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HUDSON RIVER ECOLOGICAL STUDY

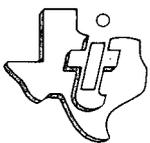
In the area of Indian Point

THERMAL EFFECTS REPORT

SEPTEMBER 1976

Prepared for
**CONSOLIDATED EDISON COMPANY
OF NEW YORK, INC.**

4 Irving Place
New York, New York 10003



by
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FOREWORD

This report includes the results of a study program conducted by Texas Instruments Incorporated under contract to Consolidated Edison Company of New York, Inc., as a part of its Hudson River Ecological Studies.



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SECTION I INTRODUCTION

A. BASIS FOR STUDIES

The environmental impact of thermal effluents has been the subject of much scientific research and legal activity during the past decade. Research regarding such effluents, particularly those from steam-electric generating stations, has ranged from the investigation of immediate problems such as thermal stress (Martin and Gentry, 1974; Cox, 1974) to the long-term alteration of community structure associated with heated effluents (Kolehmainen, Morgan, and Castro, 1974). Court actions and petitions to regulatory agencies by special-interest groups or individuals, as well as actions by governmental agencies, have spurred investigation of the ecology of waterbodies which receive heated discharges or may be used for dissipation of waste heat.

B. STUDY PROGRAMS

First studies of the Indian Point thermal effluents were mathematical models of temperature distribution by QLM (1968) and physical models of intake and discharge structures by Alden Research Associates (1969). The physical models were used to estimate the characteristics of a thermal plume for several discharge-structure configurations. New York University (NYU, 1969; 1973) and Raytheon Co. (1971) monitored fish distribution and abundance; impingement at Indian Point; and conducted preliminary temperature preference and tolerance experiments on fishes and invertebrates. Texas Instruments began its program in 1972 and completed data collection for this report at the end of 1974.

The study programs described in Sections III, IV, and V of this report were developed to meet the objectives of the Environmental Technical



Specifications and Requirements in the Indian Point operating license (DPR-26, Appendix B). The program's overall objective was "...to evaluate the effects of operation of the once-through cooling system ... on the Hudson River ecosystem, to determine the effects on the biotic stresses in the river, and to devise means and methods for minimizing effect." Specific objectives in terms of thermal discharges were:

- Determination of the biological significance of thermal and chemical additions to the Hudson River from Units 1 and 2
- Determination of the biological significance to the Hudson River ecosystem of aquatic organisms passing through or being attracted to the thermal plume and/or into the effluent canal or intake
- Determination of the acute and chronic effects of temperature on life stages and migratory habits of key fish species and on the behavior of these organisms, determination of the upper and lower temperature tolerance of the organisms, and determination of how these data relate to plant operations

C. PLANT DESCRIPTION

The Indian Point Nuclear Generating Station (Indian Point) consists of three nuclear-powered units. The Indian Point facilities have been described in detail in other documents (Con Edison, 1972; NRC, 1975) so only a general description will be presented here. Data of particular interest about each of the three units are presented in Table I-1.

The plant is located on the eastern shore of the Hudson River approximately 65 km (40 mi) north of New York City and immediately southwest of the city of Peekskill, New York. Condenser cooling water for the three units is drawn from the Hudson River and routed back to the river about 174 m (572 ft) south of the Unit-3 intake structure (Figure I-1) through a common discharge structure (Figure I-2). This structure was designed to promote rapid



Table I-1

Summary of Physical and Operational Features of
Indian Point Nuclear Generating Station

Item	Units			
	1	2	3	Combined
Reactor type	PWR* with oil-fired super heater	PWR	PWR	
Year of first commercial operation	1962	1973	1976**	
Net electrical output, MW [†]	265	873	1033	2171
Temperature rise (ΔT) Across condensers, °C(°F) [†]				
Normal flow rate	6.7(12.0)	8.1(14.6)	9.6(17.2)	8.5(15.3)
60% flow rate	10.3(18.6)	13.2(23.8)	15.6(28.0)	13.7(24.7)
Condenser flow [†] [m ³ /s (cfs)]				
Normal flow rate	20.1(708)	54.9(1938)	54.9(1938)	129.9(4585)
60% flow rate	12.1(459)	32.9(1190)	32.9(1190)	77.9(2838)
*Pressurized water reactor **Projected [†] NRC (1975)				

mixing and reduction of temperature of the thermal effluent. The present discharge structure replaced the modified discharge canal of Unit 1, anticipating operation of Units 2 and 3 (Con Edison, 1972).

D. REPORT CONTENTS

The impact of the Indian Point thermal effluent is evaluated in this report. Specific areas covered are the effects on (1) the physical and chemical characteristics of the Hudson River in the immediate vicinity of Indian Point, (2) distribution and abundance of fishes, (3) community

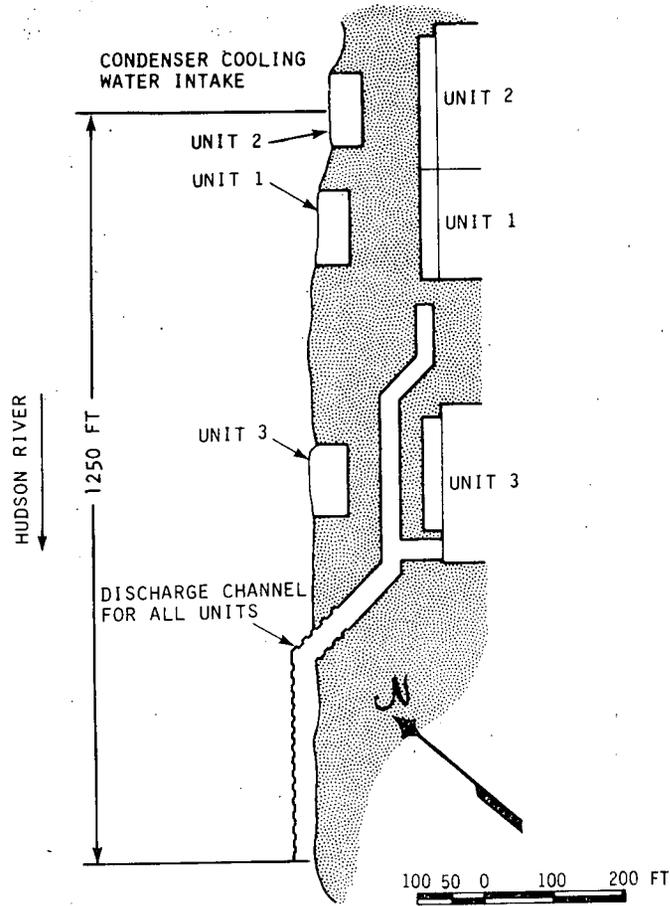


Figure I-1. Schematic Plan of Indian Point Facility Showing Relative Locations of Intake Structures, Power Generation Facilities, and Discharge Structures (Modified from Environmental Report, Indian Point Unit 3)

composition and relative abundance of benthic organisms, (4) tolerance and sensitivity of certain fishes to temperature changes, and (5) preferred temperatures of certain fishes.

- Section II contains a topical summary of results and the conclusions.
- Section III discusses the physical and chemical studies conducted to determine the extent and nature of the thermal plume from Indian Point and its effect on the distribution and abundance of certain fishes.

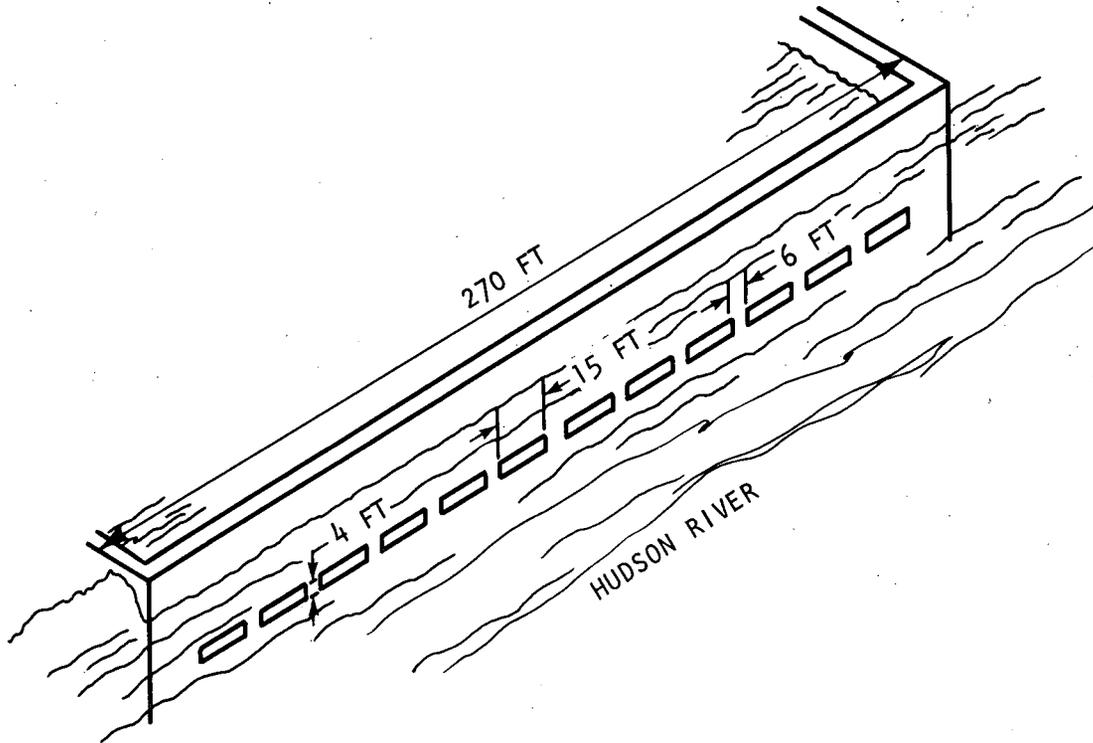


Figure I-2. Diagrammatic Representation of Discharge Structure (Adapted from NRC, 1975)

- Section IV presents distribution, abundance, and species of benthic organisms in the immediate plant area and in a control area and analyzes community structure, discussing in detail the population dynamics of one important benthic organism, the isopod *Cyathura polita*.
- Section V presents complete data and final analyses of a series of laboratory investigations of temperature preference and avoidance, thermal shock, median tolerance limits (TL_m), and active respiration rates of striped bass (*Morone saxatilis*), white perch (*Morone americana*) and somewhat less extensive investigations on the Atlantic tomcod (*Microgadus tomcod*).



SECTION II

SUMMARY OF RESULTS AND CONCLUSIONS

The results summarized in this section are the principal findings of three essentially separate research programs which dealt with (1) physical and chemical characteristics of the Hudson River, (2) benthic communities in the vicinity of Indian Point, and (3) temperature-related aspects of the physiology and behavior of fishes, especially striped bass and white perch. The results for each study are presented point-by-point. The conclusions are integrated and presented at the end of this section.

A. SUMMARY OF RESULTS

1. Physical and Chemical Studies

- Salinity in the vicinity of Indian Point is strongly influenced by (1) turbulent mixing of the saltwater and freshwater masses induced by tides, (2) freshwater flow, and (3) interaction of the above factors with the diverse morphometry of the river channel.
- Temperatures in the main stream of the Hudson River approach 0°C (32°F) during January and February, with a gradual slope to a temperature of about 25°C (77°F) during July, August, and early September; summer temperatures rarely exceed 26°C (79°F).
- Dissolved oxygen concentrations are highest (~13 mg/l) during winter (December to March), declining to 5-6 mg/l during summer when temperatures and oxygen demands are highest. Depression of dissolved-oxygen levels during late spring and summer is associated with higher seasonal temperatures and large variations in freshwater flow.
- Peaks in turbidity are strongly related to high freshwater flows which carry large amounts of dissolved and suspended matter.



- Variations in pH are generally restricted to the 6.5-8.0 range, which is well within the normal range for natural waters.
- The thermal plume formed by the heated effluent from Indian Point is compressed along the eastern shore during ebb and flood tides; during slack tides the plume forms a "pool" of warmer water in front of the discharge structure. Dimensions of the plume (defined by the +4 °F isotherm) during operation of Unit 2 have not exceeded 48% of the river surface width or 19% of the cross-sectional area at the Indian Point discharge; the depth of the plume is generally <3 m (10 ft) from the surface except immediately in front of the discharge ports; river-channel depths range from 10 m (33 ft) to 24 m (80 ft).
- Abundance (based on catch per unit effort) of fish in the Indian Point region is high during late spring and again during fall when salinities are increasing and decreasing respectively.
- Peak impingement rates of Atlantic tomcod and white perch (the two species comprising the bulk of impinged fish at Indian Point) are strongly associated with passage of the salt front (defined as ~0.1 ‰ salinity) past Indian Point. Increases in impingement of white perch and striped bass are associated with low ambient temperatures [0-10 °C (32-50 °F)] as well as with salt-front movement.
- No relation among fish abundance, impingement rate and thermal additions was detected.

2. Benthic Studies

- The dominant benthic assemblage in both the test and control areas consisted of 10 taxa which comprised > 97% of all organisms found.
- Diversity of organisms was not significantly different between test and control areas or between years.
- Biomass in the test and control areas typically reached its peak during autumn and had a smaller peak during early spring.



- The benthic intertidal and immediate subtidal communities are relatively uniform in the vicinity of Indian Point, with species composition changing seasonally with temperature and salinity.
- Fouling communities in the Indian Point region are dominated by the barnacle *Balanus improvisus*, the clam *Congeria leucophaeta*, and the hydroid *Cordylophora lacustris*; these organisms' settling rates and production are directly related to increasing salinity during the summer.
- The epibenthic community is dominated by various crustaceans, the most abundant being calanoid copepods and the amphipod *Gammarus*.
- Sediments in the Indian Point region are predominantly sandy clay-silt with patches of pebbles, and the oxidation-reduction potential indicates that interstitial conditions below the upper 1-2 cm of sediments are practically anoxic. With few exceptions during the sampling period, sediment temperatures in the test and control areas were consistently higher (by 0.3 to 1.0°C) than those of the overlying waters; no significant differences were observed between test and control areas for sediment temperatures or the temperatures of the water near the bottom.
- The average density of the isopod *Cyathura polita* throughout the study area was approximately 161/m². Abundance peaked during summer and early fall when young-of-the-year are most numerous; peak densities of almost 1000/m² occurred in summer 1974 in test and control areas.
- Length-frequency distributions indicated that the *Cyathura polita* population is composed of three year classes.
- Reproduction for *Cyathura* in the Hudson River begins in late April and extends through August. Although the test area's number of young per female was double that of the control area, total theoretical natality and standing crops in late 1974 were practically the same for the two areas. Production of biomass (g/m²) was higher in the test area in 1973, but there was little difference in 1974.



- Biomass (g/m^2) for all species combined was greater in the test area than in the control area. Relative differences were greatest in late 1972 and early 1974.

3. Physiology and Behavior Studies

- Temperatures preferred by white perch and striped bass after extended exposure (27.5 hr) to a temperature gradient ranged from $3^\circ\text{-}6^\circ\text{C}$ ($5.4^\circ\text{-}10.8^\circ\text{F}$) to $10^\circ\text{-}15^\circ\text{C}$ ($18^\circ\text{-}27^\circ\text{F}$) above the acclimation temperature from summer to winter respectively. Immediate (1.5-hr) preferences were $3^\circ\text{-}7^\circ\text{C}$ ($5.4^\circ\text{-}12.6^\circ\text{F}$) above acclimation temperatures during all seasons; acclimation temperatures ranged from $3^\circ\text{-}4^\circ\text{C}$ ($37.4^\circ\text{-}39.2^\circ\text{F}$) during winter to 26°C (78.8°F) in summer.
- Striped bass juveniles and, to a lesser extent, white perch were sometimes incapable of avoidance of lethal thermal conditions in the laboratory, especially when acclimation temperatures were $<8^\circ\text{C}$ (46°F). Temperatures above acclimation which elicited avoidance behavior ranged from $5^\circ\text{-}8^\circ\text{C}$ ($9^\circ\text{-}14.4^\circ\text{F}$) during summer and $6^\circ\text{-}21^\circ\text{C}$ ($10.8^\circ\text{-}37.8^\circ\text{F}$) during winter. Juvenile white perch generally avoided lower temperatures for particular acclimation temperatures than did juvenile striped bass or adult white perch. Atlantic tomcod avoided temperatures that were $8^\circ\text{-}16^\circ\text{C}$ ($14.4^\circ\text{-}28.8^\circ\text{F}$) above acclimation temperatures of $0.5^\circ\text{-}8.9^\circ\text{C}$ ($32.9^\circ\text{-}48.0^\circ\text{F}$).
- Thermal tolerance limits (temperature causing 50% mortality in 96 hr) for striped bass and white perch were $9^\circ\text{-}19^\circ\text{C}$ ($16.2^\circ\text{-}34.2^\circ\text{F}$) above acclimation temperatures of $8^\circ\text{-}26^\circ\text{C}$ ($46.4^\circ\text{-}78.8^\circ\text{F}$), the difference being greatest at the lowest acclimation temperatures. The thermal tolerance limit for Atlantic tomcod was 16.3°C (61.3°F) for an acclimation temperature of 1°C (33.8°F).
- Rapid decline in temperature from 15°C (59°F) to 2°C (35.6°F) in less than 3 hr (50% of decline in <15 min) resulted in 100% mortality of juvenile striped bass over 96 hr, and a drop from 20°C (68°F) to 2°C (35.6°F) caused 50% mortality of white perch over 96 hr. Neither



white perch nor striped bass experienced equilibrium loss or death when temperatures were dropped from 10°C (50°F) to 2°C (35.6°F) at the same rate.

- Active metabolic rates for white perch acclimated and tested at 8°C (46.4°F) and 24°C (75.2°F) were 176 and 322 mg O₂/kg/hr respectively; corresponding values for striped bass were 192 and 574 mg O₂/kg/hr. Standard metabolic rates (metabolic rate at "zero" activity back-calculated from rates at different activity levels) for striped bass are greater than those for white perch except at the lowest test temperatures.

B. CONCLUSIONS

The following conclusions are drawn from the data and discussions presented in the following sections of this report.

- The thermal plume produced by operation of the Indian Point facility is restricted to the upper portion of the water column in the river and is well within the temperature, width, and cross-section limits required at the power-generation level (up to 1075 MWe for Units 1 and 2) during field surveys conducted during 1974.
- Abundance of fishes, especially those most often impinged at the Indian Point intakes, is more strongly associated with salinity distribution in the vicinity of the plant than with a particular thermal regime.
- Thermal discharges from Indian Point have no detectable effect on the benthic communities in the region. Species composition and abundance are governed by seasonal and annual variations in the temperature and salinity regimes and by differences in the microhabitats in the river.



- White perch (*Morone americana*) and striped bass (*Morone saxatilis*) prefer temperatures above those to which they are acclimated; temperatures avoided by these fishes are several degrees above those preferred; critical temperatures are above those avoided.
- Atlantic tomcod (*Microgadus tomcod*) avoid temperatures expected in the thermal plume of Units 2 and 3 combined.
- Thermal tolerance limits and critical temperatures for striped bass and white perch are above the thermal plume temperatures expected to occur at Indian Point.
- Effects of temperature decreases (such as could be produced by plant shutdown) depend on the magnitude of the decrease, the rate of change, and the final temperature. Rapid decreases to near-freezing from 15°-18°C (59°-64°F) can cause mortality among white perch and striped bass. However, maximum plume temperatures are only about 10°C (18°F) above ambient winter temperatures so mortality from cold shock is unlikely.
- Temperatures in the thermal plume when river temperatures are highest (near 26°C or 79°F) do not exceed those which elicit avoidance behavior from white perch and striped bass.
- Due to highly variable size and distribution of the thermal plume from Indian Point and its restriction to the surface of the river, it is unlikely that any fishes become "resident" in the plume or that the plume blocks their movements.
- Based on the physical, chemical, and biological data relating to thermal effluents from the Indian Point facilities, there is little detectable impact on the ecology of the Hudson River in the vicinity of Indian Point.



SECTION III

PHYSICAL AND CHEMICAL STUDIES

A. INTRODUCTION

1. Basis for Studies

The Hudson River Estuary below Poughkeepsie is influenced by seawater intrusion as well as tidal activity. Consequently, there is a continual interaction between freshwater flow and tide-related mixing which controls the extent of saline intrusion within the estuary. Recent studies of the Hudson River have begun to give insight into the interactions between the salt-intrusion process and power-generation activities as well as other natural processes. This section deals with physical and chemical processes and is directed toward the interpretation and synthesis of data and information relating to these interactions. This section addresses:

- Basic knowledge concerning physical and chemical processes in the estuary
- The relation of the Indian Point thermal-plume size to the New York thermal standards
- The importance of thermal additions to biological communities
- Interactions between impingement at Indian Point and thermal additions.

2. General Methods for Measurements

Factors responding to power-plant influences, tidal activities, and freshwater flow were measured *in situ* at locations shown in Figure III-1. The environmental factors measured concurrently with biological sampling included temperature, conductivity (a measure of salinity), dissolved-oxygen (D. O.) concentrations, pH (a measure of hydrogen ion concentrations), and turbidity.

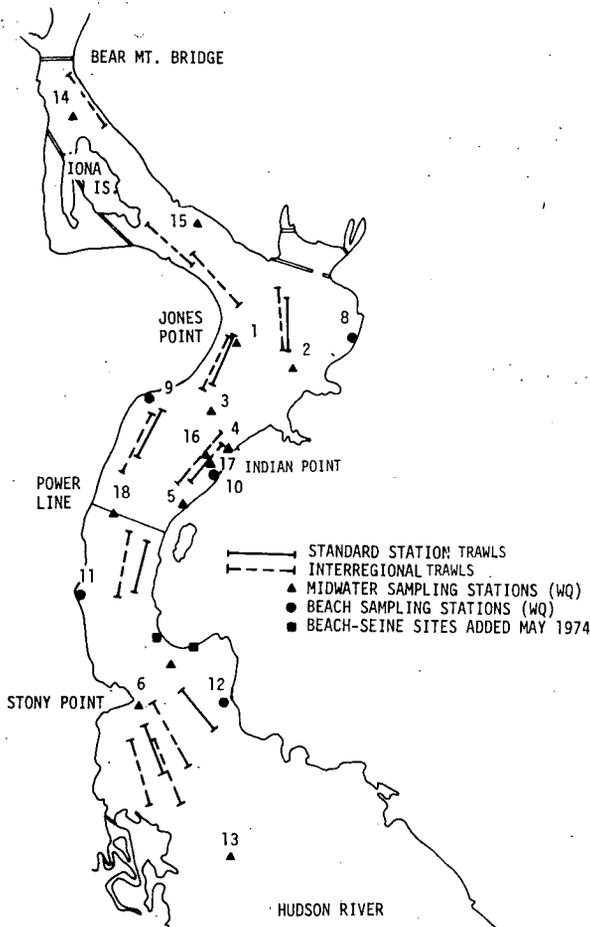


Figure III-1. Water-Quality Sampling Locations for 1973-1974 with 1974 Trawling/Water-Quality Tow Locations

All water-quality factors except turbidity were measured with a Martek Mark II monitor until August 1973; a Hydrolab 6-D monitor system was used for subsequent measurements. Both systems used the same types of sensors. Turbidity was measured with a Hydroproducts 210 transmissometer until mid-1973 when use of a Hach 2100A turbidimeter, a nephelometer using repeatable formazin standards (APHA, 1971), was begun. Water-quality information derived from interregional trawl and ichthyoplankton-associated water-quality monitoring was included. Detailed methods are presented in Volume I of the *First Annual Report for the Multiplant Impact Study of the Hudson River Estuary* (TI, 1975a).

Freshwater flow and predicted tidal fluctuations were obtained from the United States Department of the Interior Geological Survey office in Albany (USGS, 1972; 1973; 1974) and from the National Ocean Survey of the United States Department of Commerce (NOS, 1972; 1973; 1974) respectively. Trawl and beach seine catch-per-unit-effort (CPUE) data are derived from catches of fishes at the standard sampling stations in the vicinity of Indian Point (Figure III-1). These gear are described in detail in reports related to the Hudson River Ecological Studies in the vicinity of Indian Point (TI, 1973; 1974; 1975).



B. PHYSICAL AND CHEMICAL CONDITIONS

1. Salinity (as Indicated by Specific Conductance)

Salinity intrusion into the Hudson River estuary is controlled by an interaction between freshwater and tidal flows. The result of this interaction is an essentially exponential decrease in conductivity upstream from the Battery, approximating an asymptote at the salt-front position (defined as 0.1 ‰ salinity for the present study). The longitudinal and temporal distribution of conductivity in the southern half of the estuary is related to the temporal distribution of conductivity at Indian Point (Figure III-2). These distribution curves are set on a base describing the temporal distribution and distance the salt-wedge intrudes.

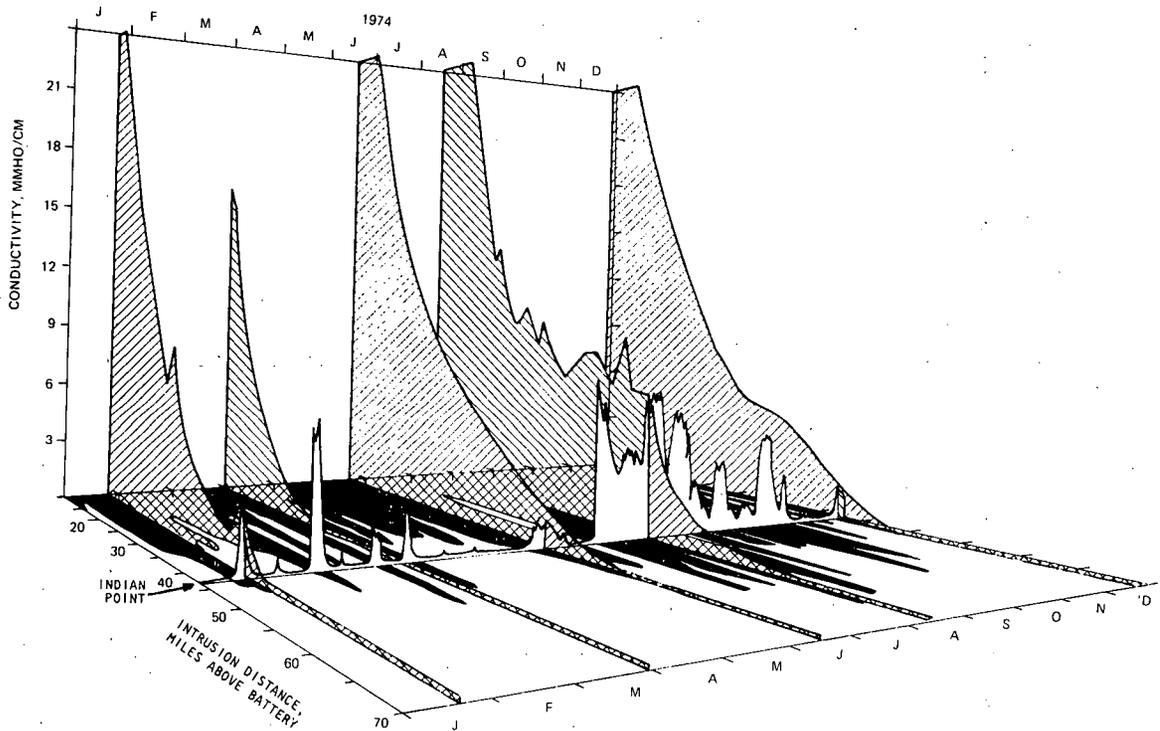


Figure III-2. 3-Dimensional Representation of Salinity (Conductivity) Distribution in Lower Hudson River and at Indian Point during 1974



Salt intrusion into the Indian Point region responds to dilution by fresh water, with peak salinities occurring during short-term periods of low mixing and/or low flow; these periods are regularly spaced throughout the early months of the year (January-June). The most extensive and prolonged intrusion generally occurs between July and November when freshwater flows are lowest (Figures III-3, III-4, and III-5). Temporal distributions of salinity-related parameters are illustrated in the present study, tidal amplitude (the mean daily difference between high and low tide) is used as the index potential for mixing of fresh and salt water. The index of freshwater flow (Figures III-3, III-4, and III-5) is freshwater discharge at Green Island, New York, 153 mi (245 km) upstream from the Battery.

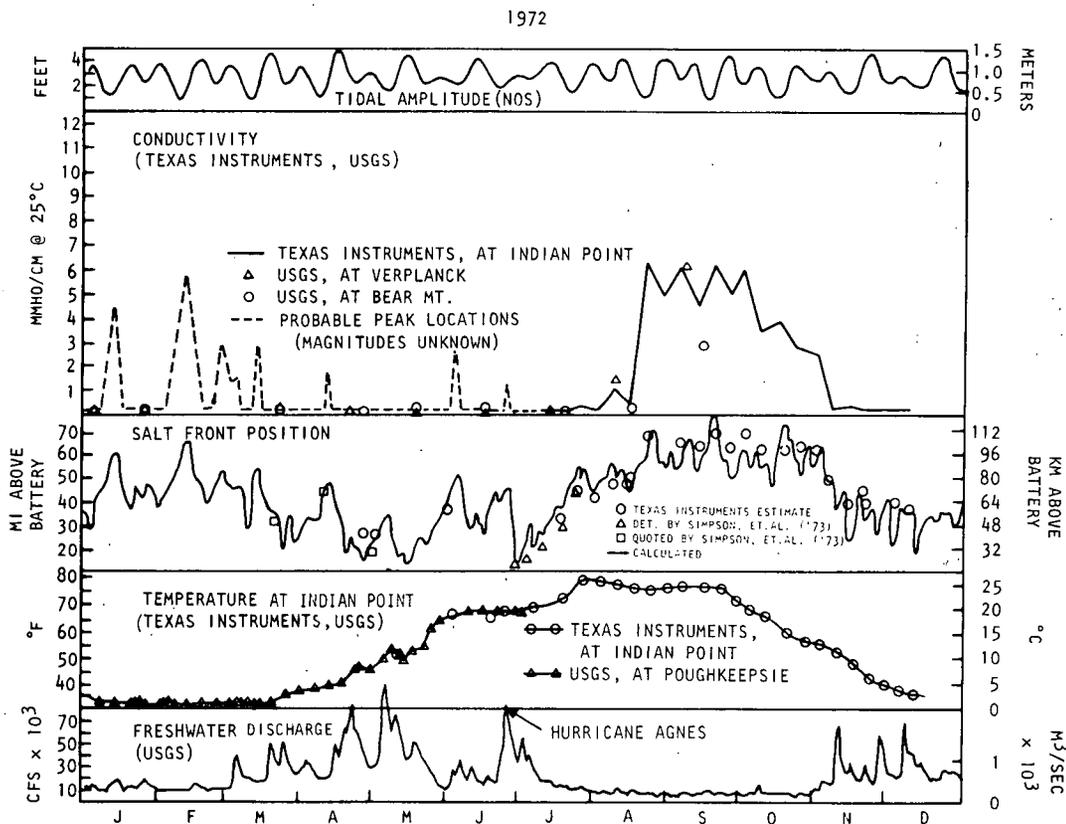


Figure III-3. Temporal Distribution of Variables Related to Salinity Intrusion during 1972

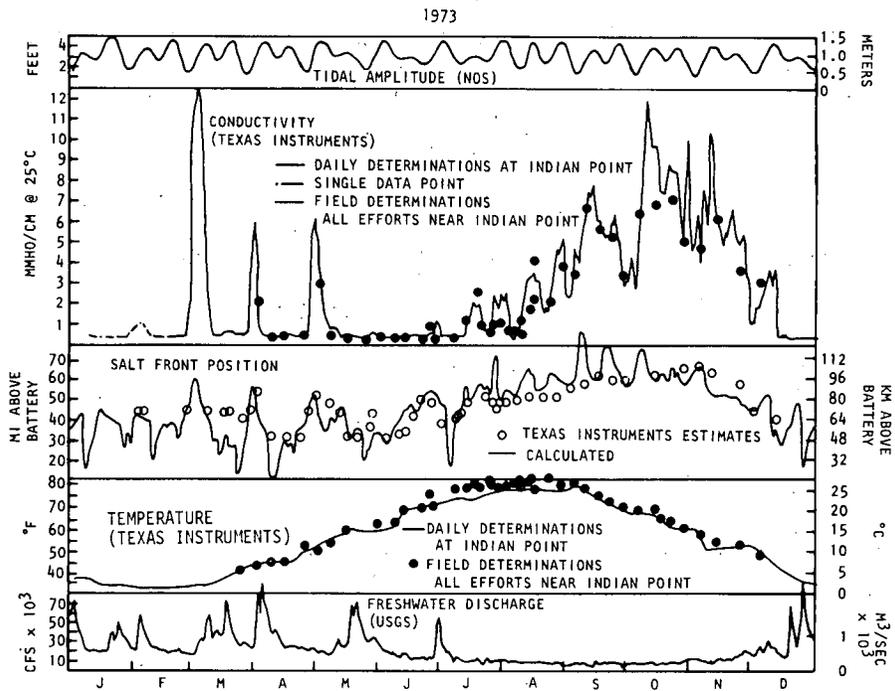


Figure III-4. Temporal Distribution of Variables Related to Salinity Intrusion during 1973

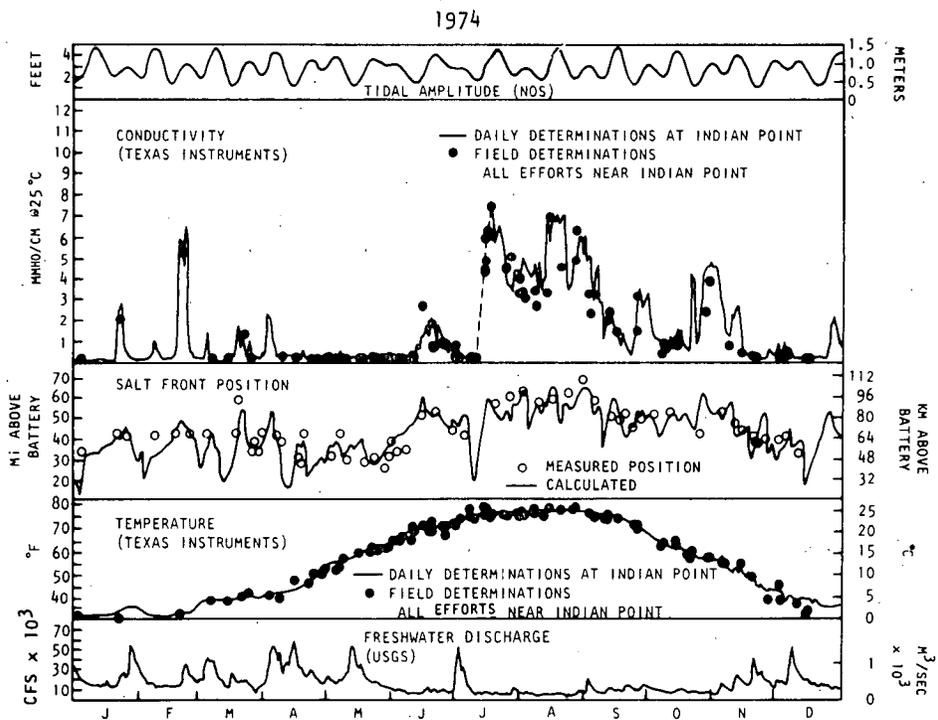


Figure III-5. Temporal Distribution of Variables Related to Salinity Intrusion during 1974



At times, the salt front's rate of movement suggests minimal mixing of fresh- and saltwater. The salt front's upstream movement is frequently as rapid as 5 mi (8 km) per day. These high rates occur during periods of minimal tide amplitude, apparently allowing gravitationally induced influxes of denser saltwater into the essentially level channel of the river (there is a negligible increase in bottom elevations between the Battery and Albany). Maximum intrusion distance is usually about 65 mi (104 km) above the Battery (Figure III-6), although it has historically reached above Poughkeepsie (RM 75).

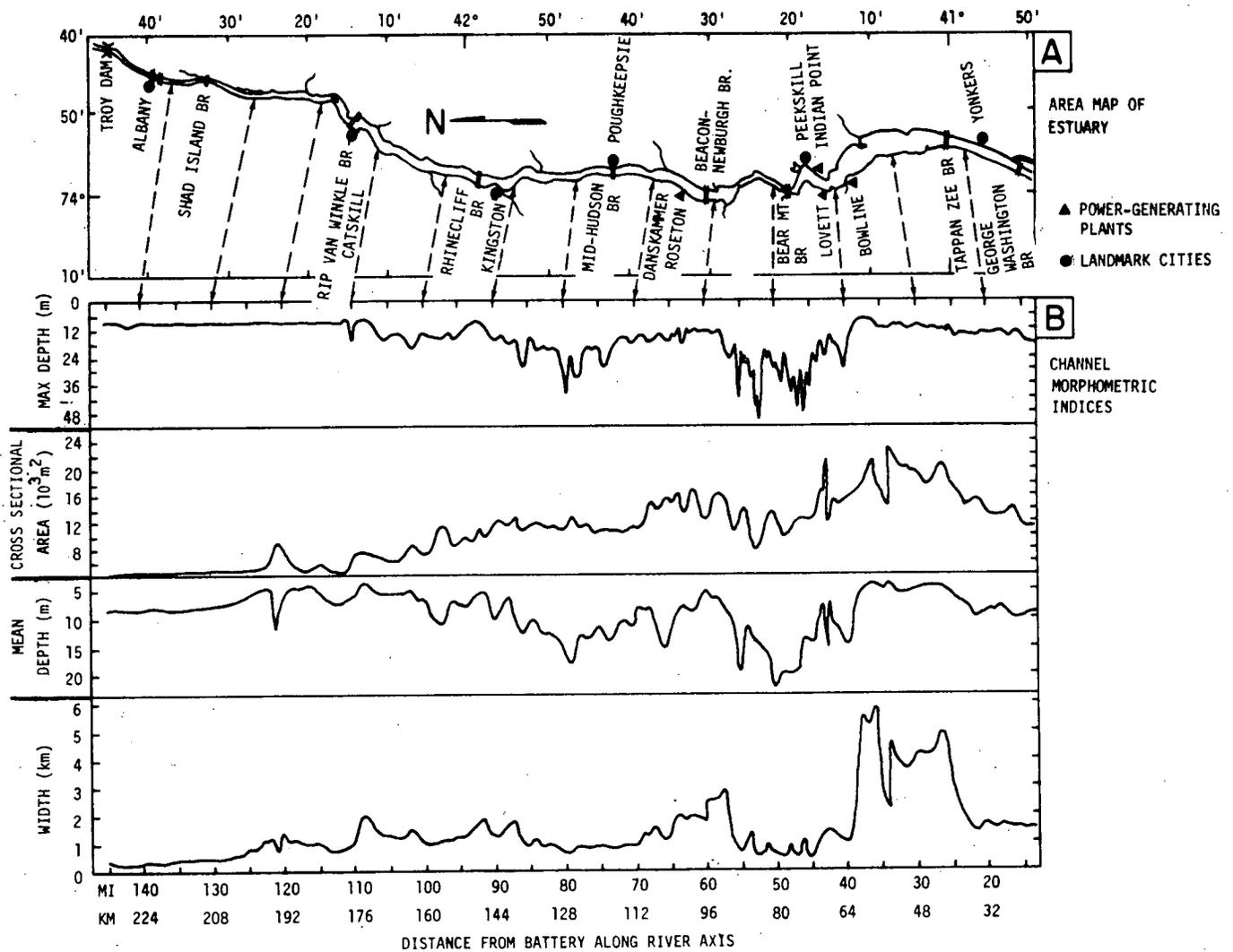


Figure III-6. Major Morphometric Characteristics of Lower Hudson River Estuary



Intrusion rates are modified by morphometric characteristics which accentuate tidal mixing. Particularly important to salinity intrusion are shallow areas (e. g., between RM 38 and 42, Figure III-6B) which inhibit salt-front movement past Indian Point. Salinities rarely exceed 5 ‰ at Indian Point (9 mmho/cm).

The relationship of saltwater, intrusion distance, tidal amplitude, and freshwater flow was presented in detail in an earlier report (TI, 1975a). The position of the salt front can be estimated by

$$L_{RM} = 78.17 - 17.33 (\ln F_5) + \frac{25.59}{T_4} \quad (1)$$

where

L_{RM} = estimated location of salt front (0.1 ‰ salinity) in river miles above the Battery at New York City

F_5 = freshwater flow at Green Island, New York, 5 days before estimate

T_4 = tidal amplitude 4 days before estimate

Conductivity at Indian Point can be estimated by a similar equation

$$C_{IP} = 9.82 - 4.22 (\ln F_5) + \frac{6.23}{T_4} \quad (2)$$

where

C_{IP} = conductivity, mmho/cm at 25°C at Indian Point

2. Temperature and Dissolved Oxygen

The dependence of dissolved-oxygen (D. O.) concentrations on temperature dictates concurrent discussion of these parameters. Changes



in temperature have dual effects on the ambient concentration of D. O. A baseline temporal D. O. distribution resembling an inverted annual temperature curve is dictated by solubility of oxygen in water (less soluble at higher temperatures); further, an increase in temperature causes a general increase in respiration (biochemical oxygen demand) which, in turn, can cause additional oxygen-concentration reductions. Dissolved-oxygen depletions ranging from mild and localized to severe and extensive have occurred in the Hudson River estuary (TI, 1975a; 1975b). Such depletions occurred 28-31 May and 12-17 June 1974 and are contrasted with the weeks immediately preceding and following in Figure III-7 (TI, 1974a).

Large variations in temperature are generally limited to the bay areas (Haverstraw, Tappan Zee, Peekskill, and Newburgh) where temperatures are somewhat higher than in channel areas. These temperature elevations are seldom accompanied by noticeable depressions in dissolved oxygen because the turbulence and surface promote increased diffusion of oxygen from the air which also suppresses diurnal variation (Ruttner, 1963).

High freshwater flows can depress temperatures during summer. During spring when water temperatures increase rapidly, the rate of increase can be decreased or reversed by high flows. Temperature reductions may also be accelerated during fall by cold runoff water.

3. Turbidity

Periodic depressions of temperature and dissolved oxygen seem to accompany elevated turbidity values (Figure III-8). This may be attributed to increased amounts of watershed-derived particulate matter carried by high freshwater flows.

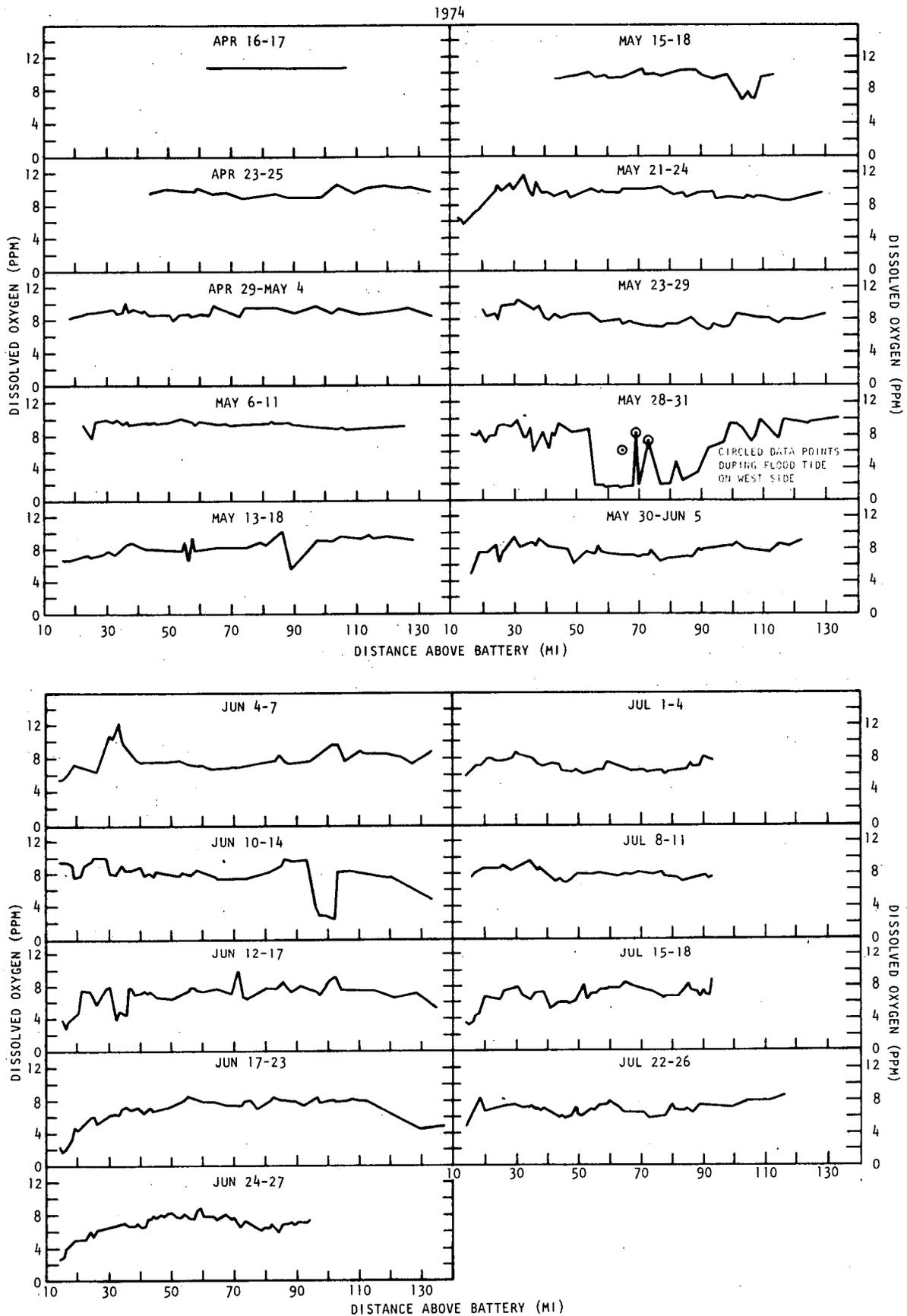


Figure III-7. Longitudinal Distribution of Dissolved-Oxygen Concentration in Hudson River during April, May, June, and July 1974

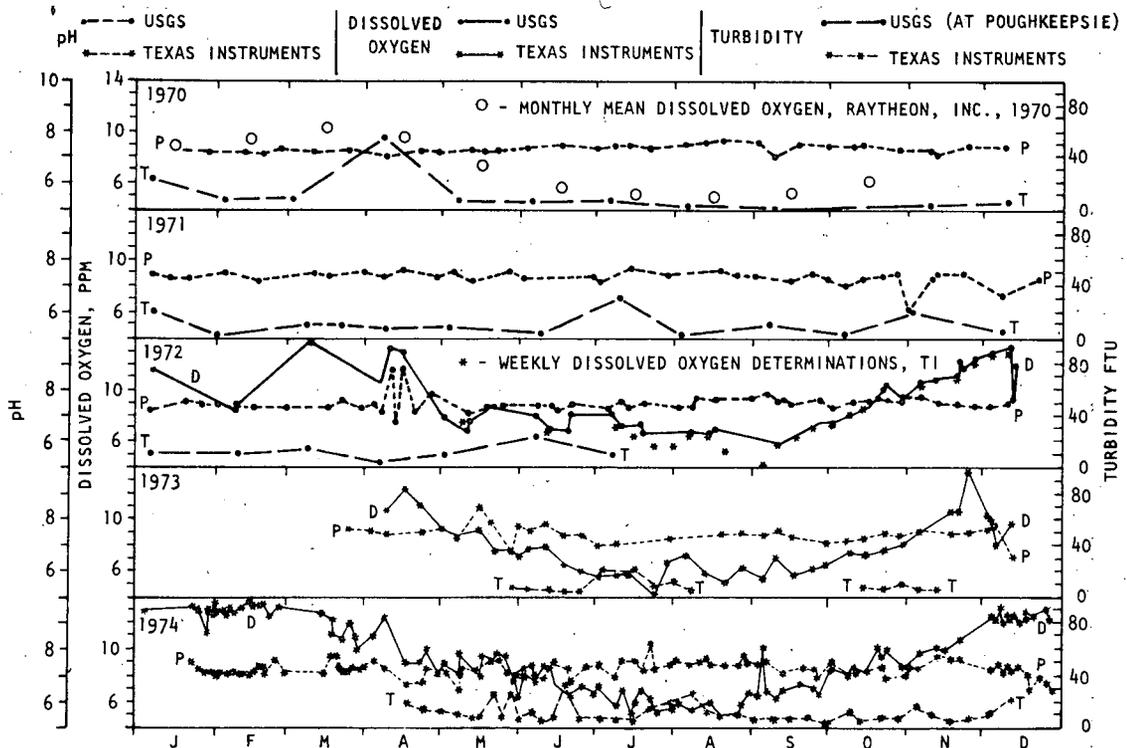


Figure III-8. Temporal Distribution of Dissolved-Oxygen, Turbidity, and pH in Indian Point Area, 1970-1974

4. pH

The only appreciable variations in pH within the Hudson River estuary are restricted to the areas around Albany and New York City where some depression below pH 6 (increase in hydrogen ion concentration) occasionally occurs. Between Albany and New York City, pH values typically remain between 6.5 and 8.0.

C. THERMAL-PLUME STUDIES

Three aspects of the thermal studies made in the Indian Point region are pertinent from a physical/biological standpoint:

- Determination of the possibility of the thermal plume blocking the movement of fishes, especially migratory species



- Determination of the plume's possible influences on the benthic community in the area of Indian Point
- Determination of the possibility of attraction to or avoidance of the thermal plume

The first of these aspects will be treated only in this section. Background information regarding the second aspect will be presented here and field and laboratory studies relating to potential power-plant impact on the benthic community discussed in Section IV. The third aspect will be treated in two parts: one relating fish distributions to environmental variables is discussed in this section; the second relating to laboratory studies designed to assess the degrees of preference or avoidance reactions by certain species is presented in Section V of this report.

1. Plume Maps and Infrared Imagery

Plume shape and expanse has been determined by field and laboratory methods. Field methods have included scanning the plume with infrared detection equipment, accompanying ground truth and vertical temperature profiles at thermal grid sites. Physical modeling (Alden Associates, 1970; 1972) and mathematical modeling (QLM, 1969) have provided estimates of plume shape and size.

Table III-1

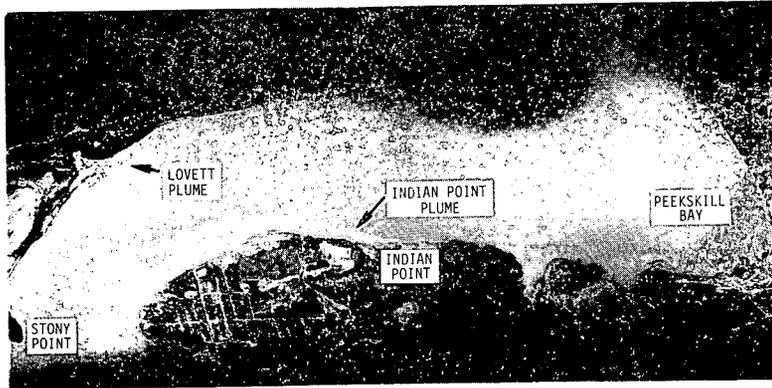
Estimated Percent of River Surface Width and Cross-Sectional Area Occupied by Thermal Plume as Defined by 4° + Isotherm Above Ambient at Indian Point

Tide Stage	Field Estimates by Dames and Moore		
	(1974a) May 1974	(1974b) June 1974	(1974c) July 1974
Flood	15(2)*		20(15)
High slack	10(4)	15(12)	26(13)
Ebb	25(6)	37(7)	40(8)
Low slack	46(19)	48(16)	30(13)
Flood	15(1)	21(14)	14(13)
High slack		20(9)	

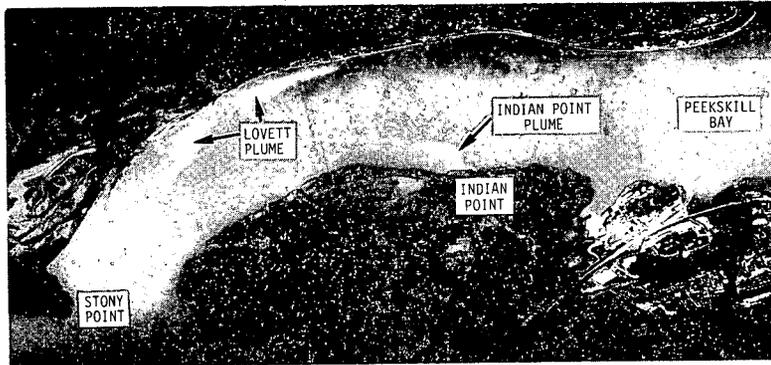
*Maximum plume surface width as percent of total river surface width; numbers in parentheses are maximum plume cross-sectional area as percent of total river cross section.



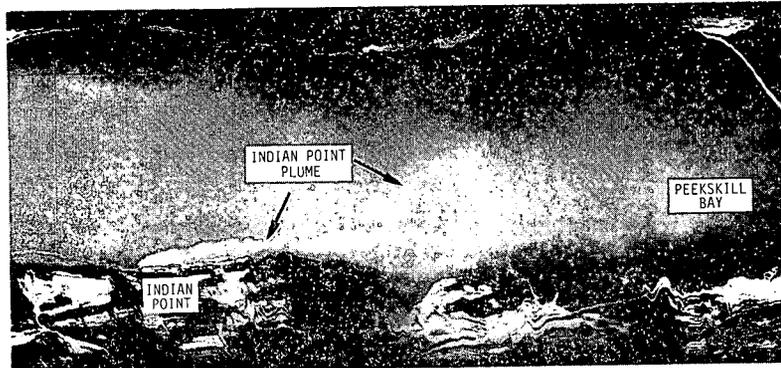
Maximum
Ebb



Slack
After
Ebb



Maximum
Flood



Slack
After
Flood

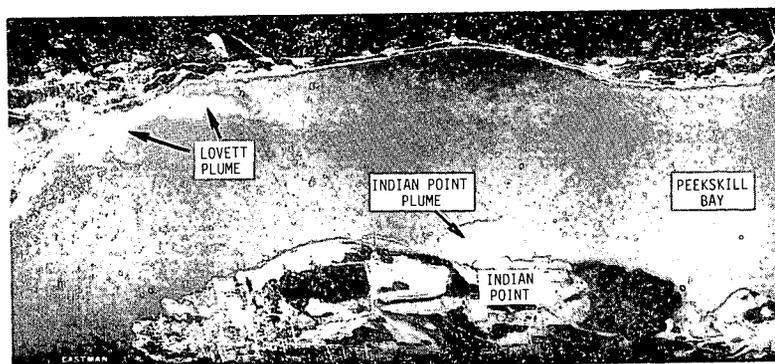


Figure III-9. Infrared Images of Thermal Plumes from Indian Point and Lovett Stations, 10 August 1972.



Plume shape is strongly influenced by tidal flow and river-channel shape (morphometry). These influences have been effectively demonstrated during infrared imagery studies (Figure III-9) in which the thermal plume was shown to be compressed against the eastern shore during flood and ebb tides. The plume covered a large area in Peekskill Bay during flood tide, representing the movement of the "pool" of warmer water formed during the previous slack.

Indian Point plume depths are apparently limited to about 3 m (10 ft) from the river surface (Dames and Moore, 1974a; 1974b; 1974c) except immediately adjacent to the effluent canal since effluent ports are centered approximately 3.7 m (12.0 ft) below the surface at mean tide level. The thermal plume then is best described as a surface phenomenon, since river depths in the vicinity of Indian Point range from 11 m (36 ft) to 24 m (80 ft).

The sizes of thermal plumes produced by neighboring generating plants have necessarily been measured since interactions (linking) of plumes could produce thermal blockage, at least in surface layers. Information from the Alden model studies (Alden Associates, 1972), infrared imagery photographs (TI, 1972), and the plume mapping studies (Dames and Moore, 1974a; 1974b; 1974c) have shown no significant connection or linking between plumes from the Lovett and Indian Point generating plants.

2. Interrelationships between Temperature, Salinity, Density, and Flow-Induced Turbulence

At a constant temperature, an increase in salinity results in an increase in density (Figure III-10). The maximum salinity-induced densities in the Indian Point region approximate 1.0080 g/ml (corresponding to about 10 ‰ salinity). An increase in temperature generally results in a decrease in density when salinity is constant. The only deviation from this pattern is a slight increase in density with increase in temperature between

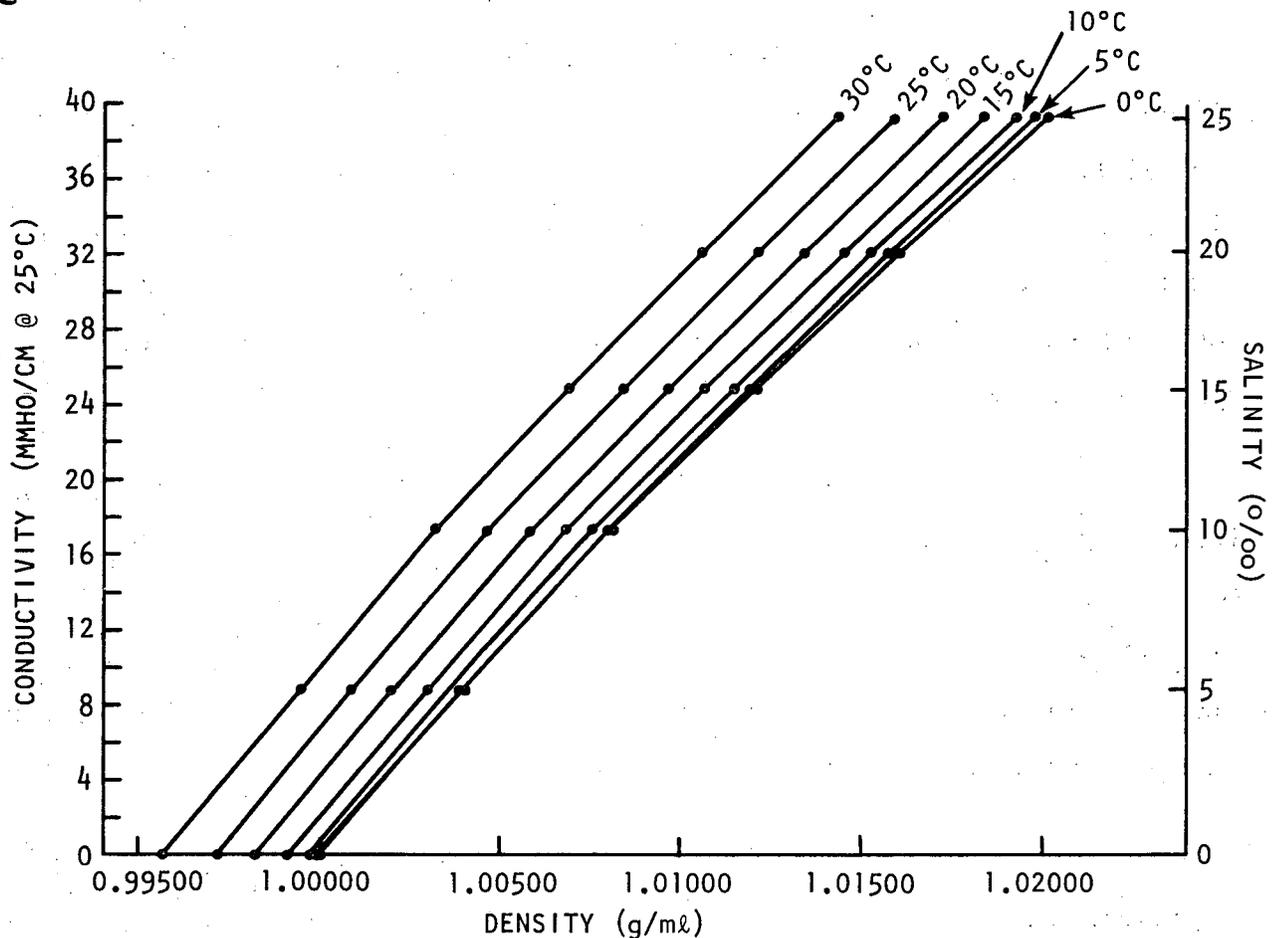


Figure III-10. Density of Water as Function of Temperature and Salinity (Conductivity)

0 and 4°C. The density differential between the two temperatures decreases progressively as the salinity increases, becoming nonexistent at 9.43 ‰ (where the 0 and 4°C lines cross, corresponding to a density of 1.00756 g/ml).

This tendency for increasing densities between 0 and 4°C has been used to suggest that the thermal plume may lose buoyancy and sink when temperatures approach 4°C (Clark, 1973). A very small salinity differential between plume and underlying river waters will prevent the plume from sinking below the surface. This differential is illustrated in Figure III-11 in which 0 and 4°C lines have been isolated showing the wedge-shaped area of "inverted" temperature effects; this wedge exists below a salinity of 9.43 ‰, at which point the 0 and 4°C lines cross. The maximum differential (at salinity = 0)



is 0.000132 g/ml. As shown in Figure III-12, this density difference is equivalent to a salinity increase of only 0.25 ‰ (or about 455 $\mu\text{mho/cm}$ at 25°C). Since salinity intrusion into the Indian Point region depends on steep salinity gradients and since intake and effluent structures are at comparable depths, any loss of plume buoyancy is unlikely during periods of salt intrusion. The thermal plume will sink when there is no salinity-induced stratification and ambient temperatures are less than 4°C (39°F).

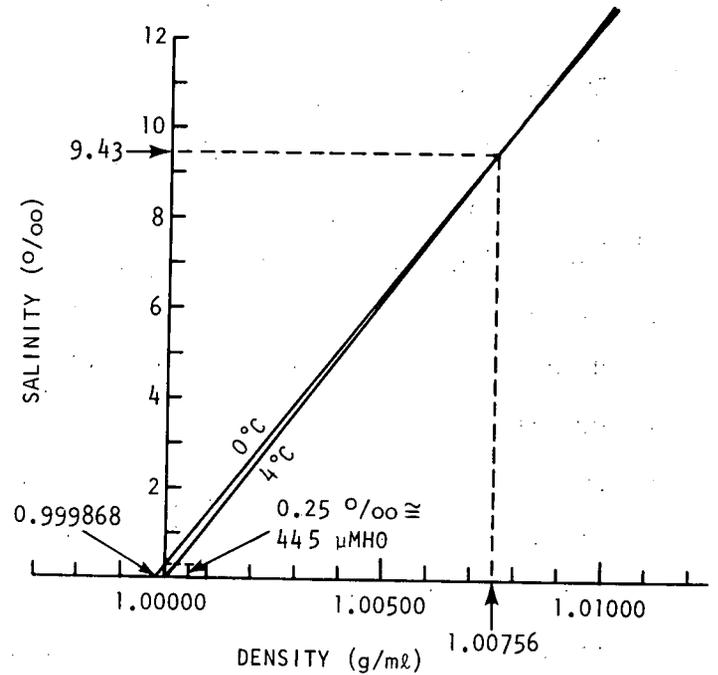


Figure III-11. Density of Water as Function of Temperature and Salinity, with 0 and 4°C Lines Isolated

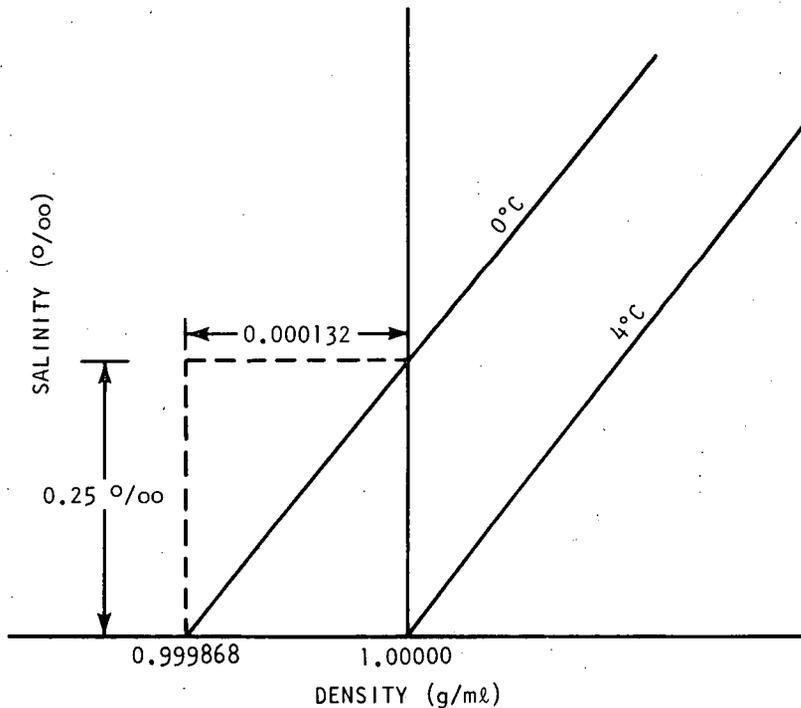


Figure III-12. Density of Water as Function of Temperature and Salinity, Illustrating Maximum Density Rise between 0 and 4°C



The portion of the river immediately in front of the Indian Point plant is subjected to turbulent mixing due to tidal flows traversing the relatively shallow area at river mile (RM) 42. Simpson et al (1973) observed stalling of salt-wedge intrusion at this point apparently due to increased mixing accompanying large changes in cross-sectional area (ranging between 12,000 and 22,000 m²). Such turbulent mixing is maximal above the 15-m depth (50 ft). Since tidal flow follows the east side of the river, water in the plume area is usually turbulent. Penetration of the plume to the bottom of the river would require passage through turbulence sufficient to prevent intrusion of saltwater. Since the density differential between 0 and 0.5 ‰ salinity is four times that between 0 and 4.0°C (at 0 salinity), the mixing intensity necessary to disperse an intruding salt front in the vicinity of Indian Point would easily disperse the thermal plume. The intrusion of the salt front past Indian Point during all but summertime freshwater flows is associated with tidal amplitudes (mean daily difference between high and low water levels) near 1.5 ft (~0.5 m). Values of <1.5 ft occur approximately 30 days/year at 3- to 5-day intervals. The minimum value reached during these periods is ~1.0 ft (0.3 m) at which times significant intrusion of a highly stratified salt wedge occurs, further reducing the possibility of plume sinking.

D. DISTRIBUTION OF FISHES RELATIVE TO PHYSICAL/CHEMICAL CONDITIONS

1. Temporal Distributions near Indian Point

The most frequently observed temporal pattern for both seining and trawling efforts in the area of Indian Point is best described as a bimodal increase in catch per unit effort (CPUE); it results from peak catches as conductivities in the Indian Point area begin to increase in the summer and again as conductivities approach a freshwater condition. This phenomenon has expressed itself throughout the study in collections made with a variety of gear including trawls, beach seines, fish traps, and even in the power-plant intakes (impingement collections).



The first suggestion of fish having distinct associations with the migrating salt front was a sudden rise in striped bass beach-seine catches in the area of Indian Point (Figure III-13) as the saline wedge reentered the area immediately following the high flows of Hurricane Agnes (12-28 July 1972, Figure III-14). The changes were particularly evident in monthly average catches of striped bass (Figure III-15), and trap and bottom-trawl catches of white perch (Figures III-16 and III-17).

In 1972, the late start of impingement collection, temporal intrusion proximity, and maximum retreat of summer salinity tended to confound interpretation of the relationship between standard station abundance and impingement abundance. However, the association of major impingement periods with salt intrusion or retreat times was suggested by the data (Figures III-18, III-19, and III-20).

The field collection data of 1973 continued to indicate peak fish abundance in the area of Indian Point when the salt front was in the vicinity of the power plant (Figures III-21 through III-31). In general, clupeids exhibited this phenomenon in surface-trawl catches while, depending on age, white perch and striped bass catches rose in beach seines and bottom trawls.

Impingement collections during 1973 appear to be closely related to salinity intrusion; many peaks in collections were associated with salinity intrusion periods (Figures III-32, III-33, and III-34). Furthermore, tomcod, striped bass, and white perch showed strong seasonal specificity; the warm-weather spawning white perch and striped bass tended to be impinged during cooler periods of salt intrusion, while the winter spawning tomcod young were impinged during summer as the salt front made its way into the Indian Point area.

