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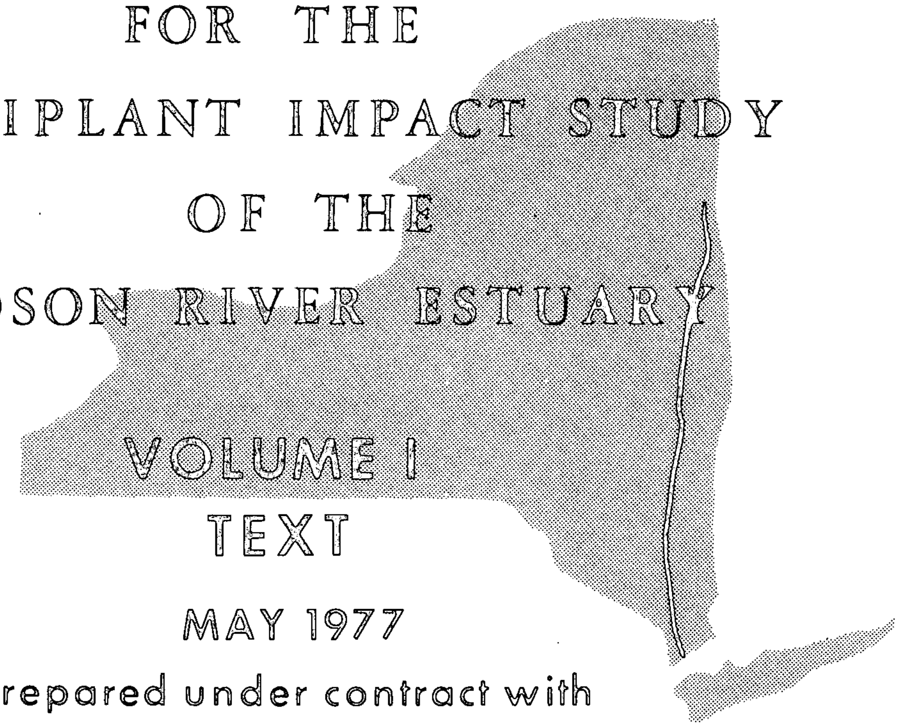
1974 YEAR-CLASS REPORT FOR THE MULTIPLANT IMPACT STUDY OF THE HUDSON RIVER ESTUARY



VOLUME I
TEXT

MAY 1977

Prepared under contract with

CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
4 Irving Place
New York, New York 10003

Jointly financed by

Consolidated Edison Company of New York, Inc.
Orange and Rockland Utilities, Inc.
Central Hudson Gas and Electric Corporation

by

TEXAS INSTRUMENTS INCORPORATED
ECOLOGICAL SERVICES
P.O. Box 5621
Dallas, Texas 75222

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SECTION I

INTRODUCTION

The goal of this 3-volume report is to present the results of analyses of populations of key fishes (striped bass, white perch, Atlantic tomcod, and American shad) in the Hudson River estuary, which may be subjected to mortality from entrainment (passage through the condenser cooling system) and impingement (entrapment on the cooling water intake screens) at the Bowline, Lovett, Indian Point, Roseton, and Danskammer electrical generating plants. Volume I contains a continuation of the data analyses of the 1974 year class of striped bass, white perch, and Atlantic tomcod initiated in the *First Annual Report for the Multiplant Impact Study of the Hudson River* (TI, 1975a) and adds analyses of the 1974 year class of American shad. Included are data on striped bass, white perch, and Atlantic tomcod collected from October 1974 through June 1975 and data on American shad collected from April 1974 through June 1975 in the estuary from river mile (RM) 12 to 152 (KM 19-243). Data on striped bass, white perch, and Atlantic tomcod collected before October 1974 were discussed previously (TI, 1975a).

The following are the primary objectives addressed in this report:

- Describe trends in the abundance of striped bass, white perch, and American shad stocks from 1931 through 1974 based on commercial fishery records (Section IV.B)
- Describe fluctuations in annual abundance of juvenile American shad and Atlantic tomcod from 1965 through 1974, excluding 1971 (Section IV.C)
- Describe the potential relationships of the annual abundances of juvenile striped bass, white perch, Atlantic tomcod, and American shad vs several biotic and abiotic environmental factors (Section IV.D)
- Synthesize the fisheries literature and sampling data from the estuary, compile life history/behavior information, and describe biological factors that may influence the vulnerability of American shad life stages to power plants (Section V.B)

- Describe the longitudinal abundance and distribution of the life stages of striped bass, white perch, Atlantic tomcod, and American shad (Section V.C)

- Describe the vertical, lateral, diel, and tidal distributions of the life stages of striped bass, white perch, Atlantic tomcod, and American shad in the nearfield vicinity of the five power plants (Section V.D)

- Describe the relationships of the longitudinal distributions of striped bass, white perch, Atlantic tomcod, and American shad vs water temperature, conductivity, and dissolved oxygen (Section V.E)

- Describe the seasonal movements of individually marked striped bass, white perch, and Atlantic tomcod (Section V.F)

- Assess the vulnerability of the life stages of striped bass, white perch, Atlantic tomcod, and American shad to the five power plants (Section V.G) and examine the available data base for evidence of compensation (Section VI).

- Examine the available data base for evidence of compensation (Section VI).

An overview of the field and laboratory methods and materials used during 1974 and 1975 is presented in Section III.

Volume II of this report contains the data tables and figures that support and supplement the results presented in Volume I. Volume III contains the results of the Lower Estuary Study, which was conducted during 1974-75 primarily to recapture in the lower bay areas the striped bass, white perch, and Atlantic tomcod that had been marked within the confines of the Hudson River.

SECTION II
SUMMARY AND CONCLUSIONS

A. GENERAL INTRODUCTION

In this section are the salient conclusions of the analyses presented in this report. Methods and data analyses are detailed in the major report sections (IV through VI) of this volume and in Volume III. Additional details and data appear in the appendices (Volumes II and III). This section, therefore, is a brief synopsis of a great deal of scientific work. Serious readers will wish to pursue specific interests in the main body of the report and in the appendices. Additionally, much relevant data were analyzed and discussed in a previous report (TI, 1975a).

B. HISTORICAL DATA BASE (SECTION IV)

1. Introduction

Analyses of several years of abundance data on the key fish species in the Hudson River permit evaluation of the impact of a power plant or group of power plants in a historical sense. Since power plant operations vary annually, as do other abiotic and biotic environmental factors, one may use multivariate statistical techniques to analyze historical data (given a sufficient number of years of pre- and postoperational data) to determine if the power plants have had any significant effect on abundance. Several years of data are also often helpful in elucidating cyclic fluctuations in abundance and in determining relationships between spawner abundance and the abundance of recruits produced by that spawning population.

2. Commercial Fishery Trends

Fluctuations in the abundance of spawning stocks of striped bass, American shad, and white perch were examined from a series of yield-per-effort (Y/f) estimates of relative abundance based on available commercial fishery data from 1931 through 1974. Commercial gill net fishing effort in the Hudson River has declined drastically since the mid-1940s; however, slight increases occurred in 1973 and 1974. Also influencing fishing effort was the change from natural fibers to nylon as net material during the mid-1950s.

Striped bass abundance fluctuated at relatively low levels from 1931 through 1954. After 1954, Y/f values varied but remained well above pre-1955 levels. White perch abundance declined in 1944 after reaching peaks in 1935 and 1942. The white perch abundance index fluctuated at low levels from 1944 until the early 1970s when it was at its lowest level; however, this apparent population decline is difficult to interpret because of a diminishing market and subsequent adjustments in fishing gear and effort to avoid white perch. American shad abundance has shown extreme fluctuations over the past 40 years; major peaks were in 1942, 1956, and 1972, but the stock generally declined after 1942.

3. Year-Class Strength

Annual variations in the abundance of juvenile American shad taken in beach seines were used as estimates of fluctuations in year-class strength. Between 1969 and 1974, abundance varied by a factor of 17.5 for standard station catches in the area of the Indian Point power plant and by a factor of >500 for riverwide catches. The riverwide and standard station sampling programs revealed strong year classes in 1973 and 1974. Riverwide estimates indicated poor year classes in 1967, 1968, and 1972 and intermediate year classes in 1965, 1966, 1969, and 1970.

Annual abundance of juvenile Atlantic tomcod was derived from standard station bottom trawls in the area of the Indian Point power plant. From 1969 to 1974, abundance varied by a factor of 12.3. Two years were significantly different ($\alpha = 0.05$): the 1970 year class was larger than the 1974 year class. A weak year class occurred in 1973, and there were intermediate year classes in 1969 and 1972.

American shad abundance was plotted against several abiotic and biotic factors that are thought to influence year-class strength. Juvenile shad abundance was not significantly correlated with four of the five environmental factors tested (freshwater inflow, surface water temperature, adult shad abundance, and bluefish abundance). A positive correlation with power plant cooling water withdrawal did exist ($r = +0.853$; $p = 0.003$) but did not necessarily reflect a causal relationship. The generally increasing trend in juvenile shad abundance since 1965 may also be associated with generally improving water quality in the Hudson River. Additional data are needed, however, to verify this relationship.

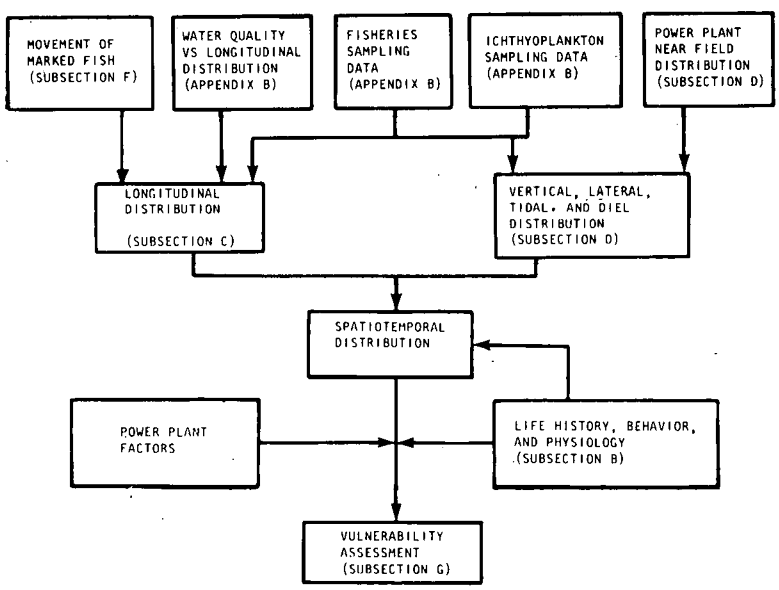
Annual fluctuations in the abundance of juvenile Atlantic tomcod were correlated with March water temperatures at an alpha (α) level of 0.10; higher temperatures were associated with lower abundance. A positive correlation occurred between abundance and April freshwater flow. Increased tomcod abundance usually occurred during years characterized by large freshwater inflow and low water temperatures during late winter and early spring. Spawning stock abundance could not be estimated. Bluefish abundance and power plant withdrawals were not significantly related to tomcod year-class strength.

C. DISTRIBUTION AND VULNERABILITY ASSESSMENT (SECTION V)

1. Introduction

Information on the life histories, behavior, distribution, and movements of striped bass, white perch, Atlantic tomcod and American shad was compiled and analyzed to assess each species' relative vulnerability to entrainment and impingement at the Bowline, Lovett, Indian Point, Danskammer, and Roseton power plants. "Vulnerability" refers to the relative degree of exposure of early life stages to power plants and not to the probability that an individual egg or larva will be entrained or an individual juvenile impinged.

Data from several sources were combined into an overall assessment of vulnerability, as illustrated in the following diagram:



2. Life History/Behavior

Literature on the life history and behavior of white perch, striped bass, and Atlantic tomcod was summarized in a previous report (TI, 1975a). American shad has been added to this report. Based on the available literature on American shad life history and behavior, the species should be relatively invulnerable to entrainment because most of its spawning and larval development occurs upstream from the designated power plants. Shad would be briefly vulnerable to impingement at all five plants during their fall migration to the sea.

3. Spatiotemporal, Longitudinal, and Power Plant Region Distribution and Abundance

a. Striped Bass

Striped bass spawning began in late April. Peak egg deposition occurred between river miles (RM) 39 (KM 62) and 55 (KM 88) during 15-18 May. Shortly after spawning and during the peak period for standing crops, 28 May-23 June, larvae were concentrated between RM 39 (KM 62) and RM 76 (KM 122). Early juveniles were most abundant between RM 24 (KM 38) and RM 61 (KM 98) but gradually shifted their distribution downstream during August and September. Most of the juvenile population had left the river by late December or had moved to deep water inaccessible to sampling.

Striped bass eggs and larvae were exposed rather uniformly to all five power plants, although yolk-sac larvae were relatively more abundant in the vicinity of Roseton and Danskammer than at the other plants. Juveniles were concentrated in the lower river during periods of peak standing crops, so their exposure to impingement was highest at Bowline, Lovett, and Indian Point.

b. White Perch

White perch spawning began in early May, and egg abundance peaked from 30 May to 5 June in the Tappan Zee and Haverstraw Bay areas [RM 24-38 (KM 38-61)]. During the peak standing crop period of 21 May to 17 June, larvae were abundant in the upper river [RM 94-106 (KM 150-170)] until late August to mid-September when their distribution shifted downstream to the lower river regions. Juveniles left the shore zone in late November for deeper water. Most overwintered in the river.

White perch eggs generally are demersal, adhesive, and therefore relatively invulnerable to entrainment. Larval exposure to entrainment at the five power plants was similar. Vulnerability of the juveniles to impingement was relatively low during most of the summer and early fall because they were concentrated in the upper river. In late October, they were more concentrated in the lower river, so their exposure to impingement at Bowline, Lovett, and Indian Point increased.

c. Atlantic Tomcod

Atlantic tomcod spawned at the end of their first year of life, from mid-December through January, mostly between RM 39 (KM 62) and RM 61 (KM 98). Distribution of eggs and larvae in the river could not be determined because most tomcod had reached the juvenile stage before ichthyoplankton sampling began. The demersal eggs should be relatively invulnerable to entrainment, but the larvae may be subject to entrainment, particularly at the downstream plants (Bowline, Lovett, and Indian Point). Juveniles were most abundant throughout the year in the channel areas of the lower river [RM 14-33 (KM 22-53)], so they would be most exposed to impingement at Indian Point and Lovett. Juvenile tomcod would be relatively invulnerable to impingement at Bowline because of the shallow intake area.

d. American Shad

American shad began to spawn before late April, with egg deposition peaking between RM 94 (KM 150) and RM 124 (KM 198) from 23 May to 5 June. Larval distribution exhibited a slight downriver shift; during the peak standing crop period of 28 May-23 June, they were concentrated between RM 86 (KM 137) and RM 124 (KM 198). Juveniles were found throughout the river until mid-October when they began to migrate to the sea. By late November, almost all juveniles had apparently left the river.

Shad eggs and larvae were relatively invulnerable to entrainment at the five power plants because they were concentrated upstream from the plants. Juveniles were exposed to impingement in the late summer, particularly at Bowline, Lovett, and Indian Point as they migrated seaward.

4. Vertical, Lateral, Diel, and Tidal Distribution and Abundance

a. Striped Bass

Striped bass eggs were concentrated day and night in the mid-water and bottom areas of the river [>20 ft (6 m) deep]. Yolk-sac larvae were similarly distributed during the day but appeared to be dispersed throughout the water column at night. Post yolk-sac larvae were concentrated near the bottom during the day, dispersed throughout the water column at night, but were found also in shoal areas. Early juveniles were abundant near the bottom in areas >20 ft (6 m) deep and in shoal areas. By mid-August, most of the population had apparently moved into the shoals and shore zone. Juveniles first appeared in the shore zone in late June and remained there until early November when they moved into deeper waters. Juveniles were more abundant in the shore zone at night, regardless of tidal stage.

b. White Perch

White perch eggs were concentrated near the bottom in shoals and areas >20 ft (6 m) deep. Yolk-sac larvae in riverwide samples were uniformly distributed throughout the water column, with somewhat lower surface densities during the day. Post yolk-sac larvae in riverwide samples were most abundant in areas >20 ft (6 m) deep and were uniformly distributed from surface to bottom during both day and night. Nearfield sampling in the vicinity of Indian Point showed a somewhat different distribution for larvae; yolk-sac larval densities were highest in bottom and midwater strata during day and night, whereas post yolk-sac larvae concentrated in deep water during the day but dispersed throughout the water column at night. Larval distribution patterns at Bowline, Lovett, and Roseton-Danskammer were inconclusive. Juveniles were abundant in all strata except those >40 ft (12 m) deep. They first appeared in the shore zone in early July and were relatively abundant there until late August when movement to deeper water was noted. This movement accelerated in early November. Juveniles in the shore zone were always most abundant at night, regardless of tidal stage.

c. Atlantic Tomcod

Atlantic tomcod juveniles were concentrated near the bottom in areas of the river deeper than 20 ft (6 m) and in the west shoal through mid-August; later, they were concentrated primarily near the bottom of areas deeper than 20 ft (6 m). When spawning began in mid-December, they entered the shoals and shore zone. Juveniles were never abundant in the shore zone during spring, summer, and fall in either the daytime or nighttime.

d. American Shad

American shad eggs were concentrated during day and night near the bottom in areas deeper than 20 ft (6 m). Yolk-sac larvae were most abundant in midwater and bottom strata in areas deeper than 20 ft (6 m) during the day but dispersed throughout the water column at night. Post yolk-sac larvae were uniformly distributed from surface to bottom during day and night in areas deeper than 20 ft (6 m), and some post yolk-sac larvae were collected in the shoals. Juveniles were abundant in several strata [the shore zone, shoal areas, and bottom and midwater strata >20 ft (6 m) deep]. In late October, catches in all gear declined sharply as juveniles left the river. Juveniles were always more abundant in the shore zone during daylight, regardless of tidal stage.

5. Longitudinal Distribution and Abundance in Relation to Physicochemical Variables

a. Striped Bass

Striped bass spawned in freshwater areas of the river. Egg deposition peaked when water temperatures ranged from 15 to 19°C. Larvae developed in fresh to slightly brackish water and completed transformation to juveniles before water temperatures reached 23°C. Juveniles moved to the shoals and shore zone in early summer as water temperatures increased to 20°C and then left the shore in the fall as temperatures dropped below 17°C. Juveniles moved into the lower river regions in early September, but there were no obvious movements in association with the salt front.

b. White Perch

White perch spawned in freshwater and slightly brackish areas, with peak deposition occurring when water temperatures were 14-21°C. Larvae developed in the freshwater and slightly brackish zones of the river and completed transformation into juveniles before water temperatures reached 23°C. Juveniles began to move to the shoals and shore zone as water temperatures increased to 25°C but left the shore zone when temperatures declined below 15°C. White perch juveniles were widely distributed throughout the river until mid-October when they apparently moved offshore and downriver to the area of the salt front.

c. Atlantic Tomcod

Atlantic tomcod spawned in freshwater or slightly brackish areas at water temperatures below 5°C. Larvae developed in either fresh or brackish water and transformed into juveniles prior to the occurrence of 11°C water temperatures. Juvenile distribution was generally associated with the salt front and was bimodal; one peak occurred in relatively high salinity and another at the salt front. Juveniles were most abundant near the bottom.

d. American Shad

American shad spawned in freshwater areas of the river, with peak egg deposition occurring when water temperatures were 11-18°C. Most larval development also occurred in fresh water, with transformation into juveniles occurring before water temperatures reached 24°C. Juveniles began to move to the shoals and shore zone as water temperatures increased to 24°C, and they began to leave the river when temperatures declined to 15°C. Juveniles were distributed widely throughout the river until late October when they began their seaward migration.

6. Movement of Marked Fish

Extensive bidirectional movements of marked juvenile striped bass, all ages of white perch, and adult Atlantic tomcod were noted. Apparently, an unknown portion of the juvenile striped bass population overwintered in the lower river regions and white perch overwintered in deep areas of the river. Adult Atlantic tomcod exhibited much bidirectional movement early in the spawning period (December) but moved downriver after spawning in January and February and generally left the freshwater portion of the river before June.

7. Vulnerability to Power Plants

Of the four species discussed in this report, striped bass were most vulnerable to entrainment, especially during the yolk-sac larval stage at Roseton and Danskammer. A large proportion of the white perch eggs were exposed to power plants, particularly Bowline, Lovett, and Indian Point, but their generally adhesive and demersal characteristics greatly reduced vulnerability. The exposure of Atlantic tomcod eggs to power plants could not be assessed. Of the four species, American shad was apparently the least vulnerable to entrainment since most of the eggs and larvae were concentrated in the upper river.

On the basis of exposure time, white perch is the species most vulnerable to impingement since it is a resident species and is exposed to the plants for a much larger portion of its life span than are the other species, which are primarily anadromous (i.e., mature outside the Hudson River but return to spawn). Striped bass exposure to impingement was greatest at the downstream plants (Bowline, Lovett, and Indian Point) during late summer and fall before emigration from the river. Atlantic tomcod were exposed to impingement during their first summer, but only at Lovett and Indian Point. Their exposure increased during the winter spawning period, particularly at Roseton and Danskammer. Young American shad leave the estuary in late fall, so they are most vulnerable to impingement during a brief period when they pass the plants on their migration seaward.

Overall, the degree of exposure to entrainment and impingement at the five power plants is probably highest for white perch, followed by striped bass, Atlantic tomcod, and American shad in that order.

D. COMPENSATION (SECTION VI)

1. Introduction

An earlier report (TI, 1975a) discussed evidence of compensation in the Hudson River striped bass population. Striped bass show density-dependent growth as juveniles, and stock abundance appears to be regulated in a density-dependent manner following a stock recruitment curve of the Ricker type. There has been no evidence of compensation for white perch or American shad. Additional data have been examined in this report for evidence of compensation.

2. Conclusions

Adult striped bass abundance at time t was plotted against an estimate of recruitment (commercial catch-per-effort data at time t + 5) for 1931-74. A dome-shaped relationship, i.e., a Ricker-type stock recruitment curve, seemed appropriate for the data. This relationship supported the hypothesis of density-dependent mortality in the striped bass population and the existence of compensatory capability.

Striped bass and American shad stock recruitment relationships were also investigated by comparing adult abundance with juvenile abundance over the 9 years that such data were available. The relationship between juvenile abundance and adult abundance was not significant for either species ($r = +0.531$, $p = 0.737$ for striped bass; $r = -0.011$, $p = 0.98$ for American shad). Therefore. the technique provided no additional information on the presence or absence of compensation in these fishes.

E. LOWER ESTUARY STUDY (VOLUME III)

1. Introduction

The Lower Estuary Study surveyed the more saline waters below the mouth of the Hudson River (beyond the Battery), which may serve as nursery areas for migratory fish of Hudson River origin. The study was particularly designed to supplement the mark/recapture program for Hudson River striped bass, Atlantic tomcod, and white perch by providing marking and recapture effort in this area. The primary areas of study were the northwest shore of Long Island into the East River, the southwest shore of Long Island including Jamaica Bay, the lower bay including Staten Island, and the Hackensack River.

2. Conclusions

The major study areas except the Hackensack River contained diverse fish fauna, both marine and anadromous. Yearling striped bass of probable Hudson River origin inhabit much of the shore zone of western Long Island, Staten Island, and the Hackensack River from May through October. Young-of-the-year striped bass apparently began moving from the Hudson River to the extreme lower estuary in the fall or early winter. Hatchery-reared striped bass stocked in the Hudson River during the fall appeared to move similarly to wild juveniles and were found in many areas of the lower estuary by the following spring. White perch were uncommon in the lower estuary, perhaps having originated from sources other than the Hudson (e.g., local streams and ponds). Young-of-the-year Atlantic tomcod frequently occupied the lower estuary from May through early August, but these fish were of unknown origin. Adult Atlantic tomcod were rare in the lower estuary study area.

SECTION III

FIELD PROCEDURES

This section describes the field methods and materials used in 1974 to collect and process ichthyoplankton, fisheries, and water quality samples. The laboratory procedures for all programs were described in an earlier report (TI, 1975a).

A. ICHTHYOPLANKTON SAMPLING

The ichthyoplankton sampling program provided data with which to describe in this report the distribution of the key fish species (striped bass, white perch, Atlantic tomcod, and American shad) in the Hudson River estuary. The sampling program in 1974 comprised two major tasks: the longitudinal river survey and the fall shoals survey. Table III-1 summarizes these sampling tasks.

Table III-1

Summary of Ichthyoplankton Sampling Tasks (Including Sampling Time) in Hudson River Estuary, 1974

1974 Tasks	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Longitudinal river survey		▬	▬	▬	▬	▬				
Fall shoals survey						▬	▬	▬	▬	▬

1. Longitudinal River Survey

The longitudinal river survey provided data with which to describe the distribution and abundance of early life stages (eggs, larvae, and early juveniles) of selected fish species in the Hudson River estuary. The regions of the estuary sampled were Yonkers through Albany, river miles (RM) 14 (KM 22) through 140 (KM 224). Samples were collected from bottom, channel, and shoal strata (TI, 1975a) from mid-April through mid-August using a 1.0-m^2

epibenthic sled and a 1.0-m^2 Tucker trawl rigged with opening and closing plankton nets (505-μ mesh). The 1974 allocation of sampling effort conformed with a stratified random design based on the distribution of the early life stages of striped bass during 1973. Day or night sampling was conducted (Table III-2) for a total of approximately 100-170 samples during each river survey. Effort was concentrated in areas in which striped bass eggs and larvae had been abundant in 1973. Coordinates of locations to be sampled within each strata were selected from a random-numbers table (TI, 1975a).

The vessels used in 1973 towed the ichthyoplankton gear in 1974. Tow directions varied with weather conditions, sampling locations, and gear deployment but were generally north to south, regardless of tidal stage. Tow direction and tidal direction were recorded for every sample. Relative (to the water) tow speeds ranged from 0.4 to 1.0 m/sec for the epibenthic sled and 0.9 to 1.2 m/sec for the Tucker trawl. Generally, a cable length/depth ratio of 1.5/1 was maintained for the Tucker trawl and a ratio of 1.8/1 for the epibenthic sled; occasionally, however, the ratio varied with tidal velocity, tow speed and direction, and sampling depth. The cable length/depth ratios were monitored using the same methods as in 1973.

Digital and electronic flowmeters mounted on the sampling gear measured the volume of water filtered by the net and the tow speed, respectively. Flowmeters were calibrated at the beginning of the season and at intervals during the season.

2. Fall Shoals Survey

The shoal survey, which was conducted from mid-August through December, provided additional data on species composition, abundance, distribution, and movement of juvenile fishes in relatively shallow areas of the river. The objectives were to determine the importance of shoals (areas of the river $\leq$ 6 m deep) as nursery grounds for young-of-the-year fish and mark adult white perch and recapture marked white perch and striped bass.

Sampling was done with an epibenthic sled rigged with a single 3000-μ mesh plankton net having a 1.0-m^2 opening. An enlarged fyke cod-end cover had

Table III-2

Collection Dates, River Miles (RM) Sampled, and Day-vs-Night Collections during 1974 Ichthyoplankton Longitudinal River Survey

River Survey No.	Dates Collected	Sampling Range (RM/KM)*	Time Collected **
1***	Apr 16-17		
2	Apr 23-25	134-44 (214-70)	Day
3	Apr 29-May 4	126-18 (202-29)	Night
4	May 6-11	134-20 (214-32)	Night
5	May 13-18	128-12 (205-18)	Night
6	May 15-18	137-44 (219-70)	Day
7	May 21-24	140-12 (224-19)	Day
8	May 23-29	130-20 (208-32)	Night
9	May 28-31	143-14 (229-22)	Day
10	May 30-Jun 5	132-14 (211-22)	Night
11	Jun 4-7	140-14 (224-22)	Day
12†	Jun 6-9	—	—
13	Jun 10-14	126-14 (202-22)	Day
14	Jun 12-17	134-15 (214-24)	Night
15	Jun 17-23	139-14 (222-22)	Night
16†	Jun 24-27	94-14 (150-22)	Night
17†	Jul 1-5	93-14 (149-22)	Night
18†	Jul 8-11	92-16 (147-26)	Night
19†	Jul 15-18	93-14 (149-22)	Night
20†	Jul 22-26	116-14 (186-22)	Night
21	Jul 29-Aug 2	131-14 (210-22)	Night
22	Aug 5-9	130-14 (208-22)	Night
23	Aug 12-15	138-14 (221-22)	Night

*Numbers in parentheses indicate kilometers.

**Day was defined as time between 0.5 hr after sunrise and 0.5 hr before sunset.

***Test session, data not included in report.

†Equipment malfunctions, sampling effort limited or samples voided.

been added to reduce water velocity in the cod end of the net and to increase survival of specimens. Sampling was conducted weekly at night between RM 14 (KM 22) and RM 77 (KM 123). A stratified random sampling design was used, and each tow was in a downstream direction (north to south), regardless of tidal stage, at a boat speed of approximately 1.0 m/sec (relative to the water) for 5 min. Throughout the six regions (Yonkers-Poughkeepsie) in the 12 sampling strata, 100 samples per week were collected. The allocation of samples was based on the 1973 distribution of juvenile striped bass and white perch. Sampling locations were selected and recorded in the same procedure as described for the ichthyoplankton longitudinal river survey (TI, 1975a).

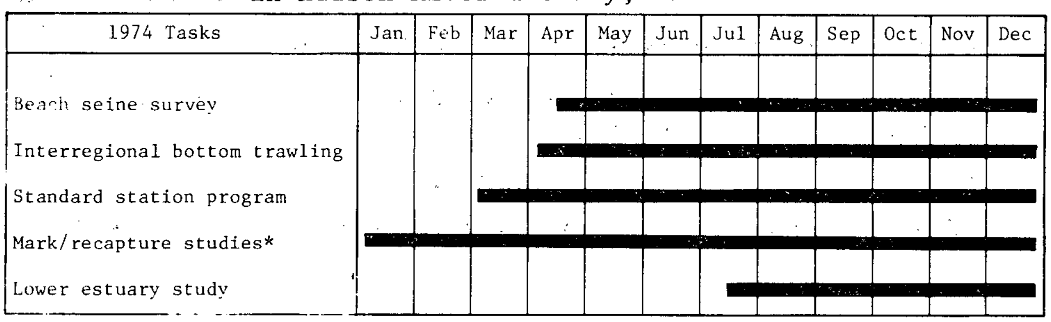
In the field, yearling and older fish were identified, enumerated, and released. Age II and older white perch were marked with an internal anchor tag and released.

The juveniles of all fish species collected were returned to the laboratory for identification and enumeration. Total lengths (TL) were measured in millimeters from a random subsample.

B. FISHERIES SAMPLING

Fisheries sampling provided data with which to describe the distribution, life history, and population dynamics of juvenile and older life stages of selected fish species (striped bass, white perch, Atlantic tomcod, American shad, and other *Alosa* spp.) The 1974 program comprised five major tasks: beach seine survey, interregional bottom trawl survey, Indian Point standard station program, mark/recapture studies, and the lower estuary study. Table III-3 summarizes these tasks.

Table III-3
Summary of Fisheries Sampling Program (Including Sampling Time) in Hudson River Estuary, 1974



*During July and August, only recapturing was conducted.

services group

1. Beach Seine Survey

The beach seine survey was designed to provide data on species composition, relative abundance, distribution, movement, and growth of juvenile and adult fishes in the shore zone (depths ≤3 m) and to supply the major sampling effort for the mark/recapture studies. Additionally, regional and total estuary standing crop estimates were made for juveniles of the selected fish species by extrapolating beach seine catch per unit effort (C/f) values to the total shore zone of the river. These estimates not only provided a check for the mark/recapture estimates of the juvenile striped bass and white perch populations in the form of a lower bound but provided a means of estimating the minimum juvenile population size for those fish species not included in the mark/recapture study.

Regions of the estuary sampled were from Yonkers through Albany [RM 12-152 (KM 19-243)]. Locations were selected based on a stratified random design using a random numbers table. Collections were made with a 100-ft (30.5-m) beach seine on a weekly basis during daylight from early April through December. Additionally, night sampling was done on a weekly basis from early August through November in the Croton-Haverstraw, Indian Point, West Point, and Cornwall regions [RM 34-61 (KM 54-98)].

To recapture fish marked during 1974, the entire estuary [RM 12-152 (KM 19-243)] was sampled in 1975 on a biweekly basis (day only) beginning in early April. On alternate weeks, beach seining was concentrated in the Yonkers-Cornwall regions [RM 12-62 (KM 19-99)].

2. Interregional Bottom Trawl Survey

Interregional bottom trawling was designed to provide data on species composition, abundance, distribution, and movement of juvenile and adult fish, particularly striped bass, white perch, and Atlantic tomcod, in shoal and channel areas of the estuary and to supply deep-water recovery effort for the striped bass, white perch, and Atlantic tomcod mark/recapture studies.

An otter-type bottom trawl equipped with a small-mesh cover (12.5-mm stretch) over the cod end sampled the estuary during daylight biweekly from early April through December. A total of 42 predetermined sampling locations between the George Washington and Newburgh-Beacon Bridges [RM 14-62 (KM 22-99)] were available; 39 were consistently sampled until 1975, when the number was reduced to 32 distributed between the Tappan Zee and Newburgh-Beacon Bridges [RM 27-62 (KM 43-99)].

3. Indian Point Standard Station Program

The standard station program provided a data base for yearly comparisons of abundance of fish species in the vicinity of the Indian Point Nuclear Power Station [RM 39-43 (KM 62-68)] and provided a recovery effort for marked fish. Beach seine samples were collected weekly from March through December with a 100-ft (30.5-m) seine during daylight at low tide at five sites in the Indian Point vicinity (TI, 1975b). Bottom trawling was done biweekly from April through December during the day at seven sites in the Indian Point vicinity (TI, 1975b). Additionally, on the day preceding or following regular standard station bottom trawling, a bottom trawl equipped with a knotless nylon cod-end liner of 0.5-in. (13.0-mm) stretched mesh was used from late July through December to obtain information on individuals or species that would have passed through the larger mesh of the unlined cod end. Surface samples were collected with a modified midwater trawl at seven sites in the Indian Point vicinity (TI, 1975b) biweekly during the day from mid-July through December.

4. Mark/Recapture Studies

The mark/recapture studies were designed to estimate population size, describe movements, and evaluate survival of striped bass, white perch, and Atlantic tomcod in the estuary. The marking program was divided into three seasonal efforts. Limiting factors included species abundance within the estuary and mortality induced by high water temperatures.

Atlantic tomcod were collected in box traps (Figures III-1 and III-2) during the winter (January-February 1974 and December 1974-February 1975).

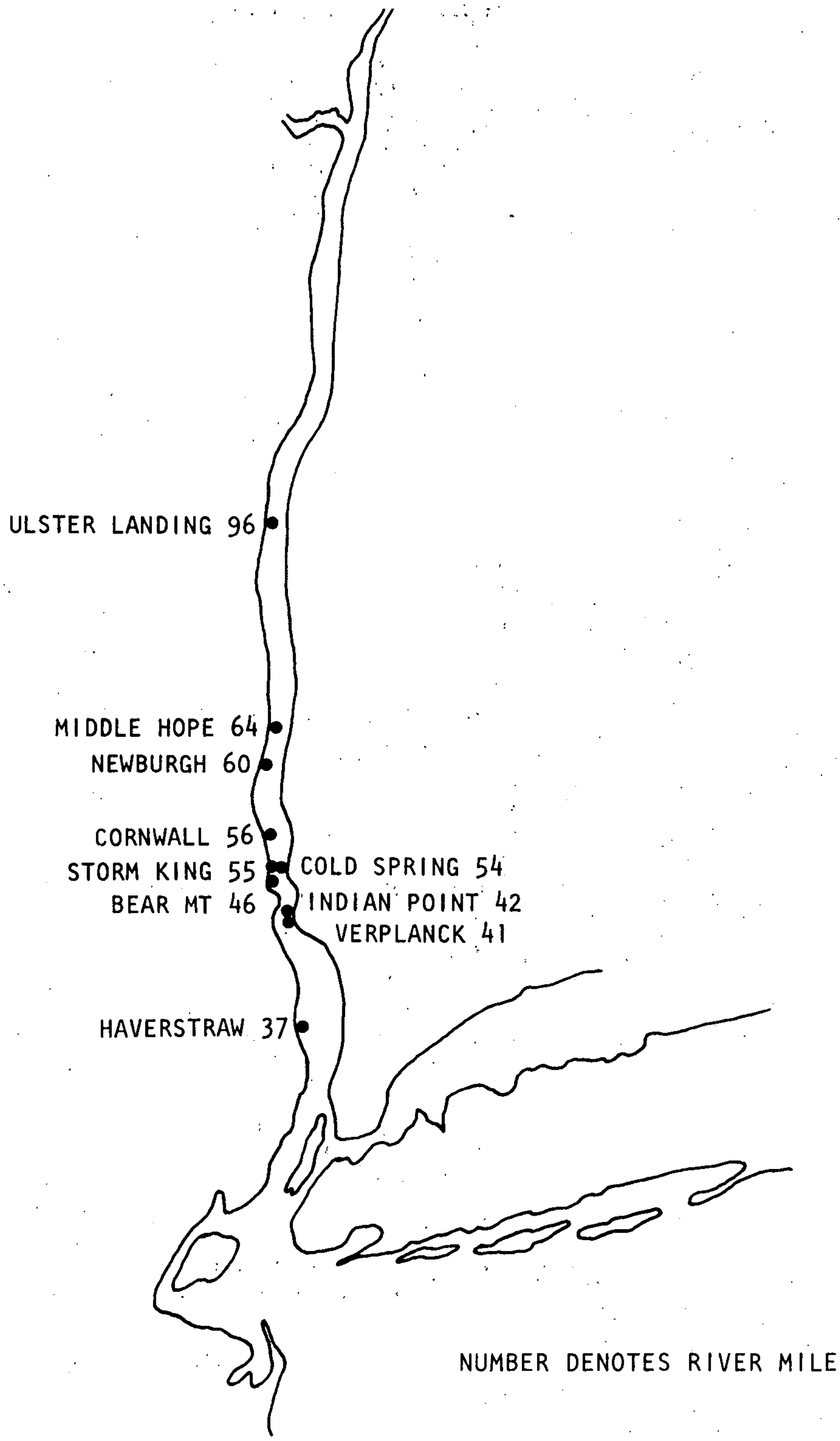


Figure III-1. Box Trap Sites for Collecting Atlantic Tomcod in Hudson River Estuary, January-February 1974

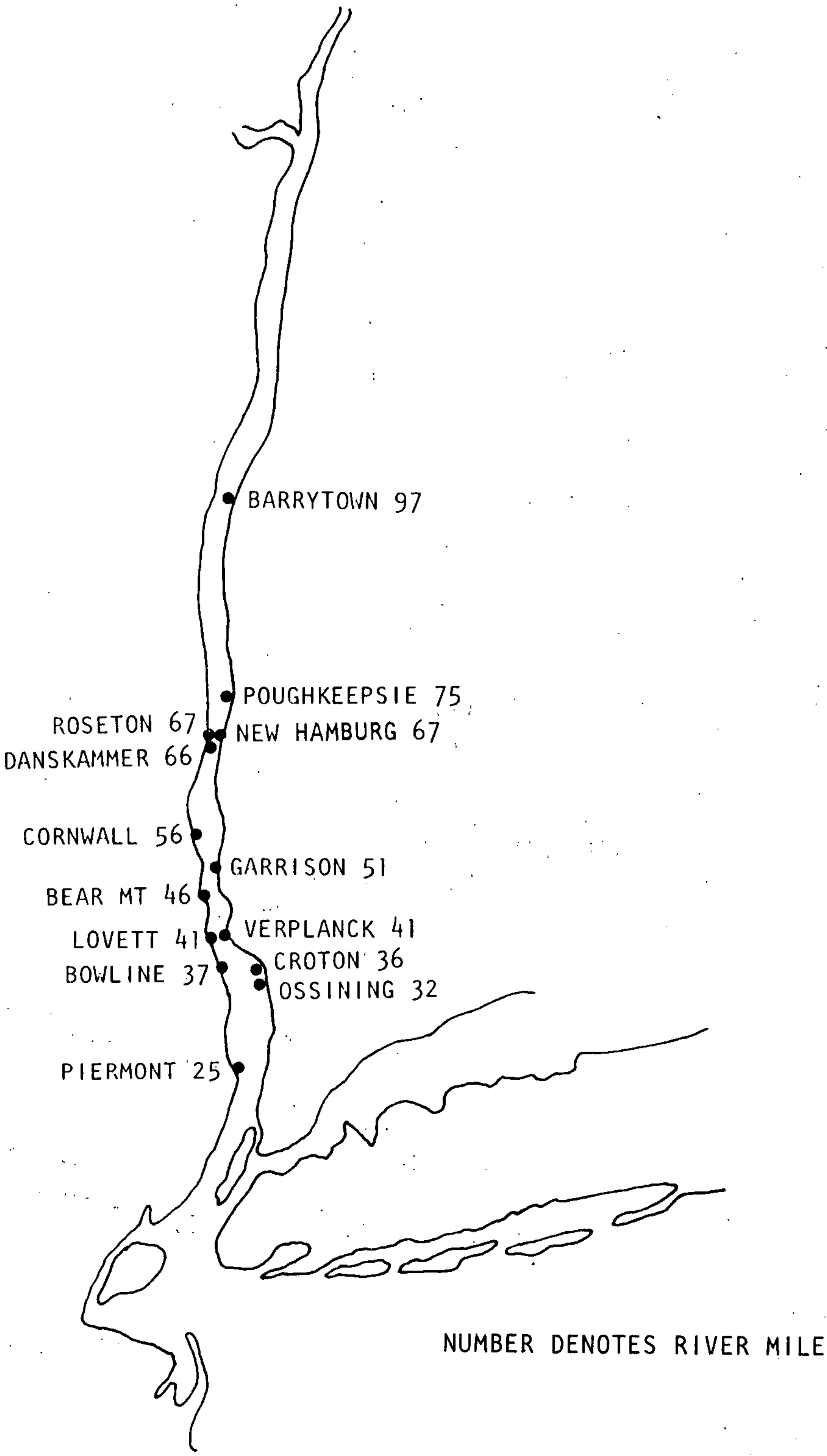


Figure III-2. Box Trap Sites for Collecting Atlantic Tomcod in Hudson River Estuary, December 1974-February 1975

Beach seines and box traps were used to collect striped bass during the fall (September-December 1974) and during the following spring (April-June 1975), and gill nets were used during the spring to collect large striped bass. During the fall, additional large (>150 mm) white perch were collected with epibenthic sleds. Mark type depended on age or size and species. Before July, young-of-the-year and yearling striped bass and white perch were finclipped; after July, yearling and older white perch were tagged with either a Floy fingerling tag (fish <150 mm) or a Floy internal anchor tag (fish ≥150 mm). Atlantic tomcod were either finclipped or tagged with a Carlin tag. Striped bass were tagged with either a Floy fingerling tag (fish 150-249 mm) or a Floy internal anchor tag (fish ≥250 mm). An attempt was made to distribute the marking effort for all species in proportion to their abundance within the various sampling regions.

All types of TI field sampling gear were employed for the continual recapture of marked fish throughout 1974 and through June 1975 (for this report). Additional recaptures were provided by impingement sampling at each power plant and field sampling by Lawler, Matusky, and Skelly Engineers (LMS), the New York State Department of Environmental Conservation, and sport and commercial fishing. Appendix C explains in detail the data collection and processing procedures for the mark/recapture studies.

5. Lower Estuary Study

The lower estuary study was designed primarily to supplement the mark/recapture studies through a recovery effort for striped bass, white perch, and Atlantic tomcod marked and released in the main sampling area above the George Washington Bridge (RM 12 [KM 19]). Selected areas below the George Washington Bridge were sampled with a 200-ft (61-m) haul seine from July through November 1974 and from April through mid-July 1975. Most of these areas were sampled also with an otter-type bottom trawl or an epibenthic sled from September through December 1974 and in March 1975. Also, gill nets and box traps were used from September through November 1974 to sample many areas intermittently, including western portions of the north and south shores of Long Island, the eastern shore of Staten Island, lower New York bay, and the Hackensack River. Volume III of this report discusses additional methods and presents a summary of the data collected during the lower estuary study.

SECTION IV

HISTORICAL DATA BASE

A. INTRODUCTION

Complete evaluation of the impact of power plants on Hudson River fish stocks requires consideration of trends in abundance and the extent to which factors other than power plants influence these trends. To evaluate the relative effects of power plants, biological factors, and physicochemical envoronmental factors on abundance trends, data on these factors and the abundance of four key fish species (striped bass, white perch, Atlantic tomcod, and American shad) were gathered from a variety of sources and combined to form the historical data base. Data from each of four components — ecological surveys, commercial fishery landings, water quality monitoring, and power plant operation — were compiled and selected subsets analyzed according to the following objectives:

- Summarize overall trends in abundance of striped bass, white perch, and American shad spawning stocks in the Hudson River from 1931 through 1974 based on commercial fishery statistics

- Describe annual fluctuations in abundance in the Hudson River of juvenile (young-of-the-year) Atlantic tomcod from 1969 through 1974, excluding 1971, and American shad from 1965 through 1974, excluding 1971

- Examine potential relationships of the annual abundance of juvenile American shad and Atlantic tomcod with various environmental factors

- Examine potential effects of spawning stock abundance, cannibalism, and predation on annual abundance of juvenile American shad and Atlantic tomcod

- Examine potential relationships of combined power plant operations with annual abundance of juvenile American shad and Atlantic tomcod

B. COMMERCIAL FISHERY TRENDS

Objective: Summarize overall trends in abundance of striped bass, American shad, and white perch spawning stocks in the Hudson River from 1931 through 1974 based on commercial fishery statistics

1. Description of Fishery

The Hudson River is fished commercially from Weehawken, New Jersey, to Hudson, New York, a distance of approximately 110 mi (177 km). Records of reported commercial landings of striped bass, American shad, and white perch between 1931 and 1974 were obtained from Fred Blossum (National Marine Fisheries Services, Patchogue, Long Island), along with records of the gear used (including total square yards of licensed stake, anchor, and drift gill nets and number of licensed nets of each type) and number of licensed commercial fishermen. Landing data separated by county (New York) and gear type for 1965-71, 1973, and 1974 also were obtained from Fred Blossum for these species. County landing data for 1972 are not available and are believed to have been lost during a change in NMFS personnel. The New York State Department of Conservation (DEC), Albany, provided information on maximum hours of gill net fishing allowed per week and other regulations during those years, and striped bass and white perch landing data for 1942 and 1949-51 were obtained from DEC annual reports in Albany, New York. Striped bass and white perch landings for 1954 were determined by subtracting New York marine landings (U.S. Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries) from New York State landings (Fisheries Statistics of U.S., NOAA, NMFS) to approximate Hudson River landings. New Jersey commercial fishing regulations were obtained from Gene LaVerde (National Marine Fisheries Service, Toms River, New Jersey) and Bob Soweidel (Department of Environmental Protection, Division Fish, Game, and Shell Fisheries, Lebanon, New Jersey).

a. Gear

Striped bass, American shad, and white perch are taken from the Hudson River primarily with the gill net, a wall of webbing that is suspended vertically in the water by weights (lead) on the bottom and floats on the top line. The webbing may be constructed of natural or synthetic fibers. Mesh size varies, depending on the species and size of fish desired by the fisherman. Stake and anchor and gill nets are held in position by stakes driven into the river bottom or by anchors. Drift gill nets are suspended in wide stretches of rivers and drift with the current (Rounsefell, 1975:146).

The stake and anchor gill net fishery is concentrated between Weehawken, New Jersey, and Peekskill, New York. The drift gill net fishery extends primarily upstream from Peekskill to Hudson, New York (Figure IV-1). Drift, stake, and anchor gill nets are important in the shad fishery (Burdick, 1954), but stake and anchor gill nets are primarily used to take striped bass (Table IV-1). Based on 10 years of available data (1965-71, 1973, and 1974), stake and anchor gill nets were effective in taking most white perch (82%); the remaining 18% were captured in haul seines and fyke and dip nets (Table IV-1).

The total number of licensed gill nets in the Hudson River fishery (Figure IV-2) fluctuated from 123 in 1931 to 711 in 1936. Numbers remained high throughout World War II and during the immediate post-war years but declined steadily after 1950, recording the lowest levels in the late 1960s and early 1970s. The number of gill nets licensed in the Hudson River increased to 73 and 87 in 1973 and 1974 respectively.

The total area (square yards) of licensed gill nets varied over the 44 years, peaking at approximately 900,000 yd^2 in 1938 and declining rapidly to <400,000 yd^2 in 1942 (Figure IV-3). Yardage reached the highest reported level in 1947 and then fell to just over 400,000 yd^2 in 1953. A slower decline lasted into the late 1960s and early 1970s. A rather steady increase began in 1972, and 182,000 yd^2 was reached in 1974.

The average area (square yards) per drift gill net was higher than the average area per stake and anchor gill net (Figure IV-4). The former had a relatively constant pattern in the 1960s and early 1970s, a large decrease in 1973, and an increase in 1974. The average area per stake and anchor gill net remained essentially unchanged in the late 1960s and early 1970s.

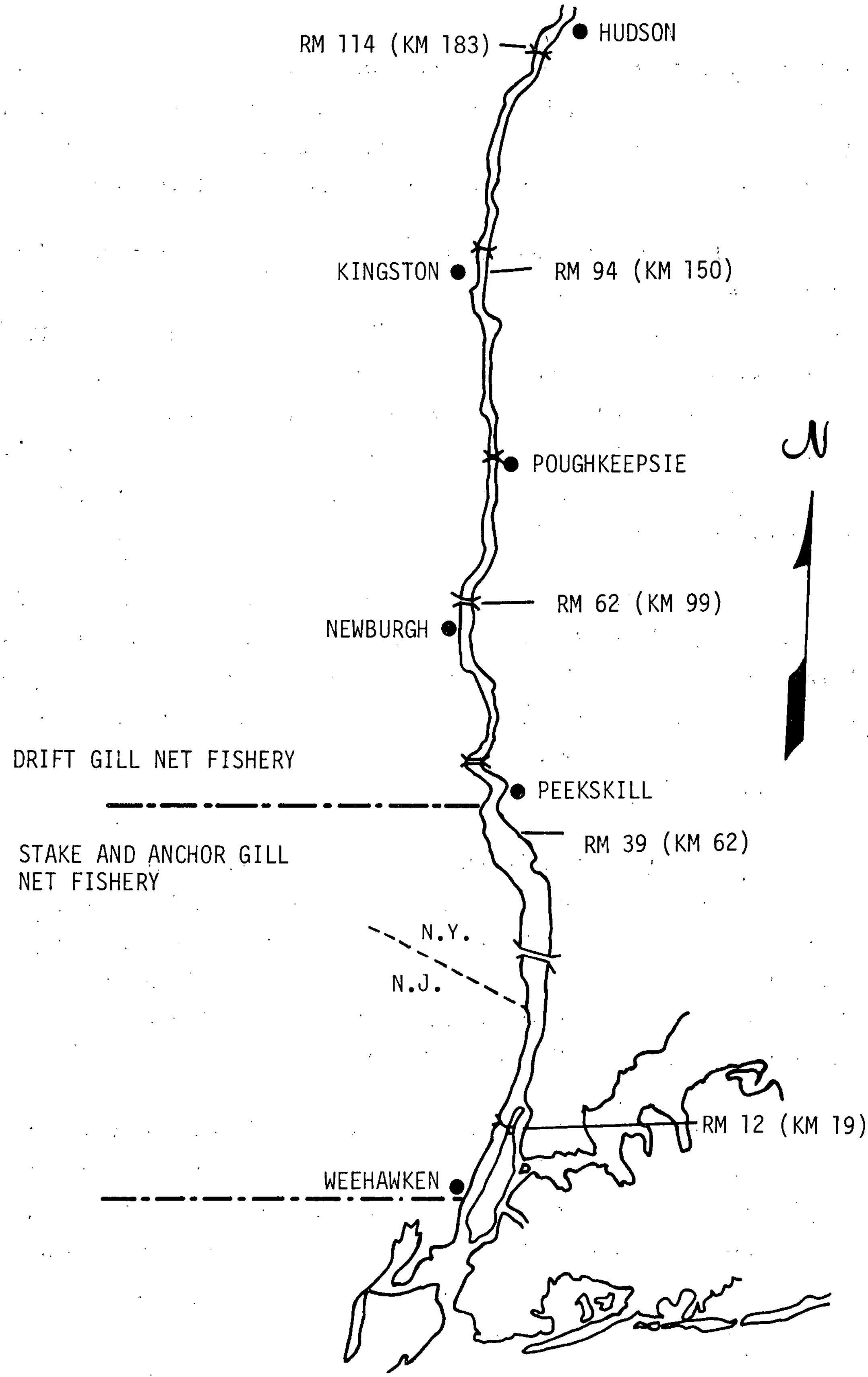


Figure IV-1. Locations of Major Drift Gill Net and Stake and Anchor Gill Net Fisheries in Hudson River South of Troy, New York. (RM refers to river mile; KM refers to kilometer)

Table IV-1

Percentage of Reported Commercial Landings of Striped Bass, White Perch, and American Shad Taken in Various Gear in Hudson River during 1965-71, 1973, and 1974

Gear	Species		
	Striped Bass*	American Shad**	White Perch*
Gill nets			
Anchor and stake	93.5	73.8	81.8
Drift	5.0	25.6	3.2
Haul seines	1.4	0.6	0.3
Fyke nets	0	0	12.1
Dip nets	0	<0.01	2.6

*New York only.

**New York and New Jersey.

The proportion of licensed gill nets that were drift type has fluctuated, ranging from a high of 0.87 in 1932 to a low of 0.17 in 1936 (Figure IV-5). In 1973, the proportion of drift nets was 0.68, the most since the late 1930s. The proportion of drift nets decreased to 0.31 in 1974.

The number of licensed commercial fishermen increased irregularly from 1931 to 1947 when there were almost 1200 (Figure IV-2); thereafter, the number of fishermen fell sharply until the mid-1950s and then gradually declined to a low of <50 in 1971 before increasing to >250 in 1974. The number of licensed fishermen has been directly related to the number of licensed gill nets (Figure IV-2), especially since the mid-1940s, indicating that most commercial fishermen operating in the Hudson River licensed at least one gill net.

