that 69,000 fishermen along the Atlantic coast caught 4,856,000 lb of shad in 1970; > 87% of these came from the Middle Atlantic sport fishery district south of the Hudson River, which includes Chesapeake Bay; only 625,000 lb came from the North Atlantic district (Table 5.4-3). Both estimates are probably greater than actual catches (Section 5.4). There are no records of sport catches from the Hudson River, but Medeiros (1974:36) suggested that exploitation was well below its potential due, in part, to the offshore migratory pathway of shad in the Hudson River, which makes them inaccessible to most fishermen and in part to the fact that there is little concentration of the fish at any point along their route.

American shad were excluded from the PCB-related restrictions imposed during 1976 on the catch and sale of Hudson River fish. However continued monitoring has revealed PCB levels in excess of the 5 ppm maximum in 25% of the shad examined through July 1976 (NYDEC, personal communication). Because of the adverse publicity, the price paid to fishermen for Hudson River shad declined sharply in 1976 (NYDEC, personal communication).

5.5.3 ATLANTIC TOMCOD. Information on the role of juvenile Atlantic tomcod in the estuarine community of the Hudson River is limited. Presumably, postspawning adults leave the estuary. Both adults and juveniles consume a variety of prey (Section 5.3) including eggs of striped bass, white perch, shad, and herring; however, the impact on these prey populations is unknown. Competition with striped bass, white perch, and American shad juveniles is likely. The importance of tomcod as food for other predators is unknown, although Boyle (1969:219) reported their presence in the stomachs of overwintering striped bass and they comprised over 12% of the identifiable fish remains in bluefish stomachs (TI 1976a:II-7).

The Atlantic tomcod is the object of both sport and commercial fishing effort wherever it is abundant, but the extent of the fishery is poorly documented (Scott and Crossman 1973:649). Tomcod are more extensively utilized in eastern Canada than in the United States. Tomcod are not recognized separately in commercial landings records; rather, they are included with other species as "unclassified food fish." The last year for which information was available for the Hudson River was 1965, when 2,000 lb were marketed (Fred Blossum, NMFS, personal communication). Prices paid to Hudson River fishermen for tomcod have declined and fishing effort has consequently dwindled (Fred Blossum, NMFS, personal communication). No records of sport fishery landings of tomcod exist for the Hudson River.

5.5.4 BLUEBACK HERRING. Juvenile blueback herring within the Hudson River estuary probably compete with other species consuming zooplankton. Marcy (1976b:152-153) suggested that competition from blueback herring and alewives reduced the growth of juvenile American shad in the Connecticut River. Saila and Pratt (1971:6-73) indicated that young herring are important forage for coastal and estuarine predators. Bluebacks in the Hudson River estuary are eaten by bluefish (TI 1976a:II-7) and by striped bass (TI 1974a:IV-44), and clupeid eggs are important in the diet of white perch (TI 1976f: V-40).

The quantity of blueback herring marketed is unknown because they are included with alewives in commercial fishery statistics. Because of their boniness and small size, they are used primarily for industrial purposes, although some are pickled or smoked. The 1975 landings of alewives and blueback herring along the Atlantic coast totaled 23,522,000 lb valued at $807,000 (Table 5.5-3), with most (77%) reported from south of New Jersey and only 11,000 lb ($500) landed in the Middle Atlantic district. Landings in the Middle Atlantic region have not exceeded 30,000 lb since 1966 when purse seiners took 4,200,000 lb, seeking substitutes for declining menhaden stocks. Even that catch was insufficient to support processing plants in New York, and the industrial fishery there is now virtually nonexistent (McHugh 1972:588-589).

5.5.5 SHORTNOSE STURGEON. This species, unlike the Atlantic sturgeon, probably spends its life within the confines of the estuary. Adapted for bottom feeding, the shortnose sturgeon is assumed to compete with other bottom-feeding species such as suckers and the Atlantic sturgeon (Scott and Crossman 1973:82). Nothing is known of predation on the shortnose sturgeon.

While the flesh is considered good and the eggs desirable for caviar, shortnose sturgeon are rare and not currently exploited either commercially or for sport although some may be marketed inadvertently with

Table 5.5-3 Commercial Landings (Thousands of Pounds) and Value to Fishermen (Thousand of Dollars) of Blueback Herring and Alewife Reported along Atlantic Coast since 1965

Region	1965	1966	1967	1968	1969	1970	1971	1972	1973*	1974**	1975**
Hudson River†											
Pounds											
Dollars	--	--	--	--	--	--	--	--	--	--	--
New York ‡											
Pounds	24	4,188	4	7	9	11	--	1.0	22	1.0	0.3
Dollars	<0.5	63	<0.5	<0.5	1	<0.5	--	<0.5	<0.5	<0.1	<0.1
Mid-Atlantic ‡											
Pounds	46	4,200	13	15	14	19	10	15	30	12	11
Dollars	2	63	<0.5	<0.5	1	1	<0.5	<0.5	<0.5	<0.5	<0.5
New England ‡											
Pounds	10,400	8,693	7,323	2,643	2,132	3,076	2,279	4,204	3,437	3,478	5,432
Dollars	129	119	114	51	50	63	54	83	106	121	156
Chesapeake ‡											
Pounds	38,292	29,968	30,444	36,282	33,904	21,110	13,096	12,141	11,300	14,730	12,055
Dollars	551	514	611	597	677	44	294	316	346	460	424
So. Atlantic ‡											
Pounds	15,607	15,336	21,288	18,345	21,737	11,621	13,440	11,534	8,359	6,331	6,024
Dollars	189	190	374	283	334	196	215	202	226	254	226
TOTAL											
Pounds	64,345	58,197	59,968	57,285	57,285	35,826	28,825	27,894	23,126	24,551	23,522
Dollars	871	886	1,099	931	1,062	304	563	601	678	836	807

* From USNOAA, 1975; Current Fisheries Statistics, District Summaries
** From USNOAA, 1976; Current Fisheries Statistics

† Not available
‡ From USNOAA, 1967-74; Fisheries Statistics of the United States

Atlantic sturgeon. In the 1800s this species was considered more desirable than the larger Atlantic sturgeon (Scott and Crossman 1973:82). In 1967, it was designated a rare and endangered species (32 Fed Reg 4001 [1967]). Extremely slow growth and late maturation are considered to be the major causes of the species' inability to withstand exploitation (Scott and Crossman 1973:82; Dovel 1976:12). Several sources suggest, however, that the shortnose sturgeon is more prevalent than its official designation might indicate (Scott and Crossman 1973:82; Dovel 1976:12).

5.6 STRUCTURE OF FISH COMMUNITY OF HUDSON RIVER ESTUARY

5.6.1 GENERAL FISH COMMUNITY STRUCTURE. The Hudson River estuary is a complex of physical, chemical, and biological habitats (Section 2); thus, the community structure is complex. A perusal of the list of fish species collected within the estuarine portion of the Hudson River (Table 5.6-1) reveals a greater diversity than one might expect for a single body of water. Marine species such as Atlantic menhaden and bluefish seemingly coexist with freshwater species such as bluegill and largemouth bass. Euryhaline species, (those tolerant of changing salinities) and anadromous species, which mature in saltwater but return to freshwater to spawn, are also predominant members of the community. A diverse, productive fish community is not uncommon for estuaries, adding much to the value of estuaries both ecologically and economically. For a better understanding of the relationship between the diversity of the fish community and its environment, the physical and chemical properties of the estuary will be briefly reviewed with respect to habitat for fishes.

The Hudson River from the Battery at its mouth to the federal dam at Troy (i.e., the estuarine portion) can be divided into at least three major areas based on river width and depth ~~(Curran and Ries 1938)~~ (Curran and Ries 1937). The uppermost area above Kingston (RM 93: km 149) is frequently called the "Flats" because of its shallowness; mean depths are usually < 33 ft (10 m)(TI 1975c:III-12). This area is tidal and freshwater. Below

Table 5.6-1 Fish Species Caught during Surveys of Hudson River Estuary, 1936 and 1965-75

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Petromyzontidae	*Petromyzon marinus*	Sea lamprey	Oc	E	?	R
Rajidae	*Raja laevis*	Barndoor skate	Oc	M	0	R
Acipenseridae	*Acipenser brevirostrum*	Shortnose sturgeon	Y	E	Sp	R
	Acipenser oxyrhynchus	Atlantic sturgeon	A	E	Sp	U
Anguillidae	*Anguilla rostrata*	American eel	C	E	0	A
Clupeidae	*Alosa aestivalis*	Blueback herring	A	E	Sp	A
	Alosa pseudoharengus	Alewife	A	E	Sp	A
	Alosa mediocris	Hickory shad	Oc	E	?	R
	Alosa sapidissima	American shad	A	E	Sp	A
	Brevoortia tyrannus	Atlantic menhaden	S	M	0	C
	Clupea harengus	Atlantic herring	Oc	M	0	R
	Dorosoma cepedianum	Gizzard shad	Oc	E	?	U
	Etrumeus teres	Round herring	Oc	E	?	R
Engraulidae	*Anchoa mitchilli*	Bay anchovy	Y	E	Sp-S	A
	Anchoa hepsetus	Striped anchovy	Oc	M	0	R
Salmonidae	*Salmo trutta*	Brown trout	Oc	F	0	R
	Salvelinus fontinalis	Brook trout	Oc	F	0	R
Osmeridae	*Osmerus mordax*	Rainbow smelt	A	E	Sp	A
Umbridae	*Umbra limi*	Central Mudminnow	Oc	F	0	R
	Umbra pygmaea	Eastern mudminnow	Oc	F	0	R
Esocidae	*Esox americanus*	Redfin pickerel	Y	F	W-Sp	U
	Esox lucius	Northern pike	Oc	F	?	R
	Esox niger	Chain pickerel	Y	F	W-Sp	U
Synodontidae	*Synodus foetens*	Inshore lizardfish	Oc	M	0	R

Table 5.6-1 (Page 2 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning †	Abundance ‡
Cyprinidae	*Carassius auratus*	Goldfish	Y	F	Sp	A
	Cyprinus carpio	Carp	Y	F	Sp-s	C
	Exoglossum maxillingua	Cutlips minnow	Oc	F	?	R
	Hybognathus nuchalis	Silvery minnow	Y	F	Sp	C
	Notemigonus crysoleucas	Golden Shiner	Y	F	Sp-s	A
	Notropis amoenus	Comely shiner	Oc	F	?	R
	Notropis analostanus	Satinfin shiner	Y	F	Sp-s	R
	Notropis atherinoides	Emerald shiner	Y	F	Sp-s	A
	Notropis bifrenatus	Bridle shiner	Oc	F	?	R
	Notropis cornutus	Common shiner	Y	F	Sp-S	R
	Notropis hudsonius	Spottail shiner	Y	F	Sp-s	A
	Notropis rubellus	Rosyface shiner	Oc	F	?	R
	Notropis spilopterus	Spotfin shiner	Oc	F	?	R
	Notropis volucellus‡	Mimic shiner	Oc	F	?	R
	Pimephales promelas	Fathead minnow	Oc	F	?	R
	Pimpehales notatus	Bluntnose minnow	Oc	F	?	R
	Rhinichthys atratulus	Blacknose dace	Oc	F	?	R
	Rhinichthys cataractae	Longnose dace	Oc	F	?	R
	Semotilus atromaculatus	Creek chub	Oc	F	?	R
	Semotilus corporalis	Fallfish	Oc	F	?	R
Catostomidae	*Catostomus commersoni*	White sucker	Y	F	Sp	C
	Erimyzon oblongus‡	Creek chubsucker	Oc	F	?	R
	Hypentelium nigricans	Northern hogsucker	Oc	F	?	R
Ictaluridae	*Ictalurus catus*	White catfish	Y	E	Sp	A
	Ictalurus natalis	Yellow bullhead	Oc	F	?	R
	Ictalurus nebulosus	Brown bullhead	Y	F	Sp-s	C
Percopsidae	*Percopsis omiscomaycus*	Trout-perch	Oc	F	?	R
Gadidae	*Enchelyopus cimbrius*	Fourbeard rockling	Oc	M	O	R
	Merluccius bilinearis	Silver hake	Oc	M	O	R
	Microgadus tomcod	Atlantic tomcod	Y-A	M-E	W	A
	Pollachius virens	Pollock	Oc	M	O	R
	Urophycis chuss	Red hake	Oc	M	O	R
	Urophycis regius	Spotted hake	Oc	M	O	R

Table 5.6-1 (Page 2 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning+	Abundance‡
Cyprinidae	*Carassius auratus*	Goldfish	Y	F	Sp	A
	Cyprinus carpio	Carp	Y	F	Sp-s	C
	Exoglossum maxillingua	Cutlips minnow	0c	F	?	R
	Hybognathus nuchalis	Silvery minnow	Y	F	Sp	C
	Notemigonus crysoleucas	Golden Shiner	Y	F	Sp-s	A
	Notropis amoenus	Comely shiner	0c	F	?	R
	Notropis analostanus	Satinfin shiner	Y	F	Sp-s	R
	Notropis atherinoides	Emerald shiner	Y	F	Sp-s	A
	Notropis bifrenatus	Bridle shiner	0c	F	?	R
	Notropis cornutus	Common shiner	Y	F	Sp-S	R
	Notropis hudsonius	Spottail shiner	Y	F	Sp-s	A
	Notropis rubellus	Rosyface shiner	0c	F	?	R
	Notropis spilopterus	Spotfin shiner	0c	F	?	R
	Notropis volucellus‡	Mimic shiner	0c	F	?	R
	Pimephales promelas	Fathead minnow	0c	F	?	R
	Pimpehales notatus	Bluntnose minnow	0c	F	?	R
	Rhinichthys atratulus	Blacknose dace	0c	F	?	R
	Rhinichthys cataractae	Longnose dace	0c	F	?	R
	Semotilus atromaculatus	Creek chub	0c	F	?	R
	Semotilus corporalis	Fallfish	0c	F	?	R
Catostomidae	*Catostomus commersoni*	White sucker	Y	F	Sp	C
	Erimyzon oblongus‡	Creek chubsucker	0c	F	?	R
	Hypentelium nigricans	Northern hogsucker	0c	F	?	R
Ictaluridae	*Ictalurus catus*	White catfish	Y	E	Sp	A
	Ictalurus natalis	Yellow bullhead	0c	F	?	R
	Ictalurus nebulosus	Brown bullhead	Y	F	Sp-s	C
	Ictalurus punctatus	**Channel catfish**	**0c**	**F**	**0**	**R**
Percopsidae	*Percopsis omiscomaycus*	Trout-perch	0c	F	?	R
Gadidae	*Enchelyopus cimbrius*	Fourbeard rockling	0c	M	0	R
	Merluccius bilinearis	Silver hake	0c	M	0	R
	Microgadus tomcod	Atlantic tomcod	Y-A	M-E	W	A
	Pollachius virens	Pollock	0c	M	0	R
	Urophycis chuss	Red hake	0c	M	0	R
	Urophycis regius	Spotted hake	0c	M	0	R

Table 5.6-1 (Page 3 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning‡	Abundance‡
Ophidiidae	*Rissola marginata*	Striped cusk-eel	Oc	M	O	R
Belonidae	*Stongylura marina*	Atlantic needlefish	Y	M	O	U
Cyprinodontidae	*Fundulus diaphanus*	Banded killifish	Y	E	Sp-s	A
	Fundulus heteroclitus	Mummichog	Y	E	Sp-s	A
	~~*Fundulus luciae*~~	~~Spotfin killifish~~	~~Oc~~	~~M~~	~~?~~	~~R~~
	Fundulus majalis	Striped killifish	Oc	M	?	R
Atherinidae	*Membras martinica*	Rough silverside	Oc	M	?	R
	Menidia beryllina	Tidewater silverside	Y	E	Sp-s	C
	Menidia menidia	Atlantic silverside	Y	M	Sp-s	C
Gasterosteidae	*Apeltes quadracus*	Fourspine stickleback	Y	E	Sp-s	C
	Culaea inconstans	Brook stickleback	Oc	F	?	R
	Gasterosteus aculeatus	Threespine stickleback	Oc	E	?	R
Syngnathidae	*Hippocampus erectus*	Lined seahorse	Oc	M	?	R
	Syngnathus fuscus	Northern pipefish	Y	M	?	U
Percichthyidae	*Morone americana*	White perch	Y-A	E	S	A
	Morone chrysops	White bass	Oc	F	?	R
	Morone saxatilis	Striped bass	A	E	S	A
Centrarchidae	*Ambloplites rupestris* ‡	Rock bass	Y	F	S	U
	Enneacanthus gloriosus ‡	Blue-spotted sunfish	Oc	F	?	R
	Lepomis auritus	Redbreast sunfish	Y	F	S	A
	Lepomis cyanellus ‡	Green sunfish	Oc	F	?	R
	Lepomis gibbosus	Pumpkinseed	Y	F	S	A
	Lepomis macrochirus	Bluegill	Y	F	S	A
	Micropterus dolomieui	Smallmouth bass	Y	F	S	U
	Micropterus salmoides	Largemouth bass	Y	F	S	C
	Pomoxis annularis	White crappie	Oc	F	?	R
	Pomoxis nigromaculatus	Black crappie	Y	F	S	U
	Lepomis gulosus	Warmouth	Oc	F	?	R
Percidae	*Etheostoma olmstedi*	Tessellated darter	Y	F	Sp	A
	Perca flavescens	Yellow perch	Y	F	Sp	C
	Percina caprodes	Logperch	Oc	F	O	R
	Percina peltata ‡	Shield darter	Oc	F	?	R
	Stizostedion vitreum	Walleye	Oc	F	O	R

Table 5.6-1 (Page 3 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Belonidae	*Stongylura marina*	Atlantic needlefish	Y	M	O	U
Cyprinodontidae	*Fundulus diaphanus*	Banded killifish	Y	E	Sp-s	A
	Fundulus heteroclitus	Mummichog	Y	E	Sp-s	A
	Fundulus luciae	Spotfin killifish	Oc	M	?	R
	Fundulus majalis	Striped killifish	Oc	M	?	R
Atherinidae	*Membras martinica*	Rough silverside	Oc	M	?	R
	Menidia beryllina	Tidewater silverside	Y	E	Sp-s	C
	Menidia menidia	Atlantic silverside	Y	M	Sp-s	C
Gasterosteidae	*Apeltes quadracus*	Fourspine stickleback	Y	E	Sp-s	C
	Culaea inconstans	Brook stickleback	Oc	F	?	R
	Gasterosteus aculeatus	Threespine stickleback	Oc	E	?	R
Syngnathidae	*Hippocampus erectus*	Lined seahorse	Oc	M	?	R
	Syngnathus fuscus	Northern pipefish	Y	M	?	U
Percichthyidae	*Morone americana*	White perch	Y-A	E	S	A
	Morone chrysops	White bass	Oc	F	?	R
	Morone saxatilis	Striped bass	A	E	S	A
Centrarchidae	*Ambloplites rupestris* ‡	Rock bass	Y	F	S	U
	Enneacanthus gloriosus‡	Blue-spotted sunfish	Oc	F	?	R
	Lepomis auritus	Redbreast sunfish	Y	F	S	A
	Lepomis cyanellus ‡	Green sunfish	Oc	F	?	R
	Lepomis gibbosus	Pumpkinseed	Y	F	S	A
	Lepomis macrochirus	Bluegill	Y	F	S	A
	Micropterus dolomieui	Smallmouth bass	Y	F	S	U
	Micropterus salmoides	Largemouth bass	Y	F	S	C
	Pomoxis annularis	White crappie	Oc	F	?	R
	Pomoxis nigromaculatus	Black crappie	Y	F	S	U
Percidae	*Etheostoma olmstedi*	Tessellated darter	Y	F	Sp	A
	Perca flavescens	Yellow perch	Y	F	Sp	C
	Percina caprodes	Logperch	Oc	F	O	R
	Percina peltata ‡	Shield darter	Oc	F	?	R

Table 5.6-1 (Page 4 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning†	Abundance‡
Pomatomidae	*Pomatomus saltatrix*	Bluefish	S	M	O	A
Carangidae	*Caranx hippos*	Crevalle jack	S	M	O	U
	Selene vomer	Lookdown	Oc	M	O	R
	Vomer setapinnis	Atlantic moonfish	Oc	M	O	R
Sparidae	*Stenotomus chrysops*	Scup	Oc	M	O	R
Sciaenidae	*Bairdiella chrysura*	Silver perch	Oc	M	O	R
	Cynoscion regalis	Weakfish	S	M	O	C
	Leiostomus xanthurus	Spot	S	M	O	R
	Menticirrhus saxatilis	Northern kingfish	Oc	M	O	R
	Micropogon undulatus	Atlantic croaker	Oc	M	O	R
Labridae	*Tautoga onitis*	Tautog	Oc	M	O	R
Mugilidae	*Mugil cephalus*	Striped mullet	Oc	M	O	R
	Mugil curema	White mullet	Oc	M	O	R
Uranoscopidae	*Astroscopus guttatus*	Northern stargazer	Oc	M	O	R
Ammodytidae	*Ammodytes americanus*	American sandlance	Oc	M	O	R
Eleotridae	*Dormitator maculatus*	Fat sleeper	Oc	M	O	R
Gobiidae	*Gobiosoma ginsburgi*	Seaboard Goby	Oc	M	O	R
Stromateidae	*Peprilus triacanthus*	Butterfish	Oc	M	O	R
Triglidae	*Prionotus carolinus*	Northern searobin	Oc	M	O	R
	Prionotus evolans	Striped searobin	Oc	M	O	R
Cottidae	*Myoxocephalus aeneus*	Grubby	Oc	M	O	R

Table 5.6-1 (Page 5 of 5)

Family	Scientific Name	Common Name	Residency*	Salinity Preference**	Spawning[†]	Abundance[‡]
Bothidae	*Paralichthys dentatus*	Summer flounder	Oc	M	O	R
	Paralichthys oblongus	Fourspot flounder	Oc	M	O	R
	Scophthalmus aquosus	Windowpane	Oc	M	O	R
Pleuronectidae	*Pseudopleuronectes americanus*	Winter flounder	Oc	M	O	R
Soleidae	*Trinectes maculatus*	Hogchoker	Y	E	S	A
Tetraodontidae	*Sphaeroides maculatus*	Northern puffer	Oc	M	O	R

* Y, year-round or life resident; A, anadromous; C, catadromous; S, seasonal use for nursery; Oc, occasional or infrequent occurrence

** F, freshwater; E, euryhaline or salt-change tolerant; M, marine

† Sp, Spring; S, Summer; F, Fall; W, Winter; O, outside estuarine portion of Hudson River; ?, uncertain spawning location

‡ A, abundant; C, common but less abundant; U, uncommon; R, rare

‡‡ Specimens not available for positive identification

Kingston (RM 85: km 138) to about Indian Point (RM 42; km 68), the depth increases as the river passes through the Highlands from Newburgh (RM 61; km 99) to Peekskill (RM 44; km 71); in this area, the maximum depth is approximately 174 ft (53 m), mean depths range from 16 to 79 ft (5 to 24 m), and salinity may vary greatly with the intrusion of the salt front during periods of low freshwater flow or low tidal mixing of salt and freshwaters layers. The third area, from Indian Point to the Battery, is shallow again, with mean depths of < 33 ft (10 m). The upper portion consists of the wide Croton and Haverstraw Bays (maximum width of 19,689 ft or 6 km), where the salt front is most frequently positioned. Below the Tappan Zee Bridge (RM 24; km 39), the depth increases gradually as the width decreases, and the salinity is greater and less variable.

The physical and chemical environment in the river's shore zone (depths of < 10 ft or 3 m) is further influenced by backwater coves and the confluence of freshwater tributaries, particularly from Newburgh to the Battery. The river morphometry and the addition of fresh water from tributaries prevent rapid salinity changes in many parts of the shore zone, and emergent and submergent vegetation provide ideal cover for many fish species. Thus, even in areas of salt intrusion, freshwater habitats are also available, allowing the apparent coexistence of marine and freshwater fish species.

Further discussion of fish communities in this section will employ an arbitrary division of shore zone communities (depths < 10 ft or 3 m) and shoal and channel zone communities (depths > 10 ft or 3 m). This division is based on the sampling gear used to collect fish species and conforms to depth strata presented in Sections 6 and 7 but unfortunately does not correspond to rigid ecological limitations for the fish since many individuals inhabit more than one depth stratum during a 24-h period. The seasonal distribution of fish species in the two zones will be discussed first. Next, probable species associations within zones during daylight will be discussed in an attempt to delineate communities within the zone. A hypothetical trophic structure will be given for a representative community of common species. Finally, the composition of fish species in the river through time will be investigated with reference to the persistence of these species and possible effects of power plant operation.

5.6.2 SEASONAL DISTRIBUTION. Analysis of fish community structure requires an understanding of the seasonal cycle of occurrence of fish species. The Hudson River estuary is an open ecosystem, with ingress and egress of fish species as a normal, seasonal phenomenon. Many species are year-long residents of the river, but anadromous species enter the river as adults to spawn, usually in the spring or early summer and, after spawning, return to the sea, leaving their offspring to occupy the river as a nursery area for the remainder of the year or longer. Striped bass, American shad, alewife, and blueback herring are anadromous species exhibiting this seasonal pattern. Other species (primarily marine such as bluefish and Atlantic menhaden) enter the river only briefly, either using the river as a nursery after being spawned outside or occurring infrequently in the lowermost portion of the river; such species are normally residents of the marine waters of Long Island Sound, the New York Bight, and adjoining bays. Finally, some of the freshwater species that are infrequently caught may only be strays from tributaries and not established within the river.

The number of species present during a season and the evenness with which individuals are distributed among these species are often interpreted as indicators of the health of an ecosystem. Numerical indices, called species diversity indices, have been devised as tools with which to compare one community with another. They are also used to detect changes in a community through time, as might be induced through man's activities (e.g., pollution or power plant operation). While diversity indices may have been overly developed and incorrectly applied in the past (Hurlbert 1971), they can be used effectively to summarize a large body of data if the sensitivity of the index to community changes is determined. Dahlberg and Odum (1970), after comparing four diversity indices for a Georgia estuary with seasonal cycles of fish abundance, concluded that indices reflecting species "richness" (number of species) were less affected by seasons than those reflecting species "equitability" (evenness of distribution of individuals among species). Therefore, the simplest of all indices, the number of species present (without regard to individual distribution), was chosen for spatial and temporal comparisons of the shore zone community in the Hudson River.

From April through December 1975, there were consistent temporal and spatial patterns in the abundance of species present in the shore zone of the Hudson River. The number of species increased through the spring months to a peak during July, then decreased through December. The shore zones of other estuaries (McErlean et al. 1973), as well as deeper zones (Dahlberg and Odum 1970, McErlean et al. 1973, Massman 1962), also have exhibited increases in numbers of species during summer months. Such an increase appears to be caused by movement into the shore zone from deeper water and movement into the estuary by seasonal and occasional fish species (Table 5.6-1). The seasonal disappearance and reappearance of otherwise common resident species can best be explained by a seasonal onshore-offshore movement by these species, many of which are found by deep-water sampling gear during their absence from the shore zone. Other species appear to occur only in summer and early autumn; these include marine and freshwater species. Occasional or seasonal marine species invade the lower estuary often to the position of the salt front, providing much of the increase in species number for the lower third of the river (Fig. 5.6-1). A large increase in freshwater species occurs in the uppermost, Albany region (above RM 125; km 200). Throughout the remainder of the river, the number of species increases during summer and early autumn as a result of onshore movement of resident species, occasional occurrence of rare or uncommon species, and a gradual upriver shift in the distribution of some marine or brackish-water species

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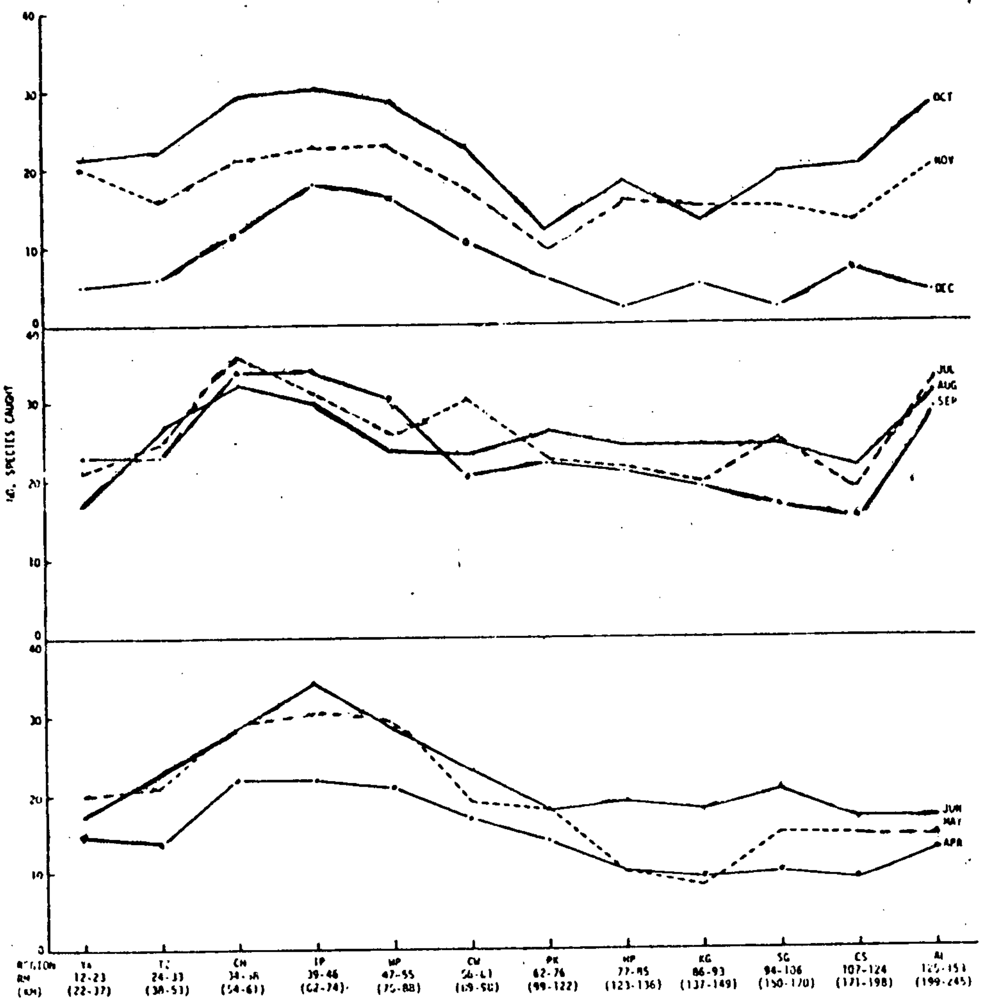


Figure 5.6-1 Number of Fish Species Caught by Beach Seines in 12 Geographical Regions of Hudson River Estuary, April-December 1975

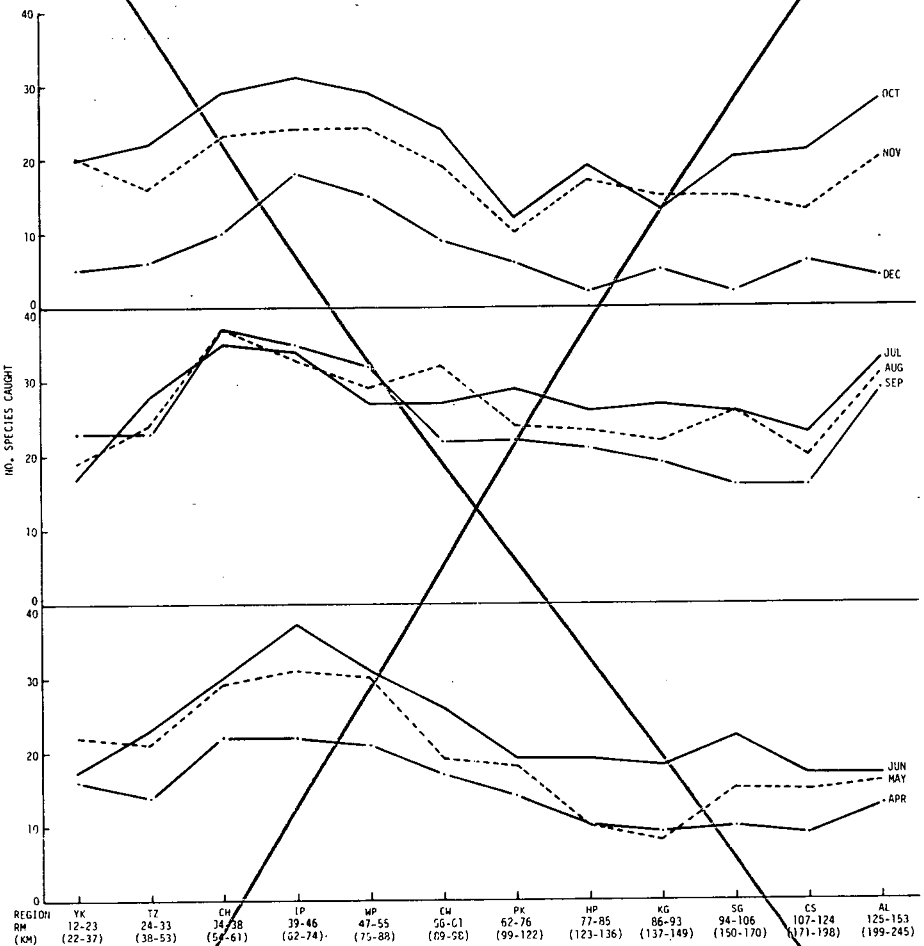


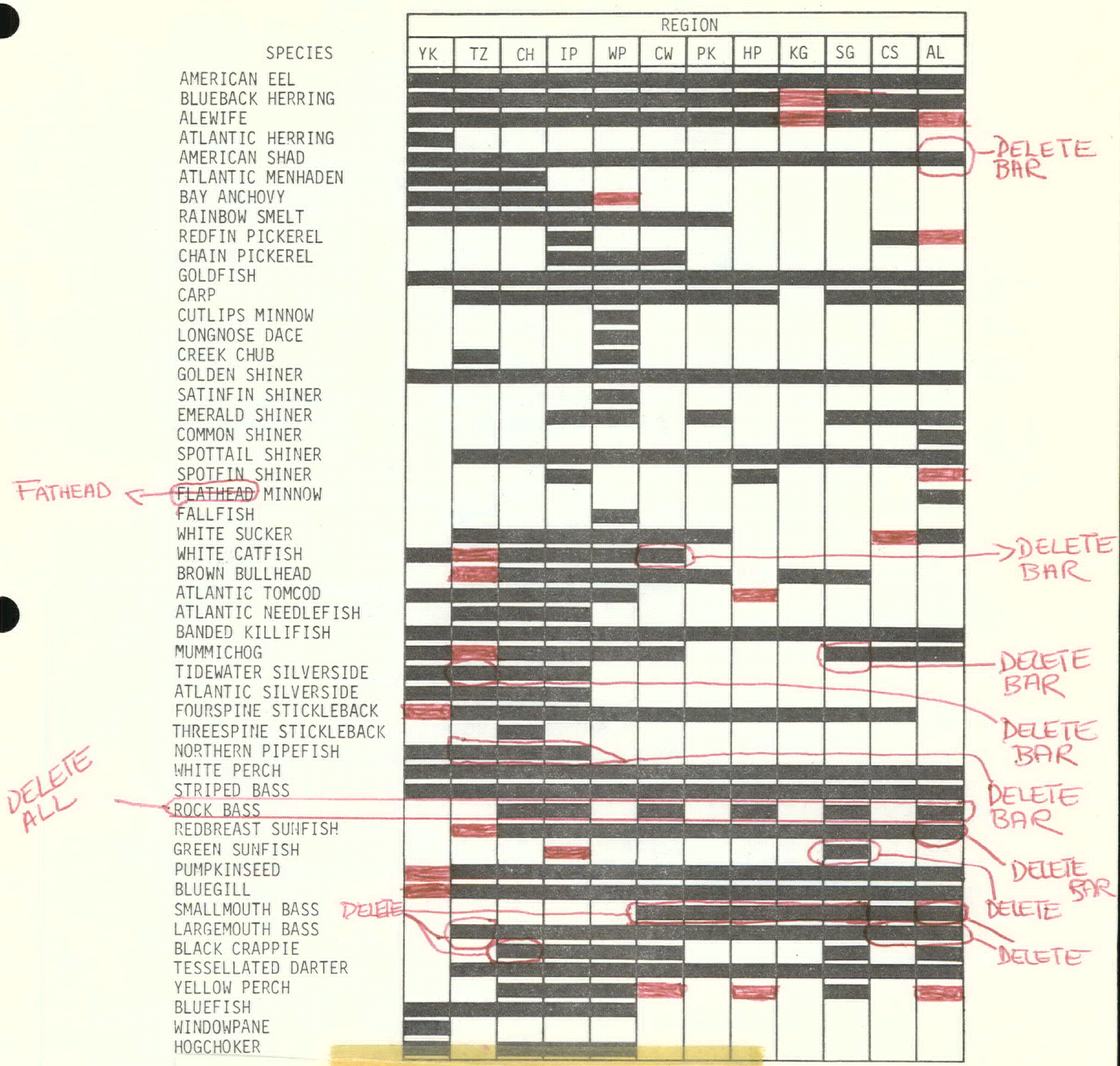
Figure 5.6-1 Number of Fish Species Caught by Beach Seines in 12 Geographical Regions of Hudson River Estuary, April-December 1975

(Figs. 5.6-2, 5.6-3) as the salt front advances upriver during periods of low freshwater discharge.

More species tend to be collected as sampling effort increases. This phenomenon may be partially responsible for the greater species numbers below the Poughkeepsie region, where more samples are collected, than in the upriver regions. However, many species have been caught in the Albany region (above RM 125; km 200) despite relatively light sampling. The seasonal consistency of species richness in the lower portion of the river indicates that the lower estuary, particularly from Haverstraw Bay (RM 34; km 54) to Cornwall (RM 56; km 89), has the most diverse fish community. This diversity occurs near the interface between the distributions of species preferring freshwater and those preferring brackish or salt water.

Four of the "important" fish species (striped bass, white perch, blueback herring, and American shad) described earlier (Sections 5.2 and 5.3) are ubiquitous in the Hudson River estuary and occur in the shore zone of nearly every region during April-December (Figs. 5.6-2, 5.6-3 and 5.6-4). The shortnose sturgeon and the Atlantic tomcod contrast sharply with this pattern: the former is rare everywhere in the estuary and infrequently enters the shore zone; the latter is abundant as young-of-the-year but is usually found in deeper water. The ubiquitous four species are part of a variety of more complex species assemblages throughout most of the year. Spatial and temporal distributions of all six species are presented in detail in Section 6.

Sampling in the channel and shoals with trawls and gill nets is less extensive than sampling in the shore zone; however, a seasonal pattern is evident for the channel and shoal zones. During 1975, species numbers increased from 20 in the spring (April-June) to 27 in the summer (July-September), then decreased to 24 in the autumn (October-December). Almost all the species were found also in the shore zone; a notable



Add Eastern Mudminnow in the species column and an occurrence bar in CW

Add Summer Flounder in the species column and an occurrence bar in YK

Add Brook Stickleback in the species column and an occurrence bar in IP

Add Winter Flounder in the species column and an occurrence bar in YK

Add Rough Silverside in the species column and occurrence bars in YK, TZ, CH, and IP

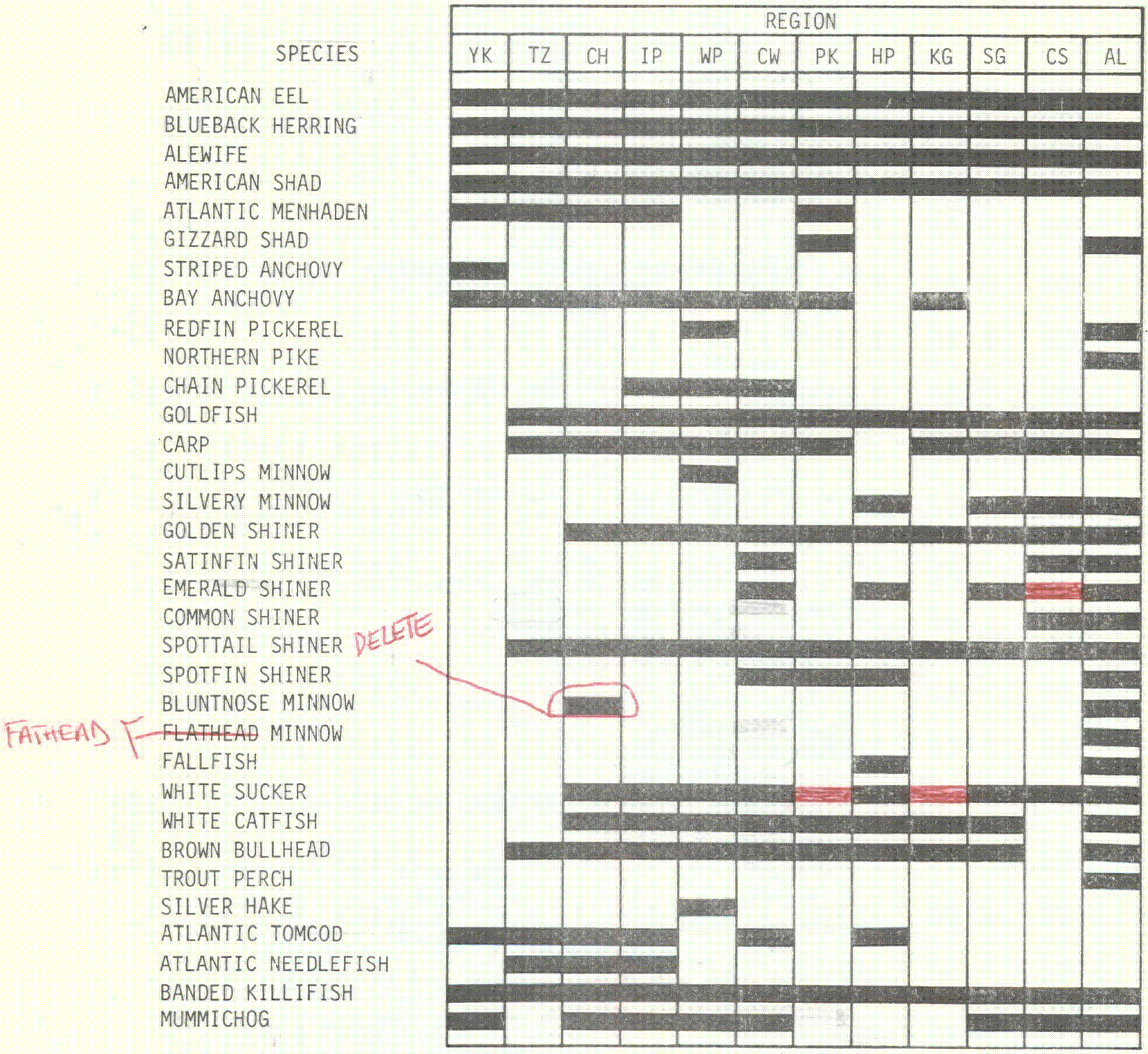


Figure 5.6-3 Distribution of Fish Species Caught by Beach Seines in Hudson River Estuary, July-September 1975. (Regions defined in Table 6.2-1)

Figure 5.6-3 (Contd)

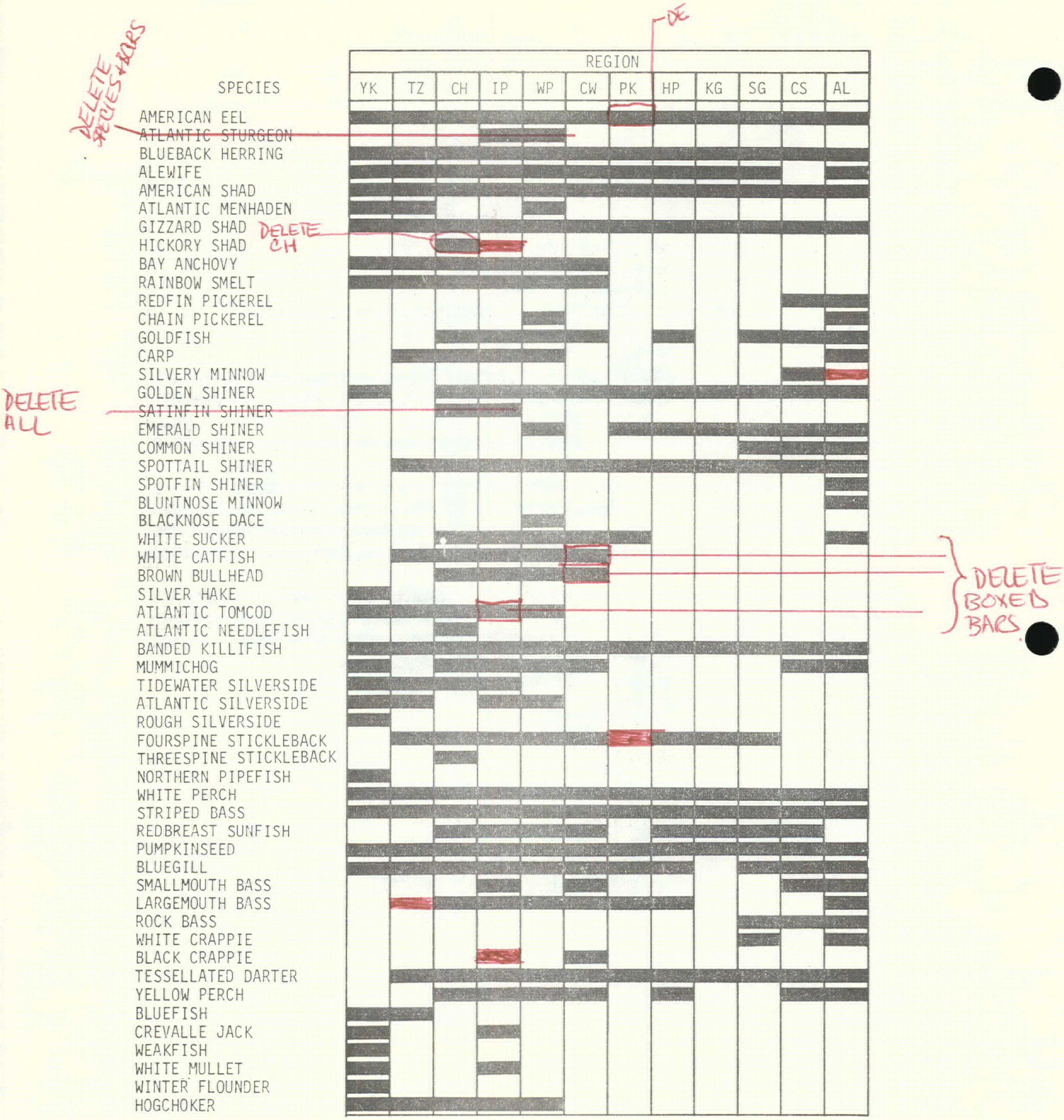


Figure 5.6-4 Distribution of Fish Species Caught by Beach Seines in Hudson River Estuary, October-December 1975 (Regions defined in Table 6.2-1)

exception being the shortnose sturgeon. Spatial patterns of species occurrence (Figs. 5.6-5, 5.6-6, and 5.6-7) are not as obvious as for the shore zone, probably because of the restricted sampling range (Newburgh to Tappan Zee) and more variable environment (particularly salinity) in the channel and shoals.

5.6.3 SPECIES AGGREGATIONS. The term "community" in this section has been loosely applied to the assemblage of all fish species occurring in the Hudson River estuary. The community concept is important in ecological theory and practice since it implies an interaction of each species with coexisting species. The elimination or sudden dominance of a species may cause changes in the populations of other species. Delimiting fish communities, however, has always been difficult, especially when sharp boundaries such as contrasting habitat types are not apparent. The following discussion examines the species composition of the 1975 catch for species associations that may define communities and describe possible interactions among these species.

The estuarine portion of the Hudson River includes many habitat types and may contain many communities. Depth, salinity, and temperature are obvious physical factors that may separate these communities. Fishes are typically very mobile organisms that can tolerate diverse environments. The euryhaline species for example, are little affected by changing salinity (Table 5.6-1) and are found over much of the river. Many species occur throughout the shore zone, shoals, and channels (Section 5.5.2). Habitat preferences and species associations continue to change as fish grow from larval to mature life stages. Thus delimiting functional communities of fishes in a system as large and diverse as the Hudson River is difficult. It is more realistic to speak of "species aggregations" than of "communities" under these circumstances. For simplicity, only the juvenile and adult life stages of common species of the shore zone will be considered.

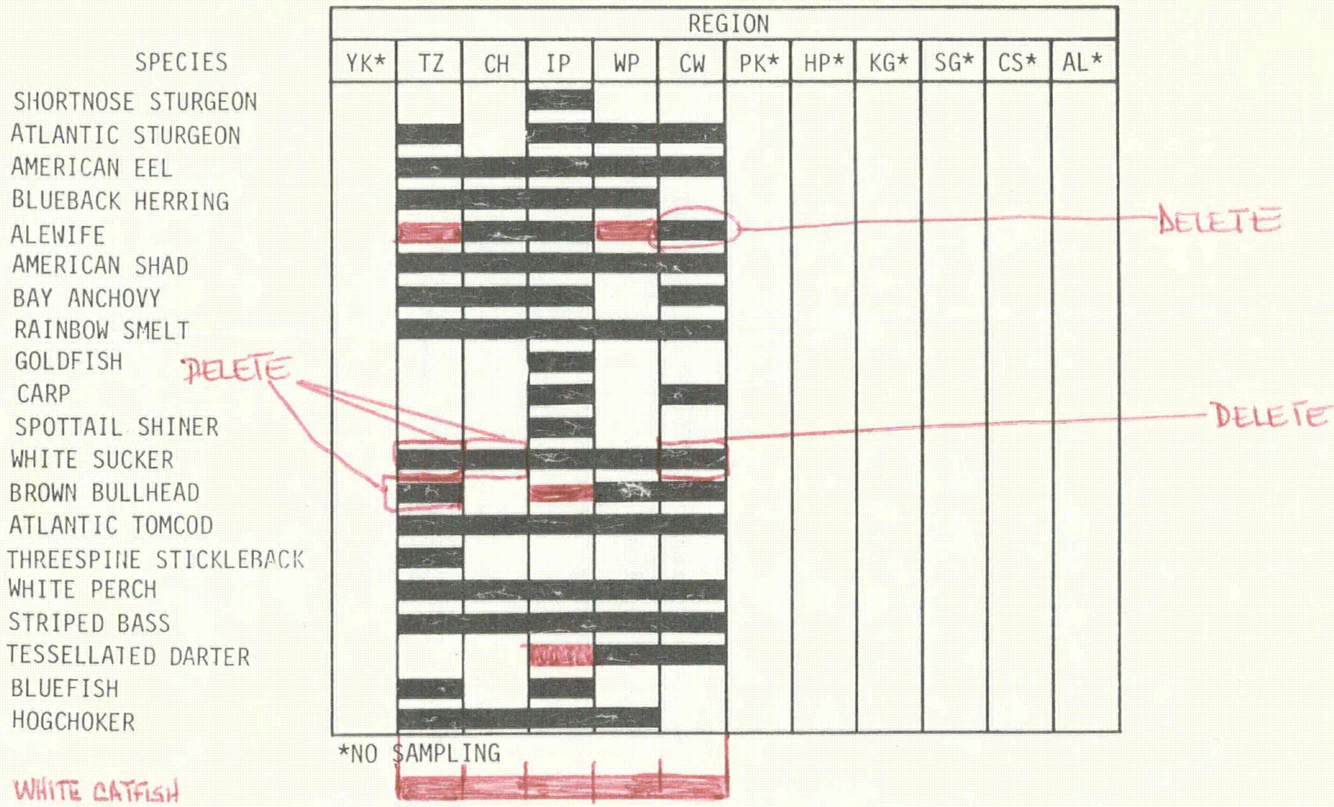


Figure 5.6-5 Distribution of Fish Species Caught by Bottom Trawls and Gill Nets in Hudson River Estuary, April-June 1975 (Regions defined in Table 6.2-1)

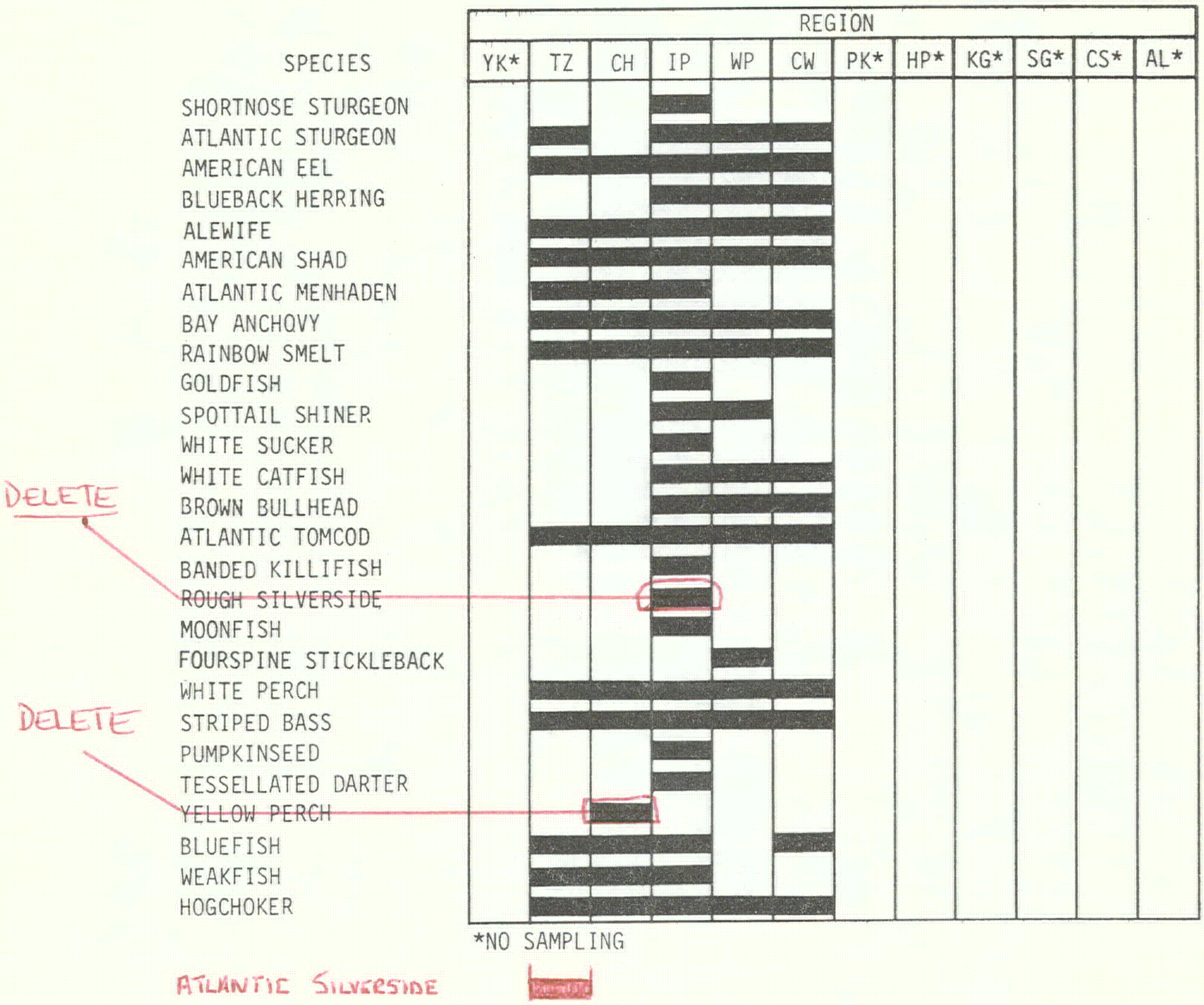


Figure 5.6-6 Distribution of Fish Species Caught by Bottom Trawls and Gill Nets in Hudson River Estuary, July-September 1975 (Regions defined in Table 6.2-1)

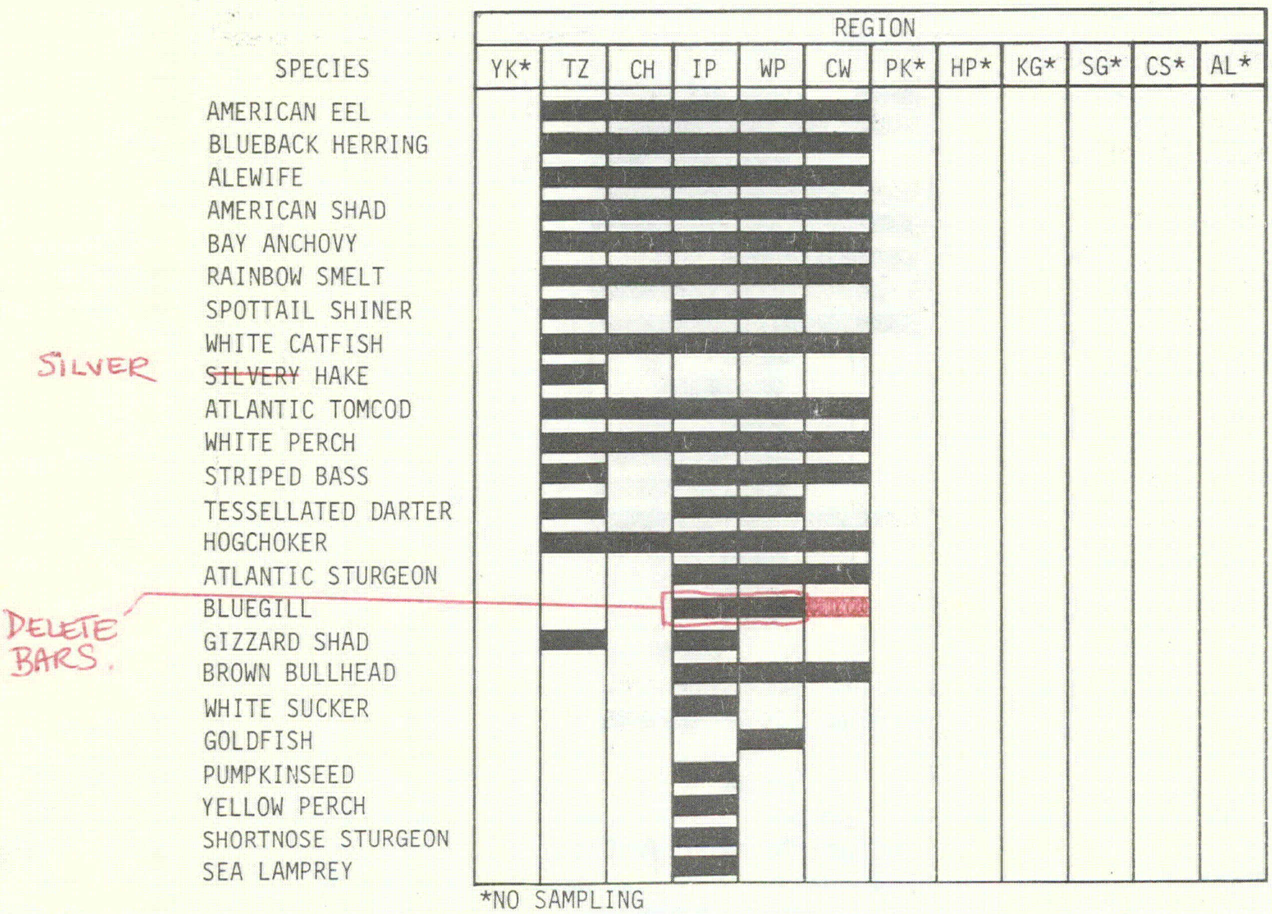


Figure 5.6-7 Distribution of Fish Species Caught by Bottom Trawls and Gill Nets in Hudson River Estuary, October-December 1975 (Regions defined in Table 6.2-1)

Species associations were investigated by cluster analysis using catch data from 100-ft (31-m) beach-seine sampling in the shore zone of the river from RM 12 to 152 (km 19 to 243) during 1975. Cluster analysis is an exploratory statistical technique used to discover structure in complex bodies of data. This technique groups data units or variables into "clusters" having a high degree of similarity or "association" among members within the cluster and little similarity among members of different clusters. Coefficients of association (Jaccard 1908) among all possible pairs of 29 common species were subjected to cluster analysis. The young-of-the-year of five species (striped bass, white perch, Atlantic tomcod, alewife, and blueback herring) were differentiated from older age groups because of suspected age-group differences in species associations and because of the importance of these species. Jaccard coefficients of association were computed from presence-absence data as follows:

$$S_{ij} = \frac{a}{a+b+c}$$

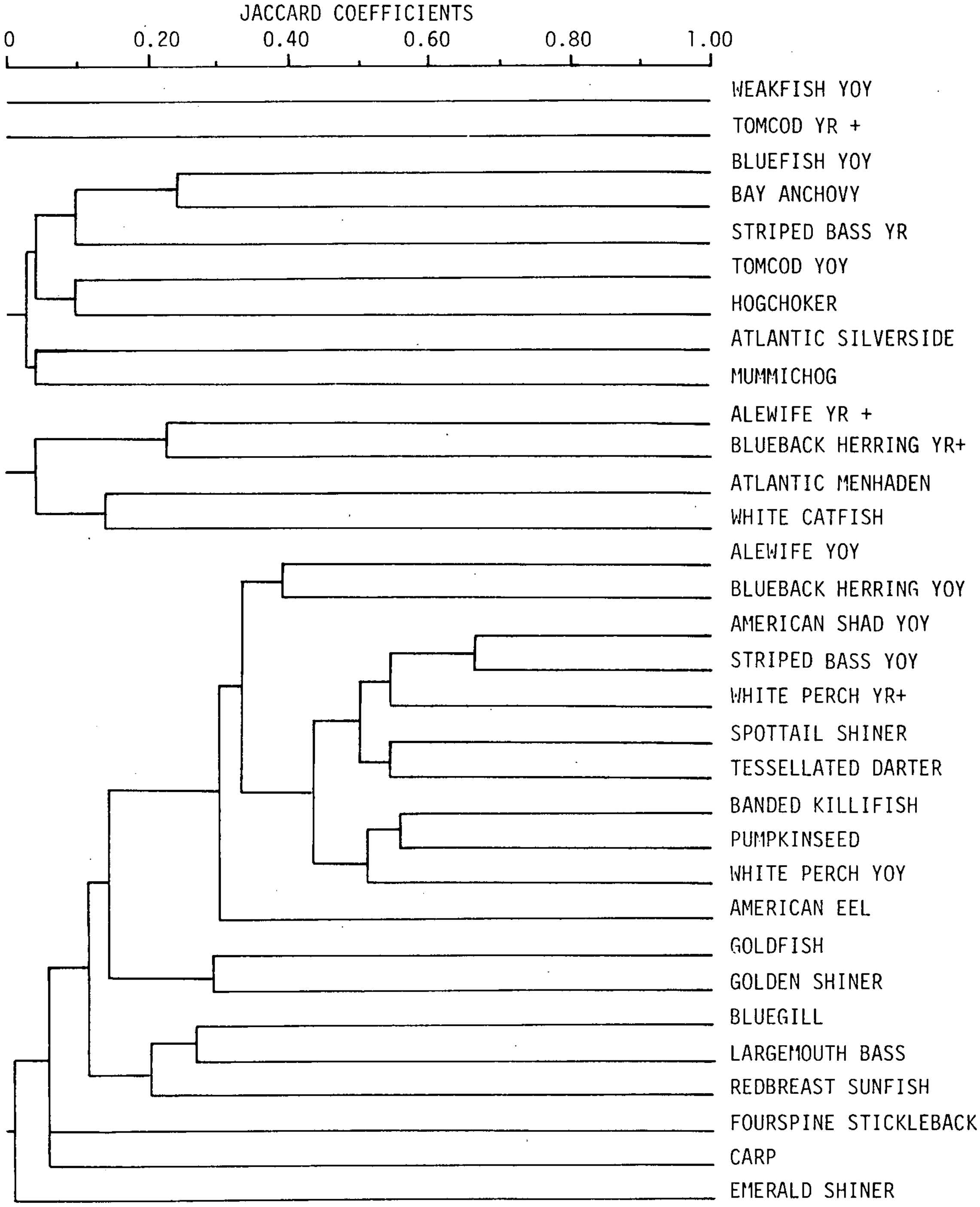
where

a = number of collections containing both species i and species j

b = number of collections containing species i but not species j

c = number of collections containing species j but not species i

Coefficients of association were clustered using complete linkage (Dixon 1975). To illustrate the hierarchical clustering of species, dendrograms were constructed (Fig. 5.6-8 and 5.6-9) plotting the clusters on a scale of 0 (no association) to 1.00 (perfect association). Cluster analysis has been performed frequently on presence-absence data in order to determine the effects of perturbations such as pollution on community structure at standard station sampling locations (Roback et al 1969, Hocutt et al 1974, Cairns and Kaesler 1969). The methodology presented here represents a modification that emphasizes associations among species rather than among sampling locations.



YOY = YOUNG-OF-THE-YEAR
YR = YEARLING
YR+ = YEARLING AND OLDER

Figure 5.6-8 Cluster Analysis of Associations among Fish Species Occurring during Daytime Sampling with 100-ft (31-m) Beach Seines in Hudson River Estuary, July-September 1975

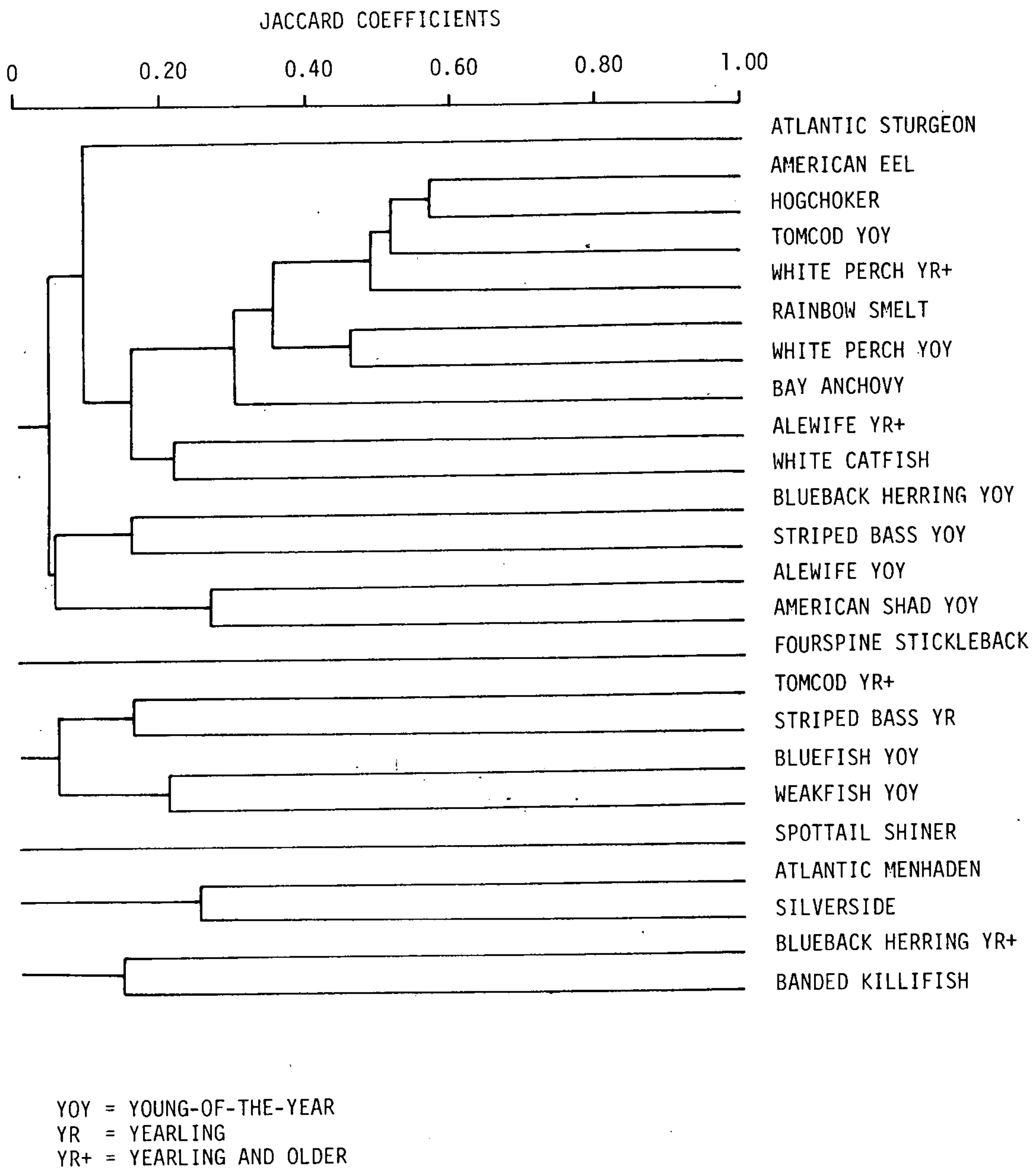


Figure 5.6-9 Cluster Analysis of Associations among Fish Species Occurring during Daytime Sampling with Bottom Trawls in Hudson River Estuary, July-September 1975

Cluster analysis was performed separately for each season (spring, summer, autumn); species not appearing in the catch during a season were not included in the analysis for that season. Two major species aggregations (defined as the largest possible cluster) appeared through all three seasons. An analysis from the summer season is presented as an example (Fig. 5.6-8). The larger aggregation contained species found more frequently in the upper and middle regions of the estuary; this included most of the freshwater species such as as spottail shiner, American eel, and sunfish species, and many anadromous species such as young-of-the-year striped bass, white perch, and American shad. The smaller aggregation contained species commonly found in the lower regions; this included salt-tolerant species such as Atlantic tomcod, bluefish, and bay anchovy. A few minor aggregations contained two or three species each; these species usually were uncommon for the season of analysis and frequently became clustered with one of the two major aggregations during another season when they were more common. For further discussion, the two major species aggregations are assumed to be distinct communities.

Similar cluster analyses were performed for species caught by bottom trawl in the shoal and channel zones during 1975 ~~zones 1975~~. Only one major aggregation was clearly distinguishable, but there were many minor aggregations consisting of species infrequently caught by trawls (Fig. 5.6-9). A single major aggregation or community may reflect the limited sampling range of bottom trawling (Tappan Zee to Newburgh) or the frequently changing environment, particularly with respect to salinity. As the salt front moved through the channel and shoals, the distribution of species within these zones often conformed to its position (TI 1976g: III-33); the changing salt front position eliminated permanent physical boundaries within which species aggregations could occur.