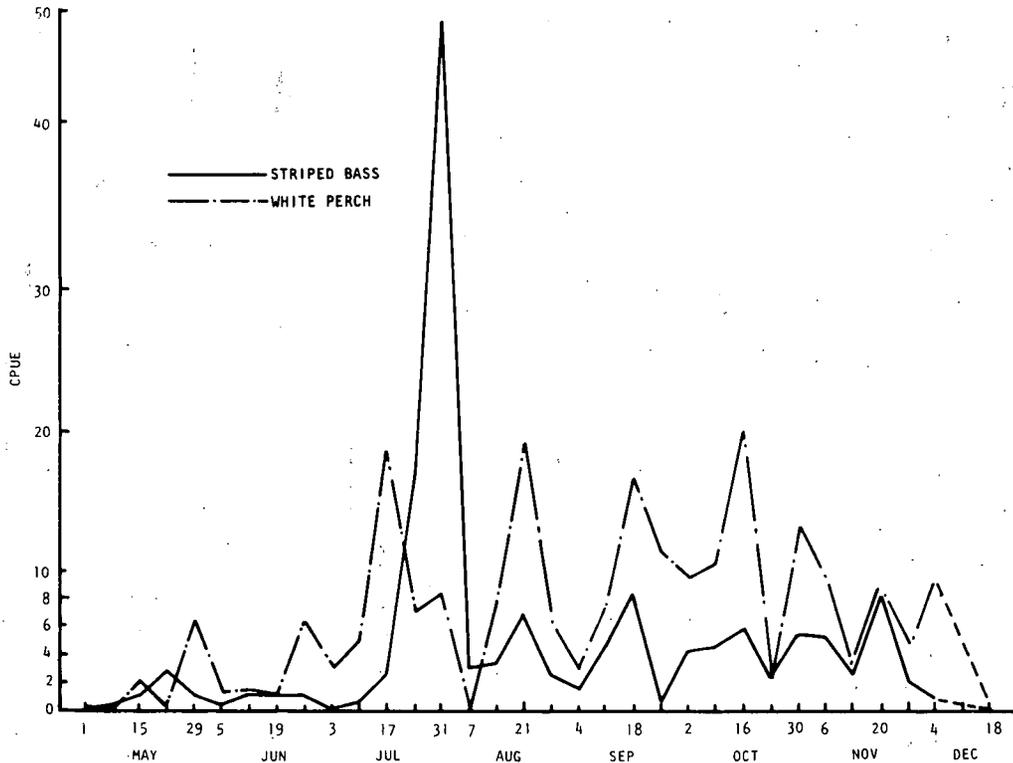


Figure III-13. Average Catch per Unit Effort for White Perch and Striped Bass Taken with Beach Seine in Indian Point Study Area, Hudson Estuary, 1972

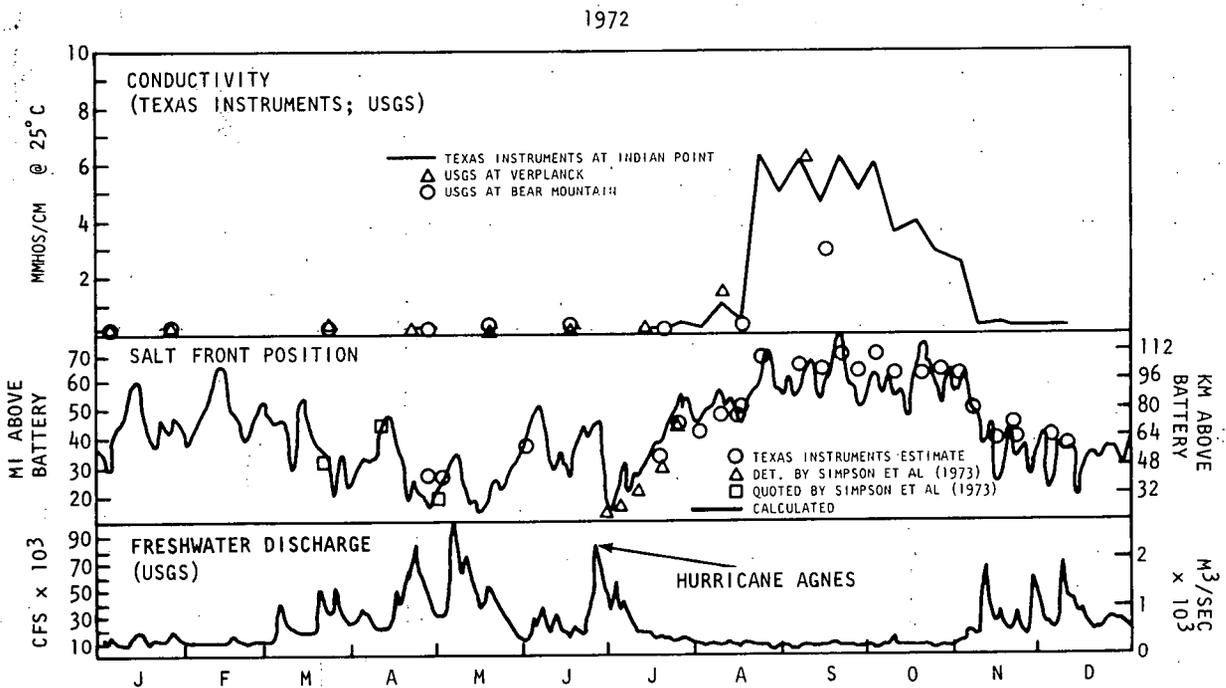


Figure III-14. Temporal Distribution of Conductivity, Salt-Front Location, and Freshwater Flow during 1972

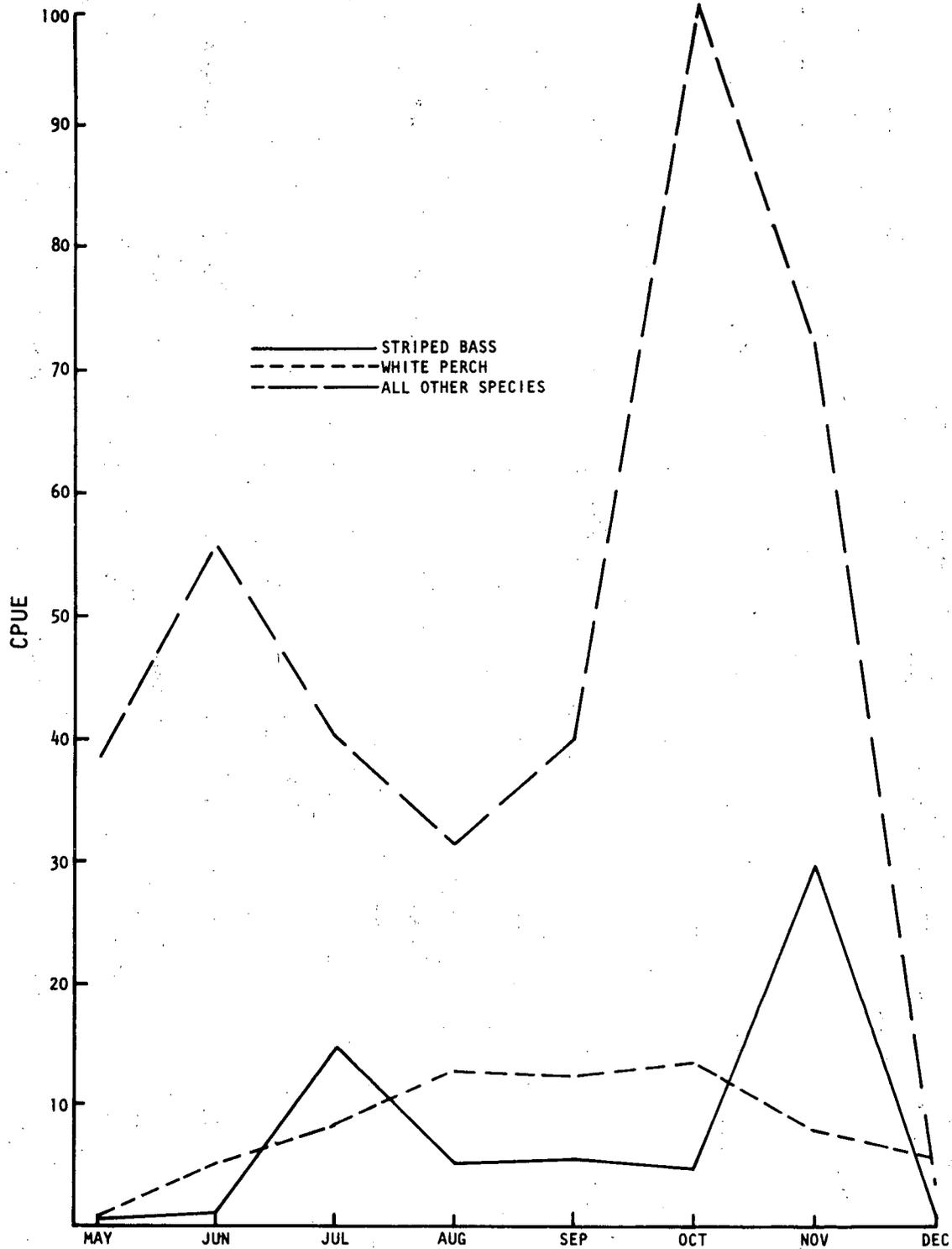


Figure III-15. Average Monthly Catch per Unit Effort for White Perch, Striped Bass, and All Other Species Taken with Beach Seine in Indian Point Study Area, Hudson Estuary, 1972

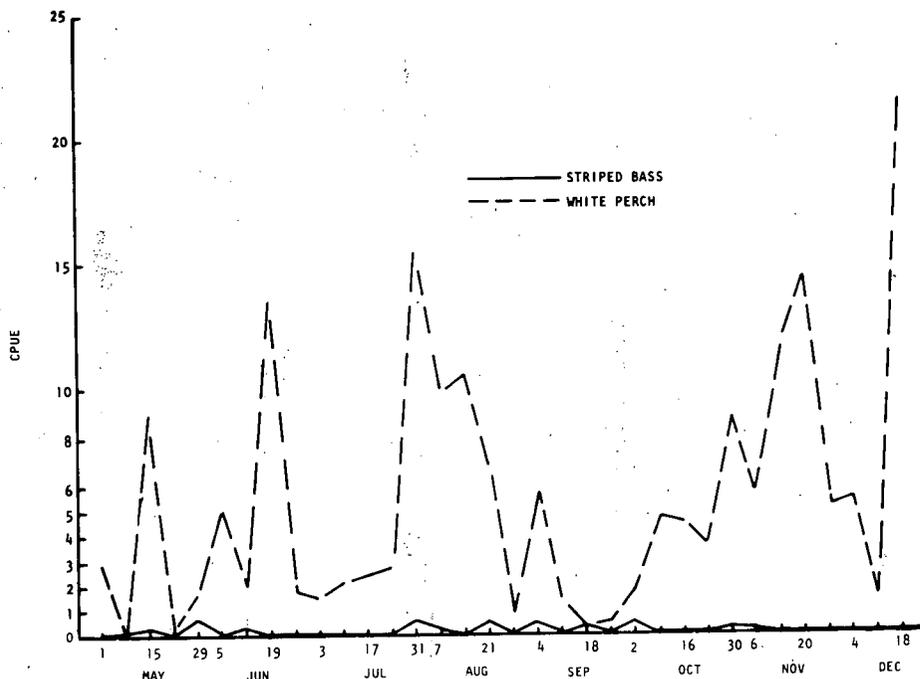


Figure III-16. Average Catch per Unit Effort for Bottom-Trawl Catch of White Perch and Striped Bass in Indian Point Study Area, Hudson Estuary, May-December 1972

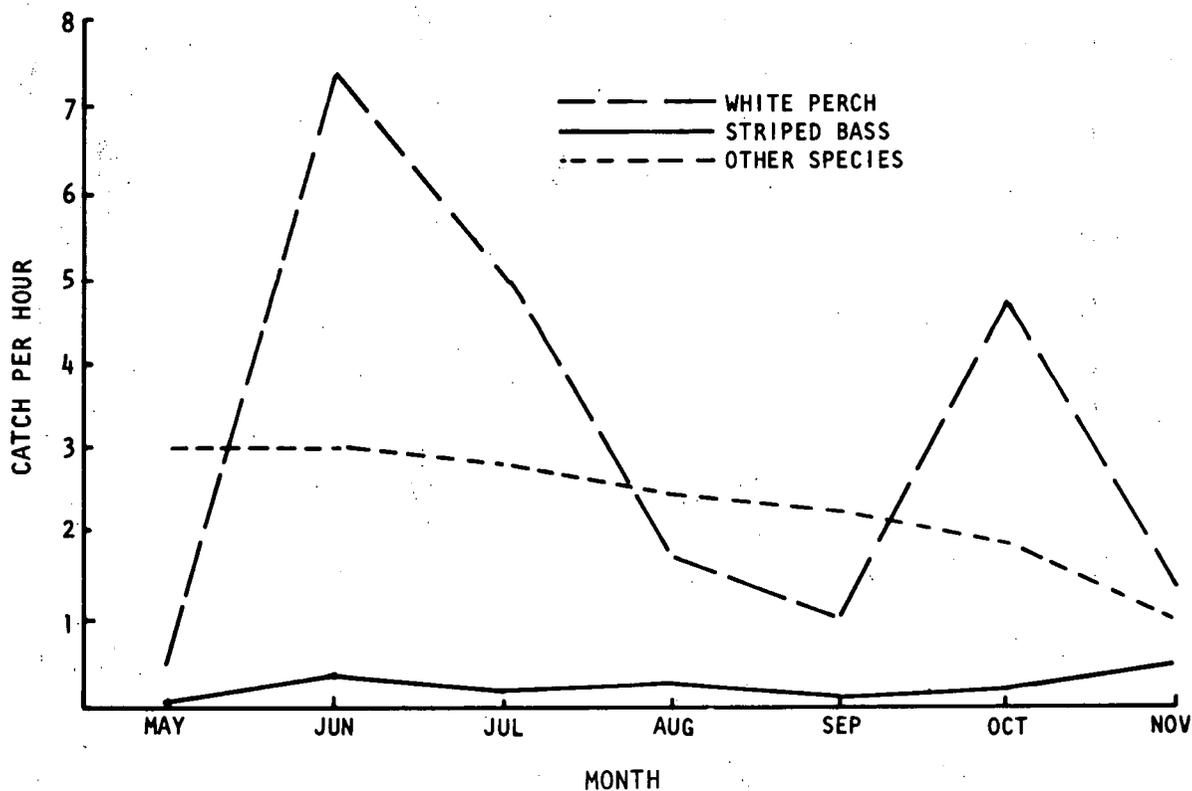


Figure III-17. Average Catch per Unit Effort for Trap-Caught White Perch, Striped Bass, and Other Species, Indian Point Study Area, Hudson Estuary, May-December 1972

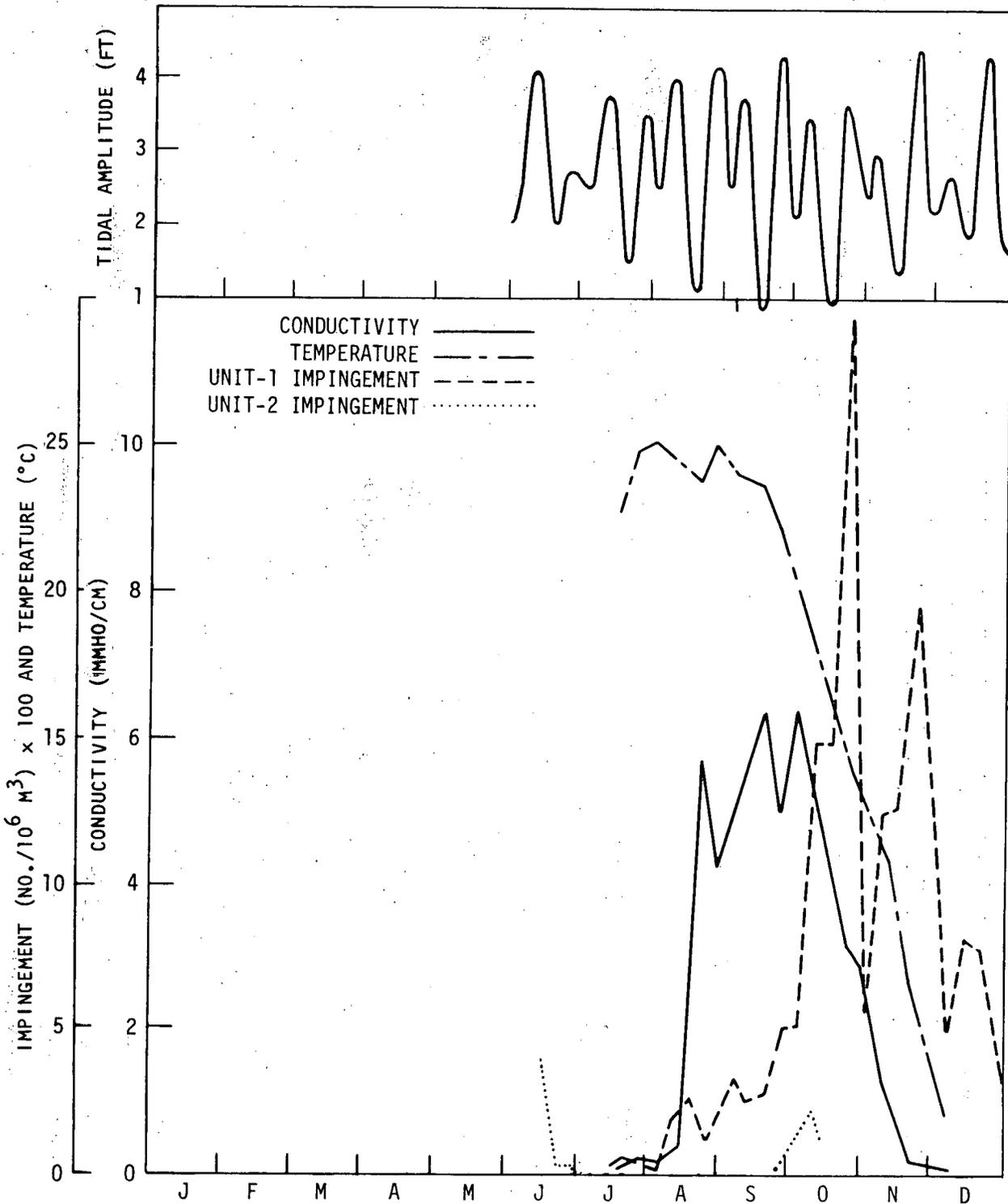


Figure III-18. Weekly Mean White-Perch Impingement Rates and Environmental Measurements at Indian Point Generating-Station Intakes during 1972. (Tidal amplitudes from United States Department of Commerce tide-height tables)

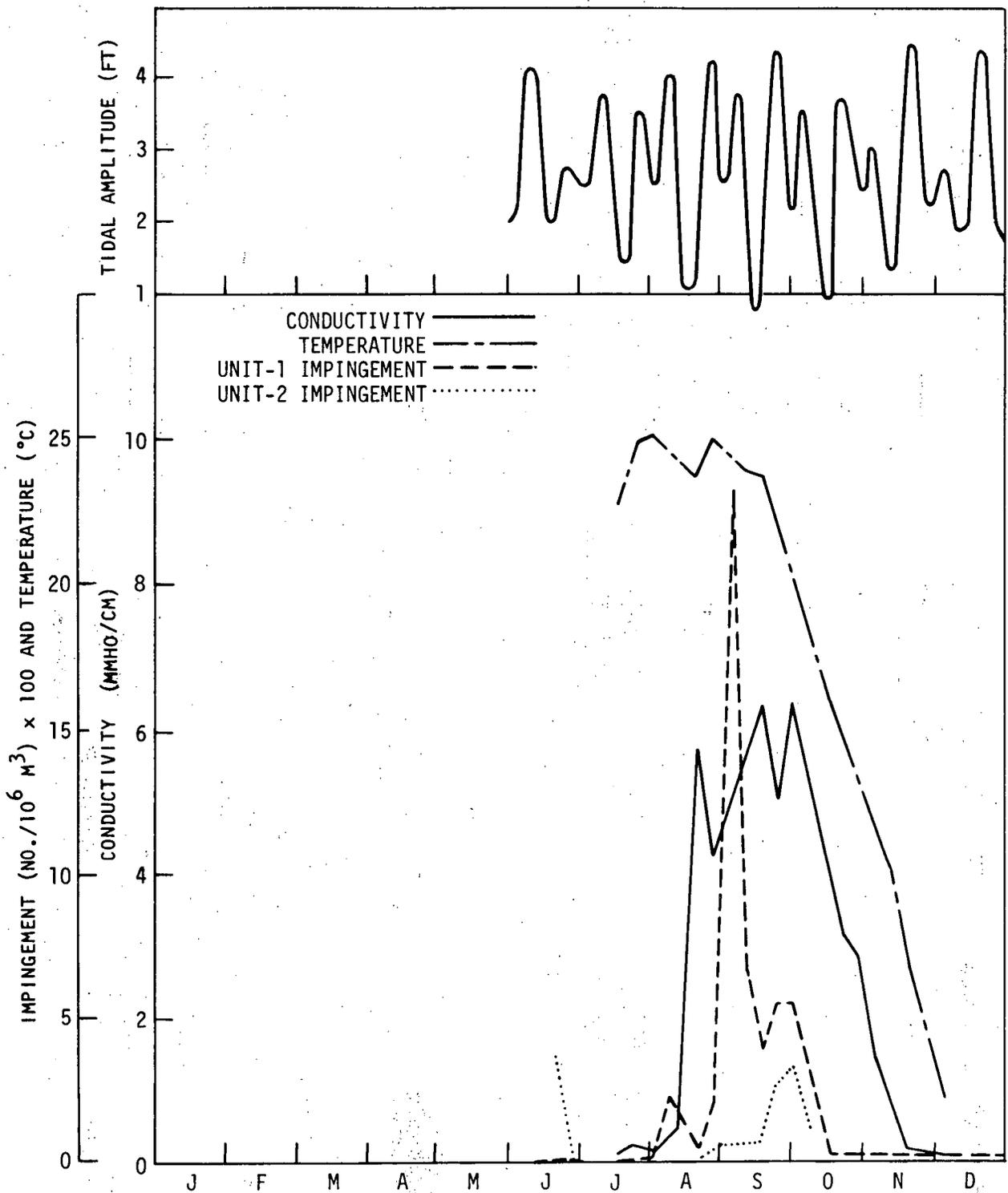


Figure III-19. Weekly Mean Tomcod Impingement Rates and Environmental Measurements at Indian Point Generating-Station Intakes during 1972. (Tidal amplitudes from United States Department of Commerce tide-height tables)

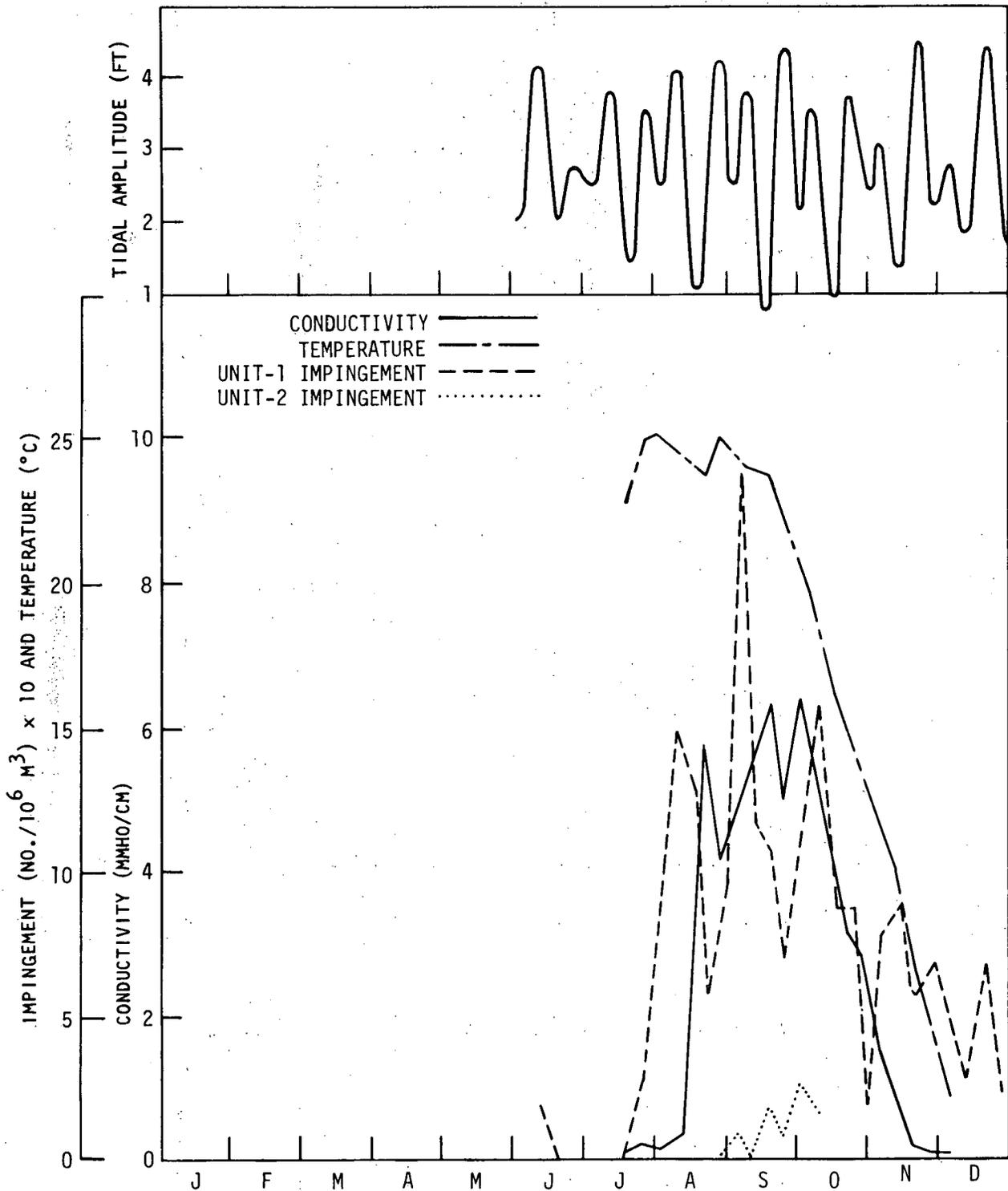


Figure III-20. Weekly Mean Striped-Bass Impingement Rates and Environmental Measurements at Indian Point Generating-Station Intakes during 1972. (Tidal amplitudes from United States Department of Commerce tide-height tables)



The following applies to Figures III-21 through III-31.

- CPUE Catch per unit effort values are discrete samples.
- Conductivity
- Temperature
- Dissolved oxygen
- Missing data points
- Vertical dashed-dotted line Approximate time of peak spawning activity

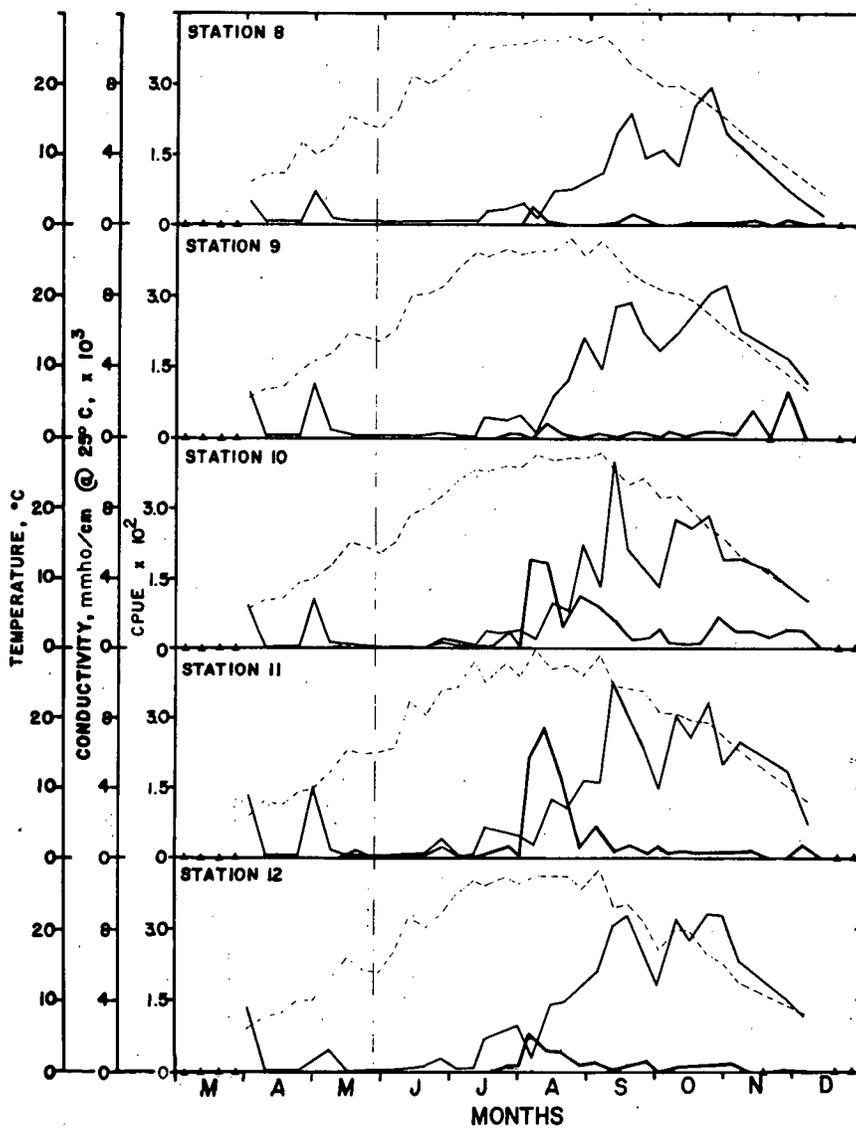


Figure III-21. Beach-Seine Weekly Mean Catch per Unit Effort, Striped Bass, Plotted with Conductivity and Temperature Vs Time during 1973

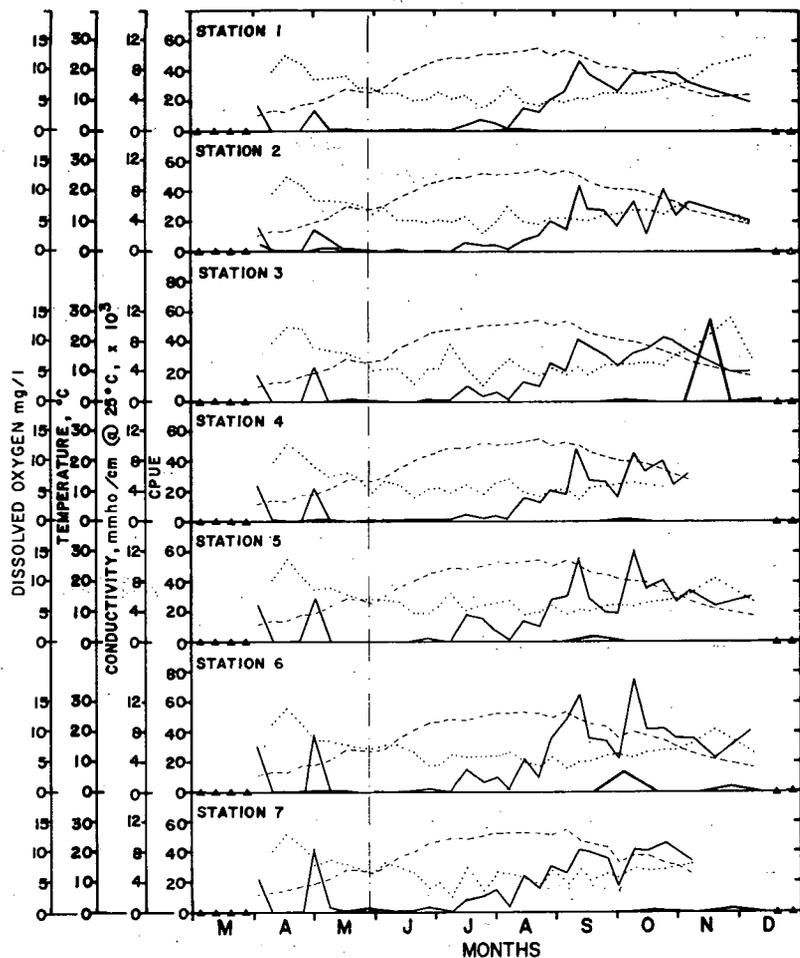


Figure III-22. Bottom-Trawl Biweekly Catch per Unit Effort, Striped Bass, Plotted with Conductivity, Temperature, and Dissolved-Oxygen Concentrations Vs Time during 1973

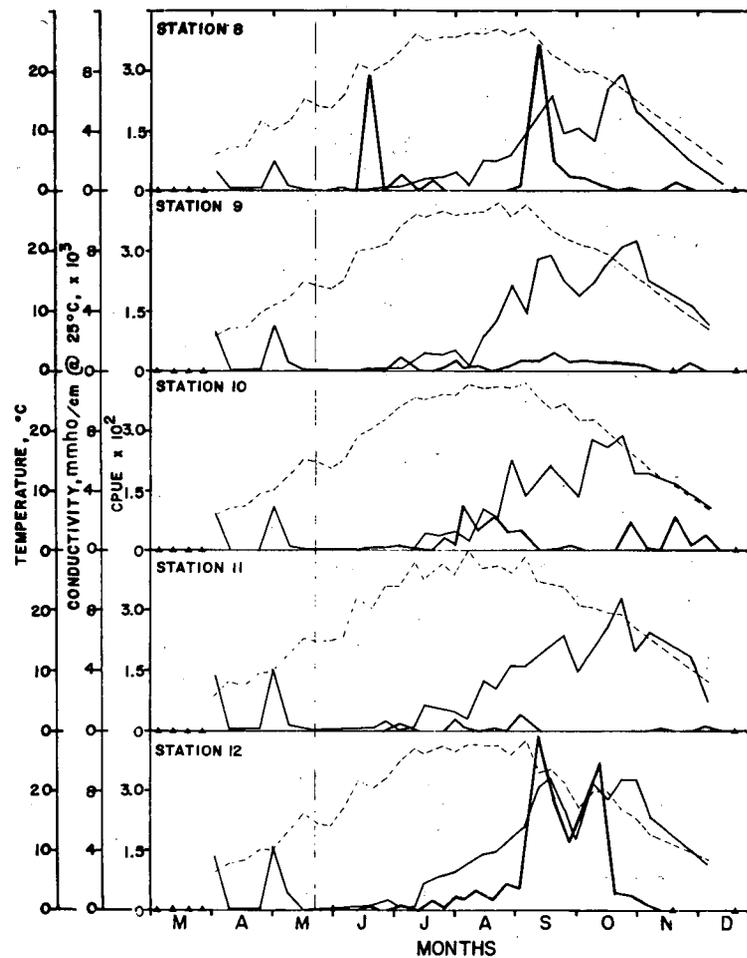


Figure III-23. Beach-Seine Weekly Mean Catch per Unit Effort, White Perch, Plotted with Conductivity and Temperature Vs Time during 1973

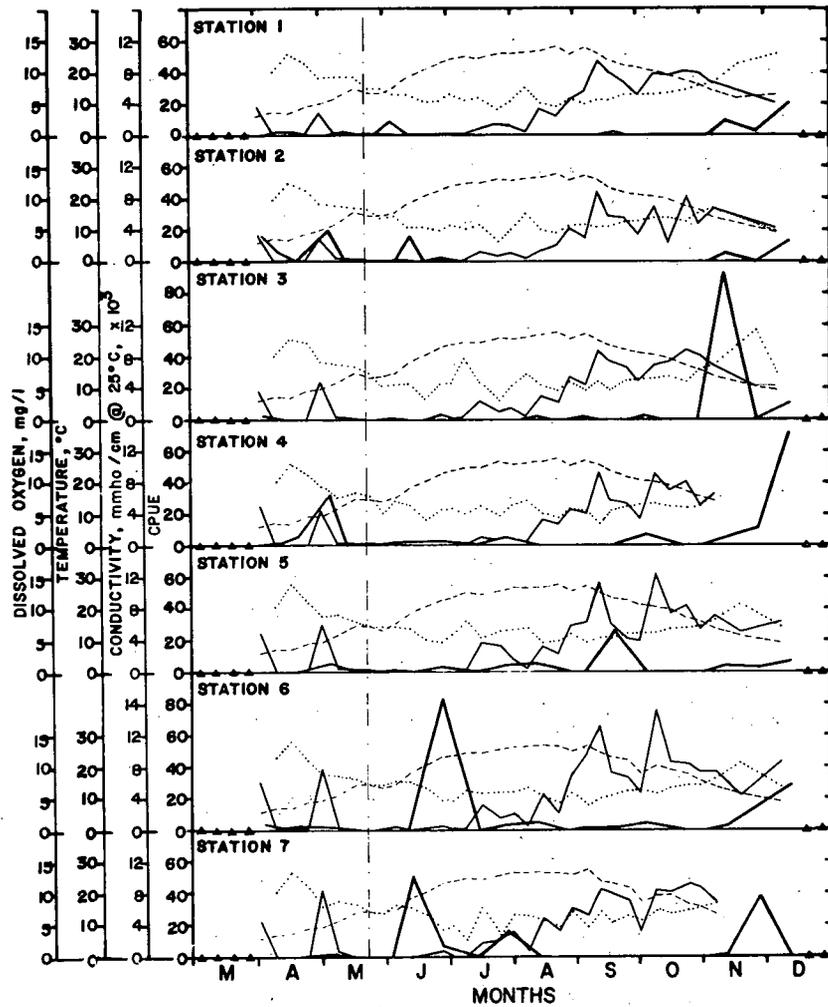


Figure III-24. Bottom-Trawl Biweekly Catch per Unit Effort, White Perch, Plotted with Conductivity, Temperature, and Dissolved-Oxygen Concentrations Vs Time during 1973

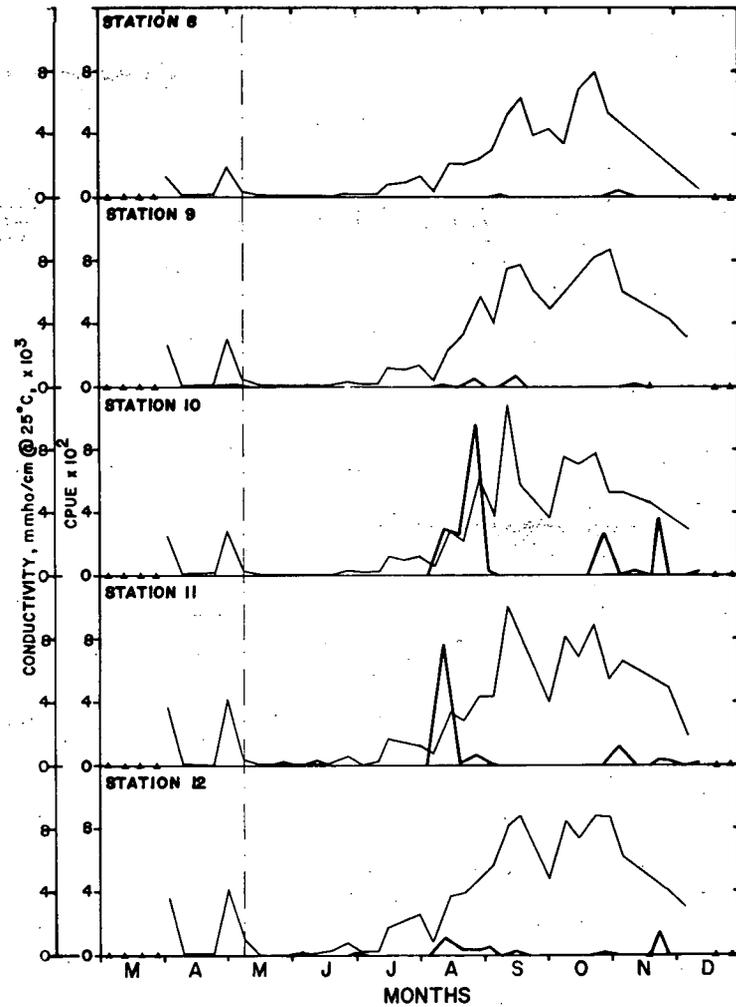


Figure III-25. Beach-Seine Weekly Mean Catch per Unit Effort, Blueback Herring, Plotted with Conductivity Vs Time during 1973



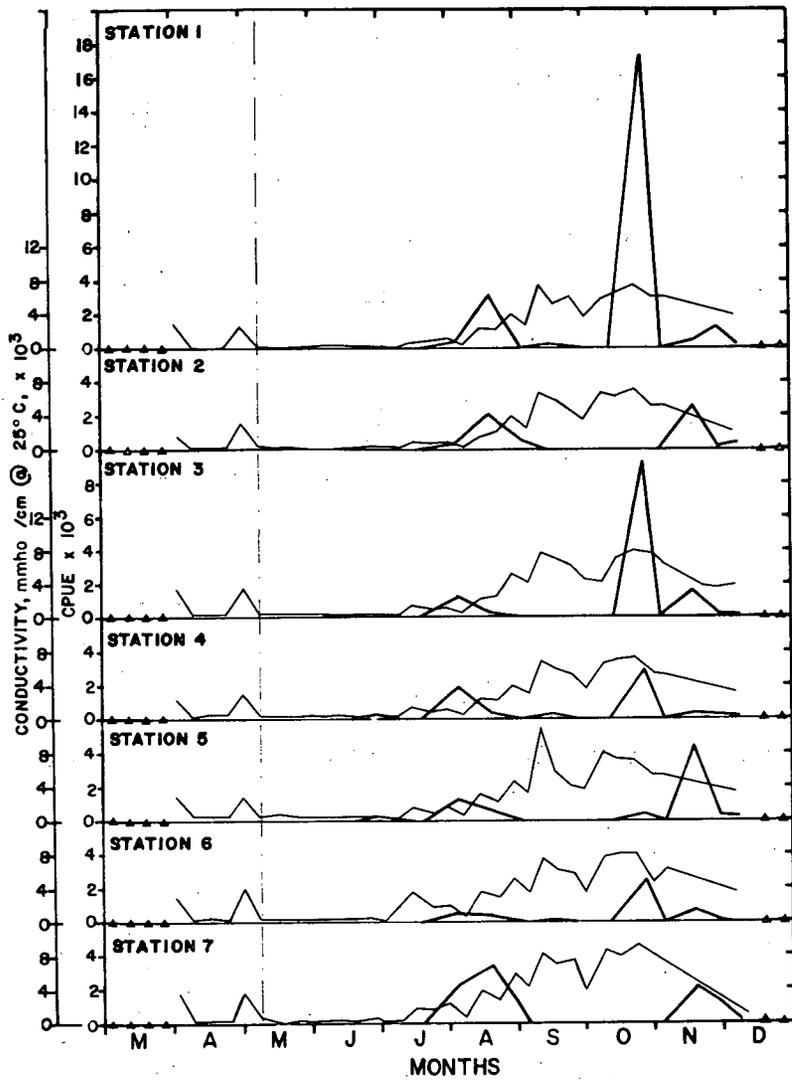


Figure III-26. Surface-Trawl Biweekly Catch per Unit Effort, Blueback Herring, Plotted with Conductivity Vs Time during 1973

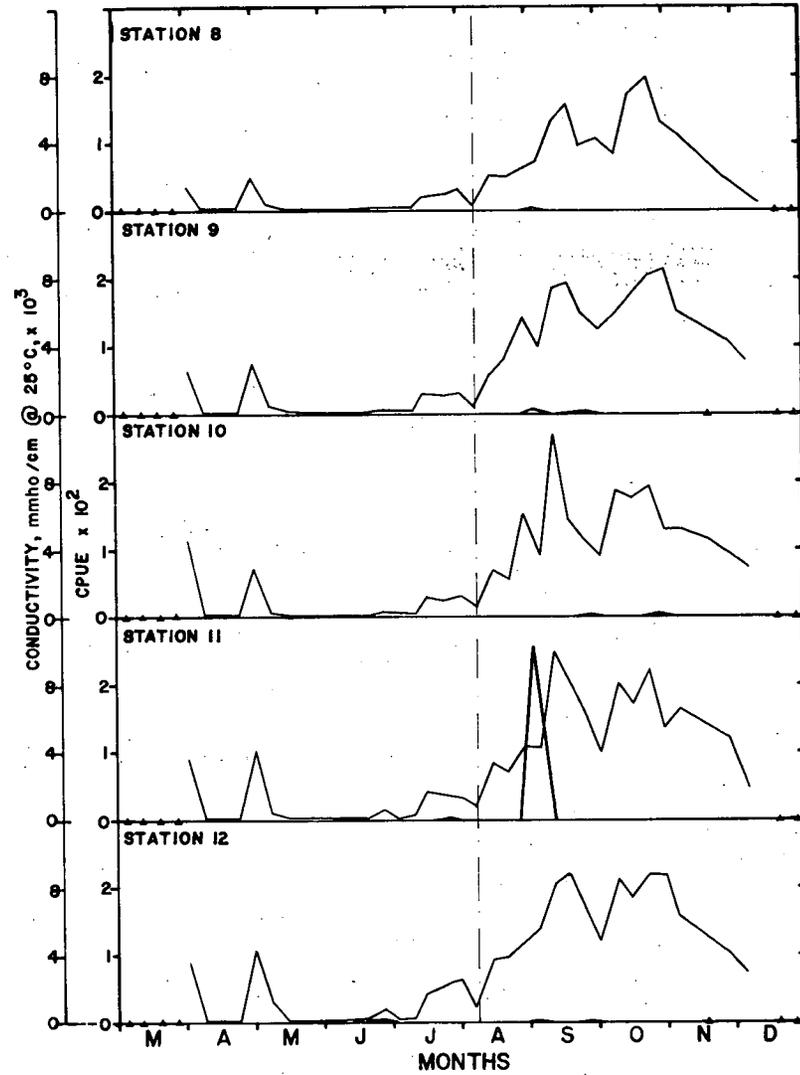


Figure III-27. Beach-Seine Weekly Mean Catch per Unit Effort, Bay Anchovy, Plotted with Conductivity Vs Time during 1973



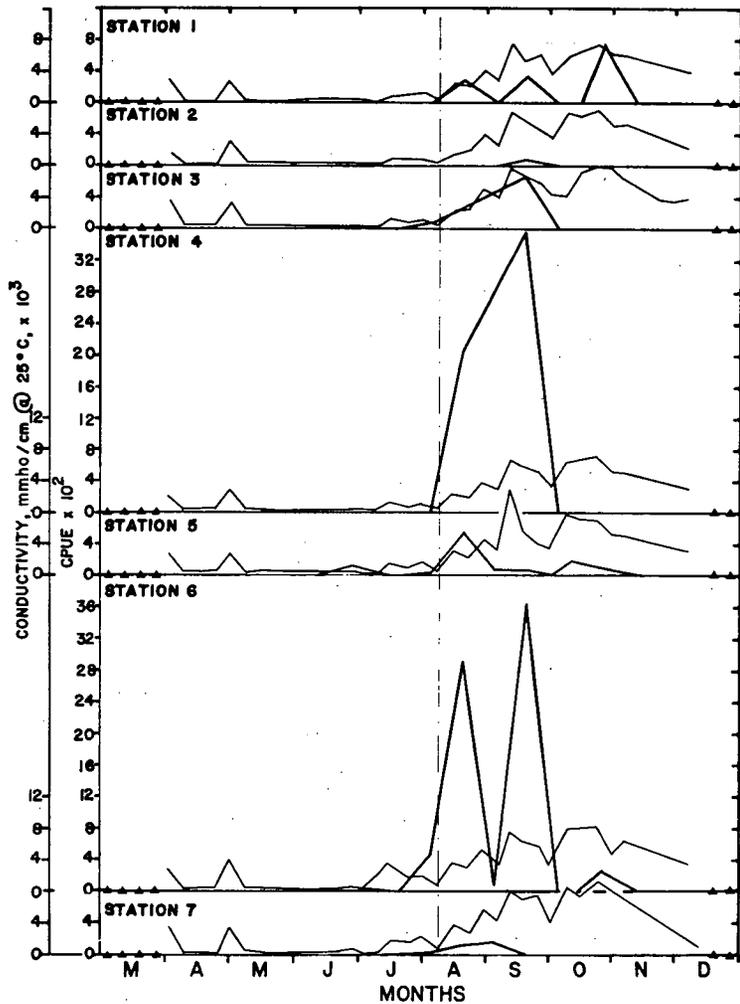


Figure III-28. Surface-Trawl Biweekly Catch per Unit Effort, Bay Anchovy, Plotted with Conductivity Vs Time during 1973

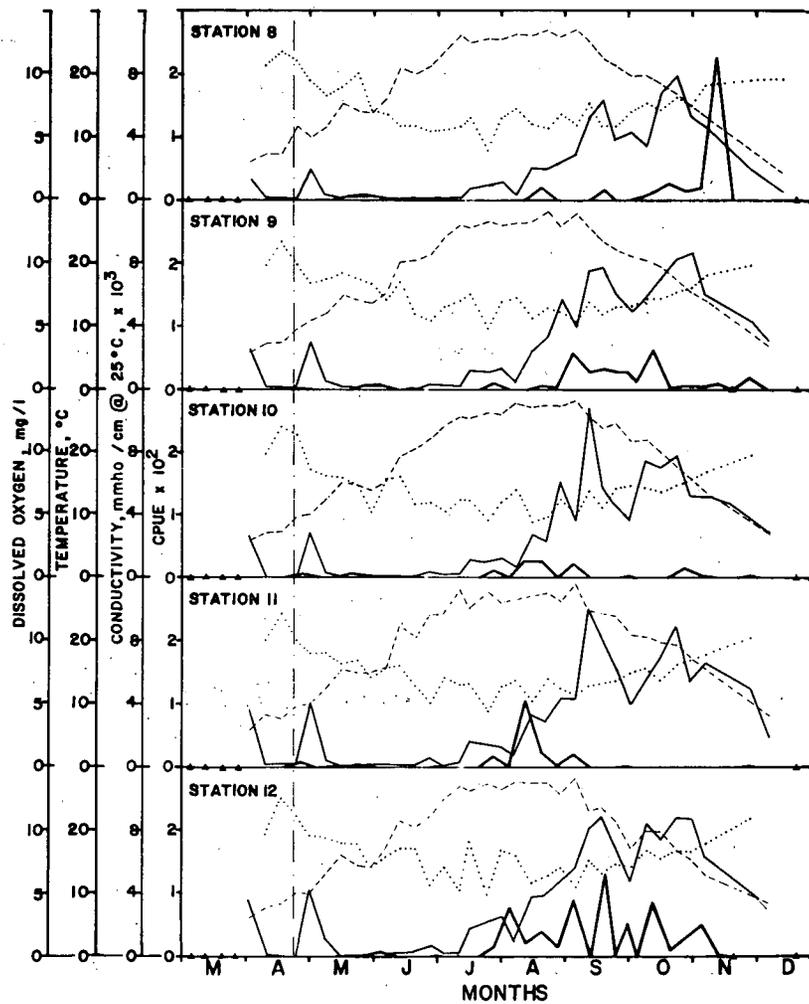


Figure III-29. Beach-Seine Weekly Mean Catch per Unit Effort, Alewife, Plotted with Conductivity, Temperature, and Dissolved-Oxygen Concentrations Vs Time during 1973

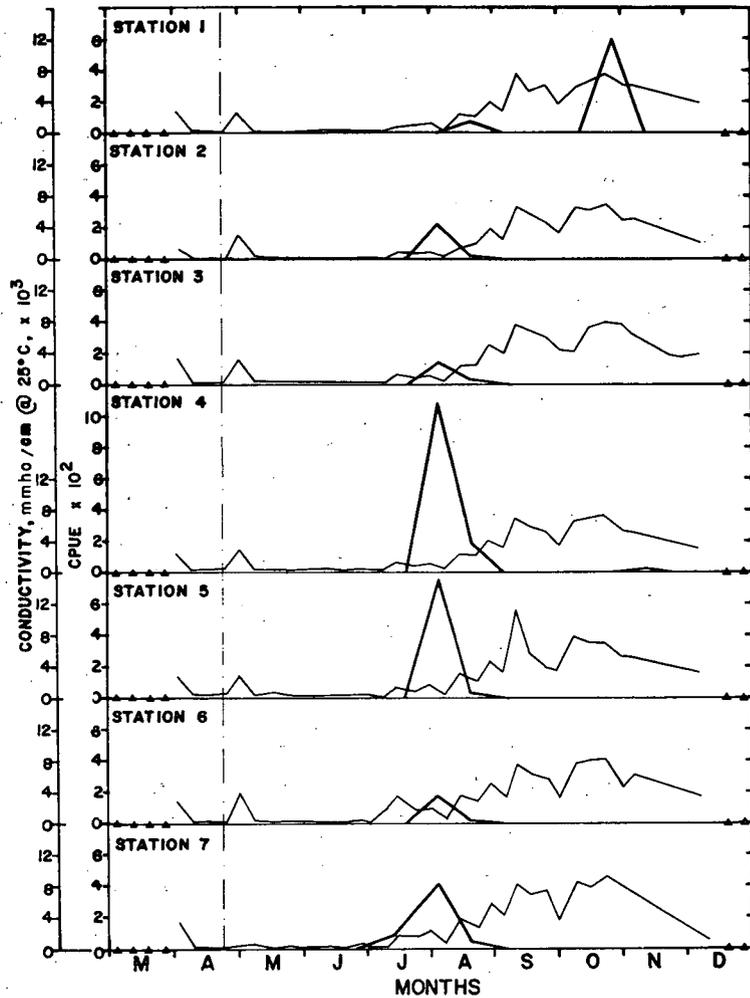


Figure III-30. Surface-Trawl Biweekly Catch per Unit Effort, Alewife, Plotted with Conductivity Vs Time during 1973

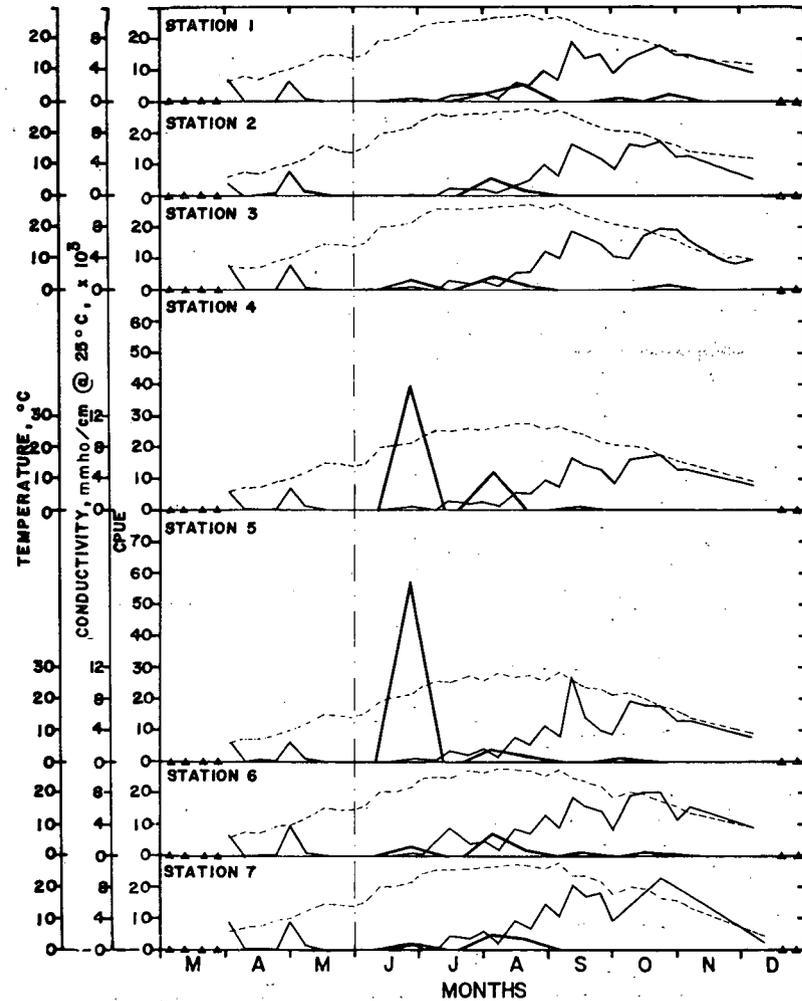


Figure III-31. Surface-Trawl Biweekly Catch per Unit Effort, Bluefish, Plotted with Conductivity and Temperature Vs Time during 1973



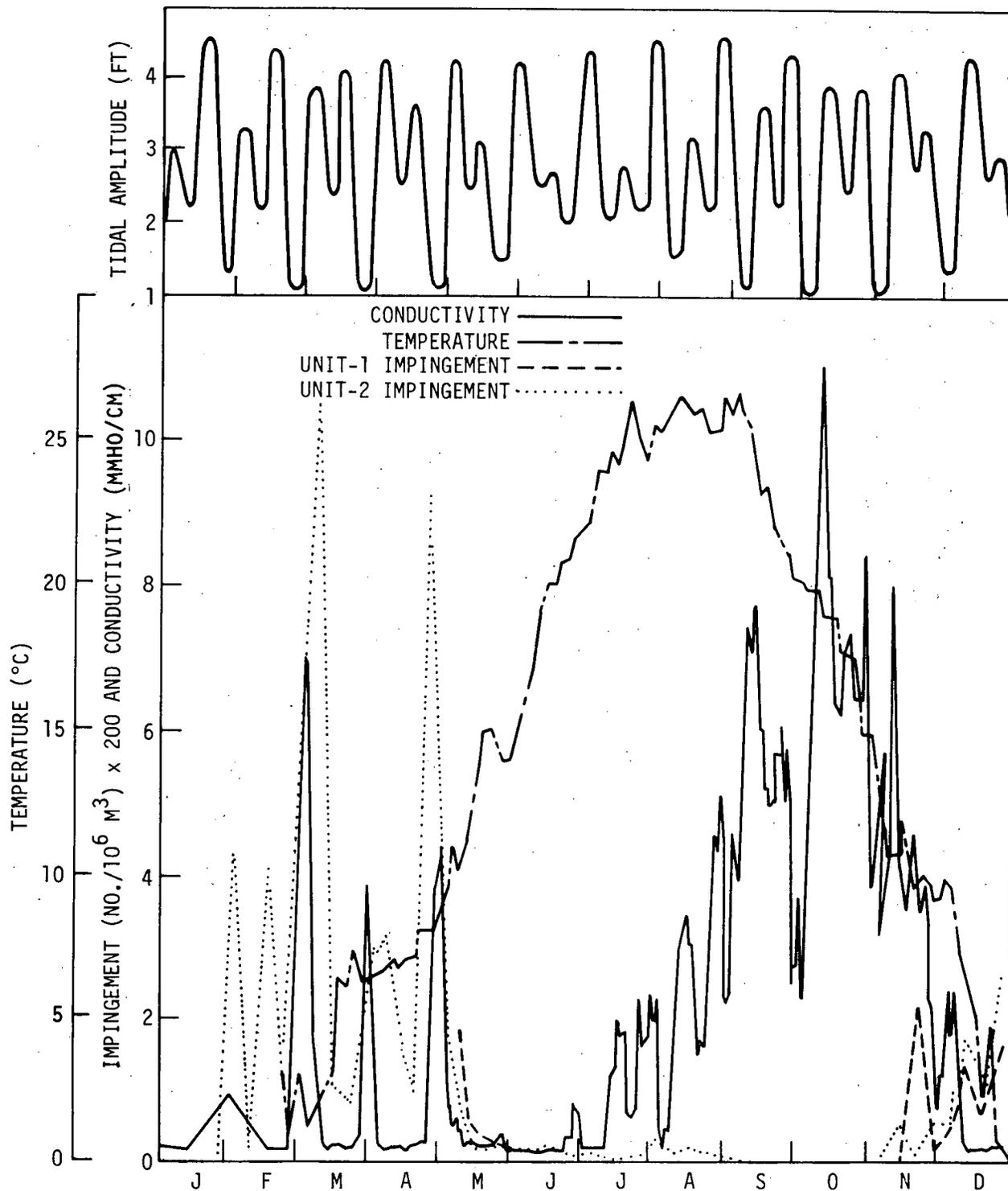


Figure III-32. Weekly White Perch Impingement Rates and Environmental Measurements at Indian Point Generating-Station Intakes during 1973. (Tidal amplitudes from United States Department of Commerce tide-height tables. Conductivity values are daily measurements; temperatures are plotted for every third day.)

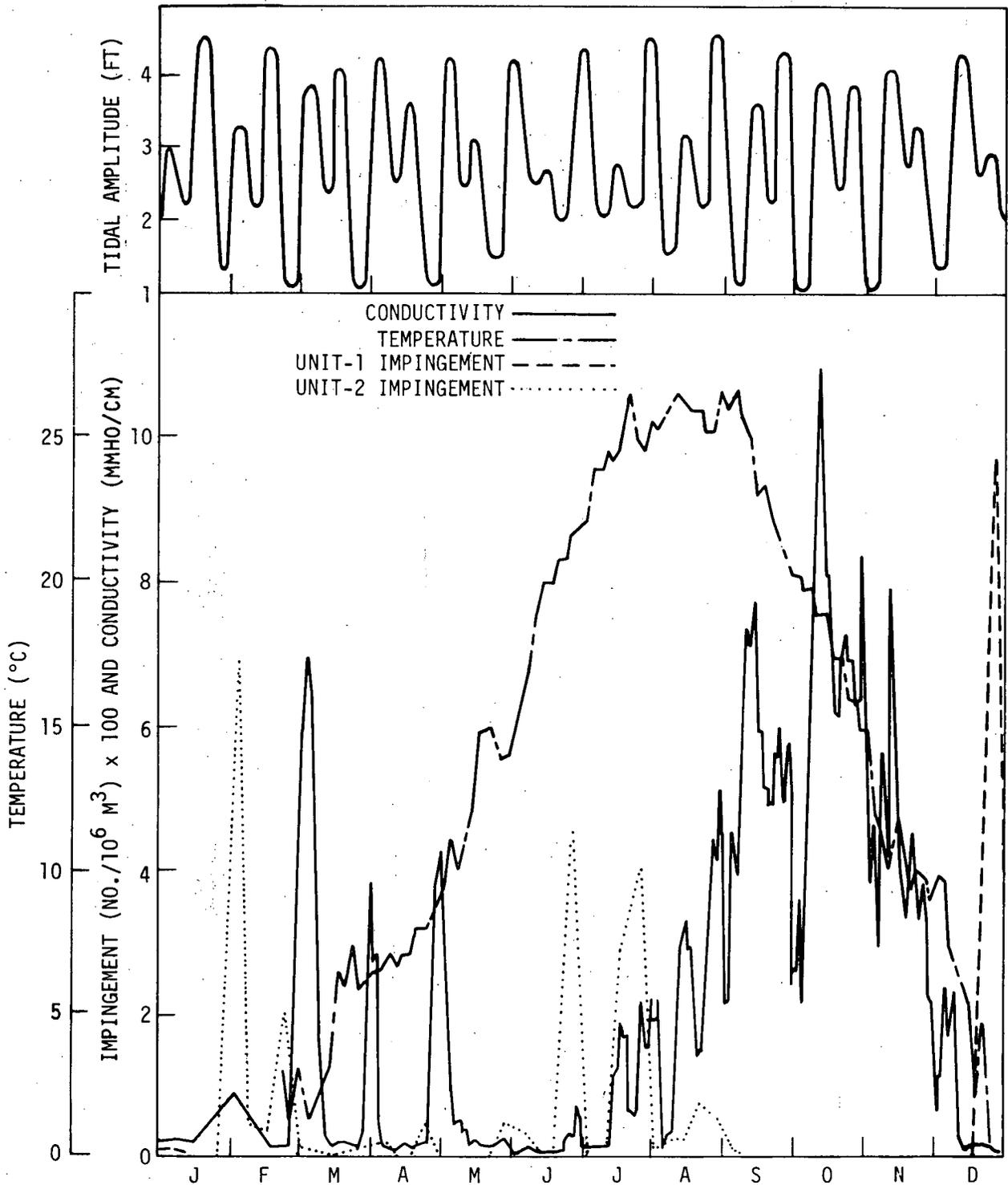


Figure III-33. Weekly Tomcod Impingement Rates and Environmental Measurements at Indian Point Generating-Station Intakes during 1973. (Tidal amplitudes from United States Department of Commerce tide-height tables. Conductivity values are daily measurements; temperatures are plotted for every third day.)

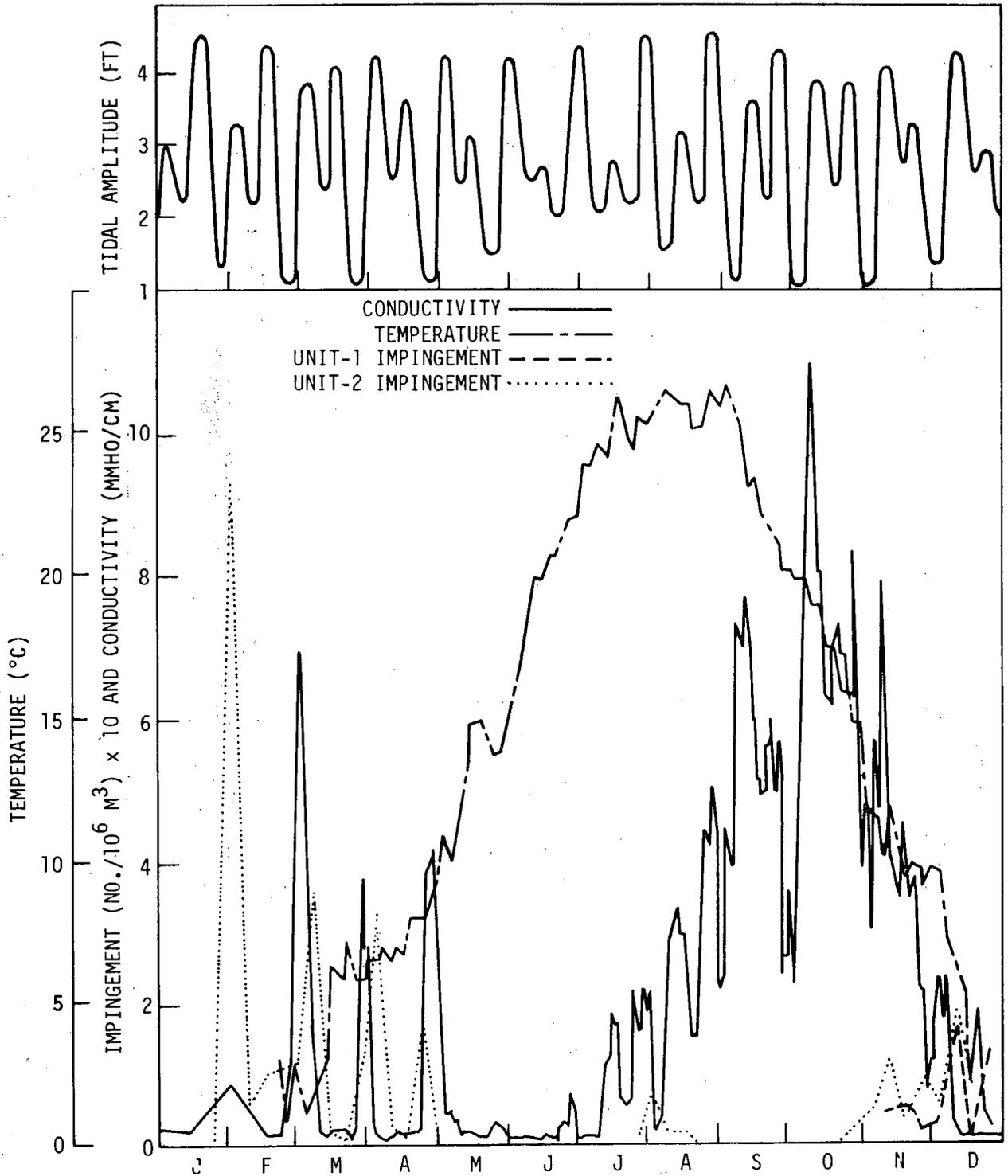


Figure III-34. Weekly Mean Striped Bass Impingement Rates and Environmental Measurements at Indian Point Generating-Station Intakes during 1973. (Tidal amplitudes from United States Department of Commerce tide-height tables. Conductivity values are daily measurements; temperatures are plotted for every third day.)



The abundance of young-of-the-year striped bass fell sharply in 1974. Regardless of the reason for the reduction in catches, the result was a minimal trawl CPUE for striped bass. Other species, however, tended to exhibit bimodality around the summer intrusion period. In fact, some rather large tomcod and white perch catches were made near the summer intrusion period (Figure III-35). Beach-seine catches (Figure III-36) continued the bimodal pattern, even exhibiting the high catches of striped bass as the summer intrusion of salt water began (a phenomenon observed throughout the study period). Clupeid catches seemed to respond to salt intrusion in a more general manner, exhibiting peaks near the salt-intrusion or retreat times at upstream stations (8, 9), while tending to follow conductivity peaks at downriver stations (10, 11, 12, 21, and 22).

The impingement collection data of 1974 illustrate the predominance of white perch during cooler months. During the January-May period (Figure III-37), white perch constituted the majority of all impinged fish. Between early June and late August, tomcod predominated in impingement collections, with white perch regaining dominance during October and November. As in previous years, the association between impingement peaks and salt intrusion was maximal during the period of greatest impingement, December through July of the following year.

2. Spatial Distribution of Fishes Relative to Physical/Chemical Variables

a. Salt Intrusion/Freshwater Effects

Longitudinal distributions of fish relative to the salt front appear to be well defined, particularly in the case of those fish species most subject to impingement. The case of Atlantic tomcod illustrates the phenomenon of salt-front association quite well since this species exhibits little tendency to move from deeper water (shoals) to beach areas (as is the case with white perch). Throughout the year, tomcod appear to migrate in moderately deep water in association with the salt front.