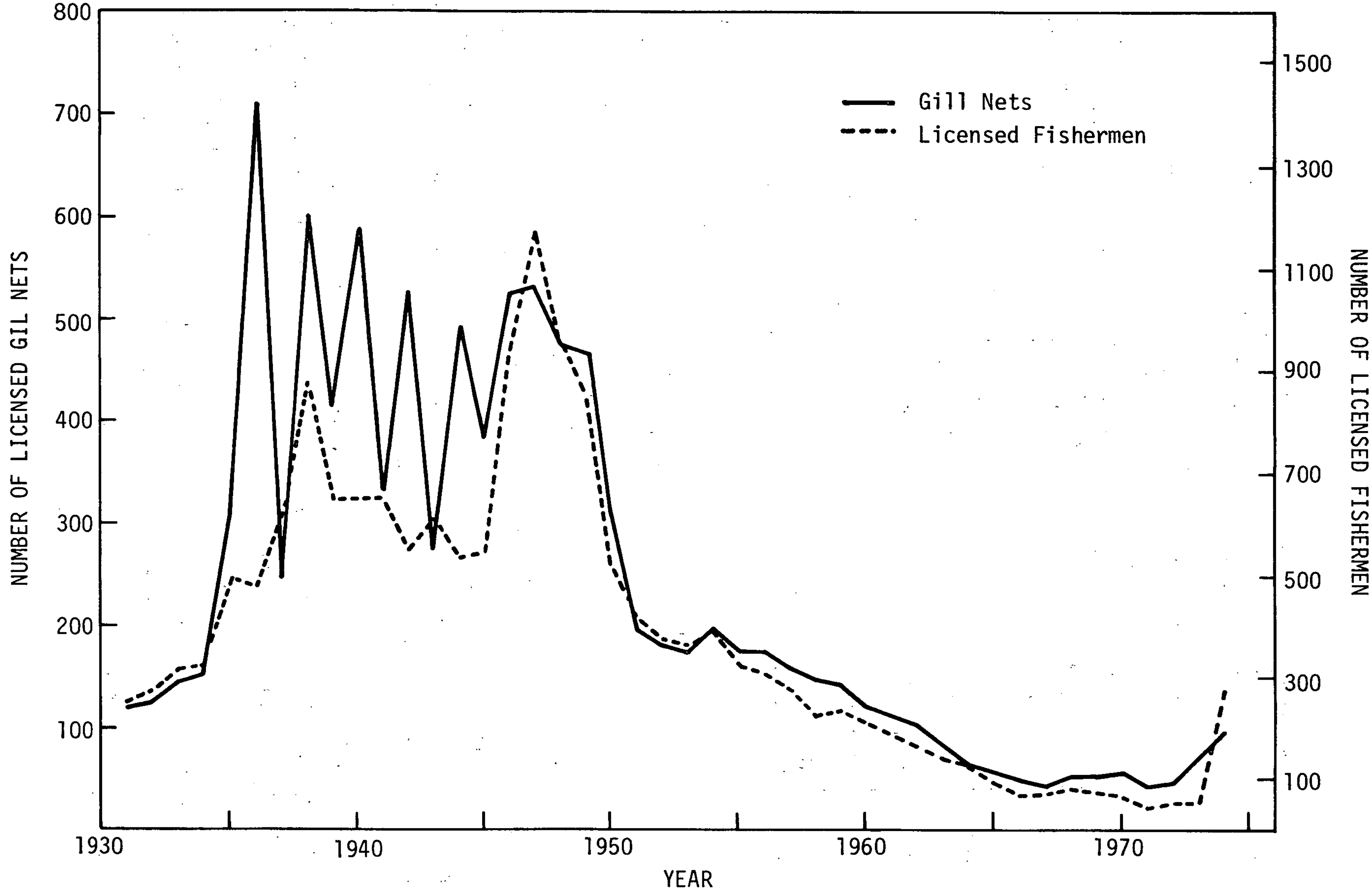


Figure IV-2. Number of Licensed Gill Nets and Fishermen in Hudson River from Weehawken, New Jersey, to Hudson, New York, 1931-74

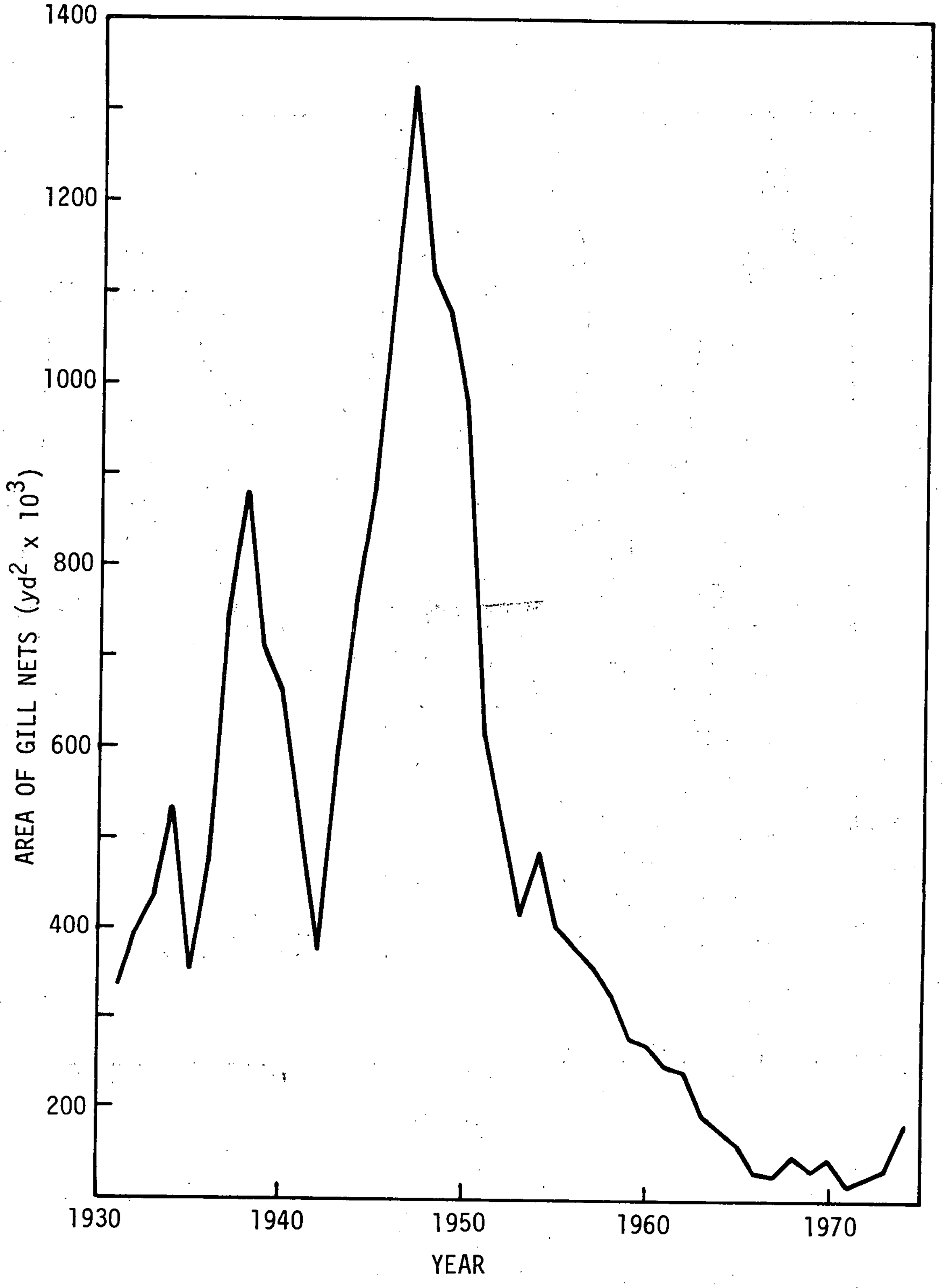


Figure IV-3. Total Square Yards of All Licensed Gill Nets in Hudson River from Weehawken, New Jersey, to Hudson, New York, 1931-74

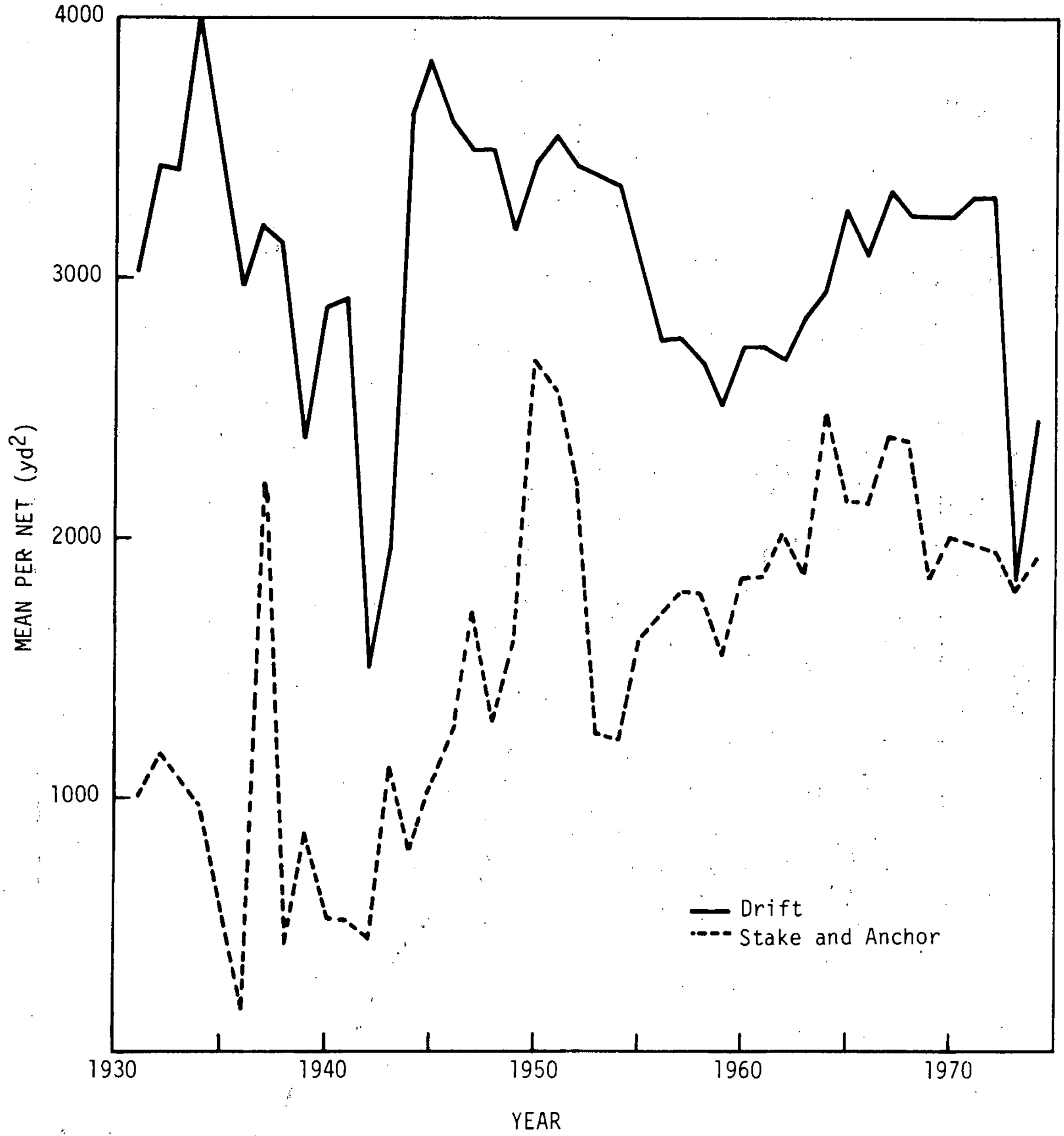


Figure IV-4. Mean Square Yards per Net for Licensed Stake and Anchor Gill Nets and Drift Gill Nets Licensed in Hudson River, New York and New Jersey, 1931-74

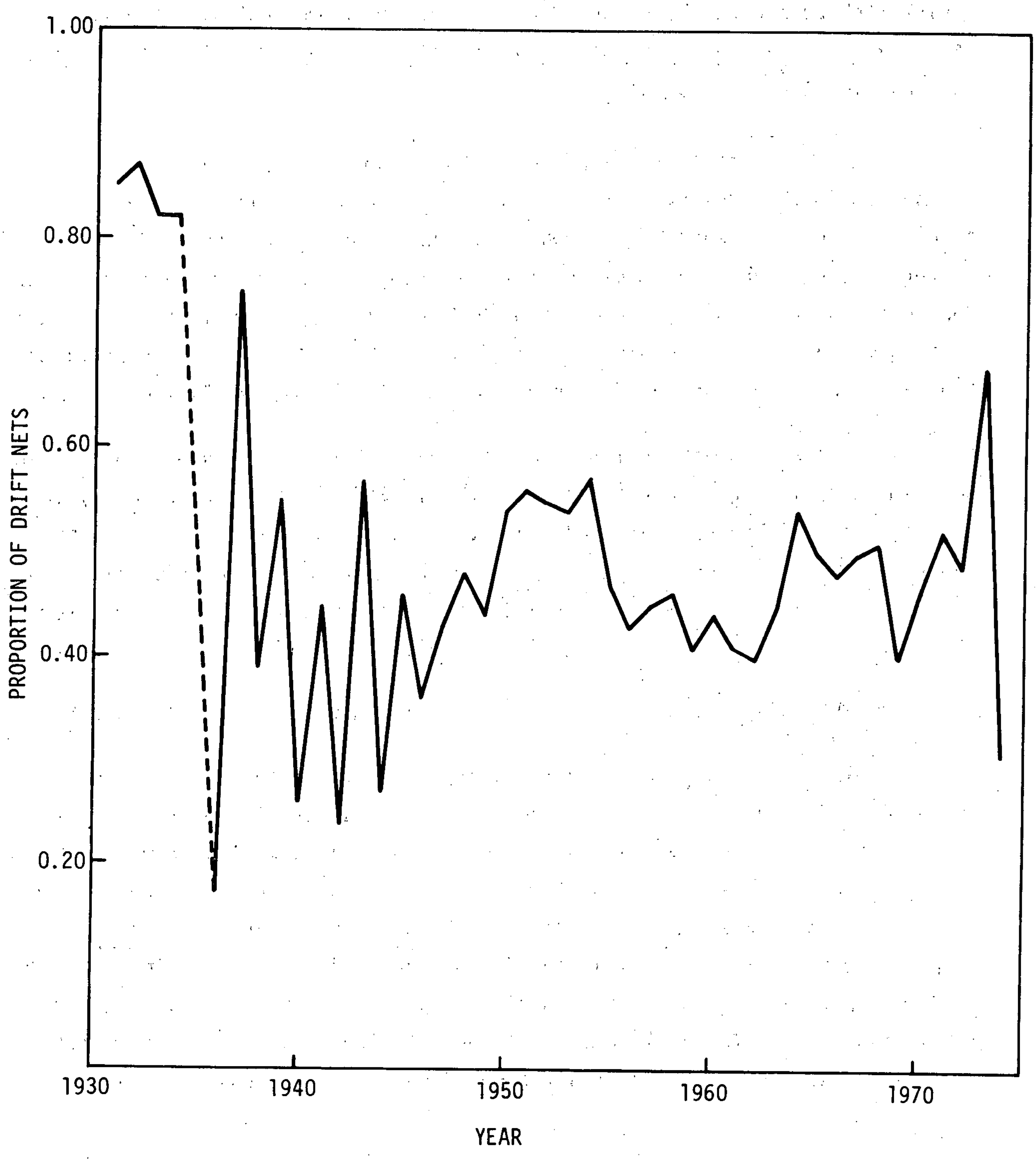


Figure IV-5. Proportion of Licensed Drift-Type Gill Nets Used in Hudson River, 1931-74

b. Regulations

The Hudson River commercial fishery is controlled by regulations defining fishing seasons, restricted areas, minimum size limits, escapement (net lift) periods, minimum distances between gill nets, maximum gill net length, and minimum gill net mesh size.

The commercial fishing season for striped bass in 1974 was from 16 March through 30 November (New York only). There is no commercial gill net fishery for striped bass in the New Jersey areas of the Hudson River. The winter fishing season for striped bass has been closed since 1949-50. The open season for American shad extends from 15 March through 1 June. No commercial netting of any kind is permitted from 15 March through 15 June on a portion of the major shad spawning grounds known as "the Flats" [RM 91-96 (KM 146-154)].

A change in the regulations in 1949 eliminated the use of haul seines and fyke nets in the capture of striped bass. Since 1938, the minimum legal size for striped bass in New York has been a fork length of 16 in. (406 mm); before 1938, the minimum size had been a fork length of 12 in. (305 mm). No minimum size limit for American shad is specified in New York or New Jersey regulations.

There is no closed season or minimum limit size for white perch.

The length of the potential escapement period for striped bass, American shad, and white perch is reflected by the hours of gill net fishing allowed per week during the 15 March-1 June shad season (Figure IV-6). Since 1940, net lift periods in New York and New Jersey have coincided; in 1959, they were set at 48 hr/wk (6:00 a.m. EST on Friday to 6:00 a.m. EST on Sunday), thus permitting 120 hr/wk of fishing. The long weekend net lift periods during the 1930s in New York were substantially reduced in the 1940s. From 1951 through 1958, legal fishing time for gill nets was reduced to 108 hr/wk. Other commercial gear can be set and operated at any time during the open season.

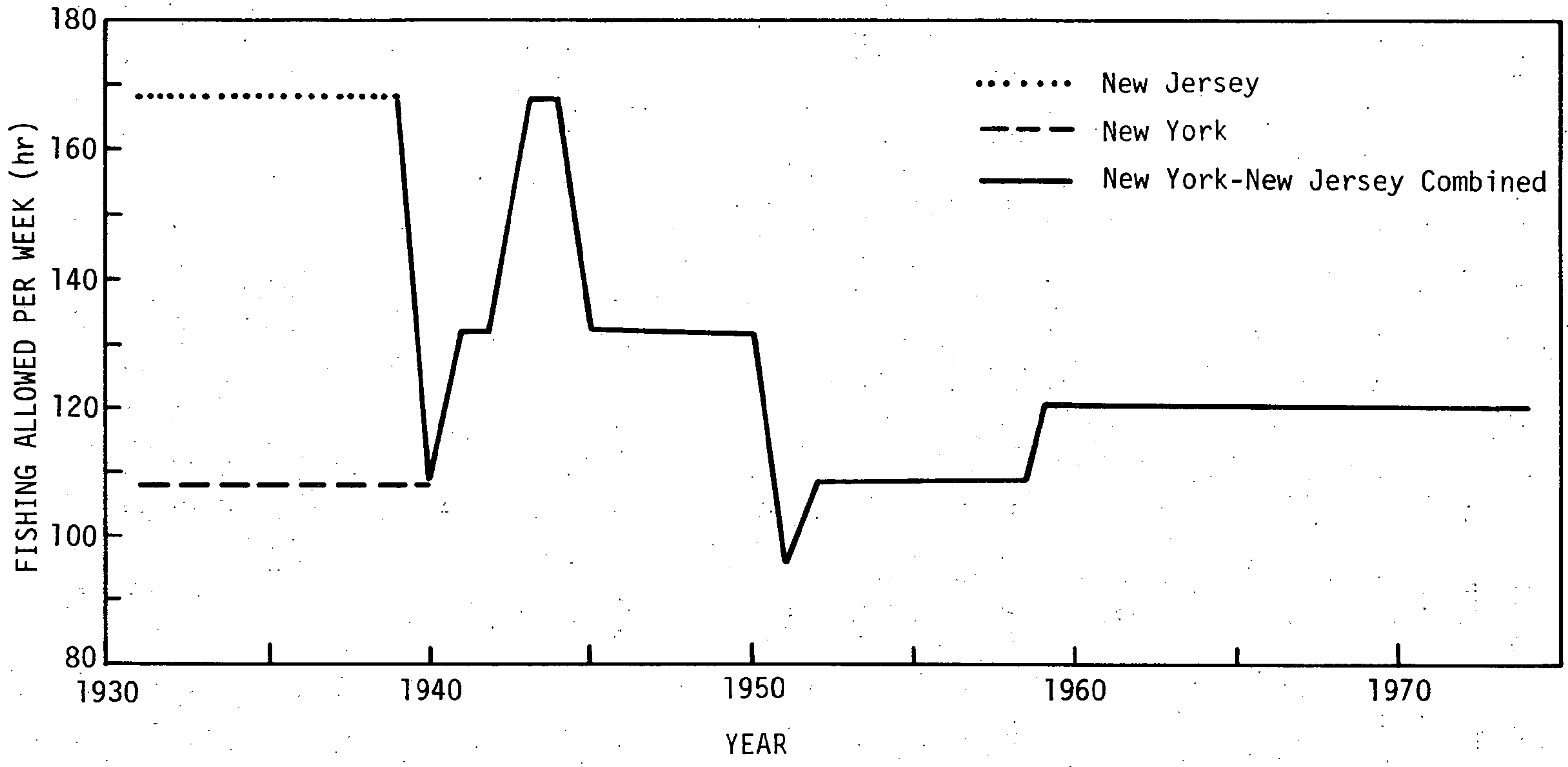


Figure IV-6. Hours of Gill Net Fishing Allowed Weekly in Hudson River, New York and New Jersey, 1931-74

Stake and anchor gill nets in New York may not exceed 1200 ft (366 m), and drift gill nets may not exceed 2000 ft (610 m) in length. Minimum mesh size must be at least 2.25 in. (5.7 cm) for fish other than smelt and Atlantic tomcod. New Jersey drift nets may not exceed 1200 ft (366 m), and the minimum mesh size for all legal species is 2.75 in. (7.0 cm). Stake and anchor nets licensed in New Jersey may not exceed 300 ft (91 m), and the minimum mesh size for all legal species is 5 in. (12.7 cm). Minimum legal distance between stake and anchor gill nets is 1500 ft (457 m).

c. Landings (Yield)

1) Striped Bass

Striped bass yield (landings in pounds) increased steadily in the 1930s and early 1940s, reaching a peak of 79,000 lb in 1945 (Figure IV-7 and Table IV-2), which corresponded with the large number of gill nets licensed during World War II. Landings then declined in the late 1940s and early 1950s but reached high levels again in 1956, 1959, and 1960. Landings declined in the early 1960s but peaked in 1969. Another decline resulted in a low of 18,000 lb in 1962. A peak occurred in 1973 and another decrease in 1974.

2) American Shad

American shad landings in gill nets increased steadily from 1931 to 1944 when they peaked at 3,781,000 lb (Figure IV-8 and Table IV-3). Landings then decreased until 1951 but increased again to 1,679,000 lb in 1956. Since 1956, American shad landings have steadily declined except for slight increases in 1973 and 1974.

3) White Perch

Recorded white perch landings from 1931 to 1944 are believed to have included yellow perch landings and thus are not reliable for white perch landing values (Table IV-2). White perch landings peaked in 1948, 1950, and 1958, reaching 61,000 lb in 1935 and declining to <1000 lb in the 1970s (Figure IV-9 and Table IV-2). In 1973 and 1974, white perch landings were approximately 800 lb.

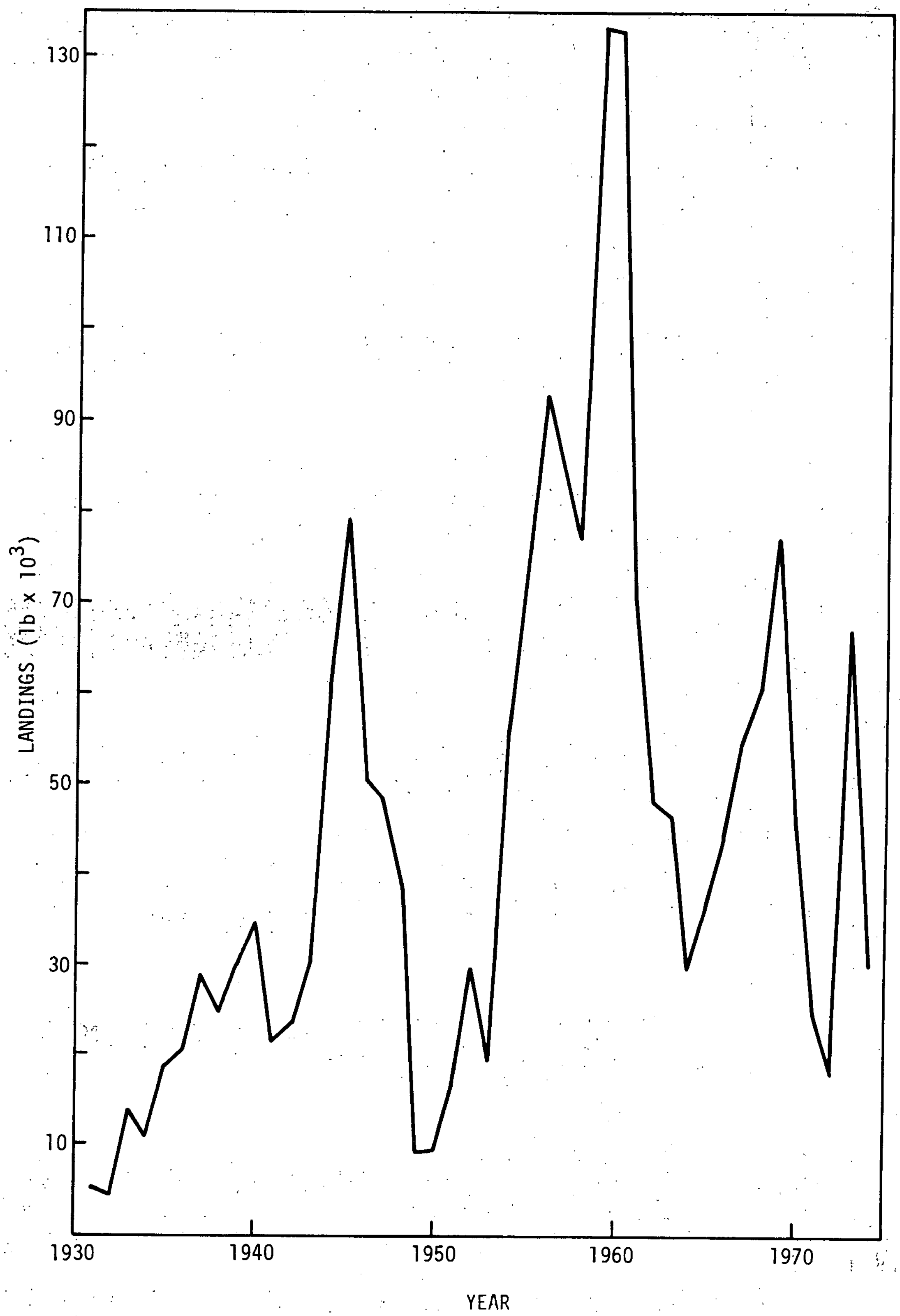


Figure IV-7. Striped Bass Landings in Hudson River, New York, 1931-74

Table IV-2

Commercial Fishery Statistics for Striped Bass and White Perch Taken from Hudson River in New York, 1931-74

Year	Landings of Striped Bass (lb)	Landings of White Perch (lb)	Stake and Anchor Gill Nets (yd^2)	Drift Gill Nets (yd^2)	Total Gill Nets (yd^2)	Gill Net Fishing Allowed Weekly (hr)	Gill Net Fishing Effort (f) ($yd^2 \cdot h \cdot 10^{-6}$)	Striped Bass Yield per Effort (Y/f)	White Perch Yield per Effort (Y/f)
1931	5,330	14,436†	12,167	315,298	327,465	108	35.36	151	408
1932	4,508	16,325†	9,072	376,884	385,956	108	41.68	108	392
1933	13,616	19,235†	13,370	404,873	418,243	108	45.17	301	426
1934	10,905	31,225†	2,410	505,050	507,460	108	54.81	199	570
1935	18,667	60,552†	---	---	317,555	108	34.30	544	1,766
1936	20,120	46,856†	32,240	368,490	400,730	108	43.28	465	1,083
1937	28,854	26,538†	3,599	595,499	599,098	108	64.70	446	410
1938	24,579	35,421†	6,993	727,751	734,744	108	79.35	310	446
1939	29,937	24,479†	4,632	551,604	556,236	108	60.07	498	407
1940	34,634	39,856†	103,176	426,850	530,026	108	57.24	605	696
1941	21,336	46,426†	25,142	430,094	455,236	132	60.09	355	773
1942	23,565	37,457†	59,628	188,300	247,928	132	32.73	720	1,144
1943	30,889	30,155†	13,280	460,880	474,160	168	79.66	388	379
1944	60,918	13,848†	166,211	474,500	640,711	168	107.64	566	129
1945	79,350	17,166	69,400	675,500	744,900	132	98.33	807	175
1946	50,622	8,458	112,800	680,500	793,300	132	104.72	483	81
1947	48,453	8,992	85,500	806,000	891,500	132	117.68	412	19
1948	38,830	21,028	91,000	794,000	885,000	132	116.82	332	180
1949	9,133	11,784	57,125	621,000	678,125	132	89.51	102	132
1950	9,539	20,108	55,628	538,500	594,128	132	78.42	122	256
1951	17,338	6,067	40,275	390,400	430,675	96	41.34	419	147
1952	29,847	2,901	41,025	340,100	381,125	108	41.16	725	70
1953	19,352	9,320	41,280	316,255	357,535	108	38.61	501	241
1954	56,000*	8,000*	68,670	378,800	447,470	108	48.33	1,159	166
1955	73,400	9,205	113,340	251,177	364,517	108	39.38	1,864	234
1956	92,824	3,446	114,526	209,707	324,233	108	35.02	2,651	98
1957	84,500	6,000	113,415	199,163	312,578	108	33.76	2,503	178
1958	77,100	12,500	112,385	182,324	294,709	108	31.83	2,422	393
1959	133,100	8,400	101,359	145,489	246,848	120	29.62	4,494	284
1960	132,900	4,350	92,960	144,415	237,375	120	28.49	4,665	153
1961	70,700	6,300	92,639	125,873	218,512	120	26.22	2,696	240
1962	48,100	4,100	96,329	113,059	209,388	120	25.13	1,914	163
1963	46,700	5,800	66,434	101,784	168,218	120	20.19	2,313	287
1964	29,500	5,700	57,423	103,484	160,907	120	19.31	1,528	295
1965	36,700	3,600	54,448	94,822	149,270	120	17.91	2,049	201
1966	44,342	1,130	50,280	74,480	124,760	120	14.97	2,962	75
1967	54,642	1,490	41,782	73,748	115,530	120	13.86	3,942	107
1968	60,800	1,700	50,600	87,720	138,320	120	16.60	3,663	102
1969	77,155	2,600	58,125	71,390	129,515	120	15.54	4,965	167
1970	45,900	1,400	59,390	83,965	143,355	120	17.20	2,669	81
1971	24,747	200	38,912	76,315	115,227	120	13.83	1,789	14
1972	17,946	---	43,994	76,316	120,310	120	14.44	1,243	---
1973	67,035	847	38,703	92,024	130,727	120	15.69	4,272	54
1974	30,331	780	110,580	66,348	176,928	120	21.23	1,429	---

*Estimated landings from New York state and New York marine landings statistics.
†Believed to include yellow perch landings.

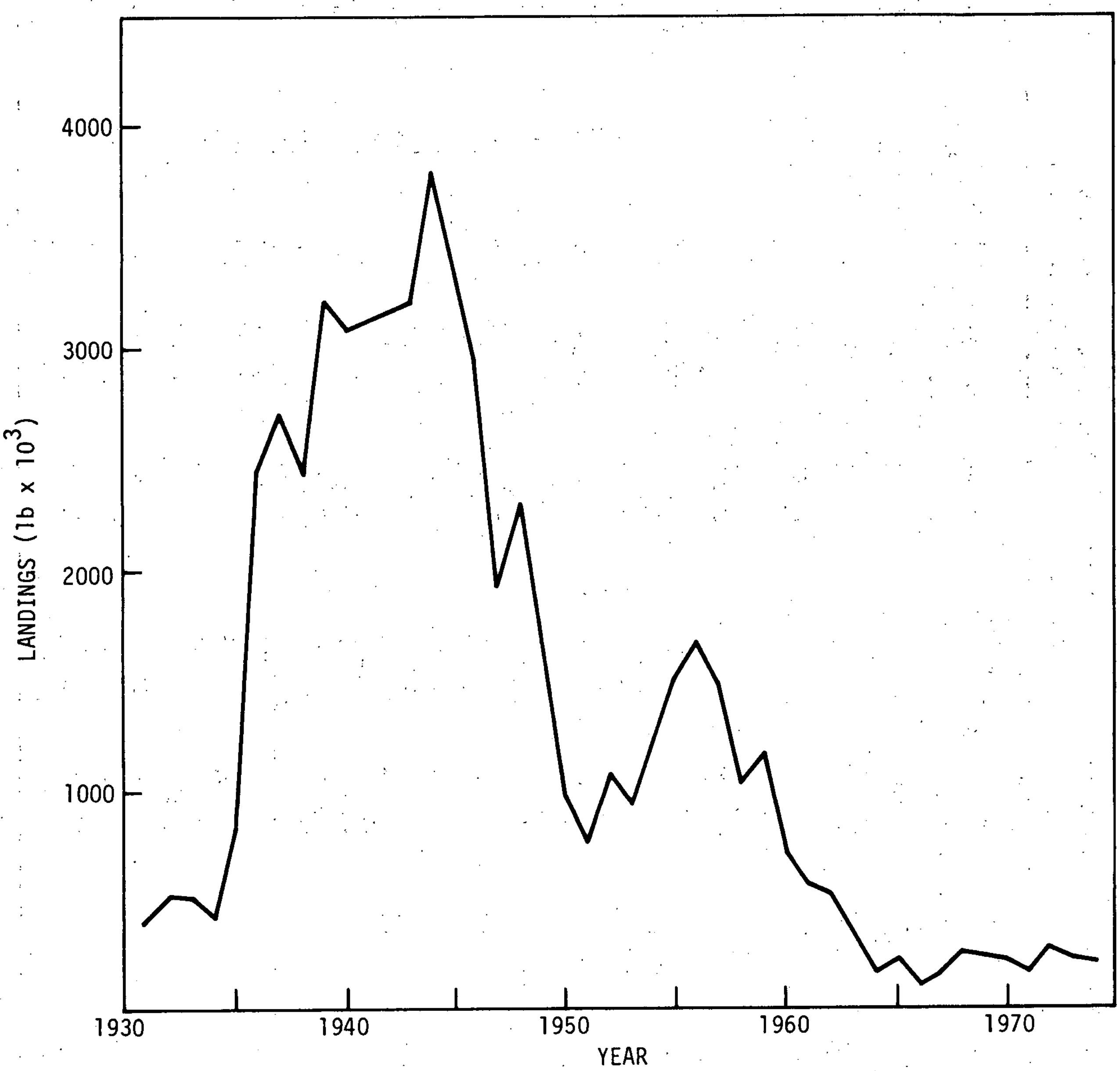


Figure IV-8. American Shad Landings (in Gill Nets Only), Hudson River, Weehawken, New Jersey, to Hudson, New York, 1931-74

Table IV-3

Commercial Fishery Statistics for American Shad Taken from Hudson River between Weehawken, New Jersey, and Hudson, New York, 1931-74

Year	Landings (lb) Haul Seines	Other Gear	Gill Nets	Stake and Anchor Gill Nets (yd^2)	Drift Gill Nets (yd^2)	Total Gill Nets (yd^2)	Gill Net Fishing Allowed Weekly (hr) NY	NJ	Gill Net Fishing Effort (f) ($yd^2 \cdot h \cdot 10^{-6}$)	Gill Net Yield per Effort (Y/f)
1931	3,815	1,438	409,358	19,167	315,298	334,465	108	168	36.54	11,203
1932	1,350	100	528,304	18,748	376,884	395,632	108	168	43.31	12,198
1933	1,670		517,010	28,760	406,871	435,631	108	168	48.09	10,751
1934	3,000	4,800	430,200	27,330	505,050	532,380	108	168	58.99	7,293
1935	10,200	8,600	828,600			353,735	108	168	40.37	20,525
1936	16,800	700	2,450,400	103,180	368,490	471,670	108	168	55.20	44,391
1937	19,700		2,712,500	137,375	597,529	734,904	108	168	87.52	30,993
1938	11,600		2,455,400	151,472	729,111	880,583	108	168	103.85	23,644
1939	59,600		3,211,100	159,210	552,804	712,014	108	168	86.24	37,234
1940	15,900		3,098,500	232,808	430,379	663,187	108	108	71.62	43,263
1941	4,600		3,128,900	94,511	432,106	526,617	132	132	69.51	45,014
1942	2,900	1,100	3,181,900	183,384	191,100	374,484	132	132	49.43	64,372
1943	11,400	4,000	3,209,950	132,859	462,970	595,829	168	168	100.10	32,068
1944	28,300		3,781,100	284,601	475,835	760,436	168	168	127.75	29,598
1945	48,800	28,600	3,399,800	214,400	677,700	892,100	132	132	117.76	28,871
1946	23,300		2,948,843	422,800	680,500	1,103,300	132	132	145.64	20,247
1947	42,900	4,600	1,934,292	519,360	806,000	1,325,360	132	132	174.95	11,056
1948	65,500		2,288,900	322,160	800,360	1,122,520	132	132	148.17	15,448
1949	43,300		1,684,070	425,686	653,500	1,079,186	132	132	142.45	11,822
1950	27,900		981,000	387,828	583,080	970,908	132	132	128.16	7,654
1951	7,400		756,700	224,915	390,400	615,315	96	96	59.07	12,810
1952	3,200		1,073,900	180,027	340,100	520,127	108	108	56.17	19,119
1953	3,400		935,322	99,600	316,255	415,855	108	108	44.91	20,827
1954	4,225		1,245,061	104,267	379,889	484,156	108	108	52.29	23,811
1955	3,000		1,507,340	150,008	252,777	402,785	108	108	43.50	34,651
1956	2,000		1,679,166	168,826	210,151	378,977	108	108	40.93	41,025
1957	3,100		1,494,580	158,495	199,913	358,408	108	108	38.71	38,610
1958	2,311		1,043,454	140,793	182,768	323,561	108	108	34.94	29,864
1959	1,134		1,170,078	132,225	146,022	278,247	120	120	33.39	35,043
1960	3,281		720,291	125,463	145,109	270,572	120	120	32.47	22,183
1961	1,800		587,189	122,661	125,873	248,534	120	120	29.82	19,691
1962	2,400		525,280	127,281	113,059	240,340	120	120	28.84	18,214
1963	1,700		346,318	85,677	105,338	191,015	120	120	22.92	15,110
1964			181,865	74,555	103,484	178,039	120	120	21.36	8,514
1965			237,521	62,203	94,822	157,025	120	120	18.84	12,607
1966			116,332	55,791	74,480	130,271	120	120	15.63	7,443
1967			176,358	52,893	73,748	126,641	120	120	15.20	11,603
1968			254,372	61,555	87,720	149,275	120	120	17.91	14,203
1969			243,104	61,209	71,390	132,599	120	120	15.91	15,280
1970			231,571	62,474	83,965	146,439	120	120	17.57	13,180
1971			170,798	41,911	76,315	118,226	120	120	14.19	12,037
1972			288,760†	46,994	76,316	123,310	120	120	14.80	19,511
1973	5,000		247,205	41,703	92,024	133,727	120	120	16.05	15,402
1974	9,500	10	222,121	115,913	66,348	182,261	120	120	21.87	10,156

*These records supersede data presented in earlier report (TI, 1975a).
†May also include landings in haul seines and other gear.

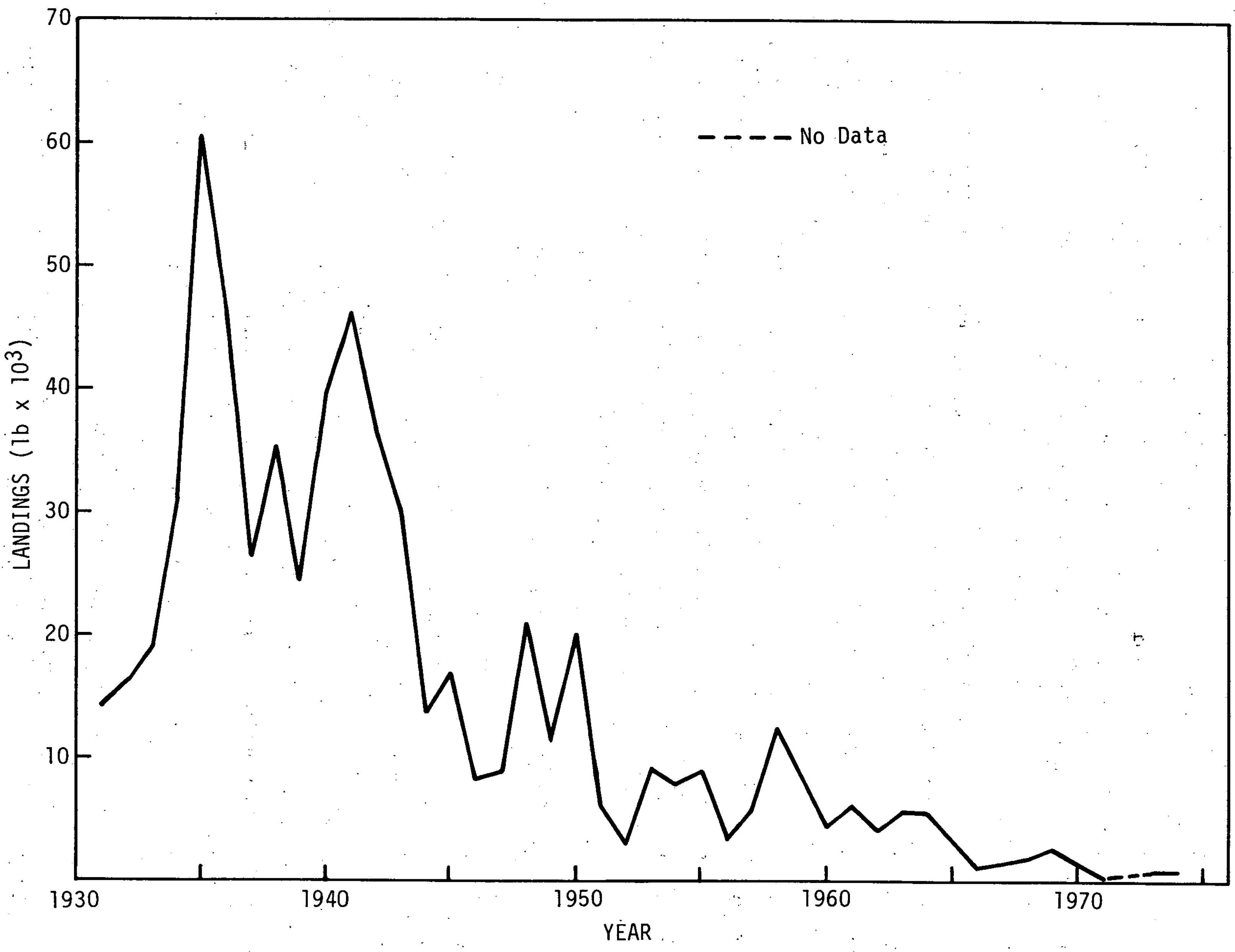


Figure IV-9. White Perch Landings in Hudson River, New York, 1931-74

2. Index of Fishing Effort

a. Calculation of Fishing Effort

An index of fishing effort (f) for each year between 1931 and 1974 was calculated as the product of square yards of all licensed gill nets, hours of legal gill net fishing per week, and a scaling factor:

$$f = yd^2 \cdot h \cdot 10^{-6}$$

Gill net data were used to generate the index of fishing effort because the breakdown of 1965-71, 1973, and 1974 catches by gear (Table IV-1) indicated that the majority of striped bass, American shad, and white perch had been taken in gill nets (anchor, stake, and drift). The square yardage of nets licensed in New York waters was used to calculate the index of striped bass and white perch fishing effort; the square yardage of nets licensed in New York and New Jersey was used to calculate American shad fishing effort. Fishing efforts for New York and New Jersey were calculated separately and then summed because of the difference in legal fishing hours per week (Figure IV-6).

b. Trends in Fishing Effort

1) American Shad

The index of gill net fishing effort for American shad in New York and New Jersey increased from 1931 through the late 1930s and then declined rapidly to a low in 1942 (Figure IV-10 and Table IV-3). Fishing effort then increased rapidly to the highest recorded level in 1947 when yardage was at its peak and 132 hr/wk of fishing was allowed. Effort remained high until 1950 and declined abruptly in 1951, with the decline continuing gradually through the 1950s and early 1960s. A stabilization at very low levels occurred in the late 1960s and early 1970s. A slight increase occurred in 1973 and 1974.

2) Striped Bass and White Perch

The gill net fishing effort index for striped bass and white perch (New York only) increased irregularly during the 1930s and 1940s, reaching its

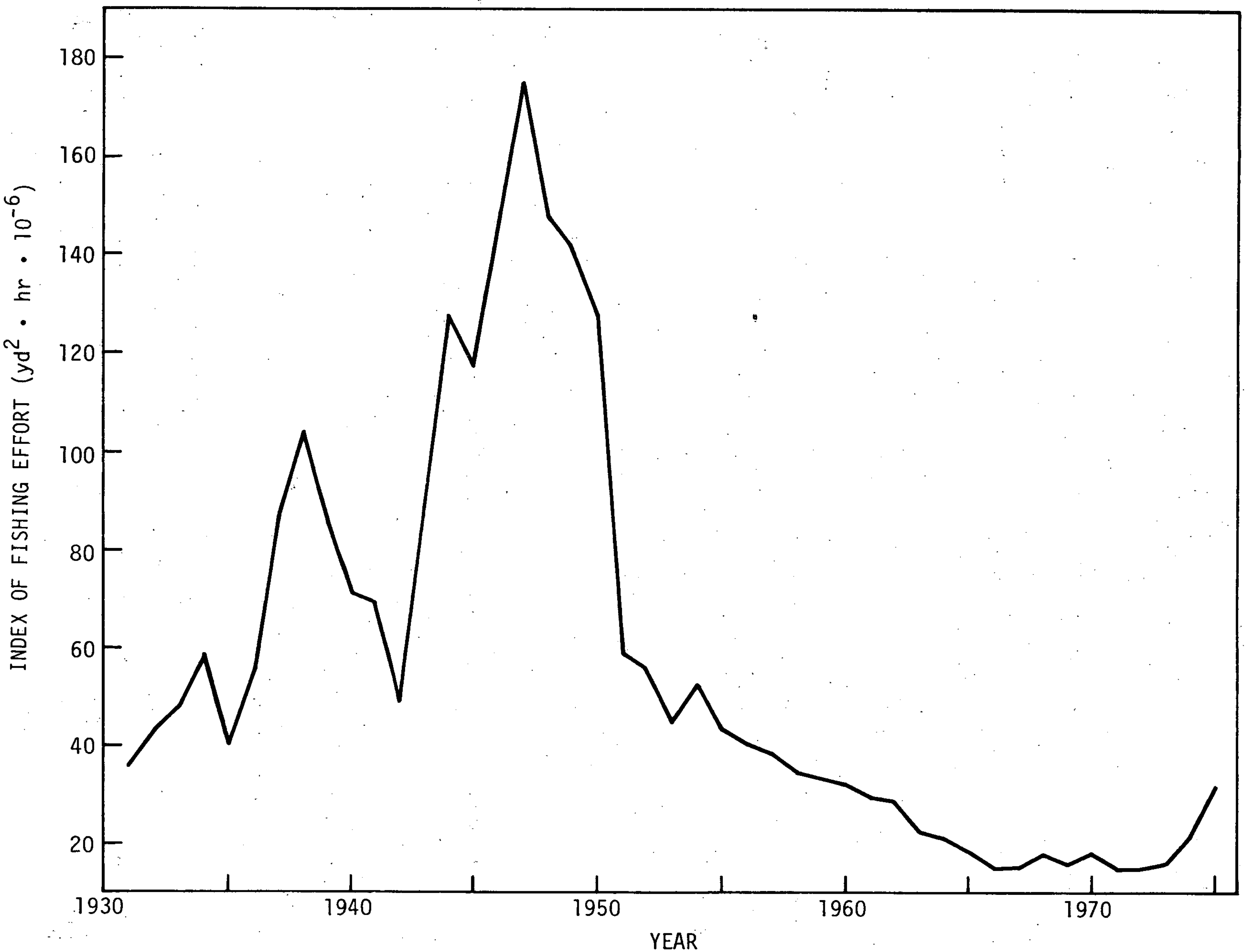


Figure IV-10. Gill Net Fishing Effort for American Shad Caught in Hudson River, New York and New Jersey, 1931-74 highest value in 1947 (Figure IV-11 and Table IV-2). There was a rapid decline during the late 1940s and early 1950s, and a low was reached in 1953. Fishing effort increased slightly in 1954 and then steadily declined through the late 1950s and the 1960s. From 1971 to 1974, effort increased slightly.

The declining trend in commercial fishing effort in the Hudson over the last 28 years is evident also in the number of licensed fishermen (Figure IV-2). A major factor contributing to the decline in fishing effort seems to have been the steady departure of older fishermen without replacement.

3. Abundance Index

a. Calculations, Assumptions, and Biases

A yield-per-effort index of abundance (Y/f) was developed to estimate relative striped bass, American shad, and white perch stock sizes since 1931. Effort was represented by the appropriate index of fishing effort (f), and yield (Y) was the reported commercial landings in pounds (lb). Therefore, the Y/f for each of the three species was estimated as follows:

$$Y/f = \frac{\text{lb landed}}{f}$$

Shad landings in the entire region of the river from Weehawken, New Jersey, to Hudson, New York, were used in abundance calculations (Table IV-3) since American shad were well represented in the catch of both stake-anchor and drift nets (Burdick, 1954; Talbot, 1954). Striped bass and white perch abundance indices were based on New York landings only (Table IV-2) since striped bass may not be legally taken in gill nets in New Jersey and there are records of white perch landings in New Jersey. White perch abundance index values from 1931 to 1944 are unreliable indicators since they are believed to be based on an unknown percentage of yellow perch landings as well.

The use of commercial Y/f statistics as valid indices of striped bass, American shad, and white perch abundance requires the satisfaction of two assumptions: that the catch and effort records be accurate or at least representative of the actual data and that the Y/f index vary directly with stock abundance.

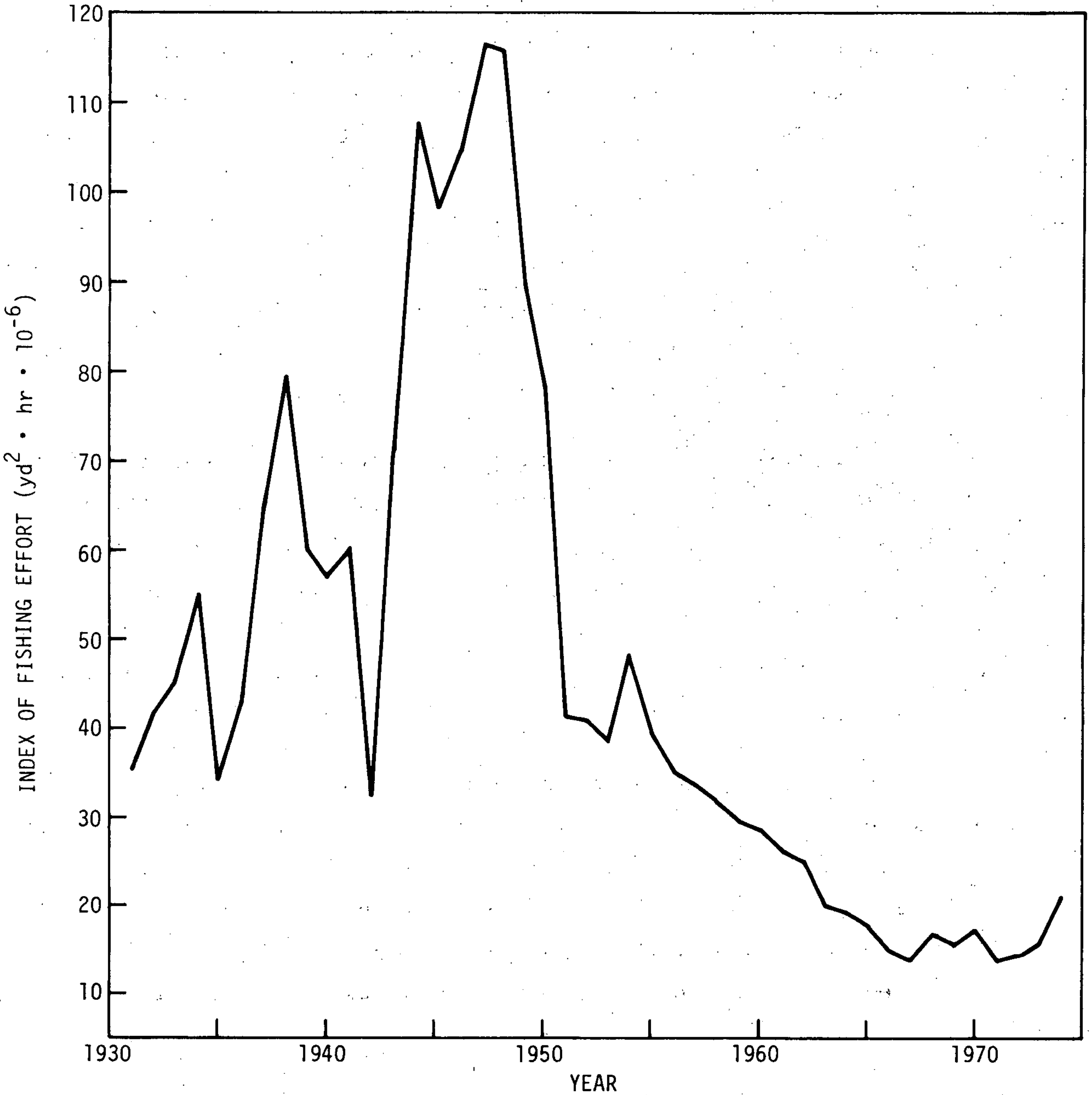


Figure IV-11. Gill Net Fishing Effort for Striped Bass and White Perch Caught in Hudson River, New York, 1931-74

Several potential sources of bias may influence the Y/f values. The index of fishing effort assumes that the proportional utilization of all licensed nets and hours of fishing allowed per week is constant throughout all years. Therefore, factors affecting either the square yards of licensed gill nets in use or the number of hours actually fished per week would cause actual fishing effort to fluctuate. For example, stormy weather may limit the actual hours per week that the fishermen tend their gill nets. Also, dramatic increases in the retail prices of fish, meat, and poultry from 1972 through 1974 (USDC, 1974) could have caused an unmeasured increase in fishing effort, i.e., a higher proportion of licensed nets than usual or longer hours of fishing and more frequent tending of nets. These factors have always existed to some extent, creating measured fluctuations in fishing effort. However, there is no way of correcting for any biases introduced by these factors.

An error affecting square yardage is suspected in the number of stake gill nets reported by the U.S. Fish and Wildlife Service for the New York Hudson River shad fishery between 1934 and 1945 (Medeiros, 1974). The number of stake gill nets was very large on alternate years, whereas neither the catch by stake gill nets nor the number of drift gill nets fluctuated in this manner. If fishermen were to license many nets but not use them all maximally, effort would be overestimated by our methods. Conversely, Y/f would be underestimated.

The accuracy of the catch data also affects the accuracy of the abundance indices. Numerous factors may cause errors in reporting fisheries statistics (Medeiros, 1974): individual fishermen may not keep accurate records of catches or honestly report their landings; inaccurate transcription of data by collecting agencies is possible; and, in the case of shad, large numbers of bucks are often thrown overboard to prevent their low value from depressing the prices of more highly valued females.

b. Abundance Indices

1) Striped Bass

Striped bass abundance fluctuated at low levels until a marked increase in 1954 and 1955. Since that time, stock abundance has varied but has been well above pre-1955 levels (Figure IV-12 and Table IV-2). The replacement of natural fiber gill nets by nylon nets in the mid-1950s may have produced the increase in abundance in 1954 and 1955 due to the probable increased effectiveness of nylon nets. Changes in commercial fishing regulations, which eliminated the use of haul seines and fyke nets and closed the winter fishing season, presumably reduced fishing pressure in 1949 and 1950 and may have permitted increased escapement spawning success, first reflected in the commercial catch 5 to 6 years later (1954 and 1955) when those year classes were fully recruited to the fishery. Since the mid-1950s, stock abundance has peaked three times — 1960, 1969, and 1973. Levels were low in 1964, 1972, and 1974.

