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1556

1983 YEAR CLASS REPORT FOR THE HUDSON RIVER ESTUARY MONITORING PROGRAM

VOLUME 1. TEXT

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1.0 INTRODUCTION

1.1 BACKGROUND

Since 1973, Hudson River Utilities[a] have financed large-scale ecological studies designed to assess the environmental impact of power plant operation on the fish populations of the Hudson River estuary. These programs have provided an extensive data base on the estuarine ecosystem of the river. Most of the prior effort consisted of commercial fish landings, water quality data and limited ecological surveys.

A large percentage of this joint effort focused on striped bass (*Morone saxatilis*), white perch (*Morone americana*) and Atlantic tomcod (*Microgadus tomcod*). The principal objectives of these programs were (1) to assess the effect of power plant cooling water withdrawal from the river on the aquatic biota and (2) to develop a clearer understanding of the major aspects of the life history and population dynamics of Hudson River fish species. The results of these efforts were summarized by McFadden *et al*. (1978), Texas Instruments Incorporated (TI, 1977, 1978a, 1979a, 1980a,b, 1981), Battelle (1983) and Normandeau Associates, Inc. (NAI, 1984a).

The Hudson River Settlement Agreement was executed in December 1980 and became effective in May 1981. This agreement was a compromise out-of-court settlement, culminating 17 years of legal controversy between the Utilities and the United States Environmental Protection Agency in regard to Section 316(b) of the Clean Water Act requiring the Utilities to convert from once-through cooling to cooling towers (Docket No. C/IIWP7701). The main emphasis of the Settlement Agreement was on

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[a] Consolidated Edison Company of New York, Inc. (Con Edison), New York Power Authority, Orange and Rockland Utilities, Inc., Niagara Mohawk Power Corporation, and Central Hudson Gas and Electric Corporation.

mitigative measures to offset power plant impacts on the aquatic environment, with the ultimate goal being the protection of the Hudson River fisheries resources (Christensen *et al.*, 1981).

The Settlement Agreement included a monitoring program that was consistent with requirements of state and federal regulatory agencies concerned with the protection of the river's resources. The primary function of the Monitoring Program is to evaluate the success of mitigation in decreasing mortality associated with impingement and entrainment of fish species. In addition, a hatchery program designed to supplement the naturally-reproducing striped bass population was implemented, with the first fingerlings released in 1983. The mark and recapture data from this program can be used to evaluate the contribution of hatchery-reared fish to the fishery and the spawning stock.

1.2 ICHTHYOPLANKTON AND JUVENILE FISH PROGRAMS

Several programs have been implemented to assess the distribution and abundance of 12 selected fish species in the Hudson River estuary. These include 10 designated by the United States Environmental Protection Agency as representative and important species in monitoring programs at one or more Hudson River power stations; and two additional species, important ecologically and commercially (Table 1.2-1). Among these fisheries programs are three which focus primarily on the early life stages, and have been conducted throughout the tidal portion of the estuary from the George Washington Bridge to Troy Dam above Albany.

The Longitudinal River Survey has been conducted to provide information on abundance, distribution, and population dynamics of eggs, larvae, and early juveniles of the selected species. This ichthyoplankton survey has utilized an epibenthic sled and a Tucker trawl, both equipped with 505-µm mesh nets. The same gear, fitted with coarser (3000-µm) mesh, has been utilized in the Fall Shoals Survey to provide data on the relative abundance, distribution and movements of

TABLE 1.2-1. FISH SPECIES SELECTED FOR HUDSON RIVER ECOLOGICAL STUDIES.

A. REPRESENTATIVE AND IMPORTANT SPECIES

Morone saxatilis	striped bass
Morone americana	white perch
Microgadus tomcod	Atlantic tomcod
Alosa pseudoharengus	alewife
Anchoa mitchilli	bay anchovy
Cynoscion regalis	weakfish
Ictalurus catus	white catfish
Notropis hudsonius	spottail shiner
Acipenser oxyrhynchus	Atlantic sturgeon
Acipenser brevirostrum	shortnose sturgeon

B. ECOLOGICALLY AND COMMERCIALLY IMPORTANT

Alosa sapidissima	American shad
Alosa aestivalis	blueback herring

young-of-the-year and older fish. And finally, the Beach Seine Survey has yielded data on relative abundance, distribution and movements of juvenile and older fish in the shore zone.

1.3 YEAR CLASS REPORT SERIES

As part of the Utilities' monitoring program, a series of reports has been prepared to summarize and synthesize information on the key fish species of the Hudson River. These reports present data on the early life stages of various species, including spatial and temporal abundance patterns observed in the estuary, to explain possible reasons for changes in abundance in the adult populations. The first of these reports was the First Annual Multiplant Report (TI, 1975) which combined the riverwide sampling approach of a study begun in 1973 associated with the proposed Cornwall pump-storage facility with an empirical estimation of individual and combined impacts of five electric generating stations on striped bass, white perch and Atlantic tomcod.

In 1974, the multiplant effort was refined and renamed the Year Class Report (TI, 1977) to emphasize a "fish year", an 18-month period from January of the spawning year through June of the following year, which would include a full year's growth of the new year class for striped bass, white perch and tomcod. The 1975 report (TI, 1978a) examined in greater detail patterns of abundance and distribution of early life stages for the 1975 year class, but excluded direct impact estimates. The 1976 report (TI, 1979a) started to focus on ecological relationships of selected fish populations. The 1977 and 1978 reports (TI, 1980a,b) examined the concept of life history studies as a tool in the evaluation of power plant effects. The 1979 report (TI, 1981) further expanded the life history and distributional studies to include nine other species, and extended the analysis to include predictions of impact based on population age structure and age-specific survival. It also included statistical analysis of biocharacteristic data available from 1973 to 1979 for the three initial key species.

The 1980 and 1981 Year Class Report (Battelle, 1983) was the first report after the Settlement Agreement and was a continuation of life history and population dynamics studies of selected Hudson River fish species. It also included the first year (1981) in which the length of the sampling season was reduced to focus on specific periods within the first year of life. These periods had been previously identified as indicators of the effects of the mitigative measures on the populations of the selected species. The 1982 Year Class Report (NAI, 1984a) continued the objectives of the 1980 and 1981 Year Class Report and extended the historical data base provided by previous year class reports to include the 1982 year class of selected fish species. This report also included an evaluation of the analytical methods used to provide an index of year class strength for striped bass and white perch, and developed associated confidence intervals.

This 1983 Year Class Report represents the tenth report in the series of year class reports. The primary objective of this report is to present and discuss the results of the Longitudinal River ichthyoplankton and Fall Shoals/Beach Seine juvenile surveys. This effort adds to the historical data base provided by previous year class reports by describing the major aspects of early life history and population dynamics of the 1983 year class of selected fish species. As in 1981 and 1982, sampling effort was directed at detecting major changes in the populations based on abundance and distribution of early life stages and juvenile year class abundance of the selected species. Hatchery-reared striped bass recaptures from the Hudson River are discussed. The relationships between environmental variables and early life history of striped bass, white perch and American shad are also evaluated in this report.

1.4 REPORT ORGANIZATION

The 1983 Year Class Report is organized into six major text sections. Section 2.0, Methods and Materials, details the field and laboratory procedures used in the collection, identification, and processing of specimens. A complete description of all analytical methods utilized is included. Section 3.0, Water Quality, describes the general patterns of water quality parameters measured during the study period. Section 4.0 discusses the spatiotemporal distribution and relative abundance of various early life stages of the selected fish species listed in Table 1.2-1. This includes all early life stages of striped bass, white perch and American shad; the late larval stage and juvenile stage of Atlantic tomcod; the egg and larval stages of alewife/blueback herring; and the juvenile and older stages of blueback herring, alewife, bay anchovy, weakfish, white catfish, spottail shiner, Atlantic sturgeon and shortnose sturgeon.

Section 5.0 presents and discusses growth and mortality estimates for the late larval and juvenile stages of striped bass, white perch, American shad, Atlantic tomcod and bay anchovy. Section 6.0 deals with annual abundance indices for juvenile striped bass and white perch in the summer and fall, and includes comparisons with past years' indices to estimate relative year class strengths. Section 7.0 discusses the relationships between environmental variables and growth, mortality and abundance of larval and juvenile striped bass, white perch and American shad.

2.0 METHODS AND MATERIALS

2.1 FIELD AND LABORATORY PROCEDURES

In 1983, sampling programs were conducted during the periods of 2 May-10 July (ichthyoplankton) and 1 August-30 October (juvenile) in the tidal portion of the Hudson River between the George Washington Bridge at river kilometer (km) 19.3 and the Federal Lock at Troy (km 246.2). Sampling was stratified among 12 geographic regions (Figure 2.1-1). Those 12 regions were further subdivided into strata based on depth: (1) shoals, that portion of the river from the shore to a depth of 6 m at mean low tide; (2) bottom, that portion, excluding the shoals, that is within 3 m of the bottom; and (3) channel, that portion that is not considered to be shoals or bottom (Figure 2.1-2). Sampling programs in 1983 were identical to those of 1982, including an ichthyoplankton survey (Longitudinal River Survey), and two juvenile fish surveys (Fall Shoals Survey and Beach Seine Survey). A river-wide water quality monitoring program, identical to that conducted in 1982, was conducted to provide associated environmental data.

For discussion of general geographic trends, the 12 regions were grouped into three areas with relatively distinct morphometrics and physical and chemical environments (TI, 1981). The lower estuary extends from km 19 through km 63 and encompasses the Yonkers, Tappan Zee and Croton-Haverstraw sampling regions. The middle estuary extends from km 63 through km 124, and includes the Indian Point, West Point, Cornwall and Poughkeepsie regions. The remaining five sampling regions, Hyde Park, Kingston, Saugerties, Catskill and Albany, comprise the upper estuary, from km 124 through km 246.

2.1.1 Longitudinal River Survey

All strata within each of the 12 geographic regions between km 22.5 and 225.2 were sampled, except those that were too limited due to

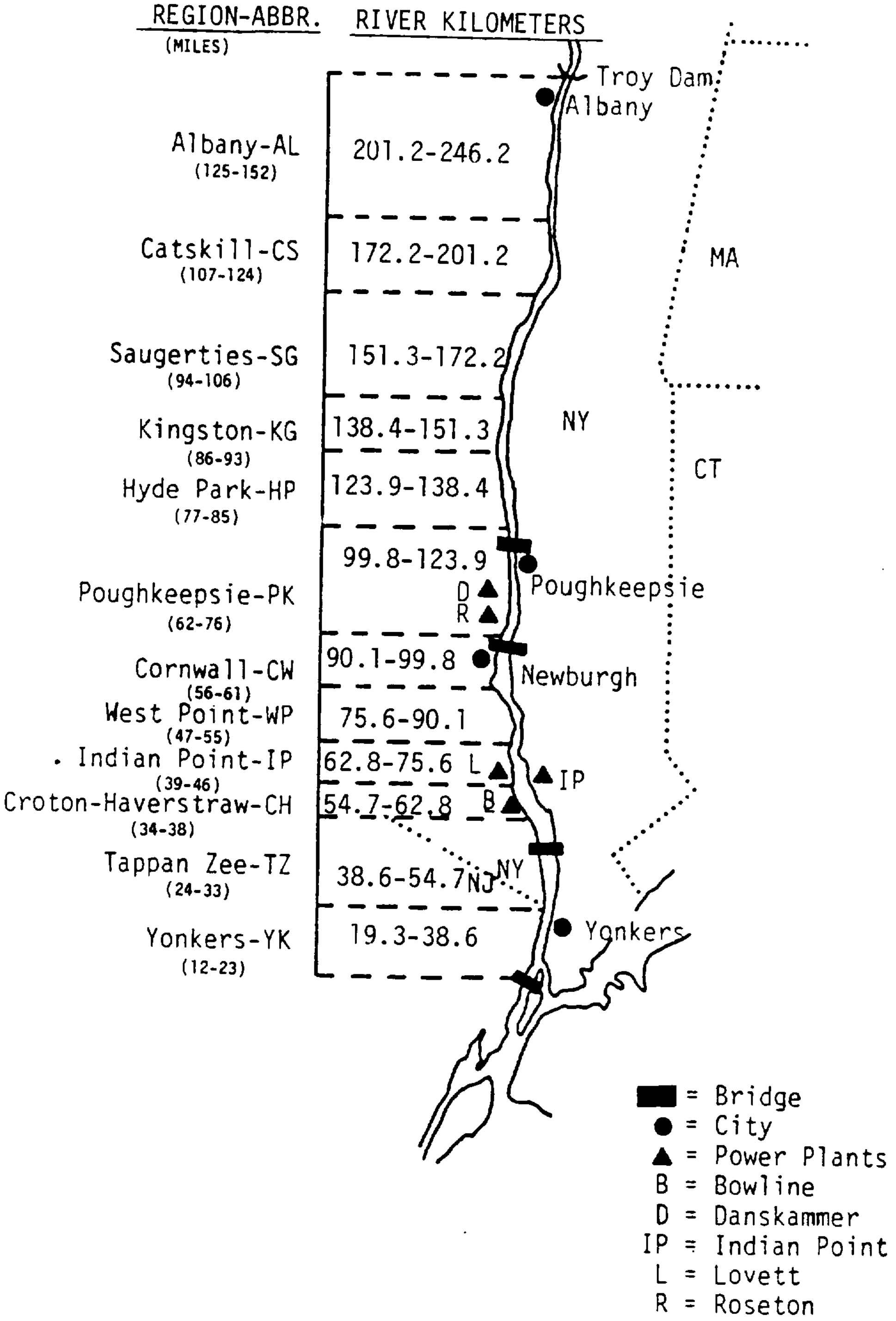
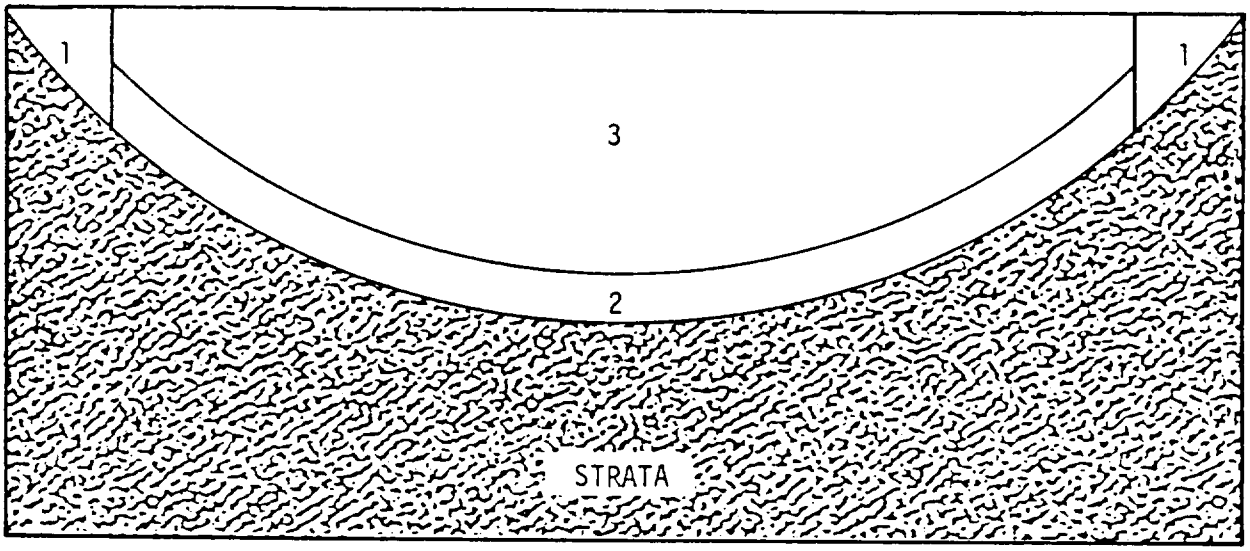


Figure 2.1-1. Location of 12 geographical regions (with river mile and kilometer boundaries) used during field sampling programs in the Hudson River estuary, 1983.



1= Shoal [depths ≤ 6 m]
2= Bottom [bottom 3 m of depths > 6 m]
3= Channel [above bottom 3 m of depths > 6 m]

Figure 2.1-2. Cross section of estuary showing strata sampled in 1983 Longitudinal River and Fall Shoal Surveys, Hudson River estuary.

size or sampling obstructions (Table 2.1-1). Approximately 200 samples were collected in each of ten weekly sampling periods (river runs) from early May to early July (Table 2.1-2). Sampling was conducted during the day for the first seven river runs, but at night during the last three in order to decrease gear avoidance by post yolk-sac larvae and juveniles.

Sampling effort utilized a stratified random design, with effort allocated to regions and strata based upon the distribution of the early life stages from previous years. Location and depth of each sample were randomly selected within the region and stratum. Prior to 1982, the number of samples allocated to each stratum and region were based on the distribution (peak standing crops averaged over three prior years) of eggs, yolk-sac and post yolk-sac striped bass. After a minimum of three samples were assigned to each region, the remainder (of 200 samples per river run) were proportionately allocated. In the laboratory, 78.5% of the samples collected in each stratum were randomly selected for analysis (i.e., 157 samples per river run). During 1982, (1) the allocation of samples to river regions was modified to reflect also the distribution of eggs, yolk-sac, and post yolk-sac American shad, (2) the Neyman method of allocating samples (Cochran, 1977) was used, which assigned the highest numbers of samples to regions where density data showed the highest variances, and (3) all samples collected in the field were analyzed in the laboratory. The 1977-1980 striped bass and American shad ichthyoplankton data were used to develop the Neyman allocations. As in prior years, a minimum of three samples was assigned to each region so that samples would still be taken in regions where abundance of striped bass or American shad was low or non-existant. A similar method of allocating samples was used in 1983.

Channel samples were collected with a 1-m^2 Tucker trawl (505-μm mesh), bottom samples were collected with a 1-m^2 epibenthic sled (505-μm mesh), and shoal samples were collected using both gear types. When used in the shoal stratum, the Tucker trawl required a minimum river depth of four meters. The tow speed of the epibenthic sled was maintained at approximately 1 m/sec and the Tucker trawl speed

TABLE 2.1-1. STRATA SAMPLED BY LONGITUDINAL RIVER AND FALL SHOALS SURVEYS WITHIN THE TWELVE GEOGRAPHIC REGIONS OF THE HUDSON RIVER ESTUARY DURING 1983.

GEOGRAPHIC REGION		RIVER KILOMETERS	STRATUM		
			BOTTOM	CHANNEL	SHOAL
Albany	(AL)	201.2-246.2	X	*	*
Catskill	(CS)	172.2-201.2	X	X	*
Saugerties	(SG)	151.3-172.2	X	X	*
Kingston	(KG)	138.4-151.3	X	X	*
Hyde Park	(HP)	123.9-138.4	X	X	*
Poughkeepsie	(PK)	99.8-123.9	X	X	*
Cornwall	(CW)	90.1-99.8	X	X	X
West Point	(WP)	75.6-90.1	X	X	*
Indian Point	(IP)	62.8-75.6	X	X	X
Croton-Haverstraw	(CH)	54.7-62.8	X	X	X
Tappan Zee	(TZ)	38.6-54.7	X	X	X
Yonkers	(YK)	19.3-38.6	**	X	X

X - Stratum sampled
* - Not sampled - stratum too limited
** - Not sampled due to obstructions

TABLE 2.1-2. WEEKLY SAMPLE ALLOCATIONS FOR THE LONGITUDINAL RIVER SURVEY, HUDSON RIVER ESTUARY, 1983.

	RIVER RUN 1-3 (2 MAY-22 MAY)				RIVER RUN 4-6 (23 MAY-12 JUNE)				RIVER RUN 7-10 (13 JUNE-10 JULY)			
REGION	SHOAL	BOTTOM	CHANNEL	TOTAL	SHOAL	BOTTOM	CHANNEL	TOTAL	SHOAL	BOTTOM	CHANNEL	TOTAL
Albany	-	5	-	5	-	3	-	3	-	3	-	3
Catskill	-	3	3	6	-	3	3	6	-	3	3	6
Saugerties	-	3	3	6	-	5	3	8	-	4	2	6
Kingston	-	6	7	13	-	4	6	10	-	4	6	10
Hyde Park	-	9	11	20	-	7	12	19	-	5	9	14
Poughkeepsie	-	10	10	20	-	16	22	38	-	7	15	22
Cornwall	5	12	5	22	5	9	5	19	3	12	13	28
West Point	-	4	31	35	-	7	23	30	-	8	25	33
Indian Point	4	7	25	36	3	6	14	23	5	5	16	26
Croton-Haverstraw	6	3	6	15	5	4	4	13	4	6	6	16
Tappan Zee	3	4	3	10	3	4	4	11	3	5	6	14
Yonkers	3	-	3	6	3	-	3	6	1	-	8	9
TOTAL	21	66	107	194	19	68	99	186	16	62	109	187

at approximately 0.9 m/sec, as determined by the use of calibrated electronic flowmeters deployed along with the net. If the flowmeters failed in operation, then tow speed was estimated based on engine RPM.

A calibrated digital flowmeter was suspended within the net in order to determine volume sampled. Standard tow duration was 5 min unless large numbers of fish were consistently captured, at which time 2-min tows were made. At the completion of each tow, the net was rinsed and the contents of the collection cup examined.

All larger specimens (yearling and older) were identified, enumerated by length class (Table 2.1-3) and released. The remaining sample was preserved in 10% formalin and returned to the laboratory for processing.

Fish eggs, larvae and juveniles collected in the ichthyoplankton surveys were separated from the detritus and inorganic material after staining the sample with rose bengal and then rinsing it through a 375-µm mesh screen. Organisms were placed in vials containing 5% formalin according to taxonomic group (species or family) and stage of development (eggs, yolk-sac larvae, post yolk-sac larvae and young-of-the-year; Table 2.1-4). If the sample were estimated to contain over four thousand fish eggs or bay anchovy larvae, then the sample was split to not less than 1/8 of the original using a Folsom plankton splitter. Larvae of species other than bay anchovy were always sorted from the whole sample. Specimens were then identified to the lowest practical taxonomic level (usually species) and enumerated by life stage. In each sample up to 30 larvae and/or juveniles of striped bass, white perch and American shad were measured for total length (TL). When available, at least 10 individuals per life stage (yolk-sac, post yolk-sac and young-of-the-year) were measured. When fewer than 10 specimens for a particular life stage were encountered the remainder of the quota was allocated to the remaining available life stages. The identification process was aided by reference collections and the appropriate taxonomic literature.

TABLE 2.1-3. LENGTH CLASS DIVISIONS, HUDSON RIVER ESTUARY, 1983.

LENGTH CLASS	TOTAL LENGTH RANGE (millimeters)
1	0 - Division I
2	Division I+1 - Division II
3	Division II+1 - 250
4	≥ 251

NOTE: Division I and Division II represent empirically determined cut-off lengths which are intended to represent the upper limits for young-of-the-year and yearling age groups, respectively. Division I and Division II were determined separately for each species as part of the impingement program at the Indian Point power station.

TABLE 2.1-4. CRITERIA USED FOR STAGING ICHTHYOPLANKTON.

EGG	This embryonic stage commences with spawning and continues until hatching.
YOLK-SAC LARVA	This stage begins with hatching and continues until the development of a complete and functional digestive system.
POST YOLK-SAC LARVA	This stage begins with the initial development of a complete digestive system and continues until a full complement of adult fin rays is acquired.
YOUNG-OF-THE-YEAR	This stage begins when the full complement of adult fin rays is acquired and continues until 31 December of the year spawned. (Also referred to as juvenile).

2.1.2 Fall Shoals Survey

Two hundred samples per river run (Table 2.1-5) were collected biweekly within km 22.5-225.2 from August through October. Samples were taken at night, and location and depth were randomly selected. Samples within the shoal and bottom strata were collected with a 1-m^2 epibenthic sled with a 3000-µm mesh net with a conical fyke inside the enlarged cod end. The channel stratum was sampled with a 1-m^2 Tucker trawl, also with a 3000-µm mesh net. Standard tow duration was 5 min. As with the ichthyoplankton survey, digital flowmeters were employed to determine volume sampled, and electronic flowmeters were used to determine tow speed. Tow speeds for the epibenthic sled and the Tucker trawl were maintained at approximately 1.5 m/sec.

At the completion of a tow the contents of the collection cup (or cod end) were rinsed. All yearling and older fish were identified, enumerated by length class (Table 2.1-3), and released. The remaining sample (juveniles) was preserved in 10% formalin and returned to the laboratory for identification and enumeration by species. If any of the juveniles were observed to have been tagged (either a fin-clip on the soft dorsal fin or a colored nose tag) then the pertinent information regarding the recapture of the fish was recorded. Length (mm TL) and weight (g) measurements were also recorded. In each biweekly period, up to 20 young-of-the-year per region of each selected species were measured for total length. This length quota was filled by randomly selecting a maximum of five specimens per sample. In those regions where biweekly sample allocations were fewer than 10 (Table 2.1-5), then no more than 10 specimens per sample were selected.

TABLE 2.1-5. BIWEEKLY SAMPLE ALLOCATION FOR FALL SHOALS SURVEY, HUDSON RIVER ESTUARY, 8 AUGUST-30 OCTOBER 1983.

GEOGRAPHIC REGION	SHOAL	BOTTOM	CHANNEL	
	EPIBENTHIC SLED	EPIBENTHIC SLED	TUCKER TRAWL	TOTAL
Albany	*	8	*	8
Catskill	*	15	6	21
Saugerties	*	12	6	18
Kingston	*	9	6	15
Hyde Park	*	6	4	10
Poughkeepsie	*	5	3	8
Cornwall	5	5	3	13
West Point	*	5	3	8
Indian Point	6	5	3	14
Croton-Haverstraw	16	8	3	27
Tappan Zee	30	8	8	46
Yonkers	7	*	5	12
Total	64	86	50	200

* = stratum too limited for sampling.

2.1.3 Beach Seine Survey

Sampling was conducted biweekly from August through October. During each sampling period, 100 samples were randomly collected (Table 2.1-6) using a 30.5-m beach seine (Table 2.1-7). Sampling locations within each region and time period were selected randomly. The seine was deployed by attaching one end to the boat and holding the other at the shore. The net was set as the boat moved perpendicularly away from the shore. The seine was then hauled clockwise in a semicircular path until it reached shore. The completed tow swept an area of approximately 450 m^2 (TI, 1981).

Samples were sorted and enumerated by species and length class (Table 2.1-3). All yearling and older fish were processed in the field and then released. All juveniles were preserved in 10% formalin and returned to the laboratory for identification and enumeration by species. As with the Fall Shoals Survey, all striped bass juveniles were observed for the presence of either a fin-clip or nose tag. If a tag was noticed then all information regarding the recapture as well as length and weight measurements were recorded. Length measurements were taken for all selected species (up to 20 per region per species) and recorded to the nearest mm TL.

2.1.4 Water Quality

Water quality data (temperature 0.1°C, oxygen 0.1 mg/ℓ, and conductivity 1.0 µS/cm) were collected to provide associated environmental data for each survey. For each of the ichthyoplankton and Fall Shoals surveys, 164 water quality samples were collected per sampling period (Table 2.1-8). Water chemistry measurements were made *in situ* at fixed site locations and depths. Surface and bottom measurements were taken in the shoals, and surface, mid-depth and bottom measurements were taken in the channel. The *in situ* probes were lowered over the side to within 1 m of the bottom. After the

TABLE 2.1-6. BIWEEKLY SAMPLE ALLOCATION FOR BEACH SEINE SURVEY, HUDSON RIVER ESTUARY 1 AUGUST - 23 OCTOBER 1983.

GEOGRAPHIC REGION	RIVER KILOMETERS	NUMBER OF BEACHES SAMPLED
Albany	201.2-246.2	7
Catskill	172.2-201.2	10
Saugerties	151.3-172.2	9
Kingston	138.4-151.3	5
Hyde Park	123.9-138.4	5
Poughkeepsie	99.8-123.9	5
Cornwall	90.1-99.8	6
West Point	75.6-90.1	5
Indian Point	62.8-75.6	5
Croton-Haverstraw	54.7-62.8	14
Tappan Zee	38.6-54.7	24
Yonkers	19.3-38.6	5
Total	19.3-246.2	100

TABLE 2.1-7. DIMENSIONS OF 30.5-METER SEINE USED IN THE BEACH SEINE SURVEY, HUDSON RIVER ESTUARY, 1983.

Number of wings	2
Length of wings	12.2 m
Depth of wings	2.4 m
Wing mesh stretch	1.9 cm
Length of bag	6.1 m
Depth of bag	3 m
Bag mesh stretch	0.9 cm

TABLE 2.1-8. WATER QUALITY SAMPLE ALLOCATION AND FIXED SITE LOCATIONS (RIVER KILOMETER) FOR EACH SAMPLING PERIOD OF THE 1983 LONGITUDINAL RIVER AND FALL SHOALS SURVEYS, HUDSON RIVER ESTUARY.

	SITE LOCATIONS[a]		SAMPLING STATIONS[b]			
GEOGRAPHIC REGION	SHOALS	CHANNEL	EAST SHOAL	CHANNEL	WEST SHOAL	NUMBER OF SAMPLES PER REGION
Albany	-	204,211,217,222	-	4	-	12
Catskill	-	175,183,190,196	-	4	-	12
Saugerties	-	154,159,164,169	-	4	-	12
Kingston	-	140,143,146,150	-	4	-	12
Hyde Park	-	125,129,132,135	-	4	-	12
Poughkeepsie	-	101,108,114,121	-	4	-	12
Cornwall	95	90,92,95,98	1	4	1	16
West Point	-	79,82,85,88	-	4	-	12
Indian Point	69	64,67,69,74	1	4	1	16
Croton-Haverstraw	58	56,58,60,61	1	4	1	16
Tappan Zee	47	40,43,47,51	1	4	1	16
Yonkers	30	22,27,30,35	1	4	1	16
TOTAL			5	48	5	164

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[a] River kilometer location

[b] Dash indicates that no sample was taken due to limited stratum.

bottom measurements were taken the probe was raised to the mid-depth region (channel only) and then to 1/2 m below the surface for surface measurements.

During the Beach Seine Survey, 100 water quality samples were collected per sampling period (river run) in conjunction with the seine hauls from August through October. Water quality measurements were taken near the surface approximately 15 m offshore, after the seine haul was completed.

2.2 ANALYTICAL PROCEDURES

2.2.1 Preparation of Data for Analysis

The data used to prepare the 1983 Year Class Report were received from Con Edison on a magnetic tape. The tape contained three files of 1983 data and the software programs developed and used for the preparation of the 1980-1981 Year Class Report.

All data sets were created in a pseudo-hierarchichal SAS file structure compatible with previous year class reports. Level 3 contains general sample information (date, time, site, river run, etc.); level 4 contains information on the gear type; level 5 has information on the catch, such as the number of specimens of each species and life stage taken, or water quality; level 6 contains length data on individual specimens. The magnetic tape was unloaded and duplicated using an IBM 4381 computer system. A quality control audit was then performed to determine the accuracy of the transferred data against the original data sheets. The audit procedure insured an accuracy level of 1% AOQL by using a Military Standard lot inspection plan MIL-STD-105D (ASQCSC, 1981).

2.2.2 Software

To ensure comparability between the 1983 Year Class Report and those of previous years, all analytical procedures were identical to those described by Normandeau Associates, Inc. in the 1982 Year Class Report (NAI, 1984a). All algorithms used were identical to those used and described previously (TI, 1981; NAI, 1984a).

2.2.3 Calculations

Equations referred to in this section are presented in Appendix A.

2.2.3.1 Water Quality

To assess the effects of abiotic variables on the population dynamics of the Hudson River fish populations, water quality data for each week were averaged by region and by estuary segment for each parameter (dissolved oxygen concentration, temperature and conductivity). Regional means were weighted by stratum volumes and segment means were weighted by regional volumes (Equations 1 and 2).

2.2.3.2 Abundance and Standing Crop

Catch data from Ichthyoplankton, Fall Shoals and Beach Seine surveys were used to estimate the total abundance (standing crop) of the 1983 year class of the selected species in the river. A standard error was calculated for each estimate.

Ichthyoplankton and Fall Shoals density estimates were calculated for each tow by life stage and taxon from the catch data and tow volume (Equation 3). Density estimates were then averaged by stratum within region (Equation 4). A standing crop estimate was then calculated by sampling period for each stratum within each region by multiplying mean density by river volume (Equation 5). Strata which were not sampled were assumed to support populations in the same densities as adjacent sampled strata. Therefore the unsampled strata were accounted for by adding their volumes to contiguous sampled strata before converting densities to standing crops (Table 2.2-1). These standing crop estimates were combined to give totals for each of the three strata (Equation 6), for each of the 12 regions (Equation 7) and for the entire river (Equation 8).

Standing crop is an estimate of the number of individuals of a particular species in an area at a given time. Stratum standing crops show the relative abundance of a species in each stratum and can be used to show relative movements within each region. Because of large differences in river volume among strata and among regions, a higher standing crop in one area does not necessarily mean a higher concentration or density there.

For the 30.5-m beach seine, catch-per-unit-effort (CPUE), defined as the number of individuals per haul, was calculated to estimate relative abundance for each of the 12 regions (Equation 9). Standing crop estimates were calculated for each region by multiplying CPUE by the ratio of regional shore zone surface area to the area sampled by one seine haul (Equation 10), and then combined to estimate standing crop for the entire river (Equation 11). The shore zone surface area (m^2) from 0 to 3 m deep for each of the 12 regions was calculated by TI (1981) from USGS depth contour maps (Table 2.2-2). The area sampled by a seine was estimated as 450 m^2 by TI (1981), based on empirical measurements in addition to an analysis of how the area swept is affected by variation in the distance along the shore between the two ends of the net when it initially closes.

Distribution indices were computed by life stage to determine trends in geographic and temporal distributions. The geographic and temporal distribution indices for each life stage were calculated as the relative percentage of standing crop contained by each region or by each

TABLE 2.2-1. STRATUM VOLUMES (MILLION M^3) USED IN STANDING CROP CALCULATIONS FOR ANALYSIS OF HUDSON RIVER 1983 LONGITUDINAL RIVER AND FALL SHOALS SURVEYS.

				STRATA			
GEOGRAPHIC REGION	BOTTOM	%[a]	CHANNEL	%[a]	SHOAL	%[a]	TOTAL ACROSS
Albany	13.5	19.0	32.0[b]	45.0	25.6[b]	36.0	71.1
Catskill	42.3	26.3	83.9	52.2	34.5[b]	21.5	160.7
Saugerties	42.8	24.3	113.1	64.2	20.3[b]	11.5	176.2
Kingston	35.5	25.1	93.7	66.2	12.3[b]	8.7	141.5
Hyde Park	32.0	19.3	131.2	79.3	2.3[b]	1.4	165.5
Poughkeepsie	63.2	21.2	229.0	76.8	6.0[b]	2.0	298.2
Cornwall	36.8	26.3	94.9	67.9	8.1	5.8	139.8
West Point	26.0	12.5	178.8	86.2	2.6[b]	1.3	207.4
Indian Point	33.4	16.0	162.3	77.9	12.6	6.1	208.3
Croton-Haverstraw	32.5	22.0	61.3	41.5	53.9	36.5	147.7
Tappan Zee	62.1	19.3	138.0	42.9	121.7	37.8	321.8
Yonkers	59.3[c]	25.9	143.4	62.5	26.6	11.6	229.3

[a] % stratum of total strata for that region.

[b] For analytical purposes these volumes were added to the bottom stratum volumes.

[c] For analytical purposes this volume was added to the channel volume.

TABLE 2.2-2. EXTENT OF SHORE ZONE SURFACE AREA (M^2) FROM 0-3 M DEEP IN 12 GEOGRAPHIC REGIONS OF HUDSON RIVER ESTUARY USED TO CALCULATE STANDING CROP ESTIMATES FROM BEACH SEINE CATCHES IN 1983.

GEOGRAPHIC REGION	LENGTH (kilometers)	SHORE ZONE SURFACE AREA (m^2)
Albany	45.0	6,114,000
Catskill	29.0	8,854,000
Saugerties	20.9	7,900,000
Kingston	12.9	3,874,000
Hyde Park	14.5	558,000
Poughkeepsie	24.1	3,193,000
Cornwall	9.7	4,793,000
West Point	14.5	1,186,000
Indian Point	12.8	4,147,000
Croton-Haverstraw	8.1	12,101,000
Tappan Zee	16.1	20,446,000
Yonkers	19.3	3,389,000
TOTAL		76,555,000

weekly (or biweekly) sampling period (Equations 12 and 13). The higher the index value, the higher the standing crop was in a particular region or sampling period relative to the surrounding regions or sampling periods during the same year.

2.2.3.3 Growth and Mortality

Procedures used to estimate growth and mortality rates were consistent with those of previous year class reports as described by TI (1981) when the appropriate data were available. Some modifications were made to accommodate differences in the data due to changes in sampling schedule (NAI, 1984a). Additional details and rationale for these modifications are given in Section 5.0.

Daily Growth Rate Estimated from Mean Lengths

Mean lengths of larvae and early juveniles collected in ichthyoplankton samples were calculated for each sampling week by weighting the mean length for each stage by the abundance (standing crop) of that stage (Equation 14). The means were weighted in this manner because larvae and juveniles were not selected for measurement in proportion to their abundance. Mean lengths from fall juvenile sampling were used to estimate a logarithmic growth curve by linear regression (Equation 15). The date on which the mean length for the population reached 60 mm was then estimated from that logarithmic growth curve (Equation 16). Growth during the post yolk-sac and early juvenile stages was estimated by an exponential growth curve generated by linear regression of length data from the ichthyoplankton and fall juvenile sampling (Equation 17). An estimate of the date when the recruitment length was reached was calculated from the exponential growth equation (Equation 18). These dates were used to estimate the average daily growth from hatching to recruitment length and from recruitment length to 60 mm (Equation 19).

Daily mortality rate estimated from population decline

Mortality of striped bass larvae and early juveniles (<20 mm) was estimated in earlier year class reports by a method developed by Sette (1943) which uses length-frequency data (TI, 1981). This method requires length and abundance data throughout the entire period when the fish are growing through the size range under consideration, so that mortality is not overestimated by underestimating the abundance of the larger size intervals in this range (NAI, 1984a). Because ichthyoplankton sampling in 1983 ended well before growth to 20 mm was completed, mortality was estimated instead from the rate of population decline.