5.6.4 TROPHIC STRUCTURE. Communities consist of species interacting either directly or indirectly in a manner than can best be expressed in terms of energy flow. Whole communities have producers that assimilate energy from the sun, herbivores or primary consumers that feed on the producers, carnivores or secondary consumers that feed on the herbivores, and so on to the top carnivores that fall prey to no other organism. In this classic ecological relationship, each group named represents a trophic level through which energy flows within the overall trophic structure of the community. The sequence of prey and their predators has been called the food chain. Unfortunately, nature is never simple: often, some species may occupy more than one trophic level at a time. As feeding relationships become more complex, the food chain takes the form of a complicated food web. Undoubtedly, feeding relationships among Hudson River fishes are better characterized by a food web. Although food habit studies have been made for only a few species of the Hudson River, probable trophic relationships may be inferred for the remaining species from the literature (Scott and Crossman 1973, Bigelow and Schroeder 1953, Thomson et al. 1971). Daytime shore zone communities during July-September will be used to hypothesize the trophic structure, since communities during the other months would not differ greatly from these. During this time two major species aggregations or communities are apparent (Section 5.6.3). Within each community, there are at least two trophic levels of fishes (Fig. 5.6-10). The first level feeds predominantly on insects, crustaceans, molluscs, snails, and other invertebrates and includes primarily smaller fish species (commonly called forage fish) plus the young of larger, piscivorous species; some fish such as carp and goldfish feed on plant material as well and thus could be considered both herbivorous and carnivorous. The second level feeds on the first and includes just two species in each community: the striped bass and bluefish in the lower estuary community and the American eel and largemouth bass in the upper-middle estuary community.

There are difficulties in assigning fish to such a simplified trophic structure. The adults of many species assigned to the first trophic level will occasionally eat fish eggs or small fishes. The four piscivorous species assigned to the second level will occasionally consume

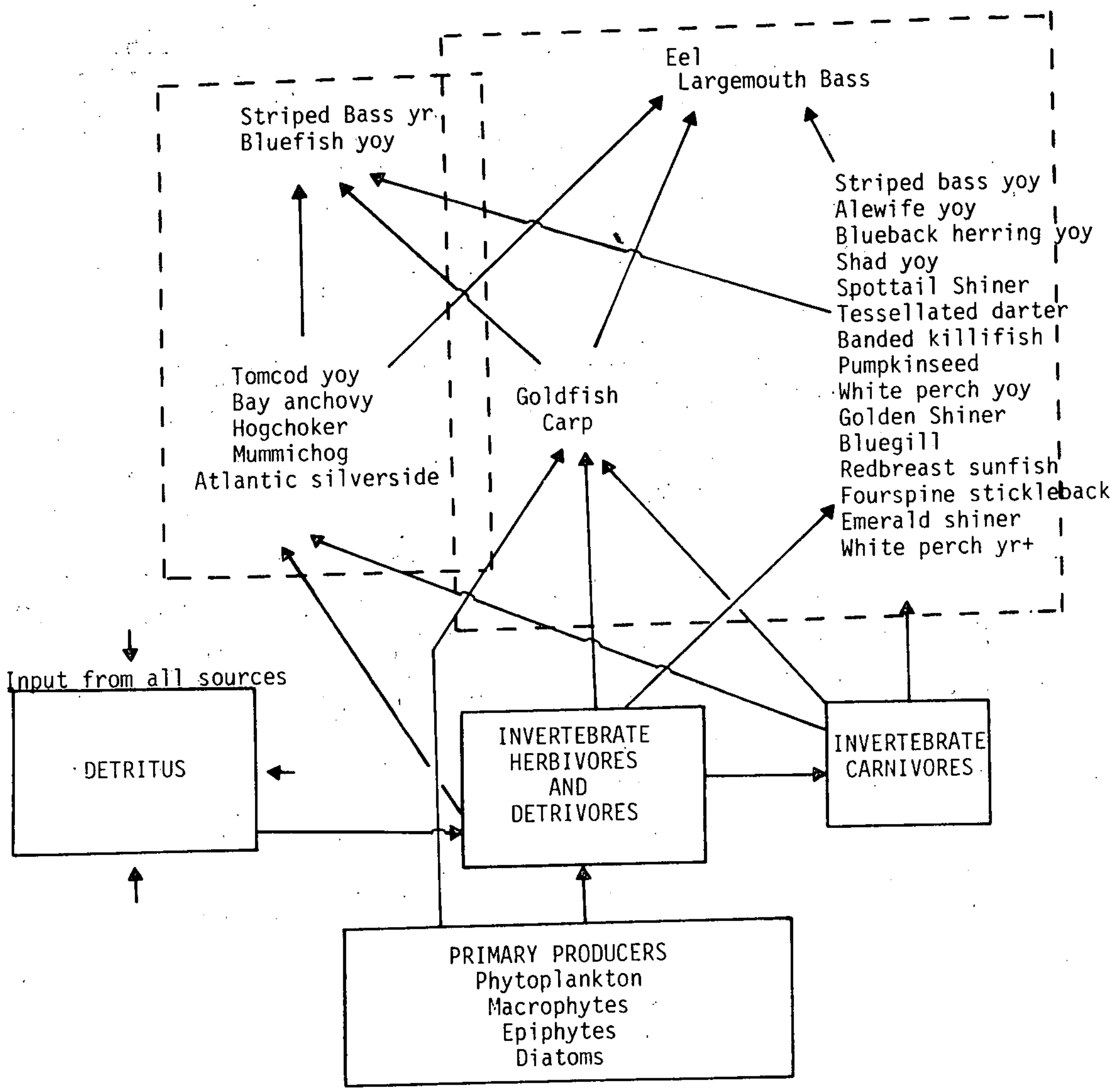


Figure 5.6-10 Simplified Trophic Structure for Two Fish Communities in Shore Zone of Hudson River Estuary

invertebrates and probably conform least to the boundaries of the two hypothetical communities. Predators are typically very mobile, and their coexistence with other species in small samples may not clearly represent the trophic relationships (Pielou 1972:126). Food habit studies on the stomach contents of these fishes are more reliable indicators of their trophic level. Such studies on the bluefish and striped bass (TI 1976a:II-5, TI 1974a:IV-44) show a combination of prey species from both communities. Common food items for other key species are listed in Sections 5.2 and 5.3.

Species coexisting at the same trophic level in a community are potential competitors for the same food sources. The cluster analyses presented in Section 5.6.3 provide a heuristic approach to the examination of potential competition among fish species. During summer, for example, young-of-the-year striped bass are most closely associated with young-of-the-year shad and adult white perch (Fig. 5.6-8); during other seasons, with young-of-the-year alewives and blueback herring. The same close associations were also noted in an earlier survey of the Hudson River (Curran and Reis 1937) in which it was found that striped bass were more likely to be with shad during the day and "herring" during the night.

Not all species are equally important in the community. The importance may be defined best as the sum of changes in productivity over all species if the particular species is removed from the community (Hurlbert 1971: 578). On an ecological basis, the importance of the key Hudson River species could best be interpreted in these terms, but estimates of productivity of most of the species are not readily available.

5.6.5 HISTORICAL TRENDS IN FISH COMMUNITY. Recent ecological theory has equated species diversity and trophic relationship complexity with community or ecosystem stability. The preceding analysis of community structure provided information on the potential ability of the Hudson River fish community to withstand natural or man-made perturbations (e.g., from power plant operation). This section reviews recent concepts of stability and community structure and examines the recent history of species composition in the Hudson River estuary for possible instability that might be associated with the operation of power plants.

Much of the traditional theory concerning the relationship between community stability and species diversity originates from empirical observations of natural and experimental communities. Communities showing the least fluctuations in species composition and numbers of individuals per species are frequently those with the greatest species diversity (as defined in Section 5.6.2). Paine (1966) hypothesized that predators are a necessary component of a community since they are capable of preventing monopolies among their prey species by opportunistically feeding on the most abundant species. Thus, abundant species are checked so that less abundant species can perpetuate themselves, preserving diversity of species. The relationship between diversity and stability is mutual, and the keys to this relationship are the alternate pathways for energy flow during times of need.

Recently the diversity stability theory has been subjected to much review (Holling 1973, Goodman 1975), especially concerning the validity of the assumption that diversity creates stability. The term "stability" has been particularly confusing since it connotes an equilibrium state to which a system will return after a temporary disturbance. For the Hudson River fish community, the equilibrium state would be a set number of individuals within a population. Since such stability is rarely if ever observed in fish populations that fluctuate widely yet do not become extinct, the term "resilience" has been adopted to denote the persistence of systems subject to disturbance but maintaining the same relationships among species populations (Holling 1973). If Hudson River fish communities are resilient, power plant operation or other environmental disturbances would have little effect on their structure and species likely would not become extinct, unless very large impacts were imposed. Even ~~though May~~ R.M. May (1971, 1974) has demonstrated mathematically that "stability" is not a necessary consequence of diversity, "resilience" may be.

There were reasonably comprehensive surveys of fish populations during 1936 (Greeley 1937) and 1965-75 (TI 1975b:V-49, V-53). Although comparable estimates of abundance are not available, the numbers of species during these years can be compared to detect trends that may be interpreted with respect to power-plant operations. During the 12 yr of survey, there was no apparent decline in the number of species in the river (Table 5.6-2). The number of species caught appeared to be determined by the range and intensity of sampling; the 1936 and 1973-75 surveys were the farthest-ranging geographically and comprised the greatest number of samples. Despite differences in sampling effort, the composition of major species appeared not to have changed dramatically from 1936 to 1975; differences consisted of uncommon species (listed earlier as "occasionals")(Table 5.6-1). The 1975 survey yielded ~~87~~ 90 species, compared with ~~59~~ 58 species during 1936. The differences probably originated from the greater sampling effort in 1975, especially in the lower portion of the river.

Therefore, there are no indications that power plant operation or any other environmental variable has appreciably changed the structure of the fish community. Although the relative abundance of each species may have changed, it would be difficult from present data to determine whether power plant operation or natural environmental variables were the cause. Hudson River fish communities appear to be diverse and considerably resilient.

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There were reasonably comprehensive surveys of fish populations during 1936 (Greeley 1937) and 1965-75 (TI 1975b:V-49, V-53). Although comparable estimates of abundance are not available, the numbers of species during these years can be compared to detect trends that may be interpreted with respect to power-plant operations. During the 12 yr of survey, there was no apparent decline in the number of species in the river (Table 5.6-2). The number of species caught appeared to be determined by the range and intensity of sampling; the 1936 and 1973-75 surveys were the farthest-ranging geographically and comprised the greatest number of samples. Despite differences in sampling effort, the composition of major species appeared not to have changed dramatically from 1936 to 1975; differences consisted of uncommon species (listed earlier as "occasionals")(Table 5.6-1). The 1975 survey yielded 87 species, compared with 59 species during 1936. The differences probably originated from the greater sampling effort in 1975, especially in the lower portion of the river.

Therefore, there are no indications that power plant operation or any other environmental variable has appreciably changed the structure of the fish community. Although the relative abundance of each species may have changed, it would be difficult from present data to determine whether power plant operation or natural environmental variables were the cause. Hudson River fish communities appear to be diverse and considerably resilient.

Table 5.6-2 Fish Species Caught during Surveys of Hudson River Estuary, 1936 and 1965-75* (Page 1 of 3)

Species	Year											
	36	65	66	67	68	69	70	71	72	73	74	75
Sea lamprey						X					X	X
Barn-door skate	X											
Shortnose sturgeon	X		X	X	X	X	X	X	X	X	X	X
Atlantic sturgeon	X	X	X	X	X	X	X	X	X	X	X	X
American eel	X	X	X	X	X	X	X	X	X	X	X	X
Blueback herring	X	X	X	X	X	X	X	X	X	X	X	X
Alewife	X	X	X	X	X	X	X	X	X	X	X	X
American shad	X	X	X	X	X	X	X	X	X	X	X	X
Atlantic herring												X
Atlantic menhaden	X	X	X	X	X	X	X	X	X	X	X	X
Round herring											X	
Gizzard shad									X	X	X	X
Hickory shad												X
Bay anchovy	X	X	X	X	X	X	X	X	X	X	X	X
Striped anchovy												X
Brown trout	X								X	X		
Brook trout										X		
Rainbow smelt	X		X	X	X	X	X	X	X	X	X	X
Central mudminnow											X	
Eastern mudminnow												X
Redfin pickerel	X									X	X	X
Northern pike									X	X	X	X
Chain pickerel	X		X	X	X	X			X	X	X	X
Inshore lizardfish										X		
Goldfish	X	X	X	X	X	X	X	X	X	X	X	X
Carp	X	X	X	X	X	X	X	X	X	X	X	X
Cutlips minnow	X									X	X	X
Silvery minnow	X		X	X			X			X	X	X
Golden shiner	X	X	X	X	X	X	X	X	X	X	X	X
Comely shiner	X										X	
Satinfin shiner			X				X			X	X	X
Emerald shiner			X	X	X	X				X	X	X
Bridle shiner	X									X	X	
Common shiner	X										X	X
Spottail shiner	X	X	X	X	X	X	X	X	X	X	X	X
Rosyface shiner											X	
Spotfin shiner	X		X	X						X	X	X
Mimic shiner										X	X	
Fathead minnow											X	X
Bluntnose minnow	X											X
Blacknose dace	X									X	X	X
Longnose dace	X											
Creek chub	X											X
Fallfish	X								X		X	X
White sucker		X	X	X	X	X	X	X	X	X	X	X
Creek chubsucker	X											
Northern hogsucker	X									X	X	
White catfish	X	X	X	X	X	X	X	X	X	X	X	X

This is a replacement Table.

Table 5.6-2 Fish Species Caught during Surveys of Hudson River Estuary, 1936 and 1965-75* (Page 1 of 3)

Species	Year											
	36	65	66	67	68	69	70	71	72	73	74	75
Sea lamprey						X				X	X	X
Barn-door skate	X											
Shortnose sturgeon	X		X	X	X	X	X	X	X	X	X	X
Atlantic sturgeon	X	X	X	X	X	X	X	X	X	X	X	X
American eel	X	X	X	X	X	X	X	X	X	X	X	X
Blueback herring	X	X	X	X	X	X	X	X	X	X	X	X
Alewife	X	X	X	X	X	X	X	X	X	X	X	X
American shad	X	X	X	X	X	X	X	X	X	X	X	X
Atlantic herring												X
Atlantic menhaden	X	X	X	X	X	X	X	X	X	X	X	X
Round herring											X	
Gizzard shad						X			X	X	X	X
Hickory shad												X
Bay anchovy	X	X	X	X	X	X	X	X	X	X	X	X
Striped anchovy												X
Brown trout	X								X	X	X	X
Brook trout									X	X		
Rainbow smelt	X		X	X	X	X	X	X	X	X	X	X
Central mudminnow											X	
Eastern mudminnow												X
Redfin pickerel	X		X				X			X	X	X
Northern pike									X	X	X	X
Chain pickerel	X		X	X	X	X			X	X	X	X
Inshore lizardfish											X	
Goldfish	X	X	X	X	X	X	X	X	X	X	X	X
Carp	X	X	X	X	X	X	X	X	X	X	X	X
Cutlips minnow										X	X	X
Silvery minnow	X		X	X	X				X	X	X	X
Golden shiner	X	X	X	X	X	X	X	X	X	X	X	X
Comely shiner	X									X	X	
Satinfin shiner	X		X				X		X	X	X	X
Emerald shiner			X	X	X	X			X	X	X	X
Bridle shiner	X									X	X	
Common shiner	X										X	X
Spottail shiner	X	X	X	X	X	X	X	X	X	X	X	X
Rosyface shiner										X	X	
Spotfin shiner			X	X							X	X
Mimic shiner										X	X	
Fathead minnow											X	X
Bluntnose minnow												X
Blacknose dace	X									X	X	X
Longnose dace	X											X
Creek chub	X										X	X
Fallfish	X								X		X	X
White sucker	X	X	X	X	X	X	X	X	X	X	X	X
Creek chubsucker	X											
Northern hogsucker	X									X	X	
White catfish	X	X	X	X	X	X	X	X	X	X	X	X

Table 5.6-2 (Page 2 of 3)

Species	36	65	66	67	68	69	70	71	72	73	74	75
Yellow bullhead										X	X	X
Brown bullhead	X	X	X	X	X	X	X	X	X	X	X	X
Channel catfish											X	
Trout-perch										X	X	X
Fourbeard rockling									X			
Silver hake						X	X			X	X	X
Atlantic tomcod	X	X	X	X	X	X	X	X	X	X	X	X
Pollock												X
Red hake											X	X
Spotted hake												X
Striped cusk-eel										X		
Atlantic needlefish	X	X					X		X	X	X	X
Banded killifish	X	X	X	X	X	X	X	X	X	X	X	X
Mummichog	X	X	X	X	X	X	X	X	X	X	X	X
Striped killifish								X		X		X
Rough silverside												X
Tidewater silverside	X	X	X	X		X	X	X	X	X	X	X
Atlantic silverside	X	X	X	X	X	X	X	X	X	X	X	X
Fourspine stickleback	X	X	X	X	X	X	X	X	X	X	X	X
Brook stickleback										X	X	X
Threespine stickleback							X		X	X	X	X
Lined seahorse										X		
Northern pipefish	X	X	X	X	X	X	X		X	X	X	X
White perch	X	X	X	X	X	X	X	X	X	X	X	X
White bass												X
Striped bass	X	X	X	X	X	X	X	X	X	X	X	X
Rock bass	X		X		X				X	X	X	X
Blue-spotted sunfish	X											
Redbreast sunfish	X	X	X	X	X	X	X	X	X	X	X	X
Green sunfish									X		X	X
Pumpkinseed	X	X	X	X	X	X	X	X	X	X	X	X
Warmouth												X
Bluegill	X		X	X	X	X	X	X	X	X	X	X
Smallmouth bass	X		X	X	X			X	X	X	X	X
Largemouth bass	X	X	X	X	X	X	X	X	X	X	X	X
White crappie							X		X	X	X	X
Black crappie	X	X	X	X	X			X	X	X	X	X
Tessellated darter	X	X	X	X	X	X	X	X	X	X	X	X
Yellow Perch	X	X	X	X	X	X	X	X	X	X	X	X
Logperch	X									X	X	
Shield darter	X											
Walleye	X									X	X	
Bluefish	X	X	X	X	X	X	X	X	X	X	X	X
Crevalle jack	X	X	X	X		X	X	X	X	X	X	X
Lookdown										X	X	X
Atlantic moonfish												X
Scup						X					X	
Silver perch									X	X	X	
Weakfish					X	X	X	X	X	X	X	X
Spot										X	X	X

Table 5.6-2 (Page 2 of 3)

Species	36	65	66	67	68	69	70	71	72	73	74	75
Yellow bullhead											X	X
Brown bullhead	X	X	X	X	X	X	X	X	X	X	X	X
Trout-perch										X	X	X
Fourbeard rockling							X					
Silver hake							X				X	X
Atlantic tomcod	X	X	X	X	X	X	X	X	X	X	X	X
Pollock												X
Red hake										X	X	X
Spotted hake												X
Atlantic needlefish	X	X	X				X		X	X	X	X
Banded killifish	X	X	X	X	X	X	X	X	X	X	X	X
Spotfin killifish												X
Mummichog	X	X	X	X	X	X	X	X	X	X	X	X
Striped killifish								X	X			
Rough silverside												X
Tidewater silverside	X	X	X	X		X	X	X		X	X	X
Atlantic silverside	X	X	X	X		X	X	X	X	X	X	X
Fourspine stickleback	X	X	X	X	X	X	X		X	X	X	X
Brook stickleback										X	X	X
Threespine stickleback							X			X	X	X
Lined seahorse										X		
Northern pipefish	X	X	X	X	X	X	X		X	X	X	X
White perch	X	X	X	X	X	X	X	X	X	X	X	X
Striped bass	X	X	X	X	X	X	X	X	X	X	X	X
Rock bass	X		X		X				X	X	X	X
Blue-spotted sunfish	X											
Redbreast sunfish	X	X	X	X	X	X	X	X	X	X	X	X
Green sunfish									X		X	X
Pumpkinseed	X	X	X	X	X	X	X	X	X	X	X	X
Warmouth												X
Bluegill	X		X	X	X	X	X	X	X	X	X	X
Smallmouth bass	X		X	X	X			X	X	X	X	X
Largemouth bass	X	X	X	X	X	X	X	X	X	X	X	X
White crappie							X		X	X	X	X
Black crappie	X	X	X	X	X			X	X	X	X	X
Tessellated darter	X	X	X	X	X	X	X	X	X	X	X	X
Yellow perch	X	X	X	X	X	X	X	X	X	X	X	X
Logperch	X									X	X	
Shield darter	X											
Walleye	X									X	X	
Bluefish	X	X	X	X	X	X	X	X	X	X	X	X
Crevalle jack	X	X	X	X		X	X	X	X	x	X	X
Lookdown											X	X
Atlantic moonfish												X
Scup						X	X		X			
Silver perch									X	X	X	
Weakfish						X	X	X	X	X	X	X
Spot										X	X	X

Table 5.6-2 (Page 3 of 3)

Species	36	65	66	67	68	69	70	71	72	73	74	75
Northern kingfish										X	X	X
Atlantic croaker									X	X	X	
Tautog							X					
Striped mullet							X			X	X	X
White mullet		X									X	X
Northern stargazer											X	
American sandlance												X
Fat sleeper										X	X	
Seaboard goby											X	X
Butterfish									X	X	X	X
Northern searobin										X		
Striped searobin										X		X
Grubby											X	X
Summer flounder	X										X	X
Windowpane											X	X
Winter flounder	X					X				X	X	X
Hogchoker		X	X	X	X	X	X	X	X	X	X	X
Northern puffer												X
TOTAL NUMBER OF SPECIES	59	34	43	40	36	40	45	36	49	72	88	87

* TI 1975b; Greeley 1937; QLM 1973 and 1974a,b

Table 5.6-2 (Page 3 of 3)

Species	36	65	66	67	68	69	70	71	72	73	74	75
Northern Kingfish										X	X	X
Atlantic croaker									X	X	X	
Tautog										X		
Striped mullet							X		X	X	X	X
White mullet		X	X							X	X	X
Northern stargazer											X	
American sandlance												X
Fat sleeper										X	X	
Seaboard goby											X	X
Butterfish							X		X	X	X	X
Northern searobin										X		
Striped searobin									X	X		X
Grubby												X
Summer flounder	X											X
Fourspot flounder											X	
Windowpane											X	X
Winter flounder	X					X				X	X	X
Hogchoker		X	X	X	X	X	X	X	X	X	X	X
Northern puffer									X			X
TOTAL NUMBER OF SPECIES	58	34	44	40	39	42	43	37	58	80	91	90

*TI 1975b; Greeley 1937; QLM 1973a and 1974a,b,c; LMS 1974b; TI 1975m

SECTION 6

VULNERABILITY OF SELECTED FISH SPECIES DURING FIRST YEAR OF LIFE TO POWER PLANTS IN HUDSON RIVER ESTUARY

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SECTION 6

VULNERABILITY OF SELECTED FISH SPECIES DURING FIRST YEAR OF LIFE TO POWER PLANTS IN HUDSON RIVER ESTUARY

6.1 INTRODUCTION

The magnitude of power plant effects on fish populations in the Hudson River estuary is directly related to vulnerability (exposure) of (1) eggs, larvae, and early juveniles to entrainment (passage through the condenser cooling system) and (2) later juveniles, yearlings, and for some species older age groups as well to impingement (entrapment on the cooling water intake screens). The key factor influencing the vulnerability of a specie's life stages is the longitudinal or macrodistribution in relation to power plant sites. For example, if eggs or larvae are concentrated many miles upstream or downstream from a particular power plant, the vulnerability to entrainment of that species' larval population is negligible at that power plant; conversely, if most of the eggs or larvae are concentrated within the same river mile as the power plant, vulnerability to entrainment is very high at that power plant. Numbers of eggs or larvae actually entrained depend on other factors as well, such as microdistribution patterns near the plant intakes (e.g., vertical distribution in the water column); the behavior, physiology, and condition of the larvae; and power plant factors such as intake design, zone of water withdrawal, velocities at the screen face, screen mesh size, pumping rates, operation schedules, etc.

In this section, the term vulnerability refers to the exposure of entire populations of early life stages to power plants rather than to the probability that an individual egg, yolk-sac larva, etc., will be entrained. The degree of exposure is primarily based on the longitudinal distribution or abundance of organisms in each of the 12 sampling regions (Table 6.1-1). The sampling regions have been defined on the basis of morphometric characteristics such as depth, width, and extent of shoals

Table 6.1-1 Sampling Regions, Boundaries and Brief Description of Hudson River Estuary between George Washington Bridge and Troy Dam, with Regional Location of Each Power Plant

Delete and add: [14-23]** [(22-37)]

Area	Sampling Region	River Mile (km)	Morphometric Characteristics	Power Plant & Location
Lower Estuary	Yonkers (YK)	12-23* [14]** (19-37) [22]	Narrow & moderately deep, shoals are rare***	
	Tappan Zee (TZ)	24-33 (38-53)	Very wide and shallow, shoals abundant	
	Croton-Haverstraw (CH)	34-38 (54-61)	Very wide and shallow, shoals abundant	Bowline (RM 37; km 60)
Middle Estuary	Indian Point (IP)	39-46 (62-74)	Narrow and deep, shoals rare	Lovett (RM 41; km 66) Indian Point (RM 42; km 69)
	West Point (WP)	47-55 (75-88)	Narrow and deep, shoals rare	
	Cornwall (CW)	56-61 (89-98)	Wide and moderately deep, shoals common	
	Poughkeepsie (PK)	62-76 (99-122)	Narrow and moderately deep, shoals rare	Roseton (RM 65; km 105) Danskammer (RM 66; km 106)
Upper Estuary	Hyde Park (HP)	77-85 (123-136)	Narrow and moderately deep, shoals rare	
	Kingston (KG)	86-93 (137-149)	Wide and moderately deep, shoals rare	
	Saugerties (SG)	94-106 (150-170)	Narrow and moderately deep, shoals common	
	Catskill (CS)	107-124 (171-198)	Wide and shallow, shoals common	
	Albany (AL)	125-152 [140] (200-243) [224]	Narrow and shallow, shoals common	

Delete, insert in its place: [125-152] [(200-224)]

*Inclusive

**Regional boundaries for ichthyoplankton sampling are given in brackets where they differ from beach seine and interregional bottom trawl boundaries.

***Shoals are defined as areas ≤ 20 ft (6 m) deep.

(areas $\leq$ 6m deep). For general descriptions of longitudinal distribution, the 12 sampling regions can be combined and viewed as three areas possessing distinct physical and chemical environments -- the lower, middle, and upper estuary (Table 6.1-1). All power plants except Bowline are in the middle estuary, a relatively deep area with few shoals (Table 6.1-1 and Fig. 6.1-1). Bowline is at the upstream end of the lower estuary adjacent to a wide, shallow portion of Haverstraw Bay. The degree of vulnerability (exposure) of the population of each life stage during a given time period is characterized as high, moderate, or low, depending on the approximate proportion of that population located near the five power plants, as follows:

- High - the population is concentrated in the middle estuary, i.e., that area where most of the power plants are located.
- Moderate- the population is widely dispersed from the upstream portion of the lower estuary, through the middle estuary, and into the downstream portion of the upper estuary.
- Low - the population is restricted to either the upper and/or lower estuary, i.e., away from the power plants.

6.2 STRIPED BASS

To describe distributions of the early life stages of striped bass in the Hudson River estuary and assess their vulnerability to the Bowline (RM 37; km 60), Lovett (RM 41; km 66), Indian Point (RM 42; km 69), Roseton (RM 65; km 105), and Danskammer (RM 66; km 106) power plants, several 1974 and 1975 Texas Instruments (TI) data sets (epibenthic sled and Tucker trawl ichthyoplankton survey, fall epibenthic sled survey, beach seine survey, and interregional bottom trawl survey) were compiled and examined. If the longitudinal distributions were similar during 1974 and 1975, only the 1975 data are discussed but any major differences between years are described. Abundance estimates derived from the ichthyoplankton

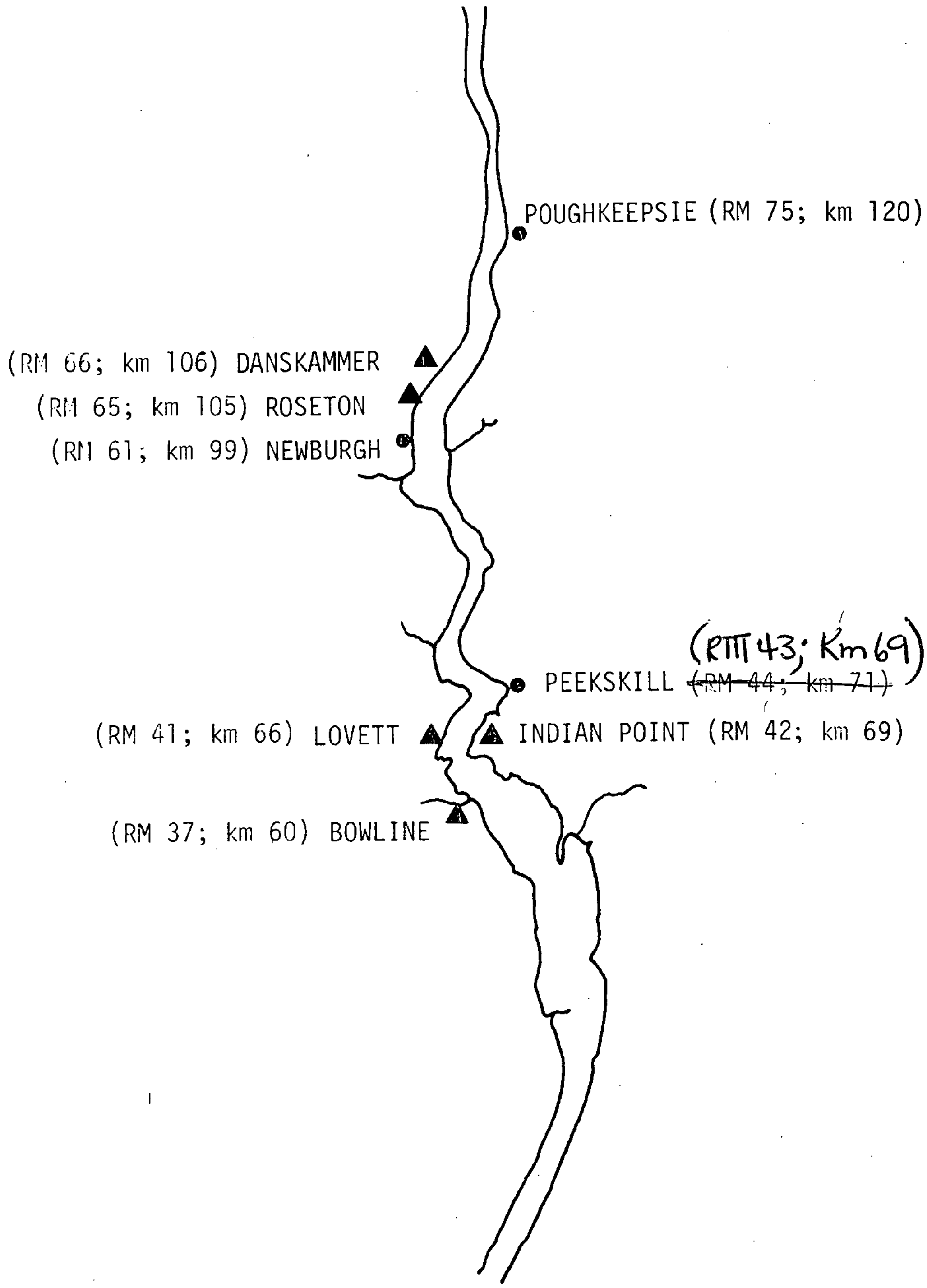

Figure 6.1-1 Locations of Bowline, Lovett, Indian Point, Roseton, and Danskammer Power Plants on Hudson River Estuary

survey and fall epibenthic sled survey are presented as densities (number of individuals per 1000 m^3 of water strained). Abundance estimates derived from the beach seine survey and interregional bottom trawl survey are presented as catch per unit effort (number of individuals per tow).

Not all sampling gear were equally useful for describing the longitudinal distribution of every life stage, so separate abundance estimates representing different depth strata were calculated for the various life stages. Early life stages (eggs, yolk-sac larvae, post yolk-sac larvae) have relatively short durations, ranging from hours to several weeks, and are collected in Tucker trawls and epibenthic sleds. Highly mobile life stages (juveniles and yearlings) have longer durations (several months) and are collected in many gears: e.g., Tucker trawls, epibenthic sleds, beach seines, and bottom trawls. Seasonal trends in the depth distribution of juveniles and yearlings were examined to determine which gear best described longitudinal distribution of the population during each month. Indices of trends in depth distribution were derived from the proportion of the standing crop estimates present in each of three depth strata <10 ft, 10-20 ft, and >20 ft (<3 m, 3-6 m, and >6 m) for the area of the river sampled by all gear (the lower and middle estuary). Methods used to calculate these strata standing crops and assumptions are presented in Section 7.9.

Because of sampling variability, all differences in regional abundance estimates may not necessarily have represented real differences in population abundance between regions. However, the differences in sample estimates represented by the larger peaks and troughs, which appear in 3-dimensional plots of the data do reflect the real spatial, temporal distribution of young fish. Additional insight into the distribution and vulnerability of the entrainable life stages (eggs, larvae, early juveniles) was gained by comparing abundance estimates from different depth strata. In three sampling regions (Tappan Zee, Croton-Haverstraw and Indian Point), three depth strata were compared:

- Shoal - areas on the east and west side of the river where depths are $\leq$ 20 ft (6 m)

- Bottom - areas of the river $\leq$ 10 ft (3 m) from the bottom where depths are $\geq$ 20 ft (6 m)

- Channel - areas of the river $\geq$ 10 ft (3 m) from the bottom where depths are > 20 ft (6 m)

In the remaining seven regions where shoals are limited (West Point, Cornwall, Poughkeepsie, Hyde Park, Kingston, Saugerties and Catskill), only two depth strata (bottom-shoal combined and channel) were compared.

The results of two additional 1975 studies, the Texas Instruments Cornwall Study and the New York University Indian Point Study (Sections 7.2, 7.3, and 7.4) were also examined to describe the depth distributions of early life stages of striped bass.

6.2.1 DISTRIBUTION. The anadromous striped bass spawns during spring and summer in the Hudson River estuary (Section 5.2), and their nonadhesive semibuoyant eggs occur throughout most of the estuary from early May through June (Fig. 6.2-1 and Table 6.2-1). Spawning peaks during May in freshwater areas of the middle estuary and most upstream regions of the lower estuary (Fig. 6.2-1) when water temperatures range from 14-20°C (Section 7.2). Eggs are significantly more abundant both day and night (α = 0.05) in the bottom stratam than in the channel or shoal strata.

Yolk-sac larvae are widely distributed throughout the estuary from early May through late June, with greatest abundances occurring in the Croton-Haverstraw through Kingston regions (Fig. 6.2-1 and Table 6.2-2). Numbers peak in late May and early June. Yolk-sac larvae are capable of irregular swimming movements (Section 7.3) and appear to disperse through the water column at night; during the day, their distribution is similar to eggs with highest concentrations near the bottom.

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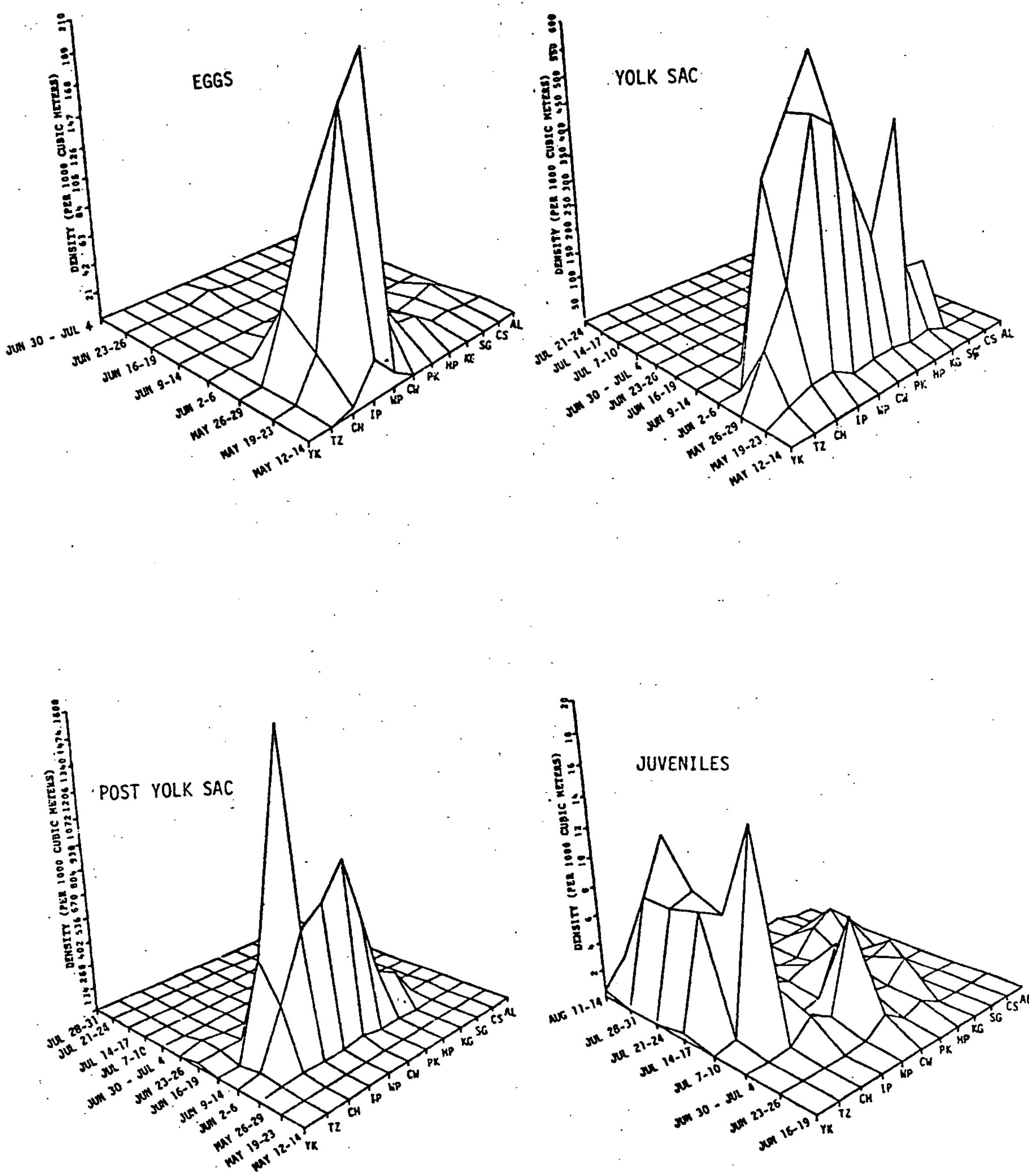

Figure 6.2-1 Longitudinal Distribution of Early Life Stages of Striped Bass during 1975 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples

Table 6.2-1 Regional Densities of Striped Bass Eggs during 1975 in Hudson River Estuary (RM 14-140; km 23-225) based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

delete

Time Period	Regional Densities (no. $m^{-3} \times 10^3$)*											
	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
May 12-May 14	NC	NC	3.8 (3.6)*	27.5 (10.9)	9.9 (7.8)	NC	NC	NC	NC	NC	NC	NC
May 19-May 23	NC	0.8 (0.5)	27.5 (13.6)	177.0 (29.7)	205.8 (84.2)	42.4 (9.2)	18.6 (14.1)	15.6 (8.1)	4.7 (3.6)	5.1 (2.1)	2.9 (1.7)	2.1 (1.4)
May 26-May 29	NC	0.2 (0.2)	47.5 (17.2)	99.5 (16.2)	98.6 (21.1)	62.1 (14.7)	10.8 (5.4)	9.4 (4.9)	1.5 (1.5)	4.2 (2.1)	8.8 (2.6)	NC
Jun 2-Jun 6	NC	0.7 (0.7)	NC	6.1 (4.6)	13.4 (6.2)	14.2 (5.2)	0.4 (0.2)	0.3 (0.3)	NC	NC	NC	NC
Jun 9-Jun 14	NC	NC	NC	NC	0.5 (0.2)	<0.1 **	NC	NC	NC	NC	NC	NC
Jun 16-Jun 19	NC	NC	NC	NC	0.9 (0.5)	<0.1 **	0.5 (0.3)	NC	NC	0.7 (0.7)	1.7 (1.7)	NC
Jun 23-Jun 26	NC	NC	NC	NC	4.4 (4.1)	0.7 (0.3)	0.1 (0.1)	0.5 (0.3)	NC	NC	NC	NC
Jun 30-Jul 4	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

NC = no catch

* = Numbers in parentheses are one standard error around density estimate

** = Standard error <0.1

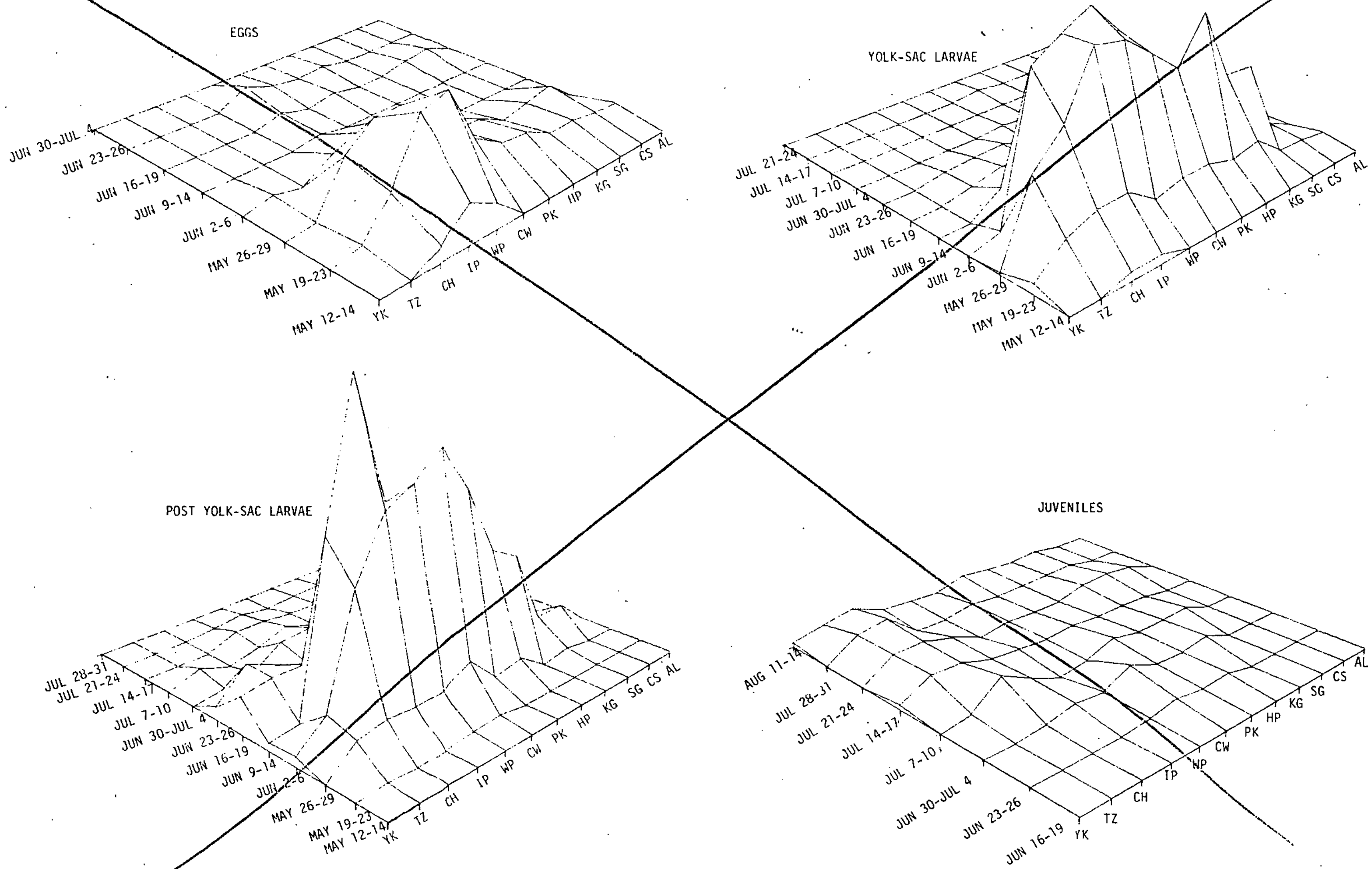

Figure 6.2-1 Longitudinal Distribution of Early Life Stages of Striped Bass during 1975 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples

Table 6.2-2 Regional Densities of Striped Bass Yolk-Sac Larvae during 1975 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

delete.

Time Period	Regional Densities (No. $m^{-3} x10^3$)*											
	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
May 12-May 14	NC	NC	1.2 (0.6)*	1.6 (1.2)	NC	NC	NC	NC	NC	NC	NC	NC
May 19-May 23	2.0 (1.8)	22.4 (6.4)	39.8 (8.0)	42.5 (14.0)	14.7 (2.4)	23.4 (7.1)	23.8 (8.2)	14.3 (3.0)	20.4 (18.2)	2.5 (1.4)	1.9 (1.0)	0.7 (0.7)
May 26-May 29	0.1 (0.1)	103.5 (43.1)	206.4 (77.6)	491.3 (118.4)	461.5 (101.7)	336.5 (94.3)	229.5 (67.3)	440.2 (204.4)	134.5 (70.0)	128.6 (87.4)	3.2 (1.7)	NC
Jun 2-Jun 6	NC	1.3 (0.9)	380.9 (84.5)	482.4 (84.3)	580.2 (80.4)	390.1 (64.0)	151.5 (30.4)	101.3 (41.7)	3.6 (1.6)	19.4 (2.2)	NC	NC
Jun 9-Jun 14	NC	NC	7.2 (3.3)	20.1 (8.4)	14.6 (4.2)	0.3 (0.2)	NC	NC	NC	NC	NC	NC
Jun 16-Jun 19	NC	NC	0.7 (0.7)	3.0 (1.0)	1.2 (0.6)	0.2 (0.2)	0.6 (0.3)	NC	NC	1.1 (1.1)	NC	NC
Jun 23-Jun 26	NC	NC	0.5 (0.5)	1.0 (0.5)	1.4 (0.5)	NC	0.3 (0.2)	NC	NC	NC	NC	NC
Jun 30-Jul 4	NC	NC	NC	NC	NC	0.1 (0.1)	NC	NC	NC	NC	NC	NC
Jul 7-Jul 10	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Jul 14-Jul 17	NC	NC	NC	NC	NC	NC	0.2 (0.2)	NC	NC	NC	NC	NC
Jul 21-Jul 24	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

NC = no catch

* = Numbers in parentheses are one standard error around density estimates

Post yolk-sac larvae occur throughout the estuary from mid-May through July (Fig. 6.2-1 and Table 6.2-3). Their longitudinal distribution is similar to yolk-sac larvae during the June peak abundance period. During both day and night, post yolk-sac larvae orient more strongly to the bottom than do yolk-sac larvae but still exhibit some dispersion through the water column at night (Section 7.4). The population of post yolk-sac larvae and early juveniles apparently begins to move shoreward during June with increased movements in early July (Fig. 6.2-2).

Juveniles first appear in mid- to late June in the channel bottom strata, but in mid-July the population begins to move to the shoals and shorezone (Fig. 6.2-2 and 6.2-3). Juveniles were most abundant in the lower and middle estuary during July 1975 (Fig. 6.2-1 and Table 6.2-4) but were also abundant in the upper estuary in July 1974 (Fig. 6.2-4 and Tables 6.2-5, 6.2-6, 6.2-7, and 6.2-8). Juveniles averaging 20-25 mm (range, 14-31 mm) in total length first appear in the shorezone ($\leq$ 10 ft [3 m] deep) in mid-June (Fig. 6.2-2). Shoreward movements continue through mid-September, when most of the juvenile population is in the shorezone (Fig. 6.2-3). By early September, juveniles average 75-80 mm (range, 32-128 mm) in total length. During August and September, the juvenile population also moves gradually downstream and becomes most abundant in the shorezones of the downstream regions of the middle estuary and the entire lower estuary (Fig. 6.2-5 and Tables 6.2-9 and 6.2-10). The downstream movement of juvenile striped bass continues through October and November; by early November, they are beginning to move away from the beaches to the deeper shoals (10-20 ft [3-6 m] deep) at an average total length of about 90 mm (range, 53-149 mm). These offshore and downstream movements continue through December (Fig. 6.2-3). By late December, catches of juveniles are small (Fig. 6.2-5), suggesting that they either migrate from the sampling area (below RM 12; km 19) or move to deep water and are less accessible to the sampling gear.

Table 6.2-3 Regional Densities of Striped Bass Post Yolk-Sac Larvae during 1975 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

delete

Time Period	Regional Densities (No. $m^{-3} \times 10^3$)*											
	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
May 12-May 14	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
May 19-May 23	NC	0.1 (0.1)*	NC	NC	0.2 (0.1)	0.4 (0.3)	NC	NC	NC	NC	NC	NC
May 26-May 29	NC	11.0 (4.0)	15.9 (6.3)	13.1 (5.8)	13.8 (3.9)	32.2 (7.4)	3.6 (1.8)	7.0 (4.2)	NC	0.4 (0.4)	NC	NC
Jun 2-Jun 6	1.9 (1.9)	20.9 (7.2)	318.4 (59.6)	651.3 (93.6)	752.5 (78.3)	933.0 (91.4)	581.8 (80.9)	232.8 (86.0)	170.7 (119.5)	11.9 (7.6)	12.2 (0)	NC
Jun 9-Jun 14	1.2 (1.2)	2.5 (1.8)	513.3 (275.2)	1607.4 (264.0)	578.0 (137.4)	106.3 (56.9)	34.1 (4.3)	17.6 (8.5)	85.4 (41.6)	6.8 (5.4)	0.8 (0.8)	NC
Jun 16-Jun 19	25.2 (7.2)	30.6 (3.3)	28.7 (5.2)	44.8 (4.5)	6.6 (1.7)	10.3 (3.4)	7.4 (2.1)	27.0 (12.6)	16.0 (6.0)	10.9 (10.3)	1.6 (0)	NC
Jun 23-Jun 26	3.4 (2.1)	30.7 (12.0)	13.1 (3.2)	4.6 (0.7)	3.9 (0.7)	5.5 (2.1)	5.6 (1.2)	33.9 (17.6)	36.4 (17.2)	24.7 (6.9)	NC	NC
Jun 30-Jul 4	NC	0.3 (0.2)	0.6 (0.3)	11.0 (2.4)	12.9 (5.8)	21.2 (7.1)	7.2 (2.8)	4.6 (2.0)	10.0 (3.5)	1.5 (1.0)	0.8 (0.8)	NC
Jul 7-Jul 10	NC	2.1 (2.1)	NC	0.8 (0.4)	4.7 (2.6)	0.8 (0.4)	6.1 (2.5)	15.6 (7.1)	18.8 (7.2)	8.4 (3.5)	23.3 (9.9)	NC
Jul 14-Jul 17	NC	NC	NC	2.1 (1.1)	1.7 (1.1)	0.7 (0.3)	0.5 (0.3)	0.7 (0.3)	0.6 (0.3)	0.8 (0.8)	1.6 (1.6)	NC
Jul 21-Jul 24	NC	NC	NC	0.1 (0.1)	0.5 (0.4)	NC	0.1 (0.1)	0.2 (0.2)	NC	NC	NC	NC
Jul 28-Jul 31	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

NC = no catch

* = Numbers in parentheses are one standard error around density estimates

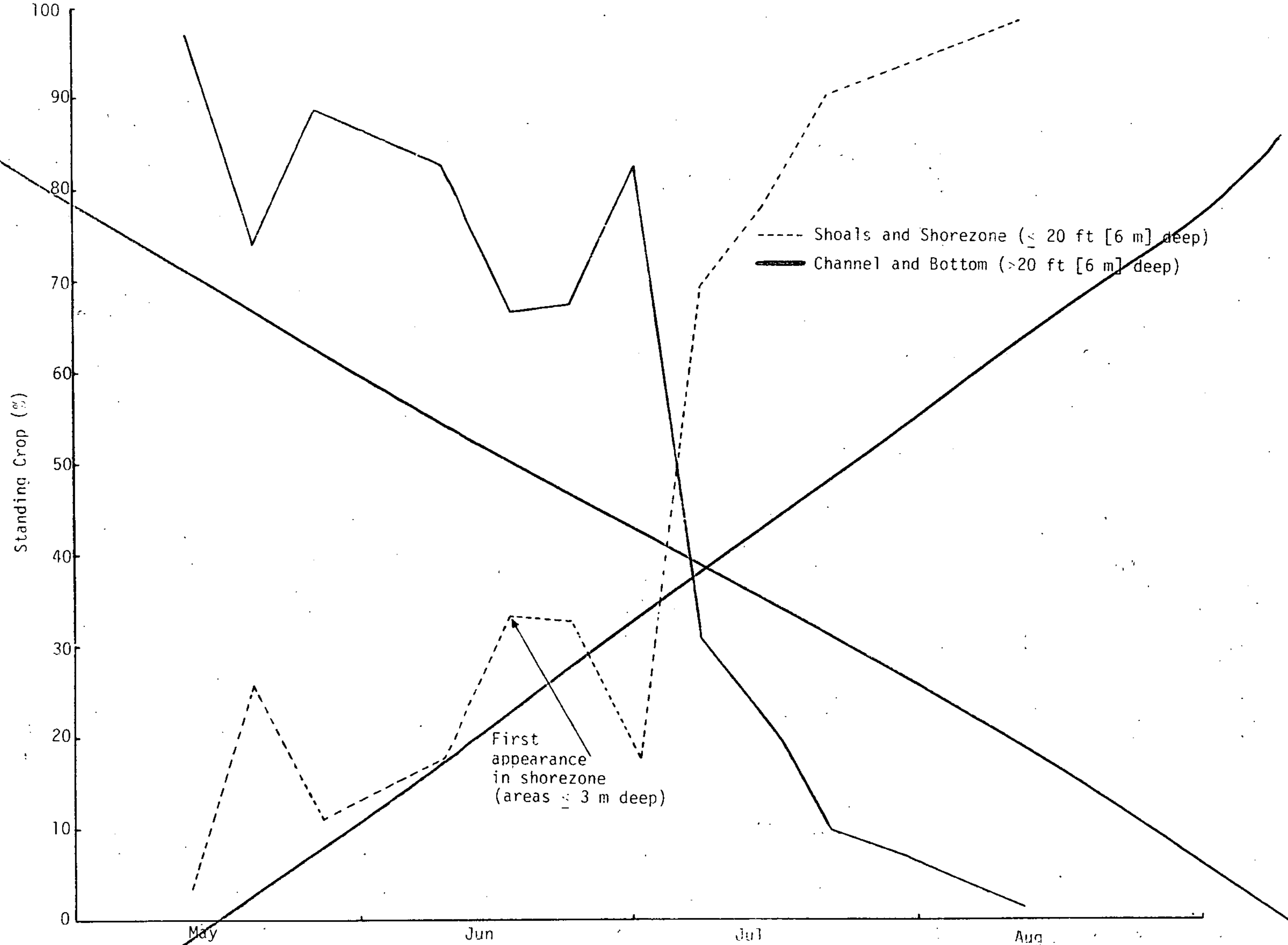

Figure 6.2-2 Depth Distribution of Striped Bass Population (All Life Stages Combined: Eggs to Early Juveniles) in Hudson River Estuary during 1975 Based on Strata Standing Crop Estimates (Section 7.9)

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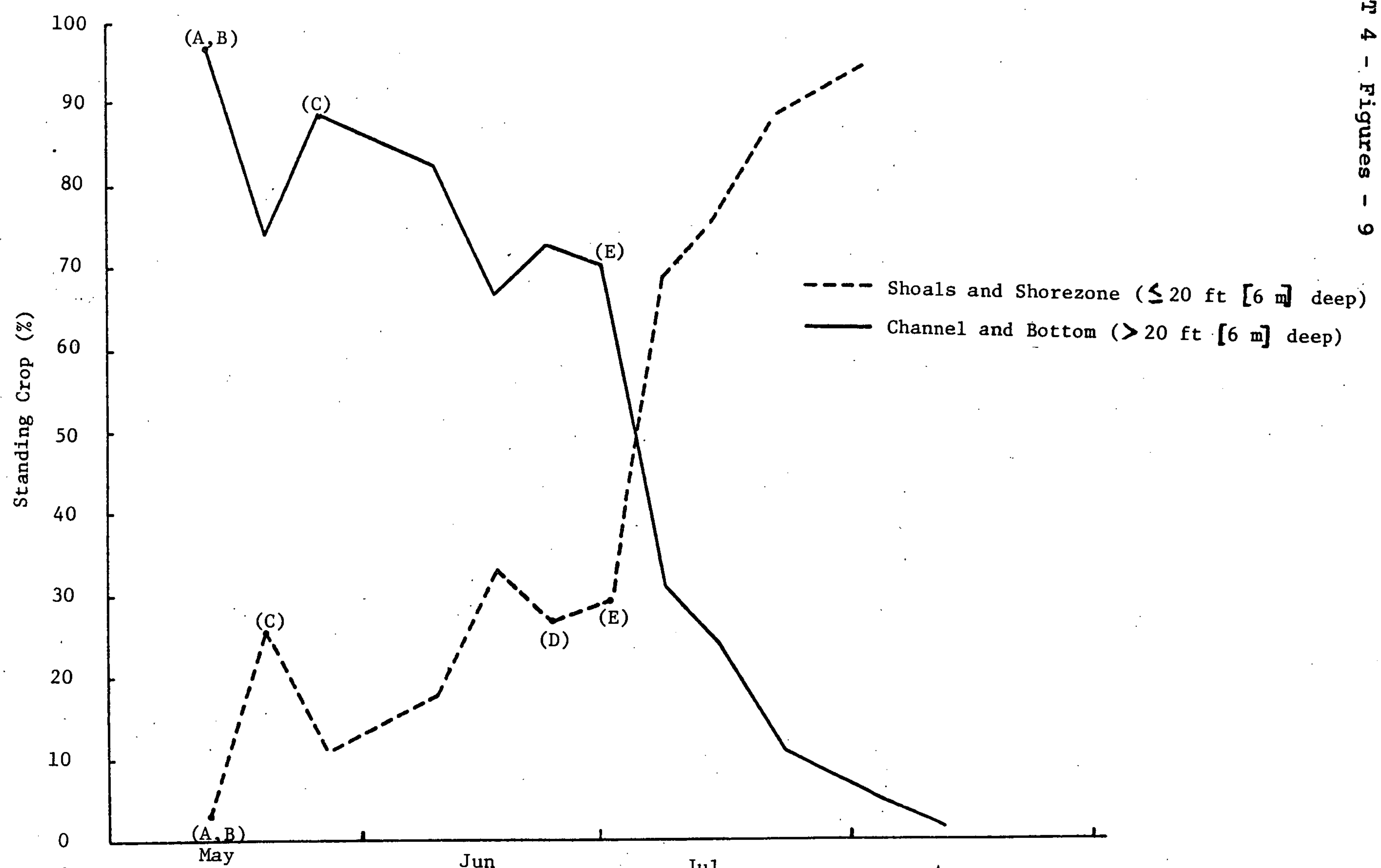

Figure 6.2-2 Depth Distribution of Striped Bass Population (All Life Stages Combined: Eggs to Early Juveniles) in the Yonkers-Indian Point regions (RM12-46) of the Hudson River Estuary during 1975 Based on Strata Standing Crop Estimates (Section 7.9)
A=approximate time for first appearance of eggs
B=approximate time for first appearance of yolk-sac larvae
C=approximate time for first appearance of post yolk-sac larvae
D=approximate time for first appearance of juveniles in shorezone
E=approximate time for first appearance of juveniles in shoals and channel/bottom

NOTE: This is a replacement figure.

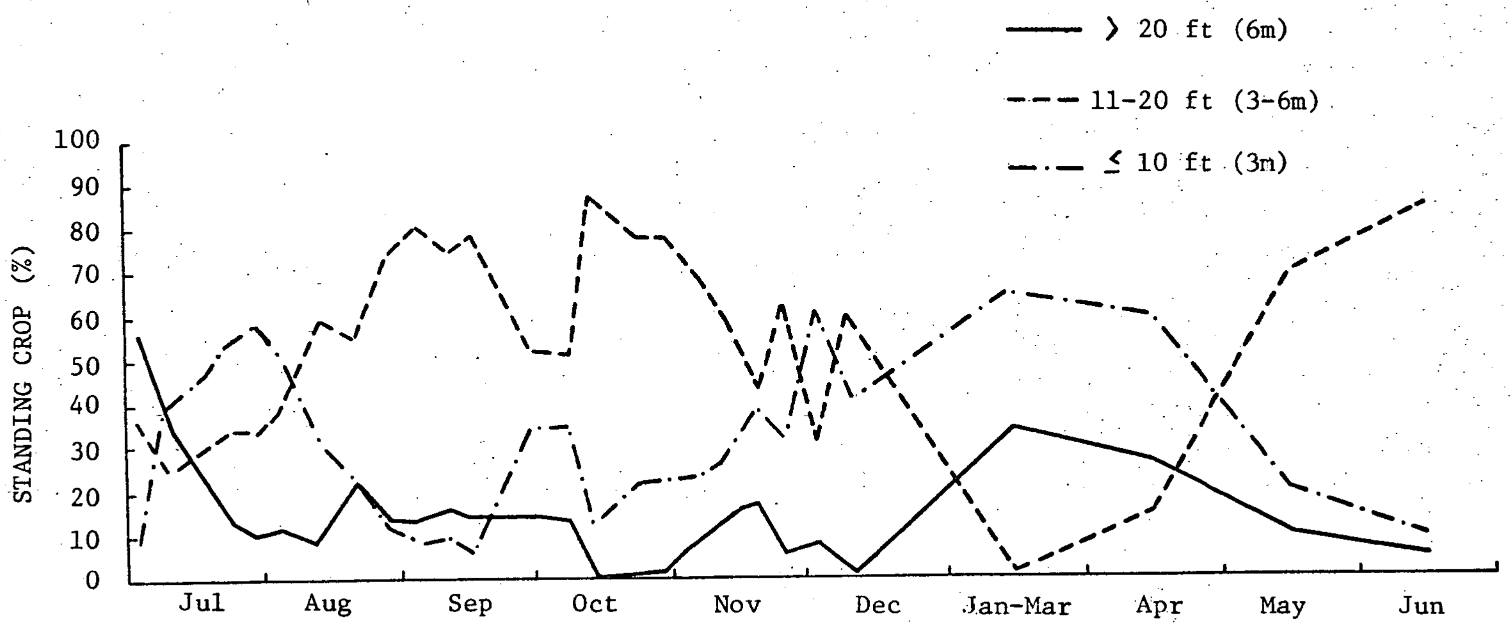

Figure 6.2-3 Depth Distribution of Juvenile Striped Bass during 1975 (Based on Strata Standing Crop Estimates from Section 7.9) and Yearling Striped Bass in Early 1976 (Estimated from 1975 Beach Seine and Bottom Trawl Catches), Hudson River Estuary, (RM14-76; km19-122) (Depth Distribution in Late December, January, February, and March is Hypothesized and Not Based on Actual Sampling)

Table 6.2-4 Regional Densities of Striped Bass Juveniles during 1975 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

delete *

Time Period	Regional Densities (No. m^{-3} x 10^{-3})*											
	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Jun 16-Jun 19	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Jun 23-Jun 26	NC	NC	NC	NC	0.2 (0.1)*	1.3 (1.1)	0.3 (0.2)	0.8 (0.8)	NC	NC	NC	NC
Jun 30-Jul 14	NC	NC	0.2 (0.2)	1.6 (1.1)	0.8 (0.4)	7.0 (2.9)	1.2 (0.8)	0.9 (0.4)	2.3 (1.4)	NC	NC	NC
Jul 7-Jul 10	NC	0.4 (0.3)	13.7 (9.2)	2.5 (0.9)	NC	0.3 (0.3)	3.7 (1.5)	1.3 (0.6)	1.5 (0.7)	2.0 (1.2)	NC	NC
Jul 14-Jul 17	0.5 (0.5)	8.0 (4.0)	7.2 (2.3)	2.1 (0.9)	1.2 (0.6)	0.6 (0.2)	1.2 (0.6)	0.6 (0.3)	0.6 (0.3)	0.4 (0.4)	NC	NC
Jul 21-Jul 24	NC	7.4 (4.6)	8.1 (3.3)	3.0 (1.9)	NC	0.5 (0.3)	0.2 (0.2)	0.2 (0.2)	1.9 (1.2)	2.8 (1.8)	1.6 (0)	NC
Jul 28-Jul 31	NC	7.4 (3.3)	11.2 (3.4)	NC	NC	0.5 (0.3)	0.1 (0.1)	0.2 (0.2)	0.3 (0.2)	0.5 (0.5)	NC	NC
Aug 11-Aug 14	0.5 (0.4)	2.4 (1.9)	5.2 (3.0)	0.4 (0)	0.1 **	<0.1 **	1.2 (0.8)	0.4 (0.2)	0.1 (0.1)	0.4 (0.4)	NC	NC

NC = no catch

*Numbers in parentheses are one standard error around density estimates
**Standard error <0.1

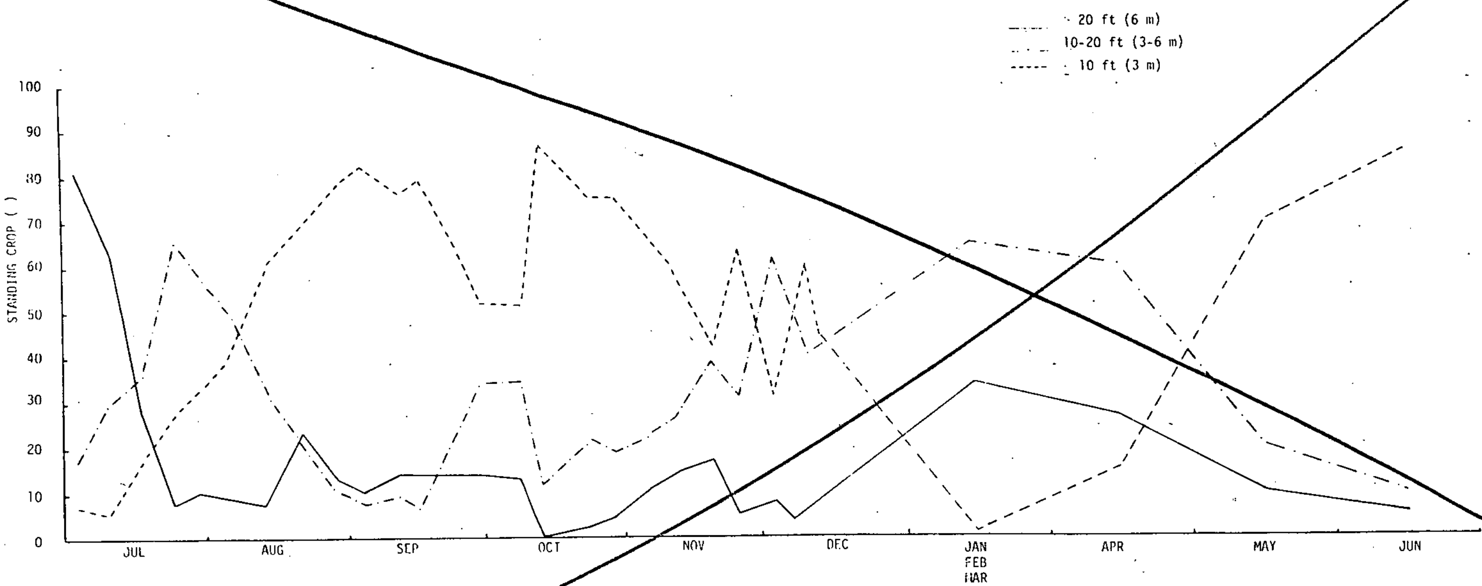

Figure 6.2-3 Depth Distribution of Juvenile Striped Bass during 1975 (Based on Strata Standing Crop Estimates from Section 7.9) and Yearling Striped Bass in Early 1976 (Estimated from 1975 Beach Seine and Bottom Trawl Catches), Hudson River Estuary. (Depth Distribution in January, February, and March is Hypothesized and Not Based on Actual Sampling)

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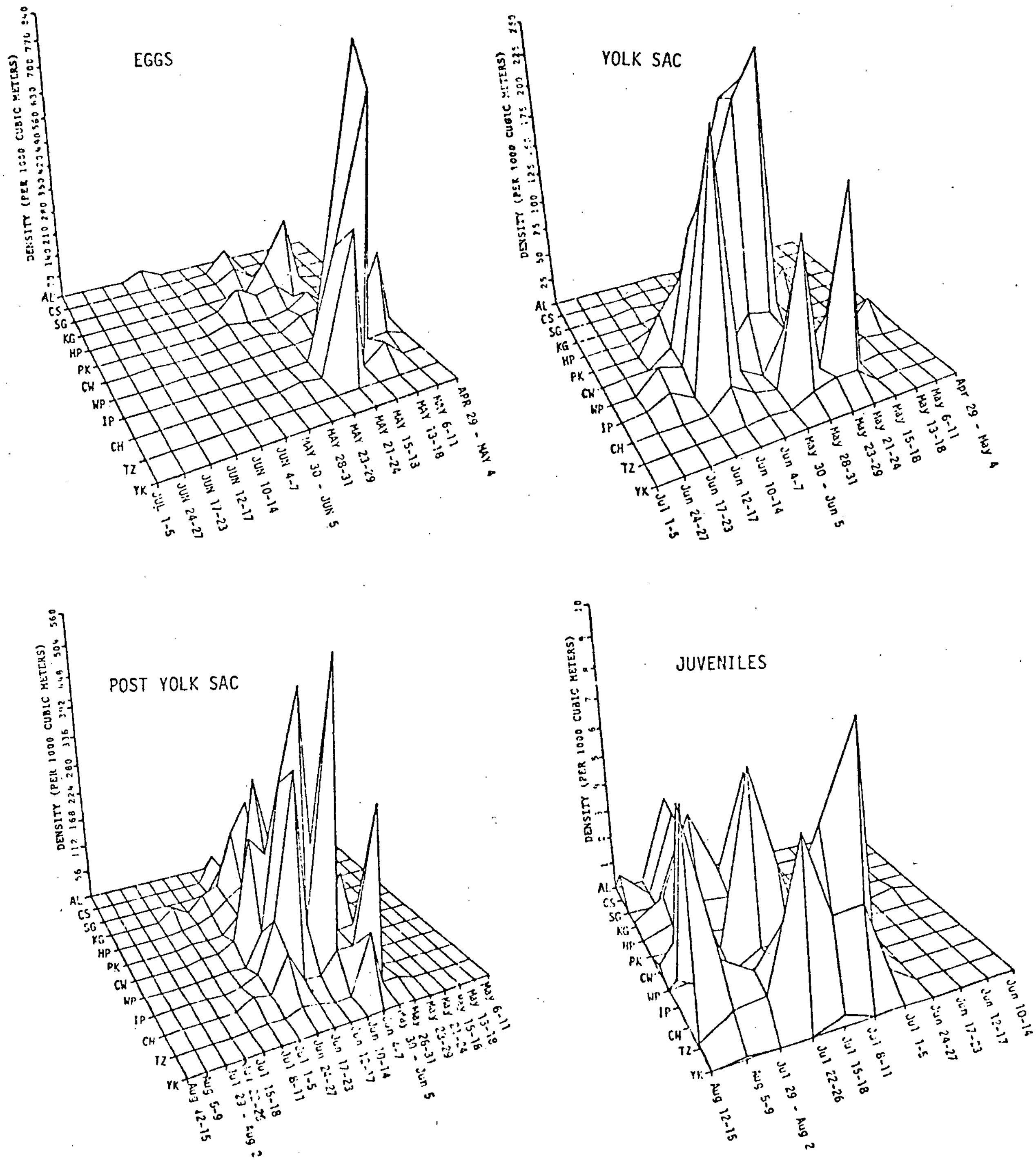