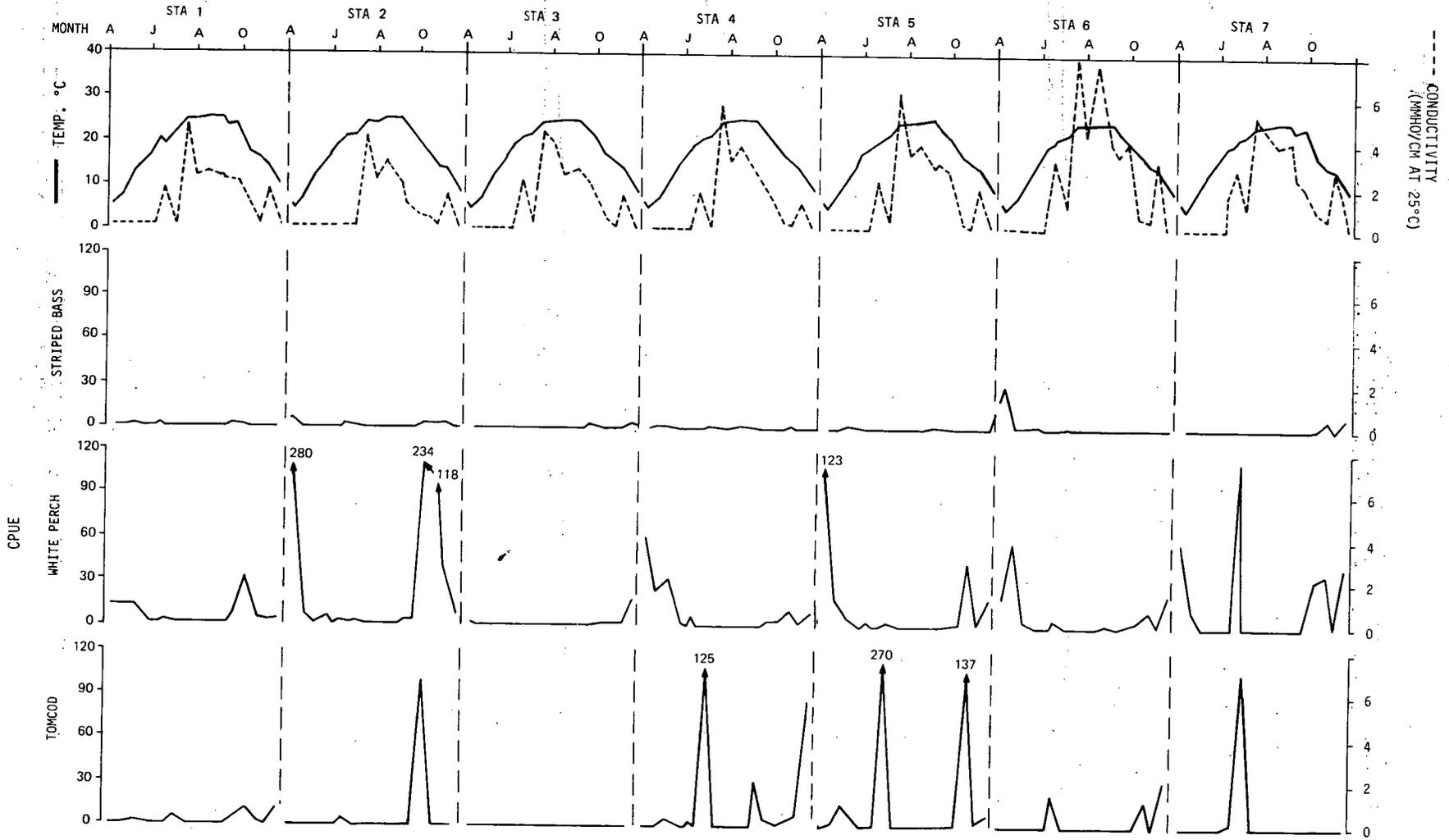


Figure III-35. Comparison of Temporal Distributions of Environmental Variables and Catch per Unit Effort for Striped Bass, White Perch, and Atlantic Tomcod at Standard Bottom-Trawl Stations near Indian Point during 1974

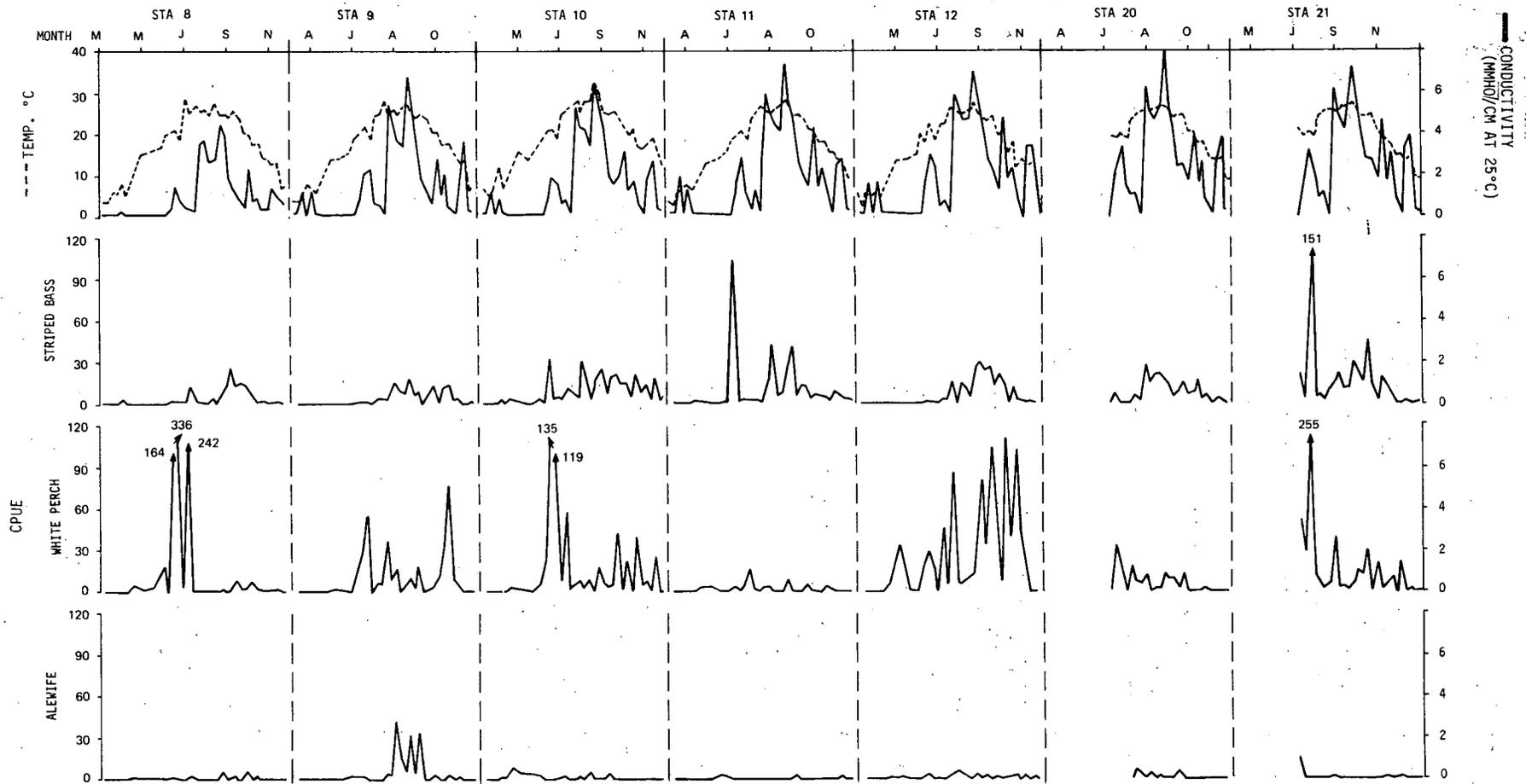


Figure III-36. Comparison of Temporal Distributions of Environmental Variables and Catch per Unit Effort for Striped Bass, White Perch, and Selected Clupeids at Standard Beach-Seine Stations near Indian Point during 1974 (Page 1 of 2)

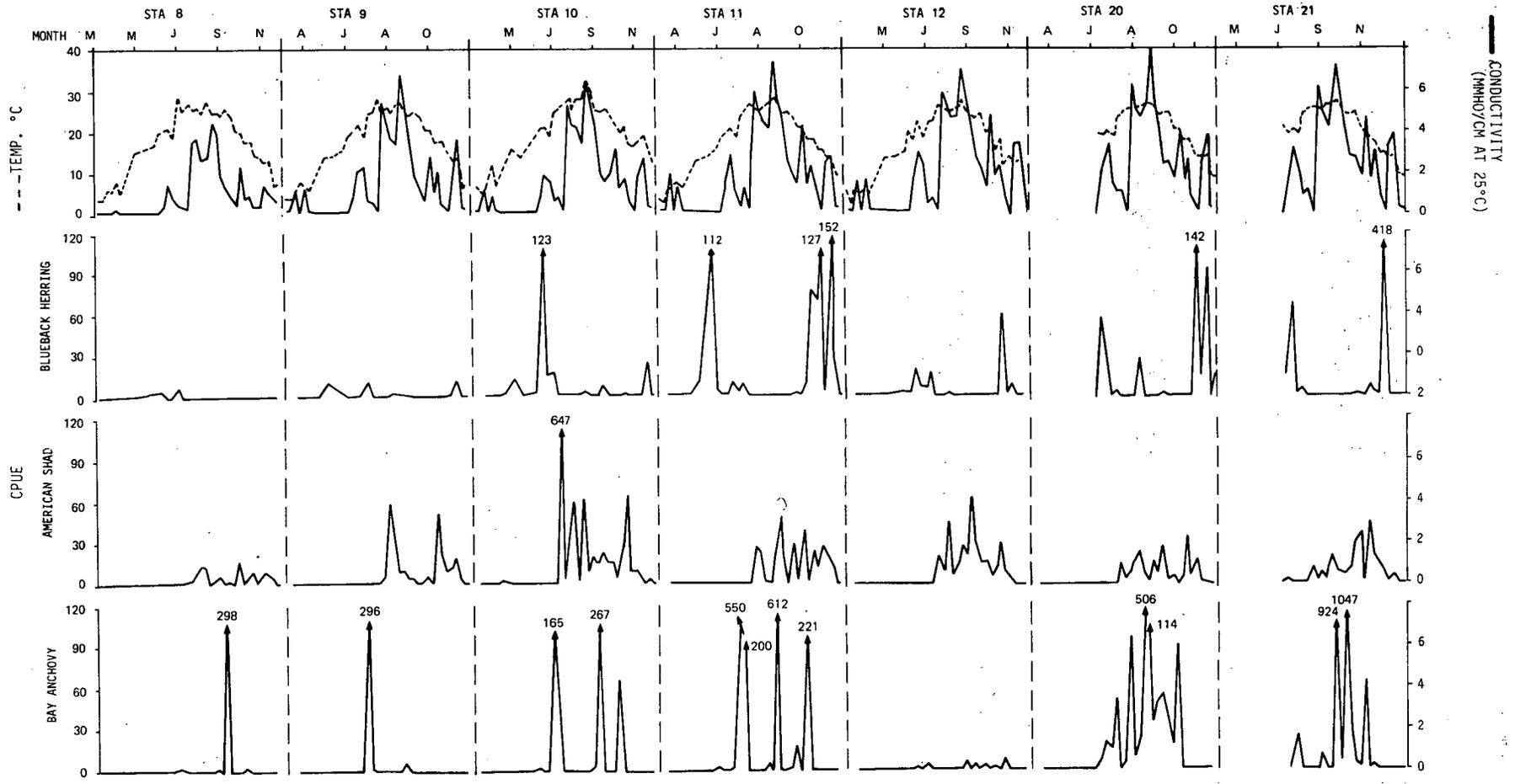


Figure III-36. (Page 2 of 2)



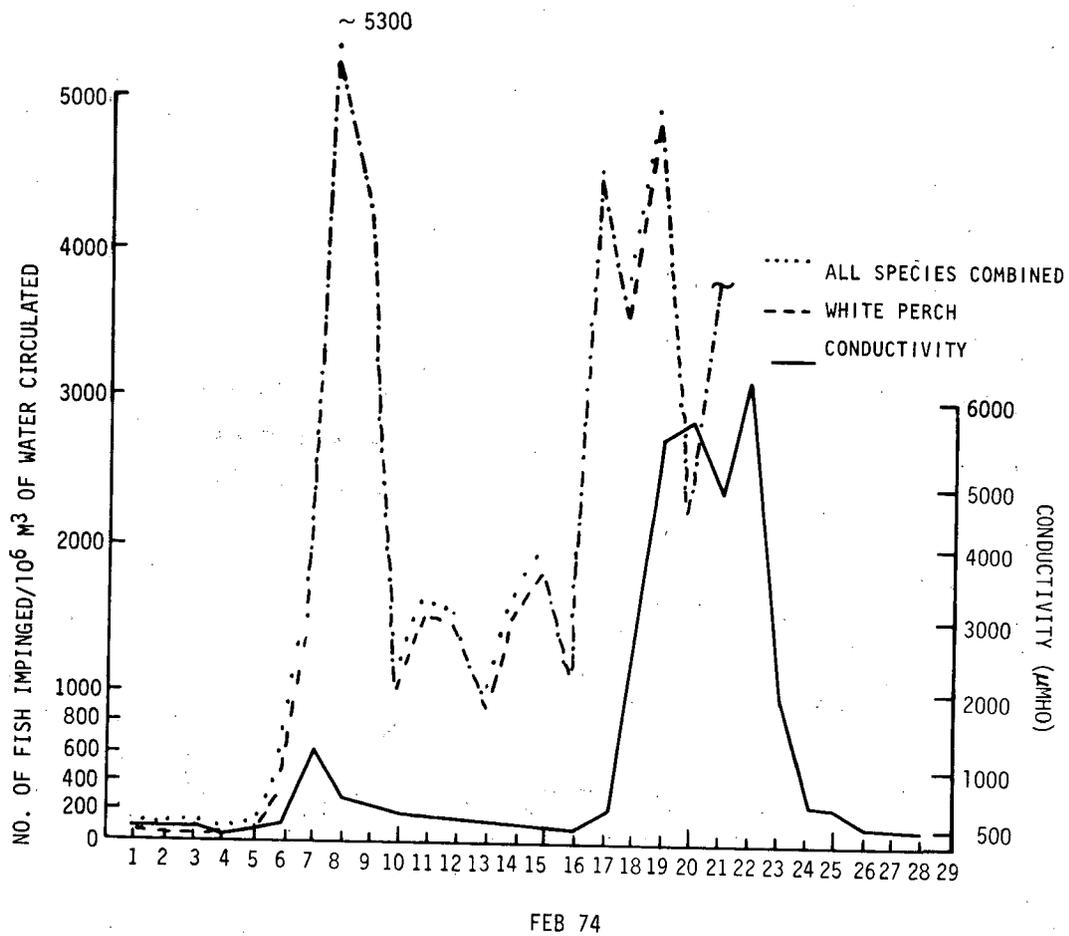
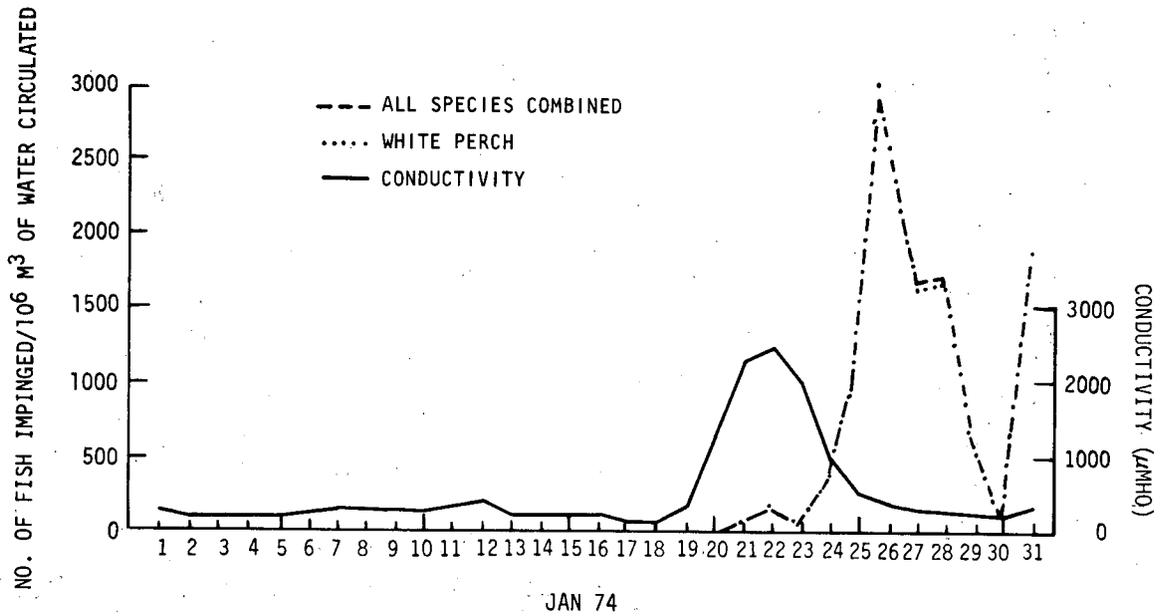


Figure III-37. Fish Impingement Rates and Conductivity Measurements at Indian Point Unit 2 during 1974. (Page 1 of 6)

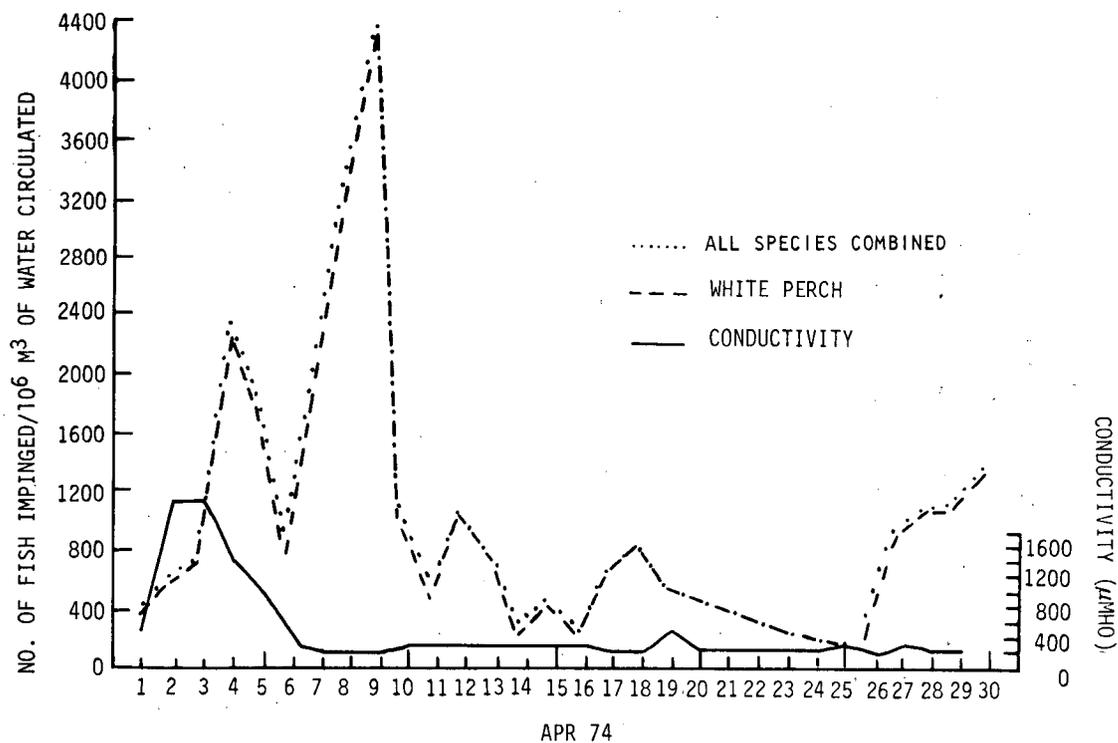
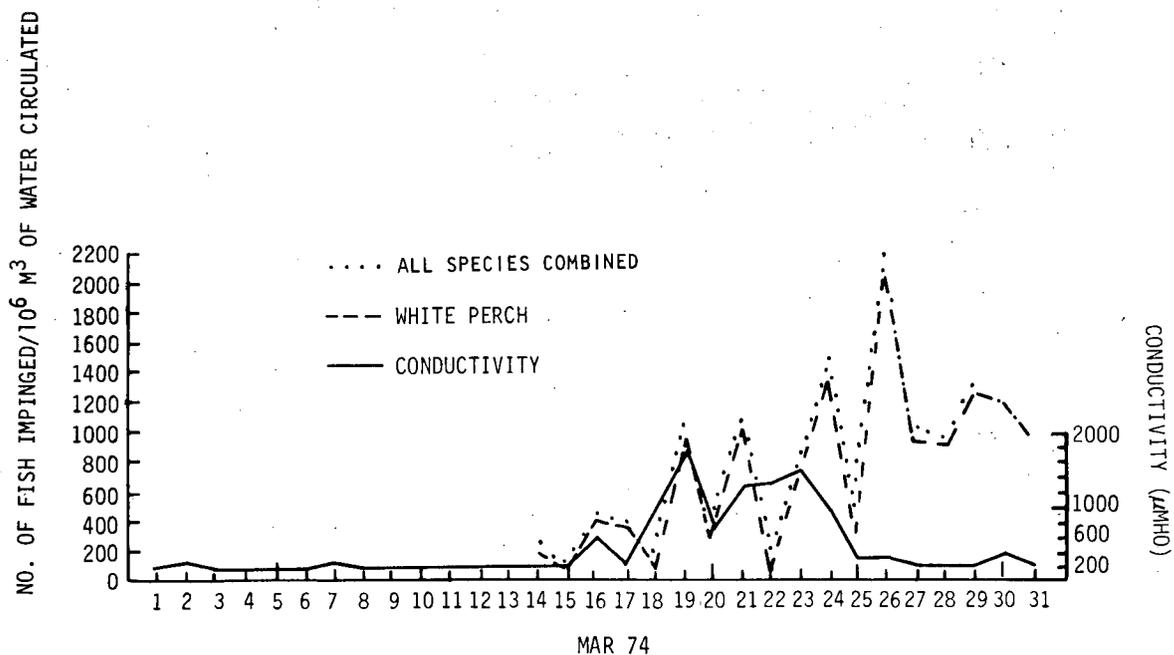


Figure III-37. (Page 2 of 6)

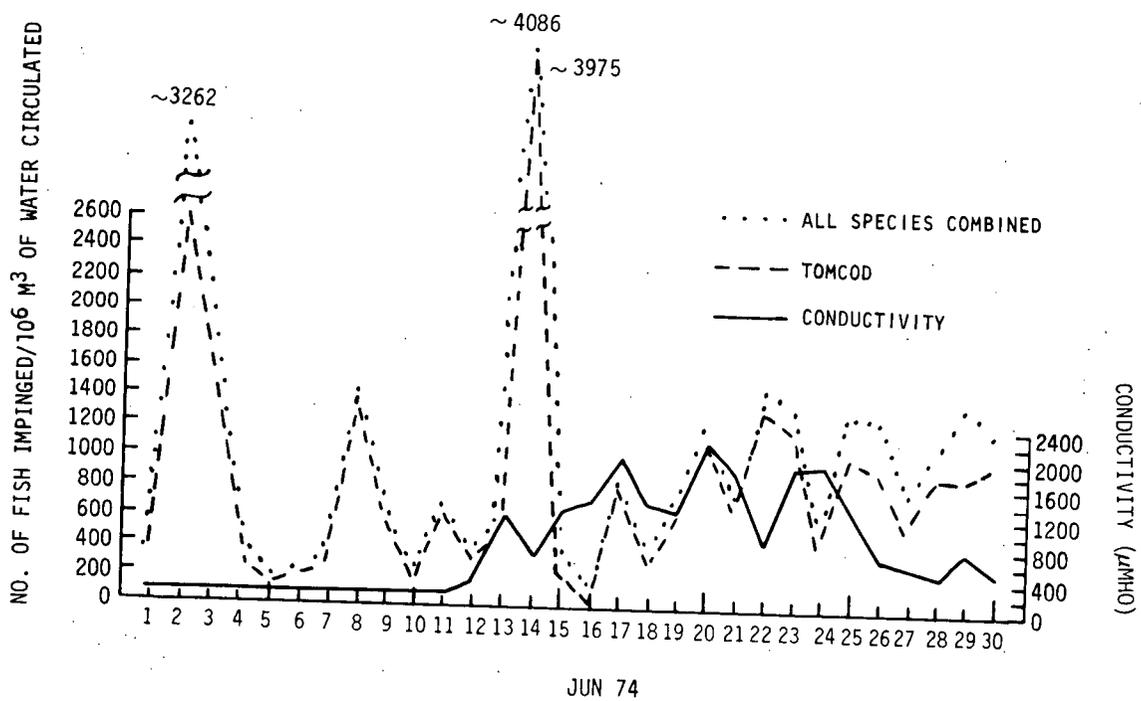
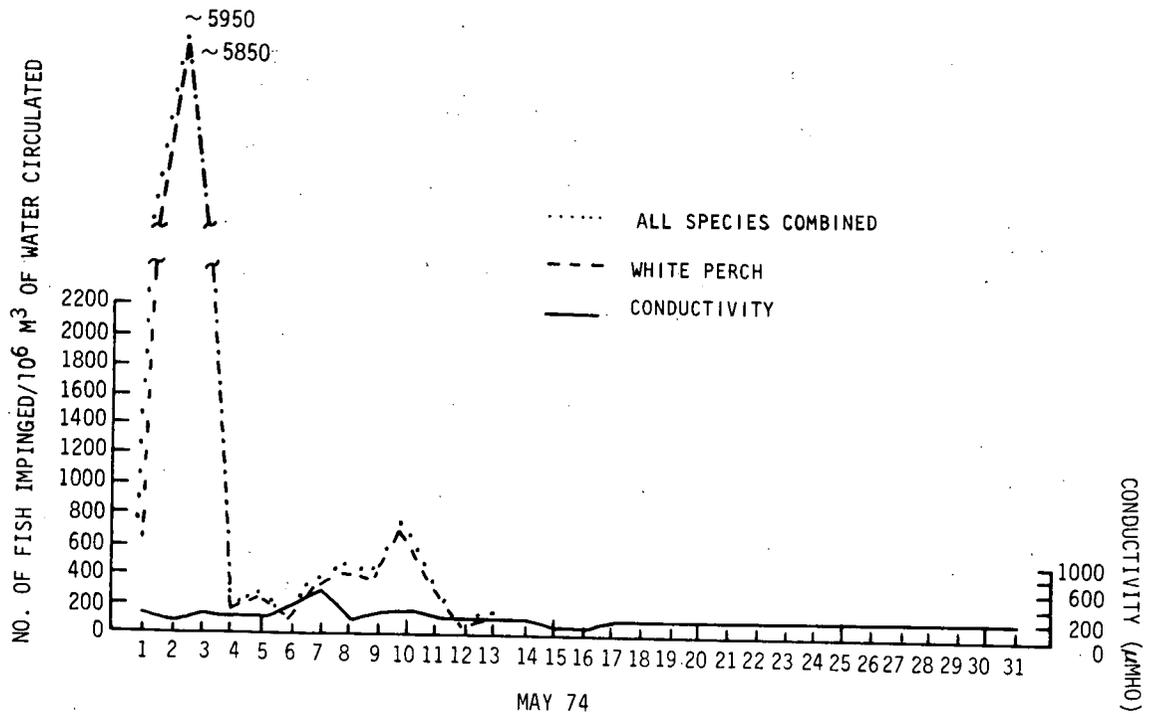


Figure III-37. (Page 3 of 6)

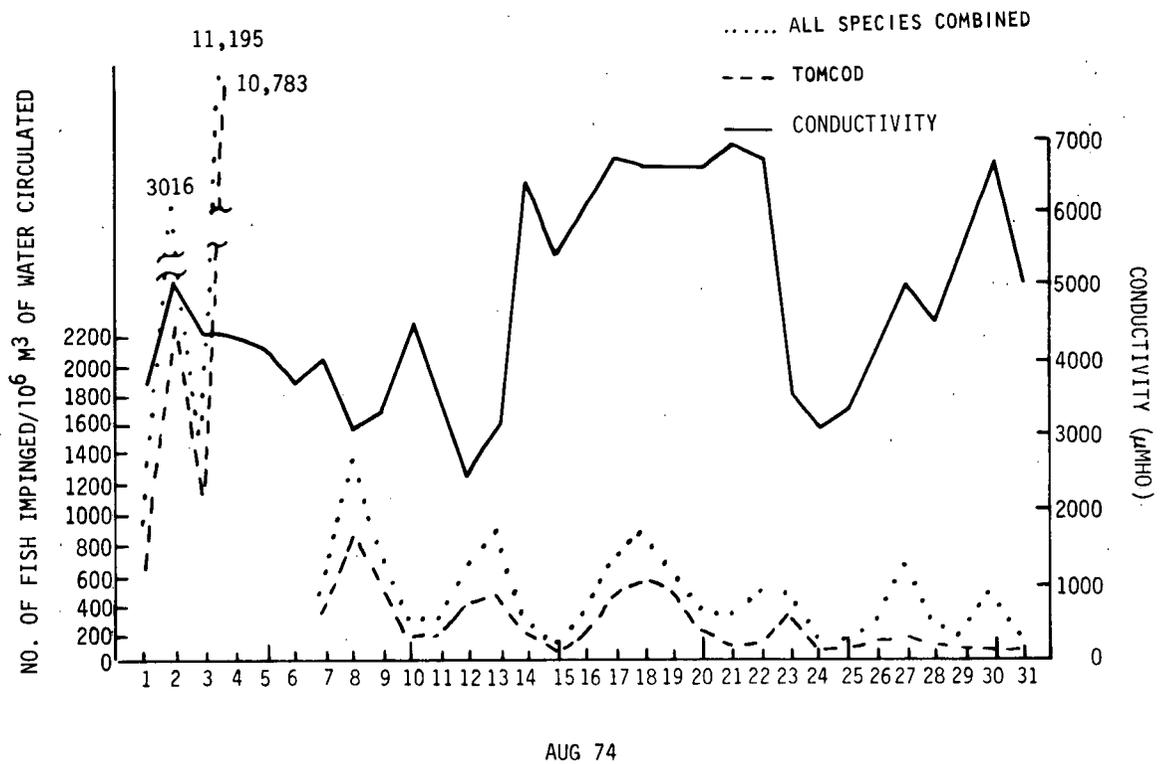
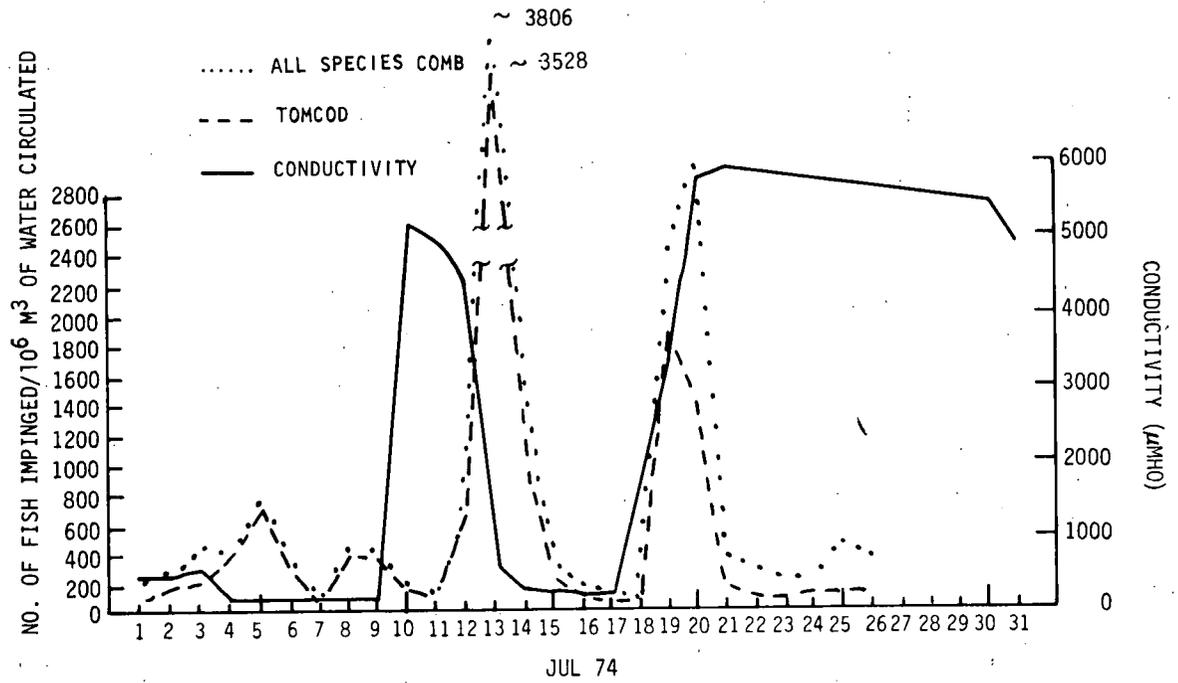


Figure III-37. (Page 4 of 6)

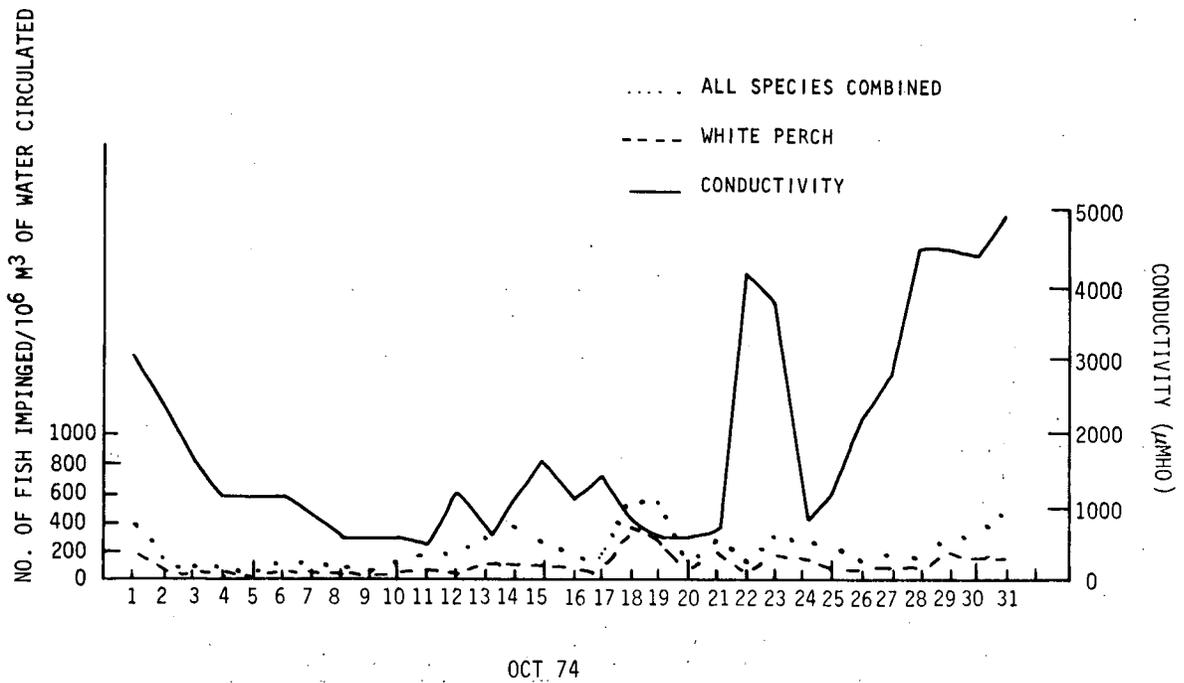
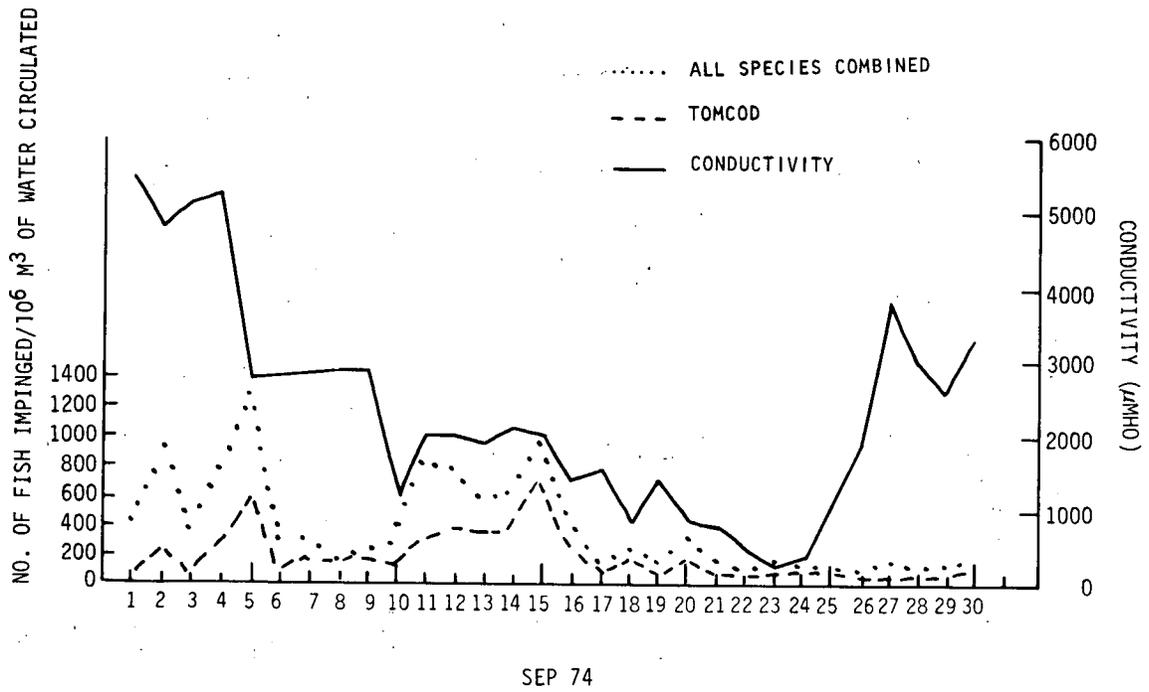


Figure III-37. (Page 5 of 6)

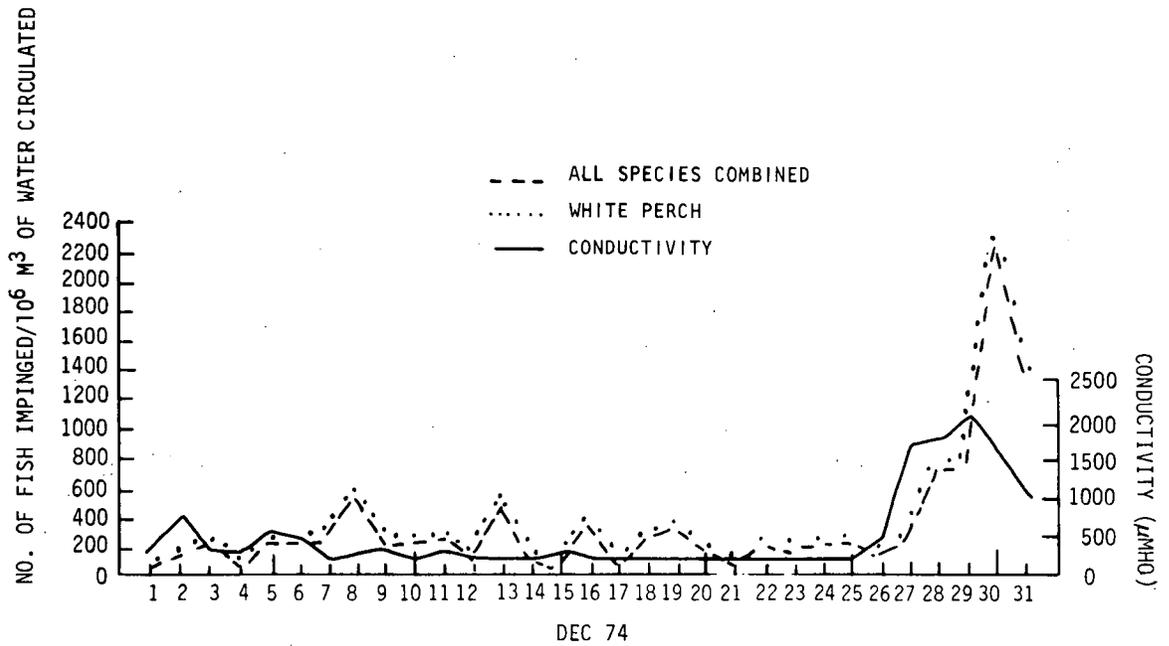
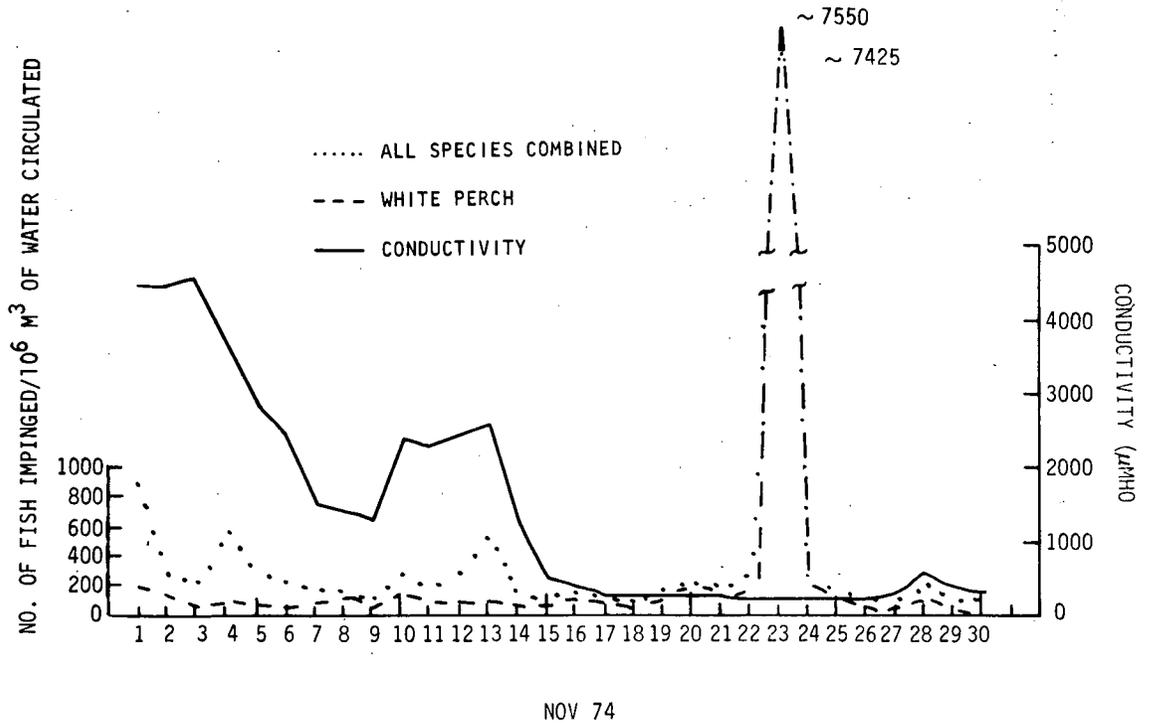


Figure III-37. (Page 6 of 6)



Figure III-38 shows longitudinal distributions of conductivity, temperature, and tomcod catches in ichthyoplankton gear; only maximum catch values for 5-mi longitudinal intervals beginning at RM 11 (km 17.6) have been plotted in an effort to eliminate gear and schooling biases while illustrating the trends in relative longitudinal density. Peak catches in every case were associated with the salt front (indicated by the point at which the conductivity curve becomes asymptotic to the abscissa).

White perch have been shown to move into channel areas during November (TI, 1974a) where they are believed to overwinter (Bigelow and Schroeder, 1953; Mansueti, 1961); during this overwintering period, white perch apparently are more vulnerable to impingement than during the period between May and November. Evidence is accumulating that, during their period of deep-water overwintering, white perch respond to the salt front in much the same manner as do tomcod (Figure III-39).

The temporal impingement patterns of striped bass resemble those of white perch although striped bass impingement is an order of magnitude less than for white perch at Indian Point. Striped bass also seem to exhibit a movement pattern between deep and shallow water, reminiscent of white perch movements. The major difference between the two species is a tendency for yearling striped bass to begin moving downriver toward the mouth of the Hudson which may result in the low percentage of total impingement attributable to striped bass (generally <2%).

b. Effect of River Morphometry

The major influence of river-bottom topography in the area of Indian Point is to present impingement-vulnerable species directly to the plant intakes. The interaction of salt-front movement and channel proximity to the intakes allows the fish associated with the salt front to move into the vicinity of the intakes (Figure III-40).

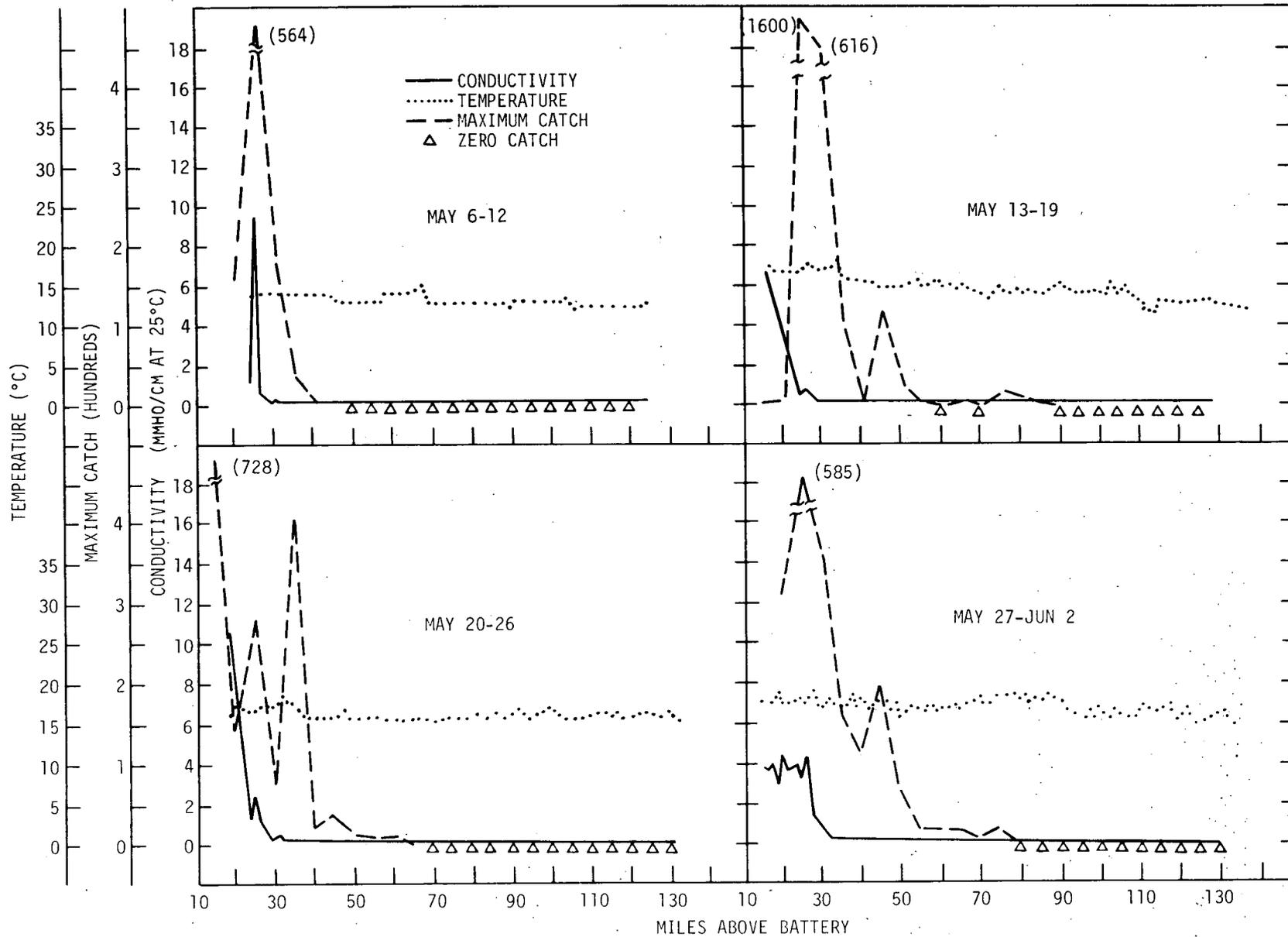


Figure III-38. Longitudinal Distributions of Atlantic Tomcod Young-of-the-Year, Conductivity, and Temperature during Weekly Ichthyoplankton Sampling. (Catch values are maximum for indicated 5-river-mile interval) (Page 1 of 7)



III-45

services group

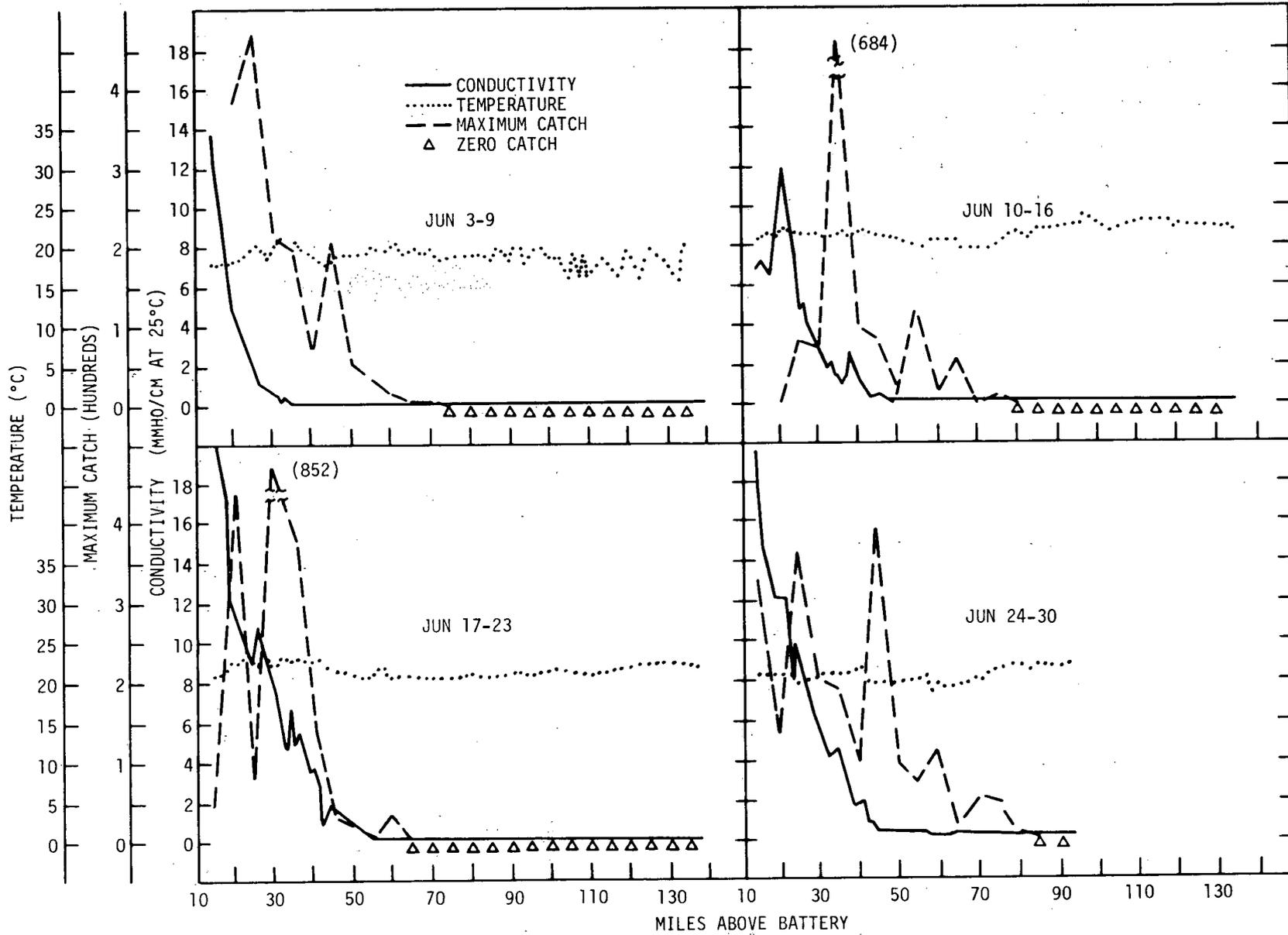


Figure III-38. (Page 2 of 7)

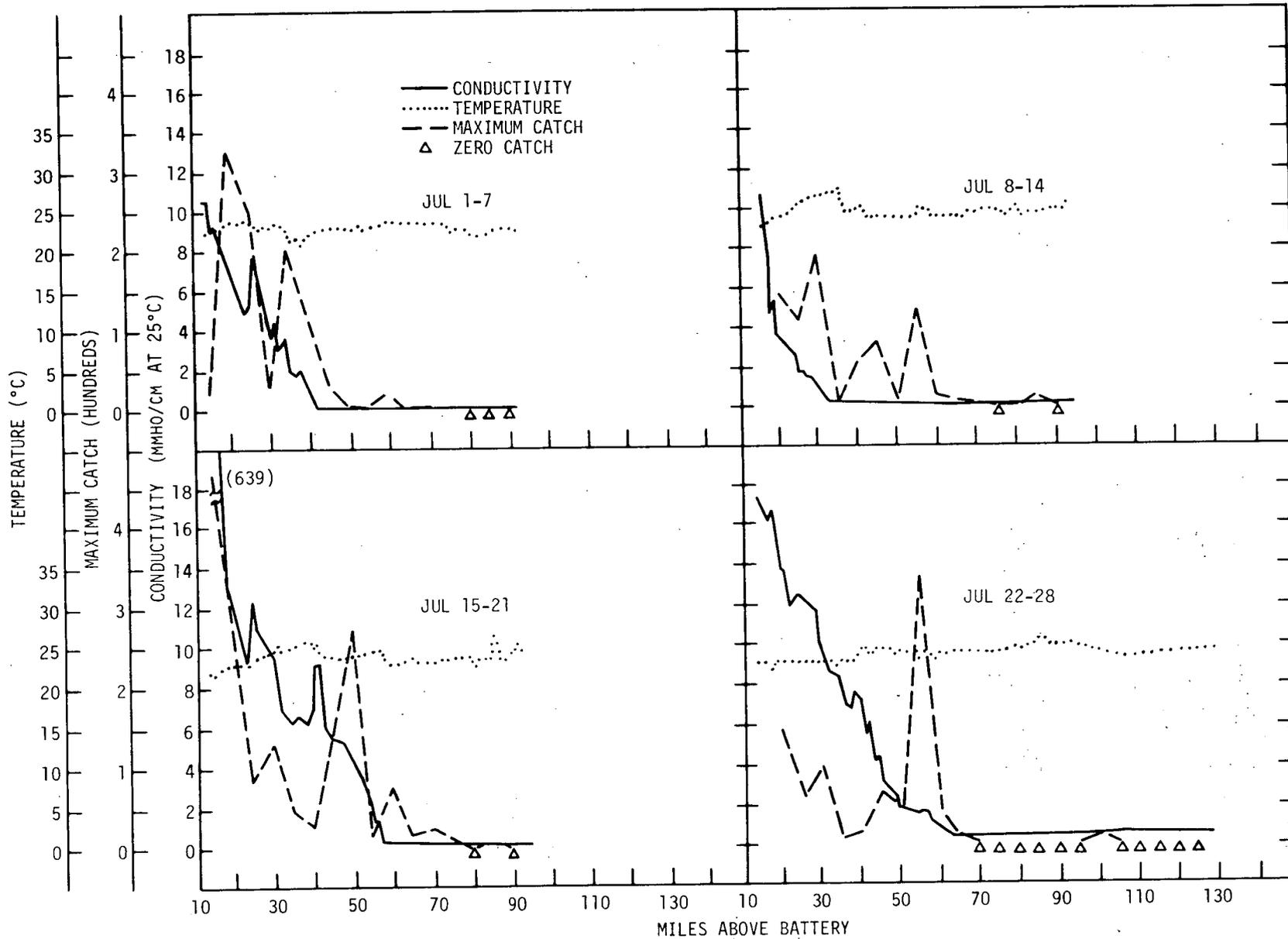


Figure III-38. (Page 3 of 7)





III-47

services group

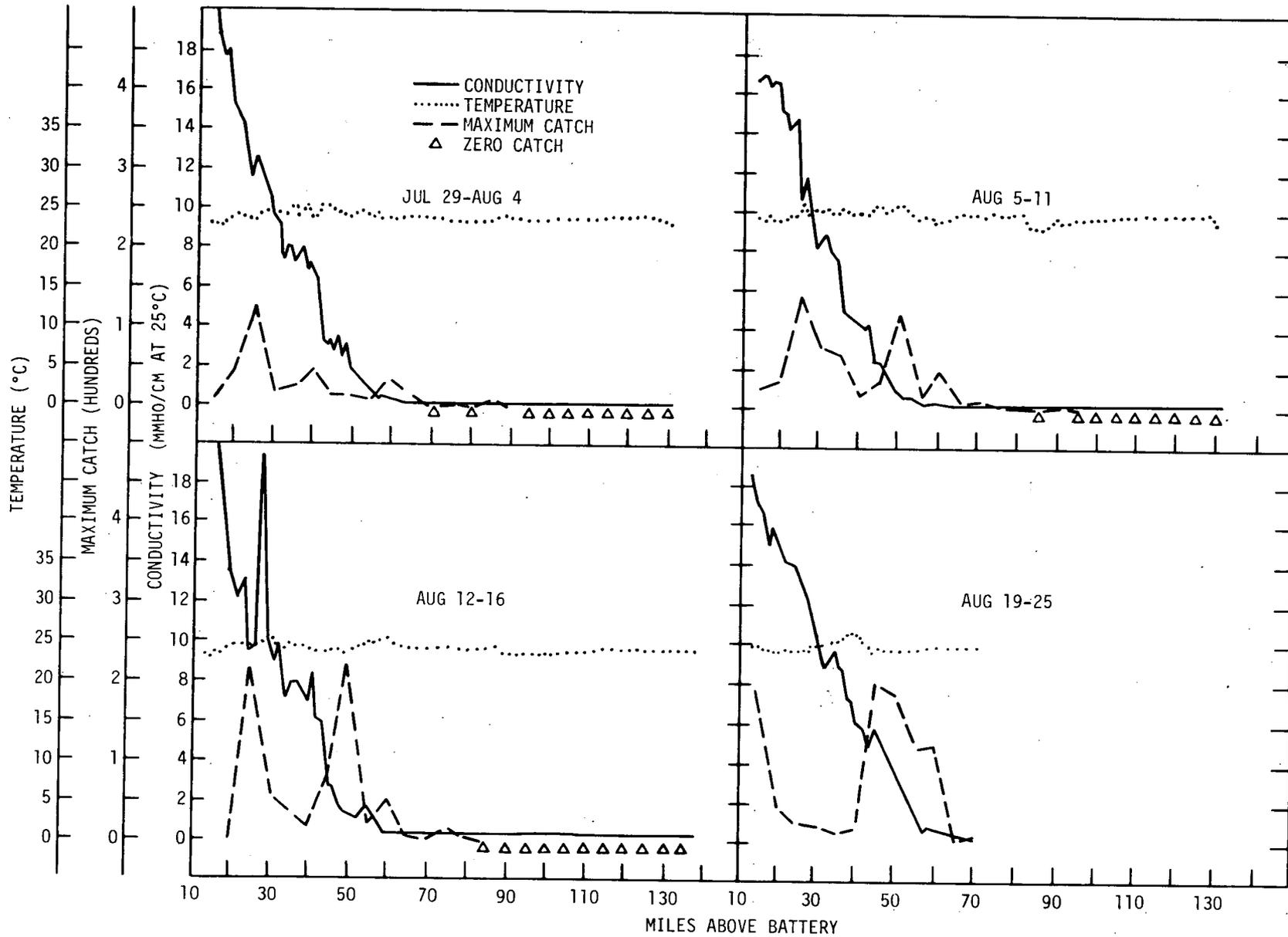


Figure III-38. (Page 4 of 7)

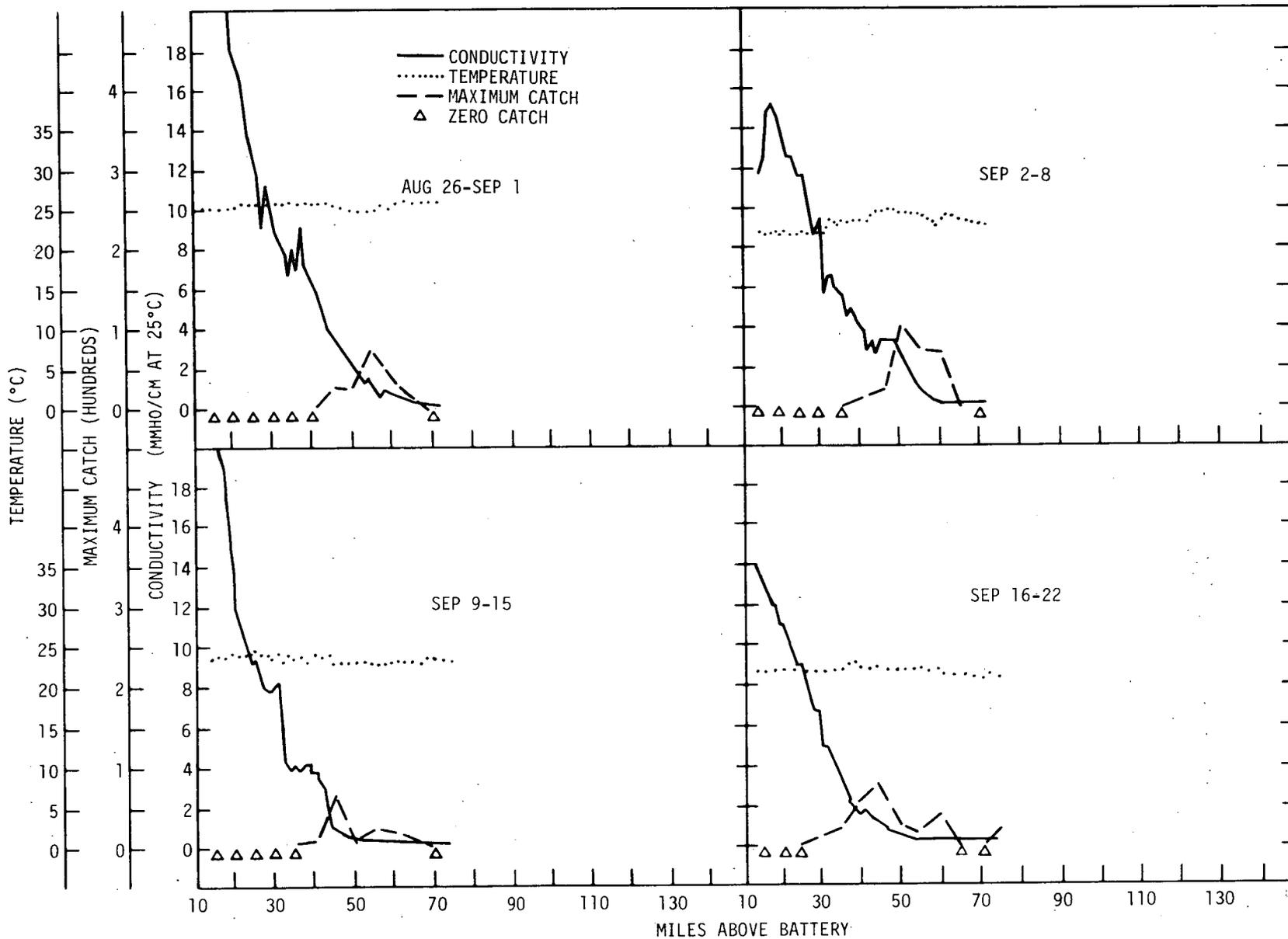


Figure III-38. (Page 5 of 7)



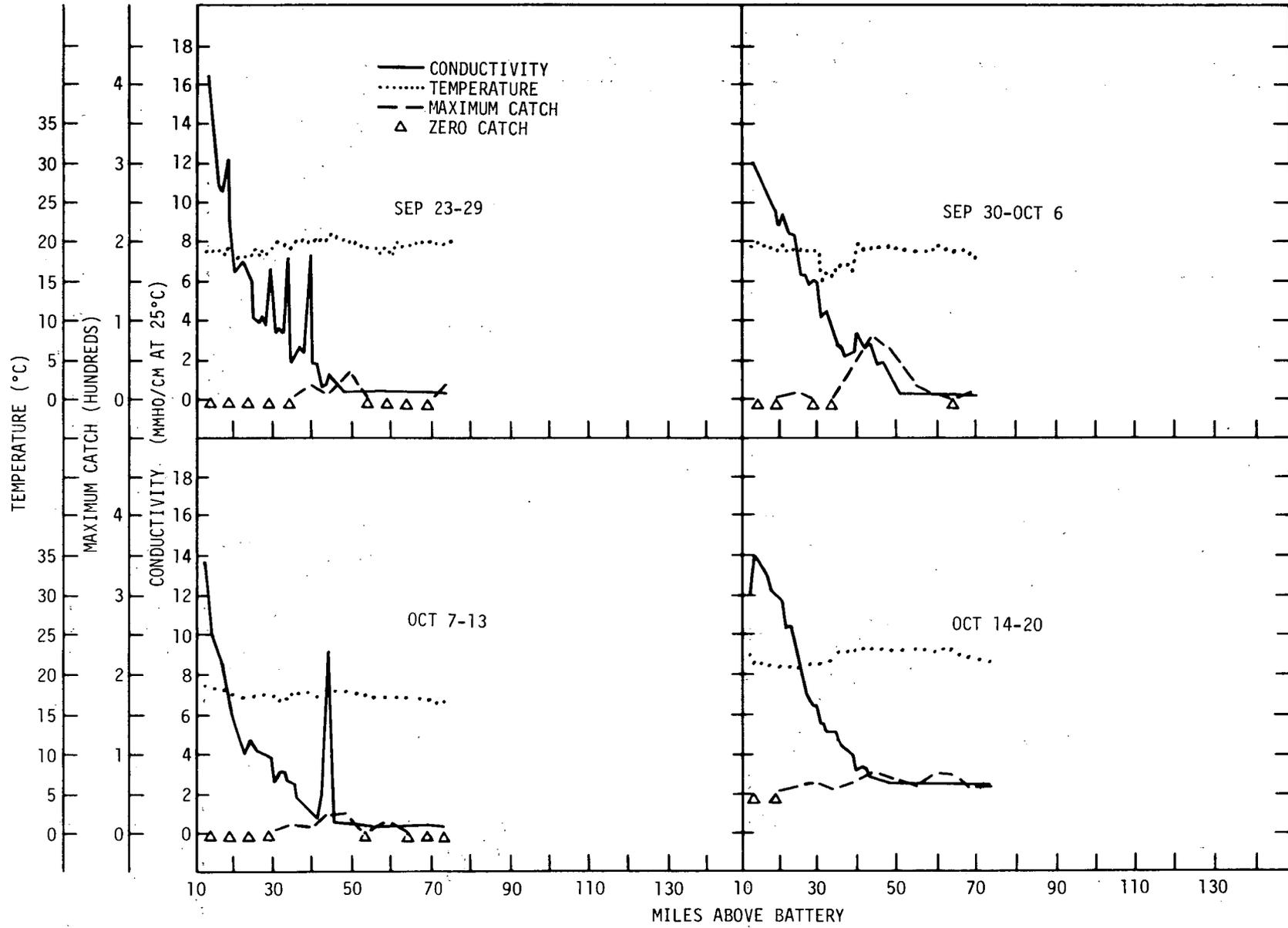


Figure III-38. (Page 6 of 7)



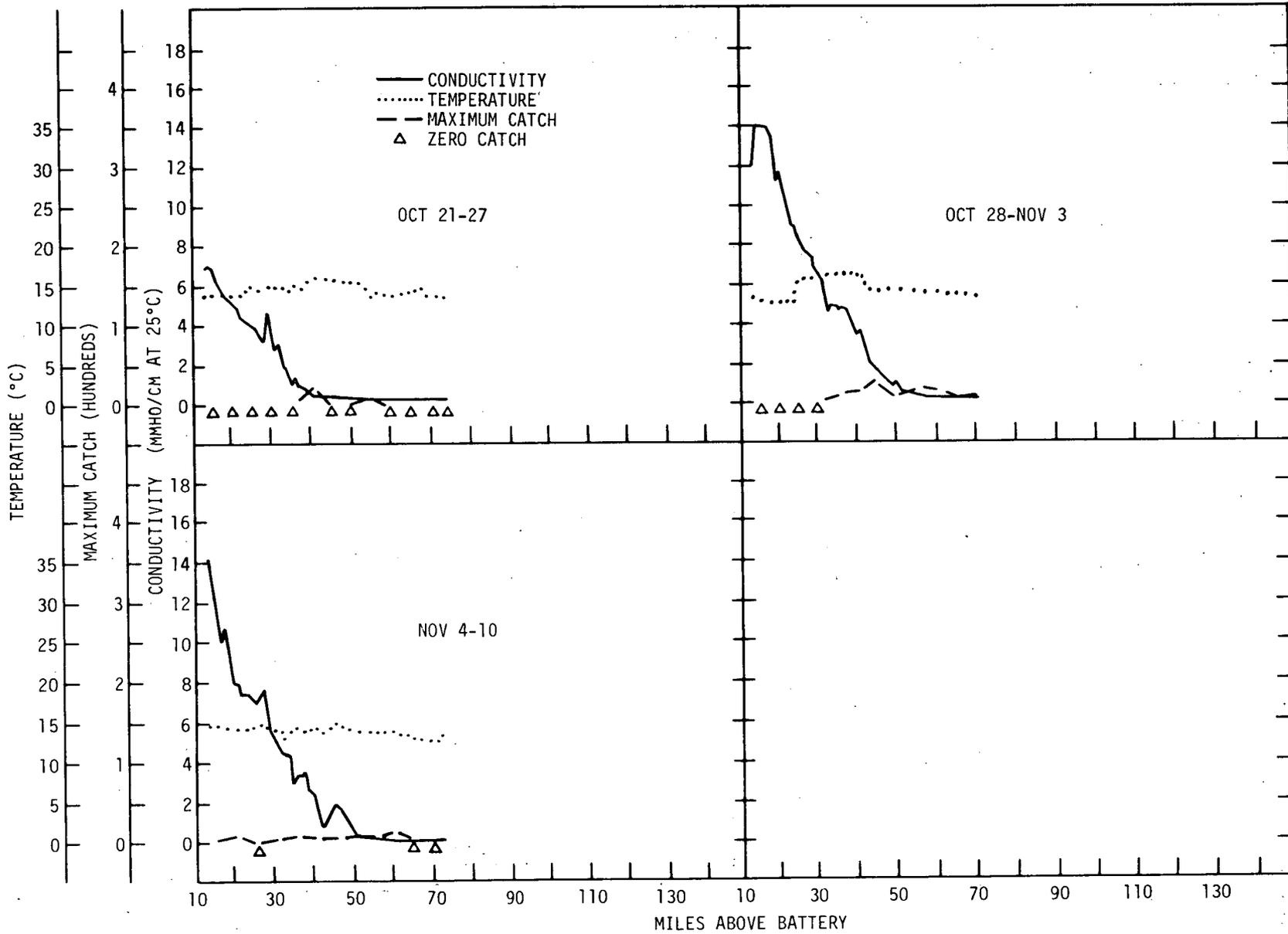


Figure III-38. (Page 7 of 7)



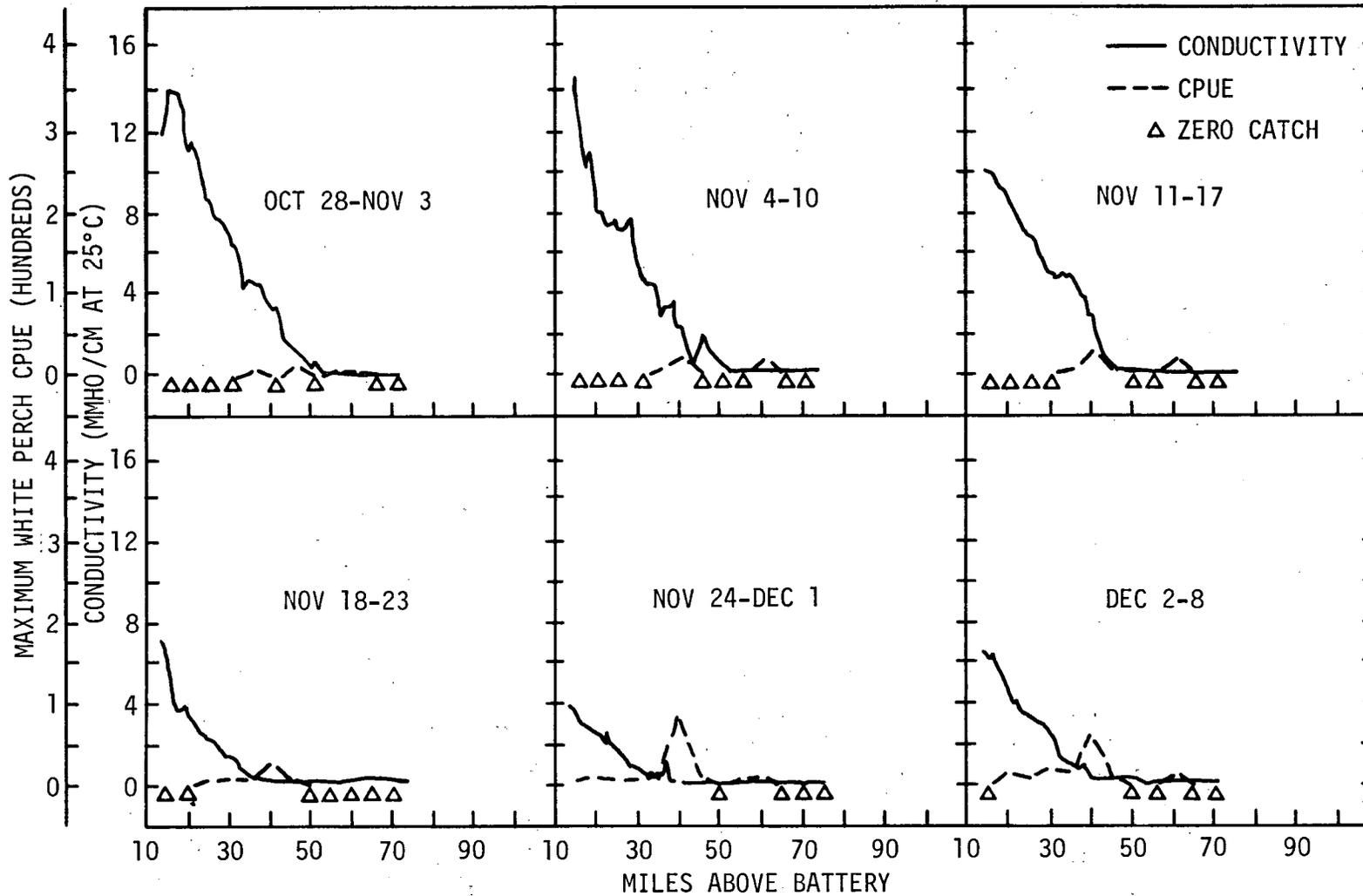


Figure III-39. Longitudinal Distributions of White Perch Young-of-the-Year and Conductivity during Weekly Ichthyoplankton Sampling. (Catch values are maximum for indicated 5-river-mile interval)

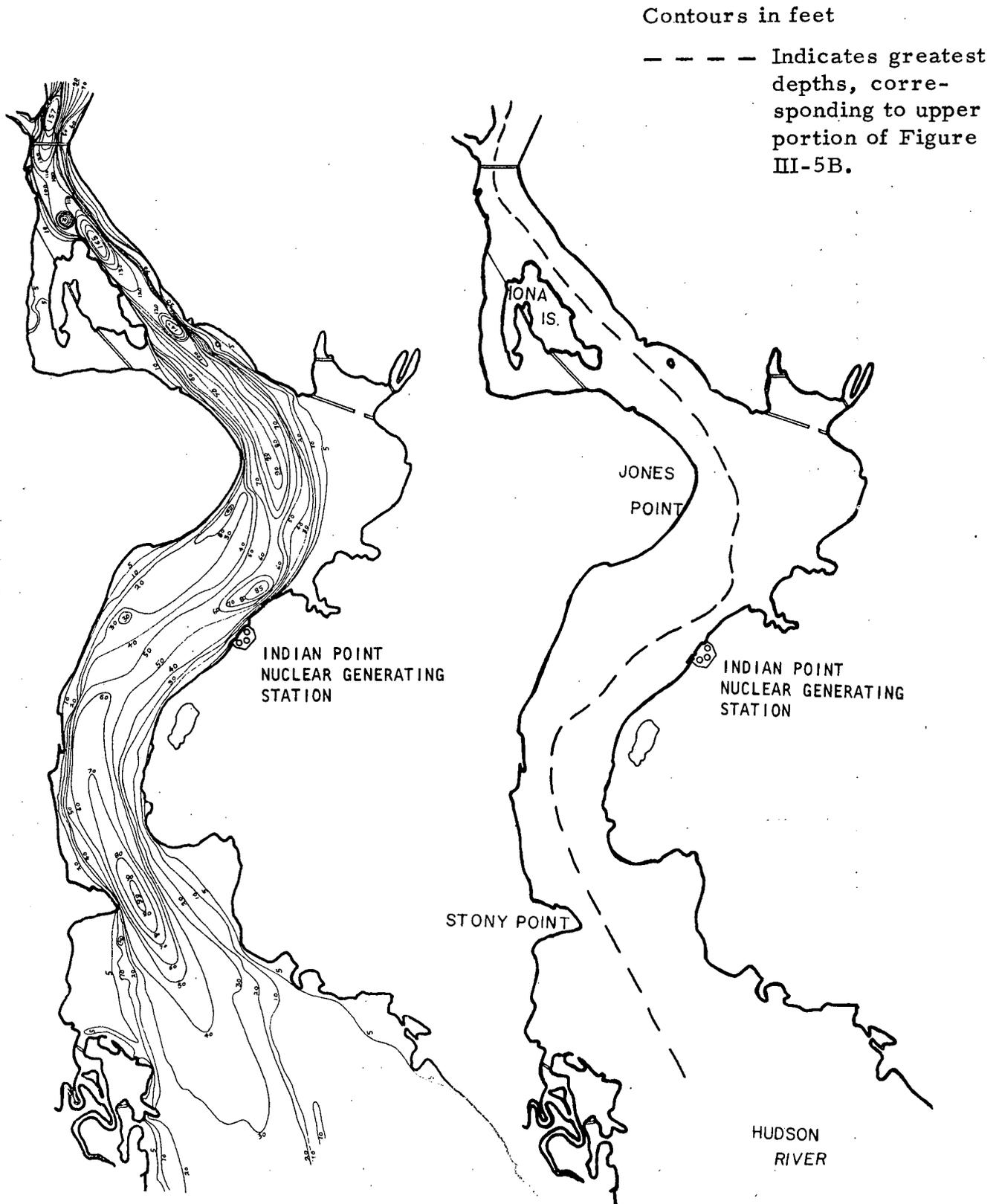


Figure III-40. Bottom-Contour Characteristics within Indian Point Region



c. Temperature Effects and Impingement

The vulnerability of young-of-the-year and yearling white perch to impingement increases dramatically with the onset of cold weather (with accompanying reduction in ambient river temperatures). The available data suggest a reduction in swimming ability at reduced temperatures (see Section V), but there is insufficient information regarding endurance at the ambient temperatures at which most white perch impingement occurs (0-10°C). At present, then, there is only circumstantial evidence that white perch, having once moved out of beach areas, are more subject to impingement due to increased availability and reduced swimming ability. Although striped bass impingement is a small fraction of total impingement, the striped bass impingement patterns are essentially the same as those for white perch.

d. Thermal Regime and Dissolved Oxygen

Atlantic tomcod is the only fish species appreciably subject to impingement during the summer periods of lower ambient dissolved-oxygen (D.O.) levels; white perch and striped bass are impinged principally in winter when ambient D.O. levels are high (8.5 mg/l or above). This relationship may be coincidental but a negative relationship between tomcod impingement and D.O. concentration during 1973 and 1974 (Figure III-41) was sometimes apparent.