The population decline method does not rely on length-at-age estimations. Rather it utilizes standing crop estimates for successive weeks to measure the rate of population decline. It is therefore appropriate when length data or the length-at-age relationship are unavailable. It is also applicable during the late summer period when the variation in length at any particular age is much greater than it was in the larval and early juvenile stages.

The weekly abundance of all early life stages combined was estimated from ichthyoplankton samples (Equation 8). Recruitment to the population was considered to be essentially complete during the last week when eggs and small yolk-sac larvae accounted for a substantial proportion of the total standing crop. The rate of population decline from the week when recruitment was complete through the last week of ichthyoplankton sampling was then estimated by linear regression (Equation 20) and expressed as a daily mortality rate (Equation 21). The weekly abundance of juveniles was estimated by the combined standing crop calculated from the Fall Shoals Survey and the Beach Seine Survey data, which were adjusted to account for day-night catch differences and for gear efficiencies (see Section 2.2.3.4). The rate of population decline from the week of peak abundance through the end of fall juvenile sampling was estimated by linear regression (Equation 20, with t = days after 1 August) and expressed as a daily mortality rate (Equation 21).

2.2.3.4 Annual Abundance Indices

Weekly Combined Standing Crop

To evaluate the overall strength of the 1983 year class for striped bass and for white perch, the total abundance of these species was examined during the late summer-early fall period. It was felt that the best way to estimate the size of the entire population of a fish species would be to combine data from more than one sampling gear, representing different habitats. Therefore, data from the Ichthyoplankton, Fall Shoals and Beach Seine surveys have been combined in previous year class reports (with appropriate adjustments made for gear type) to present the best quantitative estimate of juvenile abundance in the Hudson River estuary.

In 1983, however, ichthyoplankton sampling ended a month before the juvenile sampling began. Because of (1) the difficulty in making any meaningful estimates for the long period when there was no sampling in 1983, and (2) recruitment to the juvenile stage being far from complete by the end of ichthyoplankton sampling, the 1983 ichthyoplankton data were not utilized in the combined standing crop analysis.

To calculate weekly standing crop estimates from biweekly samples, the missing weeks were estimated using the average of the previous week and the following week (Fall Shoals) or by using the previous week's value (Beach Seine). Missing strata were accounted for by multiplying the density estimate from an adjacent sampled stratum by the river volume of the unsampled stratum. To avoid overlap between the shore zone (0-3 m) and the shoal stratum (0-6 m), standing crops of shoal strata were reduced by 25% under the assumption that if the bottom slope is fairly uniform then the shore zone contains 25% of the water from 0 to 6 m deep.

The night/day catch ratio was used to adjust the shore zone estimate because the Beach Seine Survey was conducted during the day and the Fall Shoals Survey at night. The adjustment avoided excluding fish which might stay in deeper water during the day and move into the shore zone at night. This ratio, calculated when both night and day beach seine collections were made (1973, 1974, and 1978), was calculated to be 2.136 for striped bass and 1.685 for white perch (TI, 1981).

Catch efficiency adjustments were also included, because no particular gear type is 100% efficient in sampling. The estimated catch efficiency values of the 30.5-m beach seine, which were empirically derived (TI 1978b, 1979b), are 0.255 for striped bass and 0.182 for white perch. Efficiency values for the epibenthic sled and Tucker trawl were assumed to be 50% based upon data presented by Kjelson and Colby (1977) and TI (1980b).

After the night/day and gear efficiency adjustments had been made, standing crops estimated by the two juvenile surveys were combined within each region (Equations 22 and 23). The regional combined standing crops for each week were then summed to give the weekly combined standing crop representing the entire river (Equation 24).

Combined Standing Crop Index

The weekly combined standing crops (CSC) were calculated for the period beginning with the week of 8 August. The week beginning 1 August was not included because there were no Fall Shoals data until the following week. These values were used to estimate an exponential mortality curve by linear regression (Equation 20, with t = days after 1 August, and N_o = CSC 1 August equivalent). If a non-significant regression model for the summer CSC index was obtained, then the population was considered to have reached a period of relative stability. The extrapolation of these weekly CSC values back to 1 August would make the interpretation of the 1 August population questionable because the method assumes significant mortality to be occurring. A fall CSC index was calculated by linear regression of the CSC in the five-week period beginning with the week containing 1 September, and then calculating an estimate for 15 September from the resulting exponential curve (Equation 20, with t = days after 1 August, N_o = regression line intercept, and N_{45} = 15 September estimate = Fall CSC Index). If a non-significant regression were found, then a geometric mean of the fall weekly CSC values was used for the fall CSC index.

Weekly and Combined Standing Crop Index Confidence Intervals

Confidence limits for weekly CSC estimates of young-of-the-year striped bass and white perch were calculated from the product of standard error of the CSC estimate (Equation 24) and the t-statistic from Student's t-distribution (NAI, 1984a). Widest (most conservative) confidence limits were based on the fewest degrees of freedom (df), one fewer than the number of samples in the smallest stratum or 2 df. Narrowest (least conservative) confidence limits were based on the maximum number of degrees of freedom for the weekly CSC estimate, one less than the total number of samples collected in a week or 299 df.

When a significant exponential regression equation (Equation 20) occurred, confidence limits for the CSC index were computed for the predicted 1 August or 15 September index using Equations 25 and 26 (Sokal and Rohlf, 1981). If a significant regression was not found for the fall CSC index, a geometric mean CSC for the five-week period symmetric about 15 September was calculated, and confidence limits were obtained from the product of the simple standard error of the geometric mean and student's t-statistic for df of one less than the number of weeks in the mean.

2.2.3.5 Environmental Effects on Growth, Mortality and Abundance

Physical factors (e.g., dissolved oxygen, temperature and conductivity) may act singly or in combination to affect growth, mortality or abundance of fish. In order to support the normal metabolic and physiological activity, dissolved oxygen concentrations must be above a minimal level. However, this minimum can be affected by fluctuations in water temperature (Hoar *et al*., 1979). Temperature and salinity may synergistically influence the survival of estuarine organisms (Otwell and Merriner, 1975; Morgan *et al*., 1981). Temperature tolerance limits vary according to the physical factors of acclimatization (e.g., season, photoperiod, salinity and dissolved oxygen) and the biological factors of age, size and geographic race (Houston, 1982). Since one physical factor may mask the action of another, simple correlation analysis of the effects of a single physical factor will not likely be fruitful.

A three-stage process was employed to elucidate the effects of temperature and other physical variables on growth, mortality and abundance of the early life stages of striped bass, white perch and American shad ichthyoplankton for the period 1975-1983, and juveniles from 1976-1983. First, observed temperatures or dissolved oxygen concentrations that were at or beyond known tolerance limits for these species were noted. Extraordinary events, such as mass mortality of larvae as a result of severe fluctuations in water temperature (Dey, 1981), were excluded from further analyses.

Since a discussion of the effects of temperature on field data was likely to be nebulous without the consideration of interacting factors, the second phase of the analysis was the production of univariate scatter plots of the effect of each of the following independent variables, and bivariate response surface diagrams of the combined effect of each possible pair, on each of the following dependent variables:

INDEPENDENT VARIABLES	DEPENDENT VARIABLES
temperature	mortality (%/day)
dissolved oxygen	growth (%/day)
conductivity	
freshwater flow	
abundance (standing crop)	
year	

Abundance was treated as an independent variable to investigate the possibility of density-dependent effects on the populations. The effect of environmental variables on abundance (i.e., abundance as a dependent variable) was not analyzed directly, because abundance at any particular time is always dependent upon the abundance at a previous time. Instead, the effect of environmental variables on the rate of change of abundance (i.e., mortality) was examined.

The univariate scatter plots were based on weekly ichthyoplankton and biweekly Fall Shoals standing crop estimates (see Section 2.2.3.2 and Appendix A; Equations 3 - 8). Because heterogeneity in temperature and conductivity was expected, estuary-wide weekly averages of these water quality parameters were calculated for each life stage of each species by weighting regional water quality means by the corresponding standing crop of the particular stage and species being analyzed (Equation 27). This resulted in an average exposure per individual. Examination of these graphs provided qualitative information concerning the relationships between these variables (e.g., linear, exponential or inverse) and suggested appropriate transformations to linearize the relationships for the next phase of the analysis.

Time series of each dependent variable were also plotted, which suggested separate analyses for certain time periods (e.g., an expression of life-stage dependent growth or mortality). The use of weekly or biweekly data was necessary to provide sufficient data points for a statistically meaningful analysis. Only eight annual data points were available, which is an insufficient number for most analyses.

The third phase of the analysis was multiple regression and factorial analysis of variance (ANOVA) of the simultaneous effects of the independent variables on each dependent variable. In terms of statistical power, factorial ANOVA is a serious competitor with multivariate techniques (Harris, 1975), but its interpretation is much more straightforward. Each ANOVA and its corresponding multiple regression were run using the SAS GLM procedure (SAS, 1982). The ANOVA provided statistical significance levels for each factor and the interaction of these factors, and the multiple regression coefficients described the response surface for each dependent variable.

2.2.4 Quality Control

A quality assurance program was designed to insure accurate analysis of the data and a high quality level for the finished report. Specific quality control procedures were performed to verify the reliability and validity (accuracy, precision and completeness) of all report figures and report tables. These procedures used the MIL-STD-105D normal inspection level sampling plans for inspection by attributes (ASQCSC, 1981). Lot size was the total number of calculations or data points for a set of data, table or figure. Randomly selected data points were traced to the original data or verified computer analysis. In the case of calculations, the appropriate number of calculations were recalculated utilizing original data. If the recalculated value differed from the original value by greater than rounding error, that data point was rejected. If the number of rejected data points equaled the reject number for the sampling plan at a 1% AOQL, the entire data set was recalculated. A quality assurance audit was performed to insure that all quality control procedures were correctly and completely implemented.

3.0 WATER QUALITY

Water temperature, dissolved oxygen concentration and conductivity were measured in conjunction with the Longitudinal River, Fall Shoals and Beach Seine Surveys. This section presents a brief discussion of the temporal trends in these parameters for the lower, middle and upper segments of the Hudson River estuary, as well as temporal trends in freshwater flow at Green Island, N.Y. (approximately RM 153; km 246).

Water quality data obtained from the Longitudinal River and Fall Shoals Surveys were averaged by stratum (shoal and channel from surface to bottom) and region (1-12) and presented as weighted mean values by sampling period and segment. The water quality data set obtained from the Beach Seine Survey was averaged by region and also weighted to obtain weighted mean values by segment. This data set is presented separately since it did not conform in time or location to the data from the Longitudinal River and Fall Shoals Surveys. Data from the three surveys are also presented by region, stratum and date in Appendix C. Freshwater flow data for Green Island, N.Y. are presented as monthly averages for the years 1971 through 1983 and as long-term monthly averages encompassing the years 1918-1982.

Each of these abiotic environmental variables influences population dynamics of Hudson River fishes, and consequently they represent important factors influencing the structure of Hudson River fish populations. More specific information on temperature and conductivity is presented where appropriate in the discussions on distribution of selected species (Section 4.0).

3.1 WATER TEMPERATURE

Mean water temperatures recorded in the offshore strata of the Hudson River estuary from May through October varied among the lower, middle and upper segments by only about 1.2°C (Figure 3.1-1).

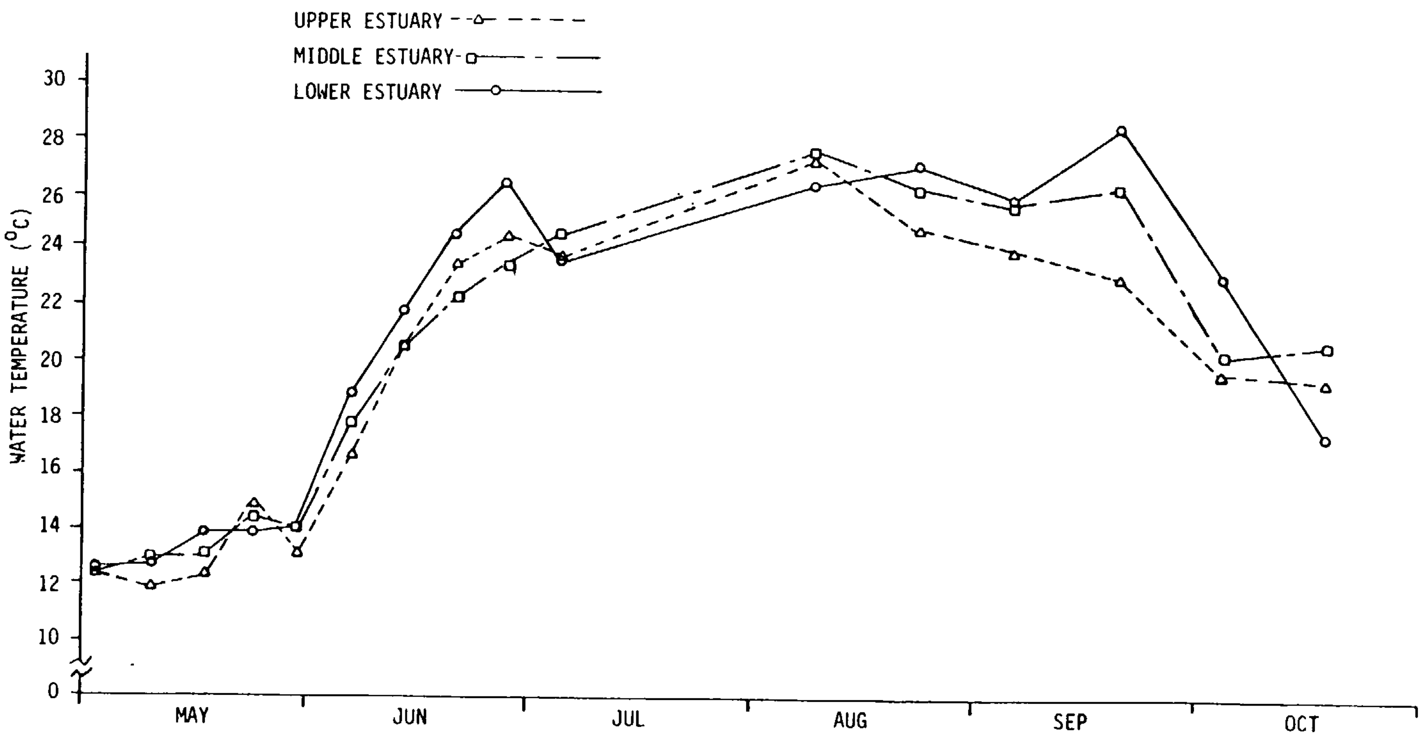

Figure 3.1-1. Weekly mean water temperature (^{o}C) in the offshore strata of the lower, middle and upper segments of the Hudson River estuary, 1983.

Water temperatures increased from May to early August to peaks of 27.5° and 27.3°C in the middle and upper estuary respectively, and subsequently declined. In the lower estuary, water temperature continued to increase through August reaching a maximum of 28.5°C in mid-September. The largest temperature differences among segments were recorded during mid-September when average temperatures in the lower estuary were 2.2° and 5.4°C warmer than those in the middle and upper segments, respectively. Peak water temperatures recorded in each segment were within the range of peak temperatures recorded during the 1979 through 1981 surveys (26.5-28.5°C). In 1982, lower and upper segment temperatures ($\bar{x}$ = 25.2°C and 25.1°C, respectively) were slightly below this range, while middle segment temperatures ($\bar{x}$ = 29.3°C) exceeded this range (NAI, 1984a).

Shore zone temperatures recorded as part of the Beach Seine Survey during August, September and October were generally similar to temperatures recorded in the offshore strata (Figure 3.1-2). In most instances temperatures varied between the shore zone and offshore strata less than 1°C. Exceptions occurred during late August and early September when the shore zone in the upper segment was 4.8°C warmer than the offshore strata, and during mid-September when the shore zone in the lower segment was 3.7°C cooler than the offshore strata. Higher variability of water temperatures in the shore zone is expected due to more rapid warming and cooling of the shallow waters.

3.2 DISSOLVED OXYGEN

On the average, dissolved oxygen concentrations in the offshore strata varied among segments by less than 1 mg/ℓ. Dissolved oxygen declined steadily from May through June and remained at these seasonally low levels of 6.0-7.5 mg/ℓ through October (Figure 3.2-1). An increase in dissolved oxygen was observed in the upper estuary during early October but this was short-lived, with concentrations returning to levels similar to those observed in the lower and

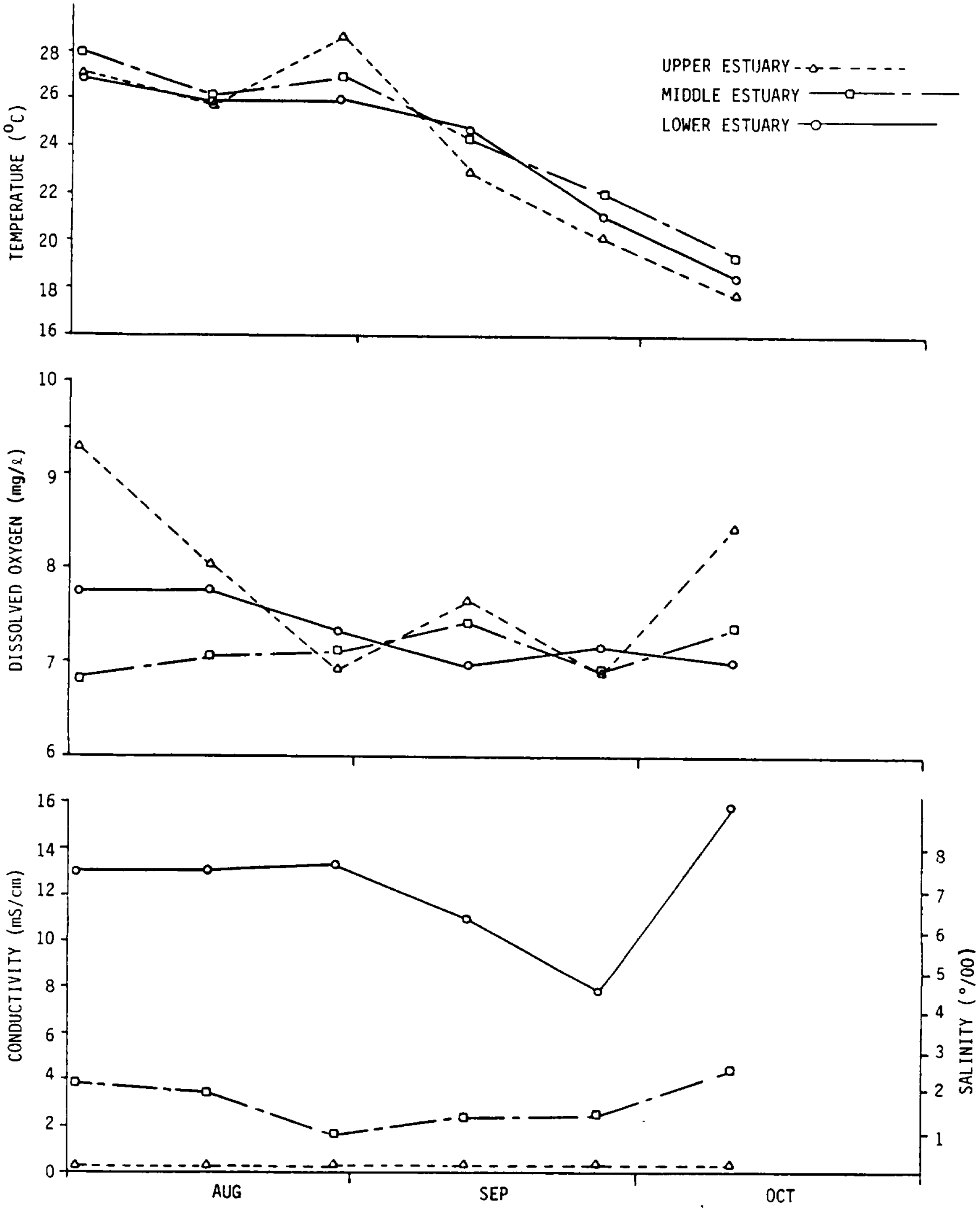

Figure 3.1-2. Weekly mean temperature, dissolved oxygen and conductivity in the shore zone of the lower, middle and upper segments of the Hudson River estuary, 1983.

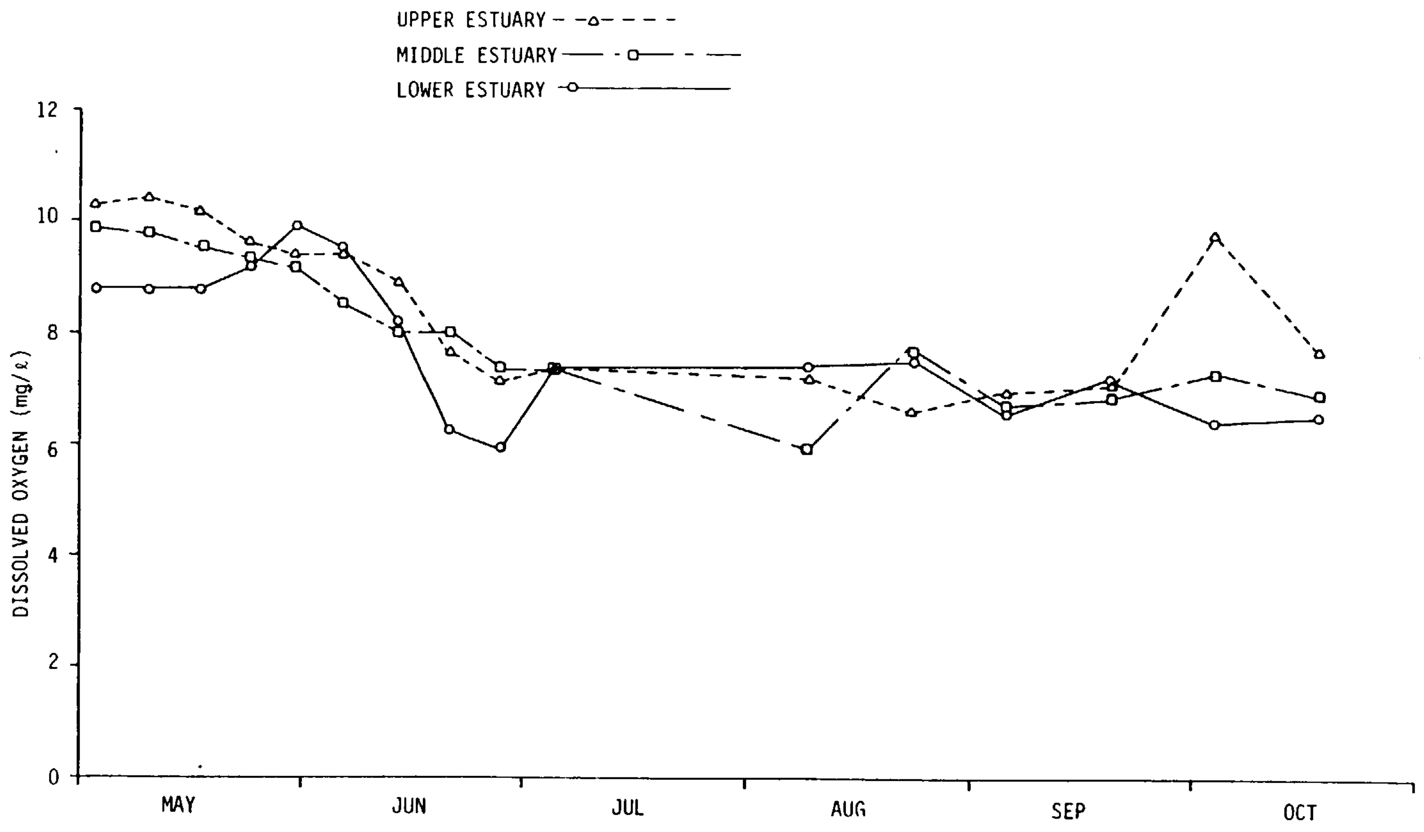

Figure 3.2-1. Weekly mean dissolved oxygen (mg/ℓ) in the offshore strata of the lower, middle and upper segments of the Hudson River estuary, 1983.

middle segments by the following sampling period. The high spring concentrations (9.0-10.5 mg/ℓ) and low summer concentrations (6.0-7.5 mg/ℓ) were consistent with past years' observations.

Shore zone dissolved oxygen concentrations (Figure 3.1-2) in each segment were, on the average, slightly (0.3 mg/ℓ) higher than those observed in the offshore strata.

3.3 CONDUCTIVITY

Conductivity to salinity conversions are presented in Table 3.3-1 to facilitate comparisons between these two closely related environmental variables. As anticipated, mean conductivity in the offshore strata varied considerably among the lower, middle and upper estuary (Figure 3.3-1). In the upper estuary, mean conductivity during the May through October sampling periods was consistently less than 0.35 mS/cm. Similarly low values were recorded in past years in this segment, which experiences only minimal saltwater intrusion. Seasonal conductivity variations in the lower and middle estuary were also similar to previous years (NAI, 1984a), and as expected, followed a pattern that was essentially opposite to freshwater flow (Figure 3.3-2). In the middle estuary, conductivity increased from a low of less than 0.3 mS/cm during late June to 4.3 mS/cm during late August. Following a dip in values during early September, conductivity in the middle segment reached a high of 5.3 mS/cm during mid-September. This late summer peak was similar to the late summer peaks observed in 1981 and 1982 when conductivity in the middle segment reached 6.0 and 5.0 mS/cm, respectively (Battelle, 1983; NAI, 1984a). In the lower estuary, mean conductivity values were lowest during mid-May (<0.3 mS/cm), and highest during early September (18.4 mS/cm). Similarly high late summer conductivity values were recorded in 1980 and 1981 when mean conductivity values reached approximately 20 mS/cm (Battelle, 1983).

TABLE 3.3-1. CONDUCTIVITY TO SALINITY CONVERSION TABLE[a].

CONDUCTIVITY (mS/cm)	SALINITY[b] (o/oo)	CONDUCTIVITY (mS/cm)	SALINITY[b] (o/oo)
0.50	0.28	16.00	9.39
1.00	0.56	16.50	9.70
1.50	0.84	17.00	10.01
2.00	1.13	17.50	10.32
2.50	1.40	18.00	10.63
3.00	1.69	18.50	10.94
3.50	1.98	19.00	11.25
4.00	2.27	19.50	11.57
4.50	2.55	20.00	11.88
5.00	2.84	20.50	12.20
5.50	3.13	21.00	12.52
6.00	3.42	21.50	12.83
6.50	3.71	22.00	13.15
7.00	4.00	22.50	13.47
7.50	4.29	23.00	13.79
8.00	4.59	23.50	14.12
8.50	4.88	24.00	14.44
9.00	5.17	24.50	14.76
9.50	5.47	25.00	15.09
10.00	5.77	26.00	15.74
10.50	6.06	27.50	16.73
11.00	6.36	30.00	18.40
11.50	6.66	32.50	20.10
12.00	6.96	35.00	21.83
12.50	7.26	37.50	23.58
13.00	7.56	40.00	25.37
13.50	7.86	42.50	27.19
14.00	8.17	45.00	29.05
14.50	8.47	47.50	30.94
15.00	8.78	50.00	32.87
15.50	9.08	52.50	34.83
		55.00	36.83

---

[a] From TI (1981)

[b] $$S = -100 \ln \left(1 - \frac{C_{25}}{178.5}\right)$$

where S = salinity, C_{25} = conductivity ($mS \bullet cm^{-1}$e $25^{o}C$)

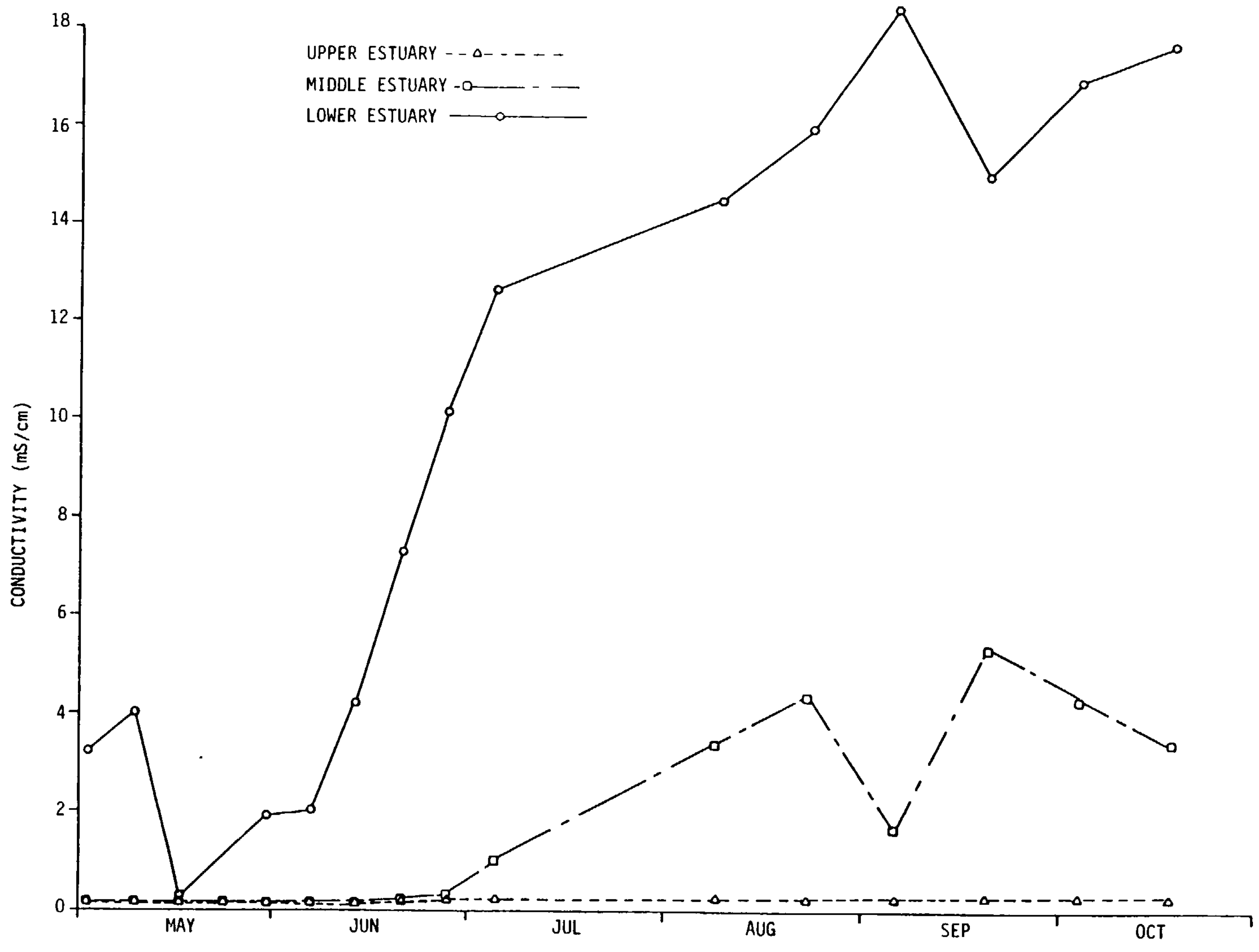

Figure 3.3-1. **Weekly mean** conductivity (mS/cm) in the offshore strata of the lower, middle and upper segments of the Hudson River estuary, 1983.

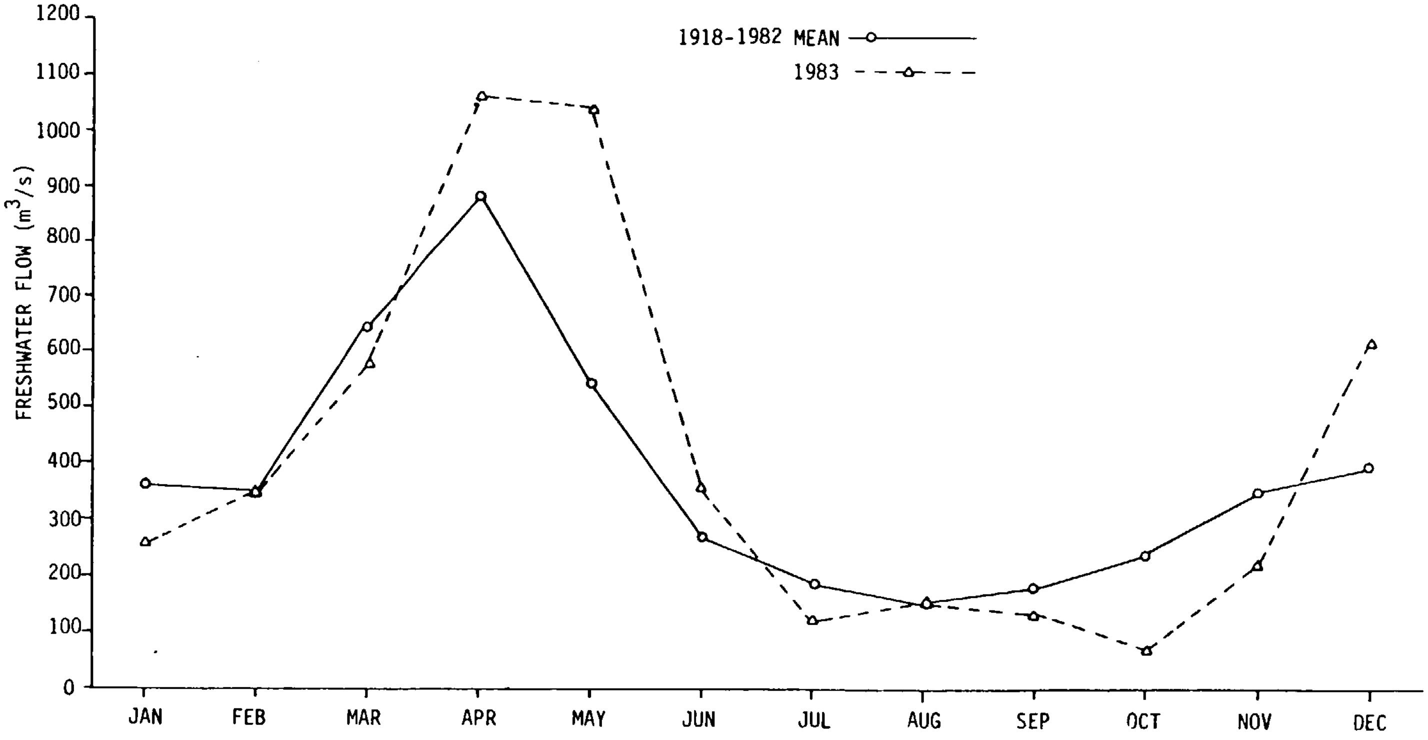

Figure 3.3-2. Monthly averaged freshwater flows at Green Island, N.Y. for 1983 and long-term (1918-1982).

Conductivity values throughout the estuary were consistently 15 to 20 percent lower in the shore zone (Figure 3.1-2) than in the offshore strata. In the lower estuary where conductivity values were highest, shore zone conductivity values were, on average, 4.0 mS/cm lower than in the offshore strata. In the middle and upper estuary, shore zone conductivity values were lower by 0.7 and 0.03 mS/cm, respectively.

3.4 FRESHWATER FLOW

Freshwater flow rates at Green Island, N.Y. during 1983 were slightly above normal, averaging 108 percent of the long-term annual mean (Table 3.4-1). Freshwater flows reached peak levels during April and May, and subsequently declined to lowest levels in October (Table 3.4-2 and Figure 3.3-2). During November, flows increased again and reached moderate levels by December. This trend in freshwater flow was similar to the pattern for the long-term (1918-1982) average monthly flows (Figure 3.3-2).

Although spring flows are normally high, peak flows in 1983 recorded in April (1063 m^3/s) and May 1983 (1037 m^3/s) were 120 and 189 percent greater than the average flow recorded for these months from 1918-1982. Conversely, record low flows were recorded in October when the average monthly flow rate (72 m^3/s) was only 30 percent of normal. This was the lowest average monthly flow rate on record for October and was very close to the record low flow for all months since 1918 (70 m^3/s).

TABLE 3.4-1. MONTHLY FRESHWATER FLOW AT GREEN ISLAND, N.Y. DURING 1983 AS A PERCENT OF LONG-TERM (1918-1982) AVERAGE.

MONTH	1983 PERCENT OF LONG-TERM MONTHLY AVERAGES
Jan	71
Feb	99
Mar	90
Apr	120
May	189
Jun	131
Jul	66
Aug	98
Sep	73
Oct	30
Nov	63
Dec	156
Jan-Dec	108

TABLE 3.4-2. MONTHLY AVERAGED FRESHWATER FLOWS AT GREEN ISLAND, N.Y. (cubic meters per second).

													YEARLY STATISTICS		
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN[a]	MAX	MIN
1971	255	343	573	1055	998	208	177	253	264	221	207	481	420	1055	177
1972	380	310	761	1075	1147	839	521	216	179	207	740	765	595	1147	179
1973	742	579	833	877	782	370	294	158	136	160	235	748	493	877	136
1974	623	528	587	854	650	249	334	180	294	256	487	549	465	854	180
1974	540	549	671	724	566	367	211	254	482	663	637	532	516	724	211
1976	417	885	897	1041	901	431	433	414	271	658	508	399	604	1041	271
1977	225	227	1232	1149	454	207	162	154	408	854	664	752	543	1233	154
1978	745	400	619	950	530	282	132	169	175	244	227	303	398	950	132
1979	751	336	1253	1079	554	236	132	149	221	314	465	430	479	1253	132
1980	256	128	634	748	274	192	144	130	118	156	242	273	275	748	118
1981	148	852	349	385	328	169	140	134	233	457	394	319	322	851	134
1982	321	361	620	1085	354	432	182	125	122	124	196	233	345	1085	122
1983	259	352	580	1063	1037	358	127	155	133	72	224	624	416	1063	72

LONG-TERM SUMMARY: 1918-1982

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MAX	961	885	1595	1461	1156	839	637	414	612	854	929	948	
MEAN[b]	365	356	646	884	550	274	194	158	182	241	355	401	384
MIN	91	86	178	290	137	92	81	70	81	72	93	123	
N	65	65	65	65	65	65	65	65	65	65	65	65	

[a] Mean of monthly means weighted by number of days/month

[b] Mean is simple mean of monthly means

Source: United States Geological Survey (1983, 1984)

4.0 SPATIAL AND TEMPORAL DISTRIBUTION AND ABUNDANCE OF SELECTED SPECIES

4.1 STRIPED BASS

The striped bass, *Morone saxatilis*, is an anadromous bass in the family Percichthyidae. It is a tolerant and widespread species, with an Atlantic coast distribution north to the St. Lawrence River and south to the St. Johns River in northern Florida and into the Gulf of Mexico. During the 19th century striped bass were introduced to the Pacific coast in the vicinity of San Francisco and today range between the Canadian and Mexican borders. In the Hudson River, striped bass have been observed throughout the estuary north to the Troy Dam in Albany (TI, 1981).