Figure 6.2-4 Longitudinal Distribution of Early Life Stages of Striped Bass during 1974 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples

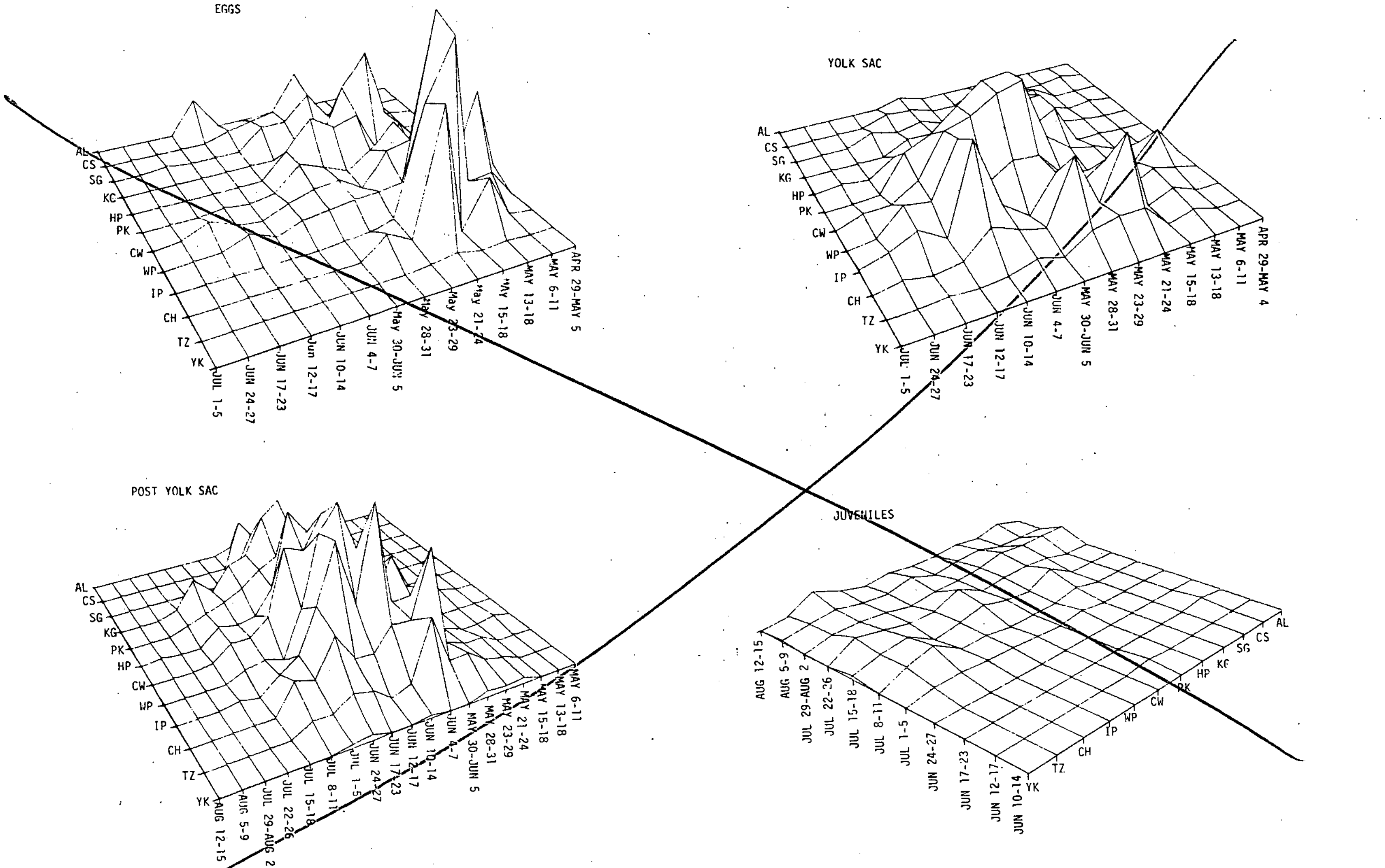

Figure 6.2-4 Longitudinal Distribution of Early Life Stages of Striped Bass during 1974 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples

Table 6.2-5 Regional Densities of Striped Bass Eggs during 1974 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

delete

Time Period	Regional Densities (No. $m^{-3} \times 10^{-3}$)*											
	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Apr 29-May 4	NC	NC	NC	NC	4.7 (1.1)*	1.3 (0.9)	NC	NC	NC	NC	NC	NC
May 6-May 11	NC	NC	0.3 (0.3)	21.3 (21.0)	233.5 (1.5)	NC	NC	NC	NC	0.2 (0.2)	NC	NC
May 13-May 18	NC	0.1 (0.1)	55.2 (51.3)	17.2 (11.2)	5.4 (3.5)	4.6 (4.6)	1.6 (1.6)	16.2 (14.8)	NC	0.2 (0.2)	NC	NC
May 15-May 18	NS	NS	NS	725.8 (717.6)	829.5 (177.8)	48.2 (20.9)	57.0 (42.3)	NC	13.8 (11.9)	NC	NC	NC
May 21-May 24	NC	0.9 (0.8)	414.2 (216.7)	330.4 (95.2)	12.2 (10.8)	37.0 (16.5)	14.2 (6.9)	54.5 (26.9)	222.5 (214.7)	5.8 (3.7)	0.2 (0.2)	NC
May 23-May 29	NC	0.1 (0.1)	0.9 (0.9)	2.1 (1.4)	8.9 (7.5)	0.7 (0.7)	1.3 (0.9)	37.5 (28.2)	96.5 (50.8)	51.5 (46.7)	77.9 (55.2)	NC
May 28-May 31	NC	NC	10.7 (7.6)	0.3 (0.3)	8.1 (6.7)	11.1 (8.2)	7.5 (5.0)	74.3 (36.8)	1.6 (0.9)	11.7 (9.4)	8.7 (8.1)	NC
May 30-Jun 5	NC	NC	NC	0.1 (0.1)	5.5 (2.6)	8.7 (4.5)	18.5 (17.8)	15.8 (15.8)	3.0 (3.0)	11.1 (2.1)	4.4 (0.4)	NC
Jun 4-Jun 7	NC	NC	NC	NC	3.3 (1.7)	2.7 (2.3)	0.4 (0.3)	NC	NC	NC	1.7 (1.7)	NC
Jun 10-Jun 14	NC	NC	NC	NC	0.1 (0.1)	NC	NC	NC	NC	NC	NC	29.4 (0)
Jun 12-Jun 17	NC	NC	NC	NC	3.9 (3.9)	0.2 (0.2)	0.2 (0.2)	NC	NC	NC	NC	NC
Jun 17-Jun 23	NC	NC	NC	NC	0.2 (0.2)	5.0 (5.0)	NC	NC	NC	0.2 (0.2)	NC	NC
Jun 24-Jun 27	NC	NC	NC	NC	0.1 (0.1)	0.2 (0.2)	NC	NC	NC	NS	NS	NS
Jul 1-Jul 5	NC	NC	NC	NC	NC	NC	NC	NC	NC	NS	NS	NS

NC = no catch
NS = no samples

*Numbers in parentheses are one standard error around density estimates

Table 6.2-6 Regional Densities of Striped Bass Yolk-Sac Larvae during 1974 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

delete

	Regional Densities (No. m^{-3} x 10^{3})*											
Time Period	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Apr 29-May 4	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
May 6-May 11	NC	NC	NC	1.1 (1.1)*	23.1 (0.1)	NC	NC	NC	0.2 (0.2)	NC	0.3 (0.3)	NC
May 13-May 18	2.2 (1.2)	1.1 (0.5)	2.5 (0.6)	4.2 (3.8)	0.3 (0.3)	NC	0.1 (0.1)	0.2 (0.2)	NC	NC	NC	NC
May 15-May 18	NS	NS	NS	NC	1.9 (1.9	2.8 (2.1)	0.1 (0.1)	1.2 (1.2)	1.2 (1.2)	4.8 (4.7)	NC	NC
May 21-May 24	NC	14.8 (4.6)	159.1 (75.7)	35.2 (11.3)	1.7 (1.0)	5.9 (1.3)	45.6 (23.8)	45.2 (36.0)	20.9 (7.8)	3.3 (1.6)	NC	NC
May 23-May 29	NC	15.2 (3.8)	8.5 (5.1)	10.1 (5.1)	3.2 (1.9)	28.8 (18.5)	20.7 (10.0)	43.2 (33.8)	11.9 (6.8)	4.8 (4.1)	3.4 (3.4)	NC
May 28-May 31	NC	9.4 (3.8)	127.7 (25.6)	36.9 (5.4)	38.4 (22.6)	242.4 (96.6)	214.7 (106.9)	121.0 (18.2)	9.0 (0.8)	5.8 (3.4)	NC	NC
May 30-Jun 5	NC	0.1 (0.1)	2.7 (1.2)	0.2 (0.1)	42.9 (19.8)	208.5 (187.7)	202.6 (93.1)	35.9 (10.4)	14.0 (4.3)	NC	NC	NC
Jun 4-Jun 7	NC	2.2 (1.6)	6.9 (2.6)	11.6 (2.8)	15.7 (11.9)	143.7 (78.4)	126.2 (63.2)	4.7 (3.4)	3.6 (0.8)	2.2 (2.2)	1.4 (0.8)	1.3 (1.3)
Jun 10-Jun 14	NC	0.1 (0.1)	19.4 (17.4)	210.5 (166.8)	145.1 (91.2)	115.9 (46.2)	61.4 (29.5)	NC	3.8 (3.1)	0.4 (0.3)	2.0 (1.0)	NC
Jun 12-Jun 17	NC	NC	0.4 (0.4)	0.8 (0.8)	13.9 (7.3)	17.5 (13.3)	35.4 (34.2)	7.0 (6.4)	NC	2.9 (1.0)	NC	NC
Jun 17-Jun 23	NC	0.1 (0.1)	NC	12.5 (8.0)	19.7 (8.3)	2.5 (1.6)	0.1 (0.1)	NC	NC	NC	NC	NC
Jun 24-Jun 27	NC	NC	0.6 (0.3)	2.6 (1.0)	0.3 (0.2)	2.1 (1.1)	NC	0.2 (0.1)	NC	NS	NS	NS
Jul 1-Jul 5	NC	NC	NC	0.2 (0.1)	NC	NC	NC	NC	NC	NS	NS	NS

NC = no catch
NS = no samples

*Numbers in parentheses are one standard error around density estimates

Table 6.2-7 Regional Densities of Striped Bass Post Yolk-Sac Larvae during 1974 Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

Regional Densities (No. m^{-3} x 10^{3})* delete

Time Period	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
May 6-May 11	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
May 13-May 18	NC	NC	NC	0.3 (0)*	NC	NC	NC	NC	NC	NC	NC	NC
May 15-May 18	NS	NS	NS	NC	NC	0.5 (0.4)	NC	NC	NC	NC	NC	NC
May 21-May 24	0.8 (0.8)	1.3 (0.8)	2.1 (1.2)	NC	NC	NC	NC	NC	NC	NC	NC	NC
May 23-May 29	0.4 (0)	2.9 (1.0)	1.9 (1.1)	1.1 (1.1)	NC	0.5 (0.5)	NC	NC	NC	NC	NC	NC
May 28-May 31	0.9 (0.4)	13.9 (7.9)	6.4 (1.4)	63.1 (7.6)	39.4 (37.6)	8.1 (4.4)	15.3 (12.1)	2.3 (0.7)	NC	NC	NC	NC
May 30-Jun 5	NC	13.1 (6.4)	317.6 (5.3)	67.6 (27.0)	142.6 (71.7)	50.4 (19.7)	40.6 (10.8)	3.6 (2.1)	2.6 (2.6)	NC	NC	NC
Jun 4-Jun 7	NC	120.5 (43.4)	62.8 (50.4)	64.6 (24.3)	40.3 (31.4)	55.8 (12.1)	27.7 (15.8)	4.8 (4.0)	1.1 (1.1)	0.7 (0.7)	NC	NC
Jun 10-Jun 14	0.2 (0.2)	4.2 (2.0)	64.6 (20.5)	551.7 (240.2)	213.5 (89.8)	134.8 (55.8)	80.0 (27.9)	4.5 (2.7)	2.0 (1.1)	0.6 (0.4)	2.1 (1.8)	NC
Jun 12-Jun 17	NC	0.7 (0.5)	22.1 (1.7)	93.7 (46.6)	491.3 (143.4)	339.6 (75.3)	183.3 (75.0)	115.4 (80.0)	211.9 (64.1)	4.8 (1.8)	NC	NC
Jun 17-Jun 23	NC	8.7 (3.6)	23.8 (2.0)	376.7 (70.1)	335.7 (98.1)	183.9 (50.2)	303.4 (119.6)	67.9 (21.1)	154.6 (41.4)	54.6 (16.7)	54.8 (10.6)	0.8 (0.8)
Jun 24-Jun 27	0.8 (0.6)	13.5 (2.9)	85.5 (18.6)	118.7 (17.0)	64.3 (1.8)	220.3 (51.7)	40.0 (3.9)	46.1 (8.6)	48.8 (13.1)	NS	NS	NS
Jul 1-Jul 5	0.3 (0.3)	2.9 (1.4)	13.6 (6.3)	20.3 (11.6)	0.7 (0.3)	24.8 (8.2)	6.5 (1.7)	21.0 (9.9)	36.2 (16.9)	NS	NS	NS
Jul 8-Jul 11	NC	3.0 (1.1)	20.1 (9.0)	6.0 (1.3)	3.4 (0.9)	6.9 (2.2)	3.9 (1.5)	9.7 (4.8)	5.7 (1.9)	NS	NS	NS
Jul 15-Jul 18	NC	NC	NC	NC	1.8 (0.6)	6.8 (1.8)	6.2 (2.6)	4.3 (1.8)	26.0 (17.7)	NS	NS	NS
Jul 22-Jul 26	NC	NC	NC	0.3 (0.3)	NC	0.2 (0.2)	NC	1.0 (0.7)	1.1 (0.4)	NC	NC	NS
Jul 29-Aug 2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Aug 5-Aug 9	NC	NC	NC	NC	NC	NC	0.1	NC	NC	NC	NC	NC
Aug 12-Aug 15	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

NC = no catch
NS = no samples

*Numbers in parentheses are one standard error around density estimates

Table 6.2-8 Regional Densities of Striped Bass Juveniles during 1974 in Hudson River Estuary (RM 14-140; km 23-225) Based on Epibenthic Sled and Tucker Trawl Samples (See Table 6.1-1 for definition of region abbreviations)

	Regional Densities (No. m^{-3} x 10^{-3})* delete											
Time Period	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Jun 10-Jun 14	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Jun 12-Jun 17	NC	NC	NC	NC	NC	NC	0.2 (0.2)*	NC	NC	NC	NC	NC
Jun 17-Jun 23	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	0.2 (0.2)	NC
Jun 24-Jun 27	NC	NC	NC	NC	NC	NC	NC	NC	NC	NS	NS	NS
Jul 1-Jul 5	NC	0.7 (0.5)	0.9 (0.6)	0.4 (0.3)	0.3 (0.3)	0.1 (0.1)	NC	0.3 (0.2)	NC	NS	NS	NS
Jul 8-Jul 11	NC	3.2 (1.8)	8.3 (4.1)	0.2 (0.1)	0.3 (0.2)	NC	NC	NC	0.6 (0.4)	NS	NS	NS
Jul 15-Jul 18	0.4 (0.3)	3.1 (2.1)	5.4 (1.8)	NC	0.6 (0.5)	2.8 (0.5)	0.5 (0.4)	0.1 (0.1)	4.8 (3.1)	NS	NS	NS
Jul 22-Jul 26	NC	5.8 (2.8)	2.8 (0.8)	0.7 (0.5)	0.6 (0.3)	6.2 (2.8)	0.2 (0.1)	0.9 (0.7)	1.4 (0.6)	0.8 (0.8)	NC	NS
Jul 29-Aug 2	NC	1.1 (0.7)	1.3 (0.6)	0.6 (0.3)	NC	0.3 (0)	0.4 (0.4)	1.0 (0.9)	3.7 (2.0)	2.7 (1.9)	2.9 (0.8)	3.1 (3.1)
Aug 5-Aug 9	0.1 (0.1)	0.9 (0.6)	2.0 (0.8)	0.4 (0.4)	0.1 (0.1)	1.8 (0.8)	NC	0.4 (0.3)	0.9 (0.6)	NC	NC	NC
Aug 12-Aug 15	NC	0.2 (0.2)	6.8 (2.9)	1.0 (0.7)	NC	0.3 (0.3)	NC	NC	0.2 (0.2)	NC	1.0 (1.0)	NC

NC = no catch
NS = no samples

*Numbers in parentheses are one standard error around density estimates

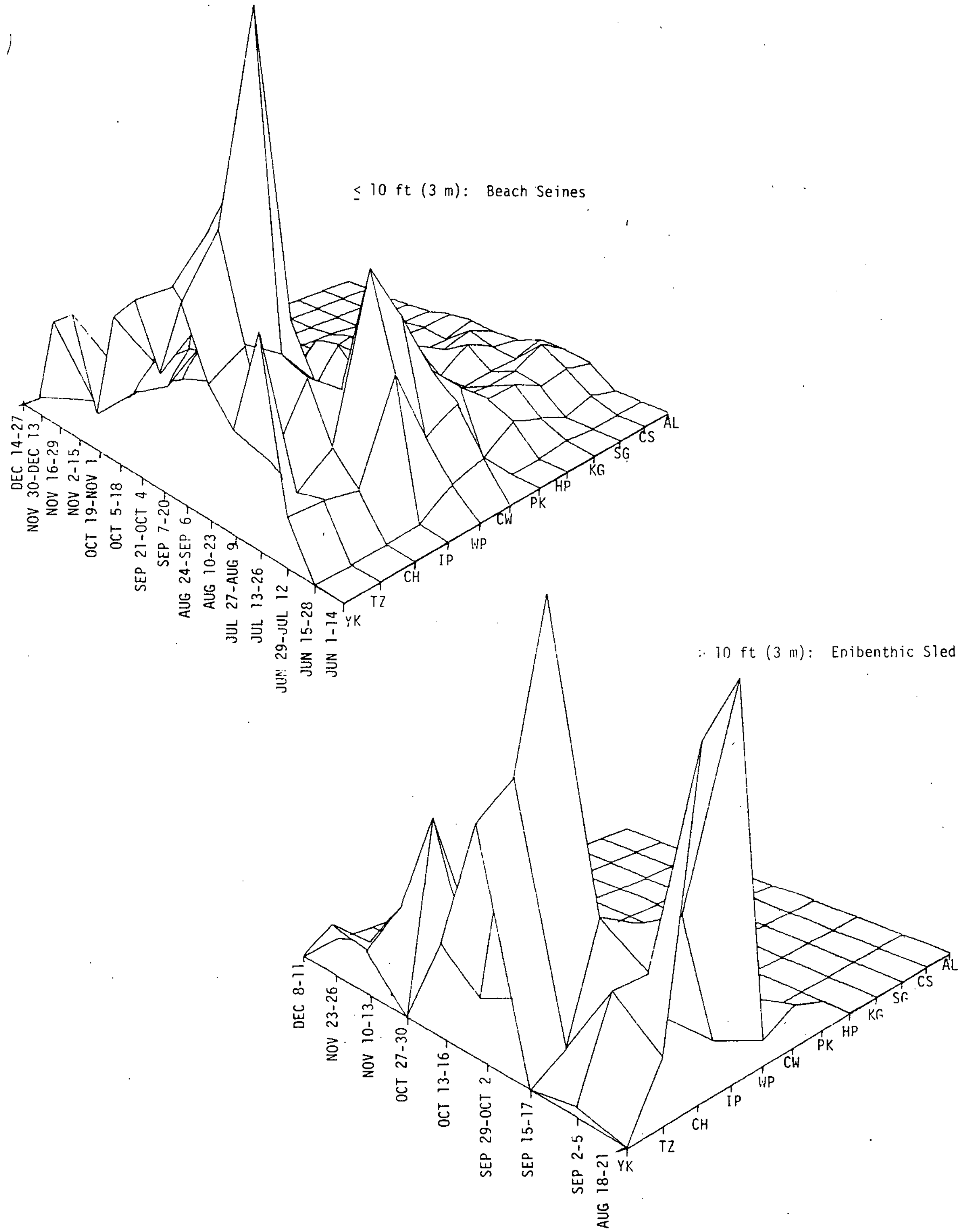

Figure 6.2-5 Longitudinal Distribution of Juvenile Striped Bass during 1975 in Hudson River Estuary (no samples at depths > 3 m above Poughkeepsie [PK] region) See Table 6.1-1 for Definition of Region Abbreviations (the two plots have different vertical scales, see Tables 6.2-9 and 6.2-10).

Table 6.2-9 Regional Catch per Effort (C/f) for Striped Bass Juveniles Captured in Beach Seines during 1975 in Hudson River Estuary (RM 12-152; km 19-243) (See Table 6.1-1 for definition of region abbreviations)

	Region											
Time Period	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Jun 1-Jun 14	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Jun 15-Jun 28	0.1* (0.1)*	NC	0.1 (0.1)	0.2 (0.1)	2.1 (0.7	3.0 (1.2)	NC	NC	0.3 (0.3)	NC	NC	NC
Jun 29-Jul 12	4.3 (2.2)	4.1 (1.9)	3.4 (1.0)	11.6 (3.1)	5.0 (1.5)	6.6 (1.5)	0.3 (0.3)	2.3 (1.9)	1.3 (1.0)	NC	0.8 (0.5)	NC
Jul 13-Jul 26	17.6 (5.8)	3.4 (1.2)	5.8 (1.2)	19.2 (8.0)	14.1 (5.1)	8.4 (1.2)	5.6 (2.4)	3.3 (1.1)	3.4 (0.8)	1.9 (0.8)	2.4 (1.3)	1.7 (1.1)
Jul 27-Aug 9	8.8 (1.9)	4.7 (1.4)	10.5 (1.8)	8.2 (2.6)	3.6 (0.8)	6.6 (1.4)	3.4 (1.3)	2.4 (1.0)	2.2 (1.0)	2.4 (1.0)	3.8 (1.4)	2.0 (0.8)
Aug 10-Aug 23	11.5 (2.0)	13.4 (6.3)	11.4 (3.2)	7.8 (1.4)	3.5 (0.8)	5.2 (2.4)	3.0 (1.4)	0.7 (0.3)	1.0 (0.6)	1.3 (0.7)	1.3 (0.4)	2.1 (0.8)
Aug 24-Sep 6	17.0 (2.7)	21.7 (8.3)	37.9 (15.0)	12.1 (2.4)	2.7 (0.8)	3.2 (0.8)	1.0 (0.5)	1.7 (1.7)	1.0 (0)	3.0 (0.8)	1.5 (0.6)	1.1 (1.0)
Sep 7-Sep 20	10.2 (1.2)	13.0 (7.6)	23.5 (6.3)	7.0 (1.1)	6.3 (1.6)	0.9 (0.3)	2.2 (0.6)	1.3 (0.6)	3.0 (1.0)	1.4 (0.4)	2.3 (0.7)	0.9 (0.6)
Sep 21-Oct 4	15.4 (3.3)	15.4 (2.8)	19.0 (5.4)	8.6 (1.9)	2.8 (0.8)	0.5 (0.2)	4.5 (2.4)	2.0 (1.2)	2.0 (0)	0.3 (0.3)	0.3 (0.3)	1.2 (0.8)
Oct 5-Oct 18	13.0 (2.8)	7.9 (1.7)	7.9 (1.3)	5.9 (1.6)	2.2 (0.4)	0.9 (0.3)	4.0 (1.0)	0.4 (0.2)	NC	0.8 (0.6)	0.6 (0.6)	0.9 (0.4)
Oct 19-Nov 1	3.5 (0.1)	4.1 (1.1)	3.5 (0.7)	6.2 (1.4)	1.0 (0.3)	0.9 (0.2)	NS	0.3 (0.3)	1.0 (1.0)	NC	0.2 (0.2)	0.3 (0.2)
Nov 2-Nov 15	11.4 (3.0)	5.7 (1.2)	2.6 (0.5)	1.8 (0.4)	0.2 (0.1)	0.2 (0.1)	NC	0.3 (0.3)	0.3 (0.3)	NC	NC	0.1 (0.1)
Nov 16-Nov 29	9.8 (3.0)	1.1 (0.3)	0.3 (0.1)	1.1 (0.6)	0.3 (0.2)	0.1 (0.1)	NC	NC	NC	NC	NC	NC
Nov 30-Dec 13	1.7 (0.9)	0.2 (0.2)	<0.1 **	0.1 (0.1)	<0.1 **	NC	NC	NC	NC	NC	NC	NC
Dec 14-Dec 27	NS	NC	NC	NS	NC	NC	NS	NS	NS	NS	NS	NS

NC = no catch
NS = no samples

*Numbers in parentheses are one standard error around c/f estimates
**Standard error <0.1

Table 6.2-10 Regional Densities of Striped Bass Juveniles Captured in Epibenthic Sleds during 1975 in Hudson River Estuary (RM 14-140; km 23-225)(See Table 6.1-1 for definition of region abbreviations)

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	Regional Densities (No. $m^{-3} \times 10^{3}$)*											
Time Period	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Aug 18-Aug 21	NC	2.5 (2.1)*	12.6 (3.0)	14.2 (3.0)	1.0 (0.6)	1.7 (0.8)	1.2 (0.8)	NS	NS	NS	NS	NS
Sep 2-Sep 5	0.4 (0.4)	4.0 (1.8)	4.0 (1.1)	5.5 (2.5)	NC	1.1 (0.7)	NC	NS	NS	NS	NS	NS
Sep 15-Sep 17	NC	0.9 (0.4)	5.2 (1.6)	4.4 (2.5)	NC	1.3 (0.9)	NC	NS	NS	NS	NS	NS
Sep 29-Oct 2	9.0 (4.9)	10.1 (2.2)	15.9 (4.6)	NC	NC	NC	0.6 (0.6)	NS	NS	NS	NS	NS
Oct 13-Oct 16	3.8 (2.4)	1.0 (0.3)	0.4 (0.2)	NC	NC	NC	NC	NS	NS	NS	NS	NS
Oct 27-Oct 30	NC	0.7 (0.4)	2.0 (0.5)	NC	NC	NC	NC	NS	NS	NS	NS	NS
Nov 10-Nov 13	1.9 (0.6)	3.2 (0.7)	1.1 (0.4)	0.9 (0.4)	NC	NC	NC	NS	NS	NS	NS	NS
Nov 23-Nov 26	2.2 (1.6)	0.8 (0.4)	0.2 (0.1)	NC	NC	NC	NC	NS	NS	NS	NS	NS
Dec 8-Dec 11	NC	0.2 (0.2)	0.1 (0.1)	NC	NC	NC	NC	NS	NS	NS	NS	NS

NC = no catch
NS = no samples

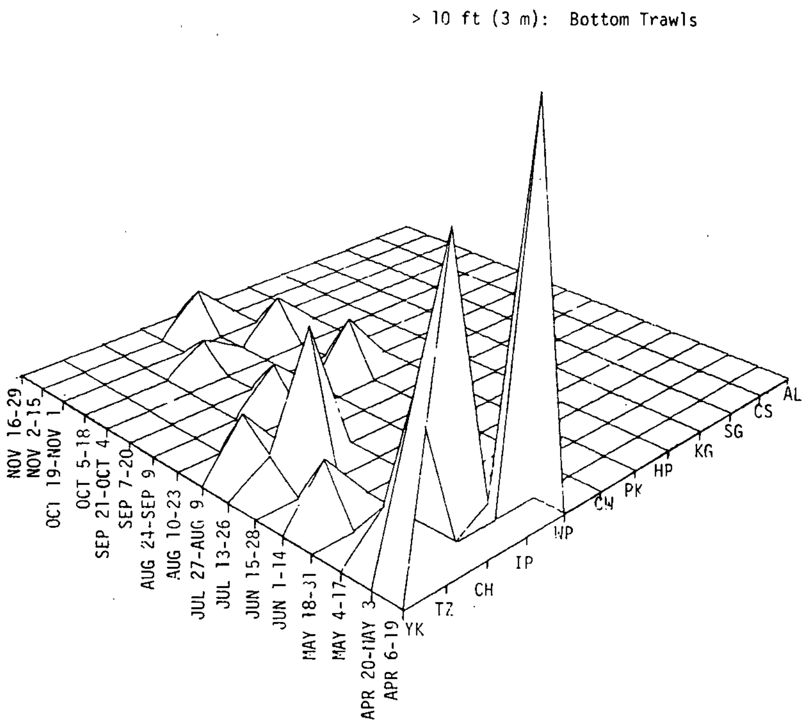
*Numbers in parentheses are one standard error around density estimates

The distribution of yearling striped bass in the following spring (Fig. 6.2-6 and Tables 6.2-11 and 6.2-12) suggests that a portion of the juvenile population overwinters in the offshore areas of the lower estuary and downstream regions of the middle estuary (Section 7.5). By June, however, the remaining yearlings are distributed throughout the estuary (Fig. 6.2-6 and Section 7.6), primarily in the shorezone (Table 6.2-13).

6.2.2 VULNERABILITY. The vulnerability of striped bass eggs and larvae to entrainment at Hudson River power plants is high throughout the peak abundance period (May and June) because most of the population is distributed in the middle estuary. The eggs are probably somewhat less vulnerable because they are concentrated near the bottom. Yolk-sac and post yolk-sac larvae exhibit diel (day/night) differences in vulnerability. During the day, they are concentrated near the bottom and should be vulnerable primarily to power plants withdrawing water from near the bottom; at night, however, they disperse through the water column and should become more vulnerable to plants withdrawing water from midwater and surface strata. Post yolk-sac larvae are more strongly oriented to the bottom than are yolk-sac larvae regardless of time of day but exhibit some dispersion upward at night, suggesting that their overall vulnerability is less than that of yolk-sac larvae.

Most of the juvenile population is entrainable through mid-July and highly vulnerable but may be better able to avoid entrainment than eggs and larvae since swimming ability increases greatly after transformation to the juvenile stage (Section 7.5). As the juveniles reach impingeable size during July (Section 7.5), the population continues to move downstream

(FIGURE 6.2-5) and shoreward (Table 6.2-13). Vulnerability of juveniles to power plants (via impingement) is high during July but decreases to moderate in August and September as the population continues to move downstream and leaves the vicinity of Roseton and Danskammer. During August and September, the juvenile population is most vulnerable to impingement at Bowline, which withdraws cooling water from ~~the shoals~~ an inshore pond (Section 2). Vulnerability to



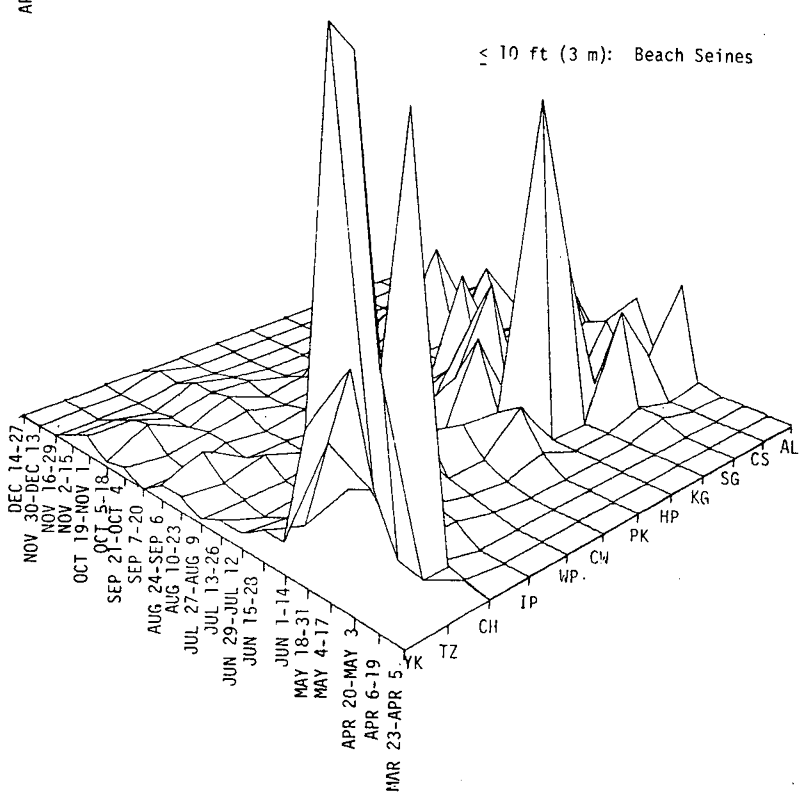


Figure 6.2-6 Longitudinal Distribution of Yearling Striped Bass during 1975 in Hudson River Estuary (no samples at depths > 3 m above Cornwall [CW] region) See Table 6.1-1 for Definition of Region Abbreviations (the two plots have different vertical scales, see Tables 6.2-11 and 6.2-12).

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Table 6.2-11 Regional Catch per Effort (C/f) for Yearling Striped Bass Captured in Beach Seines during 1975 in Hudson River Estuary (RM 12-152; km 19-243)(See Table 6.1-1 for definition of region abbreviations)

Time Period	Region YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Mar 23-Apr 5	8.2* (3.2)	1.0 (1.0)	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Apr 6-Apr 19	4.3 (1.2)	0.5 (0.3)	0.1 (0.1)	<0.1 *	<0.1 *	NC	NC	NC	NC	NC	NC	NC
Apr 20-May 3	8.8 (1.9)	0.6 (0.2)	0.2 (0.1)	<0.1 **	NC	<0.1 **	NC	NC	NC	NC	NC	NC
May 4-May 17	9.1 (1.6)	1.6 (1.0)	0.3 (0.2)	0.3 (0.2)	0.1 (0.1)	NC	NC	NC	NC	0.2 (0.2)	NC	NC
May 18-May 31	2.8 (1.0)	3.5 (2.3)	0.3 (0.1)	0.4 (0.3)	0.2 (0.1)	0.1 (0.1)	0.3 (0.2)	NC	NS	0.2 (0.2)	NC	0.1 (0.1)
Jun 1-Jun 14	0.6 (0.2)	2.0 (0.8)	0.8 (0.2)	1.3 (0.4)	0.3 (0.1)	0.3 (0.1)	1.0 (1.0)	NC	NC	2.0 (0.6)	0.8 (0.6)	2.0 (1.3)
Jun 15-Jun 28	0.6 (0.3)	0.3 (0.1)	0.6 (0.2)	1.1 (0.4)	1.0 (0.5)	0.8 (0.4)	0.7 (0.3)	6.3 (3.5)	3.0 (1.5)	0.3 (0.3)	0.4 (0.4)	0.4 (0.2)
Jun 29-Jul 12	0.3 (0.2)	0.2 (0.1)	0.1 **	0.5 (0.2)	0.5 (0.2)	0.2 (0.1)	2.0 (1.4)	0.3 (0.3)	0.3 (0.3)	NC	1.2 (0.6)	1.4 (0.8)
Jul 13-Jul 26	0.3 (0.2)	NC	0.1 (0.1)	0.1 (0.1)	0.3 (0.2)	0.7 (0.4)	1.0 (0.6)	2.6 (2.6)	NC	0.4 (0.3)	1.0 (0.7)	0.1 (0.1)
Jul 27-Aug 9	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)	0.2 (0.1)	0.2 (0.2)	0.4 (0.2)	1.6 (1.6)	0.6 (0.6)	0.1 (0.1)	1.8 (1.1)	0.4 (0.2)
Aug 10-Aug 23	0.3 (0.2)	0.2 (0.1)	0.4 (0.3)	0.1 (0.1)	0.2 (0.1)	0.3 (0.2)	0.1 (0.1)	0.5 (0.5)	NC	0.1 (0.1)	0.4 (0.2)	0.1 (0.1)
Aug 24-Sep 6	0.3 (0.2)	0.6 (0.4)	0.1 **	0.1 (0.1)	NC	0.1 (0.1)	NC	NC	2.0 (0)	0.3 (0.3)	0.3 (0.2)	0.5 (0.3)
Sep 7-Sep 20	<0.1 **	NC	0.2 (0.1)	0.1 **	0.2 (0.1)	0.2 (0.1)	NC	NC	NC	0.2 (0.2)	0.1 (0.1)	NC
Sep 21-Oct 4	0.2 (0.1)	0.1 (0.1)	0.2 (0.1)	0.3 (0.1)	0.1 **	0.2 (0.1)	0.3 (0.3)	0.3 (0.3)	NC	NC	1.3 (1.0)	0.2 (0.2)
Oct 5-Oct 18	0.1 (0.1)	0.5 (0.3)	0.1 (0.1)	0.4 (0.3)	0.1 (0.1)	0.2 (0.2)	1.0 (1.0)	0.2 (0.2)	0.5 (0.5)	1.8 (1.6)	0.2 (0.2)	0.4 (0.2)
Oct 19-Nov 1	0.4 (0.4)	0.4 (0.2)	0.1 (0.1)	0.3 (0.1)	0.2 (0.1)	<0.1 **	NS	NC	0.5 (0.5)	NC	0.2 (0.2)	0.3 (0.2)
Nov 2-Nov 15	0.2 (0.1)	0.2 (0.1)	NC	0.3 (0.2)	0.1 **	<0.1 **	NC	NC	NC	NC	NC	NC
Nov 16-Nov 29	NC	NC	NC	0.1 (0.1)	<0.1 **	NC	NC	NC	NC	NC	NC	NC
Nov 30-Dec 13	NC	NC	NC	0.2 (0.1)	NC	NC	NC	NC	NC	NC	NC	NC
Dec 14-Dec 27	NS	NC	NC	NS	NC	NC	NS	NS	NS	NS	NS	NS

NC = no catch
NS = no samples
* = Number in parentheses are one standard error around density estimates
** = Standard error < 0.1

Table 6.2-12 Regional Catch per Effort (C/f) for Yearling Striped Bass Captured in Bottom Trawls during 1975 in Hudson River Estuary (RM 12-152; km 19-243) (See Table 6.1-1 for definition of region abbreviations)

	Region											
Time Period	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS	AL
Apr 6-Apr 19	NS	2.3 (1.4)*	0.4 (0.4)	2.9 (1.4)	NC	NC	NS	NS	NS	NS	NS	NS
Apr 20-May 3	NS	1.2 (0.6)	NS	NC	NC	0.5 (0.5)	NS	NS	NS	NS	NS	NS
May 4-May 17	NS	0.3 (0.3)	NC	0.3 (0.2)	NC	NC	NS	NS	NS	NS	NS	NS
May 18-May 31	NS	NC	NC	0.2 (0.2)	NC	NC	NS	NS	NS	NS	NS	NS
Jun 1-Jun 14	NS	0.4 (0.3)	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Jun 15-Jun 28	NS	NC	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Jul 13-Jul 26	NS	0.2 (0.2)	1.0 (1.0)	NC	NC	NC	NS	NS	NS	NS	NS	NS
Jul 27-Aug 9	NS	0.4 (0.4)	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Aug 10-Aug 23	NS	NC	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Agu 24-Sep 6	NS	NC	NC	0.3 (0.2)	NC	0.4 (0.4)	NS	NS	NS	NS	NS	NS
Sep 7-Sep 20	NS	NC	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Sep 21-Oct 4	NS	NC	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Oct 5-Oct 18	NS	NC	NC	0.2 (0.2)	NC	0.3 (0.3)	NS	NS	NS	NS	NS	NS
Oct 19-Nov 1	NS	NC	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS
Nov 2-Nov 15	NS	NC	NC	NC	0.3 (0.3)	NC	NS	NS	NS	NS	NS	NS
Nov 16-Nov 29	NS	NC	NC	NC	NC	NC	NS	NS	NS	NS	NS	NS

NC = no catch
NS = no samples

*Numbers in parentheses are one standard error around c/f estimates

This is a replacement Table.

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Table 6.2-13 Depth Distribution of Young Striped Bass in Hudson River Estuary during Their First Year of Life*

Month	Area of Estuary		Index of Depth Distribution		
	Rm	km	Channel (>20 ft [6m])	Shoal (10-20 ft [3-6m])	Shorezone (<10 ft [3m])
July**	12- 76	19-122	28	41	31
August**	12- 76	19-122	14	29	57
September**	12- 76	19-122	14	16	70
October**	12- 76	19-122	4	23	73
November**	12- 76	19-122	11	31	58
December** (through Dec 15)	12- 76	19-122	4	51	45
January† February March	12- 76	19-122	34	65	1
April‡	12- 76	19-122	25	60	15
May‡	12- 76	19-122	10	20	70
June‡	12- 76	19-122	5	10	85

*Monthly summary of Figure 6.2-3

**Calculated from 1975 standing-crop estimates based on epibenthic sled, Tucker trawl, and beach seines (calculations and assumptions presented in Section 7.9)

†Hypothesized; no sampling

‡Estimated from catches in beach seines and bottom trawls during 1975

Table 6.2-13 Depth Distribution of Young Striped Bass in Hudson River Estuary during Their First Year of Life*

Month	Area of Estuary Rm	Area of Estuary km	Index of Depth Distribution: Channel (>20 ft [6m])	Shoal (10-20 ft [3-6m])	Shorezone (<10 ft [3m])
July**	12-152	19-243	40	40	20
August**	12-152 until Aug 15, then 12-76	19-243 19-122	13	29	58
September**	12-76	19-122	13	16	71
October**	12-76	19-122	5	22	73
November**	12-76	19-122	12	30	58
December** (through Dec 15)	12-76	19-122	4	51	45
January† February March	12-76	19-122	34	65	1
April‡	12-76	19-122	25	60	15
May‡	12-76	19-122	10	20	70
June‡	12-76	19-122	5	10	85

* Monthly summary of Figure 6.2-3

** Calculated from 1975 standing-crop estimates based on epibenthic sled, Tucker trawl, and beach seines (calculation and assumptions presented in Section 7.9)

† Hypothesized; no sampling

‡ Estimated from catches in beach seines and bottom trawls during 1975

impingement decreases at all plants during October, November, and December as most of the juveniles move offshore and into or through the most downstream region of the lower estuary to the lower bays. Vulnerability to impingement of the unknown (but presumably small) portion of the juvenile population that overwinters in the lower estuary is low to moderate.

6.3 OTHER SPECIES. Data sets from several surveys conducted during 1974 and 1975 (TI's long river surveys) were examined to determine the distribution of each life stage of white perch, American shad, Atlantic tomcod, blueback herring, and shortnose sturgeon in the Hudson River estuary and to assess the vulnerability of these species to the Bowline (RM 37; km 60), Lovett (RM 41; km 66), Indian Point (RM 42; km 68), Roseton (RM 65; km 105), and Danskammer (RM 66; km 106) power plants. If the longitudinal distributions during 1974 and 1975 were similar, only the 1975 data are discussed, but any major differences in distribution between years are described. Abundance estimates derived from the ichthyoplankton survey and fall epibenthic sled survey are presented as densities (number of individuals per 1000 m^3 of water strained). Abundance estimates derived from the beach seine survey and interregional bottom trawl survey are presented as catch per unit effort (number of individuals per tow). Box trap survey abundance estimates for Atlantic tomcod are presented as catch per hour.

Not all sampling gear were equally useful for describing the longitudinal distribution of every life stage, so separate abundance estimates representing different habitats or depth strata were calculated for the various life stages. Early life stages (eggs, yolk-sac larvae, post yolk-sac larvae) have relatively short durations, ranging from hours to several weeks, and are collected with Tucker trawls and epibenthic sleds. Highly mobile stages (juveniles and yearlings) have much longer durations (several months) and are collected in more types of gear e.g., Tucker trawls, epibenthic sleds, beach seines, and bottom trawls.

Seasonal trends in the depth distribution of juveniles and yearlings were examined to determine which gear best described longitudinal distribution (i.e., sampled the majority of the population) during each month. Indices of trends in depth distribution in the area of the river sampled by all gear (the lower and middle estuary) were derived as follows: standing crop estimates in three depth strata (<10 ft, 10-20 ft, and >20 ft [<3 m, 3-6 m, and >6 m]) were calculated for white perch and Atlantic tomcod (calculation methods and assumptions are presented in Section 7.9); and biweekly mean abundance estimates were plotted separately by gear type for all species except shortnose sturgeon. Thus, changes in the catch by a particular gear provided an estimate of changes in depth distribution. For example, a decrease in beach seine catch just prior to an increase in epibenthic sled catch would suggest that fish were moving away from the shorezone to deeper shoal or channel areas.

Additional insight into the depth distribution of the entrainable life stages (eggs, larvae, early juveniles) was gained by comparing abundance estimates for different depth strata as follows. In three sampling regions--Tappan Zee, Croton-Haverstraw, and Indian Point, three depth strata were compared:

- Shoal - areas on the east or west side of the river where depths are <20 ft (6 m)
- Bottom - areas of the river ≤10 ft (3 m) from the bottom where depths are >20 ft (6 m)
- Channel - areas of the river >10 ft (3 m) from the bottom where depths are >20 ft (6 m)

In seven regions where shoals are limited (West Point, Cornwall, Poughkeepsie, Hyde Park, Kingston, Saugerties, and Catskill), only two depth strata (bottom-shoal combined and channel) were compared.

To facilitate a general description of longitudinal distribution and assess vulnerability to power plant operations, abundance in each of the sampling regions (Table 6.1-1) was categorized as follows:

- No Catch - the life stage might have been present but did not occur in collections
- Occasional - that portion of the life stage's abundance range (from 0 to maximum) between 0 and the lower one-eighth of the entire range
- Frequent - that portion of the life stage's abundance range from the lower one-eighth to the lower one-fourth of the entire range
- Common - that portion of the life stage's abundance range from the lower one-fourth to the lower one-half of the entire range
- Abundant - that portion of the life stage's abundance range in the upper one-half of the entire range

Abundance ranges were determined separately by gear and life stage using the largest monthly regional abundance estimate for the particular life stage (the minimum abundance estimate is 0). For example, assume that juvenile blueback herring were caught in beach seines from June through December 1975 and that the largest monthly mean abundance estimate (catch per tow), 64, occurred in August; then, the abundance range for juvenile blueback herring in beach seines in 1975 would equal 64 and the abundance of juvenile blueback herring in any sampling region with a monthly mean catch per tow between 0 and 8 (i.e., between 0 and the lower one-eighth of the entire range) would be defined as "occasional."

6.3.1 WHITE PERCH DISTRIBUTION AND VULNERABILITY. The white perch is a resident species which spawns during spring and summer in the Hudson River estuary (Section 5.3), with eggs occurring throughout the estuary from early May into early July (Fig. 6.3-1). Spawning peaks in May and early June when water temperatures range from 14-21°C. Although white perch eggs have been reported to be deposited on the bottom and usually attached to the substrate (Section 5.3), TI collected significantly more ~~(p <0.01)~~ ($\alpha = 0.05$) eggs in the channel stratum than in the bottom stratum during the peak abundance period (late May), showing that all white perch eggs in the Hudson River do not adhere to the substrate but many are suspended in the water column >10 ft (3 m) from the bottom.

Yolk-sac larvae are also widely distributed throughout the estuary from early May through early July, with peak abundance in late May-early June. The longitudinal distribution of yolk-sac larvae is similar to that of eggs (Fig. 6.3-1). Yolk-sac larval densities were significantly higher ~~(α = 0.01)~~ ($\alpha = 0.05$) in the channel stratum than in the bottom stratum.

Post yolk-sac larvae occur throughout the estuary from mid-May through July (Fig. 6.3-1), but peak abundance is generally in June. Post yolk-sac larvae were significantly more abundant ($\alpha = 0.05$) in the bottom stratum during the day in mid to late May. All sampling was done at night during June when peak abundance of post yolk-sac larvae occurred, and they were ~~more~~ significantly more abundant ~~(α = 0.01)~~ ($\alpha = 0.05$) in the channel stratum than near the bottom, suggesting that they disperse through the water column at night.

Juveniles first appear in late June and become increasingly abundant through July and August. Early juveniles (July-August) are concentrated in the middle and upper estuary (Fig. 6.3-1), but their distribution gradually shifts downstream during September to the lower and middle estuary. Juvenile depth distribution changes seasonally. Until mid-July, they are most abundant in areas deeper than 20 ft (6 m)(Figs. 6.3-2 and 6.3-3). The first appear in the shorezone (<10 ft [3 m] deep) in late

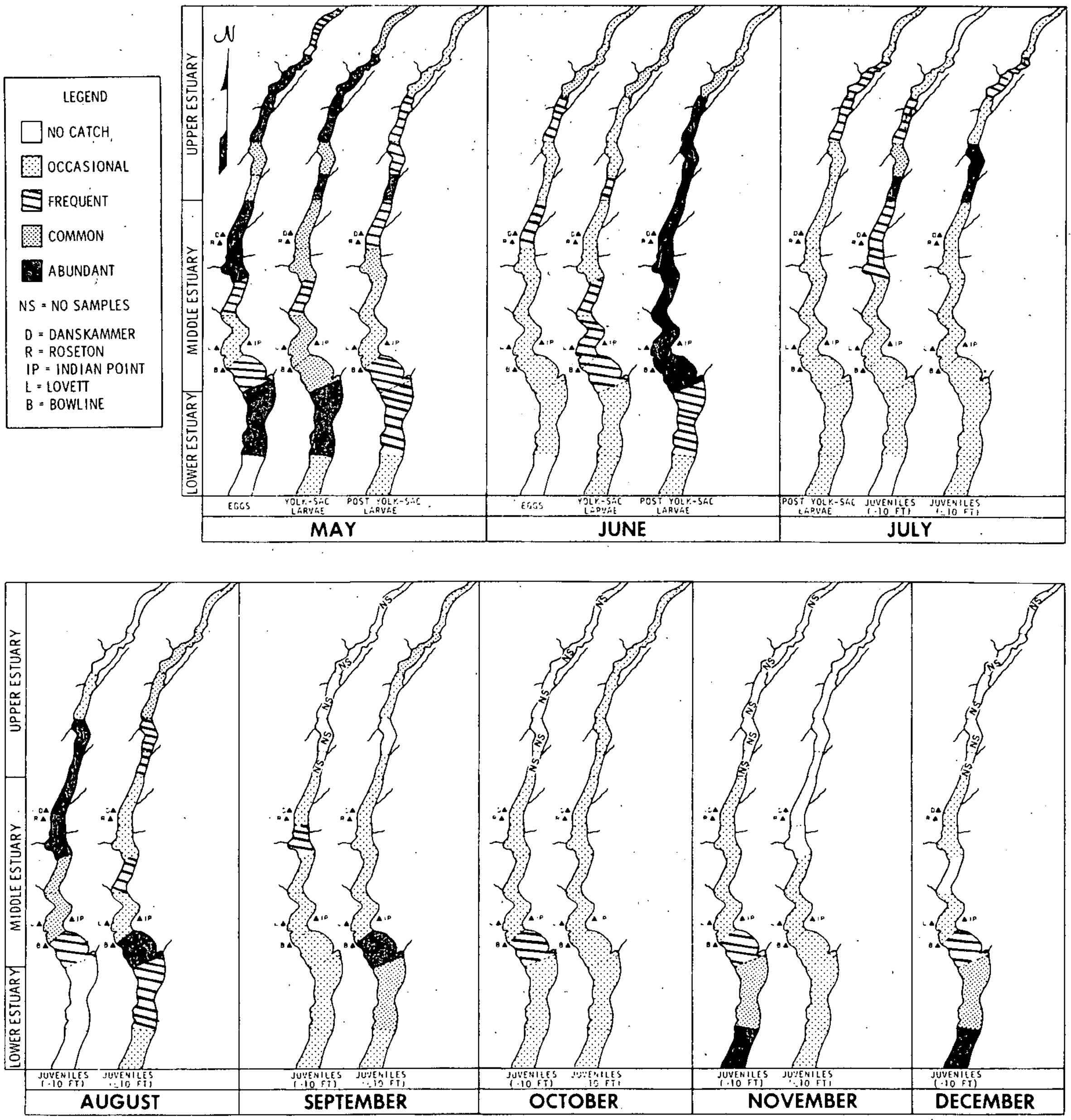


Figure 6.3-1 Longitudinal Distribution of White Perch in Hudson River Estuary during 1975. (Measurements in feet represent river depth)

(RM 12-152; Km 19-243)

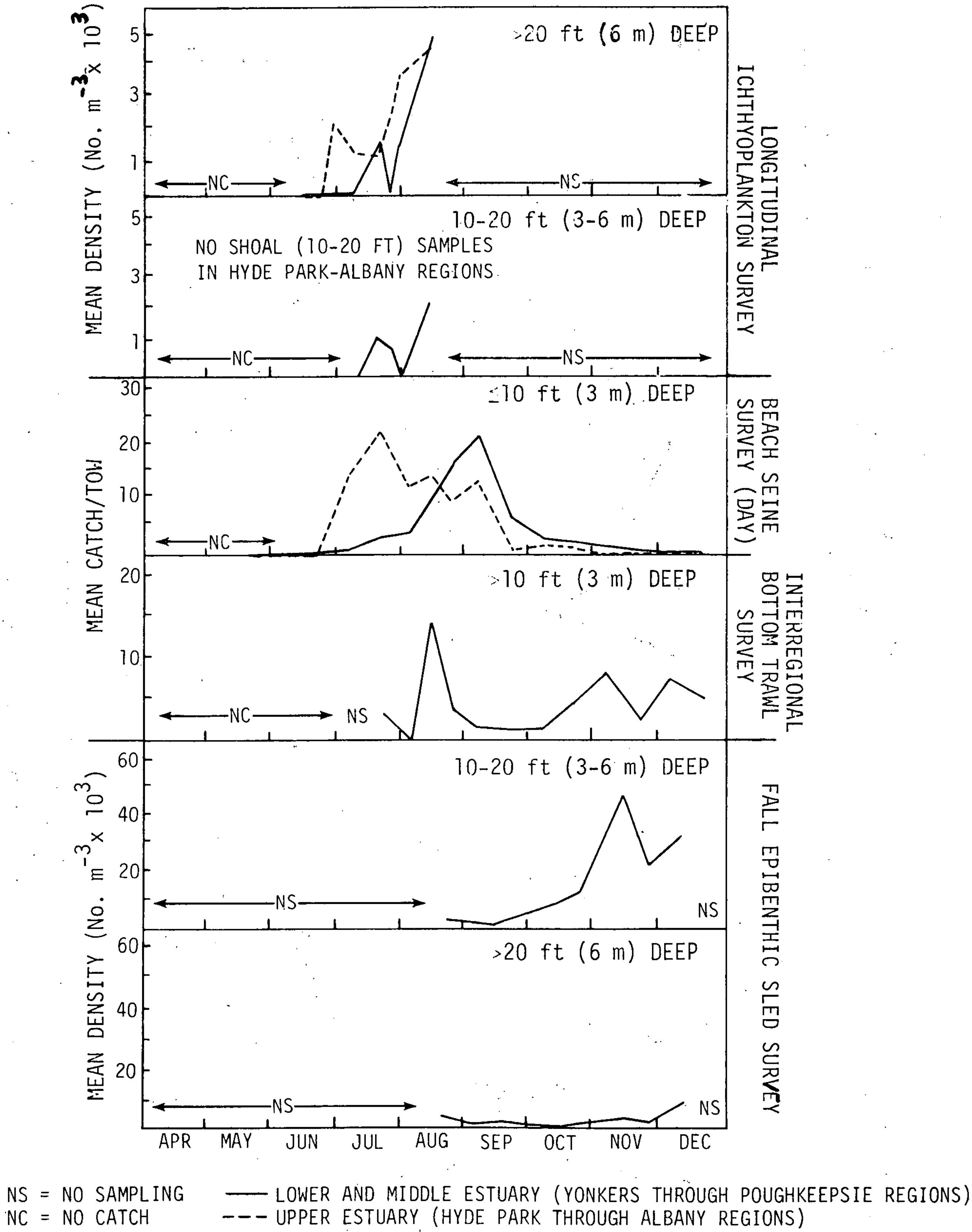


Figure 6.3-2 Catches of Juvenile White Perch, by Gear, in Hudson River Estuary during 1975. (There was no sampling with bottom trawls and fall epibenthic sleds upstream from the Poughkeepsie region)

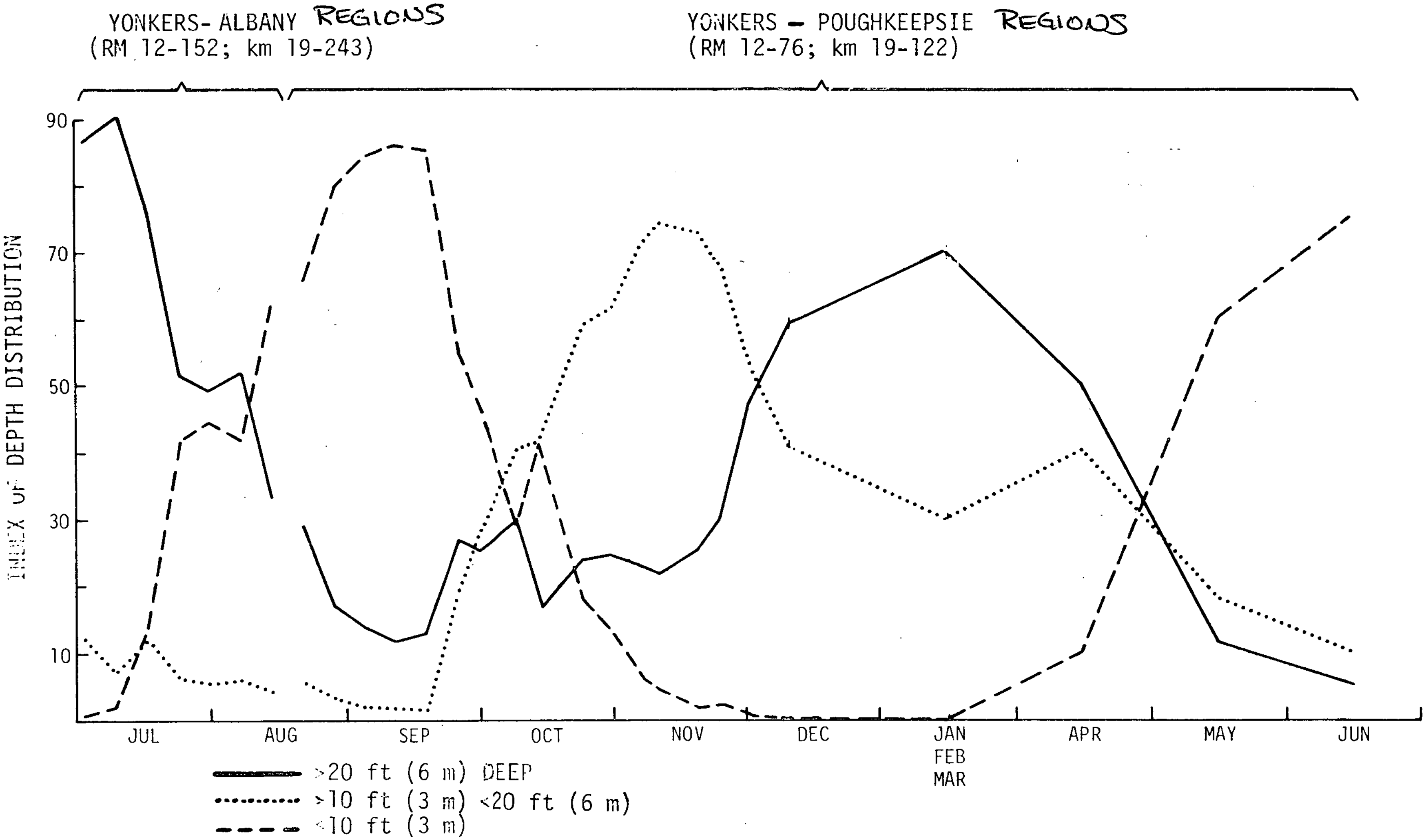


Figure 6.3-3 Depth Distribution (Night) of Juvenile White Perch during 1975 (Based on strata standing crop estimates) and Yearling White Perch in Early 1976 (Estimated from 1975 beach seine and bottom trawl catches) Hudson River Estuary. (Depth Distribution from January-March is Hypothesized and Not Based on Actual Samples.)

June-early July at an average total length of approximately 20 mm (range, 13-32 mm) and reach an initial peak abundance in the shorezone of the upper estuary (Hyde Park through Albany) during mid-July (Fig. 6.3-2). This accelerated movement to the shorezone continues through August in the lower and middle estuary (Fig. 6.3-3), to a peak in mid-September as the juveniles move gradually downriver (Fig. 6.3-1). In late September, when water temperatures decrease to approximately 20°C, juveniles begin to move off the beaches to the deeper shoal areas (10-20 ft [3-6 m] deep) (Fig. 6.3-3). This offshore movement is complete by the end of November when water temperatures approach 5°C. Juveniles are abundant in areas deeper than 20 ft (6 m) in the lower and middle estuary during the winter where they presumably remain until the following spring.

In 1974 and 1975, overwintering locations apparently differed. In November and December 1975, juveniles were primarily restricted to the offshore areas of the most downstream regions of the lower estuary (Fig. 6.3-1); in 1974, however, they were abundant and presumably overwintered throughout the deeper areas of most of the lower and middle estuary in the vicinity of the Indian Point and Lovett plants (Fig. 6.3-4). Yearling distribution during the following spring reflected this overwintering location of the 1974 year class (Fig. 6.3-4).

White perch eggs, larvae, and early juveniles exhibit moderate vulnerability to entrainment in May and June and low vulnerability during July at the five power plants. The generally adhesive, demersal characteristics of the eggs reduce their chances of being entrained; however, since eggs are collected in the water column, some will be entrained. Eggs and yolk-sac larvae are more vulnerable to Roseton and Danskammer than to Bowline, Lovett, and Indian Point. Post yolk-sac larvae are moderately vulnerable to the five plants, but their vulnerability may exhibit diel (day/night differences: during the daytime, they should be more vulnerable to any power plant withdrawing water from the bottom stratum; at night, however, they disperse through the water column and should become more vulnerable to plants withdrawing water from midwater and surface strata.

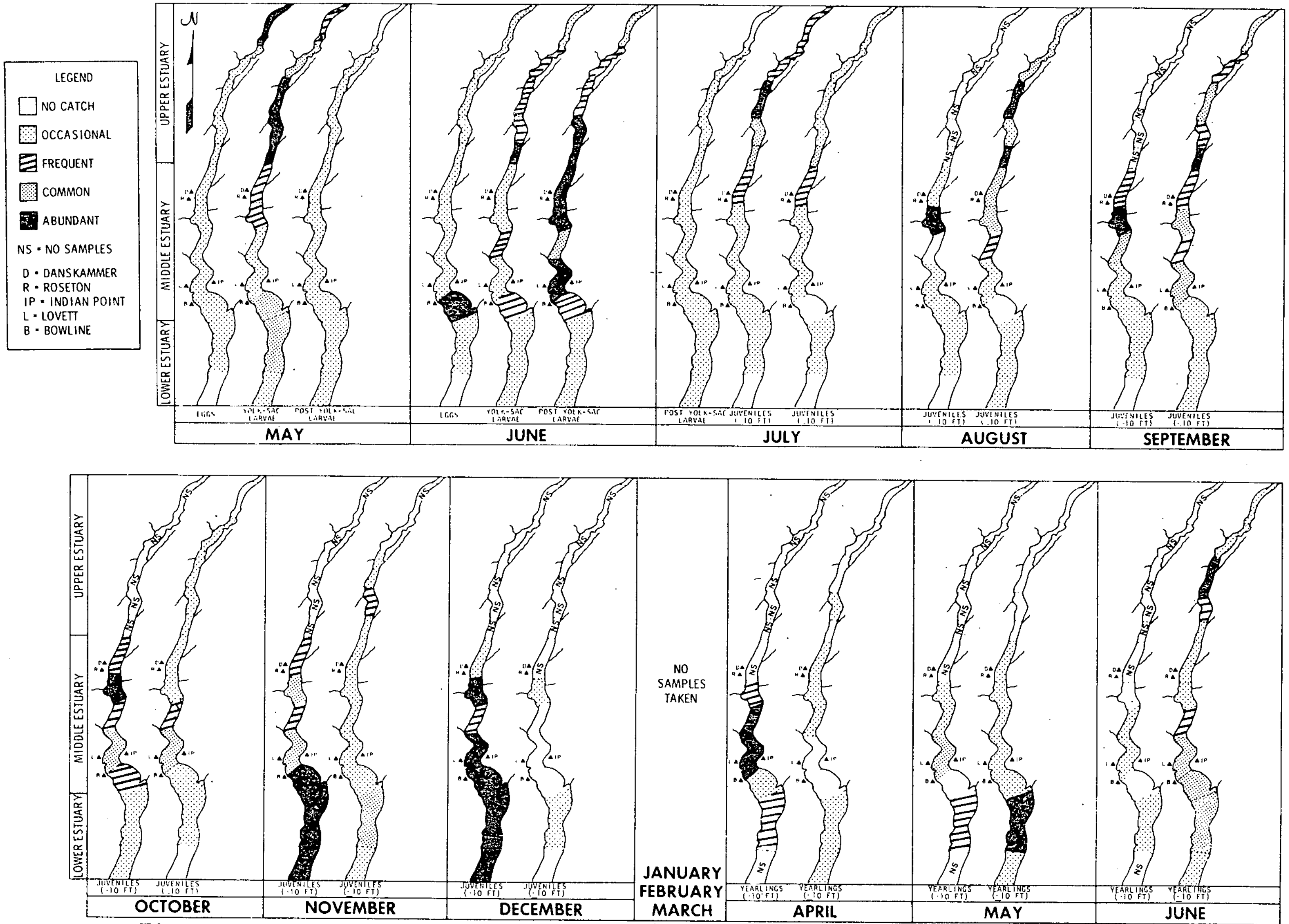


Figure 6.3-4 Longitudinal Distribution of White Perch in Hudson River Estuary during 1974-75. (Measurements in feet represent river depth)

(RM 12-152; Km 19-243)

Juveniles become vulnerable to impingement by late July and from August through October their vulnerability is moderate; but vulnerability increases during late fall and winter. As the population moves downstream through the shorezone in August and September (Figure 6.3-1) & (Table 6.3-1), it becomes vulnerable to any power plant withdrawing cooling water from the ~~shoals~~ shorezone (Section 2). Vulnerability would increase during late fall and winter (November-March), as in 1974 when juveniles concentrated and overwintered in the deeper areas of the lower and middle estuary (Table 6.3-1) and remained in the vicinity of the Indian Point and Lovett plants (Fig. 6.3-4).

6.3.2 AMERICAN SHAD DISTRIBUTION AND VULNERABILITY. The anadromous American shad spawns during spring and early summer in the Hudson River estuary (Section 5.3). Eggs are collected from late April through June, but peak spawning activity occurs in late May-early June when water temperatures range from 11-18°C. Principal spawning areas are in the upper estuary, particularly in the Saugerties and Catskill regions (Fig. 6.3-5). Eggs are significantly more abundant ~~(α = 0.01)~~ (α = 0.05) in the channel stratum than in the bottom stratum, reflecting their semibuoyant and nonadhesive characteristics (Section 5.3).

Although yolk-sac larvae are collected from early May through June, peak abundance is in the channel stratum of the upper estuary (Fig. 6.3-5) during late May. In 1975, yolk-sac larvae were collected in portions of the lower and middle estuary during the first week of June; in 1974, however, they were rare below the Poughkeepsie region.

Post yolk-sac larvae are abundant in the upper estuary from mid-May through July (Fig. 6.3-5), but most abundant in June. They are significantly more abundant ~~(α = 0.01)~~ (α = 0.05) in the bottom stratum than in the channel stratum during daytime, but at night the channel and bottom strata densities are similar ($p > 0.10$), suggesting a dispersion of post yolk-sac larvae through the water column at night.