2) American Shad

The American shad abundance index fluctuated from 1931 through 1972. Peaks occurred in 1936, 1942, 1956, and 1972. Abundance was relatively low in 1934, 1950, 1966, and 1974 (Figure IV-13 and Table IV-3). Hudson River shad abundances through 1951, reported by Burdick (1954) and Talbot (1954), corresponded roughly with our Y/f values; Burdick's abundance values corresponded most closely with our data because Talbot weighted the New Jersey nets five times as heavily as the New York nets as the result of tagging studies conducted in 1950. Both Talbot's and Burdick's calculated abundance values may have been less accurate than our values: they used numbers of nets rather than area of nets for part of their index of fishing effort, and individual gill net size varies tremendously.

3) White Perch

White perch abundance fluctuated throughout the 44 years, reaching highest Y/f values in 1935 and 1942 (Figure IV-14 and Table IV-2). These two peaks occurred when yellow perch landings are believed to have been included in white perch landing records. This would have caused Y/f values to have been biased high. From 1944 to 1974, white perch abundance values declined and were relatively constant compared with pre-1944 values. Abundance declined further from 1970 to 1974.

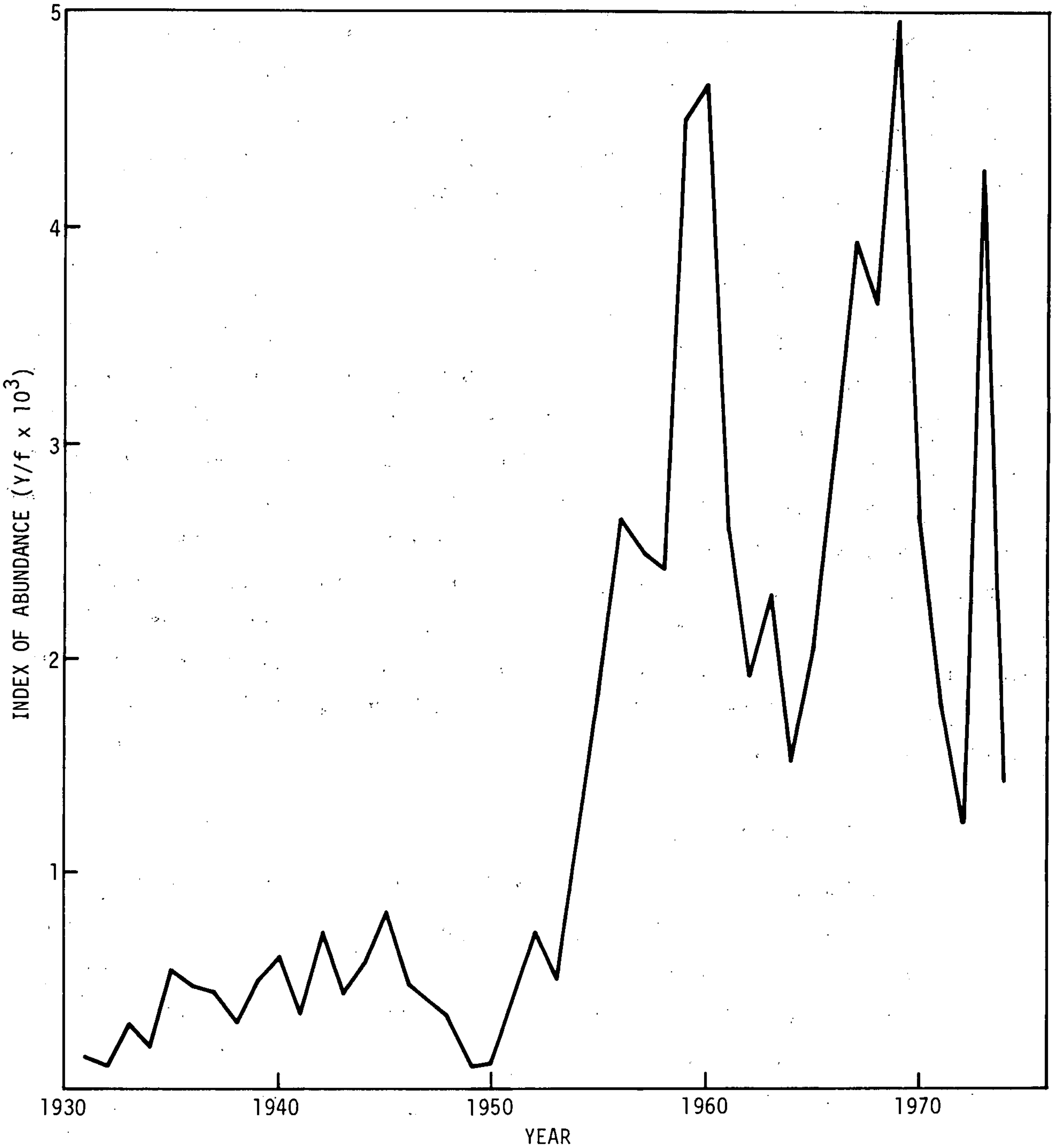


Figure IV-12. Striped Bass Yield-per-Effort Index of Abundance in Hudson River, New York, 1931-74

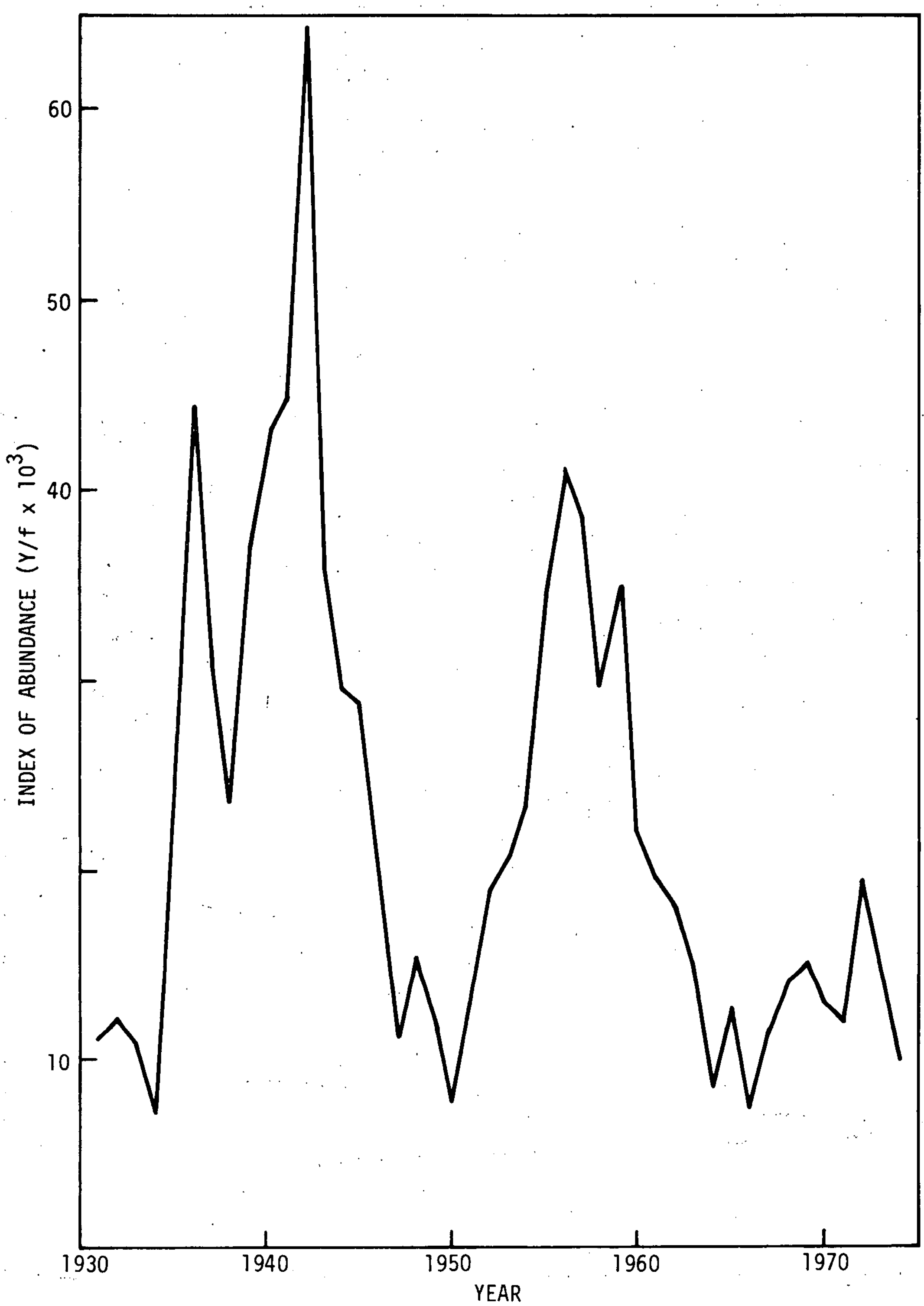


Figure IV-13. American Shad Yield-per-Effort Index of Abundance in Hudson River, Weehawken, New Jersey, to Hudson, New York, 1931-74

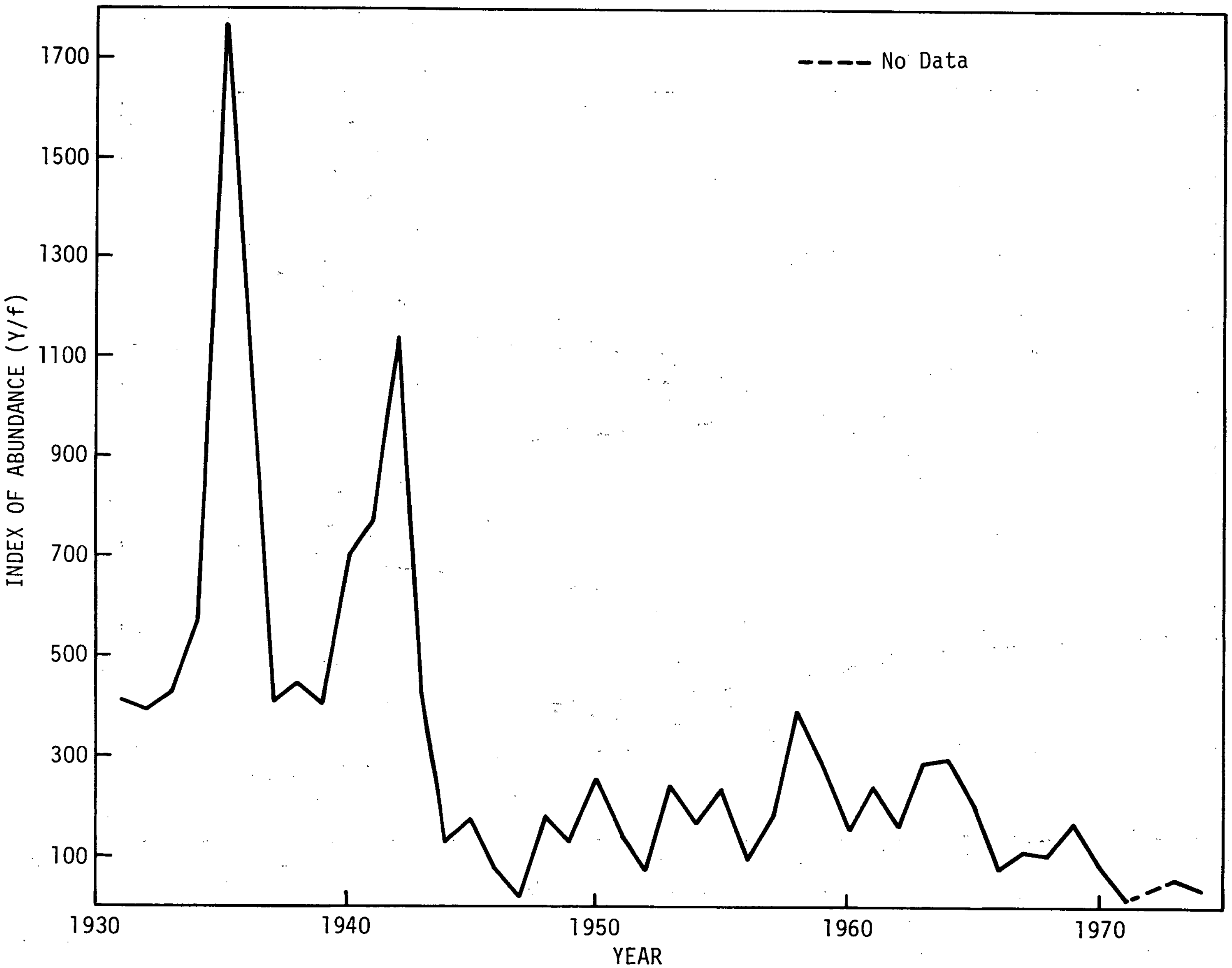


Figure IV-14. White Perch Yield-per-Effort Index of Abundance in Hudson River, New York, 1931-74

Interpretation of white perch Y/f values is difficult because commercial fishermen have altered their gear and fishing methods to avoid catching the numerous small (less than optimum marketable size) white perch (Bob Gabrielson, Hudson River commercial fisherman, personal communication). Also, these abundance estimates do not include white perch fishing effort by haul seines and fyke and dip nets because these gear are difficult to quantify.

4. Summary

Trends in the abundance of striped bass, American shad, and white perch stocks in the Hudson River (1931-74) based on commercial fishing can be summarized as follows:

- Commercial gill net fishing effort has declined drastically since the mid-1940s, but 1973 and 1974 exhibited a slight increase.
- Striped bass abundance fluctuated irregularly at a relatively low level from 1931 through 1954 and fluctuated at higher levels from 1955 through 1974 than before 1955.
- American shad abundance had its highest recorded level in 1942 and then declined until 1950 but increased through the mid-1950s. Abundance between 1955 and 1974 declined from a peak in 1955 to a nadir in 1964 and increased irregularly to another peak in 1972, then decreased through 1974.
- White perch abundance decreased in 1944 after reaching high values in 1935 and 1942; since 1944, it has fluctuated at relatively low levels. A generally diminishing market demand for white perch and all adjustments of fishing gear and effort to avoid white perch make the decline in the Y/f index of abundance difficult to interpret.

C. YEAR-CLASS ABUNDANCE

Objective: Describe annual fluctuation in abundance in the Hudson River of juvenile (young-of-the-year) Atlantic tomcod from 1969 through 1974, excluding 1971, and American shad from 1965 through 1974, excluding 1971

Since 1936, there have been 12 years of ecological surveys of portions of the Hudson River biota. TI examined subsets of this data base to describe fluctuations in the abundance of juvenile Atlantic tomcod from 1969 through 1974 and juvenile American shad from 1965 through 1974; 1971 was excluded in both cases because samples were insufficient. Annual abundance trends of juvenile striped bass and white perch have already been discussed in an earlier report (TI, 1975a).

1. Methods

The underlying assumptions, gear comparability adjustments, time-period selections, and calculations of annual abundance indices from catch data in beach seines were described in a previous report (TI, 1975a). To use these catch data in a comparative manner, the relative efficiencies of the 50-ft (15.2-m), 75-ft (22.9-m), and 100-ft (30.5-m) beach seines must be considered. In both size and deployment procedure, the 50-ft seine is the least similar and potentially least efficient. TI conducted an efficiency test of a 50-ft and 100-ft seine comparing the catches on the basis of per unit area swept. The 75-ft and 100-ft seines were not compared because it is highly probable that they have similar efficiencies when expressed on the basis of catch per unit area swept.

Gear efficiency was tested in the Hudson River on an extensive beach area on the north side of Croton Point on 19 September 1974. The 50-ft seine's dimensions and deployment were comparable to those used by NYU in 1965-69 (Table IV-4). A standard 100-ft beach seine was deployed in the normal RAY-TI manner (Table IV-4 and TI, 1975a).

All seine hauls were made adjacent to one another, with a minimum of 30 m between them, between 0830 and 1230 on the same day. During the tests, tides shifted from high slack to ebb.

Juvenile striped bass represented the only species and age group caught in sufficient numbers for comparison, but it is assumed that the results are applicable to other key species.

Table IV-4

Beach Seine Information from Ecological Survey Subsets of Historical Data Base Used To Assess Annual Fluctuations in Juvenile American Shad Abundance, Hudson River, 1965-74 (Page 1 of 3)

Study (data base subset)	Year	Month Sampled	Length (ft)†	Mesh Size	Deployment Method	Sampling Station: Identification Number	Sampling Station: River Mile††	Shore
New York University (NYU)	1965	Jun Jul Aug	50 (15.2)	0.38-in. stretch	Pulled parallel to shoreline from distance offshore where depth ≤ 4 ft (1.2 m)	IW3	27 (43)	West
						IIW1	41 (66)	West
						IIW2	45 (72)	West
						IIW2A	57 (91)	West
						IIIW2	68 (109)	West
						IVW1	87 (139)	West
	1966	Jun Jul Aug	50 (15.2)	0.38-in. stretch	Pulled parallel to shoreline from distance offshore where depth ≥ 4 ft (1.2 m)	IW3	27 (43)	West
						IIW1	41 (66)	West
						IIE1	41 (66)	West
						IIE3	44 (70)	East
						IIW2	45 (72)	West
						IIW2A	57 (91)	West
						IIIW2	60 (96)	West
						IVW1	87 (139)	West
						IVW2	96 (154)	West
						IVW3	102 (163)	West
						IVW4	105 (168)	West
	1967	Jun Jul Aug	50 (15.2)	0.38-in. stretch	Pulled parallel to shoreline from distance offshore where depth ≥ 4 ft (1.2 m)	IW3	27 (43)	West
						IIW1	41 (66)	West
						IIW2	45 (72)	West
						IIW2A	57 (91)	West
						IIIW2	68 (109)	West
						IVW1	87 (139)	West
						IVW2	96 (154)	West
	1968	Jun Jul Aug	50 (15.2)	0.38-in. stretch	Pulled parallel to shoreline from distance offshore where depth ≤ 4 ft (1.2 m)	IW3	27 (43)	West
						IIE1	41 (66)	East
						IIW1	41 (66)	West
						IIW2	45 (72)	West
						IIW2A	57 (91)	West
						IVW1	87 (139)	West
						IVW2	96 (154)	West
						IVW3	103 (165)	West
						IVW4	105 (168)	West
	1969	Apr May Jun Jul Aug Sep	50 (15.2)	0.38-in. stretch	Pulled parallel to shoreline from distance offshore where depth ≥ 4 ft (1.2 m)	IIE1	41 (66)	East
						IIW1	41 (66)	West
						IIW2A	57 (91)	West
						IVW1	87 (139)	West

*Sampled from Sep-Dec only.

†Numbers in parentheses indicate meters.

††Numbers in parentheses indicate kilometers.

Table IV-4 (Page 2 of 3)

Study (data base subset)	Year	Months Sampled	Length (ft)†	Mesh Size	Deployment Method	Sampling Station		Shore
						Identification Number	River Mile††	
Raytheon (RAY) Studies in vicinity of Indian Point	1969	Jun Jul Aug Sep Oct Nov Dec	75 (22.9) until Sep 10, then 100 (30.5)	0.25-in. bar → 75 ft 0.38-in. bar (wings) } 100 ft 0.25-in. bar (bag) } 100 ft	Set perpendicular to shoreline and then towed around in a semi-circle to shore	31	35 (56)	West
						32	35 (56)	East
						33	40 (64)	East
						34	42 (67)	East
						35	43 (69)	West
						36	44 (70)	East
						37	47 (75)	West
						38	40 (64)	West
						39	41 (66)	East
	1970	Apr May Jun Jul Aug Sep Oct	100 (30.5)		Set perpendicular to shoreline and then towed around in a semi-circle to shore	31	35 (56)	West
						32	35 (56)	East
						33	40 (64)	East
						34	42 (67)	East
						35	43 (69)	West
						36	44 (70)	East
						37	47 (75)	West
						38	40 (64)	West
						39	41 (66)	East
Texas Instruments (TI) Hudson River Ecological Study	1972	Apr May Jun Jul Aug Sep Oct Nov Dec	75 (22.9) at stations 6, 7, 7A 100 (30.5) at stations 8-12	0.5-in. stretch → 75 ft 0.75-in. stretch (wings) } 100 ft 0.5-in. bar (bag) } 100 ft	Set perpendicular to shoreline and then towed around in a semi-circle to shore	6	35 (56)	East
						7	32 (51)	East
						7A	34 (54)	East
						8	43 (69)	East
						9	42 (67)	West
						10	42 (67)	East
						11	40 (64)	West
						12	40 (64)	East
						IB*	52 (83)	East
						CNM*	54 (86)	West
						LSP*	55 (88)	East
						CN*	57 (91)	West
						PP*	58 (93)	West
						DP*	59 (94)	East
						13*	38 (61)	East
						14*	38 (61)	West

*Sampled from Sep-Dec only.

†Numbers in parentheses indicate meters.

††Numbers in parentheses indicate kilometers.

Table IV-4 (Page 3 of 3)

Study (data base subset)	Year	Month Sampled	Length (ft)†	Mesh Size	Deployment Method	Sampling Station: Identification Number	Sampling Station: River Mile††	Shore
	1973	Apr	100 (30.5)	0.75-in. stretch (wings)	Set perpendicular to shoreline and then towed around in a semi-circle to shore	8	43 (69)	East
		May		0.5-in. stretch (bag)		9	42 (67)	West
		Jun				10	42 (67)	East
		Jul				11	40 (64)	West
		Aug				12	40 (64)	East
		Sep				Plus random-site beach-seine survey	Sites from RM 12-152 (19-243)	East and West
		Oct						
		Nov						
		Dec						
	1974	Apr	100 (30.5)	0.75-in. stretch (wings)	Set perpendicular to shoreline and then towed around in a semi-circle to shore	8	43 (69)	East
		May		0.5-in. stretch (bag)		9	42 (68)	West
						10	42 (68)	East
						11	40 (64)	West
						12	40 (64)	East
						20	40 (64)	East
						21	40 (64)	East
						20	40 (64)	East
						21	40 (64)	East
						Plus random-site beach-seine survey	Sites from RM 12-152 (19-243)	East and West

* Sampled from Sep-Dec only

† Numbers in parentheses indicate meters.

†† Numbers in parentheses indicate kilometers.

A paired experimental design systematically reversed the seine pair sequence to eliminate any possibilities of a systematic bias resulting from disturbance by the previous gear in any given pair. The sequence of eight pairs was as follows:

ABAB BABA ABAB BABA

where

A = 100-ft seine

B = 50-ft seine

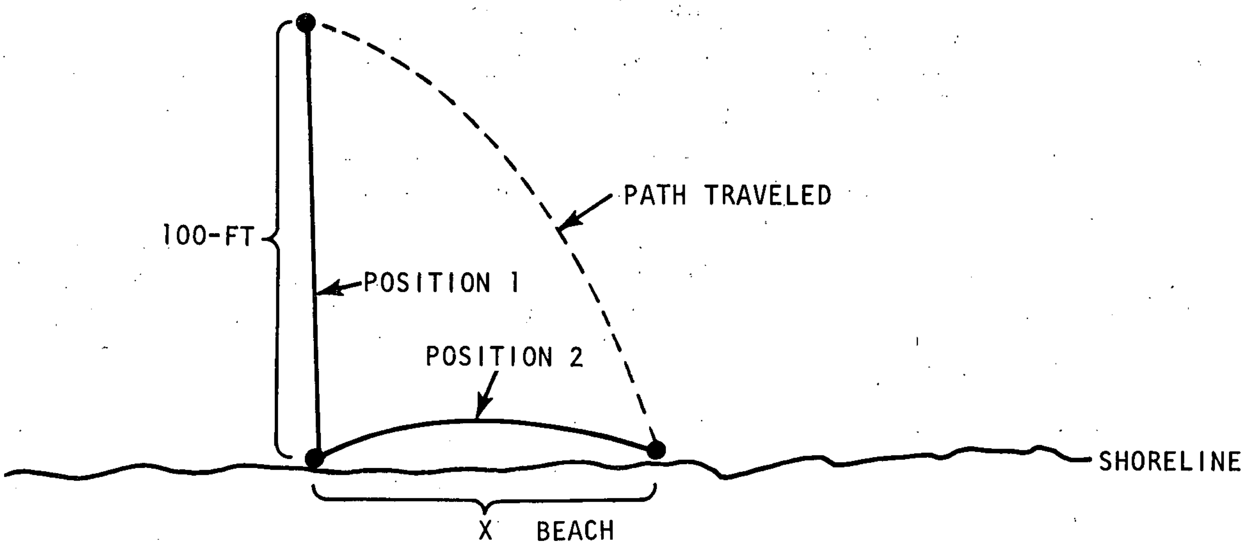
The area swept by each seine was calculated by measuring the distance x for each 100-ft seine haul (Figure IV-15) and the distances y and z for each 50-ft seine haul (Figure IV-16). Three paired tests were used to analyze the data: Wilcoxon signed rank, log (x + 1) transform t, and square root transform t. The three unpaired tests were Wilcoxon rank sum, log (x + 1) transform t, and square root transform t. Catches in the two seines were compared on the basis of catch per unit area swept (No./10,000 ft^2 swept).

On a catch-per-unit-area swept basis, there were no significant differences ($\alpha = 0.05$) between the 50-ft (NYU) and 100-ft (RAY and TI) seines in catches of juvenile striped bass (Table IV-5). Based on this single comparison, the assumption appears to be valid that the efficiencies of the 50-ft beach seine deployed by NYU during 1965-69 and the 100-ft beach seine deployed by RAY and TI during 1969-74 were similar when catches were expressed on the basis of per unit area swept.

2. Abundance Indices

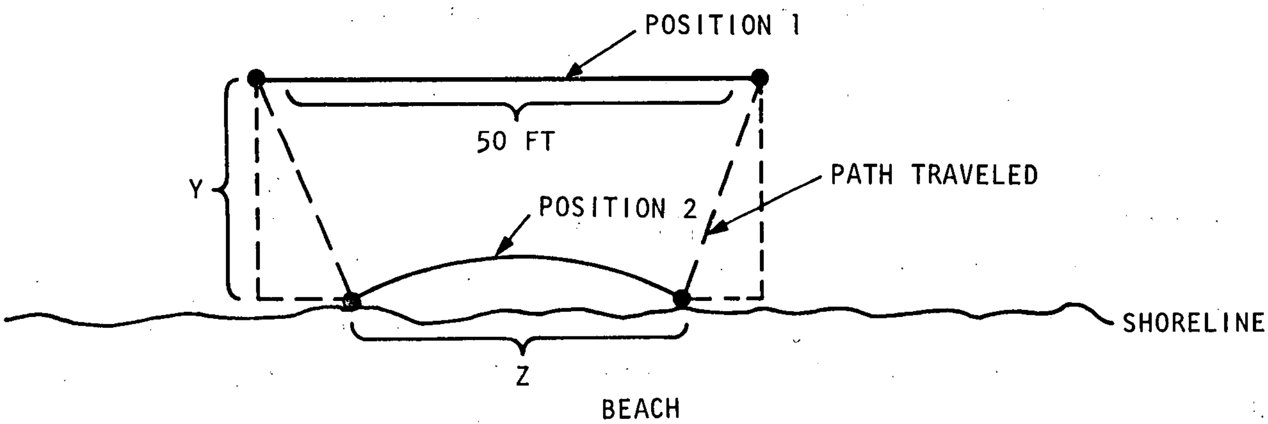
a. American Shad

An abundance index of juvenile American shad was calculated for all years from 1965 through 1974, except 1971, using catch data from beach seine samples collected during the New York University (NYU) surveys, 1965-69; the Raytheon Company (RAY) studies in the area of Indian Point, 1969-70; and the Hudson River ecological study conducted by Texas Instruments (TI), 1972-74. Although the Hudson River Fisheries Investigation (HRFI) also sampled with beach seines during 1965-68, the area swept per seine haul was not recorded, so the data could not be used to calculate an abundance index.



Area swept = 4844 ft^2 (450 m^2) approximated from average x of 60 ft (18.3 m) as described by Texas Instruments, 1975a

Figure IV-15. Deployment Diagram for 100-Ft Beach Seine Used by RAY (1969-70) and TI (1972-75) and Dimensions Needed To Calculate Area Swept per Haul



$$\text{Area swept} = y \times 50 - \frac{y(50-z)}{2}$$

Figure IV-16. Deployment Diagram for 50-Ft Beach Seine Used by NYU (1965-69) and Dimensions Needed To Calculate Area Swept per Haul

Table IV-5

Comparison of Juvenile Striped Bass Catch per 10,000 Ft^2 Swept (CPUA) for 50-Ft Beach Seine (as Deployed by NYU, 1965-69) and 100-Ft Beach Seine (as Deployed by RAY, 1969-70, and TI, 1972-74)

Pair	100-Ft Beach Seine			50-Ft Beach Seine		
	Catch	Area Swept (ft^2)	Catch per 10,000 Ft^2 Swept (CPUA)	Catch	Area Swept (ft^2)	Catch per 10,000 Ft^2 Swept (CPUA)
1	84	4844	173.4	1	1628	6.1
2	47	4844	97.0	0	1840	0
3	7	4844	14.4	2	1350	14.8
4	26	4844	53.7	5	1410	35.5
5	17	4844	35.1	8	1425	56.1
6	5	4844	10.3	1	1457	6.9
7	5	4844	10.3	11	1358	81.0
8	15	4844	31.0	5	1455	34.4

Fluctuations in juvenile shad abundance were examined for two sets of data:

- 1969-74 (except 1971), standard stations, Indian Point area, August-October
- 1965-74 (except 1971), riverwide, July-August

b. Atlantic Tomcod

Annual abundance indices for juvenile Atlantic tomcod were calculated using bottom trawl catch data collected at standard stations (Indian Point) by the RAY studies (1969-70) and TI studies (1972-74). Table IV-6 compares bottom trawl types, cod-end mesh sizes, deployment methods, and sampling stations. The choice of time periods was limited because before July 1969 RAY had done little trawl sampling.

Five years of bottom trawl data collected by RAY (1969-70) and TI (1972-74) from four standard stations in the vicinity of Indian Point were compared using mean catch per tow (C/f) for July, August, and September of each year as the index of abundance for juvenile Atlantic tomcod. Standard stations were chosen because of their comparability over a relatively long time period, and trawl surveys covering extensive areas of the river have been taken only during 2 years (1973 and 1974) (Table IV-6), which is an insufficient time interval in which to detect trends in the data.

The Indian Point region should produce a valid abundance index for the time period in which data are available (July and later months). Juvenile Atlantic tomcod are concentrated in the lower estuary early in the year but move upstream in the summer months, apparently following the salt wedge (Section V and TI, 1975a); therefore, they are present in the Indian Point area during the months used for the abundance index (July-September). It is assumed that an abundance index calculated from samples taken during late summer reflects year-class strength even though considerable mortality and emigration may have occurred between April and June.

RAY stations 12, 11, 10, 16, 8, and 9 corresponded to TI stations 2, 3, 4, 5, 6, and 7, respectively; RAY stations 11 and 8 were not directly comparable to TI stations 3 and 6 because tow depths varied greatly between the two studies even though longitudinal location of the stations remained constant. Therefore, only the four remaining stations were used to calculate the abundance index.

A comparison of the total number of tows taken during July, August, and September (day only) at RAY stations 12, 10, 16, and 9 and at TI stations 2, 4, 5, and 7 yielded the following:

Study	Year	No. of Tows
RAY	1969	32
RAY	1970	68
TI	1972	51
TI	1973	28
TI	1974	28

Certain assumptions and catch correction factors were applied to provide the necessary comparability for analysis of these bottom trawl data.

Table IV-6

Bottom Trawl Information from Ecological Survey Subsets of Hudson River Historical Data Used To Assess Annual Fluctuations in Juvenile Atlantic Tomcod Abundance (1969, 1970, 1972, 1973, 1974)

			Gear		Deployment			Sampling Station		
Study (data base subset)	Year	Month Sampled	Type, Length, Etc.	Cod-End Mesh Size	Tow Speed	Tow Duration	Tow Direction	Identification Number	RM	(KM)
Raytheon (RAY) studies in vicinity of Indian Point	1969	Jun Jul Aug Sep Oct Nov Dec	25-ft (8-m) semiballoon bottom trawl; doors 36 in. long x 17 in. wide	1.25-in. stretch mesh with 0.25-in. stretch mesh nylon liner	About 3 knots (5.1 fps)	10 min until 8 Aug when changed to 7 min	Against the flow	3 4 5 6 7 8 9 10 11 12 13 14 15 16	35 35 36 38 38 39 40 42 42 44 45 47 40 41	(56.3) (56.3) (57.9) (61.1) (61.1) (62.6) (64.4) (67.6) (67.6) (70.8) (72.4) (75.6) (64.4) (65.9)
	1970	Mar Apr May Jun Jul Aug Sep Oct	25-ft (8-m) semiballoon bottom trawl; doors 36 in. long x 17 in. wide	1.25-in. stretch mesh with 0.25-in. stretch mesh nylon liner	About 3 knots (5.1 fps)	7 min	Against the flow	3 4 5 6 7 8 9 10 11 12 13 14 15 16	35 35 36 38 38 39 40 42 42 44 45 47 40 41	(56.3) (56.3) (57.9) (61.1) (61.1) (62.6) (64.4) (67.6) (67.6) (70.8) (72.4) (75.6) (64.4) (65.9)
Texas Instruments (TI) Hudson river ecology study	1972	Apr May Jun Jul Aug Sep Oct Nov Dec	25-ft (8-m) semiballoon bottom trawl; doors 30 in. long x 16 in. wide	1.50-in. stretch mesh cod end, no liner	3-4 fps	10 min	Against the flow	0-1 0-2 0-3 0-4 0-5 1 2 3 4 5 6 7 15 16	35 33 32.5 31 30 43 43 42 42 41 39 40 38 38	(56.3) (53.1) (52.3) (49.9) (48.3) (69.2) (69.2) (67.6) (67.6) (65.9) (62.6) (64.4) (61.1) (61.1)
	1973	Mar Apr May Jun Jul Aug Sep Oct Nov Dec	25-ft (8-m) semiballoon bottom trawl; doors 30 in. long x 16 in. wide for standard stations and 48 in. long x 30 in. wide for interregional trawls	1.50-in. stretch mesh cod end, no liner	3-4 fps	10 min for standard stations, 5 min for interregional trawls	Against the flow	1 2 3 4 5 6 7 (also RM-24-61)	43 43 42 42 41 39 40	(69.2) (69.2) (67.6) (67.6) (65.9) (62.6) (64.4)
	1974	Mar Apr May Jun Jul Aug Sep Oct Nov	25-ft (8-m) semiballoon bottom trawl; doors 30 in. long x 16 in. wide for standard stations and 48 in. long x 30 in. wide for interregional trawls	1.50-in. stretch mesh cod end; also 0.5-in. stretch mesh liner for standard stations and 0.5-in. stretch cod-end cover for interregional trawls	3-4 fps	10 min. for standard stations, 5 min for interregional	Against the flow	1 2 3 4 5 6 7 (also RM 12-61)	43 43 42 42 41 39 40	(69.2) (69.2) (67.6) (67.6) (65.9) (62.6) (64.4)

Since TI had not used a small mesh liner in the trawl cod end during 1972 and 1973 (Table IV-6), trawl catches from those years were adjusted to maximize comparability. The monthly correction factors applied to TI catches in 1972 and 1973 were estimated from comparisons of TI's 1974 and 1975 interregional bottom trawl catches of juvenile Atlantic tomcod in the cod end [1.50-in. (38-mm) stretch mesh] and the cod-end cover [0.5-in. (13-mm) stretch mesh]. Biweekly catch per effort (C/f) in the cod end and cod-end cover was used to calculate a correction ratio as follows:

$$\text{Ratio} = \frac{\text{C/f in cod end + C/f in cod-end cover}}{\text{C/f in cod end}}$$

The two biweekly ratios within each month (July, August, September) were averaged for 1974 and 1975 to yield monthly catch correction factors that were assumed to be estimates of the percentage change in TI's 1972-73 bottom trawl catches had the trawl cod-end liners been present. Then, TI's 1972-73 trawl catches were multiplied by the appropriate monthly correction factor (July = 470%, August = 288%, September = 250%) to make them comparable to RAY for 1969-70 and TI for 1974. Thus:

TI's 1972-73 C/f (Jul) x 4.70 = RAY's 1969-70 and TI's 1974 C/f (Jul)

TI's 1972-73 C/f (Aug) x 2.88 = RAY's 1969-70 and TI's 1974 C/f (Aug)

TI's 1972-73 C/f (Sep) x 2.50 = RAY's 1969-70 and TI's C/f (Sep)

All TI catches of Atlantic tomcod were seperated into juvenile and yearling-plus age groups. TI's analysis of tomcod length-frequency distribution in the RAY catches permitted a separation of the RAY data into juvenile and yearling-plus age categories. RAY's 1969 and 1970 C/f values were then adjusted accordingly to represent only juvenile catches:

Month	RAY 1969 Juveniles (%)	RAY 1970 Juveniles (%)
Jul	93.8	77.5
Aug	98.4	85.9
Sep	93.2	90.4

Catch-per-unit-effort values (C/f) were not adjusted for different tow speeds and durations used in the various years (Table IV-6): all tow speeds were recorded in relation to river flow, and no corrections were made for tidal current or surface and bottom water velocity differences. Thus, the speed of the trawl relative to the bottom in any particular tow could not be determined, nor could the area covered during each tow be calculated or meaningful adjustment values estimated.

3. Results and Discussion

Annual variations in the abundance of juvenile American shad taken in beach seines and juvenile Atlantic tomcod taken in standard station bottom trawls were used as estimates of fluctuations in year-class strength. The following paragraphs examine two sets of beach seine data for shad and one set of bottom trawl data for tomcod.

a. American Shad

1) Statistical Test of Year-Class Abundance at Standard Stations in Vicinity of Indian Point

A Friedman analysis of variance of beach seine catches at standard stations in the vicinity of Indian Point during August-October 1969-74 (excluding 1971) provided a statistical test of juvenile American shad abundance and indicated significantly different ($\alpha = 0.05$) annual fluctuations. The catch data used in the statistical test were highly comparable over the 5 years, so the results reflected true annual differences in abundance at the stations sampled. The catch-per-unit-effort (C/f) estimates of juvenile abundance were comparable because all catches were made at the same four stations, samples were taken each year at comparable times throughout the same three months (August, September, and October), and the same seine sizes and deployment procedures were used at all times except August and part of September 1969 when RAY employed 75-ft (22.9-m) seines.

From 1969 to 1974, the abundance of juvenile American shad varied by a factor of 17.5 (Table IV-7). The largest year class, 1974, was significantly larger ($p \leq 0.05$) than 1972, 1970, and 1969 but was not significantly larger than 1973; the latter was relatively large and was significantly larger ($p \leq 0.05$) than 1972 and 1969 but was not significantly larger than 1970:

Year	Mean Rank		Differences 1969	1970	1972	1973	1974
1969	1.8						
1970	3.0	1969	0	1.2	0.1	2.1*	3.0*
1972	1.9	1970		0	1.0	0.7	1.8*
1973	3.7	1972			0	1.8*	2.8*
1974	4.8	1973				0	1.1
		1974					0

Least significant difference ($p \leq 0.05$) = 1.8

*Significant difference between years ($p \leq 0.05$)

Table IV-7

Year-Class Abundance of Juvenile American Shad and Atlantic Tomcod Based on Standard Station Beach Seine (Shad) and Standard Station Bottom Trawl (Tomcod) Catch Data, Hudson River, 1969-74

Year	Indian Point Standard Stations: Shad C/f†	Tomcod C/f
1965	*	*
1966	*	*
1967	*	*
1968	*	*
1969	0.8	60.1
1970	3.2	108.8
1971	*	*
1972	1.0	45.8
1973	8.4	8.8
1974	14.0	17.2

†Catch per unit effort.

*No samples in Indian Point area.

Based on beach seine catches in the vicinity of Indian Point from 1969 through 1974, American shad had relatively strong year classes in 1973 and 1974, relatively weak year classes in 1969 and 1972, and a somewhat intermediate size year class in 1970.

2) Year-Class Abundance, Riverwide

In riverwide beach seine catches during July-August 1965-74, the abundance of juvenile American shad fluctuated greatly (Table IV-8). The largest abundance index, 1973, was >500 times greater than the relatively small indices in 1967 and 1972. Based on these riverwide samples, strong year classes occurred in 1973 and 1974 and poor year classes in 1967, 1968, and 1972. Intermediate year classes occurred in 1965, 1966, 1969, and 1970.

Table IV-8

Year-Class Abundance Index for Juvenile American Shad Based on Riverwide Beach Seine Catches during July-August, Hudson River, 1965-74

Year	Abundance Index Mean Catch per Unit Area Swept (CPUA)
1965	7.5
1966	4.9
1967	0.1
1968	0.2
1969	2.8
1970	7.5
1971	*
1972	0.1
1973	53.0
1974	29.2

*No extensive riverwide samples

The assumption that a July-August index of juvenile shad abundance was representative of juvenile abundance later in the fall (September-October) was tested with the Spearman Rank Correlation analysis. Only 1969 through 1974 could be compared because NYU did not sample during September-October 1965-68. For the 5 years tested, the relationship between the July-August index and a September-October index was positive and significant ($rs = +0.90$, $df = 3$, $p \leq 0.02$), indicating that juvenile shad abundance represented by the July-August index reflected year-class strength.

To ascertain whether the abundance index derived from Indian Point standard stations (Table IV-7) represented the riverwide population during July and August, a Spearman Rank Correlation test was calculated using those years (1969-74, excluding 1971) for which data were available from both the standard station and riverwide surveys. Although some variation did occur, year-class rankings between the two data sets were similar (rs = +0.80, df = 3, p = 0.106). Since juvenile American shad are distributed in the upper river for much of the summer (Section V), Indian Point abundance may not always reflect riverwide abundance but generally appears to do so.

b. Atlantic Tomcod

A Friedman analysis of variance of bottom trawl catches at standard stations in the vicinity of Indian Point during July-September 1969-74 (excluding 1971) provided a statistical test of Atlantic tomcod year-class strength and indicated a significant difference between 2 years, 1970 and 1973 ($\alpha = 0.05$). The catch data used in the statistical tests were fairly comparable over the 5 years since all catches were made at the same four standard trawling stations and the samples were taken at comparable times throughout the same 3 months (July, August, and September) of each year.

From 1969 to 1974, the abundance of juvenile tomcod varied by a factor of 12.3 (Table IV-7). The largest year class, 1970, was significantly larger than 1973 ($p \leq 0.05$) but was not significantly different from 1969, 1972, and 1974 ($\alpha = 0.05$). No other significant differences among year classes were detected at the $\alpha = 0.05$ level. The 1970 year class was significantly larger than the 1974 year class at the $\alpha = 0.10$ level (as shown below):

			Differences				
Year	Mean Rank		1969	1970	1972	1973	1974
1969	3.6	1969	0	0.8	0.6	1.7	1.4
1970	4.4	1960		0	1.5	2.6*	2.2
1972	2.9	1972			0	1.1	0.7
1973	1.9	1973				0	0.4
1974	2.2	1974					0

Least significant difference ($p \leq 0.05$) = 2.4

*Significant difference between years ($p \leq 0.05$)

Based on bottom trawl catches at Indian Point standard stations from 1969 through 1974, Atlantic tomcod had a relatively strong year class in 1970 and weak ones in 1973 and 1974. Intermediate year classes occurred in 1969 and 1972.

4. Summary

Fluctuations in the annual abundance of juvenile American shad and Atlantic tomcod in the Hudson River can be summarized as follows:

- Annual abundance of juvenile American shad (1965-74) and Atlantic tomcod (1967-74) was highly variable (Tables IV-7 and IV-8).
- Shad year classes were relatively weak in 1967, 1968, and 1972; stronger in 1973 and 1974; and intermediate in 1965, 1966, 1969, and 1970.
- Estimates of shad year-class abundance based on samples taken in the Indian Point area were not completely representative of the entire river in absolute magnitude but did reflect trends in year-class strength.
- Atlantic tomcod had relatively small year classes in 1973 and 1974, a strong year class in 1970, and intermediate year classes in 1969 and 1972.

D. FACTORS INFLUENCING YEAR-CLASS ABUNDANCE

Objectives: Examine potential relationships of the annual abundance of juvenile American shad and juvenile Atlantic tomcod with various environmental factors

Examine potential effects of spawning stock abundance, cannibalism, and predation on annual abundance of juvenile American shad and Atlantic tomcod

Examine potential relationships of combined power plant operations with abundance of juvenile American shad and Atlantic tomcod

1. Methods

The following groups of environmental factors were hypothesized to to be important influences on the abundance of juvenile American shad and Atlantic tomcod in the Hudson River.

a. Physical Factors

Physical environmental conditions prevailing in the estuary from 1965 through 1974 have been described in an earlier report (TI, 1975a). For this report, the riverwide indices of year-class abundances of American shad (1965-74) and Atlantic tomcod derived from standard station samples (1969-74) were compared to measurements of the two environmental factors that were comparably recorded across all years and considered to be potentially important to the survival of the early life stages of the two species:

- Freshwater inflow was measured by water released from the Green Island Dam at Troy, New York [RM 153 (KM 245)]. Mean daily freshwater inflows for January-December were available for comparison with year-class abundance (Table IV-9).

- Water temperature was measured by several investigators (TI, 1975a, Appendix C) in the vicinity of Indian Point [RM 42 (KM 67)] and Poughkeepsie [RM 75 (KM 120)]. Mean biweekly surface temperatures for January-December were available for comparison with year-class abundance (Table IV-10). Measurements taken near Indian Point were outside any influence of heated discharges from power plants (TI, 1975a).

Freshwater inflow and water temperature represent potential density-independent population regulatory factors.

b. Biological Factors

The relationship between spawning stock abundance and the abundance of juvenile American shad was examined by comparing an index of stock abundance derived from commercial fishery landings and effort (subsection B) with the index of juvenile abundance. For Atlantic tomcod, however, such a comparison was not possible because there were no valid commercial fishery catch and effort data. Bottom trawl data would have been a source of adult tomcod abundance trends for those years in which spatially adequate samples were collected during November and December when adults were present in the estuary; however, tomcod spawning activity was concentrated between RM 39 (KM 62) and RM 61 (KM 98) (Section V), so only 1973 and 1974 bottom trawl surveys would have provided an adequate sample of the spawning region (Table IV-6). This would not have been sufficient for assessment of adult tomcod abundance.

Table IV-9

Mean Daily Freshwater Inflow by Month, 1965-74, Hudson River at Green Island Dam, Troy, New York [RM 153 (KM 245)]*

	Jan		Feb		Mar		Apr		May		Jun	
	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s
1965	5,314	150	9,108	258	9,123	258	19,280	546	8,309	235	3,573	101
1966	8,130	230	11,630	329	23,090	653	15,630	442	19,410	549	8,270	234
1967	9,616	272	7,633	216	11,360	322	30,940	876	17,060	483	6,197	175
1968	8,867	251	9,513	269	24,860	704	18,300	518	18,490	523	15,710	445
1969	11,680	331	12,760	361	17,470	494	40,730	1,153	20,910	592	9,995	283
1970	8,206	232	15,340	434	15,060	426	39,350	1,114	14,550	412	6,404	181
1971	9,002	255	12,110	343	20,220	572	37,270	1,055	35,240	997	7,334	208
1972	13,410	379	10,931	309	26,860	760	37,960	1,074	40,520	1,147	29,630	839
1973	26,210	742	20,460	579	29,410	833	30,960	877	27,600	782	13,050	370
1974	22,010	623	18,640	528	20,730	587	30,170	854	22,960	650	8,791	249

	Jul		Aug		Sep		Oct		Nov		Dec	
	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s	ft^3/s	m^3/s
1965	3,082	87	2,912	82	4,009	113	7,298	207	10,680	302	10,850	307
1966	3,674	104	4,233	120	5,630	159	5,847	165	7,042	199	9,118	258
1967	5,074	144	5,749	163	4,934	140	6,973	197	11,740	332	16,510	467
1968	9,795	277	4,440	126	4,463	126	5,173	146	14,400	407	15,600	441
1969	5,430	154	6,102	173	4,133	117	4,856	137	14,270	404	11,800	334
1970	5,997	170	3,923	111	6,165	174	8,186	232	9,333	264	11,390	322
1971	6,233	176	8,929	253	9,315	264	7,811	221	7,291	206	17,000	481
1972	18,380	520	7,616	216	6,309	179	7,190	203	25,600	724	26,900	761
1973	10,390	294	5,591	158	4,791	136	5,650	160	8,280	234	26,420	748
1974	11,780	334	6,359	180	10,390	294	9,049	256	17,180	486	19,380	549

*Data obtained from United States Geological Survey records at Green Island Dam.

Table IV-10

Mean Biweekly Hudson River Surface Temperatures (°C) in Vicinity of Indian Point, RM 42 (KM 67), 1965-70 and 1972-74, and at Poughkeepsie, RM 75 (KM 120) during 1971*

Year	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
	1-15	16-31	1-15	16-28 (9)	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31
1965	3.0	1.9	0.5	0.7	0.6	1.5	3.5	8.0	11.5	15.0	18.5	21.5	23.0	23.5	24.6	24.7	23.5	21.8	18.3	15.4	12.1	9.6	6.9	4.5
1966	1.7	1.0	1.0	0.9	1.1	3.0	5.5	8.7	11.0	14.3	19.2	22.7	25.5	25.5	25.1	25.6	23.9	20.9	17.4	17.0	13.4	11.5	8.8	6.5
1967	4.2	3.6	3.3	3.2	3.2	3.8	6.9	9.0	11.5	14.5	18.0	22.0	24.0	25.6	26.6	25.4	23.6	21.8	20.4	17.0	12.7	7.0	5.3	3.7
1968	1.8	0.9	0.8	0.8	1.6	4.8	7.7	12.0	15.0	17.0	19.0	22.3	24.5	25.8	25.8	25.2	23.0	22.6	20.1	17.2	13.6	7.8	3.8	1.3
1969	0.3	0.9	0.9	0.9	1.1	3.6	6.6	10.0	12.5	17.7	20.5	22.5	23.3	24.0	25.7	25.5	24.5	22.8	20.0	16.5	11.7	8.0	4.7	1.8
1970	1.2	1.5	2.0	1.2	0.5	2.1	3.7	8.8	10.2	16.5	19.0	21.5	23.0	24.0	25.9	25.5	23.7	22.1	20.4	17.0	13.0	9.4	5.3	1.5
1971	0.7	0.6	0.7	0.8	0.8	3.0	6.2	8.0	9.5	14.0	18.0	22.0	24.7	25.0	25.1	25.0	23.2	22.0	18.5	16.2	14.5	9.4	4.0	2.8
1972	1.3	0.7	0.8	0.7	0.8	2.5	4.0	8.8	10.7	15.5	19.7	19.7	20.5	23.5	24.5	23.8	24.0	22.7	17.0	14.8	11.3	5.5	2.8	3.1
1973	2.0	0.8	0.4	0.6	1.4	4.9	6.7	8.5	12.5	14.5	16.5	20.5	22.0	23.5	24.7	24.6	24.8	21.0	18.0	15.5	12.4	10.7	8.1	3.0
1974	0.8	2.0	0.9	1.5	3.5	5.0	6.0	8.7	14.0	16.5	20.0	21.5	23.5	24.8	25.1	25.3	24.4	22.4	17.5	14.3	12.6	8.0	5.7	3.9

*Data obtained from measurements taken by the United States Geological Survey (1965-1968, 1971), Raytheon Company (1969-1970), and Texas Instruments (1972-1974).

To examine the potential effect of mortality from predation, the abundance of juvenile American shad and Atlantic tomcod were compared with the abundance of potential predators — bluefish (*Pomatomus saltatrix*), yearling and older white perch (*Morone americana*), and yearling and older striped bass (*Morone saxatilis*) (Table IV-11) — and the food habits of these potential predators evaluated. The potential role of cannibalism as an influence on American shad and Atlantic tomcod year-class abundance was determined by evaluating those species' life histories and food habits.

Table IV-11

Year-Class Abundance Index for Yearling and Older Striped Bass, Yearling and Older White Perch, and Young Bluefish Based on Riverwide Beach Seine Catches during July-August, Hudson River, 1965-74

Year	Abundance Index Mean Catch per Unit Area Swept (CPUA) Striped Bass	White Perch	Bluefish
1965	0.4	7.9	0.3
1966	0.1	10.6	0
1967	0.2	8.8	0.1
1968	0.02	8.4	0.1
1969	0.3	21.2	0.1
1970	1.3	17.3	0.7
1971	*	*	*
1972	1.6	12.2	3.1
1973	1.0	8.0	1.4
1974	2.5	26.2	5.8

*No extensive riverwide samples

c. Power Plant Factors

The potential influence of power plant operation on American shad and Atlantic tomcod year-class abundance was examined by comparing the juvenile abundance indices with an index of power plant operation. Since the entrainment and impingement of eggs, larvae, and juveniles are directly related to the withdrawal of power plant cooling water, maximum combined daily water withdrawal of all operating units at Bowline, Lovett, Indian Point, and Danskammer was used as the index of power plant operation (Table IV-12). The volume of water withdrawal was assumed to be directly proportional to capacity. For details concerning percent of capacity for any unit as well as the online schedule criteria, please refer to an earlier report (TI, 1975a).

Table IV-12

Index of Combined Power Plant Operations on Hudson River Estuary [RM 37-66 (KM 59-106)], 1949-74, Based on Maximum Daily Water Withdrawal with All Units Operating at 100% Capacity

Year	No. of Generating Units On Line	Unit Location*	Maximum Daily Water Withdrawal ($m^3 \times 10^3$/day)
1949	1	L1	137
1950	1	L1	137
1951	1	L1	137
1952	3	L1, L2, D1	503
1953	3	L1, L2, D1	503
1954	3	L1, L2, D1	503
1955	5	L1, L2, L3, D1, D2	961
1956	5	L1, L2, L3, D1, D2	961
1957	5	L1, L2, L3, D1, D2	961
1958	5	L1, L2, L3, D1, D2	961
1959	5	L1, L2, L3, D1, D2	961
1960	6	L1, L2, L3, D1, D2, D3	1,484
1961	6	L1, L2, L3, D1, D2, D3	1,484
1962	6	L1, L2, L3, D1, D2, D3	1,484
1963	7	L1, L2, L3, D1, D2, D3, I1	3,217
1964	7	L1, L2, L3, D1, D2, D3, I1	3,217
1965	7	L1, L2, L3, D1, D2, D3, I1	3,217
1966	8	L1, L2, L3, L4, D1, D2, D3, I1	3,786
1967	8	L1, L2, L3, L4, D1, D2, D3, I1	3,786
1968	9	L1, L2, L3, L4, D1, D2, D3, D4, I1	4,604
1969	10	L1, L2, L3, L4, L5, D1, D2, D3, D4, I1	5,258
1970	10	L1, L2, L3, L4, L5, D1, D2, D3, D4, I1	5,258
1971	10	L1, L2, L3, L4, L5, D1, D2, D3, D4, I1	5,258
1972	10	L1, L2, L3, L4, L5, D1, D2, D3, D4, I1	5,258
1973	12	L1, L2, L3, L4, L5, D1, D2, D3, D4, I1, I2	12,094
1974	13	L1, L2, L3, L4, L5, D1, D2, D3, D4, I1, I2, B1, B2	14,188

L = Lovett, B = Bowline, I = Indian Point, D = Danskammer.