The striped bass is a euryhaline species and may be found in salt, brackish or fresh water. Those adults found in fresh water usually consist of spawning groups or of stragglers. When in salt water they remain relatively close to the shore, rarely being recorded more than 16 kilometers offshore (Raney, 1976).

The spawning bass are usually located near the mouths of rivers just above brackish water, although some have been observed spawning up to 300 kilometers from any salt water (Raney, 1976; Dovel, 1981). Areas of intense striped bass spawning appear to occur a short distance upstream from the limit of brackish water (Rathjen and Miller, 1957). Spawning in the Hudson River occurs in the early spring, beginning with the upstream migration into fresh water in the area between Croton-Haverstraw (km 55) and West Point (km 88). Clark (1968) has shown that the Hudson River, particularly that area in the vicinity of Haverstraw, is an important spawning area for the striped bass and that the stock produced there is an important fishery resource around New York Harbor and the western part of Long Island Sound.

After spawning is complete, some adults remain in the estuary, although most tend to leave and return to sea. During the fall months along the Atlantic coast, a massive southward migration to the wintering grounds in Chesapeake and Delaware Bays begins. Some of these southward migrants break off and enter the lower reaches of the Hudson River. Here they remain to overwinter and spawn during the following spring.

Striped bass eggs are deposited near the surface in areas of strong currents ensuring that they do not settle to the bottom, where the danger of suffocation is present (Bigelow and Schroeder, 1953). The eggs are spherical, semi-buoyant and non-adhesive and are found in the entire water column from surface to bottom, with densities being greater near the bottom in areas of slow currents (Albrecht, 1964). Eggs are 3-4 mm in diameter and hatch in 37 hours at a temperature of 21°C (Rogers *et al.,* 1977).

The number of eggs released varies with the size of the female, with 100,000 eggs being produced by a 2-kg female and up to 5 million by a 25-kg female (Raney, 1976). Some females reach sexual maturity by Age IV, with virtually all being mature by age IX. Most males reach maturity by age II or III, with all reaching sexual maturity by age IX.

On hatching, the larvae are approximately 2-5 mm in length, and begin to move into areas of low salinity. This seems to enhance their survival and growth (Dovel and Edmunds, 1971). The yolk sac is absorbed in 6-7 days at which time the larvae have reached a total length of 6 mm. During the first summer the young remain in small schools, feeding on small pelagic and benthic invertebrates and fish. The young are most commonly found in the shore zone and prefer sand or gravel beaches where the current is moderate. Toward the fall, juvenile striped bass move downstream and during winter, they presumably reside in the deeper parts of the lower estuary or farther seaward.

The striped bass is a powerful and fierce predator eating a variety of animal foods as juveniles and becoming increasingly piscivorous as they grow (Trent and Hassler, 1966). The striped bass is a long-lived species which can attain a total length of 1100 mm and a weight of more than 14 kg (Bigelow and Schroeder, 1953).

4.1.1 Eggs

Striped bass eggs were first collected during the week of 9 May between Croton-Haverstraw and Kingston. Temperatures at this time were approximately 13°C and conductivities were less than 0.2 mS/cm (Appendix C; Tables C-1 and C-5). The area of concentration was in the middle estuary and the extreme lower reaches of the upper estuary (km 75-137). The peak concentration of eggs was in the Hyde Park region (Figure 4.1-1) occurring primarily during the week of 30 May. Prior to this sampling period, the majority of the striped bass eggs were collected in the Indian Point and West Point regions (Figure 4.1-2), as was the case during 1974-1982 (TI, 1981; Battelle, 1983; NAI, 1984a). This area of concentration was similar to that noted by Rathjen and Miller (1957) and may be associated with the strong currents of this relatively narrow river region. Spawning continued through June with eggs being collected in very small numbers through early July, attributable to a few late spawners.

The distribution of eggs among river regions during the weeks of peak abundance showed a shift from the initial site of egg deposition (Indian Point) north to Hyde Park (Figure 4.1-2). This movement has also been observed in previous years (NAI, 1984a) and can be attributed in part to an upriver movement of spawning adults to areas of lower salinities, as well as to tidal drift of eggs. Hardy (1978) states that striped bass eggs are easily floated by agitation and can drift with the currents, reaching speeds up to 2 km/hr and traveling distances of up to 150 km. In all cases, striped bass eggs were collected in waters with conductivity values below 0.9 mS/cm.

At the time the ichthyoplankton sampling began the water temperature in the middle estuary was 12°C. Temperatures remained relatively constant (14°C) through the week of 30 May when peak abundance of eggs was observed. At this temperature, eggs would be expected to hatch in about 70 hours (Rogers *et al.*, 1977).

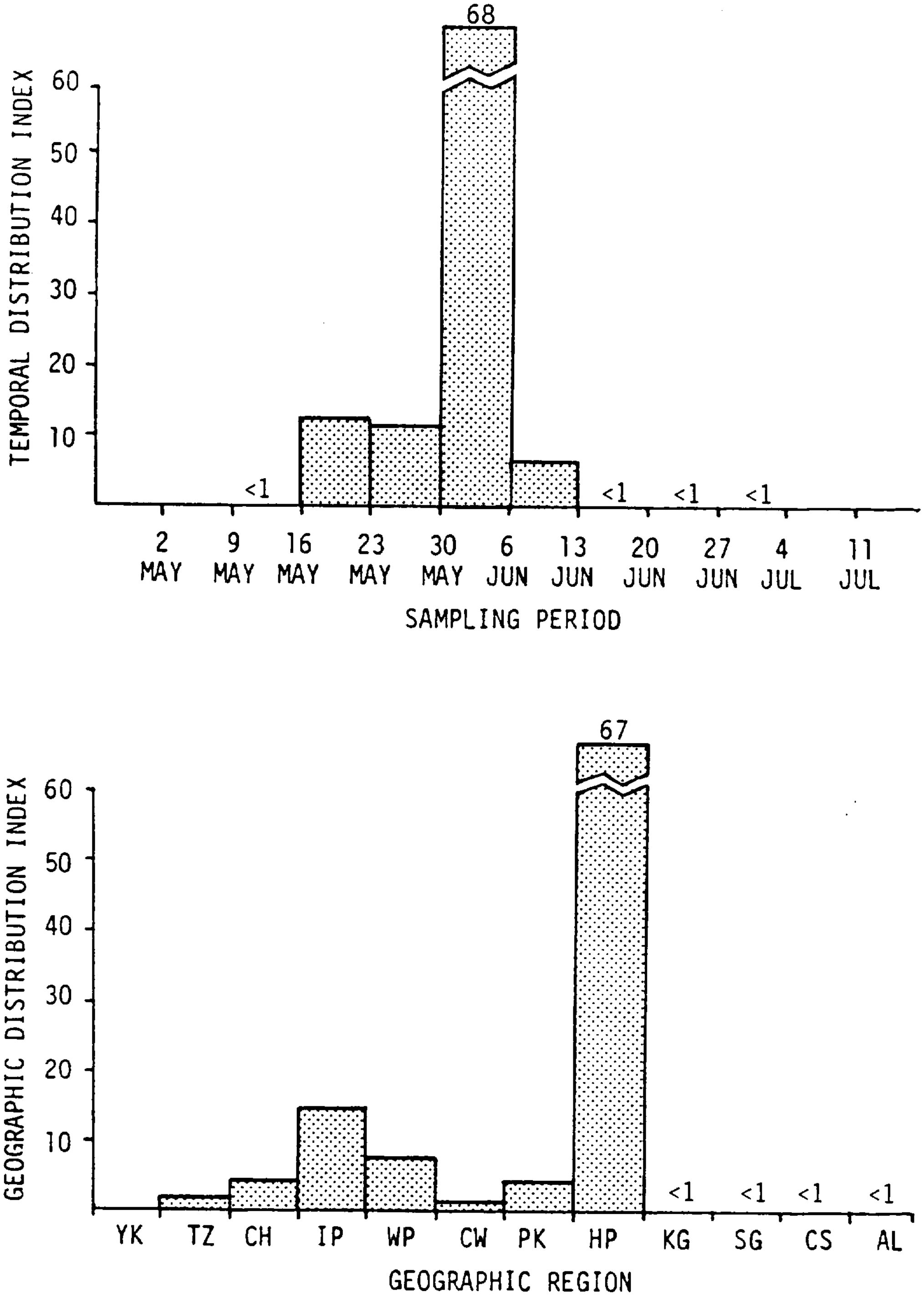

Figure 4.1-1. Temporal and geographic distribution of striped bass eggs based on ichthyoplankton sampling, Hudson River estuary, 1983.

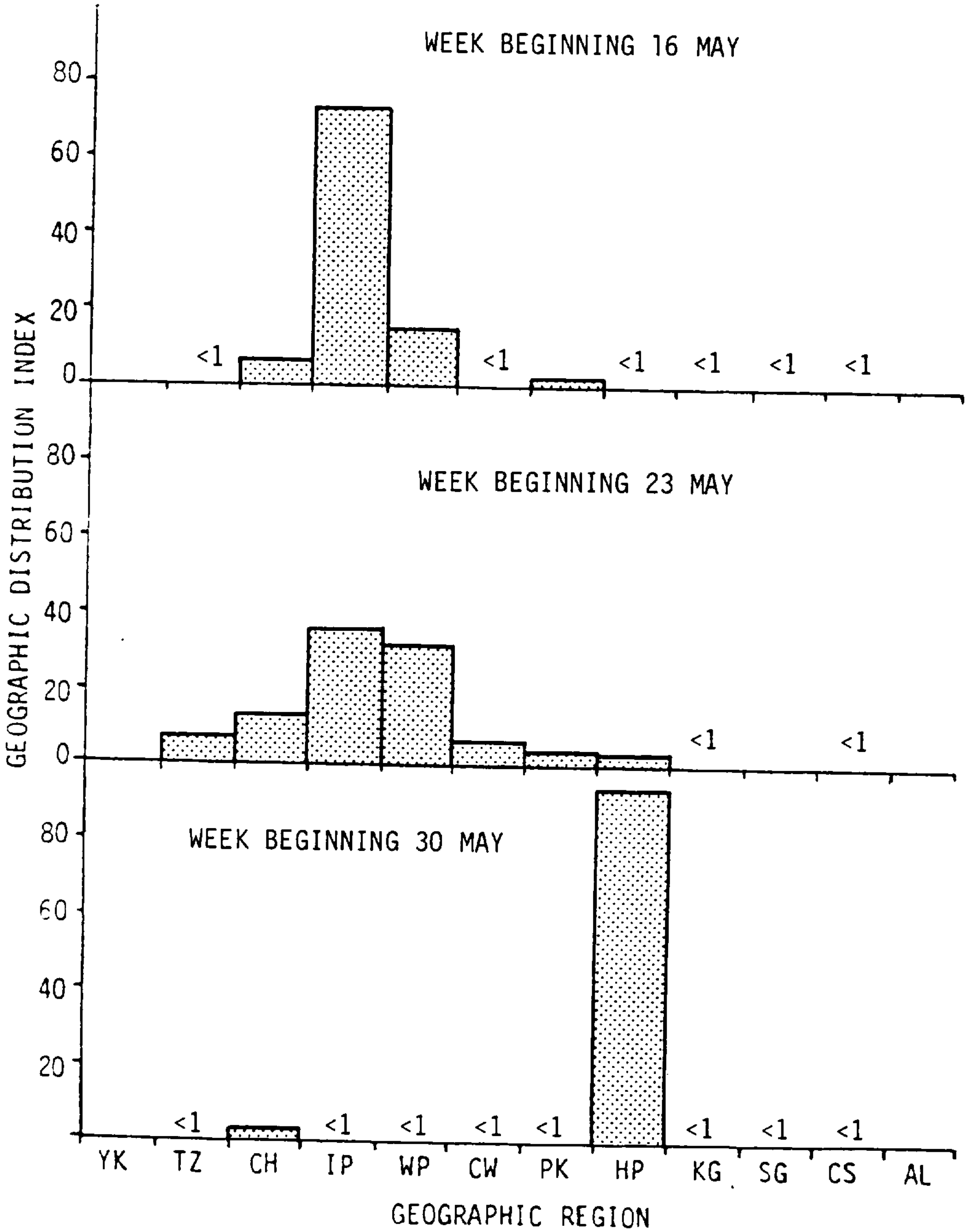

Figure 4.1-2. Weekly geographic distribution of striped bass eggs during the period of peak occurrence, based on ichthyoplankton sampling, Hudson River estuary, 1983.

The period of peak egg abundance for 1983 and previous years occurred when the water reached an average temperature of 14°C and conductivity of 0.14 mS/cm. This period has usually occurred around the third week of May (Table 4.1-1).

4.1.2 Yolk-Sac Larvae

Yolk-sac larvae were first collected during the week of 9 May in the middle estuary with densities less than 3/1000 m^3. Peak abundance of yolk-sac larvae occurred during the week of 13 June, two weeks after peak occurrence of eggs. Water temperatures from 30 May (peak egg abundance) to 19 June (peak yolk-sac larva abundance) increased from 14°C to 21°C, decreasing in half, from 10 days to 5 days, the time interval from hatching to yolk-sac absorption. Yolk-sac larvae were continually collected throughout June and until the end of the sampling period at temperatures of 18° - 24°C (densities averaged less than 100/1000 m^3).

In 1983, peak yolk-sac larva abundance appeared to be in the same general area of peak egg deposition (Figure 4.1-3). The region of peak abundance in 1983 was Poughkeepsie, where during this period of abundance, mean water temperature was 20°C and mean conductivity was 0.16 mS/cm (Appendix C; Tables C-1 and C-5). At the start of the 1983 sampling, highest yolk-sac larva abundance appeared to be in the Tappan Zee region (Figure 4.1-4), but a shift northward was observed weekly with the final area of concentration being in the Poughkeepsie region during the week of 13 June. This movement has also been observed in previous years (TI, 1981; Battelle, 1983; NAI, 1984a) as well as in other estuarine systems (Setzler-Hamilton *et al.*, 1981), and is usually associated with the movement of the salt front. In 1983, this shift in concentration is probably due more to an increase in spawning activity (as temperatures increased) further upriver rather than to any transport suggested by shifting conductivities.

TABLE 4.1-1. MEAN TEMPERATURE (°C) AND CONDUCTIVITY (mS/cm) DURING THE PERIODS OF PEAK STRIPED BASS EGG ABUNDANCE IN THE REGIONS OF GREATEST ABUNDANCE,[a] HUDSON RIVER ESTUARY, 1974-1983.

YEAR	PEAK PERIOD	TEMPERATURE (°C)		CONDUCTIVITY (mS/cm)	
		MEAN	RANGE	MEAN	RANGE
1974	12 May-25 May	15.4	13.0-16.5	0.164	0.155-0.176
1975	18 May-31 May	19.0	17.9-22.0	0.137	0.114-0.178
1976	23 May-05 Jun	15.0	13.0-17.0	0.152	0.139-0.176
1977	15 May-28 May	14.6	12.0-17.0	0.147	0.126-0.218
1978	21 May-27 May	15.7	15.0-17.0	0.162	0.141-0.253
1979	06 May-19 May	16.2	12.5-19.5	0.192	0.110-2.000
1980	19 May-22 May	16.3	15.4-16.8	0.242	0.169-0.383
1981	18 May-21 May	15.9	15.8-16.1	0.208	0.180-0.237
1982	24 May-28 May	17.1	17.0-17.4	0.340	0.144-0.729
1983	16 May-05 Jun	13.6	12.5-14.8	0.150	0.130-0.170

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[a] Indian Point, West Point and Poughkeepsie in 1974-1981 (TI, 1981; Battelle, 1983); West Point, Poughkeepsie and Hyde Park in 1982 (NAI, 1984a); Indian Point, West Point and Hyde Park in 1983.

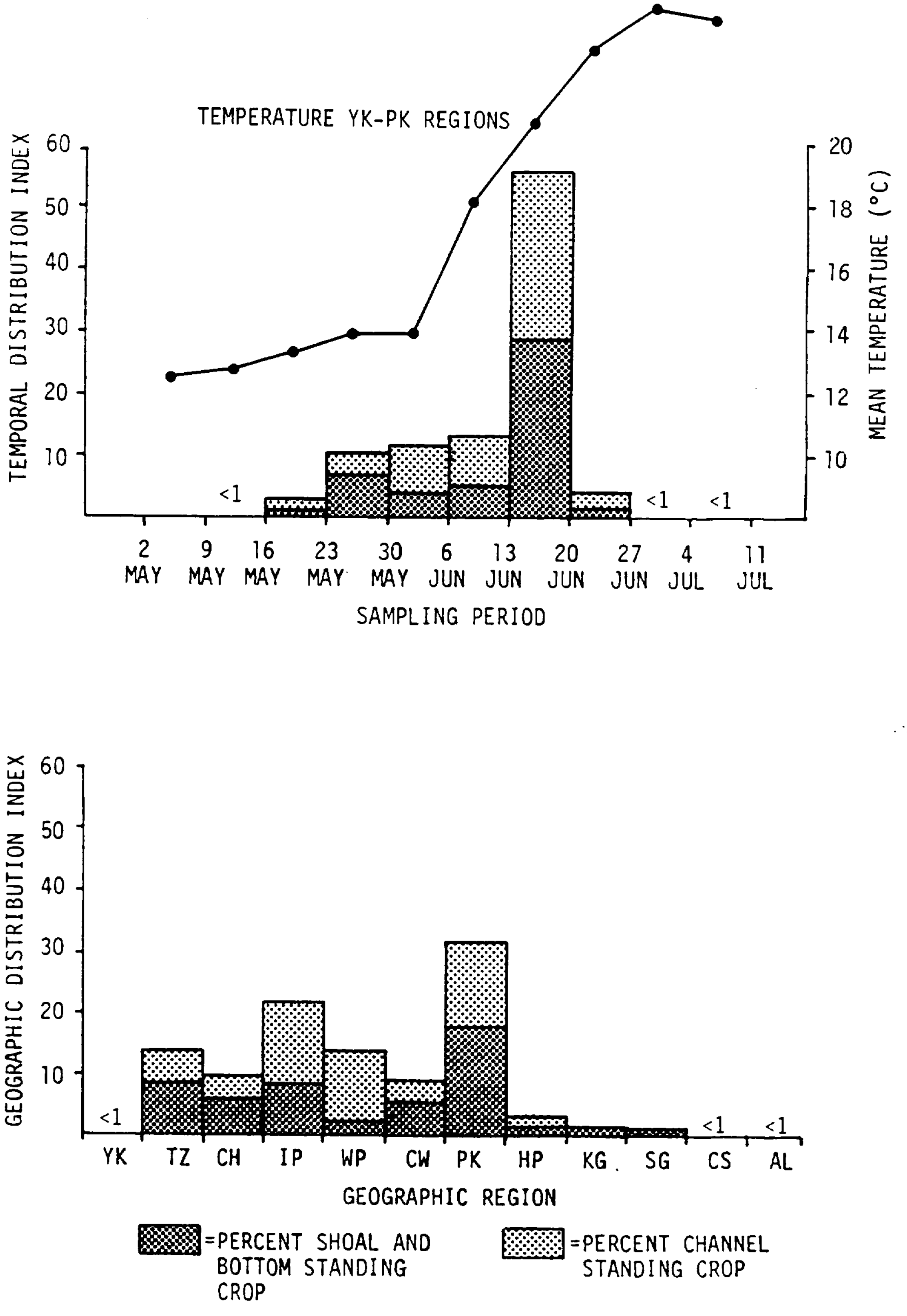

Figure 4.1-3. Temporal and geographic distribution of striped bass yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

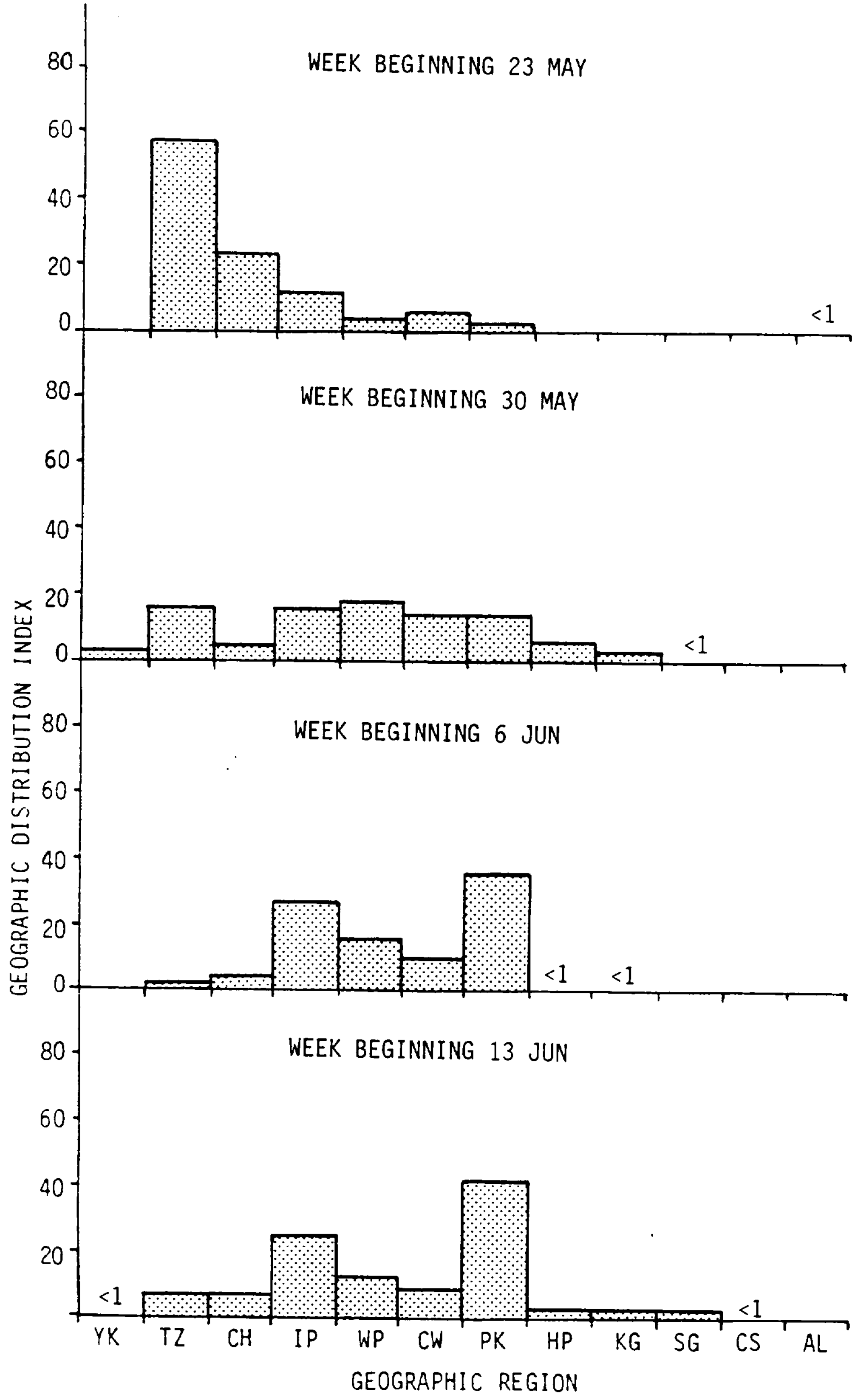

Figure 4.1-4. Weekly geographic distribution of striped bass yolk-sac larvae during the period of peak occurrence, based on ichthyoplankton sampling, Hudson River estuary, 1983.

Mean regional temperatures (Yonkers through Poughkeepsie) during the period of greatest yolk-sac larva abundance were 21°C. At this temperature, duration of this stage would be two days. Temperatures near 18°C appear to be optimum for development (Morgan *et al.*, 1981). Peak abundance of yolk-sac larvae from 1974 to 1983 occurred when water temperatures reached a mean of 16° - 20°C and a conductivity of 0.15 - 0.34 mS/cm (Table 4.1-2).

Yolk-sac larvae are believed to be attracted toward light, and are distributed within the entire water column, rarely dropping to the bottom (Hardy, 1978). McFadden *et al.* (1978) observed striped bass yolk-sac larvae to be more concentrated in lower portions of the water column during the day and in the upper portions at night in the Cornwall area of the Hudson. Toward the end of the yolk-sac stage, as feeding begins, larvae tend to concentrate closer to the bottom. This change in depth distribution has been observed to occur approximately one week after hatching in the Hudson River estuary (Rathjen and Miller, 1957) and in Chesapeake Bay and the Delaware River (Kernehan *et al.*, 1981). In 1983, these observations of diel differences in vertical distribution and increasing bottom densities as yolk-sac larvae mature were supported by the relative densities in the channel and bottom strata. Although the majority of the yolk-sac larvae were found in the channel stratum during 1983, the percentage taken in the bottom stratum was greater than for eggs, particularly in those areas that are essentially fresh water (Figure 4.1-3).

4.1.3 Post Yolk-Sac Larvae

Abundance of striped bass post yolk-sac larvae peaked during the third week of June, one week after the peak abundance of yolk-sac larvae occurred. During the time of highest abundances of yolk-sac larvae, mean water temperature was 21°C (Table 4.1-3). At this temperature Rogers *et al.* (1977) estimated that the duration of the yolk-sac stage would be 2-3 days. Post yolk-sac larvae continued to be collected throughout the remainder of the sampling season. The average

TABLE 4.1-2. MEAN TEMPERATURE (°C) AND CONDUCTIVITY (mS/cm) DURING THE PERIODS OF PEAK STRIPED BASS YOLK-SAC LARVAE ABUNDANCE IN THE REGION OF GREATEST ABUNDANCE,[a] HUDSON RIVER ESTUARY, 1974-1983.

YEAR	PEAK PERIOD	TEMPERATURE (°C) MEAN	TEMPERATURE (°C) RANGE	CONDUCTIVITY (mS/cm) MEAN	CONDUCTIVITY (mS/cm) RANGE
1974	26 May-08 Jun	17.5	16.2-19.0	0.175	0.136-0.312
1975	25 May-07 Jun	19.9	18.2-22.0	0.158	0.010-0.884
1976	30 May-12 Jun	16.4	14.5-19.0	0.155	0.142-0.220
1977	22 May-04 Jun	17.0	14.5-21.0	0.162	0.135-0.221
1978	28 May-10 Jun	20.2	19.0-21.8	0.152	0.095-0.282
1979	20 May-02 Jun	18.2	14.5-22.0	0.173	0.120-1.550
1980	27 May-30 May	17.2	16.3-17.7	0.176	0.173-0.180
1981	18 May-21 May	15.9	15.8-16.1	0.208	0.180-0.237
1982	24 May-28 May	17.1	17.0-17.4	0.340	0.144-0.729
1983	06 Jun-19 Jun	19.2	17.4-20.6	0.178	0.160-0.190

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[a] Indian Point, West Point and Poughkeepsie in 1974-1979 (TI, 1981), 1981 (Battelle, 1983) and 1983; West Point, Poughkeepsie and Hyde Park in 1980 (Battelle, 1983) and 1982 (NAI, 1984a).

TABLE 4.1-3. MEAN TEMPERATURE (°C) AND CONDUCTIVITY (mS/cm) DURING THE PERIODS OF PEAK STRIPED BASS POST YOLK-SAC LARVAE ABUNDANCE IN THE REGIONS OF GREATEST ABUNDANCE,[a] HUDSON RIVER ESTUARY, 1974-1983.

YEAR	PEAK PERIOD	TEMPERATURE (°C)		CONDUCTIVITY (mS/cm)	
		MEAN	RANGE	MEAN	RANGE
1974	09 Jun-22 Jun	21.5	19.9-23.5	1.032	0.125-3.351
1975	01 Jun-14 Jun	20.6	19.5-22.0	0.579	0.070-4.808
1976	06 Jun-19 Jun	18.6	16.0-22.0	0.154	0.144-0.221
1977	29 May-18 Jun	19.3	17.5-21.2	0.770	0.138-5.217
1978	04 Jun-17 Jun	20.7	19.5-23.1	0.162	0.095-0.282
1979	27 May-02 Jun	18.4	14.5-22.0	0.155	0.125-0.245
1980	02 Jun-13 Jun	18.2	17.5-19.0	1.600	0.400-4.500
1981	01 Jun-13 Jun	18.0	17.0-19.0	1.300	1.000-1.600
1982	31 May-09 Jun	18.5	17.9-18.9	0.267	0.159-0.477
1983	13 Jun-26 Jun	21.7	20.3-24.3	0.296	0.160-1.070

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[a] Indian Point, West Point and Poughkeepsie in 1974-1981 (TI, 1981; Battelle, 1983); Indian Pont, West Point, Poughkeepsie and Croton-Haverstraw in 1982 (NAI, 1984a) and 1983.

duration of the post yolk-sac stage is 23-25 days at 21°C (Rogers *et al.*, 1977).

The regions of peak post yolk-sac abundance were centered in the middle estuary (Figure 4.1-5). Early post yolk-sac larvae were most concentrated in the Indian Point region (Figure 4.1-6). As swimming ability increased, older post yolk-sac larvae were taken in a broader area (still centered around Indian Point) with trace abundance reaching into the upper estuary. Previous year class reports noted that there was a general tendency for dispersal downriver and towards the bottom as feeding begins (TI, 1981; Battelle, 1983; NAI, 1984a).

4.1.4 Young-of-the-Year

Transformation of post yolk-sac larvae to juveniles began in the latter part of June, during the ichthyoplankton sampling (Figure 4.1-7). Temperatures at this time averaged 24-25°C with conductivities averaging 5 mS/cm in the Tappan Zee to Indian Point regions. Juvenile abundance at the time of transformation was concentrated in the upper reaches of the lower estuary where conductivities were higher than those previously encountered during the post yolk-sac stage. Rathjen and Miller (1957) noted that those specimens making their way downriver to higher salinities tended to grow faster than those captured upriver in fresh water.

Peak abundance of early juveniles in the offshore strata (channel, bottom, and shoals) probably occurred during the month of July (Figure 4.1-7) through the early part of August (Figure 4.1-8). The juveniles had begun moving into the shore zone prior to the first of August (Figure 4.1-9), with abundance reaching its peak during mid-September, after densities had decreased in the offshore strata.

The general pattern of juvenile distribution in the offshore strata suggests that dispersion of striped bass from the study area began in late August and continued through September. The increase in

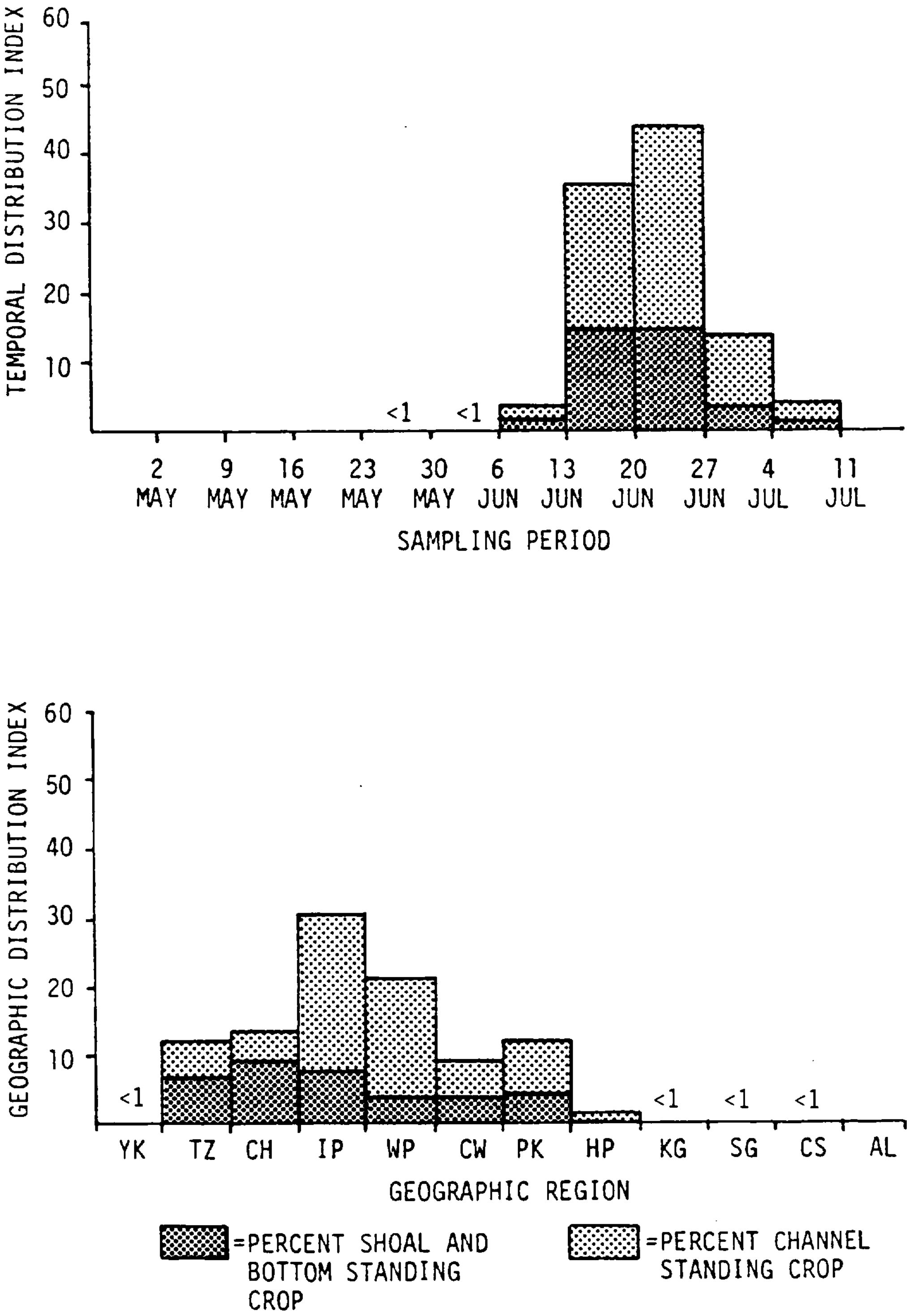


Figure 4.1-5. Temporal and geographic distribtuion of striped bass post yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

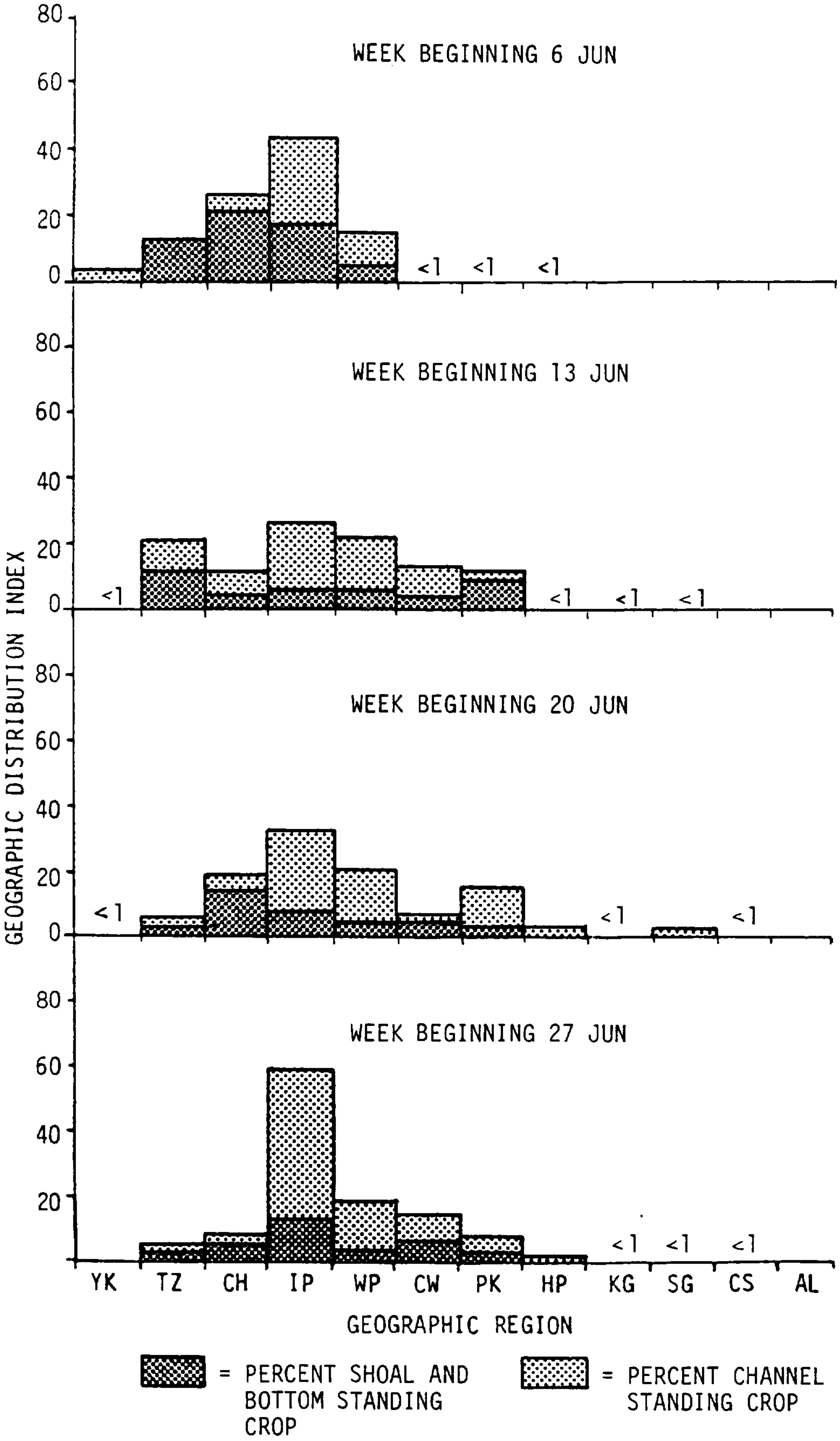


Figure 4.1-6. Weekly geographic distribution of striped bass post yolk-sac larvae during the period of peak occurrence, based on ichthyoplankton sampling, Hudson River estuary, 1983.