Table 6.3-1 Depth Distribution of Young White Perch in Three Depth Strata of Hudson River Estuary during Their First Year of Life*

Month	Area of the Estuary Rm	Area of the Estuary km	Index of Depth Distribution Channel >20 ft [6m]	Shoal 10-20 ft [3-6m]	Shorezone <10 ft[3m]
July**	12-152	19-243	71	9	20
August**	12-152 until 8/15, then RM 12-76	19-243 19-122	33	5	62
September**	12-76	19-122	18	10	72
October**	12-76	19-122	24	51	25
November**	12-76	19-122	25	71	4
December**	12-76	19-122	53	47	<1
January† February March	12-76	19-122	70	30	0
April‡	12-76	19-122	50	40	10
May‡	12-76	19-122	12	18	70
June‡	12-76	19-122	5	10	85

* Summary of Figure 6.3-3

** Calculated from 1975 standing crop estimates based on epibenthic sled, Tucker trawl, and beach seine samples (calculation methods and assumptions similar to those described in section 7.9)

† Hypothesized - no sampling

‡ Estimated from 1975 catches in beach seines and bottom trawls

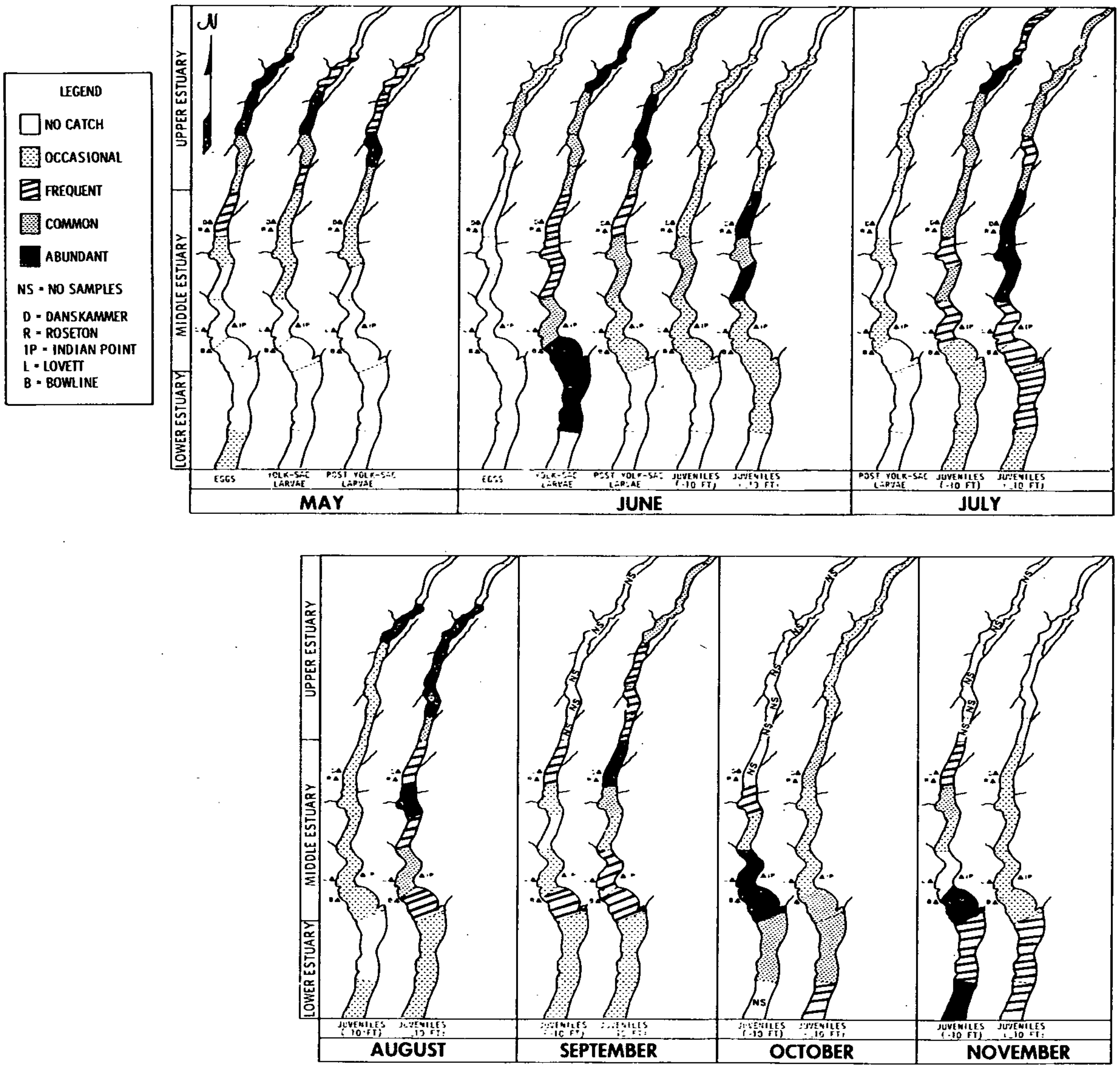


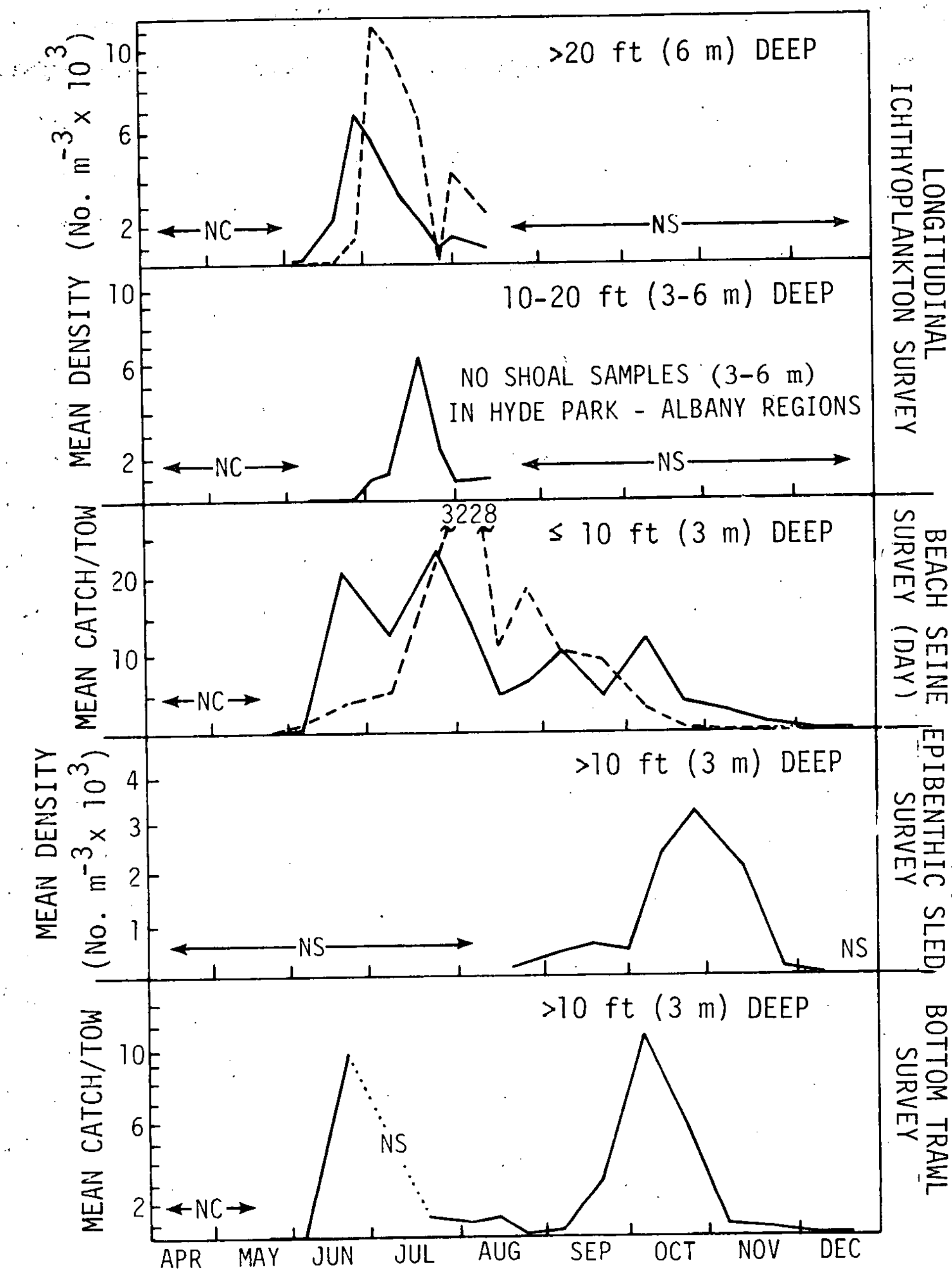
Figure 6.3-5 Longitudinal Distribution of American Shad in Hudson River Estuary during 1975. (Measurements in feet represent river depth)

(RIII 12-152; Km 19-243)

Juveniles appear in early June and become increasingly abundant throughout the upper and middle estuary in late June to mid-July (Fig. 6.3-5). They are significantly more abundant ($\alpha = 0.10$) in the channel stratum than in the bottom stratum at night; their vertical distribution during the daytime is unknown since all ichthyoplankton sampling was done at night after early June. Night sampling produced greater catches and has provided more realistic estimates of abundance. Juvenile shad appear in the shorezone of the upper and middle estuary in early June when averaging approximately 20 mm (range, 15-29 mm) in total length. Abundance in the shorezone peaks in early August (Fig. 6.3-6) when the juveniles are most abundant in the upper and middle estuary. The juveniles gradually begin to leave the shorezone in early September and migrate downstream; by October, most of them are concentrated in the lower estuary and downstream regions of the middle estuary. They continue to move to deeper water during October and early November (Fig. 6.3-6), then accelerate their movement seaward as water temperatures drop to $<15^{\circ}C$. By the end of November, most juvenile shad have apparently left the estuary (none were collected in December).

Vulnerability of American shad eggs, larvae, and early juveniles to entrainment is low based on their longitudinal distributions. Eggs and yolk-sac larvae are restricted to the upper estuary far upstream from the power plants. Some post yolk-sac larvae and early juveniles (through July) are collected in the middle estuary, but exposure to the most downstream plants (Lovett, Indian Point, and Bowline) is negligible.

Prior to October, juvenile shad vulnerability to impingement is low at Bowline (RM 37; km 60), Lovett (RM 41; km 66), and Indian Point (RM 42; km 69), and moderate at Roseton (RM 65; km 105) and Danskammer (RM 66; km 106). As they move seaward and into deeper water during October and November, they leave the vicinity of Roseton and Danskammer and pass the Indian Point, Lovett, and Bowline plants. During this migration, vulnerability is high but only for a brief period, since the juveniles are rapidly migrating out of the estuary.



——— LOWER AND MIDDLE ESTUARY (YONKERS THROUGH POUGHKEEPSIE REGIONS)

- - - - - UPPER ESTUARY (HYDE PARK THROUGH ALBANY REGIONS)

NS = NO SAMPLE

NC = NO CATCH

Figure 6.3-6 Catches of Juvenile American Shad, by Gear, in Hudson River Estuary during 1975. (There was no sampling with bottom trawls and fall epibenthic sleds upstream from the Poughkeepsie region)

6.3.3 ATLANTIC TOMCOD DISTRIBUTION AND VULNERABILITY. The Atlantic tomcod is presumably an anadromous species that spawns from mid-December to mid-January in the Hudson River estuary (Section 5.3). Although no eggs have been collected, it is assumed that the major spawning areas are shallow, fresh or slightly brackish areas of the middle estuary, particularly the West Point and Cornwall regions (Section 5.3).

Yolk-sac larvae occur from at least early March through April and are concentrated in the lower estuary and downstream regions of the middle estuary (Fig. 6.3-7). Since yolk-sac larvae were present in the estuary before sampling began in March 1975, they may have been distributed farther upstream during January and February. Yolk-sac larvae are equally abundant ($p > 0.10$) in the shoal, channel, and bottom strata during the day. Night sampling during the studies reported did not begin until early June, so vertical distribution at night is not known.

Post yolk-sac larvae are abundant in the lower estuary from at least early March through early May (Fig. 6.3-7), suggesting a downstream displacement during the yolk-sac and early post yolk-sac larval stages. Abundance of post yolk-sac larvae peaks in early April in the most downstream regions of the lower estuary. Post yolk-sac larvae are significantly more abundant ($\alpha = 0.05$) in the channel stratum than in the shoal and bottom strata. This apparent downstream transport during the early post yolk-sac larval stage may be assisted by the concentration of post larvae in the channel stratum, where currents are stronger and a slight net downstream flow occurs.

Juvenile tomcod begin to appear in ichthyoplankton samples collected on the bottom at depths >20 ft (6 m) in early April. Abundance increases to a peak in mid-May, when the population is concentrated in the extreme downstream regions of the lower estuary (Fig. 6.3-7), but catches of juveniles are also high in the deep areas of the Indian Point region (Figs. 6.3-7, 6.3-8, 6.3-9) ~~(Figs. 6.3-8 and 6.3-9)~~. During summer and early fall (June-September), juveniles are occasionally collected in the upper estuary, but most are

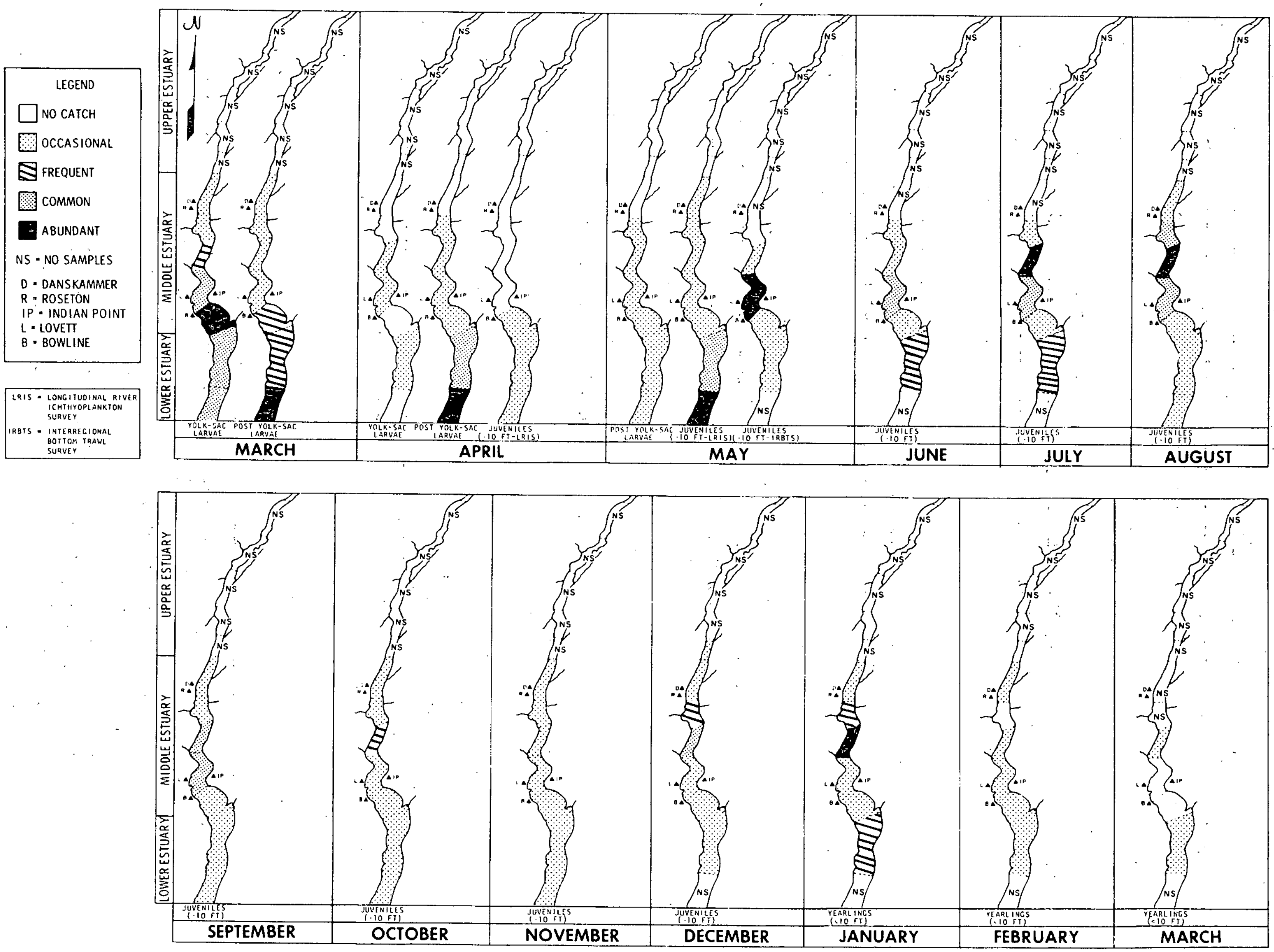


Figure 6.3-7 Longitudinal Distribution of Atlantic Tomcod in Hudson River Estuary during 1975-76. (Measurements in feet represent river depth)
(RM 12-152 ; Km 19-243)

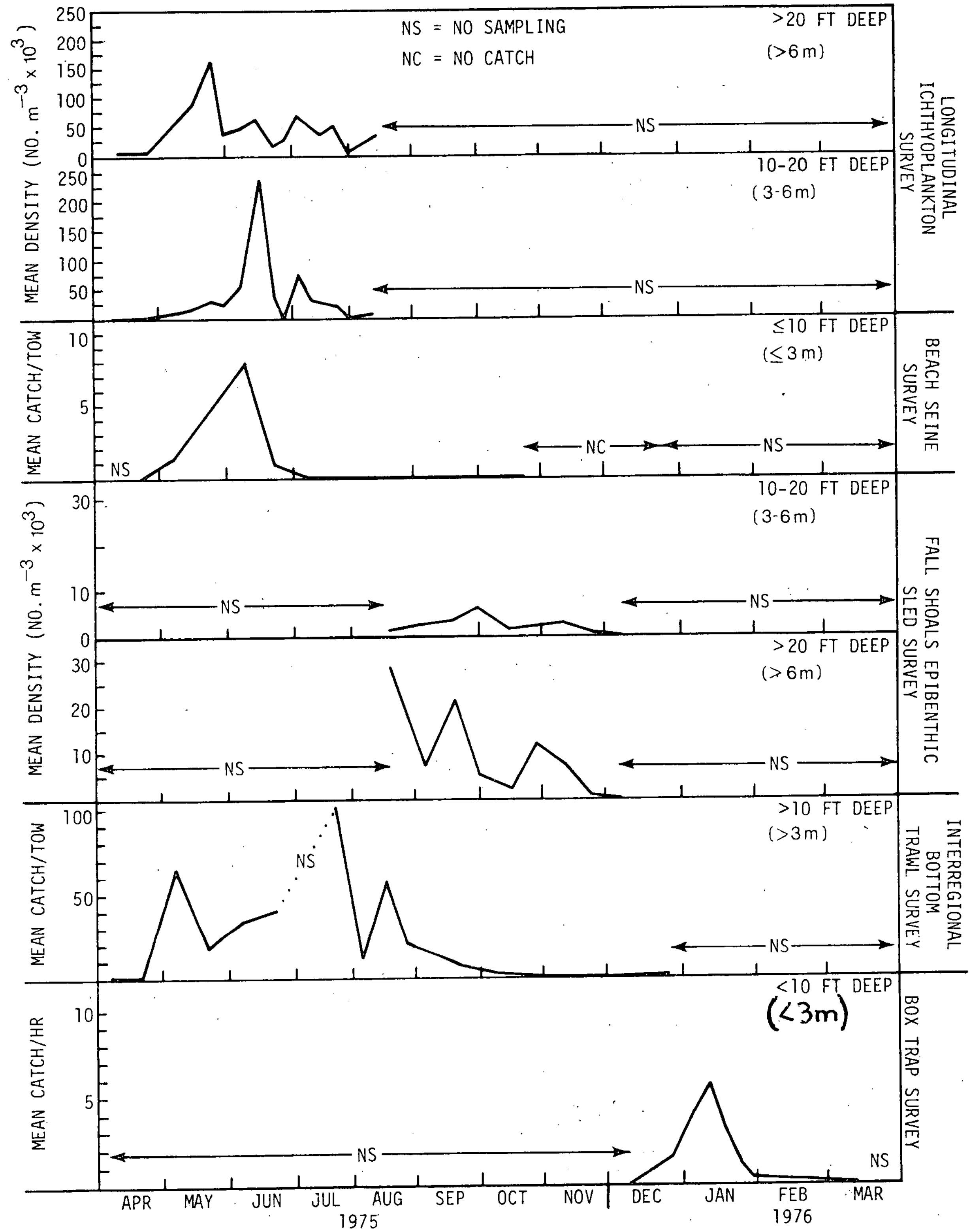


Figure 6.3-8 Catches of Juvenile and Yearling Atlantic Tomcod, by Gear, in Hudson River Estuary (Yonkers-Poughkeepsie regions [RM 12-76; km 19-122]) during 1975-76. (As of 1 January 1976, juveniles from the 1975 year class are classified as yearlings)

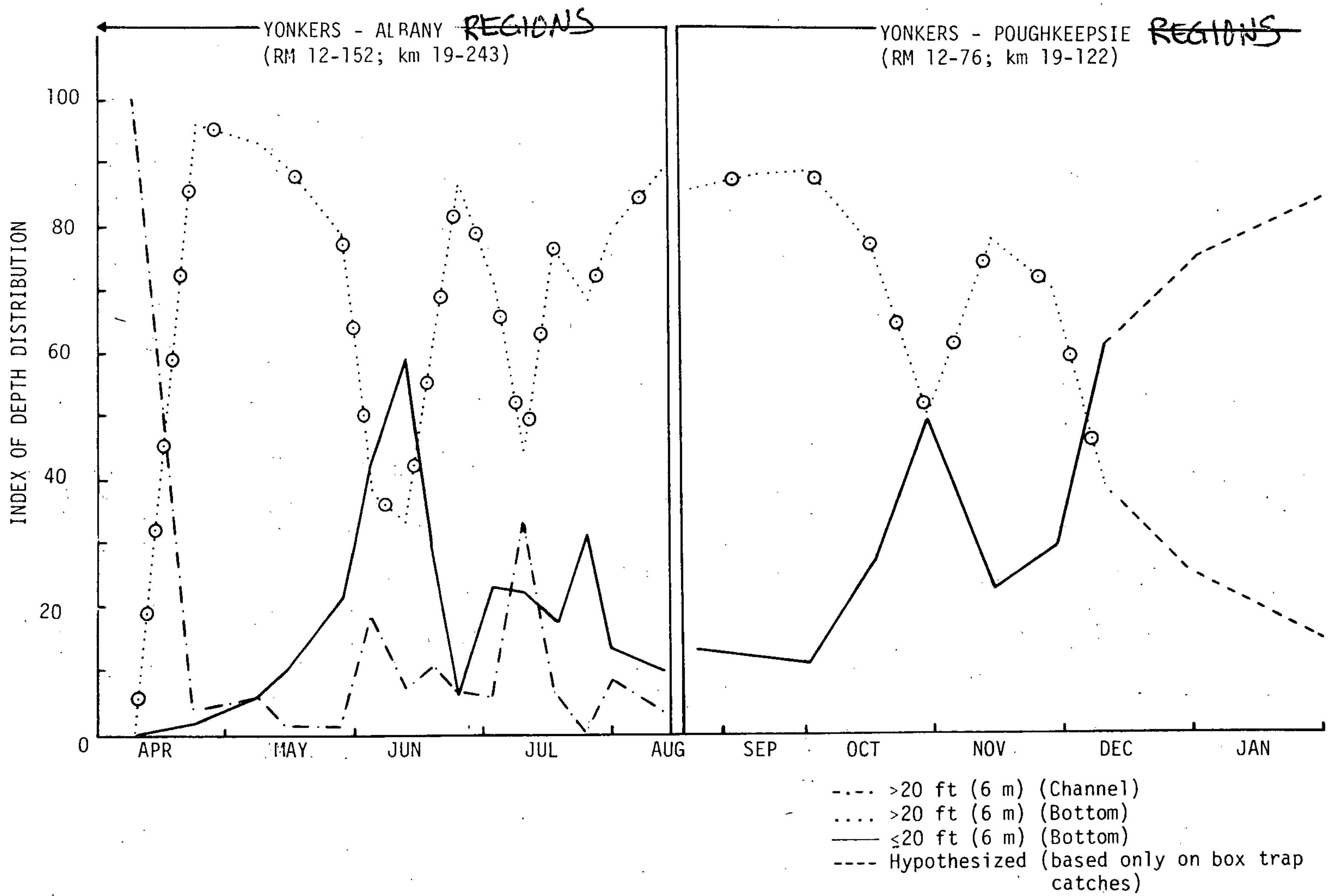


Figure 6.3-9 Depth Distribution of Juvenile Atlantic Tomcod during 1975 (Based on strata standing crop estimates) and Yearling Atlantic Tomcod in Early 1976 (Hypothesized from box trap catches) in Hudson River Estuary

concentrated near the bottom in the middle estuary at depths >20 ft (6 m) (Figs. 6.3-7 and 6.3-9). The population apparently disperses upstream during late May and early June. These upstream movements coincide with intrusion of the salt front (TI 1975e, 1976g). Catches of juveniles decrease in October and November throughout the estuary but this may be due to increased gear avoidance as well as a decrease in population size. Juvenile tomcod reappear in the shorezone of the middle estuary in mid-December as sexually mature individuals (100-250 mm in total length) preparing to spawn. Shorezone abundance and spawning activity peak during January (Figs. 6.3-7 and 6.3-8).

Vulnerability of Atlantic tomcod eggs, larvae, and early juveniles to entrainment at power plants is moderate to low. The eggs are essentially invulnerable because they are demersal and probably adhesive (Section 5.3).

Yolk-sac larvae and early juveniles (through May) are vulnerable to entrainment at Bowline, Lovett, and Indian Point. Post yolk-sac larvae are concentrated in the extreme lower estuary, so vulnerability to all plants is low.

Juvenile tomcod vulnerability to impingement is high during summer and early fall and moderate during the winter spawning period. During summer and fall, they are most vulnerable to Indian Point and Lovett; least to Bowline because of its shallow intake pond and to Roseton and Danskammer because of their upriver locations (Section 2). Vulnerability to Roseton and Danskammer increases somewhat during the winter (December-February) when Atlantic tomcod move into the shoals and shorezone near these plants to spawn.

6.3.4 BLUEBACK HERRING DISTRIBUTION AND VULNERABILITY. The blueback herring is an anadromous ~~anadramous~~ species which spawns during late spring and early summer in the Hudson River estuary (Section 5.3). Since its early life stages (eggs, larvae, and juveniles <30 mm in total length) are very difficult to positively distinguish from those of the alewife (Dovel 1971:4), the distribution and vulnerability assessment of the early life stages represent these two *Alosa* species combined. The two species can be accurately separated once the juveniles first appear in beach seines and bottom trawls in mid-June when about 30 mm in total length. Thus, the ratios of juvenile blueback herring to juvenile alewives in beach seine, bottom and surface trawl, and epibenthic sled samples (Table 6.3-2) provide an estimate of their relative abundance as eggs, larvae, and early juveniles, assuming that the two species experience similar survival rates during the early weeks of life. During 1974-75, the overall mean ratio over all gear (August-November) varied between and within the 2 years, but blueback herring were consistently more abundant (by a factor of 54.9 in 1975). Hence, it is assumed that the distribution and vulnerability of the eggs, larvae, and early juveniles of *Alosa* spp (blueback herring and alewife combined) reflect predominantly the distribution and vulnerability of blueback herring.

Table 6.3-2 Ratio of Blueback Herring:Alewife Juveniles in Catch of Various Sampling Gear, Hudson River Estuary, 1974-75

1974

Month	Beach Seine Survey Day	Beach Seine Survey Night	Interregional Bottom Trawl Survey (Day)	Standard Station Surface Trawls (Day)	Fall Shoals Epibenthic Sled Survey (Night)	Mean Over All Gear
June	0.07	NS	3.00	a	NS	---
July	5.60	NS	0.03	0 10	NS	---
August	11.53	0.004	9.84	b	7 49	7.22 (without ST*)
September	11.42	0.02	6.58	b	11.64	7.42 (without ST*)
October	19.62	0.04	6.73	411.98	9.68	89.61 (with ST*) 9.02 (without ST*)
November	114.40	0.05	1.47	721.03	3.61	168 11 (with ST*) 29.88 (without ST*)
December	a	a,b	a,b	NS	3 00	---
						mean of Aug-Nov without ST* 13 39
						mean of Oct-Nov with ST* 128.86

1975

Month	Beach Seine Survey (Day)	Interregional Bottom Trawl Survey (Day)	Standard Station Surface Trawls (Day)	Fall Shoals Epibenthic Sled Survey (Night)	Mean Over All Gear
June	0.09	a,b	NS	NS	---
July	1 73	0.69	2 21	NS	---
August	20.10	3 15	45.26	36.79	26.33 (with ST*) 20.01 (without ST*)
September	16.86	1.43	29.57	29.18	19.26 (with ST*) 15.82 (without ST*)
October	38.74	2.29	489 98	19.43	137.61 (with ST*) 20.15 (without ST*)
November	117.74	0.69	22.90	4.05	36.35 (with ST*) 40.83 (without ST*)
December	a	0 62	a	0.25	---
				mean of Aug-Nov without ST* 24.20	
				mean of Oct-Nov with ST* 86.98	
				mean of Aug-Nov with ST* 54.89	

a = no alewife caught
b = no blueback herring caught
NS = no samples taken
ST* = surface trawls

Alosa spp eggs are collected from mid-April through June, but peak spawning occurs during May. Like the American shad, these other ~~Clupeids~~ clupeids spawn principally in the upstream regions of the upper estuary, although some spawning occurs throughout the estuary (Fig. 6.3-10).

Alosa spp yolk-sac and post yolk-sac larvae are also concentrated in the upper estuary during the period of peak abundance from mid-May to early June (Fig. 6.3-10). Yolk-sac larvae are not collected after June, but a few post yolk-sac larvae are still found in mid-August.

Juvenile *Alosa* spp are distributed similarly to eggs and larvae, peaking in abundance during July in the channel stratum of the upper estuary (Fig. 6.3-10). The juveniles averaging 30 mm in total length (range, 19-35 mm) begin to move into the shorezone in mid-July (Fig. 6.3-11), when they can be accurately identified as blueback herring or alewife. By early August, juvenile blueback herring are very abundant in the shorezone of the upper estuary (Fig. 6.3-10) and also begin to move downstream to the middle estuary (Fig. 6.3-10), ~~(Fig. 6.3-11)~~. The larger fish appear to move downstream earlier than the smaller fish (Table 6.3-3). Movement into the middle and lower estuary accelerates in late September and, by mid-October, the juveniles are also leaving the shorezone and moving to deeper water (Figs. 6.3-10 and 6.3-11). By the end of November, most of the population has apparently migrated to the ocean.

Blueback herring vulnerability to power plants is generally low throughout most of the year. Vulnerability of eggs, larvae, and early juveniles to entrainment is low to negligible since they are concentrated in the upper estuary. Through mid-September and early October, vulnerability to impingement increases, first at Roseton and Danskammer, then at the downstream plants (Lovett, Indian Point, and Bowline) as the juveniles migrate seaward. This period of increased vulnerability continues only through November.

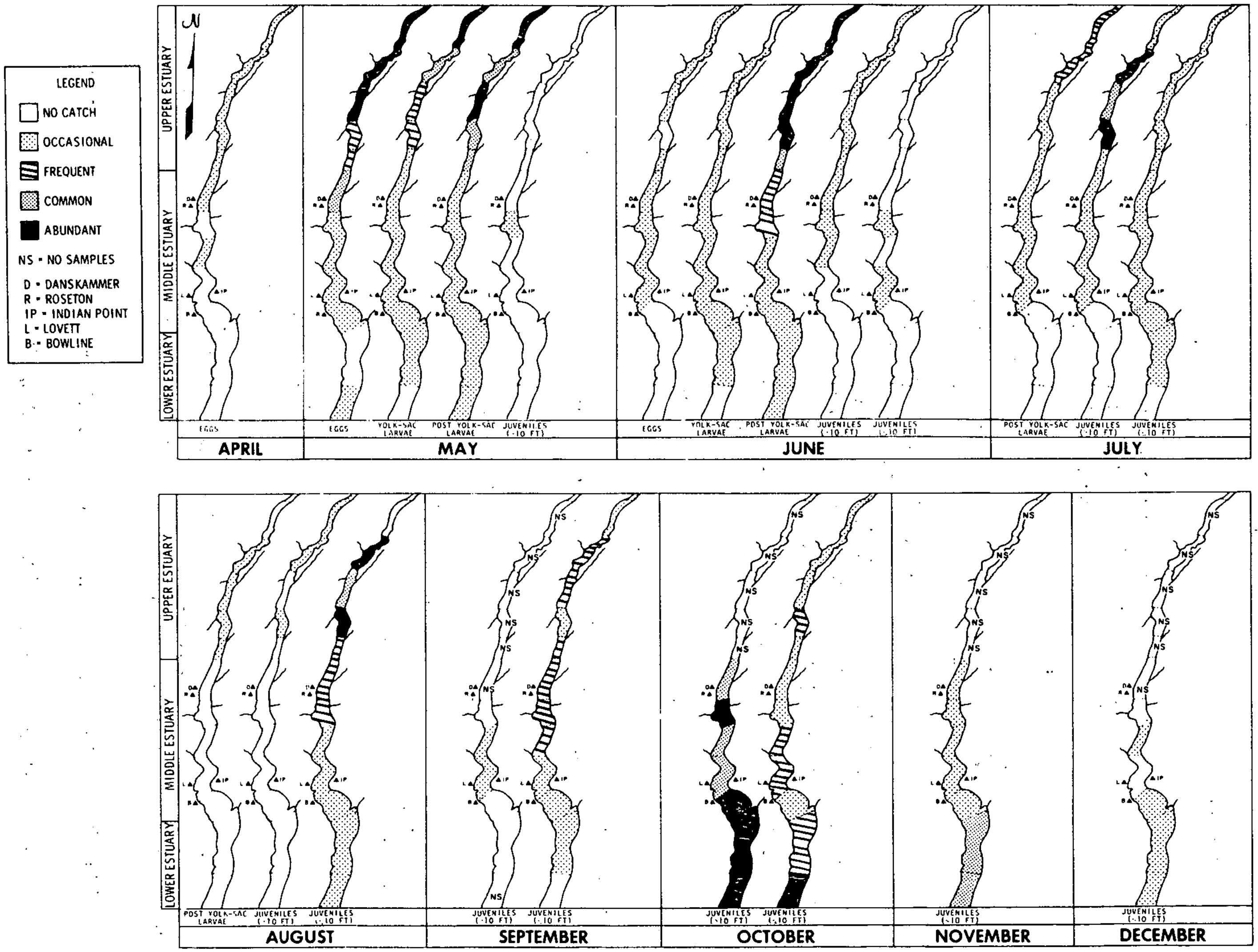


Figure 6.3-10 Longitudinal Distribution of Blueback Herring in Hudson River Estuary during 1975 (RM 12-152; Km 19-243) (Eggs, larvae, and early juveniles are *Alosa* spp; measurements in feet represent river depth; no juveniles were caught during November and December in beach seines [areas ≤ 10 ft deep]).

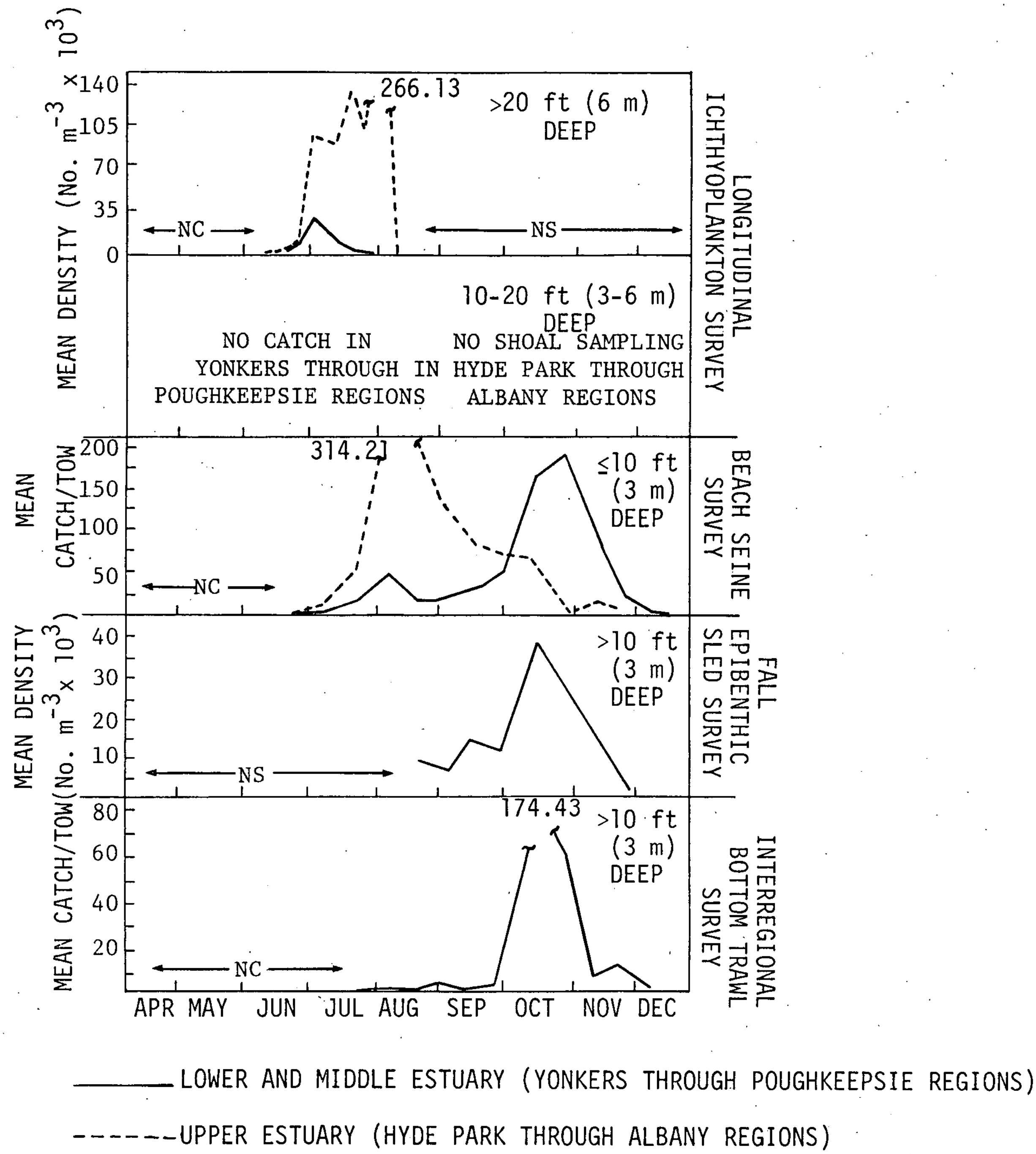


Figure 6.3-11 Catches of Juvenile Blueback Herring, by Gear, during 1975. (There was no sampling with bottom trawls and fall epibenthic sleds upstream from the Poughkeepsie region)

Table 6.3-3 Comparison of Mean Total Lengths for Juvenile Blueback Herring Collected in 1975 by 100-ft (30.5-m) Beach Seine during Daytime in Regions of Upper Hudson River Estuary vs Regions of Lower and Middle Estuary

Time Period	Mean Total Length (mm)	
	Lower and Middle Estuary**	Upper Estuary***
7/13-7/26*	54.9	45.2
7/27-8/9	62.4	44.8
8/10-8/23	68.5	47.8
8/24-9/6	69.9	49.9
9/7-9/20	68.5	54.4
9/21-10/4	66.7	57.7
10/5-10/18	63.4	55.8
10/19-11/1	62.8	56.5
11/2-11/15	66.7	NS
11/16-11/29	67.6	NS
11/30-12/13	67.4	NS

*First biweekly period when juvenile blueback were collected throughout the estuary

**Croton-Haverstraw, Indian Point and West Point regions

***Saugerties, Catskill, and Albany regions

NS = No samples

6.3.5 SHORTNOSE STURGEON DISTRIBUTION AND VULNERABILITY. The shortnose sturgeon is a species that spawns during the spring in the Hudson River estuary (Section 5.3). No sturgeon eggs and relatively few larvae and early juveniles have been collected (Table 6.3-4), and because shortnose and Atlantic sturgeon are difficult to distinguish from one another during early life stages, it is not known how many very young shortnose sturgeon, if any, have been collected. An evaluation of the vulnerability of shortnose sturgeon to entrainment at the five power stations must be based on inference rather than direct observation. The eggs are demersal and adhesive, so their vulnerability should be negligible.

Table 6.3-4 Total Number of Unidentified Sturgeon (Shortnose and Atlantic Combined) Eggs, Larvae, and Juveniles Collected (by Texas Instruments) in Hudson River Estuary during 1974 and 1975

	Life Stage		
Year	Eggs	Larvae	Juveniles
1974	0	19	13
1975	0	23	1
Total	0	42	14

The limited information on *Acipenser* spp (shortnose and Atlantic sturgeon combined) indicates that larvae and juveniles are found from late May through July (Table 6.3-5) in the deep middle estuary in proximity to Danskammer, Roseton, Indian Point, and Lovett. If the ratio of shortnose to Atlantic sturgeon in samples of larvae and juveniles is comparable to the ratio observed among the yearling and older fish which can be identified to species (Table 6.3-6), then all the samples of larvae and juveniles collected in 1974 and 1975 (Table 6.3-4) probably contained a total of only one or two shortnose sturgeon. It is even possible, as mentioned earlier, that no shortnose sturgeon have been collected during the early life stages; hence, it is not certain that any early distributional data at all are available for the species.

Table 6.3-5 Density of Unidentified Sturgeon (Shortnose and Atlantic Combined) Larvae and Juveniles Collected in Hudson River Estuary during 1974 and 1975 by Epibenthic Sleds and Tucker Trawls (See Table 6.1-1 for definition of region abbreviations)

			Density (No. m^{-3} x 10^3)										
Year	Life Stage	Time Period	YK	TZ	CH	IP	WP	CW	PK	HP	KG	CS	AL
1974	Yolk-sac larvae	5/21-5/24										.312	
		5/30-6/5							.686	2.855			
		6/24-6/27					.104			.373	NS	NS	NS
		7/1-7/5							.108		NS	NS	NS
		7/15-7/18									NS	NS	NS
	Post yolk-sac larvae	5/21-5/24											
		5/30-6/5											
		6/24-6/27				.050			.855		NS	NS	NS
		7/1-7/5									NS	NS	NS
		7/15-7/18						.491			NS	NS	NS
1975	Yolk-sac larvae	6/2-6/6					.188	.030					
		6/9-6/14							.050				
		6/16-6/19							.151				
		6/23-6/26							.234				
		6/30-7/4											
		7/7-7/10											
		7/14-7/17											
	Post yolk-sac larvae	6/2-6/6							.073				
		6/9-6/14							.144				
		6/16-6/19											
		6/23-6/26							.042				
		6/30-7/4						.080	.117				
		7/7-7/10											
		7/14-7/17											
	Juveniles	6/2-6/6											
		6/9-6/14											
		6/6-6/19											
		6/23-6/26											
		6/30-7/4						.103					
		7/7-7/10											
		7/14-7/17						.109					

NS = no samples

Yearling and older sturgeon are more frequently collected in the estuary than eggs, larvae and juveniles (Table 6.3-6). The limited data suggest that Atlantic sturgeon are more numerous than shortnose sturgeon by a factor of approximately 31. The 15 shortnose sturgeon collected in 1974-75 were distributed from the lower part of the upper estuary to the upper part of the lower estuary (Table 6.3-7), suggesting that the shortnose sturgeon should be vulnerable to some degree at any power plant withdrawing water from near the channel bottom. However, their ~~theri~~ demersal nature should greatly reduce their exposure. Vulnerability is negligible at Bowline because of the shallow intake area and at Danskammer because of the shoreline intake canal.

6.4 SUMMARY

The degree of vulnerability during the first year of life of striped bass, white perch, American shad, Atlantic tomcod, and blueback herring to all five power plants (Bowline [RM 37; km 60], Lovett [RM 41; km 66], Indian Point [RM 42; km 69], Roseton [RM 65; km 105], and Danskammer [RM 66; km 106]) differs among the life stages within a species and between species. All five species are vulnerable in differing degrees to each of the power plants.

Catches of shortnose sturgeon were not sufficient to adequately assess their vulnerability, but their demersal nature should greatly reduce their exposure to power plants.

Of all life stages for the five species listed in Table 6.4-1, striped bass yolk-sac larvae appear to be most vulnerable to entrainment. Relative vulnerability to impingement is highest for Atlantic tomcod and white perch, lowest for American shad and blueback herring, with striped bass being intermediate. Overall vulnerability to power plants is lowest for American shad and blueback herring; their period of highest vulnerability occurs briefly during the fall when they are exposed to impingement as they pass the plants on their seaward migration. Only white perch

(by Texas Instruments)

Table 6.3-6 Total Numbers of Yearling and Older Shortnose and Atlantic Sturgeon Collected in Hudson River Estuary during 1974 and 1975, Excluding Impingement Samples

Year	Shortnose Sturgeon	Atlantic Sturgeon
1974	10	190
1975	5	270
Total	15	460

Table 6.3-7 Distribution of All Yearling and Older Shortnose Sturgeon Collected in Hudson River Estuary during 1974 and 1975

Year	Number Caught	Month	Geographical Region	Gear
1974	1	Jun	Tappan Zee	Epibenthic sled/Tucker trawl
	1	Jul	West Point	Epibenthic sled/Tucker trawl
	1	Jul	Hyde Park	Epibenthic sled/Tucker trawl
	3	Aug	Indian Point	Epibenthic sled/Tucker trawl
	1	Aug	West Point	Epibenthic sled/Tucker trawl
	1	Aug	Hyde Park	Epibenthic sled/Tucker trawl
	1	Aug	Kingston	Epibenthic sled/Tucker trawl
	1	Dec	Indian Point	Bottom trawl
1975	1	Mar	Croton/Haverstraw	Gill net
	2	Apr	Indian Point	Gill net
	1	Sep	Indian Point	Bottom trawl
	1	Dec	Indian Point	Bottom trawl

Table 6.4-1 Index of Vulnerability (Exposure) of Striped Bass, White Perch, American Shad, Atlantic Tomcod, and Blueback Herring Populations during First Year of Life (Egg → Yearling) to Power Plants (Bowline, Lovett, Indian Point, Roseton, Danskammer) in Hudson River Estuary

Species	Life Stage	Index of Vulnerability*																	
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Striped Bass	Eggs	NS	NS			8	8							NS	NS	NS			
	Yolk-sac Larvae	NS	NS			10	10							NS	NS	NS			
	Post Yolk-sac Larvae	NS	NS			5	9	5						NS	NS	NS			
	Juveniles/Yearlings	NS	NS					8	6	7	4	3	2	NS	NS	NS	5	4	2
White Perch	Eggs	NS	NS			5	4							NS	NS	NS			
	Yolk-sac Larvae	NS	NS			6	4							NS	NS	NS			
	Post Yolk-sac Larvae	NS	NS			5	7	3						NS	NS	NS			
	Juveniles/Yearlings	NS	NS					3	7	5	4	7	8	NS	NS	NS	6	4	3
American Shad	Eggs	NS	NS			2	1							NS	NS	NS			
	Yolk-sac Larvae	NS	NS			1	4							NS	NS	NS			
	Post Yolk-sac Larvae	NS	NS			1	3	2						NS	NS	NS			
	Juveniles/Yearlings	NS	NS				6	5	5	5	10	7		NS	NS	NS			
Atlantic Tomcod	Eggs**	NS	NS											NS	NS	NS			
	Yolk-sac Larvae	NS	NS	7	5									NS	NS	NS			
	Post Yolk-sac Larvae	NS	NS	3	2	5								NS	NS	NS			
	Juveniles/Yearlings	NS	NS		4	6	8	9	10	9	5	5	7	8	5	2	2	1	
Blueback Herring	Eggs†	NS	NS		4	2	4							NS	NS	NS			
	Yolk-sac Larvae†	NS	NS			1	4							NS	NS	NS			
	Post Yolk-sac Larvae†	NS	NS			1	2	4	1					NS	NS	NS			
	Juveniles/Yearlings	NS	NS				5†	1†	3	6	8	4	2	NS	NS	NS			

NS = no sampling

*Vulnerability is based on longitudinal distributions during 1974 and 1975 and life-stage characteristics. Vulnerability is assessed for those months when a life stage was present and collected in sufficient numbers. 1 = negligible, 2 = low minus, 3 = low, 4 = low plus, 5 = moderate minus, 6 = moderate, 7 = moderate plus, 8 = high minus, 9 = high, and 10 = high plus.

**none collected

†based on distribution of other *Alosa* spp. (alewife-blueback herring combined)

and striped bass are even moderately vulnerable to the power plants beyond the yearling age. White perch is a resident species, so exposure to the plants is for a much longer proportion of its life span than for the anadromous species. The period of entrainment vulnerability for the five species at the five power plants occurs during spring and early summer, primarily May and June; vulnerability to impingement occurs throughout the year, with peak periods in late summer and winter.

SECTION 7

THE STRIPED BASS POPULATION OF THE HUDSON RIVER

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SECTION 7

THE STRIPED BASS POPULATION OF THE HUDSON RIVER

7.1 INTRODUCTION

This section discusses available information concerning the life history and ecology of the striped bass in the Hudson River. Where specific information was not available for the Hudson River population, data from other striped bass populations were considered. An understanding of the basic biology and population status is essential for assessing man-induced impact on the Hudson River striped bass.

Four general topics are discussed. Combined, they form a foundation of information on the Hudson River striped bass population upon which estimates of power plant impact are developed in the later sections of this report. Section 7.2 describes the importance of the Hudson River striped bass to the sport and commercial fisheries and reviews long-term fluctuations in abundance. Sections 7.3 through 7.8 detail the history of each life stage, egg through adult. Within Section 7.9, population estimates are presented and the many factors affecting abundance analyzed. Section 7.10 presents estimates of the relative contribution of Hudson River striped bass to the Atlantic coastal striped bass fishery.

7.2 INTRODUCTION AND HISTORICAL DESCRIPTION OF THE STRIPED BASS COMMERCIAL FISHERY

Striped bass were abundant in the Hudson River when the Dutch settlers and the Indians first inhabited its banks. Often referred to as "Twalft" or "rock," the striped bass during the 18th century was one of the most common species in the Hudson and the favorite fish of the Indians, who caught them in nets constructed from swamp milkweed (Boyle 1969:38, 43). Despite a Commissioners of Fisheries report in 1869 stating that striped bass resided in the Hudson River year-round, it is now evident that they contribute to coastal fisheries and that large striped bass enter the Hudson from the sea to spawn. Tagging studies indicate that the striped bass population has been lightly exploited in the Hudson River (~~State of New York~~ Hudson River Valley Commission 1966:5).

Striped bass is an excellent food and game fish and an important part of the commercial catch (Curran and Reis 1937:127 and Section 5.4), although American shad has historically been the most important commercial fish in the Hudson River (Boyle 1969:109). During the past 40 yr, American shad landings have been approximately 10 times greater than striped bass landings. Little information on the sport fishery for striped bass is available, but commercial fishery data have been recorded for many years. Anglers seeking striped bass concentrate their efforts on the coast where commercial catches are also large, but only a few anglers regularly take advantage of striped bass fishing in the Hudson River (Boyle 1969:131, and Section 5.4). A striped bass sport fishery exists in the Croton River, a tributary of the Hudson River (Boyle 1973-1974:6-11). Analysis and discussion in Section 7.2 are based on available commercial fishery data.

The market for Hudson River striped bass has fluctuated over the past 15 yr, but wholesale prices have generally increased. Based on 1959-75 data available from the Department of Commerce, National Marine Fisheries Service, the wholesale price of striped bass at the Fulton fish market in New York City has ranged from 8.5¢ to 87.5¢ lb^{-1}, varying with the time of year and size of the fish. The Department of Commerce "green sheets," the data source for wholesale prices, do not always separate Hudson River striped bass from those caught elsewhere. April and May midpoint wholesale prices coincide with the striped bass spawning run in the Hudson River and the influx of these striped bass into the market during the spring. May prices tend to be higher than April prices, but during the 1960s and early 1970s both followed the same increasing trend (Fig. 7.2-1).

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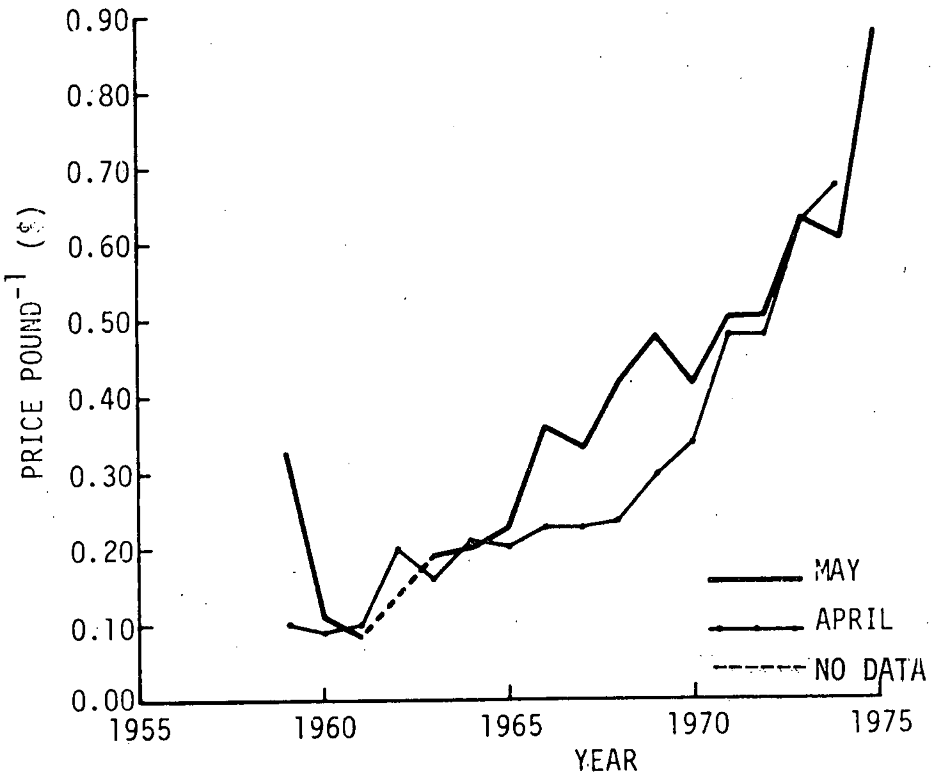

Figure 7.2-1 Midpoint Wholesale Prices for Striped Bass Caught in New York during April and May, 1959-75. (NMFS Fulton Fish Market Green Sheet)

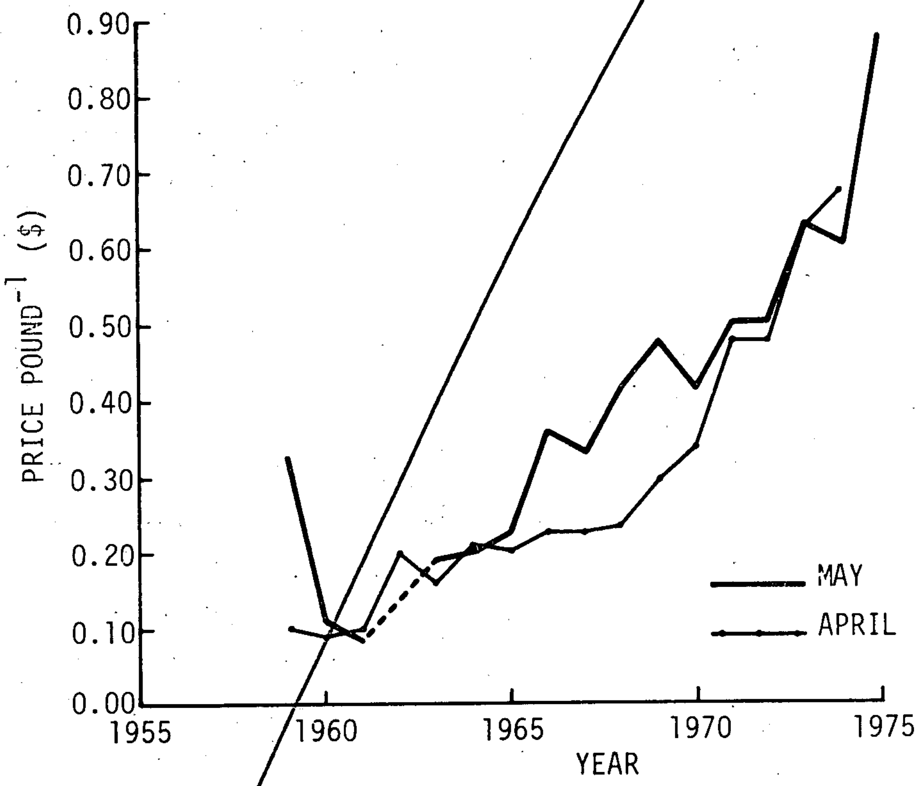

Figure 7.2-1 Midpoint Wholesale Prices for Striped Bass Caught in New York during April and May, 1959-75. (NMFS Fulton Fish Market Green Sheet)

The striped bass appears to be hardy and capable of enduring increasing environmental stresses ~~(Section 2.2.10)~~, and Mansueti (1961a:123) hypothesized "that civilization and striped bass populations are compatible; i.e., increasing fertilization from artificial and natural sources brought down to the estuary by runoff and freshets may be indirectly responsible for the dominant year classes." Striped bass eggs and larvae apparently can survive in the turbid and high-nutrient waters with low dissolved oxygen levels that result from the influx of sewage effluents (Mansueti 1961a:128). The large semibouyant eggs withstand buffeting in some waters and are transported to areas of increased salinity where suspended particles are neutralized and precipitated (Mansueti 1961a:128).

The major waters fished commercially in the Hudson River extend from Weehawken, New Jersey (RM 5; km 8) to Hudson, New York (RM 117; km 188), a distance of approximately 112 mi (180 km) (Fig. 7.2-2). Records of reported striped bass commercial landings and total square yards of stake and anchor gill nets from 1931 to 1975, number of licensed stake and anchor gill nets, and number of licensed commercial fishermen from 1955 to 1975 were obtained from Fred Blossum, National Marine Fisheries Service (NMFS), Patchogue, Long Island. Commercial fishing regulations were obtained from the New York State Department of Environmental Conservation (NYSDEC) at Albany, New York.

Fishing effort and yield-per-effort (Y/f) indices (Section 7.2.4) were calculated for all possible years from 1931 to 1975 (Table 7.2-1). Subsequent discussion of these indices and all variables used in their calculation covers 1955 through 1975. These 20 yr constitute the only continuous and comparable records of striped bass landings from all gear in New York (NMFS). Square yardage of stake and anchor gill nets was selected from 1955 to 1975 to provide data comparable in terms of gear and fishing regulations. From 1931 to 1938, the legal size limit for striped bass was 12 in (305 mm) fork length; this was subsequently increased to 16 in (407 mm) (Section 7.2.2). During those 7 yr, a younger

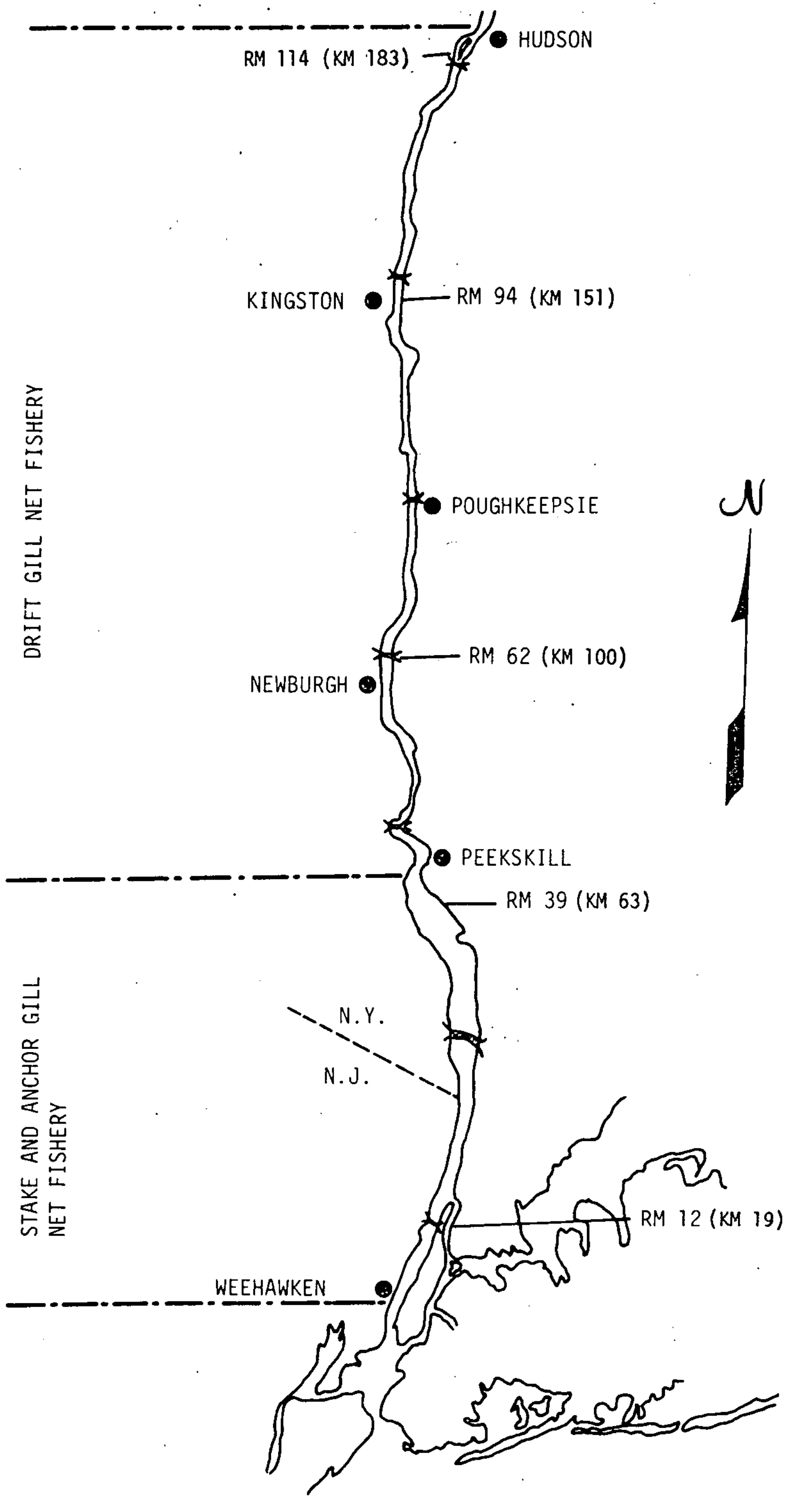

Figure 7.2-2 Locations of Major Drift Gill Net and Stake and Anchor Gill Net Fisheries in Hudson River South of Troy, New York

Table 7.2-1 Commercial Fishery Statistics for Striped Bass Taken from Hudson River in New York, 1931-75

Year	Landings of Striped Bass (lb)	Yd^2 Stake and Anchor Gill Nets	New York Fishing Hours Allowed Weekly	Fishing Effort (f)	Striped Bass Y/f (Landings/f)
1931	5,330	14,600*	108	1.58	3,373
1932	4,508	10,886*	108	1.18	3,820
1933	13,616	16,044*	108	1.73	7,871
1934	10,905	2,892*	108	0.31	35,177
1935	18,667	--	108	--	--
1936	20,120	38,688*	108	4.18	4,813
1937	28,854	4,319*	108	0.47	61,391
1938	24,579	8,392*	108	0.91	27,010
1939	29,937	5,558*	108	0.60	49,895
1940	34,634	123,811*	108	13.37	2,590
1941	21,336	30,170*	132	3.98	5,361
1942	23,565	71,554*	132	9.45	2,494
1943	30,889	15,936*	150	2.39	12,924
1944	60,918	199,453*	168	33.51	1,818
1945	79,350	83,280*	132	10.99	7,220
1946	50,622	135,360*	132	17.87	2,833
1947	48,453	102,600*	132	13.54	3,579
1948	38,830	109,200*	132	14.41	2,695
1949	9,133	68,550*	132	9.05	1,009
1950	9,539	66,754*	132	8.81	1,083
1951	17,338	48,330*	96	4.64	3,737
1952	29,847	49,230*	108	4.73	6,237
1953	19,352	49,536*	108	4.76	4,006
1954	56,000**	82,404*	108	7.91	7,080
1955	73,400	136,008*	108	14.69	4,997
1956	92,824	137,431*	108	14.89	6,255
1957	84,500	136,098*	108	14.70	5,748
1958	77,100	134,862*	108	14.57	5,292
1959	133,100	121,631*	120	14.60	9,116
1960	132,900	111,552*	120	13.39	9,925
1961	70,700	111,167*	120	13.34	5,300
1962	48,100	115,595*	120	13.87	3,468
1963	46,700	79,721*	120	9.57	4,880
1964	29,500	68,908*	120	8.27	3,567
1965	36,700	62,407	120	7.49	4,900
1966	44,342	60,663	120	7.28	6,091
1967	54,642	53,541	120	6.42	8,511
1968	60,800	70,214	120	8.43	7,212
1969	77,155	64,356	120	7.72	9,994
1970	45,900	71,456	120	8.57	5,356
1971	24,747	40,960	120	4.92	5,030
1972	17,946	52,793*	120	6.34	2,831
1973	67,035	38,703	120	4.64	14,447
1974	30,331	110,580	120	13.27	2,286
1975	46,179	127,239	120	15.27	3,024

*Adjusted square yardage values to account for square yardage omitted by NMFS that primarily caught striped bass (NMFS value•1.2).

**An approximate estimate of pounds of striped bass landed (Fishery Statistics of U.S. for N.Y. state minus N.Y. Marine Landings (NOAA) approximates pounds landed in the Hudson River).

Table 7.2-1 Commercial Fishery Statistics for Striped Bass Taken from Hudson River in New York, 1931-75

Year	Landings of Striped Bass (lb)	Yd^2 Stake and Anchor Gill Nets	New York Fishing Hours Allowed Weekly	Fishing Effort (f)	Striped Bass Y/f (Landings/f)
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1941	21,336	30,170*	132	3.98	5,361
1942	23,565	71,554*	132	9.45	2,494
1943	30,889	15,936*	~~150~~ [168]	~~2.39~~ [2.68]	~~12,924~~ [11526]
1944	60,918	199,453*	168	33.51	1,818
1945	79,350	83,280*	132	10.99	7,220
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1950	9,539	66,754*	132	8.81	1,083
1951	17,338	48,330*	96	4.64	3,737
1952	29,847	49,230*	108	[5.32] ~~4.73~~	~~6,237~~ [5610]
1953	19,352	49,536*	108	~~4.76~~ [5.35]	~~4,006~~ [3617]
1954	56,000**	82,404*	108	~~7.91~~ [8.90]	~~7,080~~ [6292]
1955	73,400	136,008*	108	14.69	4,997
1956	92,824	137,431*	108	~~14.89~~ [14.84]	6,255
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*Adjusted square yardage values to account for square yardage omitted by NMFS that primarily caught striped bass (NMFS value•1.2).

**An approximate estimate of pounds of striped bass landed (Fishery Statistics of U.S. for N.Y. state minus N.Y. Marine Landings ~~(NOAA)~~ [(USNOAA)] approximates pounds landed in the Hudson River).

[--No Data]

age class was included in total landings; therefore, the abundance index would be inconsistent with data after 1938. Prior to closure of the winter fishery in 1949 (Section 7.2.2), yield values were based on spring and winter landings and spring and winter gill net effort was not separable. Thus, the striped bass abundance index from 1931 to 1949 would not be comparable with later years. From 1950 to 1955, fishermen were gradually changing over to nylon nets, so data from those and earlier years are not comparable with data from later years. As a result of all these gear and regulation changes, only the 1955-75 data are strictly comparable for calculating a Y/f index of relative abundance.

7.2.1 GEAR. Striped bass are taken from the Hudson River primarily in gill nets. A gill net is a wall of webbing suspended vertically in the water by means of lead weights on the bottom and floats on the top line (Fig. 7.2-3). The webbing may be constructed from natural or synthetic fibers. Mesh size varies according to the different species and sizes of fish being sought. Anchor and stake gill nets are positioned with stakes driven into the river bottom or with anchors set on the bottom, and fish must swim into them (Rounsefell 1975:146). Drift gill nets are suspended in wide stretches of rivers and drift with the current (Rounsefell 1975:146).

The stake and anchor gill net fishery is concentrated approximately between Weehawken, New Jersey, and Peekskill, New York (RM 5 to 43; km 8 to 69), whereas the drift gill net fishery extends approximately from Peekskill, New York to Hudson, New York (RM 43 to 117; km 69 to 188) (Fig. 7.2-2). Y/f indices of abundance for striped bass are calculated using stake and anchor gill net statistics because, based on ~~10 yr~~ 11 yr of data available from the NMFS ~~(1965-1971, 1973-1975)~~ (1965-1975), these types of gill nets capture an average of 93% of the striped bass ~~in~~ taken from the Hudson River in New York.

Discrepancies in total square yards of stake and anchor gill nets occur between special shad summary sheets (Fisheries Statistics of the U.S.)

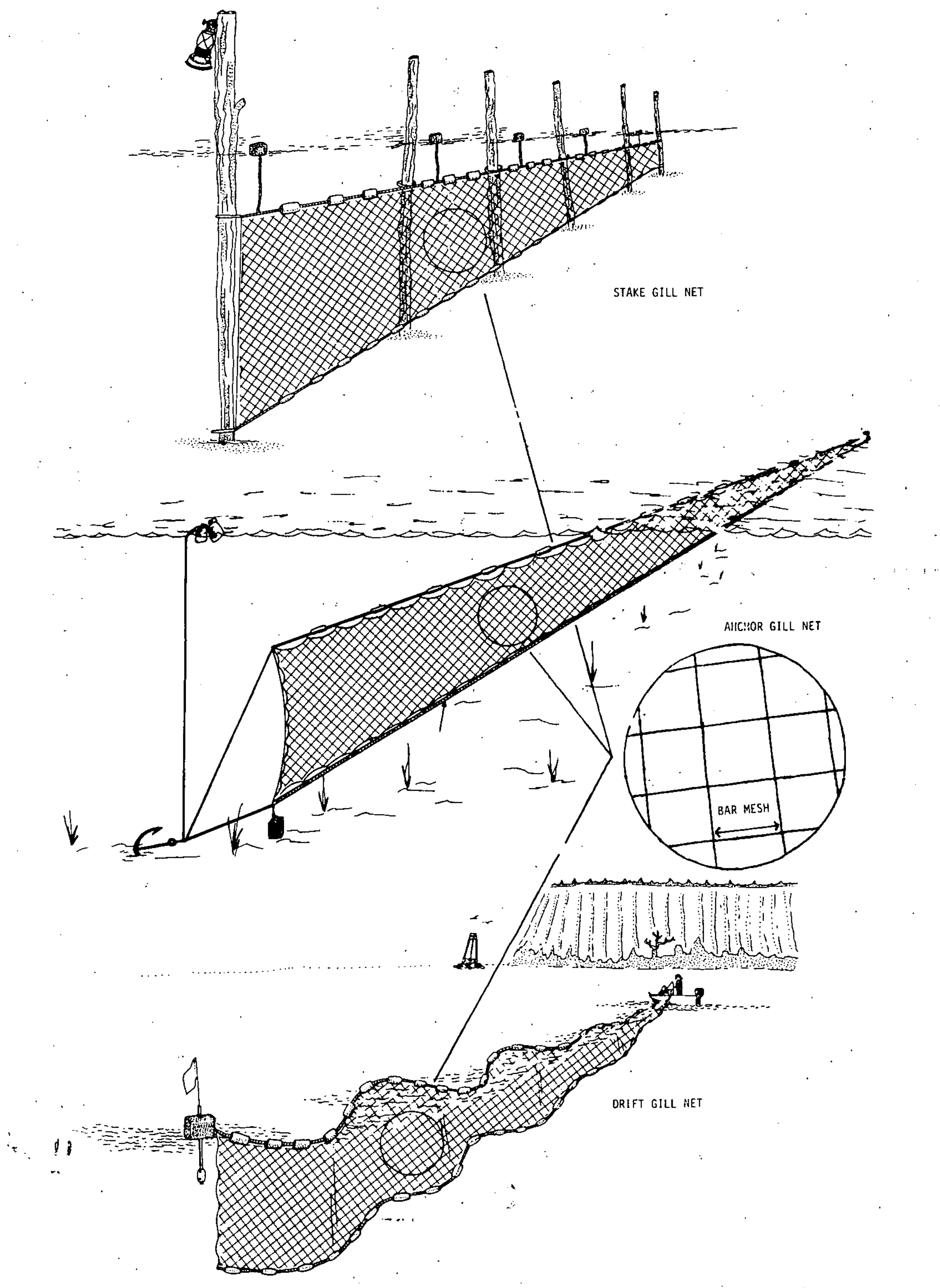

Figure 7.2-3 Example of Gill Nets Used in Commercial Fishery

published by the NMFS and data obtained from Fred Blossum (NMFS) from 1965 to 1971. Mr. Blossum's values are higher because the NMFS, in tabulating its special shad summary sheets, omits any fishing effort that does not take American shad. Therefore, any stake and anchor gill nets primarily taking striped bass are not included in the total square yardage (personal communication, Churchill Smith, former NMFS employee). Comparing data for these 7 yr (1965-71), the average ratio between Mr. Blossum's and the shad summary sheets' (NMFS) total square yards of stake and anchor gill nets is 1.20, with ratios ranging from 1.05 to 1.39. NMFS square yardage values (obtained from the shad summary sheets) were multiplied by 1.20 to estimate the total square yardage from 1931 to 1964 ~~and 1972~~ and to be consistent with Mr. Blossum's NMFS 1965-~~71~~75 and ~~1973-75~~ values (Table 7.2-1).