E. DISCUSSION

It is apparent that the influences of the Indian Point thermal additions to the Hudson River estuary are minimal based on data and analyses presented here. This low level of influence is attributable to:

- Tidal influences on the system
- High turbulence associated with a diverse morphometry in the Indian Point vicinity
- Association of fishes with the mobile salt salt

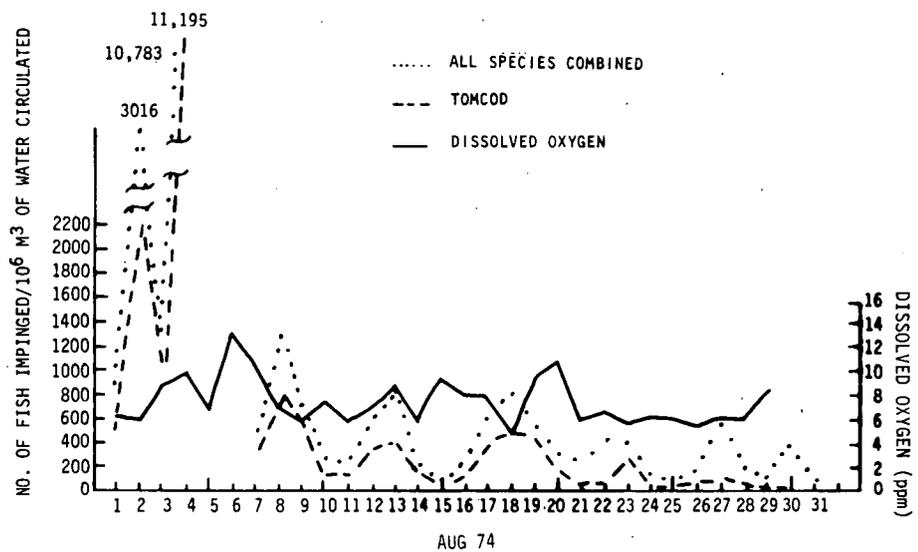
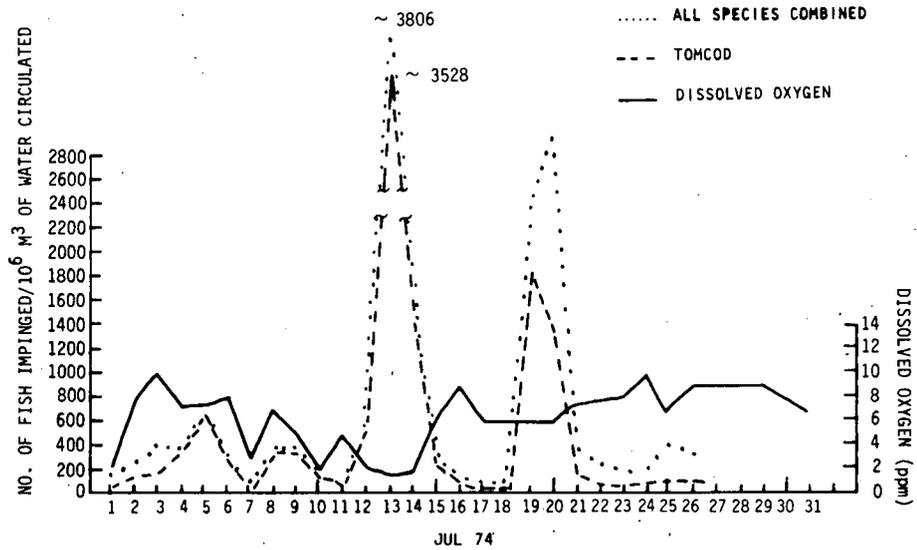
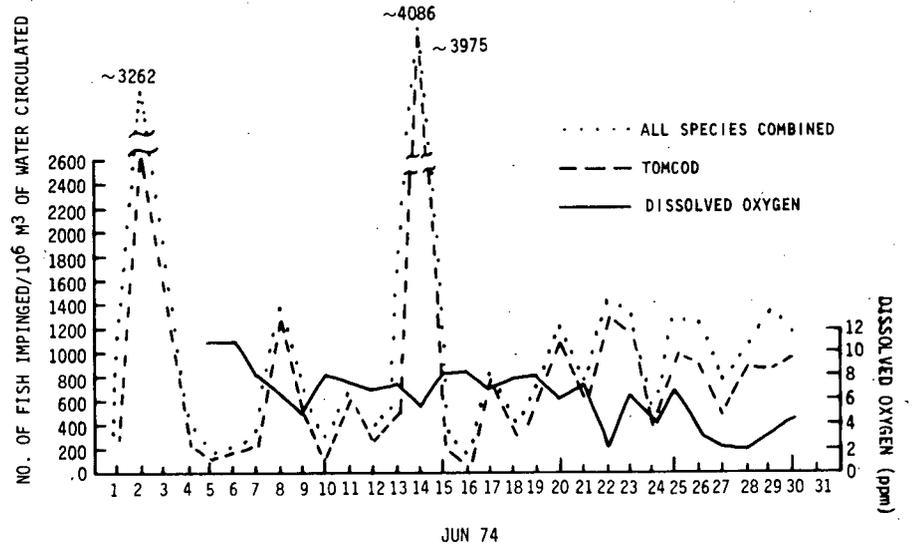


Figure III-41. Fish Impingement Rates and Dissolved-Oxygen Measurement at Indian Point Unit 2 during 1974



- Compression of the thermal plume (during most flow periods) on the surface against the east shore of the river
- The restriction of the plume to surface layers under virtually all demonstrated conditions

F. CONCLUSIONS

The thermal plume produced by operation of the Indian Point generating plant during 1972-1974 appears to be within the standards established for the Hudson River estuary. The thermal plume occupies only a small fraction of the upper water column in the far field. Impingement of white perch and Atlantic tomcod appears to be strongly associated with movement of the salt front. The association lasts throughout the year for tomcod, with peak impingement occurring during or after the spawning run in early winter and during periods associated with the summer intrusion of salt water. White perch impingement at Indian Point is generally restricted to periods of low ambient temperatures; the peak impingement of this species is also associated with intrusion and retreat of the salt front. The specific thermal regime in the near field of the Indian Point station as altered by plant operations is not related to abundance of particular fishes as shown in beach seine and trawl collections as well as impingement collections.



5. Littoral Survey

Qualitative monthly shore sampling was conducted at six stations between June and December 1972 in the Indian Point area. Beaches and associated shallow areas were sampled during daylight hours at low tide. All stations had similar sediment type — a mixture of sand, mud, clay, and rock, with vegetative debris — but stations B4 and B6 had higher percentages of coarse sand and pebbles than did the other stations. The throw net proved best for littoral collections in the water column and for epibenthic forms, whereas the sweep net was best for sampling forms inhabiting heavy vegetation.

Samples were briefly examined before being preserved to assay the more frequently occurring protozoans and invertebrates that would be rendered unidentifiable by preservation (Table IV-6). Since live-sample analysis was not comprehensive nor were identifications absolute, the identification of algae, protozoa, flatworms, and rotifers must be considered only a tentative representation of the shore biota. Of the 12 genera of algae identified, three were blue-green (Cyanophyta), *Oscillatoria*, *Merismopedia*, and *Spirulina*; and nine were green algae (Chlorophyta), *Eudorina*, *Euglena*, *Spirogyra*, *Closterium*, *Pandorina*, *Cladophora*, *Pediastrum*, *Cosmarium*, and *Scenedesmus*. The dominant green and blue-green algae encountered were, respectively, the filamentous *Cladophora* and *Oscillatoria*.

Protozoa were the most common protistans, with the sessile peritrichs comprising nine of the 20 taxa encountered; this probably reflects a situation in which most of the mobile forms, being smaller than 500 μ , would pass through the collection nets but the sessile protozoa, being firmly attached to the larger substrates, would be retained. Also encountered were a variety of gastropods. *Ammicola*, frequently very numerous in Petersen-grab benthic samples, was also found in littoral samples. The freshwater snails *Lymnaea*, *Physa*, *Helisoma* sp., *Helisoma anceps*, and *Gyraulus* were also present, although



4. Diversity

Benthic community diversity in the Indian Point region was consistent throughout the study period; no significant ($P = < 0.05$) differences in diversity were observed among the seven survey stations during 1972 or between the test and control areas during 1973 and 1974. Nonparametric analyses among stations for the 1973 and 1974 data (Table IV-5) showed a tendency toward higher diversity (Shannon-Weaver) and evenness (Heip) in the test area than in the control area. The data also indicated somewhat lower diversity and greater single species dominance in the river-channel.

Annual variation in diversity was slight, with only the spring-summer control-area community structure during 1973 showing any appreciable variation (Appendix E).

Table IV-5
Benthic Diversity in Indian Point Test and Control
Areas in 1972, 1973, and 1974

	Year	T vs C	Stations
Heip Evenness	1972	—	NS
	1973	NS	DFA > O D > R
	1974	NS	A > FR
Shannon-Weaver	1972	—	NS
	1973	NS	ACDF > O DF > R
	1974	NS	AC > R



3. Biomass

Mean wet-weight biomass per square meter generally increased through the study period (Figure IV-3). Annual patterns of fluctuation were consistent between 1972 and 1974, with mean weights decreasing from the initial sampling period in April to a low level during the summer period, increasing in late summer-early autumn, and again decreasing with the onset of winter. The pattern during the 1973 collection season was similar, but the early spring depression apparently occurred somewhat earlier and was not observed. The magnitude of the autumnal increase was also reduced during 1973. Tabular presentations of biomass data appear in Appendix D.

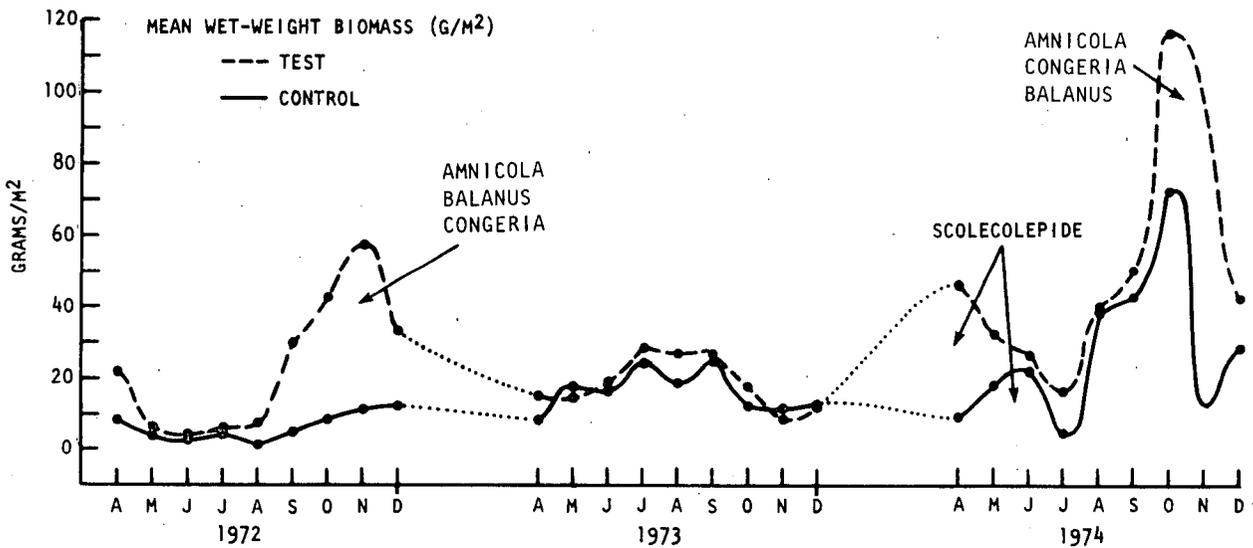


Figure IV-3. Mean Weight Biomass per Square Meter in Indian Point Test and Control Areas in 1972, 1973, and 1974



During 1972 when 0.25-mm screens were used exclusively in sample washing, copepods, especially the Harpacticoida, and ostracods were present in extremely high numbers, their abundance reaching a peak during the autumn months and a secondary peak during early spring. The presence of these forms in collections during 1973 and 1974 was generally a function of entanglement in organic detritus in the sample since the majority of the specimens pass through the 0.50-mm sieves usually employed for washing. One sample was processed each month during 1973 and 1974 using a 0.25-mm screen for each collection area. The resulting data indicated that the 1972 seasonal abundance pattern was characteristic for the Copepoda and Ostracoda of the region.

Numerical ranks based on 3-year mean numbers of specimens per square meter other than copepods and ostracods (Table IV-4) showed that the 10 most numerous taxa comprised more than 97% of the total numbers of organisms present in both the test and control areas. While these taxa varied somewhat in absolute ranking between areas, the same taxa comprised the dominant assemblage in both areas.

Table IV-4

Numerical Ranks Based on Mean Numbers per Square Meter in Indian Point Test and Control Areas in 1972, 1973, and 1974

Test Region			Control Region		
Taxon	%	Cumulative %	Taxon	%	Cumulative %
<i>Amnicola</i> sp.	26.5	26.5	<i>Limnodrilus</i> sp.	42.3	42.3
<i>Limnodrilus</i> sp.	24.9	51.4	<i>Boccardia hamata</i>	15.4	57.7
<i>Scolecoclepidis viridis</i>	17.7	69.1	<i>Scolecoclepidis viridis</i>	14.7	72.4
<i>Balanus improvisus</i>	7.3	76.4	<i>Amnicola</i> sp.	9.0	81.4
<i>Cyathura polita</i>	5.1	81.5	<i>Balanus improvisus</i>	5.8	87.2
<i>Gammarus</i> spp.	5.0	86.5	<i>Cyathura polita</i>	4.8	92.0
<i>Congerina leucophaeta</i>	3.8	90.3	<i>Gammarus</i> spp.	2.8	94.8
<i>Boccardia hamata</i>	2.7	93.0	<i>Corophium</i> sp.	1.2	96.0
Chironomid larvae	2.7	95.7	Chironomid larvae	0.7	96.7
<i>Corophium</i> sp.	1.4	97.1	<i>Congerina leucophaeta</i>	0.7	97.4
<i>Peloscoclex</i> sp.	0.6	97.7	<i>Peloscoclex</i> sp.	0.4	97.8
<i>Chaoborus</i> sp.	0.4	98.1	<i>Edotea</i> sp.	0.4	98.2
<i>Rhithropanopeus harrisi</i>	0.2	98.3	<i>Chaoborus</i> sp.	0.3	98.5
Nematoda	0.2	98.5	<i>Chiridotaea almyra</i>	0.3	98.8
<i>Chiridotaea almyra</i>	0.1	98.6	Nematoda	0.1	98.9
Nudibranchia	0.1	98.7	<i>Rhithropanopeus harrisi</i>	0.1	99.0
<i>Leptocheirus</i> sp.	0.1	98.8	<i>Hypaniola</i> sp.	< 0.1	> 99.0
<i>Edotea</i> sp.	0.1	98.9	Nudibranchia	< 0.1	> 99.0
<i>Hypaniola</i> sp.	0.1	99.0	<i>Leptocheirus</i> sp.	< 0.1	> 99.0



Table IV-3

Annual Mean Numbers of Individuals per Square Meter in Indian Point
Test and Control Areas, 1972, 1973, and 1974

Dominant Taxa	1972			1973		1974	
	Survey	Test	Control	Test	Control	Test	Control
<i>Limnodrilus</i> sp	547.7	324.7	415.7	1349.5	2870.8	2730.9	3601.6
<i>Cyathura polita</i>	162.0	201.3	219.9	244.6	137.8	467.5	434.6
<i>Boccardia hamata</i>	215.0	132.2	783.9	221.4	767.1	133.6	955.0
<i>Scölecolepides viridis</i>	74.6	89.9	69.1	212.4	244.0	2824.5	2086.8
<i>Gammarus</i> sp	82.8	156.1	93.0	442.4	219.1	287.4	154.4
<i>Ammicola</i> sp	992.1	662.8	486.9	15.7	3.5	4008.3	975.8
<i>Balanus improvisus</i>	133.4	240.9	22.9	47.8	108.9	1016.9	825.8
<i>Congerina leucophaeta</i>	123.9	290.2	11.0	97.6	35.4	295.9	74.3
Chironomid larvae	191.1	129.3	43.4	121.7	26.2	226.9	52.0
<i>Corophium</i> sp	56.8	48.8	15.2	57.8	27.2	150.2	158.7
<i>Chaoborus</i> sp	2.6	5.1	1.6	26.8	12.1	46.2	43.4
<i>Pelosclex</i> sp	56.8	85.9	62.1	23.5	13.8	8.2	3.6
<i>Chironomus almyra</i>	2.6	2.3	6.3	2.9	12.2	21.9	30.1
<i>Edotea</i> sp	2.6	1.1	5.3	6.3	25.1	12.8	32.1
Nematoda	25.7	18.4	21.2	7.6	0.9	12.5	4.0
<i>Rhithropanopeus harrisi</i>	6.3	17.5	1.2	10.9	1.1	18.7	18.9
<i>Hypaniola</i> sp	4.8	2.7	5.1	5.1	4.4	10.7	2.0
Nudibranchia	2.8	1.1	1.1	1.7	1.8	21.0	4.6
<i>Monoculodes</i> sp	0.2	0.3	0.2	1.9	2.2	5.4	4.0
Paleonemertea	0.4	0.4	0.2	0.5	0.9	3.8	2.8
Hydracarina	0.7	1.1	0.2	0.1	0.1	0.3	0.3
<i>Piscicola</i> sp	0.3	0.5	1.0	0.2	0.2	0.5	0.1
Trichoptera - adult	0.1	0.1	0.3	0.2	0.1	0.7	1.0
<i>Leptocheirus</i> sp	1.4	0.9	-	2.0	0.7	18.9	5.8
Planariidae	8.9	13.3	2.9	-	-	0.4	0.2
<i>Sphaerium</i> sp	0.3	-	0.2	-	-	4.5	1.6
Collembola	0.1	-	0.2	-	-	0.3	0.2
Chironomid pupae	0.1	-	0.2	-	-	3.1	0.4
<i>Hydra americana</i>	0.1	-	-	-	0.6	0.2	-
<i>Daphnia</i> sp	0.1	0.1	-	-	-	0.1	1.2
<i>Cassidina lunifrons</i>	0.1	0.1	-	-	-	0.2	0.4
Acanthocephala	0.1	0.1	-	0.1	-	-	-
<i>Nereis succinea</i>	0.1	0.1	-	-	-	-	0.2
Sipunculida	0.1	0.1	-	-	-	-	-
<i>Dugesia</i> sp	0.1	0.2	-	-	-	-	-
<i>Palpomyia</i> sp	0.1	0.1	-	-	-	-	-
<i>Enallagma</i> sp	0.1	-	-	-	-	-	-
Decapod - larva	0.1	0.1	-	-	-	-	-
Turbellaria	0.1	0.3	-	-	-	-	-
<i>Neomysis americana</i>	-	-	-	0.1	0.1	0.2	-
Odonata - larva	-	-	-	0.1	-	-	0.1
<i>Agraylea</i> sp	-	-	-	0.1	-	-	-
Glossiphoniidae	-	-	-	-	0.1	-	-
<i>Elleptio</i> sp	-	-	-	-	-	0.2	-
Ceratopogonidae	-	-	-	-	-	0.1	0.2
<i>Ferrissia</i> sp	-	-	-	-	-	0.1	0.1
<i>Crangonyx</i> sp	-	-	-	-	-	0.1	-
<i>Crangon septemspinosa</i>	-	-	-	-	-	-	0.3
Ephemeroptera - adult	-	-	-	-	-	-	0.2
Naididae	-	-	-	-	-	-	0.1
<i>Leptodora</i> sp	-	-	-	-	-	-	0.1
Harpacticoida	4344.1	7836.7	2527.2	0.2	0.1	52.5	10.3
Ostracoda	208.3	198.8	82.9	-	-	0.1	0.1
Cyclopoida	17.6	23.6	11.4	0.4	-	34.5	18.9
Calanoida	1.0	1.2	1.3	0.2	-	11.1	0.3
Macrothricidae	0.3	-	2.0	-	-	-	0.3
Total No. of Taxa	44	38	32	31	28	40	43
Mean Total No/m ²	7268.5	10488.5	4895.1	2901.7	4516.5	12409.2	9500.7



Table IV-2

Taxon List for Hudson River Ecological Survey Benthic Collections
at Indian Point, April 1972-December 1974

CNIDARIA		
<i>Cordylophora lacustris</i> <i>Hydra americana</i>		
PLATYHELMINTHES		
Planariidae <i>Dugesia</i> sp <i>Dugesia tigrina</i>		
NEMERTEA		
Paleonemertea		
NEMATHELEMENTHES		
Unidentified Nematoda		
ACANTHOCEPHALA		
Sipunculida		
ANNELIDA		
Polychaeta	Oligochaeta	Hirudinea
<i>Scolecoclepidus viridis</i> <i>Boccardia hamata</i> <i>Hypaniola</i> sp <i>Nereis</i> larvae <i>Nereis succinea</i> Serpulidae	<i>Limnodrilus</i> sp <i>Pelocolex</i> sp <i>Stylaria</i> sp Unidentified Naididae*	Hirudinia Glossiphoniidae <i>Pisicoola</i> sp
ARTHROPODA		
Crustacea	Insecta	Arachnida
Decapoda	Phloethripidae Isotomidae-Collembola Unidentified insect larvae <i>Agraylea</i> sp Leptoceridae Trichopteran adult <i>Limnophora</i> sp <i>Amphiagrion</i> sp <i>Enallagma</i> sp <i>Ischnura</i> sp Cdonata larvae <i>Cryptochironomus</i> sp <i>Palpomyia</i> sp Chironomid larvae Chironomid pupae <i>Chaoborus</i> sp Trichopteran larvae* Ephemeropteran larvae* Dipteran pupae* Ceratopogonidae larvae*	Hydracarina
<i>Crangon septempinosus</i> <i>Rhithropanopeus harrisi</i> <i>Orconectes limosus</i> <i>Palaemonetes pugio</i> <i>Callinectes sapidus</i> Mysidacea <i>Neomysis americana</i>		
Amphipoda		
<i>Gammarus</i> sp <i>Monoculodes</i> sp <i>Corophium</i> sp <i>Leptocheirus</i> sp Unidentified <i>Crangonyx</i> sp *		
Isopoda		
<i>Livoneca ovalis</i> <i>Cassidina lunifrons</i> <i>Cyathura polita</i> <i>Edotea</i> sp <i>Chiridotea almyra</i> <i>Asellus</i> sp		
Cumacea		
Unidentified		
Cirripedia		
<i>Balanus improvisus</i>		
Copepoda		
Harpacticoida Cyclopoida Calanoida		
Ostracoda		
Unidentified		
Cladocera		
Cladoceran ephippium Macrothricidae <i>Daphnia</i> sp <i>Bosmina</i> sp <i>Latona</i> sp <i>Leptodora kindtii</i> *		
MOLLUSCA		
Gastropoda	Pelecypoda	
<i>Amnicola</i> sp Nudibranchia Unidentified juvenile <i>Ferussia</i> sp *	Lamsilinae Sphaeridae <i>Congeria leucophaeta</i> <i>Pisidium</i> sp <i>Elliptio</i> sp	
ECTOPROCTA		
<i>Cristatella mucedo</i> <i>Hyalinella</i> sp <i>Pectinatella magnifica</i> <i>Lophodella carteri</i>		

* Taxa added during 1974



The mean of X_{ij} and $Y_{6, j+1}$ is computed to estimate the number of individual in the original i^{th} class from j to $j+1$. Finally, the production is estimated by

$$\text{Production from } j \text{ to } j+1 = \sum_{i=2}^{26} W_i (X_{ij} + Y_{ij})/2$$

where the observed length interval of *Cyathura* ranged from 2 to 26 mm. The production and mean number of individuals were then compared using a Wilcoxon signed rank test (Hollander and Wolfe, 1973). Notice that, if the estimates of the W_i 's are incorrect by a constant factor, the conclusions and significance levels are unchanged.

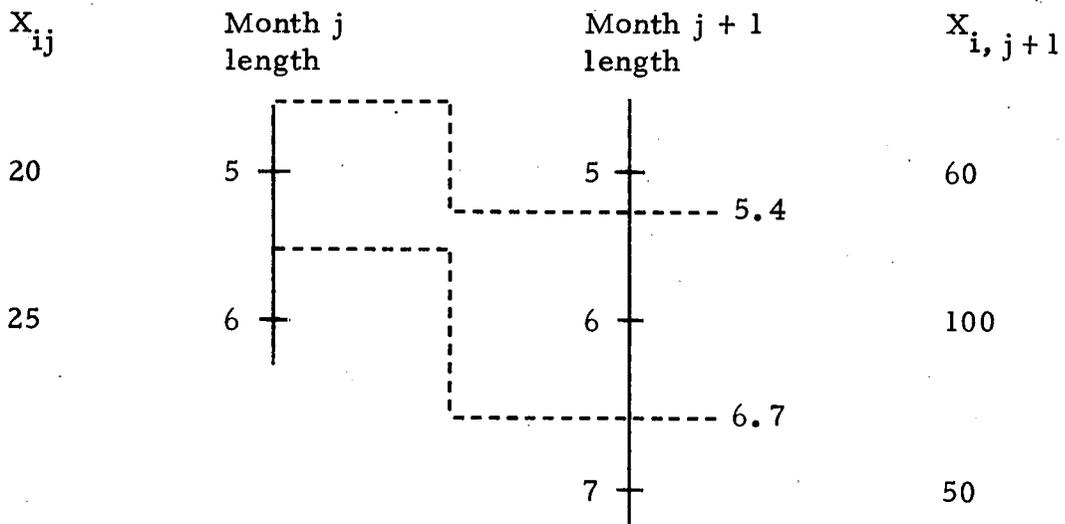
C. RESULTS

1. Community Composition

Collections from the macrobenthic infaunal community of the Indian Point region between April 1972 and December 1974 included 86 taxa representing nine phyla (Table IV-2). This assemblage was dominated in numbers of taxa by the Crustacea (30), Insecta (19), and Annelida (14).

2. Relative Abundance

Throughout the study period, the tubificid worm *Limnodrilus* sp. was the most common macrobenthic form in the Indian Point area (Table IV-3). However, this numerical dominance was not absolute due to the seasonal appearance of very high numbers of immature *Ammicola* sp. (Gastropoda) and barnacles (*Balanus improvisus*) during the autumn months of both 1972 and 1974 and progressive increases in numbers of the polychaete *Scolecoides viridis* (Appendix C).



Thus, individuals of length i in month j were said to have been interval $(i - 0.5) + \Delta_{i-0.5}, i + 0.5 + \Delta_{i+0.5}$ in month $j+1$.

Finally, the weight gain was obtained from the least squares equation

$$W_i = \text{monthly weight gain of an individual in length class } i$$

$$= a \left(\frac{(i + 0.5 + \Delta_{i+0.5}) + (i - 0.5 + \Delta_{i-0.5})}{2} \right) - a i^b$$

It was necessary to estimate the number of individuals that had a weight gain W_i to compute production. Assume that the $X_{k, 2+1}$ individuals found in $(k - 0.5, k + 0.5)$ were uniformly distributed over the interval. Letting $Y_{i, j+1}$ = the estimate of the number of individuals in month $j+1$ that were in $(i - 0.5, i + 0.5)$ in month j , the $Y_{i, j+1}$ individuals were proportionally allocated to an X_{ij} . For example, consider the allocation of X 's in the previous illustration, letting $\Delta_{4.5} = 0.9$ and $\Delta_{5.5} = 1.2$. Now, $Y_{6, j+1} = (5.5 - 5.4) 60 + 100 + (7 - 6.7) 50 = 121$ individuals are associated with the i^{th} growth interval.



equation for October-December was used for April-June. An attempt was made to fit the obtained growth equations to the standard Bertalanffy and logistic growth equations (Poole, 1974); however, the least squares fit produced residuals that were too large so graphical methods were used.

The correlation analysis produced an approximate monthly growth increment in terms of length. However, production growth estimation must be in terms of weight, so it was necessary to use the 1974 (July-December) length-weight data to convert lengths to weights. This was done by linear regression of log-transformed lengths and weights; regression lines were compared for the test and control areas for July-September and October-December. It was found that test and control areas for July-September did not differ significantly ($P = 0.26$), and the result was similar for October-December ($P = 0.08$). Thus, estimates of the regression parameters were obtained for the equation $\log \text{ weight} = \log a + b \log \text{ length}$. Since untransformed lengths and weights were to be used, least squares estimates for a and b were obtained for $\text{weight} = a (\text{length})^b$ from a nonlinear estimation program. The equations used to convert lengths to weights were as follows:

July-September	$W = 0.0236L^{2.58}$
October-December	$W = 0.0081L^{2.95}$

where length is in mm and weight in mg.

Letting X_{ij} be the number of individuals of length i in the j^{th} month, a monthly weight change for a length class was computed. Since lengths were measured to the nearest 0.5 mm, the X_{ij} individuals of length i had actual lengths in the interval $(i - 0.5, i + 0.5)$. The monthly growth increments for the endpoints $\Delta_{i-0.5}$ and $\Delta_{i+0.5}$ were derived from a comparison of month j length and length at month $j + 1$:



smaller length classes the previous month. The 9 months of sampling were divided as follows: April-June, July-September, and October-December. A single growth equation was computed for the test and control areas combined, using 1973 and 1974 data, to prevent bias of the production estimates. The effect of small frequencies was negated by combining the data from the three replicates for each of the six test and control stations. The analysis did not use a station if the total catch was < 20 for a month, nor frequencies of two or less.

The growth equation was estimated by a correlation analysis for the frequencies in length classes. The monthly lagged length that most closely correlated with a length was computed from the weighted average of the significant (0.05 level) correlations. The longest sequence of positive correlations was used for cases in which there were no significant correlations.

Letting c_k denote the correlation of the k^{th} lagged length class with a length i and letting n_k be the number of observations used to compute c_k , then the weighted lagged length associated with a month's growth from length i is

$$\sum_{k=s}^t k c_k n_k / \sum_{k=s}^t c_k n_k$$

if c_s, \dots, c_t is the sequence of significant correlations. The estimate weights larger correlations and samples with large correlations.

This procedure produced adequate growth curves for July-September and October-December, but the April-June analysis did not produce a smooth curve. As a possible explanation, there were only two monthly increments in this time period as opposed to three for the others; alternatively, sample sizes may have been too small or reproduction could have been affecting growth determinations. Based on comparable temperatures, the growth



Weaver measure of diversity (Margalef, 1957). A pooled index was computed by combining all replicates at a station for each month. Pooled measures are known to have a more stable and representative value. Analyzing the replicates separately was not possible. Evenness as given by Heip (1974) is calculated by:

$$E = (e^H - 1) / (S - 1)$$

where

E = evenness

e = base of natural logarithm

H = Shannon Weaver information function

S = number of species

The Shannon-Weaver index [Shannon-Weiner information function (Dahlberg and Odum, 1969; Heip and Engels, 1974)] is calculated as follows:

$$H = \sum P_i \log_{10} P_i$$

where

E = diversity

P_i = proportion of all individuals in the i th species.

The variances of diversity and evenness measures for the replicates were shown by Levene's test to differ between stations ($P < 0.05$). Therefore, the pooled measures of evenness and diversity were analyzed by a Friedman nonparametric analysis of variance. If significant differences were found between the stations, individual stations were compared by a nonparametric multiple comparison (Hollander and Wolfe, 1973).

d. Estimation of *Cyathura* Production

Cyathura length-frequency distributions were not sufficiently distinct to separate year classes and to allow use of the methods described by Holme and McIntyre (1971). The growth equation and size distribution of individuals were estimated using an alternate approach (Winberg, 1971). The distribution of *Cyathura* lengths was determined for the test and control sites in 1973 and 1974. However, no growth data were available for a single cohort. To approximate the growth equation, the number of individuals in a length class for a month was correlated with the number of individuals in



was not included. Major associations between species were determined on the basis of significant correlations. These associations are indicated by brackets in the left-hand margins of the Appendix B tables.

b. Regression Analysis of Species Abundance on Physical Parameters

To investigate the linearity of relationships between physical variables and abundance, the most complete set of physical data was used in a stepwise regression (Draper and Smith, 1966). The benthic data were the separate mean (of the three 1974 replicates) for the intake (station A) and effluent (station C) sites. The physical data (temperature, dissolved oxygen, and conductivity) for each station were a weekly mean of the bottom intake and effluent stations.

The dependent variable in the stepwise regression was the monthly change in abundance for a species; thus, for the 9 months sampled, eight changes were observed. The dependent variable was the change in abundance, since abundance changes were possibly the result of changes in physical variables. Independent variables were considered at lag times ranging from 0 to 6 weeks. The first group of dependent variables was the weekly mean of the data. The grand mean for the 8 months considered was subtracted from each variable to minimize correlation among the independent variables (Marquardt and Snee, 1975). The second group of variables was the square of the variables in the first group; this variable represents seasonal variations, since both temperature (and correspondingly dissolved oxygen) and salinity have yearly peaks and depressions. The last group of variables was the absolute change (defined as $|X_{t-1} - X_t| + |X_t - X_{t+1}|$) of a variable over a time interval of 3 weeks; this variable seeks to determine if change in physical variables can account for changes in the abundance of a species.

c. Benthic Evenness and Diversity Analysis

Each year (1972, 1973, and 1974) was analyzed separately for possible changes in Heip's measure of evenness (Heip, 1974) and the Shannon-



In general, it is thought that the variance is a function of the mean for many benthic species, but this may not always be the case. Note that since the logarithmic transformation seemed to stabilize the variance, the standard deviation is possibly proportional to the mean. The Friedman test was used since an additive model is not needed for comparisons between the stations (Puri and Sen, 1971). An additive model is most likely inappropriate for standard deviations.

a. Cluster Analysis

Cluster analyses performed (Dixon, 1975) to determine if species groups have similar abundance patterns used the correlation between species abundance to form groups with higher correlations between group members. The cluster analyses appear in Appendix B.

The clustering process is most easily explained by an example. Consider the clustering of four species. The procedure first groups the two species which have the largest correlation, say species 2 and 4, and then must decide between the groupings of 1&3, 1,2&4, and 3,2&4. Each group respectively is given the following score: the correlation 1 with 3; the average of the correlation 1 with 2 and 1 with 4; the average of the correlation 3 with 2 and 3 with 4. Finally, the grouping with the largest score is chosen as the next cluster. This process continues until all species are grouped together. The cluster analysis also adjusts each grouping score to have a range between 0 (no association) and 100 (perfect association). Thus, the degree of association between groups of species can be compared.

Each cluster analysis was performed seasonally for both the test and control areas because association among species may change between seasons. Eighteen species were considered, although some species were frequently absent from the collection (i. e., more than 20% zero catches); these cases were included in the analysis only for completeness. When there were less than two individuals of a species in the month considered, that species



3. Data-Analysis Procedure

Test- and control-area stations were compared on the basis of three replicate samples for each station. Equal variances for all stations are necessary if a parametric analysis is to be used. Data for several species were subjected to Levene's test (Draper and Hunter, 1969) and Barlett's test (Winer, 1971) to compare station variances. The logarithmic transformation stabilized the variance for a given month; when several months were combined, however, significant differences in variances were observed. Parametric seasonal analyses were therefore not possible, so nonparametric methods were used. To avoid the possibility of tied ranks, which is undesirable for nonparametric procedures, only months which had sufficient non-zero catches for the zero catches were considered. A Wilcoxon signed rank test (Hollander, 1973) was performed to determine if the test and control areas had different mean catches; this method uses the mean of abundance for the test and control stations for overall comparison of the two areas. Possible differences in mean abundance between stations were analyzed by one of two nonparametric analyses: if the number of months (blocks) was < 9 , a Friedman testing procedure was used (Conover, 1971); otherwise, a rank order test [ranking all aligned observations (Puri and Sen, 1971)] was performed. Procedures of both the Friedman and the rank order tests are appropriate for an analysis using replicates. Most species had a large number of zero catches, resulting in numerous tied tanks. Both procedures are inappropriate for a large number of ties. Therefore, the mean of the three replicates was used in the analysis. In some cases, a species was abundant and it was possible to analyze all replicates instead of the means. This results in more sensitive comparisons.

In addition to the analyses of species abundance just discussed, the standard deviation of the three replicates was computed and a Friedman analysis performed to determine if variability was the same among stations.



Table IV - 1

U.S. Standard Mesh Sizes Employed for Sample Washing

	1972 (mm)	1973 (mm)	1974 (mm)
Petersen grab	0.25	0.5 and 0.25	0.5 and 0.25
Biological dredge	4.0	4.0	
Epibenthic sled			0.25
Fouling plates	0.25		
Littoral samples	0.5		

Specimens were then separated by taxa and enumerated. (Appendix A presents the list of taxonomic keys employed.) Qualitative samples (littoral, biological dredge) and semiquantitative samples (fouling plates) were analyzed by the same procedures, but the resultant enumeration was used only as a general indication of relative abundance.

Wet weight and wet volume biomass were determined for all grab samples. After being picked, the samples were placed on preweighed filter papers in a Buchner funnel to be air-dried without dessication. A sample's total weight was determined to the nearest 0.1 g. The samples were then placed in a graduated cylinder containing a measured amount of 70% ethanol, and the volume of the sample was determined as the difference between initial and final volume in the graduated cylinder.

Sediment samples were washed through a nested series of U.S. Standard sieves (8, 4, 2, 1, 0.5, 0.25, 0.125, and 0.064 mm mesh sizes) to determine particle-size distribution. All sediment fractions were dried in a dessicating oven and weighed to the nearest 0.1 g (Welch, 1948).



Sediment samples from each of the seven primary stations were collected with a Phleger corer (Figure IV-2) six times during the 1972 sampling season. Supplementary sampling was conducted in the test and control regions for the 1973-1974 studies (TI, 1973a).

2. Laboratory Procedures

All samples were returned to the laboratory intact to be variously prepared and preserved under more controlled conditions than those available in the field. Littoral samples were examined in the fresh state to assess those organisms which preservation would render unidentifiable and were then treated in the same manner as other types of samples. Washing on U.S. Standard sieves (Table IV-1) removed extraneous sediments and detritus. Attached forms were scraped from both natural and artificial substrates and included with free, living forms; then, specimens, residual detritus, and sediments were transferred to storage containers for preservation. Samples were preserved in a 4% formaldehyde solution (10% formalin) to which Rose Bengal stain had been added as an aid to sorting. Following the picking/sorting procedures, specimens were transferred to 70% ethanol for permanent storage.

Littoral samples (qualitative) were initially examined while fresh under both compound and dissecting microscopes. Aliquots of the samples were scanned on depression slides and gridded petri dishes and the composition and relative abundance of the assemblage noted. The samples were then preserved and further analyzed as for other types of samples.

Quantitative samples (Petersen grab, epibenthic sled) were examined under dissecting microscopes. A small portion of the sample was placed in a petri plate and scanned; the organisms were picked from the residual debris with jewelers' forceps. Each aliquot was picked twice to assure completeness of the procedure. This procedure was continued until the entire sample had been picked.



The motile epibenthic community at Indian Point was sampled qualitatively with a biological dredge having a 6.35-mm mesh bag. One 3-min tow was made at each station monthly during 1972, but this sampling was reduced to one tow per region (test and control) in 1973. Quantitative sampling of the community during 1974 employed a metered 0.25-m² epibenthic sled (Figure IV-2) with 500- μ mesh nets.

Indian Point littoral fauna were collected bimonthly during 1972 using sweep nets, minnow seines, sand sieves, and dip nets to obtain the best qualitative assessment consistent with substrate conditions. Artificial substrate apparatus consisting of aluminum racks containing 12 asbestos siding plates (6 in. x 6 in.) were deployed at six locations in the Indian Point region during 1972 to provide qualitative and semiquantitative data on sessile epibenthos (Figure IV-2). Following 1 month's exposure, one plate was removed from each rack and replaced. Throughout the remainder of the study, two plates were removed for analysis each month: one plate exposed for the duration of the period and one exposed only for the previous month.

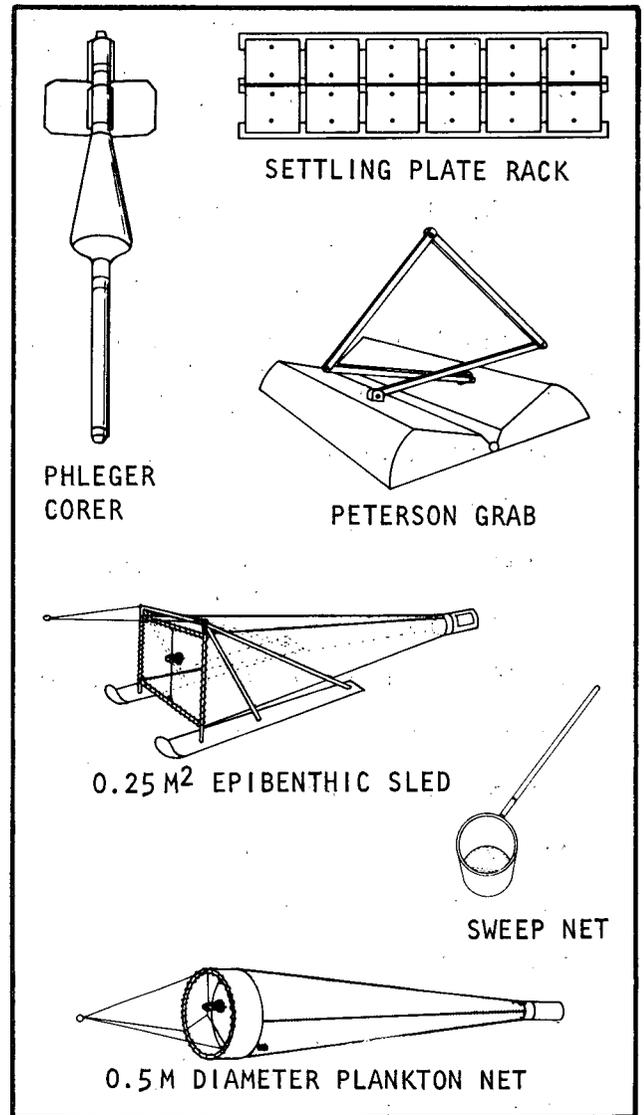


Figure IV-2. Indian Point Benthic Collection Gear.



Bottom sediments in the Peekskill area are dominated by fine sediments (63μ) with moderate amounts of medium, fine, and very fine sand (TI, 1973a) and contain relatively large amounts of detritus of terrestrial origin. Little natural stone or gravel exists in the sediments. Nearshore areas show man's influence to varying extents through the presence of spoil areas which may contain construction debris, cinders, brick rubble, and a wide variety of household refuse.

B. METHODS

Studies of the effects of thermal and chemical effluents from Consolidated Edison's Indian Point Nuclear Generating Facility on Hudson River benthos were begun in April 1972. Preliminary investigations were conducted over a broad area (Figure IV-1) to characterize the benthic community in terms of species composition and relative abundance, diversity, standing-crop biomass, and seasonal response to physical and chemical variation. Test and control areas were established for the 1973 and 1974 sampling programs to provide direct comparisons of benthic community structure and response in more restricted areas within and beyond the effluent plume of the plant (Figure IV-1).

1. Field Procedures

Benthic infauna and sessile epifauna were sampled once monthly during the 1972-1974 sampling seasons (April-December). Quantitative collections were made with a 0.1-m^2 Petersen grab.

Preliminary investigations during 1972 employed five replicate samples taken while the vessel was anchored at the respective stations. The 1973-1974 sampling comprised three replicate grabs taken at random within a 100-m-diameter circle. Samples were transferred to individual containers and transported to the field laboratory for washing and preservation.

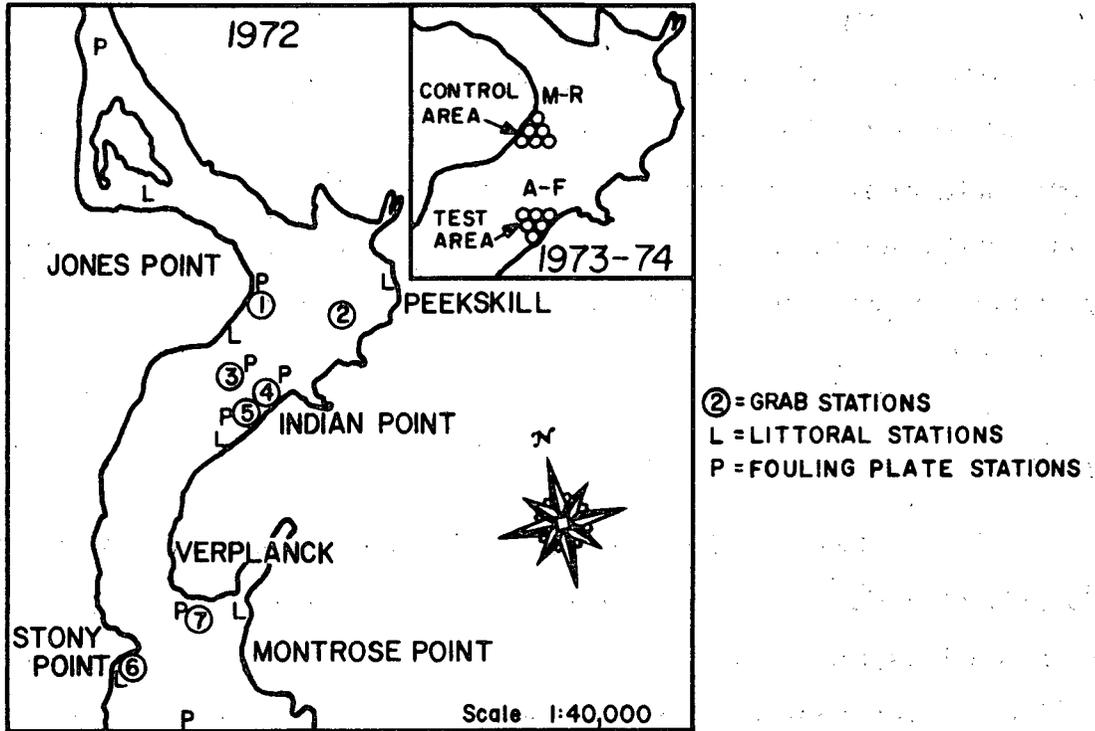


Figure IV-1. Location of Benthic Sampling Stations in Hudson River near Peekskill, New York, during 1972, 1973, and 1974

The main seaward flow of the river sweeps along the mouth of Peekskill Bay past Indian Point and moves westward diagonally across the river before being deflected eastward by Stony Point. Mid-channel depths at Indian Point range between 18 and 20 m (mean low water). The river bottom drops relatively steeply away from the eastern shoreline, reaching depths of approximately 14 m within the first 100 m, and then slopes more gradually outward to the channel. The western shoreline exhibits a more pronounced shelf behind the prominence of Jones Point, which slopes gently from 10 m near the shore to approximately 14 m at the perimeter of the area sheltered from major current flow; beyond this sheltered area, the bottom drops rapidly to the 18- to 20-m depths characteristic of the channel. The Peekskill region is subject to semidiurnal tidal fluctuations ranging in amplitude from 0.3 to 1.5 m.



1. Purpose of Study

Studies of the Hudson River benthic community near Peekskill, New York, from April 1972 through December 1974 assessed the biological significance of thermal and chemical additions from Units 1, 2, and 3 of the Consolidated Edison of New York, Inc., Indian Point Nuclear Power Generating Facility. As subsidiary objectives:

- (1) Community composition, diversity, and standing-crop biomass of benthos in the Indian Point area during the different seasons were estimated.
- (2) Sediment particle-size composition in the Indian Point region was characterized.
- (3) Response of the benthic community to naturally occurring physicochemical variations was evaluated.
- (4) Benthic community structure and seasonal variation in a test area at the generating facility were compared with those of a control area beyond the effects of plant operation.
- (5) The population dynamics of the estuarine isopod *Cyathura polita* in test and control areas were compared.

2. Study Area

The Hudson River near Peekskill, New York, is broad and bay-like (Figure IV-1). Above Peekskill for a distance of approximately 17 km (10.6 mi); the river is basically a narrow fjord bounded by rocky shores rising abruptly from the water line and, in many cases, dropping equally as precipitously to the bottom at depths of 18 m to 24 m. This natural channelization serves to increase relative velocity and reduce deposition of silt and organic detritus through these highlands, with corresponding increase in deposition at its outfall. The net result of this geological configuration is a concentration of silt and detrital material in Peekskill Bay and, to a lesser but still appreciable extent, in an eddy area near the western shore south of Jones Point.



SECTION IV

EFFECTS OF NUCLEAR ELECTRIC-GENERATING FACILITY'S THERMAL AND CHEMICAL EFFLUENTS ON BENTHOS OF HUDSON RIVER NEAR PEEKSKILL, NEW YORK

A. INTRODUCTION

Thermal and chemical effluents from once-through cooling processes have frequently been cited as sources of potential detriment to the aquatic community of the receiving waters. This conclusion is derived from the premise that a stable faunal assemblage is adapted to the existing chemical, physical, and geological regime and that the dominance hierarchy is established on the competitive superiority relative to these conditions. On this basis, perturbations which result in prolonged alteration of any of these factors could be expected to suppress or exclude species not favored by the modified conditions. The significance of externally imposed change, then, would be a function of the degree of modification, the tolerance limits and adaptive potential of the existing fauna, and the trophic position of stressed species. The long-term effect of stress might be either negligible if no major species deletions or shifts in relative abundance occurred or quite drastic if a species critical to energy flow through the community were excluded.

Benthic organisms, by virtue of their more sedentary nature, are more susceptible to stresses imposed by prolonged disturbance of the ecosystem than are the more motile pelagic forms which have the ability to migrate into or out of stress areas. Since the benthic community also is an important source of food for higher trophic levels, seasonal and annual fluctuations in community composition, relative abundance, and response to physico-chemical variables provide indices of the ultimate effects of environmental changes on the benthic community.



Helisoma anceps was found only in July and August and only in Peekskill Bay. The limpet *Ferrissia* was encountered only in the August samples but was present at four of the six stations. An unidentified marine nudibranch (Mollusca; Gastropoda) also frequently appeared in Petersen-grab samples.

Townes (1937) reported *Physa*, two species of *Helisoma* including *Helisoma anceps*, as well as *Lymnea*, *Gyraulus parvus*, and *Ferrissia fuscua*, in the Hudson River. *Amnicola* and *Physa* were reported in the Hudson in 1966 (Hirschfield, Rachlin, and Leff, 1966), and *Lymnea*, *Helisoma anceps*, and *Physa* were again reported in the lower Hudson in 1969 (Howells, Musnick, and Hirschfield, 1969).

The isopods *Chiridotea*, *Edotea*, *Cassidina lunifrons*, and *Cyathura polita* were present in the shore regions, with *Cyathura* being present from June through December and *Edotea* and *Chiridotea* only during later months.

Cassidina was not encountered until August but then was present monthly through December. Petersen grab collected all of these isopods also at the benthic stations; however, *Cassidina* appears to be much more numerous in the shallow areas. Townes (1937) reported all of the isopods in the 1936 study of the Hudson River.

In the shore samples, only two genera of amphipods were collected, the epibenthic *Gammarus* and the tubicular *Corophium*: the former throughout the study, being one of the most numerous macroinvertebrates encountered; and the latter only in the August-December samples and never numerous. The amphipods *Leptocheirus* and *Monoculodes*, which were sometimes collected in benthic grabs, did not appear in the shore regions.

One specimen of the uncommon endoproct *Urmatella gracilis* was collected at Peekskill Bay.



6. Fouling Community Analysis

Fouling organisms in the Indian Point region were dominated by *Balanus improvisus*, *Congeria leucophaeta*, and *Cordylophora lacustris* (Tables IV-7 and IV-8). *Balanus* proved to be the initial colonizing form, continuing to increase through September. Peak production and subsequent settling occurred during August, probably in response to increases in salinity. No additional settling was observed after collections in early October. Following much the same pattern as *Balanus* was the pelecypod *Congeria*; it initially appeared on plates collected in September, showing early reproduction in August with a peak in September. No additional settling occurred after early October. *Cordylophora* (hydroid) appeared between July and December. The appearance of *Hydra* sp. on settling plates was sporadic; they were present in great numbers at station 5 during August but established no pattern in their areawide distribution. Freshwater sponges were observed only once, during October, and then were attached to colonies of *Cordylophora* rather than directly to the settling plate.

Numbers of attached organisms varied from station to station on both 1-month and duration plates, but only general patterns could be determined. Station 7 showed the highest total numerical population development of attached forms, while station 3 was highest for *Congeria* and *Cordylophora*. *Hydra* were collected in high numbers only at station 5. The barnacle set seemed to be relatively constant throughout the area, although mean numbers were lower on duration plates at stations 3 and 5. Unattached forms associated with the plates were generally representative of those appearing in littoral and benthic samples at a particular time. They have been enumerated in this report; the values, however, cannot be considered truly valid due to losses incurred in lifting and removing the plates.

Density comparisons of *Balanus improvisus*, *Congeria leucophaeta*, and *Corophium* between 1970 (Raytheon, 1971) and 1972 revealed fewer specimens present on the 1972 plates throughout the sampling area.



Table IV-7
Indian Point Settling-Plate Results
(1-Month Plates)

Taxon	Month	May					Jun			Jul			Aug		Sep			Oct			Nov		Dec	
	Station	1	3	5	6	7	2	5	7	2	5	7	5	7	2	3	5	3	5	7	5	7	2	
<i>Bosmina</i> sp.		1																						
Calanoida		1						2	3															
Dipteran larvae		1	21	3		7	81	2	7	38	14	43			33	7	8	8	2	2			1	
Harpacticoida				1		2	3	2															3	
<i>Gammarus fasciatus</i>		5	4	8		1	1			1				139	2	2	92	23	273	263	20		4	
<i>Balanus improvisus</i>				1										52	115	1250	1045	2400	1004	1	167			
<i>Corophium</i> sp.			1												8	10	9	10				3		
<i>Stylaria</i> sp.			1				152																	
Isotomidae			1																					
<i>Limnodrilus</i> sp.		1		2					2	19					1									
<i>Hypaniola</i> sp.					1																			
Nematoda			6	1	1		2																	
<i>Hydra</i> sp.					1									404										
Cyclopoida			1	2																				
Oligochaeta (unidentified)				3			27																	
Ostracoda							1																	
<i>Latona</i> sp.								1																
Phloethnoidae								1																
Hydrachnellae									1															
<i>Daphnia</i> sp.										1														
<i>Ammicola</i> sp.										1	1										15		3	
<i>Cordylophora lacustris</i>											X				X	X	X	X	X	X	X	X	X	X
Planaridae													1						19					
<i>Congeria leucophaeta</i>															1	24	8	82	6	44				
<i>Rithropanopeus harrisi</i>																2				4				
Nudibranchia																		80						
<i>Nereis succinea</i>																			1					
<i>Cassidina lunifrons</i>																								
<i>Ferrissia</i> sp.																							1	
<i>Scolecopides viridis</i>																							1	
Tricoptera																								1

IV-27

services group



Table IV-8
 Indian Point Settling-Plate Data
 [Duration Plates Species List, Settling Plate (Duration)]

Taxon	Month																					
	May		Jun			Jul		Aug			Sep			Oct			Nov			Dec		
	Station																					
	2	3	5	7	2	7	2	5	7	2	3	5	7	2	3	5	7	2	3	5	7	5
Dipteran larvae	36	44	3	18	35	46	2		6	19	2		8	3	10	9	3			4	22	21
<i>Gammarus fasciatus</i>	2	2	1		1	5		50	23	12	182	1	196	44	521	50	213	36	133	72	54	45
<i>Hydra</i> sp.	2			1				842														
<i>Limnodrilus</i> sp.	61			8	72	10																
Oligochaetes (unidentified)	5																					
<i>Latona</i> sp.			1																			
Nematoda				1										1								
<i>Balanus improvisus</i>				1		27	36	1439	1320	204	1352	4315	3387	1288	1480	1665	3774	310	653	2627	844	
Phloothripidae				2																		
<i>Lophopodella carteri</i>				2																		
<i>Daphnia</i> sp.					1																	
<i>Cordylophora lacustris</i>								✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
<i>Ammicola</i> sp.		2													6		3		2	3		
Calanoida						2																
<i>Rhithropanopeus harrisi</i>								5			2					4						
Harpacticoida								2									2					2
Planaridae							1				2		2	1						20		20
<i>Congerina leucophaeta</i>									46	1	17	24	155	103	121	110	113	93	142	112		174
<i>Corophium</i> sp.										10			92	22	8	36	153	6	35	1	36	7
<i>Boccardia hamata</i>													1			2	23					
<i>Cassidina lunifrons</i>													1									
<i>Nereis succinea</i>													1							1		
Spongillidae																	4					
Ostracoda																1						
Tricoptera														5								
<i>Ferrissia</i> sp.														35								
Nudibranchia																					6	
<i>Cyathura polita</i>																	1					
<i>Pisiccola</i> sp.																1						
<i>Scolecoclepidus viridis</i>															1							
<i>Crangon septempinnosa</i>																				1		2
<i>Leptocheirus</i> sp.																					1	2
Cyclopoida																						
<i>Chaeborus</i> sp.																				1		



7. Epibenthic and Plankton Community

During 1974, the epibenthic and planktonic macroinvertebrate collections at Indian Point included 29 and 31 taxa, respectively – primarily Arthropoda (20 Crustacea and nine Insecta). Epibenthic macroinvertebrates were heavily concentrated in the area that was 10 to 60 cm above the bottom sediments and were far less frequent in the upper waters during daylight hours (Table IV-9).

Other studies on the Hudson River have indicated that many of these organisms are more evenly distributed throughout the water column at night (TI, 1975b; LMS, 1975). Except for calanoid copepods, numbers of individuals were somewhat higher in the control-area epibenthic-sled collections and somewhat lower in plankton-net collections than in corresponding test-area collections. This phenomenon is probably attributable to an eddy area below Jones Point which would facilitate more rapid sinking rates and concentrate animals near the bottom.

8. Comparison of 1972 Sampling Stations

Analysis of covariance of grab data for the seven primary stations employed during 1972 indicated that station 2 was consistently lower in all biological factors tested except numbers of the tubificid worm *Limnodrilus* and dipteran larvae. The same was generally true of station 6, but stations 1, 4, 5, and 7 showed significantly higher numbers of species. Station 3 was highly variable because of areas of brick and concrete debris and scouring which presented great diversity of microhabitats. Station 3 approximated an intergrade between pollution conditions and conditions of stations 1, 4, 5, and 7, which may be attributable to its position near and downcurrent from Peekskill Bay.

There is no ready explanation for the reduced benthic community found at station 6. Its location immediately downstream from and behind Stony Point on the edge of an area of rapid depth increase and resultant instability of currents, sediments, and tidal effects may be responsible for the erratic results observed.



Table IV-9

Numbers of Epibenthic and Planktonic Organisms/1000 M³ in Indian Point Test and Control Areas during 1974

Taxon	Epibenthic Sled		Plankton Net	
	Test	Control	Test	Control
Calanoida	19532.8	2101.3	172.0	134.8
<i>Daphnia</i> sp	1784.2	2202.2	216.7	238.5
<i>Neomysis americana</i>	2614.7	6435.5	3.6	1.8
<i>Gammarus</i> sp	3749.2	3487.1	9.0	5.3
<i>Monoculodes</i> sp	1144.7	2205.5	-	-
<i>Leptodora kindti</i>	1421.1	316.2	16.6	19.2
<i>Chaoborus</i> sp	1031.0	379.1	4.2	2.3
<i>Amnicola</i> sp	11.5	3265.0	76.9	1.1
Amnicolidae	27.9	66.2	2.3	114.6
<i>Balanus improvisus</i>	211.9	270.3	72.8	19.6
Cyclopoida	50.6	68.5	65.4	13.5
<i>Cordylophora lacustris</i>	24.4	24.7	3.1	3.7
Chironomid larvae	10.2	1.5	33.7	3.2
Chironomid pupae	10.2	1.5	65.4	13.5
Hydracarina	1.8	10.0	2.6	5.5
Zoeal larval	3.5	6.2	5.2	5.5
<i>Piscicola</i> sp	0.8	2.6	0.7	1.1
<i>Sida</i> sp	212.7	149.5	2.1	-
<i>Corophium</i> sp	12.8	10.4	0.5	-
<i>Scolecopleides viridis</i>	44.2	191.1	-	-
<i>Crangonyx</i> sp	11.6	157.7	-	-
<i>Chironomus almyra</i>	6.3	27.8	-	-
<i>Edotea</i> sp	2.6	22.8	-	-
<i>Pectinatella magnifica</i> (Floatoblast)	4.2	-	-	-
Collembola	2.2	-	-	-
<i>Cyathura polita</i>	-	4.0	-	-
<i>Rhithropanopeus harrisi</i>	-	2.6	-	-
<i>Leptocheirus</i> sp	-	1.4	-	-
<i>Lophopodella carteri</i> (Floatoblast)	-	23.6	1.8	-
Naididae	-	-	1.0	1.3
Macrothricidae	-	-	39.5	-
Cladoceran ehippia	-	-	1.8	-
<i>Hydra americana</i>	-	-	1.4	-
Ostracoda	-	-	0.9	-
Ephemeroptera	-	-	0.7	-
Oligochaeta	-	-	0.5	-
Trichopteran larvae	-	-	0.5	-
Bosminidae	-	-	-	7.3
Trichopteran Adult	-	-	-	1.8
<i>Hyalinella</i> sp (Floatoblast)	-	-	-	1.4
<i>Stylaria</i> sp	-	-	-	0.9
Total No. of Taxa	26	28	27	21
Annual Mean No./1000 m ³	32622.5	21460.6	800.9	595.9



9. Comparison of 1973-1974 Test and Control Areas

Analysis of variance of numbers of specimens in the test and control areas during 1973 showed significant variations in abundance ($P < 0.01$) both between the test and control areas and among stations within areas. These variations were generally the result of variations in microhabitat associated with sediment composition, quality of the interstitial water, or a combination of these factors. Somewhat higher percentages of sand characterized control-area sediments, while higher levels of silt and clay were in the test area.

Of the taxa differing significantly between the test and control areas, *Rhithropanopeus harrisi* and *Ammicola* sp. were also found to respond ($P < 0.01$ and $P < 0.05$ respectively) to variations in the sand/silt/clay composition of the sediments. Their selectivity in sediment type corresponded to the observed variations between the test and control areas.

Depth in the control area was 8-21 m; in the test area, 11-22 m. Littoral sampling (sweep and throw nets) during 1972, although not quantitative, indicated that *Chiridotea almyra* and *Edotea* sp. were more abundant in littoral areas than in deeper offshore areas. These species' variations in abundance may be attributable to littoral preference.

The total number of taxa and annual mean number of specimens per square meter were greatly increased during 1974 in both the test and control areas. *Balanus improvisus*, *Ammicola* sp., *Congerina leucophaeta*, and *Rhithropanopeus harrisi*, all annually reproducing species which had been present in relatively low numbers during 1973, increased considerably during 1974. Other species such as *Scolecopides viridis* showed progressive increases in 1973 and 1974 over their 1972 population levels. The number of taxa observed during 1974 was increased over 1973 not only by the reappearance of halophilic



(salt-loving) forms (*Cassidina lunifrons*, *Nereis succinea*), which were collected during 1972 but were missing in 1973, but by the collection of several taxa (*Crangon septemspinosa*, *Crangony* sp.; *Ferrissia* sp.) which had not been taken previously in grab samples. These increases apparently reflected the influence of greater duration of salt exposure in the Indian Point area during both 1973 and 1974, which resulted in higher levels of community diversity and production than those observed during 1973.

Analysis of combined 1973-1974 benthic data indicated significant variations ($P < 0.05$) between the Indian Point test and control areas for major species (Table IV-10); however, with the single exception of chironomid larvae, no consistent pattern of areawide dominance was discernible. In most instances in which the areas (test and control) were found to differ significantly in numbers of a major species, the variation was localized at an extremely high or low number of that species at a particular station or pair of stations rather than reflecting overall superiority in the area.

10. Comparison with Previous Studies

Indian Point benthic community structure during 1972-1973 (TI, 1973a, 1974a) and that reported for 1969-1970 (Raytheon, 1971) indicated shifts in community composition from dominance by halophilic forms during the former study period toward less salt-tolerant forms during the latter as a result of variations in the salinity regime. Bottom salinities at Indian Point during 1969-1970 (Raytheon, 1971) were approximately the same as those observed during 1972-1973, but length of exposure during the earlier study considerably exceeded those of the later study; the earlier study comprised the end of a period of low rainfall and reduced runoff, which greatly increased both duration and extent of the annual incursion of the salt front into the Indian Point region (U.S. Department of Interior, 1965-1970). During 1973 and 1974, duration of salt intrusion in the Indian Point region increased over the 1971-1972 period. By 1974, benthic-community composition and relative abundance had shown a general reversal of the earlier trend, again favoring the halophilic forms (Tables IV-11 and IV-12).