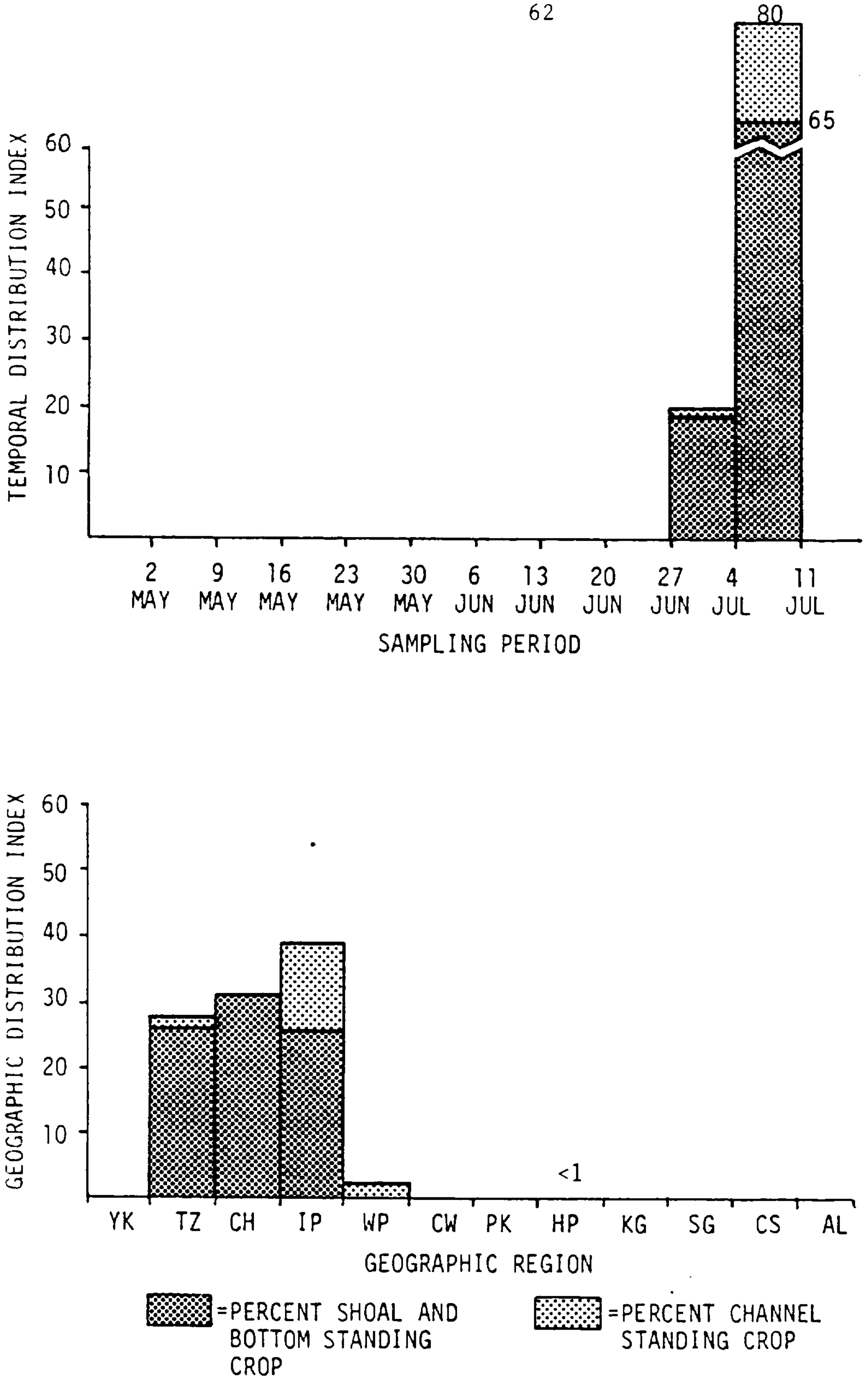
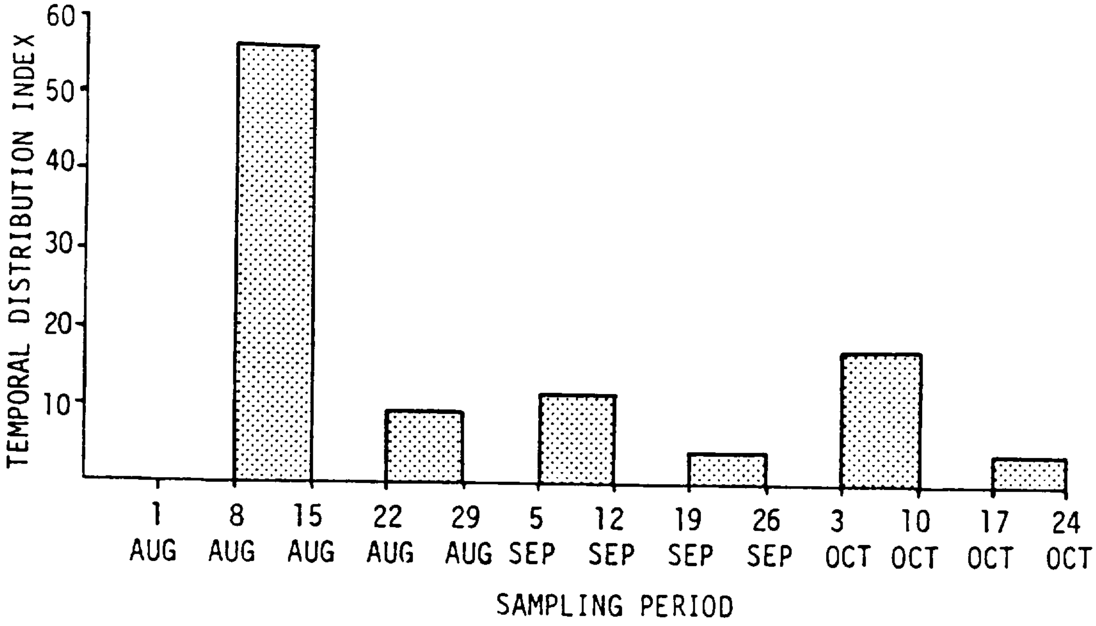


Figure 4.1-7. Temporal and geographic distribution of striped bass young-of-the year based on ichthyoplankton sampling, Hudson River estuary, 1983.



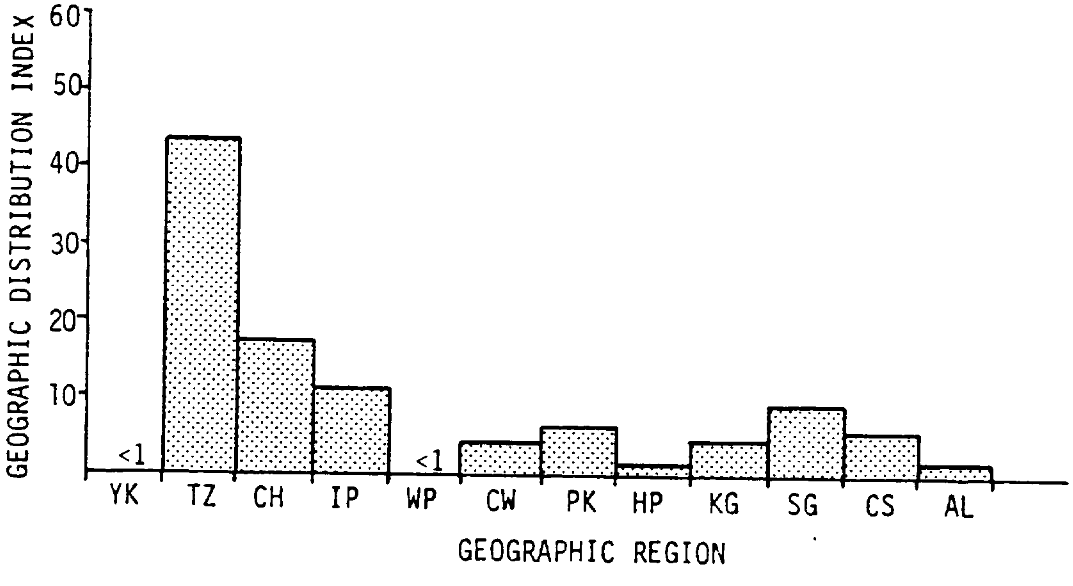
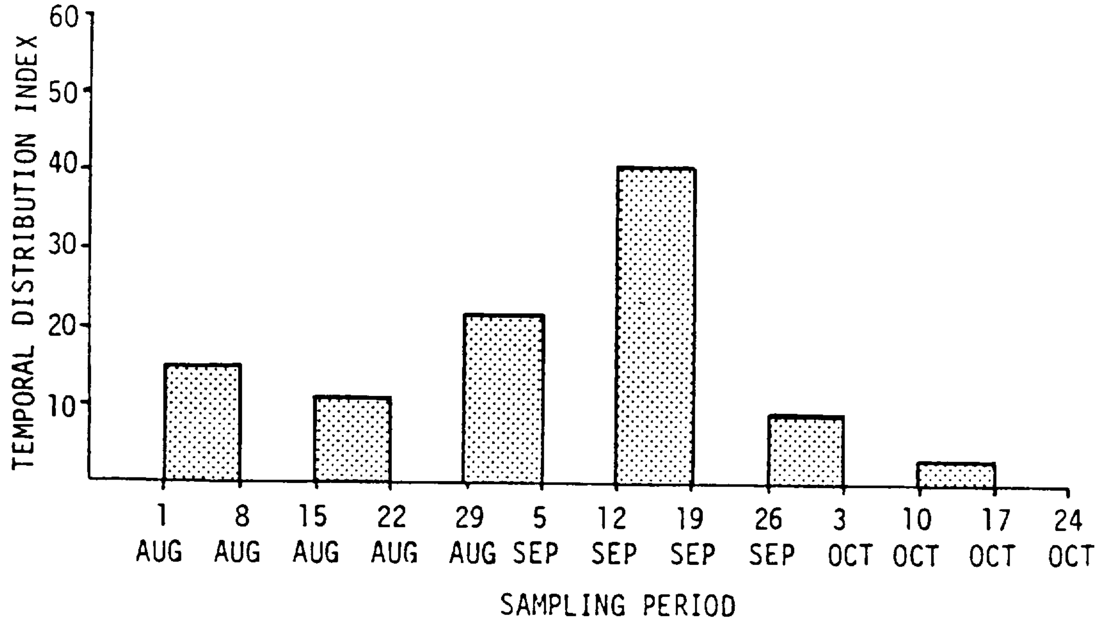


Figure 4.1-8. Temporal and geographic distribution of striped bass young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.



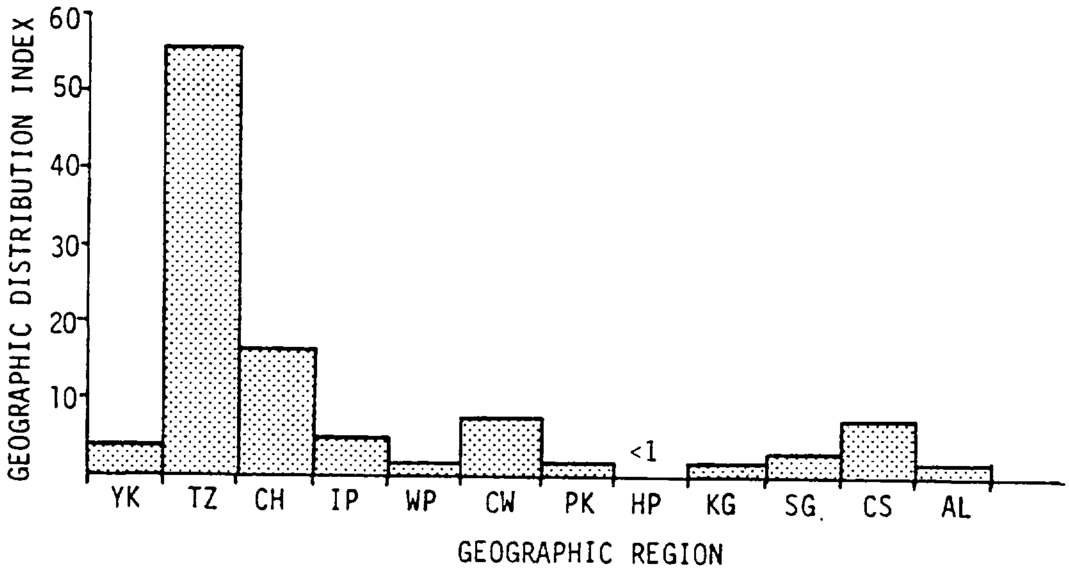


Figure 4.1-9. Temporal and geographic distribution of striped bass young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

the shore zone abundance was less than the decrease in the offshore strata (Appendix B; Tables B-5 and B-6). It appears therefore that emigration for those juveniles leaving in August was by way of the deeper offshore strata. Those remaining until the end of fall and/or those overwintering in the estuary tended to move into the shore zone of the lower estuary.

Shore zone conductivities in the lower estuary were approximately 12 mS/cm (range 6.5-18.7) from 1 August to mid-September (Appendix C-6). Juvenile abundance in the shore zone remained relatively constant throughout August, increasing in September and then decreasing in October as the young striped bass in the shore zone began to disperse downriver from the middle and upper estuary, accumulating in the lower estuary prior to and during their seaward migration (Appendix B; Table B-6). Most of the juvenile striped bass move out of the estuary during the fall; however some fish presumably do remain in the deeper parts of the lower estuary to overwinter (McFadden *et al.*, 1978; McLaren *et al.*, 1981; TI, 1981; NAI, 1984a).

4.1.5 Yearling and Older Fish

A total of 134 yearling striped bass (members of the 1982 year class) were collected throughout the Hudson River estuary from 16 May through 23 October. Twenty-five of these individuals were taken during the ichthyoplankton survey (Figure 4.1-10). Most of these were taken in the lower estuary, particularly in the Tappan Zee region. Of the 109 yearling striped bass collected during the fall juvenile sampling programs, most were taken in the shore zone throughout the entire estuary (Figure 4.1-11 and Figure 4.1-12). The majority of these striped bass yearlings occurred in August, decreasing thereafter as the fish started their seaward migration.

A total of twelve older (1981 or earlier year classes) striped bass were taken, most frequently in the offshore strata. These fish

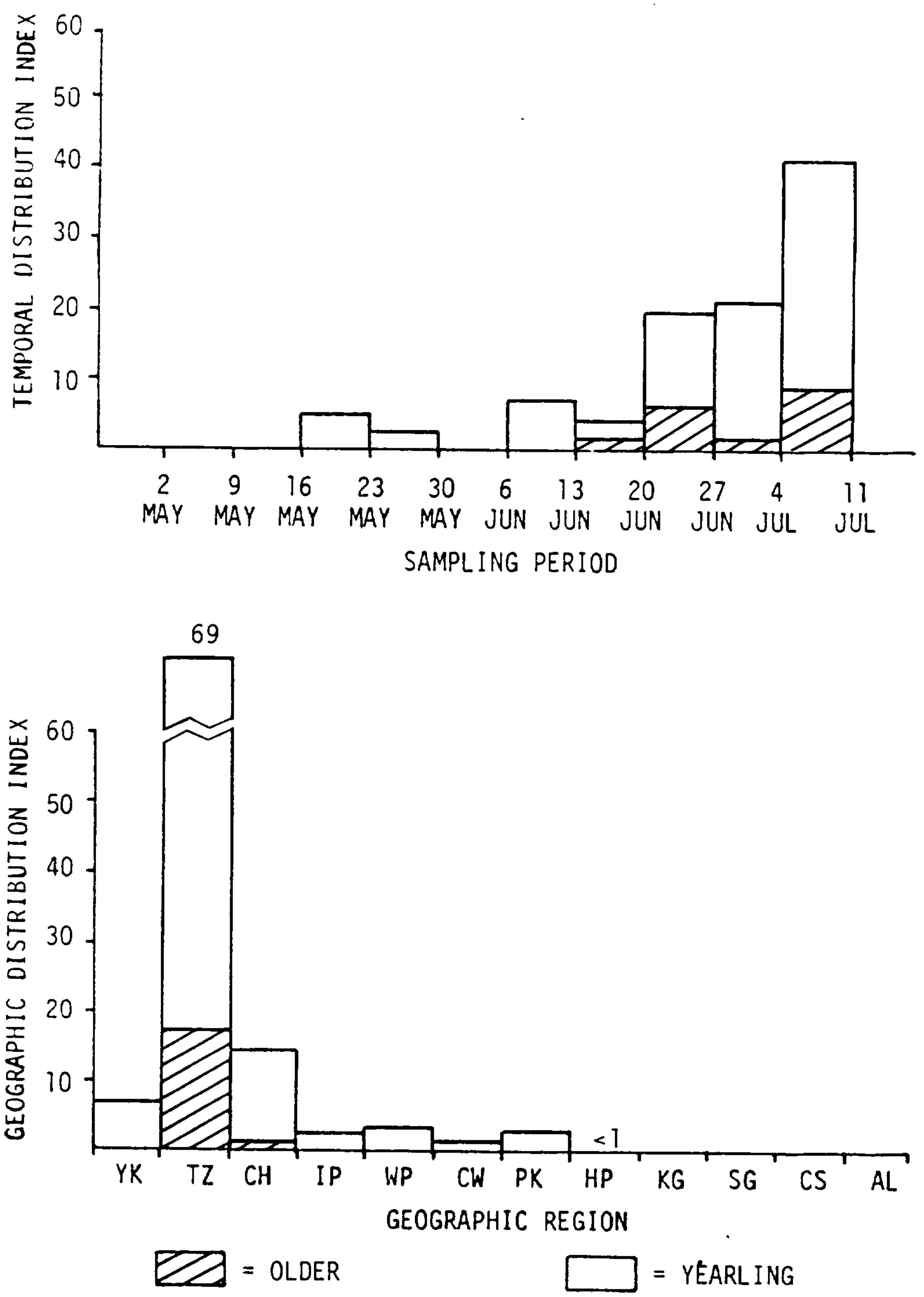


Figure 4.1-10. Temporal and geographic distribution of striped bass yearling and older fish based on ichthyoplankton sampling, Hudson River estuary, 1983.

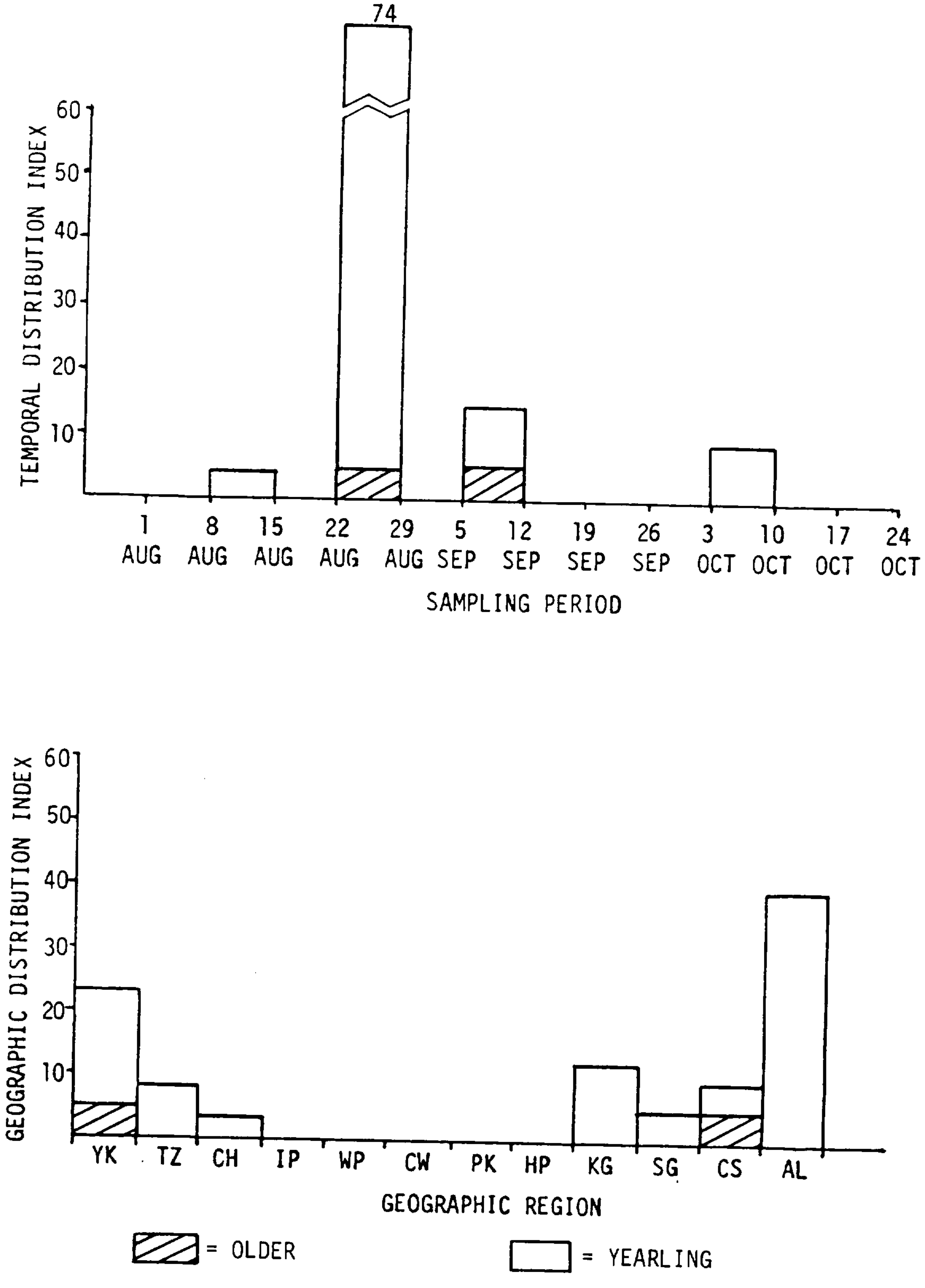


Figure 4.1-11. Temporal and geographic distribution of striped bass yearling and older fish based on the Fall Shoals Survey, Hudson River estuary, 1983.

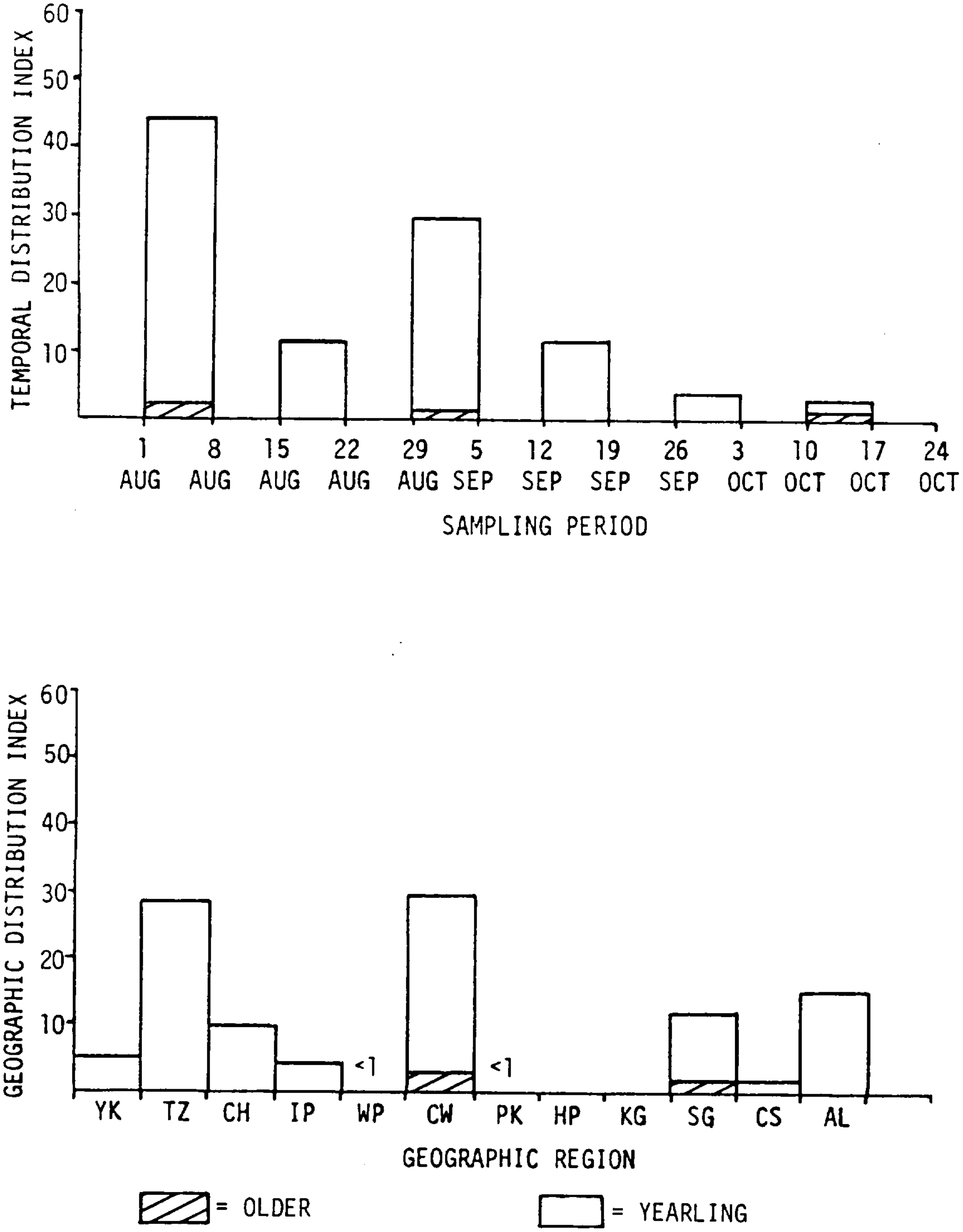


Figure 4.1-12. Temporal and geographic distribution of striped bass yearling and older fish based on the Beach Seine Survey, Hudson River estuary, 1983.

were taken between Yonkers and Catskill with the greatest concentration in the lower estuary within the bottom stratum.

4.1.6 Recaptured Hatchery-Reared Fish

During the first year of operation, the striped bass hatchery released a total of 61,357 juveniles into the lower section of the Hudson River estuary (Table 4.1-4). When released these fish averaged ≥76 mm TL, with no more than 10% <76 mm and none <71 mm. Of these fish stocked, a total of 15 juveniles (75-121 mm TL) were recaptured. Eight were taken in Croton-Haverstraw, two in Tappan Zee and five in Indian Point (Table 4.1-5). Most of these were recaptured in the same area and time period as released; however, four individuals released during the 1-15 August period in Indian Point (km 62.8-74.0) were recaptured downriver in Croton-Haverstraw (km 61.2) approximately one month later during the week of 12 September.

Due to the limited amount of recapture data, an accurate assessment regarding distributional patterns of hatchery-reared fish cannot be made.

4.2 WHITE PERCH

The white perch, *Morone americana*, is a common resident species in estuaries along the Atlantic coast from Nova Scotia to South Carolina (Bigelow and Schroeder, 1953; Scott and Crossman, 1973). It has been introduced into freshwater systems along the Atlantic coastal plain and has become established in the Great Lakes (Mansueti, 1961; Scott and Christie, 1963; Hardy, 1978). The distribution of white perch in the Hudson River extends from the Battery at Manhattan (km 0) north to the Troy Dam at Albany N.Y. (km 246) (TI, 1981). A euryhaline species, white perch are found in waters with salinity concentrations ranging from 0 to 30 $^{o}/oo$ but are most common in brackish water locations.

TABLE 4.1-4. SUMMARY OF DAILY STOCKING BY REGION OF HATCHERY-REARED STRIPED BASS YOUNG-OF-THE-YEAR, HUDSON RIVER ESTUARY, 1983.

		TAPPAN ZEE km 38.6-54.7		CROTON-HAVERSTRAW km 54.7-62.8		INDIAN POINT km 62.8-75.6	
DATE	TOTAL STOCKED	WEST SHOAL	EAST SHOAL	WEST SHOAL	EAST SHOAL	WEST SHOAL	EAST SHOAL
AUG 12	343	---	---	---	---	---	343
13	31	---	---	---	---	---	31
14	302	---	---	---	---	---	302
15	86	---	---	---	---	---	86
16	2,291	---	---	---	2,291	---	---
17	3,936	---	---	---	3,936	---	---
18	4,364	4,364	---	---	---	---	---
19	5,978	---	5,978	---	---	---	---
21	386	---	---	---	---	---	386
23	12,567	---	---	6,935	5,549	---	83
24	4,704	---	4,704	---	---	---	---
25	5,372	5,272	---	---	---	---	100
26	1,166	---	---	---	---	---	1,166
30	5,282	---	5,282	---	---	---	---
31	5,909	---	5,909	---	---	---	---
SEP 01	3,065	---	---	---	---	---	3,065
02	1,645	---	---	---	---	---	1,645
06	176	---	---	---	---	---	176
07	370	---	---	---	---	---	370
12	3,874	---	---	---	---	---	3,184
16	200	---	---	---	---	---	200
Total	61,357	9,636	21,873	6,935	11,776	0	11,137

TABLE 4.1-5. RECAPTURE DATA FOR HATCHERY-REARED STRIPED BASS YOUNG-OF-THE-YEAR, HUDSON RIVER ESTUARY, 1983.

FISH NUMBER	RECAPTURE DATE (1983)	RECAPTURE LENGTH (mm TL)	RECAPTURE WEIGHT (g)
1	3 Sep	93	10.1
2	13 Aug	88	8.3
3	31 Aug	82	5.4
4	30 Aug	90	7.9
5	5 Oct	88	5.6
6	27 Sep	85	4.5
7	31 Aug	108	12.2
8	31 Aug	110	12.8
9	1 Sep	109	14.4
10	1 Sep	121	19.3
11	14 Sep	75	5.3
12	14 Sep	93	9.7
13	14 Sep	84	6.8
14	14 Sep	81	5.8
15	14 Sep	98	11.8

The white perch is semi-anadromous and occasionally undergoes extensive spawning migrations within estuarine systems (Mansueti, 1961). The extent of spawning migrations is related to the proximity of overwintering and spawning grounds (Klauda *et al.,* in review). In the Hudson River estuary, deep offshore areas suitable for overwintering are present throughout the river particularly in the lower and middle estuary (TI, 1981). During spring, white perch move shoreward and upstream into the shallows. In the main stem of the estuary, most of the suitable spawning habitat is in the upper segment and it is here that peak spawning usually occurs and that eggs and larvae are concentrated. Spawning generally takes place in fresh water but may occur in water with salinity values up to 2 $^{o}/oo$ (Mansueti, 1961; Lippson *et al.,* 1980; TI, 1981). Consequently, eggs and larvae may be found throughout much of the estuary. During fall, there is a gradual return to the deepwater overwintering areas. Although white perch are semi-anadromous, they generally do not leave their natal estuary. In addition, they are indigenous to particular estuarine systems and exhibit little mixing with white perch populations in other regions (Mansueti, 1961).

Larval and juvenile white perch feed on rotifers, copepods, cladocerans and insects. Adults are largely non-specific rapacious feeders and consume a wide variety of prey types (Loos, 1975). In turn, white perch are prey for striped bass, bluefish and larger white perch. No major commercial fishery exists for white perch in the Hudson River (McHugh and Ginter, 1978); however, they are an important commercial species in other locations such as the Chesapeake Bay (Mansueti, 1961; Lippson *et al*., 1980).

4.2.1 Eggs

White perch eggs are demersal and adhesive, thus they are relatively invulnerable to ichthyoplankton sampling gear. Eggs sampled by this program are largely those which have become dislodged and are free-floating. Therefore, data collected on white perch eggs by ichthyoplankton sampling may not provide a realistic representation of the magnitude or spatiotemporal distribution of white perch egg deposition in the estuary. Only if the ratio of dislodged eggs to attached eggs is consistent spatially and temporally can the occurrence of dislodged eggs provide information on spatiotemporal trends in spawning. During 1982, there was a reasonably high correlation (r=0.88) of percent egg standing crop to freshwater flow thus suggesting that the number of dislodged eggs collected during a particular sampling period was related, in part, to the magnitude of freshwater flows (NAI, 1984a). It was inferred from this relationship that fluctuations in freshwater flow, and the resulting physical disturbance may produce fluctuations in the proportion of eggs that are dislodged from the bottom. Thus, seasonal and annual trends in egg standing crop as estimated by ichthyoplankton sampling may be biased by seasonal variations in freshwater flow. In addition, as indicated in the 1980 and 1981 Year Class Report (Battelle, 1983) white perch eggs are adhesive and may stick together in large masses; recovery of one or more such egg masses could also bias the estimated distribution. Spatial trends are also subject to bias for similar reasons. Thus, this study does not make the assumption that spatiotemporal trends in free-floating eggs necessarily represent spatiotemporal trends in spawning.

During 1983, white perch eggs were present when sampling began on 2 May (Figure 4.2-1). No correlation was observed between freshwater flow and egg abundance (r=0.3). Eggs were most abundant during the second and third weeks of May (mean temperature = 12.1°C), and after a slight decline remained at relatively constant levels through mid-June. This apparently prolonged spawning period is probably related to the very slow rate of increase in water temperature that was recorded during May (Table 4.2-1). Years when spawning appeared to be concentrated over a 2-3 week period (1975, 1977, 1978) typically had rapidly increasing temperatures during May, while years with a prolonged spawning period (4-6 weeks) had slowly increasing water temperatures (1974, 1976, 1979) (TI, 1979a). During 1983, temperatures in early May were comparable to past years; however, little temperature increase occurred during the month and by the end of May temperatures were about 4°C cooler than

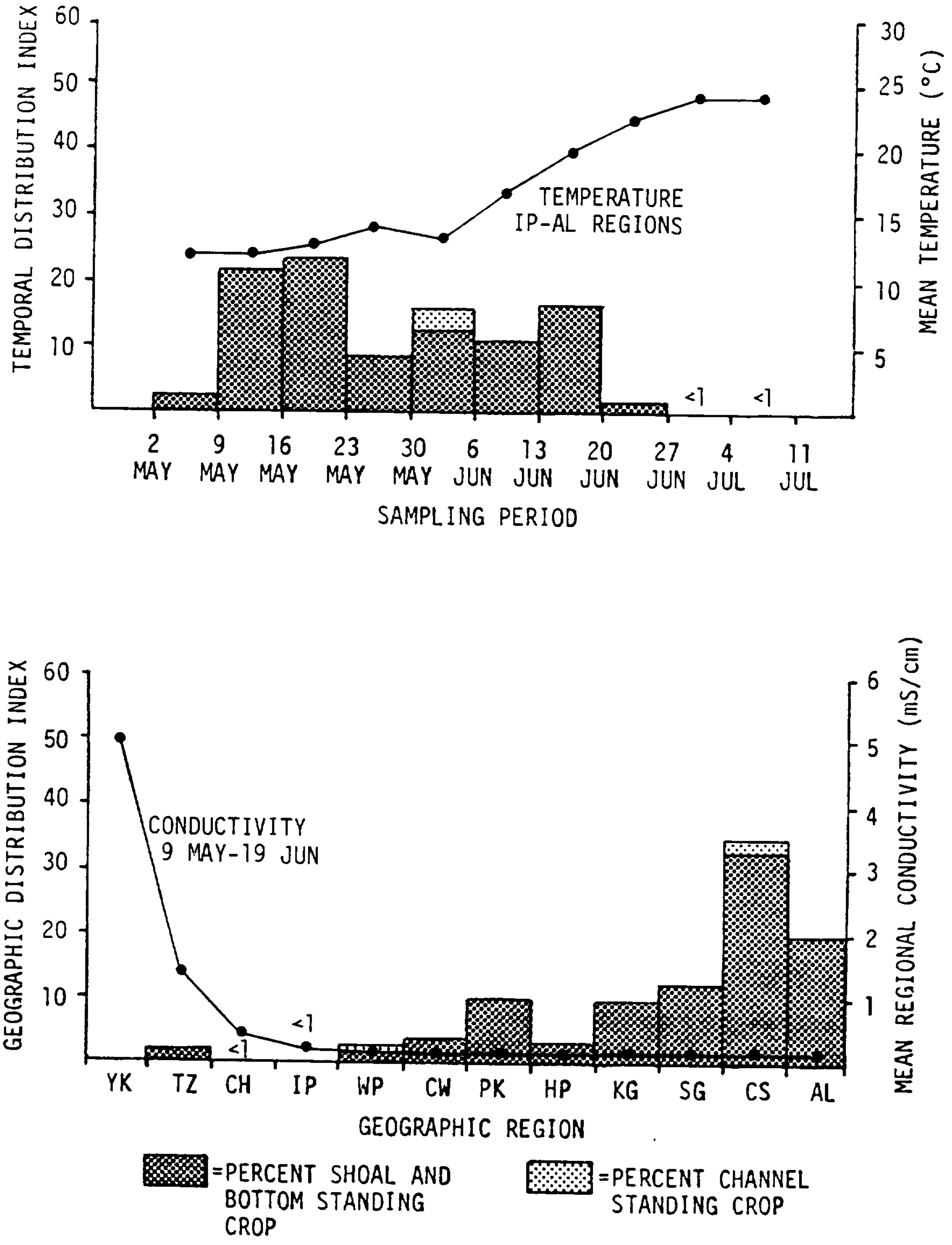


Figure 4.2-1. Temporal and geographic distribution of white perch eggs based on ichthyoplankton sampling, Hudson River estuary, 1983.