The total number (obtained from the shad summary sheets) of licensed stake and anchor gill nets in the Hudson River fishery fluctuated from 77 in 1955 to a low of 19 in 1967 and 1971 (Fig. 7.2-4). Again, NMFS shad summary sheet values tended to exclude nets that primarily took striped bass rather than shad; however, this effect was minimal and the data extremely useful in noting trends in fishing intensity. The number of licensed stake and anchor gill nets [generally] ~~consistently~~ decreased from 1955 to 1967, then fluctuated between 19 to 31 nets for the next 6 yr. There was a marked increase in 1974 and 1975, with 60 and 73 gill nets being licensed respectively in those 2 yr.

The total area of licensed stake and anchor gill nets varied over 20 yr, reaching a peak of 137,000 yd^2 (114,546 m^2) in 1956 and declining irregularly to 39,000 yd^2 (32,608 m^2) in 1973 (Fig. 7.2-5). Square yardage increased to 111,000 (92,807 m^2) and 127,000 (106,185 m^2) in 1974 and 1975, corresponding to the increased number of nets during those 2 yr.

The number of licensed commercial fishermen in the portion of the Hudson River regulated by New York gradually decreased from 252 in 1955 to a low of 39 in 1971 (Fig. 7.2-6). A large increase occurred in 1974 and published by the NMFS and data obtained from Fred Blossum (NMFS) from 1965 to 1971. Mr. Blossum's values are higher because the NMFS, in tabulating its special shad summary sheets, omits any fishing effort that does not take American shad. Therefore, any stake and anchor gill nets primarily taking striped bass are not included in the total square yardage (personal communication, Churchill Smith, former NMFS employee). Comparing data for these 7 yr (1965-71), the average ratio between Mr. Blossum's and the shad summary sheets' (NMFS) total square yards of stake and anchor gill nets is 1.20, with ratios ranging from 1.05 to 1.39. NMFS square yardage values (obtained from the shad summary sheets) were multiplied by 1.20 to estimate the total square yardage from 1931 to 1964 and 1972 and to be consistent with Mr. Blossum's NMFS 1965-71 and 1973-75 values (Table 7.2-1).

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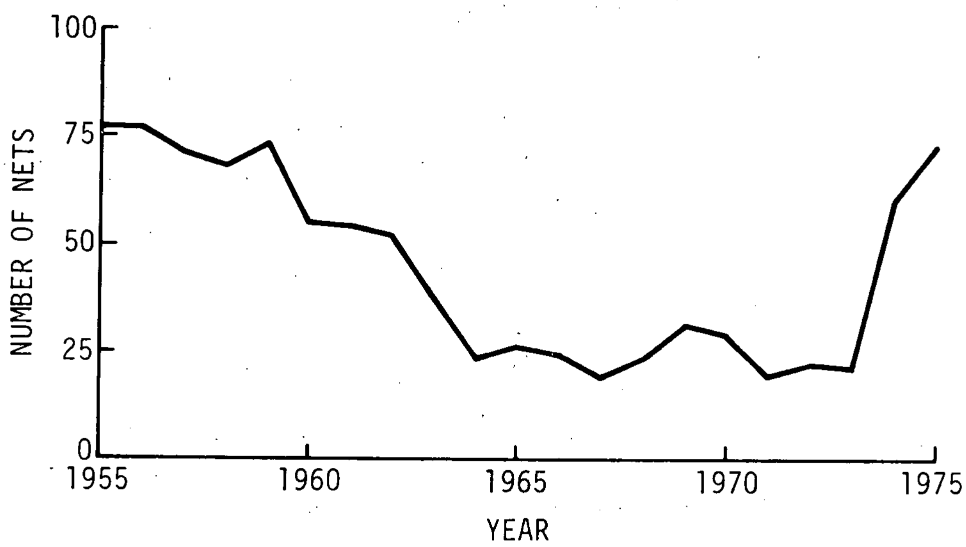

Figure 7.2-4 Number of Licensed Stake and Anchor Gill Nets in Hudson River in New York, 1955-75 (Fishery Statistics of U.S., Statistical Digests, obtained from Fred Blossum, NMFS)

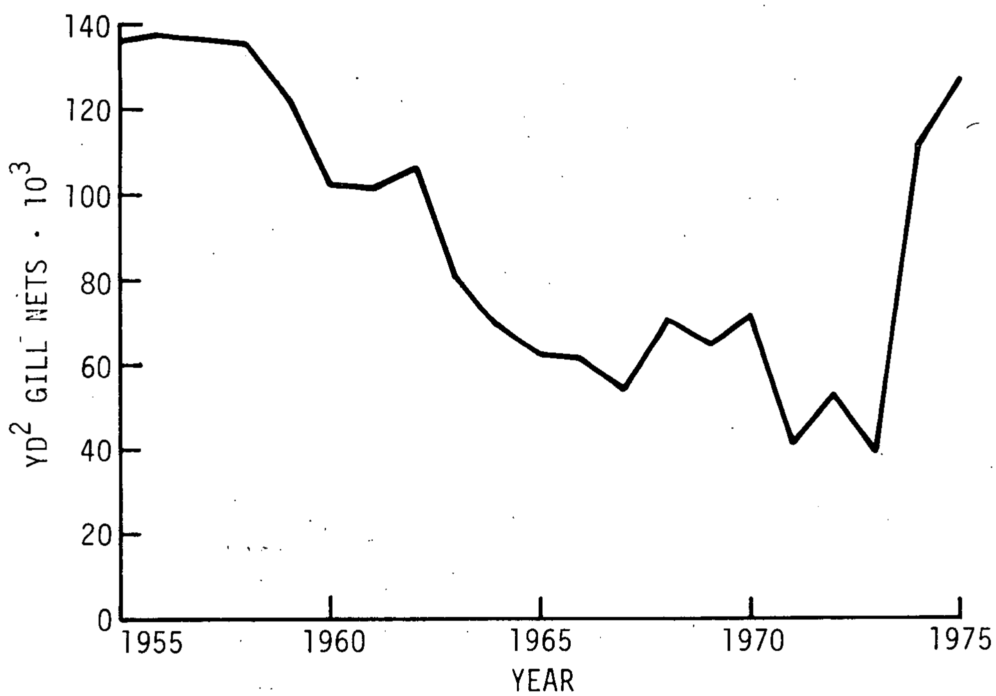

Figure 7.2-5 Total Square Yards of Licensed Stake and Anchor Gill Nets in Hudson River in New York, 1955-75. (Obtained from Fred Blossum, NMFS)

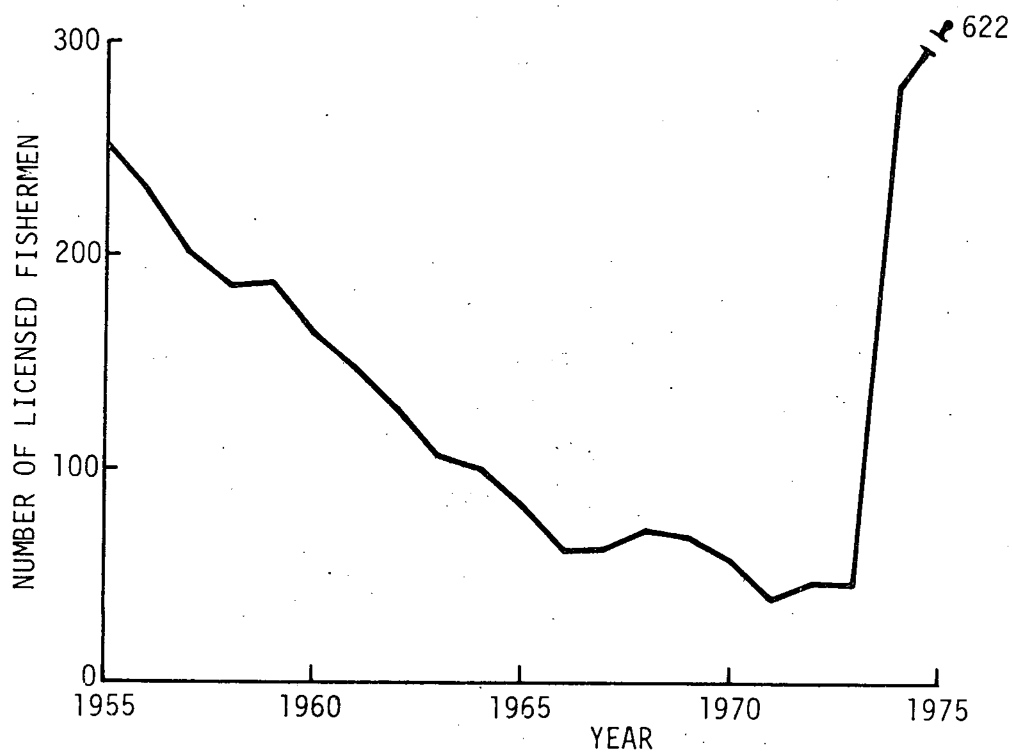

Figure 7.2-6 Number of Fishermen Licensed for Hudson River in New York, 1955-75. (Fishery Statistics of U.S., Statistical Digest, obtained from Fred Blossum, NMFS)

1975, with 273 and 622 fishermen being licensed for New York Hudson River waters. This increase in number of fishermen was paralleled by increases in 1974 and 1975 in the number and square yardage of stake and anchor gill nets. This may indicate a renewed interest in fishing following large landings of striped bass in 1973 and may also be partly the result of the high rate of unemployment in 1974 and 1975 (Perrin 1975:56).

7.2.2 REGULATIONS. The Hudson River commercial fishery for striped bass in New York is regulated by rules defining gill net length and mesh size, fishing seasons, restricted areas, minimum size limits, and escapement (net lift) periods. Stake and anchor gill nets may be no longer than 1200 ft (366 m) and must have a minimum bar mesh size of 2.25 in (5.72 cm) (Fig. 7.2-3). The open fishing season for striped bass ran from March 15 through November 30 until 1976 when it was closed due to high PCB (polychlorinated biphenyl) levels in striped bass (Section 5.4). The winter fishing season for striped bass was closed in 1949, prohibiting the capture of striped bass between December 1 and March 15. No commercial netting of any kind is allow from March 15 to June 15 on the shad spawning grounds known as "the Flats," RM 91-96 (km 146-154). The length of the potential escapement period for striped bass is reflected by the gill net fishing hours allowed per week during the March 15 to June 15 shad season since the shad fishing season coincides with the striped bass spawning run. Since 1959, the legal maximum has been 120 h of fishing per week, with the lift period occurring between 0600 EST on Friday to 0600 EST on Sunday. From ~~1951~~ 1952 through 1958, the legal fishing time allowed per week for gill nets was 108 h wk^{-1}. There is no commercial gill net fishery for striped bass in New Jersey.

7.2.3 LANDINGS. Striped bass landings in all gear increased in the 1930s, 1940s, and 1950s, peaked in 1959 and 1960, then declined irregularly into the 1970s (Fig. 7.2-7). Landings increased steadily in the 1930s and early 1940s, peaking at 79,000 lb (35,834 kg) in 1945. Landings

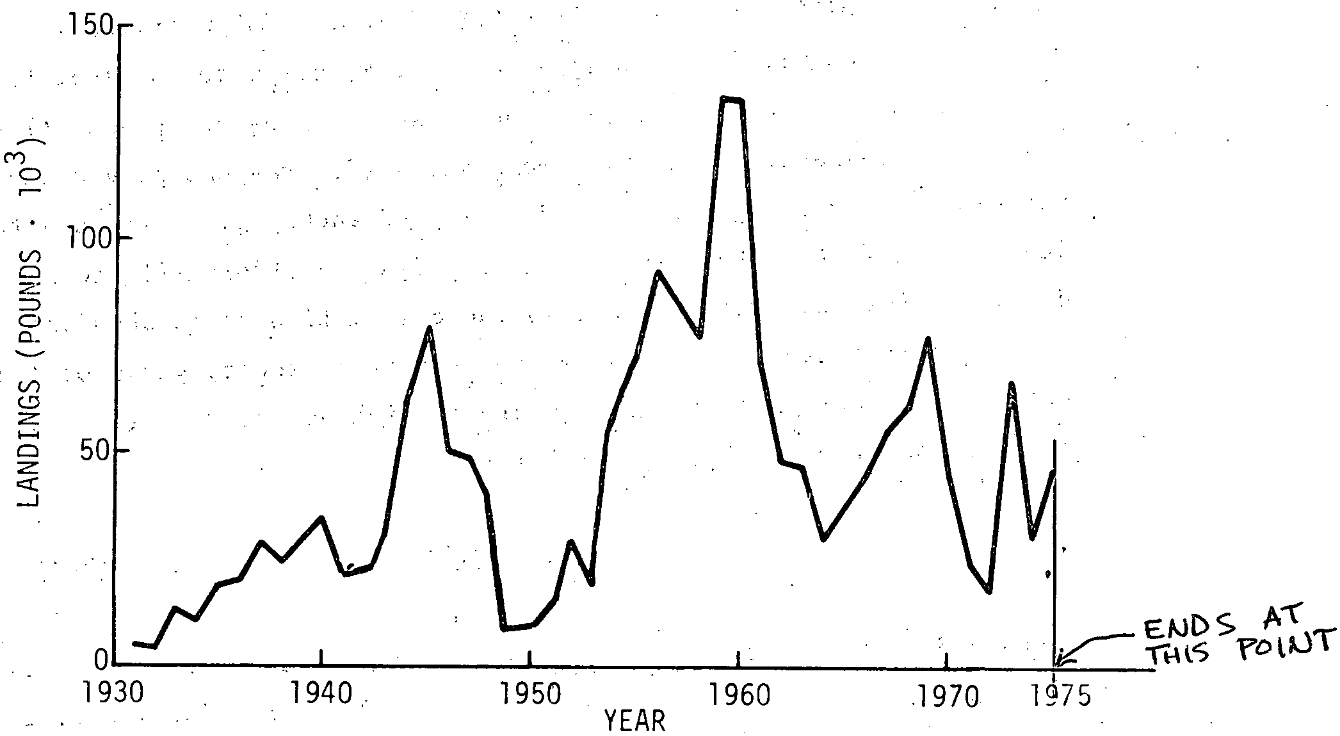

Figure 7.2-7. Landings of Striped Bass from Hudson River in New York 1931-75. (Obtained from Fred Blossum, NMFS)

then declined in the late 1940s and early 1950s but peaked again in 1956, 1959, and 1960. In the early 1960s, landings declined but peaked again in 1969. There was another decline in 1972, followed by a high of 67,000 lb (30,391 kg) in 1973, a decrease to 30,000 lb (13,608 kg) in 1974, and another small increase to 46,000 lb (20,866 kg) in 1975.

7.2.4 FISHING EFFORT AND ABUNDANCE INDICES. Calculations to estimate the relative magnitude of striped bass stock were made for 1931 through 1975, but only those for 1955-75 were based on consistent data (Table 7.2-1) and believed comparable among years (for reasons previously discussed). By using the area of stake and anchor gill nets and the length of time that they were fished, a fishing effort (f) index was developed for each year for use in the calculation of an abundance index. Fishing effort was calculated as the product of square yards of licensed stake and anchor gill nets (A), hours of fishing per week (t), and a scaling factor of 10^{-6} (Table 7.2-1):

$$f = A \cdot t \cdot 10^{-6} \qquad (7\text{-}1)$$

Stake and anchor gill net fishing effort for striped bass was relatively constant from 1955 to 1962, declined until 1967, then fluctuated somewhat until 1973. Effort increased dramatically in 1974 and 1975, equaling that of the late 1950s (Fig. 7.2-8).

The declining trend in commercial fishing effort in the Hudson River from the late 1950s through the early 1970s was also evident in the number of licensed fishermen (Fig. 7.2-6). While the average size of gill nets being fished and the number of hours of fishing allowed per week influenced the fishing effort index, the major factor contributing to the decline in fishing effort seems to have been the steady departure of older fishermen with little replacement. In 1974 and 1975, a renewed interest in the fishery was evidenced by the large increase in licensed fishermen.

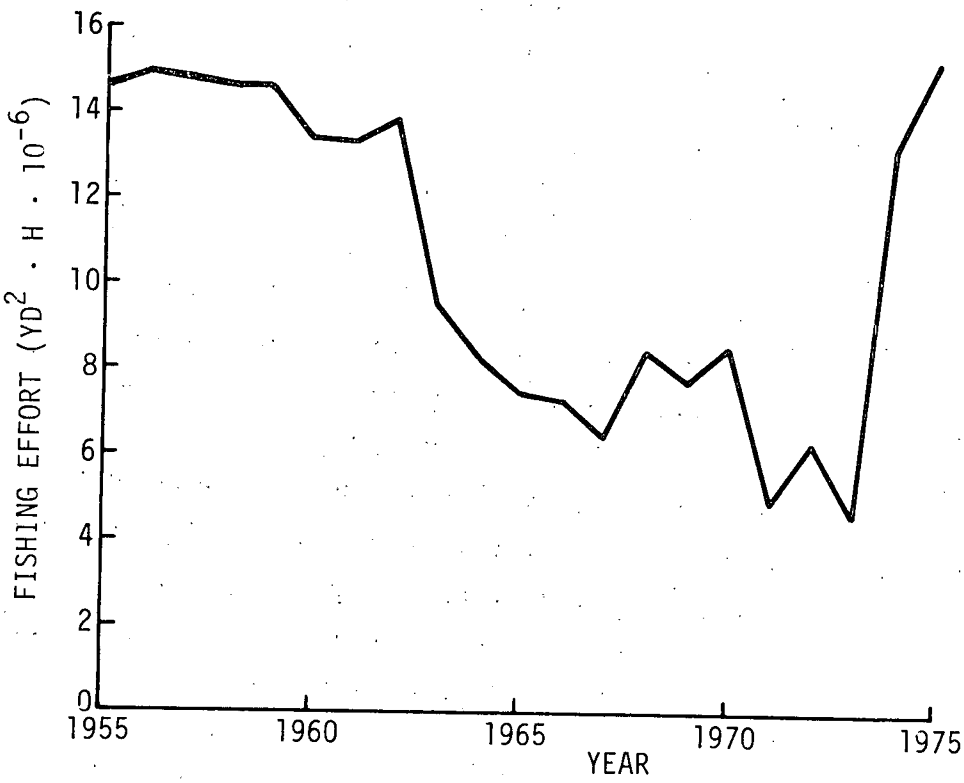

Figure 7.2-8   Stake and Anchor Gill Net Fishing Effort for Striped Bass in Hudson River in New York. (Based on DEC and NMFS data)

A yield-per-effort index of abundance (Y/f) was developed to estimate the relative abundance of the striped bass population (Table 7.2-1). Effort was represented by the index (f) defined in equation 7-1, and the yield was the reported commercial landings in pounds. The Y/f index was estimated by the standard formula in which yield (in pounds) was divided by effort (f). The use of commercial fishery data to calculate indices of striped bass abundance assumed that the reported catch and effort data were indicative of actual catch and effort and that trends in Y/f indices reflected trends in stock abundance.

Several potential sources of bias could influence the Y/f values for striped bass. The index of fishing effort assumes that the proportional utilization of all licensed nets and hours of fishing allowed per week is constant throughout all years. Therefore, factors affecting either the square yards of licensed gill nets in use or the number of hours actually fished per week would cause actual fishing effort to fluctuate. Stormy weather, for example, may limit the actual hours per week during which fishermen are able to tend their gill nets or the dramatic increases in retail prices of fish, meat, and poultry from 1972 to 1974 (USDC) (~~Statistical Abstract of the United States 1974~~) could have caused an unmeasured increase in fishing effort (particularly in 1973 when some meat products were being withheld from the market). Such an increase could be effected by either fishing a higher proportion of the licensed nets than usual or by fishing longer hours and tending nets more frequently. Such factors are always operative to some extent, creating unmeasured fluctuations in fishing effort.

The accuracy of catch data will also affect the accuracy of the striped bass abundance index. Errors in reporting fisheries statistics may be due to numerous factors (Medeiros 1974:22). The individual fisherman may not keep accurate records of his catch or honestly report his landings, and inaccurate transcription of data by collecting agencies is possible. Landings data collected by the NMFS is based on personal follow-up interviews and is used here because it is thought to be more accurate than other data collection methods. Reporting biases are undoubtedly present every year, and although they might affect the actual landings, year-to-year fluctuations would still be discernable.

The striped bass abundance index fluctuated with major peaks in 1960, 1969, and 1973 (Fig. 7.2-9). Abundance (Y/f) increased irregularly from 1955 to 1960, peaking at 10,000, and then declined in 1961, remaining at a low level through 1965. Y/f increased irregularly, peaking at 10,000 again in 1969. Abundance declined to 2,800 in 1972, then reached its highest peak in 1973 at 14,000 Y/f units. In 1974, abundance was at its lowest level (2,300) then increased slightly in 1975. While fluctuations in the abundance index may have been somewhat affected by factors such as poor weather conditions, data errors, or economic conditions, the major factor influencing the index almost surely was recruitment into the fishery, i.e., actual variations in abundance. Thus, the Y/f abundance index is a valuable indicator of the relative magnitude of the striped bass stock.

7.2.5 SUMMARY. The historical overview of Hudson River striped bass abundance based on commercial and sport fishery data can be summarized as follows:

- The striped bass has been a common species in the Hudson River since at least the 18th century and is considered to be an excellent food and game fish.
- The striped bass is an important item in the commercial catch; although historically, the American shad has been the most important commercial fish in the Hudson River.
- Few anglers regularly take advantage of striped bass fishing in the Hudson River.

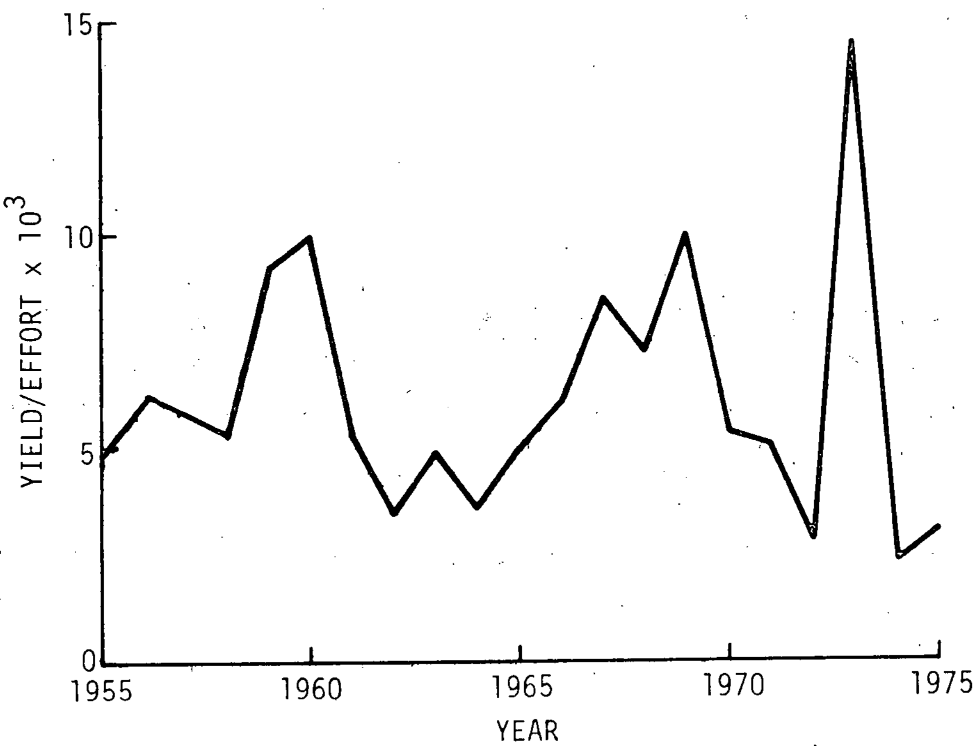

Figure 7.2-9 Striped Bass Yield per Effort in Hudson River in New York, 1955-75. (Based on NYSDEC and NMFS data)

- The wholesale market price for striped bass has been on an increasing trend since 1960.
- The striped bass appears to have successfully endured increasing environmental stresses in the Hudson River.
- The majority of striped bass are taken in the stake and anchor gill net fishery, which is concentrated between Weehawken, New Jersey, and Peekskill, New York.
- Stake and anchor gill net fishing effort declined irregularly in the 1960s and early 1970s, followed by a marked increase in 1974 and 1975.
- Striped bass abundance can be calculated from 20 yr of comparable data (1955-75) to estimate the relative magnitude of the striped bass stock.
- Striped bass abundance has fluctuated over the past 20 yr with peaks occurring in 1960, 1969, and 1973.

7.3 STRIPED BASS EGGS

7.3.1 PHYSICAL DESCRIPTION. The striped bass egg is characterized by a large oil globule atop a lightly granulated yolk mass (Mansueti 1958:8), a wide ~~perivitteline~~ perivitelline space, and a clear egg capsule (Fig. 7.3-1). The egg is nonadhesive and semibuoyant (Mansueti 1958:5, Lippson and Moran 1974:173), so it drifts in the current without sticking to the bottom or to objects in the water. The capsule diameter of a freshly deposited egg measures 1.3 mm (Lippson and Moran 1974:174) before water absorption into the perivitteline space, a process called water-hardening that requires 1 to 1.5 h (Mansueti 1958:7), after which the egg is turgid and firm to the touch (Lagler et al. 1962:303). Water-hardened,

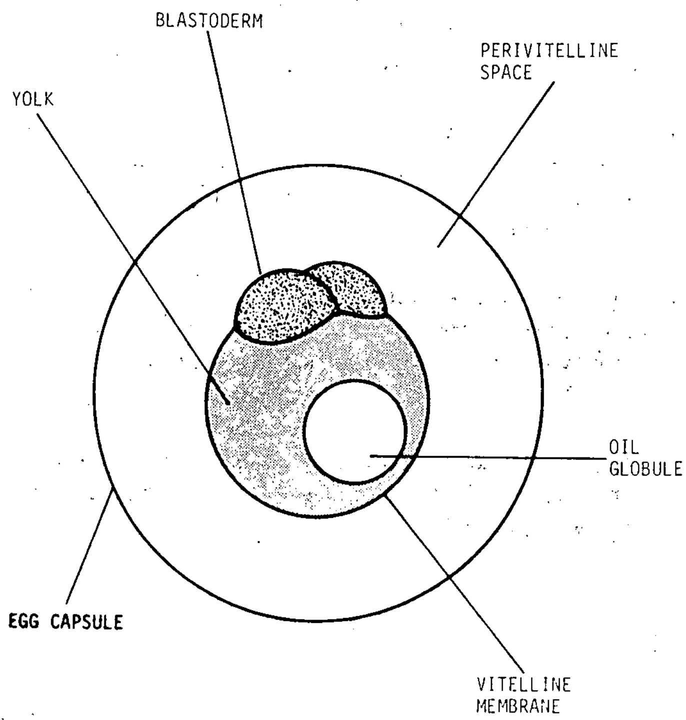

Figure 7.3-1 Developing Striped Bass Egg in Early Cleavage

the egg capsule diameter averages 3.4 mm, the yolk mass 1.2 mm, and the oil globule 0.6 mm (Lippson and Moran 1974:173); capsule diameter is inversely proportional to the salinity and hardness of the water in which the egg is deposited (Bayless 1972:49). Striped bass eggs from the Sacramento River have a mean specific gravity of 1.0005, with a range of 1.0003 to 1.00065 (Albrecht 1964:102), and a mean settling rate of approximately 2.4 mm s^{-1} in fresh water (California Department of Fish and Game 1974:64); 90% of the eggs tested settled slower than 3.4 mm s^{-1}, older eggs were more buoyant and settled more slowly, and smaller-diameter eggs settled more rapidly than large eggs (California Department of Fish and Game 1974:64).

Laboratory experiments by Albrecht (1964:104) showed that the suspension of eggs within the water column is important to their development; eggs in suspension had an 81% hatch ~~survival~~ rate, while only 8% of those allowed to rest on the bottom hatched ~~survived~~. Suspension can be maintained by a vertical water movement sufficient to carry the eggs upward or by an increase in salinity. The first factor, water velocity, is by far the most important. Smith (quoted by Talbot 1966:40) found that water-hardened striped bass eggs remained suspended in water moving vertically at 1.25 mm min^{-1}. Albrecht (1964:110) stated that in the Sacramento River system a horizontal velocity of 0.3 m s^{-1} (18 m min^{-1}) was necessary to keep striped bass eggs in suspension. The horizontal current velocity in the Newburgh area of the Hudson River estuary is less than 0.3 m s^{-1} approximately 14 ~~16~~ h of every 24 (USDC 1973:54); during those slow current periods, striped bass eggs may tend to sink. Results of field sampling showed that eggs concentrate in near-bottom depths (Carlson and McCann 1969:20; Woodhull 1947:101). Salinity is also an important suspension factor, however; theoretically, approximately 2 o/oo at 18°C would be required to suspend a striped bass egg with a specific gravity of 1.0005. Since striped bass eggs in the Hudson River estuary are almost always found in fresh water (TI 1975b:VI-109), it appears that salinity does not often serve to keep the eggs suspended.

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7.3.2 EFFECTS OF MECHANICAL STRESSES. Merriman (1941:19) described the striped bass egg as tough and able to withstand turbulent stream conditions. Later investigators examined three major forces that could damage eggs: rapid velocity changes, shear, and pressure change.

Ulanowicz (1975:6) found that the velocity at which striped bass eggs are accelerated can be damaging. Velocity changes near the outlet or intake of power plants are slight and do not appear to damage eggs; but accelerative forces in eddies associated with the cooling water discharges could be potentially injurious. Shear forces are also damaging to striped bass eggs. Ulanowicz (1975:77-87) and Morgan et al. (1976: 149-154) stated that shear force fields (measured in dynes cm^{-2} exerted tangentially on the surface of the egg) are present when the velocity of water varies from one point to another. Velocity changes are common as water passes a solid surface such as conduit walls, pump impellers, boat propellers, and screens: the water clinging to the solid surface has a velocity of 0 while the water farther from the solid surface moves faster. When the egg enters the shear force field, it is first rotated, then deformed. Rotation stresses the egg capsule in all stages of egg development, disintegrates the yolk in early stages, and separates the embryo from the yolk in later developmental stages. If the egg actually contacts the wall, the chorion may become damaged through abrasion. Morgan et al. (1976:151-152) found that all egg developmental stages were equally affected. Morgan et al. (1976:152) also stated that 50% of all striped bass eggs would be killed if subjected to the following shear field stresses: 542 dynes cm^{-2} for 1 min, 255 dynes cm^{-2} for 2 min, ~~and~~ or 190 dynes cm^{-2} for 4 min. Morgan et al. (1976:153), in investigating the shear force field created by a large ship (except for the propeller), found that an ocean-going vessel 135 m in length, 17.4 m in breadth, drawing 8.5 m of water, traveling 5.6 km h^{-1} against a tidal flow of 5.2 km h^{-1} creates a shear force field of 78.9 dynes cm^{-2}. Eggs would not be expected to remain in the shear force field for more than 1 min, which is well below the level at which 50% of the eggs would be killed.

Beck et al. (1975:181) found that striped bass eggs were not harmed when held at pressures to 51.6 kg cm^{-2} (approximately 49 times greater than atmospheric pressure) for 15 min. Eggs subjected to pressures of 0.41 to 0.40 kg cm^{-2} (<50% atmospheric pressure) for 10 to 15 s were similarly unaffected. In Section 8.3.3, estimates of the survival of striped bass during entrainment are presented. It is clear that some eggs are killed during passage through power plant cooling systems, and mechanical stresses such as discussed here may be responsible for some portion of the mortality. The Separate ~~seperate~~ contributions of various agents of mortality have not been quantified, however.

7.3.3 FACTORS AFFECTING FERTILIZATION. Successful fertilization depends on water temperature, salinity, and how soon eggs and sperm come into contact after being deposited in the water. The activity (motility) of the sperm is crucial to fertilization success. Scofield (1910:114) found that striped bass spermatozoa were active for about 3 min after first contact with water; Bayless (1972:35) however, reported that the spermatozoa were active for only 30 to 50 s. This difference may be due, in part, to the difficulty in observing activity of spermatozoa. Scofield (1910:114) found that sperm were most active at 20°C, sluggish at 5.5°C, and dead at temperatures >37.8°C. A solution of 5 o/oo salinity stimulates sperm activity (Scofield 1910: 114). Bayless (1972:37) stated that fertilization is possible but diminished in a saline environment and that no fertilization occurs at 17.5 o/oo salinity.

Bayless (1972:36) found that fertilization success was reduced if striped bass eggs were placed in water but not fertilized immediately. A test was made to compare the effect of delayed contact between sperm and eggs for 2, 3, and 4 min; approximately 90% of the eggs that were mixed immediately with sperm were fertilized, only 80% were fertilized when contact with sperm was delayed 2 min, and fertilization was 40% after a delay of 3 min and 20% after 4 min. Bayless (1972: ~~1973~~:36) suggested that the micropyle, the principal port of sperm entry, closes during water-hardening.

7.3.4 TEMPERATURE, OXYGEN, SALINITY, AND TURBIDITY TOLERANCES

7.3.4.1 Temperature. Striped bass eggs develop at a rate directly proportional to temperature; i.e., a higher temperature decreases time to hatch. Most studies that report hatching time agree closely; the discrepancies that exist may be due partly to the various methods used in defining hatching time. For example, Rogers et al. (1976:7) recorded hatching time as the period between fertilization and the point at which half the eggs hatched, while Bayless (1972:46) used the period between fertilization and hatch of the first egg.

Rogers et al. (1976:19) found that over the 12 to 27°C range, the relationship between hatching time and temperature is best described by the equation:

$$H = 258.5e^{-0.0934T}$$

where H = hatching time in hours and T = temperature in ~~degress~~ degrees. Celsius; while at temperatures between 15 and 24°C, the relationship between temperature and hatching time was best described by the linear function:

$$H = -4.616\ T + 134.310$$

Shannon and Smith (1967:2-3) found that the percent of malformed and dead larvae increased as incubation temperatures increased from 21.1 to 26.6°C. At 23.4°C, all larvae were dead within 70 h after hatching. Bayless (1972:48) found that the percent of striped bass eggs that hatched began to decrease above 18.9°C rather than at 23.4°C as reported by Shannon and Smith (1967:3). This difference may have been due to factors other than temperature (Bayless 1972:48). The lowest temperature at which striped bass eggs can hatch appears to be 12°C (Rogers et al. 1976:19). Bayless (1972:48) reported that optimum incubation temperatures at the Monck's Corner Hatchery, North Carolina were between 16.6 and 18.3°C. At 16.6°C the hatching time is 56 h; at 18.3°C the hatching time is reduced to 48 h (Bayless 1972:46). Turner (1976:116)

~~Found~~ found that water ~~Temperature~~ temperature changed the time of spawning but not the spawning location in the Sacramento River; the time of spawning was significantly correlated with mean monthly water temperature for April and May (Turner 1976:111). In a review article, Talbot (1966:42) reported that the lowest temperature at which striped bass spawn extensively is 14.4°C and that peak spawning occurs between 15.6 and 19.4°C. In 1974 in the Hudson River, striped bass eggs were taken at temperatures ranging from 12 to 23°C (Fig. 7.3-2), with peak catches occurring in the 14-18°C range. During 1975, striped bass eggs were again collected in the 12-23°C range (Fig. 7.3-2), but spawning peaked at slightly higher temperatures (16-20°C). The peak spawning temperatures in 1975 were in the range that Bayless (1972:110) considered to be optimum for incubation success.

7.3.4.2 <u>Oxygen</u>. ~~O'Malley~~ O'Mally and Boone (1972:1) suggest that eggs can tolerate low dissolved oxygen levels but that the larvae do not develop normally. Eggs exposed to dissolved oxygen concentrations of 4.9-9.8 mg litre^{-1} (50-100% saturation) developed normally, whereas those hatched in 2.0 mg litre^{-1} oxygen (25% saturation) developed more slowly and the larvae were smaller and less active. Oxygen levels of 0.98 mg litre^{-1} (10% saturation) resulted in inactive, stunted, deformed larvae that died before reaching 2.5 mm in length.

Currents may carry eggs into unfavorable water conditions. During 1974, Texas Instruments collected some eggs where dissolved oxygen levels ranged from 1 to 4 mg litre^{-1} (Fig. 7.3-3), but it is not known whether the low oxygen levels resulted in increased egg mortalities. During 1975, striped bass eggs were collected where oxygen levels were high (Fig. 7.3-3): peak catches were in the 8-11 mg litre^{-1} range.

7.3.4.3 <u>Salinity</u>. Striped bass usually spawn in the first 25 mi (40.5 km) of fresh water in large river systems (Tresselt 1952:98) and not in brackish water (Albrecht 1964:111).

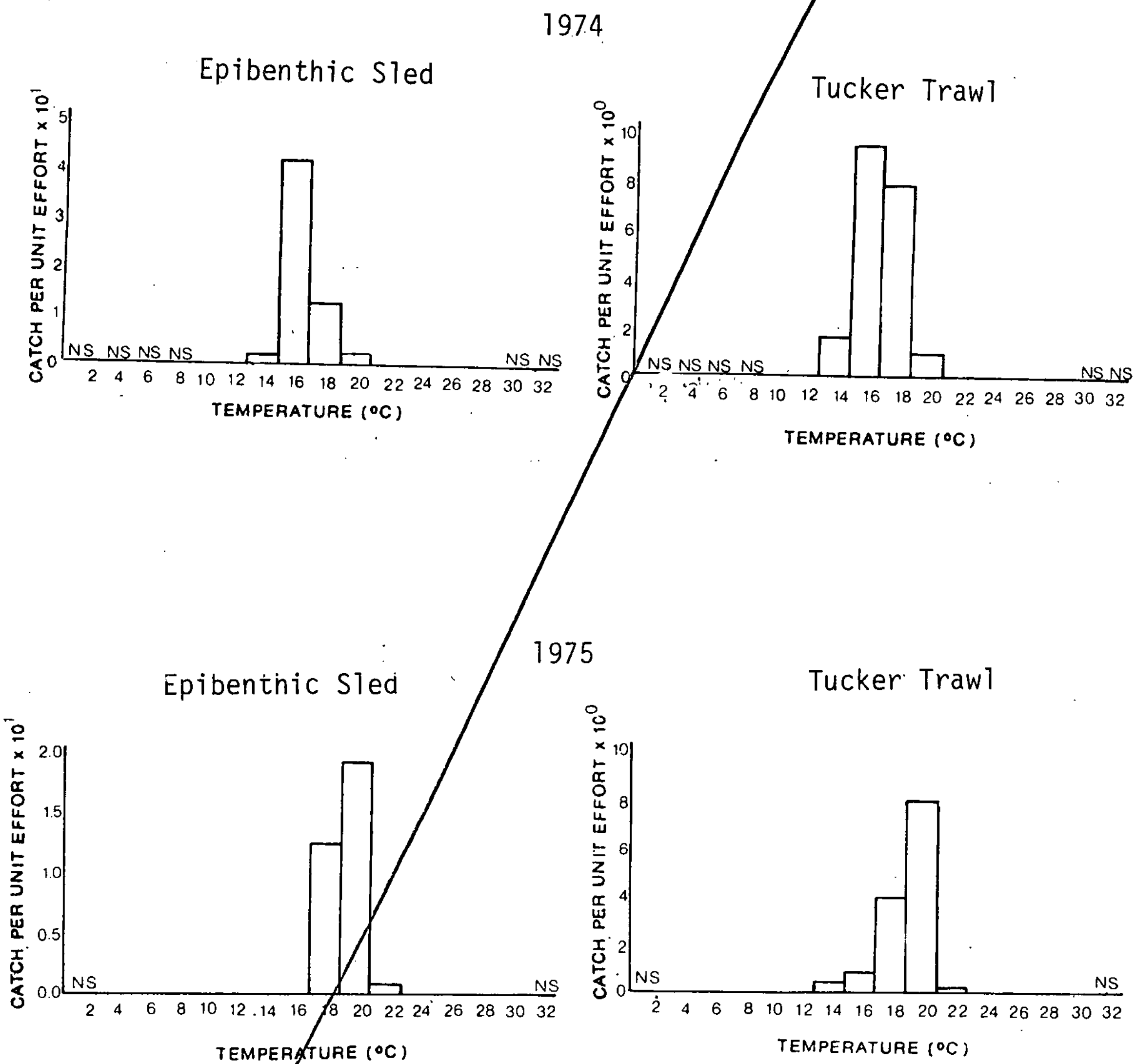
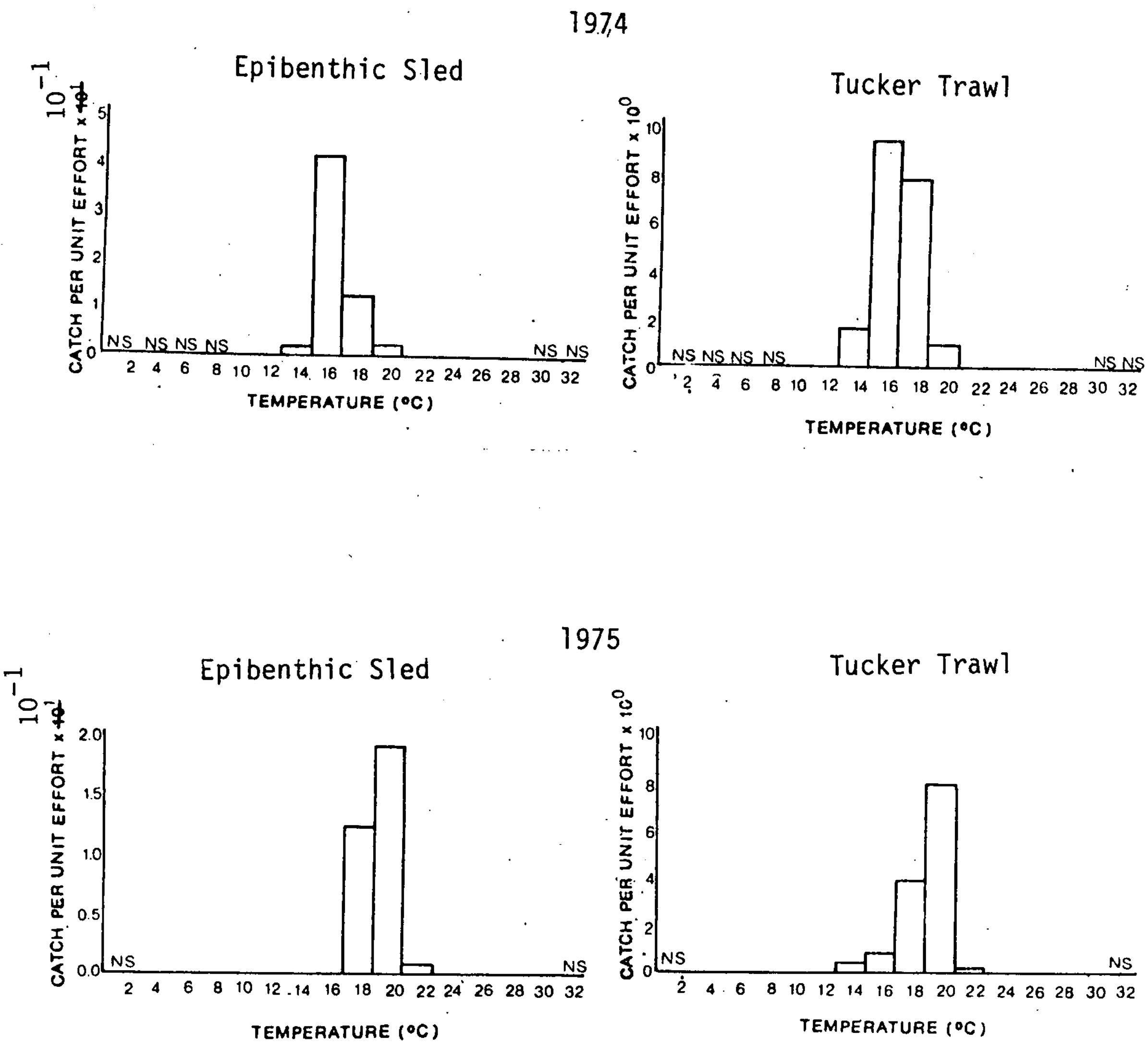


Figure 7.3-2 Catch Per Unit Effort of Striped Bass Eggs Collected at Various Temperatures by Epibenthic Sled and Tucker Trawl during 1974 and 1975 in Hudson River Estuary (RM 14-140; km 23-227)

This is a corrected figure.



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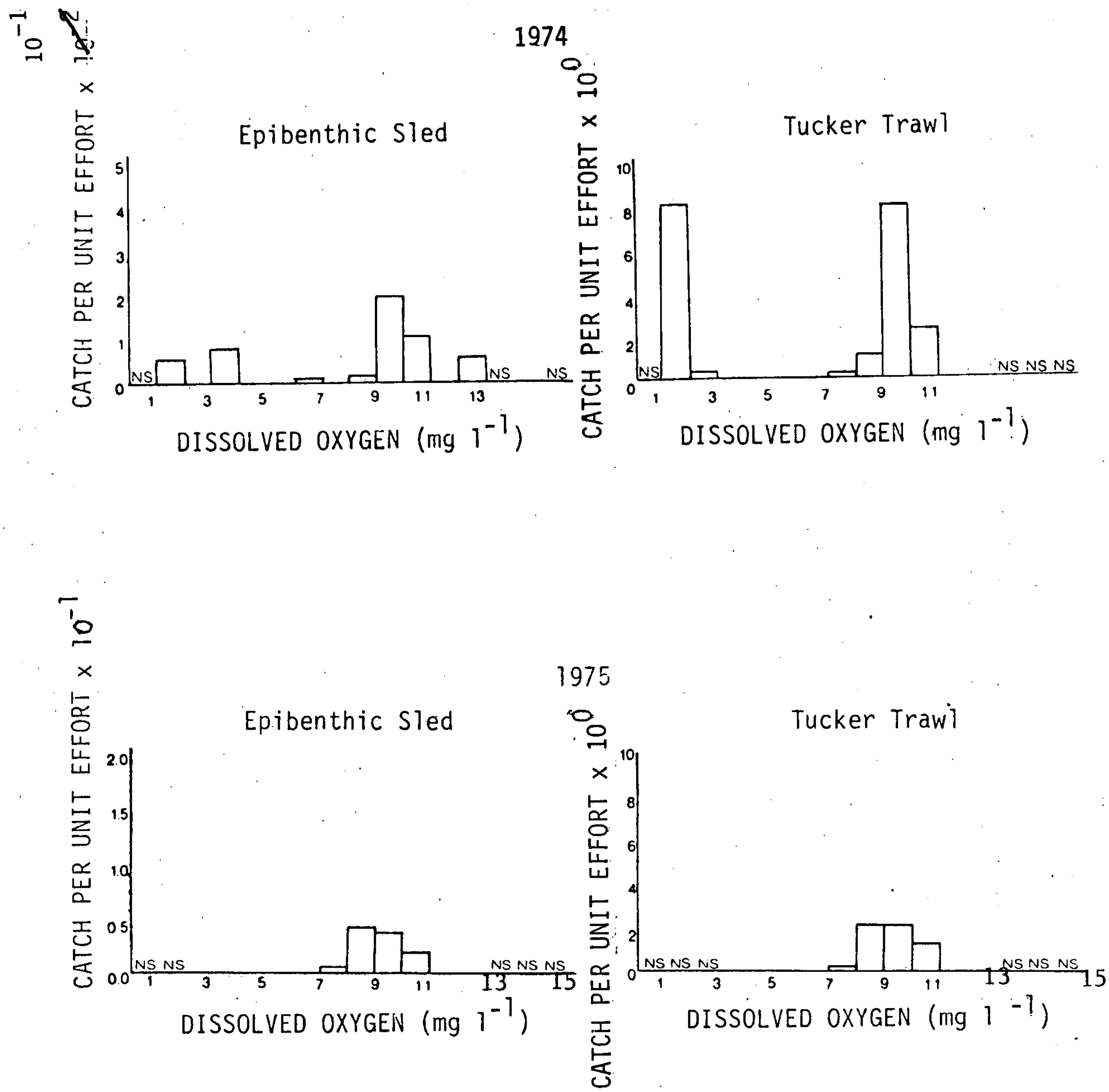

Figure 7.3-3 Catch Per Unit Effort of Striped Bass Eggs Collected by Epibenthic Sled and Tucker [Trawl~~s~~] during 1974 and 1975 at Various Dissolved Oxygen Concentrations in Hudson River Estuary (RM 14-140; km 23-227)

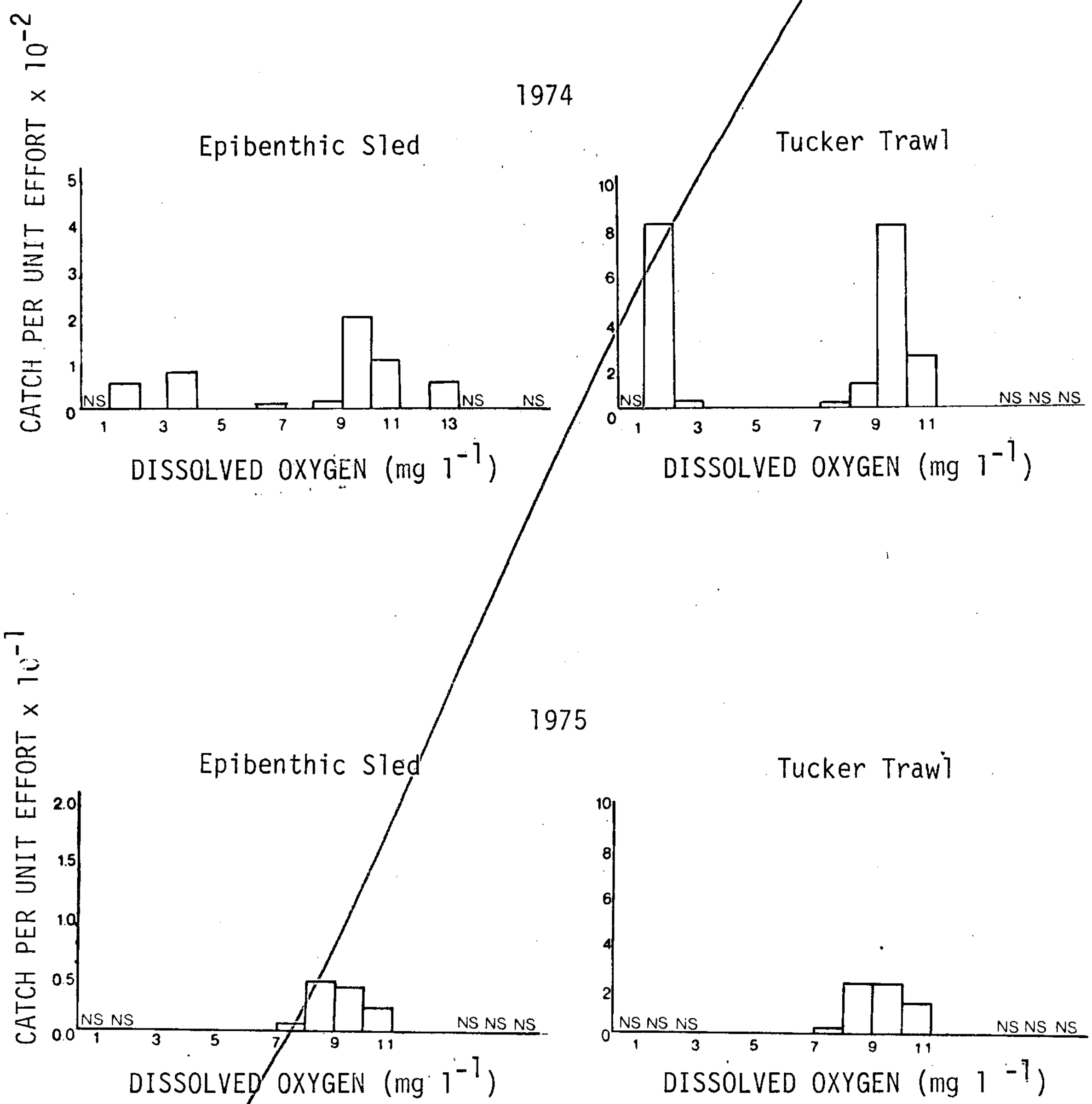

Figure 7.3-3 Catch Per Unit Effort of Striped Bass Eggs Collected by Epibenthic Sled and Tucker Trawls during 1974 and 1975 at Various Dissolved Oxygen Concentrations in Hudson River Estuary (RM 14-140; km 23-227)

Turner and Farley (1971:268-273) conducted two series of tests on the effects of temperature and salinity on striped bass eggs; in one test, the eggs were placed directly under test conditions; in the second, the eggs were water-hardened in fresh water for 2 h at 18.3°C before being placed under test conditions. Test temperatures ranged from 14.4 to 22.2°C and salinities from 0.13 to 10.00 o/oo. A control group (a similar group of eggs kept in ideal conditions throughout the experiment) was used for comparison. At >1.0 o/oo salinity, survival was 50-60% for eggs hardened in fresh water and 0-20% for those hardened in test salinities at temperatures of 18.3 to 22.2°C; at 14.4°C, survival was better for both groups.

Albrecht (1964:105-106) collected developing striped bass eggs from the Sacramento and San Joaquin Rivers and returned them to the laboratory for salinity experiments. Eggs were incubated in fresh water and in salinities ranging from 0.076 to 14.100 o/oo; temperature was not considered an experimental variable. Freshwater survival ranged between 76 and 97%, whereas tests at salinities of 0.076 to 14.100 o/oo yielded survival rates of 63-100%. Albrecht (1964:105) stated that survival was high in salinities to 9.48 o/oo. During 1974 and 1975, nearly all spawning in the Hudson River occurred in fresh water (Fig. 7.3-4). In 1975, some eggs were collected in the 0.45 mS cm^{-2} conductivity range (approximately 0.25 o/oo salinity) (Fig. 7.3-4).

7.3.4.4 Turbidity. Suspended particles in the water column (turbidity) can change spawning location and affect egg survival. Turbid conditions are common in striped bass spawning areas and may increase survival of striped bass eggs and larvae by making them less visible to predators; however, high turbidity levels may also inhibit egg development and suffocate larvae. Auld and Schubel (1974:54-55) found that hatching

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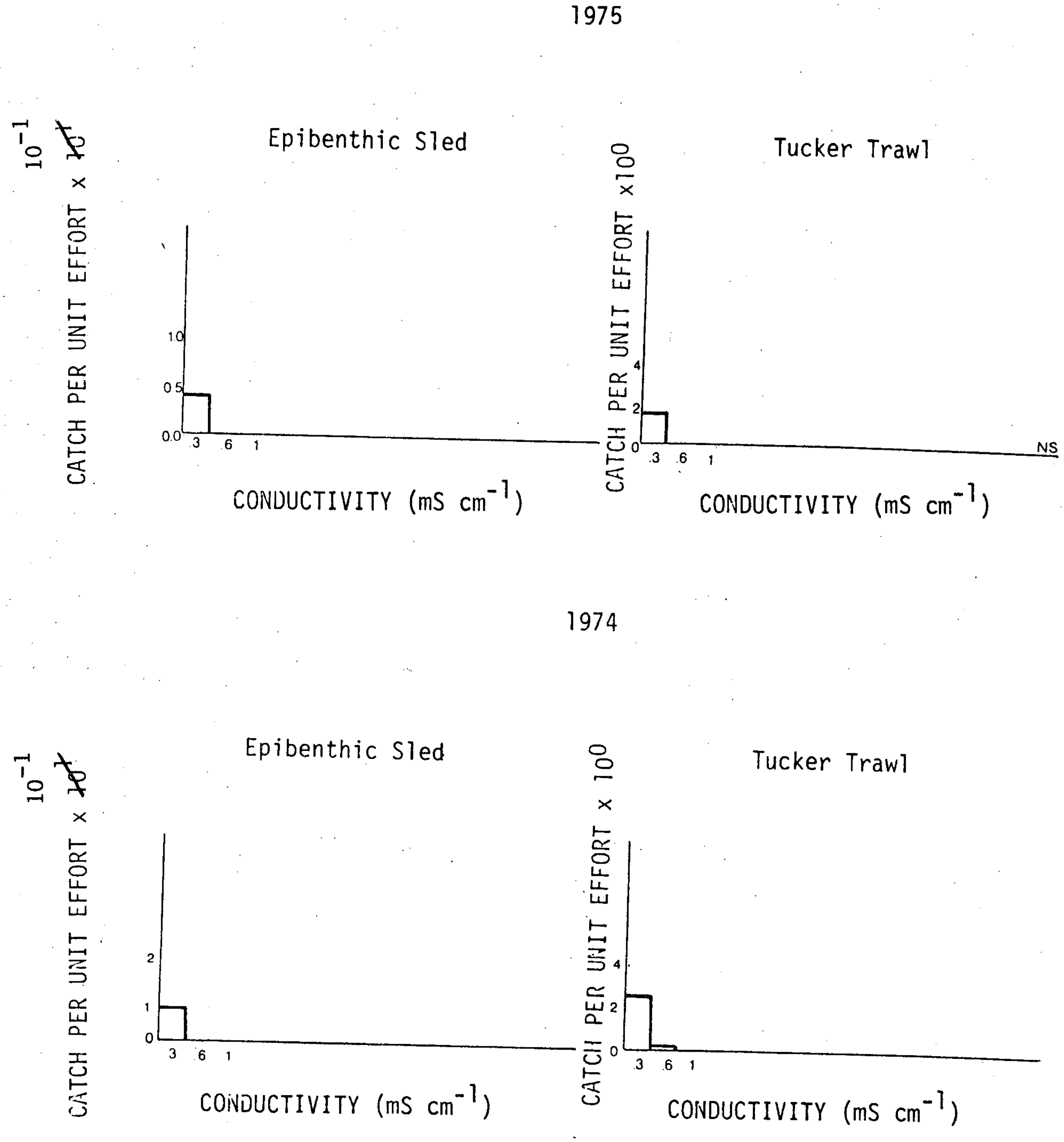

Figure 7.3-4. Catch Per Unit Effort of Striped Bass Eggs Collected at Various Conductivities ~~Collected~~ by Epibenthic Sled and Tucker Trawl during 1974 and 1975 in Hudson River Estuary (RM 14-140)

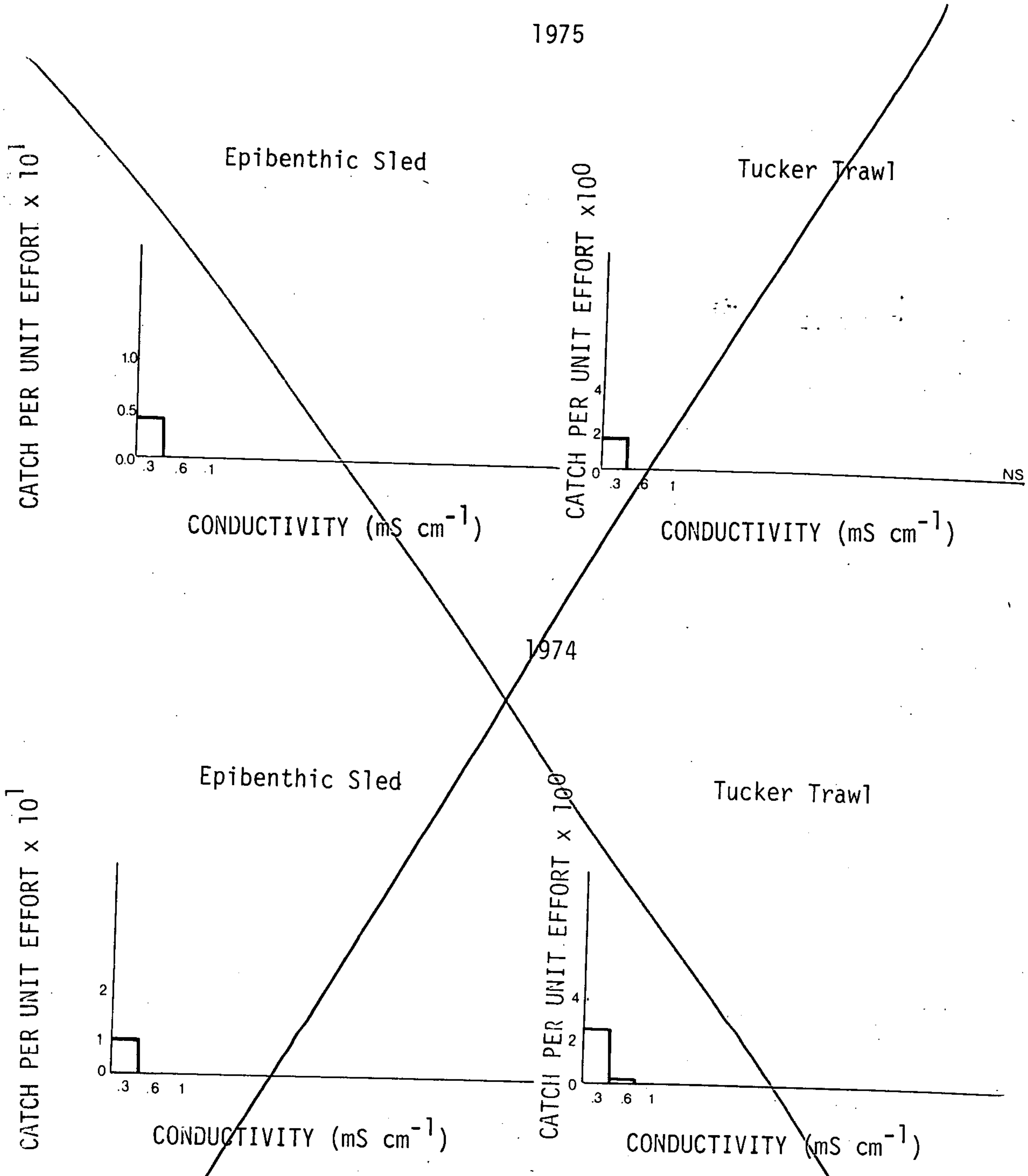

Figure 7.3-4. Catch Per Unit Effort of Striped Bass Eggs Collected at Various Conductivities Collected by Epibenthic Sled and Tucker Trawl during 1974 and 1975 in Hudson River Estuary (RM 14-140)

success was not significantly reduced until the level of suspended fine-grained sediments reached 1000 mg litre^{-1}. While not necessarily injurious to eggs, high turbidity levels may act as a barrier to spawning fish. Striped bass do not travel as far upstream in the Coos River, Oregon, during seasons when muddy water from logging operations is encountered (Morgan and Gerlach 1950:27-28). In the Beacon, New York, area (RM 65; km 105) of the Hudson River on May 14, 1975, the suspended solids level (expressed as total nonfilterable residue) was 57 mg litre^{-1} (USDIGS 1974-1975) ~~(USGS 1975)~~, which is well below the total suspended solid load that might adversely affect the hatching success of striped bass eggs.

7.3.5 MICRODISTRIBUTION. Two areas of the Hudson River, Cornwall (RM 56; km 90) and Indian Point (RM 42; km 69), have been studied intensively to determine if striped bass eggs and larvae are evenly distributed throughout the water column. The river regions must be considered separately since each is unique with respect to current velocities, upwellings, and water depths. Care must be exercised in applying findings in one area to another. Some trends such as vertical distribution, however, appear in both Indian Point and Cornwall studies and in the literature and clearly reflect biological phenomena that occur generally throughout the river.

In these studies, the densities of organisms present in the water mass were sampled on different dates, in daytime and at night, at different depths and lateral positions, etc. The counts vary greatly among samples due to the effects of factors such as mentioned above and due also to the patchy distribution of organisms caused by chance or by other unmeasured environmental factors. The basic statistical approach used here (analysis of variance, Snedecor and Cochran 1967) partitions the variation in densities of organisms observed among the samples and assigns each portion of the variation to a specific factor. For example, 40% of the variability might be shown to be associated with differences between surface and bottom depths; 25% with differences between day and night; and 35% with differences among locations along the river.

Standard statistical tests are applied to determine whether differences in sample values among sampling locations, between day and night, etc., are attributable to real differences in the river population rather than to chance occurrences in the data values (sampling error). Real phenomena may cause variations in the densities of organisms large enough to be discerned against the background "noise" of sampling error. Judgments about the reality of effects ascribed to the factors tested in the study are made in the form of probability statements at three levels of confidence - 99% ($p \leq$ ~~0.10~~ 0.01); 95% ($p \leq 0.05$); and 90% ($p \leq 0.10$). For example a judgment or conclusion reached at the 99% confidence level will be correct unless a chance sampling event, which has a probability not greater than 1% ($p \leq 0.01$), has occurred.

Where significant effects are identified through the analysis of variance, the specific observations or group of observations within the data set that differ from one another are identified by a second statistical technique called Newman-Keuls multiple comparisons (Miller 1966:81). For example, the analysis of variance might show significant differences among a set of seven sampling locations; Newman-Keuls multiple comparisons would show which locations differed from the others.

The simplest questions tested through analysis of variance are of the form: "do daytime densities differ from night?" or "are the variations among longitudinal river regions significant?" To answer these questions, the data are averaged across all dimensions of the study except the one that the questions addresses. For example, the data are averaged across all dates, depths, and sampling locations to carry out the day-vs-night comparisons.

More complex questions can be asked. For example, "is the difference in density of organisms between surface and bottom waters the same in daytime as at night?" Questions of this form deal with interactions between the different sources of variation measured in the study. The example question above deals with a 2-way interaction (depth x time); 3 and 4-way interactions can be tested as well in these studies.

The analytical approach outlined here was used in studying the micro-distributions of eggs, as presented in this section, and the micro-distribution of yolk-sac larvae and post yolk-sac larvae (Section 7.4) as well.

7.3.5.1 Texas Instruments Cornwall Study. The Cornwall study was designed to characterize the distribution of striped bass eggs and larvae between RM 53 and 59 (km 84.8 - 94.4). The area was divided into three longitudinal regions (Fig. 7.3-5), each of which was sub-divided into three lateral zones - west, channel, and east. The west and east strata were sampled at the surface (sample depth, <13 ft [4m]) and at the bottom. In the channel, mid-depths as well as surface and bottom were sampled. Thus, there were seven sampling strata in each longitudinal region. For this analysis all strata were sampled during each of two weeks in May, during the day and night, with two replicate samples taken in each stratum during each time period.

Two separate analyses were conducted. The first (6-stratum design) included sampling period, longitudinal region, lateral zone, relative depth (surface and bottom only) and time of sampling (day or night). The second (3-stratum) design used the same main effects but also included mid-depth samples and excluded the west and east lateral zones. Results of the analysis of variance of the distribution of eggs in the 6- and 3-stratum designs are presented in Tables 7.3-1 and 7.3-2. Several of the main effects and interactions were found to be significant.

More eggs were collected during the May 22-23 sampling period than during May 28-29 (Fig. 7.3-6). Spawning peaked before May 28-29 (Section 6.2). Striped bass eggs were found to be concentrated at near bottom depths in the Cornwall area (Fig. 7.3-7). However, the depth distribution of eggs depended on longitudinal region and lateral zone (Fig. 7.3-8, 7.3-9, 7.3-10, and 7.3-11). These differences are probably due to physical differences in the river such as tidal currents and associated upwellings.