Table IV-10

Comparison of Means and Standard Deviations between Test and Control Areas, Indian Point, 1973-1974, Showing Probability of Area Variations and Station Differences

Species	MEAN			STANDARD DEVIATION	
	Months Analyzed	Test vs Control	Pairwise Station Differences (0.05 level) Stations	Test vs Control	Pairwise Station Differences (0.05 level) Stations
<i>Gammarus</i>	Apr-Dec Apr-Dec	Test P=0.02	A, B, C, E > R [†] A, C, E > O C, E > D, M, N, P C > F, Q	Test P=0.07	A > O, R
<i>Cyathura</i>	Apr-Dec Apr-Dec	Test P=0.03	B, C, E, Q > M, O [†] C, Q > R C > A, D, F, N, P	Test P=0.22	None
<i>Limnodrilus</i>	Apr-Dec Apr-Dec	Control P=0.002	O, R > A, C, D, E, M, N [†] R > F, P, Q	Control P=0.003	Q, R > E R > D
Chironomid	Apr-Dec Apr-Dec	Test P=0.001	A, B, C, D, E, F > M, N, O, P, Q, R [†]	Test P=0.001	A, B, C, D, F > P B, D > M, N, O A, B, D, F > Q
<i>Balanus</i>	Oct-Dec Jul-Dec	Test P=0.5	C > M, P, R	Test P=0.46	A, B, C > R
<i>Congerina</i>	Sep-Dec Sep-Dec	Test P=0.004	None*	Test P=0.004	None*
<i>Scolecoplepides</i>	Apr-Dec Apr-Dec	Test P=0.13	C, D, E, F, P, Q, R > A [†] C, D, E, F, R > B, M F > N, O	Test P=0.31	None*
<i>Boccardia</i>	Sep-Dec Apr-Dec	Control P=0.02	Q > D, F, N, O	Control P=0.007	Q > O
<i>Hypaniola</i>	Nov-Dec Nov-Dec	Test P=0.06	None*	Test P=0.06	None
<i>Corophium</i>	Sep-Dec Aug-Dec	Control P=0.33	None*	Test P=0.29	A, C > R C > O
<i>Chironotea</i>	Jul-Sep Apr-Aug	Control P=0.004	N > A	Control P=0.004	None*
<i>Edotea</i>	Oct-Dec Aug-Nov	Control P=0.05	P > A	Control P=0.04	P > A

*Nonparametric 2-way analysis of variance considering all stations was significant at 0.05 level, but no pairwise station difference was significant.

[†]Larger area reported and associated significance level. Analysis uses all three replicates, not the mean.



Table IV-11

Comparison of Relative Abundance of Dominant Taxa during August-December Periods of 1969, 1972, 1973, and 1974

Taxon	Mean No./m ²					
	1969*	1972	1973		1974	
			Test	Control	Test	Control
<i>Congeria leucophaeta</i>	56	192	124	64	521	134
<i>Gammarus</i> sp	104	72	320	137	189	76
<i>Cyathura polita</i>	160	192	280	138	555	654
<i>Leptocheirus</i> sp	384	2	3	<1	24	10
<i>Balanus improvisus</i>	1408	227	86	197	1803	1486
<i>Monoculodes</i> sp	0	<1	<1	3	9	7
Nemertea	16	<1	<1	2	6	44
<i>Rhithropanopeus harrisi</i>	0	8	9	<1	31	22
<i>Corophium</i> sp	0	27	94	48	236	285
<i>Edotea</i> sp	16	5	11	45	23	58

*From Raytheon, 1971

Table IV-12

Comparison of Relative Abundance of Dominant Taxa during January-October Periods of 1970, 1972, 1973, and 1974

Taxon	Mean No./m ²					
	1970*	1972	1973		1974	
			Test	Control	Test	Control
<i>Congeria leucophaeta</i>	560	107	89	45	239	83
<i>Gammarus</i> sp	320	83	353	211	287	181
<i>Cyathura polita</i>	316	162	260	139	448	411
<i>Leptocheirus</i> sp	224	1	2	<1	16	6
<i>Balanus improvisus</i>	116	130	62	141	816	943
<i>Monoculodes</i> sp	52	<1	<1	2	2	2
Nemertea	36	<1	<1	1	4	3
<i>Rhithropanopeus harrisi</i>	24	7	9	1	16	12
<i>Corophium</i> sp	8	66	72	34	94	195
<i>Edotea</i> sp	<1	3	8	32	14	40

*From Raytheon, 1971



11. Sediment Particle-Size Composition

Bottom sediments in the Indian Point region are predominantly sandy clay/silt, with patches of pebbles (Table IV-13). Shoreward areas show pronounced effects of human activities through the presence of construction debris, cinders, and various forms of household refuse. Test-area sediments contained slightly higher percentages of gravel and clay/silt, while the control area was generally somewhat sandier.

12. Sediment-Temperature Studies

Simultaneously with monthly sampling during 1974, temperatures of sediments and overlying water were determined for each station in the test and control areas. *In situ* apparatus designed and built for this application permitted simultaneous measurement of sediment temperature 1 cm below the interface and water temperature 2.5 and 30 cm above the interface. Annual and monthly mean test- and control-area temperatures for these three strata appear in Table IV-14.

Analysis of variance between stations, areas, months, and strata indicated that temperatures of sediments were significantly higher than those of the overlying waters, although the differences were relatively small. No significant differences among individual stations or between the test and control areas were detected.

13. Distribution/Physicochemical Analyses

Two analyses of the relationship between patterns of distribution of benthic organisms and physicochemical variation in the environment were performed. The first analysis provided correlation matrices for the abundance of major taxa with temperature, dissolved oxygen, salinity, and the



Table IV-13

Mean Particle-Size Composition of Sediments in Test and Control Areas, October and November 1973

	Station	Particle Size (mm)								
		> 8	4 - 8	2 - 4	1 - 2	0.5 - 1	0.25 - 0.5	0.125 - 0.25	0.63 - 0.125	< 0.63
Test	A	14.8	6.8	3.8	3.0	1.5	8.1	3.9	5.5	54.4
	B	0	0.9	0.8	2.4	1.4	11.7	6.7	8.2	67.9
	C	3.2	3.9	2.3	2.8	0.8	3.7	3.9	5.0	74.4
	D	1.5	0.8	0.6	1.4	0.8	4.3	4.4	9.2	81.5
	E	0	0	0.04	2.4	0.8	2.2	2.8	7.9	83.8
	F	0	0.7	1.5	0.6	0.6	2.9	2.9	5.0	87.8
	Mean	3.25	2.18	1.51	2.10	0.98	5.48	4.1	6.8	74.97
Control	M	5.2	2.7	3.4	3.5	1.9	14.3	19.9	10.4	41.3
	N	4.1	13.8	11.2	12.0	3.6	7.7	10.1	10.9	31.6
	O	0.3	0.5	0.4	0.8	0.7	11.1	9.8	7.0	62.0
	P	3.7	3.6	1.9	1.3	4.2	5.5	10.8	7.9	64.4
	Q	0	0	1.6	0.4	0.3	1.6	3.9	10.0	82.6
	R	0.7	2.1	1.2	0.5	0.4	3.8	9.1	7.7	78.7
	Mean	2.33	3.78	3.28	3.08	1.85	7.33	10.6	8.98	60.1

Table IV-14

Mean *In Situ* Water and Sediment Temperature (°C) for Test and Control Areas 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



various combinations of these factors and considered rate of change in abundance and time lag in response (Table IV-15). Salinity and temperature are positively correlated while temperature and dissolved oxygen are negatively correlated. To gain an indication of the relative importance of each factor to distribution, a stepwise regression considered abundances relative to the means of the physicochemical variables at various intervals, the absolute change during a time interval, and the squares of each of these values (Table IV-16). Results of the analyses appear in Table IV-17.

14. *Cyathura polita* Studies

An alternate approach in documenting plant effect on the benthic portion of the ecosystem is an in-depth quantitative study of one important species in the system. In 1972, *Cyathura polita* was chosen for a preliminary study because it was important on a biomass and numerical basis, was exploited as food, and was more truly benthic (in contrast to *Gammarus* which is epibenthic to pseudo-planktonic). The life history and biological and morphological characteristics of *Cyathura polita* were studied.

Sample analysis revealed that *Cyathura polita* was present throughout the study area at a mean density of 161.5/m². Statistically significant differences in numbers of *Cyathura polita* among stations each month were determined with Friedman 2-way analyses of variance.

There were significant differences ($\alpha = 0.05$) in the number of cyathurans each month, station 2 having significantly less than stations 3, 4, and 5 over the 7-month period.

During the collection year, salinity (as reflected by conductivity) and temperature varied greatly, with temperature reaching approximately 25°C during August and salinity peaking during September. The possible role of salinity in seasonal variation and reproduction is compatible with the 1969 and 1972



Table IV-15
Variables Considered in Stepwise Regression

Description	Symbol
1. Temp lagged 0 weeks - Mean temp for 0-week lag	TP 0
2. D.O. lagged 0 weeks - Mean D.O. for 0-week lag	DO 0
3. Cond lagged 0 weeks - Mean cond for 0-week lag	CD 0
.	.
.	.
.	.
19. Temp lagged 6 weeks - Mean temp for 6-week lag	TP 6
20. D.O. lagged 6 weeks - Mean D.O. for 6-week lag	DO 6
21. Cond lagged 6 weeks - Mean cond for 6-week lag	CD 6
22. Absolute change* in temp from week 0 to 1 and 1 to 2	C TP 1
23. Absolute change in D.O. from week 0 to 1 and 1 to 2	C DO 1
24. Absolute change in cond from week 0 to 1 and 1 to 2	C CD 1
.	.
.	.
.	.
34. Absolute change in temp from week 4 to 5 and 5 to 6	C TP 5
35. Absolute change in D.O. from week 4 to 5 and 5 to 6	C DO 5
36. Absolute change in cond from week 4 to 5 and 5 to 6	C CD 5
37. Square of variable 1	S TP 0
38. Square of variable 2	S DO 0
39. Square of variable 3	S CD 0
.	.
.	.
.	.
55. Square of variable 19	S TP 6
56. Square of variable 20	S DO 6
57. Square of variable 21	S CD 6
58. Y variable is change in abundance, i. e., difference abundance at time t minus abundance at time t minus 1	

* Let X_i be the value of an observed physical variable for i lagged weeks; then, absolute change is defined as $|X_{i-1} - X_i| + |X_i - X_{i+1}|$ for this analysis.

Table IV-16

Multiple Correlation Coefficients Derived from Stepwise Regression Analysis of
Physicochemical Data Relative to Distribution of Benthic Organisms

Species	Intake			Effluent		
	Variable*	Multiple Correlation Coefficient	F To Remove ⁺	Variable*	Multiple Correlation Coefficient	F To Remove ⁺
<i>Gammarus</i>	S DO 3	-0.929	38.8	S DO 0	-0.758	25.1
	C CD 4	+0.964	4.6	C DO 1	+0.915	8.1
<i>Cyathura</i>	S CD 1	-0.673	452.5	S CD 2	-0.719	717.5
	DO 2	-0.859	356.3	TP 1	+0.944	390.3
	S TP 2	+0.997	174.3	S DO 2	+0.998	88.9
<i>Limnodrilus</i>	C DO 4	-0.855	185.0	S CD 1	-0.816	418.9
	C TP 3	+0.964	24.1	S TP 2	+0.945	159.9
	S CD 3	-0.994	19.3	DO 3	-0.996	52.8
Chironomid larvae	S DO 6	-0.822	38.1	C TP 1	+0.796	31.7
	C TP 2	+0.967	19.7	TP 2	-0.930	8.5
<i>Balanus</i>	C DO 1	-0.610	76.2	C DO 1	-0.785	33.5
	S CD 1	-0.850	61.7	S CD 5	+0.907	42.6
	DO 5	-0.986	37.0	C TP 2	+0.987	23.8
<i>Congerina</i>	S TP 0	-0.617	24.2	S DO 0	-0.795	29.1
	C CD 4	+0.847	19.2	S CD 6	+0.954	15.4
	C TP 1	+0.961	10.9			
<i>Scolecopides</i>	S DO 4	+0.880	29.9	S TP 2	+0.764	12.0
	CD 1	+0.933	3.8	S DO 4	+0.933	11.1
<i>Boccardia</i>	S TP 0	-0.686	15.9	C CD 1	+0.715	90.9
	C CD 4	+0.895	8.3	C TP 3	+0.974	43.3
<i>Ammicola</i>	S TP 0	-0.775	34.2	C CD 5	+0.609	68.2
	C TP 2	+0.952	16.5	CD 1	-0.857	81.2
				S DO 2	-0.986	33.2

* Variables entered until a temperature, dissolved oxygen, or conductivity variable is repeated or until a large multiple correlation coefficient is obtained.

⁺ Presented only for last set of variables in regression.





Table IV-17

Trends in Responses of Major Benthic Invertebrates
to Variations in Temperature, Dissolved Oxygen, and Conductivity

Species	Temperature	Dissolved Oxygen	Conductivity
<i>Limnodrilus</i> sp.	+	-	-
<i>Ammicola</i> sp.	-	+	0
<i>Scolecopides viridis</i>	-	+	0
<i>Boccardia hamata</i>	+	+	+
<i>Balanus improvisus</i>	+	-	+
<i>Cyathura polita</i>	+	0	-
<i>Gammarus</i> spp.	-	+	-
<i>Congerina leucophaeta</i>	+	0	+
Chironomid larvae	-	+	0
<i>Corophium</i> sp.	+	0	+
<i>Rhithropanopeus harrisi</i>	+	-	+
Nematoda	+	-	+
<i>Hypaniola</i> sp.	-	+	0

Note: + = positive correlation, - = negative correlation, 0 = no response

Analysis of sediment particle size reflected considerable variation among stations in the Indian Point and Ossining areas. In both areas, clay and silt (0.062 mm) dominated and the average silt/clay fraction was approximately 80%. The amount of sand present and its particle-size distribution within the sand fraction appeared to influence *Cyathura* densities. Of the 13 stations sampled, two (Ossining stations 1 and 4) had large percentages of sand (39.5 and 39.3, respectively) in the size range of 0.5 to 0.062 mm and had the lowest mean *Cyathura* densities.



In April 1972, the number of *Cyathura* collected in the Indian Point area decreased steadily through the July sampling period and then rapidly increased from August through November. This phenomenon largely reflected increases in the number of juveniles collected.

a. Population Dynamics

Seasonal variation in population density of the estuarine isopod *Cyathura polita* (Stimpson) during 1974 was similar in the Indian Point test and control areas; both areas exhibited relatively low numbers during the early months, high reproduction and corresponding increases in total numbers during May-September, and general decreases through fall and early winter (Figure IV-4). This pattern is consistent with those determined for the test area during 1972-1973 and for the control area during 1972. While seasonal fluctuations in the control area during 1973 generally followed this pattern, reproductive success and corresponding population numbers were low; this population disruption was probably due to *Cyathura's* intolerance to low dissolved-oxygen conditions (Dean and Haskin, 1964; Burbanck, 1964) which resulted from deposition of large amounts of detrital material in the area early in the reproductive period and was apparently associated with reduction of free oxygen. This phenomenon was discussed more completely in the Indian Point 1973 Annual Report (TI, 1974a).

b. Length-Frequency Distribution

Length-frequency distribution in 1972 and 1973 (TI, 1974a,) indicated that the *Cyathura polita* population was composed of three year classes and that a fourth class appeared at about the same time as, or slightly before, the disappearance of the last remnants of the oldest group. These data support the 3-year life span suggested by Burbanck (1962). Distribution during 1972 and 1973 indicated that reproduction occurs in a relatively

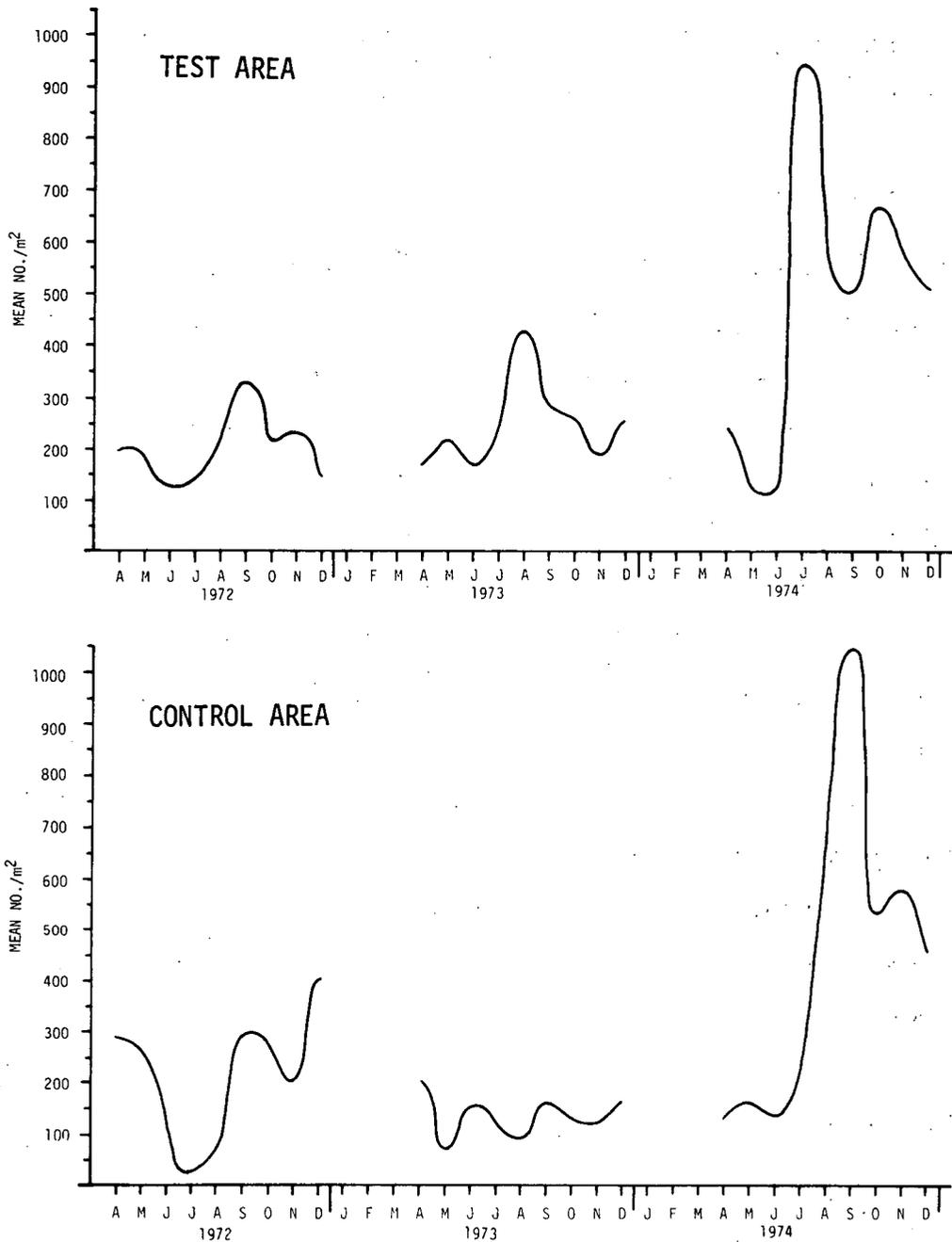


Figure IV-4. Mean Monthly Density of *Cyathura polita* (Stimpson) in Indian Point Test and Control Areas, April 1972-December 1974



short period during the summer, with year-class numbers reaching their peak within 3 months; these numbers then begin to decline, decreasing to approximately 50% of their original at the end of the first year. The population continues to decline slowly before disappearing completely at the end of the third year.

Length-frequency distributions of *Cyathura polita* in the Indian Point test and control areas during 1974 (Tables IV-18 and IV-19) were similar; the only apparent variation was in maximum size, which was somewhat higher (20 vs 23 mm total length) in the test area. This variation may have been attributable entirely to chance, however, since relative numbers of large individuals were low.

c. Length/Weight Relationship

Length/weight regression analysis of *Cyathura polita* populations indicated no significant difference ($P = 0.05$) between populations in the test and control areas during 1973. Regressions calculated for the respective areas during July 1973 are illustrated in Figure IV-5.

d. Fecundity (Reproduction)

The reproductive season of *Cyathura polita* during 1973 extended from late May through August. Numbers of eggs and embryos observed within the marsupia of reproducing females varied from 1 to 36 with no observable relation to the size of the individual. The process of deposition of eggs in the marsupium apparently extended over a prolonged period; thus, low numbers of eggs present in the marsupium did not necessarily mean low levels of reproduction but could simply have been a function of collection early in the egg-deposition process. Three distinct developmental stages — egg, embryo, and



Table IV-18

Cyathura polita Size-Class Frequency Distribution
in 1974 Control-Area Collections

Size Class (mm)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1						1			
2						238	80		
3				247	104	314	165		
4	11	25	5	6	101	214	224	65	52
5	29	57	12		178	124	150	221	191
6	33	53	28	2	302	138	70	292	197
7	27	27	31	8	96	140	54	120	112
8	23	17	25	24	72	174	26	41	77
9	15	18	16	16	8	159	35	56	39
10	16	16	29	21	6	88	16	45	36
11	11	9	15	7	16	58	12	27	28
12	18	13	14	9	28	60	7	19	16
13	13	10	8	4	22	31	8	12	17
14	11	6	6	2	7	22	9	4	7
15	4	2	1	1	3	14	2	9	8
16	5	3	6	1	2	4	6	5	9
17	3	1			1	5		5	7
18		1	2	1			2	3	3
19	2	2		2				1	2
20	1								1
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
Total	222	262	198	351	946	1784	866	925	802

Table IV-19

Cyathura polita Size-Class Frequency Distribution
in 1974 Test-Area Collections

Size Class (mm)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1						2			
2						158	71	4	
3				109	37	213	199	63	58
4	4	12	5	1076	70	88	120	293	174
5	15	70	12	88	88	120	293	213	174
6	44	44	28	1	177	62	152	216	195
7	54	59	31		39	107	123	105	108
8	57	28	25	16	47	44	138	108	83
9	35	28	-16	27	17	26	69	44	52
10	52	25	29	32	10	27	36	66	49
11	41	11	15	46	10	11	20	28	31
12	15	10	14	27	13	8	18	22	16
13	16	10	8	46	19	8	17	12	15
14	11	6	6	30	14	14	11	20	10
15	5	5	1	15	6	9	17	14	15
16	2	1	6	18	2	6	15	15	12
17	7	5		8	1	11	10	8	6
18	7	2	2	3		5	6	8	7
19	6			3	1	1	2	6	3
20	7	2		2			1	1	7
21	2								1
22	2								
23	2						1		
24									
25									
26									
27									
28									
29									
30									
Total	384	318	186	1547	551	832	1199	953	843

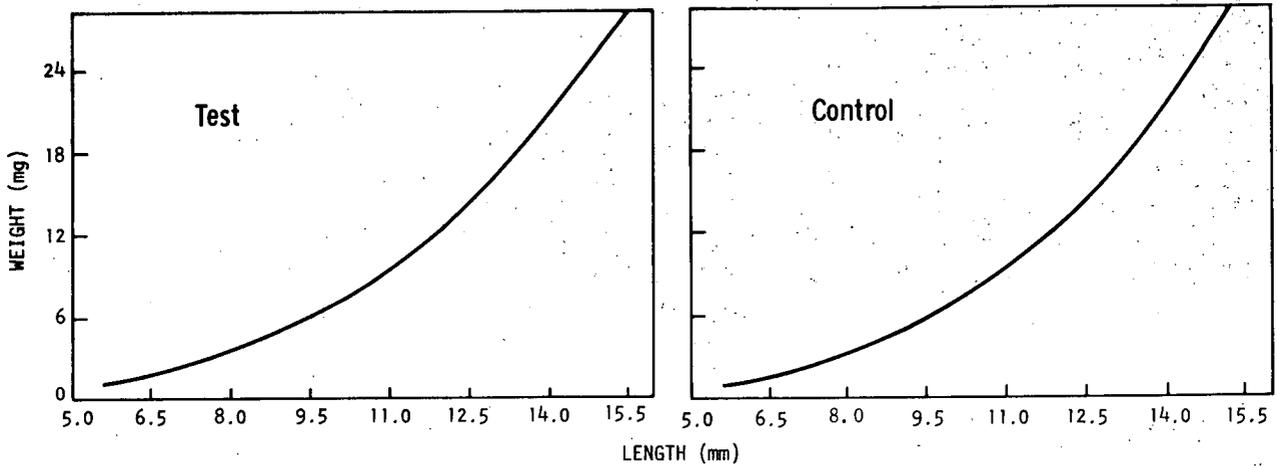


Figure IV-5. Length/Weight Regressions for *Cyathura polita* Calculated on Basis of Data Derived from Test- and Control-Area Collections during July 1973

larva - could be detected within the marsupium (Figure IV-6). Eggs were generally round to slightly oval and varied in diameter from 0.5 to 0.7 mm. The length of embryos varied between 0.8 and 1.5 mm, with larvae reaching a maximum length of 2.0 mm.

The release of young also occurred over an interval rather than in an instantaneous explosion. Immature *Cyathura* were released from the marsupia of adult females between late April and the end of August 1973. Immature specimens 4 mm long appeared in monthly collections during the reproductive period. A few 3-mm specimens and one 2-mm specimen were taken in 1973 collections. The virtual absence of 2- and 3-mm specimens may have been the result of extremely rapid growth immediately following emergence from the marsupium and of gear selectivity during sampling.

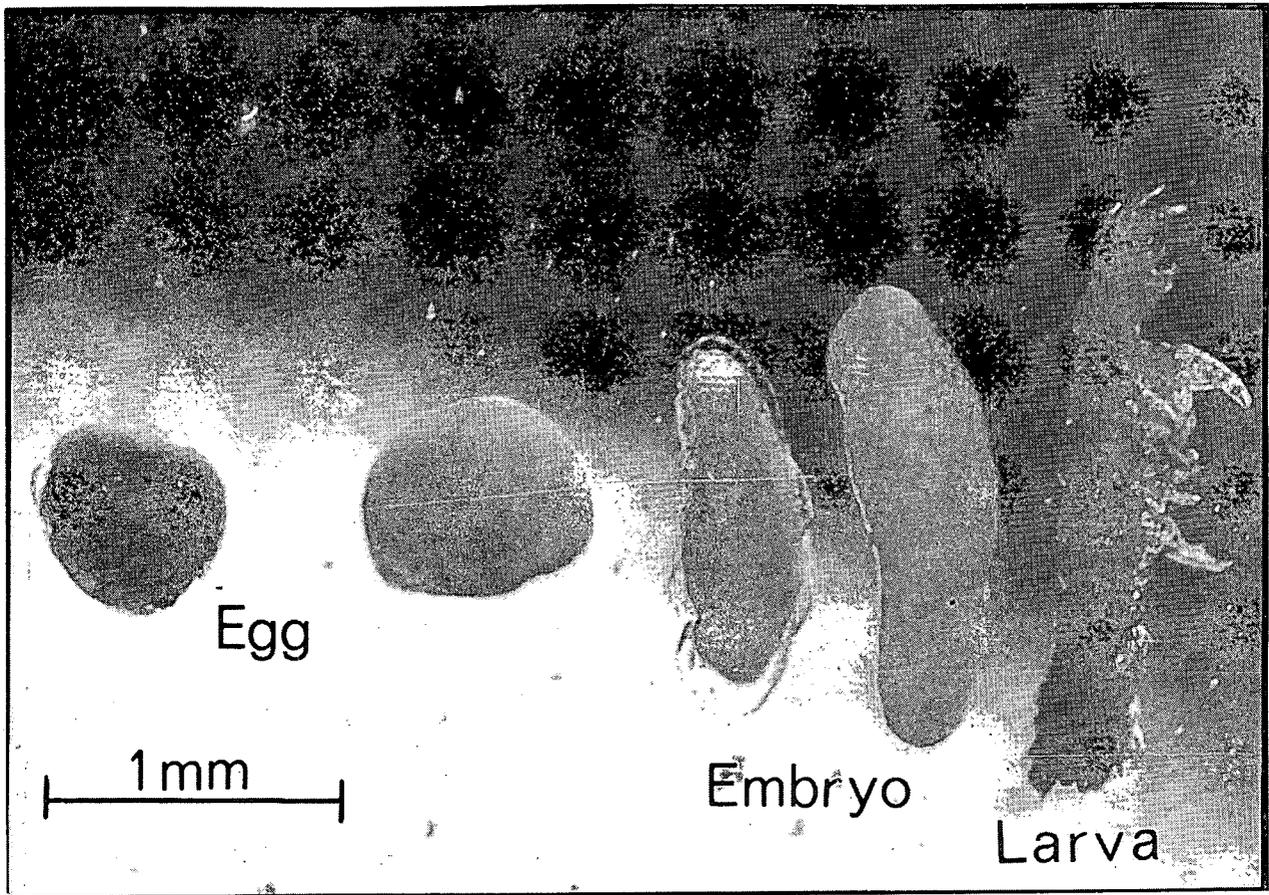


Figure IV-6. Developmental Stages of *Cyathura polita* Observed within Marsupia of Adult Female Specimens Collected during 1973

During 1974, 127 and 68 reproductive female *Cyathura* were collected in the Indian Point test and control regions, respectively (Table IV-20); these included recently spent individuals as well as all specimens containing eggs, embryos, and larvae within the marsupium. Calculations of mean number of young based only on those individuals containing young within the marsupium indicated that control-area young per reproductive female considerably exceeded those in the test area (test = 23.0; control = 42.2). It is interesting to note, however, that theoretical total natality for the two areas (test = 1621.5; control = 1595.3) was almost identical, as was standing crop in the two areas in the latter months of 1974, even though control-area density was significantly lower during 1973.



Table IV-20

Theoretical Natality of *Cyathura polita*
in Indian Point Test and Control Areas during 1974

	Month (1974)	Total No. Reproductive (N)	No. Reproductive/m ² (N/m ²)	Mean No. of young (n)	Theoretical Natality/m ²
Test	June	8	4.4	23.0	101.2
	July	52	28.9	23.0	664.7
	August	56	31.1	23.0	715.3
	September	11	6.1	23.0	140.3
	Total	127			1621.5
Control	June	14	7.8	42.2	329.2
	July	8	4.4	42.2	185.7
	August	32	17.8	42.2	751.2
	September	14	7.8	42.2	329.2
	Total	68			1595.3

e. Population

During 1973, numbers of *Cyathura polita* collected in the test area were significantly higher (Chi-square, $P = 0.05$) than those collected in the control area. This was probably attributable to reduced survival of immature forms concurrent with the appearance of large amounts of detrital material in the control area following local heavy rains in late April. The relatively low overall flow of the river at this time seems to have facilitated minimal dispersal of the material and concentrated deposition in the eddy area below Jones Point. In the first sampling (May 1973) following this deposition, total numbers of *Cyathura polita* were reduced, with the greatest impact due to decreases in the immature portion of the population. The effects of the disruption, observable during May, June, and July, were limited to reproduction, population instability, and generally decreased numbers. By August, the control-area population had stabilized at a reduced level and throughout the remainder of the year followed a pattern of seasonal variation similar to that in the test area.



Statistical analysis (Chi-square) of the year-class composition of 1972 and 1973 *Cyathura polita* populations during April showed no significant variation ($P < 0.5$) either between years or areas. Control-area data for the remainder of the year clearly illustrated the effects of community disruption in late April, with reproductive success significantly reduced (Chi-square, $P = 0.05$) from either the 1972 season or the test region during the same period. Survival of members of the oldest year class (1970) in the test area during 1973 was significantly higher (Chi-square, $P = 0.05$) than that of their counterparts (1969) during 1972, and total reproductive success and survival in the Indian Point region (test and control areas combined) was significantly increased so that area populations of *Cyathura* seem to have increased during 1973 despite the effects of detrital deposition in the control area.

f. Production

Cyathura polita production per square meter in test and control areas increased during 1974 in both areas (Table IV-21). Comparisons of mean numbers of individuals and productivity showed that the test area was higher for both parameters during 1973 but that there was no difference during 1974 (Table IV-22). No significant difference between numbers of individuals or production in the test area was found for the 2 years, but control-area values were significantly higher during 1974.

D. DISCUSSION

The benthic community of the Hudson River near Peekskill, New York, is typical of upper estuarine (low salinity) soft-bottom communities along much of the eastern coast of North America (Hirschfield et al, 1966; Bowman, 1955; Dean and Haskins, 1964; Jones and Burbank, 1959; Townes, 1937). Historical records indicate that the area has not experienced appreciable change in community composition during the past 40 years (Williams et al, 1975); during this period, however, there have been relatively abundant cyclic shifts apparently associated with short- and long-term climatic variability.



Table IV-21

Estimated *Cyathura polita* Production (Grams per Square Meter)
in Indian Point Test and Control Areas during 1973 and 1974

Interval	1973				1974			
	Test		Control		Test		Control	
	Mean No.	Production						
Apr-May	165.6	0.413	144.7	0.343	195.0	0.728	134.4	0.416
May-Jun	176.9	0.557	100.3	0.242	140.0	0.481	127.8	0.408
Jun-Jul	205.6	0.845	120.0	0.437	481.4	0.647	152.5	0.354
Jul-Aug	323.3	1.001	95.8	0.394	582.8	0.693	360.3	0.510
Aug-Sep	320.0	0.763	110.6	0.328	384.2	0.678	758.3	1.509
Sep-Oct	240.3	0.740	135.0	0.477	564.2	0.893	726.1	1.604
Oct-Nov	208.1	0.621	129.7	0.396	597.8	1.306	497.5	0.724
Nov-Dec	204.2	0.687	137.0	0.436	498.9	1.216	479.7	1.042
Annual mean no./m ²	230.5		121.3		430.5		404.6	
Total annual production		5.631		3.055		6.646		6.571

Table IV-22

Comparison of Mean Number of Individuals and Production of *Cyathura*
for Test and Control Areas in 1973 and 1974

Comparison	Mean No. of Individuals	Production
1973 test vs control	Test higher (P=0.004)	Test higher (P=0.004)
1974 test vs control	No difference (P=0.273)	No difference (P=0.371)
1973 vs 1974 test	1974 higher (P=0.012)	No difference (P=0.230)
1973 vs 1974 control	1974 higher (P=0.008)	1974 higher (P=0.008)



Community composition and relative abundance in estuaries vary predictably from marine to freshwater conditions along the salinity gradient (Figure IV-7). Water quality is relatively stable and total number of species relatively high at either the freshwater or marine extremes of an estuary. With increasing dilution of seawater in the lower estuary or its reciprocal at the upper extreme, species begin to gradually disappear. The most tolerant species of either the freshwater or marine assemblages may extend well into the zone of gradation; additionally, truly estuarine forms adapted to conditions between the two extremes may exist. This pattern results in a minimum number of species at some point along the dilution range, with total number of species which comprise the local assemblage increasing with distance toward either extreme.

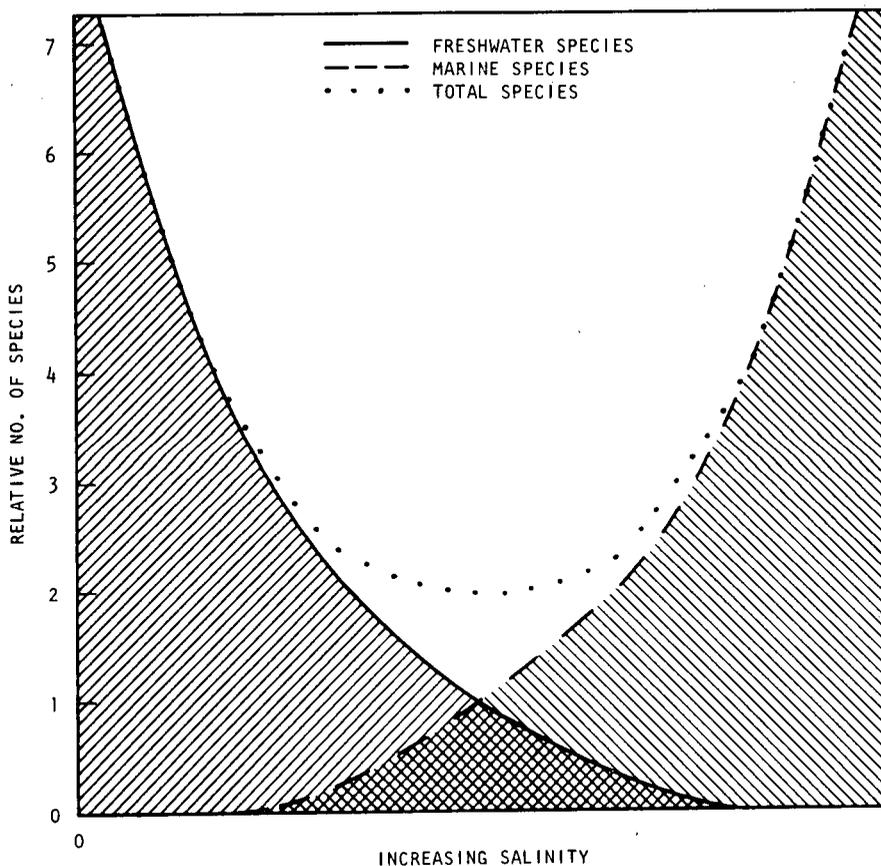


Figure IV-7. Simplified Representation of Specific Numbers through the Freshwater-Marine Salinity Gradient. Adapted from Reid (1961).



In the Hudson River estuary, a given locale experiences intermittent exposure to salinity as a function of alternate mixing and stratification of the salt front because of interaction of tidal amplitude and freshwater runoff (TI, 1975b); thus, annual variations in rainfall and freshwater runoff determine total days of salt exposure. The dominant assemblage will not vary appreciably in its species composition over a relatively long stretch of the upper estuary, but the total number of species at a particular location may fluctuate considerably from year to year. Additionally, standing crop biomass, which in the Hudson estuary is sensitive to numbers of the barnacle *Balanus improvisus* and the clam *Congeria leucophaeta*, will respond to fluctuations in salt exposure but this response will be expressed on a 1-year lag. This is readily explained in terms of increased reproductive success and the survival of larvae of these species when more favorable salinity conditions occur. At Indian Point, total saltwater incursion varied between 131 and 278 days/year during the 9-year period from 1965 through 1974 (Appendix F). The higher of these values occurred during the mid- to late 1960s as a function of several years of very low rainfall. The literature for this period (Hirschfield et al, 1964; Raytheon, 1971) indicates that the benthic assemblage at Indian Point was reasonably diverse and indeed contained a relatively large number of species generally found toward the lower extremes of the estuary. Total rainfall increased during 1971 and again in 1972, resulting in fewer days' total exposure to salt at Indian Point so that numbers of species and standing-crop biomass decreased, reaching a low point during 1973 and then increasing in response to lower rainfall during 1973 and 1974.

Within this framework of normal community fluctuation in response to the salinity regime, distribution of a particular species is restricted further by microhabitat variables such as sediment composition, dissolved oxygen, temperature, and depth. Each species within the system, through its response to microhabitat fluctuations, is either favored or hampered in its competition for survival and consequently dominates or is dominated under specific



conditions. Thus, species composition or relative abundance within a restricted area may vary appreciably from that of an adjacent area while the community as a whole may exhibit no significant variation. In the Indian Point region is a variety of microhabitats which may render the assemblage contained in a single grab quite dissimilar from that of another sample collected nearby; in toto, however, the assemblage is relatively stable and quite representative of the area.

Comparisons of the Indian Point test and control areas have shown no significant differences ($P < 0.05$) in standing-crop biomass, diversity or evenness, sediment composition, oxidation-reduction potential, or sediment temperature. Additionally, population-dynamics studies of the estuarine isopod *Cyathura polita* showed no significant variation between the areas during 1972 and 1974. The difference ($P > 0.05$) between the areas during 1973 was directly attributable to environmental variation associated with deposition of detritus at the southern extreme of the control region following heavy rains in early May; this disrupted the region's *Cyathura polita* population. The mean differences observed between stations and areas were attributable to localized variations in habitat and did not represent trends in community development. Annual variations were attributable principally to climatic variation. Earlier observations of the Hudson River benthic assemblage (Townes, 1937; Bowman, 1955; Hirschfield et al, 1966) indicated no appreciable change over a period of 40 years.

The operation of Indian Point Unit 1 since 1962 and the independent or simultaneous operation of Unit 2 using once-through cooling has had no significant adverse effect on Hudson River benthos beyond limited scouring at the effluent portals. Additionally, it may be concluded that simultaneous operation of Units 1 and 2 at proposed levels will not result in any harm to the benthic community or change its composition.



E. CONCLUSIONS

The operation of Indian Point Units 1 and 2 has had no discernible effect on the benthos of the Hudson River beyond a limited scour area in the immediate vicinity of the effluent ports. On the basis of TI's investigations, there is no reason to believe that simultaneous operation of Indian Point Units 1 and 2 at proposed levels will result in any appreciable detriment to the benthic community of the Hudson River in the future.



SECTION V
PHYSIOLOGY AND BEHAVIOR

A. INTRODUCTION

The physiology/behavior study program was conducted to determine the acute and chronic effects of temperature on important Hudson River fishes. This program supports the general Hudson River Ecological Study in determining the ecological impact of the Indian Point facility. Specific efforts were to determine (1) behavioral responses (thermal preference and avoidance) to above-ambient temperatures and (2) physiological effects (temperature tolerance and active respiration) to increases and decreases of environmental temperature. The relationship of results to plant operation was evaluated.

Fish exposed to artificial or natural thermal gradients typically seek a preferred temperature (Meldrim and Gift, 1971; Coutant, 1974; Ferguson, 1958). Thermal preference experiments provided information on the Indian Point thermal plume's potential to attract white perch and striped bass during each season.

Alabaster (1963) and Nakatani (1971) reported that there had been few instances of fish kills due to lethal effluent temperatures at electric-generating stations and concluded that this was probably due to the ability of fish to actively avoid such areas. Gift and Westman (1971) documented this ability in white perch (*Morone americana*) and striped bass (*Morone saxatilis*) in the laboratory.

This investigation was to determine whether a potential exists for exclusion of either species from the Indian Point vicinity because of high discharge temperature and whether the thermal plume can impede the movement of migratory fish such as striped bass.



Determination of lethal high or low temperatures relative to a given thermal acclimation level delineates the habitable temperature range of the species. This study has provided this information by determining incipient lethal thermal levels (i.e., 96-hr TL_m or LD_{50}) and resistance times to equilibrium loss and death.

Organisms utilize food as the energy source for supporting osmoregulation, feeding, growth, migration, reproduction, and other processes. The rate of energy expenditure in cold-blooded (poikilothermic) animals such as fish is directly regulated by environmental temperature; i.e., as temperature increases, rate of energy expenditure increases, doubling or even tripling with each $10^{\circ}C$ rise in temperature (Hoar, 1975). If temperature increases above a critical level, energy requirements for maintaining necessary life processes limit the amount of energy available for growth, reproduction, and other processes (Phillips, 1969). The respiratory rate is the best single index for identifying the critical temperature level at which energy becomes limiting for necessary activity (Fry, 1971).

B. METHODS AND MATERIALS

1. General Experimental Design

The investigation used adult white perch (> 140 mm in total length [TL]), juvenile white perch (TL < 120 mm), juvenile striped bass (TL < 150 mm), and adult Atlantic tomcod (*Microgadus tomcod*); several avoidance and tolerance experiments used hatchery-reared striped bass (TL < 232 mm and age < 1 year) from Hudson River stock. At the termination of each experiment, fish were measured (TL) and released. Each specimen was used only once to avoid potential conditioned responses during subsequent tests. When possible, tests were replicated for each species and size group. All behavioral experiments were conducted during the same time of day to minimize variation due to circadian rhythms (Schwassman, 1971). Behavioral and thermal tolerance tests were scheduled throughout the year to coincide with 2° - $3^{\circ}C$ incremental changes in ambient river-water temperature; this schedule was occasionally modified to adjust for fish availability.



The body temperature of poikilothermic organisms is very near that of their environment. Because specimens were held in a continuous flow of water drawn directly from the river, acclimatization temperature (Fry, 1967) and ambient river temperatures were nearly the same in all except cold-tolerance and active-respiration tests. The acclimatization temperature (T_a) and the ambient river temperature are the same in this report except where fish for cold-tolerance and respiration experiments were held at constant temperatures.

The relationship of temperature preference, avoidance, and tolerance of each species and size class with acclimatization temperature was determined separately for the changes of rising and falling river temperature. Also on this basis, inter- and intraspecific comparisons were made. The rationale for these procedures was fourfold:

- Fish acclimate more rapidly to increasing than to decreasing temperatures (Brett, 1944)
- Season influences preference (Sullivan and Fisher, 1953) and tolerance (Hoar, 1955)
- Size (or age) is known to influence the thermal responses of fish, although the effect has been found to vary (Hart 1947; McCauley and Read, 1973)
- Thermal responses are generally species-specific

The relationship between thermal response and acclimatization temperature for each species was determined by least squares regression analysis, and intra- and interspecific comparisons of thermal responses were made using analysis of variance (Armitage, 1973). The equation describing these responses takes the form

$$T_R = aT_a^b$$



where

T_R = upper avoidance temperature (T_{ua}) or preferred temperature (T_p)

T_a = acclimatization temperature ($^{\circ}C$)

a = y intercept of regression line

b = slope of regression line

2. Collection and Maintenance of Fish

Fish were captured by beach seine and trap net in the Indian Point vicinity and transferred directly to the laboratory where they were held in 1500- ℓ 120-cm-diameter circular fiberglass tanks receiving a once-through flow of river water at ambient temperature and salinity. Seasonal photoperiods were maintained artificially. Specimens were fed commercially available brine shrimp (*Artemia*). Fish were held 3 to 10 days before testing during summer while fish for winter experiments were held a maximum of 3 months.

Prophylactic treatments to inhibit disease (4 ppm of potassium permanganate or 0.4 ppm of malachite green for 1 to 4 hr) were administered on the day of capture and repeated, when necessary, during the holding period. Testing began no earlier than 2 days after prophylaxis. For active respiration experiments, treatment was terminated at least 1 week prior to testing.

3. Thermal Preference

Fish were transferred 15 hr before testing to permit habituation to the aluminum epoxy-coated 0.9 x 0.9 x 2.4-m vertical temperature gradient tank (Figure V-1)(modified from the design of Hurley and Woodall, 1968). Temperatures in the apparatus differed by $<1^{\circ}C$ from the holding temperature at the time of transfer. The thermal-preference apparatus was enclosed by opaque black polyethylene sheeting to isolate test organisms from

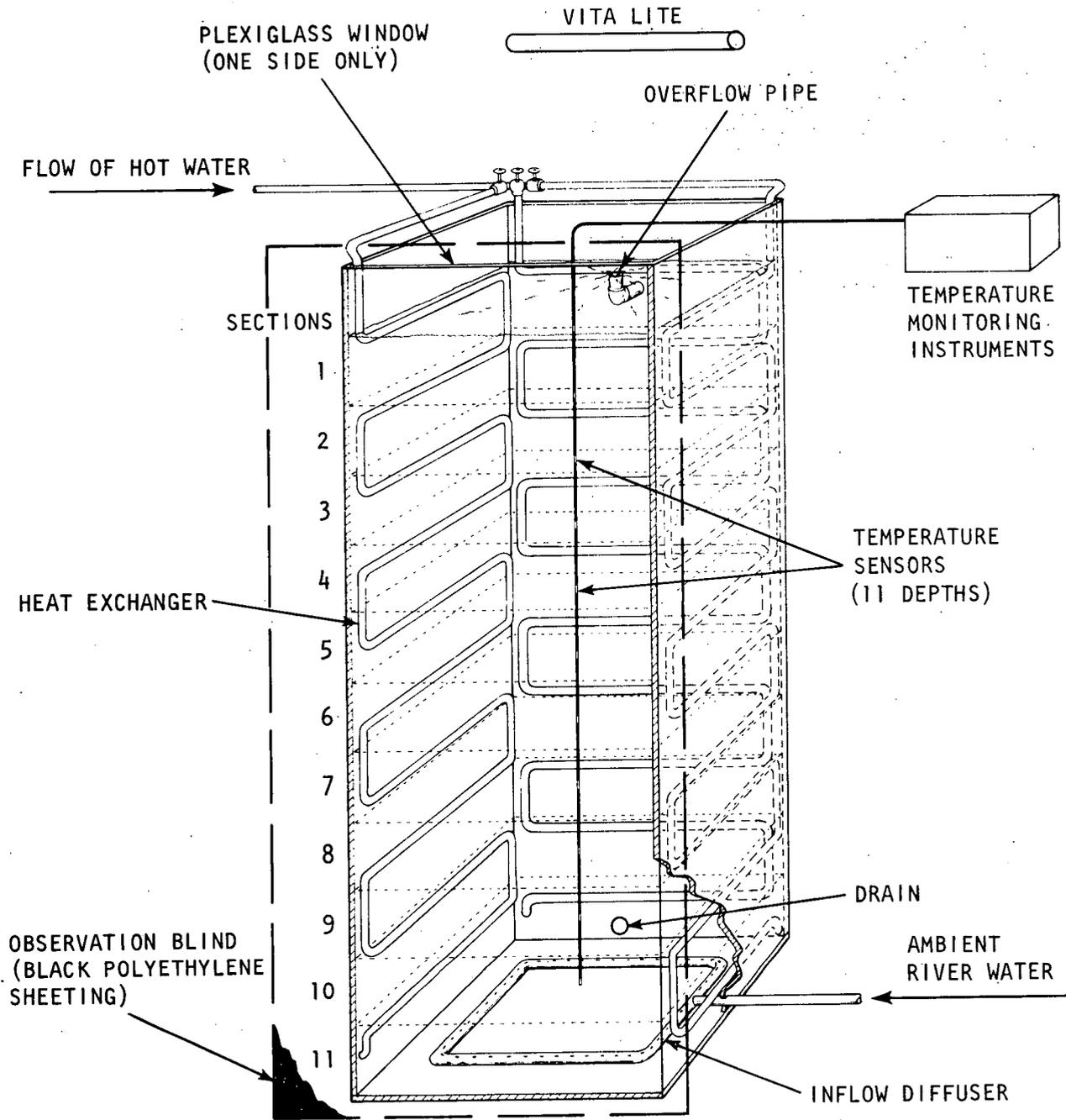


Figure V-1. Vertical Temperature Gradient Tank
Used for Thermal-Preference Testing



external stimuli. All observations were made through a 2.5-cm acrylic window from behind a blind 3 m from the apparatus. A single 80-W Duro Test Vita Lite fluorescent lamp, providing a spectral-energy distribution resembling that of natural sunlight (manufacturer's technical specifications), was centered 30 cm above the water surface. A light gradient in the preference tank ranged from 86 to 32 lux, surface to bottom, respectively.

Following the habituation period, fish positioning and behavior were recorded at 2.5-min intervals for 22.5 min (designated an "observation period") to provide a reference for positioning effects (control). A temperature gradient 2.2 m in depth was then initiated by manipulating the flows of hot water downward through S-shaped stainless steel tubing and of ambient temperature river water percolating upward through a diffuser system on the tank bottom. A record of thermal selection responses at 1.5, 3.5, 5.5, 7.5, 23.5, 25.5, and 27.5 hr after the gradient had been initiated was obtained in the same manner as during the control. Gradient temperatures were estimated to the nearest 0.1°C [Yellow Springs Instruments (YSI) telethermometer Model 44 TD and YSI general-purpose temperature probes] from surface to bottom at 20-cm intervals before and after each observation period. Previous studies had indicated that water temperature varied by <0.3°C within a given depth interval. The thermal regime was stabilized before each observation period to provide an accurate description of the fishes' thermal response. The gradient (position of isotherms) was altered between observation periods to insure that specimens were responding to temperature and not to depth (pressure) or light intensity.

The preferred temperature (T_p) was defined as the mean temperature of the level most frequently occupied by test specimens during an observation period. The temperature range over which 75% of all observations occurred was calculated for each observation series. The 1.5-hr and 27.5-hr

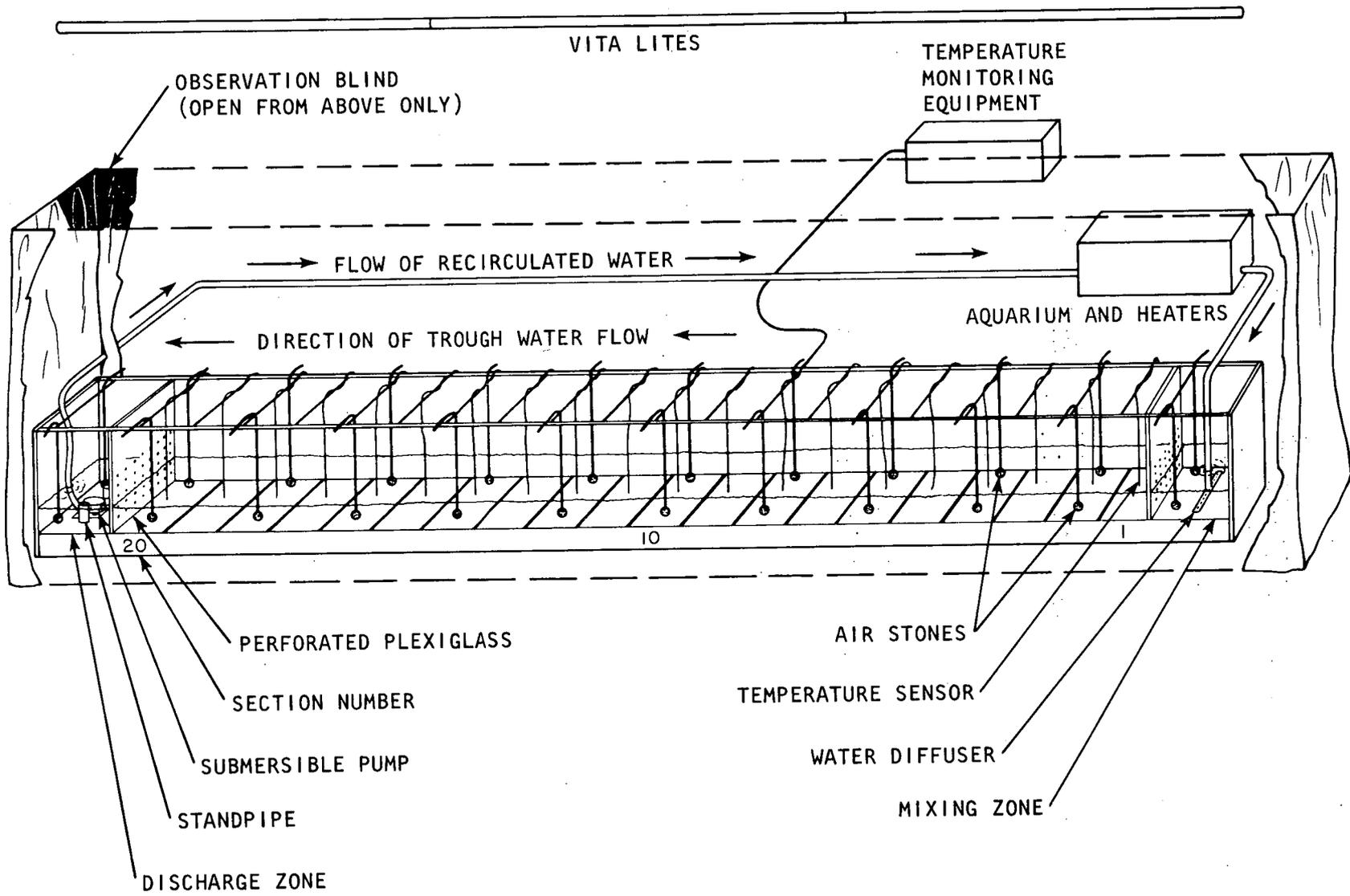


preferences were considered indicative of the immediate and long-term responses of the organisms to above-ambient temperatures for a given acclimatization temperature (T_a). Observations between 1.5 hr and 27.5 hr provided information on behavioral changes during prolonged exposure to above-ambient river temperatures.

4. Thermal Avoidance

Examination of avoidance response to elevated temperatures was patterned after Gift and Westman (1971). A horizontal, moving, thermal gradient was established in a resin-coated plywood trough 610 cm long x 61 cm wide x 61 cm deep (Figure V-2); 20 equally spaced transverse lines painted across the trough bottom and a temperature probe in each section permitted quick determination of fish location related to temperature. Temperature was estimated to the nearest 0.1°C with a multichannel telethermometer (YSI Model 44 TD). Aeration in alternate sections limited vertical thermal stratification to <0.2°C as heated water moved linearly the length of the apparatus at approximately 0.4 cm/sec, a current to which fish never responded rheotactically. Water depth was maintained at 15 cm. A submersible pump delivered water from the downcurrent end of the trough to an aquarium where four immersion heaters increased the temperature at a mean rate of 2.9°C/hr; the water returned via plastic piping to the testing area for distribution evenly across the width of the trough. A 5°-6°C temperature differential was established between ends within 60-90 min and was maintained for the experiment duration. Three 80-W Duro Test Vita Lite fluorescent lamps extending the length of and centered above the apparatus provided direct lighting, producing a light intensity of 100 lux across the trough bottom. Opaque black polyethylene sheets were hung around the trough and above the lights to prevent extraneous stimuli from influencing behavioral responses of the test fish.

At the initiation of each test, 3-10 fish were placed in the apparatus containing circulating ambient-temperature river water; 1 hr was allowed for habituation to the trough environment. After habituation,



8-8

services group

Figure V-2. Horizontal Temperature Gradient Trough Used for Thermal-Avoidance Testing



behavioral patterns under ambient temperature conditions (control) were recorded for positioning effects once per minute for 5 consecutive minutes at four 15-min intervals during 1 hr.

When control observations had been completed, all heaters in the aquarium were energized to heat the water as it was circulated through the system. Observations of fish positioning and behavior were recorded once/min for 10 consecutive min at alternate 10-min intervals for the experiment duration. Temperatures in alternate trough sections were recorded before and after each series of observations.

The upper avoidance temperature (T_{ua}) is defined as that temperature (or temperature range) causing repeated explicit movements of the fish school or individuals to some lower trough temperature. Temperature at this point became a directive factor (Fry, 1971) to the test organisms. The experiment was terminated after this behavior had been observed for 1 hr.

5. Thermal Tolerance

a. Heat Shock

The median tolerance limit (TL_m) is defined as that temperature above which 50% of the test population (representing an "average" fish) cannot survive for an indefinite time (Fry, 1974) — in the present investigation, 96 hr.

Six to 10 fish of one species and size class were transferred from holding facilities, placed randomly in each of eight 142-ℓ aquaria, and observed for 1 hr to detect any immediate effects from handling. After 1 hr, heated water was introduced from a reservoir into six aquaria, providing two replicates of three above-ambient test temperatures at 1°-3°C intervals; temperatures in the two remaining aquaria were maintained at river ambient (control). Water was circulated by pump through each reservoir-aquarium unit to maintain temperature and saturated oxygen levels during the experiment.



The condition of each fish was noted at progressively less frequent intervals during the first 8 hr and during subsequent days at 3-hr intervals for a total of 96 hr. Equilibrium loss and death as well as behavioral changes were noted at each reading. Cessation of opercular movement and failure to respond to mechanical stimulation were the criteria for death.

White perch were analyzed by size class during falling temperatures. During rising temperatures insufficient numbers of white perch were available for analysis by size class. The 96-hr TL_m was determined from a plot of test temperature vs percent survival (Brett, 1952). The median resistance time to equilibrium loss or mortality of 50% of the test fish at the various shock temperatures was obtained by plotting cumulative percent equilibrium loss or mortality against the logarithms of resistance times (Brett, 1952). Supplemental resistance times were determined at lethal temperatures intermediate to those of the 96-hr test.

The relative thermal tolerances ($TL_m - T_a$) for rising (spring) and falling (autumn) temperatures for striped bass and white perch were compared by linear regression and analysis of variance (Sokal and Rohlf, 1969). The relationship of $TL_m - T_a$ to T_a is linear (McErlean et al, 1969) with a negative slope. Treatment of the TL_m data in this manner enables statistical comparison which is not possible using the upper temperature tolerance triangles of Fry et al (1942) and McErlean et al (1969). The regression model takes the form $T_d = a - bT_a$ where $T_d = TL_m - T_a$.

b. Cold Shock

The apparatus utilized for cold-tolerance determination was that used for heat tolerance, but experimental procedures differed. Groups of 10 adult white perch and 10 hatchery-reared yearling striped bass (TL 135-220 mm) were acclimated to 10°, 15°, or 20°C for at least 3 days and then subjected to varying rates of temperature decrease to a minimum of



2°C. Times to equilibrium loss and death and percent survival over 96 hr were recorded. The time required for 50% of the potential temperature change to occur in an experiment varied from 10 to 15 min, depending on the initial T_a . The full temperature change for each experiment required < 3 hr.

6. Active Respiration

A respiration chamber similar to that described by Brett (1964) was employed to determine white perch and striped bass metabolic responses to various levels of activity and temperature change. Fish were held for at least 2 weeks at 8° or 24°C prior to experimentation. Test temperatures used in successive experiments (on different days) were 8°, 12°, 16°, 20°, and 24°C. Prior experimentation had indicated that temperatures in excess of 16°C caused avoidance behavior by white perch acclimated to 8°C. To prevent acute thermal stress, the specimens were allowed 6-8 hr to adjust partially to elevated temperatures before being placed at the test temperature. The same procedure was followed for striped bass, although the species' upper avoidance temperature at 8°C was near 23°C. Because acclimation to cooler temperatures is less rapid, the above procedure was followed when exposing specimens fully acclimated to 24°C to temperatures $\leq 16^\circ\text{C}$.

One or more individuals of one species were placed in the cylindrical swim chamber (89 mm x 508 mm) at the desired test temperature 12-16 hr before testing, permitting specimens to habituate to the apparatus. During this time, vigorous aeration maintained saturated oxygen levels while water velocity was maintained at 5 to 10 cm/sec, the minimum level which allowed for circulation of oxygenated water through the system. Water temperature in the apparatus was measured with a YSI Model 44 telethermometer and YSI general-purpose temperature-sensing probe to the



nearest 0.2°C. Test temperature was maintained by a Blue M cooler and a heat-exchanger system; flow was measured with a Mead PT-250 turbine flowmeter and flow indicator calibrated by the manufacturer in gallons per minute (accuracy, $\pm 1\%$). A 1-hp Worthington centrifugal pump with a diaphragm valve provided precise control of desired flow rates.

After the habituation period, excess air was removed from the system and the lowest activity level was established (10 cm/sec). Water velocity through the chamber was increased to 30 cm/sec in 5-cm/sec increments during the test. Dissolved oxygen was measured to the nearest 0.01 ppm seven times during each 90-min activity period at 15-min intervals using a Weston and Stack Model 350 digital oxygen analyzer. Fish were rested for approximately 60 min at 5-10 cm/sec between successive activity levels; oxygen levels in the system were returned to saturation during this time.

Metabolic rates at the various levels of activity were computed as milligrams of oxygen consumed per kilogram of wet body weight per hour ($\text{mgO}_2/\text{kg}/\text{hr}$). Although metabolic rates are more properly expressed in terms of calories, most other investigators of fish metabolism have used the rate of oxygen consumption adopted here (Hoar, 1975). Standard metabolic rate, the minimum level required to maintain body processes under resting conditions, was estimated by the method of Brett and Glass (1973), i. e., by extrapolating the relation between oxygen uptake at successive swimming speeds to zero activity. Only swimming speeds of ≥ 15 cm/sec were used in graphic and statistical analyses. To minimize size-dependent effects on metabolic rate between replicates and test temperature (Phillips, 1969), the size of specimens was restricted to 30.2-93.2 g. Food was withheld for 48 hr before beginning an experiment (Beamish, 1962).



Oxygen depletion rates (mgO_2/hr) for the respiration apparatus were determined at 10, 20, and 30 cm/sec at the 8° , 16° , and 24°C test temperatures and then estimated by least squares regression for each test temperature/velocity combination. These regressions take the form

$$R = a \cdot e^{bT}$$

where

R = metabolism ($\text{mgO}_2/\text{kg/hr}$)

T = test temperature ($^\circ\text{C}$)

e = base of natural logarithm

a = intercept of regression line

b = slope of regression line

Correction factors were applied to the respirometry data before metabolic rates were calculated. Relationships between acclimation temperature, test temperature, and activity level were examined with a response surface analysis (Draper and Smith, 1968; Guttman et al, 1971). The regression sum of squares of the analysis of variance for the response surface analysis was partitioned successively for the different components (i. e., linear and quadratic effects of test temperature and swimming speed and interaction terms). The following statistical model was used:

$$Y = a + b_1x_1 + b_2x_2 + c_1x_1^2 + c_2x_2^2 + d x_1x_2$$

where

Y = metabolic rate ($\text{mg O}_2/\text{kg/hr}$)

x_1 = swimming speed (cm/sec)

x_2 = test temperature ($^\circ\text{C}$)

a = constant (and ordinate intercept)

b_1, b_2, c_1, c_2, d = coefficients of respective variables based on analysis of variance



Variables found not to contribute significantly ($P > 0.05$) to the model were dropped and analysis of variance performed on significant effects to yield a reduced model. Data based on the statistical model for each case were presented graphically in a response surface analysis, a method employed by Griffiths and Alderdice (1972) for a similar study. This technique permitted demonstration of potential acute temperature changes/activity-level combinations which were limiting to active respiration within the range of our data.

C. OBSERVATIONS AND RESULTS

1. Thermal Preference

Both striped bass and white perch responded immediately (1.5-hr observation period) during all seasons to the presence of above-ambient temperatures (Figures V-3 and V-4) by selecting an environment several degrees warmer than the T_a . Selected temperatures changed progressively for the duration of each experiment (27.5 hr), ranging 3° - 6° C during summer to 10° - 15° C during winter above the initial T_a (Figures V-5 and V-6). During summer, juvenile striped bass preferred temperatures 1° - 3° C less than juvenile and adult white perch. For both species, the relationship between T_p and T_a was significant ($P = 0.005$) throughout the year. Thermal-preference experiments for both species are summarized in Tables V-1, V-2, V-3, and V-4.

Time of year and age effects on selected temperatures were observed. Juvenile white perch preferred temperatures 1° - 4° C higher ($P = 0.005$) during rising than during falling river temperatures for a given T_a , while little difference ($< 1^{\circ}$ C) was found between both times of year for adult white perch and juvenile striped bass. When the entire range of rising and falling river temperatures was considered, no significant difference ($P = 0.05$) was evident between the temperatures preferred by young and adult white perch; however, as acclimatization (river) temperatures approached maximum levels during summer, juvenile perch selected temperatures 1° - 3° C higher than adults.