*Roseton Units 1 and 2 did not begin operation until after July 1974 and are not included in these analyses.

2. Results and Discussion

a. American shad

The abundance of juvenile American shad plotted against both freshwater inflow and surface water temperature (March-July) during 1965-74 showed no clear trends. Annual fluctuations in the abundance of juvenile shad in the Hudson River were apparently influenced by one or more factors not examined.

Predation by yearling and older striped bass, yearling and older white perch, and bluefish did not appear to be an important source of mortality to juvenile shad in the Hudson River. Although bluefish do consume shad (TI, 1975g), juvenile shad are distributed upriver from major bluefish concentrations throughout most of the summer (TI, 1975e, and Section V of this report). Thus, while the influence of bluefish predation on juvenile shad abundance appears to be relatively unimportant, conclusive evidence to completely disregard its effects is lacking.

Cannibalism is an unimportant source of mortality to juvenile shad since the species is nonpiscivorous at all ages (Bigelow and Schroeder, 1953; Levesque and Reed, 1972).

A plot of juvenile abundance vs power plant water withdrawal (Figure IV-17) revealed a classic example of the effect of one or two data points on a small set of data points.

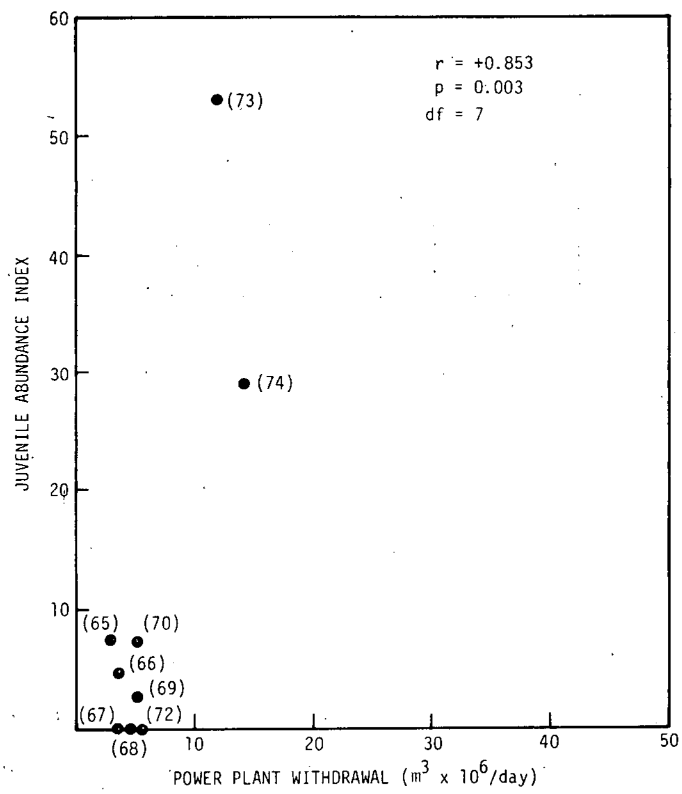


Figure IV-17. Relationships between July-August Index of Juvenile American Shad Abundance and Maximum Daily Water Withdrawal by Power Plants in Hudson River, 1965-74 (1971 Excluded)

The cluster of points representing 1965-72 indicated no relationship between juvenile shad abundance and power plant operations. Two extreme points, 1973 and 1974, produced the positive association. Hence, the overall meaning of the relationship is unclear. The most plausible explanation is simply an independent increase in both power plant withdrawals and shad abundance with no cause-and-effect relationship.

Another potentially important factor is the overall water quality of the Hudson River, particularly in the shad spawning areas above Kingston (Burdick, 1954; Talbot, 1954; TI, 1975a). A recent report (Mt. Pleasant and Bagley, 1975) indicates that general water quality in the lower Hudson River estuary, particularly below the Albany area, has noticeably improved since 1965 (Figure IV-18). The construction and operation of several sewage treatment plants in the Albany area are primarily responsible for the improving trend. Water quality has been and continues to be fairly good in the mid-Hudson region but deteriorates greatly near the metropolitan New York City area.

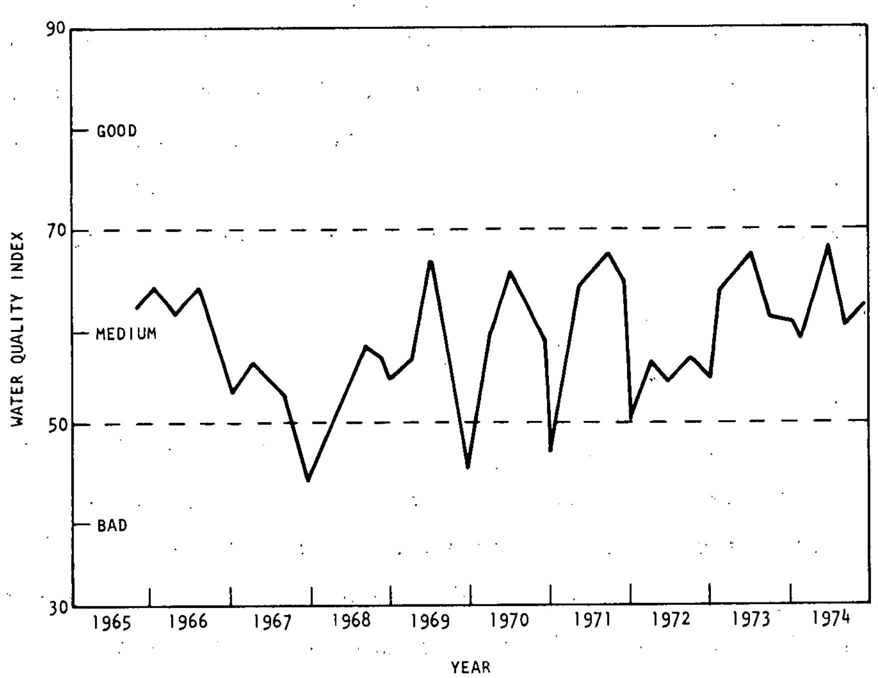


Figure IV-18. Water Quality Index for Hudson River below Albany, New York, Area, 1965-74 (Data collected and indices calculated by New York Department of Environmental Conservation; adapted from Mt. Pleasant and Bagley, 1975)

Thus, the generally increasing trend in the abundance of juvenile American shad since 1965 may be associated also with the generally improving water quality in the Hudson River above New York City. Additional data would be necessary to fully elucidate the relationship between American shad year-class abundance and environmental factors.

The July and August abundance of juvenile shad was unrelated to the index of spawning stock abundance ($r = -0.011$, $p = 0.978$, $df = 7$). The index of stock abundance was based on commercial landings and may not have reflected annual escapement (those potential spawners that escape the fishery). Previous studies of Hudson River shad populations concluded that the most important determinant of adult abundance between 1915 and 1951 was the number of fish that escaped the commercial fishery 5 years earlier (Burdick, 1954; Talbot, 1954). No significant correlations were found between the size of the fifth-year-returning adult spawning stock and stream flows (Burdick, 1954; Talbot, 1954), water temperatures, channel improvements, ship traffic, or hatchery production (Talbot, 1954). Nor was there evidence that shad runs fluctuated in natural cycles of abundance (Talbot, 1954). There are no data available with which to determine the proportion of the 1965-74 spawning stock abundance of shad that escaped the commercial fishery. Talbot's (1954) estimates of annual escapement based on tagging studies of Hudson River shad (1915-50) ranged from 21 to 80% (mean of 51%) of the estimated total spawning run. Hence, the unknown variation in percent escapement between 1965 and 1974 might have been sufficient to explain the observed variations in annual juvenile shad abundance during those years.

b. Atlantic Tomcod

Annual fluctuations in the abundance of juvenile Atlantic tomcod was almost significantly related to spring water temperatures ($p = 0.10$), with higher temperatures associated with lower abundances. The negative correlation between water temperature and abundance was best demonstrated during March (Figure IV-19). Juvenile tomcod abundance was also positively related to early April freshwater flow (Figure IV-20).

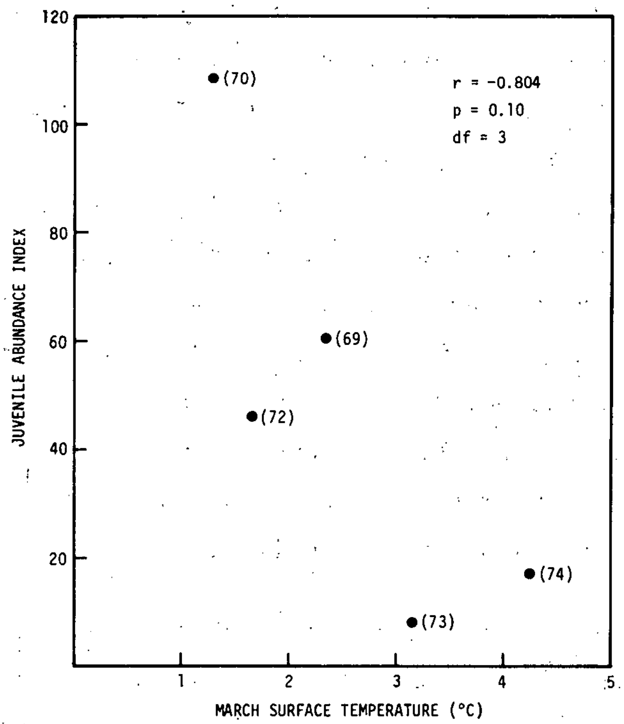


Figure IV-19. Relationship between July-August-September Index of Juvenile Atlantic Tomcod Abundance and Water Temperature in Hudson River, March 1969-74 (1971 Excluded)

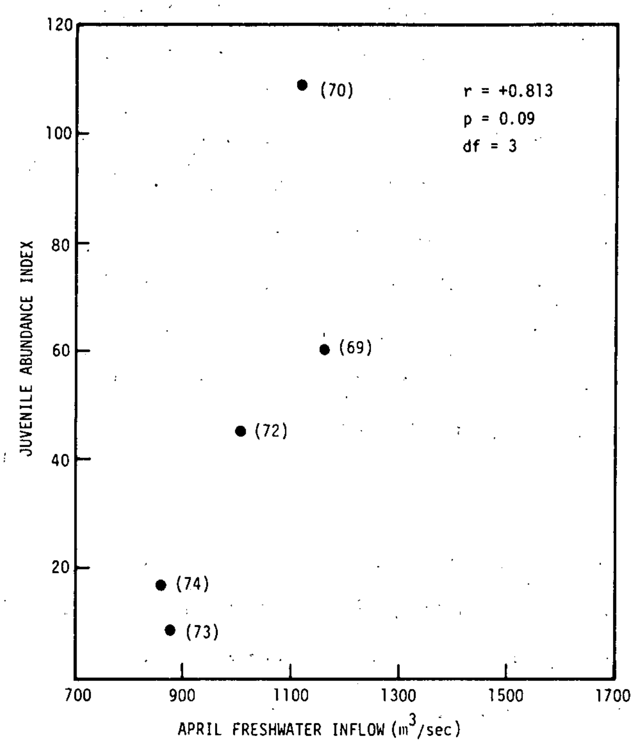


Figure IV-20. Relationship between July-August-September Index of Juvenile Atlantic Tomcod Abundance and April Freshwater Inflow in Hudson River during 1969-74 (Excluding 1971)

These trends suggest that increased juvenile tomcod abundance usually occurs during years characterized by high freshwater inflow and low water temperatures during late winter-spring. Since flow and water temperature are negatively correlated, it is not possible to clearly separate their effects. One could speculate that low water temperatures during March when tomcod larvae and early juveniles are abundant could enhance survival by retarding developmental rates and metabolic demands and thus provide more time for the young tomcod to locate sufficient food organisms. Booth (1967) demonstrated a negative correlation between tomcod year-class strength and water temperatures during the spawning period in the Mystic River, Connecticut (December-February); he suggested that low water temperatures increased year-class abundance by retaining the sheltering ice cover and suitable salinities important to spawning success.

Overall, physical environmental factors (temperature and freshwater flow) appeared to be much more important influences on juvenile tomcod abundance than did biological or power plant operational factors. Confirmation of the relative importance of the various environmental factors in determining tomcod year-class abundance in the Hudson River will require several additional years of data. Ricker (1975) suggested a minimum of $\geq$10 years for this type of analysis of fish populations; if several factors are important in determining year-class abundance, 15 to 25 years may be necessary.

The potentially important relationship between numbers of spawners and numbers of juveniles could not be examined for tomcod since estimates of spawning stock abundance were not available. A potential source of mortality, bluefish predation, is of uncertain importance because a graph of bluefish and tomcod abundance showed no clear trend ($r = -0.542$, $p = 0.345$, $df = 3$). However, 2 years of large tomcod year classes (1969 and 1970) were associated with low bluefish abundance. Bluefish are known to consume tomcod in the Hudson River (TI, 1975g).

Cannibalism is an unlikely source of juvenile tomcod mortality since all age groups of tomcod are essentially nonpiscivorous (TI, 1975b). The abundance of juvenile tomcod during July-September was not significantly related ($\alpha = 0.05$) to the index of power plant operation (Figure IV-21), although two

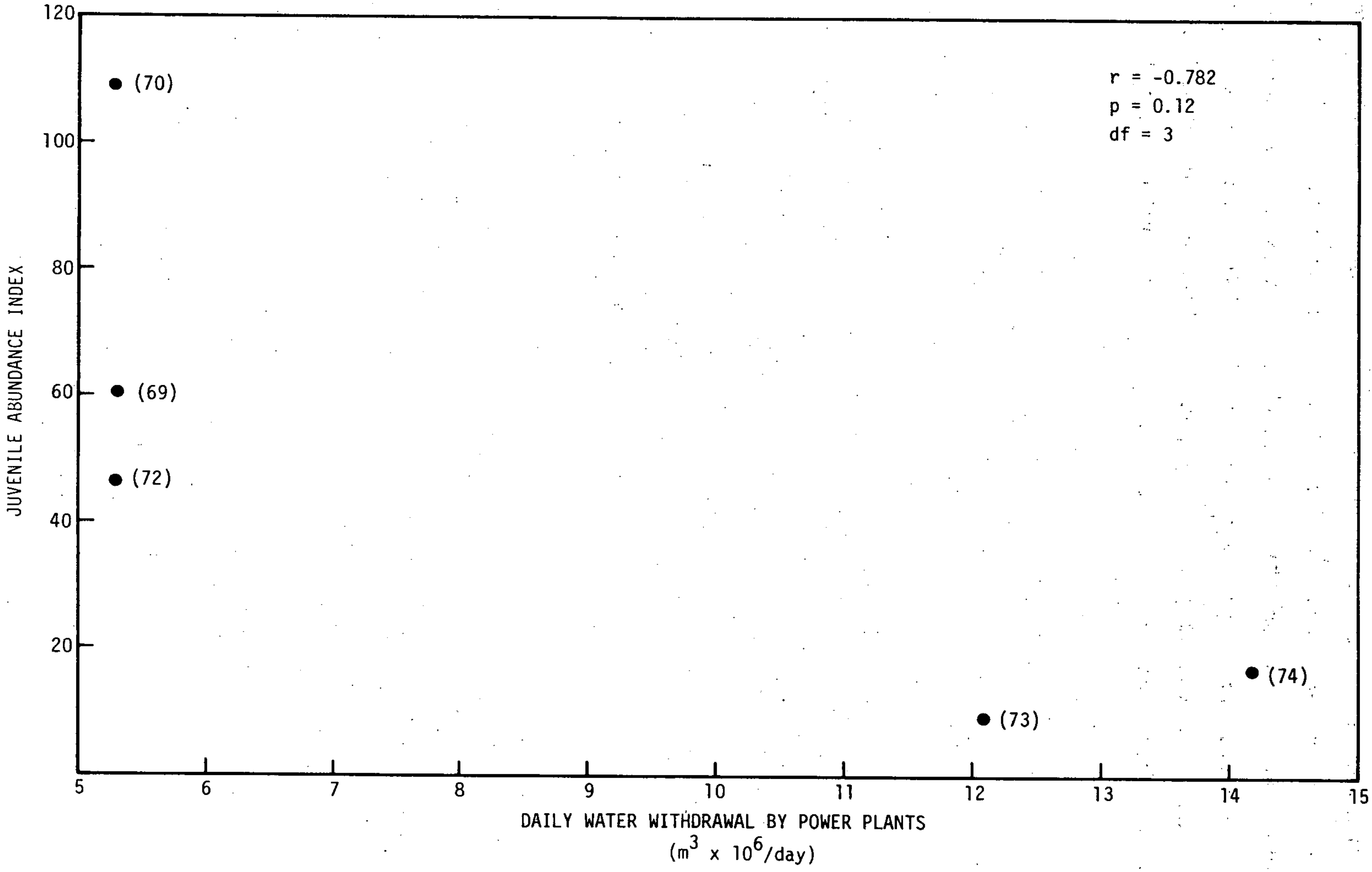


Figure IV-21. Relationship between July-August-September Index of Juvenile Atlantic Tomcod Abundance and Maximum Daily Water Withdrawal by Power Plants in Hudson River, 1969-74 (Excluding 1971) data points trended toward a negative relationship. It is important to consider that the annual index of abundance reflected the juvenile population present in the river during July-September and was based on an unknown portion of the peak juvenile standing crop present from March through early May and then presumably migrating, in part, out of the study area (TI, 1975a). Thus, some of the unexplained variation in tomcod abundance might have been due to variations in annual migration rates and/or times and longitudinal distribution in the river.

SECTION V

ASSESSMENT OF DISTRIBUTION AND VULNERABILITY

A. INTRODUCTION

The magnitude of mortality of fish populations in the Hudson River estuary induced by power plants is directly related to the vulnerability (exposure) of eggs and larvae to entrainment (passage through the condenser cooling system) and young and yearlings to impingement (entrapment on the cooling water intake screens). Some of the factors that influence vulnerability are the life histories, physiology, and behavior of the fishes; the temporal and spatial abundances and distributions of the various life stages; and power plant factors such as intake design, zone of water withdrawal, velocity at the screen face, screen mesh size, pumping rate, and operation schedule. The concept of vulnerability addressed in this section refers to the exposure of the populations of early life stages to power plants rather than the probability that an individual egg, yolk-sac larva, etc., will be entrained.

Life histories, physiology, and behavior of fishes offer a partial assessment of vulnerability: they influence the time period during which each life stage is in the estuary and determine their relative ability to avoid and/or survive entrainment and impingement.

A more complete assessment of vulnerability is derived from a description of the temporal and spatial abundances and distributions: these reveal when and where the various life stages occur in the estuary. Temporal abundance patterns provide the best estimate of the size of the population and indicate the time and duration of each life stage. Longitudinal distributions are the key vulnerability factors: they indicate where each life stage occurs and the key environmental variables that influence distribution, and they describe movements. Patterns of vertical, lateral, diel, and tidal distribution offer additional information on the location of each life stage: they suggest which life stages are most susceptible to plant-induced mortality and describe how vulnerability may vary with time of day.

The locations and intake designs of power plants influence the cooling water withdrawal zones, the effectiveness of the screens or other diversion devices protecting the intakes, how much water can be withdrawn, the velocities at the screen faces, and the particle sizes that can be entrained. The operational schedule at each plant determines the actual volume of water withdrawn, the season of maximum pumping, and changes in discharge water temperature.

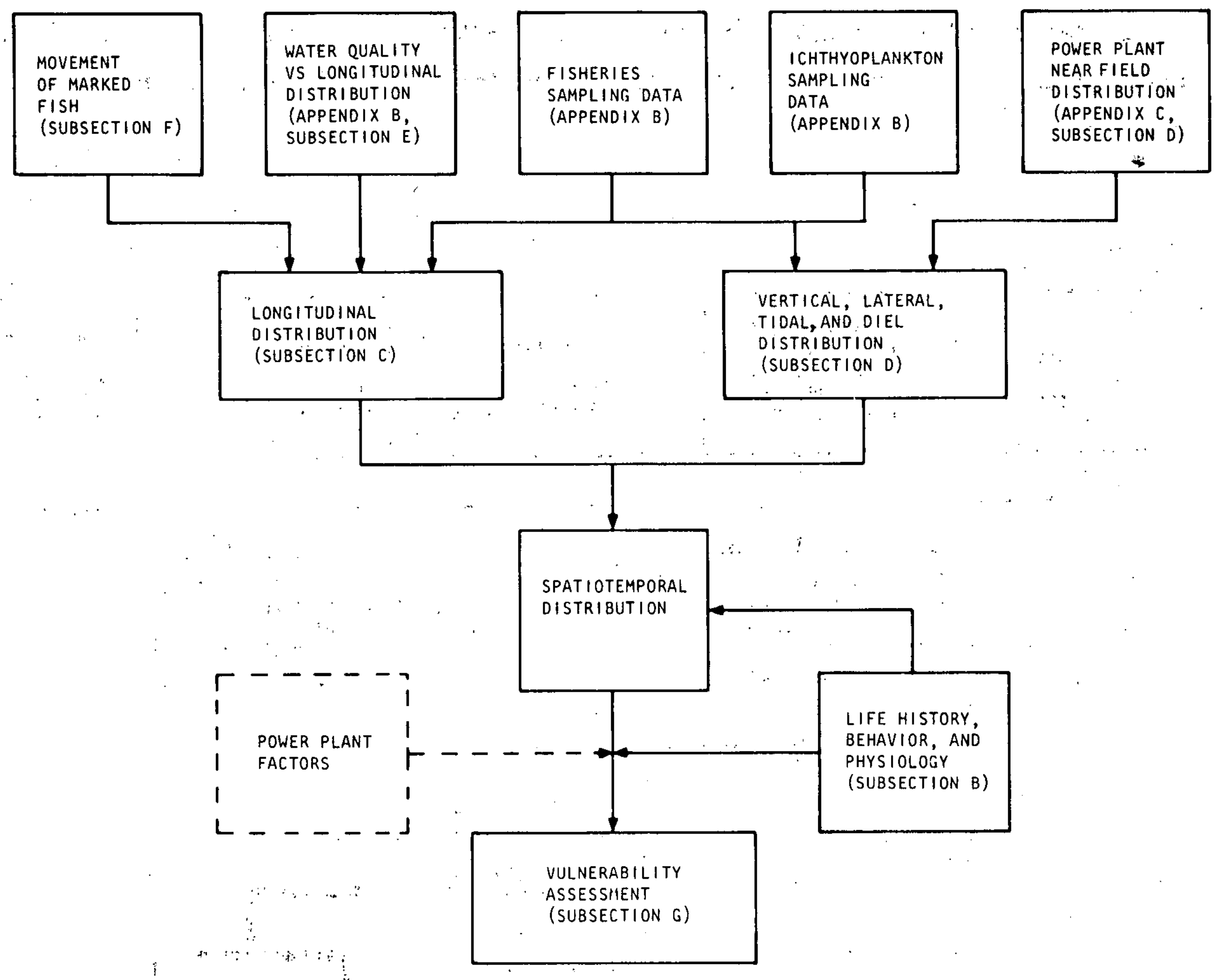
The summation of these biological and plant-related factors describe the vulnerability of each life stage. Annual variations in any of the factors can be expected to influence estimates of direct impact. Knowledge of how vulnerability factors interact to determine the magnitude of plant-induced mortality provides the basis for explaining annual differences in the empirical estimates of direct impact.

Vulnerability of striped bass, white perch, and Atlantic tomcod to the Bowline, Lovett, Indian Point, Roseton, and Danskammer electric generating stations for 1973 and 1974 (through September) was discussed in an earlier report (TI, 1975a). In this section, results of the analysis of ichthyoplankton, fisheries, and water quality data collected during 1974 are discussed relative to the following objectives:

- Synthesis of fisheries literature and data from the Hudson River estuary and other estuaries to construct a life history/behavior description for American shad and describe biological factors that may influence the vulnerability of each life stage to power plants
- Description of the longitudinal abundances and distributions of the life stages of the 1974 year class of striped bass, white perch, and Atlantic tomcod (October 1974-June 1975) and American shad (April 1974-June 1975) between RM 12 (KM 19) and RM 152 (KM 243) and in the 13-mi region around the Bowline, Lovett, Indian Point, and Roseton-Danskammer power plants
- Description of the vertical, lateral, diel, and tidal distributions of the life stages of the 1974 year class of striped bass, white perch, Atlantic tomcod, and American shad between RM 12 (KM 19) and RM 152 (KM 243) and in the vicinity of the Bowline, Lovett, Indian Point, and Roseton-Danskammer power plants
- Examination of the relationships between distributions of early life stages of striped bass, white perch, Atlantic tomcod, and American shad and selected water quality variables (temperature, conductivity, and dissolved oxygen) during 1974

- Description of the seasonal movements of individually marked striped bass, white perch, and Atlantic tomcod during 1974 and early 1975

This section is divided into a separate subsection for each objective. The following diagram illustrates the overall organization to assess the vulnerability of the key fishes to the five power plants and indicates the subsection or appendix in which the relevant information appears.

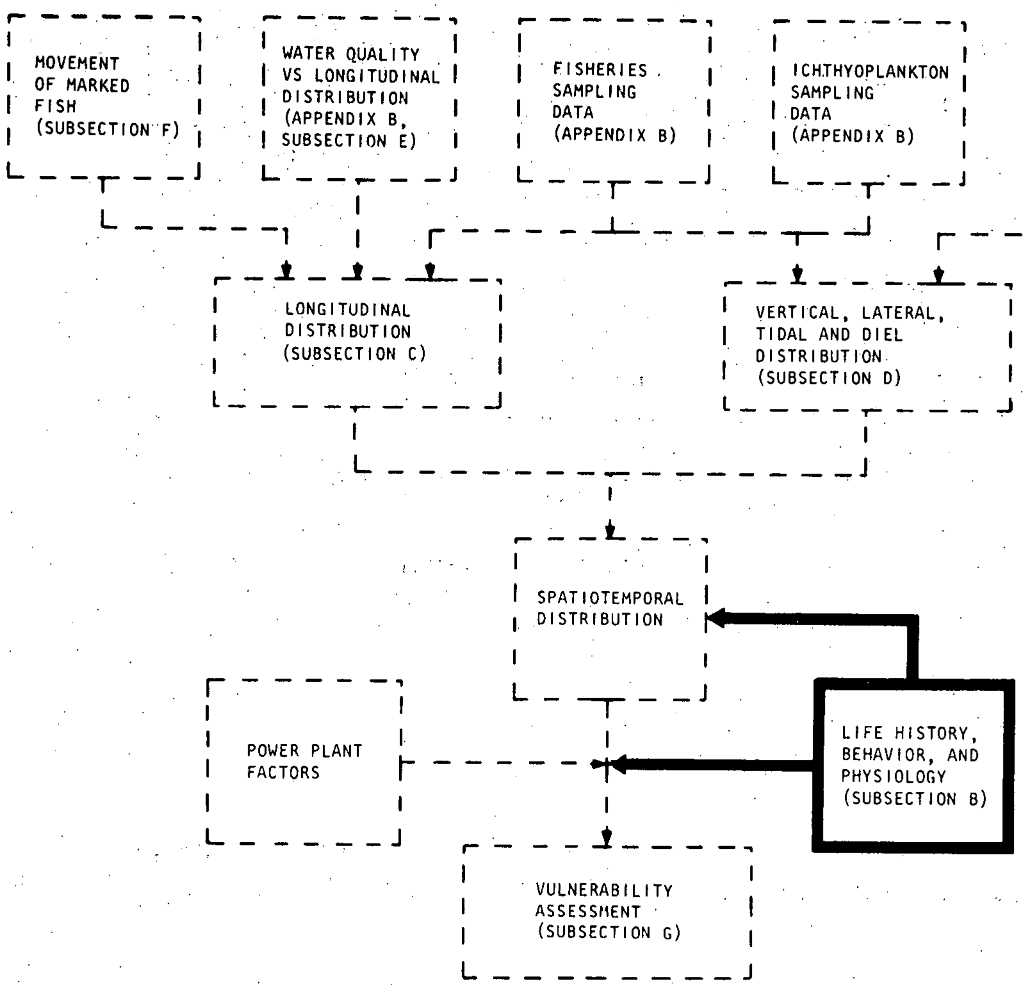


Data on power plant locations, intake designs, and operations were presented in an earlier report (TI, 1975a).

B. LIFE HISTORY/BEHAVIOR

1. Objective

Fisheries literature and data from the Hudson River estuary and other estuaries were synthesized to construct a life history/behavior description and describe biological factors that may influence the vulnerability of each life stage of American shad to power plants. The life history/behavior description also indicates factors that may influence gear efficiency in collecting the various life stages. Striped bass, white perch, and Atlantic tomcod were similarly described in an earlier report (TI, 1975a). The position of this subsection in the overall organization of Section V is illustrated in the following diagram:



2. Methods

Data on when and where American shad occur or could be expected to occur in the Hudson River estuary were integrated from literature, as were other pertinent biological factors (type of egg, incubation period, etc), to generate a life history/behavior description (Table V-1).

Table V-1

Life History/Behavior Information for American Shad (*Alosa sapidissima*) in Hudson River Estuary

	Use of Estuary						Pertinent Life Stage Characteristics			
	Adults		Young		Eggs			Larvae		Juvenile/ Yearling
Life History	Spawning Period	Spawning Areas	Nursery Period	Nursery Areas	Type	Incubation Time*	Life Stage Length Division**	Size at Initial Motility	Response to Light	Swimming Speed Capability
Anadromous	Apr mid-Jun	In tidal freshwater areas from approx RM 77-124 (KM 123-198), possibly in tributaries	Late Jun-Nov	Shoal and shore zone areas from approx RM 12-152 (KM 19-243)	Spherical, nonadhesive semibuoyant, 2.5-3.5 mm in diameter (water-hardened)	288-360 hr at 12°C 144-192 hr at 17°C 48 hr at 27°C	Yolk-sac Larvae 6.5-10.0 mm (SL) Post yolk-sac larvae 10.1-29.9 mm (SL) Juveniles 30.0 +mm (SL)	Approx 9-12 mm (TL)	No data available	No data available

*Data from Ryder, 1887; Leim, 1924; Hildebrand, 1963; Mansueti and Hardy, 1967; Medeiros, 1974.
**As defined by Texas Instruments Incorporated. Yolk-sac larvae possess a definite yolk-sac but an incomplete digestive tract. Post yolk-sac larvae, regardless of degree of yolk-sac absorption, possess a complete digestive tract but have not completed transformation, so adult morphometric characteristics are lacking. Juveniles have completed transformation but have not yet reached one year of age.
SL = standard length
TL = total length

3. Results and Discussion

American shad, an anadromous species (Hammer, 1942; Hollis, 1948; Talbot and Sykes, 1958), uses the Hudson River estuary as a spawning and nursery area, although some juveniles (young of the year) may overwinter in the estuary at the end of their first year (Hildebrand, 1963; TI, 1975e). Adult shad migrate into the estuary in March and April, spawn from about mid-April to mid-June (Talbot, 1954; Raytheon, 1971; TI, 1975e), and then leave the river and migrate northward toward the Gulf of Maine (Thomson et al, 1971). The timing of the peak of shad spawning migrations in all Atlantic coast populations is closely correlated with water temperatures ranging from 13°C to 18°C (Carscadden and Leggett, 1975).

Most Hudson River shad spawn in the tidal freshwater regions between RM 77 (KM 123) and RM 124 (KM 198), depositing some eggs downstream near Newburgh at RM 61 (KM 98) (Burdick, 1954; Talbot, 1954; TI, 1975e). Egg deposition presumably occurs in river areas dominated by extensive flats (Massman, 1952) or in sandy and pebbly shallows near the mouths of tributaries (Hildebrand and Schroeder, 1928; Bigelow and Welsh, 1925; Mansueti, 1955; Hildebrand, 1963). Spawning activity is primarily during evening hours (Massman, 1952; Whitney, 1961; Chittenden, 1969; Marcy 1972, 1976).

Shad eggs are semibuoyant and nonadhesive (Mansueti, 1955; Hildebrand, 1963; Medeiros, 1974) and therefore are somewhat vulnerable to entrainment. The rate of egg development varies with temperature, ranging from 12 to 15 days at 12°C to only 2 days at 27°C (Ryder, 1887; Leim, 1924; Thomson et al, 1971). The larvae hatch when they are about 6 to 10 mm (standard length), and they become motile soon thereafter (Mansueti and Hardy, 1967; Marcy, 1976).

Juvenile shad tend to move downstream as they develop (Bigelow and Schroeder, 1953; Hildebrand, 1963; Thomson et al, 1971; TI, 1975e; Marcy, 1976). Downstream movements are closely related to water temperature and intensify in the fall when temperatures decrease to 15 to 16°C (Hildebrand, 1963; Leggett and Whitney, 1972; Marcy, 1976). Most juveniles go to sea in late fall but some may overwinter in the deeper parts of the lower estuary and bays (Pacheco, 1973; TI, 1975e). Chittenden (1972) reports that the lowest temperatures tolerated by juvenile shad are 4 to 6°C.

Vulnerability of American shad to power plants should be concentrated in the egg, larval, and juvenile stages but, because the species spawns in the upper river sampling regions, the eggs and larvae are relatively invulnerable to entrainment at the Bowline, Lovett, Indian Point, Roseton, or Danskammer power plants, all of which are located below RM 67 (KM 107). Some early juveniles are vulnerable to entrainment at Roseton and Danskammer. The late juveniles become vulnerable to impingement at power plants as they migrate seaward in late summer and fall. The lack of information on swimming speed capability precludes a prediction of the ability of juveniles to resist the plant intake velocities.

4. Summary

Based on this synthesis of the literature on American shad life history and behavior, the species' vulnerability to power plants can be summarized as follows:

- The American shad is an anadromous species that spawns in the upper estuary; hence, the eggs and larvae are mostly distributed upstream from the Bowline, Lovett, Indian Point, Roseton, and Danskammer power plants. Vulnerability to entrainment is low.
- Juveniles migrate seaward in the fall and become vulnerable to impingement as they pass the plant intakes.

C. SPATIOTEMPORAL, LONGITUDINAL, AND PLANT REGION DISTRIBUTION AND ABUNDANCE

1. Objective

Longitudinal abundances and distributions of the life stages of striped bass, white perch, Atlantic tomcod, and American shad in the 12 sampling regions (Table V-2) and in 13-mi regions around the Bowline, Lovett, Indian Point, Roseton, and Danskammer power plants (Table V-2) are described in this section.

Table V-2

Definitions and Boundaries of Sampling and Power Plant Regions

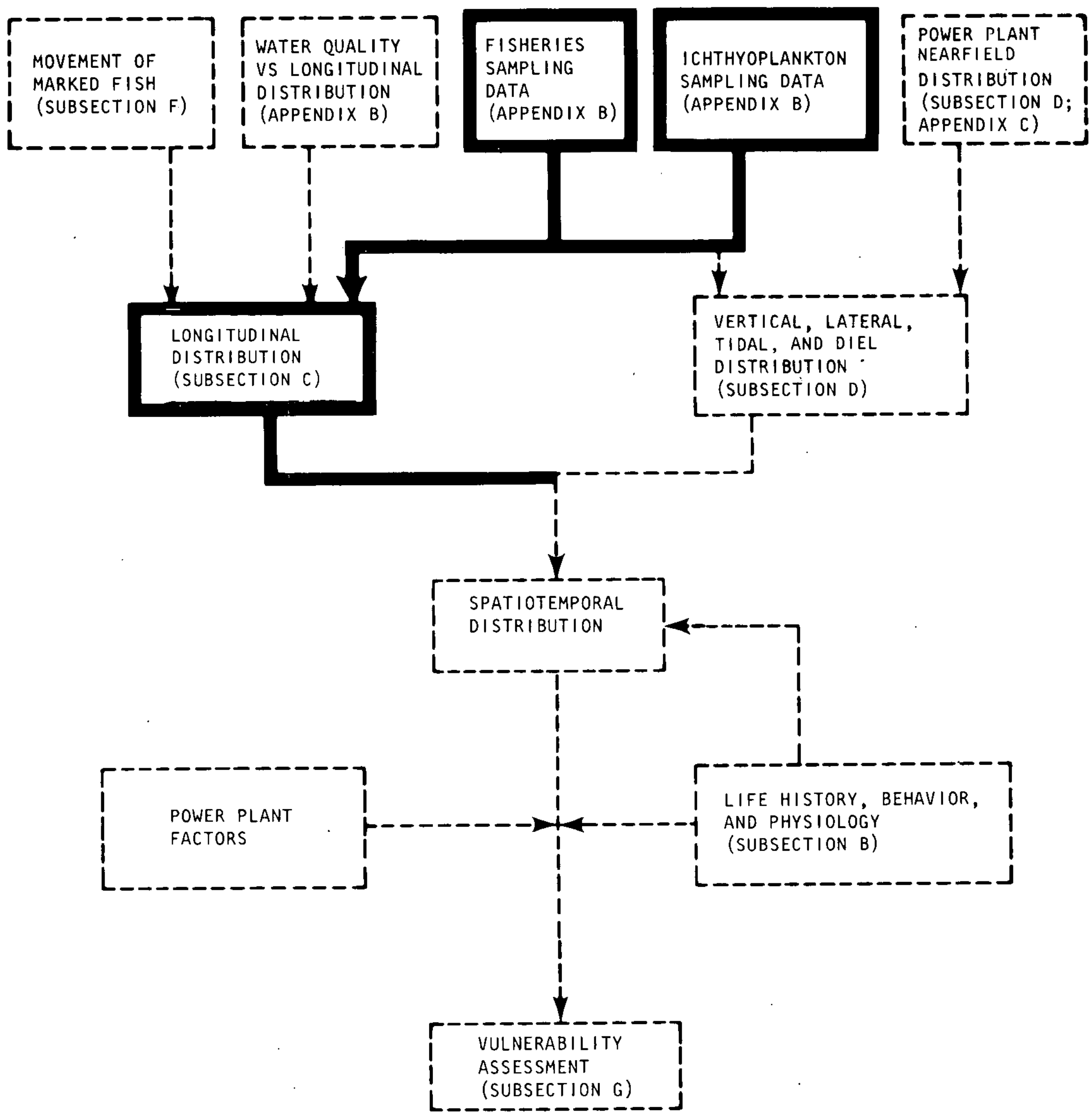
Sampling Region	Abbreviation	River Miles (Kilometers)
Yonkers	YK	14-23 (22-37),* 12-23 (19-37)**
Tappan Zee	TZ	24-33 (38-53)
Croton-Haverstraw	CH	34-38 (54-61)
Indian Point	IP	39-46 (62-74)
West Point	WP	47-55 (75-88)
Cornwall	CW	56-61 (89-98)
Poughkeepsie	PK	62-76 (99-122)
Hyde Park	HP	77-85 (123-136)
Kingston	KG	86-93 (137-149)
Saugerties	SG	94-106 (150-170)
Catskill	CS	107-124 (171-198)
Albany	AL	125-140 (199-224),* 125-152 (199-243)**

Power Plant Region	Plant Site (River Mile)	River Miles (Kilometers)
Bowline	37	31-43 (50-69)
Lovett	41	35-47 (56-75)
Indian Point	42	36-48 (58-77)
Roseton	65	59-71 (94-114)
Danskammer	66	60-72 (96-115)

*Ichthyoplankton sampling

**Beach seines

Distribitions of the 1974 year class of striped bass, white perch, and Atlantic tomcod during October 1974-June 1975, which were used to assess their vulnerability to power plants, are described in this section. Pre-October 1974 data for these species appeared in an earlier report (TI, 1975a). American shad distribution and vulnerability assessment in this section covers the time period April 1974-June 1975. This subsection's position in the overall organization of Section V is illustrated below:



2. Methods

Ichthyoplankton and fisheries field samples collected from April 1974 through June 1975 were analyzed. Field sampling has been described in Section III of this report and in an earlier report (TI, 1975a), as have methods used to calculate regional and total river abundance estimates and their underlying assumptions (TI, 1975a).

Abundance data on eggs, larvae, juveniles, yearlings, and older fish from the 12 sampling regions (Table V-2) were analyzed and examined to determine when each life stage of each species had been first collected in the estuary, when the maximum total abundance of each life stage had occurred and what the peak abundance estimate had been, in what sampling region(s) the peak abundance of each life stage had occurred, how long each life stage had been present in the estuary, and what the distribution range of each life stage had been. In addition, abundance and distribution data on eggs, larvae, and juveniles of the four species were analyzed with respect to the 13-mi regions around the Bowline, Lovett, Indian Point, Roseton, and Danskammer power plant (Table V-2) to determine the percent of the total river standing crop that had been present in each plant region during the peak standing crop period for each life stage.

3. Results and Discussion

The abundance and distribution of the early life stages of the 1974 year class — eggs, larvae, and juveniles (young-of-the-year) — received the major emphasis because their sizes, behavior, and seasons spent in the estuary make them generally more vulnerable than older individuals to power plants. The general descriptions of distribution and vulnerability are based on the data presented in Appendix Tables A-1 through A-84 and Figures A-1 through A-47.

a. Longitudinal Sampling Regions, 1974-75

1) Striped Bass

a) Juveniles, October-December 1974

After peaking between 25 August and 21 September (TI, 1975a), juvenile striped bass abundance (the 1974 year class) in the shore zone during the day declined slowly through November but decreased sharply in early December (Appendix Figure A-1) as the population either completed its movement to deeper water or migrated from the sampling area (below RM 12 [KM 19)]. The abundance of juveniles in the shore zone from October through December was restricted to the lower sampling regions, primarily Tappan Zee and Croton-Haverstraw. Also after September, juvenile abundance in the shoal and deeper areas of the estuary was concentrated in the lower regions, particularly Tappan Zee, Croton-Haverstraw, and Indian Point (Appendix Figures A-3 and A-4). Catches declined progressively through early December in all regions except Yonkers, the most downstream region sampled, suggesting that some juveniles overwinter in the offshore areas of the lower estuary.

b) Yearlings, March-June 1975

The distribution of yearling striped bass (the 1974 year class) during their first winter (mid-December 1974 through mid-March 1975) was unknown because all sampling (except that in box traps) ceased during that time period. However, as previously mentioned, some presumably overwintered in the estuary.

Catches in beach seines were greatest in the most downstream region (Yonkers) from late March through mid-May. Yearlings appeared in the middle and upper river shore zone in late May and were also collected upriver in the Hyde Park and Kingston regions (Appendix Figure A-11) by late June (the last sampling period included in this report). Bottom trawl catches in the river were highest in early April in the Tappan Zee and Indian Point regions and then steadily declined through June (Appendix Figure A-12) as the yearlings apparently moved to the shore zone or avoided the trawls.

The longitudinal distribution of yearling striped bass suggested two possible movement patterns. Some fish may have overwintered in the lower regions and then moved upstream during March and April and then into the shoals and shore zone as water temperatures increased during May and June. An alternate hypothesis is that some fish overwintered upstream from the regions sampled by epibenthic sled and bottom trawl in the fall (YK-PK) and then moved into the shoals as water temperatures increased during May and June.

c) Yearlings, October-December 1974

During October, a few yearling striped bass (the 1973 year class) were collected in the shore zone of all regions except Albany (Appendix Figure A-5).

The abundance in the shore zone declined in early November, particularly upstream from the Cornwall region. Catches in the shoal and channel areas in bottom trawls and epibenthic sleds in early November suggested that the yearlings had moved off the beaches and downstream during November (Appendix Figures A-6 and A-7). The yearlings apparently continued to move downstream through the shoal and channel areas in December.

d) Age II and Older, October-December 1974

Age II and older striped bass were distributed in small numbers throughout much of the estuary. Older fish were taken by beach seines in the most downstream and most upstream regions in early October, but abundance in the shore zone rapidly diminished in November in all except the lower regions (Appendix Figure A-8). Apparently, the Age II and older fish in the shoal and deeper areas of the river were restricted to the lower regions during October. Their abundance declined to very low levels during November-December (Appendix Figures A-9 and A-10).

2) White Perch

a) Juveniles, October-December 1974

White perch juveniles (the 1974 year class) apparently began to leave the beaches in early fall and move into deeper water. Their abundance in the shore zone during the day from October through December was low throughout the estuary except for a peak in early November in the Tappan Zee region (Appendix Figure A-13). In December, catches of juveniles in beach seines were near zero.

Catches in bottom trawls and epibenthic sleds increased in November as beach seine catches were declining (Appendix Figures A-15 and A-16), supporting the hypothesis of late fall movements from the shore zone to the shoal and channel. Juvenile abundance remained relatively high in the regions sampled by epibenthic sled and bottom trawl (Yonkers through Poughkeepsie) through the end of the sampling season in mid-December. Apparently, juvenile white perch do not migrate out of the river in late fall but many overwinter in deeper areas of the lower estuary.

b) Yearlings, March-June 1975

The distribution of yearling white perch (the 1974 year class) during their first winter (mid-December 1974 through mid-March 1975) was unknown because ice and other weather conditions limited field sampling during that time period. They apparently overwintered in the river. Bottom trawl catches were highest in early April when yearlings were collected in the Indian Point region, presumably an important overwintering area (Appendix Figure A-24). Catches in the shoal and channel areas declined in late April and early May concomitant with increased catches in beach seines (Appendix Figure A-23) as the yearlings moved to the shore zone. Abundance in the shore zone remained relatively high throughout the river, at least until the end of June (the last sampling period included in this report). The Saugerties region exhibited a large peak in early June, suggesting that the yearlings either moved upstream in April and May or overwintered in the deeper areas of the upriver region and then moved to the shore zone during late May-early June.

c) Yearlings, October-December 1974

Yearling white perch (the 1973 year class) were abundant in the shore zone during October (Appendix Figure A-17) but apparently began to move off the beaches into the shoal and channel areas in early November (Appendix Figures A-18 and A-19). Epibenthic sled catches in the Yonkers-Poughkeepsie regions suggested that the yearlings first moved to the deeper areas of the river, then moved downstream and remained fairly abundant in the Yonkers, Tappan Zee, and Croton-Haverstraw regions through mid-December (the end of the major sampling effort).

d) Age II and Older, October-December 1974

Age II and older white perch were collected throughout the river but were most abundant in the shore zone of the Yonkers and Tappan Zee regions through November (Appendix Figure A-20). Catches were consistently high in the Yonkers region in epibenthic sleds but also increased in the Tappan Zee and Croton-Haverstraw regions in November and December (Appendix Figure A-22) as the Age II and older individuals apparently moved into the offshore waters. Older perch were still present in the shoal and channel areas through mid-December when sampling ceased (Appendix Figures A-21 and A-22).

3) Atlantic Tomcod

a) Juveniles, October through Mid-December 1974

Juvenile tomcod (the 1974 year class) were concentrated in the lower estuary through December. Bottom trawl catches in the deeper shoal and channel areas of the river increased somewhat in the Tappan Zee, Croton-Haverstraw, and Indian Point regions in late November but declined by mid-December when trawl sampling ceased (Appendix Figure A-28). Epibenthic sled catches were rather low throughout October-December (Appendix Figure A-29), suggesting that juvenile tomcod were occupying the deeper areas [>20 ft (6.1 m)] rather than the shoals [≤20 ft (6.1 m)]. Juvenile tomcod were almost nonexistent in the shore zone except for about 2 weeks in early November in the Tappan Zee region (Appendix Figure A-26).

b) Yearlings and Older, December 1974-February 1975

The distribution of mature, spawning Atlantic tomcod in the shoal areas of the river was determined by box trap sampling. Almost all of the spawning population during 1974-75 was composed of 1-year-old individuals spawned during the winter of 1973-74, the 1974 year class (TI, 1975b).

Yearling tomcod (the 1974 year class) first appeared in box traps in the Cornwall region in early December (Appendix Figure A-31). Catches in box traps were highest from mid-December through mid-January, apparently the peak spawning period during 1974-75. Catches were largest in the West Point and Cornwall regions in 1974-75, presumably the major spawning areas, although tomcod were taken in box traps from the Tappan Zee-Saugerties regions. During the 1973-74 spawning season, tomcod spawned during the same time period (mid-December to mid-January), but somewhat farther downstream, in the Indian Point and West Point regions (Appendix Figure A-25). Tomcod catches in box traps declined rapidly during late January and February to nearly zero in early March, suggesting a rapid downstream or offshore migration after spawning.

c) Yearlings and Older, March-June 1975

Yearling and older tomcod were first taken in bottom trawls in early April (Appendix Figure A-33), were most abundant in early May, and then steadily declined through June. A small number of yearling and older tomcod were taken by beach seines in the shore zone of only one region, Hyde Park, during the 14-17 May sampling period (Appendix Figure A-32). A few postspawning tomcod linger in the lower river through May and then either migrate to the lower bays and Atlantic Ocean or die. The fate of these older tomcod is unknown. However, if the mortality rate for tomcod during the second year of life is similar to that during the first year (TI, 1975b) only a few 2-year-olds should be captured.

4) American Shad

a) Eggs, April through Mid-August 1974

American shad eggs were first collected in the Kingston, Saugerties, and Catskill regions during the first routine sampling period (23-25 April) and were taken in all subsequent sampling periods through 23 June (Appendix Figure A-34). They were concentrated in the upper estuary, with most being collected in the Saugerties and Catskill regions. Egg abundance peaked from 30 May through 5 June, with >90% occurring in the Saugerties region. Standing crops were also relatively high during 28-31 May. No eggs were collected in the Yonkers, Tappan Zee, Croton-Haverstraw, West Point, or Cornwall regions. The small number of eggs collected in the Indian Point region occurred early in the spawning period (mid-May) and was an exception to the general upriver pattern of shad spawning.

b) Yolk-Sac Larvae, April through Mid-August 1974

American shad yolk-sac larvae (YSL) were first collected during 13-18 May from the West Point and Poughkeepsie through the Hyde Park regions (Appendix Figure A-35). The abundance of YSL peaked between 28 and 31 May, primarily in the Saugerties and Catskill regions. No YSL were collected after 27 June. Although a few were collected in the West Point, Cornwall, and Poughkeepsie regions, they were concentrated in the upper river. The synchrony between the peak periods of egg and YSL standing crops during late May-early June reflected the short egg stage duration.

c) Post Yolk-Sac Larvae, April through Mid-August 1974

American shad post yolk-sac larvae (PYSL) were first collected during 13-18 May (Appendix Figure A-36) in the Tappan Zee through Hyde Park regions, but they were most abundant in the Kingston, Saugerties, and Catskill regions at all times. Abundance increased steadily during May and June to a peak standing crop during 17-23 June. No PYSL were collected after the 22-26 July sampling period.

Peak PSYL numbers were far greater than peak YSL numbers and almost as numerous as eggs. The higher PYSL standing crop estimates could be partially explained by a shoal-to-channel movement by PYSL (subsection D), since sampling was reduced in the shoals above the Poughkeepsie region and extensive spawning in the shoal areas of the Catskill and Saugerties regions seems likely (subsection B). Also, the short duration of the egg and YSL stages could have partially accounted for the greater PYSL standing crops.

d) Juveniles, April-December 1974

Juvenile American shad (the 1974 year class) first appeared in the shoals and channel during 21-24 May in the Tappan Zee region (Appendix Figure A-37). Through mid-June, they were collected only in the lower sampling regions below the Indian Point region, suggesting that American shad may spawn earlier in the lower river (e.g., near the mouth of the Croton River) than in the upper reaches of the estuary. Juveniles began to appear in the middle and upper sampling regions in late June, and their numbers increased rapidly to a peak standing crop during 3-11 July. Juveniles ultimately occurred in the shoals and channel of every region but were most abundant in the West Point, Cornwall, and Poughkeepsie regions.

In the shore zone, juvenile shad first appeared in the Tappan Zee region in early June (Appendix Figure A-38) at a mean total length of 35 mm (Appendix Table A-97). Abundance in the shore zone was low until early July, increased to peak levels during August and September, declined slowly through the end of October, and then declined sharply in mid-November as the juveniles left the river on their seaward migration. From early July through early October, juvenile shad were rather uniformly distributed in the shore zone of all regions. Abundance shifted to the lower river prior to the juveniles' late fall emigration.

Juvenile shad were relatively abundant in bottom trawl samples for only about 2 weeks in early July (Appendix Figure A-40); after that time, they were scarce in bottom trawl catches and disappeared entirely in early December. Epibenthic sled catches in the shoals from RM 14 (KM 22) to RM 76 (KM 122) were relatively uniform spatially and temporally until mid-November (Appendix Figure A-41). Abundance then decreased in the shoals and shallow channel areas as the juvenile shad left the river. No juveniles occurred in epibenthic sled samples after November.

e) Yearlings, March-June 1975

Yearling American shad (the 1974 year class) were uncommon in both beach seine and bottom trawl catches (Appendix Figures A-44 and A-45), suggesting that very few juvenile shad overwintered in the river. The few yearlings that were collected occurred in the lower river below the Newburgh-Beacon bridge [RM 51 (KM 98)].

f) Yearlings, April-December 1974

Yearling shad were more abundant in early 1974 than in early 1975 (Appendix Tables A-42 and A-43), reflecting the larger year class in 1973 (Section IV) and the larger number of overwintering juveniles. The abundance of yearlings in the shore zone was highest in the lower estuary until late June; thereafter, yearling catches were highest in the most upriver regions, Catskill and Albany (Appendix Figure A-42). Catches of yearlings in the shore zone were infrequent through the summer and fall and declined to zero in early November.

In the shoals and channel, yearling abundance peaked in early May, was low and irregular through the summer and fall, and then decreased to zero in late November (Appendix Figure A-43).

g) Age II and Older, April-December 1974

Age II and older American shad were rarely collected (Appendix Figure A-46), supporting the general conclusion that most shad leave the estuary as juveniles during the fall of their first year.

b. Power Plant Regions, 1974

Based on the longitudinal river abundances and distributions just described, the vulnerability (exposure) of the 1974 year class of the selected fish species life stages to power plants was partially assessed from the percent of the peak river standing crop of each life stage that occurred within each 13-mi plant region (Appendix Tables A-60 through A-74). Except for the juvenile stage, which has a relatively long duration, the peak river standing crop for each early life stage (eggs and larvae) generally represented the major portion of the total population of each life stage during 1974. This percentage provided a preliminary index of the vulnerability (or exposure) of each life stage to each power plant. It was assumed that the larger the percentage, the greater the exposure to plant-induced mortality. Roseton was not operating until September 1974, so standing crops in this plant region were estimated and were considered to be those which could have been exposed to entrainment and/or impingement at Roseton had that plant been operating throughout the entire year. A more complete assessment of vulnerability at each plant was based on the vertical and lateral distribution of each life stage in the nearfield plant vicinity (described in subsection D) and the seasonal movements of marked individuals (described in subsection F); overall assessment of vulnerability is addressed in subsection G.

1) Striped Bass

The populations of striped bass eggs and larvae were rather uniformly exposed to all five power plants except that yolk-sac larval exposure was higher at Danskammer and Roseton (Figure V-1). The downstream shift in juvenile distribution during early September was reflected in the exposure indices based on beach seine catches, which were higher at the more downstream plants, especially Bowline.