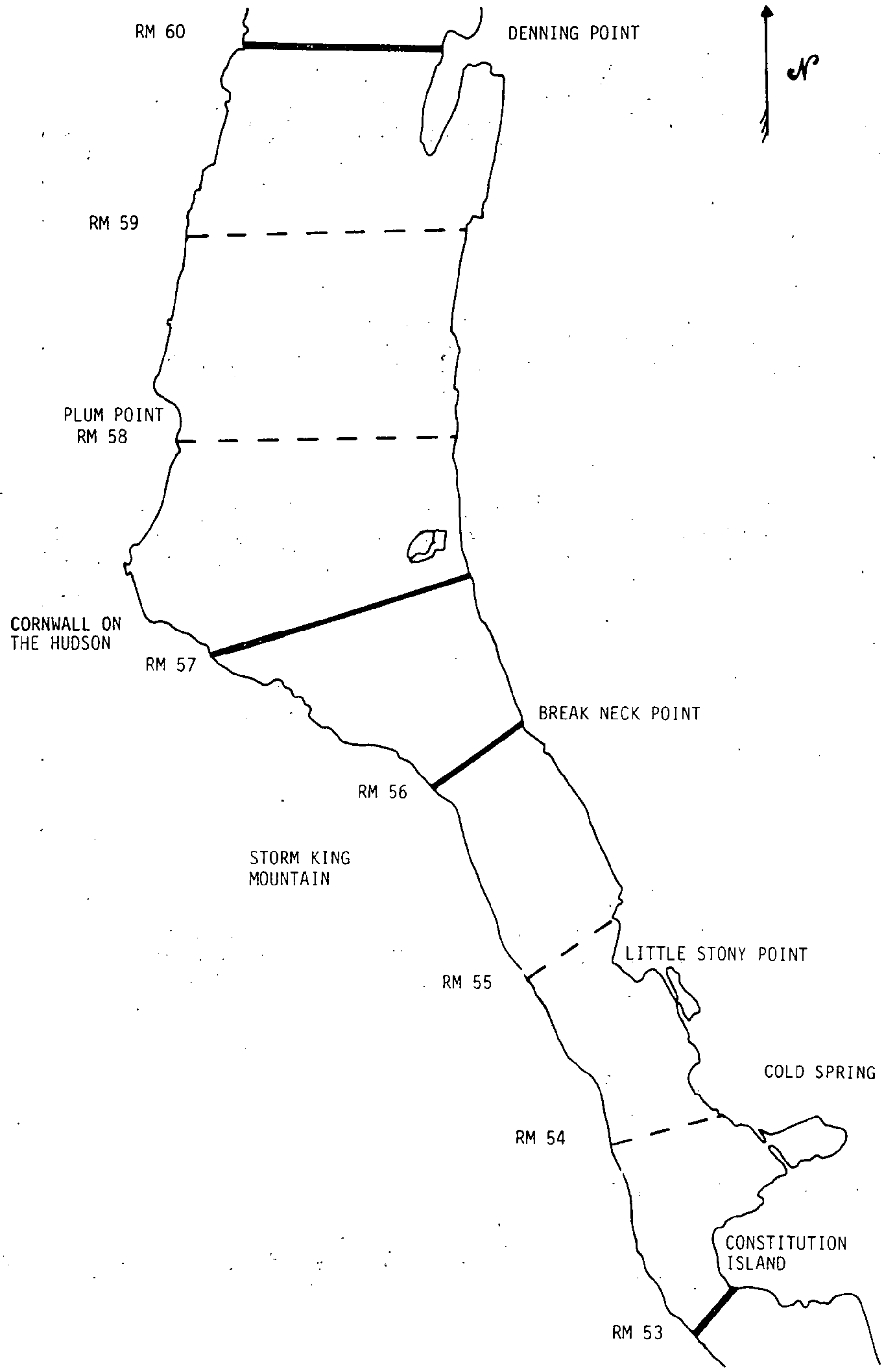

Figure 7.3-5 Texas Instruments Cornwall Study Longitudinal Regions (solid lines) and River Miles (dotted lines)

Table 7.3-1 Results of Analysis of Variance of Distribution of Eggs, 6-Stratum Design, Cornwall Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Probability F Exceeded
Mean	7.33871	1	7.33871	294.04785	0.0
(W) Sampling Period	0.37815	1	0.37815	15.15182	0.000***
(T) Day/night	0.19498	1	0.19498	7.81234	0.007***
(L) Longitudinal region	1.06510	2	0.53255	21.33818	0.000***
(S) Lateral zone	0.06648	2	0.03324	1.33180	0.271
(V) Relative depth	0.81370	1	0.81370	32.60329	0.000***
WT	0.02001	1	0.02001	0.80157	0.374
WL	0.04891	2	0.02446	0.97996	0.380
TL	0.00786	2	0.00393	0.15739	0.855
WS	0.00383	2	0.00191	0.07667	0.926
TS	0.11185	2	0.05592	2.24076	0.114
LS	0.35154	4	0.08789	3.52143	0.011**
WV	0.05712	1	0.05712	2.28885	0.135
TV	0.03352	1	0.03352	1.34319	0.250
LV	0.48834	2	0.24417	9.78339	0.000***
SV	0.19114	2	0.09557	3.82923	0.026**
WTL	0.35929	2	0.17964	7.19799	0.001***
WTS	0.08537	2	0.04269	1.71033	0.188
WTV	0.07604	1	0.07604	3.04667	0.085*
WLS	0.20334	4	0.05084	2.03689	0.099*
WLV	0.04853	2	0.02427	0.97230	0.383
TLS	0.05226	4	0.01306	0.52347	0.719
TLV	0.01575	2	0.00787	0.31550	0.730
WSV	0.02490	2	0.01245	0.49886	0.609
TSV	0.06168	2	0.03084	1.23579	0.297
LSV	0.16338	4	0.04084	1.63654	0.175
WTLS	0.05329	4	0.01332	0.53384	0.711
WTLV	0.23879	2	0.11940	4.78394	0.011**
WTSV	0.02347	2	0.01173	0.47010	0.627
WLSV	0.10864	4	0.02716	1.08825	0.369
TLSV	0.10703	4	0.02676	1.07215	0.377
WTLS	0.10384	4	0.02596	1.04020	0.393
ERROR	1.72207	69	0.02496		

* $P < 0.10$
** $P \leq 0.05$
*** $P \leq 0.01$

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(L) Longitudinal region	1.06510	2	0.53255	21.33818	0.000***
(S) Lateral zone	0.06648	2	0.03324	1.33180	0.271
(V) Relative depth	0.81370	1	0.81370	32.60329	0.000***
WT	0.02001	1	0.02001	0.80157	0.374
WL	0.04891	2	0.02446	0.97996	0.380
TL	0.00786	2	0.00393	0.15739	0.855
WS	0.00383	2	0.00191	0.07667	0.926
TS	0.11185	2	0.05592	2.24076	0.114
LS	0.35154	4	0.08789	3.52143	0.011**
WV	0.05712	1	0.05712	2.28885	0.135
TV	0.03352	1	0.03352	1.34319	0.250
LV	0.48834	2	0.24417	9.78339	0.000***
SV	0.19114	2	0.09557	3.82923	0.026**
WTL	0.35929	2	0.17964	7.19799	0.001***
WTS	0.08537	2	0.04269	1.71033	0.188
WTV	0.07604	1	0.07604	3.04667	0.085*
WLS	0.20334	4	0.05084	2.03689	0.099*
WLV	0.04853	2	0.02427	0.97230	0.383
TLS	0.05226	4	0.01306	0.52347	0.719
TLV	0.01575	2	0.00787	0.31550	0.730
WSV	0.02490	2	0.01245	0.49886	0.609
TSV	0.06168	2	0.03084	1.23579	0.297
LSV	0.16338	4	0.04084	1.63654	0.175
WTLS	0.05329	4	0.01332	0.53384	0.711
WTLV	0.23879	2	0.11940	4.78394	0.011**
WTSV	0.02347	2	0.01173	0.47010	0.627
WLSV	0.10864	4	0.02716	1.08825	0.369
TLSV	0.10703	4	0.02676	1.07215	0.377
~~WTLS~~ WTLSV	0.10384	4	0.02596	1.04020	0.393
ERROR	1.72207	69	0.02496		

* P< 0.10
** P≤ 0.05
*** P≤ 0.01

Table 7.3-2 Results of Analysis of Variance of Distribution of Eggs, 3-Statum Design, Cornwall Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Probability F Exceeded
Mean	3.97565	1	3.97565	140.53172	0.000***
(W) Sampling period	0.12479	1	0.12479	4.41121	0.043**
(T) Day/night	0.14539	1	0.14539	5.13923	0.030**
(L) Longitudinal region	0.55654	2	0.27827	9.83638	0.000***
(V) Relative depth	0.30026	2	0.15013	5.30681	0.010**
WT	0.00071	1	0.00071	0.02503	0.875
WL	0.14063	2	0.07032	2.48557	0.098*
TL	0.04097	2	0.02049	0.72416	0.492
WV	0.07153	2	0.03576	1.26420	0.295
TV	0.06954	2	0.03477	1.22908	0.305
LV	0.15537	4	0.03884	1.37298	0.263
WTL	0.06930	2	0.03465	1.22473	0.306
WTV	0.08036	2	0.04018	1.42020	0.255
WLV	0.07542	4	0.01885	0.66645	0.620
TLV	0.04521	4	0.01130	0.39951	0.808
WTLV	0.10707	4	0.02677	0.94618	0.449
ERROR	0.99015	35	0.02829		

*P <0.10
**P <0.05
***P ≤0.01

May 22-23	RM	57-59	56	53-55
	Day	.120	.266	.467
	Night	.300	.141	.331

May 28-29	RM	57-59	56	53-55
	Day	.306	.064	.313
	Night	.076	.047	.257

Figure 7.3-6 Results of Newman-Keuls Test on Sampling Period, Daylight, and Longitudinal Region Interaction. No significant difference exists between any two members of the same circled group ($P > .05$). (Values are transformed [$\sqrt{X}$] densities from 6-stratum analysis of distribution of eggs of Cornwall study)

Surface	Mid-depth	Bottom
.161	.229	.323

Figure 7.3-7 Results of Newman-Keuls Test on Relative Depth. No significant difference exists between any two members of the same circled group ($P > .05$). (Values are transformed [$\sqrt{X}$] densities from 6-stratum analysis of distribution of eggs of Cornwall study)

MAY 22-23	RM	57-59	56	53-55
	DAY	.191	.259	.467
	NIGHT	.294	.141	.332

MAY 28-29	RM	57-59	56	53-55
	DAY	.306	.064	.313
	NIGHT	.076	.047	.257

Figure 7.3-6 Results of Newman-Keuls Test on Sampling Period, Daylight, and Longitudinal Region Interaction. No significant difference exists between any two members of the same circled group (P >.05). (Values are mean transformed [$\sqrt{X}$] densities from 6-stratum analysis of distribution of eggs of Cornwall study)

Surface	Mid-depth	Bottom
.161	.229	.323

Figure 7.3-7 Results of Newman-Keuls Test on Relative Depth. No significant difference exists between any two members of the same circled group (P >.05). (Values are mean transformed [$\sqrt{x}$] densities from ~~6~~ 3-stratum analysis of distribution of eggs of Cornwall study)

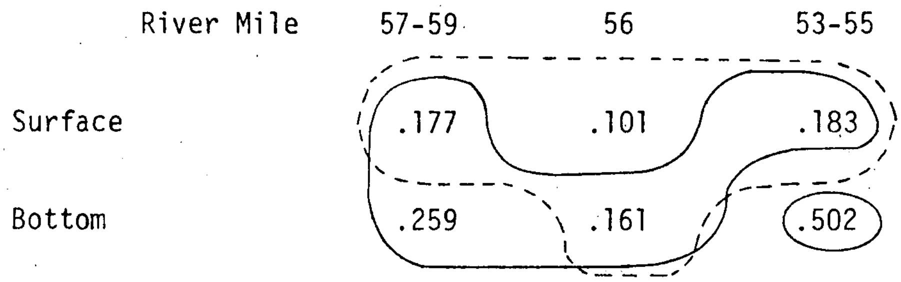

Figure 7.3-8 Results of Newman-Keuls Test on Longitudinal Region and Relative Depth Interaction. No significant difference exists between any two members of the same circled group ($P > .05$). (Values are mean transformed [$\sqrt{x}$] densities from 6-stratum analysis of distribution of eggs of Cornwall Study)

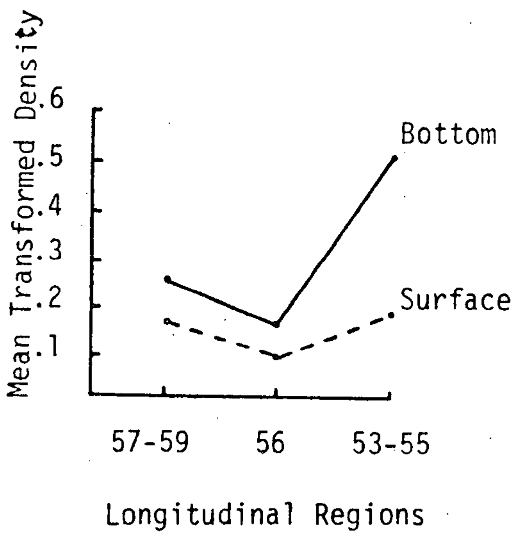

Figure 7.3-9 Graph of Mean Transformed Longitudinal Region Density of Eggs at Surface and Bottom, 6-Stratum Design, Cornwall Study

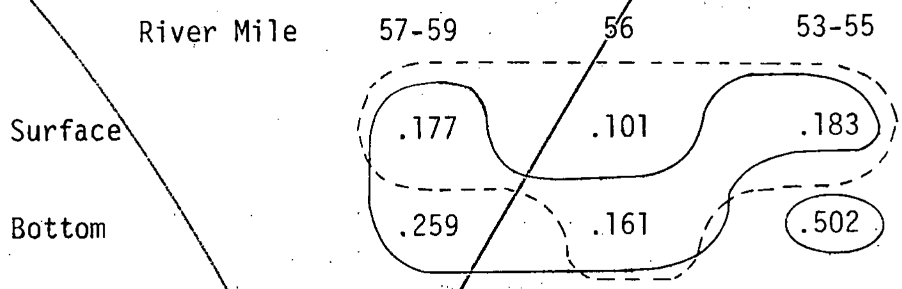

Figure 7.3-8 Results of Newman-Keuls Test on Longitudinal Region and Relative Depth Interaction. No significant difference exists between any two members of the same circled group ($P > .05$). (Values are transformed $[\sqrt{x}]$ densities from 6-stratum analysis of distribution of eggs of Cornwall Study)

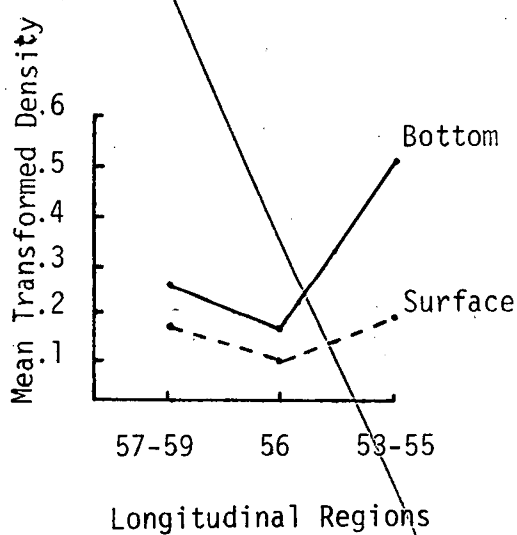

Figure 7.3-9 Graph of Mean Transformed Longitudinal Region Density of Eggs at Surface and Bottom, 6-Stratum Design, Cornwall Study

	West	Channel	East
Surface	.129	.162	.170
Bottom	.369	.323	.229

Figure 7.3-10 Results of Newman-Keuls Test on Lateral Areas and Relative Depth Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed [$\sqrt{x}$] from 6-stratum analysis of distribution of eggs of Cornwall Study)

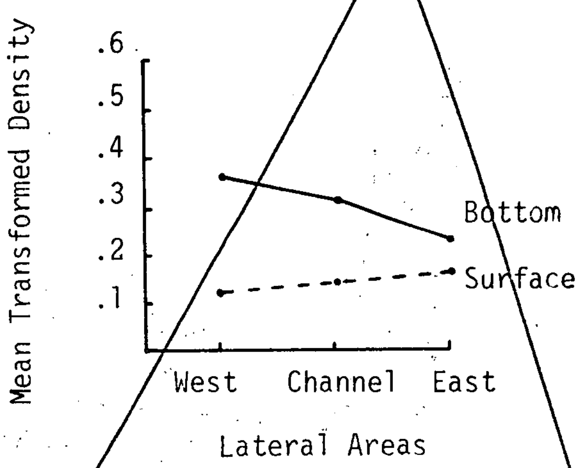

Figure 7.3-11 Graph of Mean Transformed Lateral Zone Density of Eggs at Surface and Bottom, 6-Stratum Analysis, Cornwall Study

	West	Channel	East
Surface	.129	.162	.170
Bottom	.369	.323	.229

Figure 7.3-10 Results of Newman-Keuls Test on Lateral Areas and Relative Depth Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed $[\sqrt{x}]$ densities from 6-stratum analysis of distribution of eggs of Cornwall Study)

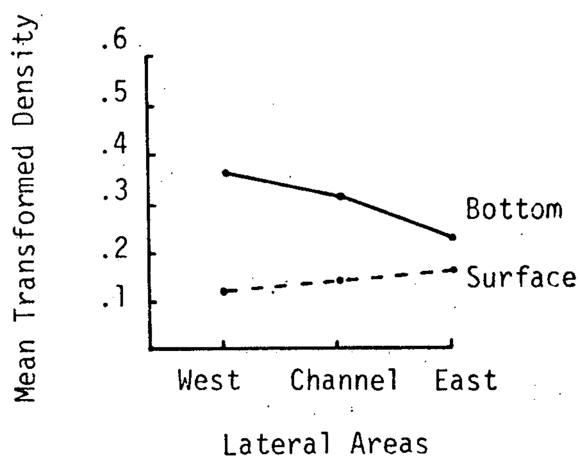

Figure 7.3-11 Graph of Mean Transformed Lateral Zone Density of Eggs at Surface and Bottom, 6-Stratum Analysis, Cornwall Study

~~eggs depended on longitudinal region~~ and lateral zone ~~(Fig. 7.3-8, 7.3~~-9, ~~7.3-10, and 7.3-11). These differences are probably due to physical differences in the river~~ such as tidal currents and ~~associated upwellings~~.

The lateral densities (west, channel, and east) also varied between regions (Fig. 7.3-12 and 7.3-13). The west side of the lower region (RM 53-55; km 84.8-88.0) had a higher density than the east and channel areas of that region during the weeks sampled. The other regions have a more homogeneous distribution across the river. Tidal currents and spawning during the sampling period possibly created the differences observed in the longitudinal densities over the two sampling periods (Fig. 7.3-14 and 7.3-15).

In summary, the highest egg densities were found during the daytime on May 23 and 24. This seems to indicate that spawning occurred after the night sampling. Higher densities in the middle and bottom strata were expected because eggs have a higher specific gravity than water (Section 7.3.1). Depth and lateral distribution were strongly dependent on the longitudinal zone, emphasizing the importance of considering each river region separately.

7.3.5.2 New York University Indian Point Study. New York University studied the distribution of ichthyoplankton in the Indian Point region by sampling seven river stations. Fixed stations were used rather than randomly selected sampling sites; thus, stations are compared rather than strata. Stations A and B were north of Indian Point; C and D opposite Indian Point, E opposite Verplanck's Point, and F and G were in Haverstraw Bay (Fig. 7.3-16). The samples used in this analysis were taken once during the day and once during the night in each of the last two weeks of May. Analysis of variance was used to compare the densities by time of day (day or night), relative depths, sampling period, and stations. These main effects were examined separately and in combination to determine the effects of interactions. The results of the analysis of variance are presented in Table 7.3-3. Two main effects, depth and station were found significant.

River Mile	57-59	56	53-55
West	.180	.112	.454
Middle	.257	.138	.332
East	.216	.165	.240

Figure 7.3-12 Results of Newman-Keuls Test on Longitudinal Region and Lateral Area Interaction. No significant difference exists between any two members of the same circled group ($P > .105$). (Values are transformed [$\sqrt{x}$] densities from 6-stratum analysis of distribution of eggs of Cornwall Study)

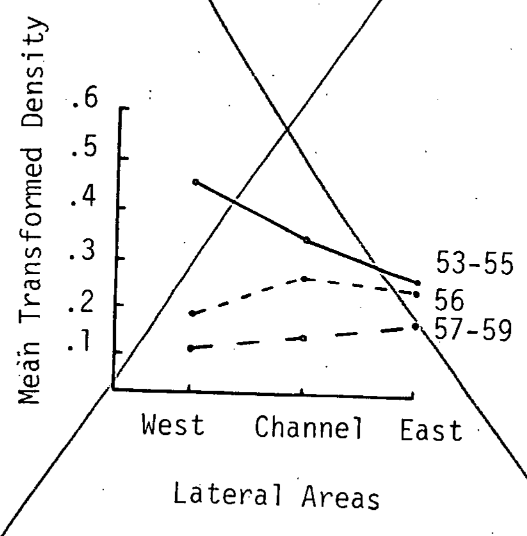

Figure 7.3-13 Graph of Mean Transformed Lateral Zone Density of Eggs in Longitudinal Regions, 6-Stratum Design, Cornwall Study

River Mile	57-59	56	53-55
West	.180	.112	.454
Middle	.257	.138	.332
East	.216	.165	.240

Figure 7.3-12 Results of Newman-Keuls Test on Longitudinal Region and Lateral Area Interaction. No significant difference exists between any two members of the same circled group [(P >.05)] ~~(P > .105)~~. (Values are mean transformed [$\sqrt{x}$] densities from 6-stratum analysis of distribution of eggs of Cornwall Study)

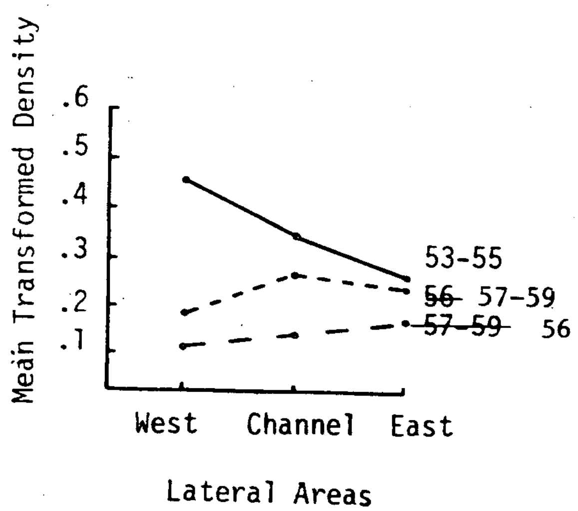

Figure 7.3-13 Graph of Mean Transformed Lateral Zone Density of Eggs in Longitudinal Regions, 6-Stratum Design, Cornwall Study

River Mile	57-59	56	53-55
MAY 22-23	.245	.180	.416
MAY 28-29	.286	.059	.244

Figure 7.3-14 Results of Newman-Keuls Test on Sampling Periods and Longitudinal Region Interaction. No Significant difference exists between any two members of the same circled group ($P > .05$). (Values are mean transformed $[\sqrt{x}]$ densities on 3-stratum analysis of distribution of eggs of Cornwall Study)

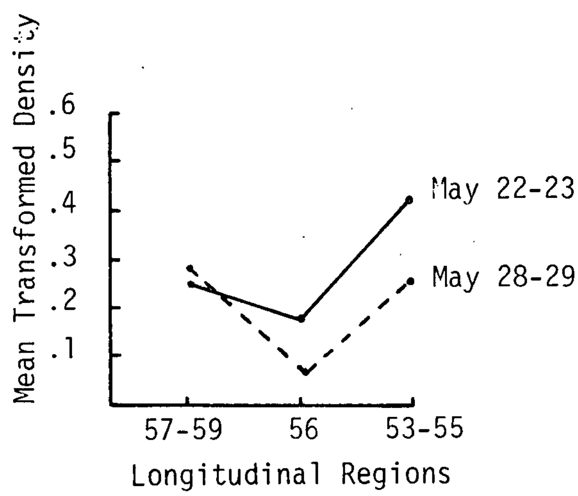

Figure 7.3-15 Graph of Mean Transformed Longitudinal Region Density of Eggs, 3-stratum Design, Cornwall Study, May 22-23 and May 28-29

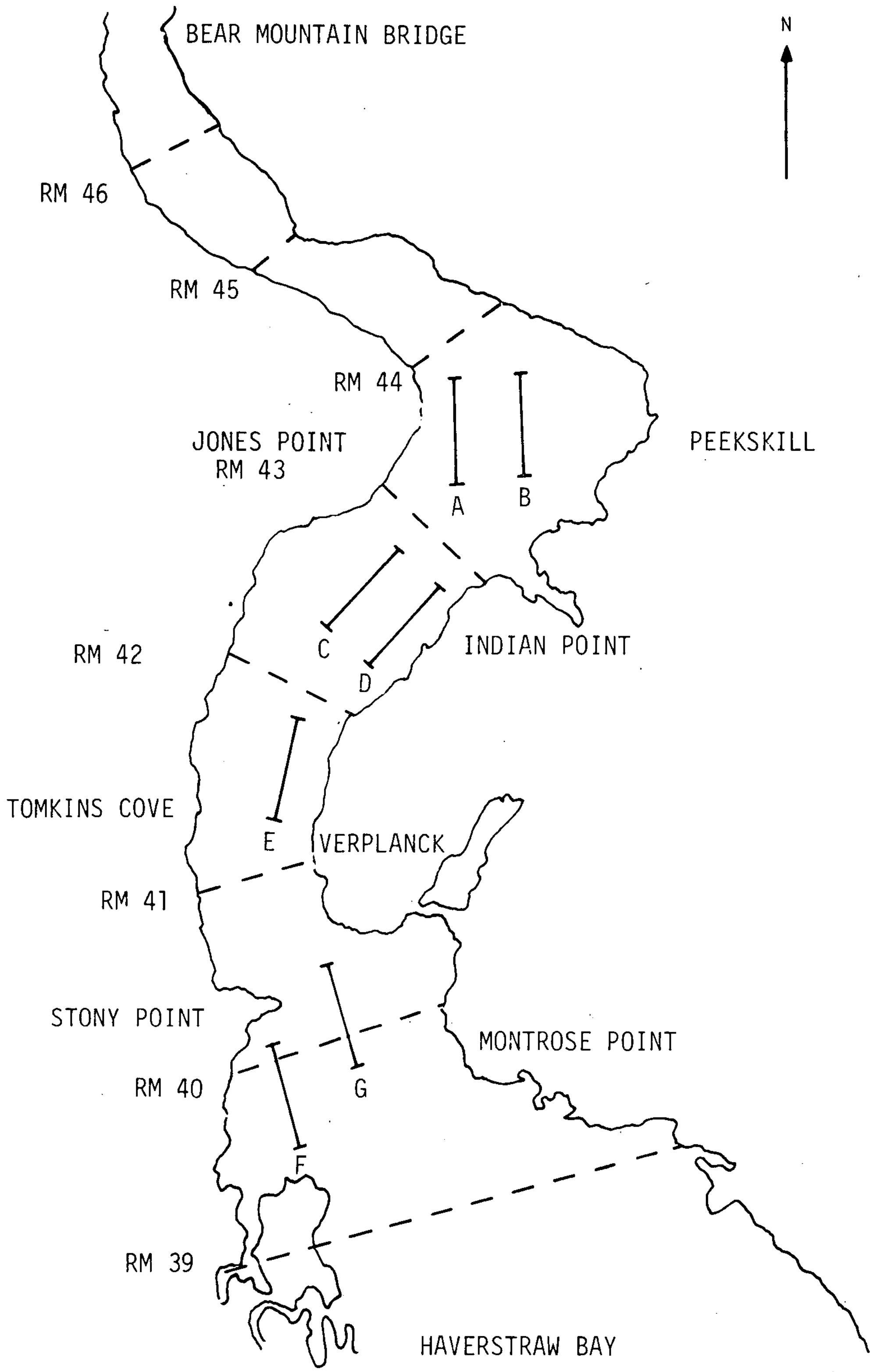

Figure 7.3-16 New York University Indian Point Nearfield Study Sampling sites during 1975

Table 7.3-3 Results of Analysis of Variance of Distribution of Striped Bass Eggs, Indian Point Survey

Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Mean	3.74430	1	3.74430	
(V) Relative depth	1.50299	2	0.75150	20.12***
(S) Station	0.70989	6	0.11832	3.168*
(N) Day/night	0.00045	1	0.00045	0.012
(W) Sampling period	0.05257	1	0.05257	1.4075
VS	0.38600	12	0.03217	0.861
VN	0.11957	2	0.05979	1.60
SN	0.21599	6	0.03600	0.964
VW	0.03047	2	0.01524	0.408
SW	0.42632	6	0.07105	1.903
NW	0.03205	1	0.03205	0.858
VSN	0.30186	12	0.02516	0.6736
VSW	0.34635	12	0.02886	0.77
VNW	0.00921	2	0.00461	~~0.1234**~~ 0.1234
SNW	0.83848	6	0.13975	3.7416**
VSNW	0.44819	12	0.03735	

* $P < 0.10$
** $P \leq 0.05$
*** $P \leq 0.01$

There was very little difference in density between stations. From the Newman-Keuls test, it was deduced that station B contained significantly fewer striped bass eggs during the day in the May 19-20 period than did station A during the day (Fig. 7.3-17). No differences between stations were found during the May 27-30 sampling period.

The highest egg densities were found at the middle and bottom depths. This result was expected because the Cornwall study (Section 7.3.5) and the literature (Section 7.3.1) indicated that striped bass eggs are more abundant near the bottom.

In summary, the Indian Point study demonstrated that striped bass eggs were concentrated near the bottom at this site. In addition, no day vs. night or sampling-period differences appeared. Egg densities were not statistically different among stations except at station B, which contained significantly fewer eggs than station A during the day in the May 19-20 period.

	Stations						
	A	B	C	D	E	F	G
Day	.6730	0.0	.5180	.1200	.1690	.0930	.1340
Night	.3100	.0430	.0780	.0820	.5950	.2930	.1430

Figure 7.3-17. Results of Newman-Keuls Test on Sampling Stations and Time of Day Interaction. (Values are transformed data [$\sqrt{x}$] from analysis of distribution of eggs, Indian Point study). No significant difference exists between any two members of the same circled group (P > .05).

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	Stations						
	A	B	C	D	E	F	G
Day	.6730	0.0	.5180	.1200	.1690	.0930	.1340
Night	.3100	.0430	.0780	.0820	.5950	.2930	.1430

Figure 7.3-17 Results of Newman-Keuls Test on Sampling Stations and Time of Day Interaction [May 19-20, 1975]. (Values are mean transformed ~~data~~ densities [$\sqrt{x}$] from analysis of distribution of eggs, Indian Point study). No significant difference exists between any two members of the same circled group (P > .05).

7.3.6 SUMMARY. The striped bass egg is characterized by a large oil globule, a slightly granulated yolk mass, a wide [perivitelline] ~~peruitteline~~ space, and a clear egg capsule. The water-hardened egg is 3.4 mm in diameter, nonadhesive, and semibuoyant. Mean density is 1.0005 and the settling rate is [2.4] 3.4 mm s^{-1}; suspension in the water column for much of its development is important for survival. Striped bass eggs may be damaged if subjected to rapid velocity changes, shear force fields, or pressure changes. Stress on the egg capsule and disruption of the yolk may occur when unequal velocities act to spin [or] and deform the egg as it passes a solid surface. Fifty percent of eggs subjected to 542 dynes cm^{-2} for 1 min, 255 dynes cm^{-2} for 2 min, and 190 dynes cm^{-2} for 4 min are killed. Eggs survived pressures from 0.40 to 51.6 kg cm^{-2} (0.5 to 49 times atmospheric pressure). Fertilization rates are highest when eggs and sperm come into contact immediately in fresh water between 16 and 18°C. Hatching time is inversely ~~directly~~ proportional to temperature, i.e., higher temperatures decrease hatching time. At 16.6°C, hatching time is 56 h; at 18.3°C, it is reduced to 48 h. Maximum hatches occur between 16.6 and 18.3°C. Hatching is possible between 12 and 27°C, but success is reduced above 18.9 to 23.4°C. In 1974, spawning in the Hudson River peaked between 14 and 18°C; in 1975, at 16-20°C. Optimum oxygen concentrations are [>4.9] mg $litre^{-1}$. Concentrations of <2.0 mg $litre^{-1}$ result in smaller, less active larvae. In the Hudson River eggs have been taken in low oxygen concentrations (1 to 4 mg $litre^{-1}$) but most have been found in water with dissolved oxygen concentrations of at least 6 mg $litre^{-1}$. At salinities >1.0 o/oo, egg survival is 50% for eggs hardened in fresh water and 0-20% for those hardened in brackish water at temperatures of 18.3-22.2°C; at 14.4°C, survival is better for both groups. During 1974 and 1975, nearly all spawning in the Hudson River occurred in fresh water. Hatching success is not significantly reduced until the suspended sediment load reaches 1000 mg $litre^{-1}$; in the Hudson River suspended solid load was well below this level.

7.3.6 SUMMARY. The striped bass egg is characterized by a large oil globule, a slightly granulated yolk mass, a wide perviteline space, and a clear egg capsule. The water-hardened egg is 3.4 mm in diameter, nonadhesive, and semibuoyant. Mean density is 1.0005 and the settling rate is 3.4 mm s^{-1}; suspension in the water column for much of its development is important for survival. Striped bass eggs may be damaged if subjected to rapid velocity changes, shear force fields, or pressure changes. Stress on the egg capsule and disruption of the yolk may occur when unequal velocities act to spin and deform the egg as it passes a solid surface. Fifty percent of eggs subjected to 542 dynes cm^{-2} for 1 min, 255 dynes cm^{-2} for 2 min, and 190 dynes cm^{-2} for 4 min are killed. Eggs survived pressures from 0.40 to 51.6 kg cm^{-2} (0.5 to 49 times atmospheric pressure). Fertilization rates are highest when eggs and sperm come into contact immediately in fresh water between 16 and 18°C. Hatching time is directly proportional to temperature, i.e., higher temperatures decrease hatching time. At 16.6°C, hatching time is 56 h; at 18.3°C, it is reduced to 48 h. Maximum hatches occur between 16.6 and 18.3°C. Hatching is possible between 12 and 27°C, but success is reduced above 18.9 to 23.4°C. In 1974, spawning in the Hudson River peaked between 14 and 18°C; in 1975, at 16-20°C. Optimum oxygen concentrations are >4.9 mg $litre^{-1}$. Concentrations of <2.0 mg $litre^{-1}$ result in smaller, less active larvae. In the Hudson River eggs have been taken in low oxygen concentrations (1 to 4 mg $litre^{-1}$) but most have been found in water with dissolved oxygen concentrations of at least 6 mg $litre^{-1}$. At salinities >1.0 o/oo, egg survival is 50% for eggs hardened in fresh water and 0-20% for those hardened in brackish water at temperatures of 18.3-22.2°C; at 14.4°C, survival is better for both groups. During 1974 and 1975, nearly all spawning in the Hudson River occurred in fresh water. Hatching success is not significantly reduced until the suspended sediment load reaches 1000 mg $litre^{-1}$; in the Hudson River suspended solid load was well below this level.

Two areas of the Hudson River, Cornwall and Indian Point have been studied intensively in order to determine the distribution of striped bass eggs and larvae in relation to time of day (day or night), relative depth, and area of the river. In the Cornwall area, more eggs were collected during May 22-23 than during May 28-29. Highest densities were during the daytime and generally concentrated in the middle and bottom regions. Depth and lateral distribution was strongly dependent on longitudinal zone.

The Indian Point study clearly demonstrated that striped bass eggs are concentrated in the deeper strata of the river. There were no time of day or sampling-period differences.

7.4 STRIPED BASS LARVAE

7.4.1 YOLK-SAC LARVAE

7.4.1.1 Physical Description. At hatching, the larvae are 2.0 to 3.7 mm long (Pearson 1938:832, Mansueti 1958:12, Bayless 1972:58). The predominant feature of the larva is the large yolk-sac with its well-defined oil globule. The speed of development depends on temperature: the yolk-sac stage lasts 4 to 6 days at 19 to 21°C (Pearson 1938:836, Mansueti 1958:12, Bayless 1972:61, Rogers et al. 1976:10). As development progresses, the eyes become pigmented, the jaws and digestive tract form, fin buds appear, and the yolk-sac and oil globule are at least partially absorbed (Mansueti 1958:12). When transformation to post yolk-sac stage occurs, the larvae are 5 to 6 mm long (Pearson 1938:836, Mansueti 1958:12).

7.4.1.2 Temperature, Dissolved Oxygen, and Salinity Tolerance. Water temperature affects the rate of development and survival of yolk-sac larvae. Speed of development varies directly with temperature; growth is rapid at high temperatures and retarded at low temperatures. Prolonged exposure to temperatures that are <12° or >24°C may be lethal (Albrecht 1964:107, Shannon and Smith 1967:4, Doroshev 1970:243). Nearly all yolk-sac larvae collected in the Hudson River during 1974 and 1975 by Texas Instruments were found in water temperatures ranging from 14 to 22°C, within the limits of larval survival. Greatest catches occurred in areas in which water temperatures were 17-20°C (Fig. 7.4-1).

There is little information concerning larval tolerance to low concentrations of dissolved oxygen. Increased mortality occurs with increased exposure to a dissolved oxygen (DO) concentration of 4 mg $litre^{-1}$ (Turner and Farley 1971:271). Doroshev (1970:244) observed high mortality among larvae exposed to a DO concentration of 1.65 mg $litre^{-1}$. Texas Instruments collected larvae over a wide range of dissolved oxygen concentrations in the Hudson River estuary in 1974 and 1975 (Fig. 7.4-2). During 1974 some yolk-sac larvae were collected in concentrations of <2 mg $litre^{-1}$; most, however, were taken in concentrations of 6-13 mg $litre^{-1}$. The survival of larvae subjected to concentrations of <2 mg $litre^{-1}$ probably would depend on the length of exposure and the physical condition of the larvae.

Salinity also may affect the growth, survival, and distribution of yolk-sac larvae. Those reared at salinities of 4-14 o/oo had higher survival and growth rates than those reared in fresh water (Doroshev 1970:244, Bayless 1972:70). Most of the yolk-sac larvae collected in the Hudson River in 1974 and 1975 (Fig. 7.4-3) were from areas in which salinity was <1.5 o/oo (3.0 mS cm^{-2} conductivity), conditions less than optimum if the survival and growth observations in the laboratory apply to larvae under natural conditions.

7.4.1.3 Orientation and Movement. The buoyancy and position of the yolk-sac cause the larvae to drift in a head-up position while making short, irregular swimming movements (Pearson 1938:832, Bayless 1972:58).

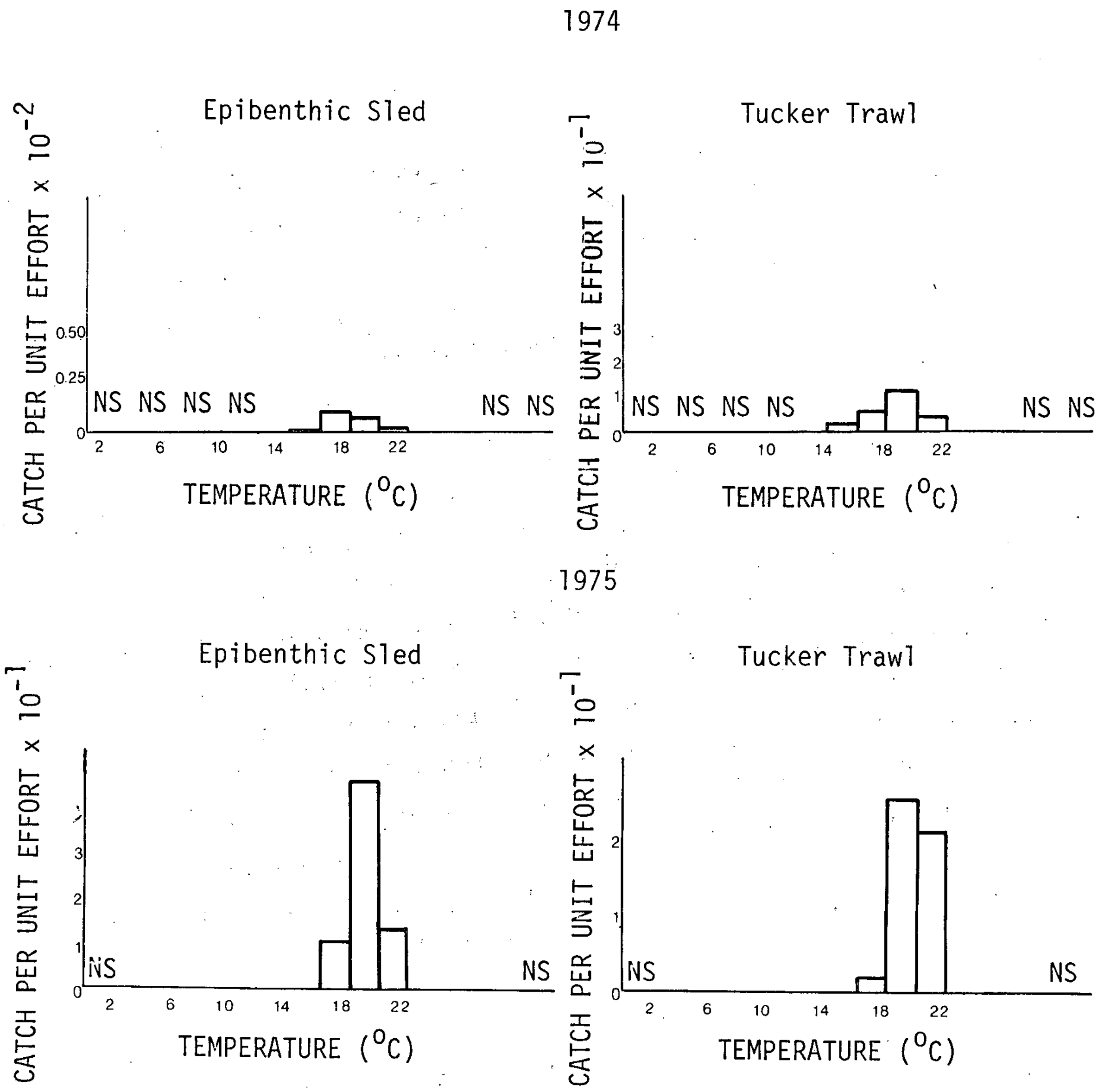

Figure 7.4-1 Catch per Unit Effort of Striped Bass Yolk-Sac Larvae Collected at Various Temperatures by Epibenthic Sled and Tucker Trawl during 1974 and 1975 in Hudson River Estuary (RM 14-140; km 23-227)

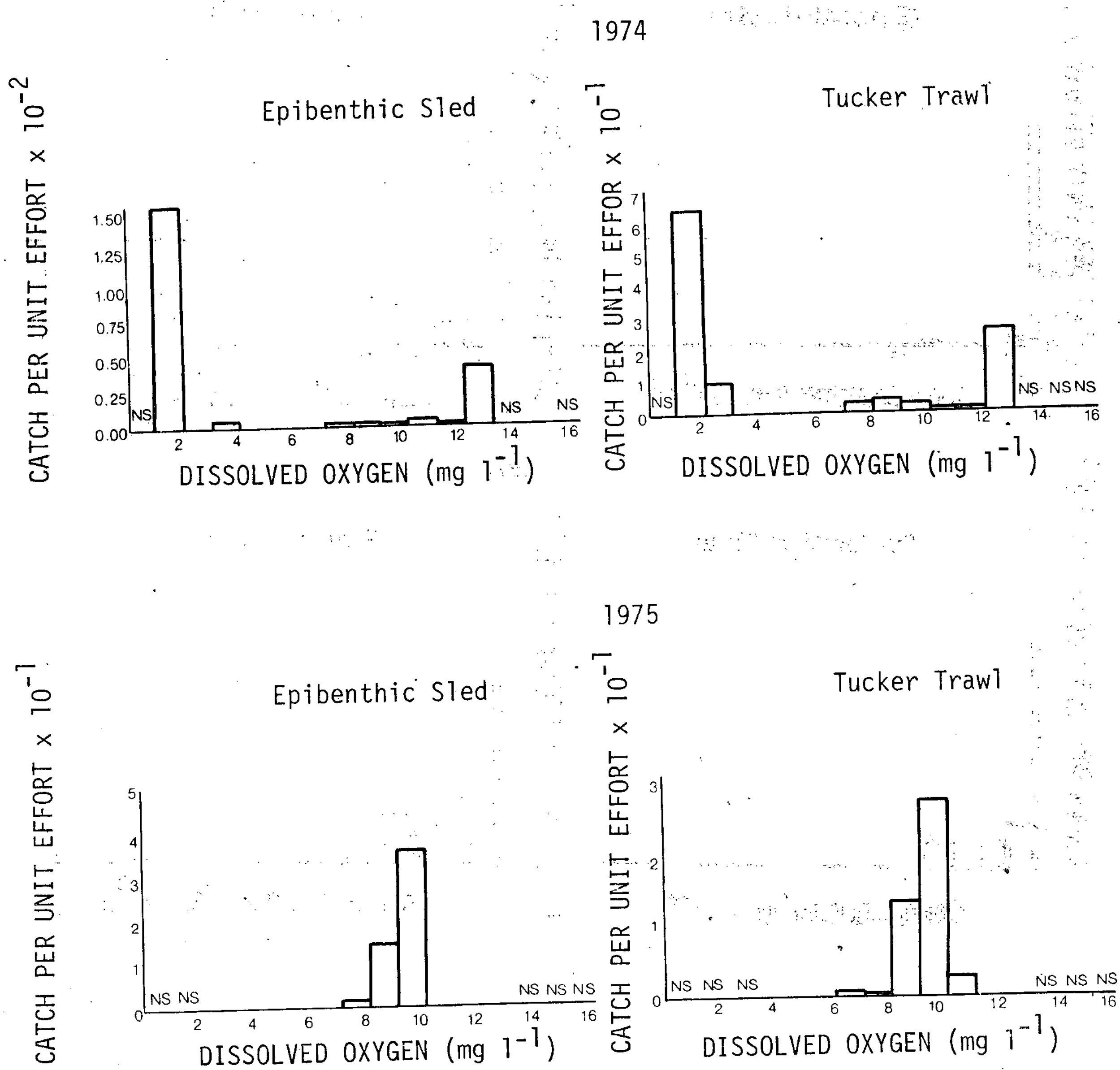

Figure 7.4-2 Catch per Unit Effort of Striped Bass Yolk-Sac Larvae Collected by Epibenthic Sled and Tucker Trawl at Various Dissolved Oxygen Concentrations in Hudson River Estuary (RM 14-140; km 23-227) during 1974 and 1975

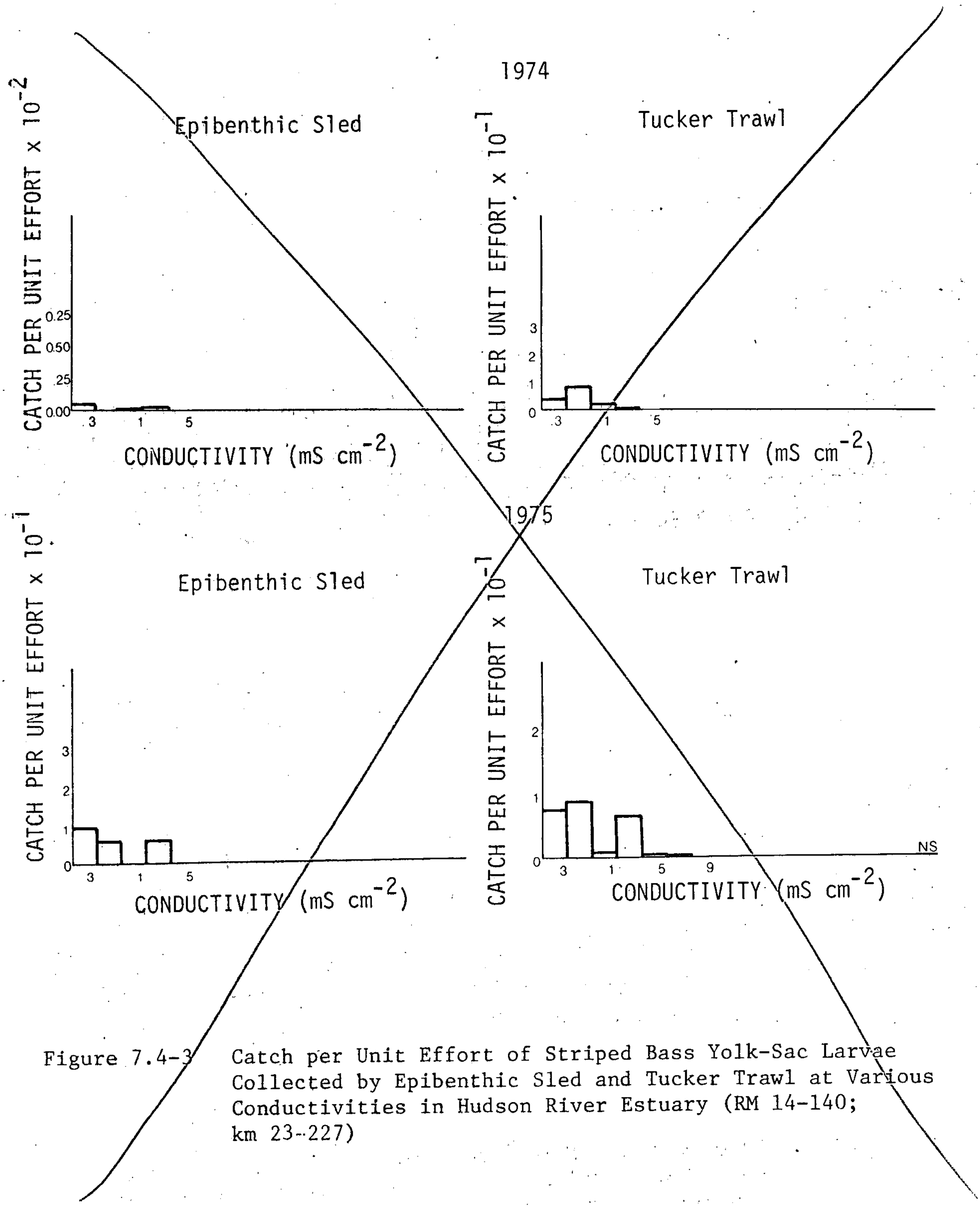

Figure 7.4-3 Catch per Unit Effort of Striped Bass Yolk-Sac Larvae Collected by Epibenthic Sled and Tucker Trawl at Various Conductivities in Hudson River Estuary (RM 14-140; km 23-227)

This is a corrected figure.

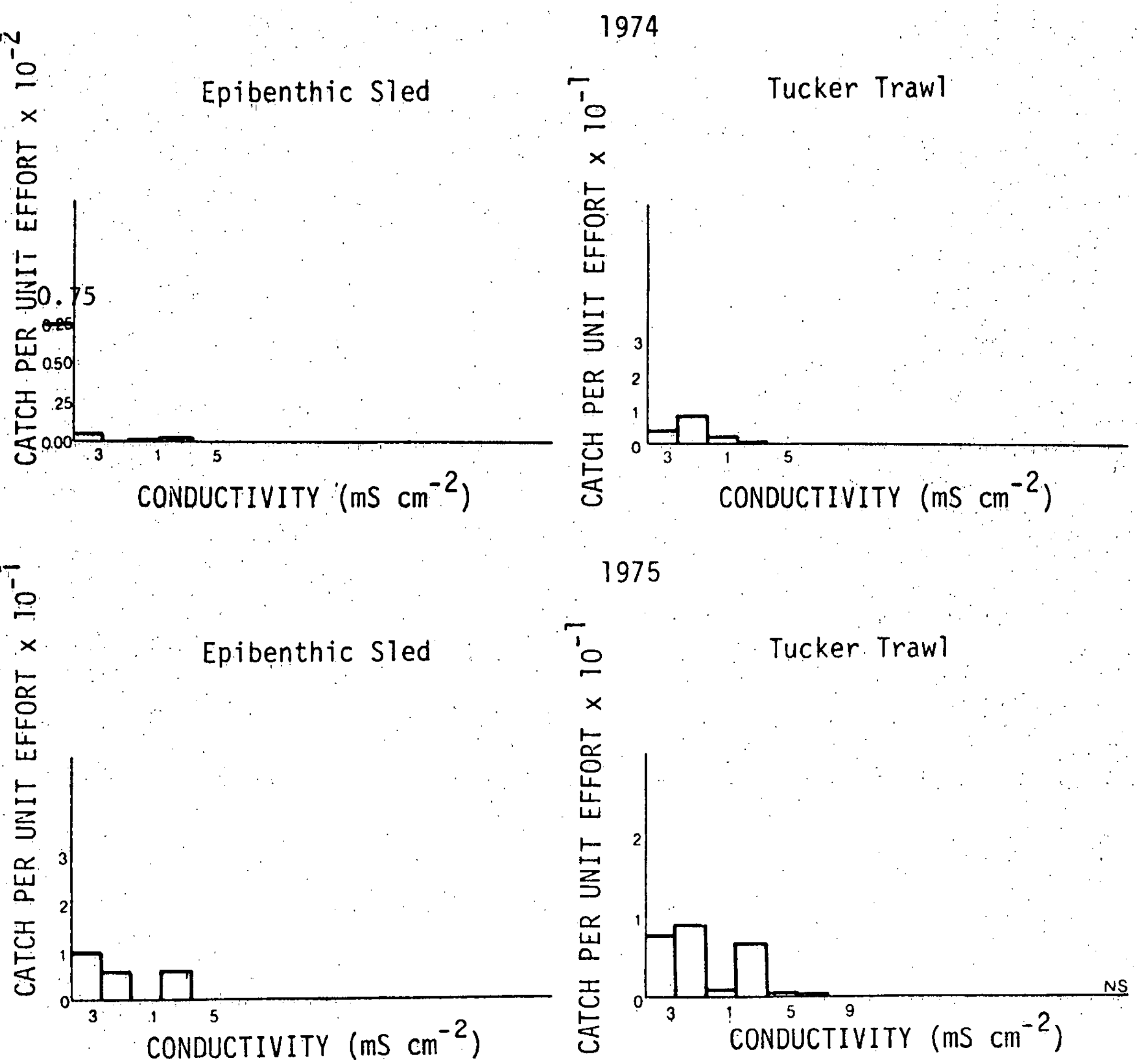

Figure 7.4-3 Catch per Unit Effort of Striped Bass Yolk-Sac Larvae Collected by Epibenthic Sled and Tucker Trawl at Various Conductivities in Hudson River Estuary (RM 14-140; km 23-227) during 1974 and 1975

Only 5% of larvae that are <5 mm in length can swim for more than 2 min against a current of 6.1 cm s^{-1} (Sazaki et al. 1973:23), but Bayless (1972:58) observed spasmodic vertical movements that vary from 100-400 mm in distance and 3-15 s in duration. Doroshev (1970:238) noted that movement becomes more vigorous as the larvae begin to absorb the yolk-sac. The movement patterns suggest that larvae drift with prevailing currents in the nursery area (Talbot 1966:37) but do not preclude the possibility that yolk-sac larvae migrate in any direction if the migration does not oppose a current.

7.4.1.4 Sources of Mortality. Mortality of yolk-sac larvae may stem from sources other than the environmental influences discussed in Section 7.4.1.2. Laboratory and hatchery studies have uncovered many abnormalities in larval development (Mansueti 1958:25-27, Doroshev 1970:240-243, Bayless 1972:68), but the causes of these abnormalities are unknown. Doroshev (1970:241) attributes deformation and disintegration of the yolk-sac to mishandling or mechanical damage. Rough handling, starvation, and water quality have been connected with distortion of the notochord and backbone (Doroshev 1970:242). Failure of pigmentation to develop and the formation of cavities in the pericardium and abdomen have been attributed to water quality variables (Doroshev 1970:241). Bayless (1972:68) observed mortality when larvae were exposed to direct sunlight. Other sources of mortality are gas bubble disease and blue-sac disease (Mansueti 1958:25-27), asynchronous resorption of the yolk-sac and oil globule, and failure of the gas bladder to fill with air (Doroshev 1970:242-243). Bioassay experiments have identified many substances (Rehwoldt et al. 1971, Hughes 1973) that are toxic to striped bass, e.g., the pesticides aldrin and dieldrin and heavy metals including copper, nickel, and zinc.

Physical stress such as shear, sedimentation, and abrasion may affect larval survival. Morgan et al. (1976:152) studied the effects of shear stress and found that 50% mortality occurred among larvae that were subjected to shear forces of 300 dynes cm^{-2} for 4 min. Shear is discussed in Section 7.3.2.

Larvae are also subject to mortality from cannibalism and predation. Several fish species in the Hudson River estuary (e.g., Atlantic tomcod, white perch, bluefish, and largemouth and smallmouth bass) probably prey on striped bass larvae. Bayless (1972:62) and Rhodes and Merriner (1973:200) observed cannibalism among hatchery-reared striped bass larvae under high density conditions. Cannibalism under natural conditions was noted by Thomas (1967:60) and Stevens (1966:87).

7.4.1.5 Microdistribution. Several characteristics of the distribution of yolk-sac larvae in the Hudson River estuary near Cornwall (RM 56; km 90) and Indian Point (RM 42; km 69) were investigated by the Texas Instruments Cornwall study and the New York University Indian Point study. The purpose of the studies was to determine if the larvae are spread evenly across the river, in an up- and downstream direction and vertically throughout the water column. Another major biological question concerned the ability of yolk-sac larvae to migrate vertically and, if migrations do occur, the potential for differences in vertical distribution between day and night.

The same sampling designs and statistical tests described in Section 7.3.5 were used to analyze the distribution of yolk-sac larvae. Data collected on May 22-23 and 28-29 were used in the analysis of the Cornwall study and data collected on May 27-30 and June 2-3 were used in the Indian Point study. Tables 7.4-1, 7.4-2, and 7.4-3 summarize the results of the analyses of variance of the Cornwall and Indian Point studies. Each analysis revealed spatial and temporal heterogeneity in the distribution of yolk-sac larvae. Several of the main effects and interactions contributed significantly to the variation in larval density. Especially important were interactions involving the day/night and relative depth effects, which were significant in many cases.

Table 7.4-1 Results of Analysis of Variance of Distribution of Yolk-Sac Larvae, 6-Stratum Design, Cornwall Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Probability F Exceeded
Mean	24.08020	1	24.08020	447.97974	0.0
W Sampling Period	6.28918	1	6.28918	117.00182	0.000***
T Day/Night	0.47964	1	0.47964	8.92315	0.004***
L Longitudinal Region	0.09404	2	0.04702	0.87473	0.422
S Lateral Zone	0.22589	2	0.11294	2.10117	0.130
V Relative Depth	0.34920	1	0.34920	6.49635	0.013**
WT	0.01823	1	0.01823	0.33908	0.562
WL	0.04960	2	0.02480	0.46138	0.632
TL	0.15539	2	0.07769	1.44540	0.243
WS	0.06307	2	0.03154	0.58667	0.559
TS	0.23496	2	0.11748	2.18556	0.120
LS	0.28143	4	0.07036	1.30889	0.275
WV	0.03955	1	0.03955	0.73570	0.394
TV	2.54316	1	2.54316	47.31210	0.000***
LV	0.08232	2	0.04116	0.76576	0.469
SV	0.26430	2	0.13215	2.45851	0.093*
WTL	0.15231	2	0.07616	1.41680	0.249
WTS	0.14286	2	0.07143	1.32883	0.271
WTV	1.95122	1	1.95122	36.29984	0.000***
WLS	0.82968	4	0.20742	3.85877	0.007***
WLV	0.01463	2	0.00731	0.13605	0.873
TLS	0.08945	4	0.02236	0.41603	0.797
TLV	0.01720	2	0.00860	0.15998	0.852
WSV	0.46955	2	0.23477	4.36766	0.016**
TSV	0.06643	2	0.03321	0.61788	0.542
LSV	0.35495	4	0.08874	1.65086	0.171
WTLS	0.09973	4	0.02493	0.46384	0.762
WTLV	0.07416	2	0.03708	0.68984	0.505
WTSV	0.18671	2	0.09336	1.73677	0.184
WLSV	0.10785	4	0.02696	0.50161	0.735
TLSV	0.11466	4	0.02867	0.53329	0.712
WTLS	0.08345	4	0.02086	0.38814	0.816
ERROR	3.70895	69	0.05375		

* $P \leq 0.10$
** $P \leq 0.05$
***$P < 0.01$

Table 7.4-2 Results of Analysis of Variance of Distribution of Yolk-Sac Larvae, 3-Stratum Design, Cornwall Study

Source	Sum Of Squares	Degrees Of Freedom	Mean Square	F	Probability F Exceeded
Mean	12.16964	1	12.16964	152.85887	0.000
W Sampling Period	3.30046	1	3.30046	41.45602	0.000***
T Day/Night	0.09090	1	0.09090	1.14182	0.293
L Longitudinal Region	0.08964	2	0.04482	0.56297	0.575
V Relative Depth	0.75914	2	0.37957	4.76767	0.015**
WT	0.00295	1	0.00295	0.03700	0.849
WL	0.11547	2	0.05773	0.72518	0.491
TL	0.14914	2	0.07457	0.93663	0.402
WV	0.18778	2	0.09389	1.17932	0.319
TV	0.76173	2	0.38086	4.78392	0.015**
LV	0.22012	4	0.05503	0.69122	0.603
WTL	0.09571	2	0.04785	0.60107	0.554
WTV	0.52271	2	0.26135	3.28278	0.049**
WLV	0.17203	4	0.04301	0.54020	0.707
TLV	0.12833	4	0.03208	0.40296	0.805
WTLV	0.11395	4	0.02849	0.35782	0.837
ERROR	2.78648	35	0.07961		

* $P \leq 0.10$
** $P \leq 0.05$
*** $P \leq 0.01$

Table 7.4-3 Results of Analysis of Variance of Distribution of Yolk-Sac Larvae, Indian Point Nearfield Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Mean	9.46414	1	9.46414	
V Relative Depth	4.00272	2	2.00136	43.28***
S Station	0.98693	6	0.16449	3.55**
N Day/Night	0.59306	1	0.59306	12.83***
W Sampling Period	0.37995	1	0.37995	8.21**
VS	1.00209	12	0.08351	1.80
VN	1.97194	2	0.98597	21.32***
SN	0.47240	6	0.07873	1.70
VW	0.09608	2	0.04804	1.04
SW	0.18921	6	0.03154	.68
NW	0.00156	1	0.00156	~~.03~~ .34
VSN	0.98782	12	0.08232	1.78
VSW	0.60441	12	0.05037	1.09
VNW	0.06234	2	0.03117	.67
SNW	0.55745	6	0.09291	2.01
VSNW	0.55492	12	0.04624	

* P ≤ 0.10
** P ≤ 0.05
*** P ≤ 0.01

Table 7.4-3 Results of Analysis of Variance of Distribution of Yolk-Sac Larvae, Indian Point Nearfield Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Mean	9.46414	1	9.46414	
V Relative Depth	4.00272	2	2.00136	43.28***
S Station	0.98693	6	0.16449	3.55**
N Day/Night	0.59306	1	0.59306	12.83***
W Sampling Period	0.37995	1	0.37995	8.21**
VS	1.00209	12	0.08351	1.80
VN	1.97194	2	0.98597	21.32***
SN	0.47240	6	0.07873	1.70
VW	0.09608	2	0.04804	1.04
SW	0.18921	6	0.03154	.68
NW	0.00156	1	0.00156	.03
VSN	0.98782	12	0.08232	1.78
VSW	0.60441	12	0.05037	1.09
VNW	0.06234	2	0.03117	.67
SNW	0.55745	6	0.09291	2.01
VSNW	0.55492	12	0.04624	

* $P \leq 0.10$
** $P \leq 0.05$
*** $P \leq 0.01$

7.4.1.5.1 Texas Instruments Cornwall Study. Daytime vertical distribution of yolk-sac larvae differed from nocturnal distribution (Fig. 7.4-4) primarily during the second sampling period (May 28-29) when larvae were abundant. The overall pattern of the density data in both the 6-stratum design and 3-stratum analysis indicated that the larvae were concentrated at the bottom during the day and that they dispersed throughout the water column at night. The existence of a difference between the distribution of striped bass eggs and yolk-sac larvae could be questioned because of the relative immobility of both stages. In this study, however, yolk-sac larvae dispersed throughout the water column at night while eggs remained concentrated near the bottom both day and night. Thus, the results indicated that yolk-sac larvae, despite their relatively weak swimming ability, were able to make active movements sufficient to cause the observed change in their distribution. The results of the Newman-Keuls tests of the relationship between depth and time of day appear in Fig. 7.4-5 and 7.4-6.

The lateral, longitudinal, and vertical distribution of yolk-sac larvae in the Cornwall area was not homogeneous. The data indicated that the distribution of larvae across the river depended on the longitudinal region in which the samples were taken. For example, during May 28-29, RM 53-55 (km 84.8-88.0) exhibited the highest larval densities on the west side of the river while RM 56 (km 89.6) exhibited the highest density on the east side (Fig. 7.4-7). Vertical distribution differed between lateral zones during the same period, but the relationship was not a strong one (Fig. 7.4-8). The channel zone contained significantly fewer larvae at the surface than at the bottom, while the surface and bottom densities in the east and west zones were not significantly different from one another. The uneven distribution demonstrated by these relationships would be difficult to explain on any biological basis at the present time. It seems more likely to be due to some physical factor not tested by the sampling design. Among the possibilities are tidal stage, bottom configuration, irregularities in the shoreline (e.g. points, bays, and islands), and variations in freshwater discharge. All these factors change current patterns, which

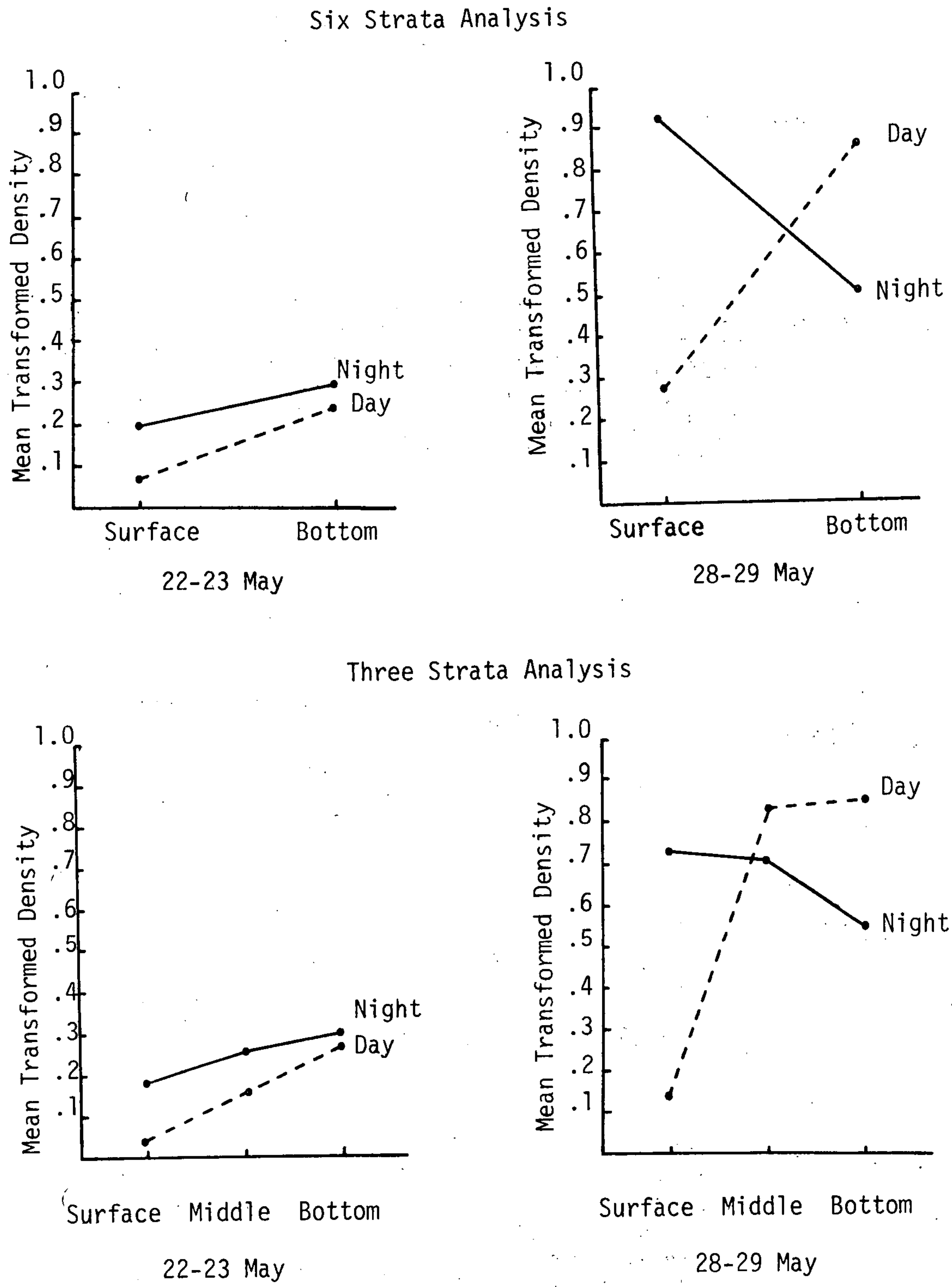

Figure 7.4-4 Mean Transformed ($\sqrt{x}$) Day/Night Density of Yolk-Sac Larvae at Surface and Bottom during Two Sampling Periods, 6- and 3- Stratum Analyses, Cornwall Study

22-23 May

	Surface	Bottom
Day	.072	.241
Night	.201	.302

28-29 May

	Surface	Bottom
Day	.272	.848
Night	.922	.480

Figure 7.4-5 Results of Newman-Keuls Test on Sampling Period, Relative Depth and Time of Day Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed [$\sqrt{x}$] densities from the 6-stratum analysis of distribution of yolk-sac larvae, Cornwall Study)

22-23 May

	Surface	Middle	Bottom
Day	.044	.154	.273
Night	.175	.248	.304

28-29 May

	Surface	Middle	Bottom
Day	.138	.829	.846
Night	.725	.712	.553

Figure 7.4-6 Results of Newman-Keuls Test on Sampling Period, Time of Day, and Relative Depth Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed [$\sqrt{x}$] densities from 3-stratum analysis of distribution of yolk-sac larvae, Cornwall Study)

22-23 May

River Miles	57-59	56	53-55
West	.110	.343	.276
Channel	.227	.170	.199
East	.228	.121	.150

28-29 May

River Miles	57-59	56	53-55
West	.720	.563	.833
Channel	.557	.518	.622
East	.436	.842	.583

Figure 7.4-7 Results of Newman-Keuls Test on Sampling Period, Longitudinal Region, and Lateral Zone Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed $[\sqrt{x}]$ densities from 6-stratum analysis of distribution of yolk-sac larvae, Cornwall Study)

22-23 May

	West	Channel	East
Surface	.129	.109	.172
Bottom	.359	.289	.169

28-29 May

	West	Channel	East
Surface	.790	.432	.570
Bottom	.619	.700	.672

Figure 7.4-8 Results of the Newman-Keuls Test on the Sampling Period, Lateral Zone Relative Depth Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed $[\sqrt{x}]$ densities from 6-stratum analysis of distribution of yolk-sac larvae, Cornwall Study)

presumably change larval distribution since yolk-sac larvae cannot oppose strong currents.

7.4.1.5.2 New York University Indian Point Study. The Indian Point study did not indicate as strong a pattern of vertical movement as detected by the Cornwall study, but the results were consistent and statistically significant (Fig. 7.4-9). Daytime distribution was sharply stratified, with larval densities at the surface significantly lower than those at the bottom. Nighttime distribution was not as stratified: mid-depth and bottom densities were almost equal. This was similar to the nocturnal dispersal observed in the Cornwall study. Larval densities were generally higher at upstream stations than at downstream stations, but only the most upstream and most downstream stations were significantly different from one another (Figure 7.4-10).

The Cornwall and Indian Point studies established that the distribution of yolk-sac larvae and eggs differ in important ways. The larvae are capable of making vertical migrations, at least when the yolk-sac has been largely absorbed. The dispersal of the yolk-sac larvae at night is an important aspect of the biology of striped bass that has not been intensively studied in the past.

7.4.1.6 Summary. The description of the biology and distribution of striped bass yolk-sac larvae has been compiled from studies in the Hudson River, other natural habitats, hatcheries, and laboratories. Length at hatching is 2.0 to 3.7 mm, and length at transformation to the post yolk-sac stage is about 5 to 6 mm. Speed of development depends on temperature: at 19 to 21°C, the yolk-sac stage lasts 4 to 6 days. In the Hudson River estuary, water temperature, dissolved oxygen, and salinity where the larvae occur are generally within the range necessary for survival. Larval mortality results from disease, physicochemical factors and predation. The major factor affecting the distribution of yolk-sac larvae is probably current patterns, but the larvae are capable of short

	Surface	Middle	Bottom
Day	.048	.309	.901
Night	.083	.371	.300

Figure 7.4-9 Results of Newman-Keuls Test on Time of Day and Relative Depth Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed $[\sqrt{x}]$ densities from analysis of distribution of yolk-sac larvae, Indian Point Study)

Station	A	B	C	D	E	F	G
	.539	.387	.422	.261	.262	.265	.214

Figure 7.4-10 Results of Newman-Keuls Test on Station Differences in Analysis of Distribution of Yolk-Sac Larvae, Indian Point Study. No significant difference exists between any two members of the same circled group (P > .05). (Data are mean transformed $[\sqrt{x}]$ densities)

swimming movements. Intensive study in the Cornwall and Indian Point areas indicates that yolk-sac larvae concentrate at the bottom during the day but disperse throughout the water column at night. Larval distribution is not laterally or longitudinally homogeneous within the Cornwall and Indian Point areas, and patterns vary in a complex way.

7.4.2 POST YOLK-SAC LARVAE

7.4.2.1 Physical Description. Transformation from the yolk-sac to post yolk-sac stage occurs 4 to 6 days after hatching when the larvae are 5 to 6 mm long (Pearson 1938:836, Mansueti 1958:12, Bayless 1972:61). The end of the yolk-sac stage is marked by the completion of the digestive tract although some of the yolk-sac and oil globule may persist. The rest of the yolk-sac is absorbed during the post yolk-sac stage, body pigmentation becomes noticeable, fins begin to form, and the larvae take on the appearance of the adult (Mansueti 1958:14). The end of the post yolk-sac stage is characterized by the development of the complete set of fin rays possessed by the adult.