TABLE 4.2-1. MEAN WEEKLY WATER TEMPERATURE[a] DURING MAY IN POUGHKEEPSIE THROUGH ALBANY REGIONS, HUDSON RIVER ESTUARY, 1974 THROUGH 1983.

	WEEKLY MEAN TEMPERATURE (°C)				AVERAGE MONTHLY INCREASE
	WEEK 1	WEEK 2	WEEK 3	WEEK 4	(°C)
1974	13.0	14.2	16.1	17.5	4.5
1975	12.0	14.3	19.1	20.8	8.8
1976	12.2	13.8	13.9	13.8	1.6
1977	12.2	13.1	16.4	19.6	7.4
1978	12.6	13.2	16.1	20.6	8.0
1979	15.2	17.0	18.0	17.5	2.3
1980[b]	9.8	15.5	16.1	17.5	7.7
1981[b]	15.5	15.5	16.1	19.5	4.0
1982	NS	13.0	16.2	17.4	≥4.4
1983	12.3	11.8	12.3	14.9	2.6

[a] Source: 1974-1979 from TI (1981); 1980 and 1981 from Battelle (1983); 1982 from NAI (1984a)

[b] Mean temperature in Hyde Park-Albany regions.

NS = Not sampled

normally observed. By the first of June, water temperature in the upper segment actually dropped to 13.1°C thus resulting in an overall temperature increase of only 0.8°C between the first week of May and the first week of June. During this four-week period when mean water temperatures in the upper estuary ranged from 12-15°C, approximately 70% of the standing crop was collected.

White perch eggs were present throughout the estuary, except in the Yonkers region, and were most abundant in the upper estuary where mean conductivity values were consistently less than 0.5 mS/cm (Figure 4.2-1). The upper estuarine concentration of white perch eggs was consistent with observations in past years. As expected, considering the demersal nature of white perch eggs, abundances were highest in the bottom and shoal strata (95% of egg standing crop).

4.2.2 Yolk-Sac Larvae

The abundance of yolk-sac larvae may more accurately reflect the spatiotemporal distribution of egg deposition than free-floating eggs. They are more vulnerable than eggs to this program's sampling gear, they exhibit only limited mobility, and they have a relatively short life-stage duration (4-13 days; Hardy, 1978). Like white perch eggs, yolk-sac larvae were present when sampling began the week of 2 May (Figure 4.2-2). The largest proportion of yolk-sac larva standing crop (70%) occurred during the last three weeks of May at average temperatures (all regions) ranging from 12.4 to 14.3°C. This is consistent with the optimal temperature for hatching (14.1°C) determined experimentally by Morgan and Rasin (1982) and indicates that peak spawning did in fact occur during mid-May. Abundance of yolk-sac larvae remained at moderate levels through mid-June thus reflecting the prolonged spawning period inferred from egg distribution (Figure 4.2-1). The temporal pattern of yolk-sac larva standing crop observed in 1983 was similar to the patterns recorded for past years (TI, 1981; Battelle, 1983; NAI, 1984a) when larval abundance typically peaked during the third or fourth week of May.

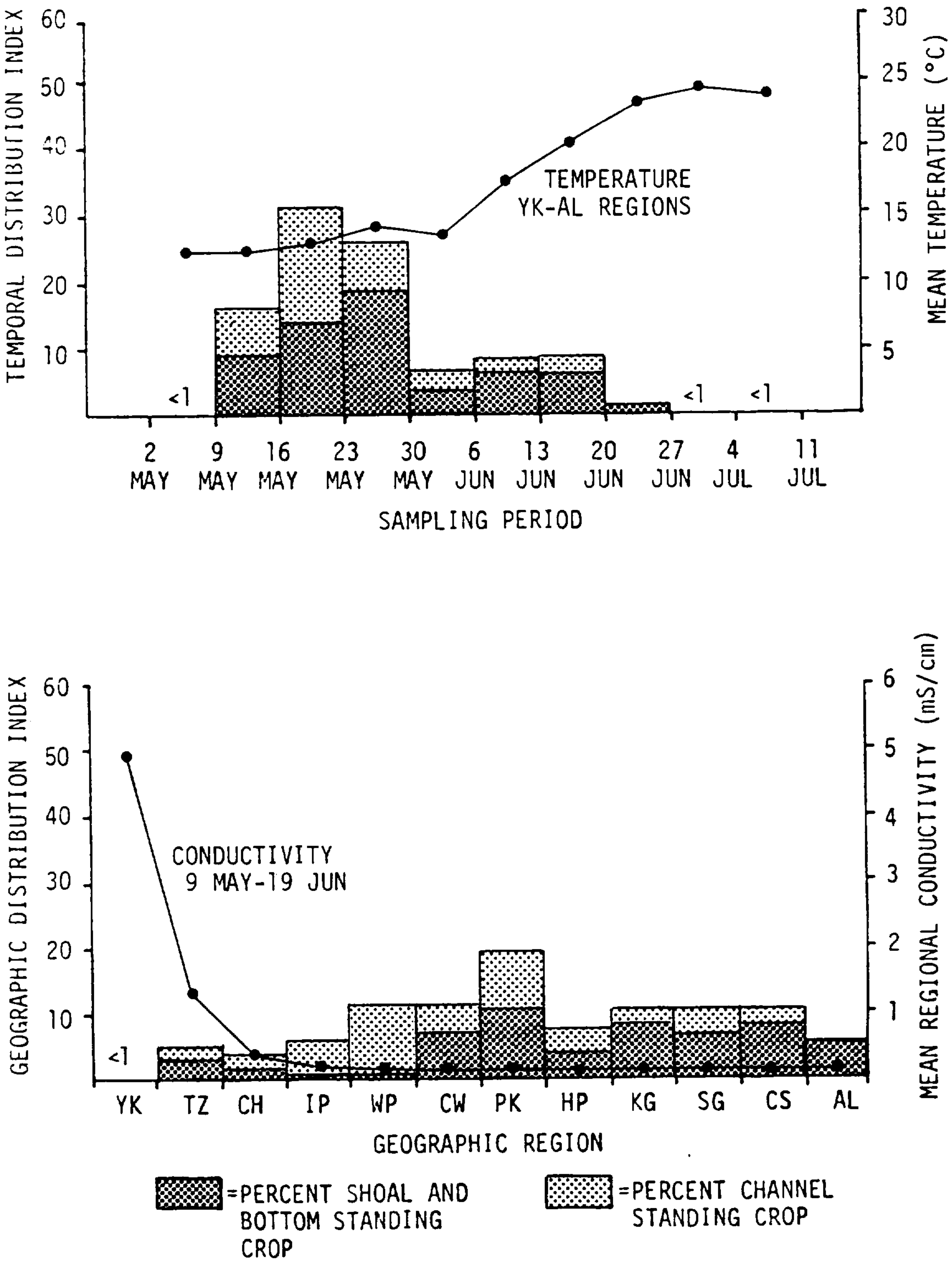


Figure 4.2-2. Temporal and geographic distribution of white perch yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

Yolk-sac larvae were fairly evenly distributed throughout the estuary. This broad distribution very likely was related to the location of the salt front downriver in the Croton-Haverstraw region (Figure 4.2-3). Early life stages of white perch appear to be largely restricted to waters with conductivity values less than 0.5 mS/cm and do not appear to extend in distribution much beyond this front (NAI, 1984a). During 1982, for example, few yolk-sac larvae occurred below Cornwall,which was the general location of the salt front during the ichthyoplankton survey of that year. Yolk-sac larvae, like eggs, were most abundant in the shoal and bottom strata (58%); however, a much greater proportion of larvae occurred in the channel compared to eggs.

4.2.3 Post Yolk-Sac Larvae

As in past years, estimated total standing crop of post yolk-sac larvae (7 billion) exceeded the estimated standing crops of both eggs (3 billion) and yolk-sac larvae (2 billion). Post yolk-sac larvae are more vulnerable to the sampling gear, due to their more pelagic nature, longer life-stage duration and larger size than earlier life stages. Post yolk-sac larvae were first collected on 9 May. However, peak abundances were not recorded until late June, approximately six weeks following the peak of eggs and yolk-sac larvae (Figure 4.2-4). This delay in the occurrence of peak post yolk-sac larva abundance may be indicative of high mortality of larvae hatched during the May peak. Since duration of the yolk-sac stage is only four to thirteen days (Hardy, 1978) a peak in post yolk-sac larva abundance would have been expected during the first or second week of June. As indicated previously, temperatures were well below normal during late May, when yolk-sac larva abundance peaked, and actually dropped during the first week of June to an average of only 13.7°C (estuary-wide). Not until the week beginning 6 June did temperatures rise appreciably. It seems reasonable to conclude that the major portion of post yolk-sac larvae which were collected from mid-June through early July originated from the early June yolk-sac larva population and not from the peak concentrations observed in May.

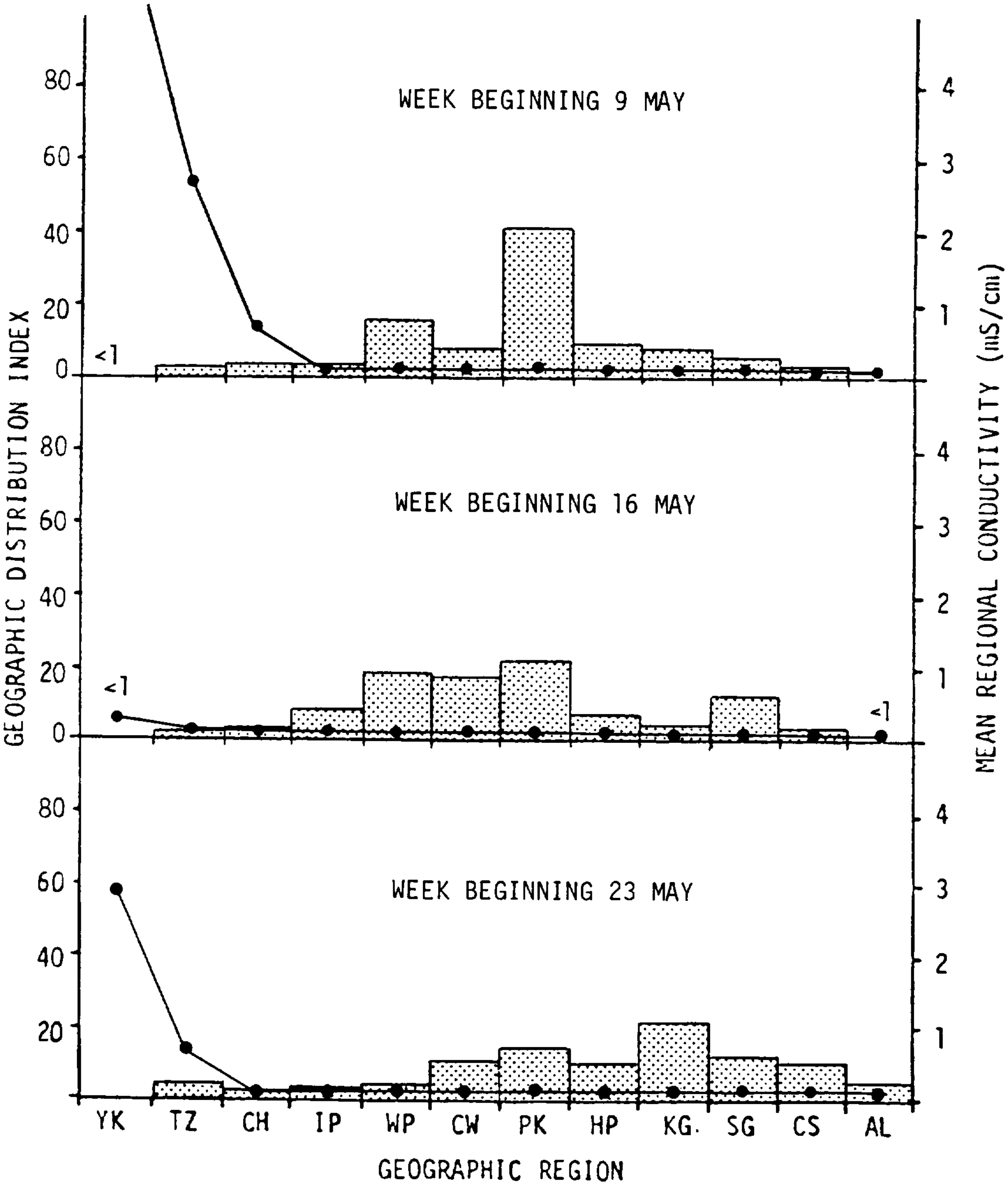


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Figure 4.2-3. Weekly geographic distribution of white perch yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

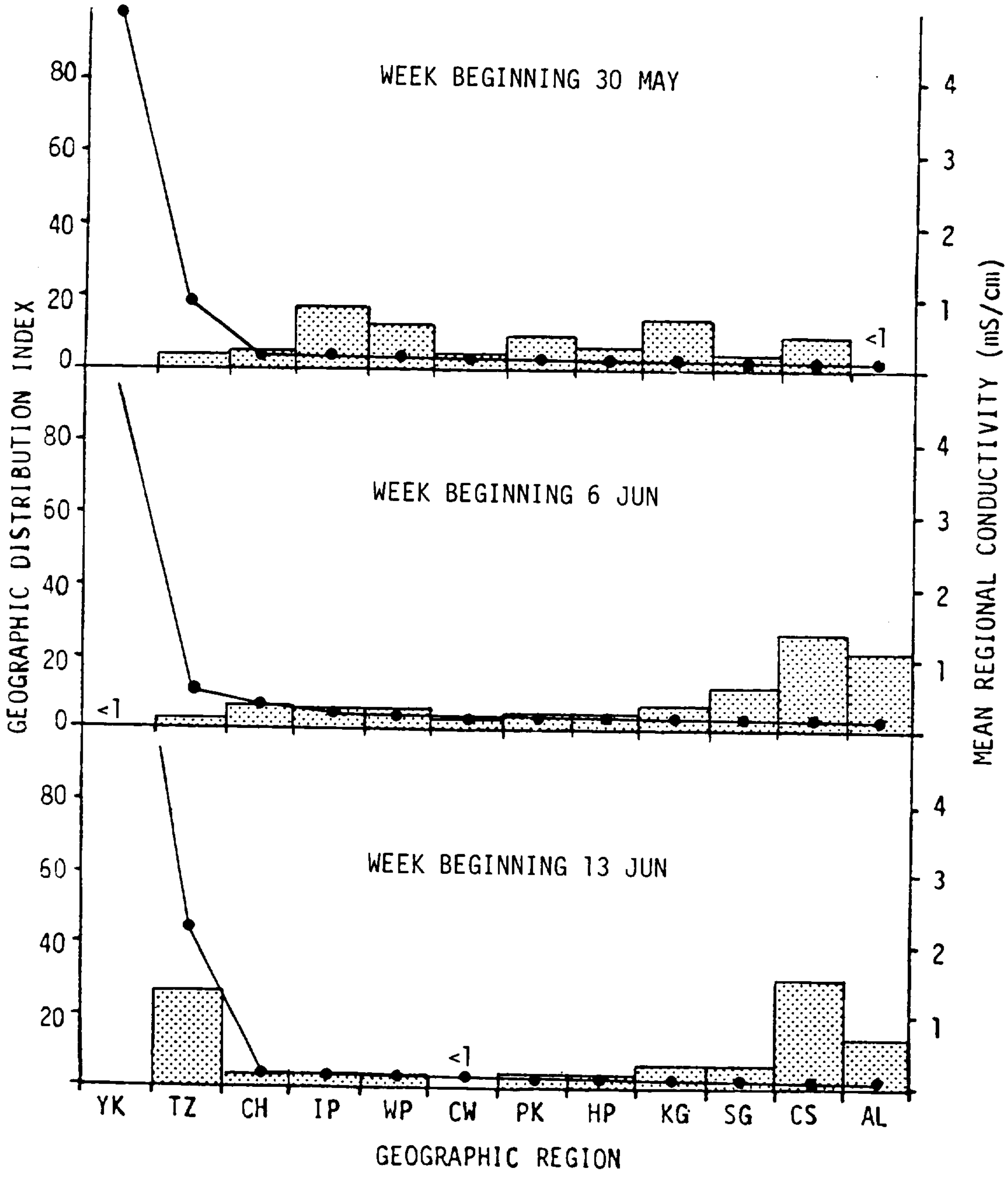

Figure 4.2-3. (Continued).

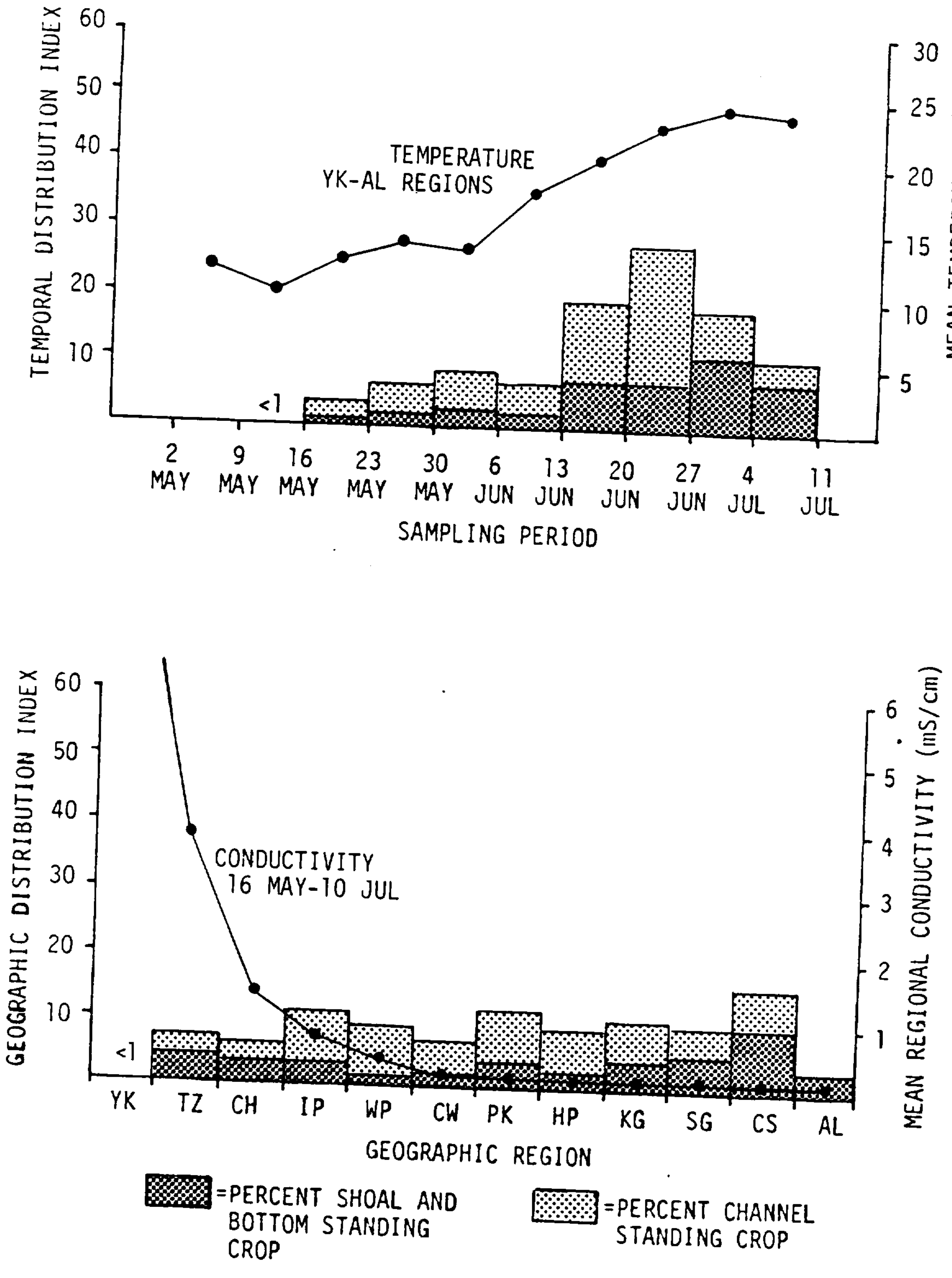

Figure 4.2-4. Temporal and geographic distribution of white perch post yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

Post yolk-sac larvae were evenly distributed throughout the estuary except in the Yonkers region where the overall geographical distribution index was <1 (Figure 4.2-4). As with yolk-sac larvae, this distribution was probably related in part to the downriver location of the salt front (Figure 4.2-5) which would allow widespread dispersion of the larvae within the estuary. A larger proportion of post yolk-sac larvae (58%) occurred in the channel stratum compared to eggs (6%) and yolk-sac larvae (42%).

4.2.4 Young-of-the-Year

Juvenile white perch were first encountered during the last two sampling periods of the ichthyoplankton survey (27 June - 10 July 1983; Figure 4.2-6), approximately six weeks following the first major occurrence of post yolk-sac larvae (week beginning 16 May). Juveniles were detected in low abundances and only in the Tappan Zee through Hyde Park regions. Their absence in the upper estuary where post yolk-sac larvae were abundant may reflect a higher growth rate in the lower estuary than in the upper estuary and thus a faster transition from the post yolk-sac to the juvenile stage. In past surveys, juveniles were also first encountered in late June and usually reached maximum abundance by mid-August (TI, 1981; Battelle, 1983).

Juvenile white perch were collected throughout the August through October Fall Shoals and Beach Seine Surveys (Figures 4.2-7 and 4.2-8). In the shore zone, high concentrations occurred both upriver in the Saugerties and Catskill regions and downriver in the Croton-Haverstraw region (Figure 4.2-8). Shore zone abundances peaked during the end of August and subsequently declined. In the offshore strata, juveniles were most abundant in the upper half of the estuary from Poughkeepsie through Albany (Figure 4.2-7). Abundance steadily increased from August through October and, unlike post yolk-sac larvae which were abundant in the channel stratum, 95% of the juveniles were collected in the shoal and bottom strata. This distribution in the shore zone and offshore strata is typical of the late summer and fall

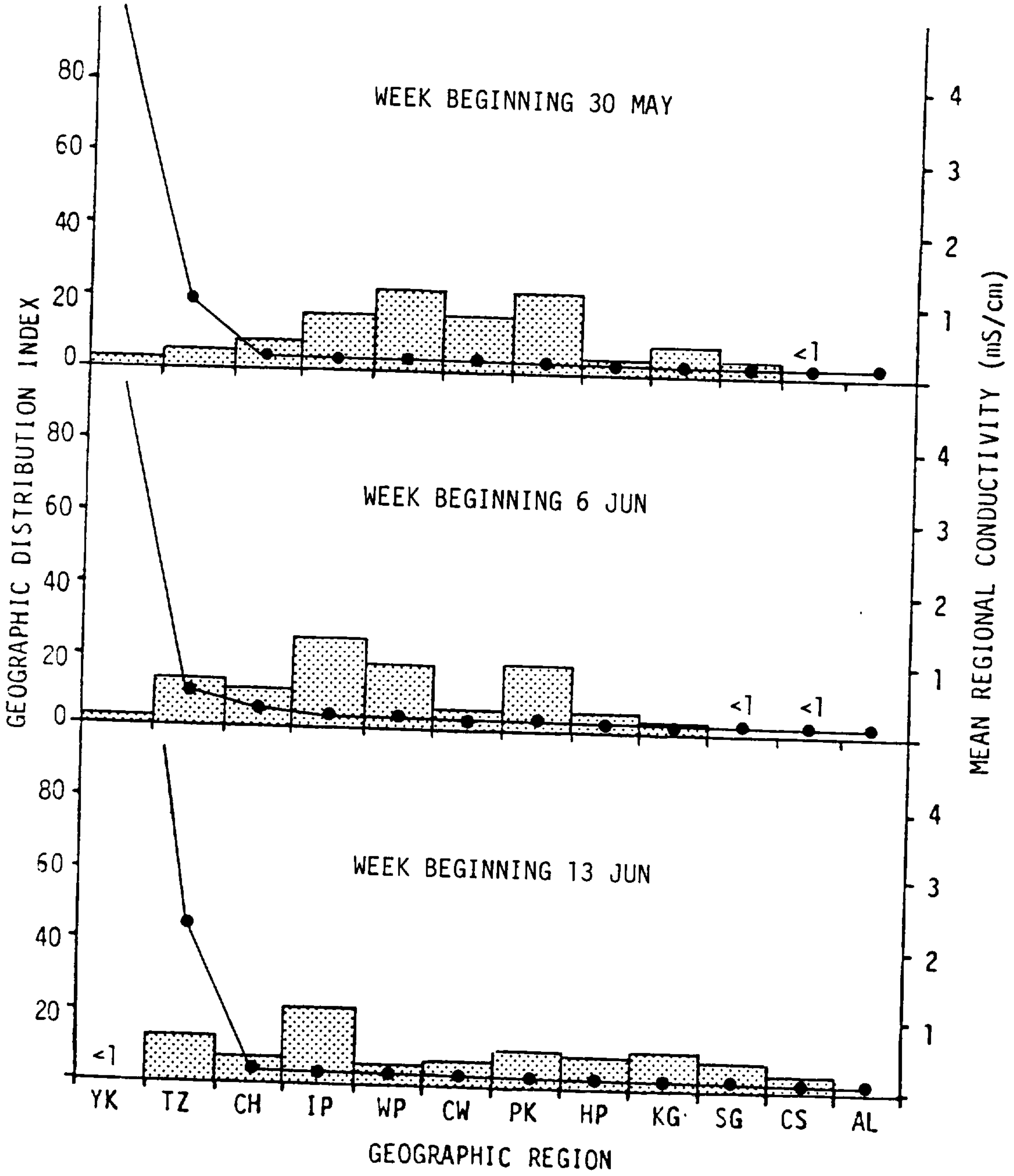

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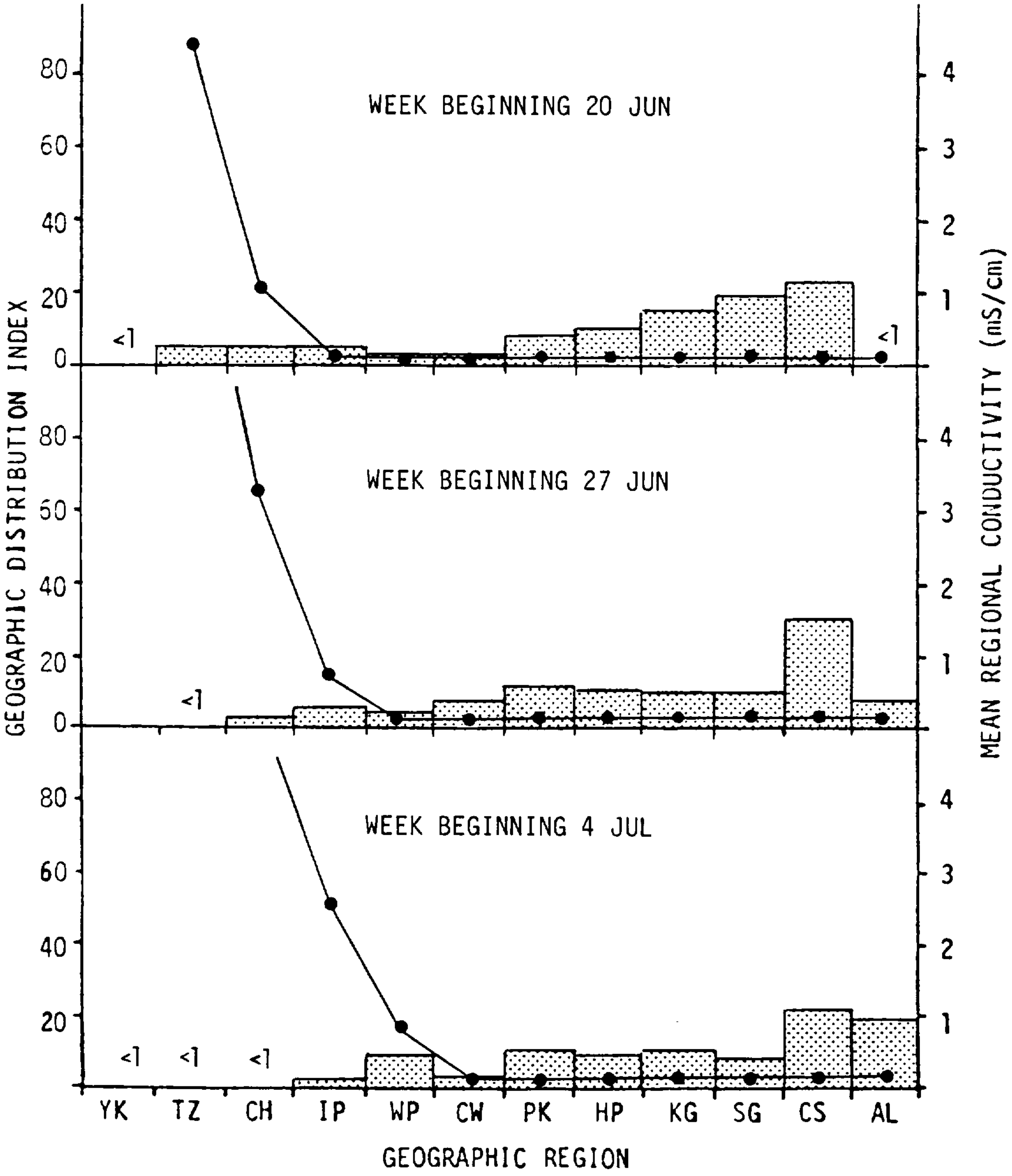
Figure 4.2-5. Weekly geographic distribution of white perch post yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.



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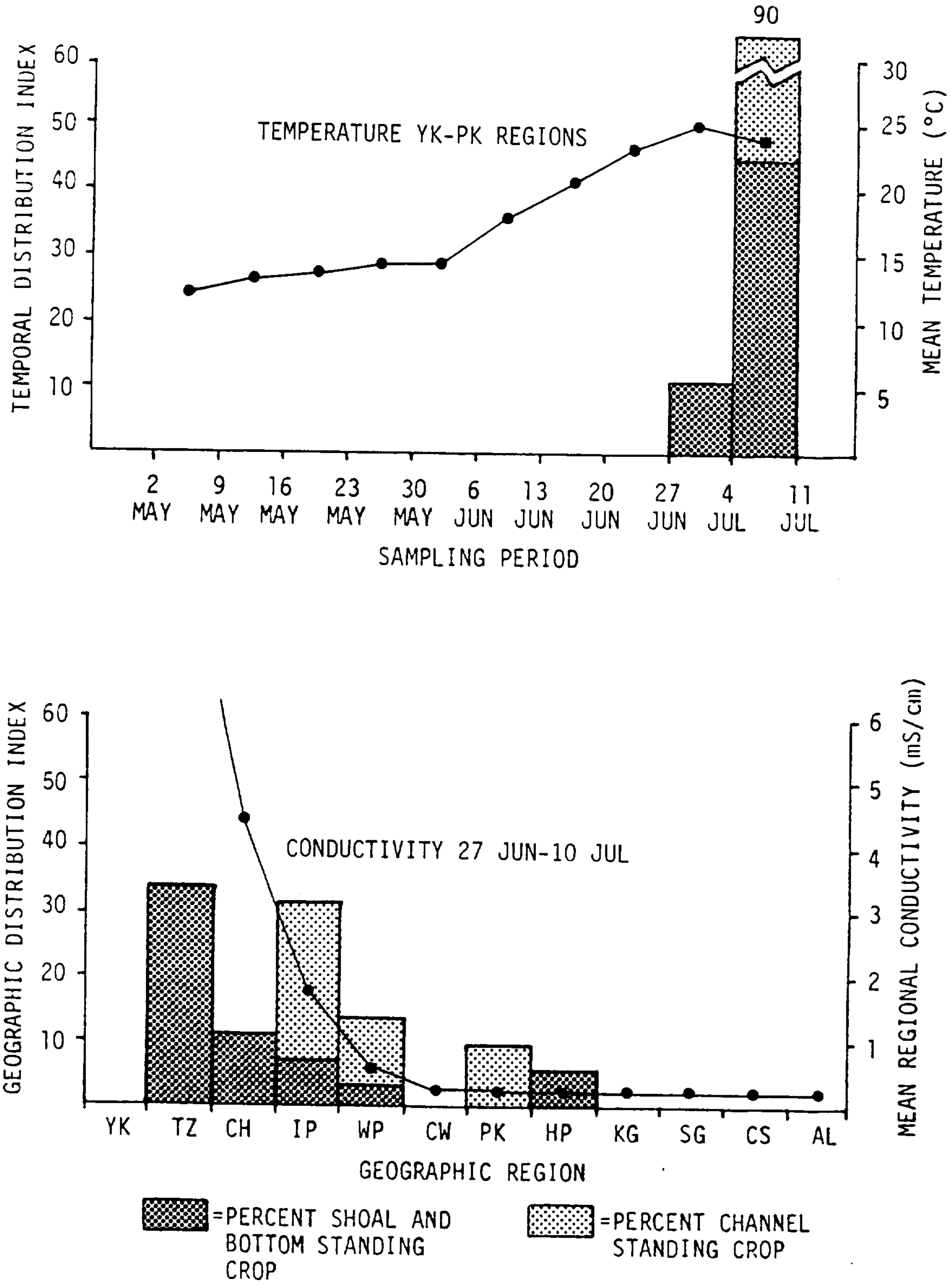


Figure 4.2-6. Temporal and geographic distribution of white perch young-of-the-year based on ichthyoplankton sampling, Hudson River estuary, 1983.

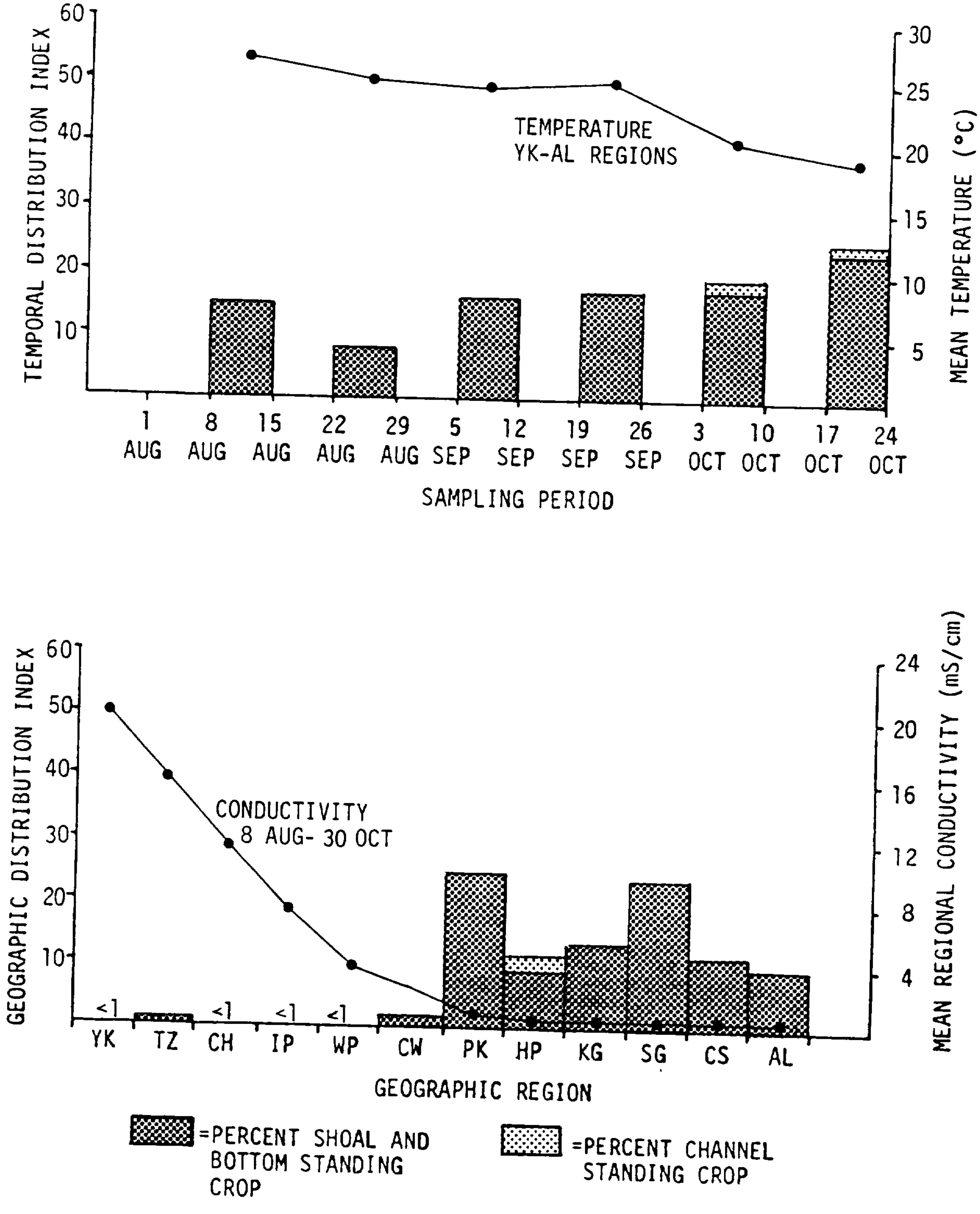
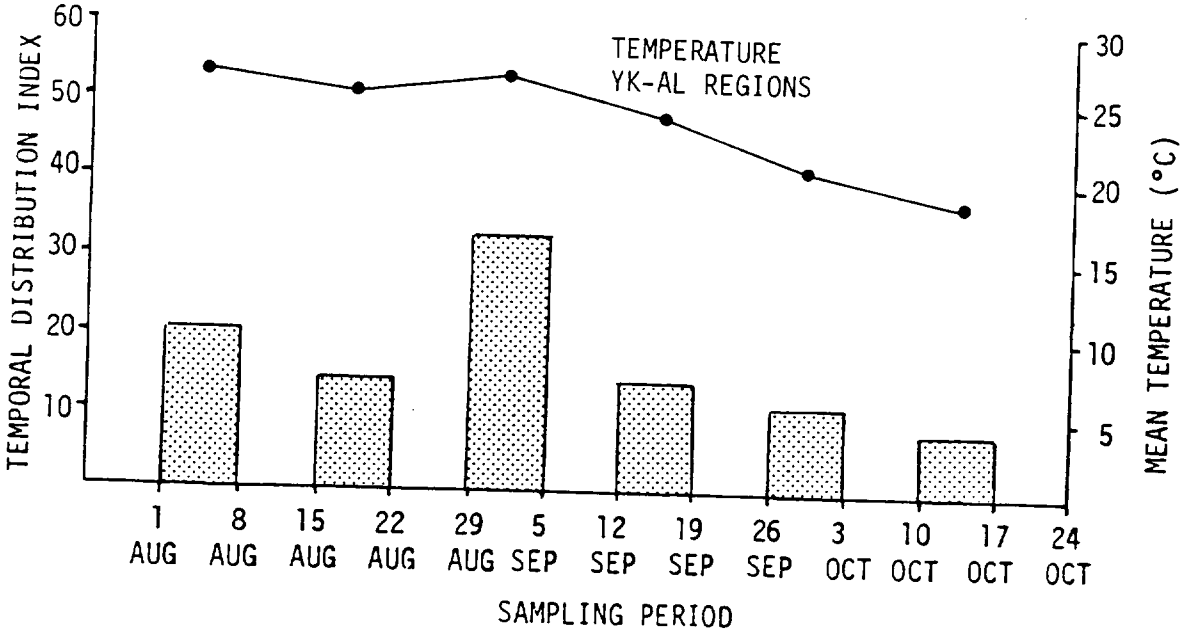


Figure 4.2-7. Temporal and geographic distribution of white perch young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.