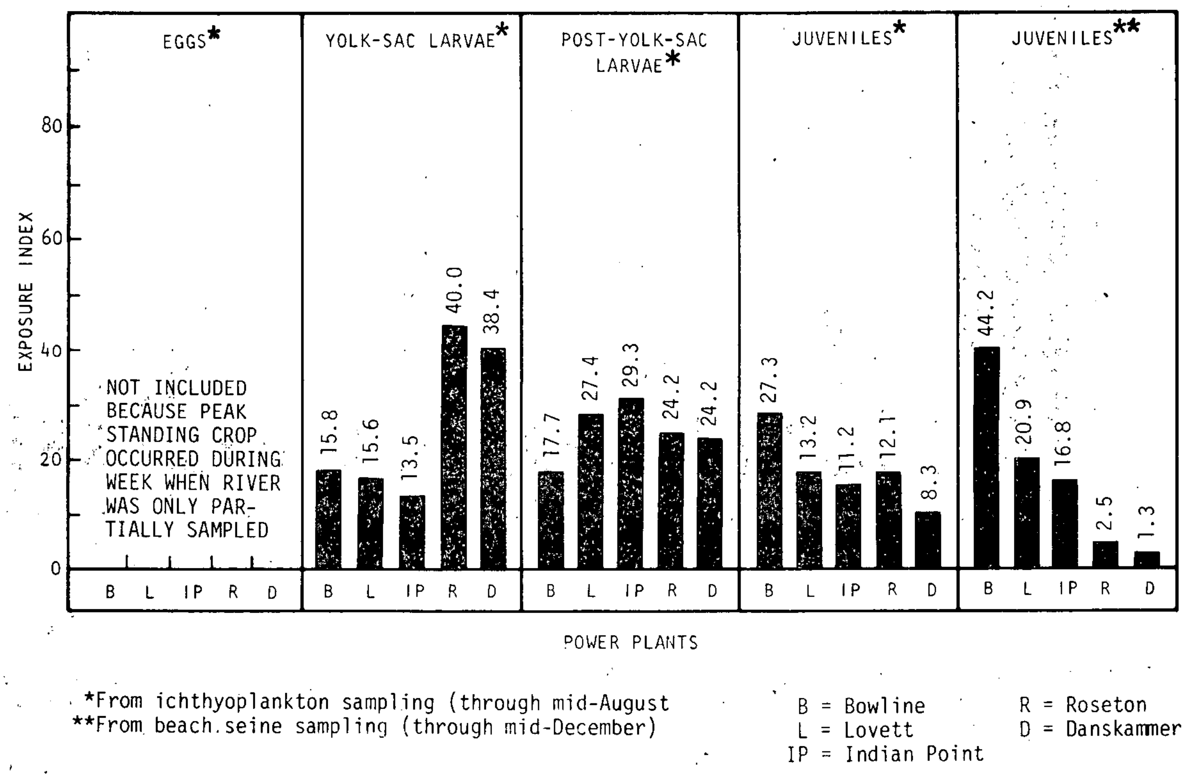
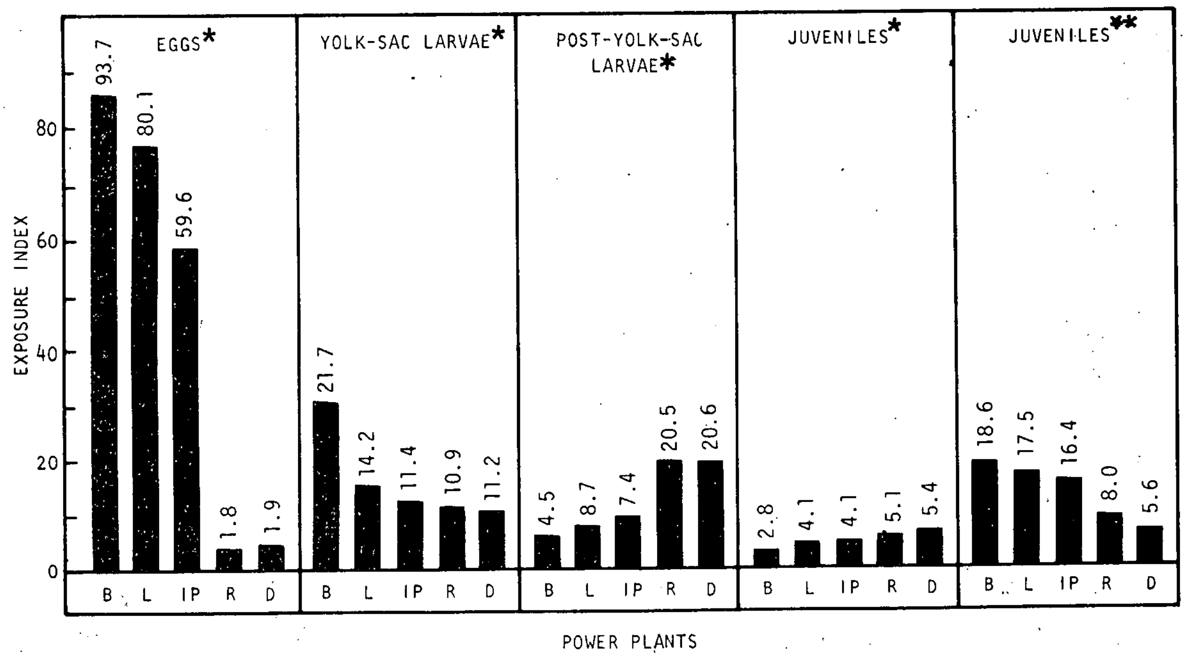


Figure V-1. Striped Bass Exposure Index (Percent of Peak Total River Standing Crop in Each Plant Region) during 1974

2) White Perch

The white perch egg population had a much higher exposure index at the downstream plants (Bowline, Lovett, and Indian Point) than at Roseton-Danskammer (Figure V-2). However, the adhesive and demersal characteristics of white perch eggs should reduce their vulnerability to entrainment.

The remaining life stages (larvae and juveniles) were rather uniformly exposed to all power plants except that the exposure of yolk-sac larvae was slightly higher at Bowline. For the population of post yolk-sac larvae, exposure indices were highest at Roseton and Danskammer. The juvenile population's exposure to impingement was generally low during the peak standing crop period of late August-early September and was slightly higher at Bowline, Lovett, and Indian Point than at Roseton and Danskammer.



*From ichthyoplankton sampling (through mid-August)
**From beach seine sampling (through mid-December)

B = Bowline
L = Lovett
IP = Indian Point
R = Roseton
D = Danskammer

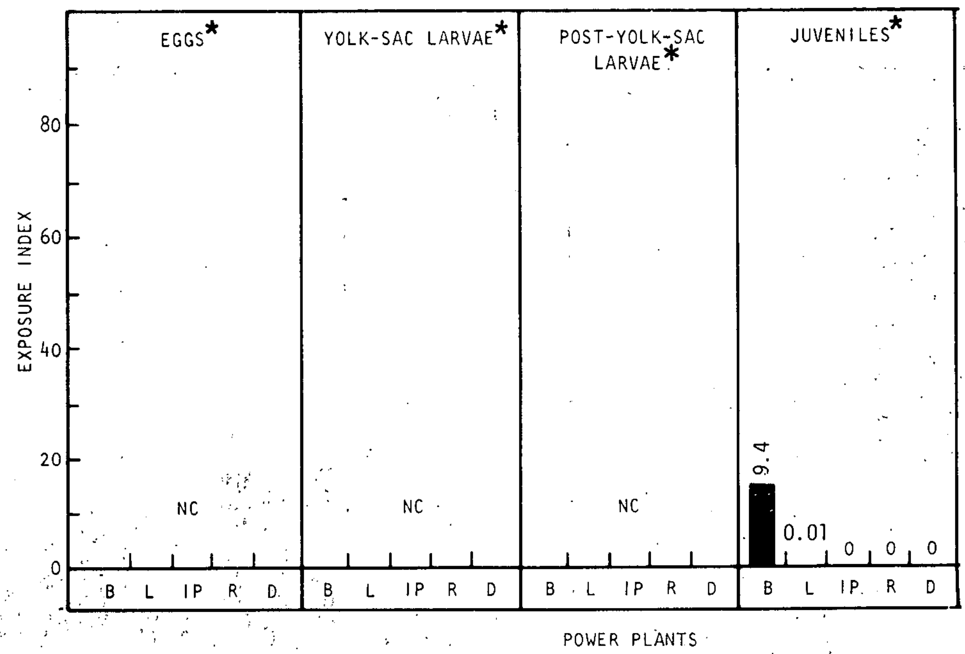
Figure V-2. White Perch Exposure Index (Percent of Peak Total River Standing Crop in Each Plant Region) during 1974

3) Atlantic Tomcod

Indices of exposure were not determined for Atlantic tomcod eggs because none were collected. However, spawning locations and egg characteristics (TI, 1975a) suggest that the eggs are relatively invulnerable to power plants in the Hudson River.

Exposure index calculations for larvae await the results of the 1975 tomcod larva sampling which began in early March, presumably before the larvae reached the juvenile stage.

Juvenile tomcod were fairly abundant throughout the summer but were concentrated in the lower estuary; hence, the higher exposure index at Bowline (Figure V-3), which is an overestimate since juvenile tomcod are concentrated in the channel areas (subsection D) and Bowline withdraws water from Bowline Pond rather than the river channel (TI, 1975a).



*From ichthyoplankton sampling (through mid-August)
NC = no catch

B = Bowline
L = Lovett
IP = Indian Point
R = Roseton
D = Danskammer

Figure V-3. Atlantic Tomcod Exposure Index (Percent of Peak Total River Standing Crop in Each Plant Region) during 1974

The distribution of the spawning population (juveniles/yearlings) from December through March based on box trap catches could not be used to calculate exposure indices. Exposure to power plants during the spawning season should be relatively high, however, particularly at the upstream plants (Roseton and Danskammer), which are located near the upper portion of the major spawning grounds.

4) American Shad

The populations of American shad eggs and larvae were relatively unexposed to the power plants (Figure V-4) since almost all spawning occurred in the upper sampling regions. The juvenile population was more dispersed, however, with exposure being highest at Bowline, Lovett, and Indian Point during the summer and becoming rather uniform at all plants in late summer and fall as the juveniles gradually moved seaward.

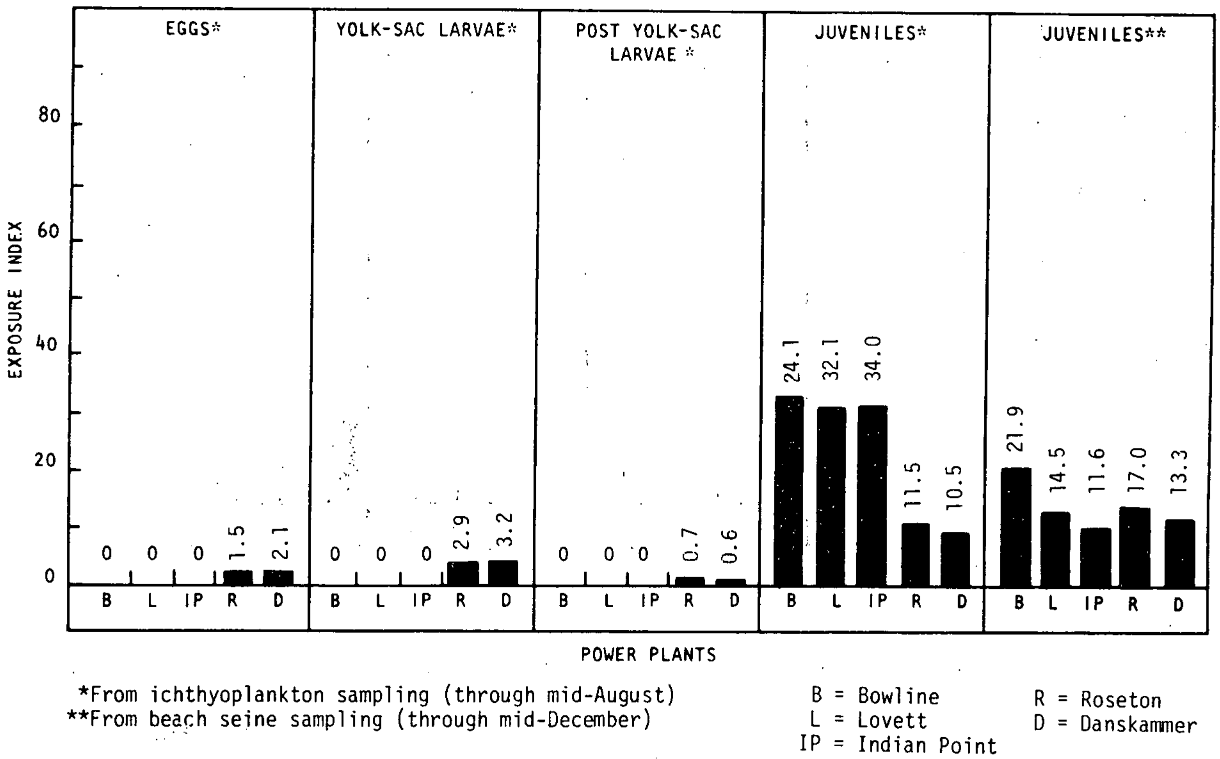


Figure V-4. American Shad Exposure Index (Percent of Peak Total River Standing Crop in Each Plant Region) during 1974

4. Summary

The general patterns in the longitudinal distributions of the various life stages of the 1974 year class of striped bass, white perch, Atlantic tomcod, and American shad in the Hudson River (April 1974–June 1975) and their exposure in the 13-mi plant regions around the Bowline, Lovett, Indian Point, Roseton, and Danskammer power stations during 1974 can be summarized as follows.

a. Striped Bass

- Striped bass began spawning in late April, with peak egg deposition occurring during 15-18 May between RM 39 (KM 62) and RM 55 (KM 88).

- Striped bass larvae were concentrated between RM 39 (KM 62) and RM 76 (KM 122) during the peak standing crop period of 28 May-23 June.

- Yolk-sac larval exposure was higher at Roseton and Danskammer than at Indian Point, Lovett, and Bowline. Overall, however, eggs and larvae were similarly exposed to all five power plants.

- Early juvenile striped bass were most abundant between RM 24 (KM 38) and RM 61 (KM 98), but their distribution gradually shifted downstream during August and September. In December, most of the juvenile population either migrated out of the estuary or moved to deep water.

- Juvenile striped bass were concentrated in the lower river regions during the peak standing crop period; hence, their exposure to impingement was highest at Bowline, Lovett, and Indian Point.

b. White Perch

- White perch began spawning in early May, with peak egg collections occurring from 30 May through 5 June between RM 24 (KM 38) and RM 38 (KM 61). Even though exposure was high at Bowline, Lovett, and Indian Point, the demersal, adhesive eggs are relatively invulnerable to entrainment.

- White perch larvae were very abundant between RM 24 (KM 38) and RM 106 (KM 170) during the peak standing crop period of 21 May-17 June. Larvae were similarly exposed to entrainment at all five power plants.

- Juvenile white perch were concentrated in the upper river during most of the summer and early fall. They were most abundant between RM 94 (KM 150) and RM 106 (KM 170) until late August to mid-September when their distribution shifted downstream to the lower sampling regions. Some juveniles moved to deep water in late November, but most overwintered in the estuary. Exposure to impingement was low at all plants until late October when the juveniles became more concentrated in the lower river; at that time, they were exposed mostly to Bowline, Lovett, and Indian Point.

c. Atlantic Tomcod

- Atlantic tomcod adult distribution suggested that most spawning occurred from mid-December through January between RM 39 (KM 62) and RM 61 (KM 98) during 1973-74. During the 1974 ichthyoplankton sampling period, mid-April through mid-August, no tomcod eggs or larvae were collected.

- Juvenile Atlantic tomcod were most abundant between RM 14 (KM 22) and RM 33 (KM 53) throughout the year. Their exposure to impingement during the peak standing crop period 29 April-4 May was highest at Bowline, but most were in the channel areas and relatively invulnerable to Bowline's intakes.

d. American Shad

- American shad were spawning in late April, and peak egg deposition was between RM 94 (KM 150) and RM 124 (KM 198) during 23 May-5 June.

- Larvae were concentrated between RM 86 (KM 137) and RM 124 (KM 198) during the peak standing crop period of 28 May-23 June.

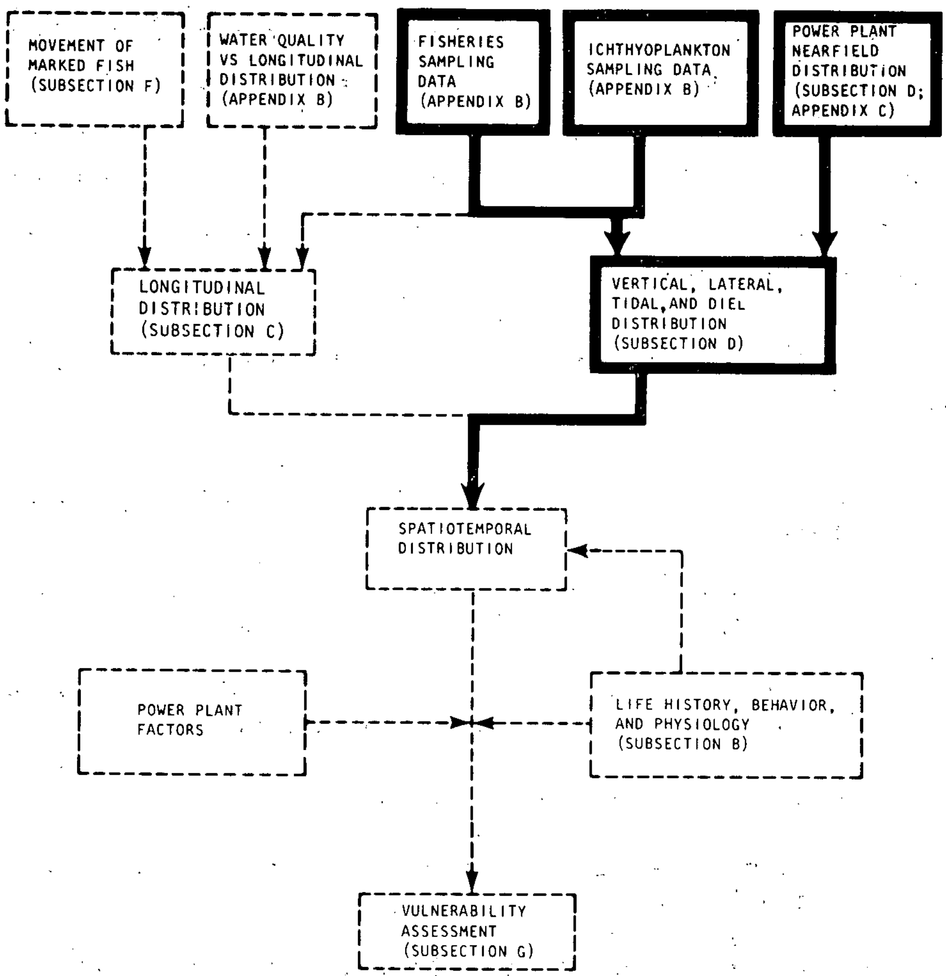
- Eggs and larvae were concentrated in the upper sampling regions and essentially were invulnerable to entrainment.

- Juvenile American shad were distributed throughout the estuary until mid-October when they began to migrate seaward. By late November, almost all juveniles had left the estuary. Juveniles were slightly more vulnerable to impingement at Bowline, Lovett, and Indian Point in early July, but exposure was low at all plants later in the year.

D. VERTICAL, LATERAL, DIEL, AND TIDAL DISTRIBUTION AND ABUNDANCE

1. Objective

This subsection describes the vertical, lateral, diel (day/night), and tidal distributions of life stages of the 1974 year class of striped bass, white perch, Atlantic tomcod, and American shad in the Hudson River [RM 12-152 (KM 19-243)] and in the nearfield vicinity of Bowline, Lovett, Indian Point, Roseton, and Danskammer power plants. These distributions were also used to assess the vulnerability of those species to power plants. Also discussed is the analysis of data collected in the nearfield vicinity of Indian Point during 1973. The following diagram shows the position of this subsection in the overall organization of Section V.



2. Methods

a. Riverwide, 1974

Data collected by Texas Instruments (TI) during March-December 1974 in the longitudinal ichthyoplankton, beach seine, interregional trawl, and fall shoals surveys were analyzed with nonparametric statistical methods to describe the vertical, lateral, diel, and tidal distributions for all life stages of striped bass, white perch, Atlantic tomcod, and American shad collected in the estuary [RM 12-152 (KM 19-243)]. Section III and an earlier report (TI, 1975a) describe field sampling procedures, laboratory processing methods, and abundance calculations.

Riverwide data were grouped into vertical (depth) and lateral strata, separated into day vs night samples and tidal stage (beach seine only), and analyzed with the appropriate test, either a nonparametric Friedman analysis of variance (Miller, 1966; Conover, 1971) or a Wilcoxon sign rank test (Hollander and Wolfe, 1973). Neither the TI ichthyoplankton nor fisheries sampling programs were specifically designed to detect diel or tidal differences; however, where possible, such comparisons were made. Sunrise and sunset were the divisions for day and night samples.

The following distribution analyses for the various life stages were completed:

- Eggs, larvae, and early juveniles (late April through mid-August)
    - Lateral distribution (west shoal, channel, east shoal strata), day and night samples combined
    - Day/night differences in vertical distribution in the channel (bottom, midwater, surface strata)
- Juveniles (July through December)
    - Lateral distribution (west shore zone vs east shore zone strata) day samples
    - Lateral distribution on bottom (west shoal, east shoal, areas >6 m ≤12 m deep, areas >12 m deep), day samples and night samples separately
    - Day/night differences in shore zone distribution, east and west shores combined

- Tidal stage differences in shore zone distribution, day samples

1) Eggs, Larvae, and Early Juveniles (Late April through Mid-August)

The 1974 longitudinal river ichthyoplankton survey data were grouped into five strata (Figure V-5) defined as follows:

West shoal (W) = that area of the river extending from the west shoreline to a depth of 20 ft (6 m)

East shoal (E) = that area of the river extending from the east shoreline to a depth of 20 ft (6 m)

Bottom (B) = that area of the river >20 ft (6 m) deep and $\leq$10 ft (3 m) from the bottom

Surface (S) = that area of the river >20 ft (6 m) deep and $\leq$10 ft (3 m) from the surface

Midwater (M) = that area of the river >20 ft (6 m) deep and extending from 11 ft (3.3 m) below the surface to 11 ft (3.3 m) above the bottom

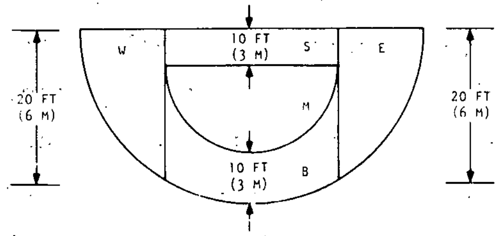


Figure V-5. Diagrammatic Cross Section of Hudson River Illustrating Five Strata Used in Egg, Larval, and Early Juvenile Vertical-Lateral, Day/Night Distribution Analyses

Table V-3 shows the distribution of sampling effort in the five strata (day and night tows combined).

Table V-3

Distribution of Longitudinal River Ichthyoplankton Survey Sampling (Number of Tows) from Late April through Mid-August 1974 in Five Strata of Hudson River Estuary [RM 14-140 (KM 22-224)]

Number of Tows				
West Shoal (W)	East Shoal (E)	Surface (S)	Midwater (M)	Bottom (B)
108	131	137	241	649

Day/night distribution analyses included only the surface, midwater, and bottom strata. Both the vertical (day versus night) and lateral (day/night combined) analyses were based on the same data; however, the mean surface, midwater, and bottom densities generated from the day/night vertical analysis were weighted according to the number of blocks (day vs night river runs) included in the analysis before they were compared to the mean surface, midwater, and bottom densities generated from the lateral distribution analysis.

2) Juveniles (July-December)

Catch data from the 1974 beach seine survey were separated into (1) two lateral strata (west shore zone vs east shore zone, day samples), (2) day vs night samples collected in the Indian Point, West Point, and Cornwall regions (east and west combined), and (3) day samples collected at each tidal stage (flood, high slack, ebb, and low slack) for comparison with nonparametric Wilcoxon sign rank tests. The number of seine hauls was sufficient to statistically compare only the flood and ebb tidal stages. Table V-4 indicates the distribution of sampling effort in the two lateral strata, the two diel periods, and the four tidal stages.

Catch data from the 1974 fall shoals survey and bottom trawl survey were separated into four lateral strata as follows: west shoal, east shoal

Table V-4

Distribution of Beach Seine Survey Sampling (Number of Hauls) by Lateral Strata, Diel Period, and Tidal Stage in Hudson River Estuary [RM 12-152 (KM 19-243)] during 1974

Number of Hauls								
Lateral Stratum*		Diel Period**			Tidal Stage*			
West Shore Zone	East Shore Zone	Day	Night	Flood	High Slack	Ebb	Low Slack	
1162	928	318	171	845	114	981	84	

*Day samples in 12 regions [RM 12-152 (KM 19-243)], June-December
**Samples in 3 regions [RM 39-61 (KM 62-98)], August-November, where sunrise and sunset were considered to be the divisions for day and night

(Figure V-5), river areas >6 m ≤12 m deep, and river areas >12 m deep. Mean densities of juveniles (number of organisms captured per thousand cubic meters) in each stratum (fall shoals) and mean catch per tow (bottom trawl) in each stratum were compared separately by gear with a Friedman analysis-of-variance test. Fall shoals samples were taken at night by epibenthic sled. Bottom trawl samples were taken during the day with an Otter-type trawl. Both gear are designed to sample on the bottom. Table V-5 shows the distribution of sampling in the four lateral strata by gear.

b. Nearfield Vicinity of Indian Point, 1973 and 1974, and Nearfield Vicinity of Lovett, Bowline, and Roseton-Danskammer, 1974

Data collected at Indian Point during 1973 and 1974 by New York University (NYU) and supplied to TI and data collected at Lovett, Bowline, and Roseton-Danskammer during 1974 by Lawler, Matusky and Skelly (LMS) and supplied to TI were analyzed to describe the vertical, lateral, and diel distribution for striped bass eggs (at Indian Point only) and larvae and white perch larvae in the nearfield vicinity of the five operating power plants located on the Hudson River between RM 37 (KM 59) and RM 66 (KM 106). Transect data collected in the nearfield vicinity of the Indian Point power plant [RM 42 (KM 67)] during 1973 and 1974 were analyzed, as were nearfield transect

Table V-5

Distribution of Night Epibenthic Sled (Mid-August through Mid-December) and Day Bottom Trawl Effort (April through Mid-December) (Number of Tows) in Four Lateral Strata of Hudson River Estuary [RM 14-76 (KM 22-122)] during 1974

Gear	Number of Tows			
	West Shoal (W)	East Shoal (E)	River Depth >6 m ≤ 12 m	River Depth >12 m
Epibenthic sled	633	527	197	243
Bottom trawl	67	165	82	74

data collected at Bowline [RM 37 (KM 59)], Lovett [RM 41 (KM 66)], and Roseton-Danskammer [RM 65-66 (KM 104-106)] during 1974. Appendix B describes the sampling stations, collection procedures, gear, sampling frequencies, and laboratory processing methods used by NYU and LMS.

The vertical (surface, midwater, and bottom), lateral (sampling station), and diel (day/night) distributions of eggs and larvae were examined by applying a nonparametric analysis to the transect data. To make catches comparable, densities (number of organisms captured per 1000 cubic meters of water strained) were computed. The volume of water strained per tow was determined by the size of the net and a flowmeter reading. Because flowmeters periodically malfunction and give spurious or erroneous readings, it was necessary to identify incorrect flowmeter readings before performing the analysis. Spurious flowmeter readings were identified by the procedures detailed in Appendix B. Criteria were developed for excluding spurious flowmeter readings and estimating replacement values from means. Very large or very small flowmeter readings result in incorrect density estimates, which can bias a parametric analytical procedure. Since a nonparametric procedure was used to compare the ranks of the observed densities, the estimated flowmeter readings eliminated empty cells in the samling design and should not have biased the results. Additional rationale for using a nonparametric analysis is discussed later in this section.

After the flowmeter readings were analyzed, a nonparametric analysis of variance (ANOVA) was performed. All densities for a particular sampling date, station sampling depth, and diel period (day or night) were averaged. Only sampling dates with nonzero catches were included in the analysis; therefore, the number of species, life stages, and dates that could be tested was limited. When only a few sampling dates were appropriate for the nonparametric ANOVA, the analysis was performed by blocking on sampling date (time) and station, permitting an overall comparison of day/night and vertical differences in abundance. When significant differences were observed among the vertical or lateral strata, nonparametric pairwise comparisons among mean densities were made (Hollander and Wolfe, 1973).

Conclusions regarding distribution patterns in the NYU and LMS transect data were limited by several factors. As mentioned, only nonzero catches were included in the analysis, so only the very abundant key fish species and life stages in the plant vicinities are discussed. Consequently, of the four key species (striped bass, white perch, Atlantic tomcod, and American shad) in the Indian Point area during 1973 and 1974, only striped bass (eggs, yolk-sac larvae, and post yolk-sac larvae) and white perch (yolk-sac and post yolk-sac larvae) were taken in sufficient numbers to test for vertical, lateral, and diel differences in abundance. An additional constraint upon the Bowline, Lovett, and Roseton-Danskammer transect data in 1974 was that LMS did not identify eggs to species and did not separate larvae into the yolk-sac and post yolk-sac stages. Hence, only striped bass and white perch larval distributions (yolk-sac and post yolk-sac larvae combined) were compared at the three LMS transects; tomcod larval distributions were compared only at Roseton-Danskammer, and juvenile tomcod distributions were compared only at Bowline and Lovett.

Based on a comparison of the limitations in the transect data sets, the 1973 and 1974 NYU data at Indian Point provided the best information on vertical, lateral, and diel abundance patterns for the early life stages of striped bass and white perch. Both years were examined to compare general distribution. The Indian Point transect analyses (1973 and 1974) supported the 1974 TI river-wide data (also analyzed and discussed herein). The 1974 LMS transect data at Bowline, Lovett, and Roseton-Danskammer provided a general picture of vertical, lateral, and diel abundance of the larvae of some key fish species in the near-field vicinity of these power plants.

c. Rationale for Using Nonparametric Analysis Techniques

Analytical problems are usually presented by ichthyoplankton and fisheries sampling designs and catch data because of unequal variances, non-normal statistical distributions, and the lack of replicate samples. Parametric analysis requires that the assumptions of equal variances and normality be satisfied for valid testing. Nonparametric techniques also require satisfaction of the equal variance assumption, but valid testing does not require the normality assumption. Hence, the nonparametric statistical technique is appropriate for the distribution analyses presented in this subsection. For additional information on the use of nonparametric techniques, see Puri and Sen (1971) and Conover (1975).

3. Results and Discussion

Vertical, lateral, diel, and tidal distributions of life stages of the key fish species (striped bass, white perch, Atlantic tomcod, and American shad) in the Hudson River estuary during 1974 [RM 12-152 (KM 19-243)] and in the nearfield vicinity of Indian Point during 1973 and 1974 and Bowline, Lovett, and Roseton-Danskammer during 1974 offer information supplemental to the riverwide and plant region longitudinal distributions discussed in subsection C, which can be used to assess vulnerability. Observed mean rank differences in densities between the various strata (vertical, diel, and tidal) were considered to be significant at $\alpha = 0.05$.

a. Riverside, Late April through Mid-August 1974

1) Striped Bass

a) Eggs

With combined day and night samples, striped bass egg densities were highest in the bottom stratum and lower in the surface, midwater, and shoal strata. Egg densities were similar in both the east and west shoals (Table V-6). Densities in all three vertical strata were lower at night than during the day (Table V-7), with highest egg densities occurring near the bottom, day and night.

Table V-6

Combined Day/Night Distribution [Mean Density (No./1000 m^3)] of Striped Bass Eggs, Yolk-Sac Larvae, Post Yolk-Sac Larvae, and Early Juveniles in Each of Five Vertical/Lateral Strata Sampled with Epibenthic Sled and Tucker Trawl, Hudson River Estuary [RM 14-140 (KM 22-224)], Late April through Mid-August 1974

Life Stage	Stratum Mean Density (No./1000 m^3) West Shoal(W)	East Shoal(E)	Surface(S)	Midwater(M)	Bottom(B)	Comparison of Mean Rank Differences among Strata*
Eggs	4.17	17.83	6.50	27.24	43.16	W E S M B
Yolk-sac larvae	6.58	8.82	12.53	23.66	31.99	W E S M B
Post yolk-sac larvae	18.01	24.41	37.96	43.24	43.30	W S M E B
Early juveniles	1.28	8.44	0.07	0.13	1.09	S M W B E

*Listed in order of increasing mean rank (left to right). Any two strata in each life stage underscored by same continuous line are not different at α = 0.05.

Table V-7

Day/Night Distribution [Mean Density (No./1000 m^3)] of Striped Bass Eggs, Yolk-Sac Larvae, and Post Yolk-Sac Larvae in Each of Three Vertical Strata (Shoals Excluded) Sampled by Epibenthic Sled and Tucker Trawl, Hudson River Estuary [RM 14-140 (KM 22-224)], Late April through Mid-July 1974

Life Stage	Time*	Stratum Mean Density (No./1000 m^3) Surface(S)	Midwater(M)	Bottom(B)	Comparisons: Comparison of Mean Rank Differences among Strata*
Eggs	Day(5)	15.66	57.97	98.12	S M B
	Night(8)	0.78	8.03	8.81	S M B
Yolk-sac larvae	Day(5)	13.64	47.06	68.31	S M B
	Night(8)	13.52	10.34	10.59	B S M
Post yolk-sac larvae	Day(5)	12.82	40.77	41.40	S M B
	Night(8)	67.91	60.97	60.61	S M B

*Number in parentheses represents river runs or time blocks included in analysis.

**Listed in order of increasing mean rank (left to right). Any two strata in each life stage underscored by same continuous line are not different at α = 0.05.

b) Yolk-Sac Larvae

With combined day/night samples, the vertical/lateral distribution of yolk-sac larvae appeared to be more uniform than that of eggs (Table V-6). The bottom and midwater strata had significantly higher densities only when compared with the west shoals. Densities of yolk-sac larvae in the east shoal, west shoal, and surface strata were similar. During the day, densities of yolk-sac larvae were higher near the bottom (Table V-7); at night, however, densities were lower than during the day and similar from surface to bottom, suggesting a vertical dispersion of yolk-sac larvae throughout the water column at night. Striped bass larvae become motile at 5 to 6 mm (Mansueti, 1958) and therefore are capable of some vertical movement in the late yolk-sac stage.

c) Post Yolk-Sac Larvae

Based on combined day/night samples, the distribution of post yolk-sac larvae was very similar to that of yolk-sac larvae; there were few differences among strata densities, vertically or laterally (Table V-6). During the day, post yolk-sac larvae were apparently concentrated near the bottom (Table V-7); at night, however, densities were more uniform from top to bottom, suggesting a vertical dispersion of post yolk-sac larvae throughout the water column at night. The generally higher densities of post yolk-sac larvae at night in all three depth strata suggested that gear avoidance may have been reduced at night.

d) Early Juveniles

Densities of early juvenile striped bass were significantly higher in the bottom and east shoals than in the surface or midwater strata (Table V-6). Early juveniles were relatively abundant in the bottom stratum, indicating that a portion of the juvenile population remained in the areas of the river >6 m deep, at least through mid-August, even though movements by juvenile striped bass to the shoals were suggested in subsection C.

2) White Perch

a) Eggs

White perch eggs did not exhibit any clear vertical/lateral distributions based on density comparisons from combined day/night samples

(Table V-8); however, surface densities were significantly lower than bottom and east shoal densities. Too few eggs were collected in the channel area to allow assessment of day/night differences in their vertical distribution; however, the vertical distribution of eggs should have been similar during day and night, with most occurring near the bottom (Table V-8).

Table V-8

Combined Day/Night Distribution [Mean Density (No./1000 m^3)] of White Perch Eggs, Yolk-Sac Larvae, Post Yolk-Sac Larvae, and Early Juveniles in Each of Five Vertical/Lateral Strata Sampled with Epibenthic Sled and Tucker Trawl, Hudson River Estuary [RM 14-140 (KM 22-224)], Late April through Mid-August 1974

Life Stage	Stratum Mean Density No./1000 m^3 West Shoal(W)	East Shoal(E)	Surface(S)	Midwater(M)	Bottom(B)	Comparison of Mean Rank Differences among Strata*
Eggs	29.82	213.48	0.27	3.46	31.69	S W M E B
Yolk-sac larvae	10.90	18.49	4.58	11.80	12.34	W S E M B
Post yolk-sac larvae	11.26	23.00	79.30	49.34	40.77	W E M S B
Juveniles	**	0.35	0.06	0.33	0.82	S E M B

*Listed in order of increasing mean rank (left to right). Any two strata in each life stage underscored by same continuous line are not different at $\alpha = 0.05$.

**Not included in test because juvenile density was always zero.

b) Yolk-Sac Larvae

Based on combined day/night samples, the vertical/lateral distribution of yolk-sac larvae was rather uniform across strata, with only bottom densities being significantly higher than west shoal densities (Table V-8). Vertical distribution of yolk-sac larvae was similar from surface to bottom, day and night (Table V-9), but there was a suggestion that densities were lower in the surface strata during the day.

c) Post Yolk-Sac Larvae

Based on day/night samples combined, white perch post yolk-sac larvae were significantly more abundant in the surface and bottom strata than in the midwater strata or east and west shoals (Table V-8). Post yolk-sac larvae

Table V-9

Day/Night Distribution [Mean Density (No./1000 m^3)] of White Perch Yolk-Sac Larvae and Post Yolk-Sac Larvae in Each of Three Vertical Strata Sampled (Shoals Excluded) by Epibenthic Sled and Tucker Trawl, Hudson River Estuary [RM 14-140 (KM 22-224)], Late April through Mid-July 1974

		Stratum Mean Density (No./1000 m^3)			Comparison of Mean Rank Differences among Strata*
Life Stage	Time*	Surface(S)	Midwater(M)	Bottom(B)	
Yolk-sac larvae	Day(5)	7.87	24.26	24.82	S M B
	Night(8)	3.10	5.48	6.08	S B M
Post yolk-sac larvae	Day(5)	66.73	55.26	36.22	B M S
	Night(11)	92.23	51.13	46.54	S M B

*Number in parentheses represents number of river runs or time blocks included in analysis.

**Listed in order of increasing mean rank (left to right). Any two strate in each life stage underscored by same continuous line are not different at $\alpha = 0.05$.

were uniformly distributed throughout the water column during the day and at night (Table V-9) and tended to occupy the surface waters more extensively during the day than did striped bass post yolk-sac larvae (Table V-7).

d) Early Juveniles

The abundance of juvenile white perch was relatively low in 1974 (Section IV and TI, 1975a). Densities were significantly higher near the bottom than in the surface stratum in day/night sampling combined (Table V-8). No juveniles were collected in ichthyoplankton gear in the west shoals between late April and mid-August, but they began to appear in beach seine catches in the shore zone in early July (TI, 1975a), suggesting a lateral movement to areas inaccessible to epibenthic sleds and Tucker trawls. Some of the juveniles, however, apparently remained in areas of the river >6 m deep.

3) Atlantic Tomcod

Juveniles were the only tomcod life stage collected by epibenthic sled and Tucker trawl in 1974. They were concentrated in the west shoal and bottom strata (Table V-10) in day/night samples combined and were almost absent from surface waters. Atlantic tomcod are demersal (TI, 1975a), so the relatively high density in the west shoal is difficult to explain unless juvenile tomcod were avoiding the freshwater inflows from the Croton River, which enters the Hudson from the east side at RM 34 (KM 54).

Table V-10

Combined Day/Night Distribution [Mean Density (No./1000 m^3)] of Juvenile Atlantic Tomcod in Each of Five Strata Sampled with Epibenthic Sled and Tucker Trawl, Hudson River Estuary [RM 14-140 (KM 22-224)], Late April through Mid-August 1974

Life Stage	Stratum Mean Density (No./1000 m^3) West Shoal(W)	East Shoal(E)	Surface(S)	Midwater(M)	Bottom(B)	Comparison of Mean Rank Differences among Strata*
Juveniles	201.36	16.90	0.32	22.74	117.26	S E M W B

*Listed in order of increasing mean rank (left to right). Any two strata in each life stage underscored by same continuous line are not different at $\alpha = 0.05$.

4) American Shad

a) Eggs

Combining day and night samples, it appeared that shad eggs were generally concentrated near the bottom of the channel (Table V-11). Egg densities were relatively low in the surface and midwater strata and were near zero in the shoal areas. However, there was limited sampling in the shoals above RM 62 (KM 99), the major shad spawning area in the Hudson River (subsection C); therefore, the relative importance of the shoals is unknown. Densities of shad eggs from surface to bottom did not change significantly on a diel basis, but a trend toward relatively low densities in the surface stratum during the day was suggested (Table V-12).

b) Yolk-Sac Larvae

Based on day and night samples combined, American shad yolk-sac larvae were most abundant in the bottom and midwater strata and least abundant in the surface waters, a pattern similar to that of the eggs (Table V-11). Shoal density estimates likely were influenced by the distribution of sampling effort, as described for the eggs. Yolk-sac larvae were concentrated near the bottom during the day but were more dispersed throughout the water column at night (Table V-12). Shad larvae become motile when about 12 mm long (Leim, 1924); thus, vertical movement in the late yolk-sac stage was possible.

Table V-11

Combined Day/Night Distribution [Mean Density (No./1000 m³) of American Shad Eggs, Yolk-Sac Larvae, Post Yolk-Sac Larvae, and Early Juveniles in Each of Five Strata Sampled with Epibenthic Sled and Tucker Trawl, Hudson River Estuary [RM 14-140 (KM 22-224)], Late April through Mid-August 1974

Life Stage	Stratum: Mean Density (No./1000 m³) West Shoal(W)	East Shoal(E)	Surface(S)	Midwater(M)	Bottom(B)	Comparison of Mean Rank Differences among Strata*
Eggs	**	***	5.95	7.63	30.07	S M B
Yolk-sac larvae	**	***	0.53	2.20	2.69	S M B
Post yolk-sac larvae	2.79	1.12	19.66	6.10	9.80	E W M S B
Juveniles	2.88	5.23	0.55	2.32	2.21	S W M B E

*Listed in order of increasing mean rank (left to right). Any two strata in each life stage underscored by same continuous line are not different at $\alpha = 0.05$.

**Not included in test because only one river run contained eggs or yolk-sac larvae.

***Not included in test because density was always zero.

c) Post Yolk-Sac Larvae

The more motile American shad post yolk-sac larvae were collected in all five strata. Based on day/night samples combined, however, they were significantly more abundant in the surface and bottom strata than in the shoal strata (Table V-11). Post yolk-sac larvae were apparently uniformly distributed throughout the water column (Table V-12).

d) Early Juveniles

Juvenile American shad were more abundant in the shoals than were the post yolk-sac larvae (Table V-11) but were still numerous everywhere except near the surface in day and night samples combined. Juveniles first appeared in beach seine catches in the shore zone in mid to late June (subsection C) at a mean total length of 25 to 35 mm (Appendix Table A-97). At least through mid-August, they were also present in areas of the river >6 m deep.

Table V-12

Day/Night Distribution [Mean Density (No./1000 m^3) of American Shad Eggs, Yolk-Sac Larvae, and Post Yolk-Sac Larvae in Each of Three Vertical Strata (Shoals Excluded) Sampled by Epibenthic Sled and Tucker Trawl, Hudson River Estuary [RM 14-140 (KM 22-224)], Late April through Mid-August 1974

		Stratum			Comparison of Mean Rank Differences among Strata**
		Mean Density (No./1000 m^3)			
Life Stage	Time*	Surface(S)	Midwater(M)	Bottom(B)	
Eggs	Day(6)	1.69	13.07	19.70	S M B
	Night(6)	11.20	3.46	45.44	M S B
Yolk-sac larvae	Day(4)	0.43	4.66	5.05	S M B
	Night(3)	1.15	1.12	2.08	S M B
Post yolk-sac larvae	Day(5)	23.75	8.60	8.55	M B S
	Night(9)	19.57	5.39	11.56	M S B

*Number in parentheses represents river runs or time blocks included in analysis.

**Listed in order of increasing mean rank (left to right). Any two strata in each life stage not underscored by same continuous line are different at $\alpha = 0.05$.

b. Beach Seine Survey, July-December

1) Juvenile Striped Bass

Juvenile striped bass abundance was similar in the east and west shore zone at $\alpha = 0.05$ (Table V-13), indicating no apparent preference for either shore zone in the 11 geographical regions. Data were insufficient to test east-west differences in the Yonkers region.

During early August-November, juvenile striped bass abundance was greater ($p = 0.012$, Wilcoxon sign rank test, 2-tailed) at night in the shore zone of those regions sampled day and night [Indian Point, West Point, and Cornwall, RM 39-61 (KM 62-98)]. Overall mean catch per unit effort was 8.6 for night catches and 3.9 for day catches, suggesting that juvenile striped bass moved into the beach areas at night. Because length-frequency distributions in both day and night samples were similar (Appendix Tables A-85 and A-86), decreased gear avoidance at night would not explain the diel differences in shore zone distribution.

Table V-13

Daytime Distribution (Mean Catch per Unit Effort) of Juvenile Striped Bass in East and West Shore Zones Sampled by 100-Ft (30.5-m) Beach Seines in 12 Geographical Regions of Hudson River Estuary [RM 12-153 (KM 19-243)], July-December 1974

	Mean Catch per Unit Effort		Comparison of Mean Rank Differences between Shore Zones*	
Geographical Region	West Shore Zone (W)	East Shore Zone (E)	Direction of Rank Difference	p-Value (2-Tailed)
Yonkers**	---	---	---	---
Tappan Zee	3.4	12.9	E>W	0.094
Croton-Haverstraw	3.2	5.7	E>W	0.070
Indian Point	2.9	3.3	E>W	0.910
West Point	1.9	2.0	E>W	0.542
Cornwall	4.1	1.1	W>E	0.056
Poughkeepsie	0.9	1.5	E>W	0.168
Hyde Park	0.5	3.5	E>W	0.426
Kingston	0.3	0.5	E>W	0.360
Saugerties	0.5	1.9	E>W	0.204
Catskill	1.9	2.3	E>W	0.160
Albany	0.7	1.7	E>W	0.946

*East and west shore zones compared with Wilcoxon sign rank tests.
**Sample size inadequate to validly test east-west differences.

Juvenile striped bass were caught uniformly in day beach seines over all tidal stages (Table V-14). Riverwide differences in mean catch per unit effort between flood and ebb tide for July-December were similar ($p > 0.05$, Wilcoxon sign rank test). For night seine catches, flood vs ebb tidal stage differences also were similar, suggesting that tidal fluctuations are unrelated to juvenile striped bass abundance in shore zone areas, day or night.

2) Juvenile White Perch

Juvenile white perch did not exhibit any general riverwide preference for the east or west shore zones during the daytime (Table V-15), but they were

Table V-14

Distribution of Juvenile Striped Bass in Day Beach Seines over Four Tidal Stages, Hudson River Estuary [RM 12-152 (KM 19-243)], 1974

	Mean Catch per Unit Effort			
Month	Flood	High Slack	Ebb	Low Slack
Apr	0	0	0	0
May	0	0	0	0
Jun	0.02	0	0.26	0
Jul	2.27	0.67	3.01	0.33
Aug	4.85	0	5.61	12.60
Sep	6.60	6.59	4.78	18.69
Oct	3.37	1.79	4.06	4.58
Nov	3.32	1.56	3.30	0.17
Dec	0.20	0	1.78	0
Overall Means	2.29	1.18	2.53	4.04

more abundant in the west shore zone in the Tappan Zee, Cornwall, and Poughkeepsie regions. Data were insufficient to test east-west differences in the Yonkers region. In the remaining seven regions, shore zone differences were not significant ($p > 0.05$).

In each of the three regions where juvenile white perch abundance was greater in the west shore zone, a major tributary stream enters from the east side: Croton River in the Tappan Zee region, Fishkill Creek in the Cornwall region, and Wappingers Creek in the Poughkeepsie region. Juvenile white perch may either avoid those areas of freshwater inflow or move into those tributaries during summer and early fall. In either case, they would become unavailable to beach seines and thus reduce C/f values in the east shore zone of these three regions.

Diel and tidal shore zone abundance patterns for juvenile white perch were similar to those already described for juvenile striped bass, i.e., greater abundance at night ($p = 0.005$, Wilcoxon signed rank test,

Table V-15

Distribution (Mean Catch per Unit Effort) of Juvenile White Perch in East and West Shore Zones Sampled during Daytime by 100-Ft (30.5-m) Beach Seines in 12 Geographical Regions of Hudson River Estuary [RM 12-152 (KM 19-243)], Mid-June through Mid-December 1974

	Mean Catch per Unit Effort		Comparison of Mean Rank Differences between Shore Zones*	
Geographical Region	West Shore Zone (W)	East Shore Zone (E)	Direction of Rank Difference	p-Value (2-Tailed)
Yonkers**	---	---	---	---
Tappan Zee	2.2	0.1	W>E	0.006
Croton-Haverstraw	0.5	0.4	W>E	0.578
Indian Point	1.1	2.8	E>W	0.168
West Point	1.2	1.4	E>W	0.762
Cornwall	2.4	0.7	W>E	0.020
Poughkeepsie	4.2	1.1	W>E	0.002
Hyde Park	6.5	4.3	W>E	0.678
Kingston	1.8	1.4	W>E	0.944
Saugerties	7.3	7.4	E>W	1.000
Catskill	2.2	1.6	W>E	0.696
Albany	0.5	0.5	E>W	0.570

*East and west shore zones compared with Wilcoxon sign rank test.
**Sample size inadequate to validly test east-west differences.

2-tailed) in those regions where day and night samples were taken and no differences in catch per unit effort across the four tidal stages (Table V-16). Overall mean catch per unit effort was 8.1 for night and 3.6 for day in the Indian Point, West Point, and Cornwall regions during August-November. Similarity between day/night length-frequency distributions suggested that gear avoidance was not a factor in this diel distribution pattern in the shore zone (TI, 1975a, and Appendix Tables A-89 and A-90).

3) Juvenile Atlantic Tomcod

Juvenile Atlantic tomcod are demersal, deep-water fish and are relatively less abundant in shallow shore zone areas than in deeper shoal and channel areas (TI, 1975a); therefore, no analyses of tomcod catches in beach seines were performed.

Table V-16

Distribution of Juvenile White Perch in Day Beach Seines over Four Tidal Stages, Hudson River Estuary [RM 12-152 (KM 19-243)], 1974

	Mean Catch per Unit Effort			
Month	Flood	High Slack	Ebb	Low Slack
Apr	0	0	0	0
May	0	0	0	0
Jun	0	0	0	0
Jul	0.99	0	0.60	0.67
Aug	3.67	0.20	5.20	1.40
Sep	2.08	2.18	7.25	0.46
Oct	2.47	0.59	1.41	2.88
Nov	2.20	0.13	1.15	0.17
Dec	0.03	0	0	0
Overall Means	1.27	0.34	1.73	0.62

4) Juvenile American Shad

Juvenile American shad did not exhibit general riverwide differences in preference for the east and west shore zones (Table V-17), but abundance was greater in the west shore zone ($\alpha = 0.05$) in three regions (Croton-Haverstraw, Saugerties, and Albany). Data were insufficient to test east-west differences in the Yonkers region. In the remaining eight regions, shore zone differences were not significant.

In the three geographical regions sampled by beach seine both day and night in 1974 (Indian Point, West Point, and Cornwall), juvenile shad were over three times more abundant in day catches ($p = 0.009$, Wilcoxon sign rank test, 2-tailed). Mean catch per unit effort was 19.3 in the daytime and 6.2 at night. This diel pattern was directly opposite that of juvenile striped bass and white perch and act to reduce niche overlap. Juvenile shad abundance in the shore zone was unrelated to tidal stage during both day and night sampling (Table V-18).

Table V-17

Distribution (Mean Catch per Unit Effort) of Juvenile American Shad in East and West Shore Zones Sampled during Daytime by 100-Ft (30.5-m) Beach Seines in 12 Geographical Regions of Hudson River Estuary [RM 12-152 (KM 19-243)], June-December 1974

Geographical Region	Mean Catch per Unit Effort		Comparison of Mean Rank Differences between Shore Zones*	
	West Shore Zone (W)	East Shore Zone (E)	Direction of Rank Difference	p-Value (2-Tailed)
Yonkers**	---	---	---	---
Tappan Zee	9.8	6.8	W>E	0.530
Croton-Haverstraw	7.0	4.9	W>E	0.050
Indian Point	6.4	6.9	E>W	0.528
West Point	6.2	6.5	E>W	0.718
Cornwall	14.9	13.1	W>E	0.456
Poughkeepsie	13.6	18.1	E>W	0.228
Hyde Park	5.9	6.6	E>W	0.674
Kingston	6.4	5.3	W>E	0.668
Saugerties	10.8	5.9	W>E	0.012
Catskill	7.2	7.1	W>E	0.806
Albany	9.0	4.3	W>E	0.020

*East and west shore zones compared with Wilcoxon sign rank test.
**Sample size inadequate to validly test east-west differences.

Table V-18

Distribution of Juvenile American Shad in Day Beach Seines over Four Tidal Stages, Hudson River Estuary [RM 12-152 (KM 19-243)], 1974

Month	Mean Catch per Unit Effort			
	Flood	High Slack	Ebb	Low Slack
Apr	0	0	0	0
May	0	0	0	0
Jun	0.08	0.48	1.09	0.10
Jul	15.77	9.00	10.21	9.00
Aug	13.04	10.80	17.73	12.20
Sep	13.64	13.32	13.33	5.62
Oct	16.34	10.72	11.97	6.50
Nov	3.97	3.81	2.63	0.83
Dec	0	0	0	0
Overall Means	6.98	5.35	6.33	3.81

c. Fall Shoals Survey (Mid-August through December) and Interregional Bottom Trawl Survey (July through December)

1) Striped Bass

Juvenile striped bass were distributed uniformly in shoal and shallow channel [≤40 ft (12.2 m) deep] areas but were least abundant on the bottom in depths >40 ft (12.2 m) (Tables V-19 and V-20). Strata densities in epibenthic sled samples fluctuated regularly and were roughly parallel in the east shoal, west shoal, and >20-ft (6.1-m) ≤40-ft (12.20-m) stratum from mid-August through late October (Figure V-6). Juveniles were generally scarce in areas >40 ft (12.2 m) deep, except for a slight increase near the end of October. Bottom trawl catches also increased slightly near the end of October. These deep strata increases coincided with a sharp and continuous decline in juvenile abundance in the shore zone (Figure V-6), suggesting that juvenile striped bass began moving to the deeper areas of the river in late October-early November.

Table V-19

Distribution [Mean Density (No./1000 m^3)] of Juvenile Striped Bass, White Perch, Atlantic Tomcod, and American Shad in Each of Four Lateral Strata Sampled by Night Epibenthic Sled, Hudson River Estuary [RM 14-76 (KM 22-122)], August-December 1974

	Stratum Mean Density No./1000 m^3		River Depth		Comparison of Mean Rank Differences among Strata**
Species*	West Shoal (W)	East Shoal (E)	DA†	DB††	
Striped Bass	1.88	2.40	1.85	0.14	DB DA E W
White Perch	2.58	3.92	4.91	1.07	DB W DA E
Atlantic Tomcod	3.31	1.56	12.01	23.19	E W DA DB
American Shad	2.41	1.81	3.48	1.07	DB E W DA

*Mean for 17 time blocks (19 Aug-12 Dec) used for all species except American shad in which two time blocks were eliminated because of zero catches.

**Listed in order of increasing mean rank (left to right). Any two strata within a species not underscored by the same continuous line are significantly different at $\alpha = 0.05$.

†DA = river depth >20 ft (6.1 m) but ≤40 ft (12.2 m).