In laboratory studies conducted by Rogers et al. (1976:30), the duration of the post yolk-sac stage was 31 days at 21°C and transformation to the juvenile stage occurred when the larvae were about 16 mm long. Other laboratory work produced similar results (Mansueti 1958:14, Doroshev 1970:239), but the growth of larvae used in the studies was retarded by rearing conditions. Data collected by Pearson (1938:832-837) from pond-raised larvae indicated faster growth.

The duration of the post yolk-sac stage is probably somewhat shorter than 30 days under natural conditions, and the size at transformation may be somewhat larger. Growth curves developed for Hudson River larvae indicated that they attain a length of 16 mm at 20-30 days after hatching (Section 7.7).

7.4.2.2 Temperature, Dissolved Oxygen, and Salinity Tolerance. Temperature, dissolved oxygen, and salinity may affect the survival and distribution of post yolk-sac larvae. Since investigators generally have combined yolk-sac and post yolk-sac larvae in discussions of tolerances, these data have been summarized in Section 7.4.1. Post yolk-sac larvae spatial distribution relative to these factors differs from that of yolk-sac larvae because of the early summer conditions that exist as the larvae develop. In 1974, most post yolk-sac larvae were collected in areas having water temperature ranging from 16 to 24°C (Fig. 7.4-11); in 1975, the highest catches occurred over a narrower range (18 to 24°C). These temperatures are within the range necessary for survival noted in Section 7.4.1. Dissolved oxygen concentrations of from 6 to 13 mg litre^{-1} prevailed in areas where post yolk-sac larvae were collected in 1974 (Fig. 7.4-12), but catches were high in water having a dissolved oxygen concentration of 1 to 2 mg litre^{-1}. Larvae subjected to these conditions for long periods could be expected to suffer increased mortality. During 1975, high catches were restricted to a narrower range of dissolved oxygen concentration (6-10 mg litre^{-1}, Fig. 7.4-12). Salinity values of <4 o/oo (7.0 mS cm^{-2} conductivity) were dominant where post yolk-sac larvae were collected in 1974 and 1975 (Fig. 7.4-13). Salinities of 4-14 o/oo improved survival among hatchery-reared larvae (Doroshev 1970:244, Bayless 1972:70). The effect of low salinity (<1 o/oo) on larval growth and survival in the Hudson River estuary is unknown. The range of temperature, dissolved oxygen, and salinity conditions in which larvae occur probably does not result from active selection of these conditions by the larvae but rather reflects environmental conditions during the period when the larvae occur.

7.4.2.3 Movement and Behavior. Post yolk-sac larvae are active swimmers. Sazaki et al. (1973) found that almost 52% of larvae 10.1-12.5 mm long were still swimming after 4-min exposure to a current of 12.2 cm s^{-1}; in a second test, 72% were still swimming after the same exposure. Larvae 5.1-7.5 mm long, however, could not swim for 4 min against a 12.2 cm s^{-1} current.

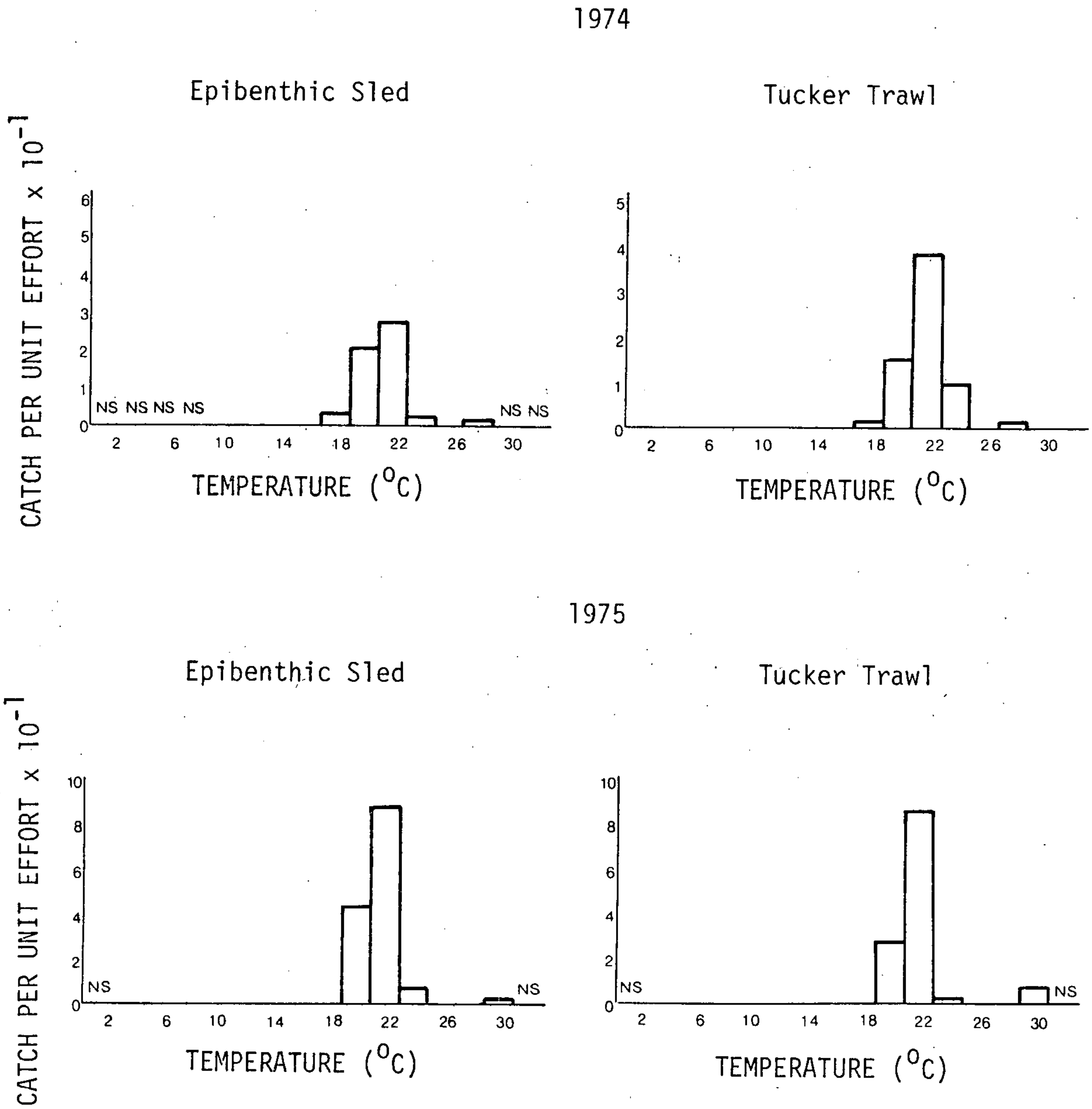

Figure 7.4-11 Catch per Unit Effort of Striped Bass Post Yolk-Sac Larvae Collected by Epibenthic Sled and Tucker Trawl at Various Water Temperatures in Hudson River Estuary (RM 14-140; km 23-227) during 1974 and 1975

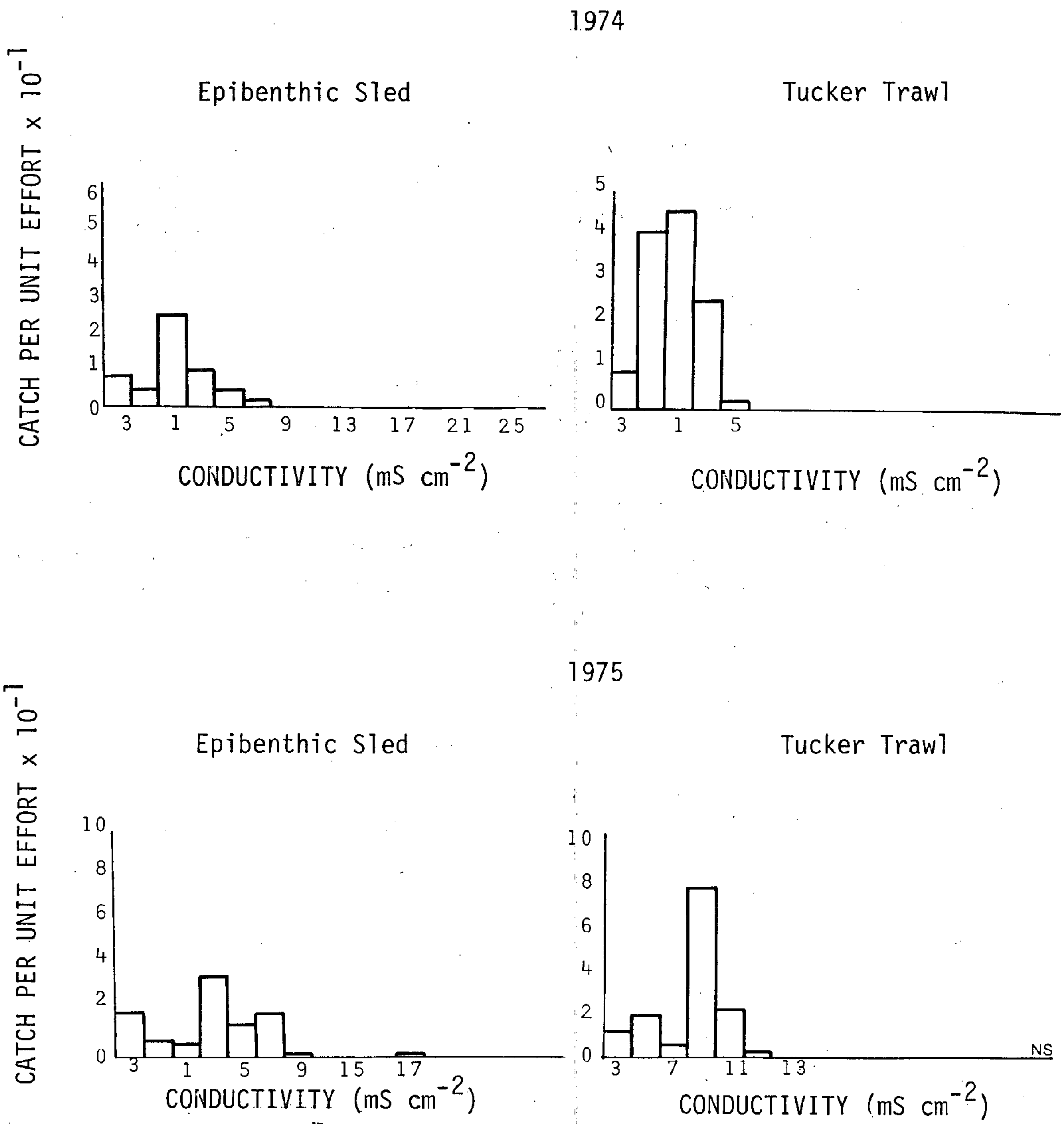

Figure 7.4-13. ~~Catch per Unit Effort of Striped Bass Post Yolk-Sac Larvae Collected at Various Conductivities by Epibenthic Sled and Tucker Trawl during 1974 and 1975 in the Hudson River Estuary (RM 14-140)~~

CAPTION SHOULD READ:

"Catch per Unit Effort of Striped Bass Post Yolk-Sac Larvae Collected by Epibenthic Sled and Tucker Trawl at Various Conductivities in the Hudson River Estuary (RM 14-140; km 23-227) during 1974 and 1975"

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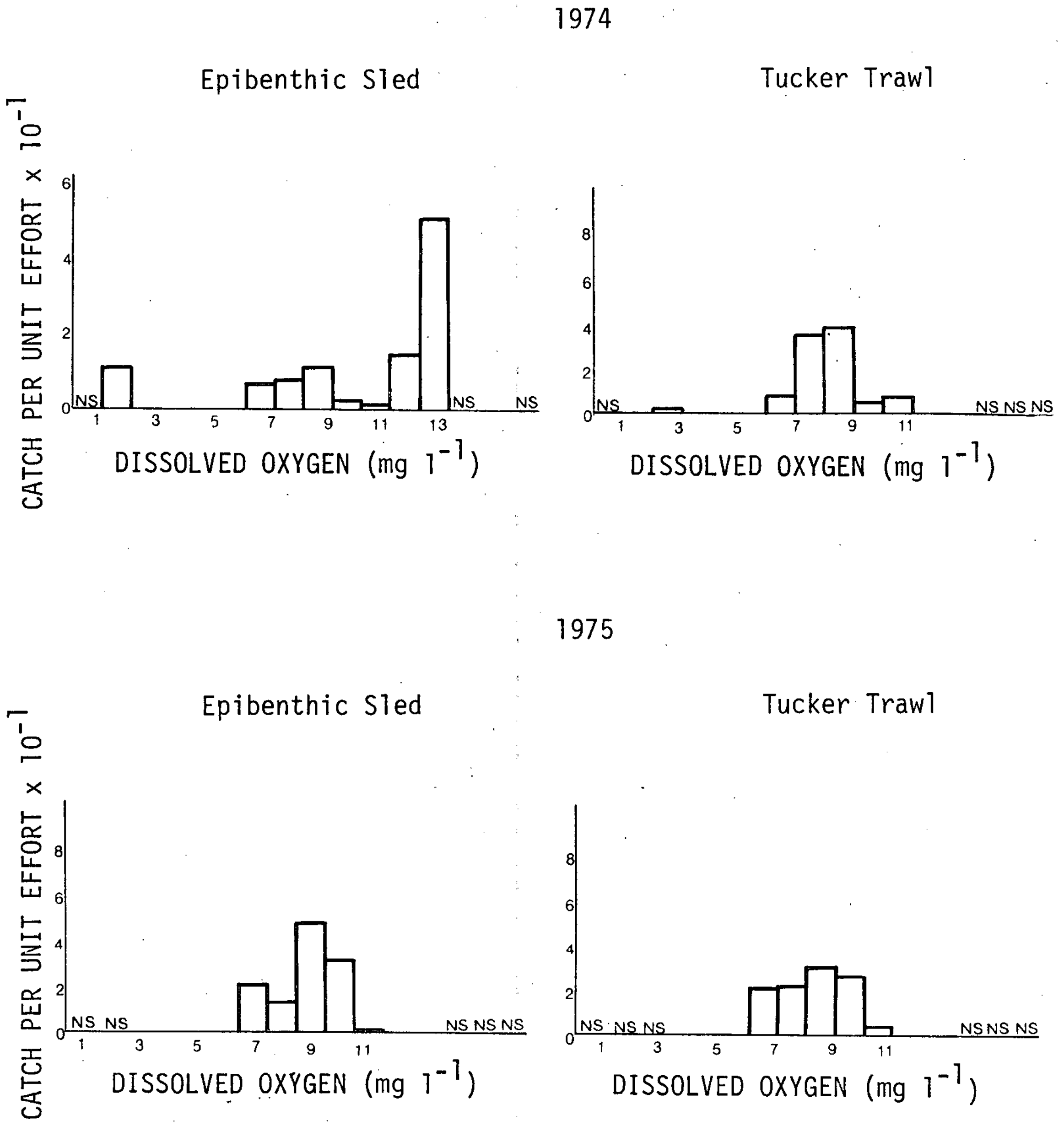

Figure 7.4-12 Catch per Unit Effort of Striped Bass Post Yolk-Sac Larvae Collected by Epibenthic Sled and Tucker Trawl at Various Dissolved Oxygen Concentrations in Hudson River Estuary (RM 14-140; km 23-227) during 1974 and 1975

Post yolk-sac larvae are more capable of strong, directed movement than are yolk-sac larvae and can oppose currents, pursue prey, and avoid predators and environmental stress. Presumably, the post yolk-sac larvae are also capable of gear avoidance, which could affect the results in any study of their distribution. High tow speeds and larger net mouths help reduce avoidance but probably do not eliminate it.

7.4.2.4 Foods and Feeding. Larvae begin to feed actively at the beginning of the post yolk-sac stage. According to Bayless' (1972:62) observations of fish under hatchery conditions, a critical period exists 7 to 10 days after hatching: larvae that had not begun to feed during that period never began feeding, and death from starvation followed. The first foods eaten are usually small planktonic organisms (Kretser 1973:12). The size range of the first particles ingested by 6- to 7-day-old larvae under hatchery conditions is 0.15-0.30 mm (Doroshev 1970:246), while larvae 2 wk old ingest food particles ranging in size from 0.4 to 1.0 mm.

The stomachs of larvae collected in the Hudson River contained many different species of invertebrates (Kretser 1973:11). No food was found in the stomachs of larvae <5.3 mm long. The stomachs of the smallest post yolk-sac larvae contained copepods and cladocerans. These organisms occurred more frequently than any other food throughout the post yolk-sac stage. Larger larvae preyed on amphipods, ostracods, and dipteran larvae. The increase of food particle size noted here confirms the hatchery observations made by Doroshev (1970:246).

7.4.2.5 Sources of Mortality. With the exception of many developmental abnormalities, most of the sources of mortality affecting yolk-sac larvae (Section 7.4.1.4) also affect the post yolk-sac larvae. The major difference in the potential mortality factors between the two stages is that post yolk-sac larvae must feed. Thus, failure of the feeding response to develop and food scarcity are additional sources of mortality.

7.4.2.6 Microdistribution. The Texas Instruments Cornwall study and the New York University Indian Point study were designed to characterize the distribution of post yolk-sac larvae relative to the same factors described for yolk-sac larvae in Section 7.4.1. Since post yolk-sac larvae are capable of strong directed movements, their distribution should be less dependent on prevailing currents and more indicative of larval response to environmental stimuli than was the distribution of eggs and yolk-sac larvae. Behavioral changes that may occur as the larvae approach transformation to the juvenile stage have to be taken into account when comparing the distribution of yolk-sac and post yolk-sac larvae. Any interpretation of the results of studies of this type must also acknowledge the possibility that gear avoidance may influence the number of larvae collected. The interplay of all these factors makes the interpretation of the results of the two studies more difficult than it was for the earlier life stages.

The sampling design, analytical techniques, and approach to interpretation used to study the distribution of post yolk-sac larvae were identical to those described in Section 7.3.5. Data collected on May 28-29 and June 13-14 were used to analyze the Cornwall study. Indian Point data from May 27-30 and June 2-3, 9-10, and 16-17 were analyzed. The results of the analyses of variance of the Cornwall (RM 56; km 90) and Indian Point (RM 42; km 69) studies are listed in Tables 7.4-4, 7.4-5, and 7.4-6. Each analysis revealed spatial and temporal heterogeneity in the distribution of post yolk-sac larvae. Several of the main effects and interactions contributed significantly to the variation in larval density. Interactions involving day/night and relative depth effects were especially important and in many cases statistically significant.

7.4.2.6.1 Texas Instruments Cornwall Study. The overall pattern of post yolk-sac larval distribution reflected a stronger orientation toward the bottom, regardless of time of day, than the yolk-sac larval distribution. Dispersal at night still occurred, but not as clearly as with the yolk-sac stage. Differences in the vertical

Table 7.4-4 Results of Analysis of Variance of Distribution of Post Yolk-Sac Larvae, 6-Stratum Design, Cornwall Study

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	PROB. F EXCEEDED
MEAN	7.81304	1	7.81304	220.41125	0.000
W Sampling Period	0.25425	1	0.25425	7.17253	0.009***
T Day/Night	0.03889	1	0.03889	1.09719	0.298
L Longitudinal Region	0.06020	2	0.03010	0.84915	0.432
S Lateral Zone	0.02222	2	0.01111	0.31346	0.732
V Relative Depth	1.04690	1	1.04690	29.53365	0.000***
WT	0.06876	1	0.06876	1.93974	0.168
WL	0.14094	2	0.07047	1.98800	0.145
TL	0.00340	2	0.00170	0.04793	0.953
WS	0.27694	2	0.13847	3.90635	0.025**
TS	0.13559	2	0.06780	1.91260	0.155
LS	0.17912	4	0.04478	1.26330	0.293
WV	0.90050	1	0.90050	25.40372	0.000***
TV	0.38940	1	0.38940	10.98531	0.001***
LV	0.01595	2	0.00797	0.22493	0.799
SV	0.10900	2	0.05450	1.53749	0.222
WTL	0.10035	2	0.05017	1.41542	0.250
WTS	0.21089	2	0.10545	2.97473	0.057*
WTV	0.02685	1	0.02685	0.75742	0.387
WLS	0.31870	4	0.07968	2.24769	0.072*
WLV	0.03228	2	0.01614	0.45535	0.636
TLS	0.29970	4	0.07493	2.11372	0.088*
TLV	0.09724	2	0.04862	1.37154	0.260
WSV	0.07596	2	0.03798	1.07144	0.348
TSV	0.07941	2	0.03971	1.12011	0.332
LSV	0.22380	4	0.05595	1.57838	0.189
WTLS	0.38848	4	0.09712	2.73981	0.035**
WTLV	0.05062	2	0.02531	0.71404	0.493
WTSV	0.30198	2	0.15099	4.25950	0.018**
WLSV	0.33715	4	0.08429	2.37782	0.060*
TLSV	0.15318	4	0.03829	1.08032	0.373
WTLS	0.27946	4	0.06986	1.97091	0.108
ERROR	2.51678	71	0.03545		

* $P \leq .10$
** $P \leq .05$
*** $P \leq .01$

Table 7.4-5 Results of Analysis of Variance of Distribution of Post Yolk-Sac Larvae, 3-Stratum Analysis, Cornwall Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Probability F Exceeded
Mean	3.43236	1	3.43236	93.92451	0.000
W Sampling Period	0.12292	1	0.12292	3.36376	0.075*
T Day/Night	0.05054	1	0.05054	1.38299	0.247
L Longitudinal Region	0.01284	2	0.00642	0.17566	0.840
V Relative Depth	0.59385	2	0.29692	8.12511	0.001***
WT Relative Depth	0.21972	1	0.21972	6.01240	0.019**
WL	0.17021	2	0.08510	2.32882	0.112
TL	0.7100	2	0.03550	0.97140	0.388
WV	0.33270	2	0.16635	4.55200	0.017**
TV	0.32835	2	0.16418	4.49255	0.018**
LV	0.19821	4	0.04955	1.35597	0.268
WTL	0.14549	2	0.07274	1.99060	0.151
WTV	0.19470	2	0.09735	2.66393	0.083*
WLV	0.08634	4	0.02158	0.59066	0.672
TLV	0.04461	4	0.01115	0.30519	0.873
WTLV	0.11817	4	0.02954	0.80844	0.528
ERROR	1.31558	36	0.03654		

* P ≤ .10
** P ≤ .05
*** P ≤ .01

Table 7.4-6 Results of Analysis of Variance of Distribution of Post Yolk-Sac Larvae, Nearfield Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Mean	40.94185	1	40.94185	
V Relative Depth	8.87640	2	3.43820	64.76***
S Station	1.78929	6	0.29821	5.62***
N Day/Night	1.03987	1	1.03987	19.59***
W Sampling Period	12.15456	3	4.05152	76.31***
VS	0.26497	12	0.02208	.42
VN	1.49878	2	0.74939	14.12***
SN	0.58464	6	0.09744	1.84
VW	3.37829	6	0.56305	10.61***
SW	1.22955	18	0.06831	1.29
NW	5.05980	3	1.68660	31.77***
VSN	0.98765	12	0.08230	1.55
VSW	2.99921	36	0.08331	1.57*
VNW	0.68512	6	0.11419	2.15*
SNW	1.44999	18	0.08056	1.22
VSNW	1.91135	36	0.05305	

* P ≤ .10
** P ≤ .05
*** P ≤ .01

Table 7.4-5 Results of Analysis of Variance of Distribution of Post Yolk-Sac Larvae, 3-Stratum Analysis, Cornwall Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Probability F Exceeded
Mean	3.43236	1	3.43236	93.92451	0.000
W Sampling Period	0.12292	1	0.12292	3.36376	0.075*
T Day/Night	0.05054	1	0.05054	1.38299	0.247
L Longitudinal Region	0.01284	2	0.00642	0.17566	0.840
V Relative Depth	0.59385	2	0.29692	8.12511	0.001***
WT Relative Depth	0.21972	1	0.21972	6.01240	0.019**
WL	0.17021	2	0.08510	2.32882	0.112
TL	~~0.7100~~ 0.07100	2	0.03550	0.97140	0.388
WV	0.33270	2	0.16635	4.55200	0.017**
TV	0.32835	2	0.16418	4.49255	0.018**
LV	0.19821	4	0.04955	1.35597	0.268
WTL	0.14549	2	0.07274	1.99060	0.151
WTV	0.19470	2	0.09735	2.66393	0.083*
WLV	0.08634	4	0.02158	0.59066	0.672
TLV	0.04461	4	0.01115	0.30519	0.873
WTLV	0.11817	4	0.02954	0.80844	0.528
ERROR	1.31558	36	0.03654		

* P ≤ .10
** P ≤ .05
*** P ≤ .01

Table 7.4-6 Results of Analysis of Variance of Distribution of Post Yolk-Sac Larvae, Nearfield Study

Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Mean	40.94185	1	40.94185	
V Relative Depth	~~8.87640~~ 6.87640	2	3.43820	64.76***
S Station	1.78929	6	0.29821	5.62***
N Day/Night	1.03987	1	1.03987	19.59***
W Sampling Period	12.15456	3	4.05152	76.31***
VS	0.26497	12	0.02208	.42
VN	1.49878	2	0.74939	14.12***
SN	0.58464	6	0.09744	1.84
VW	3.37829	6	0.56305	10.61***
SW	1.22955	18	0.06831	1.29
NW	5.05980	3	1.68660	31.77***
VSN	0.98765	12	0.08230	1.55
VSW	2.99921	36	0.08331	1.57*
VNW	0.68512	6	0.11419	2.15*
SNW	1.44999	18	0.08056	~~1.22~~ 1.52
VSNW	1.91135	36	0.05305	

* P ≤ .10
** P ≤ .05
*** P ≤ .01

distribution of post yolk-sac larvae between day and night depended on which lateral zone was sampled (Fig. 7.4-14 and 7.4-15). The concentration of post yolk-sac larvae at the bottom may have been the result of a behavioral change as the larvae approached transformation to the juvenile stage. Analysis of the 3-stratum design generally supported this interpretation (Fig. 7.4-16 and 7.4-17).

The relationship between vertical and lateral distribution supported the contention that the larvae were concentrated at the bottom (Fig. 7.4-18). In almost all cases, bottom densities were higher than surface densities, although only during June 13-14 were any of the differences significant. The reason for finding significant differences only during the second sampling period may have been due to low larval density in the first period or to a behavioral change as the larvae approached the juvenile stage.

7.4.2.6.2 New York University Indian Point Study. Data from the Indian Point nearfield study generally demonstrated the same concentration of post yolk-sac larvae at the bottom that was seen in the Cornwall study although the results were less distinct (Fig. 7.4-19). The nighttime densities indicated the increased dispersal of the larvae throughout the water column that characterized yolk-sac larval distribution.

Although post yolk-sac and yolk-sac larvae exhibit similar nocturnal migration patterns, these studies indicate that the post yolk-sac larvae are more strongly oriented toward the bottom. Since the swimming abilities of post yolk-sac larvae exceed the abilities of yolk-sac larvae, a behavioral change that results in the larvae staying near the bottom regardless of time of day, seems to occur as they approach the juvenile stage.

7.4.2.7 Summary. This section ~~Section~~ has described the biology and development of striped bass post yolk-sac larvae and their distribution in the Hudson River estuary. Length at transformation to the post yolk-sac

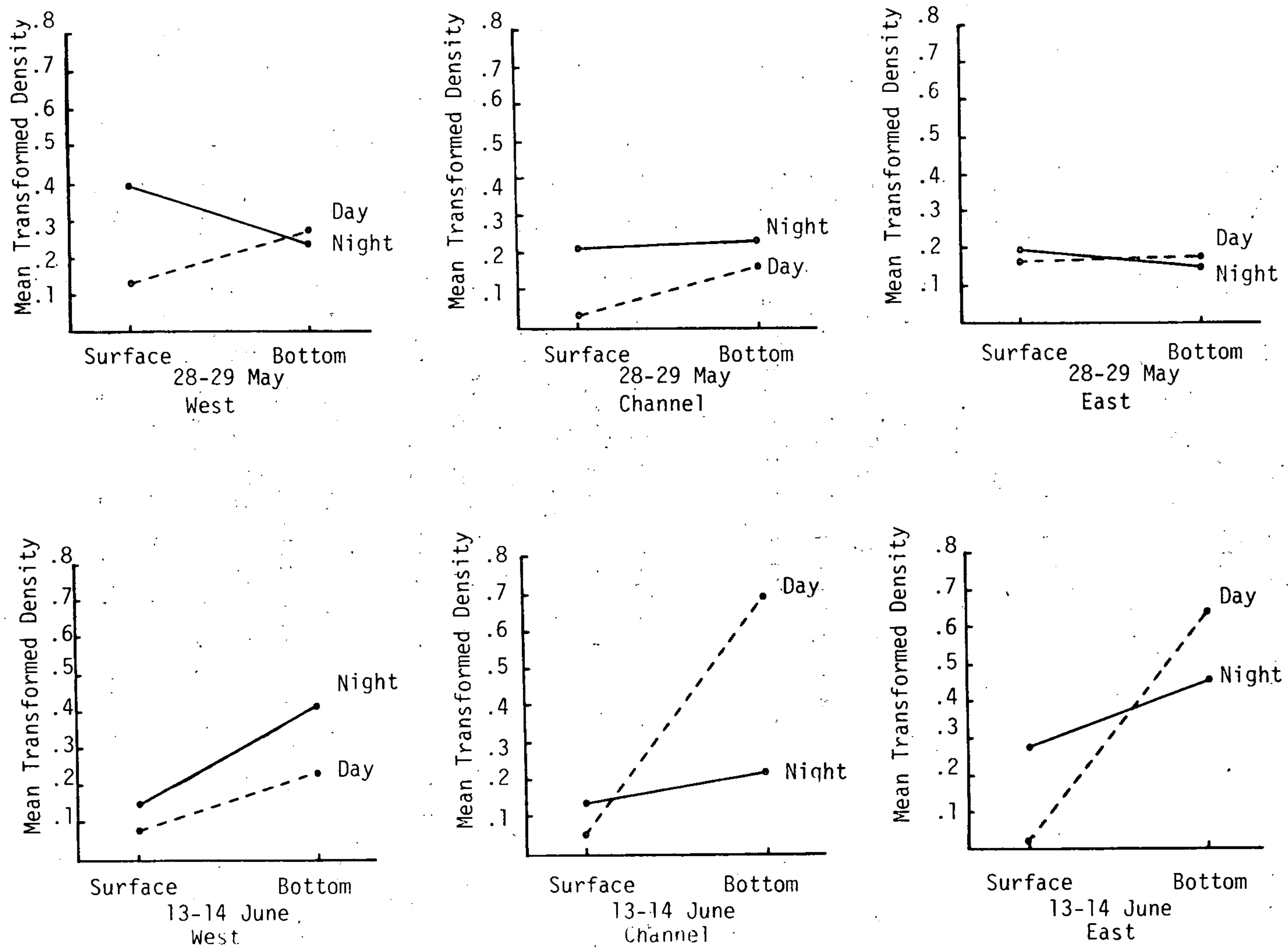

Figure 7.4-14 Mean Transformed ($\sqrt{x}$) Density of Post Yolk-Sac Larvae at Surface and Bottom in West, Channel, and East Zones at Night and during Day (6-Stratum Design) for Two Sampling Periods, Cornwall Study

28-29 May	West	Surface	Bottom
	Day	.131	.271
	Night	.388	.230

28-29 May	Channel	Surface	Bottom
	Day	.030	.156
	Night	.210	.227

28-29 May	East	Surface	Bottom
	Day	.160	.168
	Night	.191	.138

13-14 June	West	Surface	Bottom
	Day	.082	.227
	Night	.154	.413

13-14 June	Channel	Surface	Bottom
	Day	.051	.688
	Night	.135	.244

13-14 June	East	Surface	Bottom
	Day	.019	~~.627~~ .736
	Night	.227	.454

Figure 7.4-15 Results of Newman-Keuls Test on Sampling Period, Lateral Zone, Relative Depth, and Time of Day Interaction. No significant difference exists between any two members of the same circled group (P >.05). (Values are mean transformed $[\sqrt{x}]$ densities from 6-stratum analysis of distribution of post yolk-sac larvae, Cornwall study)

28-29 May	West	Surface	Bottom
	Day	.131	.271
	Night	.388	.230

28-29 May	Channel	Surface	Bottom
	Day	.030	.156
	Night	.210	.227

28-29 May	East	Surface	Bottom
	Day	.160	.168
	Night	.191	.138

13-14 June	West	Surface	Bottom
	Day	.082	.227
	Night	.154	.413

13-14 June	Channel	Surface	Bottom
	Day	.051	.688
	Night	.135	.244

13-14 June	East	Surface	Bottom
	Day	.019	.627
	Night	.227	.454

Figure 7.4-15 Results of Newman-Keuls Test on Sampling Period, Lateral Zone, Relative Depth, and Time of Day Interaction. No significant difference exists between any two members of the same circled group (P >.05). (Values are mean transformed $[\sqrt{x}]$ densities from 6-stratum analysis of distribution of post yolk-sac larvae, Cornwall study)

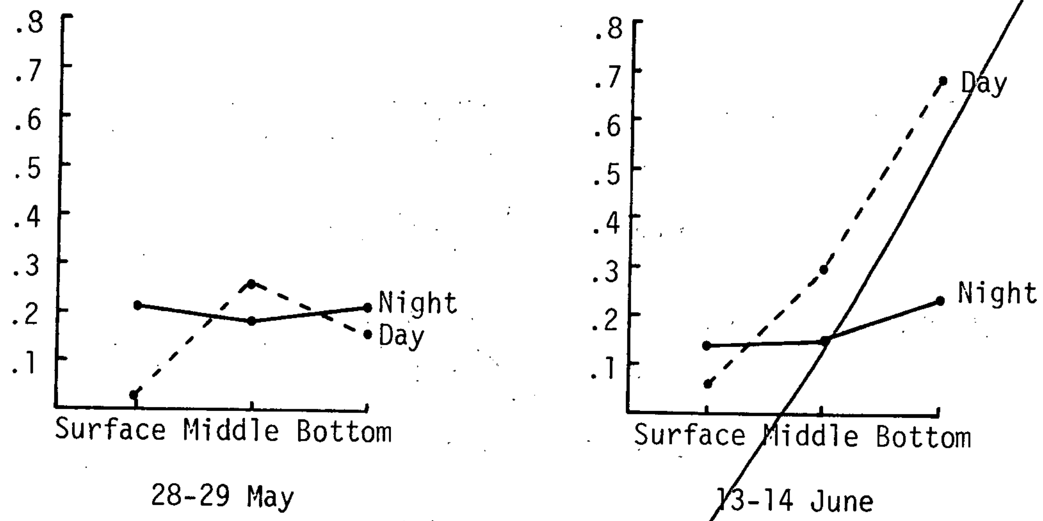

Figure 7.4-16 Mean Transformed ($\sqrt{x}$) Day/Night Density of Post Yolk-Sac Larvae at Surface, Middle, and Bottom (3-Stratum Design) during two Sampling Periods, Cornwall Study

28-29 May	Surface	Middle	Bottom
Day	.030	.259	.156
Night	.210	.180	.227

13-24 June	Surface	Middle	Bottom
Day	.051	.285	.688
Night	.135	.154	.244

Figure 7.4-17 Results of Newman-Keuls Test on Sampling Period, Time of Day, and Relative Depth Interaction. No significant difference exists between any two members of the same circled group ($P \leq .05$). (Values are mean transformed [$\sqrt{x}$] densities from 3-stratum analysis of distribution of post yolk-sac larvae, Cornwall Study)

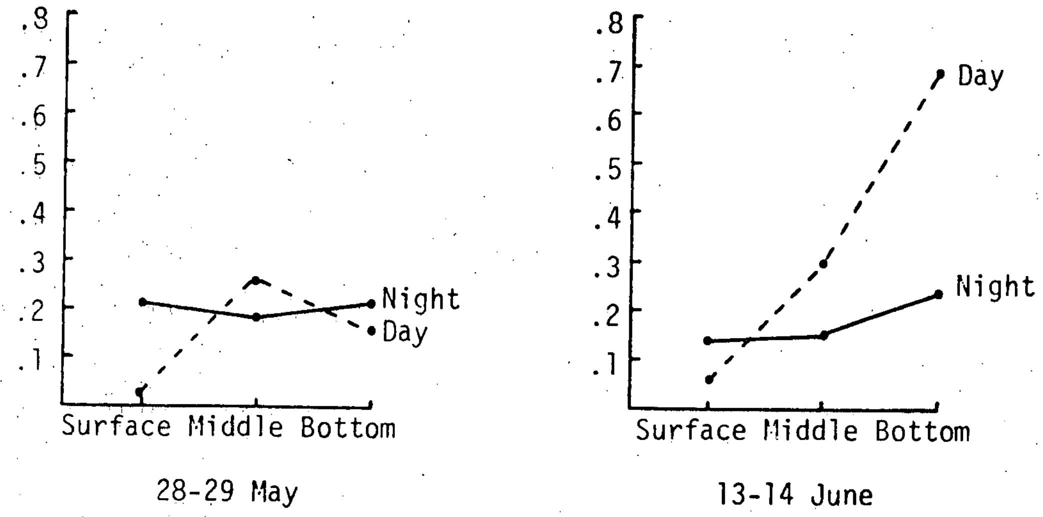

Figure 7.4-16 Mean Transformed ($\sqrt{x}$) Day/Night Density of Post Yolk-Sac Larvae at Surface, Middle, and Bottom (3-Stratum Design) during two Sampling Periods, Cornwall Study

28-29 May	Surface	Middle	Bottom
Day	.030	.259	.156
Night	.210	.180	.227

13-~~24~~ 14 June	Surface	Middle	Bottom
Day	.051	.285	.688
Night	.135	.154	.244

Figure 7.4-17 Results of Newman-Keuls Test on Sampling Period, Time of Day, and Relative Depth Interaction. No significant difference exists between any two members of the same circled group ($P \leq .05$). (Values are mean transformed [$\sqrt{x}$] densities from 3-stratum analysis of distribution of post yolk-sac larvae, Cornwall Study)

28-29 May RM 57-59

	West	Channel	East
Surface	.193	.090	.206
Bottom	.201	.162	.096

28-29 May RM 56

	West	Channel	East
Surface	.396	.175	.237
Bottom	.360	.231	.177

28-29 May RM 53-55

	West	Channel	East
Surface	.200	.094	.088
Bottom	.190 ~~.89~~	.182	.185

13-14 June RM 57-59

	West	Channel	East
Surface	.119	.134	.069
Bottom	.511	.420	.552

13-14 June RM 56

	West	Channel	East
Surface	.107	.088	.140
Bottom	.135	.312	.780

13-14 June RM 53-55

	West	Channel	East
Surface	.127	.056	.159
Bottom	.314	.664	.288

Figure 7.4-18 Results of Newman-Keuls Test on Sampling Period, Longitudinal Region, Lateral Zone, and Relative Depth Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are mean transformed [$\sqrt{x}$] densities from 6-stratum analysis of distribution of post yolk-sac larvae, Cornwall Study)

28-29 May RM 57-59

	West	Channel	East
Surface	.193	.090	.206
Bottom	.201	.162	.096

28-29 May RM 56

	West	Channel	East
Surface	.396	.175	.237
Bottom	.360	.231	.177

28-29 May RM 53-55

	West	Channel	East
Surface	.200	.094	.088
Bottom	.89	.182	.185

13-14 June RM 57-59

	West	Channel	East
Surface	.119	.134	.069
Bottom	.511	.420	.552

13-14 June RM 56

	West	Channel	East
Surface	.107	.088	.140
Bottom	.135	.312	.780

13-14 June RM 53-55

	West	Channel	East
Surface	.127	.056	.159
Bottom	.314	.664	.288

Figure 7.4-18 Results of Newman-Keuls Test on Sampling Period, Longitudinal Region, Lateral Zone, and Relative Depth Interaction. No significant difference exists between any two members of the same circled group (P > .05). (Values are transformed $[\sqrt{x}]$ densities from 6-stratum analysis of distribution of post yolk-sac larvae, Cornwall Study)

27-30 May

	Surface	Middle	Bottom
Day	.000	.717	.536
Night	.225	.275	.169

2-3 June

	Surface	Middle	Bottom
Day	.040	.826	.890
Night	.517	1.099	.762

9-10 June

	Surface	Middle	Bottom
Day	.014	.326	1.048
Night	.800	1.184	1.492

16-17 June

	Surface	Middle	Bottom
Day	.000	.221	.268
Night	.096	.099	.149

Figure 7.4-19 Results of Newman-Keuls Test on Sampling Period, Time of Day, and Relative Depth Interaction. No significant differences exist between any two members of the same circled group (P > .05). (Values are mean transformed [$\sqrt{x}$] densities from analysis of distribution of post yolk-sac larvae, Indian Point Study)

stage is 5 to 6 mm and at transformation to the juvenile stage is 16 to 20 mm. Speed of development depends on temperature: at 21°C, according to laboratory observations, the stage lasts about 30 days. In the Hudson River estuary, water temperature, dissolved oxygen, and salinity where the larvae occur are generally within the range necessary for survival. Larvae face mortality due to disease, physicochemical factors, predation, and starvation. Post yolk-sac larvae are capable of resisting currents and making other strong, directional movements. Intensive study in the Cornwall and Indian Point regions indicates that post yolk-sac larvae exhibit nocturnal migration patterns similar to those exhibited by yolk-sac larvae but are more strongly oriented toward the bottom.

7.5 JUVENILES

The completion of body development in the juvenile stage allows greater movement throughout the estuary. Beach seines, bottom trawls, Tucker trawls, and epibenthic sleds were used to sample portions of the Hudson River to determine aspects of growth and movement patterns. Growth, discussed in greater detail in Section 7.7, is examined with respect to fish distribution and the transition from entrainable to impingeable sizes at power plant intakes. Development of juvenile swimming ability is also important in the avoidance of power plant intakes and predation, areas discussed further as sources of mortality. Distribution and movements of juveniles within the estuary, already presented in detail in Section 6.2, are discussed as general riverwide abundance. The effects of tides, diel (day/night) patterns, and preference of habitat are presented as factors affecting localized movement.

7.5.1 GROWTH. Juvenile (young-of-the-year) striped bass develop the general body shape of adults at about 35 mm (TL) when scales and fully developed fins and fin rays are present (Pearson 1938:837). Adult coloration appears when the young are about 1 yr old and approximately 130 mm (Raney 1952:42).

Postlarval and early juvenile striped bass range from ~~14~~ 13 to 31 mm TL when they first appear in bottom trawl and beach seine catches in mid-June (Table 7.5-1). The upper range of lengths increases throughout July and into mid-August, while the lower range remains fairly constant, indicating a continued recruitment of early juveniles into areas sampled by these gear during this period. Recruitment after mid-August is negligible in all sampling gear (Table 7.5-1). Mean lengths of juveniles from June through September were greater in 1975 than in 1973 and 1974 (Fig. 7.5-1), perhaps as a result of differences in environmental factors among years (Section 7.7).

To predict the effects of power plants on striped bass populations, it is important to determine when the young grow from entrainable to impingeable sizes. The transition is a function of the length and depth (distance from dorsal to ventral surfaces) of the individual in relation to the 0.53 in (13.5 mm) diagonal mesh (0.38 in square mesh) of traveling or fixed screens (Fig. 7.5-2) located in front of the intakes. For length-depth measurements, juveniles 20 to 80 mm total length were selected from fresh samples, resulting in a length to depth ratio of approximately 5:1 (Fig. 7.5-2). The standard measurement of body depth does not include the fins so, on the basis of the length-depth ratio, the smallest striped bass that would be impinged by orienting head first with body depth aligned with the square measure of the intake screen theoretically would be 46mm total length. On the same basis, the largest striped bass that theoretically could be entrained by orienting head first with body depth aligned with the diagonal measure of the intake screen would be 65 mm TL (Fig. 7.5-2). Body features such as fins and "shoulder width", approach to intake screens in other than head first position, and partial clogging of intake screens will significantly reduce the size range of transition from entrainment to impingement. Probably few fish larger than 40 mm total length are entrained. Field samples suggest that the size transition from entrainment to impingement should be complete by mid-July (Fig. 7.5-1), although the transition begins earlier.

Table 7.5-1 Total Length Ranges (mm) of Juvenile (Young-of-the-Year) Striped Bass Caught by Beach Seine, Bottom Trawl, and Epibenthic Sled, June-December 1973-75

		BEACH SEINE				BOTTOM TRAWL		EPIBENTHIC SLED (NIGHT)					
		DAY			NIGHT	DAY		1973		1974		1975	
	WEEK	1973	1974	1975	1974	1974	1975	< 20' deep	> 20' deep	< 20' deep	> 20' deep	< 20' deep	> 20' deep
JUN	25	16-31		14-25			13-21						
	26		18-30	14-38									
	27	12-55	21-35	19-52									
	28		22-45	22-63									
JUL	29	22-70	28-63	17-74			29-52						
	30		20-70	28-86	30-78	29							
	31	15-90	23-75	29-83	44-85		52-65						
	32		24-75	27-90	48-80	50-71							
AUG	33	27-101	44-85	32-98	50-85		35-101					52-107	51-109
	34		41-85	44-110	45-120	NC				50-118	50-94		
	35	42-110	34-119	48-110	31-115		~~NC~~ 85			48-104	56-87	64-104	67-117
	36		32-117	47-120	48-119	NC				49-116	54-99		
SEP	37	45-112	40-119	21-120	57-129		95-100			44-108	66-89	63-115	65-121
	38		51-129	53-130	54-127	NC				47-129	62-109		
	39	51-116	62-130	28-128	49-116		61-~~70~~-101			60-116	69-89	70-133	68-129
	40		59-130	62-125	60-129	81				64-110	63-125		
OCT	41	50-125	59-129	37-148	58-125		64-110	32-141	66-114	79-119	~~95-138~~ 95-130	76-146	NC
	42		57-130	57-149	62-136	74 63				59-126	61 136		
	43	60-125	59-135	64-149	64-138		NC	68-114	35-93	74-115	67-81	76-127	69-135
	44		59-140	67-149	52-140	110-~~110~~				68-130	78-116		
NOV	45	30-122	53-138	68-148	70-138	120-123	93-122	67-125	70-117	63-129	65-113	73-149	85-141
	46		61-138	62-147	NC	64-117				62-119	70-99		
	47	62-131	18-140	61-134	65-136	90-116	~~85-71~~ 96-91	60-119	80-104	69-135	69-111	78-111	95
	48		68-135	68-142		74-87				69-116	62-117		
DEC	49	39-110	49-100	86-148			NC	57-84	74-101	65-131	68-119		
	50		62-118	67-148		109-111				73-122	76		
	51		72				92-126						

NC = NO CATCH

Beach Seine, Night 1974, Week 30-Week 47:
This column of entries should be moved down 2 weeks; i.e., the first entry should be for week 32 and the last entry should be for week 49.

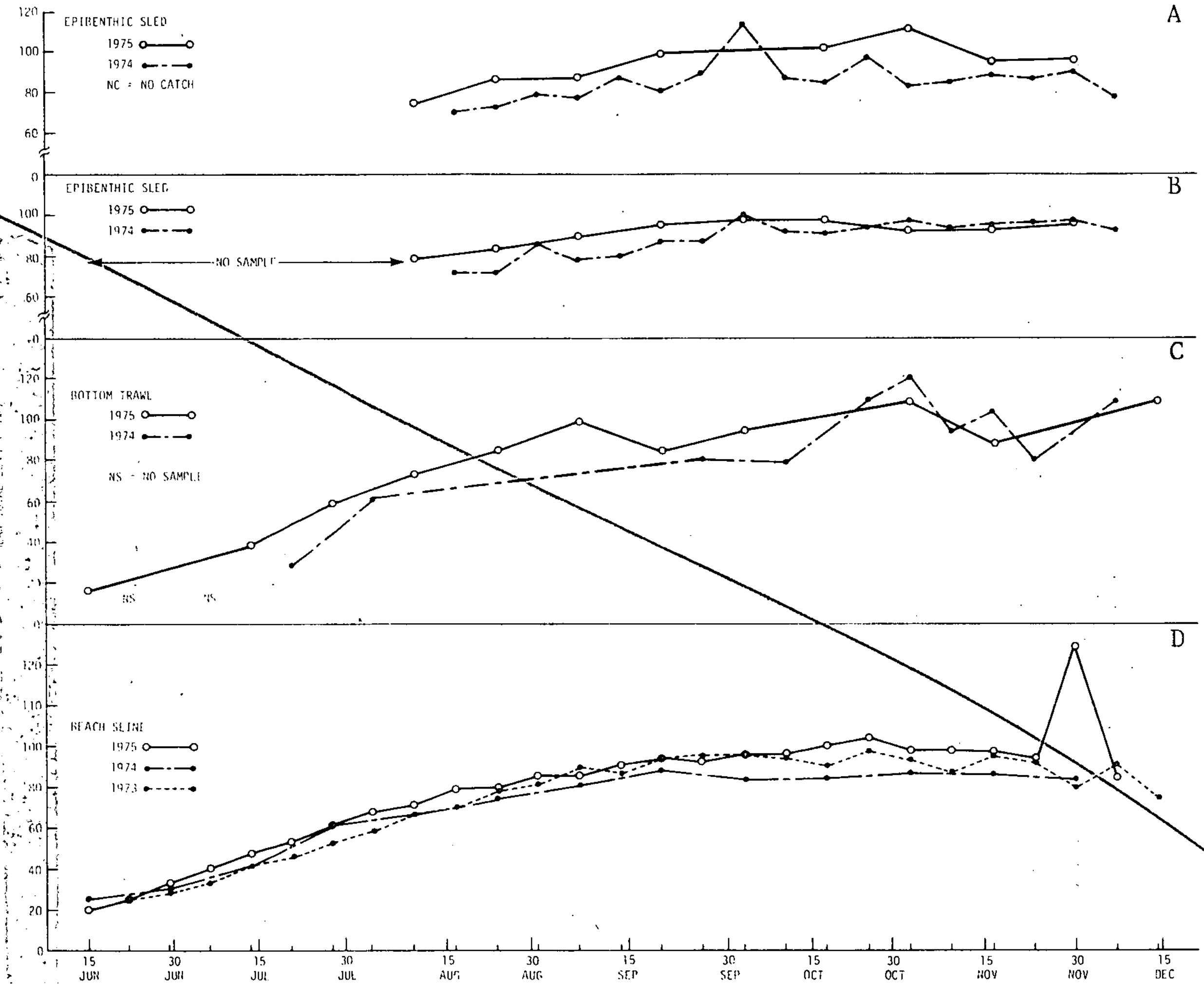

Figure 7.5-1 Mean Total Length of Juvenile Striped Bass Caught in Epibenthic Sled (A and B), Bottom Trawl (C), and Beach Seine (D) during 1973-75. In A, depth ≤20 ft; in B, depth >20 ft.

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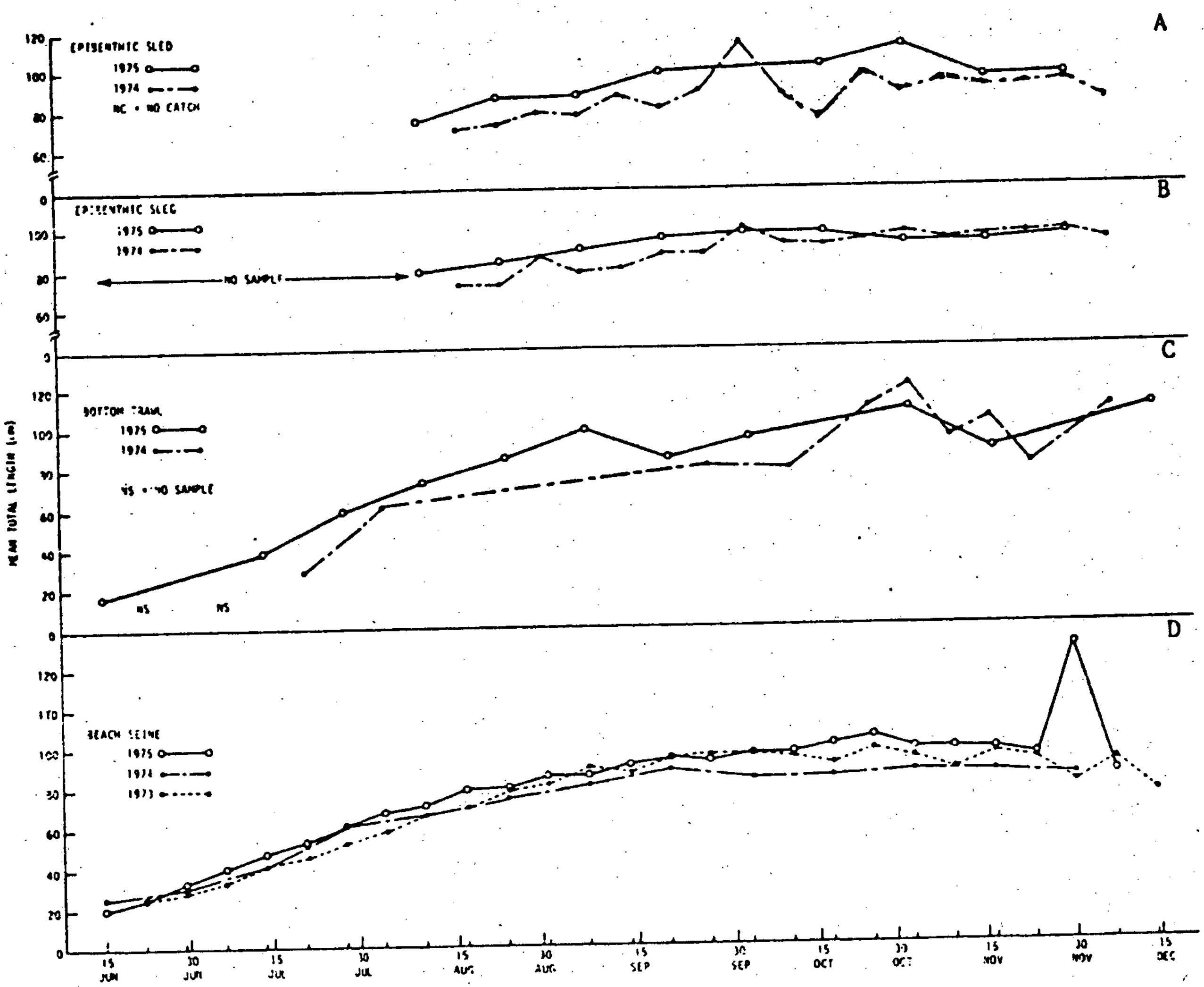

Figure 7.5-1 Mean Total Length of Juvenile Striped Bass Caught in Epibenthic Sled (A and B), Bottom Trawl (C), and Beach Seine (D) during 1973-75. In A, depth ~~20~~ >20 ft; in B, depth ~~>20~~ ≤20 ft.

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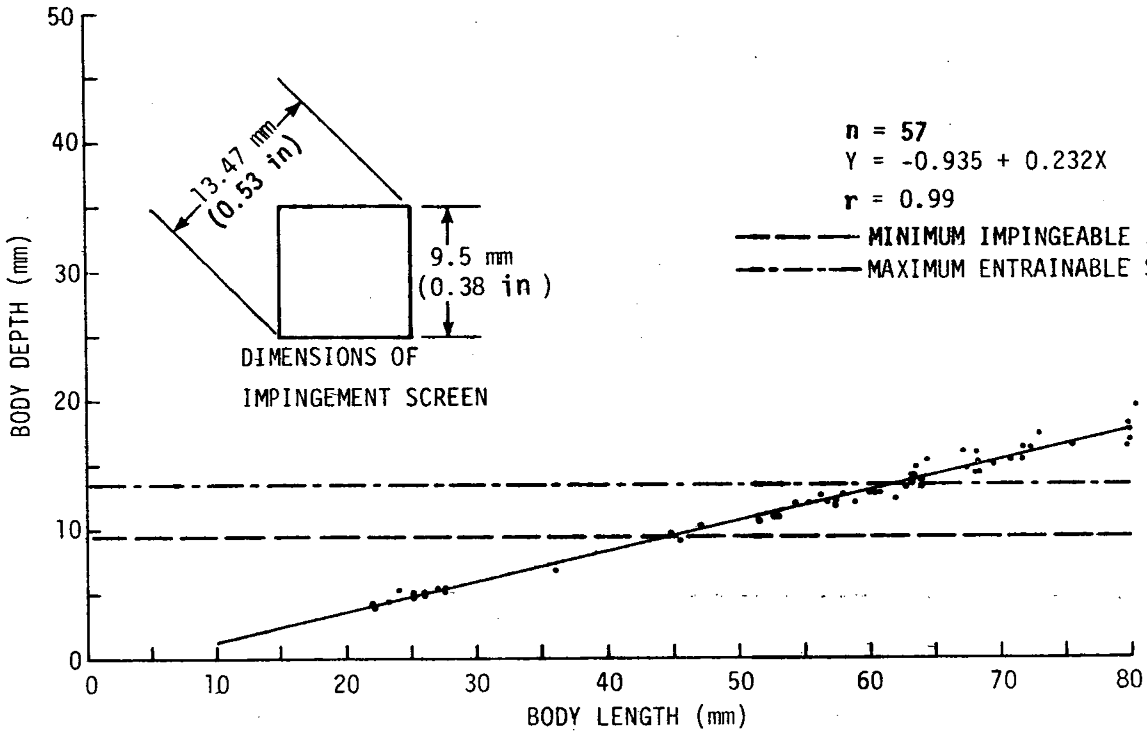

Figure 7.5-2 Theoretical Minimum Impingeable Size and Maximum Entrainable Size Shown by Regression of Body Depth on Total Body Length for Juvenile Striped Bass

7.5.2 SWIMMING ABILITY. Numerous studies on swimming speeds of fish have shown that the ability of young fish to avoid sampling gear and power plant intake structures is a combination of physical conditon (Laurence 1972, Jones 1971), maximum swimming speed and endurance (Kerr 1953, Boyar 1961, Tatham 1970), and swimming behavior (Tatham 1970, Rulifson and Huish 1975). Various environmental factors such as temperature, dissolved oxygen, and salinity also affect swimming ability (Davis et al. 1963, Dahlberg et al. 1968, Farmer and Beamish 1969, Hocutt 1973, Rulifson and Huish 1975). Published information on the swimming ability of striped bass is limited and deals primarily with the maximum swimming speed and endurance of juveniles. Sazaki et al. (1973:22) reported that some postlarvae 10-20 mm TL swam 0.4 ft s^{-1} or 10-12 bl s^{-1} (body lengths per second) in a 4-min test. Kerr (1953:132) found that 95% of 25-76 mm TL striped bass were able to swim in a current of 2 ft s^{-1} (8-24 bl s^{-1}) for 10 min. Data extrapolated from Tatham (1970) showed that the maximum swimming speed (S/max) for 32-63 mm fork length (FL) striped bass ranged from 5.3 to 8.6 bl s^{-1} for a 3-min test. Temperature apparently had no significant affect on S/max over the two temperatures (75° and 80°F) investigated in Tatham's study (Fig. 7.5-3).

It is apparent from the three studies noted above that most striped bass should be able to swim between 5.7 and 11.2 bl s^{-1} for 3 min or more and that these data may be useful in constructing a range of swimming speeds for a hypothetical population (Fig. 7.5-4). This range is based only on physical endurance and does not account for behavior of swimming fish. Tatham's (1970) study suggests that striped bass respond well to imposed currents in the laboratory; however, they may not respond as well in nature due to lack of spatial orientation and relative velocity of water flow (Rulifson and Huish 1975:39-40).

7.5.3 SOURCES OF MORTALITY. The survival of juvenile striped bass depends on three essential factors: adaptation to physicochemical conditions, availability of food, and avoidance of predators (Otwell and Merriner 1975:565). Disease and pollution also can reduce survival by detrimentally affecting the physical condition of individuals and increasing their susceptibility to predation.

7.5.2 SWIMMING ABILITY. Numerous studies on swimming speeds of fish have shown that the ability of young fish to avoid sampling gear and power plant intake structures is a combination of physical conditon (Laurence 1972, Jones 1971), maximum swimming speed and endurance (Kerr 1953, Boyar 1961, Tatham 1970), and swimming behavior (Tatham 1970, Rulifson and Huish 1975). Various environmental factors such as temperature, dissolved oxygen, and salinity also affect swimming ability (Davis et al. 1963, Dahlberg et al. 1968, Farmer and Beamish 1969, Hocutt 1973, Rulifson and Huish 1975). Published information on the swimming ability of striped bass is limited and deals primarily with the maximum swimming speed and endurance of juveniles. Sazaki et al. (1973:22) reported that some postlarvae 10-~~20~~ 12.5 mm TL swam 0.4 ft s^{-1} or 10-12 bl s^{-1} (body lengths per second) in a 4-min test. Kerr (1953:132) found that 95% of 25-76 mm TL striped bass were able to swim in a current of 2 ft s^{-1} (8-24 bl s^{-1}) for 10 min. Data extrapolated from Tatham (1970) showed that the maximum swimming speed (S/max) for 32-63 mm fork length (FL) striped bass ranged from ~~5.3~~ 4.3 to 8.6 bl s^{-1} for a 3-min test. Temperature apparently had no significant affect on S/max over the two temperatures (75° and 80°F) investigated in Tatham's study (Fig. 7.5-3).

It is apparent from the three studies noted above that most striped bass should be able to swim between 5.7 and 11.2 bl s^{-1} for 3 min or more and that these data may be useful in constructing a range of swimming speeds for a hypothetical population (Fig. 7.5-4). This range is based only on physical endurance and does not account for behavior of swimming fish. Tatham's (1970) study suggests that striped bass respond well to imposed currents in the laboratory; however, they may not respond as well in nature due to lack of spatial orientation and relative velocity of water flow (Rulifson and Huish 1975:39-40).

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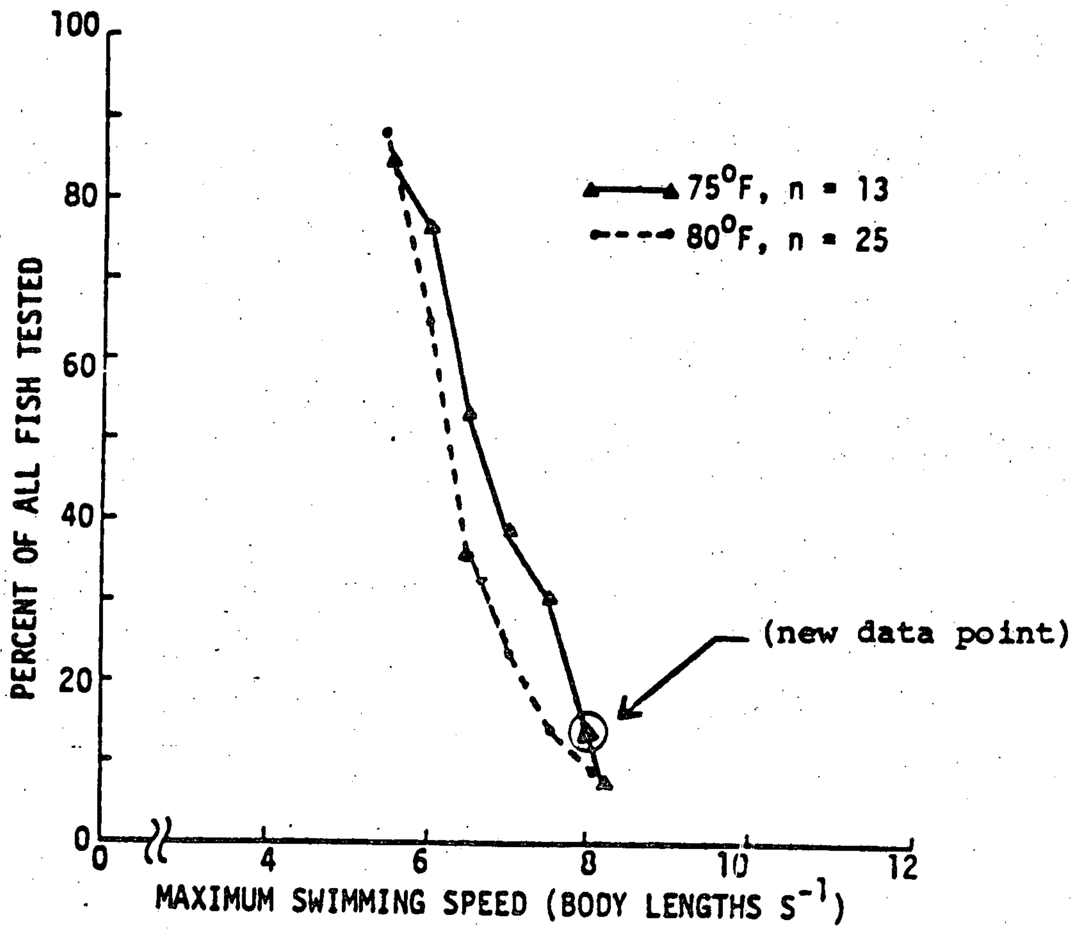
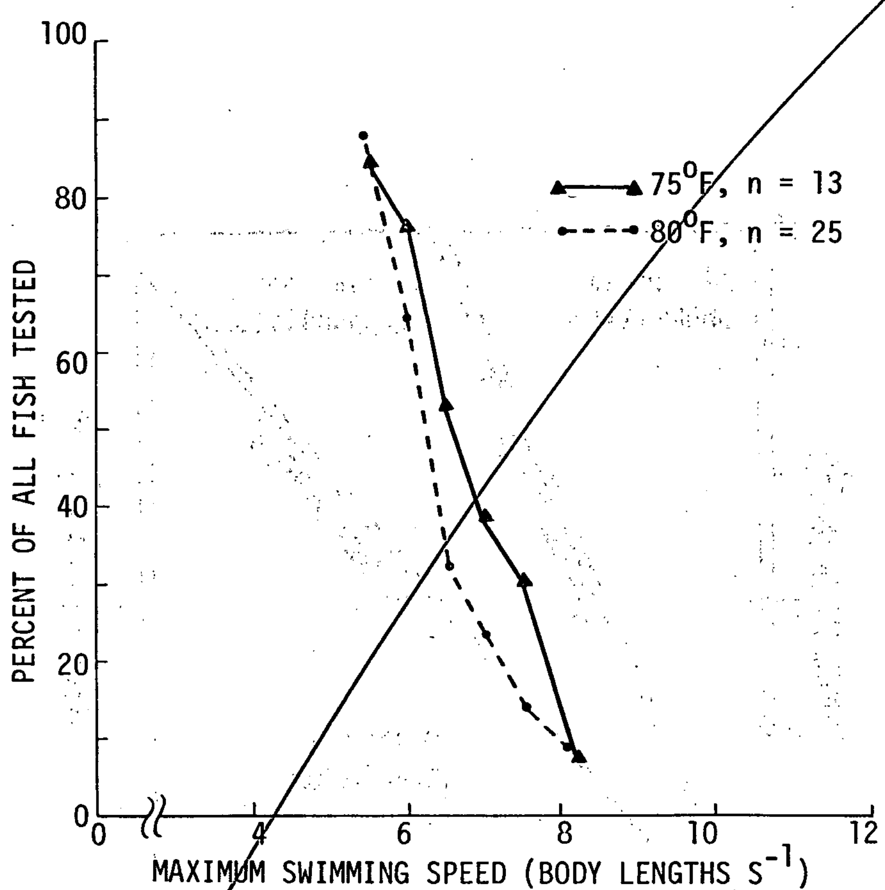


Figure 7.5-3 Percentage of All Tested Juvenile Striped Bass Able To Sustain Various Maximum Swimming Speeds for 3 Min at 75°F and 80°F. (Fish length ranged from 32 to 63 mm FL) (Tatham 1970)



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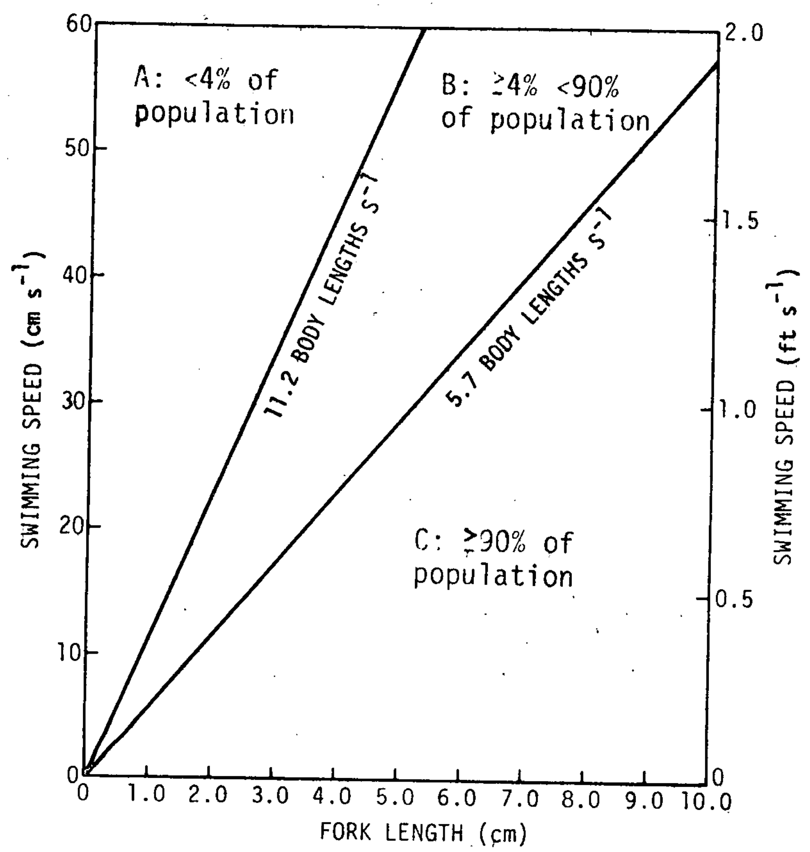

Figure 7.5-4 Range of Swimming Speed Capabilities for Hypothetical Population of Striped Bass, Based on Experimental Swimming Performance Data (Tatham 1970, Sazaki et al. 1973)

Fluctuations in the estuarine physicochemical environment, especially temperature and salinity, interact to govern the survival of striped bass (Talbot 1966:43). Juveniles are quite tolerant of slow changes in water quality within the range of upper and lower lethal limits, but sudden changes may have adverse affects, e.g., increase susceptibility to predation. Temperatures of <12°C in laboratory studies have produced sluggish avoidance reactions (Otwell and Merriner 1975:564). Abrupt change in temperature results in a shock condition characterized by a shivering, downward-spiraling swimming behavior that ends in a momentary motionless posture (Otwell and Merriner 1975:564). Reduced levels of dissolved oxygen (Dahlberg et al. 1968:49) also may impair swimming ability. Abrupt changes in salinity and dissolved oxygen alone do not constitute a threat to striped bass, but prolonged exposure to abnormal concentrations may be detrimental.