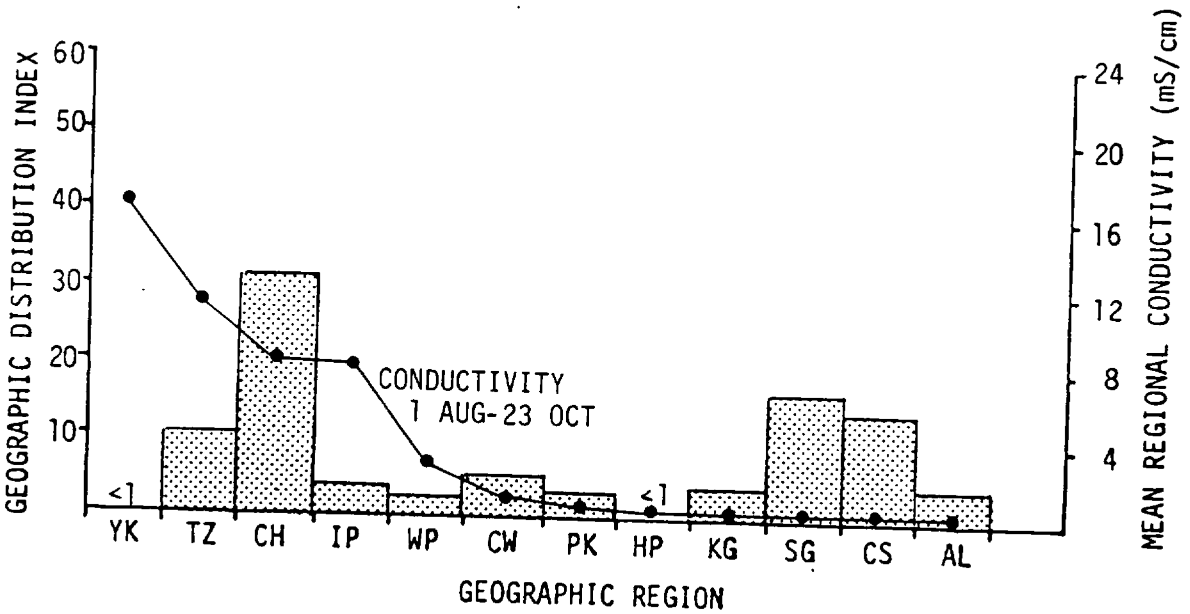


Figure 4.2-8. Temporal and geographic distribution of white perch young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

juvenile population (TI, 1981; Battelle, 1983; NAI, 1984a). The gradual decline in shore zone standing crop recorded as fall progressed, coincident with the increased abundance in the offshore strata, is indicative of the fall offshore movement to deeper waters that has been well documented in past years (TI, 1981; Klauda *et al.*, in review). This same pattern was obvious in the young-of-the-year combined standing crop data (Appendix B; Table B-20). During late October and into winter, a period that is no longer sampled by this study, white perch presumably continue their offshore movements into deeper water (TI, 1981; Klauda *et al.*, in review).

4.2.5 Yearling and Older Fish

Yearling and older white perch were collected throughout the ichthyoplankton survey and were encountered in all regions of the estuary (Figure 4.2-9). Seventy-one percent of the fish collected were older than yearling and most were taken in the shoal and bottom strata. No definite upriver vernal spawning run was observed in the data and no obvious correlation was seen between geographic distribution of older white perch and peak egg deposition in the upper estuary. Although upriver movements may have occurred prior to sampling in May, there is evidence that white perch in the Hudson River estuary are relatively non-migratory in comparison to populations in other estuarine systems. The extent of white perch spawning migrations appears to be related to the proximity of overwintering and spawning grounds (Klauda *et al.*, in review). In the Hudson River estuary, deep offshore areas appropriate for overwintering occur throughout most of the estuary, including regions in the upper estuary, e.g., Hyde Park and Kingston. Klauda *et al.* (in review) described yearling and older white perch in the Hudson River estuary as being widely dispersed with no definite spring spawning run from brackish to freshwater. Though an upstream movement during spring has been inferred from trawl and seine catch data in past years, tagging studies have shown no clear pattern of a spring upriver movement (TI, 1979a). Onshore movements of white perch from deep water into the shallows and upstream into the tributaries may well be more

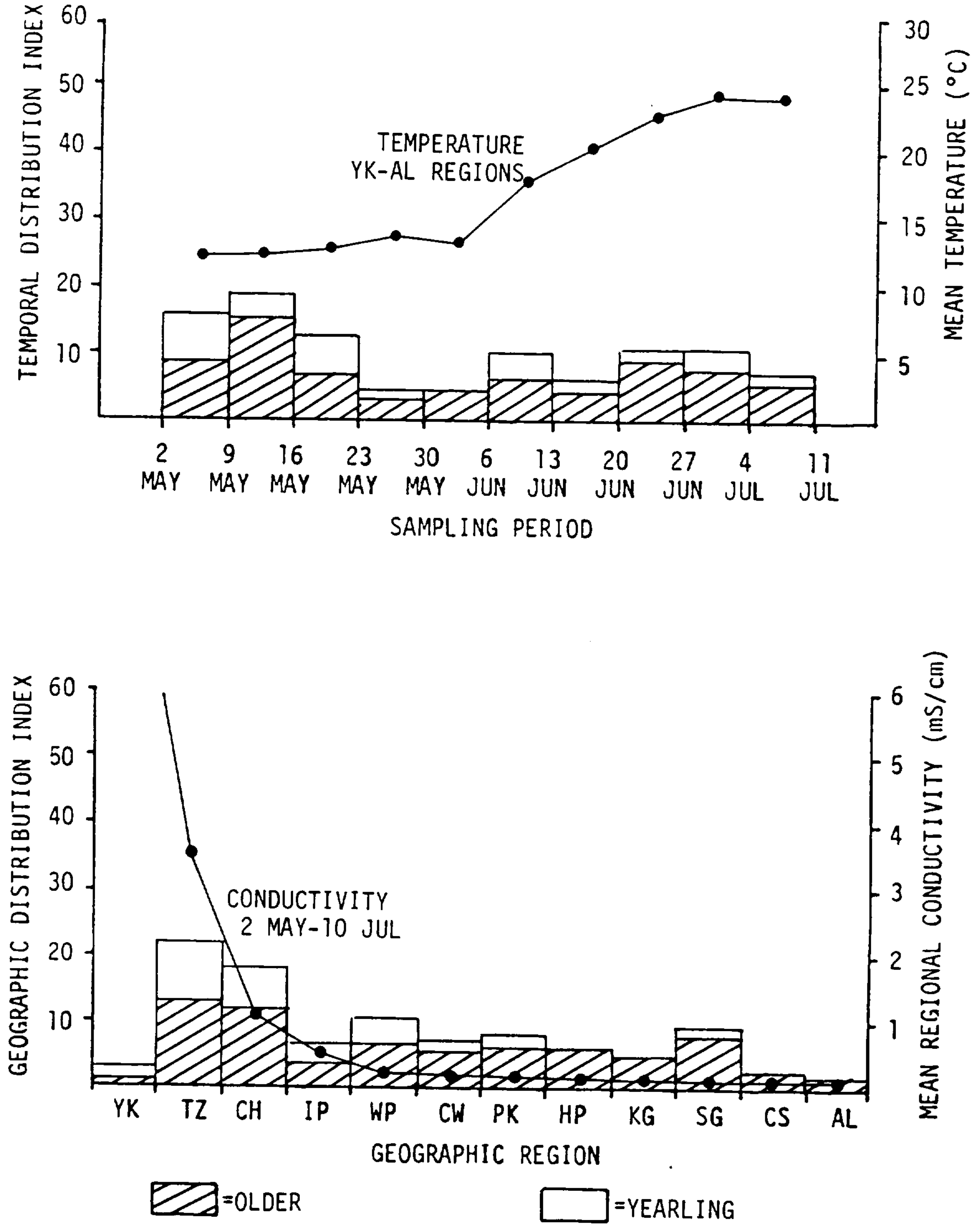


Figure 4.2-9. Temporal and geographic distribution of white perch yearling and older fish based on ichthyoplankton sampling, Hudson River estuary, 1983.

characteristic of white perch spawning runs in the Hudson River estuary than substantial upriver movements within the main stem. This is substantiated by the white perch stock assessment program, which found that Hudson River tributaries are used extensively during spring and summer by white perch yearling and older fish (NAI, 1984b). No data are available on the extent of spawning in these tributaries.

The August through October Fall Shoals and Beach Seine Surveys indicated that yearling and older fish were concentrated in the offshore strata of the upper estuary and in the shore zone of the lower estuary (Figures 4.2-10 and 4.2-11). Relatively low numbers of yearling and older white perch were collected in the offshore strata of the lower half of the estuary. This distribution is characteristic of young-of-the-year, yearling and older white perch during late summer and fall (TI, 1981; Battelle, 1983; NAI, 1984a).

Yearlings comprised 60% of the standing crop of yearling and older white perch in the shore zone, while approximately 70% of the fish in the offshore strata were older than yearling. This distribution of yearling and older fish was similar to the distribution observed in 1982 and may reflect a preference by juveniles for shallow nearshore waters during summer. Based on combined standing crop data, young-of-the-year fish were also found to be concentrated in the shore zone during late summer (Appendix B; Table B-20). Fish older than yearling may be somewhat less habitat selective during summer, and consequently, found more often in offshore waters.

4.3 AMERICAN SHAD

The American shad, *Alosa sapidissima*, is one of the representatives of the family Clupeidae found in the Hudson River estuary. American shad are anadromous and range from Newfoundland to Florida. Adult shad may be found throughout the Hudson River estuary during their spawning season in the spring.

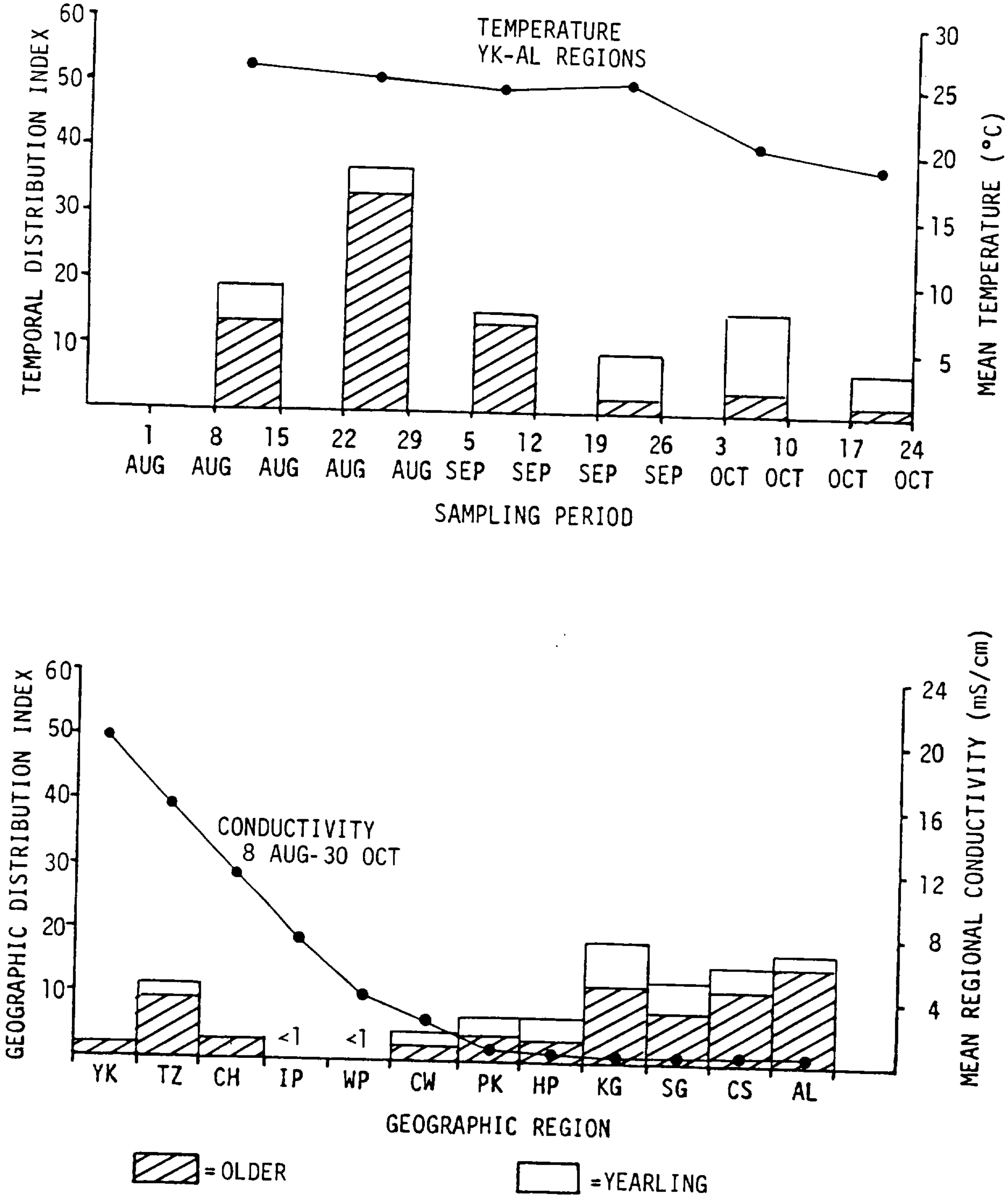


Figure 4.2-10. Temporal and geographic distribution of white perch yearling and older fish based on the Fall Shoals Survey, Hudson River estuary, 1983.

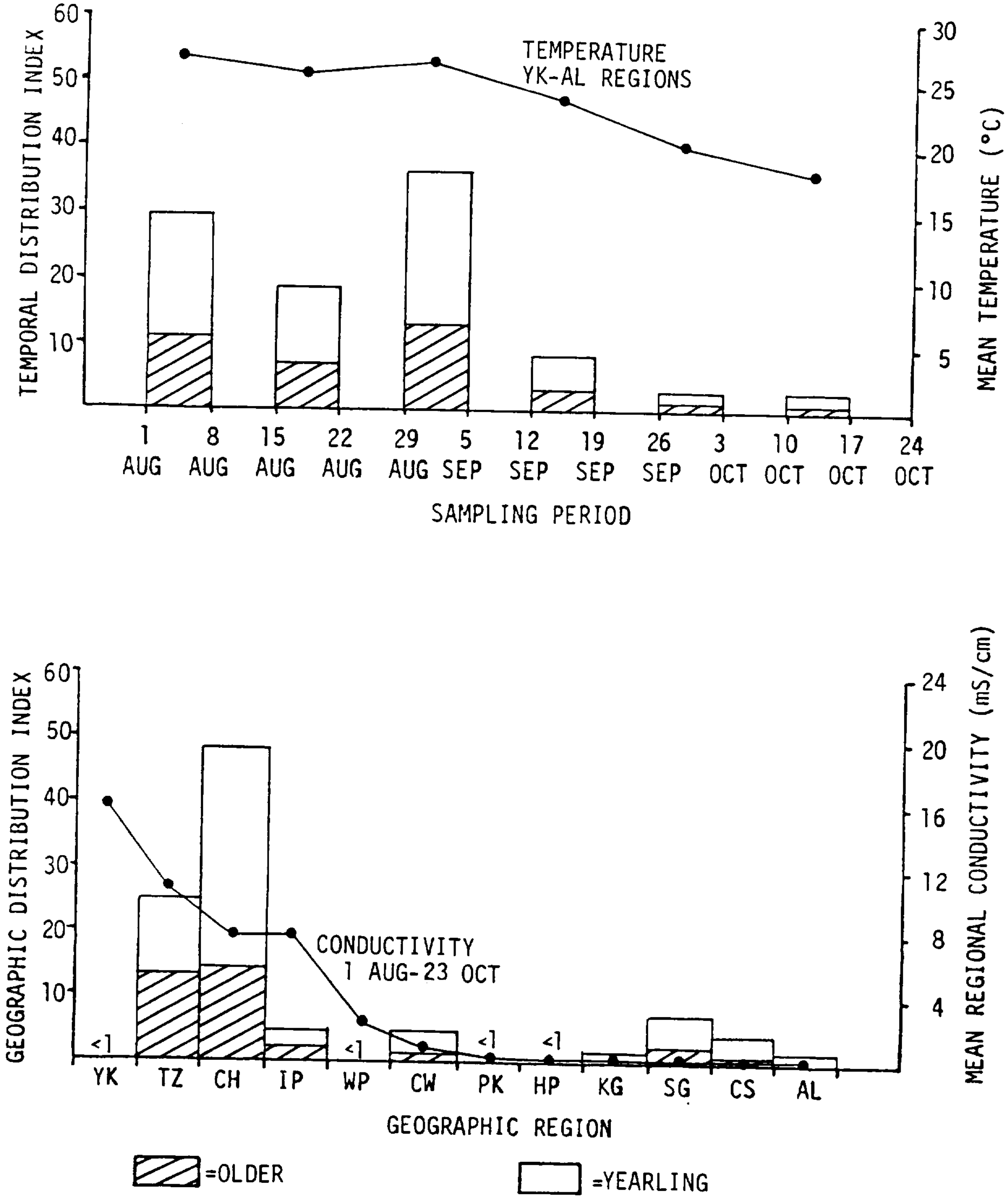


Figure 4.2-11. Temporal and geographic distribution of white perch yearling and older fish based on the Beach Seine Survey, Hudson River estuary, 1983.

American shad spend the major portion of their lives in the waters of the continental shelf (Bigelow and Schroeder, 1953) rarely being found in fresh water outside of the spawning season (Mansueti and Hardy, 1967). Spawning usually occurs in tidal fresh water over areas with extensive flats. Spawning in the the Hudson River occurs primarily in the Hyde Park to Catskill regions during spring when water temperatures range from 7° to 14°C (Talbot, 1954; TI, 1981).

Although American shad may spawn many times during their lifetime, there is a high mortality rate associated with spent American shad. This phenomenon is due to the heavy energetic demands of the spawning migration and the limited availability of suitably sized food particles in fresh water, thus leading to weight loss (Leggett, 1972). Those shad that survive leave the estuary and return to sea, migrating northward to the Gulf of Maine (Scott and Crossman, 1973).

Shad eggs are demersal and non-adhesive; incubation time ranges from 2 days at 27°C to 17 days at 12°C (Mansueti and Hardy, 1967). The yolk-sac larvae are 6-10 mm in length upon hatching and absorb their yolk sac within 5 days at 17°C, at which time they measure 9-12 mm in length (Mansueti and Hardy, 1967). They spend their first summer within the estuary, feeding on copepods, ostracods and amphipods. During fall, juvenile shad (approximately 90 mm TL) begin to migrate out of the estuary.

4.3.1 Eggs

American shad eggs were most abundant in the Hudson River estuary during the second and third weeks of May; most shad eggs occurred in the bottom stratum in the upper estuary (Figure 4.3-1; Appendix B; Table B-27). Geographic distribution was generally similar to that reported from 1979 through 1981, with highest standing crop being in the Albany region (TI, 1981; Battelle, 1983). In 1982, however, distribution was shifted downriver, with peak standing crop in the Saugerties region (NAI, 1984a). From 1976 through 1978 a bimodal

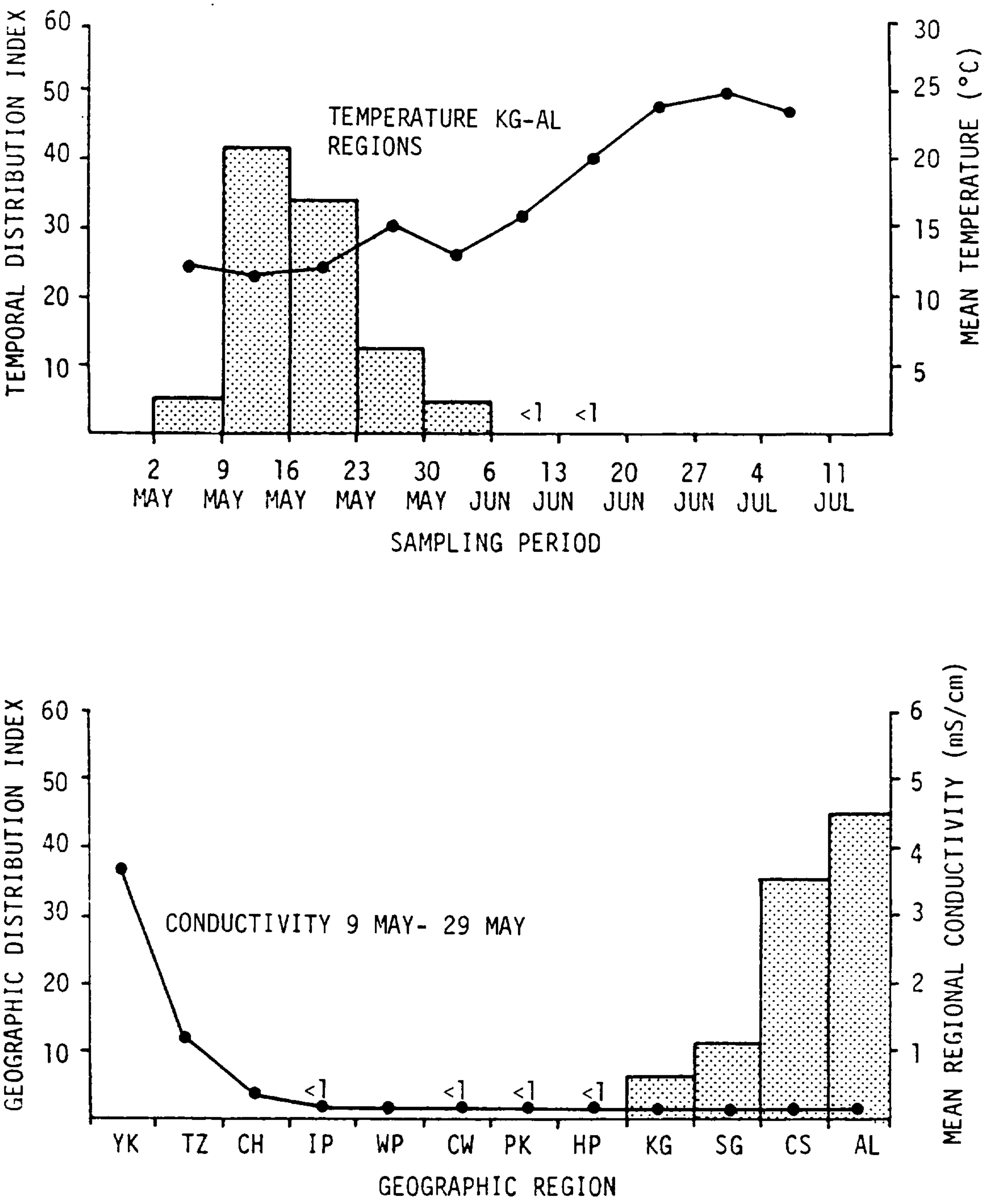


Figure 4.3-1. Temporal and geographic distribution of American shad eggs based on ichthyoplankton sampling, Hudson River estuary, 1983.

temporal distribution was observed, with maximum standing crop in the Catskill region (TI, 1981).

Temperatures in the Saugerties to Albany regions during the second and third weeks of May averaged 11.9°C (Table 4.3-1), somewhat lower than the optimum for survival and development of shad eggs (16°C; Marcy, 1972). Mean temperatures during maximum egg abundance approached or exceeded 16°C during only two of eight years since 1976 (Table 4.3-1). Thus it appears that American shad spawning in the Hudson River estuary frequently occurs earlier than the period of optimum environmental temperature. Spawning of shad during suboptimal conditions has been noted in the Connecticut River and was associated with a weakened year class (Marcy, 1976a).

4.3.2 Yolk-Sac Larvae

American shad yolk-sac larvae peaked during the first week of June, approximately three to four weeks after the egg abundance peak. Temperature at this time had risen to 16.0°C in the upper estuary (Table 4.3-1); however, upper estuarine temperatures during the three-week period between egg and yolk-sac larva abundance peaks were lower than normal, averaging approximately 13°C (Appendix C; Table C-1). The incubation period for American shad eggs is 17 days at temperatures of 12°C (Jones *et al.*, 1978). Thus, it appears that the lag between egg and yolk-sac larva abundance peaks in 1983 was at least partly a function of low water temperatures during the incubation period.

The area of greatest abundance occurred in the Albany region, with very few yolk-sac larvae found downriver from Kingston (Figure 4.3-2). Spatial distribution of shad yolk-sac larvae in 1983 was consistent with that reported from 1979 through 1982 (TI, 1981; Battelle, 1983; NAI, 1984a); however, from 1976 through 1978 this developmental stage was observed to be distributed farther downstream (TI, 1981).

TABLE 4.3-1. MEAN AND RANGE OF WATER TEMPERATURES (°C) IN REGIONS AND PERIODS OF PEAK ABUNDANCE OF AMERICAN SHAD EGGS AND LARVAE, HUDSON RIVER ESTUARY, 1976 THROUGH 1983.[a]

	EGGS			YOLK-SAC LARVAE			POST YOLK-SAC LARVAE		
YEAR	PEAK PERIOD	MEAN	RANGE	PEAK PERIOD	MEAN	RANGE	PEAK PERIOD	MEAN	RANGE
1976	02 May - 22 May	13.3	11.2-15.0	09 May- 12 Jun	15.6	12.3-20.1	13 Jun - 26 Jun	22.9	21.7-23.8
1977	01 May - 21 May	13.5	12.0-16.4	08 May - 28 May	16.6	12.6-20.4	22 May - 04 Jun	20.5	20.4-20.6
1978	30 Apr - 27 May	13.1	8.5-17.1	21 May - 03 Jun	14.8	12.9-17.1	28 May - 03 Jun	21.4	21.1-21.6
1979	13 May - 19 May	17.3	17.0-17.7	13 May - 26 May	18.0	17.1-18.9	10 Jun - 16 Jun	19.4	19.4-19.4
1980	05 May - 08 May	15.5	b	12 May - 15 May	15.5	b	02 Jun - 13 Jun	20.0	b
1981	04 May - 09 May	10.0	b	18 May - 21 May	15.8	b	18 May - 21 May	15.8	b
							and 08 Jun - 13 Jun	21.0	b
1982	10 May - 14 May	13.0	13.0-13.2	17 May - 20 May	16.6	16.5-16.7	24 May - 03 Jun	18.5	17.2-20.1
1983	09 May - 18 May	11.9	11.4-12.5	06 Jun - 09 Jun	16.0	14.9-17.5	13 Jun - 18 Jun	20.6	20.5-20.8

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[a] 1976-1979 data from TI (1981)
1980-1981 data from Battelle (1983)
1982 data from NAI (1984a)

[b] individual values not reported

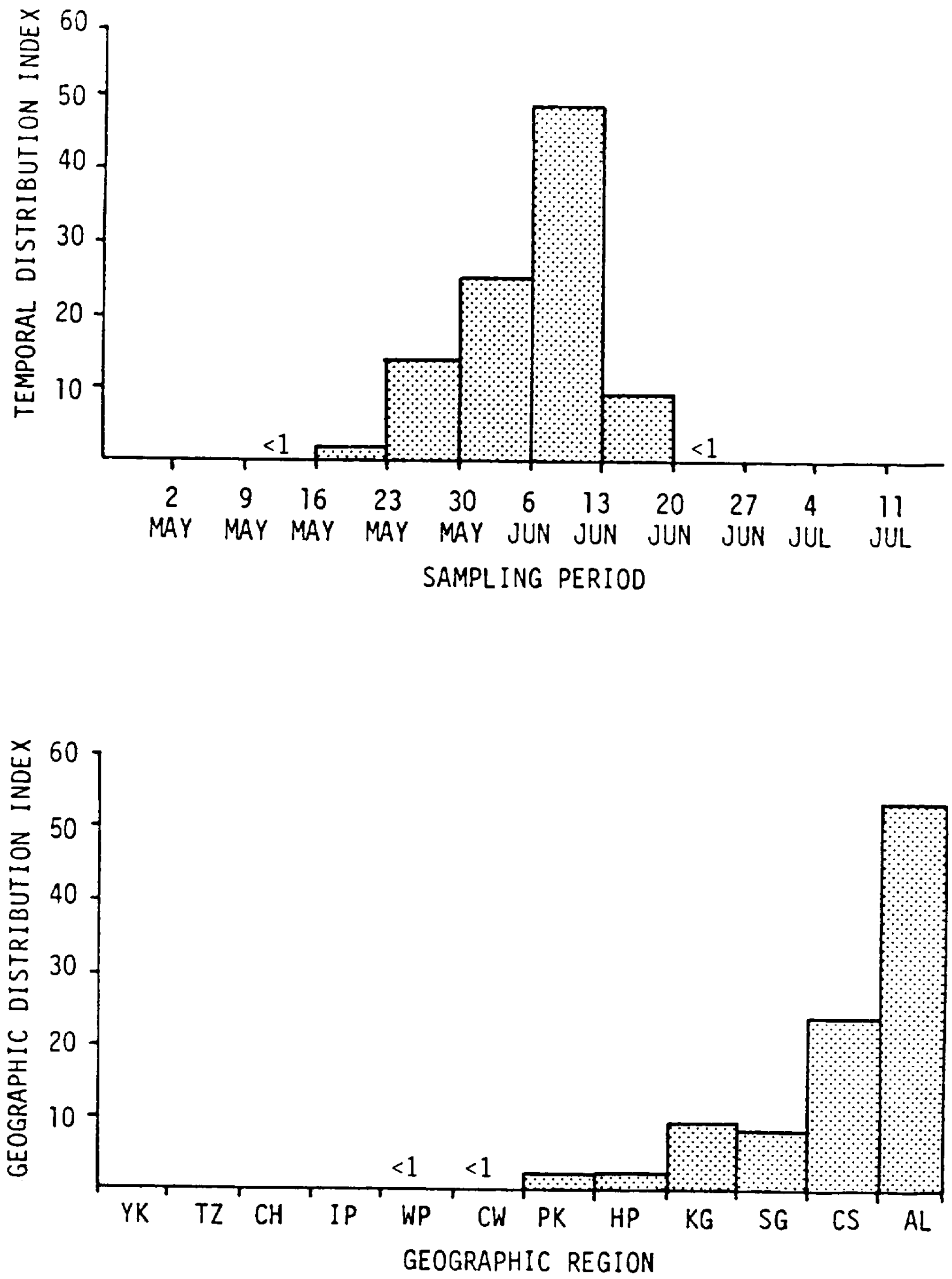

Figure 4.3-2. Temporal and geographic distribution of American shad yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

4.3.3 Post Yolk-Sac Larvae

Shad post yolk-sac larvae were most abundant in mid-June, one week after the yolk-sac larva peak (Figure 4.3-3). Downstream movement was clearly evident; larval distribution had shifted from the bottom to the channel stratum and, while still concentrated in the upper estuary, larvae were collected at all downriver locations except for Yonkers and Tappan Zee (Figure 4.3-3). This downstream movement is illustrated in Figure 4.3-4 and was most evident during the weeks of 13 and 20 June.

The spatial distribution of post yolk-sac larvae in 1983 was very similar to that reported from 1976 through 1982 (TI, 1981; Battelle, 1983; NAI, 1984a). Maximum abundance generally occurred in the last week of May and the first week in June, except in 1976, 1979 and 1983, when the peak occurred in mid- to late June (Table 4.3-1).

4.3.4 Young-of-the-Year

Transformation of American shad from the post yolk-sac to the juvenile stage began by late June (Figure 4.3-5). Water temperatures during this period averaged between 23° and $27^{\circ}C$ throughout the estuary (Appendix C; Table C-1). Unlike earlier developmental stages which were concentrated in the upper estuary, juvenile shad were dispersed throughout most of the estuary (Figures 4.3-5, 4.3-6 and 4.3-7). However, during the August to October juvenile sampling program, American shad juveniles were largely concentrated in the upper estuary.