††DB = river depth >40 ft (12.2 m).

Table V-20

Distribution (Catch per Unit Effort) of Juvenile Striped Bass, White Perch, Atlantic Tomcod, and American Shad in Each of Four Lateral Strata Sampled by Day Bottom Trawl, Hudson River [RM 24-61 (KM 38-98)], July-December 1974

	Stratum				
	Mean Catch per Unit Effort				
			River Depth		Comparison of Mean Rank
Species	West Shoal(W)	East Shoal(E)	DA**	DB†	Differences among Strata*
Striped Bass	0.11	0.19	0.17	0.07	E W DA DB
White Perch	2.94	5.90	7.36	2.82	E W DA DB
Atlantic Tomcod	1.97	13.16	58.21	31.32	E W DA DB
American Shad	3.65	14.55	2.22	2.95	DA DB W E

*Listed in order of increasing mean rank (left to right). Any two strata within a species not underscored by same continuous line are significantly different at α = 0.05.

**DA = river depth >20 ft (6.1 m) ≤40 ft (12.2 m).

†DB = river depth >40 ft (12.2).

Epibenthic sled catches generally declined from early November to early December except in the west shoal where they fluctuated around densities ranging from about 2 to 4/1000 m^3; in early December, abundance in all strata decreased sharply (Figure V-6). After 1 October, juvenile striped bass were concentrated in the lower river regions, particularly in the Yonkers, Tappan Zee, and Croton-Haverstraw regions in mid- to late November (subsection C). Juvenile movements from the shore zone to deeper areas in early November, as suggested by Figure V-6, would result in relatively high juvenile densities in the extensive west shoal areas of the three lower river regions, particularly south of Croton Point [RM 34 (KM 54)].

Length-frequency distributions of juvenile striped bass in beach seines, bottom trawls, and epibenthic sleds (Appendix Tables A-85 through A-88) in the various strata were similar. This observation lends support to the assumption that the lateral distribution patterns were not biased by differential gear avoidance.

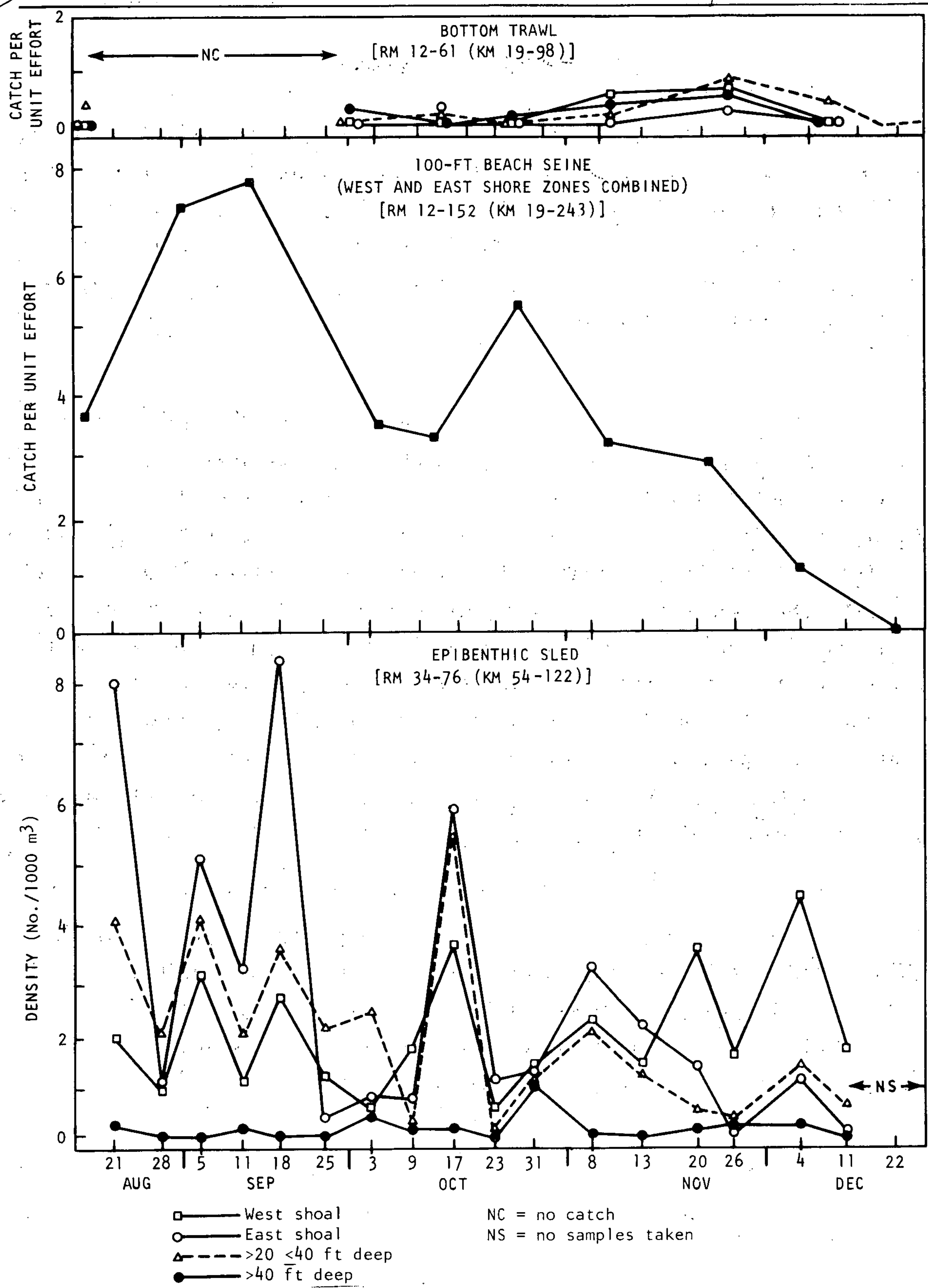


Figure V-6. Catches of Juvenile Striped Bass in Epibenthic Sled, 100-Ft (30.5-m) Beach Seine, and Bottom Trawl, Hudson River Estuary, August-December 1974

2) White Perch

Juvenile white perch were distributed rather uniformly in shoal and shallow channel [≤40-ft (12.2-m)] areas (Tables V-19 and V-20), with significantly lower densities in the deep channel [>40-ft (12.2-m)] areas (in epibenthic sled catches) than in the east shoal and shallow channel [>20-ft (6.1-m)] ≤40-ft (12.2-m)] areas (Table V-19). Bottom trawl catches of juveniles were similar in all strata (Table V-20).

Juvenile white perch apparently moved into deeper water earlier than juvenile striped bass. Beach seine catches began to decline in late August, fluctuated irregularly until early November, and then dropped to near zero (Figure V-7). Concomitant with the gradual decline in beach seine catches, epibenthic sled and bottom trawl catches increased, particularly after 1 October. Juvenile abundance in the moderately deep areas of the river [>20 ft (6.1 m) ≤40 ft (12.2 m)] remained high, at least until mid-December when epibenthic sled and bottom trawl sampling ceased. Juvenile numbers in bottom trawl and epibenthic sled samples taken in the east shoal declined in late November-early December. Epibenthic sled catches of juvenile white perch also decreased in the west shoal in early December, but bottom trawl catches in the west shoal remained high at least until sampling ceased in mid-December.

Length-frequency distributions of juvenile white perch in beach seines, bottom trawls, and epibenthic sleds (Appendix Tables A-89 through A-92) in the various strata were similar. This observation lends support to the conclusion that the abundance represented lateral distribution patterns unbiased by differential size-selective gear avoidance.

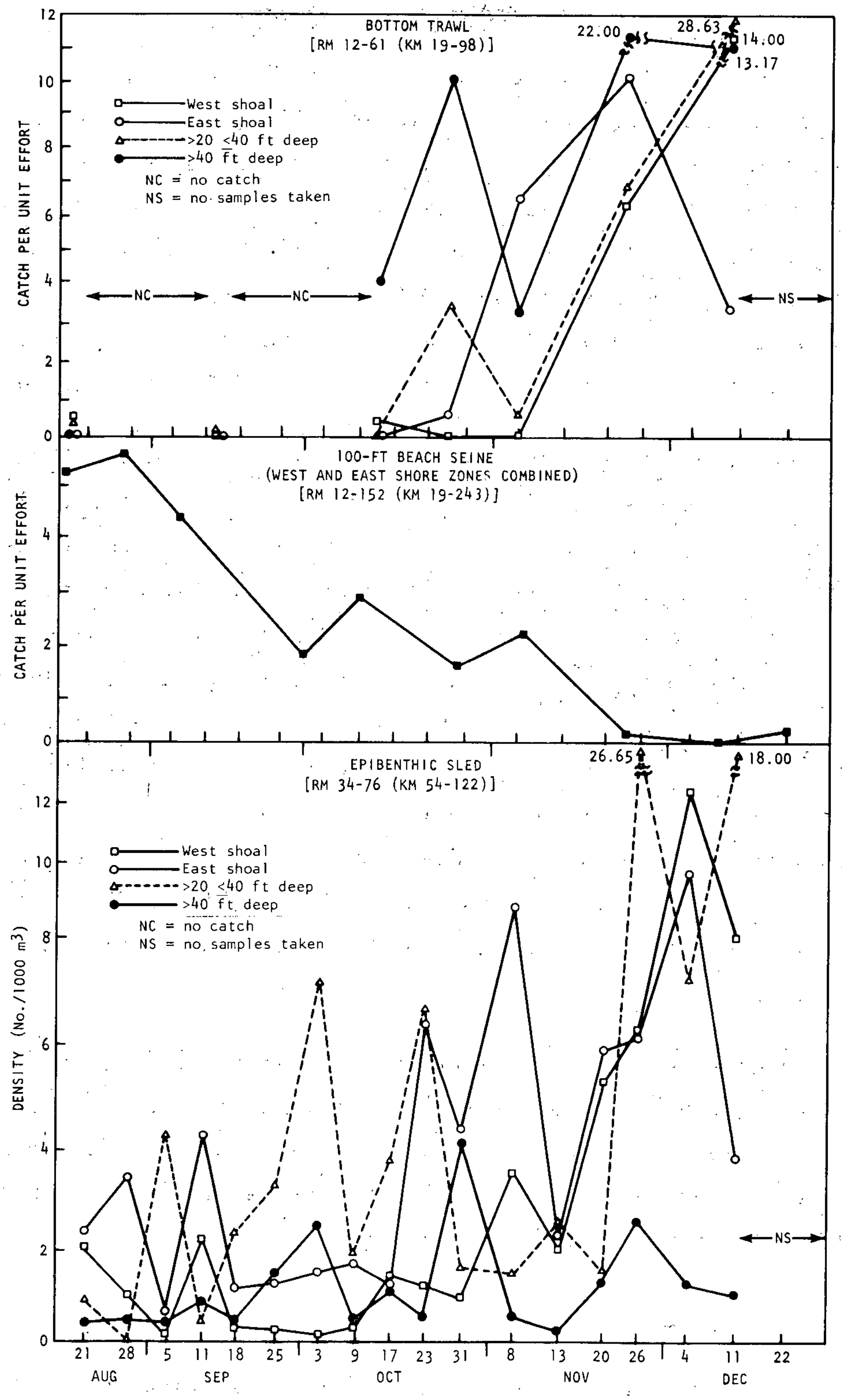


Figure V-7. Catches of Juvenile White Perch in Epibenthic Sled, 100-Ft (30.5-m) Beach Seine, and Bottom Trawl, Hudson River Estuary, August-December 1974

3) Atlantic Tomcod

Juvenile Atlantic tomcod were concentrated near the bottom in the deeper [>20-ft (6.1-m)] areas of the river (Tables V-19 and V-20). Abundance in the east and west shoals was much lower. Also, there were no differences in abundance in the >20-ft (6.1-m) ≤40-ft (12.2-m) and >40-ft (6.2-m) depth strata. However, the shoal strata had lower densities than did the two channel strata [>20 ft (6.1 m) deep] in epibenthic sled catches; shoal densities were significantly lower than the >20-ft (6.1-m) ≤40-ft (12.2-m) stratum in bottom trawl catches. Juvenile abundance in the shore zone was always very low but increased somewhat in May and June (TI, 1975a) and then declined.

Juvenile tomcod were most abundant in areas deeper than 20 ft (6.1 m) (Figure V-8). Catches were low in the shoals and shore zone. In the deeper areas of the river, abundance from August through mid-December was highest in August, declined through October (because of mortality, movement out of the sampling area, or gear avoidance), increased somewhat in mid- to late November, and then declined through mid-December when sampling ceased. Juvenile tomcod numbers in both the east and west shoals fluctuated irregularly in epibenthic sled samples but increased sharply during early December in bottom trawl samples. This early December increase may have been due to the onset of adult spawning movements into the shoal areas since most Atlantic tomcod spawn during their first year of life in the Hudson River (TI, 1975b). Spawning tomcod first appeared in box traps set in the shore zone in mid-December 1974 (subsection C).

Length-frequency distributions of Atlantic tomcod juveniles in beach seines, bottom trawls, and epibenthic sleds (Appendix Tables A-93 through A-96) in the various lateral strata were similar. This observation lends support to the conclusion that these abundances represent lateral distribution patterns unbiased by differential size-selection gear avoidance.

4) American Shad

Juvenile American shad were uniformly distributed in the shoal and channel areas of the river, although the lateral distribution patterns differed somewhat in the epibenthic sled and bottom trawl catches. Juvenile densities in sled samples were significantly higher in the >20-ft (6.1-m) ≤40-ft (12.2-m) stratum than in the east shoal and >40-ft (12.2-m) stratum (Table V-19).

Juvenile catches in bottom trawls were significantly higher in the east shoal stratum than in the <20-ft (6.1-m), ≥20-ft (6.1-m) ≤40-ft (12.2-m), and >40-ft (12.2-m) strata (Table V-20). Abundances in east and west shoals were similar.

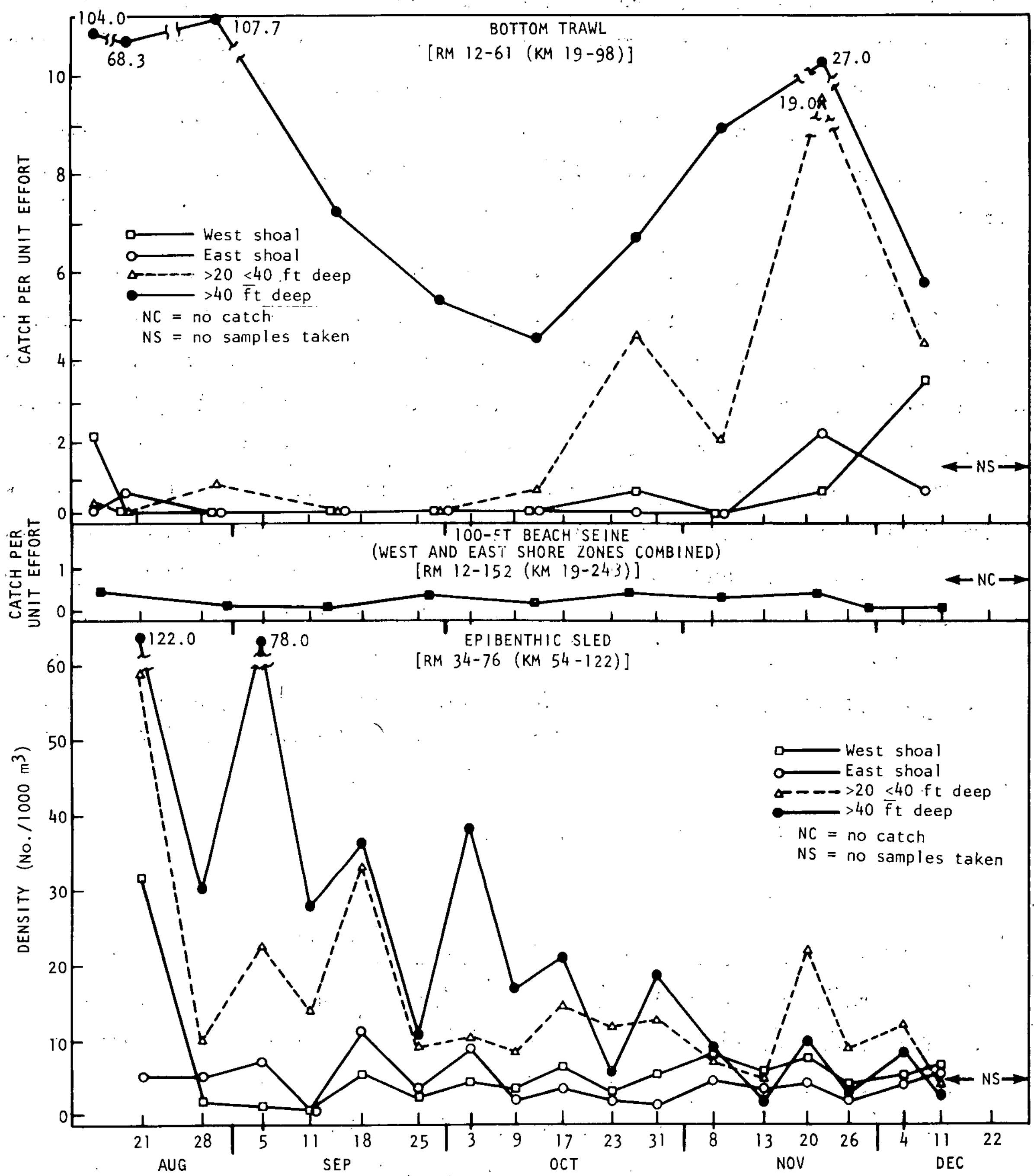


Figure V-8. Distribution of Juvenile Atlantic Tomcod in Epibenthic Sled, 100-Ft (30.5-m) Beach Seine, and Bottom Trawl, Hudson River Estuary, August-December 1974

Juvenile shad were abundant in the shore zone until mid-October (Figure V-9). Abundance in the shoal and the >20-ft (6.1-m) ≤40-ft (12.2-m) and >40-ft (12.2-m) strata increased in mid-October, indicating that the juveniles had begun to move to deep water in mid- to late October. Trends in beach seine catches (subsection C) also suggested a gradual downstream movement of juvenile shad in late October and early November; they apparently moved downstream through all strata, although they were least abundant in the >40-ft (12.2-m) stratum. Seaward migration accelerated in early to mid-November, and catches decreased sharply in all strata.

Length-frequency distributions of juvenile shad in beach seines, bottom trawls, and epibenthic sleds (Appendix Tables A-97 through A-100) in the various strata were similar until early November; after that period, juvenile shad captured in day and night beach seines tended to be smaller than individuals taken in the epibenthic sleds and bottom trawls. The larger juveniles were either leaving the beach areas or escaping the seines. However, with regard to the offshore lateral strata, the abundance data represented distribution patterns in the shoal and >20-ft (6.1-m) ≤40-ft (12.2-m) and >40-ft (12.2-m) strata unbiased by differential-size selective gear avoidance.

d. Nearfield Vicinity of Indian Point (NYU), 1973 and 1974, and Nearfield Vicinity of Lovett, Bowline, and Roseton-Danskammer (LMS), 1974

1) Striped Bass, Indian Point

a) Eggs

Striped bass egg densities were generally greater in the midwater and bottom strata in the vicinity of Indian Point based on day and night samples combined, particularly in 1974 (Table V-21). When averaged over the three depth strata, day-vs-night densities were similar. Station densities at Indian Point were not significantly different (Table V-21).

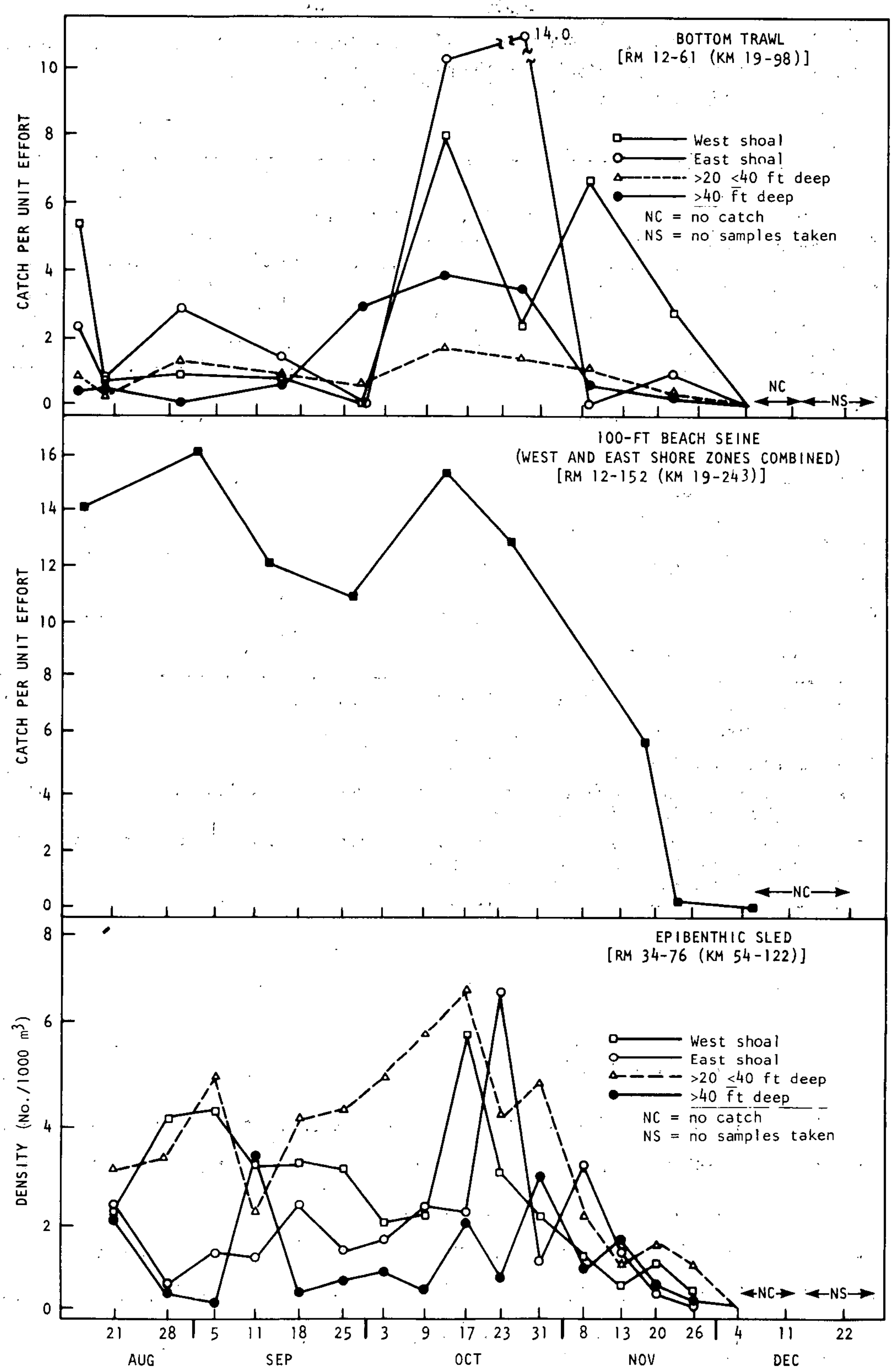


Figure V-9. Abundance of Juvenile American Shad in Epibenthic Sled, 100-Ft (30.5-m) Beach Seine, and Bottom Trawl, Hudson River Estuary, August-December 1974

Table V-21

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Striped Bass Eggs Collected by NYU at Indian Point, 1973 and 1974*

	Stratum Effect	1973** p Value†	1973** Comparisons of Mean Rank Differences among Strata††	1974** p Value†	1974** Comparisons of Mean Rank Differences among Strata††
Main	Depth	>0.25 (0.10)	***	>0.25 (0.001)	S M B
	Day/night	0.16 (>0.25)	***	>0.25 (0.06)	***
	Station	>0.25	***	>0.25	***
Interaction	Depth x day/night	0.17 (>0.25)	-	>0.25 (0.13)	-
	Depth x station	0.17		>0.25	-
	Station x day/night	0.20	-	0.21	-
	Station x depth x day/night	>0.25	-	0.18	-

*Samples collected with 0.5-m mouth diameter plankton net.

**1973 - 29 May, 11 Jun; 1974 - 14 May, 28 May, 4 Jun.

***No significant differences (α = 0.05).

†Probability (p) value in parentheses represents level of significance of strata differences when compared across all stations combined.

††Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at α = 0.05.
S = surface, M = midwater, B = bottom.

b) Yolk Sac Larvae

Striped bass yolk-sac larvae were concentrated in the midwater and bottom strata at Indian Point in day and night samples combined (Table V-22). Densities were similar at all Indian Point stations. This trend was not supported by the 1974 data. The depth-x-station interaction was significant in 1973 ($p < 0.05$), suggesting that yolk-sac larvae were uniformly distributed from surface to bottom at station R2 (Table V-22).

Table V-22

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Striped Bass Yolk-Sac Larvae Collected by NYU at Indian Point, 1973 and 1974*

	Stratum Effect	1973** p Value†	1973** Comparisons of Mean Rank Differences among Strata††	1974** p Value†	1974** Comparisons of Mean Rank Differences among Strata††
Main	Depth	0.05 (0.001)	S M B (S M underscored; B underscored)	0.05 (0.001)	S M B (S underscored; M B underscored)
	Day/night	0.08 (0.25)	***	>0.25 (>0.25)	***
	Station	0.11	***	>0.25	***
Interaction	Depth x day/night	0.09 (0.11)	-	>0.25 (>0.25)	-
	Depth x station	0.03	R1 R2 R3 R4 S 0.1‡ 0.6 0.1 0 M 0.5 1.0 0.4 0.4 B 0.7 1.0 2.3 6.4	>0.25	-
	Station x day/night	0.08	-	0.17	-
	Station x depth x day/night	0.08	-	0.12	-

*R1 through R4 and A through G are NYU sampling stations (see Appendix B for locations). Samples collected with 0.5-m mouth diameter plankton net.

**1973 - 29 May and 11, 19 Jun; 1974 - 14, 28 May and 4 Jun.

***No significant differences (α = 0.05).

†Probability (p) value in parentheses represents level of significant of strata differences when compared across all stations combined.

††Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at α = 0.05.
S = surface, M = midwater, B = bottom.

‡Mean density (No./1000 m^3).

c) Post Yolk-Sac Larvae

Densities of striped bass post yolk-sac larvae were higher in the midwater and bottom strata at Indian Point in day and night samples combined (Table V-23). When averaged over all depths, day-vs-night densities were not significantly different (at α = 0.05). The depth-x-day/night interaction effect suggested that post yolk-sac larvae in the daytime were either concentrating in the deeper areas or avoiding the sampling gear in the surface waters. At night, post yolk-sac larvae apparently dispersed throughout the water column.

Table V-23

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Striped Bass Post Yolk-Sac Larvae Collected by NYU at Indian Point, 1973 and 1974*

		1973**		1974**	
	Stratum Effect	p Value†	Comparisons across Strata††	p Value†	Comparisons across Strata††
Main	Depth	0.02 (0.001)	S M B	0.07 (0.07)	***
	Day/night	(0.07)	***	>0.25 (0.24)	***
	Station	0.18	***	0.03	G F D E C B A*
Interaction	Depth x day/night	0.12 (0.01)	D N S 0.2ǂ 16.5 M 38.9 25.8 B 35.6 28.9	0.03 (0.001)	D N S 0.1 24.7 M 23.0 16.6 B 26.2 16.5
	Depth x station	0.05	R1 R2 R3 R4 S 9.2 7.4 6.3 10.2 M 24.4 51.6 25.7 27.7 B 14.6 26.3 37.4 50.6	>0.25	-
	Station x day/night	>0.25	-	0.23	-
	Station x depth x day/night	0.02	-	0.01	-

*R1 through R4 and A through G are NYU sampling stations (see Appendix B for locations). Samples collected with 0.5-m mouth diameter plankton net.

**1973 - 11, 19, 26 June and 3, 10 Jul; 1974 - 28 May and 4, 11, 18, 25 Jun.

***No significant differences (α =0.05).

†Probability (p) value in parentheses represents level of significance of strata differences when compared across all stations combined.
S = surface, M = midwater, B = bottom, D = day, N = night.

††Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at (α = 0.05).

ǂMean density (No./1000 m^3).

Station densities were similar in 1973; in 1974, however, the two upstream stations (A and B) had higher densities of post yolk-sac larvae than did the most downstream channel station (G). Densities of post yolk-sac larvae at the other stations sampled in 1974 were similar. Depth distributions of post yolk-sac larvae differed among the various stations in 1973 but not in 1974.

2) Striped Bass — Bowline, Lovett, Roseton-Danskammer

a) Eggs

Eggs in transect samples collected by LMS at Bowline and Lovett in 1974 were not identified, separated, or enumerated. At Roseton-Danskammer, striped bass eggs were collected in insufficient numbers for analysis.

b) Larvae

Striped bass larvae in transect samples collected by LMS in 1974 were not separated into the yolk-sac and post yolk-sac stages. Larval distributions were therefore less defined in the nearfield areas of the Bowline, Lovett, and Roseton-Danskammer power plants, but some general trends were suggested. At Bowline, overall depth, day/night, and station densities were similar among the strata (Table V-24). The depth-x-day/night interactions suggested that striped bass larvae were concentrated near the bottom during the day but were in greatest numbers in the surface waters at night. At Indian Point, larvae dispersed rather uniformly throughout the water column at night (Tables V-22 and V-23). This strong shift to the surface stratum at night could have been explained partially by greater gear avoidance in the surface waters during the day. At Lovett (Table V-25), overall depth, day/night, and station densities were similar among the strata, but the station-x-day/night interaction suggested that larvae were more abundant during the night at the two shoal stations (LW and LE). At the channel station (LCH), the reverse situation occurred — greater densities in the daytime.

Densities of striped bass larvae at Roseton-Danskammer (Table V-26) were higher at night than during the day. Densities in the surface, midwater, and bottom strata were similar. Station densities were not significantly different.

Table V-24

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Striped Bass Larvae Collected by LMS at Bowline, 1974*

	Stratum Effect	Stations BW and BCH (Surface, Midwater, and Bottom) p Value†	Stations BW and BCH (Surface, Midwater, and Bottom) Comparisons across Strata	Stations BW, BCH, and BE** (Surface and Bottom) p Value†	Stations BW, BCH, and BE** (Surface and Bottom) Comparisons across Strata††
Main	Depth	>0.25 (>0.25)	***	>0.25 (>0.25)	***
Main	Day/night	>0.25 (>0.25)	***	>0.25 (0.25)	***
Main	Station	>0.25	***	>0.25	***
Interaction	Depth x day/night	0.06 (0.02)	D / N S: 12.3‡ / 229.1 M: 53.4 / 90.0 B: 105.9 / 76.1	0.08 (0.006)	D / N S: 12.7 / 175.2 B: 88.5 / 70.1
Interaction	Depth x station	>0.25	—	>0.25	—
Interaction	Station x day/night	>0.25	—	>0.25	—
Interaction	Station x depth x day/night	>0.25	—	0.22	—

*See Appendix B for locations of LMS sampling stations. Samples collected with 1.0-m mouth diameter Hensen plankton net. Sampling dates: 22 May; 5, 19, Jun; 2 Jul.

**Station BE sampled only in surface and bottom strata.

***No significant differences ($\alpha = 0.05$).

†Probability (p) value in parentheses represents level of significance of strata differences when compared across all stations combined.
S = surface, M = midwater, B = bottom, D = day, N = night.

‡Mean density (No./1000^3).

Table V-25

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Striped Bass Larvae Collected by LMS at Lovett, 1974*

	Stratum Effect	p Value**	Comparisons across Strata			
Main	Depth	>0.25 (>0.25)	***			
Main	Day/night	>0.25 (>0.25)	***			
Main	Station	>0.25	***			
Interaction	Depth x day/night	>0.25 (>0.25)	—			
Interaction	Depth x station	>0.25	—			
Interaction	Station x day/night	0.06		LW	LCH	LE†
			D	84.5‡	105.3	57.5
			N	184.5	71.9	145.4
Interaction	Station x depth x day/night	>0.25	—			

*Samples collected with 1.0-m mouth diameter Hensen plankton nets. Dates: 14, 28, May; 11, 25 Jun; 9 Jul.

**Probability value (p) in parentheses represents level of significance of strata differences when compared across all stations combined.

***No significant differences ($\alpha = 0.05$).

†LW, LCH, and LE are LMS sampling stations (see Appendix B for locations.
D = day, N = night.

‡Mean density (No./1000 m^3).

Table V-26

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Striped Bass Larvae Collected by LMS at Roseton-Danskammer, 1974*

	Stratum Effect	p Value**	Comparisons across Strata†
Main	Depth	>0.25	***
	Day/night	0.02 (0.02)	D N (each underscored separately)
	Station	0.11	***
Interaction	Depth x day/night	>0.25 (>0.25)	-
	Depth x station	>0.25	-
	Station x day/night	0.08	-
	Station x depth x day/night	0.05	-

*Sampling dates: 7, 21 May; 4, 18 Jun; 2, 16 Jul (see Appendix B for LMS sampling stations). Surface and midwater samples collected with 1.0-m mouth diameter Hensen plankton net; bottom samples with epibenthic sled.

**Probability value (p) in parentheses represents level of significance of strata differences when compared across all stations combined.

***No significant differences (α = 0.05).

†Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at α = 0.05.

3) White Perch, Indian Point

a) Eggs

White perch eggs were not collected in sufficient numbers during 1973 and 1974 at the Indian Point transect to warrant analysis of distribution patterns.

b) Yolk-Sac Larvae

When samples were averaged over day and night and compared across all seven sampling stations combined (Table V-27), white perch yolk-sac larvae were denser in the midwater and bottom strata than near the surface in the vicinity of Indian Point. Day-vs-night vertical distributions were similar. Densities of yolk-sac larvae were also similar at all sampling stations.

Table V-27

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for White Perch Yolk-Sac Larvae Collected by NYU at Indian Point, 1974*

	Stratum Effect	p Value**	Comparisons across Strata†
Main	Depth	0.14 (0.001)	S M B
	Day/night	>0.25 (>0.25)	***
	Station	>0.25	***
Interaction	Depth x day/night	>0.25 (>0.25)	—
	Depth x station	0.14	—
	Station x day/night	>0.25	—
	Station x depth x day/night	>0.25	—

*Yolk-sac larvae collections in 1973 insufficient to validly test. Samples collected with 0.5-m mouth diameter plankton net. Sampling dates: 11, 18 Jun (see Appendix B for sampling stations).

**Probability value (p) in parentheses represents level of significance of strata differences when compared across all stations combined.

***No significant differences (α = 0.05).

†Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at α = 0.05.
S = surface, M = midwater, B = bottom.

c) Post Yolk-Sac Larvae

White perch post yolk-sac larvae were concentrated near the bottom of all stations in the vicinity of Indian Point (Table V-28). The depth-x-day/night interaction suggested that the larvae were most abundant in the midwater and bottom strata during the day but dispersed upward at night in 1973. However, this pattern was not evident in 1974. Densities were greater during the daytime in 1973, but this trend did not appear in the 1974 data. Densities averaged over all depths for day and night were similar at all stations during 1973 and 1974.

Table V-28

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for White Perch Post Yolk-Sac Larvae Collected by NYU at Indian Point, 1973 and 1974*

	Stratum Effect	1973** p Value†	1973** Comparisons across Strata††	1974** p Value†	1974** Comparisons across Strata††
Main	Depth	0.02 (0.003)	S B M	0.01 (0.001)	S M B
Main	Day/night	0.08 (0.03)	N D	0.11 (0.06)	***
Main	Station	0.25	***	>0.25	***
Interaction	Depth x day/night	0.02 (0.001)	D N S 1.3‡ 4.4 M 12.1 5.8 B 8.7 5.9	>0.25 (>0.25)	-
Interaction	Depth x station	>0.25	-	0.17	-
Interaction	Station x day/night	>0.25	-	>0.25	-
Interaction	Station x depth x day/night	0.04	-	0.01	-

*Samples collected with 0.5-m mouth diameter plankton net. See Appendix B for sampling locations.

**1973 - 29 May; 11, 19, 26 Jun; 3 Jul; 1974 - 28 May; 4, 11, 18, 25 Jun; 2 Jul.

***No significant differences (α = 0.05).

†Probability value (p) in parentheses represents level of significance of strata differences when compared across all stations combined.

††Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at α = 0.05. S = surface, M = midwater, B = bottom, D = day, N = night.

‡Mean density (No./1000 m^3).

4) White Perch — Bowline, Lovett, Roseton-Danskammer

a) Eggs

Eggs in transect samples collected by LMS at Bowline and Lovett in 1974 were not identified, separated, or enumerated. At Roseton-Danskammer, white perch eggs were collected in insufficient numbers for analysis.

b) Larvae

White perch larvae in transect samples collected by LMS in 1974 were not separated into the yolk-sac and post yolk-sac stages; hence, white perch larval distributions were less defined in the nearfield areas of the Bowline, Lovett, and Roseton-Danskammer power plants. Densities at Bowline were similar at the three depths (surface, midwater, and bottom) and at two sampling stations (BW and BCH) in day and night samples combined (Table V-29). Densities were significantly greater during the daytime at stations BW and BCH. At Roseton-Danskammer and Lovett, no differences between any strata were detected at the α = 0.05 level (Tables V-30 and V-31).

Table V-29

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for White Perch Larvae Collected by LMS at Bowline, 1974*

	Stratum Effect	Stations BW and BCH (Surface, Midwater, and Bottom): p Value†	Stations BW and BCH (Surface, Midwater, and Bottom): Comparisons across Strata††	Stations BW, BCH, and BE** (Surface and Bottom): p Value†	Stations BW, BCH, and BE** (Surface and Bottom): Comparisons across Strata††
Main	Depth	>0.25 (>0.25)	***	>0.25 (>0.25)	***
Main	Day/night	>0.25 (0.03)	N D	>0.25 (>0.25	***
Main	Station	>0.25	***	>0.25	***
Interaction	Depth x day/night	>0.25 (>0.25)	-	>0.25 (0.17)	-
Interaction	Depth x station	>0.25	-	0.08	-
Interaction	Station x day/night	>0.25	-	>0.25	-
Interaction	Station x depth x day/night	>0.25	-	>0.25	-

*Samples collected with 1.0-m mouth diameter Hensen plankton net. Sampling dates: 22 May; 5, 19 Jun; 2 Jul (see Appendix B for sampling locations).

**Station BE sampled only in surface and bottom strata.

***No significant differences (α = 0.05).

†Probability (p) value in parentheses represents level of significance of strata differences when compared across all stations combined.

††Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at α = 0.05. S = surface, M = midwater, B = bottom, N = night, D = day.

Table V-30

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for White Perch Larvae Collected by LMS at Lovett, 1974*

	Stratum Effect	p Value**	Comparisons across Strata
Main	Depth	>0.25 (>0.25)	***
	Day/night	>0.25 (0.08)	***
	Station	0.11	***
Interaction	Depth x day/night	>0.25 (0.17)	-
	Depth x station	>0.25	-
	Station x day/night	0.13	-
	Station x depth x day/night	>0.25	-

*Samples collected with 1.0-m mouth diameter Hensen plankton net. Sampling dates: 28 May; 11, 25 Jun; 9 Jul (see Appendix B for sampling locations).

**Probability value (p) in parentheses represents level of significance of strata differences when compared across all stations combined.

***No significant differences at α = 0.05.

Table V-31

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for White Perch Larvae Collected by LMS at Roseton-Danskammer, 1974*

	Stratum Effect	p Value**	Comparisons across Strata
Main	Depth	>0.25 (0.10)	***
	Day/night	>0.25 (>0.25)	***
	Station	>0.25	***
Interaction	Depth x day/night	0.07 (>0.25)	-
	Depth x station	>0.25	-
	Station x day/night	>0.25	-
	Station x depth x day/night	>0.25	-

*Samples collected with 1.0-m mouth diameter Hensen plankton net. Sampling dates: 4, 18 Jun; 2, 16, 30 Jul; 13 Aug (see Appendix B for sampling locations).

**Probability (p) value in parentheses represents level of significance of strata differences when compared across all stations combined.

***No significant differences at α = 0.05.

5) Atlantic Tomcod, Indian Point

There were not enough Atlantic tomcod of any life stage at the Indian Point transect during 1973 and 1974 with which to analyze distribution patterns.

6) Atlantic Tomcod — Bowline, Lovett, and Roseton-Danskammer

a) Eggs

Eggs in transect samples collected by LMS at Bowline and Lovett in 1974 were not identified, separated, or enumerated. At Roseton-Danskammer. there were too few Atlantic tomcod eggs to permit analysis.

b) Larvae

Atlantic tomcod larvae were collected by LMS only at the Roseton-Danskammer transect in 1974, and they were not separated into the yolk-sac and post yolk-sac stages. No differences between any strata were detected at the $\alpha = 0.05$ level (Table V-32).

Table V-32

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Atlantic Tomcod Larvae Collected by LMS at Roseton-Danskammer, 1974*

	Stratum Effect	p Value**	Comparisons across Strata†
Main	Depth	>0.25 (>0.25)	***
	Day/night	>0.25 (>0.25)	***
	Station	0.10	***
Interactions	Depth x day/night	>0.25 (>0.25)	—
	Depth x station	>0.25	—
	Station x day/night	>0.25	—
	Station x depth x day/night	>0.25	—

*Samples collected with 1.0-m mouth diameter Hensen plankton net. Sampling dates: 11, 28 Mar; 10 Apr (see Appendix B for sampling locations).

**Probability (p) value in parentheses represents level of significance of strata differences when compared across all stations combined.

***No significant differences at $\alpha = 0.05$.

c) Juveniles

Juvenile Atlantic tomcod were collected only at the Bowline and Lovett transects during 1974. Juvenile densities at Bowline (Table V-33) were greater in the deeper strata at all stations, day and night. There were more juveniles at the channel station (BCH) than on the side of the river opposite the plant site (BE). The depth-x-station interaction supported the overall observation that there are more juvenile tomcod in the bottom strata, particularly at the channel station (BCH).

Table V-33

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Atlantic Tomcod Juveniles Collected by LMS at Bowline, 1974*

		Stations BW and BCH (Surface, Midwater, and Bottom)		Stations BW, BCH, and BE** (Surface and Bottom)	
	Stratum Effect	p Value	Comparisons across Strata†	p Value	Comparisons across Strata†
Main	Depth	0.02	S M B	0.03	S B
	Day/night	>0.25	***	>0.25	***
	Station	0.17	***	0.04	BE BW BCH
Interaction	Depth x day/night	>0.25	-	>0.25	-
	Depth x station	0.05	BW BCH S 2.1 0 M 1.4 7.9 B 12.6 43.6	0.06	-
	Station x day/night	0.14	-	>0.25	-
	Station x depth x day/night	0.10	-	0.06	-

*Samples collected with 1.0-m mouth diameter Hensen plankton net. Sampling dates: 22 May; 5, 19 Jun; 2, 18 Jul.

**Station BE sampled only in surface and bottom strata. BW, BCH, and BE are LMS sampling stations (see Appendix B for locations). S = surface, M = midwater, B = bottom

***No significant differences at α = 0.05.

†Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are significantly different at α = 0.05.

At Lovett (Table V-34) also, juveniles were denser near the bottom at all stations, day and night. Day/night and station differences in juvenile tomcod density were not significant at α = 0.05.

Table V-34

Results of Nonparametric Analysis of Variance of Nearfield Transect Data [Mean Density (No./1000 m^3 by Strata)] for Atlantic Tomcod Juveniles Collected by LMS at Lovett, 1974*

	Stratum Effect	p Value**	Comparisons across Strata†
Main	Depth	0.10 (0.002)	S M B (S M underscored; B underscored)
	Day/night	>0.25 (>0.25)	***
	Station	0.10	***
Interaction	Depth x day/night	0.15 (>0.25)	–
	Depth x station	0.12	–
	Station x day/night	>0.25	–
	Station x depth x day/night	>0.25	–

*Samples collected with 1.0-m mouth diameter Hensen plankton net. Sampling dates: 25 Jun; 9, 23 Jul.

**Probability (p) value in parentheses represents level of significance of strata differences when compared across all stations combined.

***No significant differences at α = 0.05.

†Listed in order of increasing mean rank (left to right). Any two strata not underscored by same continuous line are different at α = 0.05.
S = surface, M = midwater, B = bottom.

4. Summary

The general patterns or trends in the vertical, lateral, diel, and tidal distribution of the various life stages of striped bass, white perch, American shad, and Atlantic tomcod in the Hudson River during 1974 are summarized in the following paragraphs.

a. Striped Bass

Eggs were concentrated in midwater and bottom areas of the river >20 ft (6.1 m) deep, day and night. Eggs were similarly distributed in the nearfield vicinity of Indian Point.

Yolk-sac larvae were concentrated in the midwater and bottom areas of the river >20 ft (6.1 m) deep during the day but were dispersed throughout the water column at night. Post yolk-sac larvae were present in the shoal and >20-ft (6.1-m) depth areas of the river, suggesting a shoalward movement during this life stage. Post yolk-sac larvae were concentrated near the bottom during the day but were dispersed throughout the water column at night.

Distribution patterns for larvae in the nearfield vicinity of Indian Point were generally similar to those just described. Larval distribution patterns at Bowline, Lovett, and Roseton-Danskammer were inconclusive.

Juveniles were abundant near the bottom in areas >20 ft (6.1 m) deep until mid-August when most had moved into the shoals and shore zone. Juveniles first appeared in the shore zone in late June and remained relatively abundant there until early November when they moved into the deeper waters. Juveniles were more abundant at night in the shore zone, regardless of tidal stage.

b. White Perch

Eggs were concentrated near the bottom, primarily in the east shoal, west shoal, and areas >20 ft (6.1 m) deep.

Yolk-sac larvae exhibited a relatively uniform distribution throughout the water column, day and night, although a trend toward low densities in surface water during the day was suggested. Post yolk-sac larvae were more abundant in the areas of the river >20 ft (6.1 m) deep than in the shoals and were uniformly distributed from surface to bottom during day and night.

Larval distribution patterns in the nearfield vicinity of Indian Point differed somewhat from those just described. Yolk-sac larvae were denser in midwater and bottom strata day and night. Post yolk-sac larvae were also concentrated in deep water during the day but were more dispersed through the water column at night. Larval distribution patterns at Bowline, Lovett, and Roseton-Danskammer were inconclusive.

Juveniles were abundant in all strata of the river except the deepest [>40 ft (12.2 m) deep]. They first appeared in the shore zone in early July and were relatively abundant there until late August when they began to move to deeper water. Offshore movements accelerated in early November. Juveniles were more abundant in the shore zone at night, regardless of tidal stage.

c. Atlantic Tomcod

Juveniles were concentrated on the bottom in areas of the river >20 ft (6.1 m) deep and in the west shoal through mid-August and then were concentrated primarily in areas >20 ft (6.1 m) deep until spawning began in mid-December; at that time, they entered the shoals and shore zone. Juveniles were never abundant in the shore zone, day or night, during spring, summer, and fall.

The limited data on larval and juvenile distributions at Bowline, Lovett, and Roseton-Danskammer gave results generally similar to the patterns exhibited by the juveniles.

d. American Shad

Day and night, eggs were concentrated near the bottom in areas of the river >20 ft (6.1 m) deep.

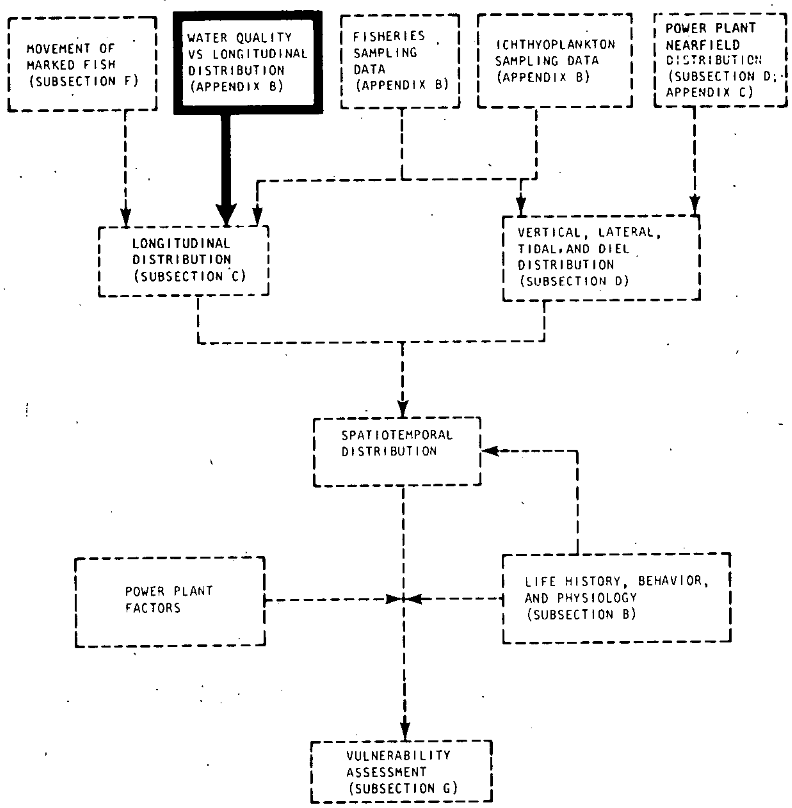
Yolk-sac larvae were concentrated in midwater and bottom areas of the river >20 ft (6.1 m) deep during the day but were dispersed throughout the water column at night. Post yolk-sac larvae were most abundant in areas >20 ft (6.1 m) deep and were uniformly distributed from surface to bottom during day and night. Some post yolk-sac larvae were collected in the shoals.

Juveniles were abundant in the shore zone, shoals, and the mid-water and bottom strata of the >20-ft (6.1-m) deep areas through October, and then catches declined sharply as the juveniles left the river. There were no obvious movements from shore zone to channel prior to the downstream migration. Juveniles were more abundant during the day in the shore zone, regardless of tidal stage.

E. LONGITUDINAL DISTRIBUTION AND ABUNDANCE IN RELATION TO PHYSICOCHEMICAL VARIABLES

1. Objective

This subsection examines the relationship between life stage distribution of striped bass, white perch, Atlantic tomcod, and American shad and selected physicochemical variables (temperature, conductivity, and dissolved oxygen) during 1974. The assessment of the vulnerability of the four species to plant-induced mortality also considered these relationships. This subsection's position in the overall organization of Section V is illustrated below:



2. Methods

Water temperature, conductivity, and dissolved oxygen were measured concurrently (same depth, site, and time) with Tucker trawl, epibenthic sled, bottom trawl, and beach seine sampling from April through December 1974. Longitudinal distribution plots (approximately weekly) of these three water quality variables in the Hudson River from RM 14 (KM 22) to RM 140 (KM 224) are presented in Appendix Figures A-73 and A-74.

Catch data for each life stage of each species collected by each of the three gear were combined across sampling periods for the following time intervals:

Mid-April through Mid-August	Eggs, larvae, early juveniles in shoals and channel by Tucker trawl and epibenthic sled
Mid-June through Mid-December	Juveniles in shore zone by beach seine
Mid-June through Mid-December	Juveniles in shoals and channel by epibenthic sled and bottom trawl

The actual periods during which given life stages were collected are discussed in subsection C and in Appendix A. The catch data were grouped with the corresponding water quality variables, separated by life stage and gear, and plotted to determine the general associations between life stage abundance and water quality variables.

3. Results and Discussion

The associations between the life stage abundances and the selected water quality variables are specific for eggs and larvae, which have limited life stage durations. The juvenile life stage, however, is defined to last until the end of the calendar year in which hatching occurred. Hence, the associations between juvenile abundance and the water quality variables represent a preliminary examination of these complex ecological relationships.

The discussion of each species is limited to a description of the general association patterns of abundance with temperature, conductivity, and dissolved oxygen. Specific details are presented in Appendix Figures A-48 and A-72.

a. Striped Bass

Water temperature and conductivity (an index of salinity) strongly influenced striped bass spawning activity in the Hudson River estuary during 1974. Spawning occurred almost exclusively in fresh water over a wide range of temperatures (10-23°C), but most eggs were collected within the rather narrow temperature range of 15-19°C (Appendix Figure A-48). Talbot (1966) also reported that striped bass generally spawn within the first 25 mi (40 km) of fresh water and that there is little or no spawning in brackish water. Peak spawning of striped bass in the Sacramento-San Joaquin estuary, California, occurred at temperatures of 15-19°C (Talbot, 1966; Albrecht, 1964). Mansueti and Hollis (1963) reported that striped bass in Chesapeake Bay tributaries spawned at 18.3°C.

Hudson River striped bass yolk-sac and post yolk-sac larvae developed primarily in fresh water or in slightly brackish water having relatively high dissolved oxygen concentrations (≥6.5 mg/liter) during 1974 (Appendix Figures A-49 and A-50). The majority of development to the juvenile stage (approximately 14 mm in total length as defined by TI, 1975a) was completed before water temperatures increased to 23°C in late July (Appendix Figures A-51 through A-54 and A-73). A relatively small portion of the egg and larval population was subjected to low dissolved oxygen concentrations (≤3.5 mg/liter) in late May (Appendix Figures A-48 through A-50 and A-74). These low dissolved oxygen levels between RM 50 (KM 80) and RM 90 (KM 144) may have been related to the removal of a Niagara-Mohawk dam near Fort Edward, New York, during the winter of 1973-74 (Joe Miakicz, NMPC, personal communication) and a downstream influx of organic detritus. The effects of these low levels on the 1974 year class are unknown; however, survival of exposed eggs and larvae might have been reduced.

Dissolved oxygen levels below 4.0 mg/liter may be lethal to striped bass eggs (Talbot, 1966). Doroshev (1970) reported high mortality of striped bass larvae (10-12 mm) when dissolved oxygen concentrations were 1.65 mg/liter (19°C); exposure time was not given. Doroshev also suggested that eggs have a similar tolerance for low dissolved oxygen concentrations.

Juvenile striped bass began to move gradually into the shoals and shore zone in early to mid-July (TI, 1975a, and subsections C and D) as water temperatures increased to approximately 25°C. As water temperatures dropped below 17°C in late October (Appendix Figure A-73), juvenile abundance in the shore zone declined but bottom trawl catches increased (Appendix Figures A-53 and A-54). This suggested that the juveniles were moving into deeper water. At temperatures below 4°C, juvenile striped bass were absent in all gear, suggesting that they had migrated out of the river or had moved to deep areas of the river inaccessible to the sampling gear.

Any associations between juvenile abundance and conductivity were not readily apparent. Early juveniles were collected in ichthyoplankton gear in either fresh or only slightly brackish water (Appendix Figure A-51). By early September, juveniles had gradually shifted their distribution to the lower river regions (TI, 1975a) where conductivities are relatively high and food organisms presumably more abundant (Massman, 1963). These lower river regions also have extensive shoal areas, so any conductivity preference by juvenile striped bass was inextricably confounded with possible physical habitat preference. However, the general pattern was a downriver movement into areas of relatively high conductivities (Appendix Figures A-52 and A-53). Juvenile striped bass did not apparently move both upstream and downstream during the summer and fall in order to remain in or near the salt front [freshwater/brackish-water interface (defined as 0.3 mmho/cm, or 0.1 $^{o}/oo$)].

No relationships between juvenile abundance and dissolved oxygen were suggested (Appendix Figures A-51 through A-54).

b. White Perch

White perch spawning activity did not appear to be strongly related to temperature or conductivity: eggs were collected over a wide range of temperatures (12-25°C), and deposition apparently peaked at temperatures of 14-21°C (Appendix Figure A-55). Most eggs were collected in fresh or slightly brackish water (0-2.5 mmho/cm), but some spawning activity was evident at conductivities to 8.5 mmho/cm.