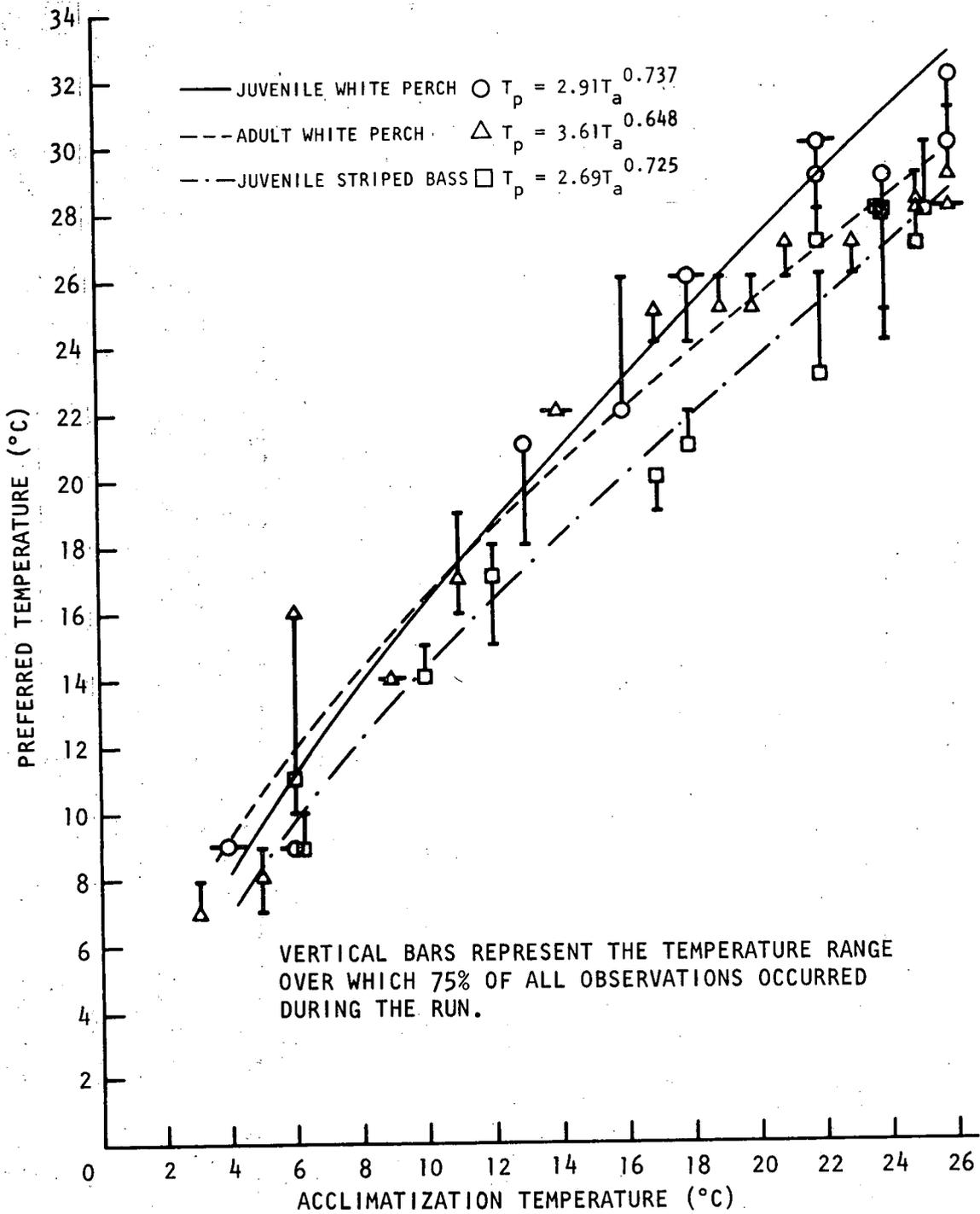


Figure V-3. Relationship of 1.5-Hr Preferred Temperature (T_p) and Acclimatization Temperature (T_a) for White Perch and Striped Bass during Rising River Temperature

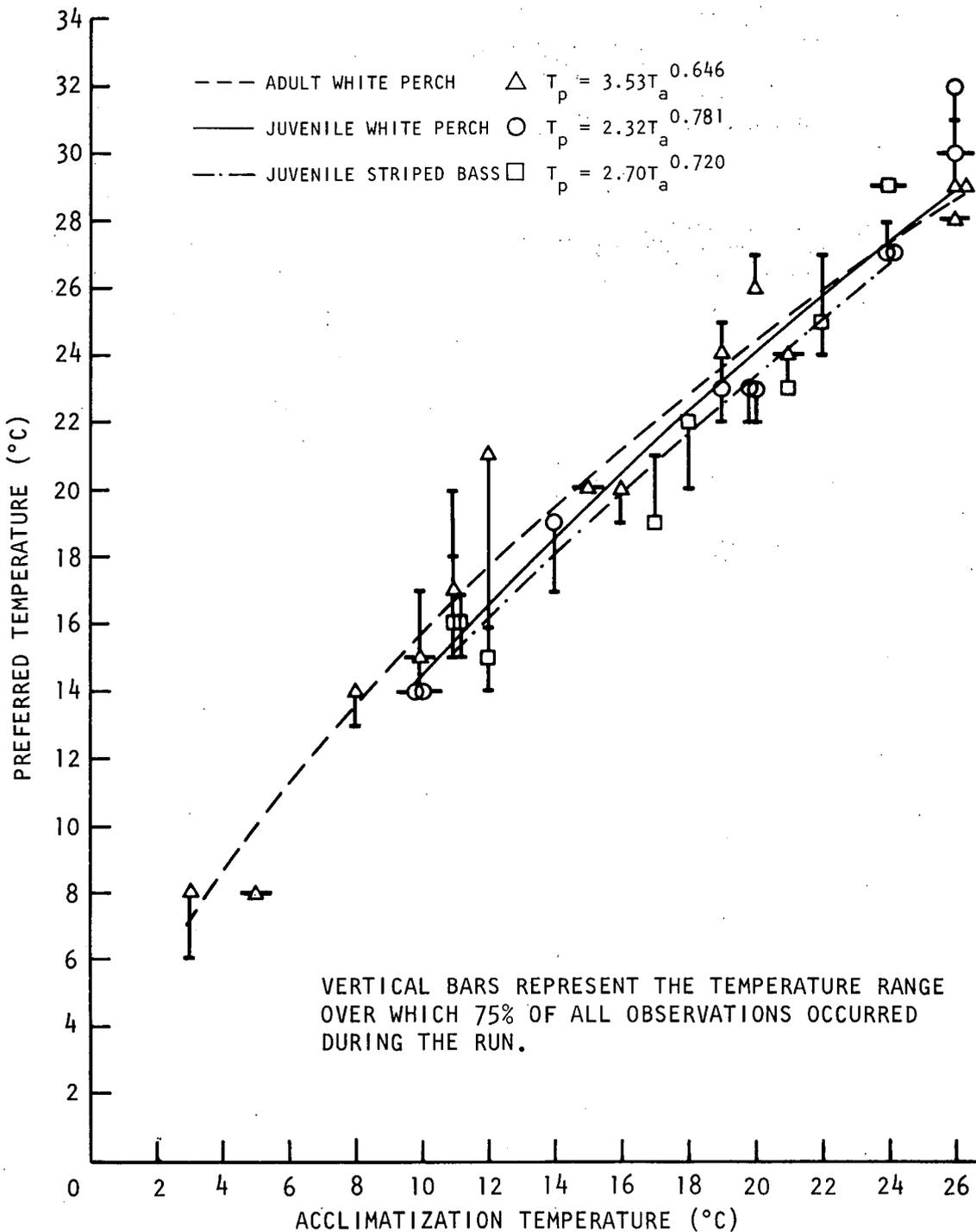


Figure V-4. Relationship of 1.5-Hr Preferred Temperature (T_p) and Acclimatization Temperature (T_a) for White Perch and Striped Bass during Falling River Temperatures

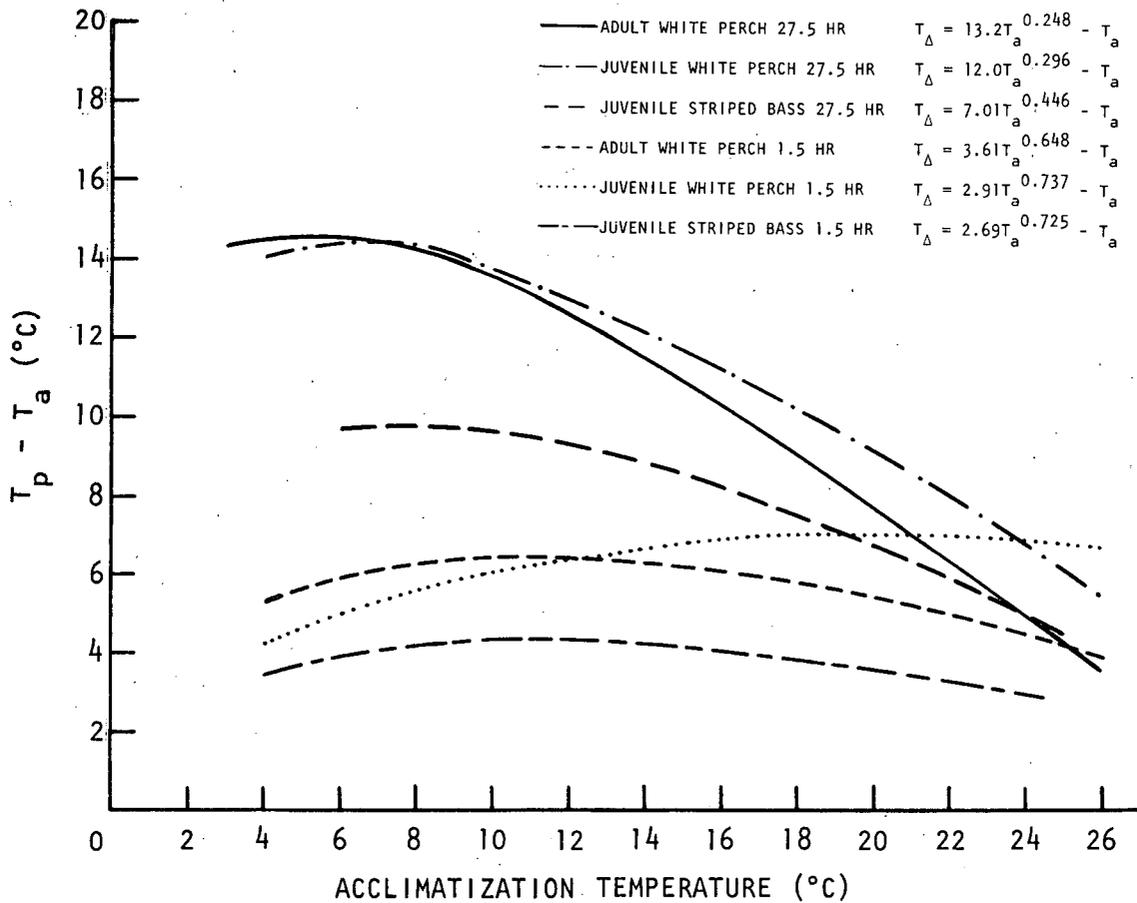


Figure V-5. Difference (°C) between Preferred Temperature (T_p) and Respective Acclimatization Temperature (T_a) for White Perch and Striped Bass at 1.5 Hr (Immediate Response) and 27.5 Hr (Long-Term Response) during Rising River Temperatures

Specimens occasionally experienced stress or death during testing. White perch showed stress behavior over a wide range of acclimatization temperatures (6°-26°C), whereas such occurrences for striped bass happened when the T_a was 10°-11°C (Table V-5).

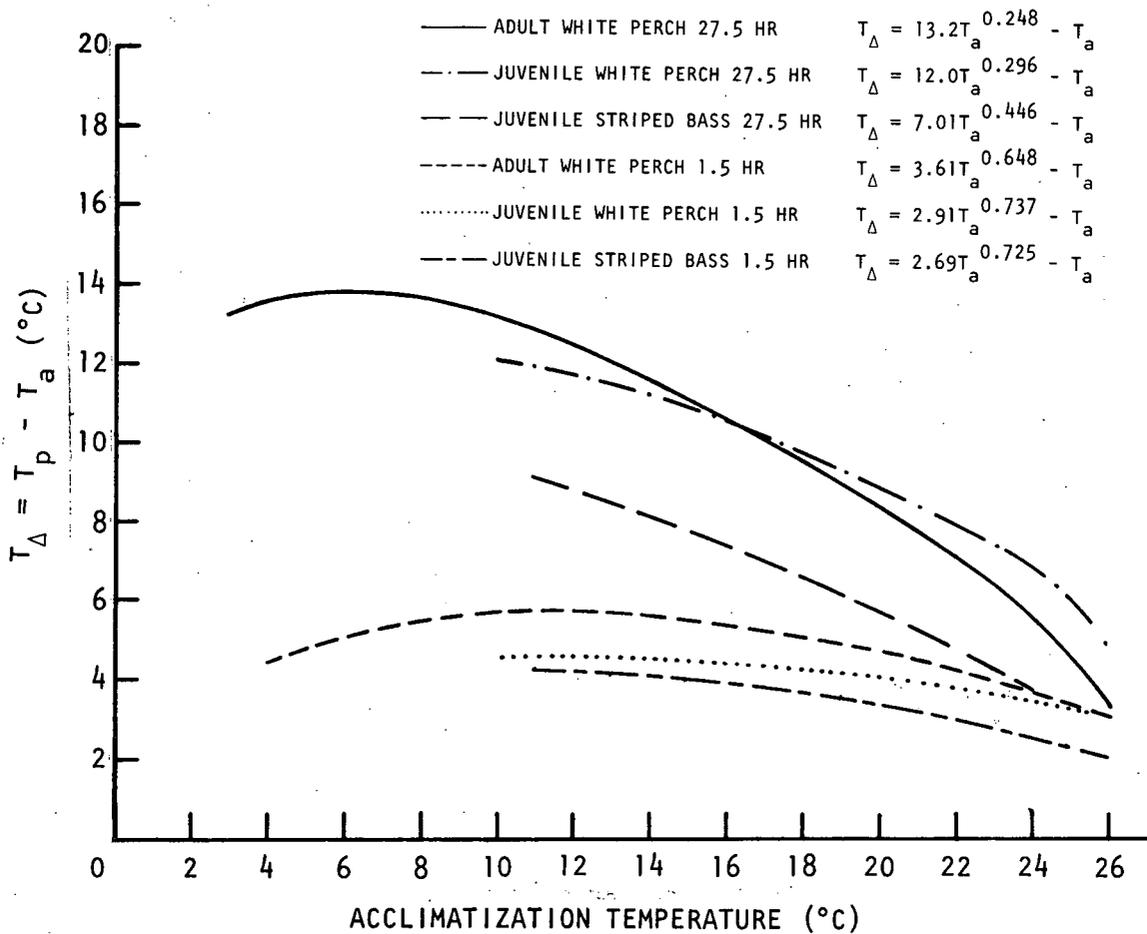


Figure V-6. Difference (°C) between Preferred Temperature (T_p) and Respective Acclimatization Temperature (T_a) for White Perch and Striped Bass at 1.5 Hr (Immediate Response) and 27.5 Hr (Long-Term Response) during Falling River Temperatures

Since the necessity of feeding during the 3- to 10-day holding period had initially been questioned, a limited study was instituted to determine the effect of food deprivation on white perch temperature preference. Subsequent data analysis showed that starvation time had no effect on thermal selection responses of juvenile white perch for the experiment duration.



Table V-1

Summary of Thermal-Preference (T_p) Experiments with White Perch during Rising River Temperatures.

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Temperature Preference* (°C)							
				Elapsed Time in Gradient (hr)							
				1.5	3.5	5.5	7.5	23.5	25.5	27.5	
1974											
2/12	5	166-182	3.0	7 (7-8)	9 (9)	8 (6-8)	10 (10)	** **	** **	17 (17-20)	
3/19	7	70-100	4.0	9 (9)	9 (9)	11 (11-12)	12 (12-13)	18 (16-18)	18 (18-21)	18 (17-24)	
3/14	6	150-180	5.0	8 (7-9)	9 (8-9)	10 (9-10)	10 (10-15)	** **	** **	17 (17-20)	
3/27	5	155-176	6.0	16 (10-16)	18 (15-23)	20 (18-20)	19 (19-20)	22 (22-24)	23 (22-23)	** **	
4/2	7	80-97	6.0	9 (9)	11 (10-11)	12 (12)	14 (14)	18 (18)	18 (18)	20 (18-22)	
4/17	6	166-185	9.0	14 (14)	19 (19)	21 (20-21)	17 (17)	25 (25)	26 (26-28)	27 (26-28)	
4/25	7	152-190	11.0	17 (16-19)	20 (19-20)	21 (21-22)	22 (22-23)	26 (24-28)	29 (26-30)	27 (24-27)	
4/30	9	73-98	13.0	21 (18-21)	20 (18-24)	25 (20-25)	25 (19-25)	27 (27)	27 (25-27)	27 (25-27)	
5/9	5	155-170	14.0	22 (22)	22 (21-23)	21 (21-23)	25 (24-25)	25 (23-25)	25 (25-27)	26 (25-26)	
5/21	6	73-85	16.0	22 (22-26)	22 (22-26)	23 (23-28)	23 (23-27)	24 (24-29)	26 (23-29)	27 (26-29)	
5/28	8	153-195	17.0	25 (24-25)	27 (25-28)	28 (27-29)	28 (26-28)	28 (26-28)	28 (26-29)	28 (27-28)	
6/4	10	79-105	18.0	26 (24-26)	26 (24-26)	28 (26-28)	27 (27-29)	27 (25-30)	28 (26-31)	28 (28)	
6/6	8	151-182	19.0	25 (25-26)	27 (27)	27 (26-27)	26 (25-26)	24 (21-24)	26 (21-26)	24 (21-27)	
6/13	7	152-184	20.0	25 (25-26)	27 (27-28)	28 (27-28)	27 (27-29)	26 (25-26)	27 (27-29)	27 (27-28)	
6/27	6	163-197	21.0	27 (26-27)	28 (28-30)	30 (29-30)	29 (29-30)	** **	28 (28)	27 (27-30)	
6/20	10	62-91	22.0	30 (28-30)	30 (30-31)	30 (28-31)	30 (30-32)	** **	30 (28-30)	28 (28-31)	
6/25	10	84-115	22.0	29 (29-30)	29 (29-30)	30 (30-31)	30 (30-31)	31 (29-31)	31 (31)	32 (32-33)	
7/5	8	153-180	23.0	27 (26-27)	29 (29)	30 (30)	29 (29)	30 (29-31)	28 (28-30)	30 (29-31)	
1973											
7/4	12	68-100	24.0	29 (28-29)	30 (30)	31 (30-31)	30 (30-31)	32 (31-32)	32 (32-33)	32 (31-32)	
8/23	6	154-171	25.0	28 (28)	28 (28-29)	28 (28)	27 (27-28)	31 (29-32)	32 (29-32)	** **	
8/28	6	142-189	25.0	28 (28-29)	29 (29)	29 (29)	28 (28)	29 (28-29)	29 (29-30)	29 (29-30)	
8/15	7	142-158	26.0	29 (29)	31 (31-32)	32 (32)	32 (32)	31 (30-31)	30 (28-31)	29 (29-31)	
8/21	6	145-160	26.0	28 (28)	28 (28)	29 (28-29)	28 (28)	28 (28-29)	29 (28-29)	29 (28-29)	
8/30	6	152-172	26.0	29 (29-30)	30 (30)	30 (30)	30 (30)	28 (28-29)	29 (28-29)	29 (28-29)	
9/4	10	56-69	26.0	32 (30-32)	31 (30-33)	33 (32-35)	33 (31-35)	30 (29-33)	34 (34)	31 (30-32)	
9/6	10	64-75	26.0	30 (30-31)	31 (31)	30 (30-31)	30 (30-31)	30 (30-31)	31 (30-32)	30 (30-33)	

*Values in parentheses represent range over which 75% of all observations occurred during an observation series.
 ** No data.



Table V-2
Summary of Preferred Temperatures (T_p) for Striped Bass
during Rising River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Temperature Preference* (°C)						
				Elapsed Time in Gradient (hr)						
				1.5	3.5	5.5	7.5	23.5	25.5	27.5
3/21/74	7	83-97	6	9 (9-10)	9 (9)	9 (8-9)	8 (8)	** **	13 (13)	14 (14-16)
4/9/74	10	80-110	6	11 (10-11)	13 (12-13)	12 (12)	12 (12-14)	16 (16-18)	17 (17-19)	17 (17-19)
4/23/74	8	76-97	10	14 (14-15)	16 (15-17)	16 (16-20)	17 (16-17)	23 (20-23)	20 (20-22)	20 (18-22)
5/2/74	4	80-115	12	17 (15-18)	21 (19-22)	19 (19-21)	23 (20-23)	25 (23-25)	24 (23-24)	23 (22-23)
5/23/74	5	95-115	17	20 (19-20)	21 (20-22)	21 (20-22)	22 (20-22)	24 (21-26)	23 (21-25)	24 (23-26)
5/30/74	12	90-105	18	21 (21-22)	23 (18-23)	24 (21-24)	22 (22-24)	26 (21-26)	24 (23-26)	24 (21-24)
6/19/74	10	77-103	22	23 (23-26)	25 (22-25)	26 (26-28)	27 (25-29)	** **	25 (24-28)	27 (26-27)
6/28/73	5	84-156	22	27 (27-28)	28 (27-28)	28 (28-30)	28 (27-28)	28 (26-30)	** **	** **
7/5/73	6	90-110	24	28 (25-28)	28 (27-29)	29 (26-29)	29 (27-30)	** **	** **	** **
7/12/73	8	30-44	24	28 (24-29)	31 (26-31)	29 (24-30)	28 (24-29)	** **	** **	** **
7/17/73	5	108-129	24	28 (28)	30 (29-30)	31 (28-31)	31 (29-31)	31 (27-31)	30 (27-32)	31 (27-33)
7/24/73	15	41-58	25	28 (28-30)	30 (29-30)	30 (30-32)	30 (30-32)	32 (25-32)	30 (25-30)	30 (25-30)
7/26/73	15	39-60	25	27 (27-29)	30 (29-30)	30 (29-31)	30 (29-31)	30 (30-31)	31 (29-32)	29 (29-32)

*Values in parentheses represent range over which 75% of all observations occurred during an observation series.
** No data.

Conductivity ($\mu\text{mho/cm}$) apparently exhibited no consistent effect on temperature selection by white perch but seemed to be occasionally inversely related to striped bass T_p during summer. The conductivities of the river water in the holding facilities during 1973-1974 are listed in Table V-6.



Table V-3

Summary of Preferred Temperatures (T_p) for White Perch during Falling River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. ($^{\circ}$ C)	Temperature Preference* ($^{\circ}$ C)						
				Elapsed Time in Gradient (hr)						
				1.5	3.5	5.5	7.5	23.5	25.5	27.5
8/15/73	7	142-158	26.0	29 (29)	31 (31-32)	32 (32)	32 (32)	31 (30-31)	30 (28-31)	29 (29-31)
8/21/73	6	145-160	26.0	28 (28)	28 (28)	29 (28-29)	28 (28)	28 (28-29)	29 (28-29)	29 (28-29)
8/30/73	6	152-172	26.0	29 (29-30)	30 (30)	30 (30)	30 (30)	28 (28-29)	28 (28-29)	29 (28-29)
9/4/73	10	56- 69	26.0	32 (30-32)	31 (30-33)	33 (32-35)	33 (31-35)	30 (29-33)	34 (34)	31 (30-32)
9/6/73	10	64- 75	26.0	30 (30-31)	31 (31)	30 (30-31)	30 (30-31)	30 (30-31)	31 (30-32)	30 (30-33)
9/10/73	10	60- 70	24.0	27 (27-28)	30 (30-31)	30 (30-32)	30 (30-32)	34 (34-36)	34 (34-35)	34 (32-34)
9/12/73	10	60- 70	24.0	27 (27-28)	29 (28-30)	29 (28-30)	30 (29-31)	31 (31-33)	34 (34)	32 (30-32)
10/4/73	6	152-179	21.0	24 (24)	25 (25)	25 (25)	24 (24)	26 (24-27)	**	**
10/2/73	10	60- 70	20.0	23 (22-23)	24 (24-27)	26 (25-27)	26 (25-26)	**	28 (26-30)	29 (26-29)
10/9/73	4	155-189	20.0	26 (26-27)	26 (26-27)	26 (26)	25 (24-25)	**	25 (25-26)	24 (24-25)
10/16/73	10	60- 80	20.0	23 (22-23)	27 (25-28)	28 (26-29)	28 (27-28)	26 (25-28)	28 (26-30)	28 (27-30)
10/11/73	6	156-185	19.0	24 (23-25)	25 (24-25)	24 (24-25)	23 (23-24)	26 (24-26)	26 (24-26)	26 (26-28)
10/18/73	12	56- 81	19.0	23 (22-23)	25 (25)	26 (26)	26 (26-27)	28 (24-28)	27 (25-28)	27 (24-28)
11/1/73	6	155-160	16.0	20 (19-20)	22 (22-23)	22 (22-23)	21 (21-22)	**	**	23 (23)
10/30/73	6	160-181	15.0	20 (20)	22 (22-23)	24 (24-25)	26 (26-28)	27 (23-27)	28 (27-30)	29 (27-30)
11/6/73	10	58- 88	14.0	19 (17-19)	22 (21-22)	22 (22-25)	22 (20-24)	28 (20-29)	28 (21-28)	26 (20-29)
11/15/73	6	150-178	12.0	21 (16-21)	24 (22-25)	24 (22-24)	25 (23-26)	25 (25-26)	25 (25-27)	27 (26-27)
11/23/73	6	165-175	11.0	17 (16-18)	20 (19-22)	23 (21-25)	21 (21-23)	28 (24-29)	29 (25-29)	29 (27-29)
12/4/73	10	62- 82	10.0	14 (14-17)	18 (17-20)	21 (20-21)	20 (20-22)	**	24 (20-27)	23 (21-26)
12/6/73	9	65- 90	10.0	14 (14)	18 (18)	19 (19)	18 (18-19)	20 (17-20)	17 (17-25)	21 (21-25)
12/11/73	6	172-190	10.0	15 (14-15)	19 (19-20)	21 (21-22)	22 (22-23)	**	**	27 (26-28)
12/13/73	3	165-180	8.0	14 (13-14)	17 (17-18)	20 (19-22)	23 (22-24)	26 (24-26)	28 (27-28)	26 (24-28)
12/27/73	5	178-198	5.0	8 (8)	9 (9)	8 (8-9)	8 (8-9)	**	**	16 (13-19)
1/30/74	5	160-180	3.0	8 (6-8)	8 (8-10)	7 (7-8)	8 (8)	**	**	14 (13-14)

*Values in parentheses represent range over which 75% of all observations occurred during an observation series.
 ** No data.



Table V-4

Summary of Preferred Temperatures (T_p) for Striped Bass during Falling River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Temperature Preference* (°C)						
				Elapsed Time in Gradient (hr)						
				1.5	3.5	5.5	7.5	23.5	25.5	27.5
9/13/74	10	107-130	24	29 (29)	26 (25-28)	25 (25-30)	30 (26-30)	25 (25-30)	29 (24-29)	29 (25-29)
9/28/73	10	75-99	22	25 (24-27)	26 (25-27)	26 (25-27)	27 (27-28)	**	**	**
9/26/73	10	80-100	21	23 (23-24)	23 (23-24)	23 (23)	23 (23-24)	26 (24-27)	24 (23-27)	26 (25-27)
10/23/73	12	76-105	18	22 (20-22)	23 (23-25)	23 (22-24)	23 (21-26)	**	24 (21-24)	25 (22-25)
10/25/73	10	91-106	17	19 (19-21)	22 (21-23)	23 (23-25)	25 (24-25)	25 (22-27)	24 (24-25)	23 (21-23)
11/13/73	10	66-95	12	15 (14-16)	17 (16-18)	17 (17-20)	19 (17-20)	18 (15-22)	19 (16-23)	18 (17-21)
11/27/73	10	70-100	11	16 (15-17)	19 (16-20)	21 (18-21)	21 (18-21)	25 (22-27)	24 (22-24)	22 (20-25)
11/29/73	10	68-105	11	16 (15-20)	18 (18-21)	19 (17-19)	20 (18-20)	**	21 (18-21)	21 (19-21)

*Values in parentheses represent range over which 75% of all observations occurred during an observation series.
 **Data not collected.

Table V-5

Summary of Experiments during Which Fish Failed To Avoid Lethal Temperatures

Date	Type of Experiment	Acclim. Temp. (°C)	Species and Size Class	No. of Fish/Experiment	No. Showing Stress or Death
2/15/74	Avoidance	1.2	Adult white perch	5	1
4/23/74		10.2	Adult white perch	6	1
5/23/74		17.0	Adult white perch	7	2
7/31/73		25.9	Adult white perch	6	1
12/18/73		3.5	Juvenile white perch	3	1
11/20/73		10.4		7	1
5/28/74		17.0		9	2
5/29/74		17.0		10	1
6/18/74		21.3	Juvenile white perch	7	1
2/11/74		3.0	Juvenile striped bass	6	6
3/5/74		4.0		6	6
4/11/74		7.2		8	8
4/24/74		10.1		7	1
5/24/74		17.0		8	3
5/30/74		17.2		10	4
6/4/74	17.6		10	2	
6/11/73	18.7		6	1	
6/17/74	Avoidance	21.2	Juvenile striped bass	7	1
3/27/74	Preference	6.0	Adult white perch	5	1
6/6/74	Preference	19.0	Adult white perch	8	1
4/30/74		13.0	Juvenile white perch	9	5
9/4/73		26.0	Juvenile white perch	10	1
4/23/74		10.0	Juvenile striped bass	8	4
11/27/73		11.0	Juvenile striped bass	10	1



Table V-6

Conductivity ($\mu\text{mho/cm}$) of River Water in Laboratory Holding Facilities,
1973-1974

Date	Conductivity ($\mu\text{mho/cm}$)	Date	Conductivity ($\mu\text{mho/cm}$)
1973		1973	
Jul 17	1400	Nov 15	5200
18	1400	21	5300
19	1400	23	3200
20	1400	26	2900
24	2000	27	3300
25	—	Dec 4	2500
30	1600	11	1100
31	1570	12	250
Aug 1	1500	18	200
2	1500	19	140
3	1100	21	260
7	800	26	140
17	2600	27	180
22	1800	28	140
24	2000	1974	
27	3400	Feb 11	180
28	3700	Mar 11	139
29	4000	18	150
31	7100	19	140
Sep 4	9500	20	450
18	6600	25	220
25	5700	Apr 10	120
26	4100	11	200
27	5200	18	135
Oct 1	4000	22	150
2	—	23	160
3	4100	24	180
4	3100	25	165
5	3500	29	180
11	10900	May 1	180
12	8800	2	210
15	7100	6	160
16	6500	8	175
17	7800	17	160
19	8200	20	170
22	8400	21	185
23	6100	23	170
29	8200	24	165
30	7200	28	170
31	6800	29	150
Nov 1	6300	30	180
2	5000	Jun 4	175
5	—	6	160
6	5700	12	160
7	6200	17	3350
8	6500	18	2050
9	7500	25	2380



2. Thermal Avoidance

Except for those instances documented in Table V-5, white perch and striped bass demonstrated the ability to successfully avoid lethal thermal environments. Relationships between T_a and upper avoidance temperature (T_{ua}) for juvenile and adult white perch were direct and significant ($P = 0.005$) throughout the year. Upper avoidance temperatures of striped bass also changed along with rising acclimatization temperatures during spring and summer ($P = 0.005$) but showed a weaker but still significant association ($P = 0.05$) during fall and winter. Graphic representations of the T_a and T_{ua} relationships for both species throughout the year appear in Figures V-7 and V-8.

Differences in avoidance response due to time of year, age, and species were apparent. Juvenile and adult white perch T_{ua} was 1° - 5°C higher ($P = 0.005$) during falling than during rising river temperatures for a given T_a . Striped bass avoidance responses were also significantly different between the two times of the year ($P = 0.05$). Size (or age) was a significant ($P = 0.005$) factor influencing the T_{ua} of white perch throughout the year, with adults avoiding temperatures 6° - 8°C higher than juveniles during winter; by summer, however, these size-specific differences were reduced to within 2°C . The upper avoidance temperatures of striped bass were significantly different ($P = 0.05$) from those of juvenile white perch over the full range of rising and falling river temperatures, with the magnitude of difference ranging from 10°C during winter to within 2°C during summer. Tables V-7, V-8, V-9, and V-10 summarize all of the temperature avoidance experiments.

The diagonal line 45° to the axes of Figures V-7 and V-8 indicates loci of equal acclimatization and avoidance temperature, providing a convenient reference for determining the magnitude of a temperature increase causing an avoidance response. Both species avoided temperatures

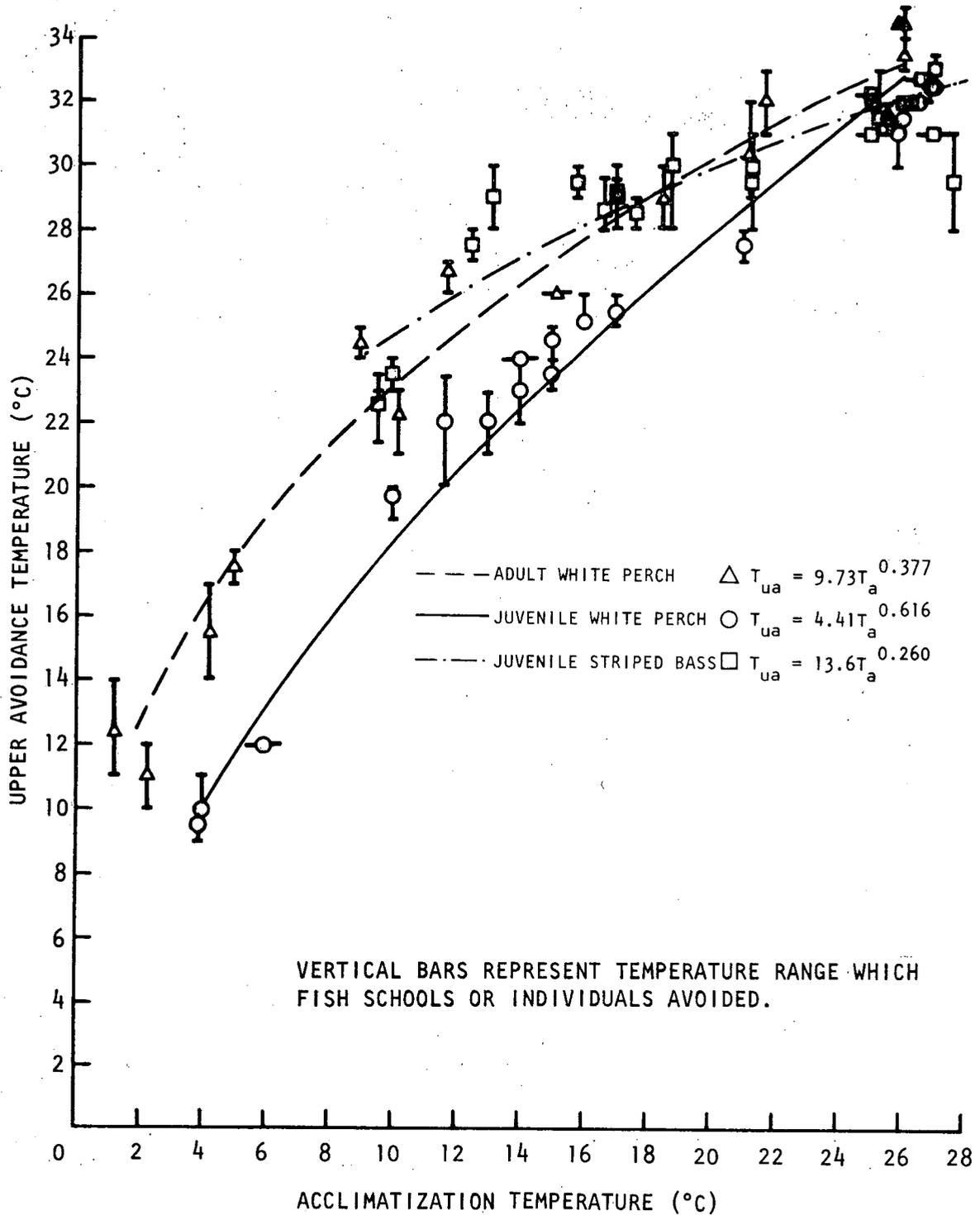


Figure V-7. Relationship of Upper Avoidance Temperature (T_{ua}) and Acclimatization Temperature (T_a) for White Perch and Striped Bass during Rising River Temperatures

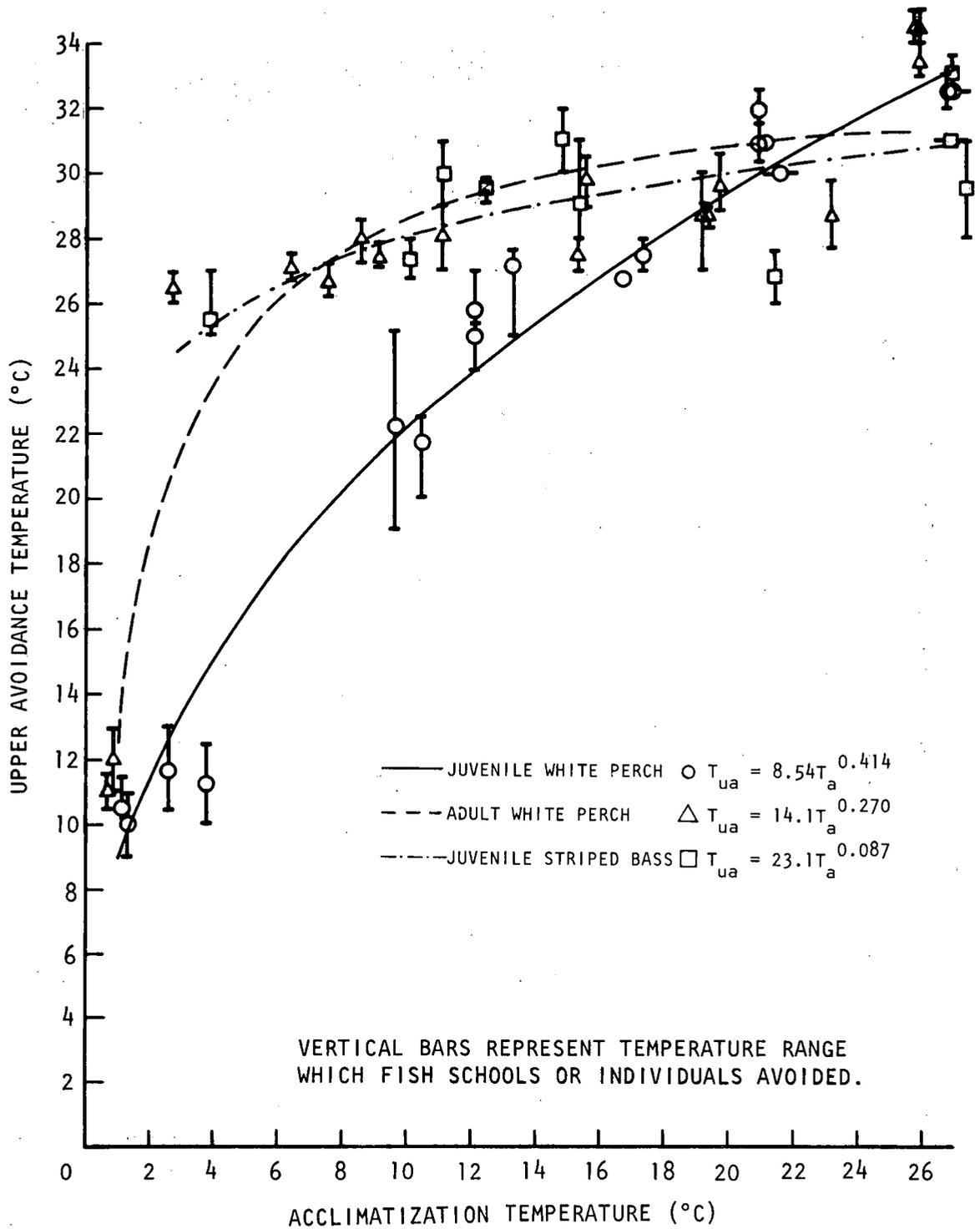


Figure V-8. Relationship of Upper Avoidance Temperature (T_{ua}) and Acclimatization Temperature (T_a) for White Perch and Striped Bass during Falling River Temperatures



Table V-7

Summary of Thermal Avoidance Experiments with White Perch during
Rising River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Upper Avoidance	
				Temp. (°C)	Temp. Range (°C)
2/15/74	5	160-195	1.2	12.5	11.0-14.0
3/3/74	6	155-198	2.4	11.0	10.0-12.0
3/11/74	8	78-100	3.7	9.5	9.0-10.0
3/18/74	7	70- 95	4.0	10.0	9.0-11.0
3/19/74	5	155-170	4.2	15.5	14.0-17.0
3/20/74	5	170-195	5.0	17.5	17.0-18.0
3/25/74	6	75- 90	6.0	12.0	12.0
4/18/74	6	156-186	9.0	24.5	24.0-25.0
4/22/74	7	70- 90	9.8	19.7	19.0-20.0
4/23/74	6	155-208	10.2	22.2	21.0-23.0
4/28/74	6	80-103	11.6	21.8	19.8-23.4
5/2/74	7	160-185	11.7	26.7	26.0-27.0
5/6/74	7	70- 85	12.7	21.9	21.2-23.0
5/16/73	6	59- 76	14.2	23.0	22.3-24.0
5/29/73	4	61- 71	14.3	24.0	24.0
5/21/73	3	65- 76	14.8	24.5	23.5-25.0
5/18/73	2	66- 77	15.0	23.5	23.0-24.0
5/17/74	7	154-195	15.2	26.0	26.0
5/21/74	7	75- 88	16.0	25.2	25.0-26.0
5/23/74	7	160-180	17.0	29.0	28.0-30.0
5/28/74	9	82-100	17.0	25.4	25.0-25.7
5/29/74	10	68- 90	17.0	25.5	25.0-26.0
6/6/74	6	151-159	18.5	29.0	28.0-30.0
6/12/74	5	151-174	21.2	30.5	29.0-32.0
6/18/74	7	65-115	21.3	27.5	27.0-28.0
6/25/74	5	153-167	21.7	32.0	31.0-33.0
7/9/74	7	90-105	24.8	32.0	31.3-32.6
7/24/73	5	157-192	25.5	31.5	31.0-32.0
7/25/73	6	160-186	25.5	31.8	31.5-32.0
7/31/73	6	160-190	25.9	34.5	34.0-35.0
8/24/73	6	53- 65	25.9	31.0	29.8-31.5
7/30/73	6	155-188	26.0	34.5	34.0-35.0
8/1/73	6	155-195	26.0	33.5	33.0-34.0
8/27/73	7	54- 65	26.0	31.5	31.0-32.0
8/28/73	6	53- 61	26.4	32.0	32.0
8/22/73	5	52- 55	26.7	32.0	32.5
8/29/73	7	50- 67	26.7	32.5	32.0-33.0
Total	226				



Table V-8

Summary of Thermal Avoidance Experiments with Striped Bass during Rising River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Upper Avoidance	
				Temp. (°C)	Temp. Range (°C)
2/11/74	6	80- 95	3.0	No avoidance	
3/5/74	6	90-110	4.0	No avoidance	
4/11/74	8	80-100	7.2	No avoidance	
4/25/74	7	78-115	9.5	22.5	21.5-23.5
4/24/74	7	90-130	10.1	23.5	23.0-24.0
5/1/74	4	77-115	12.4	27.5	27.0-28.0
5/8/74	6	160-210	13.3	29.0	28.0-30.0
5/20/74	6	175-205	15.8	29.5	29.0-30.0
6/7/73	6	81-105	16.6	28.7	28.0-29.5
6/8/73	5	80- 99	17.0	29.0	28.0-30.0
5/24/74	8	95-110	17.0	29.3	29.0-29.5
6/4/74	10	97-118	17.6	28.5	28.0-29.0
6/11/73	6	88-110	18.7	30.0	28.0-31.0
6/21/73	6	85-105	21.2	30.0	28.0-31.0
6/17/74	7	88-107	21.2	29.5	28.5-30.0
7/18/73	6	105-115	25.0	31.0	31.0
7/19/73	6	108-142	25.0	32.2	32.0-32.3
7/20/73	6	100-121	25.5	31.5	31.0-33.0
8/2/73	3	100-128	26.0	32.0	32.0
8/3/73	11	44- 66	26.2	32.0	31.5-32.5
8/7/73	10	57- 78	26.6	32.8	32.8
8/17/73	10	40- 70	27.0	33.0	32.5-33.5
8/31/73	8	65-100	27.0	31.0	31.0
9/4/73	7	76- 95	27.5	29.5	28.0-31.0
Total	165				



Table V-9

Summary of Thermal Avoidance Experiments with White Perch during
Falling River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Upper Avoidance	
				Temp. (°C)	Temp. Range (°C)
8/22/73	5	52- 55	26.7	32.5	32.5
8/29/73	7	50- 67	26.7	32.5	32.0-33.0
7/30/73	6	155-188	26.0	34.5	34.0-35.0
8/1/73	6	155-195	26.0	33.5	33.0-34.0
7/31/73	6	160-190	25.9	34.5	34.0-35.0
9/18/73	6	138-174	23.4	28.7	27.7-29.7
9/27/73	8	52- 74	21.7	30.0	30.0
10/3/73	7	65- 85	21.4	31.0	30.5-31.5
10/4/73	6	57- 78	21.1	32.0	31.6-32.6
10/5/73	5	51- 68	21.1	31.0	31.0
10/12/73	6	150-181	19.9	29.7	28.9-30.6
10/11/73	6	161-182	19.5	28.8	28.5-29.0
10/15/73	6	151-172	19.3	28.7	27.0-30.0
10/19/73	3	71- 80	17.6	27.5	27.2-28.0
10/23/73	7	70- 86	16.9	26.7	26.5-26.8
10/30/73	5	168-185	15.7	29.7	29.0-30.5
10/29/73	6	151-165	15.5	27.5	27.0-28.0
11/6/73	7	67- 80	13.4	27.2	25.1-28.6
11/7/73	8	68- 89	12.3	25.0	24.0-25.5
11/8/73	7	68- 82	12.2	25.8	24.2-26.8
11/14/73	8	158-205	11.4	28.0	27.0-29.0
11/20/73	7	68- 82	10.4	21.7	20.3-22.5
11/21/73	8	60- 79	9.7	22.2	19.0-25.3
12/5/73	6	146-185	9.3	27.5	27.2-27.9
12/4/73	6	151-186	8.9	28.0	27.2-28.6
12/11/73	6	150-168	7.7	26.7	26.2-27.2
12/12/73	5	158-175	6.5	27.2	26.8-27.6
12/18/73	3	65- 83	3.8	11.3	10.0-12.5
12/19/73	3	186-195	2.8	26.5	26.0-27.0
12/27/73	6	63- 85	2.5	11.7	10.5-13.0
12/26/73	4	77- 92	1.3	10.0	9.0-11.0
12/28/73	5	75- 95	1.2	10.5	9.7-11.5
1/3/74	5	170-205	1.0	12.0	11.0-13.0
1/2/74	5	168-200	0.8	11.0	10.5-11.5
Total	200				



Table V-10

Summary of Thermal Avoidance Experiments with Striped Bass during Falling River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Upper Avoidance	
				Temp. (°C)	Temp Range (°C)
9/4/73	7	76- 95	27.5	29.5	28.0-31.0
8/17/73	10	40- 70	27.0	33.0	32.5-33.5
8/31/73	8	65-100	27.0	31.0	31.0
9/26/73	7	86- 98	21.6	26.8	26.0-27.6
11/1/73	7	85-104	15.5	29.0	27.0-31.0
11/2/73	7	85-106	15.0	31.1	30.0-32.0
11/9/73	7	86-106	12.6	29.6	29.1-29.8
11/15/73	8	71- 90	11.4	30.0	29.0-31.0
11/27/73	8	70-100	10.3	27.3	26.8-28.0
12/21/73	4	98-115	4.0	25.5	25.0-27.0
Total	73				

5°-8°C above maximum summer acclimatization levels (26° to 27°C). Differences between T_{ua} and T_a were considerably greater during winter: 21°C for striped bass, 17°C for adult white perch, and 12°C for juvenile white perch. The 21°C value for striped bass was applicable only to early winter; during late winter, all specimens failed to avoid lethal temperatures when ambient river temperatures were rising but <9.5°C.

The inability of fish to avoid lethal temperatures was frequently evident during avoidance experiments. Specimens continued to move throughout the avoidance apparatus, even after temperatures in the warmest end had risen to well above minimum lethal levels. Greater than 80% of all instances (individual fish) of white perch equilibrium loss or death occurred at acclimatization temperatures of <17°C, while 91% of all such occurrences for striped bass happened when the T_a was <18°C (Table V-5).



All striped bass used in avoidance experiments from February through March ($T_a < 9.5^\circ\text{C}$) failed to avoid lethal conditions. Percentages of total numbers of juvenile and adult white perch and juvenile striped bass experiencing stress or death were 3.1, 5.1, and 19.4, respectively, during rising river temperatures and 1.9, 0, and 0, respectively, during falling river temperatures (Tables V-5 and V-7 through V-10).

Conductivity (Table V-6) exhibited no consistent relationship to white perch avoidance temperatures but appeared to be inversely related to striped bass avoidance responses during summer.

Two-thirds of all thermal-avoidance determinations for Atlantic tomcod were made during winter 1972-1973 at acclimatization temperatures of 0.5° to 1.0°C , corresponding to the species' peak upstream migration. Specimens actively avoided temperatures 9.6° to 13.3°C over the 0.5° to 1.0°C acclimatization temperature range and 11.7° to 20.0°C when acclimatization temperatures ranged from 1.3° to 8.9°C (Table V-11).

3. Heat Tolerance

The TL_m of each species changed ($P = 0.005$) with acclimatization temperature throughout the year and was near 34°C for white perch and striped bass during peak summertime river temperatures (Figures V-9 and V-10). Although no statistically significant difference between the TL_m of adult and juvenile perch and juvenile bass from late summer through mid-winter was evident, the TL_m of striped bass was up to 2°C higher ($P = 0.05$) than that of white perch during the remainder of the year. The TL_m of both species was 2° - 3°C lower during rising than during falling river temperatures ($P = 0.05$). All of the heat-tolerance experiments are summarized in Tables V-12, V-13, V-14, and V-15. The difference between TL_m and T_a for white perch and striped bass throughout the year varied from 14 - 19°C during winter to 6 - 9°C during summer (Tables V-12 through V-15). The median tolerance limits (TL_m) of white perch and striped bass were significantly



Table V-11

Summary of Thermal Avoidance Experiments with Atlantic Tomcod during Winter Months, 1972-1975

Date	No. of Fish/Test	Length Range (mm)	Acclim. Temp. (°C)	Upper Avoidance (°C)	Difference (°C)	Avoidance Temp. Range (°C)	Ratio Male/Female
12/18/72	6	168-192	0.5	12.1	11.6	11.5-12.7	*
2/12/73	6	120-149	0.5	10.6	10.1	10.0-11.2	1/5
2/14/73	6	136-150	0.5	10.5	10.0	8.0-14.0	4/2
2/19/73	3	91-112	0.5	10.5	10.0	9.9-11.0	5/0
1/30/73	6	94-113	0.6	12.5	11.9	10.2-15.8	4/2
1/31/73	6	115-125	0.6	12.3	11.7	12.0-12.5	3/2
2/ 1/73	6	115-120	0.6	11.4	10.8	9.8-12.5	3/1
2/ 6/73	6	151-158	0.6	10.3	9.7	5.7-13.8	1/4
2/13/73	6	137-154	0.6	9.9	9.3	9.7-10.0	4/2
2/20/73	6	118-130	0.6	11.9	11.3	11.1-14.8	2/3
2/23/73	6	163-180	0.6	11.3	10.7	10.8-11.3	1/3
2/ 5/73	6	90-115	0.7	11.2	10.5	8.0-15.0	4/2
2/ 7/73	6	164-204	0.7	9.6	8.9	8.2-10.8	2/4
2/16/73	6	165-172	0.7	13.2	12.5	12.8-13.5	1/4
2/21/73	6	141-153	0.7	12.1	11.4	11.2-13.8	5/0
2/22/73	6	125-135	0.7	11.8	11.1	10.1-14.0	4/2
2/ 8/73	4	143-175	0.9	9.9	9.0	9.9	0/6
12/29/72	6	115-131	1.0	13.3	12.3	11.8-14.7	6/0
1/29/73	6	90-118	1.0	11.9	10.9	11.1-12.6	5/1
2/ 9/73	7	161-180	1.0	12.0	11.0	12.0	0/7
1/25/73	6	165-180	1.3	15.8	14.5	15.0-16.5	0/5
1/26/73	6	162-187	1.5	11.7	10.2	10.0-12.6	0/6
12/21/72	6	112-140	1.6	13.9	12.3	12.9-14.9	6/0
12/22/72	6	130-143	1.8	15.5	13.7	14.8-17.3	6/0
12/28/72	6	107-132	2.1	12.1	10.1	11.3-13.0	*
1/ 2/75	6	165-180	2.8	15.1	12.3	14.0-16.2	3/3
1/ 3/75	6	115-135	3.0	19.0	16.0	18.0-20.0	5/1
12/15/72	6	131-150	4.0	17.5	13.5	16.9-18.2	*
12/23/74	6	145-168	5.8	13.8	8.0	13.0-14.5	3/3
12/ 3/73	2	220-230	8.9	20.0	11.1	20.0	*

* Data not collected.

higher during falling than during rising acclimation temperatures (Tables V-16 and V-17). The slopes of the regression lines for falling and rising temperature regimes (Figure V-11) are divergent, with the slope being least for falling temperature conditions, producing maximum differences at the highest acclimation temperatures.

Striped bass were more resistant than white perch to equilibrium loss (EL) or death (D) caused by exposure to high temperatures. Times to equilibrium loss or death of 50% of the test population (representing an "average" specimen) caused by a lethal temperature exposure are listed in Table V-18.

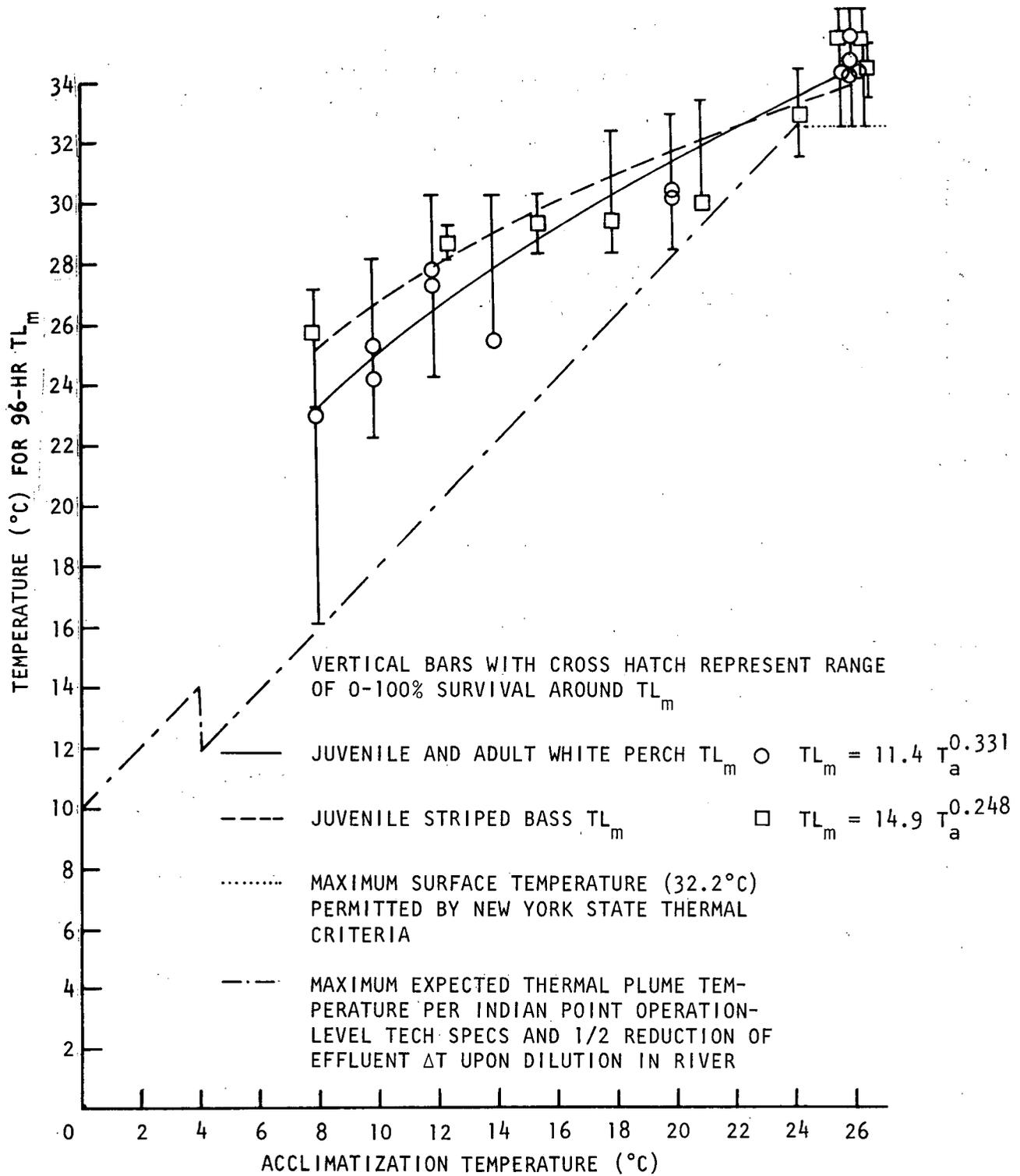


Figure V-9. Relationship of Median Tolerance Limit (TL_m) and Acclimatization Temperature (T_a) for White Perch and Striped Bass during Rising River Temperatures

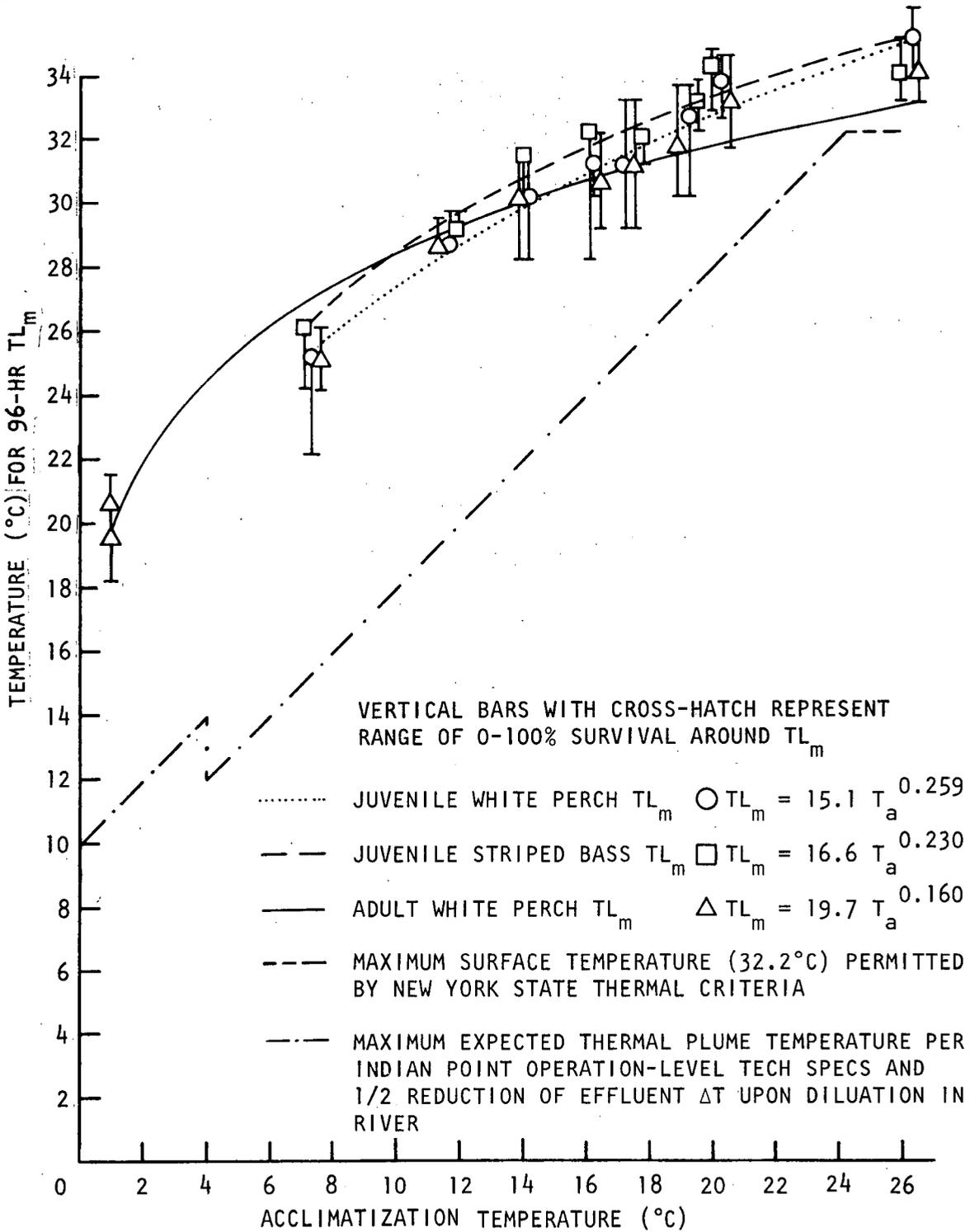


Figure V-10. Relationship of Median Temperature Tolerance Limit (TL_m) and Acclimatization Temperature (T_a) for White Perch and Striped Bass during Falling River Temperatures



Table V-12

Summary of Thermal Tolerance Experiments with White Perch during Rising River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Test Temperatures						
				°C T ₁	% Survival	°C T ₂	% Survival	°C T ₃	% Survival	TL _m °C
4/16/73	55	130-245	8.0	16.0	100	20.0	66	24.0	44	22.8
4/24/73	32	101-168	10.0	22.0	80	26.0	16	28.0	0	24.2
4/24/73	30	150-212	10.0	22.0	100	26.0	40	28.0	0	25.3
5/7/73	30	138-194	12.0	24.0	100	28.0	10	30.0	0	27.5
5/7/73	31	109-135	12.0	24.0	100	28.0	50	30.0	0	26.8
5/14/73	30	70-130	14.0	26.0	40	30.0	0	*	*	25.0
6/18/73	18	56- 87	20.0	28.0	100	30.0	50	32.5	0	30.0
6/18/73	18	56- 76	20.0	28.0	100	30.0	50	32.5	0	30.0
8/6/73	30	31- 45	26.0	31.0	90	33.0	90	35.0	0	33.7
8/11/73	30	92-138	26.0	32.0	100	34.0	90	36.0	0	34.3
8/11/73	30	137-252	26.0	32.0	100	34.0	50	36.0	0	34.0
8/20/73	30	153-214	26.0	31.0	90	33.0	90	35.0	0	33.7
8/28/73	28	36-63	26.0	34.0	100	36.0	0	*	*	35.0

*Data not collected.

Table V-13

Summary of Thermal Tolerance Experiments with Striped Bass during Rising River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Test Temperatures						
				°C T ₁	% Survival	°C T ₂	% Survival	°C T ₃	% Survival	TL _m °C
4/18/74	30	70-106	8.0	23.0	100	25.0	80	27.0	0	25.5
5/6/74	30	155-213	12.5	28.0	100	28.5	50	29.0	0	28.5
5/21/74	30	166-232	15.5	28.0	100	30.0	0	*	*	29.0
5/28/74	30	160-224	18.0	28.0	100	30.0	10	32.0	0	29.1
6/10/74	30	149-236	21.0	29.0	60	33.0	0	*	*	29.6
7/2/73	39	75-127	24.3	31.0	100	34.0	0	*	*	32.5
7/2/73	24	<30 mm	24.3	31.0	95.8	34.5	75.0	*	*	-
7/30/73	30	48- 68	25.7	32.0	100	34.0	90	36.0	0	34.8
7/30/73	30	45- 66	25.7	32.0	100	34.0	90	36.0	0	34.8
8/6/73	29	39- 70	26.0	33.0	100	35.0	0	*	*	34.0

*Data not collected.



Table V-14

Summary of Thermal Tolerance Experiments with White Perch during Falling River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Test Temperatures								
				T ₁		T ₂		T ₃		T ₄		TL _m
				°C	% Survival	°C	% Survival	°C	% Survival	°C	% Survival	°C
8/20/73	30	153-214	26.0	31.0	90	33.0	90	35.0	0	*	*	33.7
8/28/73	28	36- 63	26.0	34.0	100	36.0	0	*	*	*	*	35.0
10/8/73	30	156-191	20.0	31.5	90	32.5	30	34.5	0	*	*	33.0
10/8/73	30	55- 71	20.0	32.5	100	33.5	80	34.5	0	*	*	33.6
10/15/73	30	141-192	19.2	30.0	100	32.0	20	33.5	0	*	*	31.5
10/15/73	30	52- 80	19.2	30.0	100	32.0	90	33.5	0	*	*	32.5
10/23/73	40	151-203	17.2	29.0	100	31.0	70	31.8	20	33.0	0	31.0
10/23/73	40	56-105	17.2	29.0	100	31.0	60	31.8	50	33.0	0	31.0
10/29/73	30	138-192	16.1	28.0	100	30.0	90	32.0	0	*	*	30.5
10/29/73	31	56- 81	16.1	30.0	100	32.0	20	*	*	*	*	31.0
11/5/73	40	143-225	14.0	28.0	100	30.0	40	31.2	0	*	*	30.0
11/5/73	40	56- 95	14.0	28.0	100	30.0	90	31.2	0	*	*	30.0
11/18/73	30	151-186	11.5	28.0	70	28.5	20	29.5	0	*	*	28.5
11/18/73	30	61- 85	11.5	28.0	70	28.5	10	29.5	0	*	*	28.5
12/12/73	30	165-202	7.2	24.0	100	26.0	10	*	*	*	*	25.0
12/12/73	30	62- 90	7.2	22.0	100	24.0	90	26.0	30	*	*	25.0
1/14/74	30	155-220	1.0	16.0	90	18.0	90	20.0	40	*	*	19.5
2/11/74	40	140-205	1.0	18.5	100	20.5	50	21.5	0	*	*	20.5

*Data not collected.

Table V-15

Summary of Thermal Tolerance Experiments with Striped Bass during Falling River Temperatures

Date	No. of Fish/Test	Size Range (mm)	Acclim. Temp. (°C)	Test Temperatures							
				T ₁		T ₂		T ₃		TL _m	
				°C	% Survival	°C	% Survival	°C	% Survival	°C	
8/6/73	29	39- 70	26.0	33.0	100	35.0	0	*	*	34.0	
10/8/73	30	80-112	20.0	32.5	100	33.5	60	34.5	0	33.7	
10/15/73	30	60-108	19.2	32.0	100	33.5	0	*	*	33.0	
10/23/73	28	66-109	17.2	31.0	100	31.8	70	33.0	0	32.1	
10/29/73	30	70-110	16.1	28.0	100	30.0	80	32.0	50	32.0	
11/5/73	30	63-106	14.0	30.0	100	31.2	0	*	*	30.7	
11/18/73	30	65-91	11.5	28.0	80	29.5	0	*	*	28.6	
12/12/73	30	71-98	7.2	24.0	100	26.0	50	*	*	26.0	

*Data not collected.



Table V-16

ANOVA for Striped Bass Relative Thermal Tolerance ($T_d = TL_m - T_a$)
for Rising vs Falling Environmental Temperatures

	SS	df	MS	F
Treatment Sum of Squares	48.36	1	48.36	4.392*
Error Sum of Squares	165.13	15	11.01	
Total	213.49	16		
* $F_{0.005(1,15)} = 4.25 < 4.392 > F_{0.001(1,15)} = 5.81$				

Table V-17

ANOVA for White Perch Relative Thermal Tolerance ($T_d = TL_m - T_a$)
for Rising vs Falling Environmental Temperatures

	SS	df	MS	F
Treatment	86.21	1	86.21	9.054*
Error	276.12	29	9.52	
Total	362.33	30		
* $F_{0.01(1,29)} = 7.60 < 9.054 > F_{0.005(1,29)} = 9.23$				

Loss of equilibrium by at least 50% of the test organisms at a given shock temperature was consistently followed by mortality of similar magnitude; the single exception was a group of striped bass fry (<30 mm) acclimated to 24.3°C and exposed to 34.5°C. All specimens lost equilibrium within 25 min and did not regain normal locomotor activity for the experiment duration but experienced 75% survival over 96 hr. Larger striped bass (75 to 127 mm) exposed to nearly identical thermal conditions incurred 100% mortality over the same length of time.

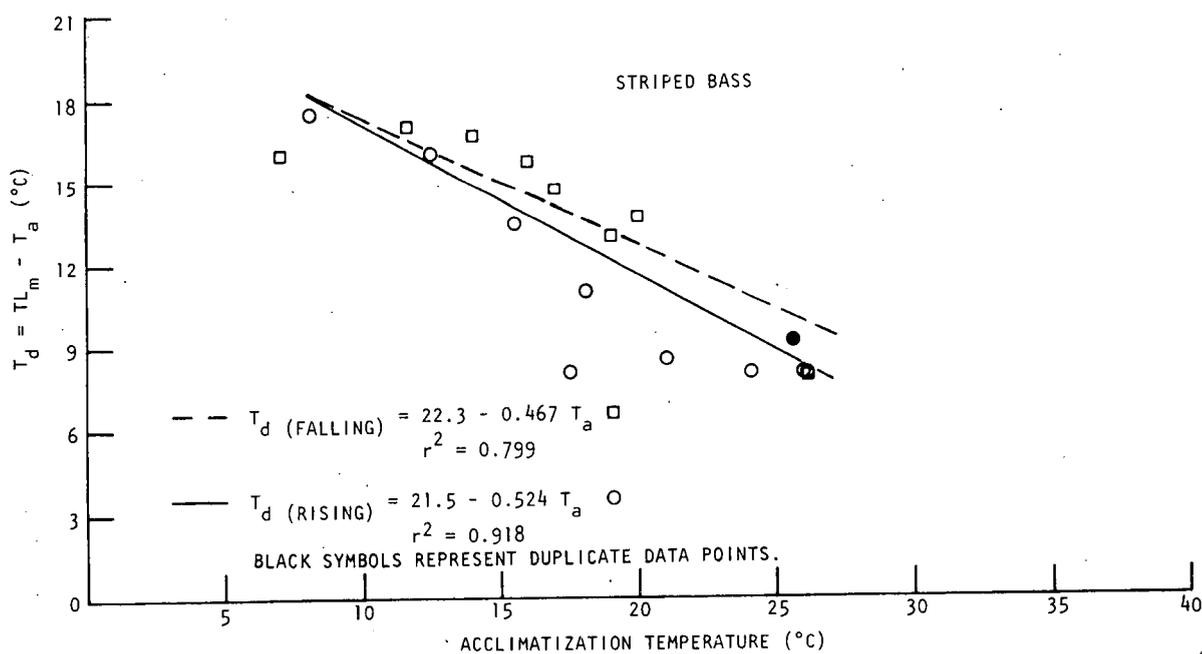
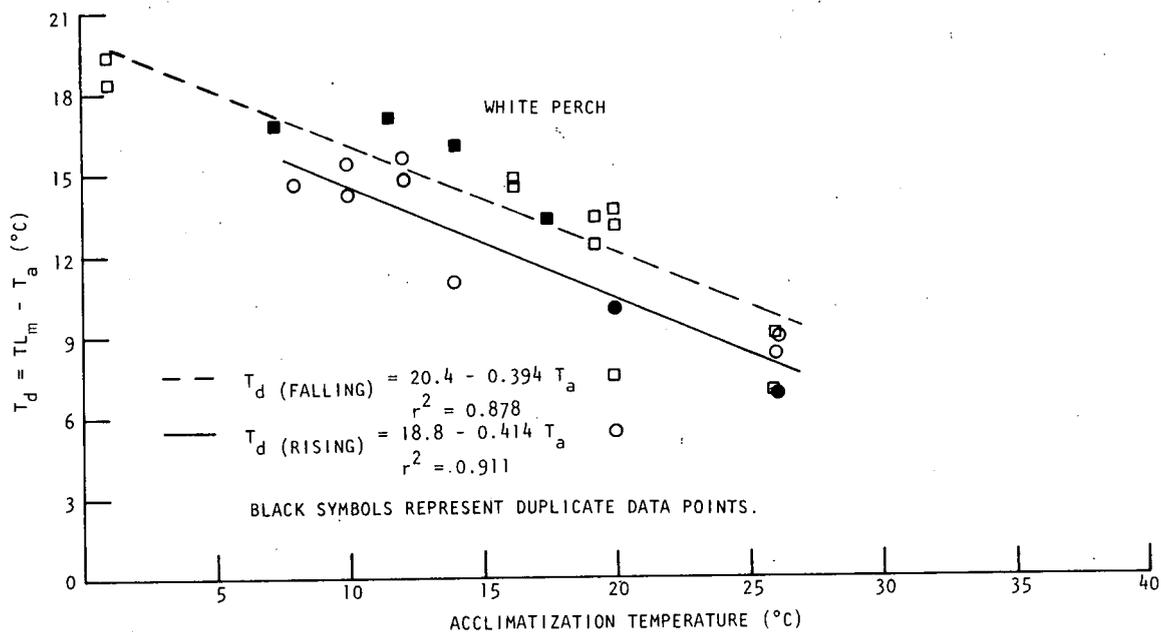


Figure V-11. Regression Lines for $T_d = TL_m - T_a$ Against Acclimation Temperature (T_a) for Striped Bass and White Perch during Falling and Rising Temperatures



Table V-18

Time in Minutes for Equilibrium Loss (EL) or Death (D) of
50% of Test Population.

Acclim. Temp.	Shock Temp.	Adult White Perch		Juvenile White Perch		Juvenile Striped Bass	
		EL	D	EL	D	EL	D
26.0	38.0	*	12.2	8.8	11.6	<9.5	13.1
26.0	37.0	34.5	36.2	17.8	28.2	18.0	31.8
26.0	36.0	*	62.2	*	116.0	34.8	59.2
26.0	35.0	*	*	*	144.0	*	173.0
21.0	35.0	*	*	*	*	<15.0	27.4
20.0	34.5	*	19.5	*	17.7	*	57.4
19.2	34.0	*	25.1	*	25.3	*	40.1
19.2	33.5	*	21.8	*	35.5	*	107.0
17.2	31.8	16.4	25.8	68.7	120.0	*	**
16.1	32.0	40.9	55.2	15.5	96.6	*	165.0
14.1	32.0	<11.0	18.7	13.2	17.5	*	24.6
14.1	31.2	15.3	23.1	14.4	21.3	25.3	46.1
12.0	28.0	10.7	30.9	*	*	*	*
11.5	29.5	*	21.6	21.8	26.3	28.0	34.1
10.4	29.0	13.5	20.5	24.6	36.2	*	90.1
10.0	28.0	<10.0	<15.0	*	*	*	*
10.0	26.0	11.3	20.7	*	*	*	*
8.0	27.0	*	*	*	*	11.6	39.3
8.0	24.0	39.7	70.8	*	*	*	*
7.2	26.0	*	15.5	*	81.5	*	85.4
7.2	25.0	<7.0	15.2	*	*	*	*
1.0	22.8	<12.0	22.2	*	*	*	*
1.0	22.5	*	*	*	*	7.1	20.5
1.0	22.0	13.3	34.1	*	*	*	*
1.0	21.6	11.5	23.6	*	*	*	*
1.0	20.0	<10.0	100.0	*	*	*	*

*Data not collected.