In the offshore strata, juvenile shad abundance peaked in late August and declined rapidly thereafter to low levels throughout the remainder of the sampling program. This decrease in standing crop occurred when water temperatures were approximately $25^{\circ}C$ (Figure 4.3-6). In the shore zone, juvenile shad were most abundant in early August followed by a general decline that lasted through mid-October (Figure 4.3-7). Weekly geographic distributions in both the offshore strata and the shore zone showed no clear evidence of downstream movement (Appendix

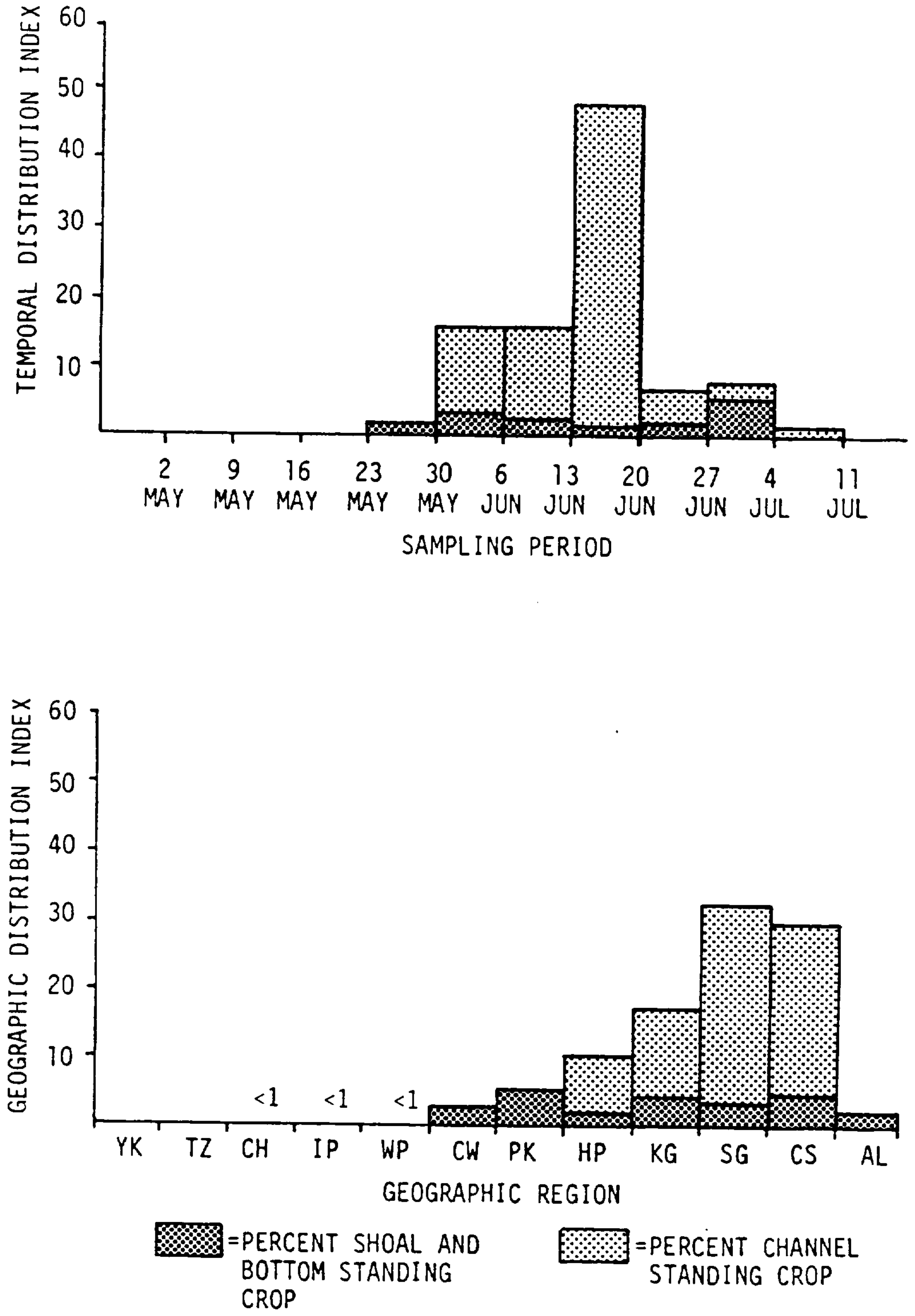

Figure 4.3-3. Temporal and geographic distribution of American shad post yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

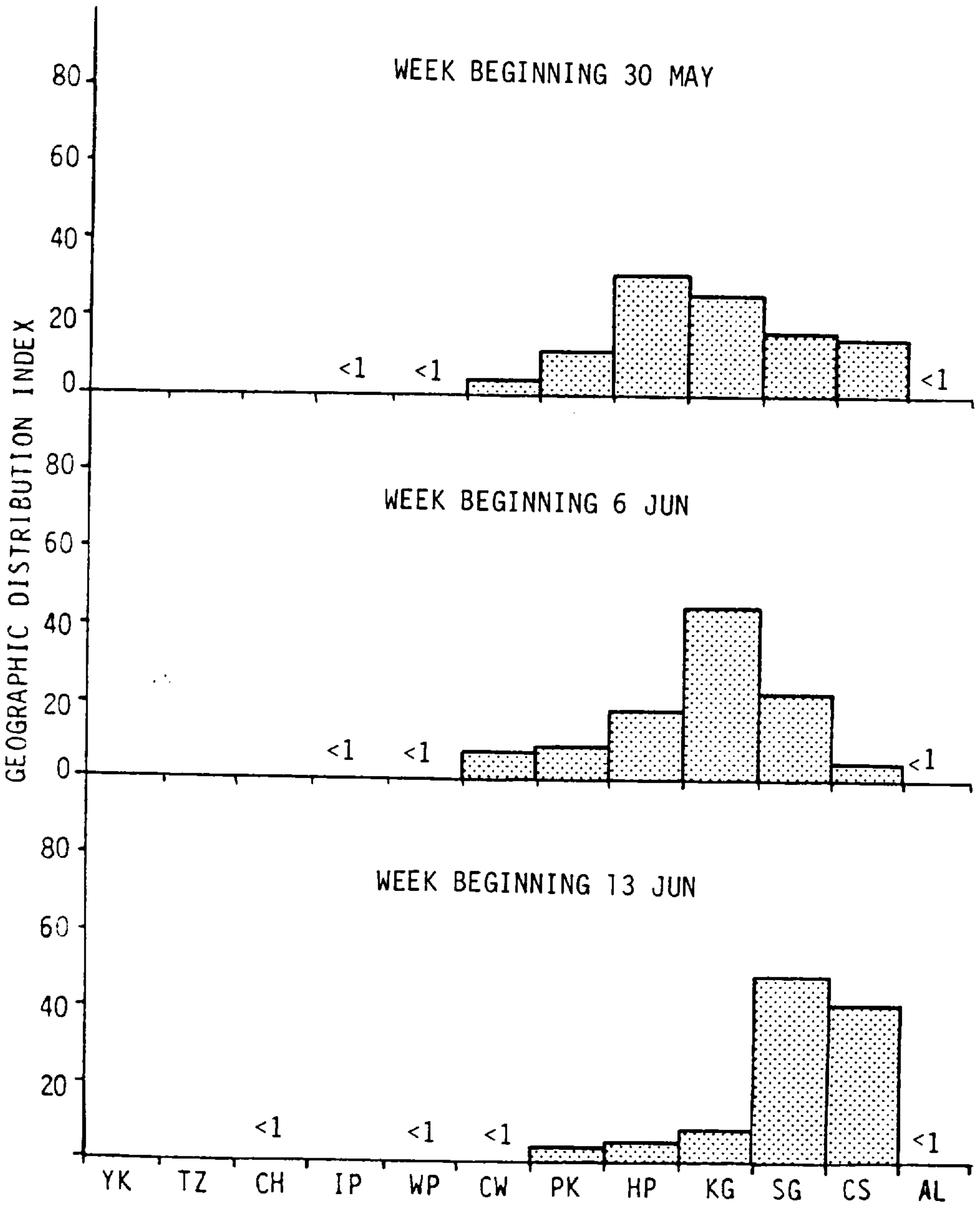

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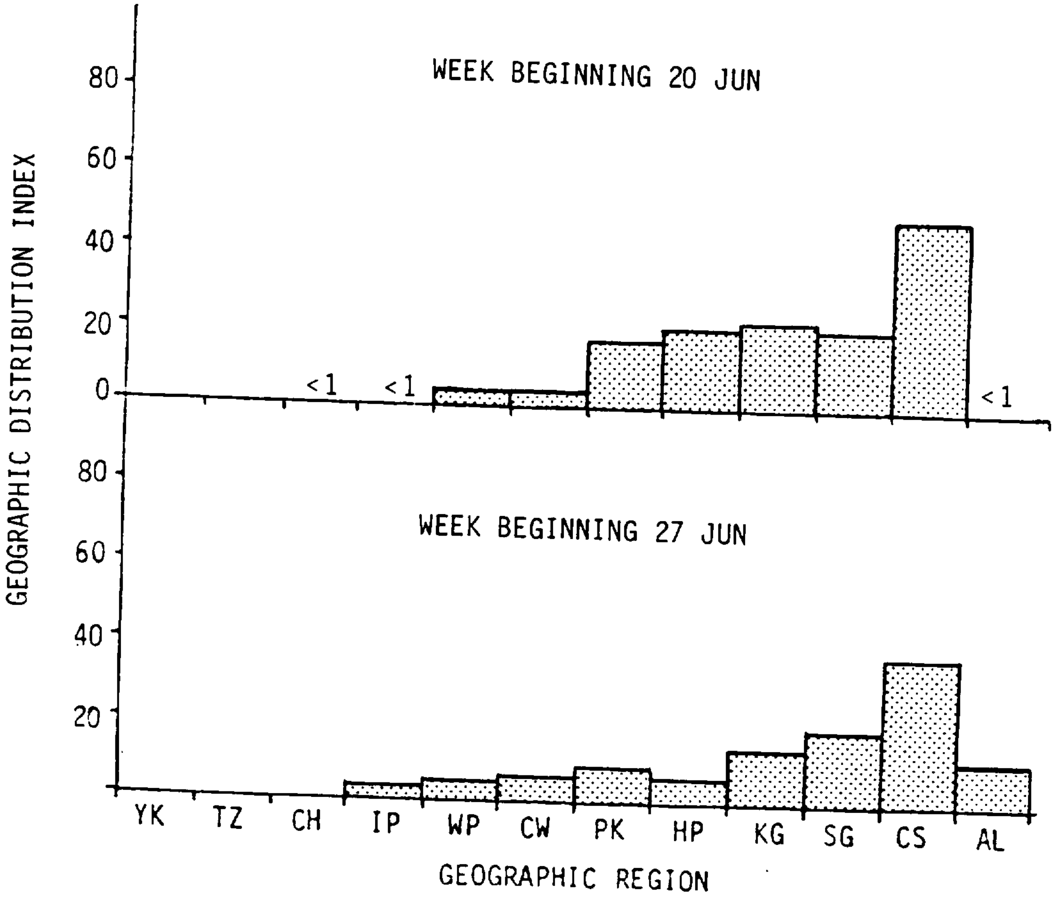
Figure 4.3-4. Weekly geographic distribution of American shad post yolk-sac larvae during the period of peak abundance, based on ichthyoplankton sampling, Hudson River estuary, 1983.



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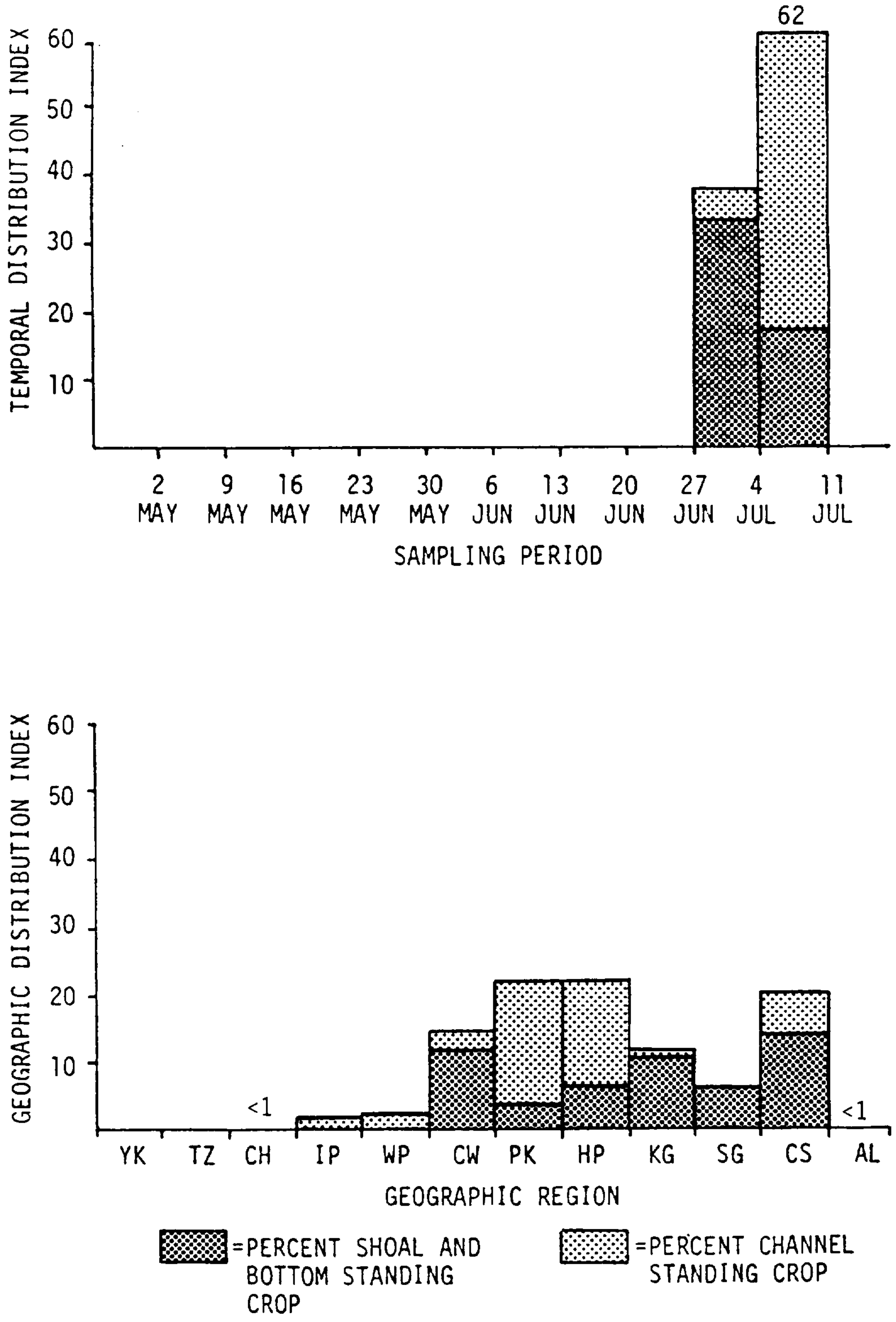


Figure 4.3-5. Temporal and geographic distribution of American shad young-of-the-year based on ichthyoplankton sampling, Hudson River estuary, 1983.

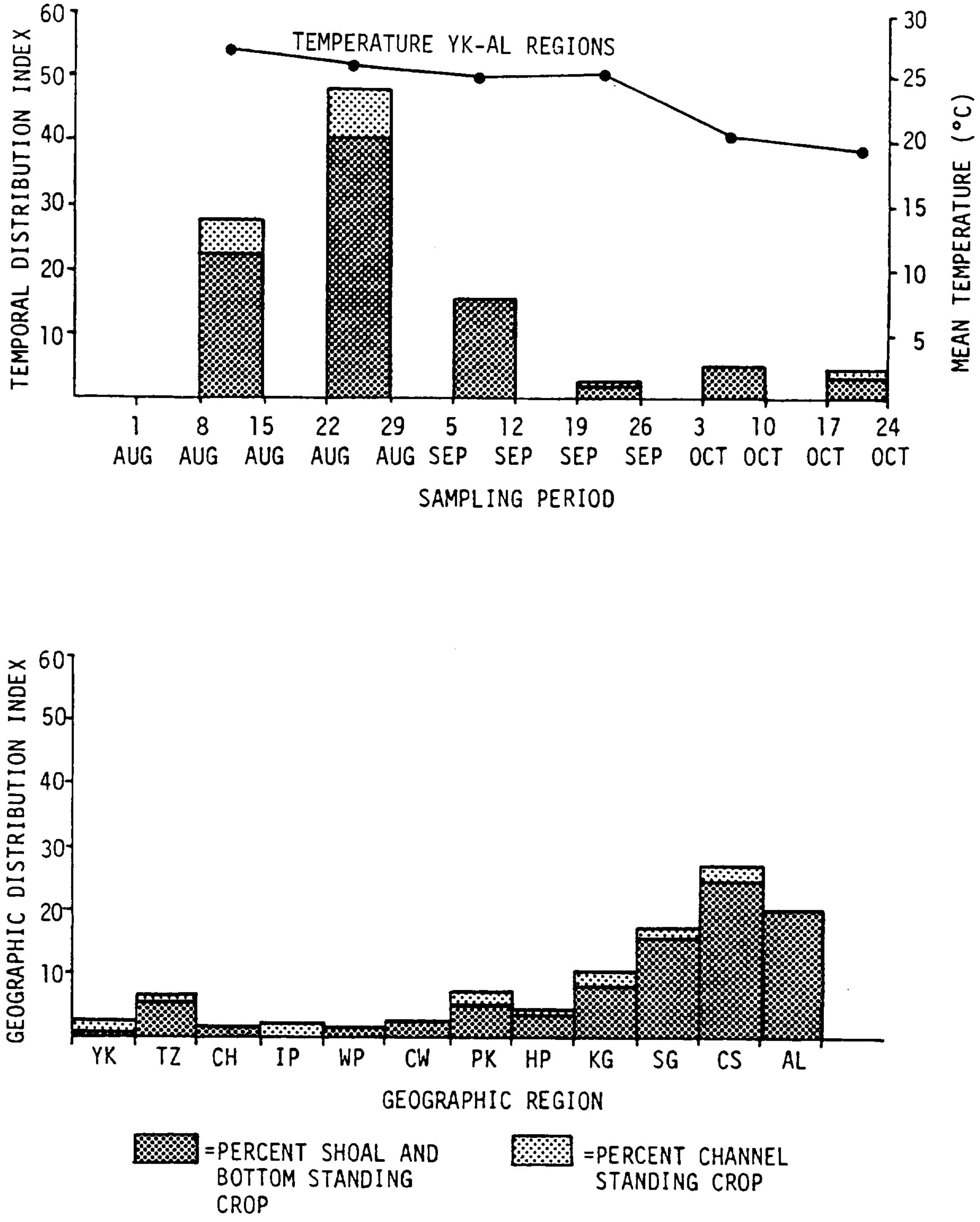
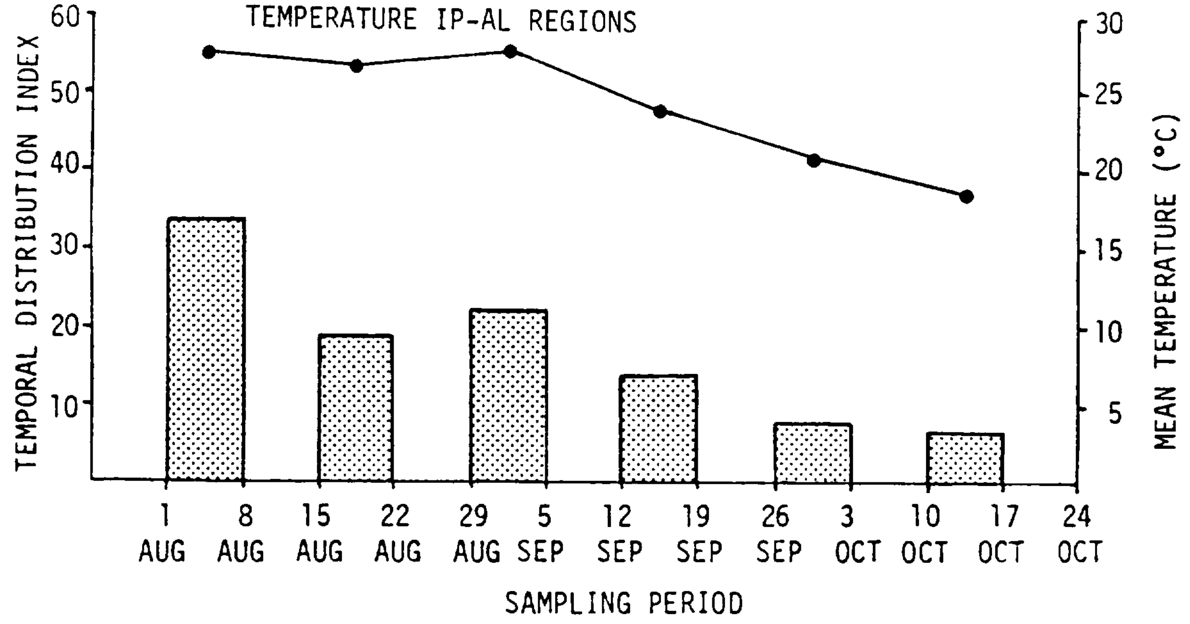


Figure 4.3-6. Temporal and geographic distribution of American shad young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.



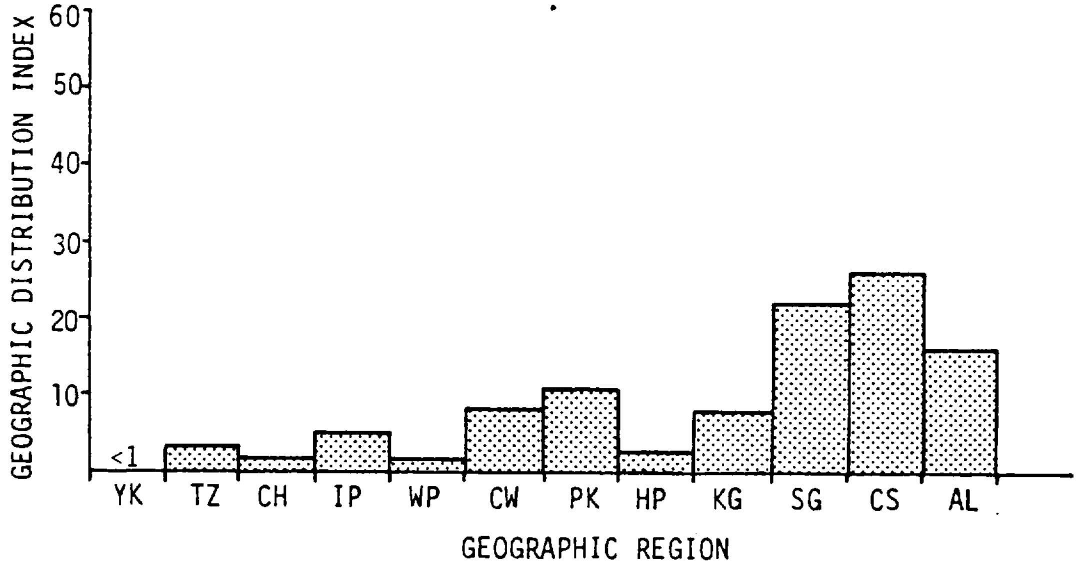


Figure 4.3-7. Temporal and geographic distribution of American shad young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

B; Tables B-31 and B-32). Peak abundance in the lower estuary occurred in early August, but from early August through early September juveniles were clearly still more abundant in the upper to middle estuary. Mortality, rather than movement out of the area, may have produced this decline in standing crop observed in both the shore zone and offshore strata.

Previous studies have indicated that dispersion downstream occurs primarily during July while water temperatures are rising (TI, 1981) and the population matures from the larval to the juvenile stage. In the Connecticut River, however, juveniles disperse seaward in August when water temperatures begin to decline (Marcy, 1976a). Emigration from the Hudson River estuary is virtually complete by late October (TI, 1981). According to Leggett and Whitney (1972), juvenile shad emigrate from rivers along the Atlantic coast following a drop in water temperature below 15.5°C for several days. In 1983, Hudson River temperatures were above 17°C in mid-October when the sampling program ended.

4.3.5 Yearling and Older Fish

Yearling and older shad were collected on only six occasions during the 1983 sampling program, and in extremely low numbers (Appendix B; Tables B-34 through B-38). No conclusions can be drawn regarding distribution.

4.4 ATLANTIC TOMCOD

The Atlantic tomcod, *Microgadus tomcod*, is a euryhaline species of the family Gadidae closely resembling its marine relative, the Atlantic cod. The Atlantic tomcod can be found along the Atlantic coast from the maritime provinces of Canada south to Virginia. Tomcod frequently occur in estuaries and their tributaries but also may be found in coastal waters, as far as 1.6 kilometers offshore (Bigelow and

Schroeder, 1953). Within the Hudson River they usually are found below Kingston (km 138) but occasionally occur as far north as Saugerties (km 170).

Atlantic tomcod spawn from November through February over sand or gravel bottoms in brackish and occasionally freshwater shoal areas (Scott and Crossman, 1973). In the Hudson River estuary adults usually reach sexual maturity by age I. The number of eggs produced is dependent upon the size of the female, and ranges from 1600 to 86,000 eggs, with an average of 20,000. The eggs are about 1 mm in diameter, demersal and adhesive. The Atlantic tomcod is a winter spawner; incubation time is about 24 days at 6°C. The newly-hatched larvae are approximately 5 mm in length and absorb the yolk sac within 4-5 days. Juveniles during the first year grow to a length of 130-150 mm (Scott and Crossman, 1973).

The tomcod is one of the smallest species of the Gadidae, obtaining a total length of 350 mm and a weight of 450 grams. Tomcod feed heavily on small crustaceans such as shrimp and amphipods.

4.4.1 Post Yolk-Sac Larvae

Since the Atlantic tomcod is a winter spawner, no eggs or yolk-sac larvae were collected. Post yolk-sac larvae were present but only in reduced numbers, as compared to previous years (TI, 1981; Battelle, 1983; NAI, 1984a), and probably had passed their peak when sampling began in May (Appendix B; Table B-39). Regional densities of post yolk-sac larvae during ichthyoplankton sampling were always below 40/1000 m^3, and in most cases densities were less than 1/1000 m^3. In previous years (1974-1980), post yolk-sac larvae reached peak abundance during April when water temperatures were between 6°-12°C and declined to trace levels in May and June (TI, 1981; Battelle, 1983). Thus, post yolk-sac larvae collected during May of the current sampling period constituted only a fraction of their total occurrence during the 1983 season. Virtually all post yolk-sac larvae were collected in

Yonkers (97%) and during the week of 2 May (96%) (Figure 4.4-1). Temperature at this time was 12.5°C (Appendix C; Table C-1) and conductivity was 5.8 mS/cm (Appendix C; Table C-5). No post yolk-sac larvae were collected north of Croton-Haverstraw or after 22 May.

The distributional patterns of demersal larvae such as Atlantic tomcod are likely to be influenced by the movement of the salt front (TI, 1981). Peterson *et al*. (1980) demonstrated that high freshwater flow rates during the hatching period tend to flush the larvae out of the spawning area and downstream toward the mouth of the estuary. In 1983, maximum water discharge at Green Island, N.Y. occurred on 26 April (mean = 2800 m^3/sec) with flow rates remaining above 1400 m^3/sec through the early part of May. These flow rates were a result of wet spring conditions (increased rainfall and meltwater runoff) along the Hudson River basin resulting in the location of the salt front farther downriver than in recent years. This probably was responsible for the relatively low concentrations of tomcod in the sampling area, particularly above the Yonkers region, compared to previous years.

4.4.2 Young-of-the-Year

Juvenile Atlantic tomcod were collected when sampling began the week of 2 May and continued to be collected consistently throughout the remainder of the sampling period (Figure 4.4-2). A slight peak was observed during the week of 20 June. This temporal distribution was different from all previous years. In 1979 and 1982, peak abundance occurred during late May - early June (TI, 1981; NAI, 1984a) and in all other years, peak abundance usually occurred during April. As described in the 1979 Year Class Report (TI, 1981), a large portion of the post yolk-sac population was probably distributed downriver of the study area, and juveniles were very likely distributed in a similar manner. Therefore, this temporal distribution may be associated with a period of movement upstream into the study area in relation to increasing conduct-

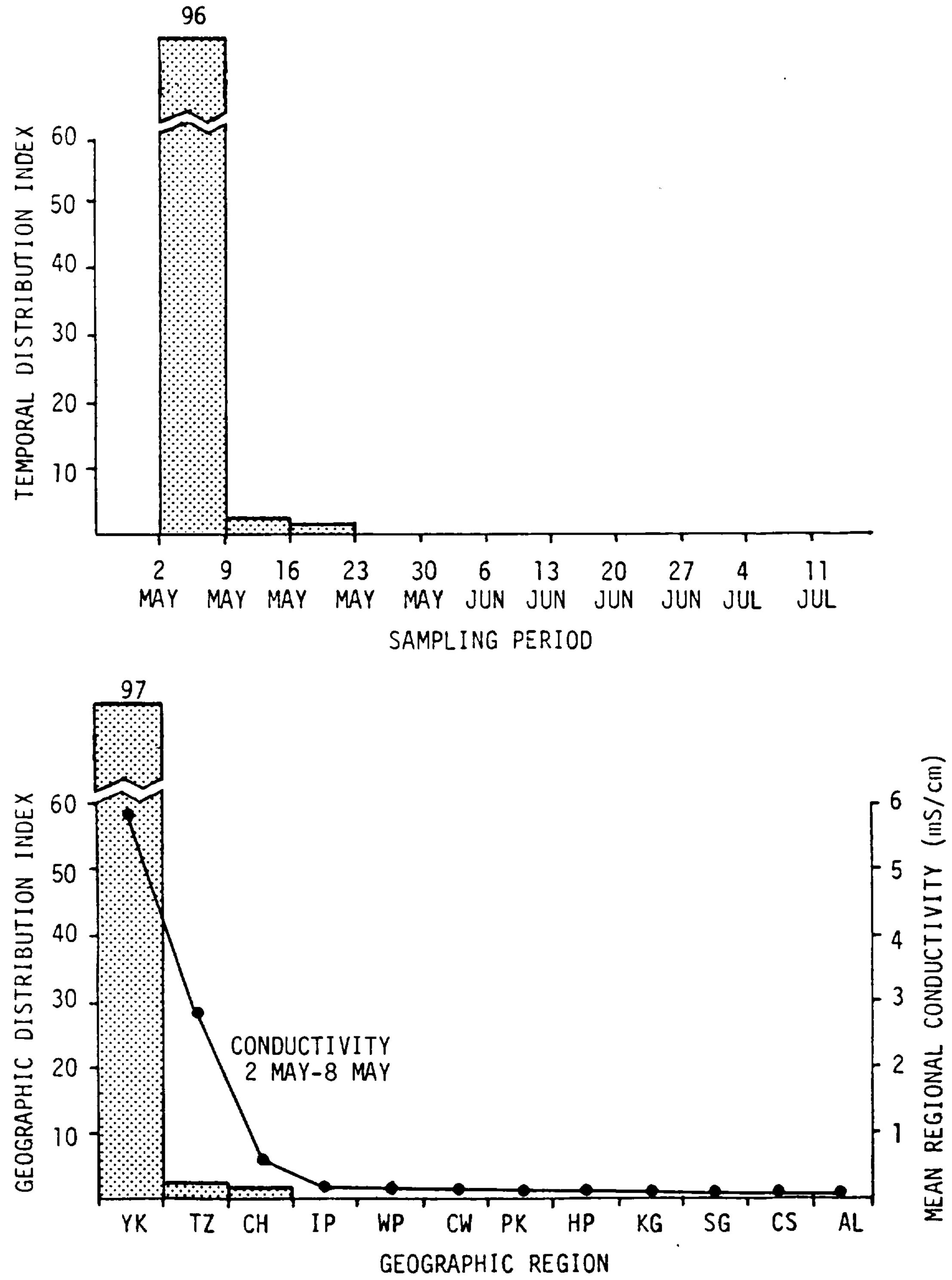
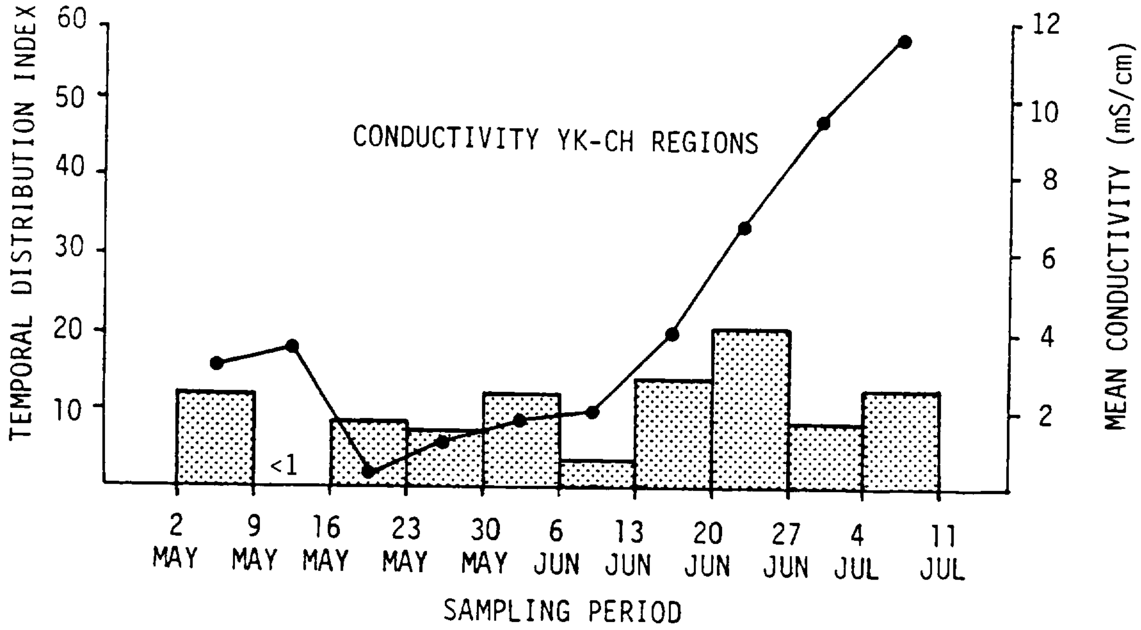


Figure 4.4-1. Temporal and geographic distribution of Atlantic tomcod post yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.



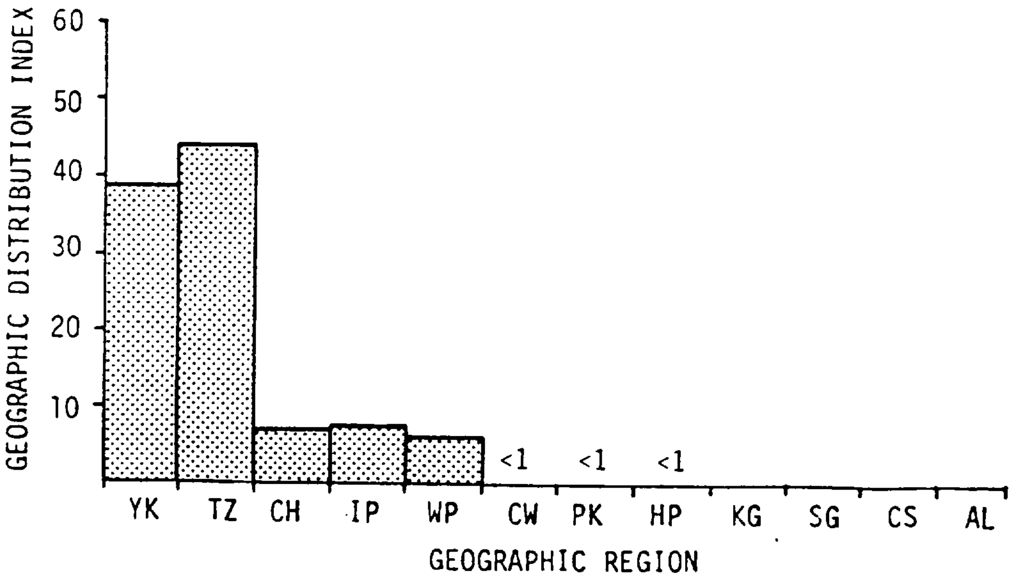


Figure 4.4-2. Temporal and geographic distribution of Atlantic tomcod young-of-the-year based on ichthyoplankton sampling, Hudson River estuary, 1983.

ivities. The spatial distribution of these early juveniles was the same as previous years, largely concentrated in Yonkers and Tappan Zee.

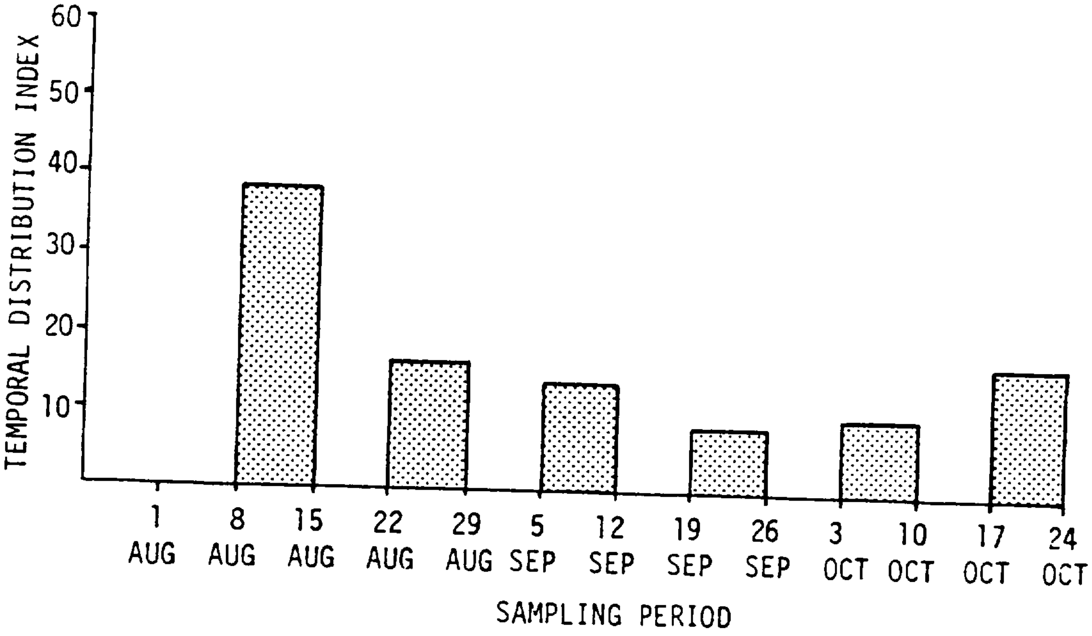
The offshore distributional pattern of juveniles from August through October (Figure 4.4-3) was similar to the patterns observed for all previous years except 1979 and 1980 (TI, 1981; Battelle, 1983; NAI, 1984a). Peak abundance of juveniles in the offshore strata occurred when sampling began in early August; most juveniles were located in the middle estuary. Conductivity during this period averaged 3.5 mS/cm (Figure 3.3-1), with the salt front located approximately in the Poughkeepsie region.

The spatial distribution of juveniles was the same as in previous years, except for 1976 and 1979 when the peaks occurred downriver in the Tappan Zee and Yonkers region (TI, 1981). These annual differences in distribution were related to lower conductivities in the middle estuary during 1976 and 1979 (TI, 1980a, 1981). Atlantic tomcod prefer brackish water and during times of relatively low conductivities may move farther downriver with the salt front.

Atlantic tomcod were already present in the shore zone when sampling began on 1 August (Figure 4.4-4). Standing crop remained relatively constant throughout the remainder of the Beach Seine sampling program. Most juveniles in the shore zone were collected in the lower estuary, particularly in the Tappan Zee region.

4.5 ALEWIFE/BLUEBACK HERRING

This category comprises the early developmental stages of two anadromous clupeids, blueback herring and alewife, which are collectively referred to as river herring. Both of these species spawn in the spring. Blueback herring spawn somewhat later than alewives, although the blueback spawning migration may overlap the end of the alewife spawning period. These species are difficult to distinguish until the metamorphosed juveniles reach a total length of 35 to 40 mm (TI, 1981).



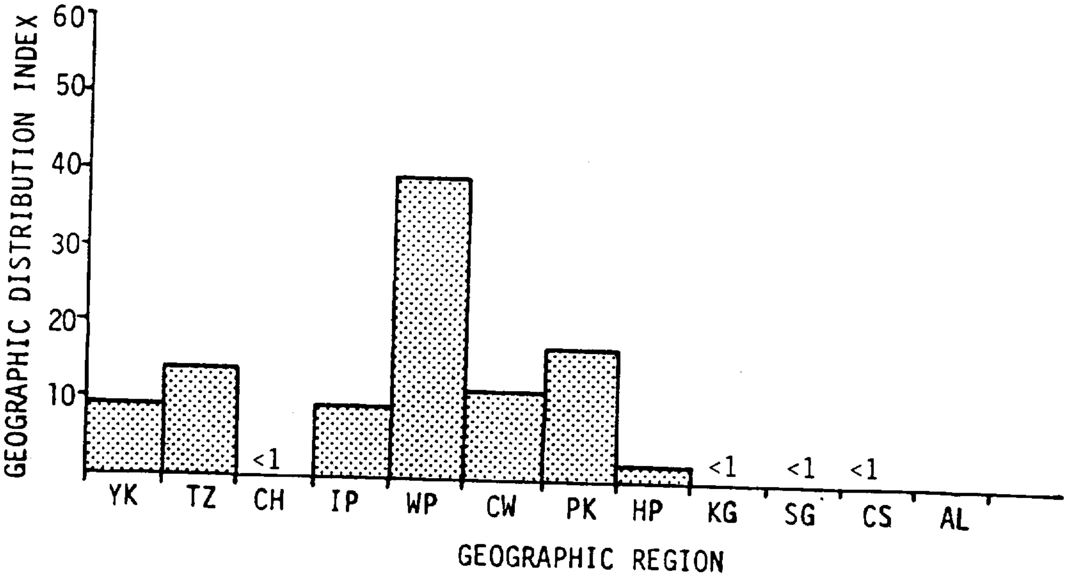


Figure 4.4-3. Temporal and geographic distribution of Atlantic tomcod young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.