Mansueti (1961, 1964) reported that white perch spawned in tidal fresh and slightly brackish water of the Chesapeake Bay region when water temperatures were between 10 and 15°C. White perch spawning activity in freshwater tributaries was reported for populations from the Delaware River (Wallace, 1971) and from the James and York Rivers of Virginia (St. Pierre and Davis, 1972). The potential role of tributary streams to the Hudson River as spawning areas for white perch has not been investigated.

The abundance of white perch yolk-sac and post yolk-sac larvae peaked at water temperatures between 15 and 23°C, primarily in fresh or only sightly brackish (<4.5 mmho/cm) water (Appendix Figures A-56 and A-57). A small portion of the eggs and larvae was exposed to a period of low dissolved oxygen concentrations (<4 mg/liter) during the last week in May. Such conditions would likely reduce the survival of the exposed eggs and larvae. The largest standing crops of eggs and larvae, however, occurred in June (TI, 1975a) when dissolved oxygen concentrations were >6 mg/liter throughout the river (Appendix Figure A-74).

After transformation from the post yolk-sac larvae stage in mid to late July, juvenile white perch began to gradually move into the shore zone (TI, 1975a) when water temperatures reached 25-27°C (Appendix Figure A-73). Juveniles remained in the shore zone through August and then began to move offshore again in mid-September (subsection D) as water temperatures decreased to 20-21°C (Appendix Figure A-73). This movement to shoal areas accelerated in early November (subsection D) as water temperatures dropped below 15°C. Beach seine catches declined rapidly at temperatures below 12°C (Appendix Figure A-61), whereas epibenthic sled catches in deeper water increased to a peak at temperatures of 7-10°C and then began to decline (Appendix

Figure A-59). However, bottom trawl catches (often even in deeper water) were highest at temperatures of 2-5°C (Appendix Figure A-60), suggesting that juvenile white perch moved to the deepest areas of the channel when water temperatures fell below 6-7°C. Temperature is an important factor in determining the depth distribution of juvenile white perch.

Longitudinal distribution of juvenile white perch appeared to be related to salinity. Catches were highest in all gear in fresh or slightly brackish (8.5 mmho/cm) water (Appendix Figures A-58 through A-61). Peak abundances were associated with conductivities representative of the salt front (i.e., the freshwater/saltwater interface, defined as 0.3 mmho/cm). In 1974, juvenile white perch in the shore zone were widely distributed throughout the estuary until mid-October (subsection C and TI, 1975a); they then moved offshore and downriver and remained in the area of the salt front. Other indications of white perch movements in association with the salt front have been discussed by Texas Instruments (1975f). White perch impingement rates during winter at the Indian Point power plant are also associated with salt intrusions into the area; impingements peak immediately before and/or just after the salt front passes the plant intakes (TI, 1975d).

Dissolved oxygen concentrations had no apparent influence on juvenile white perch distribution (Appendix Figures A-58 through A-61).

c. Atlantic Tomcod

Because tomcod are winter spawners and sampling was limited during the winters of 1973-74 and 1974-75, little can be said about the relationships between tomcod spawning activity, egg or larval distribution, and water quality in the Hudson River. However, box trap catch data (December 1974-March 1975) suggested that tomcod spawn mostly in fresh or slightly brackish water rather than in the more highly saline areas in the lower river (Figure V-22 and Appendix Figure A-31). Spawning presumably took place when water temperatures were below 5°C (TI, 1975a, and subsection C).

Water temperature, conductivity, and possibly dissolved oxygen appeared to be important water quality factors influencing juvenile tomcod distribution. Juveniles were the only life stage collected during the first complete ichthyoplankton river run (29 April-4 May) when water temperatures were 11-13°C (Appendix Figures A-69 through A-72), suggesting that transformation from post yolk-sac larvae to juveniles occurred below 11°C. Juvenile catches in epibenthic sleds remained consistently high as water temperatures increased to 23°C (Appendix Figures A-69 and A-70), indicating that some juvenile tomcod may have migrated out of the river during May and June but that many also remained throughout the year.

Most of the 1974 year class of tomcod were spawned between RM 39 (KM 62) and RM 61 (KM 98) and some perhaps as far upstream as RM 106 (KM 170) in 1973-74 (subsection C). Most were concentrated downriver in areas where conductivities ranged from 0.4 to 30.5 mmho/cm during the following spring, summer, and fall. Epibenthic sled and Tucker trawl catches per tow (mid-April through mid-August) each showed two peaks: one at a conductivity range of approximately 0.3-8.5 mmho/cm and another at a conductivity range of approximately 14.5-24.5 mmho/cm (Appendix Figure A-69). Epibenthic sled catches in the fall and early winter (mid-August through mid-December) also showed two abundance peaks related to conductivity: one at 0.2-6.5 mmho/cm and a larger one at 16.5-20.5 mmho/cm (Appendix Figure A-70). Bottom trawl catches per tow (mid-April through mid-December) were highest around a single, narrow conductivity range of 6.5-8.5 mmho/cm (Appendix Figure A-71). Beach seine catch per haul showed a single peak over a broader conductivity range of 6.5-41.5 mmho/cm (Appendix Figure A-72).

Juvenile tomcod clearly prefer brackish areas. The bimodal distribution of juveniles in areas around the salt front and in areas of relatively high salinities, however, is difficult to interpret. This question was briefly discussed in a previous report (TI, 1975f) in which maximum weekly juvenile tomcod catches in ichthyoplankton samples in 5-river-mile intervals [RM 11-140 (KM 17-224)] were plotted against the longitudinal weekly distribution of conductivity. These plots indicated two separate peaks of juvenile abundance: one which moved in association with the salt front, and another which tended to remain in areas of relatively high salinity.

There were no clear relationships between juvenile tomcod abundance and dissolved oxygen concentrations. Most of the catches in epibenthic sleds and Tucker trawls were taken over a dissolved oxygen range of 2.5-6.0 mg/liter (Appendix Figure A-69). Bottom trawl catches peaked at slightly higher levels, 7.5-9.0 mg/liter (Appendix Figure A-71).

The Atlantic tomcod is primarily a northeast Atlantic coastal species preferring cooler waters (Bigelow and Schroeder, 1953). Therefore, it is likely that the warm summer temperatures in the Hudson could potentially stress juvenile tomcod, particularly if dissolved oxygen levels were low during the summer.

d. American Shad

Water temperature and conductivity were the primary water quality factors influencing American shad spawning activity in the Hudson River. Shad spawned in the strictly freshwater, upstream regions of the river (subsection C) when water temperatures ranged from 10 to 24°C (Appendix Figure A-62). Egg deposition peaked at temperatures of 11-18°C, although the catch was bimodally distributed. There was an initial spawning peak at 11-14°C and a second peak at 16-18°C.

It has been reported that the peak in shad spawning migrations of Atlantic Coast populations is closely correlated with a narrow range of water temperatures, 13-18°C (Leggett and Whitney, 1972). Most shad enter their spawning rivers when water temperatures are between 10 and 15°C. Most egg deposition occurred between 12 and 20°C in the St. Johns River, Florida (Walburg, 1960), between 12 and 20°C in the Shubenacadie River, Nova Scotia (Leim, 1924), and between 16 and 20°C in the Connecticut River (Marcy, 1969, 1972, 1976). Optimum temperatures for shad egg and larval development under laboratory conditions ranges from 15.5 to 26.5°C (Leim, 1924; Bradford et al, 1968); therefore, those shad eggs spawned later in the spawning period may have a higher probability of survival than those from an early spawn.

Shad larvae in the Hudson River developed primarily in freshwater areas, but some post yolk-sac larvae were collected in slightly brackish waters (Appendix Figures A-63 and A-64). Eggs and larvae were usually collected in areas of relatively high dissolved oxygen concentrations (>6.0 mg/liter), but a small portion of the 1974 egg and larval population was exposed to low oxygen levels (<4 mg/liter) during the last week of May (Appendix Figures A-62 through A-64). Most larvae had transformed to the juvenile stage in early July (see subsection B for developmental criteria) by the time water temperatures had reached 24°C (Appendix Figures A-64 through A-68 and A-73).

Juvenile shad began to move into the shore zone following transformation and remained abundant there, as well as in the shoal areas, through early October (subsections C and D). As water temperatures decreased to 15°C in late October (Appendix Figure A-73), catches by all gear decreased rapidly (Appendix Figures A-66 through A-68), suggesting that the juveniles were migrating out of the river. Similar downstream movements of juvenile shad were previously reported in other Atlantic Coast estuaries (Sykes and Lehman, 1957; Chittenden, 1969; and Hildebrand, 1963). By mid-November when water temperatures in the Hudson ranged from 12 to 14°C (Appendix Figure A-73), juvenile shad were essentially absent in beach seine samples (Appendix Figure A-68) and were rapidly decreasing in epibenthic sled and bottom trawl samples (Appendix Figures A-66 and A-67). Almost all juvenile shad had left the river by late November as water temperatures dropped below 10°C (Appendix Figure A-73).

There were no obvious relationships between juvenile shad distribution and conductivity or dissolved oxygen levels (Appendix Figures A-65 through A-68). Juveniles were rather widely distributed throughout the river until late October and then moved directly out of the river during November (subsection C).

4. Summary

The general patterns or trends in the life stage distribution of striped bass, white perch, Atlantic tomcod, and American shad with respect to temperature, conductivity, and dissolved oxygen in the Hudson River during 1974 are summarized in the following paragraphs.

a. Striped Bass

Peak egg deposition occurred in freshwater areas when water temperatures ranged from 15 to 19°C. Larvae developed in fresh to slightly brackish water, transforming into juveniles before water temperatures had reached 23°C. A small portion of the eggs and larvae were exposed to dissolved oxygen levels below 3.5 mg/liter in late May 1974.

Juveniles moved to the shoals and shore zone as water temperatures increased to 20°C and then left the shore zone as temperatures dropped below 17°C. Juveniles moved into the lower river regions in early September, but no movements in association with movements of the salt front were noted.

b. White Perch

Peak egg deposition occurred in freshwater and slightly brackish areas when water temperatures ranged from 14 to 21°C. Larvae developed in fresh and slightly brackish water, transforming into juveniles before water temperatures had reached 23°C. A small portion of the eggs and larvae were exposed to dissolved oxygen levels below 3.5 mg/liter in late May 1974.

Juveniles were widely distributed throughout the river until mid-October when they moved offshore and downriver to the area of the salt front.

c. Atlantic Tomcod

Spawning occurred in fresh to slightly brackish water when water temperatures were below 5°C. Larvae developed in fresh to brackish water, transforming into juveniles before water temperatures had reached 11°C.

Juvenile distributions were associated generally with the salt front and may have been bimodal. One peak occurred in relatively high saline areas and the second at the salt front. Juveniles were most abundant in the bottom areas where dissolved oxygen levels ranged from 2.5 to 9.0 mg/liter.

d. American Shad

Peak egg deposition occurred in fresh water when water temperatures ranged from 11 to 18°C. Early larvae developed in fresh water, but some late larvae were collected in slightly brackish areas. Transformation into juveniles occurred before water temperatures had reached 24°C. A small portion of the eggs and larvae were exposed to dissolved oxygen levels below 3.5 mg/liter in late May 1974.

Juveniles began to move to the shoals and shore zone as water temperatures increased to 24°C, but they began to leave the river when temperatures decreased to 15°C. Juveniles were widely distributed throughout the river until late October when they began to migrate seaward. Their distribution showed no association with the salt front.

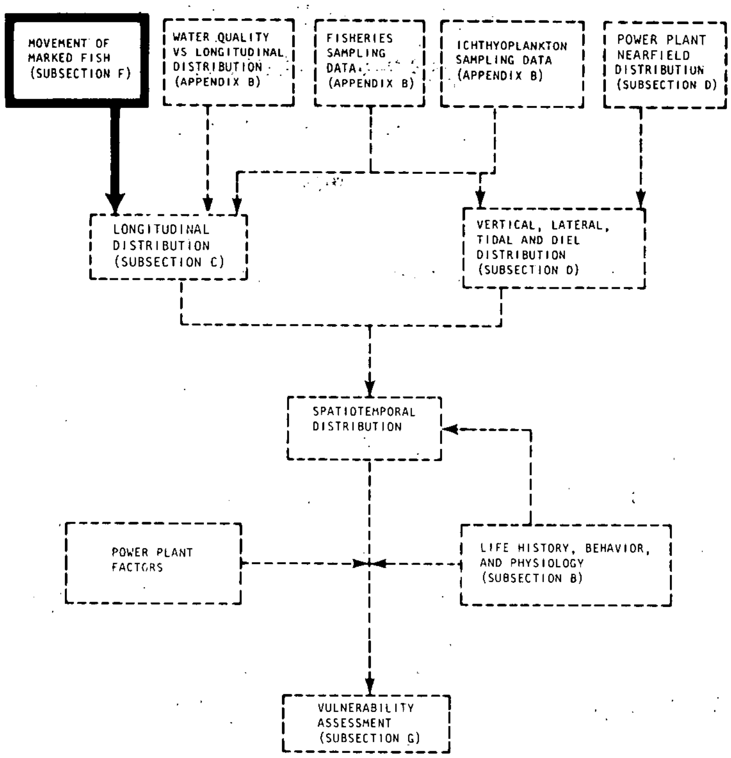
F. MOVEMENT OF MARKED FISH

1. Objective

Recoveries of individual striped bass, white perch, and Atlantic tomcod marked in the Hudson River estuary during the 1974-75 mark/recapture program (Section III) were analyzed to discern trends in their movements. This analysis was similar to that conducted for the 1973-74 program (TI, (1975a). Hence, data from the two successive annual programs are comparable.

Mark recoveries of the three species were examined on a temporal and spatial basis for indications of predictable movement patterns that would influence their vulnerability to impingement at the various power plants on the Hudson River. If movements are indeed predictable, the distribution of these fish species and their various age groups also could be predicted seasonally with respect to potential vulnerability to impingement at power plants.

This subsection's position in the overall organization of Section V is illustrated in the following diagram:



2. Methods

Five marking areas were established for the 1974-75 mark/recapture program (Figure V-10):

Area 1, RM 12-23 (KM 19-37)
Area 2, RM 24-38 (KM 38-61)
Area 3, RM 39-46 (KM 62-74)
Area 4, RM 47-61 (KM 75-98)
Area 5, RM 62-153 (KM 99-245)

Areas 1 and 2 combined represented the Area 1 of the 1973-74 program (TI, 1975a); this area was divided to allow clearer definition of movements of marked individuals found in the region [RM 12-23 (KM 19-37)] well below the salt front and individuals found within the region [RM 24-38 (KM 38-61)] of frequently varying salinity. The boundaries of the marking areas also generally conformed to the boundaries delineating areas of comparatively uniform morphology, e.g., the wide shallow Haverstraw Bay vs the deeper channel

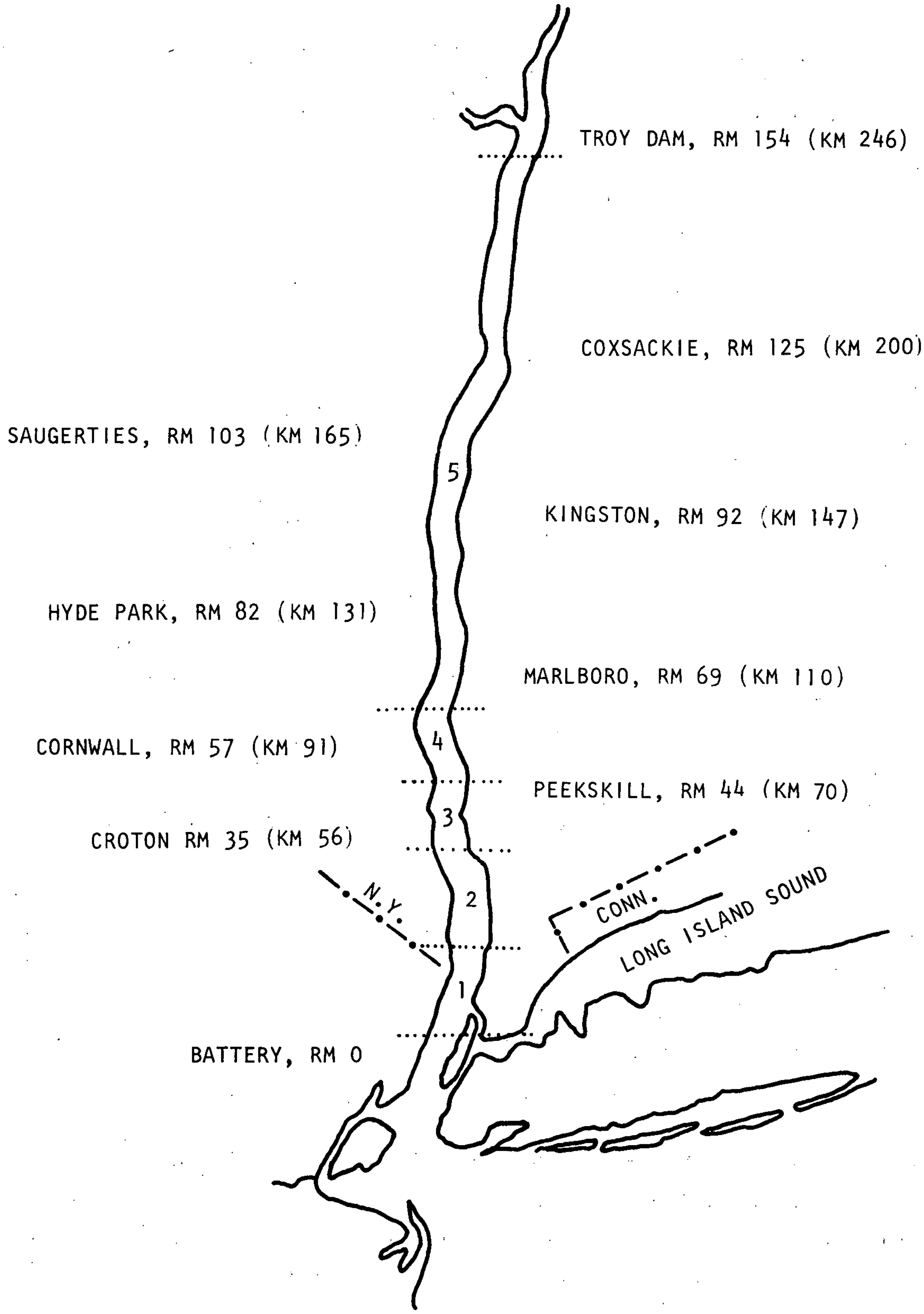


Figure V-10. Five Marking Areas of Mark/Recapture Program, August 1974-June 1975 between Indian Point and Cornwall. The marking areas were derived from combinations of the 12 geographical river regions (Table V-2).

Data recorded from the release and subsequent recapture of tagged white perch and Atlantic tomcod included sites of release and recapture, direction of movement, time at large, total length at time of release and recapture, and rate (mile per day) of movement. The effect of season on distance and direction of movement of tagged white perch was analyzed using tag return data divided into three subsets: tags released and recaptured from 16 September through 31 December 1974; tags released and recaptured from 1 January through 31 May 1975; and tags released and recaptured during June 1975. Recapture data that overlapped these periods were excluded. Trends observed during these periods were compared to trends observed during identical time periods of the 1973-74 mark/recapture program.

Because the marking of Atlantic tomcod was not initiated until the spawning season (December-February), a temporal pattern was examined by dividing recapture data into intervals roughly corresponding to prespawning (December) and spawning-postspawning (January-June). In the first interval, December 1974 tag releases were followed through their December 1974 and January 1975 recapture. In the second interval, tomcod recaptures during January-June 1975 were observed for individuals tagged during January and February 1975, along with the delayed recapture of tomcod tagged in December 1974.

Recaptures of fin-clipped fish did not provide specific data on movement of individuals as did the tag recaptures; however, movements between marking areas could be observed. Movements of fin-clipped juvenile white perch and striped bass through June 1975 were analyzed for fish marked from August-November (fall) 1974 and April-June (spring) 1975. Movement trends observed were compared with similar data from the 1973-74 mark/recapture program. Recaptures of fin-clipped tomcod were analyzed in a similar manner for the December 1974-February 1975 program. Comparable data for fin-clipped tomcod were not available from the 1973-74 program (TI, 1975a).

3. Results and Discussion

a. Fin-Clipped Striped Bass

Striped bass juveniles marked and recaptured during the fall (August-November) moved across boundaries of the first three marking areas (Figure V-11) including the Yonkers-Indian Point geographical regions [RM 12-46 (KM 19-74)], upstream and downstream. Fish marked in the Indian Point region [RM 39-46 (KM 62-74)] moved downriver to the Tappan Zee region [RM 24-33 (KM 38-53)]. Fish from the Yonkers region [RM 12-23 (KM 19-37)] moved upriver as far as the Croton-Haverstraw and Indian Point regions. No recaptured juvenile striped bass marked in area 4 [RM 47-61 (KM 75-98)] moved outside this area, nor did fall recaptures yield any juveniles marked in area 5 [RM 62-152 (KM 99-243)].

Interregional mixing was more complete by the following winter and spring (January-June). Fish marked in the Yonkers region were recaptured as far upriver as the Indian Point region and vice versa. A fin-clipped striped bass marked in uppermost Area 5 [above RM 62 (KM 99)] was recaptured in the Tappan Zee region [RM 24-33 (KM 38-53)]. No fish marked in the fall were caught above RM 47 (KM 75) during winter and spring.

The few striped bass fin-clipped and recaptured as yearlings during April-June (spring) 1975 showed little movement (Figure V-12). However, most were marked near the end of this time interval, allowing little time for extensive movement. One fish marked in Area 5 was recaptured in the Tappan Zee region.

Compared with the fall 1973 program (TI, 1975a), a greater proportion of the marked striped bass were released below the West Point region during fall 1974. Trends in recaptures were similar for the two programs. There were no recaptures above the West Point region, primarily because of the greater concentration of juvenile striped bass below rather than above this region during both years.

Young-of-the year striped bass apparently use most of the mid-Hudson River as a fall nursery, with the area between RM 12 (KM 19) and RM

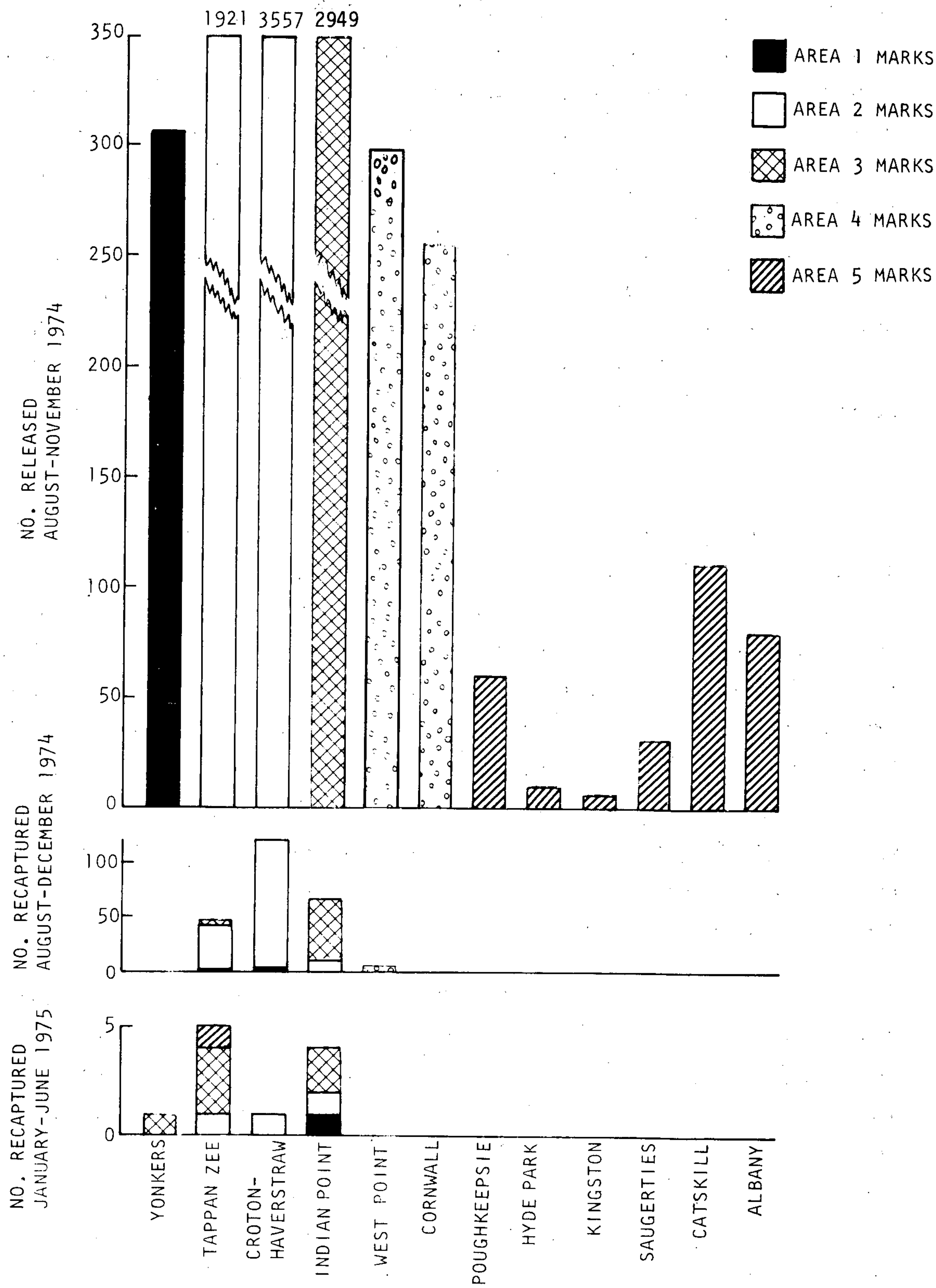


Figure V-11. Movement of Striped Bass Young-of-the-Year Marked during August-November 1974

46 (KM 74) well within the range of movement for individual fish. Because movements were observed to be bidirectional, the hypothesis of continuous downriver displacement of the entire population during fall and early winter seems inaccurate. There is evidence that many young striped bass leave the Hudson River during their first year (Volume III, Lower Estuary Study) but that some of the population remains in the river to overwinter; in fact, by the following spring, many have traversed the distance from the Yonkers region [RM 12-23 (KM 19-37)] upriver to the Indian Point region [RM 39-46 (KM 62-74)]. The result of this bidirectional movement would be a longer period of exposure to impingement — particularly at Bowline, Lovett, and Indian Point — for that portion of the population remaining in the river.

b. Fin-Clipped White Perch

Marked juvenile white perch moved considerable distances in both directions during the fall (August-December) 1974 (Figure V-13). An individi- fin-clipped in marking area 5 above the Newburgh-Beacon Bridge [RM 61 (KM 98)] was recaptured in the Indian Point region [RM 39-46 (KM 62-74)]. Individuals from the Indian Point region were found within the Tappan Zee [RM 24-33 (KM 38-53)] and Croton-Haverstraw [RM 34-38 (KM 55-61)] regions. In turn, some fish from these latter two regions had traveled upriver to the Indian Point region. By the following winter and spring (January-June 1975), the dispersal of fish marked in the fall had extended farther upriver and downriver, suggesting an intermixing of the population within at least the lower half of the estuary.

White perch of the 1974 year class marked as yearlings during April-June (spring) 1975 moved into the Indian Point region from above and below (Figure V-14). During this 3-month interval, two fish were able to move at least 16 mi from Yonkers to Indian Point. These data corroborate data from the 1973-74 program (TI, 1975a) by indicating that movement of white perch during their first year is bidirectional and can be quite extensive. Thus, a portion of the population would be exposed to impingement as it moved into the nearfield vicinity of the power plants.

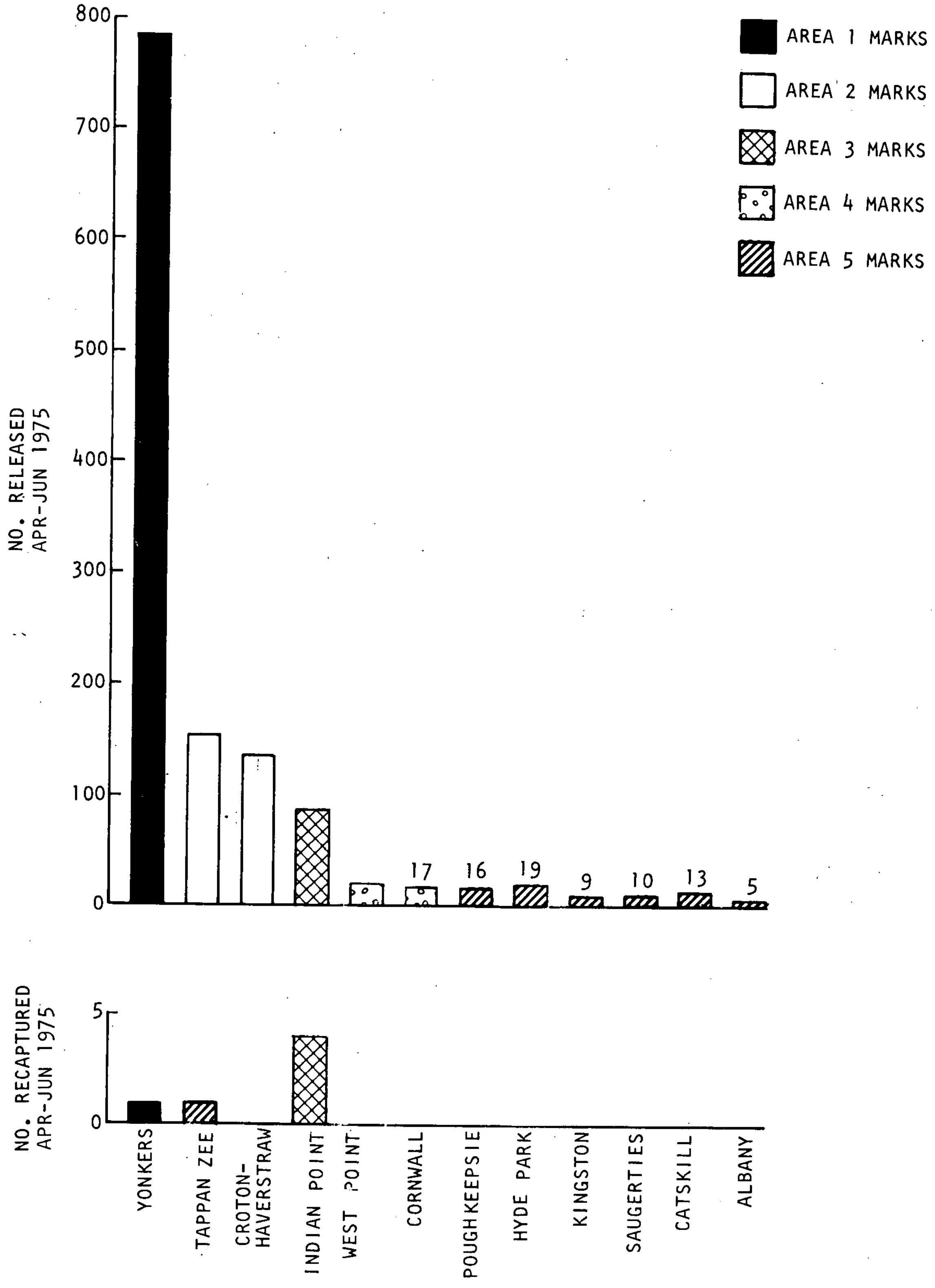


Figure V-12. Movement of Striped Bass Yearlings Marked during April-June 1975

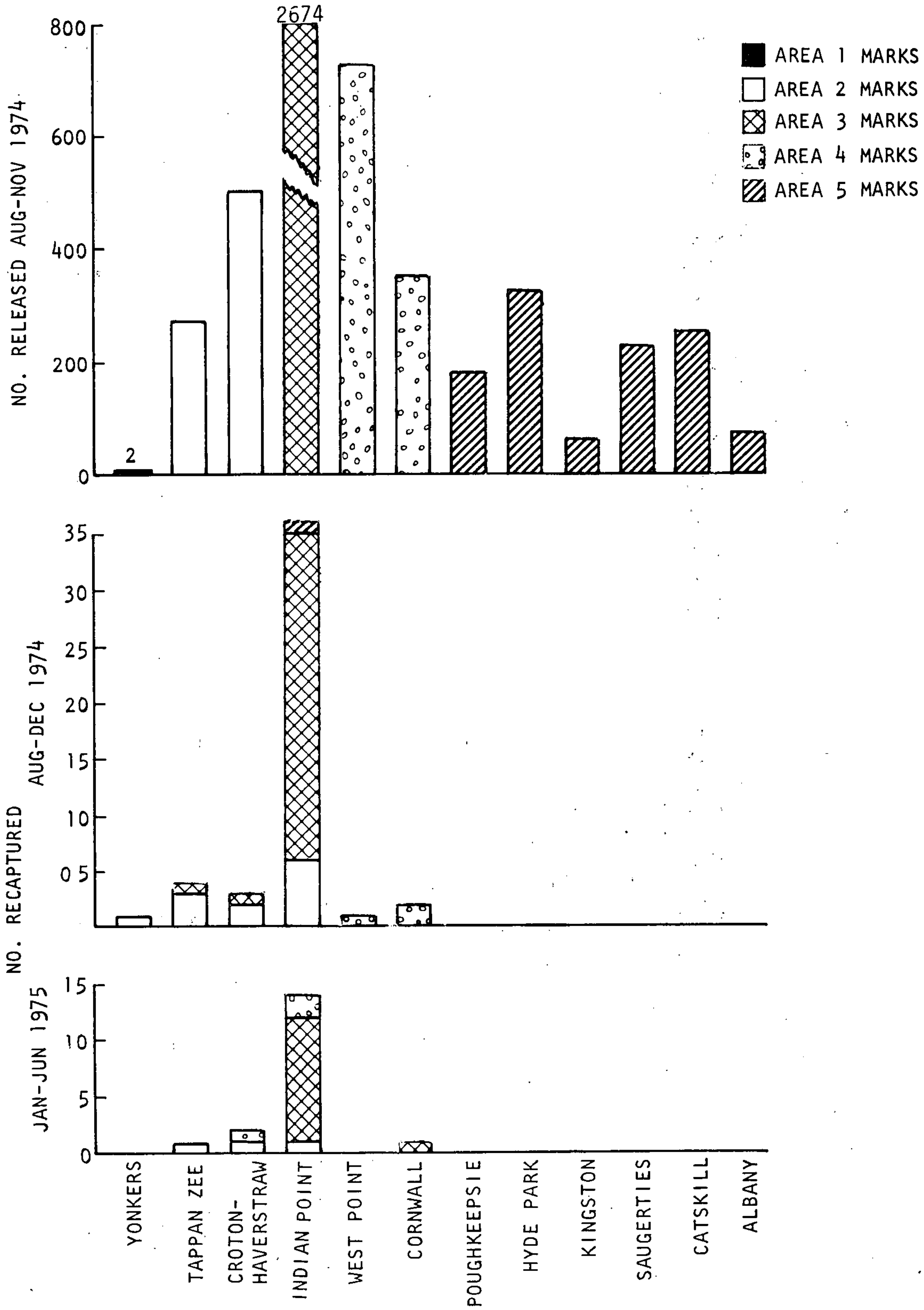


Figure V-13. Movement of White Perch Young-of-the-Year Marked during August-November 1974

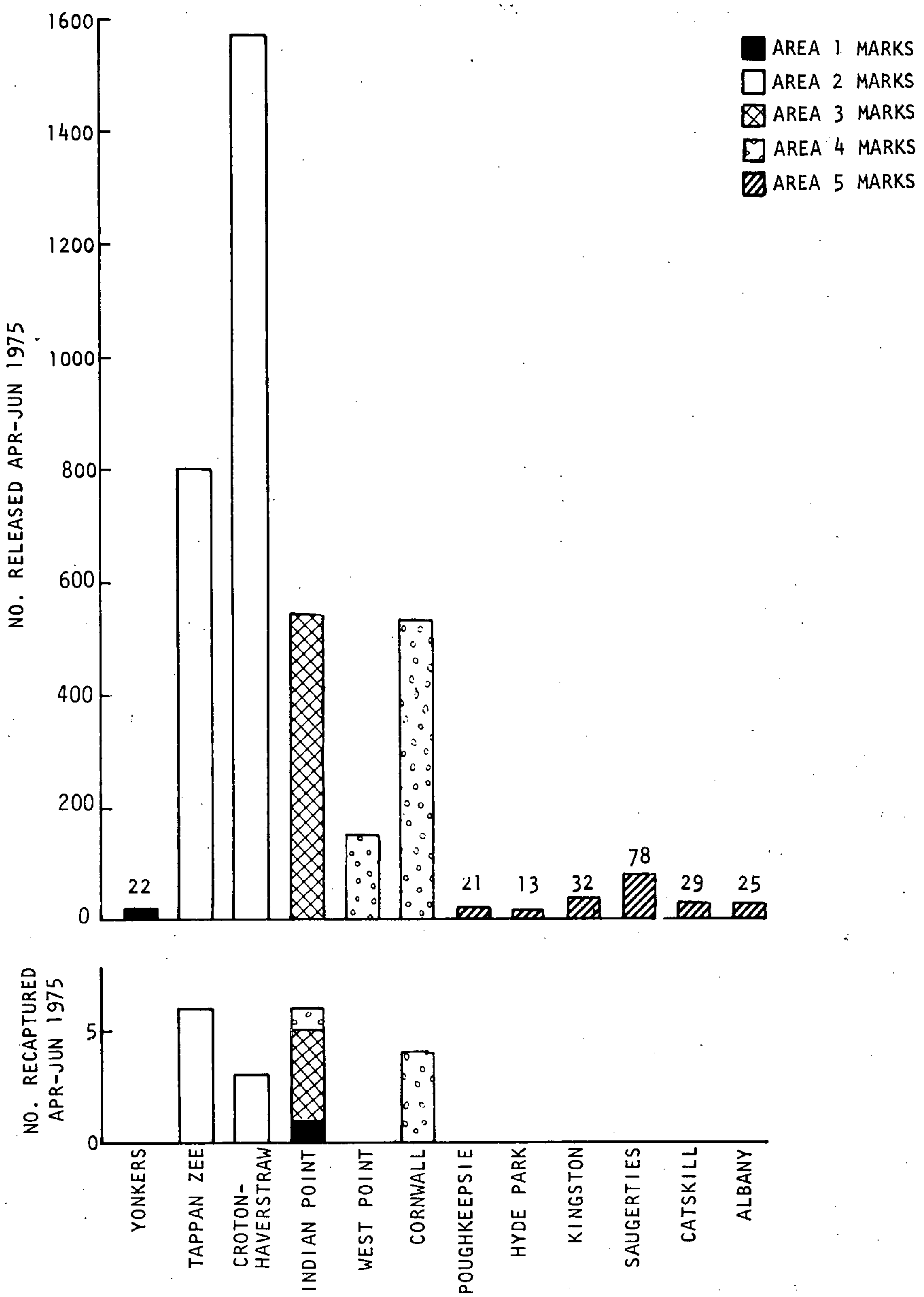


Figure V-14. Movement of White Perch Yearlings Marked during April-June 1975

Much of the discussion concerning juvenile striped bass is applicable also to juvenile white perch. Movements are bidirectional and extensive, allowing a large period of exposure to impingement at power plants. However, unlike striped bass which are temporary residents of the river, young white perch as permanent residents are subject to impingement for a much larger portion of their life span. Higher levels of white perch impingement observed at Indian Point during the winter may have been the result of the movements into this region.

c. Tagged White Perch

Unlike the 1973-74 data (TI, 1975a), there was no clear separation of active and sedentary periods for tagged white perch during 1974-75. Long-range movements [here defined as >5 mi (8 km)] were observed during all three time intervals studied: 16 September-December 1974; January-May 1975; and June 1975. However, an examination of the movements during each of these intervals revealed a pattern in the direction of long-range movements with respect to the recapture sites.

Of all recaptures of tagged white perch (Appendix Table A-101), nine were fish traveling >5 mi during September-December (Figure V-15); of these nine recaptures, six were recaptured within the Indian Point region (Table V-35). These recaptures may indicate movement to the deep water off Indian Point for overwintering, as postulated in previous reports on the Hudson River (TI, 1974, 1975a) and on other localities (Bigelow and Schroeder, 1953; Mansueti, 1961).

Unlike the results of the 1973-74 program (TI, 1975a) when movements were primarily upriver, white perch tagged and recaptured during January-May 1975 had moved great distances in both directions (Figure V-16). Fish tagged in marking areas 2 through 5 had moved >5 mi, and their sites of recapture (Table V-35) ranged between RM 34 (KM 54) and RM 69 (KM 110). The greatest distance traveled was 48 mi (77 km) in 8 days [RM 90-42 (KM 144-167)]. One tagged white perch was recaptured in Moodna Creek, RM 57 (KM 91), after being released at RM 40 (KM 64).

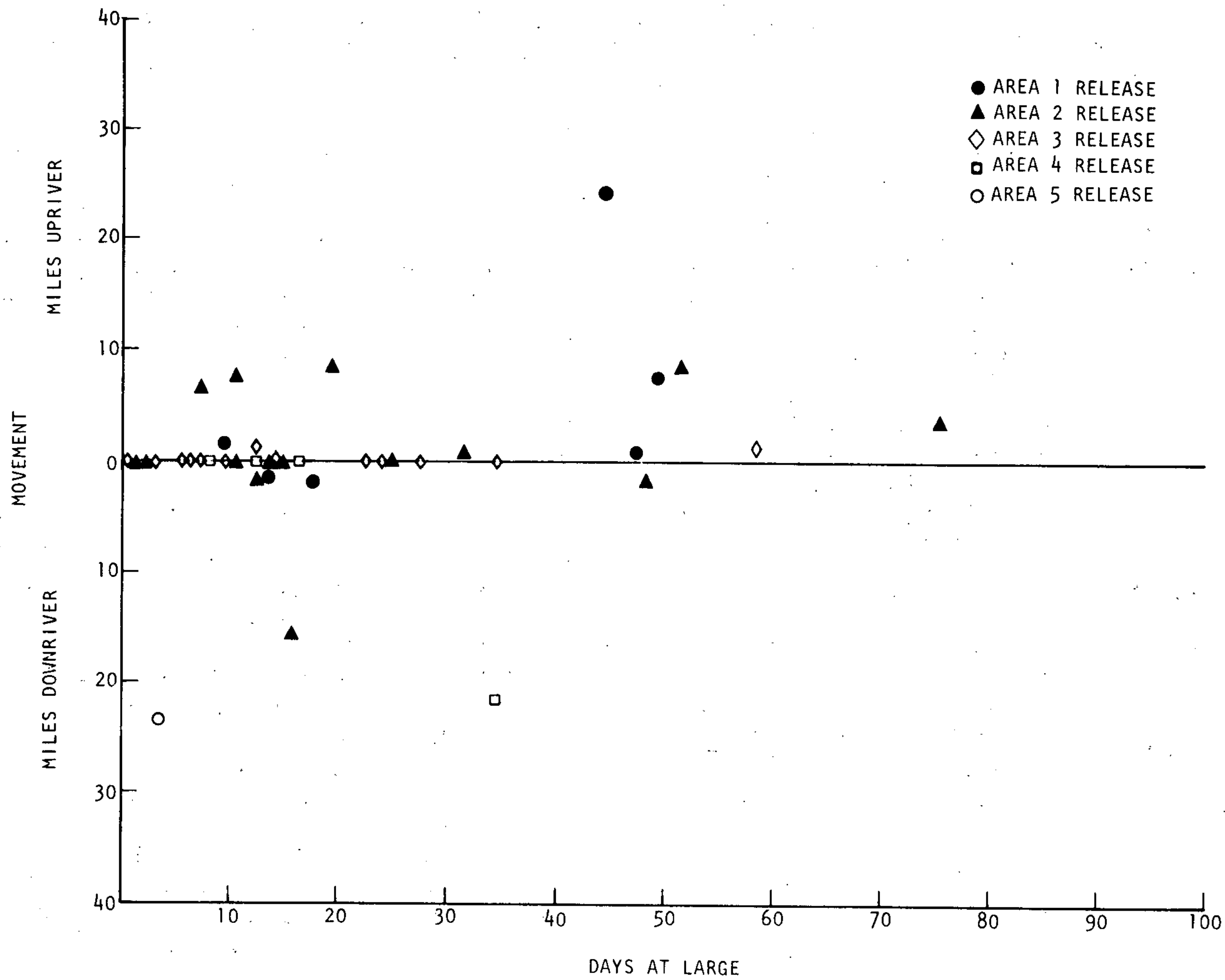


Figure V-15. Movement of Tagged White Perch during 16 September-31 December 1974

White perch showed a considerable amount of movement during June 1975 (Figure V-17), but these results are not directly comparable to the fish in the corresponding time interval of the 1974 program, which also included data from July through mid-September (TI, 1975a). June tag recaptures probably included fish influenced by late spring spawning or foraging behavior and thus do not typify the sedentary nature of the population during summer, as was earlier postulated (TI, 1975a). Most of the fish undertaking long-range movements during June 1975 were tagged in marking area 4 [RM 47-61 (KM 75-98)] and were recaptured near RM 42 (KM 67) in the vicinity of Indian Point (Table V-35).

Table V-35

Movements Greater than 5 Mi by White Perch Tagged and Recovered within Three Time Intervals during 1974-75 Mark/Recapture Program

Time Interval	Tag No.	Release Date	Release River Mile	Recovery Date	Recovery River Mile	Recovery Gear
16 Sep – Dec 1974	9-9624	Oct 3	34-East	Oct 14	42-East	Indian Point intake screens
	5-11413	18	66-West	22	42-East	Indian Point intake screens
	29-21463	3	34-East	23	43-West	Bottom trawl
	5-10964	9	59-East	Nov 13	37-West	LMS river sampling – bottom trawl
	5-12253	Nov 8	36-West	24	20-West	Epibenthic sled
	5-12496	8	35-West	16	42-East	Indian Point intake screens
	29-22423	Oct 1	23-Channel	20	31-West	Epibenthic sled
	5-12353	Nov 8	33-East	Dec 30	42-East	Indian Point intake screens
	29-27031	14	17-West	27	42-East	Indian Point intake screens
Jan – May 1975	5-20186	May 19	54-East	May 21	34-East	Stone and Webster beach seine
	5-22369	13	58-West	23	48-East	100-ft beach seine
	5-18655	21	90-West	29	42-East	Indian Point intake screens
	5-18562	5	58-West	29	34-East	500-ft haul seine
	9-28749	Apr 23	29-West	14	47-West	100-ft beach seine
	9-33725	May 8	65-West	15	58-East	200-ft beach seine
	9-30438	Apr 25	40-East	15	57-Moodna Creek	Sport fisherman
	9-28437	17	40-West	15	58-East	200-ft beach seine
	9-30602	28	34-East	29	69-East	100-ft beach seine
	5-17204	30	57-West	29	66-West	LMS river sampling – bottom trawl
Jun 1975	5-21312	Jun 5	58-West	Jun 9	42-East	Indian Point intake screens
	5-21901	5	34-East	13	42-East	Indian Point intake screens
	5-21881	9	49-West	13	42-East	Indian Point intake screens
	5-21893	9	49-West	15	42-East	Indian Point intake screens
	5-23242	4	32-West	18	42-East	Indian Point intake screens
	9-38911	6	57-West	12	41-West	Lovett intake screens
	9-39256	12	57-West	15	42-East	Indian Point intake screens
	9-36978	5	57-West	25	25-West	Sport fisherman
	9-42375	20	57-West	25	38-West	Found dead
	9-39662	9	57-West	26	27-West	100-ft beach seine
	9-42797	19	57-West	23	42-East	Sport fisherman
	9-39934	10	57-West	15	42-East	Indian Point intake screens

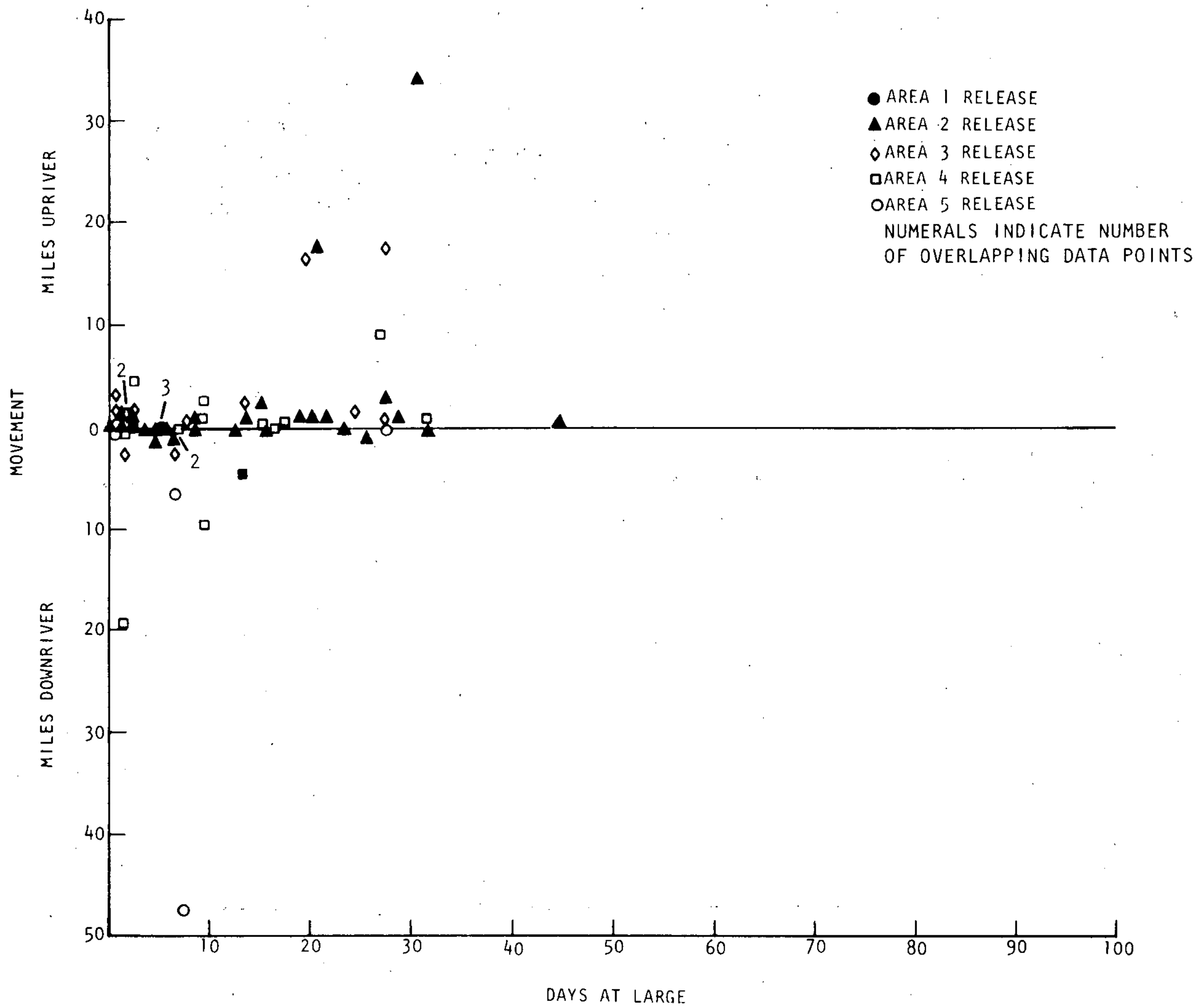


Figure V-16. Movement of Tagged White Perch during January-May 1975

Appendix Figures A-75 through A-88 are illustrations of the recapture sites of tagged fish that left their marking areas during September 1974-June 1975. Appendix Table A-101 also presents complete data on tag recaptures of white perch during this period.

Tag recaptures of subadult and adult white perch indicated that their movements may have been even more extensive than those of the young-of-the-year. Previously postulated seasonal patterns of movement in the Hudson River included an upriver spring migration associated with spawning

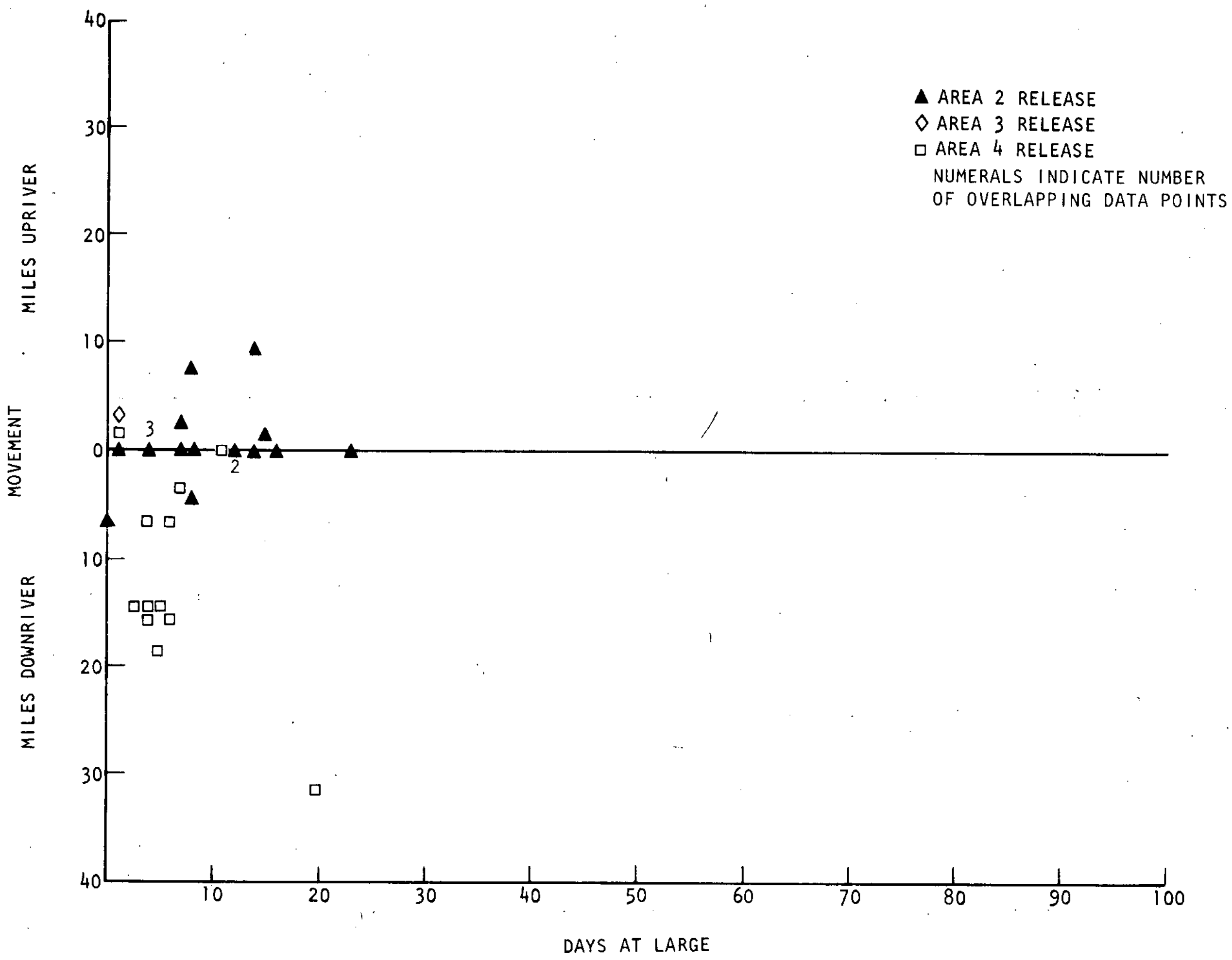


Figure V-17. Movement of Tagged White Perch during June 1975

in tributaries (TI, 1975a) and foraging on the spawn of other species, particularly alewives (TI, 1973a). An upriver movement was not clearly evident from recaptures during spring 1975. However, all recaptures of fish traveling >5 mi (8 KM) occurred between RM 34 (KM 54) and RM 69 (KM 110), an area fed by many small tributary streams; one recapture was within a tributary, Moodna Creek [RM 57 (KM 91)].