Limited availability of food can increase density-dependent mortality (Cushing 1975:127). As early juveniles (15-35 mm) feed, they grow, swim more quickly, and are better able to evade capture. As they feed, the food density is reduced, decreasing in time the chance of feeding and resulting in a density-dependent mortality.

Disease usually affects a few of the less hardy individuals in a population but occasionally can seriously deplete whole populations (Smith 1833, cited by Raney 1952; Cushing 1975:118; Paperna and Zwerner 1976:276). Nonfatal diseases, parasitic infestations, and growth abnormalities may weaken or decrease the mobility of individuals, thereby increasing mortality by lowering tolerances to changes in water quality and increasing susceptibility to predation.

Domestic and industrial pollution is a constant threat to fish populations. Talbot (1954) noted that the lower Hudson River estuary was severely polluted and unfavorable to striped bass populations. The accidental discharge of heavy metal ions (e.g., copper, nickel, and zinc) into localized areas of the river can cause significant fish kills (Rehwoldt et al. 1971:448). The use of pesticides (e.g., DDT) and the release of various industrial chemicals (e.g., PCBs) into estuaries introduce toxic substances into the food chain. The dumping of raw sewage can decrease dissolved oxygen levels and reduce the survival of fish and other aquatic organisms. The extent of the mortality of juvenile striped bass in the Hudson River due to pollution is not known.

Predation is probably one of the greatest sources of mortality for juvenile striped bass. As noted above, susceptibility to predation can increase through changes in water quality, food availability, disease, and pollution of the environment. Piscivorous fish, especially bluefish, are the principal natural predators of juvenile striped bass. Cushing (1975:122) noted that fish pass through a number of predatory fields as they grow, with each predator becoming larger and less numerous than its predecessor. Predation is also discussed in Sections 5.2, 5.4, 5.5, and 5.6.

Commercial fisheries and industrial development are also important sources of mortality. Man-induced mortality of juvenile striped bass in the Hudson River estuary is primarily through impingement at industrial and other water intakes. This aspect of mortality is discussed further in Sections 8, 10.6, 11, and 12.

7.5.4 DISTRIBUTION

7.5.4.1 <u>Riverwide Distribution</u>. The distribution of juveniles in the Hudson River estuary during summer and fall reflects a general shoreward and downstream movement from spawning areas to the shallow-water nursery areas of the lower estuary (Section 6). The transition from the postlarval to juvenile life stage is apparent in late June when juveniles are first collected in depths >20 ft (6 m) (Fig. 7.5-5). Movement to the shorezone and beaches increases as water temperatures reach the summer maximum (about 30°C). As temperatures decline to approximately

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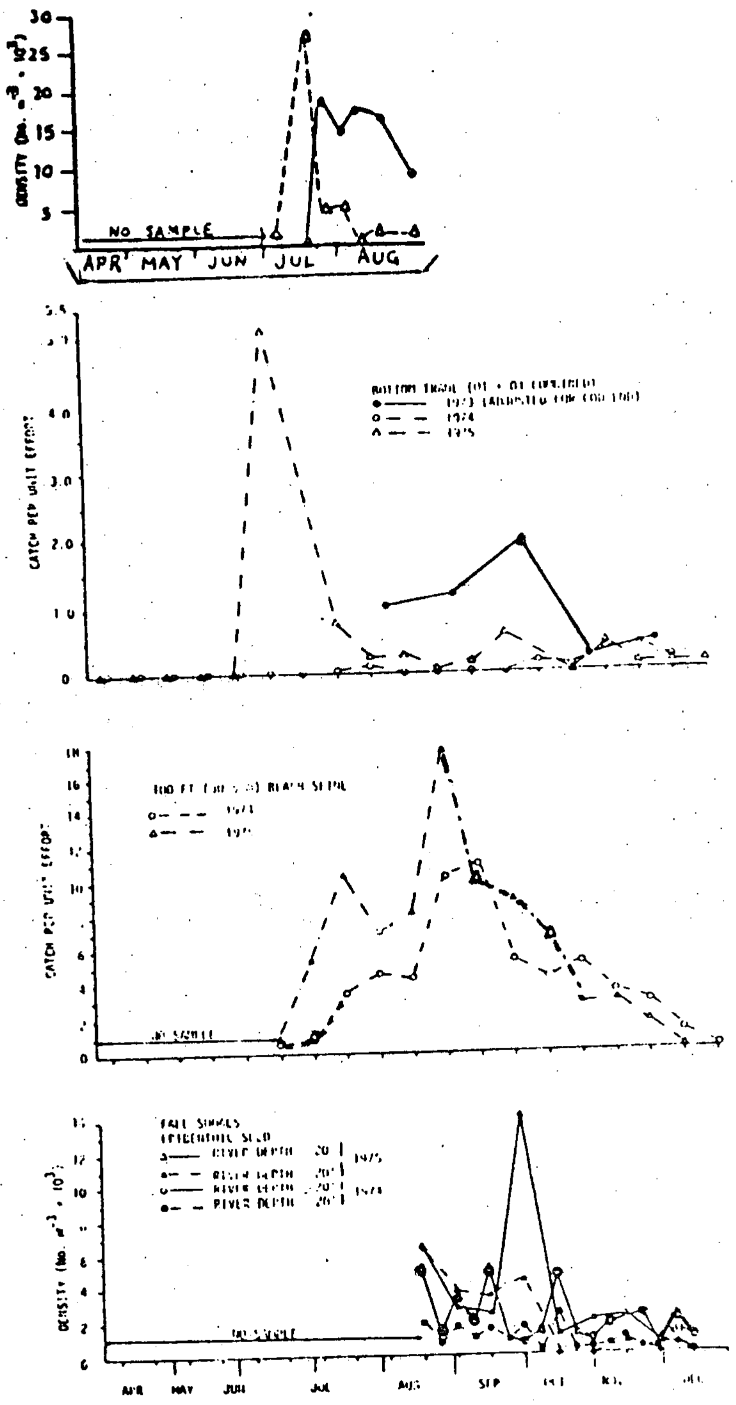
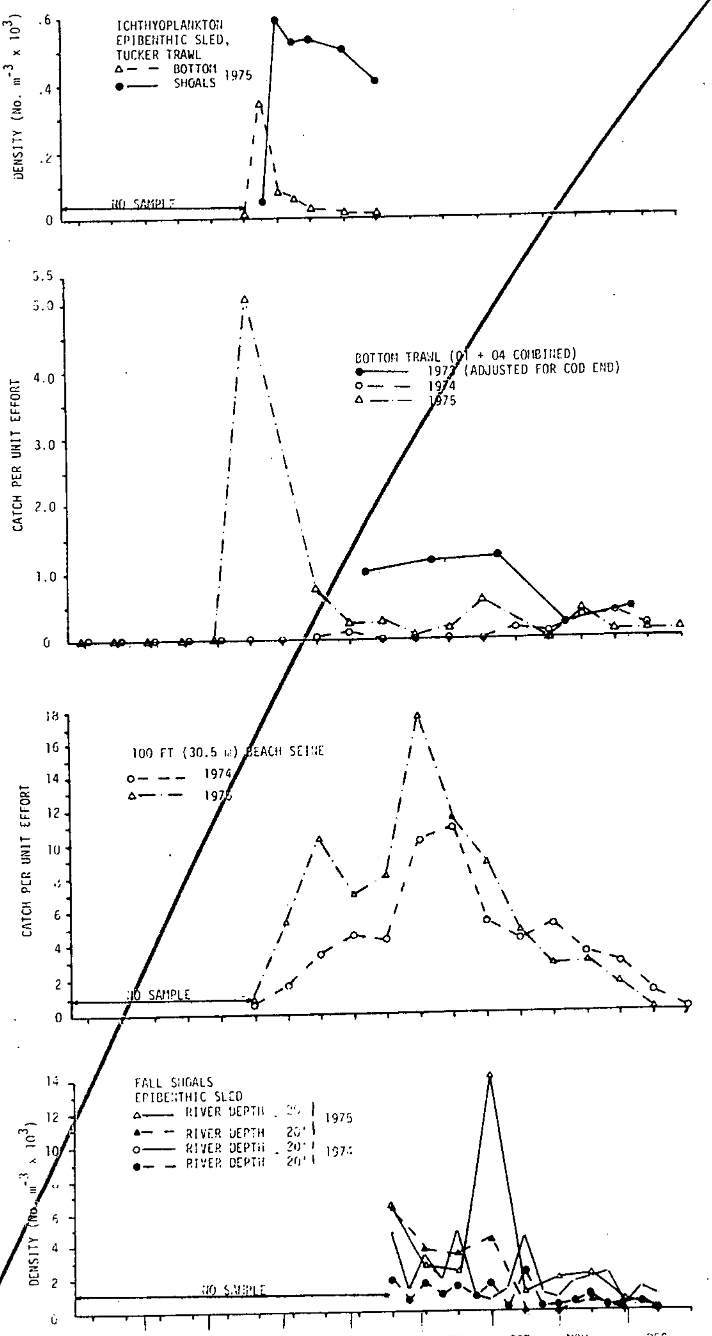


Figure 7.5-5 Abundance of Striped Bass Juveniles in Epibenthic Sled and Tucker Trawl, 100 ft (30.5 m) Beach Seine (Day Only) and Bottom Trawl Samples Taken in Hudson River Estuary (RM 12-76; km 19-~~125~~ 122) during 1973, 1974, and 1975



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12°C during fall, catches also decline in the upriver areas in all sampling gear while catches in the shorezone of the ~~Tappan~~ Tappan Zee, Croton-Haverstraw, and Indian Point regions remain high into November, suggesting net downstream movement of the population and emigration of some individuals from the estuary during October and November. By December when water temperatures drop below 10°C, juveniles are nearly absent in the shoals and shorezone; they apparently move to deeper water (Fig. 7.5-5).

Juvenile distribution in the Hudson River is apparently not limited by dissolved oxygen or salinity. Most fish were caught where dissolved oxygen levels ranged from 6 to 12 ppm (Fig. 7.5-6) and salinities ranged from 0.1 to 10.0 o/oo (0.3-17.0 mS cm^{-2}).

7.5.4.2 Indian Point Standard Stations. The inference that juveniles move shoreward and downstream during the summer and fall is supported by standard station sampling in the Indian Point area (section 7.5.4.5) ~~7.5.5.1)~~. Most striped bass spawn upstream from Indian Point, and the juveniles move into the shorezone in this area during July.

7.5.4.3 East/West Distribution. Juvenile striped bass show inconsistent differences in lateral (i.e., east vs. west) distribution. From August to December 1975, lateral distributions exhibited large variations among all sampling gear and sampling regions through time (Fig. 7.5-7). While the stratified random sampling schemes were not designed to determine east/west differences in distribution, some data could be statistically analyzed for a particular gear and region. Fall catches in epibenthic sleds in the east and west strata of the Tappan Zee region were similar. Juvenile abundance was greater in the east shore zone of the Croton-Haverstraw region ($p<0.001$) and greater in the west shore zone of the Indian Point region ($p<0.006$); however, east/west trends varied through time.

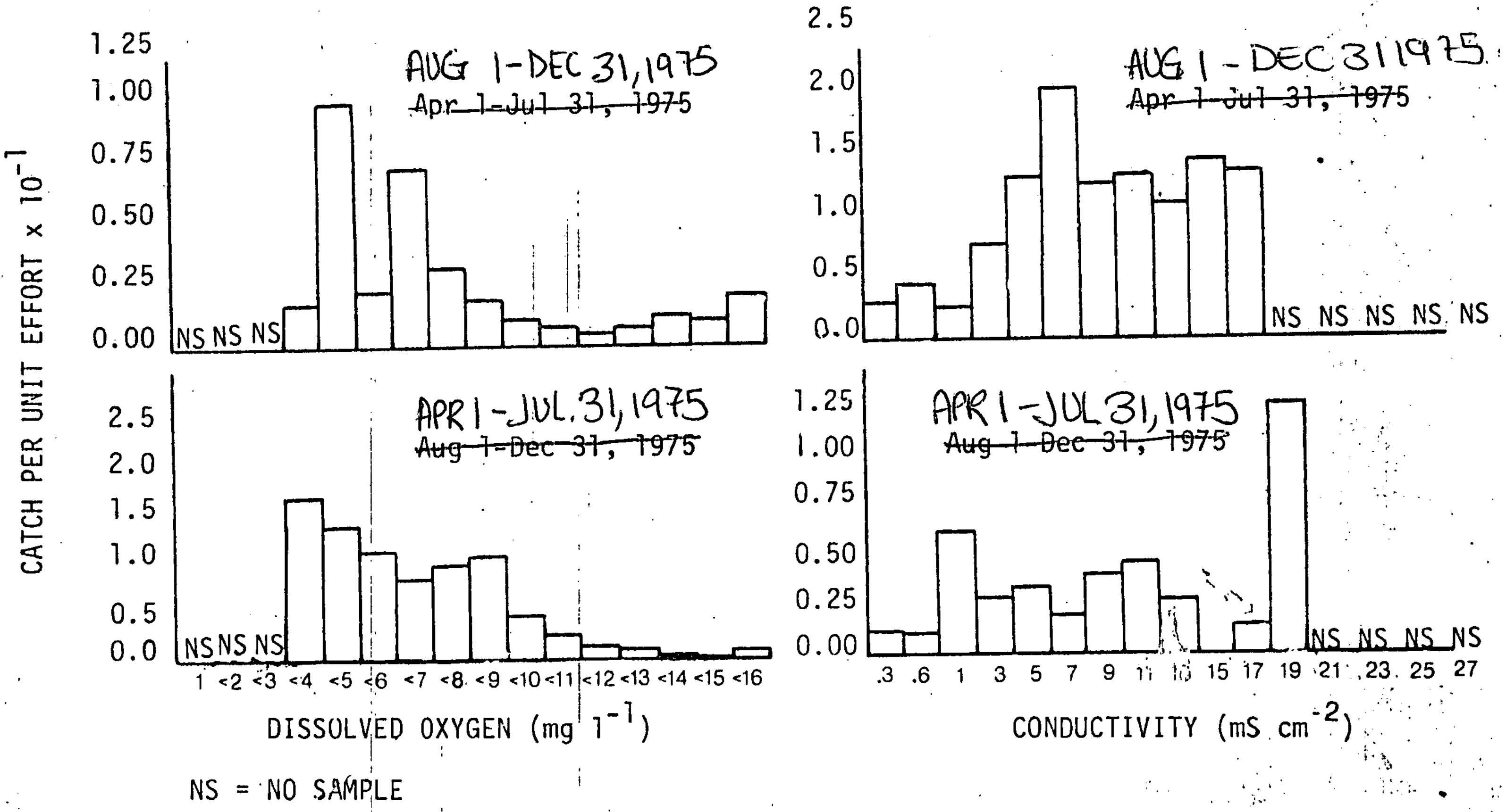
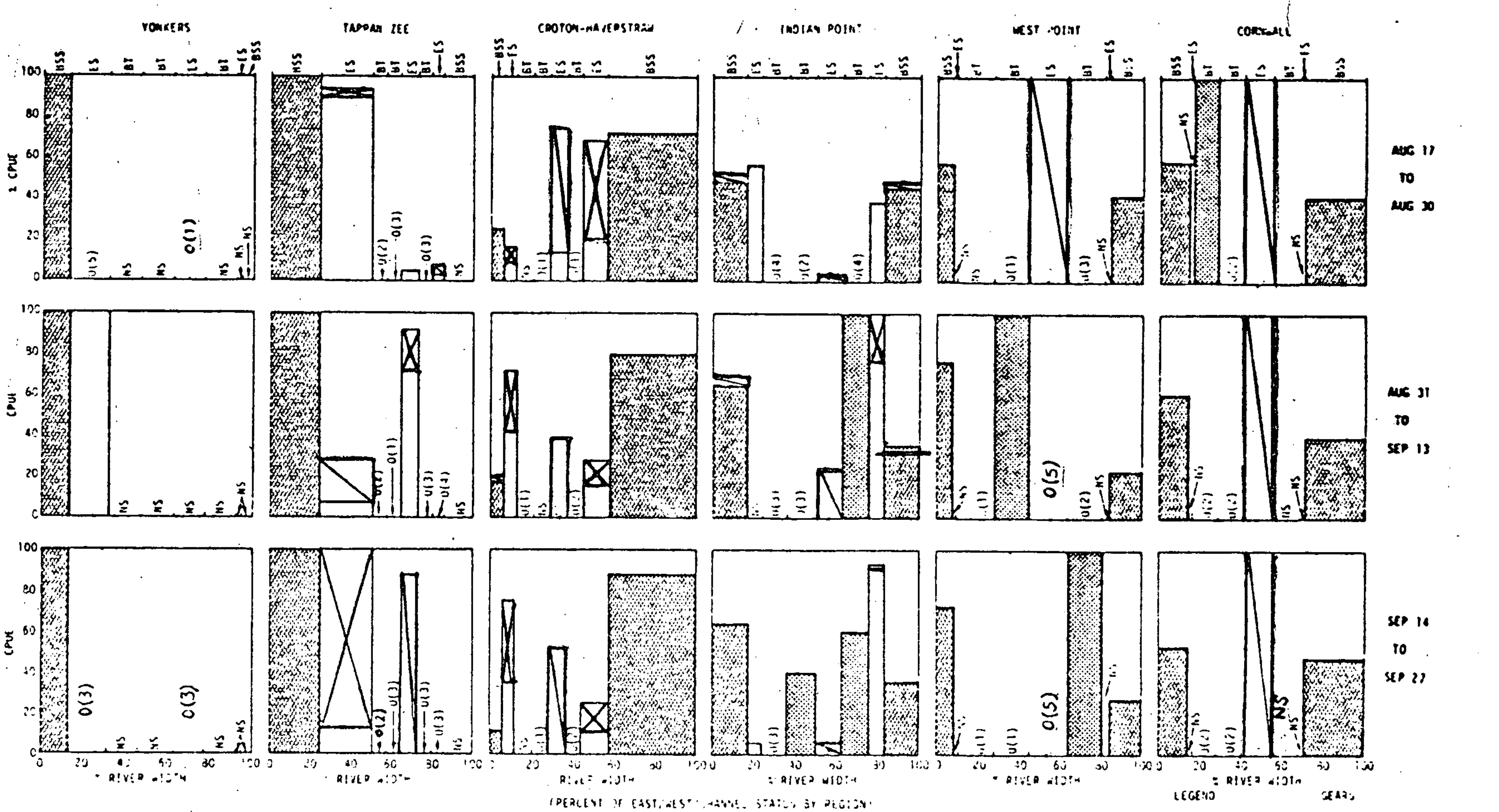


Figure 7.5-6 Beach Seine Catch per Unit Effort for Juvenile Striped Bass at Various Levels of Dissolved Oxygen (mg $litre^{-1}$) and Conductivity (ms cm^{-1}) during 1975



Note: Width of histogram bar indicates percent of substrata available to each sampling gear in each region. BSS = east, west 0-10 ft (0-3 m); ES = East, west at >10 <20 ft (>3-<6 m) and channel >20 ft (>6 m); BT = east, center, west at all depths

Figure 7.5-7 Relative Abundance of Juvenile Striped Bass by Region (Yonkers-Cornwall) Showing Lateral Distribution (East, Center, West) by Beach Seine, Epibenthic Sled, and Bottom Trawl during 1975. (Page 1 of 3)

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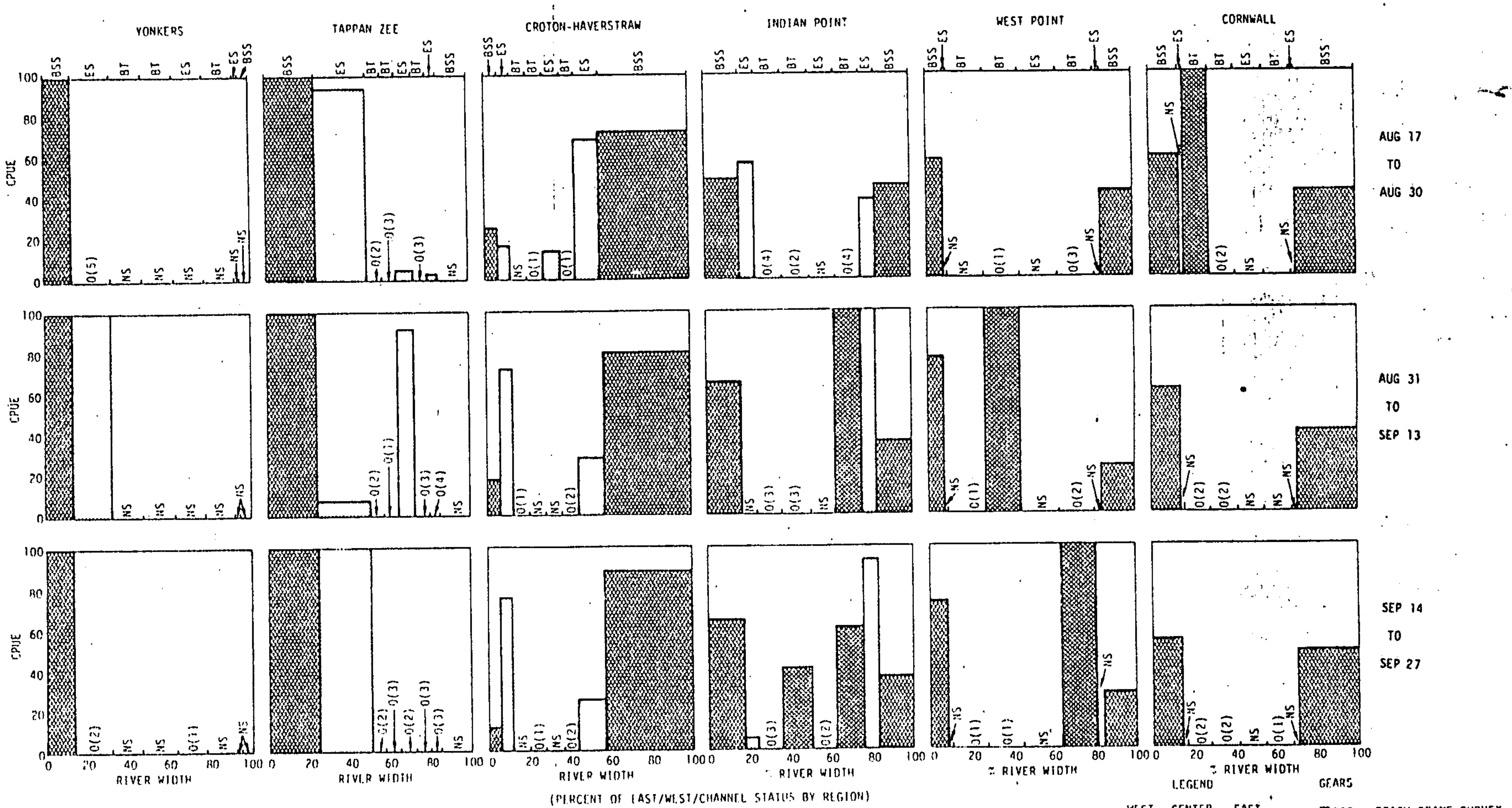

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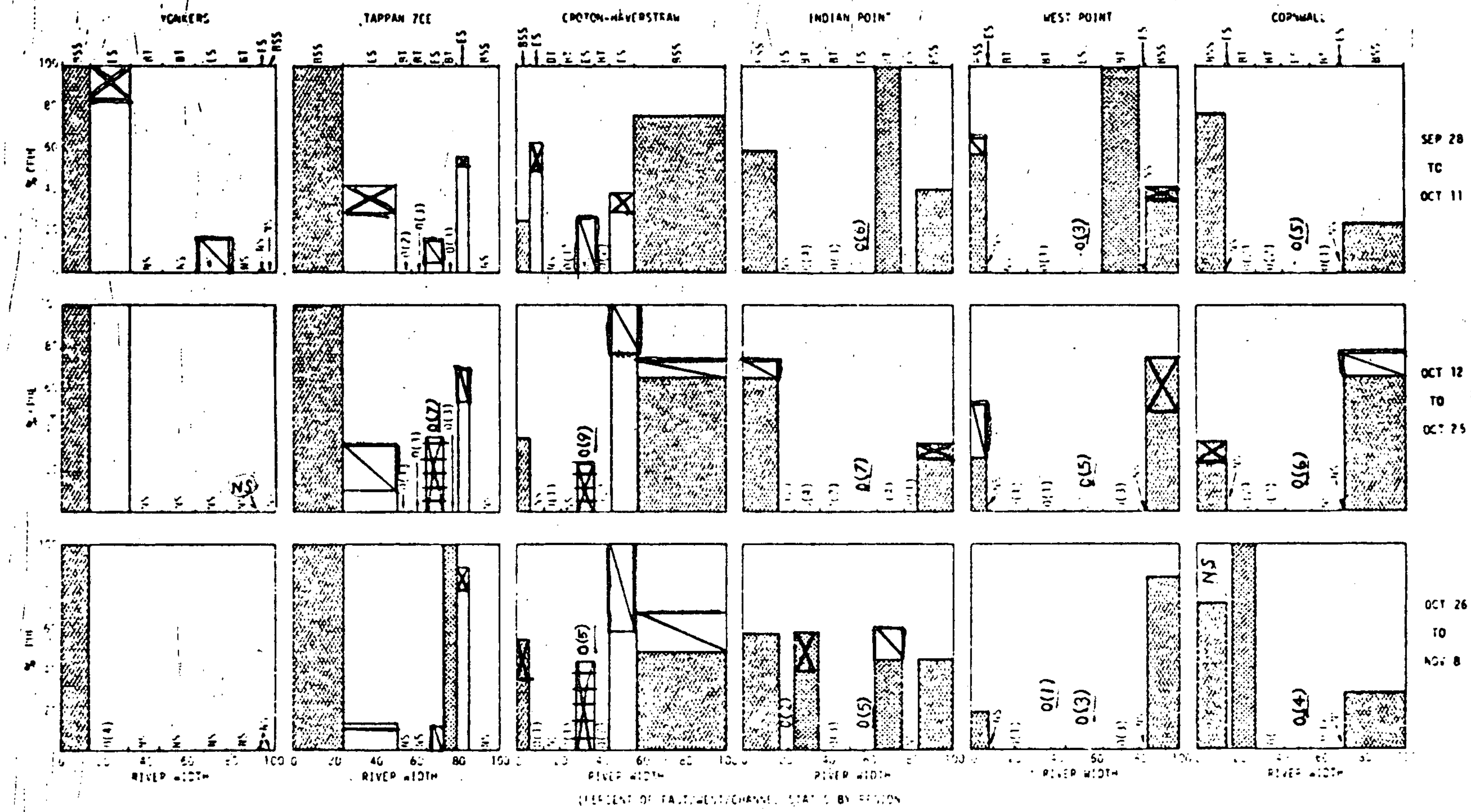

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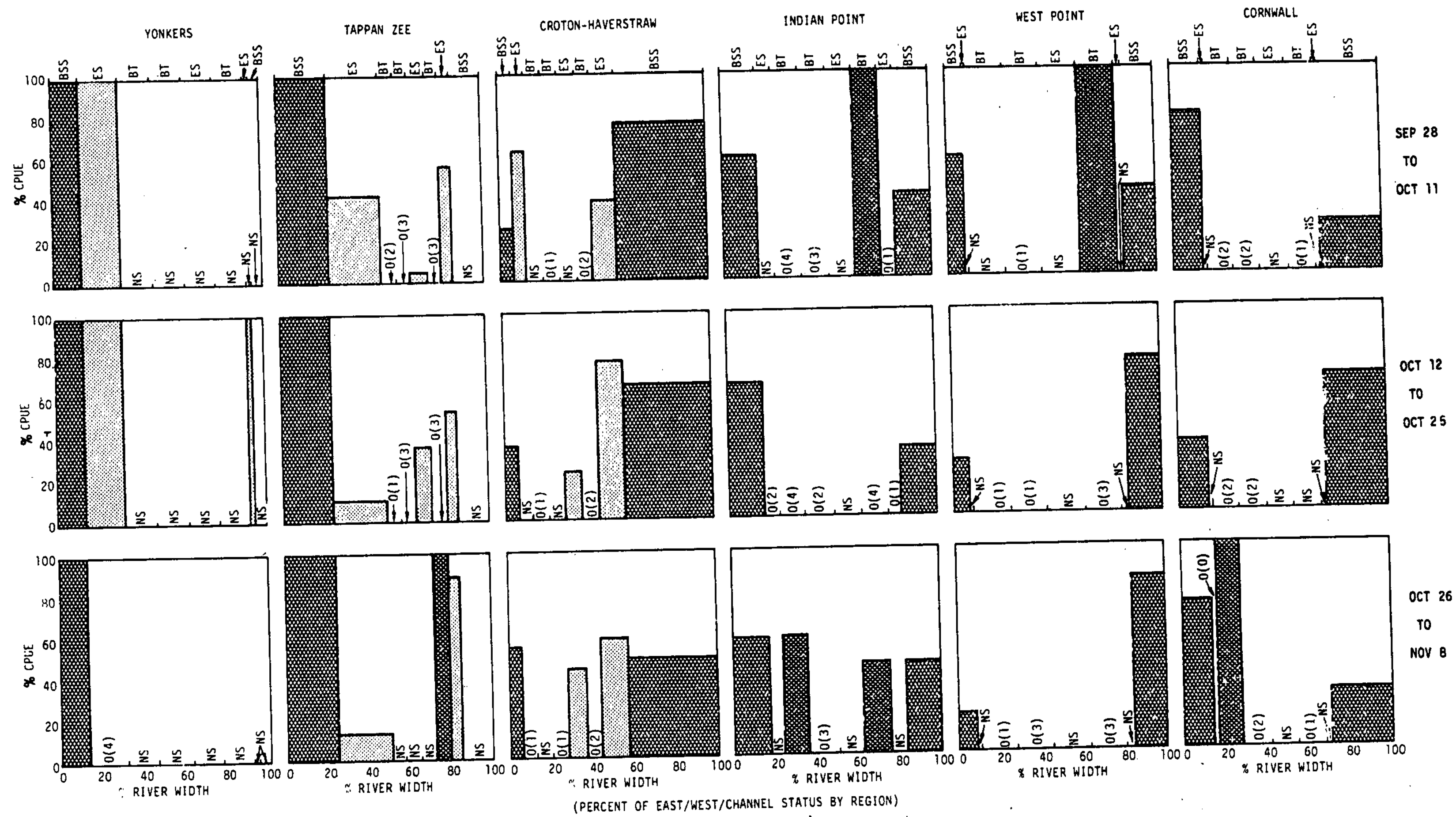

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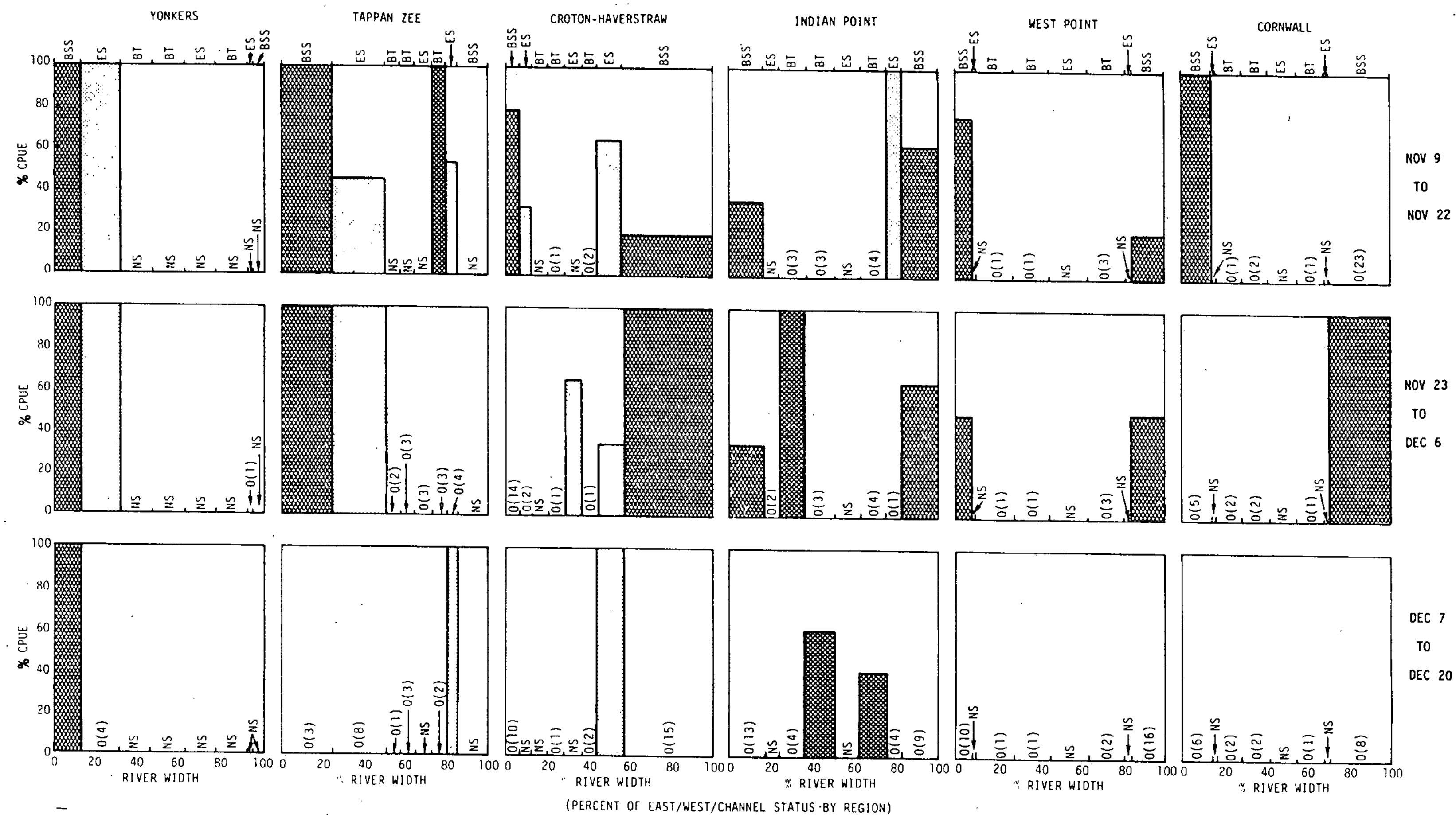

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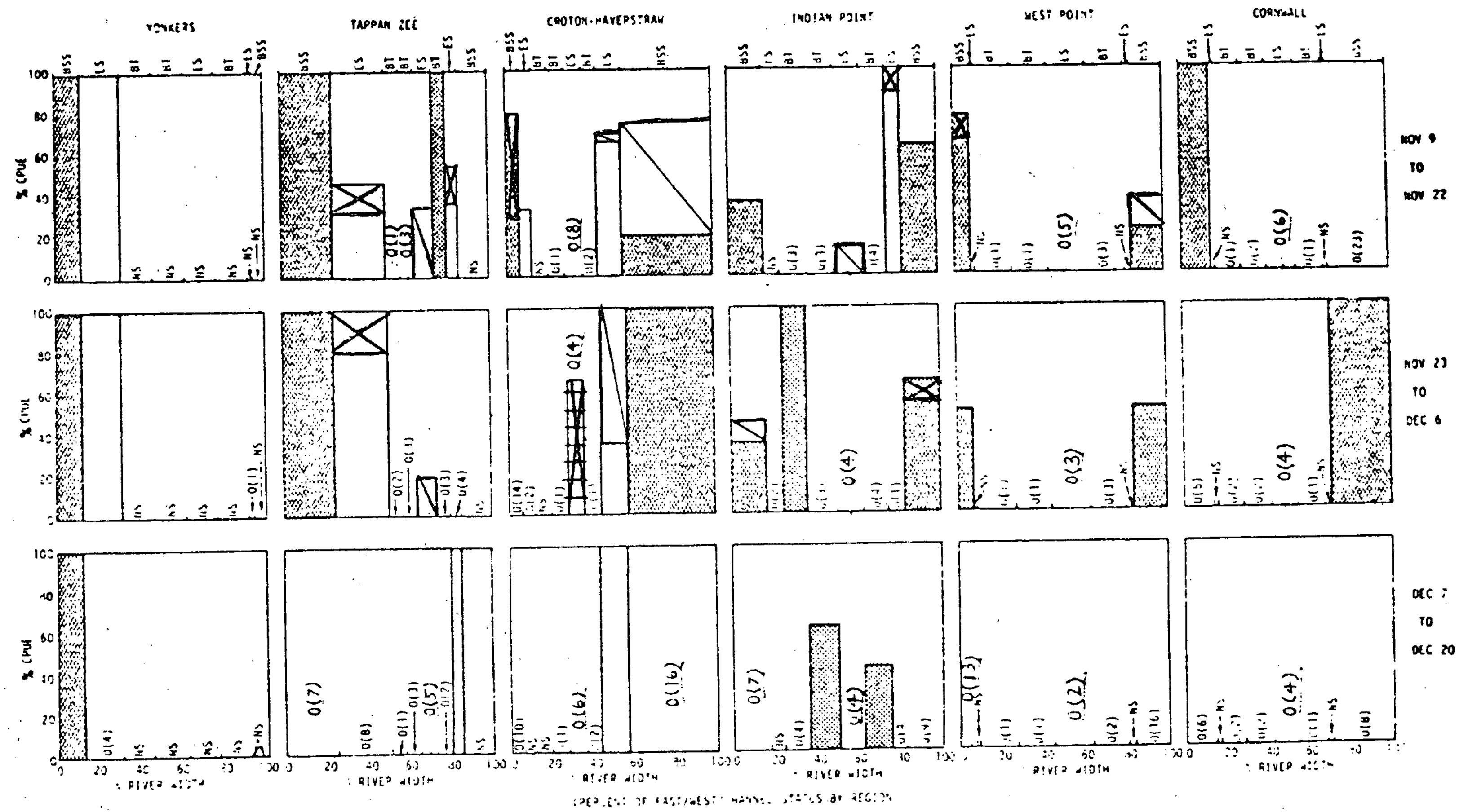

Figure 7.5-7 (Page 3 of 3)

7.5.4.4 <u>Movement - Mark/Recapture and Impingement</u>. Based on recaptures of marked fish, juvenile striped bass apparently use most of the estuary from RM 24-46 (km 38-74) as a fall nursery area. Juveniles fin-clipped in the Yonkers-Indian Point regions during August-November 1974 exhibited limited upstream and downstream movements from their respective marking areas (Table 7.5-2). No juveniles marked in the West Point-Cornwall regions (RM 47-61; km 75-98) were recaptured outside this area, nor were any juveniles marked in regions Poughkeepsie through Albany (RM 62-152; km 99-243) recaptured during fall 1974. Juvenile striped bass fin-clipped during fall (August-November) 1975 showed similar movement trends (Table 7.5-3).

A portion of the juvenile population emigrates from the fall nursery areas (RM 24-46; km 38-74) during late fall and early winter (Section 7.9). The single juvenile striped bass recaptured in Little Neck Bay (Fig. 7.5-8) in September 1975 may be indicative of the initial movement of juveniles out of the Hudson River estuary beginning in late summer-early fall. Impingement of juveniles at generating stations in the Hackensack and East Rivers in late fall and early winter is further evidence that some juveniles leave the estuary by this time. Juveniles (60-170 mm) were impinged on the intake screens of the Astoria Generating Station (Fig. 7.5-8) during November 1971 and January 1972 (QLM 1973b) and at the Essex and Kearny Generating Stations (IA 1974a, 1974b) beginning in September (1973) and December (1972) respectively. * Striped bass continued to be impinged through late spring at Astoria and Kearny but did not appear on the intake screens again until late fall. The actual timing of striped bass movements may differ from year to year, perhaps depending on the physicochemical environment or year-class abundance (Section 7.9).

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* These plants are well outside the area of intensive study of the young-of-the-year striped bass population and have not been defined as part of the multiplant impact assessment in regulatory hearings. Therefore, they are not included in impingement data in Section 9.

Table 7.5-2 Recaptures (from All Sources) of Juvenile Striped Bass Fin-Clipped in Fall (August-November) 1974 (Adjusted for 14-Day Mortality) and Recaptured in Fall (August-December) 1974

Release Area (RM)	No. Marked	12-23	24-38	Recapture Area 39-46	47-61	62-152	Total Recaptured
12-23	239		2	4			6
24-38	4687		163	9			172
39-46	2486		1	63			64
47-61	490				2		2
62-152	255						

Total Marked = 8157
No. Recaptured = 244
% Recaptured = 2.99

Table 7.5-3 Recaptures (from All Sources) of Juvenile Striped Bass Fin-Clipped in Fall (August-November) 1975 (Adjusted for 14-Day Mortality) and Recaptured in Fall (August-December) 1975

Release Area (RM)	No. Marked	12-23	24-38	Recapture Area 39-46	47-61	62-152	Total Recaptured
12-23	1239	79	1				80
24-38	9213	2	432	3			437
39-46	3200		10	224			234
47-76	710		3	2	17		22
77-152	107			1			1

Total Marked = 14469
No. Recaptured = 774
% Recaptured = 5.35

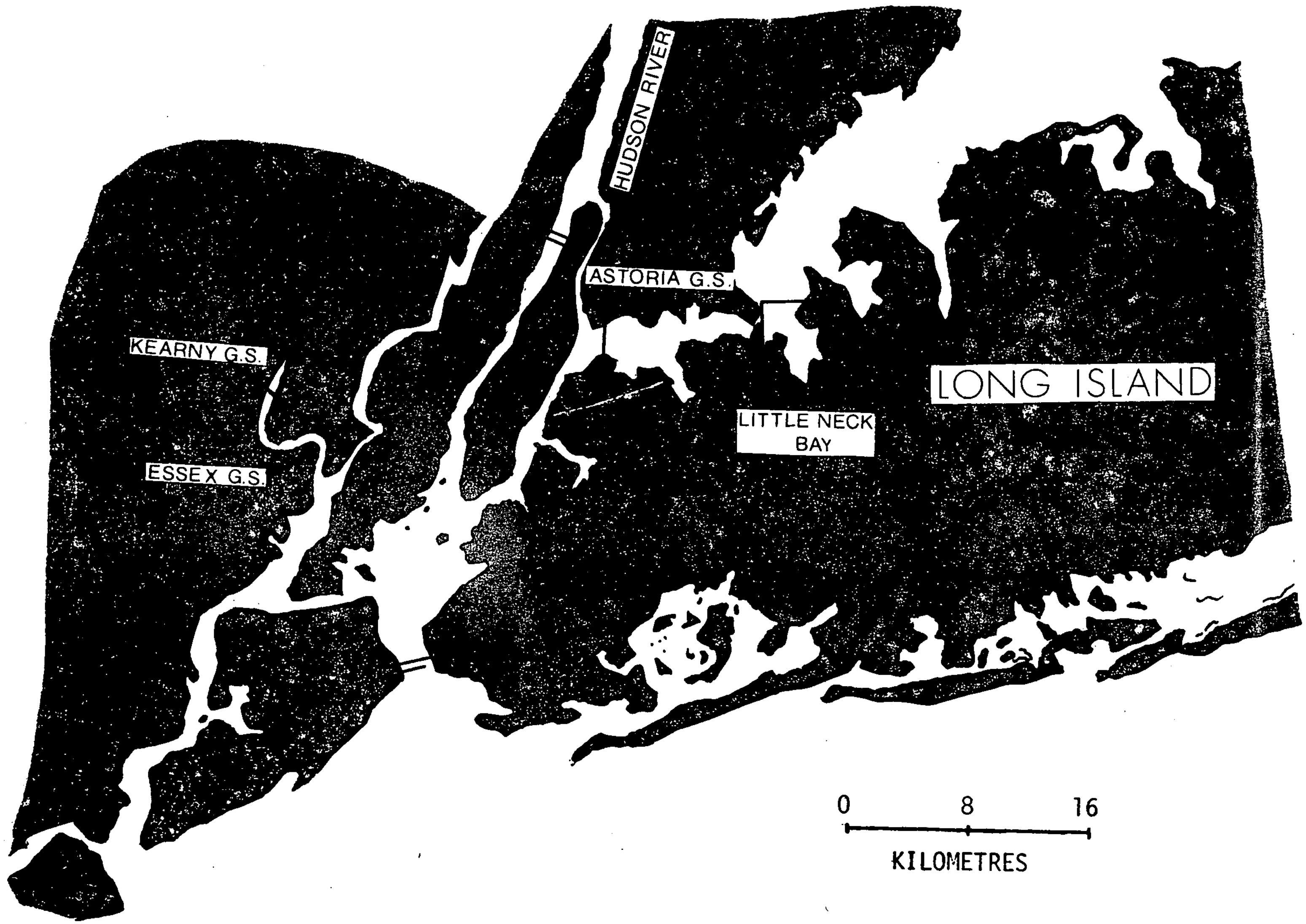

Figure 7.5-8 Lower Bays of Hudson River Estuary Showing Locations of Astoria, Essex, and Kearny Electric Generating Stations

7.5.4.5 Distribution Related to Bottom Type, Diel Periods, and Tidal Stage. From the various sampling efforts initiated in 1972, it appears that the abundance of juvenile striped bass in local areas of the Hudson River estuary is related to changes in temperature, salinity, habitat type, diel (day/night) patterns, and tidal stage. Comparisons of standard stations in the Indian Point area suggest that juveniles prefer beaches near open water with little or no cover and are most abundant with increased temperature and salinity. In a standard station sampling program initiated in 1972 to characterize the relative abundance and distribution of fishes in the area of Indian Point, beach seine samples were collected weekly with a 100-ft (30.5-m) seine during daylight hours at low tide at seven sites (Table 7.5-4 and Fig. 7.5-9) and bottom and surface trawl samples were collected during the day at seven sites but at 2-wk intervals (Table 7.5-5 and Fig. 7.5-9). Greater abundance of juvenile striped bass in the Indian Point area was associated with increased temperature and salinity (Fig. 7.5-10). The abundance of juveniles on beaches adjacent to deep water (stations 10 and 11) was significantly greater ($P < 0.05$, Friedman 2-way) than on beaches adjacent to heavily vegetated shoal areas (Tables 7.5-6 and 7.5-4).

Comparisons of day/night beach seine catches suggest that juveniles moved into the shorezone at night, probably to feed or escape predation. Nightime abundance of juvenile striped bass in the shore zone was significantly greater than daytime abundance from August through November 1974 (Fig. 7.5-11). Juveniles caught during night sample were significantly smaller ($P < 0.05$, paired t-test) than those taken during the day, suggesting that differences in day/night distribution are not due to gear avoidance.

Juvenile fish may move from the channel into beach areas on the running tides (i.e., flood and ebb). Fish may be in deeper areas of the shorezone during low slack because of reduced beach area and become more dispersed throughout the shorezone during high slack. During 1974 and 1975, four

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Comparisons of day/night beach seine catches suggest that juveniles moved into the shorezone at night, probably to feed or escape predation. [Nighttime] ~~Nightime~~ abundance of juvenile striped bass in the shore zone was significantly greater than daytime abundance from August through November 1974 (Fig. 7.5-11). Juveniles caught during night [sampling] ~~sample~~ were significantly smaller ($P < 0.05$, paired t-test) than those taken during the day, suggesting that differences in day/night distribution are not due to gear avoidance.

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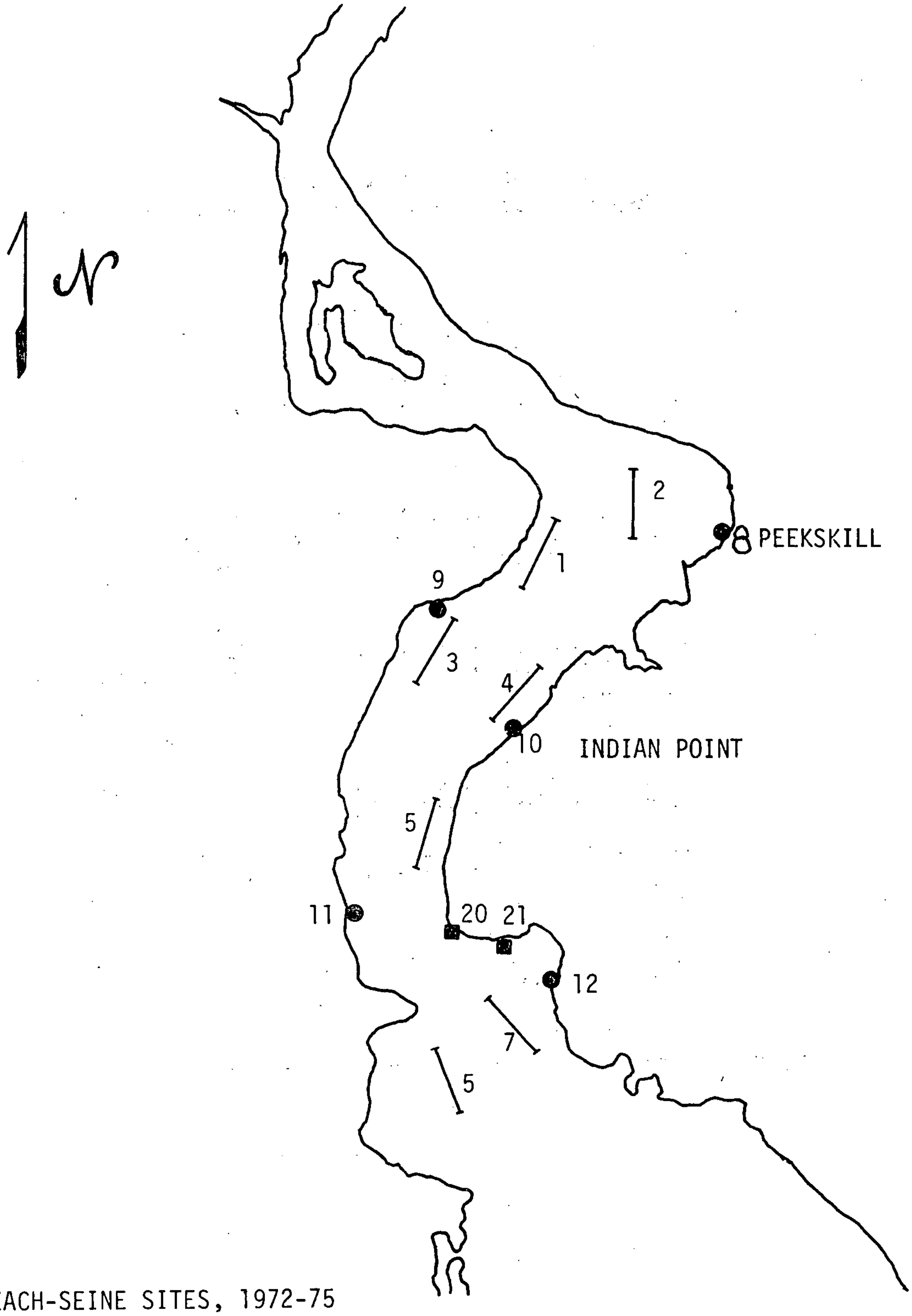
Table 7.5-4 Standard Station Beach Seine Sites, Indian Point Region, Hudson River Estuary, New York, 1972-75

Station	Location	Description
8	In Peekskill Bay (RM 43, east side) immediately south of public launching ramp	Mud but beach covered with accumulation of glass; maximum depth, 1.5 m; covered with heavy aquatic vegetation during summer
9	South of Jones Point (RM 42, west side) and adjacent to former reserve fleet headquarters	Medium sized rocks and mud changing to gravel farther out; maximum depth, 1.5 m; heavily vegetated during summer
10	Gas line 100 m south of Con Edison Indian Point discharge canal (RM 42, east side)	Sand and gravel changing to mud at greater depths; maximum depth 2 m: small stream enters river immediately south of sampling site
11	35 m south of Trap Rock Corp. barge mooring area (RM 40, west side)	Sand; drops off steeply to depth of 2.5 m
12	South of Green's Cove (RM 40, east side) 100 m south of Cortlandt Yacht Club	Gravel and crushed brick; drops off to maximum depth of 2 m; very dense aquatic vegetation during summer
20*	Verplanck Point (RM 40, east side) 10 m south of pier	Sand; drops steeply to maximum depth of 2 m
21*	Verplanck Point (RM 40, east side) 50 m south of trailer park	Sand changing to mud; maximum depth of 2m

*Two stations added in May 1974



● BEACH-SEINE SITES, 1972-75

■ BEACH-SEINE SITES, MAY-DECEMBER 1974-75

I BOTTOM-TRAWL AND SURFACE-TRAWL SITES

Figure 7.5-9 Standard-Station Beach-Seine, Bottom-Trawl, and Surface-Trawl Sites in Hudson River Estuary, RM 39-43 (km 62-69), 1972-75

Table 7.5-5 Locations of Standard Station Trawl Sites, Indian Point Region, Hudson River Estuary, New York, 1972-75

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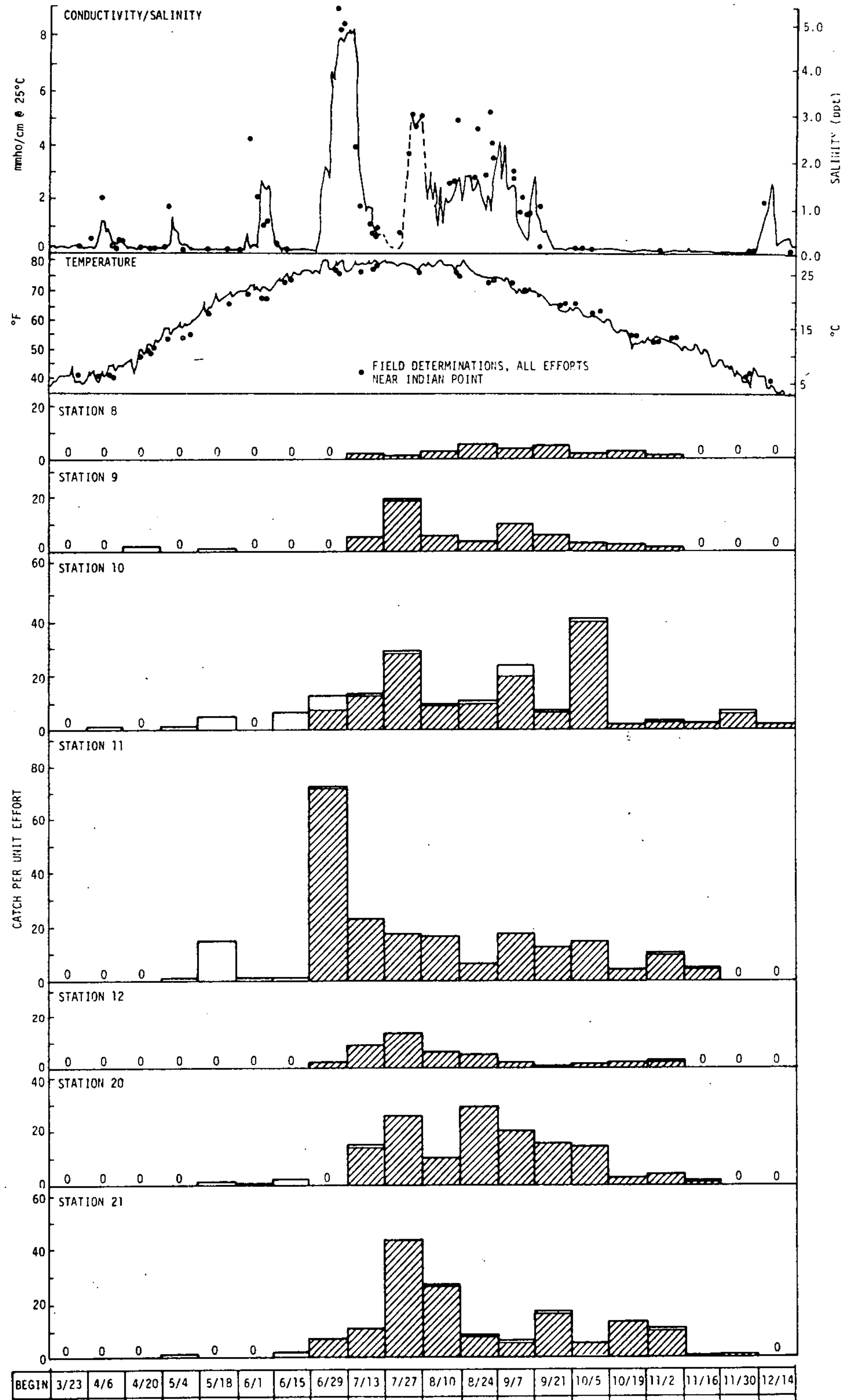
Station	RM	Approx. Depth* (m)	Approx. Tow Course* (°)	Location** Latitude	Location** Longitude
1	43	9	031	41°16'57"	73°57'17"
2	43	5	350	41°17'12"	73°56'38"
3	42	5	031	41°16'25"	73°58'16"
4	42	16	043	41°16'14"	73°57'36"
5	41	12	024	41°15'42"	73°58'03"
6	39	12	336	41°14'04"	73°57'55"
7	40	5	304	41°14'36"	73°57'28"

*True course is for upriver towing; tows are routinely made against the tide, so a tow course of 010° would be 190° during incoming tide.

**Refers to midpoint of tow.



BEGIN	3/23	4/6	4/20	5/4	5/18	6/1	6/15	6/29	7/13	7/27	8/10	8/24	9/7	9/21	10/5	10/19	11/2	11/16	11/30	12/14
END	4/5	4/19	5/3	5/17	5/31	6/14	6/28	7/12	7/26	8/9	8/23	9/6	9/20	10/4	10/18	11/1	11/15	11/29	12/13	12/27

Figure 7.5-10 1975 Beach Seine Biweekly Catch per Unit Effort (CPUE) for Striped Bass, Indian Point Region, Hudson River Estuary, New York, Showing Water Temperature and Conductivity

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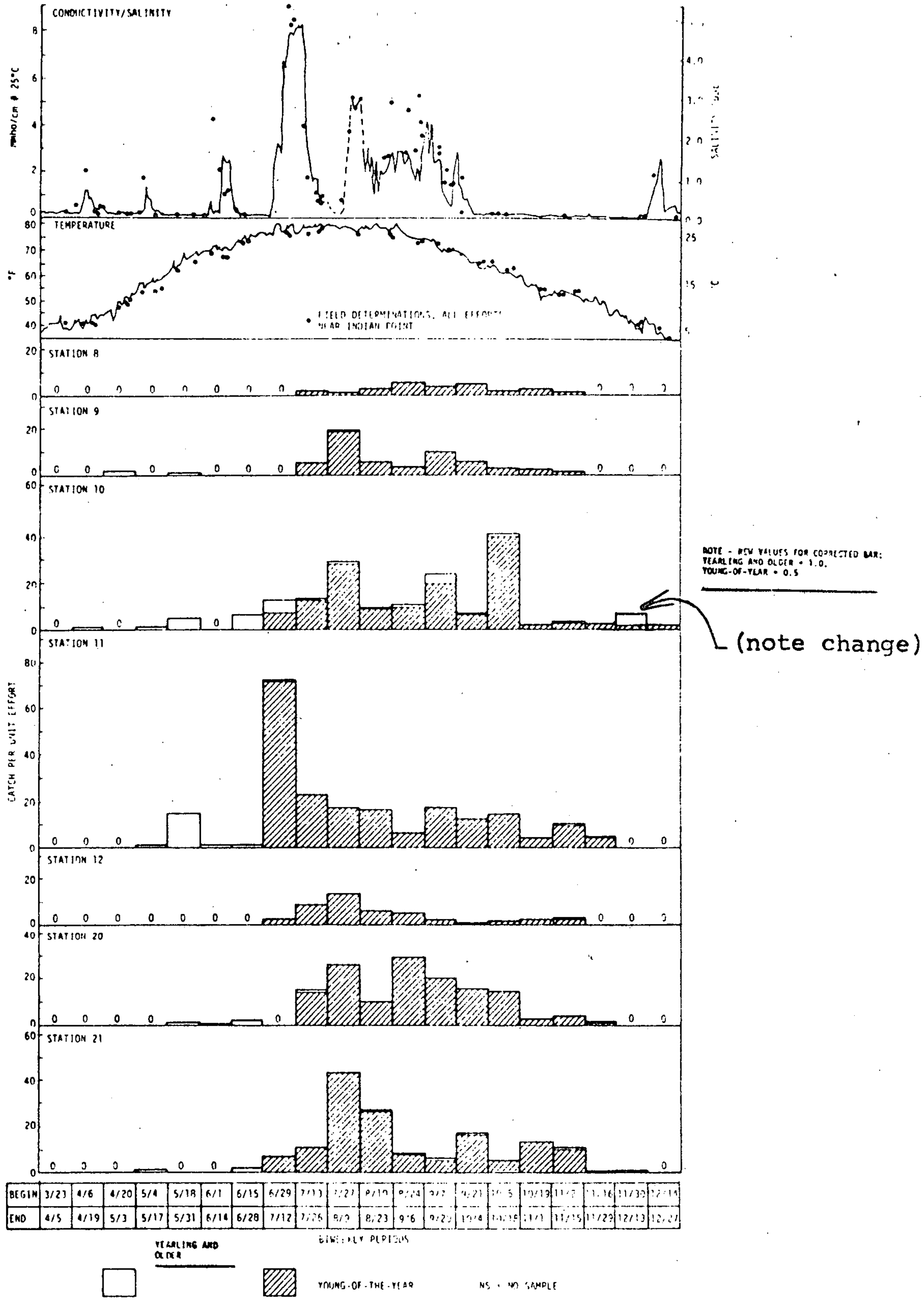

Figure 7.5-10 1975 Beach Seine Biweekly Catch per Unit Effort (CPUE) for Striped Bass, Indian Point Region, Hudson River Estuary, New York, Showing Water Temperature and Conductivity

This is a replacement table.

Table 7.5-6 Statistical Comparisons (Friedman 2-Way Analysis of Variance) of Juvenile Striped Bass Catches in Standard Station Beach Seine Samples, 1972-75*

Year	CPUE Ranked Totals by Station 8	9	10	11	12	20	21	S'	df	Multiple Comparisons by Station **
1972	34.5	20.0	18.5	16.5	30.5	--	--	13.0	4	11 10 9 12 8
1973	38.0	27.0	11.0	16.0	28.0	--	--	22.7	4	10 11 9 12 8
1974	42.5	37.0	32.5	27.0	29.0	30.5	25.5	5.8	6	21 11 12 20 10 9 8
1975	50.5	43.5	24.5	23.0	45.5	17.0	20.0	31.3	6	20 21 11 10 9 12 8

Underlining denotes no significant difference (p <0.05)

*Refer to Table 7.5-4 for beach seine site descriptions.

**Stations are ranked from left to right in order of highest to lowest abundance.

Table 7.5-6 Statistical Comparisons (Friedman 2-Way Analysis of Variance) of Juvenile Striped Bass Catches in Standard Beach Seine Samples, 1972-75*

	CPUE Ranked Totals by Station									
Year	8	9	10	11	12	20	21	x^2	df	Multiple Comparisons by Station
1972	65.0	47.5	31.0	34.5	62.0	--	--	23.9	4	10 11 9 12 8
1973	73.0	61.5	36.0	35.0	64.5	--	--	26.0	4	11 10 9 12 8
1974	73.0	71.0	31.0	47.0	65.5	56.5	48.0	21.0	6	10 11 21 20 12 9 8
1975	105.0	92.5	46.5	49.5	96.5	59.0	55.0	44.33	6	10 11 21 20 9 12 8

Underlining denotes no significant difference (p <0.05)

*Refer to Table 7.5-4 for beach seine site descriptions.

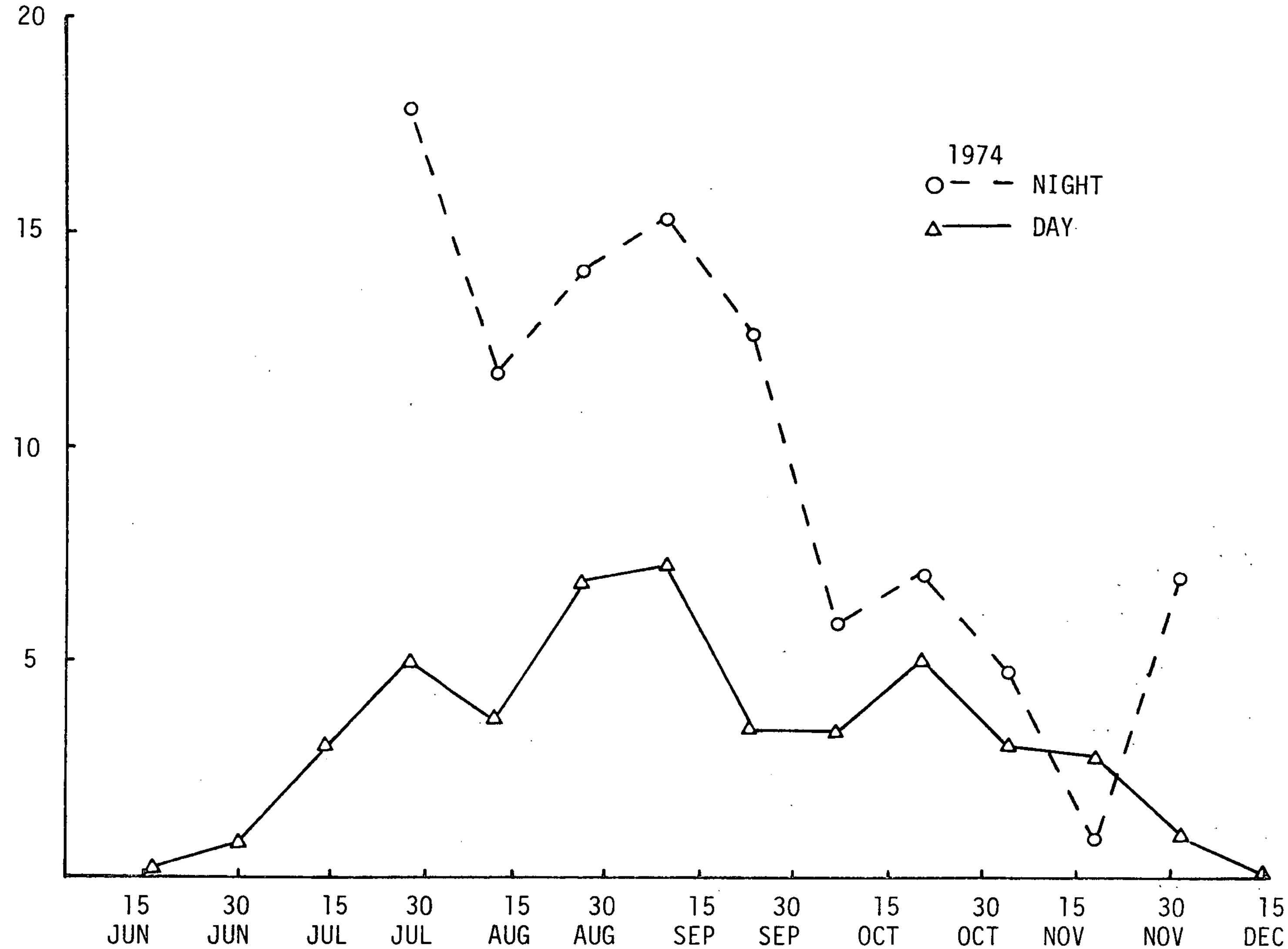

Figure 7.5-11 Beach Seine Survey Catch per Unit Effort for Striped Bass Young-of-the-Year in Day and Night Sampling during 1974. (The day-night difference is significant at the 0.01 probability level [2-tailed Wilcoxon sign rank test])

tidal stages - flood, high slack, ebb, and low slack - were statistically compared for differences in mean catch per unit effort (CPUE) from beach seine sampling. ~~Riverwide CPUE values were similar for flood and ebb tides for the periods July-December 1974 and 1975 ($P > 0.05$, Wilcoxon sign rank test).~~ ~~However,~~ CPUE values for day beach seines (Tables 7.5-7 and 7.5-8) were significantly greater during flood and ebb tides than during high and low slack tides in 1974 ($P < 0.093$) and 1975 ($P < 0.001$) when tested using ~~Wilcoxon~~ Friedman rank sum test (Hollander and Wolfe 1973). Riverwide CPUE values were similar ($P > 0.05$) for flood and ebb tides for the periods July-December 1974 and 1975 when tested using distribution-free multiple comparisons based on Friedman rank sum test (Hollander and Wolfe 1973).

7.5.5 SUMMARY. When they are 35 mm in total length, juvenile (young-of-the-year) striped bass develop the general body shape of adults and are moving shoalward, shoreward, and downstream from the spawning areas to the shallow-water nursery areas of the lower Hudson River estuary. An unknown portion of the population emigrates from this area to the ocean during late fall and early winter. Apparently, this distribution is not limited by dissolved oxygen or salinity, although abundance in local areas is related to temperature, salinity, habitat type, diel patterns, and tidal stage. Survival of juveniles in the Hudson River depends on their adaptation to the physicochemical environment, availability of food, and avoidance of predators. Disease and pollution can detrimentally affect the physical condition of individuals, increasing their susceptibility to predation. On the basis of growth and development rates, mortality due to entrainment in power plants should begin in June; the transition from entrainment to impingement should be complete by late July.

7.6 YEARLINGS.

Juvenile (young-of-the-year) striped bass are classified as yearlings on the first day of January following the year in which they were spawned; i.e., the 1975 year class spawned in the spring of 1975 became yearlings on January 1, 1976. Growth is minimal during the winter season; by spring, yearlings range from 80 to 150 mm in total length, average about 130 mm (Pearson 1938), and resemble the adults in appearance and swimming ability.

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Table 7.5-7 Distribution of Juvenile Striped Bass in Shorezone during Day over Four Tidal Stages in Hudson River Estuary (RM 12-152; km 19-243) during 1974. Data are presented as mean catch per unit effort and tested with Friedman rank sum test.

Month	Low Slack	Flood	High Slack	Ebb
Apr	0	0	0	0
May	0	0	0	0
Jun	0	0.02	0	0.26
Jul	0.33	2.27	0.67	3.01
Aug	12.60	4.85	0	5.61
Sep	18.60	6.60	6.59	4.78
Oct	4.58	3.37	1.79	4.06
Nov	0.17	3.32	1.56	3.30
Dec	0	0.20	0	1.78
Rank Totals	17	20	11	22

$S' = 6.47$ significant at $P < 0.093$

Table 7.5-8 Distribution of Juvenile Striped Bass in the Shorezone during Day over Four Tidal Stages in Hudson River Estuary (RM 12-152; km 19-243) during 1975. Data are presented as mean catch per unit effort and tested with Friedman rank sum test.

Month	Low Slack	Flood	High Slack	Ebb
Apr	0	0	0	0
May	0	0	0	0
Jun	0.12	0.62	0.19	0.56
Jul	5.67	5.18	2.47	7.71
Aug	4.63	5.99	3.31	7.52
Sep	8.54	11.76	10.52	12.15
Oct	1.14	3.90	2.75	5.18
Nov	1.75	1.67	0.62	2.53
Dec	0	0.21	0	0.03
Rank Totals	12.5	21	10.5	26

$S^{/}$ = 13.78 Significant at P <0.001