**50% mortality did not occur in 5760 min (96 hr).



Table V-19

Results of Thermal Tolerance Experiments with 79 Atlantic Tomcod from 110 to 175 mm in Total Length and Acclimatized to 1.0°C

Test Duration (hr)	Test Temperatures									
	T ₁		T ₂		T ₃		T ₄		TL _m	
	°C	% Survival	°C	% Survival	°C	% Survival	°C	% Survival	°C	
96	12	100	13	84.0	18	42.0	20	0	16.3	

A single thermal tolerance test on Atlantic tomcod at an acclimatization temperature of 1.0° resulted in a 96-hr TL_m of 16.3°C (Table V-19). All specimens exposed to 20°C showed activity indicative of stress (e.g., darting, twitching) or equilibrium loss within 30 min; 60% died within 4.5 hr and the remainder expired within 20 hr.

4. Cold Tolerance

At a given rate of temperature change, striped bass were more susceptible than white perch to shock from rapid temperature decreases (Table V-20). A drop from 15°C to 2°C caused 100% mortality of striped bass over a 96-hr period, while all white perch experiencing identical thermal conditions lost equilibrium within a few minutes but exhibited apparently normal behavior after 10.5 hr. A temperature decrease from 20°C to 2°C caused mortality of 50% of the white perch sample of 96 hr. Specimens surviving the cold shock displayed equilibrium loss at experiment termination (96 hr). Neither species incurred loss of equilibrium or death when temperatures were lowered from 10°C to 2°C although, as in all tests, activity temporarily increased when water of 2°C was introduced into the aquaria. In tests in which death occurred, the time to equilibrium loss for striped bass was less than that for white perch.



Table V-20

Summary of Cold Shock Experiments
with White Perch and Striped Bass

Date (1974)	Species	Size Range (mm)	Acclim. Temp. (°C)	Test Temp. (°C)	No. of Fish/Test	No. with Equilibrium Loss	No. Dead	Time (hr)
Mar 25	White perch	135-178	10	2	10			0
						0	0	96
Mar 25	Striped bass	150-215	10	2	10	0	0	0
Mar 6	White perch	135-185	15	2	10			0
						3	0	0.5
						10	0	1.0
						0	0	10.5
Mar 6	Striped bass	135-210	15	2	10	0	0	96.0
								0
						0	0	0
						10	0	0.3
						9	1	0.5
Mar 11	White perch	145-190	20	2	10	5	5	32.8
						0	10	46.0
								90.6
						2	0	0
						10	0	0.7
Mar 11	Striped bass	151-220	20	2	10	10	0	4.8
						10	0	45.2
						8	2	69.1
						5	5	96.0
								0
						10	0	0.7
						10	0	4.8
						6	4	45.2
						0	10	69.1

5. Active Respiration

Extremely low and negative metabolic rates which appear in Tables V-21 through V-24 could not be rejected as outliers by Dixon's test (Duncan, 1965). Random errors result from apparatus variations, test instrument errors, and differences among individuals or groups of fish. Regression lines presented in Figures V-12 to V-15 were calculated using the mean oxygen consumption rates presented in Tables V-21 through V-24.



Table V-21

Summary of Active Respiration Data for White Perch Acclimated to 8°C

Test Temp. (°C)	No. of Fish/Test	Length (mm)	Weight (gm)	Standard Metabolism*	Swimming Speed (cm/sec)				
					10	15	20	25	30
8	1	155	52.5	32	52.0	4.0	108.0	118.0	156.0
8	1	150	47.3		28.0	-17.0	87.0	206.0	196.0
Mean			49.9		40.0		97.5	162.0	176.0
12	1	180	72.8	41	143.0	88.0	74.0	143.0	190.0
12	1	175	69.0		45.0	77.0	53.0	47.0	75.0
Mean			70.9		94.0	82.5	63.5	95.0	132.5
16	1	188	76.4	27	44.0	35.0	66.0	121.0	133.0
16	1	173	67.0		18.0	25.0	70.0	87.0	121.0
16	1	170	65.3		169.0	149.0	198.0	246.0	211.0
16	1	138	35.1		-13.0	-28.0	26.0	106.0	141.0
16	1	152	56.3		133.0	122.0	243.0	318.0	391.0
16	1	165	61.2		8.0	69.0	137.0	102.0	181.0
16	1	155	59.5		94.0	112.0	162.0	201.0	239.0
16	1	175	82.4		98.0	75.0	87.0	139.0	196.0
Mean			62.9		68.9	69.9	123.6	165.0	201.6
20	1	163	58.1		61	130.0	112.0	145.0	189.0
20	1	165	63.0	225.0		192.0	315.0	434.0	491.0
Mean			60.6	177.5		152.0	230.0	311.5	395.0
24	1	156	46.8	86	158.0	162.0	179.0	354.0	386.0
24	1	170	59.1		169.0	218.0	296.0	362.0	423.0
Mean			53.1		163.5	190.0	237.5	358.0	404.5

*Metabolic rates are in mg of O₂/kg/hr.

Table V-22

Summary of Active Respiration Data for Striped Bass Acclimated to 8°C

Test Temp. (°C)	No. of Fish/Test	Length (mm)	Weight (gm)	Standard Metabolism*	Swimming Speed (cm/sec)				
					10	15	20	25	30
8	1	185	69.3	2	19.0	18.0	53.0	138.0	287.0
8	1	184	76.4		11.0	21.0	31.0	147.0	98.0
Mean			72.9		15.0	19.5	42.0	142.5	192.5
12	3	105-125	42.0	32	180.0	117.0	126.0	134.0	182.0
12	3	100-128	40.7		82.0	50.0	104.0	136.0	270.0
Mean			41.4		121.0	83.5	115.0	135.0	226.0
16	3	115-128	49.8	67	166.0	129.0	119.0	155.0	156.0
16	3	107-148	53.7		114.0	126.0	144.0	189.0	181.0
16	3	115-119	42.0		31.0	64.0	44.0	172.0	260.0
16	3	109-123	42.8		134.0	101.0	105.0	190.0	117.0
16	3	98-122	37.0		166.0	141.0	202.0	219.0	294.0
16	3	106-116	35.5		119.0	112.0	131.0	230.0	187.0
16	3	109-126	45.0		229.0	186.0	209.0	260.0	278.0
16	3	95-120	39.4		123.0	110.0	167.0	166.0	207.0
Mean			43.2		135.3	121.1	140.1	197.6	210.0
20	3	100-129	44.0		107	292.0	132.0	269.0	288.0
20	3	106-120	39.7	234.0		223.0	370.0	398.0	414.0
20	3	100-118	41.1	324.0		129.0	275.0	286.0	356.0
20	3	100-132	39.7	282.0		207.0	216.0	217.0	157.0
Mean			41.4	283.0		172.8	282.5	297.3	331.5
24	3	110-118	42.5	180	325.0	308.0	312.0	442.0	500.0
24	3	105-120	42.8		365.0	278.0	273.0	310.0	369.0
Mean			42.7		345.0	293.0	292.5	376.0	434.5

*Metabolic rates are in mg of O₂/kg/hr.



Table V-23

Summary of Active Respiration Data for White Perch Acclimated to 24°C

Test Temp (°C)	No. of Fish/Test	Length (mm)	Weight (gm)	Standard Metabolism*	Swimming Speed (cm/sec)				
					10	15	20	25	30
8**	1	158	54.7		114.0	51.0	163.0		
8**	2	125-138	55.3		98.0				
8**	2	125-135	56.8						
12	1	184	80.7		82.0	58.0	106.0	100.0	153.0
12	1	163	57.0		117.0	40.0	62.0	126.0	145.0
12	1	168	65.7		141.0	36.0	16.0	80.0	112.0
Mean			67.8	14	113.3	44.7	61.3	102.0	136.7
16	1	158	47.6		122.0	34.0	106.0	236.0	282.0
16	1	163	56.3		176.0	130.0	197.0	192.0	203.0
16	1	166	71.3		148.0	35.0	186.0	173.0	220.0
16	1	160	55.9		125.0	81.0	109.0	140.0	236.0
16	1	164	59.6		42.0	53.0	96.0	124.0	172.0
16	5	95-104	61.8		66.0	122.0	140.0	242.0	284.0
16	5	85-125	62.3		205.0	117.0	189.0	204.0	259.0
Mean			59.3	33	129.1	81.7	146.2	187.3	236.6
20	2	114-132	49.3		99.0	77.0	185.0	181.0	175.0
20	2	112-115	37.5		248.0	206.0	266.0	309.0	355.0
20	5	90-108	66.5		205.0	186.0	191.0	287.0	485.0
20	5	95-102	53.3		144.0	84.0	234.0	313.0	367.0
Mean			51.7	60	174.0	138.3	219.0	272.5	345.5
24	1	192	92.6		142.0	124.0	214.0	190.0	178.0
24	1	180	71.3		307.0	195.0	302.0	325.0	368.0
24	1	137	30.2		263.0	166.0	385.0	338.0	239.0
24	1	145	38.1		118.0	364.0	476.0	286.0	341.0
24	1	155	52.5		172.0	287.0	232.0	294.0	528.0
24	1	175	78.2		309.0	135.0	222.0	412.0	318.0
24	1	195	93.2		189.0	154.0	188.0	122.0	281.0
Mean			65.0	148	214.3	203.6	288.4	281.0	321.9

*Metabolic rates are in mg of O₂/kg/hr.
 **Data not included in graphic and statistical analyses.

Table V-24

Summary of Active Respiration Data for Striped Bass Acclimated to 24°C

Test Temp (°C)	No. of Fish/Test	Length (mm)	Weight (gm)	Standard Metabolism*	Swimming Speed (cm/sec)				
					10	15	20	25	30
8**	3	103-122	40.9		92.0	9.0	90.0		
8**	3	95-112	35.0		84.0	29.0			
12	2	111-158	45.6		94.0	32.0	130.0	77.0	123.0
12**	3	96-135	43.6		66.0	28.0	36.0	77.0	
12**	3	112-122	46.0		99.0	86.0	104.0	128.0	
Mean			45.6	16	94.0	32.0	130.0	77.0	123.0
16	5	85-105	41.3		198.0	275.0	333.0	335.0	578.0
16	5	85-130	57.7		197.0	218.0	357.0	444.0	305.0
16	2	118-135	43.7		24.0	61.0	75.0	118.0	141.0
16	2	112-135	38.8		83.0	50.0	-17.0	148.0	170.0
16	3	113-128	44.6		189.0	168.0	347.0	339.0	327.0
16	3	110-126	46.0		160.0	147.0	75.0	205.0	168.0
Mean			45.4	83	141.8	153.2	195.0	264.8	281.5
20	3	100-123	36.6		210.0	215.0	252.0	290.0	254.0
20	5	92-117	54.8		262.0	298.0	380.0	349.0	499.0
20	5	98-112	69.5		153.0	276.0	206.0	327.0	290.0
20	2	122-146	49.3		53.0	-14.0	105.0	168.0	236.0
Mean			52.6	119	169.5	193.8	235.8	283.5	319.8
24	4	85-100	42.5		501.0	507.0	508.0	751.0	818.0
24	5	105-135	74.8		468.0	484.0	530.0	689.0	488.0
24	2	132-135	41.6		306.0	308.0	408.0	380.0	417.0
Mean			53.0	324	425.0	433.0	482.0	606.7	574.3

*Metabolic rates are in mg of O₂/kg/hr.
 **Data not included in graphic and statistical analyses.

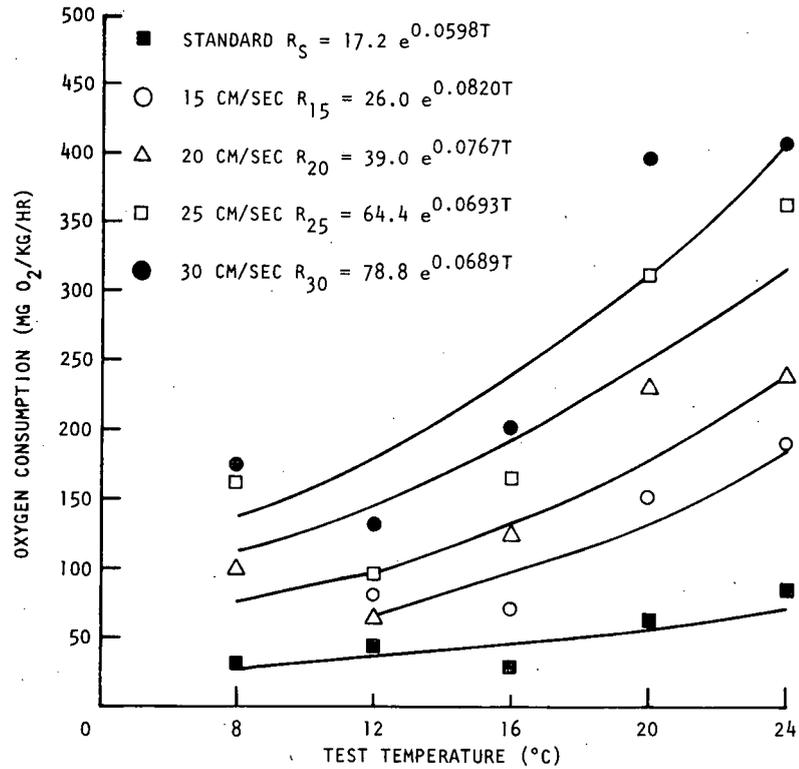


Figure V-12. Oxygen Consumption Rates of White Perch Acclimated to 8°C at Various Activity Levels in Relation to Test Temperature

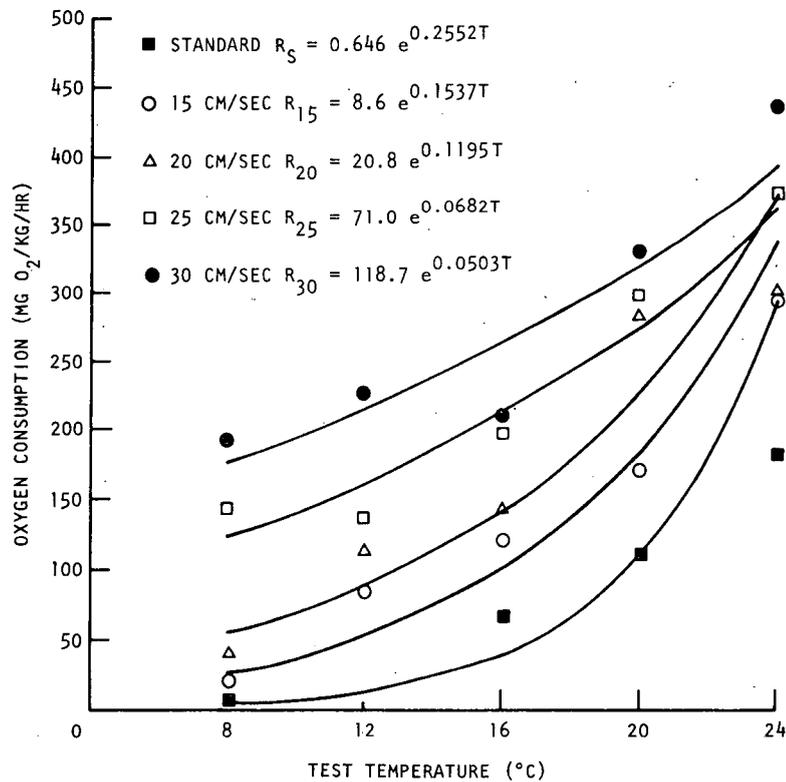


Figure V-13. Oxygen Consumption Rates of Striped Bass Acclimated to 8°C at Various Activity Levels in Relation to Test Temperature

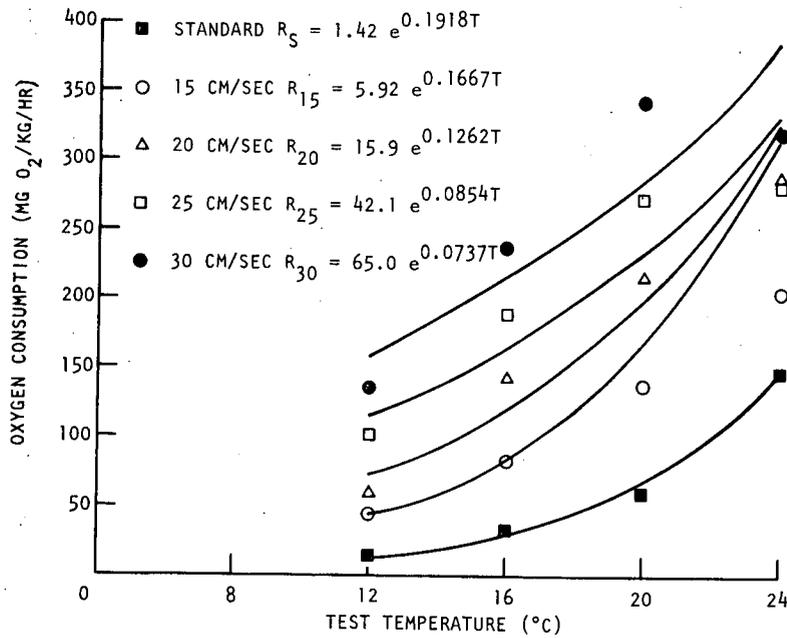


Figure V-14. Oxygen Consumption Rates of White Perch Acclimated to 24°C at Various Activity Levels in Relation to Test Temperature

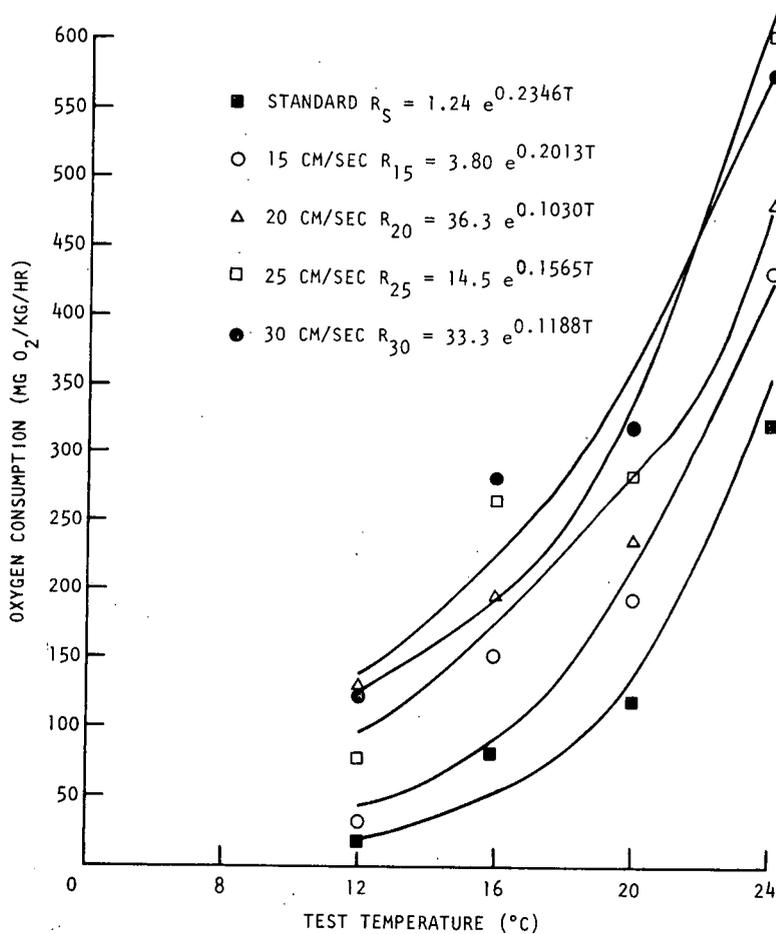


Figure V-15. Oxygen Consumption Rates of Striped Bass Acclimated to 24°C at Various Activity Levels in Relation to Test Temperature



It became apparent through repeated testing that the swimming ability of white perch and striped bass was severely impaired when specimens were subjected to an acute temperature decrease from 24° to 8°C (Tables V-23 and V-24). Test individuals in apparently healthy condition were incapable of completing the series of incremental swimming-speed increases to 30 cm/sec, a speed which specimens acclimated to 8°C showed no trouble maintaining for 1 hr. Results of cold-shock experiments appearing elsewhere in this report (page V-41) show that both species experienced acute stress or mortality when the holding temperature was changed from 15° to 2°C (ΔT , 13°C) within 3 hr. Data resulting from these experiment attempts appear in Tables V-21 and V-22 but were not utilized in graphic or statistical analyses. Otto and Rice (1974) reported that the swimming ability of yellow perch (*Perca flavescens*) decreased for several hours following a rapid sublethal environmental temperature drop of 10°C.

Metabolic rates at the lowest imposed swimming speed (10 cm/sec) were often greater than those at the next highest activity level (Tables V-19 through V-22). This was likely an artifact of the experimental procedure. Following overnight habituation, the test specimens were repeatedly disturbed by changing of the water velocity to remove air bubbles from the system prior to a test. Assuming that the level of excitement diminished as testing progressed, metabolic rate at higher levels of activity was proportionately less since metabolic rates increased with increasing swimming speeds resulting from the disturbances (Figures V-12 through V-15). Brett (1964) reached a similar conclusion during studies with juvenile sockeye salmon.

The estimated standard metabolic rates of white perch acclimated to 8° and 24°C (32 and 148 mg O₂/kg/hr, respectively) are similar to those determined by Meldrim et al (1974) (28-52 and 152-276 mg O₂/kg/hr, respectively) at identical acclimation temperatures. Mean active metabolic levels of white perch acclimatized to 8° and 24°C in this investigation were 175.0 and 321.9 mg O₂/kg/hr, respectively, values similar in



magnitude to those reported by Meldrim (140-333 and 181-280 mg O₂/kg/hr, respectively) at similar acclimation temperatures. It is also apparent from Figures V-12 through V-15 that total oxygen usage increased exponentially with test temperature.

Available dissolved oxygen in our system was never < 5 mg/l. Meldrim et al (1974) reported a critical swimming speed of 47-54 cm/sec for white perch acclimated to 24°C, suggesting that the species was fully capable of sustaining speeds much higher than those used in this study.

Differences between active (30 cm/sec) and estimated standard metabolic rates (locomotor scope) generally changed directly with test temperature (Table V-25). The most noteworthy exceptions to this trend were for white perch acclimated and tested at 24° and 24°C and at 8° and 24°C respectively. Inconsistent inverse relationships for white perch for acclimation/test temperatures of 8°/12° C and for striped bass of 8°/16°C make the significance of the 8°/24°C and 24°/24°C results subject to question.

Regression analysis of data for white perch and striped bass acclimated at 8°C revealed that the linear effects of test temperature and swimming speed and quadratic effects due to test temperature contributed significantly ($P < 0.01$) to the model (Tables V-26 and V-27). The regression coefficient for linear effects of test temperature was the dominant factor in models for both species. Components other than test temperature and swimming speed were statistically unimportant ($P < 0.05$). The response surface for each species relating metabolic rate to levels of activity and test temperature is constructed in Figure V-16. The following equations describe the response surfaces:

For white perch

$$Y = -68.26 - 15.93 X_1 + 10.29 X_2 + 0.9347 X_1^2$$

For striped bass

$$Y = -60.06 - 10.73 X_1 + 8.563 X_2 + 0.8412 X_1^2$$



Table V-25

Difference between Metabolic Rate at 30 cm/sec and Estimated Standard Metabolic Rate (Locomotor Scope) for White Perch and Striped Bass at Each Acclimation Temperature/Test Temperature Combination

Test Temp. (°C)	Acclimation Temperature			
	8°C		24°C	
	White Perch	Striped Bass	White Perch	Striped Bass
8	144.0	190.5	No data collected	
12	91.5	194.0	122.7	107.0
16	174.6	143.0	203.6	198.5
20	334.0	224.5	285.5	200.8
24	318.5	254.5	173.9	250.3

Calculations based on data appearing in Tables V-21 through V-24. Units are in mg O₂/kg/hr.

Table V-26

Analysis of Variance for Reduced Model for White Perch Acclimated to 8°C

Source of Variation	DF	SS	MS	F
Regression			166,763	30.95**
Test temp (linear)	1	250,208	250,208	46.44**
Swim speed (linear)	1	211,614	211,614	39.28**
Test temp (quadratic after temp (linear))	1	38,468	38,468	7.14**
Residual error			5,388	
Replication error	44	254,031	5,773	
Lack of fit	16	69,238	4,327	0.75
Total	63	823,559		

$r^2 = 0.61$, $n = 64$
 **Significant at $F_{0.01(3,60)} = 4.13$



Table V-27

Analysis of Variance for Reduced Model for Striped Bass
Acclimated to 8°C

Source of Variation	DF	SS	MS	F
Regression			186,100	56.35**
Test temp (linear)	1	362,060	362,060	109.63**
Swim speed (linear)	1	164,990	164,990	49.96**
Test temp (quadratic) after temp (linear)	1	31,240	31,240	9.46**
Residual error			3,300	
Replication error	52	186,820	3,590	
Lack of fit	16	33,750	2,359	0.65 NS
Total	71	782,860		

$r^2 = 0.71, n = 72$
 **Significant at $F_{0.01(3,68)} = 4.11$
 NS = Nonsignificant

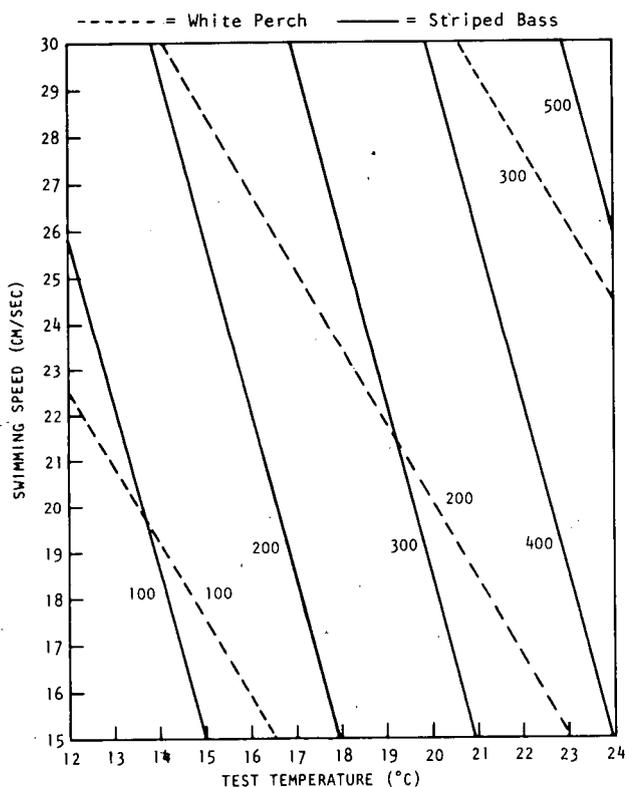


Figure V-16. Isopleths of Metabolic Rates ($\text{mg O}_2/\text{kg/hr}$) for White Perch (Broken Lines) and Striped Bass (Solid Lines) Acclimated at 8°C



Results indicated that the metabolic rates of both species increased over the ranges of swimming speeds and test temperatures, suggesting that neither test variable nor oxygen levels in the apparatus were limiting to the expression of metabolic activity. Lines of equal standard metabolic rates ($\text{mg O}_2/\text{kg/hr}$) became steeper and more closely spaced with increased temperature and activity, respectively, (Figure V-16) — factors which were indicative of an increased rate of change of metabolism as both independent variables increased over the study range. Striped bass exhibited slightly higher ($< 50 \text{ mg O}_2/\text{kg/hr}$) metabolic rate than did white perch at identical test temperatures and activity levels.

Analyses of variance on data for both species acclimated to 24°C (Tables V-28 and V-29) revealed that only linear components of speed and temperature accounted for a significant portion of variation in oxygen consumption ($P < 0.01$). Quadratic and interaction terms made no significant ($P < 0.05$) contribution to the model. The response surface representations for both species appear in Figure V-17. The following equations describe the surfaces:

For white perch

$$Y = -290.0 + 15.28 X_1 + 9.16 X_2$$

For striped bass

$$Y = -531.4 + 33.24 X_1 + 9.00 X_2$$

Metabolic rates of both species decreased linearly with test temperature and activity, suggesting that neither variable was limiting in the range of test variables. It was apparent that, with the exception of the lowest test temperatures, the metabolic rate of striped bass was approximately 1.5 times higher than that of white perch.



Table V-28

Analysis of Variance for Reduced Model for White Perch
Acclimated to 24°C

Source of Variation	DF	SS	MS	F
Regression			291,670	56.6**
Test temp (linear)	1	362,860	362,860	70.4**
Swim speed (linear)	1	220,480	220,480	42.8**
Residual error			5,150	
Replication error	68	375,380	5,520	
Lack of fit	13	41,860	3,220	0.58 NS
Total	83	1,000,580		
$r^2 = 0.58, n = 84$ **Significant at $F_{0.01(2,81)} = 4.91$ NS = Nonsignificant				

Table V-29

Analysis of Variance for Reduced Model for Striped Bass
Acclimated to 24°C

Source of Variation	DF	SS	MS	F
Regression			467,322	26.53**
Test temp (linear)	1	792,984	792,984	45.02**
Swim speed (linear)	1	141,660	141,660	8.04**
Residual error			17,616	
Replication error	40	764,426	19,110	
Lack of fit	13	169,197	13,015	0.68 NS
Total	55	1,868,267		
$r^2 = 0.50, n = 56$ **Significant at $F_{0.01(2,53)} = 5.05$ NS = Nonsignificant				

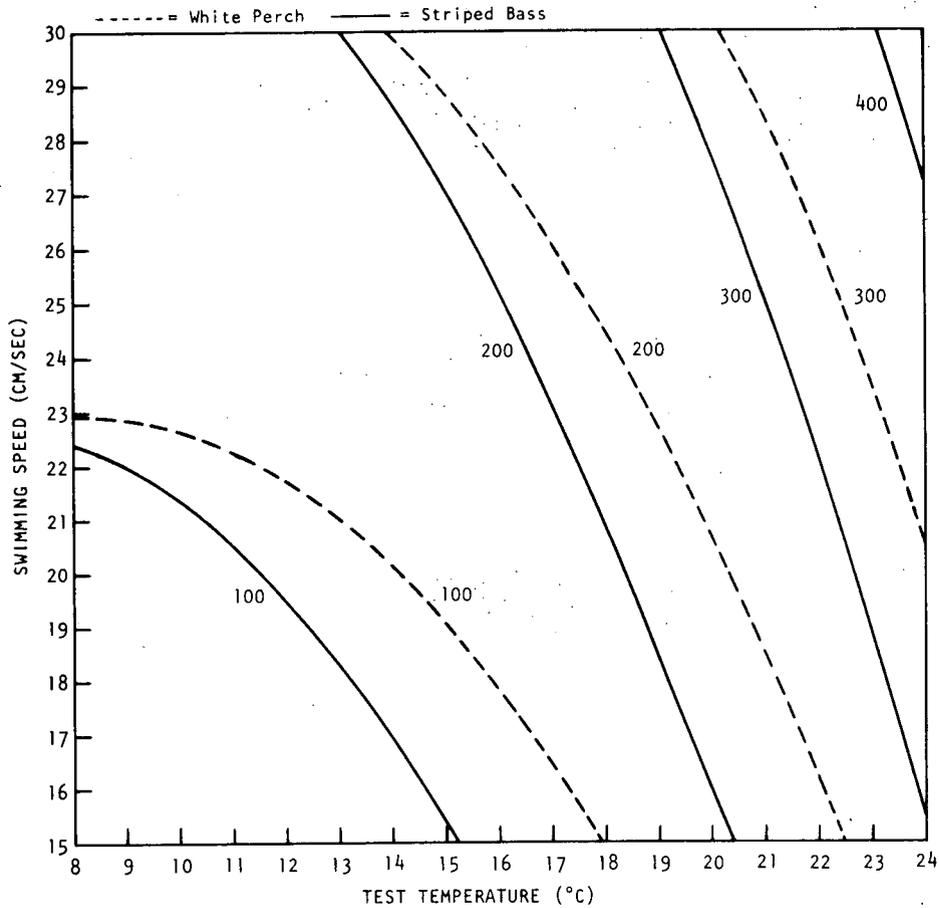


Figure V-17. Isopleths of Metabolic Rates (mg O₂/kg/hr) for White Perch (Broken Lines) and Striped Bass (Solid Lines) Acclimated to 24°C

According to the coefficient of determination (r^2) for each model, the statistical models could explain only 50-70% of the variation of oxygen consumption in the four cases (Tables V-19 through V-22). Previous investigators found that factors such as weight (Brett, 1965), season and number of individuals per test (Job, 1955), and body tissue composition (Brett, 1964) were major contributors to variation in metabolic rate. Phillips (1969) and Fry (1971) reported additional sources of variation. The addition of weight (30.2 to 93.2 g) to the models did not contribute significantly ($P < 0.05$) and accounted for only an additional 1% of the total variation in oxygen usage.



The metabolic rate of warm-acclimated striped bass was more strongly influenced when test temperatures were lower than acclimation level than was the metabolic rate of cold-acclimated bass to a temperature increase when test temperatures in both instances were identical (Figure V-18). Peterson and Anderson (1969) reported the same effect for a temperature change on the spontaneous activity and metabolic rate of underyearling Atlantic salmon.

Higher metabolic rates of striped bass acclimatized to warm temperatures were not unexpected since cold acclimation is generally accepted to be less rapid than acclimation to increasing environmental temperatures (Brett, 1944). On the basis of this, one would expect differences between metabolic contours for warm- and cold-acclimated fish (Figure V-18) to be greatest at the lower range of test temperatures if metabolism depended entirely on body temperature (at a transient acclimation state). Data for striped bass did not support this hypothesis. Peterson and Anderson (1969) found that a sudden temperature increase caused an initial overshoot of spontaneous metabolic rate followed by an undershoot prior to the gradual change to the new acclimation level. Following a temperature decrease, the metabolic rate also exceeded the level characteristic of the initial acclimation temperature before reaching stability at the lower temperature. These patterns were unlike the roughly linear progressions of temperature acclimation determined by Brett (1944).

White perch metabolism did not respond in the same manner to comparable temperature changes as did that of striped bass. Results in Figure V-19 indicate that there was little difference ($< 50 \text{ mg O}_2/\text{kg/hr}$) between metabolic responses of specimens to temperature changes for comparable temperature ranges. Within these limits, the data suggest that the rate of temperature acclimation (directly affecting metabolism) was approximately the same in both directions. If this were true, it would disagree with findings

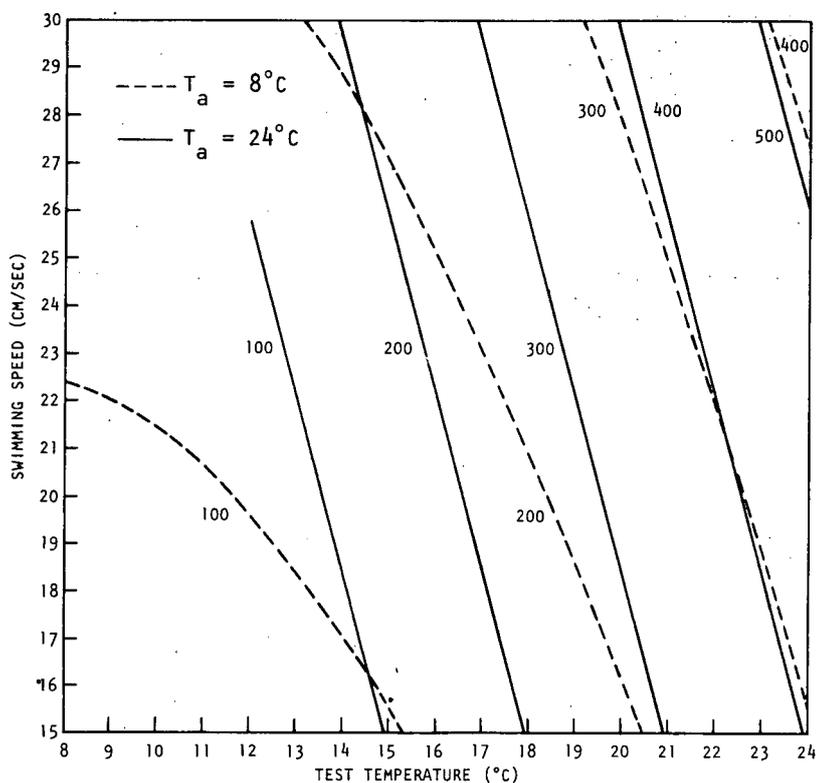
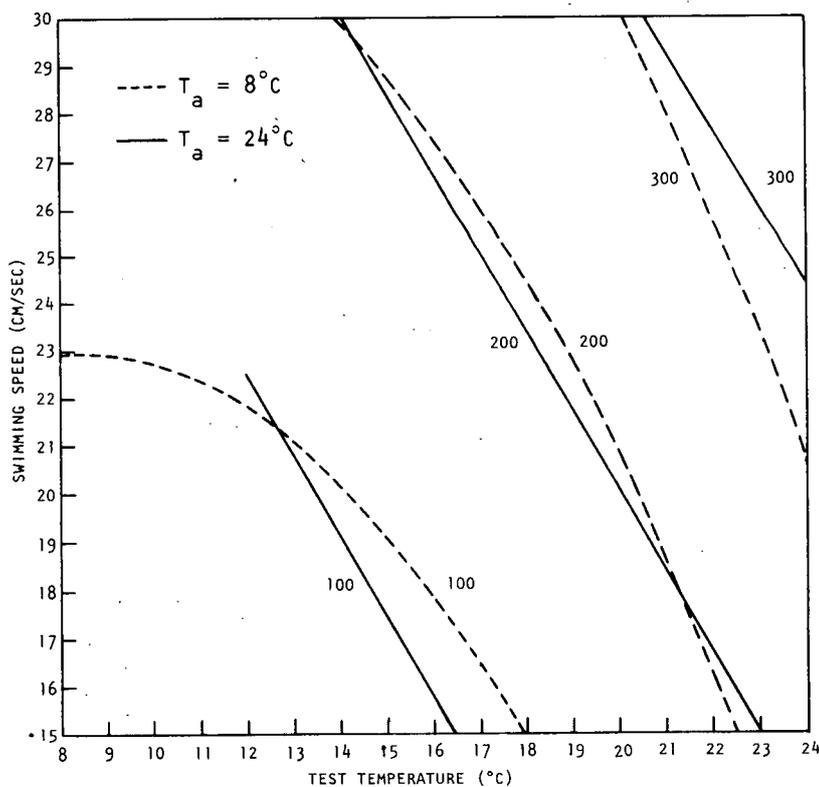


Figure V-18
Isopleths of Metabolic Rates
(mg O₂/kg/hr) for Striped Bass
Acclimated to 8°C and 24°C

Figure V-19
Isopleths of Metabolic Rates
(mg O₂/kg/hr) for White
Perch Acclimated to 8°C
and 24°C





of other investigators (Brett, 1944; Allen and Strawn, 1971); however, Peterson and Anderson (1969) found no evidence to indicate that there was any difference in time required for Atlantic salmon to acclimate to decreasing or increasing temperature.

D. GENERAL DISCUSSION

Determination of fish behavioral and physiological responses to above- or below-ambient temperatures in a laboratory can be an important tool for use in predicting reactions of fish in field situations. However, one should consider the restrictions which a laboratory necessarily places on the experimental design and potentially on the organism's response; most thermal gradients in nature are shallow, while those in a laboratory are steep due to space limitations. The size of fish which can be handled is also a consideration, oftentimes limiting experiments to juveniles. Some factors which are known to directly affect survival or to influence temperature preference or avoidance responses to elevated temperatures include:

- Thermal history (Brett, 1952)
- Age (McCauley and Read, 1973)
- Salinity (Meldrim and Gift, 1971)
- Nutritional state (Javaid and Anderson, 1967)
- Light level (Sullivan and Fisher, 1954)
- Season (Sullivan and Fisher, 1953)
- Dissolved oxygen (Brett, 1944)

Meldrim et al (1974) have provided the most comprehensive effort to date in defining the extent to which selected environmental variables can affect the behavior and physiology of estuarine fish species. Reaction to current, water chemistry, state of gonadal maturity, spawning movements, predator-prey relationships, and habitat preference may also play key roles with behavioral or physiological responses of fishes to various thermal regimes.



1. Behavioral Effects

Fry (1967) suggested that the phenomenon of thermal preference (or selection) may be an expression of a physiological mechanism to bring an organism to an optimum temperature for activity. Fry and Hart (1948) found that the final temperature preferendum and the optimum temperature for cruising speed in fully acclimated goldfish correspond closely, while Brett (1971) showed that a number of physiological parameters in sockeye salmon were maximized at 15°C, the final temperature preferendum of the species.

Loeb and Wasteneys (1912) were the first to show that the temperature acclimation process in fish was more rapid to increasing than to decreasing environmental temperatures, suggesting that the response of an organism at a given acclimatization temperature to a thermal gradient depends at least in part on the seasonal temperature regime.

Failure of the preferred temperature of juvenile white perch to follow acclimatization temperature in nearly the same manner as adult white perch suggested that thermal preference is also influenced by life stage of the organism, a finding previously documented for white perch by Meldrim and Gift (1971) and for other species by Sullivan and Fisher (1953), Barans and Tubb (1973), and Zahn (1963). Intra- and interspecific differences of preferred temperatures at a given acclimatization temperature probably reflect age and species-related physiological requirements and abilities to adapt to changing environmental temperatures.

The selection of above-ambient temperatures in the laboratory by white perch and striped bass throughout the year suggested a potential for the Indian Point thermal discharge to act as an attractant, especially from late fall to early spring. Other investigators have reported that these species are attracted to warm-water areas. Moore and Frisbee (1972) reported that white perch and striped bass were among the most frequently caught



species in the Chalk Point, Maryland, discharge canal at temperatures 2° to 5°C above ambient from January through April, and Miller and DeMont (1974) found that striped bass were highly attracted to the discharge area of a steam-electric station on Lake Norman in North Carolina from October through March when ambient lake temperatures were 4° to 7°C and maximum canal temperatures ranged from 13° to 22°C. Chadwick (1971) stated that subadult and adult striped bass exhibited a preference for a thermal discharge in the Sacramento-San Joaquin estuary of California. Moore et al (1973) reported that over one half of the legal-size striped bass (> 30.5 mm) collected during a 1-year sport fishery survey in the Patuxent estuary near Chalk Point, Maryland, came from the discharge canal of a power plant, but the effect of elevated temperature on the species' presence was unclear.

In the Indian Point discharge canal, white perch were present during summer at temperatures of 26.7° to 31.7°C when river ambient temperatures ranged from 22.2° to 26.7°C (Texas Instruments, 1973a, 1973b). The species was absent from the canal during fall (Δt present) and winter (Δt absent) and reappeared in spring (Δt absent), suggesting that its seasonal occurrence was related to its migratory movements during fall and spring. The discrepancy between results of laboratory experiments and field sampling suggests that many factors, both environmental and endogenous, determine the response of an organism to a single environmental variable.

The effect of size (or age) on thermal preference behavior of striped bass was not determined in this study. Based on evidence for white perch in this investigation and on available information for young and adults of other species, however, adult striped bass probably select temperatures several degrees lower (Barans and Tubb, 1973; McCauley and Read, 1973) or similar to (Meldrim and Gift, 1971) temperatures selected by juveniles during the same season.



Little is known concerning the exact migration routes of striped bass in the Indian Point vicinity during spring. Gill net catches of mature striped bass in the Hudson River have indicated that at least some movement occurs at depths from 1 to 6 m (4 to 20 ft) along shore. Distance from shore and the depth at which migration occurs necessarily determine whether the species will contact the Indian Point thermal discharge. Raytheon (1971) reported that American shad, another anadromous Hudson River species, followed the main river channel (a finding also reported by Merriman [1971] for shad in the Connecticut River). In light of the American shad's reported migratory behavior, it is not unreasonable to expect that Hudson River striped bass also follow the main river channel, probably responding to routes of greatest flow. The Hudson's main channel occurs on the eastern side of the river basin (Texas Instruments, 1974a) adjacent to Indian Point.

Field observations of Dames and Moore (1974a) and hydraulic modeling studies (Alden, 1969) have shown that, with a discharge volume of approximately 2600 cfs from 2-unit operation, a condenser-water Δt of 6.7° to 7.8°C (12° to 14°F), and ambient river temperatures between 10° and 20°C (50° and 68°F, the temperature range over which striped bass migration occurred during 1974 and 1975), a temperature increase of at least 1.1°C (2.0°F) will occur at a depth of 2 m (6 ft) and, depending on tidal stage, extend approximately 90 to 900 m (300 to 3000 ft) longitudinally and 90 to 300 m (300 to 1000 ft) across the river from discharge gates. The 1.1°C isotherm is projected to extend to a depth of 7 m (24 ft) in the immediate vicinity of the discharge canal and encompass a somewhat larger area under conditions of 3-unit operation (4670 cfs discharge volume and condenser Δt of 9.1°C) at similar river ambient temperatures.

No definitive statement can be made concerning the extent to which the Indian Point thermal discharge affects the migratory movements of striped bass. The proximity of the Indian Point complex to the main river channel, the results of laboratory studies reported herein, and the known



ability of fish to detect temperature changes of $<0.5^{\circ}\text{C}$ (Bull, 1928) seems to indicate that the potential does exist for the above-ambient temperatures of the thermal discharge to attract adults.

Results of other investigations concerning migratory fish species suggest that the migration instinct overrides preference for elevated temperatures. Moore and Frisbee (1972) suggested that the steadily declining sport-catch rates of white perch and striped bass in the Chalk Point discharge canal during late winter and early spring were due to upriver spawning movements. Coutant (1969) found that upstream migrant adult steelhead and chinook salmon successfully negotiated areas of warm water upwelling near the Hanford nuclear complex on the Columbia River in Washington. Merriman (1971) and Trembley (1960) concluded that several anadromous fish species including striped bass and American shad have apparently continued to migrate successfully through areas influenced by heated effluents of electric-generating stations. Fears that upstream migration of adult striped bass and other species will be blocked appear unfounded based on the results presented here and plume configuration (Alden Research Laboratories, 1969; Dames and Moore, 1974a).

Aggregation of forage fishes in the Indian Point thermal effluent during spring could induce adult striped bass to engage in opportunistic feeding, thereby temporarily delaying migration. cursory stomach analysis of adult striped bass in spring 1974 and 1975 indicated a diet consisting almost exclusively of herrings (Clupeidae, Alosa). The mean catch per effort of blueback herring was greater in the Indian Point plume (35.86) than in control areas (0.21) during fall 1972 (TI, 1973a), a time of the year when plume temperatures are similar to those during spring. Raytheon (1971) reported large numbers of alewife in the effluent of Unit 1 during fall 1969 when the plant was on line but not in 1970 when a thermal discharge was absent. Fishermen have observed striped bass chasing baitfish in thermal



effluents of Long Island Lighting Company's Glenwood Landing and Northport Harbor steam-electric stations during winter and early spring (Jensen, 1970); these areas are reported favorites of striped bass fishermen during this time of year. Some fishes, especially clupeids, may be attracted to power-plant discharges by current from the discharge rather than by warmer waters (Romberg et al, 1974). The extent of any migratory delay due to opportunistic feeding would probably be insignificant.

Plume temperatures exceeding the maximum allowable level established by New York State thermal discharge criteria (32.2°C maximum) during summer would probably create an unfavorable environment for white perch and striped bass based on their avoidance responses in the laboratory when acclimated to 26°-27°C. Meldrim et al (1974) reported upper avoidance temperatures of 32°-35°C and 33°-34°C for white perch and striped bass, respectively, acclimated to 25°-27°C during July and August. Moore et al (1973) reported that white perch catches in the Chalk Point discharge canal from May through September were less than from October through April, suggesting that canal temperatures near 32°C were at least in part responsible for the low catches. Miller and DeMont (1974) found that striped bass avoided the Chalk Point discharge canal from July through September and attributed their absence to high seasonal discharge temperatures near 30°C and to low dissolved oxygen (near 1 mg/l).

Higher upper avoidance temperatures during falling than during rising river temperatures for a given T_a for both species was not unexpected, probably reflecting the ability of fish to acclimate less rapidly to decreasing than to increasing environmental temperatures.

The occasional failure of white perch and striped bass to avoid lethal temperatures appears analogous to the low thermal responsiveness



(LTR)* of juvenile white perch reported by Meldrim and Gift (1971). The ability of juvenile striped bass to generally avoid stressful conditions when acclimatized to river temperatures $> 8^{\circ}\text{C}$ in this study (Table V-28) seems to exclude the possibility that the apparatus design did not permit their escape to a more suitable environment when acclimatized to $< 8^{\circ}\text{C}$. In Figure V-19, the steep linear increase in the difference between T_{ua} and T_a for juvenile striped bass during falling river temperatures may have been precursory to LTR. Failure of juvenile white perch to exhibit LTR at the same frequency as striped bass during rising river temperatures suggested a species-specific response, although Meldrim and Gift (1971) found that LTR was a size-related phenomenon affecting white perch < 100 mm almost exclusively at acclimation temperatures of $< 16^{\circ}\text{C}$. Meldrim and Gift (1971) conducted too few avoidance experiments on juvenile striped bass to determine to what extent LTR characterized behavioral responses of the species. Dorfman (1972) demonstrated LTR in juvenile striped bass when exposed to a very steep ($30^{\circ}\text{F}/7$ ft) thermal gradient in a small tank.

It is not known if low thermal responsiveness is confined to artificially steep thermal gradients as commonly found in laboratory situations or if it can or does occur in the usually shallower gradients of thermal effluents. The lack of evidence of fish kills near electric-generating stations due solely to upper lethal temperatures suggests that LTR is a laboratory-induced phenomenon. In the confinement of the laboratory, fish attempting escape from lethal conditions may become disoriented and, therefore, unable to perceive and avoid deleterious conditions correctly. Considering the general torpor of fish during winter, response to temperature changes may be

*Meldrim and Gift (1971) defined LTR as "the inability of a fish (or invertebrate) to avoid areas in a thermal gradient (with high or low temperatures) which provide stressful conditions."



retarded by low metabolic levels. Cold-acclimated fish in this study selected progressively higher temperatures at a slower rate than did warm-acclimated specimens (Table V-21 through V-24).

Sexually mature Atlantic tomcod actively avoided temperatures 0.4°C below to 3.3°C above the maximum expected plume temperature at 0.5°C - 1.0°C (river ambient). On the basis of laboratory results, it is apparent that adult tomcod will not encounter thermal levels which directly affect their survival (TL_m), although a plume Δt of 10°C would be moderately repellent.

2. Physiological Effects

Present evidence based on discharge-canal water temperature (Indian Point weekly operational data, August 1972-November 1973; impingement water-quality data, November 1973-present) and field studies (TI, 1972 and 1973; Dames and Moore, 1974a-c) indicates that above-ambient river temperatures immediately outside the discharge canal have not exceeded the TL_m of striped bass or white perch (Figures V-9 and V-10) over the acclimatization temperature range in which specimens were tested. New York State thermal standards allow a surface temperature up to 32.2°C (90°F) which is below the TL_m for white perch and striped bass acclimated to 26°C (79°F) (Figures V-9 and V-10). Thermal tolerance (Tables V-12 through V-15) and resistance data (Table V-18) suggest that plume temperatures of $>33^{\circ}\text{C}$ may result in mortality of white perch and striped bass if either species were present in the affected area for more than 2 hr. However, plume temperatures will apparently not exceed the standard with operation of Units 2 and 3 unless ambient river temperatures are greater than 27.8°C (82°F), an unlikely event (Figures III-3 to III-5).



Environmental temperatures exceeding those known to cause stress or death of a species do not necessarily result in harmful effects. It should be remembered that survival or stress of the organism is a function of rate of temperature change (Speakman and Krenkel, 1972; Cocking, 1959) as well as temperature and exposure time (Coutant, 1971). In addition, the organism almost always has the ability to avoid potentially lethal temperatures, as was demonstrated in this study. Several investigators have shown that sublethal temperature exposures can have potentially adverse effects. Coutant (1969) expressed the opinion that a fish exhibiting abnormal behavior from thermal shock is ecologically dead since unusual activity could provide cues to potential predators; he showed that thermally shocked juvenile rainbow trout and chinook salmon were more susceptible to predation than were unstressed fish, even when the thermal dosage level or duration was insufficient to cause equilibrium loss (Coutant, 1973). Similar findings for other fish species have also been documented (Sylvester, 1972; Yocum and Edsall, 1974). Wedemeyer (1973) found hematological changes in two juvenile salmonid species after subjecting them to rapid (3-min) temperature increases from 10° to 20°C.

Maximum allowable temperature rises above river ambient across condensers during winter are 21.1°C (38°F) and 18.9°C (34°F) for 3-unit and 2-unit operation, respectively, when river temperatures are <4°C; reduction of the Δt by one-half through discharge ports would provide a temperature rise in the river approximately 10°C above river ambient in the immediate vicinity of discharge ports. Thermal-tolerance information for white perch and striped bass at acclimation temperatures of <8°C during mid-winter is uncommon in scientific literature and was not obtained in this investigation due to limited numbers of each species. Mihursky et al (1971) reported TL_m values for white perch and striped bass 19° to 20°C above an



acclimation temperature of 5°C. Meldrim and Gift (1971) obtained limited information on responses of juvenile white perch to sudden temperature increases; fish acclimated to 3°C were stressed after experiencing an instantaneous Δt of 10°C and an exposure of 15 min, while identical thermal conditions did not affect specimens acclimated to 8°C.

Differences between TL_m and T_a of 8°C-acclimated white perch and striped bass in a present study were 15°C and 17°C, respectively. The rate of change of TL_m with T_a was approximately 0.8°C/1°C decrease of acclimatization (river) temperature at the lower end of the temperature range in which TL_m tests were performed during late winter (Figure V-10). Assuming that the rate of TL_m decrease below 8°C remained constant, the TL_m of striped bass and white perch would be approximately 8°-9°C above maximum plume temperature when river temperatures were 1°C. If extrapolated TL_m values are correct, the potential for LTR to occur seems minimal.

Smith (1972) concluded that temperature increases in winter are potentially less harmful to white perch than those during summer, a finding substantiated in this study as well as by McErlean and Brinkley (1971). Data from these investigations showed an inverse relationship between $TL_m - T_a$ and T_a .

The inconsistent relationship between white perch size and thermal resistance found in this study agrees with results of Gift and Westman (1971) who found a nonsignificant direct relationship between white perch size and thermal resistance; in studies with other estuarine fish species including striped bass, the larger fish were consistently more sensitive to temperature than were the smaller individuals. Although juvenile striped bass consistently exhibited greater resistance than did juvenile white perch (Table V-16), the difference in 96-hr TL_m between the species was nonsignificant ($P > 0.05$).



The difference between the TL_m and T_a values decreased as T_a increased for both white perch and striped bass. The higher TL_m values during falling temperature regimes (Figure V-11) probably reflect acclimation to the higher summer temperatures and the slower adaptation to lower temperatures (Brett, 1944).

This investigation yielded no significant difference between preferred temperature of adults and juveniles over the full range of rising and falling river temperatures, but adults avoided significantly higher temperatures throughout the year and were less resistant to lethal temperature shock, yet showed a 96-hr TL_m equal to that of juveniles. These relationships suggest that there may be several age-related physiological mechanisms involved with defining various thermal relationships of the organism.

The term locomotor scope (Brett, 1964) rather than scope for activity (Fry, 1971) was considered more appropriate in this instance since the highest activity level (30 cm/sec) was not always the maximum expression of activity potentially available for each species and acclimation temperature. Both are similar concepts, however. Fry (1971) defined scope for activity as the difference between resting and active metabolic rates, where the latter is determined from the maximum expression of activity for existing environmental conditions; he considered activity to be all energy-requiring processes including anabolism and locomotion. A scope which continues to increase over the range of test variables in the laboratory is indicative of a progressively more beneficial environment for expressing the organism's varied metabolic processes and activities. A scope which peaks and decreases suggests circumstances which have become less favorable and potentially harmful to the organism.

Active-respiration experiments have provided an additional approach to determining sublethal effects of environmental temperature changes on white perch and striped bass. In general, energy expenditure



(expressed by metabolic rate) did not appear to be limited by any combination of temperature change and forced level of activity within the range of each variable. Swimming ability (dependent on metabolic output) of both species was severely impaired when specimens were subjected to a 16°C drop of environmental temperature (24° to 8°C) over 6 to 8 hr followed by a 12- to 16-hr recovery. Reasons for the apparent depression of white perch metabolic rates at 24°/24°C and 25 and 30 cm/sec are unclear. Random variation in the data or possibly low (5 to 6 mg/l) oxygen levels in the testing apparatus may have contributed to final results, but the response surface analysis did not support that hypothesis.

Changes in gonadal development and spawning time are variable among species and locations. Miller and DeMont (1974) and Knox (1975) reported that several fish species residing in thermal effluents exhibited accelerated gonadal development and earlier spawning than those in control areas. Bennet and Gibbons (1975) found few differences in gonadosomatic indices and reproductive cycles between largemouth bass in heated and unheated areas of a cooling reservoir but found that juveniles were significantly larger in the heated effluent 5 km from the control area.

The literature concerning effects of temperature on survival of various early life stages of striped bass is relatively extensive. Davies (1973) reported that fry survived best at a temperature of 17.5°C. Albrecht (1964) found that 5.6°C temperature fluctuations between 14.4° and 22.8°C did not prevent egg hatching and that high percentages of eggs and larvae exposed to constant temperatures between 12.8° and 23.9°C survived for at least 6 days. Very poor survival (7%) resulted when larvae were held for 72 hr at 26.7°C. In a study by Davies (1973), 40% of a group of striped bass fry survived for 24 hr following a 14-hr temperature increase from 17.8° to 26.7°C, while 100% of all fingerlings survived for 24 hr following a 12-hr temperature increase from 16.1° to 32.2°C. The time allowed for acclimation to above-ambient temperatures significantly influenced



survival of fry and fingerlings. The ultimate upper lethal temperature for fry in Davies' study was near 35°C. Shannon (1969) found that the longer that egg development was maintained at the control temperature (18.3°C), the more tolerant the eggs became to abrupt temperature increases; he observed no significant difference in hatching success among various stages of egg development or between test temperatures from 15.6° to 23.9°C. An incubation temperature of 26.7°C was highly unsuccessful for egg hatching, however. Total dissolved solids, pH (Davis, 1973), and salinity (Albrecht, 1964), in addition to temperature, significantly affect survival of the early life stages of striped bass.

Based on the preceding information, the Indian Point plume's effect on survival of striped bass eggs and larvae is expected to be minimal, with the most critical time being when river and spawning temperatures are near 20°C. The submerged effluent design will confine plume temperatures of >26°C to the immediate vicinity of the discharge structure (Dames and Moore, 1974a).

No information seems to have been gathered regarding the optimum temperature for survival and growth or effects of increased temperatures on white perch eggs and larvae although several life-history studies, including TI's current investigation (TI, 1975b), have been performed (Mansueti, 1961; March and Richards, 1972; Pierre and Davis, 1972; Taub, 1966). Otto and Rice (1974) reported that the swimming ability of yellow perch (*Perca flavescens*) decreased for several hours following a rapid sublethal environmental temperature drop of 10°C. Coutant et al (1974) reported that the susceptibility of juvenile channel catfish and largemouth bass to predation by adult largemouth bass increased following abrupt sublethal temperature decreases. At a steam electric-generating station on Lake Wabamun, Alberta, a sudden temperature drop from 21.8° to 4.9°C during winter caused the death of spottail shiners and northern pike residing in the heated effluent of the discharge canal (Ash et al, 1974). Other than this



report, Meldrim et al (unpublished), using an instantaneous temperature change, have provided the only source of cold-shock information on white perch and striped bass. Based on their data and on results from this study, a temperature decrease of 8°C would probably not cause death or stress of either striped bass or white perch, regardless of the rate of temperature change, when maximum plume temperatures do not exceed 26°C and river temperatures are not $< 2^{\circ}\text{C}$. When specimens were subjected to temperatures $12^{\circ}\text{-}14^{\circ}\text{C}$ below their acclimation temperatures ($15^{\circ}\text{-}25^{\circ}\text{C}$), death or stress of white perch and striped bass from cold shock was apparent in both studies. Percent mortality from such temperature drop increased as the shock temperature in different experiments approached 0°C and as the rate of temperature change increased (i. e., 3 hr to instantaneous). A $12^{\circ}\text{-}16^{\circ}\text{C}$ decrease (approximately 2°C/hr) in the holding temperature for white perch and striped bass resulted in impaired swimming ability during active-respiration experiments.

E. CONCLUSIONS

A potential exists for attraction of juvenile and adult white perch and juvenile striped bass to the Indian Point thermal discharge throughout the year, especially from fall through spring. A thermal block to the migratory movement of striped bass during spring is unlikely, based on laboratory results and on physical characteristics of the present and projected discharge plumes.

Temperatures exceeding 32°C when river temperatures are at their maximum during summer create an unfavorable environment for white perch and striped bass based on thermal-avoidance experiments. Thermal-plume temperatures exceeding 33°C during summer are lethal to white perch and striped bass when transition time is < 30 min and there is no immediate escape from increased temperatures. Return of affected individuals to lower temperatures within 2 hr would probably prevent stress



or death. Maximum anticipated plume temperatures from plant operations will not exceed the upper thermal-tolerance limits of white perch or striped bass.

Striped bass were most resistant to physiological stress following exposure to a lethal temperature, while juvenile and adult white perch were least resistant. Both white perch and striped bass occasionally failed to avoid lethal thermal environments, especially when river ambient temperatures were $<18^{\circ}\text{C}$. All striped bass tested were apparently incapable of escaping lethal thermal conditions when acclimation temperatures were $<8^{\circ}\text{C}$ during late winter under laboratory conditions.

Following a sudden temperature decrease during winter, striped bass were more susceptible to physiological stress or death than were white perch. A temperature decrease of 8°C would probably not cause death or stress of either species, regardless of the rate of temperature change, when maximum plume temperatures are not $>26^{\circ}\text{C}$ and river temperatures are not $<2^{\circ}\text{C}$. A $13^{\circ}\text{-}18^{\circ}\text{C}$ decrease to 2°C over a 3-hr period caused stress or death of white perch and striped bass. Following a $12^{\circ}\text{-}16^{\circ}\text{C}$ decrease of environmental temperature over 6-8 hr, swimming abilities of both species were severely impaired for at least 15 hr.



SECTION VI
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APPENDIX A
BIBLIOGRAPHY OF INVERTEBRATE KEYS



APPENDIX A
BIBLIOGRAPHY OF INVERTEBRATE KEYS

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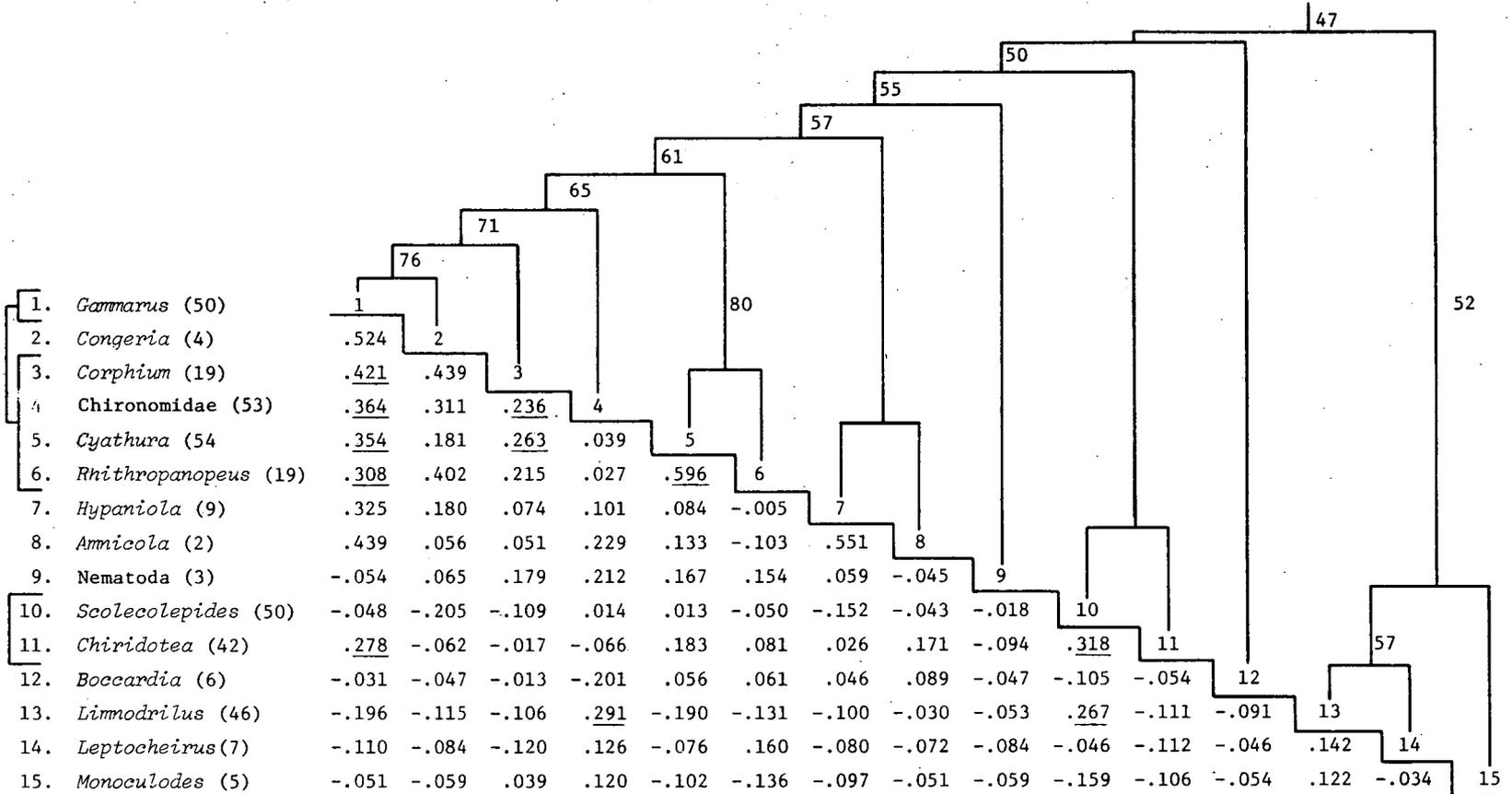


APPENDIX B
CLUSTER ANALYSIS



Table B-1

Correlation and Cluster Analysis of 1973 April, May, and June
Data for Grouping of Benthic Species in Test Area



___ Significant (P < 0.05) nonzero correlations having at least 10 nonzero catches.

() Number of days having nonzero catches out of 54 observations.

[] Significant associations.

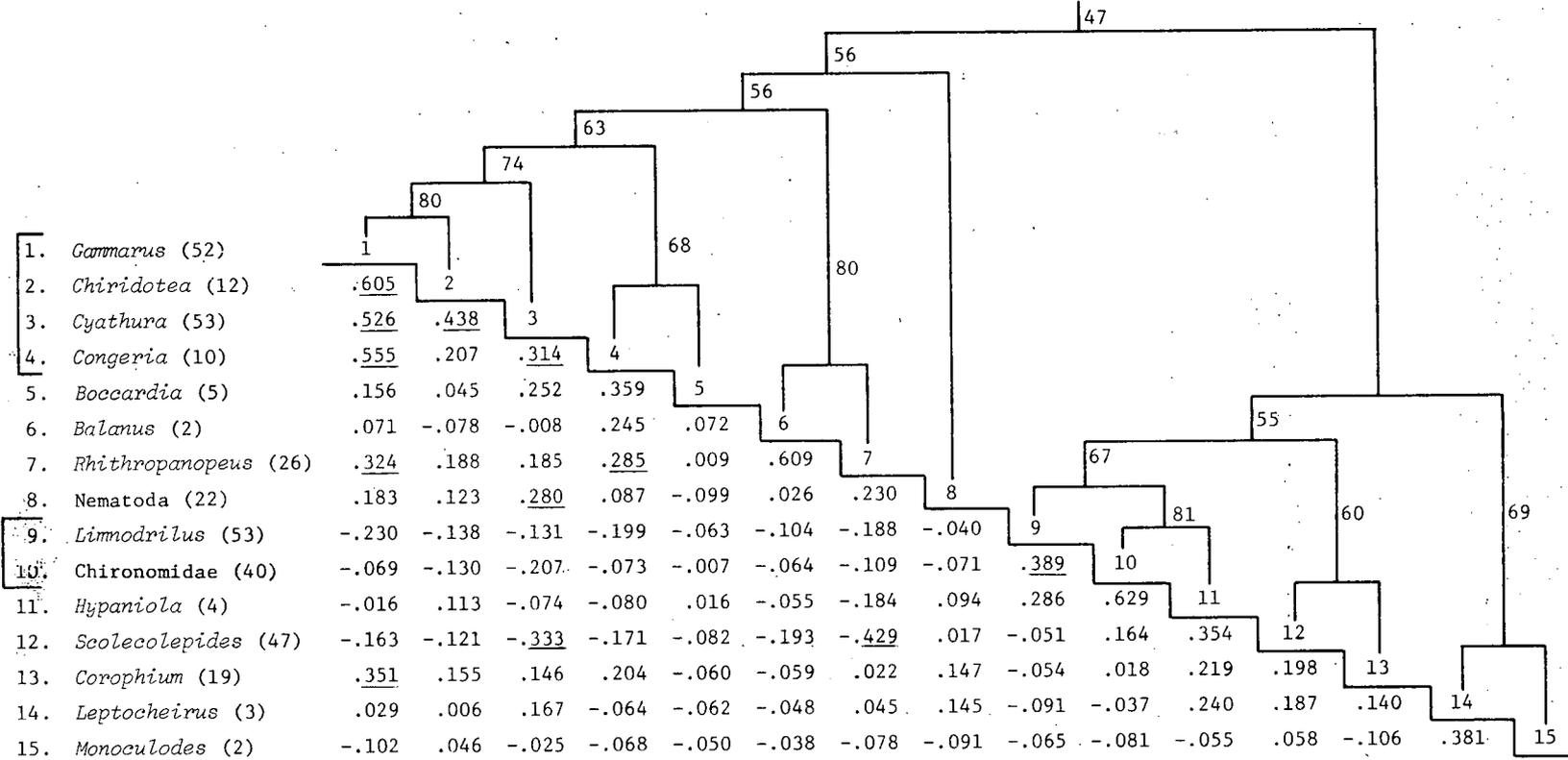
B-1

services group



Table B-2

Correlation and Cluster Analysis of 1973 July, August, and September
Data for Grouping Benthic Species in Test Area



Significant (P < 0.05) nonzero correlations having at least 10 nonzero catches.