Downriver movement by adult and subadult white perch during fall was assumed to be associated with overwintering (TI, 1975a). Fall 1974 data showed both upriver and downriver movements, but most recaptures occurred near Indian Point, a region generally considered to be overwintering grounds and heavily sampled. These movements serve to mix the populations from several regions and expose many moving fish to more than one power plant.

d. Tagged Atlantic Tomcod

Adult Atlantic tomcod tagged during December 1974 showed no consistent directional pattern of movement through January 1975 (Figure V-18). Four tomcod were recaptured as far as 15 mi (24 km) upriver from their sites of release, and another five were recaptured 14 mi (22 km) downriver from their release sites. An additional tomcod had moved 19 mi (30 km) downriver to Bowline from its release site at Cornwall [RM 56 (KM 89)]. However, tomcod tagged in January and February almost always moved downriver after their release (Figure V-19). By April 1975, after at least 90 days at large, tagged tomcod were recaptured in the lower reaches of the Hudson River 33-54 mi (53-86 km) downriver from the sites of release. Two were recaptured outside the river proper — one in upper New York Bay at Brooklyn and one at Huckleberry Island in Long Island Sound (Figure V-20). Appendix Table A-102 presents complete data on tag recaptures of tomcod.

e. Fin-Clipped Atlantic Tomcod

Although fin-clip recaptures could not reveal movements as precisely as did tag recaptures (actual release sites of fin-clipped fish cannot be pinpointed), fin-clipped tomcod that crossed boundaries of marking areas did so in a pattern similar to that of tagged tomcod. Most recaptures outside the areas of release (Figure V-21) were tomcod that had moved downriver; of those that moved upriver (19 from area 3 to area 4), most were December releases; January releases generally moved downriver. Longer-range movements of fin-clipped tomcod could not be observed because sampling for fin clips had occurred only within a limited area (Section III, mark/recapture program).

Atlantic tomcod, considered to be an inshore marine species (Bigelow and Schroeder, 1953), utilized a region of the Hudson River just

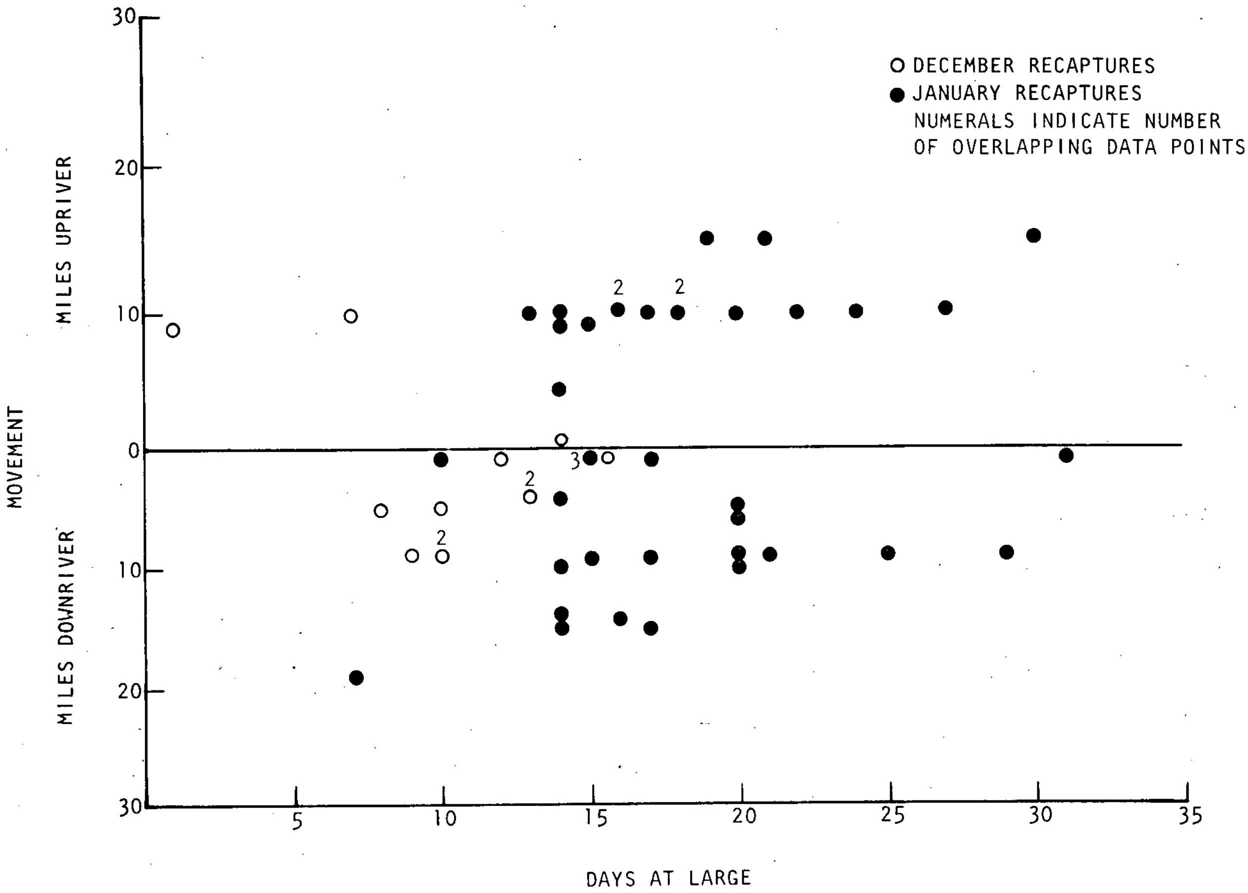


Figure V-18. Movement of Adult Atlantic Tomcod Tagged during December 1974 (Excluding Tomcod Not Moving)

above the salt front for their winter spawning. Tomcod were readily collected in box traps in the shoals and shore zone of the Hudson where spawning occurred. In December 1974, marked tomcod were observed moving both upriver and downriver.

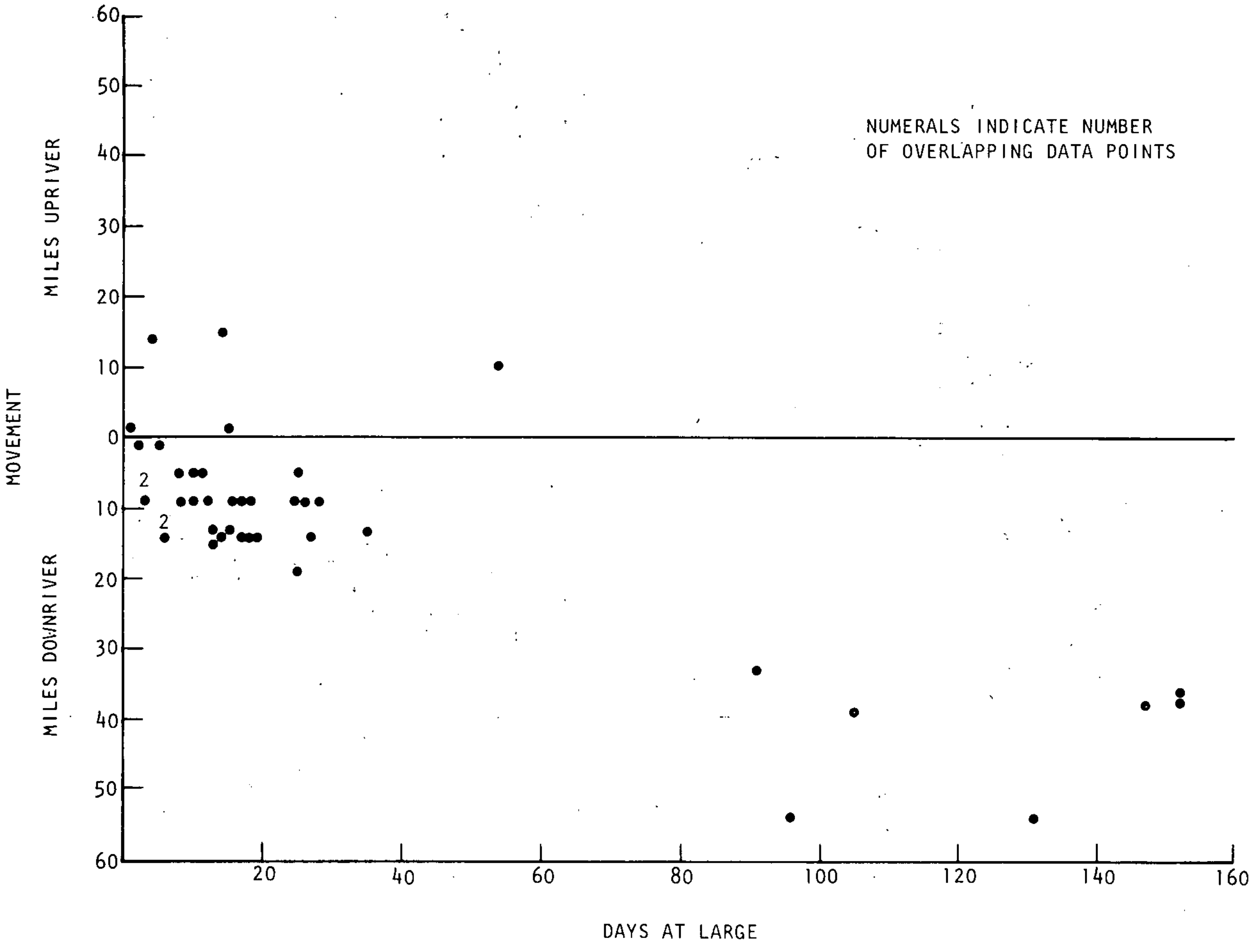


Figure V-19. Movement of Adult Atlantic Tomcod Tagged during January-February 1975 Including Post-January Recaptures of Tomcod Tagged in December 1974 (Excluding Tomcod Not Moving)

The suitability of the habitat may be related to the salinity. During 8 December 1974-18 January 1975, tomcod maintained a position just above the salt front (defined as 0.1 $^{o}/oo$ salinity) as demonstrated by a comparison of catch per hour in box traps and mean salinity (Figure V-22). An intrusion of the salt front during 22 December-11 January appeared to shift the peak distribution of tomcod upriver, and this shift may have been responsible for the observed upriver movement of some tomcod tagged in December

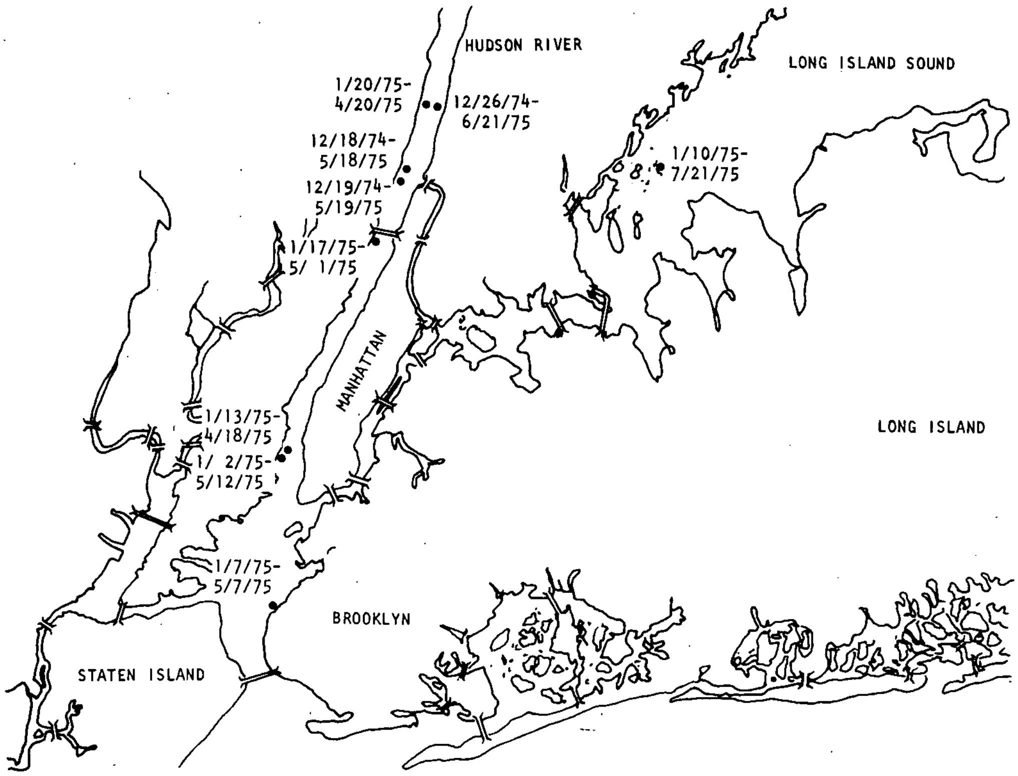


Figure V-20. Recapture Sites of Tagged Atlantic Tomcod in Lower Hudson River Estuary, 1975, with Release and Recapture Dates

(Figure V-18). Most of the tomcod sought a salinity of <0.1 ^{o}/oo. The same behavior by tomcod was observed during winter 1973-74 (Appendix B) when peak distribution occurred in the Indian Point region. In December 1973 (TI, 1974) and January 1974 (TI, 1975d), the salt front remained below the Indian Point region. This observed selection of areas in which salinity was near or below 0.1 ^{o}/oo may be related to a behavioral adaptation for successful fertilization of the eggs. Booth (1967) reported the sperm of tomcod in the Connecticut River to be more motile at low salinities, with maximum motility occurring between 1-2 ^{o}/oo and 13-14 ^{o}/oo. However, the preferred salinity observed in the Hudson River (<0.1 ^{o}/oo) was considerably below Booth's minimum values of 1-2 ^{o}/oo.

After spawning, adult tomcod moved generally downriver, reaching the mouth of the river and possibly the bays of Long Island and the New

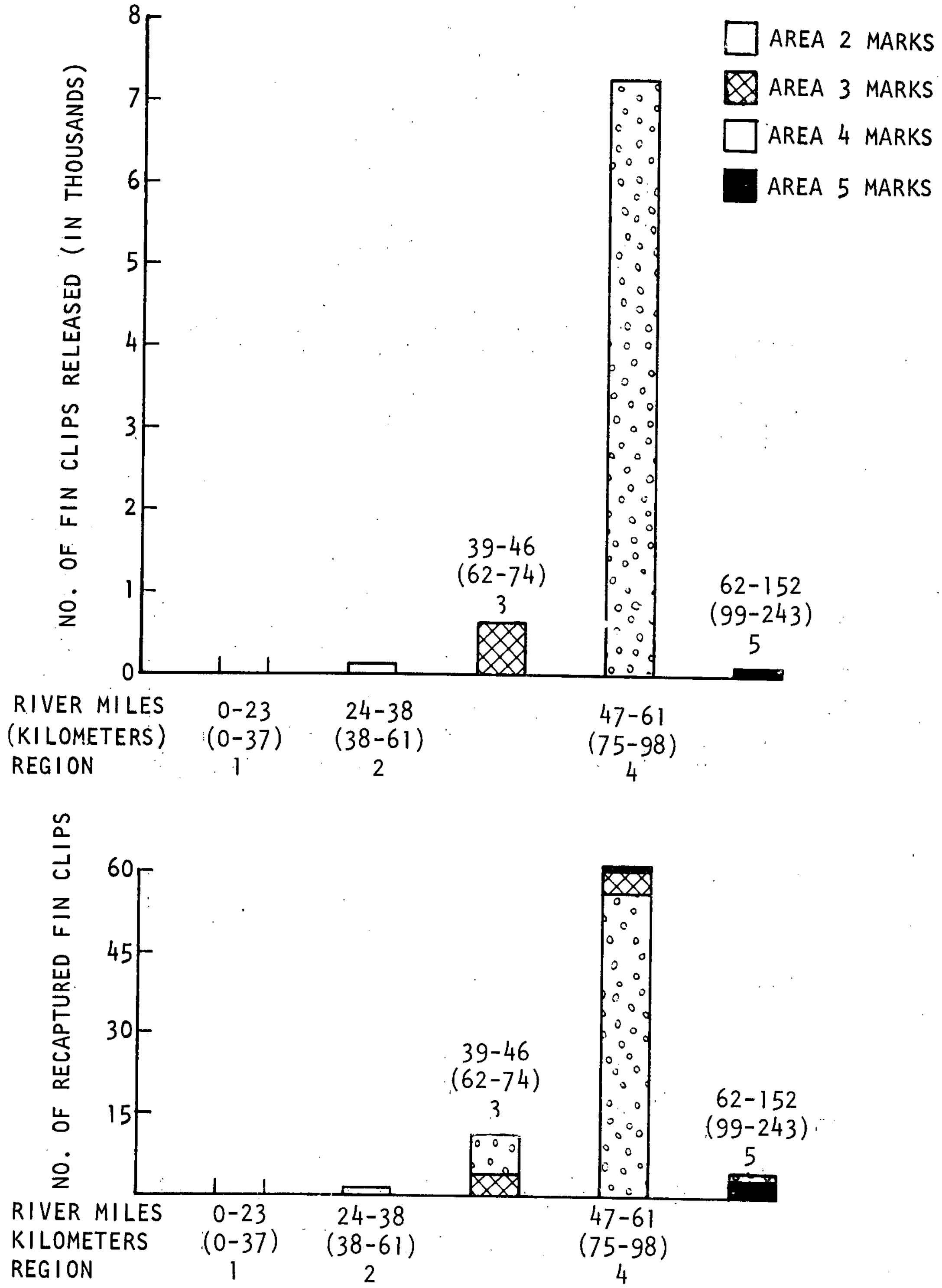


Figure V-21. Movement of Adult Atlantic Tomcod Fin-Clipped during December 1974-February 1975

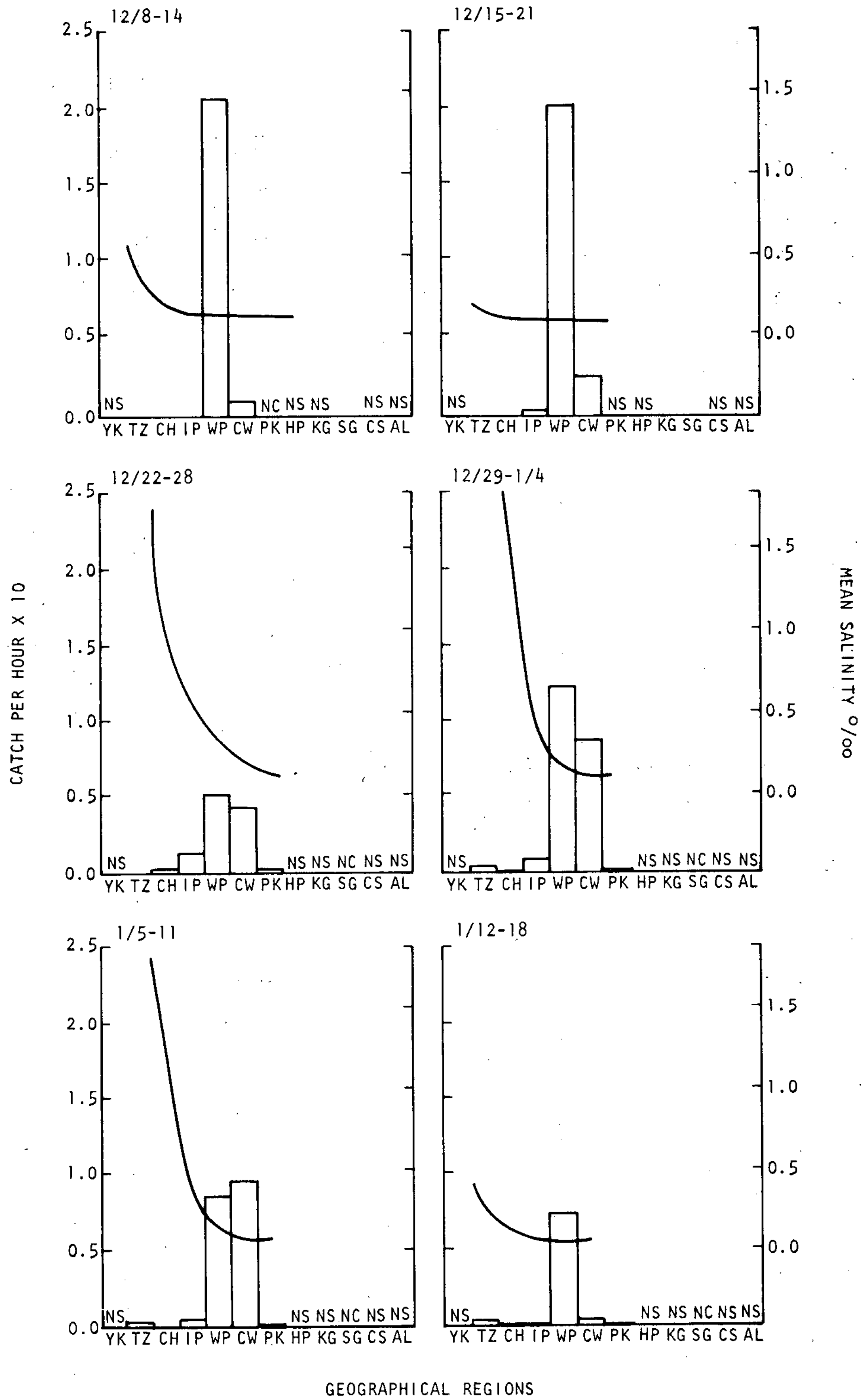


Figure V-22. Mean Salinity (Line) and Atlantic Tomcod Catch per Hour (Bars) within Nine Geographical Regions of Hudson River Estuary [RM 24-106 (KM 38-170)] Based on Day and Night Sampling with Box Traps during Winter 1974-75

York Bight by early or mid-summer. This movement removed most of the tomcod from the area of the power plants. However, some adult tomcod were still caught within the lower regions of the Hudson River during the summer (TI, 1975a).

4. Summary

The general patterns or trends in the movements of marked striped bass, white perch, and Atlantic tomcod in the Hudson River during 1973-74 and 1974-75 are summarized in the following paragraphs.

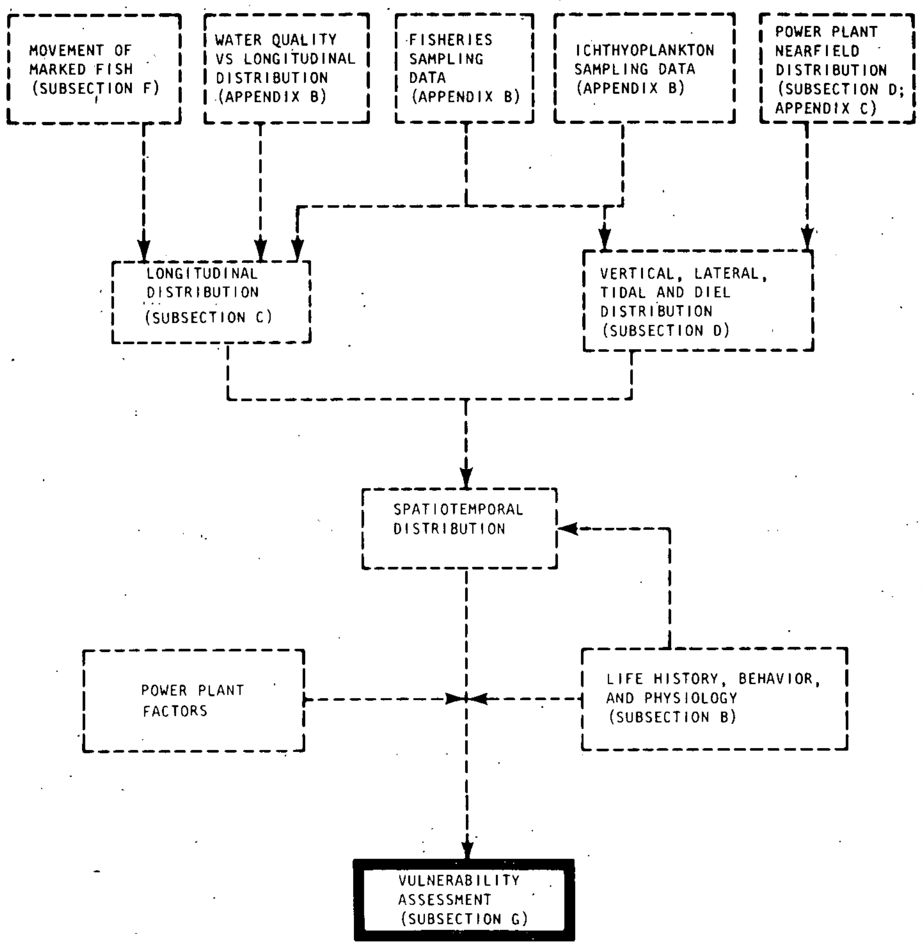
Juvenile striped bass, juvenile and older white perch, and adult Atlantic tomcod made extensive, bidirectional movements which were interpretable and predictable.

An unknown portion of the juvenile striped bass population overwintered in the lower river regions. White perch overwintered extensively in the deep areas of the river off Indian Point.

Adult tomcod exhibited considerable bidirectional movements early in the spawning period (December), presumably in search of suitable spawning conditions, but moved downstream after spawning in January and February and generally had left the river by June.

G. ASSESSMENT OF VULNERABILITY TO POWER PLANTS

This subsection addresses the relative vulnerability of striped bass, white perch, Atlantic tomcod, and American shad to mortality induced by power plants on the Hudson River estuary and how these four key fish species compare with regard to their individual degree of vulnerability to entrainment and impingement at all of the five power plants. This assessment of vulnerability integrates data and analyses presented in subsections A through F of Section V and an earlier report (TI, 1975a). The following diagram shows the position of this subsection in the overall organization of Section V.



The degree of vulnerability of the 1974 year classes of striped bass, white perch, American shad, and Atlantic tomcod to all five power plants (Bowline, Lovett, Indian Point, Roseton, and Danskammer) differed among the life stages within a species and among species.

All four species are vulnerable, but in differing degrees, to the power plants. Striped bass appear to be most vulnerable to entrainment, especially the yolk-sac larvae at the two plants located farthest upstream — Roseton and Danskammer. A large proportion of the population of white perch eggs was exposed to power plants during 1974, particularly Bowline, Lovett, and Indian Point, but their general adhesive and demersal characteristics should greatly reduce their vulnerability. Since no Atlantic tomcod eggs or larvae were collected in 1974, their exposure to the five power plants was impossible to assess. American shad vulnerability is probably the lowest of the four species since almost all of the eggs and larvae are concentrated upstream from the five power plants.

The four species are more similar in their vulnerability to impingement than in their vulnerability to entrainment. On the basis of exposure time, white perch are most vulnerable to impingement; this is a resident species and continues to be exposed to the plants for a much larger portion of its life span than are the other species which are primarily anadromous and migrate from the estuary as juveniles in their first year of life. White perch also overwinter in the deep areas near Indian Point and Lovett and are heavily impinged during the winter months. Striped bass are exposed to impingement, especially at the downstream plants (Bowline, Lovett, and Indian Point) during the late summer and fall before they emigrate from the estuary. The exposure of American shad to impingement is very similar to that of white perch during the first calendar year of life, but since American shad leave the estuary in late fall, their period of highest vulnerability occurs briefly as they pass the plants on their seaward migration. Atlantic tomcod are exposed to impingement during their first summer, but only at the downstream plants. Their exposure increases during the winter spawning period, but the proportion of the 1974 year class that returned to spawn during the winter of 1974-75 was unknown.

Overall, the degree of exposure to entrainment and impingement is probably highest for white perch, followed by striped bass, Atlantic tomcod, and American shad.

The period of entrainment vulnerability for the four species at the five power plants is relatively restricted to spring and early summer, primarily May and June. Vulnerability to impingement occurs throughout the year, but peak periods occur in late summer and winter.

SECTION VI
COMPENSATION

A. INTRODUCTION

Any ability of Hudson River fish populations to compensate for mortality (including that from entrainment and impingement) determines the long-term impact of power plants on these populations. Compensatory processes are density-dependent survival and growth processes which are inherent in fish populations and counteract the effects of density-independent sources of mortality such as entrainment and impingement. Density dependence refers to declining rates of survival, growth, or reproduction with increasing density and often caused by increased competition, predation, or cannibalism at higher densities. Density-independent sources of mortality are those which do not change in rates in response to changing density. The long-term results of density-dependent population regulation in fish populations are often expressed as asymptotic or dome-shaped relationships between parental spawning stocks and the recruitment to the fishery provided by their progeny, i.e., stock recruitment curves (Figure VI-1).

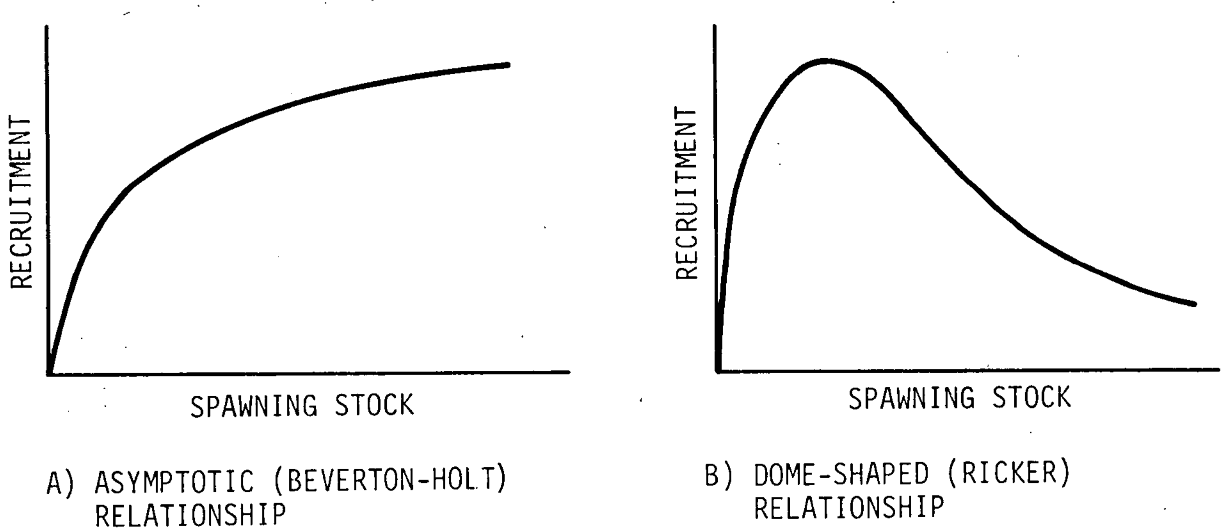


Figure VI-1. Two Types of Stock Recruitment Relationships. (For discussions of the two forms, see Ricker, 1973)

A previous report (TI, 1975a) examined potential stock recruitment relationships based on commercial fishery catch and effort data for white perch with 3-, 4-, and 5-year lags; for American shad with 4-, 5-, and 6-year lags; and for striped bass with a 5-year lag. A stock recruitment relationship of the Ricker type was inferred for the striped bass population of the Hudson River (1931-72), suggesting a strong compensatory capability. The potential relationship between density and growth rates for juvenile (young-of-the-year) striped bass and juvenile white perch was also examined. The growth rate of juvenile striped bass was shown to be density-dependent; growth was faster during years of low juvenile abundance. The most likely mechanisms of this observed density-dependent relationship are intraspecific competition, or cannibalism. Sommani (1972) also found evidence of density-dependent population regulation in a striped bass population in California. There was no evidence of compensation by white perch and American shad, but evidence of compensation by white perch has been found by other investigators (Mansueti, 1961, in the Patuxent estuary and Wallace, 1971, in the Delaware River).

Additional data relative to compensation in Hudson River striped bass and American shad populations are examined in this section. The objectives are to:

- Examine the previously developed stock recruitment (parent-progeny) relationship in the Hudson River striped bass population, based on commercial fishery data collected through 1974
- Examine the relationship of adult abundance and juvenile striped bass and American shad abundance during July-August 1965-74

B. COMMERCIAL FISHERY STOCK RECRUITMENT RELATIONSHIP

1. Objective

A previous report (TI, 1975a) noted a relationship between yield per unit effort at time t and yield per effort 5 years later in the striped bass commercial fishery data. Because the relationship was of the dome-shaped type described by Ricker (1954, 1958, 1973, 1975), a stock recruitment relationship of the Ricker type was inferred for the population of striped bass in the Hudson.

Since publication of the previous report, 2 additional years of commercial fishery data (1973 and 1974) have been provided to Texas Instruments by Fred Blossum, National Marine Fisheries Service, NOAA, Patchogue, Long Island, New York, and 5 years of commercial data previously missing (TI, 1975a) have been obtained from the New York State Department of Environmental Conservation (DEC), permitting nine other data points to be plotted on the stock recruitment curve for a total of 11 new points (Table VI-1). This section examines these additional data in light of the previously postulated Ricker stock recruitment curve.

Table VI-1

Letter Codes for 11 New Data Points Added to Ricker Type Stock Recruitment Curve for Hudson River Striped Bass (Figure VI-2)

Data Point Letter Code	Stock Recruitment Years
A	1942-47
B	1947-52
C	1949-54
D	1950-55
E	1951-56
F	1954-59
G	1955-60
H	1956-61
I	1959-64
J	1968-73
K	1969-74

2. Methods

The 11 additional data points (see Section IV) were plotted on the Ricker curve developed in a previous report (TI, 1975a).

3. Results and Discussion

With the addition of the 11 data points to the previously developed stock recruitment curve, a dome-shaped relationship, i.e., a Ricker curve, still seemed appropriate (Figure VI-2). Of the two recent data points (1973 and 1974), one (1974) fell directly on the curve, but the 1973 (J) point was quite high. The 1973 yield-per-effort (Y/f) index of abundance may have been artificially high because of a possible underestimation of fishing effort for spring 1973. This change in effort could have been precipitated by the rapidly rising meat prices and the consequent increase in the demand for fish as an alternate source of protein (see Section IV.B). Another potential explanation for the high Y/f value in 1973 was the increased escapement which may have occurred during June 1972 because of poor fishing conditions resulting from Hurricane Agnes. Those fish which escaped capture in 1972 probably returned in 1973 as much larger fish and may have increased the 1973 landings.

The nine new points derived from the DEC data are distributed over the entire curve (Figure VI-2). Points C and D (1949-54 and 1950-55 respectively) do not follow the curve closely; however, DEC personnel and survey methods changed during the late 1940s-early 1950s, and the commercial catch data may have reflected these changes. The rest of the points fit the curve fairly well. Data point E (1951-56) gives another value on the left-hand ascending limb of the curve.

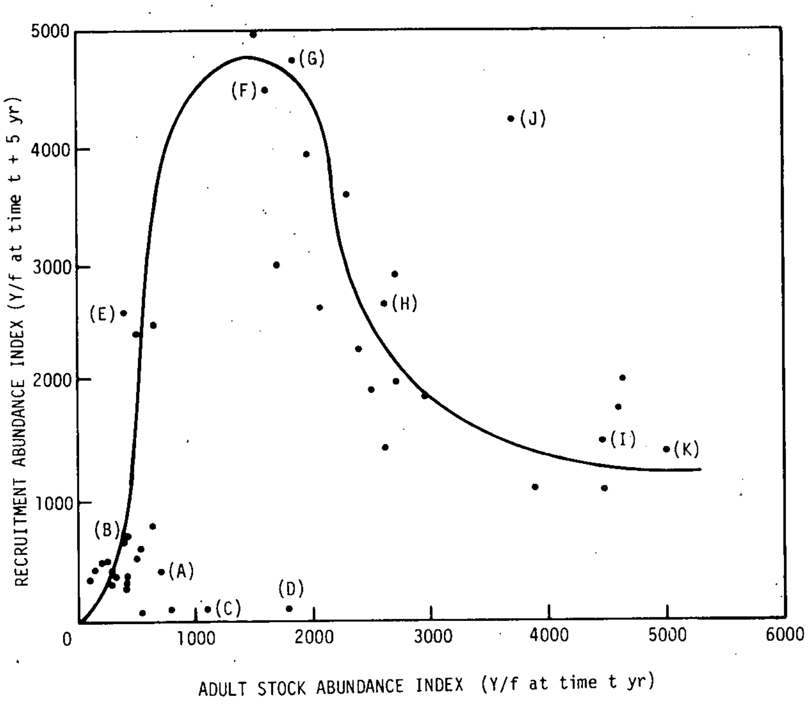


Figure VI-2. Relationship between Abundance of Adults (Stock) at t Year and Recruitment t + 5 Years Later Based on Commercial Fishery Catch and Effort Data, 1931-74. (Letters in parentheses refer to new data points added in this report and listed in Table VI-1)

C. JUVENILE ABUNDANCE RELATIVE TO ADULT (STOCK) ABUNDANCE

1. Objective

Another perspective of the relationship between stock and recruitment is obtained by comparing adult abundance over a number of years with the abundance of juvenile (young-of-the-year) fish produced by those spawning stocks. The basic assumptions underlying such a comparison are that year-class strength is established by the time juvenile abundance is measured and that the index of adult abundance is a good index of egg deposition. If density-dependent mortality occurs subsequent to the measurement of juvenile abundance, then effective year-class strength (in terms of eventual contribution to the fishery or to future generations) has not been established. Additionally, many years of data over a wide range of spawning stock abundance should be available for valid conclusions. Only 9 years of comparable data were available for American shad and striped bass. Therefore, any conclusions are tentative. Because similar data on white perch adult abundance were considered unreliable (TI, 1975a), a parent-progeny relationship for this species was not investigated.

2. Methods

Commercial yield-per-unit-effort data for striped bass and American shad adults for 1965 through 1974 (including 1971) were compared with the catch-per-unit-area index of juvenile abundance in July and August of the same year.

Some of the earlier surveys were concentrated in the Indian Point region. The 1969 and 1970 Raytheon studies and the 1972 TI study were the most restricted (see Section IV-C). The broadest data base available was a riverwide index, including all sampling stations; it should reflect the abundance of the entire river population, whereas those years with sampling restricted to the Indian Point area may result in biased estimates. A ratio of abundance in the total river to abundance at Indian Point standard stations in July and August was derived for juvenile striped bass and American shad from each year, 1973-1975, to compensate for this bias. The C/f values for striped bass during those sampling programs restricted to the Indian Point area (1969, 1970, and 1972) then were multiplied by the resulting ratio (0.37), the mean value for the ratios from 1973, 1974, and 1975; this adjustment made the 1969, 1970, and 1972 values approximate those of riverwide surveys. Since the ratio of standard station catches to riverwide catches of juvenile shad, 1973-75, showed no clear direction (i.e., varied from <1.0 to >1.0), the abundance indices for juvenile shad in 1969, 1970, and 1972 could not be validly adjusted and were used in the unadjusted form.

Any potential relationships between adult abundance during the spring and the abundance of juveniles during the following July and August were investigated with linear regression and correlation techniques.

3. Results and Discussion

Adult abundance was not significantly ($\alpha = 0.05$) related to early juvenile striped bass or American shad abundance. A nonsignificant positive relationship ($r = +0.531$, $p = 0.737$, $df = 7$) occurred between juvenile and adult striped bass abundance. The relationship between juvenile and adult American shad abundance was virtually nonexistent ($r = -0.011$, $p = 0.98$, $df = 7$); consequently, little can be said about the presence or absence of American shad compensation.

The only direct evidence of density dependence which could emerge from this type of data would be a relationship of the Ricker type (dome-shaped curve) between spawner abundance and juvenile abundance or a relationship of the Beverton-Holt type (asymptotic curve) where juvenile abundance initially increases at low levels of spawner abundance but subsequently levels off at high levels of spawner abundance. Unfortunately, when one is dealing with a small number of data points (nine in this case), the observed range of adult (stock) abundance is likely to cover only a small portion of the potential range of variation. Hence, if one finds a positive relationship between adult abundance and juvenile abundance, one cannot conclude that compensation does not occur prior to the juvenile life stage. The stock may be either at such low levels that any increase in spawners yields an increase in juvenile recruits or at levels where density-dependent mortality is affecting the slope of the stock recruitment curve as it approaches an asymptote or point of inflection but the full shape of the curve may not be discernible. Additionally, failure to find any relationship between spawning stock abundance and early juvenile abundance does not necessarily preclude density-dependent population regulation, since this situation may be of the result of:

- Data representing the asymptotic portion of a Beverton-Holt stock recruitment curve at high levels of spawner abundance
- Data from the tailing end of a Ricker stock recruitment curve at high levels of spawner abundance
- Overriding density-independent factors (e.g., freshwater flow, temperature, etc.) obscuring an underlying density-dependent relationship
- Density-dependent mortality subsequent to the life stage at which recruitment is measured
- Lack of density-dependent population control

In general, when only small portions of the total range of stock size variability are available for examination, the only positive indication of density dependence from this type of data would be a negative (inverse) relationship between adult abundance and the abundance of juveniles or recruits at other ages. In such a case, one can infer the presence of a Ricker (dome-shaped) stock recruitment relationship.

D. SUMMARY

Evidence for compensation in the Hudson River striped bass population presented in a previous report (TI, 1975a) demonstrated density-dependent growth as juveniles. Also, the abundance of the stock appeared to be regulated in a density-dependent manner following a Ricker type stock recruitment curve. There was no evidence of compensation by white perch or American shad. Additional data were examined for this report for evidence of compensation by striped bass and American shad, but very little new information was added to that presented in the earlier report (TI, 1975a). After adding 11 data points, a Ricker (dome-shaped) stock recruitment curve still seemed appropriate for Hudson River striped bass, indicating a strong compensatory capacity by this population. No significant ($\alpha = 0.05$) relationship between spawner abundance and the abundance of early juveniles was detectable for either striped bass or American shad in 9 years of data, but, as discussed in the text, this finding does not preclude the existence of compensation in these populations.

The overall conclusions in this section of the report are essentially the same as those reported previously (TI, 1975a), i.e., some evidence for the presence of compensation in the Hudson River striped bass population but little indication of compensation in the white perch or American shad populations.

SECTION VII

LITERATURE CITED

Albrecht, A.B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. Calif. Fish & Game J. 50(2):100-113.

Andrews, D.F., P.J. Bickel, F.R. Hampel, P.J. Huber, W.H. Rogers, and J.W. Tukey. 1972. Robust estimates of location. Princeton Univ. Press, Princeton, NJ.

Bigelow, H.R. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. USFWS. Fish. Bull. 53(74):1-577.

Bigelow, H.B. and W.W. Welsch. 1925. Fishes of the Gulf of Maine. U.S. Bur. Fish. Bull. (1924) 40 (pt. 1):1-567.

Booth, R.A. 1967. A description of larval stages of the tomcod, *Microgadus tomcod*, with comments on its spawning ecology. PhD Thesis. (ms), Univ. Conn. 53 p.

Bradford, A.D., J.G. Miller, and K. Buss. 1968. Bioassays of eggs and larval stages of American shad, *Alosa sapidissima*. Page 52-60. In: Suitability of the Susquehanna River for restoration of shad. USDI, Washington, D.C.

Brownlee, K.A. 1965. Statistical theory and methodology in science and engineering. 2nd ed. John Wiley & Sons, New York, NY. 590 p.

Burdick, G.E. 1954. An analysis of factors, including pollution, having possible influence on the abundance of shad in the Hudson River. NY Fish & Game J. 1(2):188-205.

Carscadden, J.E. and W.C. Leggett. 1975. Meristic differences in spawning populations of American shad, *Alosa sapidissima*: evidence for homing to tributaries in the St. John River, New Brunswick. J. Fish. Res. Bd. Can. 32:653-660.

Chittenden, M.E. 1969. Life history and ecology of the American shad, *Alosa sapidissima*, in the Delaware River. PhD Thesis, Rutgers Univ., New Brunswick, NJ. 459 p.

Chittenden, M.E. Jr. 1972. Responses of young American shad to low temperatures. Trans. Am. Fish. Soc. 101(4):680-685.

Conover, W.J. 1971. Practical nonparametric statistics. John Wiley & Sons, New York, NY. 462 p.

Conover, W.J. 1975. The use of ranks as a transformation prior to the analysis of variance. Joint Statistical Meetings, Atlanta, Ga., Sep. 25-28.

Cramer, H. 1946. Mathematical methods of statistics. Princeton Univ. Press, Princeton, NJ. 575 p.

Doroshev, S.I. 1970. Biological features of the eggs, larvae, and young of the striped bass, *Roccus saxatilis* (Walbaum), in connection with the problems of its acclimatization in the USSR. J. Ichthy. 10:235-278.

Draper, N.R. and H. Smith. 1966. Applied regression analysis. John Wiley & Sons, New York, NY. 407 p.

Hammer, R.C. 1942. The homing instinct of the Chesapeake shad, *Alosa sapidissima* (Wilson), as revealed by a study of scales. MS Thesis, Univ. Md. 45 p.

Hildebrand, S.F. 1963. Family Clupeidae. In: Fishes of the western North Atlantic. Sears Found. Mar. Res. Mem. 1(3).

Hildebrand, S.F. and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. U.S. Bur. Fish. Bull. 43 (pt. I):1-366.

Hollander, M. and D.A. Wolfe. 1973. Nonparametric statistical methods. John Wiley & Sons, New York, NY. 503 p.

Hollis, E.H. 1948. The homing tendency of shad. Sci. 108(2804):332-333.

Larson, R.A. 1969. Indian Point Model No. 2. Cooling water studies for Consolidated Edison Company of New York, N.Y. Allen Res. Lab., Worcester Poly. Inst.

Leggett, W.C. and R.R. Whitney. 1972. Water temperature and the migration of American shad. USFWS Fish. Bull. 70:659-670.

Leim, A.H. 1924. The life history of the shad (*Alosa sapidissima* [Wilson]) with special reference to the factors limiting its abundance. Contr. Can. Bio. Fish. 2:163-284.

Levesque, R.D. and R.J. Reed. 1972. Food availability and consumption by young Connecticut River shad, *Alosa sapidissima*. J. Fish. Res. Bd. Can. 29:1495-1499.

Mansueti, A.J. and J.D. Hardy Jr. 1967. Development of fishes of the Chesapeake Bay region. An atlas of egg, larval, and juvenile stages, Pt. I. Univ. Md. Natl. Resources Inst. 202 p.

Mansueti, R.J. 1955. Natural history of the American shad in Maryland waters. Md. Tidewater News 11 (suppl. 4):1-2.

Mansueti, R.J. 1958. Eggs, larvae, and young of the striped bass, *Roccus saxatilis*. Ches. Bio. Lab. Contr. 112:1-35.

Mansueti, R.J. 1961. Movements, reproduction, and mortality of the white perch, *Roccus americanus*, in the Patuxent estuary, Maryland. Ches. Sci. 2:142-205.

Mansueti, R.J. 1964. Eggs, larvae, and young of the white perch, *Roccus americanus*, with comments on its ecology in the estuary. Ches. Sci. 5(1-2):3-45.

Mansueti, R.J. and E.H. Hollis. 1963. Striped bass in Maryland tidewater. Nat. Res. Inst. Univ. Md. Ed. Series 61:1-28.

Marcy, B.C. 1969. Shad early life histories. Conn. River. Invest. 8th Semiannual. Prog. Rpt. p. 19-36.

Marcy, B.C. 1972. Spawning of the American shad, *Alosa sapidissima,* in the lower Connecticut River. Ches. Sci. 13(2):116-119.

Marcy, B.C. 1976. Early life history studies of American shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. Pages 144-168. In: The Connecticut River ecological study - the impact of a nuclear power plant (D. Merriman and L.M. Thorpe, ed). Am. Fish. Soc. Mono. 1:1-252.

Massman, W.H. 1952. Characteristics of spawning areas of shad, *Alosa sapidissima* (Wilson), in some Virginia streams. Trans. Am. Fish. Soc. 81(1951):79-93.

Massman, W.H. 1963. The "critical zone" in estuaries. SFI Bull. 141:1-2.

Massman, W.H. and A.L. Pacheco. 1957. Shad catches and water temperature in Virginia. J. Wildl. Mgmt. 21(3):351-352.

Medeiros, W.H. 1974. The Hudson River shad fishery: background, management problems, and recommendations. NY Sea Grant Prog. 53 p.

Miller, R.G. 1966. Simultaneous statistical inference. McGraw-Hill, New York, NY. 272 p.

Moss, S.A. 1970. The responses of young American shad to rapid temperature changes. Trans. Am. Fish. Soc. 99(2):381-384.

Mt. Pleasant, R.C. and H. Bagley. 1975. Toward purer waters. Prog. Rpt. Environmental Quality News. Cons. 30(2):11-111.

Pacheco, A.L. 1973. Alewife, blueback herring, and American shad. Proc. Workshop on Egg, Larval, and Juvenile Stages of Fish in Atlantic Coast Estuaries. NMFS Tech. Pub. 1:1-338.

Power Authority of the State of New York (PASNY). 1974. 1980-700 MW fossil-fueled unit, Athens site. Application to New York St. Bd. on Elec. Generation Siting and Env.

Puri, M.L. and P.K. Sen. 1971. Nonparametric methods in multivariate analysis. John Wiley & Sons, New York, NY.

Quirk, Lawler, and Matusky Engineers. 1974a. Progress report for October-December 1973. No. 4. Environmental services for a State of New York Public Service Art. VIII. Application aquatic ecology — pt. 74. Solid, liquid, and gaseous wastes — pt. 78. Water quality and quantity — pt. 80. Orange & Rockland Utilities Inc., Bowline Point and Lovett Generation Stations.

Quirk, Lawler, and Matusky Engineers. 1974b. Progress report for January-March 1974. Winter environmental programs report No. 5. Orange & Rockland Utilities Inc., Bowline Point and Lovett Generating Stations.

Rathjen, W.F. and L.C. Miller. 1957. Aspects of the early life history of the striped bass (*Roccus saxatilis*) in the Hudson River. NY Fish & Game J. 4(1):43-60.

Raytheon Company. 1971. Indian Point ecology survey. Final Rpt. to Consolidated Edison Co. of New York, Inc.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Bd. Can. 11:559-623.

Ricker, W.E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Can. Bull. 119.

Ricker, W.E. 1973. Critical statistics from two reproduction curves. Rapp. R.-V. Réun. Cons. Int. Explor. Mer. 164:33-340.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can. Bull. 191.

Rounsefell, G.A. 1975. Ecology, utilization, and management of marine fishes. C.V. Mosby Co., St. Louis, Mo. 516 p.

Ryder, J.A. 1887. On the development of osseus fishes, including marine and fresh water forms. U.S. Fish. Comm. Rpt. 1885 (Vol B):489-604.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bull. 184:1-966.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York, NY.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods. Ia. St. Univ. Press, Ames. 593 p.

Sokal, R.R. and F.J. Rohlf. 1969. Biometry, the principles and practice of statistics in biological research. W.H. Freeman, San Francisco, Ca.

Sommani, P. 1972. A study on the population dynamics of striped bass, *Morone saxatilis* (Walbaum), in the San Francisco Bay estuary. PhD Dissertation, Univ. Wash.

Statistical Abstract of the United States. 1974. Consumer prices indexes. USDC 1028 p.

Stephens, M.A. 1974. EDF statistics for goodness of fit and some comparisons. J. Am. Stat. Assn. 69:730-737.

St. Pierre, R.A. and J. Davis. 1972. Age, growth, and mortality of the white perch, *Morone americana*, in the James and York Rivers. Va. Ches. Sci. 13(4):272-281.

Sykes, J.E. and B.A. Lehman. 1957. Past and present Delaware River shad fishing and considerations for its future. USFWS Res. Rpt. 46:1-25.

Tagatz, M.E. 1961. Tolerance of striped bass and American shad to changes of temperature and salinity. USFWS Fish. Spec. Sci. Rpt. (388):1-8.

Talbot, G.B. 1954. Factors associated with fluctuations in abundance of Hudson River shad USFWS Fish. Bull. 101(56):373-413.

Talbot, G.B. and J.E. Sykes. 1958. Atlantic coast migrations of American shad. USFWS Fish. Bull. 58(142):473-490.

Talbot, G.B. 1966. Estuarine requirements and limiting factors for striped bass. Am. Fish. Soc. Spec. Pub. 3:37-49.

Texas Instruments Incorporated. 1972a. Hudson River ecological study in the area of Indian Point. 1st Semiann. Rpt. Vol. I - biological sampling. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1972b. Hudson River ecological study in the area of Indian Point. 1st Semiann. Rpt. Vol. II - Standard procedures. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1973a. Hudson River ecological study in the area of Indian Point for the period January 1 to June 30, 1973. 2nd Semiann. Rpt. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1973b. Hudson River environmental study in the area of Ossining. Final Rpt.

Texas Instruments Incorporated. 1973c. Hudson River ecological study in the area of Indian Point. 1st Ann. Rpt. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1974. Hudson River ecological study in the area of Indian Point. 1973 Ann. Rpt. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1975a. First annual report for the multiplant impact study of the Hudson River estuary. 2 Vol. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1975b. Hudson River ecological study in the area of Indian Point. 1974 ann. Rpt. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1975c. Semiannual progress report for the multiplant impact study of the Hudson River estuary. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1975d. Impingement studies report for the period 1 January 1974 through 31 December 1974. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1975e. Fisheries survey of the Hudson River, March-December 1973. Vol. IV. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1975f. Hudson River ecological study in the area of Indian Point: thermal effects report. Consolidated Edison Co. of New York, Inc.

Texas Instruments Incorporated. 1975g. Predation by bluefish in the lower Hudson River. Consolidated Edison Co. of New York, Inc.

Thomson, K.S., W.H. Weed III, and A.G. Taruski. 1971. Saltwater fishes of Connecticut. Conn. St. Geo. & Nat. Hist. Survey Bull. 105:1-165.

United States Nuclear Regulatory Commission Office of Nuclear Reactor Regulation. 1975. Final environmental statement related to operation of Indian Point Nuclear Generating Plant Unit No. 3. Docket No. 50-286. 2 Vol. Consolidated Edison Co. of New York, Inc.

Walburg, C.H. 1960. Abundance and life history of the shad, St. Johns River, Florida. USFWS Fish. Bull. 60(177):487-501.

Wallace, D.C. 1971. Age, growth, year-class strength, and survival rates of the white perch, *Morone americana* (Gmelin), in the Delaware River in the vicinity of Artificial Island. Ches. Sci. 12(4):205-218.

Weaver, C.R. 1965. Observations on the swimming ability of adult American shad (*Alosa sapidissima*). Trans. Am. Fish. Soc. 94(4):382-385.

Whitney, R.R. 1961. Report of planting and tagging operations. In: The Susquehanna fishing study, 1957-1960 (R.R. Whitney, proj. leader). A report on the desirability and feasibility of passing fish at Conowingo Dam. Md. Dept. Res. Ed., Solomons, Md., Contrib. No. 169.