() Number of days having nonzero catches out of 54 observations.

[] Significant associations.

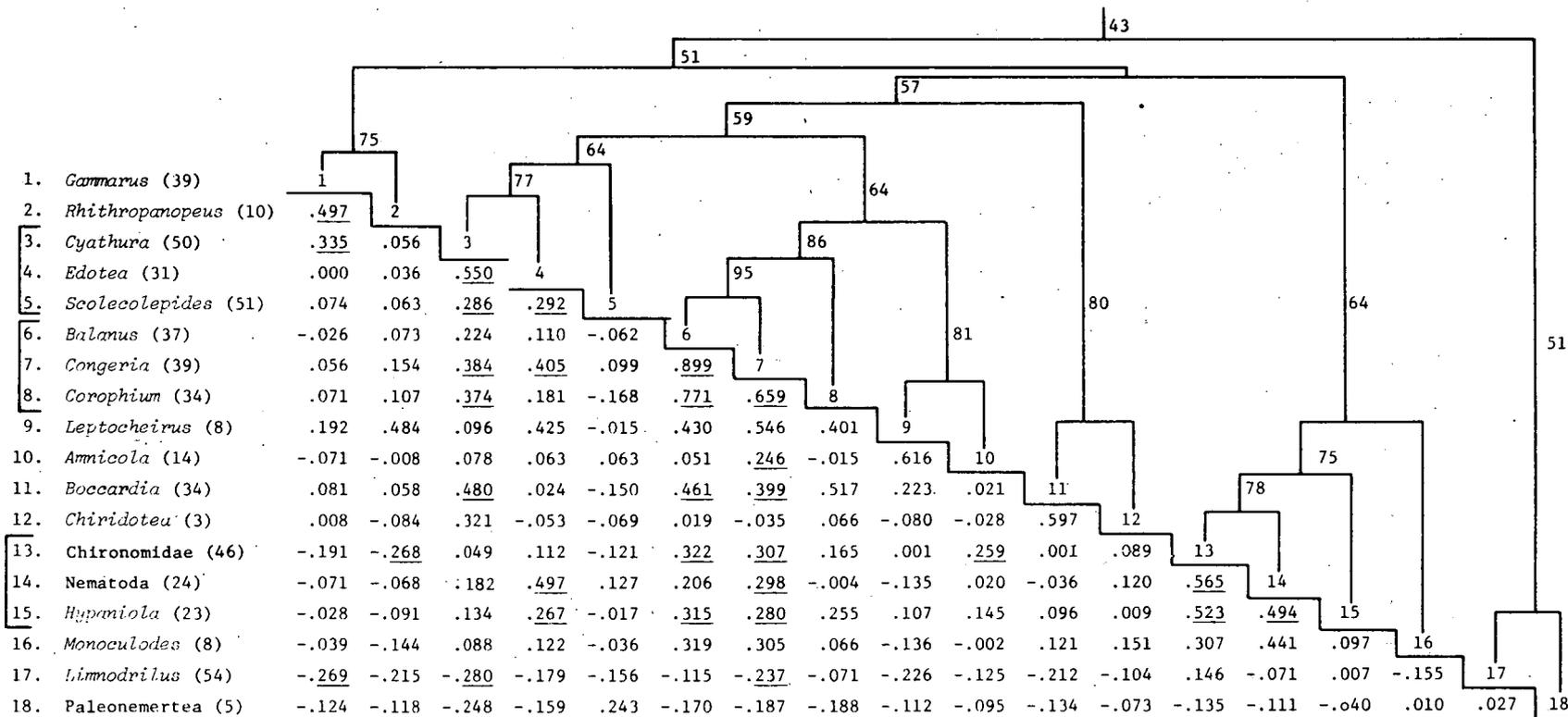
B-2

services group



Table B-3

Correlation and Cluster Analysis of 1973 October, November, and December Data for Grouping Benthic Species in Test Area



___ Significant (P < 0.05) nonzero correlations having at least 10 nonzero catches.
 () Number of days having nonzero catches out of 54 observations.
 [] Significant associations.

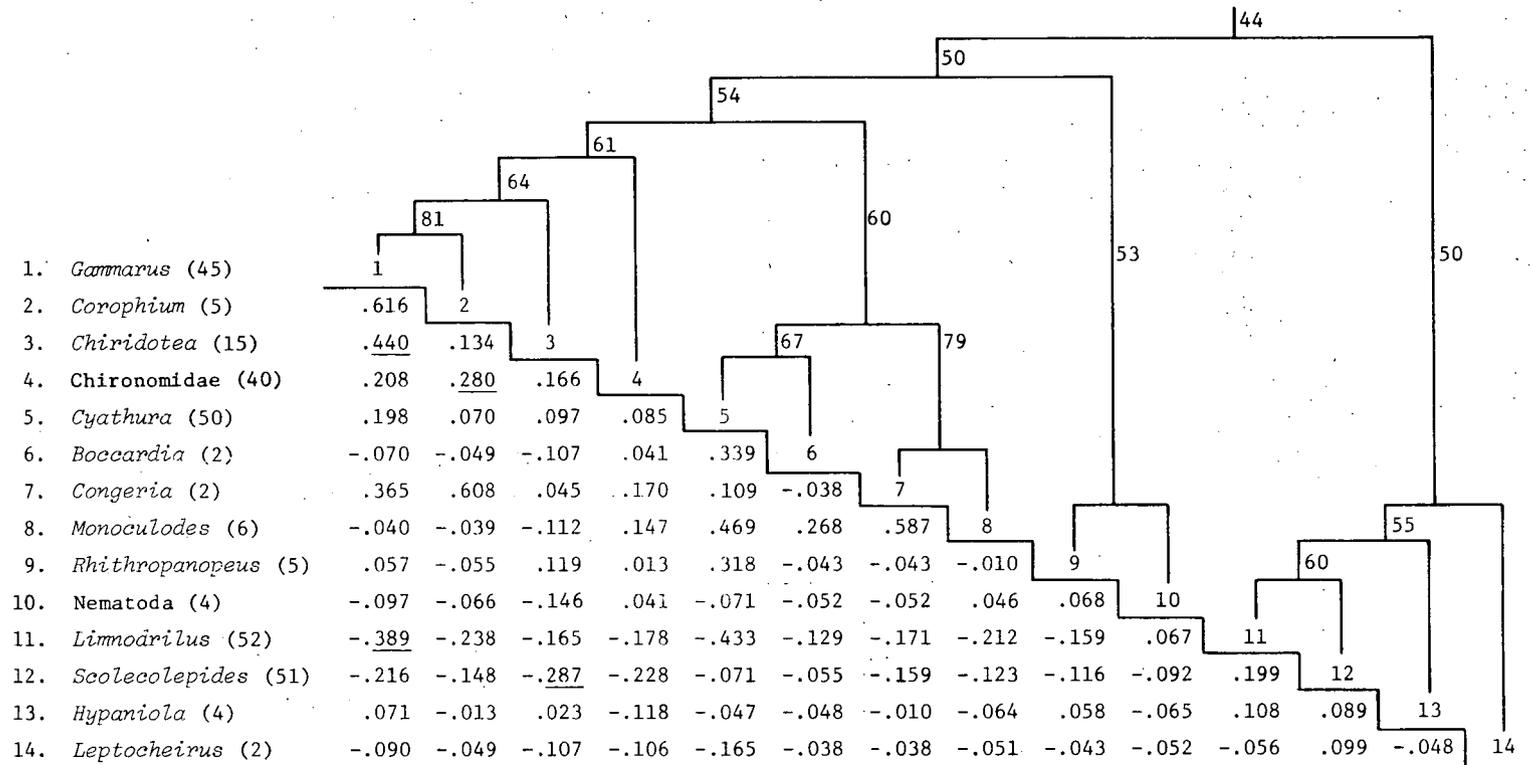
B-3

services group



Table B-4

Correlation and Cluster Analysis of 1973 April, May, and June Data for Associations among Benthic Species in Control Area



— Significant (P < 0.05) nonzero correlations having at least 10 nonzero catches.
 () Number of days having nonzero catches out of 54 observations.
 □ Significant associations.

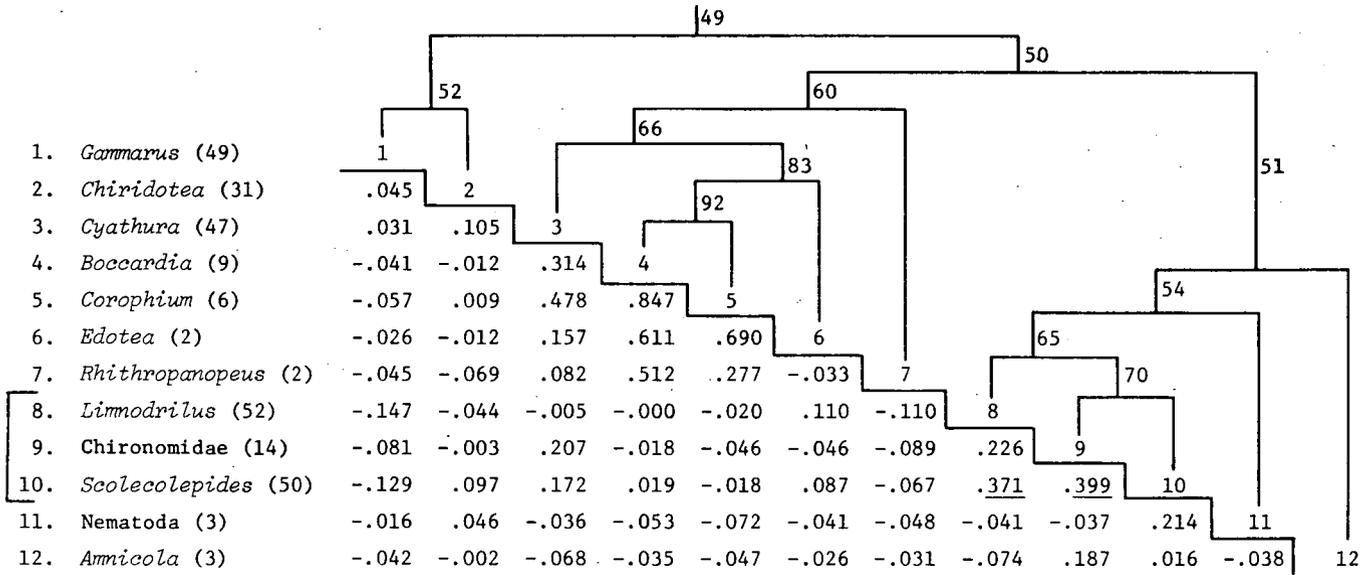
B-4

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Table B-5

Correlation and Cluster Analysis of 1973 July, August, and September Data for Grouping Benthic Species in Control Area



____ Significant (P < 0.05) nonzero correlations having at least 10 nonzero catches.
 () Number of days having nonzero catches out of 54 observations.
 [Significant associations.

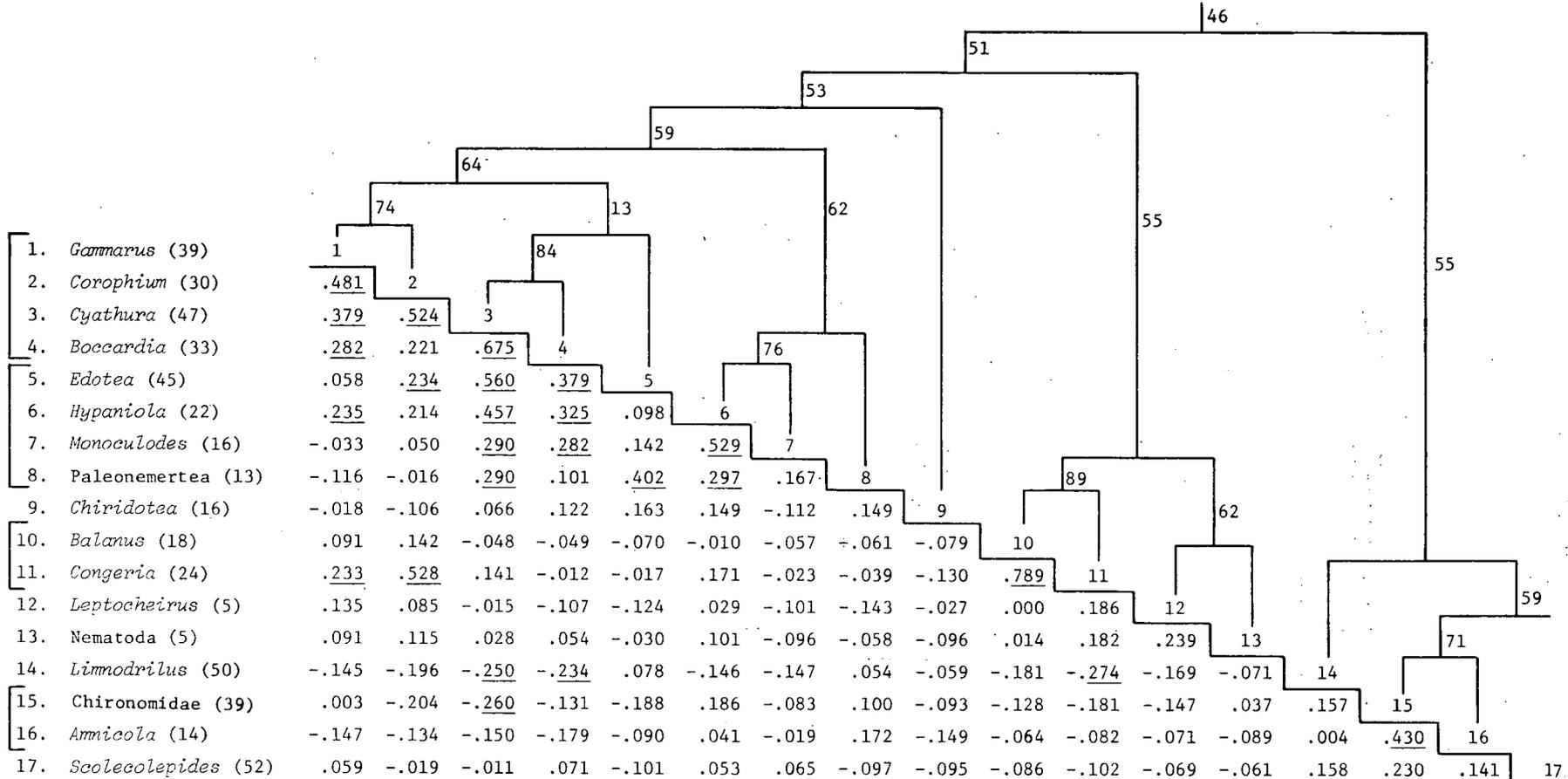
B-5

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Table B-6

Correlation and Cluster Analysis of 1973 October, November, and December Data for Grouping Benthic Species in Control Area



___ Significant (P < 0.05) nonzero correlations having at least 10 nonzero catches.

() Number of days having nonzero catches out of 54 observations.

[] Significant associations.

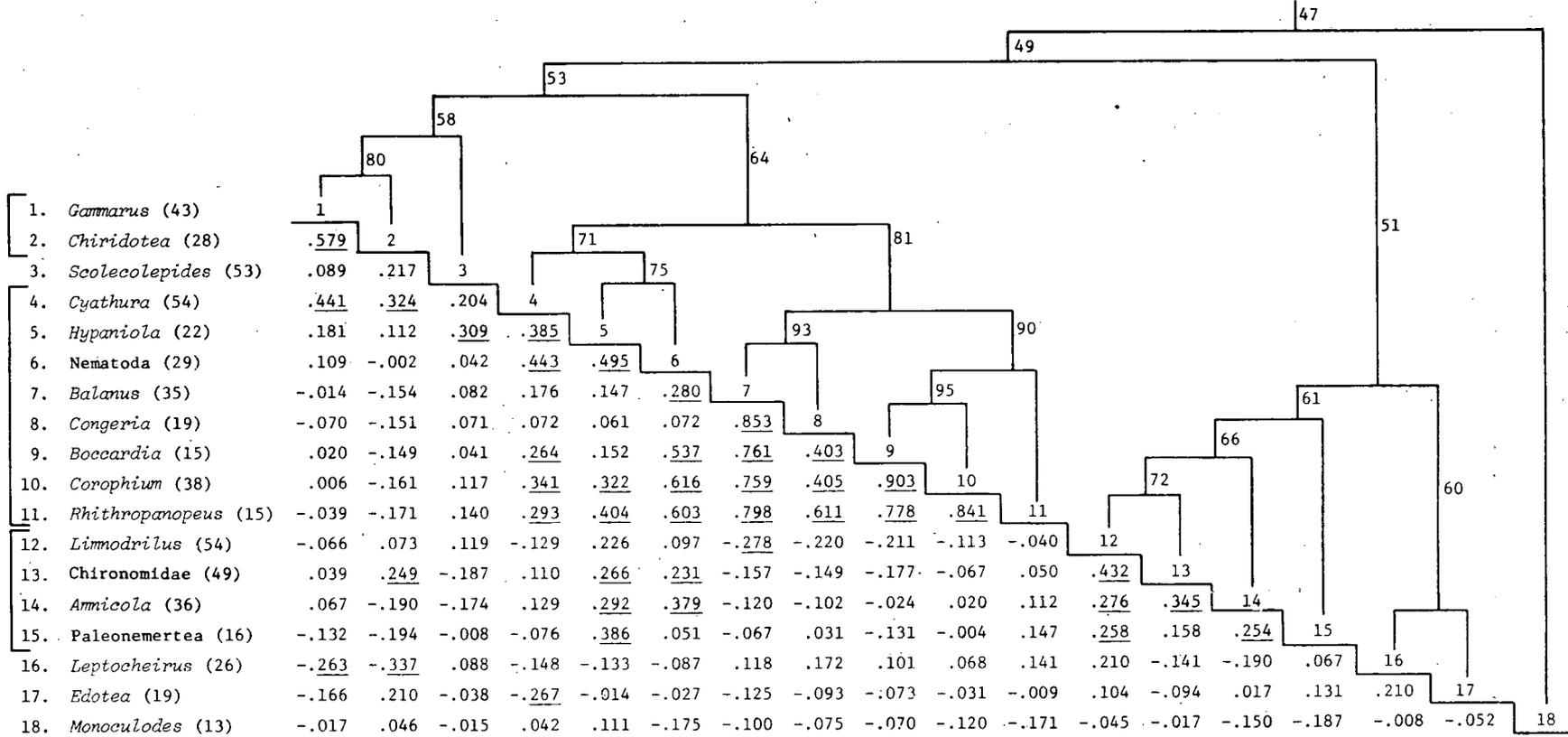
B-6

services group



Table B-8

Correlation and Cluster Analysis of 1974 July, August, and September
Data for Grouping Benthic Species in Test Area



Significant ($P < 0.05$) nonzero correlations having at least 10 nonzero catches.

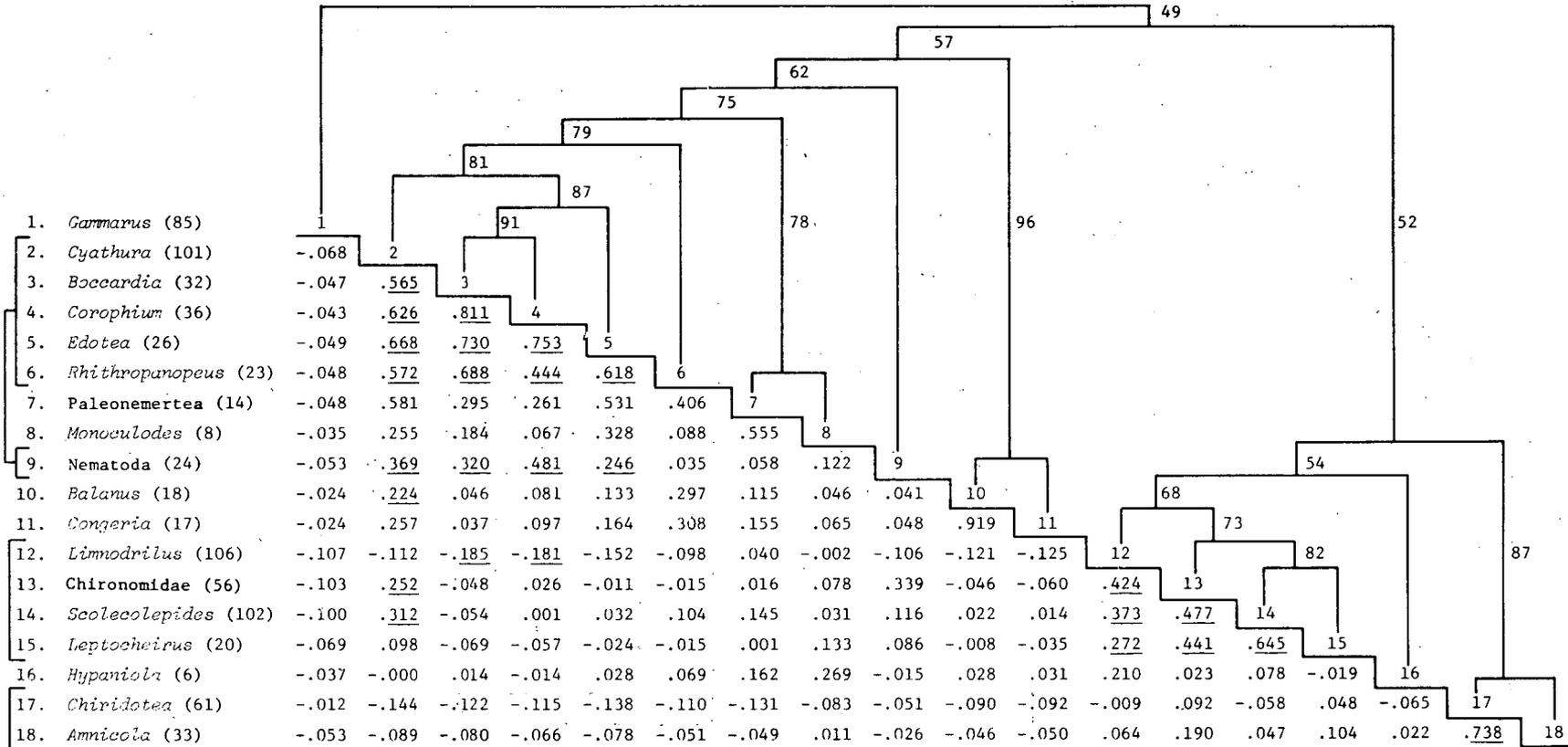
() Number of days having nonzero catches out of 54 observations.

[] Significant associations.



Table B-17

Correlation and Cluster Analysis of 1973 and 1974 July, August, and September
Data for Grouping Benthic Species in Control Area



— Significant ($P < 0.05$) nonzero correlations having at least 20 nonzero catches.

() Number of days having nonzero catches out of 108 observations.

[] Significant associations.

B-17

services group



APPENDIX C
INDIAN POINT TEST- AND CONTROL-AREA
BENTHIC-COMMUNITY COMPOSITION,
1972, 1973, AND 1974

Table C-1

Mean Number of Individuals per Square Meter in Indian Point Test Area, 1972

Species	Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Mean
	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	
<i>Ammicola</i> sp	10.0	5.8	102.0	74.1	32.0	19.1	10.0	5.4	8710.0	2490.0	13026.0	7617.7	24093.0	5053.8	17275.0	9500.4	2218.3	1639.6	7275.1
Harpacticoida	5.6	5.6	60.0	39.0	16.0	8.3	50.0	26.2	7.0	3.0	102.0	83.6	367.0	272.8	2799.0	1351.0	2558.3	1605.2	662.8
<i>Limnodrilus</i> sp	46.7	15.0	112.0	39.6	19.0	8.4	806.0	284.1	102.0	50.0	1007.0	464.0	118.0	20.4	345.0	153.9	366.7	168.0	324.7
<i>Congeria leuophaeta</i>	6.7	2.9	4.0	4.0	1.0	1.0	2.0	1.3	10.0	6.3	510.0	191.2	987.0	413.0	811.0	309.2	280.0	174.6	290.2
<i>Balanus improvisus</i>	41.0	14.1	1.0	1.0	—	—	—	—	25.0	22.9	350.0	144.4	319.0	135.4	979.0	366.8	453.3	247.9	240.9
<i>Cyathura polita</i>	198.9	38.3	179.0	42.6	123.0	44.3	142.0	38.1	217.0	36.8	328.0	71.3	216.0	54.0	228.0	45.1	141.7	43.0	197.1
Ostracoda	—	—	25.0	17.9	96.0	66.9	13.0	5.4	345.0	122.8	883.0	818.8	367.0	204.6	52.0	28.3	8.3	5.4	198.8
<i>Gammarus</i> sp	364.4	188.0	13.0	5.8	133.0	56.2	86.0	52.4	299.0	76.0	153.0	69.6	41.0	15.0	27.0	9.7	288.3	114.7	156.1
<i>Boccardia hamata</i>	32.2	12.8	2.0	2.0	11.0	9.9	—	—	5.0	5.0	129.0	98.9	629.0	347.1	375.0	168.7	6.7	4.2	132.2
Chironomid larvae	433.3	157.0	248.0	98.0	73.0	22.2	45.0	14.2	85.0	17.4	46.0	14.0	56.0	12.1	107.0	25.4	70.0	28.3	129.3
<i>Scolecoclepea viridis</i>	54.5	15.6	90.0	18.9	57.0	11.6	36.0	11.8	74.0	14.2	253.0	69.4	167.0	57.7	44.0	24.7	33.3	33.3	89.9
<i>Peloscoides</i> sp	112.2	48.3	334.0	134.2	22.0	5.9	6.0	2.7	57.0	26.3	78.0	59.7	142.0	71.7	17.0	6.2	5.0	5.0	85.9
<i>Corophium</i> sp	47.8	20.9	120.4	112.2	9.0	3.5	—	—	4.0	2.2	49.0	24.7	67.0	32.3	117.0	59.8	25.0	13.4	48.8
Cyclopoida	4.4	1.7	38.0	20.6	9.0	4.3	—	—	29.0	21.6	2.0	1.3	8.0	4.7	47.0	20.8	75.0	59.5	23.6
Nematoda	—	—	59.0	34.9	13.0	6.5	7.0	6.0	20.0	10.3	28.0	12.1	12.0	5.5	18.0	5.9	8.3	4.0	18.4
<i>Rhithropanopeus harrisi</i>	12.2	5.5	19.0	7.2	20.0	11.3	13.0	9.0	22.0	13.8	17.0	7.2	17.0	7.8	37.0	16.5	—	—	17.5
Planariidae	—	—	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Chaoborus</i> sp	8.9	3.5	13.0	4.5	2.0	1.3	—	—	1.0	1.0	7.0	6.0	3.0	2.1	3.0	2.1	8.3	4.0	5.1
<i>Hypaniola</i> sp	6.7	3.7	4.0	2.2	6.0	3.4	—	—	2.0	2.0	2.0	2.0	4.0	3.1	—	—	—	—	2.7
<i>Chiridotia almyra</i>	2.2	2.2	1.0	1.0	—	—	1.0	1.0	—	—	—	—	—	—	—	—	—	—	2.3
Calanoida	6.7	4.4	4.0	3.1	—	—	—	—	—	—	3.0	1.5	—	—	—	—	13.3	13.3	1.2
Nudibranchia	2.2	2.2	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.1
<i>Edotea</i> sp	—	—	—	—	—	—	—	—	4.0	2.2	—	—	—	—	—	—	3.3	2.1	0.9
Hydracarina	—	—	—	—	—	—	—	—	—	—	1.0	1.0	3.0	1.5	6.0	2.2	—	—	1.1
<i>Leptocheirus</i> sp	—	—	—	—	—	—	—	—	—	—	—	—	9.0	9.0	1.0	1.0	—	—	0.9
<i>Pisicola</i> sp	—	—	—	—	—	—	—	—	—	—	6.0	6.0	—	—	2.0	2.0	—	—	0.9
Paleonemertea	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0	1.0	—	3.3	—	0.5
<i>Monoeculodes</i> sp	—	—	1.0	1.0	—	—	—	—	—	—	—	—	3.0	3.0	—	—	—	—	0.4
Turbellaria	—	—	2.0	2.0	—	—	—	—	—	—	—	—	1.0	1.0	—	—	—	—	0.3
<i>Dugesia</i> sp	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3.0	1.5	—	—	0.3
<i>Cassidina latifrons</i>	—	—	—	—	—	—	—	—	—	—	—	—	2.0	2.0	—	—	—	—	0.2
<i>Daphnia</i> sp	—	—	—	—	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	0.1
<i>Palpomyia</i> sp	—	—	—	—	1.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Decapod-larva	—	—	—	—	—	—	—	—	1.0	1.0	—	—	—	—	—	—	—	—	0.1
Acanthocephala	—	—	—	—	—	—	—	—	—	—	1.0	1.0	—	—	—	—	—	—	0.1
Tricoptera-adult	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Sipunculida	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0	1.0	—	—	0.1
<i>Neretis succinea</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.0	1.0	—	—	0.1
No. of Species	19		24		19		13		21		22		24		26		20		38
No. of Specimens	1396.6		1433.8		644.0		1217.0		10,020.0		16,981.0		27,644.0		23,396.0		6569.8		9,922.4

C-1

services group

Table C-2

Mean Number of Individuals per Square Meter in Indian Point Control Area, 1972

Species	Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Mean
	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE									
Harpacticoida	—	—	38	18	20	5	2	2	9270	4335	514	419	12182	5444	616	165	103	23	2527.2
<i>Boccardia hamata</i>	36	5	—	—	2	2	—	—	4	4	1000	487	344	334	4262	693	1407	457	783.9
<i>Ammocoa</i>	—	—	62	27	—	—	—	—	4	2	12	8	528	356	316	85	3460	2016	486.9
<i>Limnodrilus</i> sp	722	102	902	431	350	143	460	163	26	19	214	168	992	331	52	19	23	18	415.7
<i>Cyathura polita</i>	288	30	270	167	140	38	28	11	68	17	298	31	278	113	206	40	403	70	219.9
<i>Gammarus</i> sp	28	23	8	5	20	8	484	442	22	13	—	—	38	31	64	17	173	67	93.0
Ostracoda	—	—	8	5	6	2	156	75	300	133	34	12	42	16	60	38	40	23	82.9
<i>Soilecolepides viridis</i>	20	7	125	56	164	63	156	45	10	6	80	42	44	8	10	5	13	7	69.1
<i>Peloscoclex</i>	64	18	223	100	36	8	32	25	10	10	6	4	180	98	8	2	—	—	62.1
Chironomid larvae	112	20	74	22	10	6	8	5	18	11	2	2	62	42	32	6	73	21	43.4
<i>Balanus improvisus</i>	—	—	—	—	—	—	—	—	—	—	—	—	44	39	22	17	140	63	22.9
Nematoda	—	—	132	72	2	2	2	2	10	8	10	8	4	4	8	4	23	11	21.2
<i>Corophium</i>	6	4	2	2	2	2	—	—	—	—	2	2	48	34	30	9	47	17	15.2
Cyclopoida	—	—	16	12	4	2	—	—	8	8	20	13	40	18	8	8	7	3	11.4
<i>Congeria leucometa</i>	—	—	2	2	—	—	—	—	—	—	—	—	22	8	20	13	57	19	11.2
<i>Chiridotea almyra</i>	—	—	4	4	2	2	8	4	—	—	4	2	—	—	2	2	37	10	6.3
<i>Edotea</i>	—	—	—	—	—	—	—	—	—	—	2	2	44	11	2	2	—	—	5.3
<i>Hypaniola</i>	2	2	22	10	—	—	—	—	—	—	18	18	—	—	4	2	—	—	5.1
Planariidae	—	—	—	—	—	—	—	—	—	—	2	2	—	—	24	5	—	—	2.9
Macrothricidae	—	—	—	—	—	—	—	—	18	18	—	—	—	—	—	—	—	—	2.0
<i>Chaoborus</i>	4	2	4	2	2	2	—	—	—	—	—	—	4	4	—	—	—	—	1.6
Calanoida	—	—	6	2	—	—	—	—	6	6	—	—	—	—	—	—	—	—	1.3
<i>Rhithropanopeus harrisi</i>	—	—	4	2	—	—	—	—	—	—	—	—	—	—	—	—	7	3	1.2
Nudibranchia	—	—	4	4	—	—	—	—	4	2	—	—	—	—	2	2	—	—	1.1
<i>Psicola</i>	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	5	1.0
Trichoptera - adult	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	3	0.3
<i>Sphaerium</i>	—	—	—	—	—	—	2	2	—	—	—	—	—	—	—	—	—	—	0.2
Collembola	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—	—	0.2
Chironomid	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—	—	0.2
<i>Monoculodes</i> sp	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—	—	0.2
Hydracarina	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	0.2
Palepneumerta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	0.2
No. of Species	11		19		14		11		15		19		17		22		18		32
Total No. of Specimens	1284.0		1906.0		760.0		1338.0		9778.0		2224.0		14896.0		5752.0		6023.0		4895.1

C-2

services group





Table C-3

Mean Number of Individuals per Square Meter in Indian Point Test Area, 1973

Species	Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Mean
	\bar{x}	SE																	
<i>Limnodrilus</i> sp	474.4	170.3	193.3	62.9	1111.1	350.0	2718.3	980.5	2351.7	602.6	948.9	187.2	1257.2	384.2	1547.8	297.7	1542.8	300.2	1349.5
<i>Gammarus</i> sp	1033.3	387.7	477.8	148.5	355.6	69.5	515.6	131.5	334.4	102.9	805.0	314.3	343.9	146.6	30.0	8.0	86.1	27.2	442.4
<i>Cyathura polita</i>	162.2	23.4	220.0	44.0	166.7	25.2	249.4	30.9	423.9	46.5	283.3	68.7	255.6	77.5	186.1	34.8	253.9	62.2	244.6
<i>Boccardia hamata</i>	1.7	1.2	7.2	6.1	0.6	0.6	0.6	0.6	—	—	—	5.6	3.2	151.7	53.7	822.8	323.7	1002.8	531.1
<i>Scolecopides viridis</i>	92.2	17.5	180.6	36.2	382.8	51.9	369.4	50.4	161.1	54.8	357.2	65.3	182.8	31.2	78.3	19.4	107.2	27.2	221.4
Chironomid larvae	202.8	26.1	137.8	21.0	132.2	25.2	64.4	21.4	12.2	3.1	10.0	3.0	17.2	5.4	216.1	23.5	302.2	48.9	121.7
<i>Congerla leuaphaeta</i>	6.7	3.9	—	—	—	—	0.6	0.6	2.8	1.9	38.9	15.3	147.2	55.9	407.8	126.2	281.7	118.5	98.4
<i>Corophium</i> sp	14.4	4.7	2.8	1.1	12.8	6.0	17.8	6.1	1.1	0.8	9.4	3.5	60.0	21.8	247.2	81.6	154.4	57.2	57.8
<i>Balanus improvisus</i>	—	—	—	—	—	—	—	—	0.6	0.6	0.6	0.6	17.2	6.6	240.0	78.2	172.2	68.6	47.8
<i>Chaoborus</i> sp	28.9	7.7	15.0	4.1	4.4	2.0	22.2	16.6	3.3	1.4	83.3	21.2	23.9	5.7	25.6	5.9	35.0	7.0	26.8
<i>Peloscoides</i> sp	7.2	6.1	—	—	77.8	39.9	47.2	17.2	6.7	4.2	2.8	2.3	5.6	2.0	34.4	11.7	29.4	11.6	23.5
<i>Ammocula</i> sp	1.1	1.1	—	—	—	—	—	—	—	—	—	—	—	—	130.0	61.0	10.6	4.9	15.7
<i>Rhithropanopeus harrisi</i>	16.7	5.4	15.6	6.7	10.6	3.7	11.1	3.7	21.1	6.1	8.3	3.8	12.2	4.6	2.2	1.3	0.6	0.6	10.9
Nematoda	1.7	1.2	0.6	0.6	—	—	7.2	3.9	19.4	8.6	8.3	4.2	6.7	2.6	7.2	2.1	17.2	6.6	7.6
<i>Edotea</i> sp	—	—	—	—	0.6	0.6	—	—	—	—	—	—	—	20.0	9.8	26.7	9.0	9.4	6.3
<i>Hypamiola</i> sp	5.6	2.1	3.3	2.3	—	—	2.2	1.0	—	—	—	—	—	1.7	0.9	12.2	5.5	20.6	8.9
<i>Chiridotia almyra</i>	2.8	1.6	6.1	3.9	5.6	2.5	—	—	4.4	1.5	5.0	2.8	—	—	—	—	2.2	1.3	2.9
<i>Leptocheirus</i> sp	2.2	1.3	0.6	0.6	1.7	0.9	0.6	0.6	1.1	0.8	—	—	—	2.8	1.8	8.9	4.0	—	2.0
<i>Monocaulodes</i> sp	11.7	5.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nudibranchia	—	—	—	—	2.8	1.4	—	—	—	—	—	—	—	—	2.2	1.0	3.3	1.6	1.9
Paleonemerta	0.6	0.6	—	—	—	—	—	—	2.8	2.3	0.6	0.6	0.6	0.6	0.6	2.2	2.0	1.3	1.7
Cyclopoida	3.3	2.8	—	—	—	—	—	—	0.6	0.6	0.6	0.6	1.1	0.8	0.6	0.6	1.1	0.8	0.5
Calanoida	1.7	0.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.4
<i>Pisicola</i> sp	1.7	1.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.2
Trichoptera - adult	—	—	0.6	0.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.2
Harpacticoida	—	—	0.6	0.6	—	—	0.6	0.6	—	—	—	—	—	0.6	0.6	—	0.6	0.6	0.2
Hydracarina	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6	0.6	—	—	0.2
Acanthocephala	—	—	0.6	0.6	—	—	—	—	—	—	0.6	0.6	—	—	—	0.6	0.6	0.6	0.1
<i>Agroylea</i> sp	0.6	0.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Odonata - larva	—	—	0.6	0.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
<i>Heomyia americana</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6	0.6	—	—	—	0.1
Total No. of Species	22		17		14		15		16		17		20		22		22		31
Total No./M ²	2073.5		1263.1		2265.3		4027.2		3347.2		2568.4		2508.6		4033.4		4035.9		2902.6

C-3

services group



Table C-4

Mean Number of Individuals per Square Meter in Indian Point Control Area, 1973

Species	Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Mean
	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	
<i>Limnodrilus</i> sp	1513.9	543.5	5151.7	1083.3	4497.8	634.2	3836.7	1364.0	2047.2	715.0	4026.7	958.71	2300.0	414.8	1168.9	322.1	1294.4	291.7	2870.8
<i>Boccardia hamata</i>	0.6	0.6	0.6	0.6	—	—	—	—	—	—	751.7	450.2	1552.2	783.5	540.6	298.0	4057.8	1232.9	767.1
<i>Scolecopides viridis</i>	91.1	20.0	372.2	55.4	243.9	63.2	299.4	78.4	206.1	63.8	280.0	48.1	170.6	23.6	113.3	20.2	419.4	165.8	244.0
<i>Gammarus</i> sp	437.2	146.1	52.2	36.5	116.7	44.1	680.0	475.7	226.7	174.5	101.1	48.4	75.0	50.6	106.1	43.3	177.2	48.6	219.1
<i>Cyathura polita</i>	202.7	47.8	68.3	20.6	151.1	31.0	128.9	28.3	97.1	32.1	160.0	43.0	136.1	38.3	129.4	32.7	166.7	39.8	137.8
<i>Balanus improvisus</i>	—	—	—	—	—	—	—	—	—	—	—	—	0.6	0.6	—	—	—	—	0.1
<i>Congeria leucophaeta</i>	0.6	0.6	—	—	—	—	—	—	—	—	—	—	23.9	11.6	232.8	95.1	61.1	51.2	35.4
<i>Corophium</i> sp	5.0	2.9	—	—	0.6	0.6	—	—	—	—	33.9	14.5	36.1	12.0	105.6	42.4	63.9	22.9	27.2
Chironomid larvae	82.8	14.2	19.4	6.9	29.4	10.7	11.7	3.9	1.1	0.8	2.2	1.3	14.4	4.3	31.1	11.9	43.9	9.5	26.2
<i>Edotea</i> sp	—	—	—	—	1.7	1.7	—	—	—	—	—	—	2.8	2.3	97.8	31.2	75.6	15.7	25.1
<i>Peloscotlex</i> sp	0.6	0.6	3.3	1.4	23.9	11.1	12.8	7.6	42.8	36.5	14.4	12.7	8.3	4.4	14.4	4.7	3.3	0.6	13.8
<i>Chiridotea almyra</i>	4.4	1.5	0.6	0.6	5.0	2.0	56.7	17.4	13.3	5.5	12.2	4.3	4.4	2.0	2.2	1.3	10.6	4.6	12.2
<i>Chaoborus</i> sp	0.6	0.6	2.2	1.7	1.1	0.8	2.2	1.3	3.3	1.8	70.6	18.6	12.2	3.9	5.6	3.6	11.1	7.1	12.1
<i>Hypanota</i> sp	0.6	0.6	18.3	10.1	—	—	—	—	—	—	0.6	0.6	0.6	0.6	6.7	2.1	12.8	2.9	4.4
<i>Ammocula</i> sp	—	—	—	—	—	—	8.9	7.7	—	—	—	—	1.1	0.8	16.7	7.2	4.4	2.5	3.5
<i>Monoculodes</i> sp	6.1	3.6	—	—	—	—	—	—	—	—	—	—	0.6	0.6	5.6	2.5	7.2	2.4	2.2
Nudibranchia	—	—	—	—	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	2.2	1.0	5.1	1.7	7.2	2.7	1.8
<i>Rhithropanopeus harrisi</i>	2.8	1.1	0.6	0.6	4.4	3.5	—	—	—	—	1.1	0.8	—	—	0.6	0.6	0.6	0.6	1.1
Nematoda	1.1	1.1	0.6	0.6	1.1	0.8	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	2.2	1.3	2.2	1.0	0.9
Paleonemerta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.7
<i>Leptocheirus</i> sp	0.6	0.6	0.6	0.6	—	—	—	—	—	—	—	—	—	—	5.0	2.5	—	—	0.6
<i>Hydra americana</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.0	4.4	0.6	0.6	0.6
<i>Pisicola</i> sp	1.1	0.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6	0.6	0.2
Harpacticoida	—	—	—	—	0.6	0.6	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Hydracarina	0.6	0.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Glossiphoniidae	0.6	0.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
Trichoptera-adult	0.6	0.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1
<i>Neomysis americana</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.0	4.4	0.6	0.6	0.6
No. of Species	20		13		14		11		10		15		19		22		22		28
No. of Specimens	2353.6		5690.6		5077.5		5038.5		2638.8		5458.5		4440.0		2579.2		6395.0		4408.2

C-4

services group



Table C-5

Mean Number of Individuals per Square Meter in Indian Point Test Area, 1974

Taxon	Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Mean
	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	
<i>Ammicola</i> sp	20.6	7.0	463.3	317.0	972.8	313.0	211.1	95.0	105.0	74.0	18.9	10.0	10736.1	2380.0	12180.6	2201.0	11366.1	2200.0	4008.3
<i>Scolecolepides viridis</i>	5362.2	1636.0	5450.0	811.0	3443.9	572.0	1815.6	517.0	4018.3	483.0	2202.2	276.0	1207.8	186.0	1062.8	314.0	857.8	151.0	2824.5
<i>Limnodrilus</i> sp	1735.0	550.0	2006.1	480.0	3883.9	710.0	3047.8	475.0	3462.8	903.0	1743.9	349.0	1895.6	388.0	3086.1	641.0	2717.2	591.0	2730.9
<i>Balanus improvisus</i>	0.6	0.6	-	-	-	-	138.3	47.0	1112.8	547.0	1035.6	489.0	3425.0	1279.0	2658.3	962.0	781.7	306.0	1016.9
<i>Cyathura polita</i>	241.7	42.0	121.1	31.0	123.3	31.0	945.6	101.1	532.8	117.0	503.9	77.0	665.6	87.0	567.8	86.0	505.6	70.0	467.5
<i>Congeria leucophaeta</i>	34.4	11.0	17.8	12.0	3.3	2.0	3.9	1.0	87.8	47.0	207.8	119.0	1316.7	511.0	720.0	309.0	271.1	103.0	295.9
<i>Gammarus</i> sp	1042.8	245.0	157.8	34.0	191.1	42.0	251.7	70.0	35.0	11.0	24.4	8.0	302.8	68.0	70.6	31.0	510.0	159.0	287.4
Chironomid	376.7	32.0	262.2	30.0	200.6	28.0	146.1	28.0	82.8	20.0	60.6	16.0	197.2	27.0	306.7	35.0	408.9	64.0	226.9
<i>Corophium</i> sp	94.4	28.0	38.9	20.0	7.2	3.0	33.3	15.0	126.7	57.0	52.2	12.0	307.2	106.0	430.6	183.0	261.1	58.0	150.2
<i>Boccardia hamata</i>	40.6	18.0	0.6	0.6	5.6	5.0	7.8	5.0	71.1	40.0	31.7	16.0	322.2	108.0	430.0	172.0	297.8	121.0	133.6
Harpacticoida	-	-	-	-	2.2	1.0	261.1	257.1	143.9	133.3	6.7	5.0	39.4	25.0	15.0	7.0	4.4	2.0	52.5
<i>Chaoborus</i> sp	24.4	6.0	17.2	5.0	16.7	7.0	10.6	3.0	93.9	17.0	31.1	8.0	58.9	26.0	75.6	27.0	87.2	32.0	46.2
Cyclopoidea	-	-	-	-	1.7	1.0	1.7	1.0	1.7	1.0	0.6	0.6	16.7	6.0	270.0	200.0	21.1	6.0	34.5
<i>Chiridotea almyra</i>	32.8	7.0	3.9	2.0	10.6	4.0	133.9	30.0	10.0	3.0	-	-	0.6	0.6	0.6	0.6	4.4	2.0	21.9
Nudibranchia	22.2	7.0	19.4	7.0	4.4	2.0	7.2	4.0	134.9	105.0	-	-	-	-	0.6	0.6	0.6	0.6	21.0
<i>Leptocheirus</i> sp	11.1	3.0	10.6	5.0	11.1	7.0	1.1	1.0	23.9	7.0	32.2	-7.0	18.9	6.0	45.6	20.0	15.6	7.0	18.9
<i>Rhithropanopeus harrisi</i>	8.3	4.0	2.8	2.0	1.1	1.0	0.6	0.6	40.6	20.0	24.4	11.1	35.6	11.0	36.7	14.0	18.3	5.0	18.7
<i>Edotea</i> sp	-	-	-	-	-	-	-	-	7.2	3.0	23.9	9.0	66.1	10.0	18.3	7.0	-	-	12.8
Nematoda	3.9	2.0	1.1	1.0	9.4	3.0	18.9	4.0	16.7	8.0	11.1	4.0	23.9	3.0	13.3	3.0	13.9	3.0	12.5
Calanoida	0.6	0.6	-	-	-	-	-	-	-	-	-	-	0.6	0.6	-	-	98.9	98.9	11.1
<i>Hypaniola grayi</i>	25.0	8.0	6.7	3.0	11.1	6.0	6.1	2.0	11.1	5.0	7.8	3.0	8.9	3.0	12.8	5.0	6.7	2.0	10.7
<i>Peloscoides</i> sp	61.1	22.0	-	-	7.8	4.0	2.8	2.0	0.6	0.6	-	-	-	-	1.1	1.0	0.6	0.6	8.2
<i>Monoculodes</i> sp	2.8	1.0	-	-	-	-	2.8	1.0	2.8	1.0	2.8	1.0	1.7	1.1	11.1	4.0	25.0	7.0	5.4
<i>Sphaerium</i> sp	0.6	0.6	0.6	0.6	2.8	1.0	10.0	4.0	22.2	12.0	3.9	2.0	-	-	-	-	0.6	0.6	4.5
Paleonemertea	2.2	1.0	1.1	1.0	2.2	1.0	1.1	1.0	3.9	2.0	7.8	2.0	6.1	1.0	8.3	2.0	1.7	1.0	3.8
Chironomid-pupae	-	-	6.7	4.0	3.9	2.0	8.3	3.0	8.3	6.0	-	-	1.1	0.7	-	-	-	-	3.1
Tricopteran-adult	-	-	1.7	1.0	-	-	0.6	0.6	0.6	0.6	1.1	1.0	1.1	1.1	-	-	1.1	1.1	0.7
<i>Pisicicola</i> sp	3.9	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	1.0	0.5
Planariidae	-	-	-	-	-	-	2.8	1.0	0.6	0.6	0.6	0.6	-	-	-	-	-	-	0.4
Hydracarina	-	-	-	-	0.6	0.6	-	-	-	-	-	-	0.6	0.6	-	-	1.7	1.0	0.3
Collembola	-	-	-	-	-	-	0.6	0.6	-	-	0.6	0.6	0.6	0.6	0.6	0.6	-	-	0.3
<i>Cassidina lunifrons</i>	0.6	0.6	-	-	-	-	0.6	0.6	-	-	-	-	-	-	0.6	0.6	-	-	0.2
<i>Hydra americana</i>	-	-	-	-	-	-	-	-	2.2	2.2	-	-	-	-	-	-	-	-	0.2
<i>Elliptio</i> sp	-	-	-	-	-	-	-	-	1.7	1.0	-	-	-	-	-	-	-	-	0.2
<i>Neomysis americana</i>	-	-	-	-	-	-	-	-	-	-	-	-	1.7	1.7	-	-	-	-	0.2
Ceratopogonidae	-	-	-	-	1.1	1.0	-	-	-	-	-	-	-	-	-	-	-	-	0.1
Ostracoda	-	-	-	-	-	-	1.1	1.0	-	-	-	-	-	-	-	-	-	-	0.1
<i>Ferriisia</i> sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.6	0.1
<i>Daphnia</i> sp	-	-	-	-	-	-	0.6	0.6	-	-	-	-	-	-	-	-	-	-	0.1
<i>Crangonyx</i> sp	-	-	-	-	-	-	-	-	-	-	0.6	0.6	-	-	-	-	-	-	0.1
Total No. of Taxa		24		20		23		30		29		25		27		25		28	40
Total Mean No. of Specimens	9148.5		9589.6		8916.7		7073.7		10161.9		6036.4		20658.7		22023.7		18275.8		12409.2

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services group



Table C-6

Mean Number of Individuals per Square Meter in Indian Point Control Area, 1974

Taxon	Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Mean
	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	\bar{x}	SE	
<i>Limnodrilus</i> sp	1712.2	366.0	3141.7	711.0	5305.6	1400.0	3305.6	694.0	6602.2	2005.0	2405.6	795.0	3539.4	845.0	3349.4	873.0	3052.8	789.0	3601.6
<i>Scolecoclepidis viridis</i>	1901.1	391.0	3724.4	679.0	4449.4	1060.0	395.6	109.0	3383.3	584.0	1679.4	364.0	1432.8	236.0	909.4	146.0	905.6	164.0	2086.8
<i>Ammicola</i> sp	5.0	2.0	68.3	26.0	136.7	49.0	49.4	28.0	30.0	9.0	1.1	1.0	2154.4	390.0	3457.8	535.0	2879.4	467.0	975.8
<i>Boccardia hamata</i>	84.4	64.0	1.7	1.7	-	-	1.1	0.7	1028.9	532.0	4208.9	1453.0	275.6	136.0	1600.0	665.0	1398.9	655.0	955.0
<i>Balanus improvisus</i>	0.6	0.6	-	-	-	-	0.6	0.6	807.2	782.0	1704.4	804.0	4086.7	1706.0	16.7	6.0	816.1	562.0	825.8
<i>Cyathura polita</i>	131.1	34.0	160.0	26.0	134.4	29.0	216.1	44.0	653.9	120.0	1047.2	16.3	533.3	91.0	577.8	113.0	457.8	113.0	434.6
<i>Corophium</i> sp	0.6	0.6	1.7	1.0	0.6	0.6	-	-	360.0	144.0	875.6	341.0	125.6	55.0	21.7	7.0	42.2	14.0	158.7
<i>Gammarus</i> sp	96.1	59.0	116.1	55.0	779.4	590.0	19.4	6.0	25.0	9.0	40.0	11.0	193.3	61.0	35.0	12.0	85.6	27.0	154.4
<i>Congeria leucophaeta</i>	-	-	-	-	-	-	-	-	34.4	29.0	151.1	72.0	397.2	164.0	3.9	2.0	82.2	63.0	74.3
Chironomid larvae	27.2	9.0	32.2	11.0	46.7	10.0	31.7	7.0	50.6	10.0	13.9	3.0	64.4	15.0	91.7	19.0	110.0	22.0	52.0
<i>Chaoborus</i> sp	-	-	1.7	0.7	2.2	2.0	2.2	1.1	60.6	16.0	12.8	5.0	126.7	30.0	69.4	20.0	115.6	30.0	43.4
<i>Edotea</i> sp	-	-	-	-	-	-	-	-	10.6	3.0	206.1	47.0	65.6	11.0	6.7	2.0	-	-	32.1
<i>Chiridotia almyra</i>	37.8	15.0	13.3	6.0	40.6	6.0	142.8	45.0	25.0	10.0	1.1	1.0	1.1	1.1	0.6	0.6	8.3	2.0	30.1
Cyclopoida	-	-	-	-	2.2	1.1	3.3	2.0	4.4	2.0	-	-	64.4	16.0	86.7	20.0	9.4	4.0	18.9
<i>Rhithropanopeus harrisi</i>	0.6	0.6	0.6	0.6	0.6	0.6	-	-	7.8	3.0	44.4	13.0	32.8	12.0	5.6	3.0	18.3	11.0	12.3
Harpacticoida	-	-	1.1	0.7	1.1	1.1	74.4	45.0	-	-	1.7	1.0	2.2	1.0	6.7	5.0	5.6	5.6	10.3
<i>Leptocheirus</i> sp	0.6	0.6	1.1	0.1	0.6	0.6	1.7	1.1	16.7	5.0	3.9	2.0	18.3	11.0	6.1	5.0	2.8	2.0	5.8
Nudibranchia	6.7	3.0	2.2	1.0	5.0	3.0	0.6	0.6	10.6	0.6	0.6	0.6	0.6	0.6	1.1	0.7	14.4	4.0	4.6
<i>Monoculodes</i> sp	1.7	1.0	-	-	-	-	-	-	1.7	1.0	7.8	4.0	1.7	0.7	7.8	4.0	15.6	5.0	4.0
Nematoda	0.6	0.6	-	-	1.1	0.7	2.8	1.0	10.6	4.0	5.6	2.0	5.0	1.0	5.6	2.0	4.4	2.0	4.0
<i>Peloscolex</i> sp	24.4	15.0	3.3	2.0	0.6	0.6	1.1	1.1	0.6	0.6	-	-	-	-	-	-	2.2	2.0	3.6
<i>Paleonemertea</i>	-	-	-	-	1.1	0.7	-	-	1.1	1.1	12.2	3.0	5.6	2.0	2.8	1.0	2.2	1.0	2.8
<i>Hypaniola grayi</i>	2.2	1.0	0.6	0.6	1.1	0.7	0.6	0.6	0.6	0.6	2.2	1.0	2.2	2.0	5.0	3.0	3.3	2.0	2.0
<i>Sphaerium</i> sp	-	-	-	-	1.1	0.7	5.0	3.0	2.2	1.0	-	-	3.3	3.0	2.8	2.0	-	-	1.6
<i>Daphnia</i> sp	10.6	10.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2
Trichopteran-adult	-	-	-	-	-	-	-	-	0.6	0.6	2.8	1.0	1.7	1.0	2.8	2.0	1.1	1.1	1.0
<i>Cassidina lunifrons</i>	-	-	1.1	0.7	-	-	-	-	-	-	0.6	0.6	1.7	1.0	-	-	-	-	0.4
Chironomid-pupae	-	-	-	-	0.6	0.6	1.7	1.1	1.7	1.0	-	-	-	-	-	-	-	-	0.4
Calanoida	1.7	1.7	-	-	-	-	-	-	-	-	-	-	1.1	1.1	-	-	-	-	0.3
Macrothricidae	-	-	-	-	0.6	0.6	1.7	1.0	-	-	-	-	-	-	-	-	-	-	0.3
<i>Crangon septemspinus</i>	-	-	-	-	-	-	-	-	1.1	0.7	0.6	0.6	0.6	0.6	-	-	-	-	0.3
<i>Hydracarina</i>	-	-	-	-	-	-	-	-	0.6	0.6	-	-	0.6	0.6	1.1	1.1	-	-	0.3
Ceratopogonidae	-	-	-	-	0.6	0.6	-	-	-	-	-	-	0.6	0.6	0.6	0.6	-	-	0.2
Collembola	-	-	-	-	0.6	0.6	1.1	1.1	-	-	-	-	-	-	-	-	-	-	0.2
<i>Nereis succinea</i>	-	-	-	-	-	-	-	-	-	-	1.7	1.0	-	-	-	-	-	-	0.2
Planariidae	-	-	-	-	-	-	-	-	-	-	1.7	1.0	-	-	-	-	-	-	0.2
Ephemeroptera-adult	-	-	-	-	-	-	0.6	0.6	-	-	-	-	-	-	-	-	-	-	0.2
<i>Pisicicola</i> sp	-	-	-	-	-	-	-	-	-	-	1.1	1.1	-	-	-	-	-	-	0.1
Ostracoda	-	-	-	-	-	-	-	-	-	-	0.6	0.6	-	-	-	-	-	-	0.1
Naididae	-	-	-	-	-	-	-	-	-	-	1.1	1.1	-	-	-	-	-	-	0.1
<i>Leptodora</i> sp	-	-	-	-	-	-	-	-	-	-	0.6	0.6	-	-	-	-	-	-	0.1
<i>Ferrissia</i> sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.6	-	-	0.1
Odonata-juvenile	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.6	0.1
Total No. of Taxa		20		17		24		22		27		28		27		27		24	43
Total Mean No. of Specimens	4045.8		7271.1		10913.1		4259.1		13132.0		12434.7		13138.5		10275.4		10034.4		9500.7

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services group



APPENDIX D
1972, 1973, AND 1974 BIOMASS
IN INDIAN POINT TEST AND CONTROL AREAS



Table D-1

1972 Mean Wet-Weight Biomass per Square Meter

Station	Monthly Mean									
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year Mean
1(M)	8.8	4.3	2.4	6.0	1.0	5.0	9.0	11.0	12.0	6.6
2	1.2	1.8	1.0	11.0	4.0	5.0	12.0	27.0	33.0	10.7
3	5.0	2.6	2.6	4.0	2.0	9.0	9.4	10.0	4.0	5.4
4(A)	28.8	12.8	4.6	4.0	5.0	21.0	62.0	54.0	59.0	27.9
5(C)	14.3	1.4	2.4	9.0	9.0	38.0	22.6	62.0	7.0	18.4
6	18.2	3.2	1.0	2.0	2.0	2.0	17.2	25.0	3.0	8.2
7	10.6	11.0	1.4	0.2	5.0	4.0	52.4	16.0	34.0	15.0
Mean	12.4	5.3	2.2	5.2	4.0	12.0	26.4	29.3	21.7	13.2
Test Mean	21.6	7.1	3.5	6.5	7.0	29.5	42.3	58.0	33.0	23.2
Control Mean	8.8	4.3	2.4	6.0	1.0	5.0	9.0	11.0	12.0	6.6

Table D-2

1973 Mean Wet-Weight Biomass per Square Meter

	Station	Monthly Mean									
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year Mean
Test Area	A	9.3	14.7	17.0	22.5	31.5	31.3	34.7	13.7	11.3	20.7
	B	13.7	11.7	20.0	36.0	17.7	21.3	14.0	9.0	18.3	20.5
	C	24.3	13.3	26.7	41.0	21.3	25.3	20.3	6.0	12.3	21.2
	D	3.7	7.3	10.3	18.3	20.0	24.0	13.7	4.7	4.7	11.9
	E	34.3	24.0	17.7	38.0	26.8	22.3	7.0	7.0	14.0	21.2
	F	3.7	17.3	16.3	17.0	40.3	35.0	15.0	9.0	7.7	17.9
	Area Mean	14.8	14.7	18.0	28.8	26.3	26.5	17.5	8.2	11.4	18.5
Control Area	M	9.7*	24.7*	15.7	23.4	5.8	17.7	15.0	6.0	2.7	13.4
	N	7.7*	18.0*	9.7	11.0	12.3	13.3	6.7	3.3	3.7	9.5
	O	8.7*	22.7*	19.7	53.0	7.0	15.7	6.0	6.7	9.3	16.5
	P	13.0*	15.0*	18.3	11.2	5.5	20.7	8.7	13.0	18.0	13.7
	Q	7.7*	10.7*	20.7	24.7	20.7	29.3	20.7	27.0	21.7	20.4
	R	7.7*	16.0*	20.7	28.0	63.7	54.0	18.3	7.0	15.0	25.6
	Area Mean	9.1	17.9	17.5	25.2	19.2	25.1	12.6	10.5	11.7	16.5

*Stations G through L



Table D-3
1974 Mean Wet-Weight Biomass per Square Meter

	Station	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Test Area	A	32.0	13.0	18.3	9.3	20.3	19.0	136.7	82.0	48.7	42.1
	B	18.7	36.3	11.7	5.7	30.7	70.3	91.0	11.7	12.0	32.0
	C	37.7	31.7	25.7	16.8	55.0	115.3	417.3	147.3	82.3	103.2
	D	39.7	41.0	43.7	9.0	35.0	42.0	15.0	113.7	18.7	39.8
	E	35.7	19.0	16.0	13.3	44.7	38.3	16.7	160.3	78.0	46.9
	F	114.0	52.0	45.3	39.3	47.3	16.0	28.0	55.7	17.0	46.1
	Area Mean	46.0	32.2	26.8	15.5	38.8	50.2	117.4	95.1	42.8	51.7
Control Area	M	10.7	8.7	7.3	2.3	21.0	13.0	43.3	27.7	5.7	15.5
	N	8.0	15.0	15.0	3.3	21.3	67.3	239.3	5.3	119.7	54.9
	O	7.3	8.3	16.7	3.3	10.3	42.7	86.0	8.7	13.0	21.8
	P	20.3	17.3	8.7	4.0	57.7	23.3	28.7	13.7	10.3	20.4
	Q	5.7	12.0	16.7	9.7	41.7	19.7	30.0	14.3	23.3	19.2
	R	7.3	40.3	79.0	7.0	49.3	89.0	10.0	7.0	5.0	32.7
	Area Mean	9.9	16.9	23.9	4.9	38.6	42.5	72.9	12.8	29.5	28.0



APPENDIX E
DIVERSITY INDICES,
INDIAN POINT TEST AND CONTROL AREAS
1972, 1973, AND 1974



Table E-1

Diversity Indices Calculated from 1973 Test- and Control-Area Data

Mo	Diversity Index	Test Area						Control Area					
		Station						Station					
		A	B	C	D	E	F	M	N	O	P	Q	R
Apr	SW	0.67	0.61	0.53	0.73	0.42	0.73	-	-	-	-	-	-
	H	2.80	1.93	1.22	3.69	0.67	3.89	-	-	-	-	-	-
	J	0.60	0.53	0.49	0.67	0.34	0.66	-	-	-	-	-	-
May	SW	0.60	0.64	0.75	0.80	0.45	0.69	-	-	-	-	-	-
	H	2.23	2.29	4.37	4.59	0.92	2.89	-	-	-	-	-	-
	J	0.63	0.61	0.72	0.77	0.42	0.69	-	-	-	-	-	-
Jun	SW	0.73	0.42	0.71	0.65	0.60	0.71	0.46	0.14	0.10	0.27	0.26	0.24
	H	3.65	0.71	3.34	2.89	2.15	3.31	0.96	0.14	0.09	0.39	0.35	0.33
	J	0.77	0.37	0.64	0.68	0.63	0.71	0.44	0.14	0.11	0.27	0.26	0.28
Jul	SW	0.50	0.26	0.32	0.68	0.68	0.66	0.38	0.33	0.15	0.47	0.46	0.32
	H	1.60	0.34	0.46	2.95	3.05	2.47	0.79	0.46	0.15	0.94	0.97	0.59
	J	0.53	0.27	0.29	0.65	0.61	0.66	0.40	0.33	0.15	0.45	0.42	0.36
Aug	SW	0.26	0.30	0.49	0.29	0.56	0.65	0.57	0.39	0.28	0.37	0.42	0.14
	H	0.35	0.46	1.29	0.44	1.98	3.19	3.37	0.73	0.44	1.12	1.04	0.18
	J	0.25	0.30	0.51	0.30	0.52	0.60	0.81	0.44	0.34	0.53	0.50	0.15
Sep	SW	0.59	0.67	0.67	0.58	0.47	0.58	0.51	0.57	0.12	0.57	0.48	0.10
	H	2.24	2.55	2.94	1.88	1.56	1.94	1.62	1.88	0.13	1.91	1.34	0.10
	J	0.57	0.62	0.62	0.58	0.60	0.51	0.57	0.53	0.13	0.55	0.42	0.12
Oct	SW	0.73	0.10	0.85	0.83	0.42	0.84	0.42	0.47	0.31	0.44	0.42	0.52
	H	2.62	0.12	4.35	4.24	0.95	4.30	0.79	1.35	0.53	0.70	0.79	1.42
	J	0.63	0.12	0.72	0.67	0.39	0.66	0.39	0.43	0.30	0.39	0.35	0.43
Nov	SW	0.81	0.70	0.65	0.93	0.77	0.96	0.88	0.61	0.30	1.01	0.64	0.75
	H	4.12	2.01	1.45	5.31	2.93	5.45	4.50	1.35	0.38	7.22	1.95	2.35
	J	0.66	0.58	0.54	0.75	0.59	0.72	0.69	0.49	0.25	0.73	0.49	0.57
Dec	SW	0.71	0.58	0.71	0.89	0.92	0.35	0.37	0.56	0.48	0.43	0.41	0.33
	H	2.28	1.17	2.05	4.12	4.88	0.47	1.30	1.06	1.13	0.77	0.57	0.47
	J	0.60	0.45	0.58	0.71	0.70	0.30	0.34	0.44	0.37	0.37	0.31	0.27

SW = Shannon-Weaver
H = Hurlbert
J = Pielou



Table E-2

Diversity Indices Calculated from 1974 Test- and Control-Area Data

Month	Index	Test Area Stations						Control Area Stations					
		A	B	C	D	E	F	M	N	O	P	Q	R
Apr	SW	0.85	0.79	0.80	0.42	0.66	0.32	0.50	0.43	0.32	0.45	0.66	0.54
	H	4.31	3.76	3.67	0.76	2.28	0.67	1.49	1.33	0.57	0.92	3.25	1.74
	J	0.63	0.60	0.6	0.33	0.49	0.25	0.45	0.41	0.29	0.38	0.66	0.47
May	SW	0.66	0.47	0.47	0.38	0.40	0.49	0.65	0.43	0.46	0.55	0.51	0.41
	H	2.21	1.43	1.35	1.08	0.97	1.29	2.14	0.99	1.45	1.70	1.55	1.24
	J	0.55	0.44	0.36	0.37	0.37	0.38	0.62	0.38	0.46	0.42	0.49	0.36
Jun	SW	0.61	0.60	0.61	0.48	0.71	0.53	0.61	0.63	0.62	0.66	0.49	0.41
	H	1.78	1.99	2.14	1.40	3.03	1.65	2.12	2.21	2.21	2.42	1.45	1.23
	J	0.49	0.50	0.47	0.39	0.54	0.41	0.51	0.51	0.53	0.64	0.37	0.35
Jul	SW	0.51	0.61	0.65	0.71	0.75	0.62	0.46	0.55	0.56	0.63	0.38	0.50
	H	0.96	1.95	2.39	2.63	3.25	2.06	1.02	1.57	1.27	1.73	0.61	1.56
	J	0.41	0.44	0.49	0.52	0.56	0.46	0.38	0.46	0.45	0.49	0.32	0.43
Aug	SW	0.58	0.80	0.75	0.65	0.34	0.36	0.67	0.74	0.49	0.48	0.62	0.25
	H	2.09	3.36	3.03	2.06	0.63	0.89	2.87	3.02	1.39	1.42	2.44	0.47
	J	0.52	0.56	0.55	0.47	0.27	0.27	0.53	0.58	0.39	0.35	0.48	0.20
Sep	SW	0.57	0.71	0.68	0.65	0.50	0.46	0.67	0.67	0.60	0.55	0.54	0.39
	H	1.91	3.15	2.52	2.23	1.23	1.19	2.55	1.94	2.39	1.20	1.36	1.09
	J	0.49	0.59	0.52	0.50	0.42	0.39	0.51	0.53	0.49	0.45	0.40	0.33
Oct	SW	0.79	0.83	0.77	0.32	0.36	0.58	0.81	0.63	0.72	0.65	0.47	0.46
	H	3.44	3.84	3.09	0.40	0.52	1.35	3.37	1.37	2.29	2.22	1.11	1.29
	J	0.63	0.60	0.58	0.25	0.27	0.44	0.61	0.46	0.56	0.50	0.38	0.38
Nov	SW	0.75	0.39	0.84	0.58	0.59	0.68	0.65	0.51	0.62	0.65	0.72	0.59
	H	2.92	0.86	4.38	1.25	1.34	1.99	2.27	1.42	2.26	2.77	3.49	1.77
	J	0.56	0.30	0.66	0.44	0.44	0.152	0.50	0.44	0.51	0.53	0.59	0.46
Dec	SW	0.73	0.55	0.71	0.53	0.66	0.36	0.60	0.76	0.67	0.60	0.58	0.42
	H	2.39	1.71	2.23	0.92	1.57	0.59	2.08	3.00	2.66	1.88	1.80	1.23
	J	0.56	0.41	0.54	0.40	0.51	0.28	0.51	0.58	0.54	0.50	0.51	0.35

*SW = Shannon-Weaver log 10
H = Hurlbert
J = Pielou



APPENDIX F

DURATION (DAYS) OF SALT INCURSION AT OR ABOVE INDIAN POINT



Table F-1
Duration (Days) of Salt Incursion
at or above Indian Point

Month	Year									Mean
	1974	1973	1972	1971	1970	1969	1968	1967	1966	
Jan	1	0	7	26	31	24	26	28	31	19.3
Feb	6	1	13	24	7	14	26	25	20	15.1
Mar	3	7	3	0	21	24	18	25	8	12.1
Apr	3	5	0	0	0	0	14	0	9	3.4
May	0	1	0	0	13	4	4	6	10	4.2
Jun	23	8	4	19	26	18	14	28	23	18.1
Jul	24	23	9	31	31	27	13	31	31	24.4
Aug	30	31	28	21	31	29	31	31	31	29.2
Sep	26	30	30	20	30	30	30	30	30	28.4
Oct	22	31	30	31	27	31	31	30	31	29.3
Nov	14	28	7	30	30	10	20	22	31	21.3
Dec	0	9	0	7	12	23	7	6	23	9.7
Total	152	174	131	209	259	234	234	262	278	214.8

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