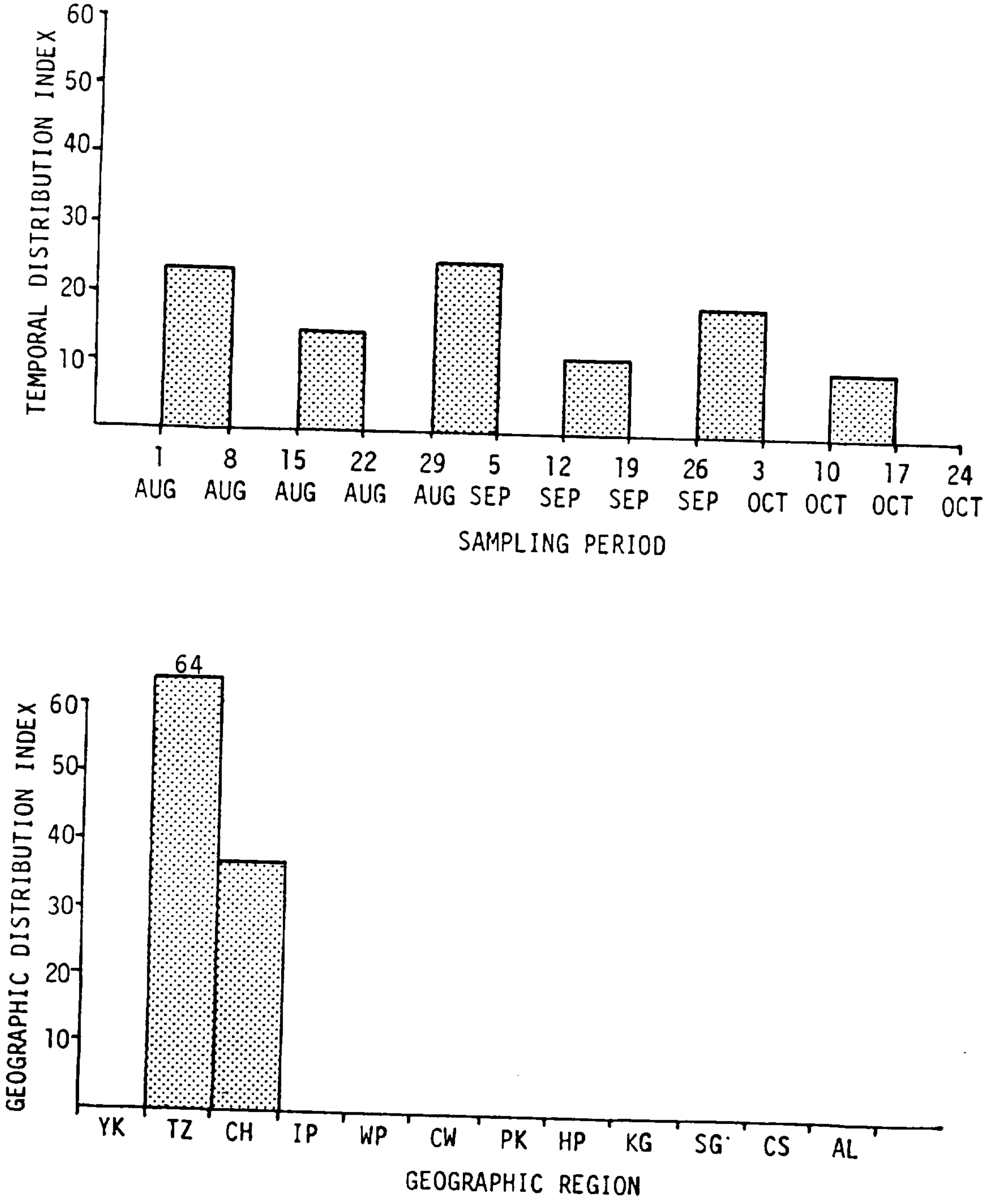


Figure 4.4-4. Temporal and geographic distribution of Atlantic tomcod young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

In the following section, the distribution of river herring eggs, yolk-sac larvae, post yolk-sac larvae and early juveniles are presented and discussed.

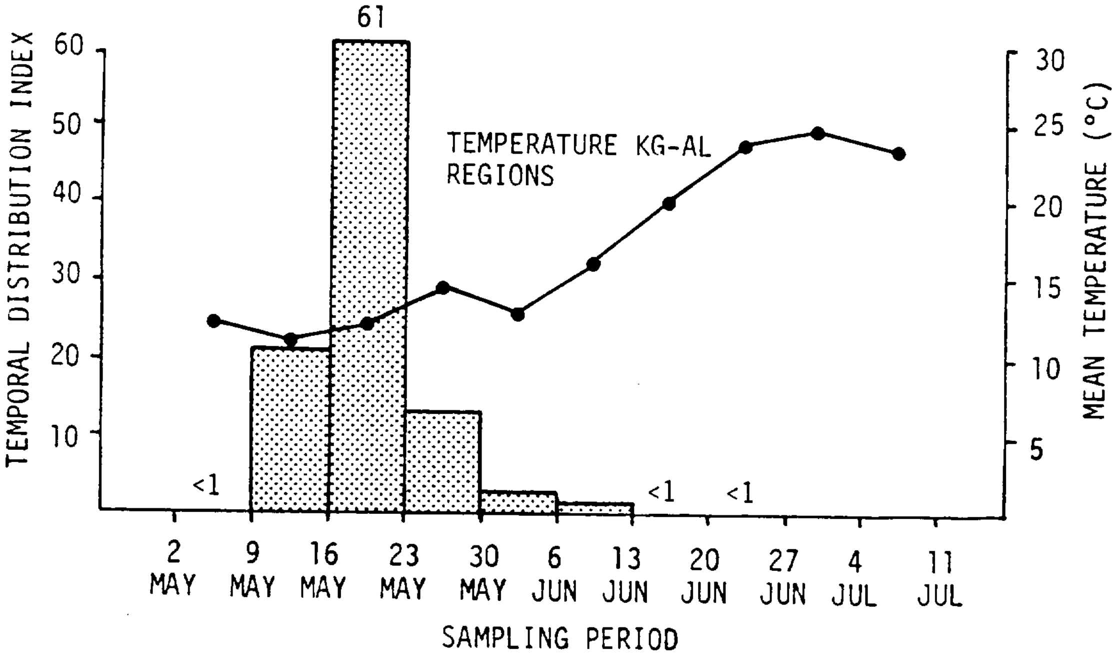
4.5.1 Eggs

Maximum standing crop of river herring eggs occurred during the third week in May (Figure 4.5-1). Eggs were concentrated in the upper estuary, primarily in the Albany region. Water temperatures in the upper estuary during this period averaged 12.3°C (Appendix C; Table C-1).

Temporal distribution of river herring eggs in the upper estuary varied with geographic region (Figure 4.5-2). Unimodal peaks in standing crop occurred in the Kingston, Catskill and Albany regions in the fourth, second and third week of May, respectively, whereas a bimodal (second and fourth weeks of May) peak was evident in the Saugerties region. In 1982, a bimodal peak occurred in the Albany region during the third week of May and the second week of June (NAI, 1984a). This bimodal distribution may represent either sequential spawning by alewives and blueback herring or a second spawning by alewives. In 1979, TI (1981) reported two peaks of river herring eggs, with the second peak coinciding with peak catches of adult blueback herring. However, since alewives may spawn twice in the Albany area (LMS, 1975, cited in TI, 1981), the second peak in 1979 may have included alewives as well as blueback herring.

4.5.2 Yolk-Sac Larvae

Abundance of river herring yolk-sac larvae peaked during the fourth week in May (Figure 4.5-3), about one week after the egg abundance peak. Yolk-sac larvae were most abundant in the upper estuary, although they were dispersed slightly farther downstream than were eggs.



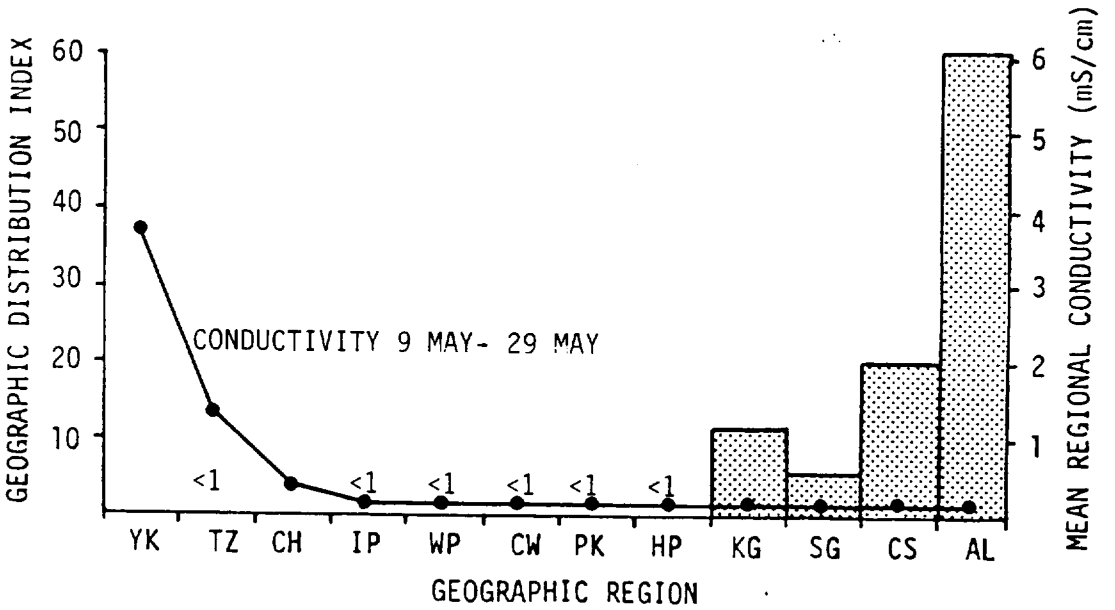


Figure 4.5-1. Temporal and geographic distribution of alewife/blueback herring eggs based on ichthyoplankton sampling, Hudson River estuary, 1983.

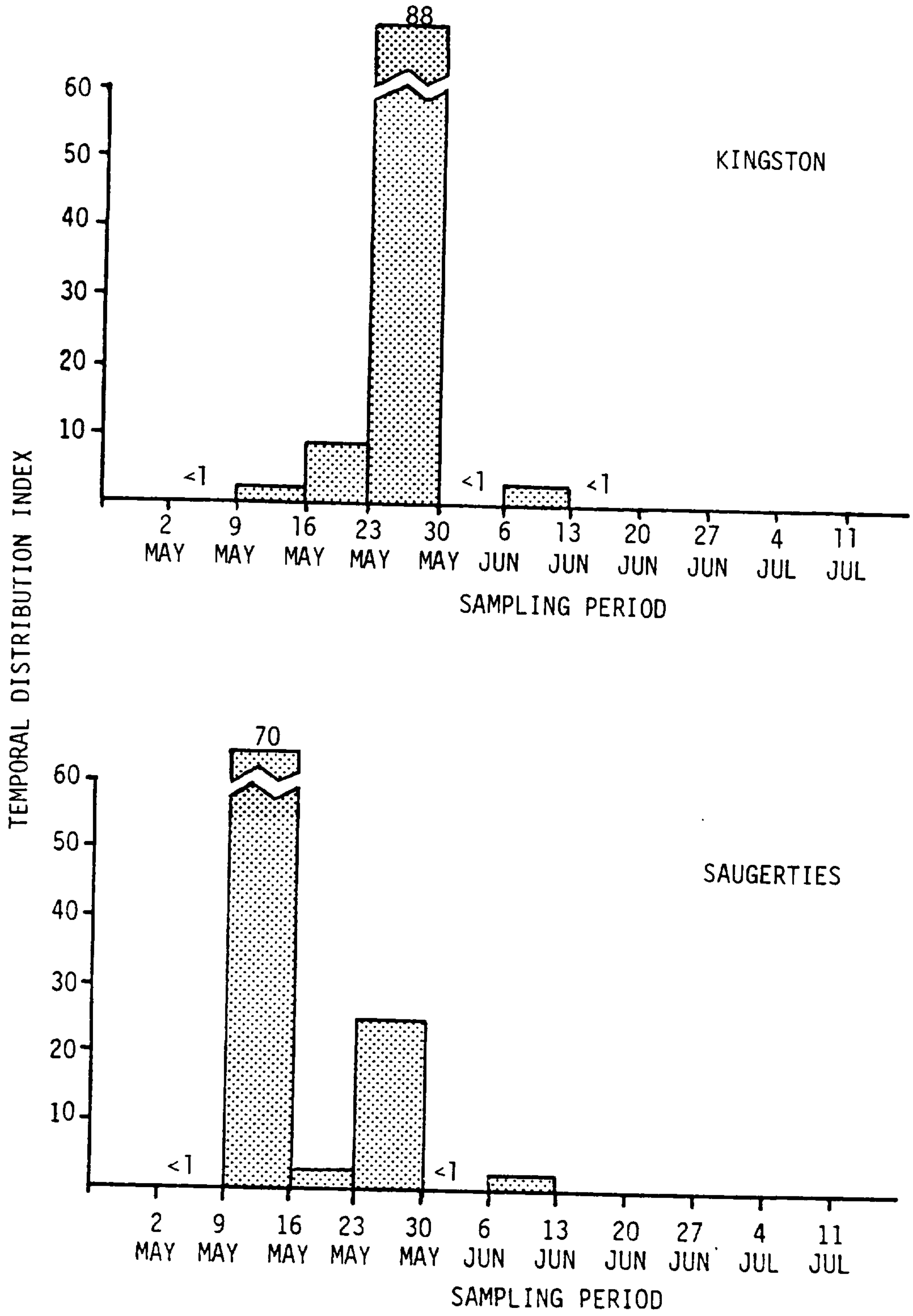


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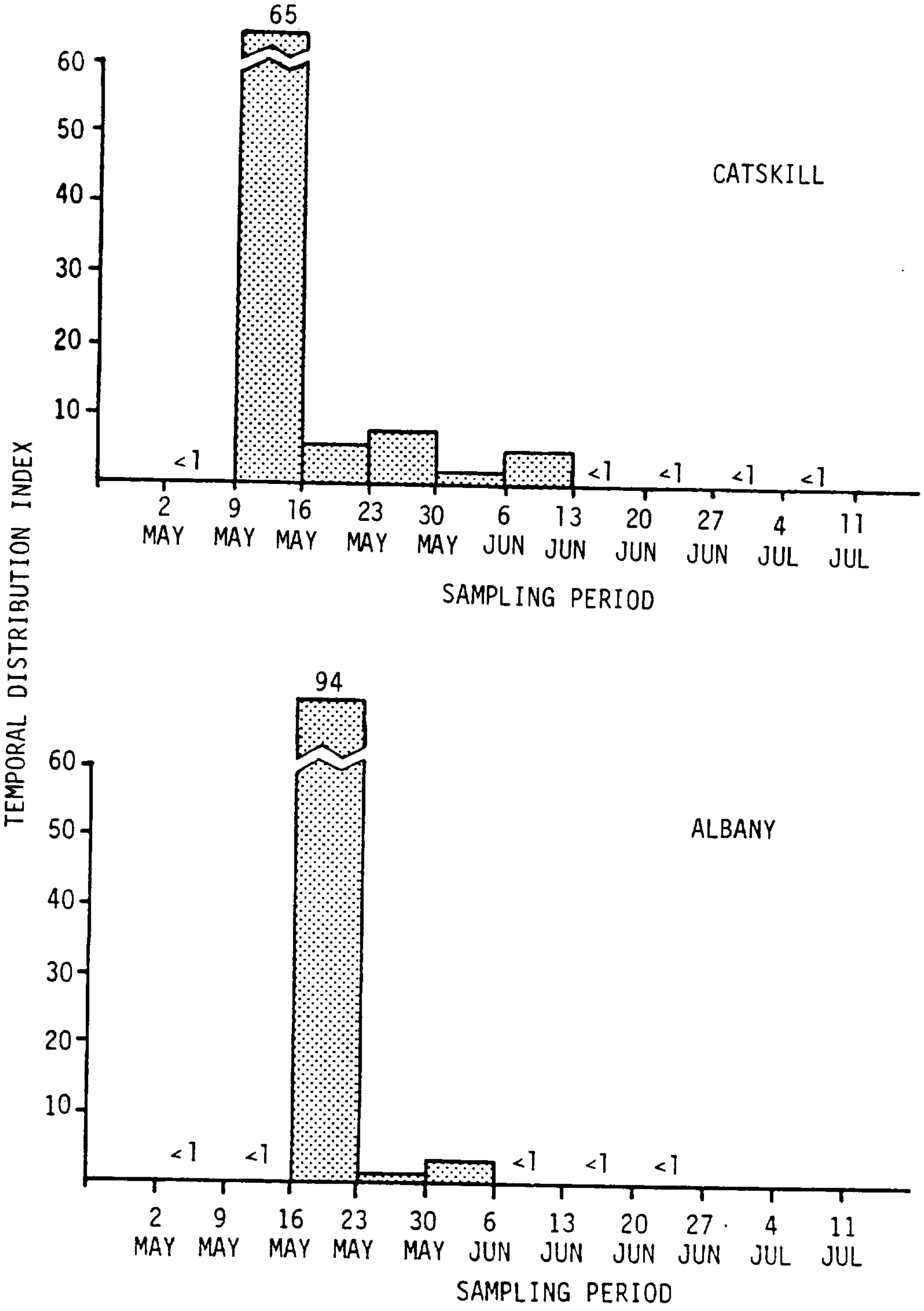
Figure 4.5-2. Weekly temporal distribution of alewife/blueback herring eggs in regions of peak abundance, based on ichthyoplankton sampling, Hudson River estuary, 1983.



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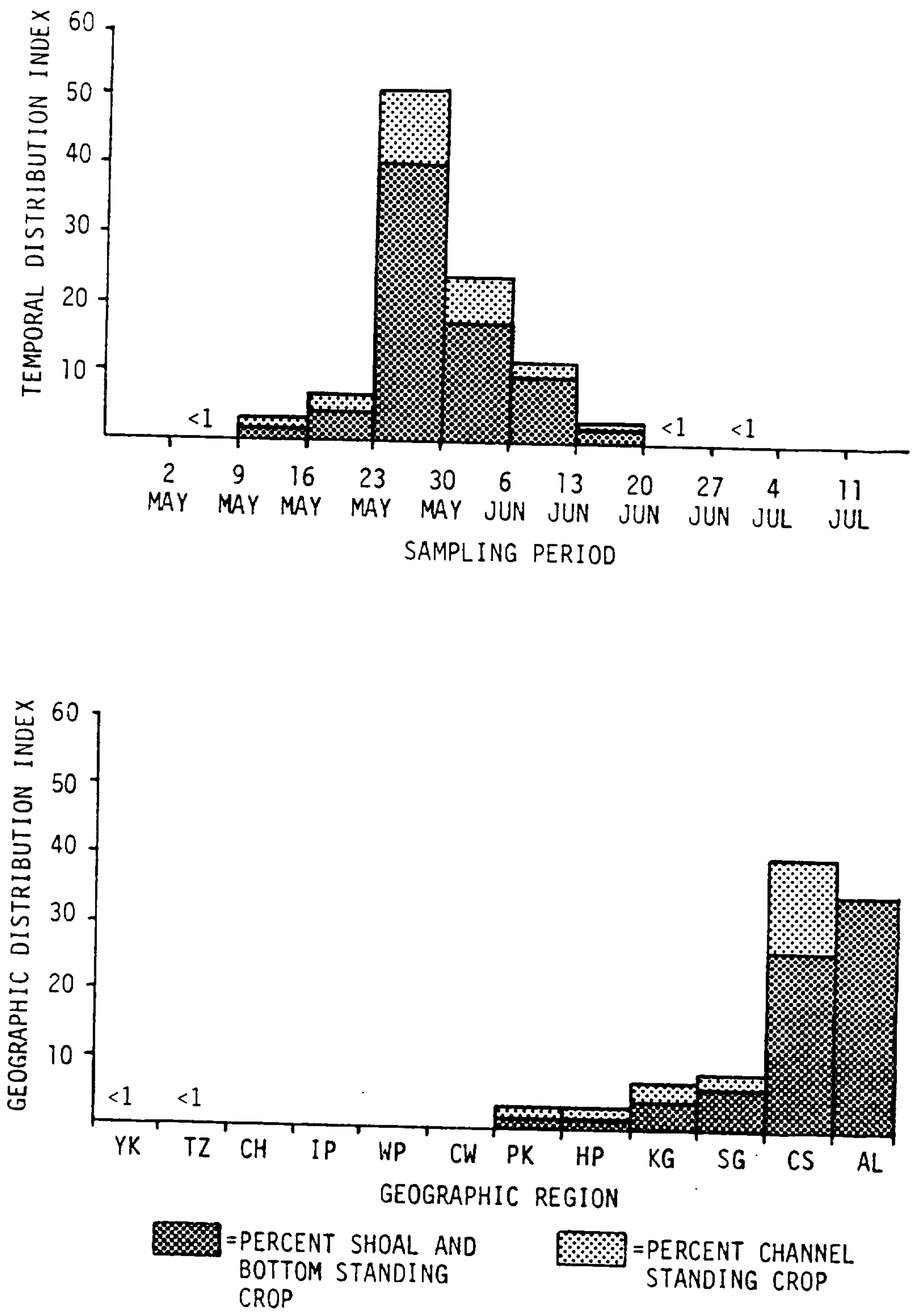

Figure 4.5-3. Temporal and geographic distribution of alewife/blueback herring yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

Both eggs and yolk-sac larvae were concentrated in the bottom stratum; however, dispersion of yolk-sac larvae into the channel was evident.

Regional differences in yolk-sac larvae abundance peaks were apparent (Figure 4.5-4). In the Kingston, Catskill and Albany regions yolk-sac larvae peaked around the fourth week in May or first week in June, whereas in the Saugerties region, a bimodal distribution (third week of May and first week in June) was observed.

4.5.3 Post Yolk-Sac Larvae

River herring post yolk-sac larvae were present during the first week in May and reached peak abundance during the first week in June (Figure 4.5-5). Downriver dispersion was clearly evident. Compared to yolk-sac larvae, a greater proportion of post yolk-sac larvae were found in the channel than near the bottom. Variation in temporal distribution among regions from Catskill through Poughkeepsie was observed (Figure 4.5-6). From Poughkeepsie through Saugerties, the primary peak occurred during the week of 30 May, whereas in the Catskill region the peak occurred two weeks later during the week of 13 June. Bimodal temporal distributions were evident in both the Kingston and Saugerties regions.

4.5.4 Early Young-of-the-Year

River herring young-of-the-year first appeared in ichthyoplankton samples during the week of 20 June and were most abundant during the last sampling period of the survey (Figure 4.5-7). Standing crop was highest in the middle estuary; few river herring young-of-the-year were collected either downstream from Cornwall or upstream from Hyde Park.

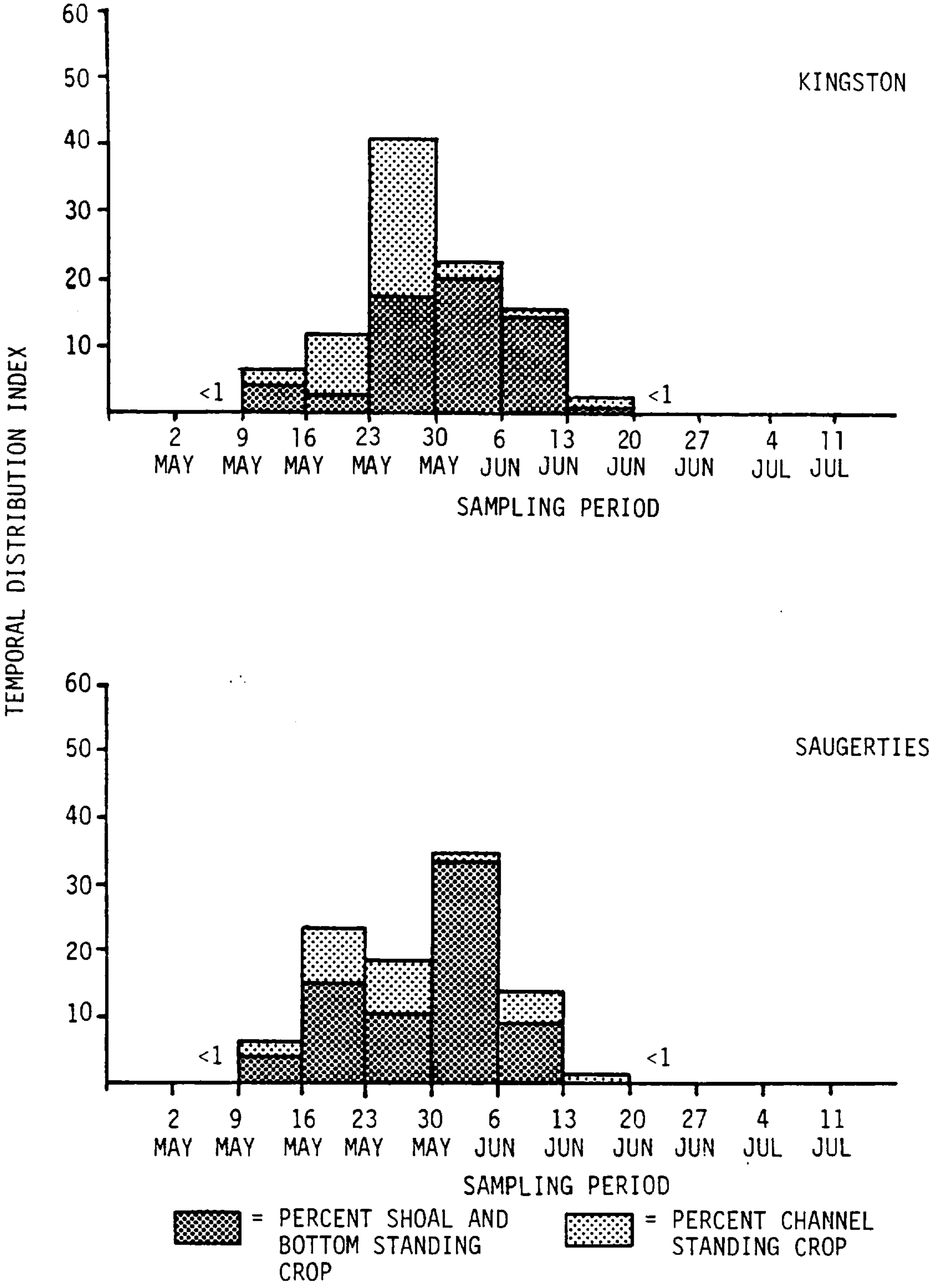

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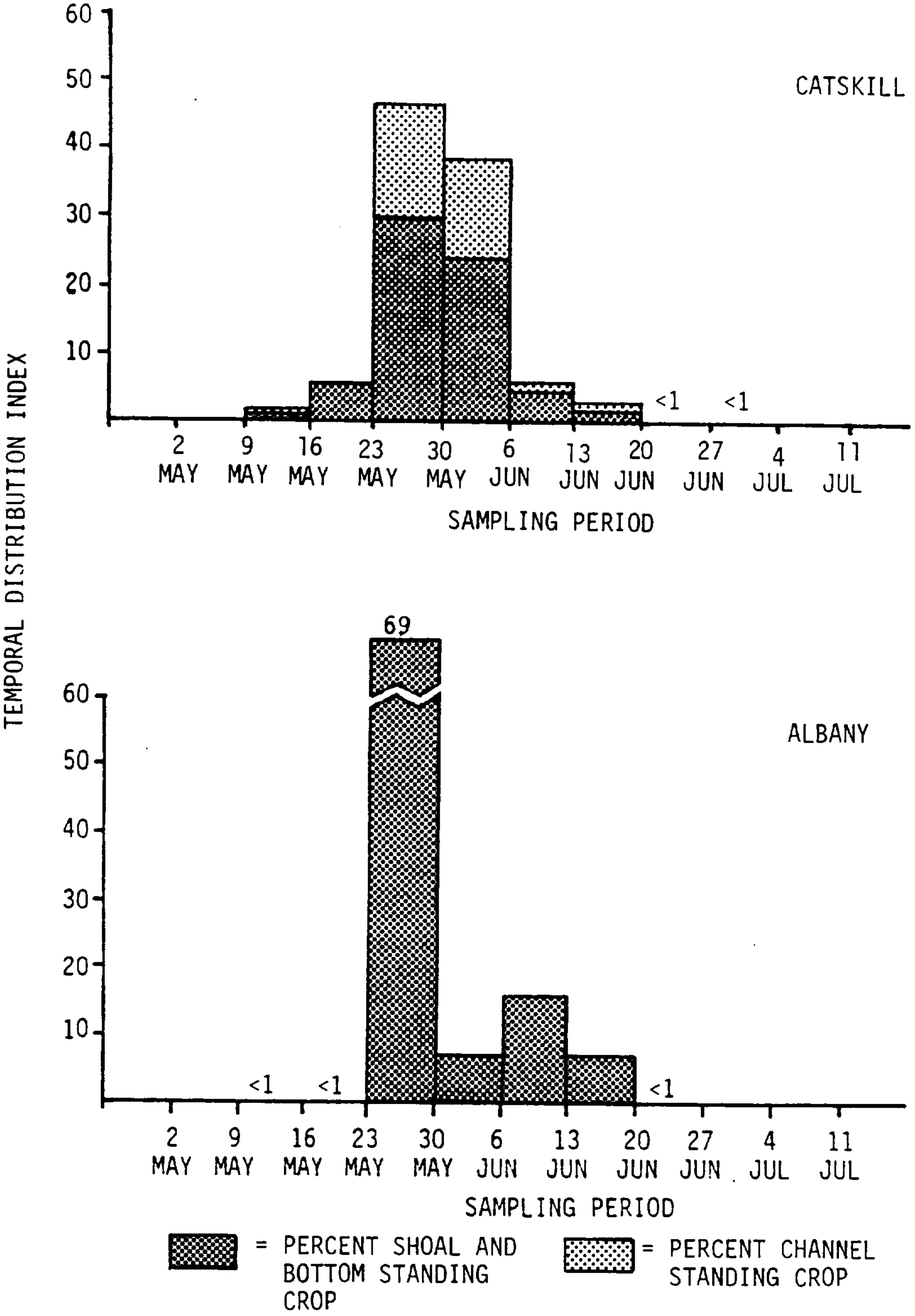
Figure 4.5-4. Temporal distribution of alewife/blueback herring yolk-sac larvae in the regions of peak abundance, based on ichthyoplankton sampling, Hudson River estuary, 1983.



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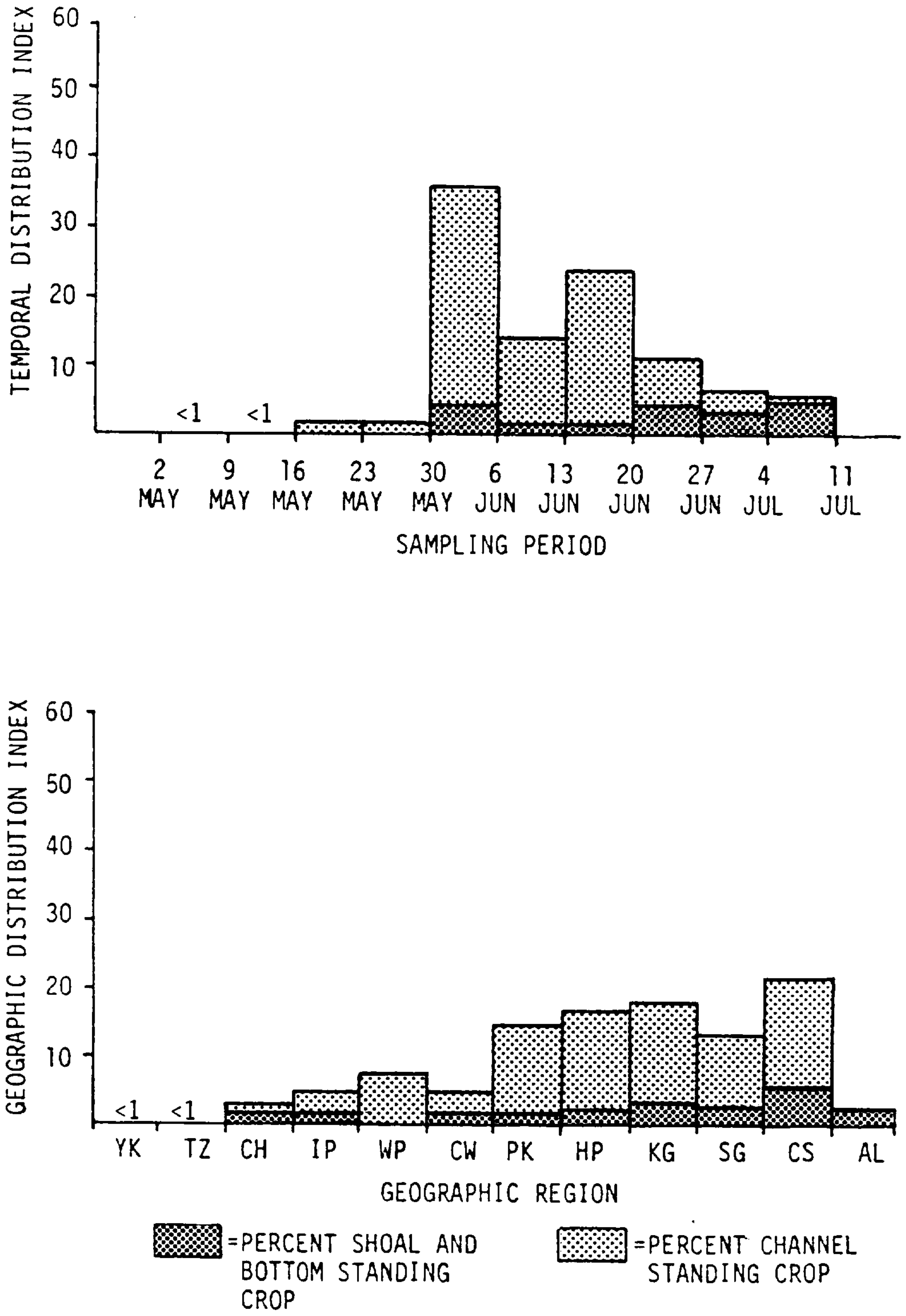

Figure 4.5-5. Temporal and geographic distribution of alewife/blueback herring post yolk-sac larvae based on ichthyoplankton sampling, Hudson River estuary, 1983.

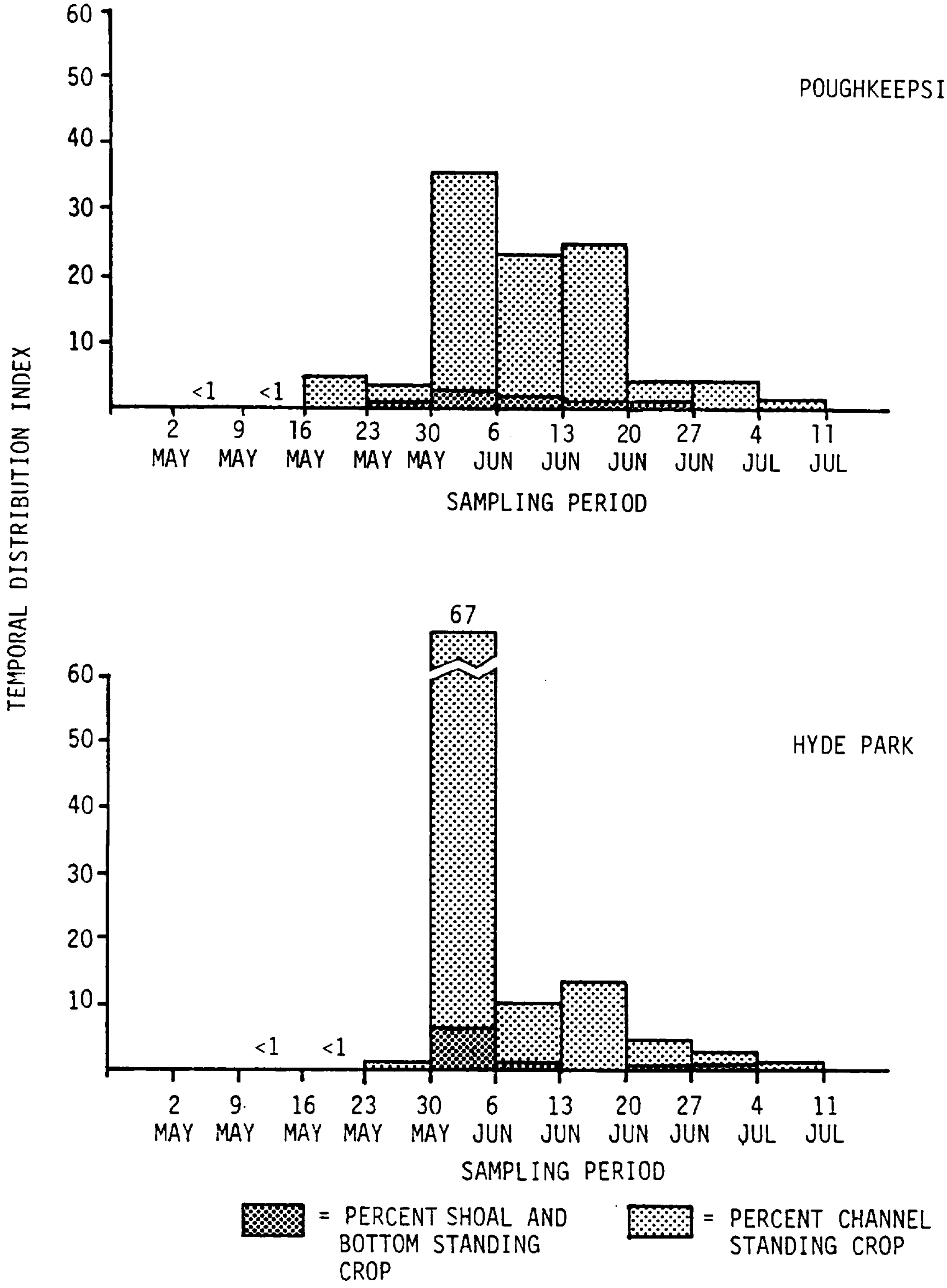

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Figure 4.5-6. Temporal distribution of alewife/blueback herring post yolk-sac larvae in the regions of peak abundance, based on ichthyoplankton sampling, Hudson River estuary, 1983.

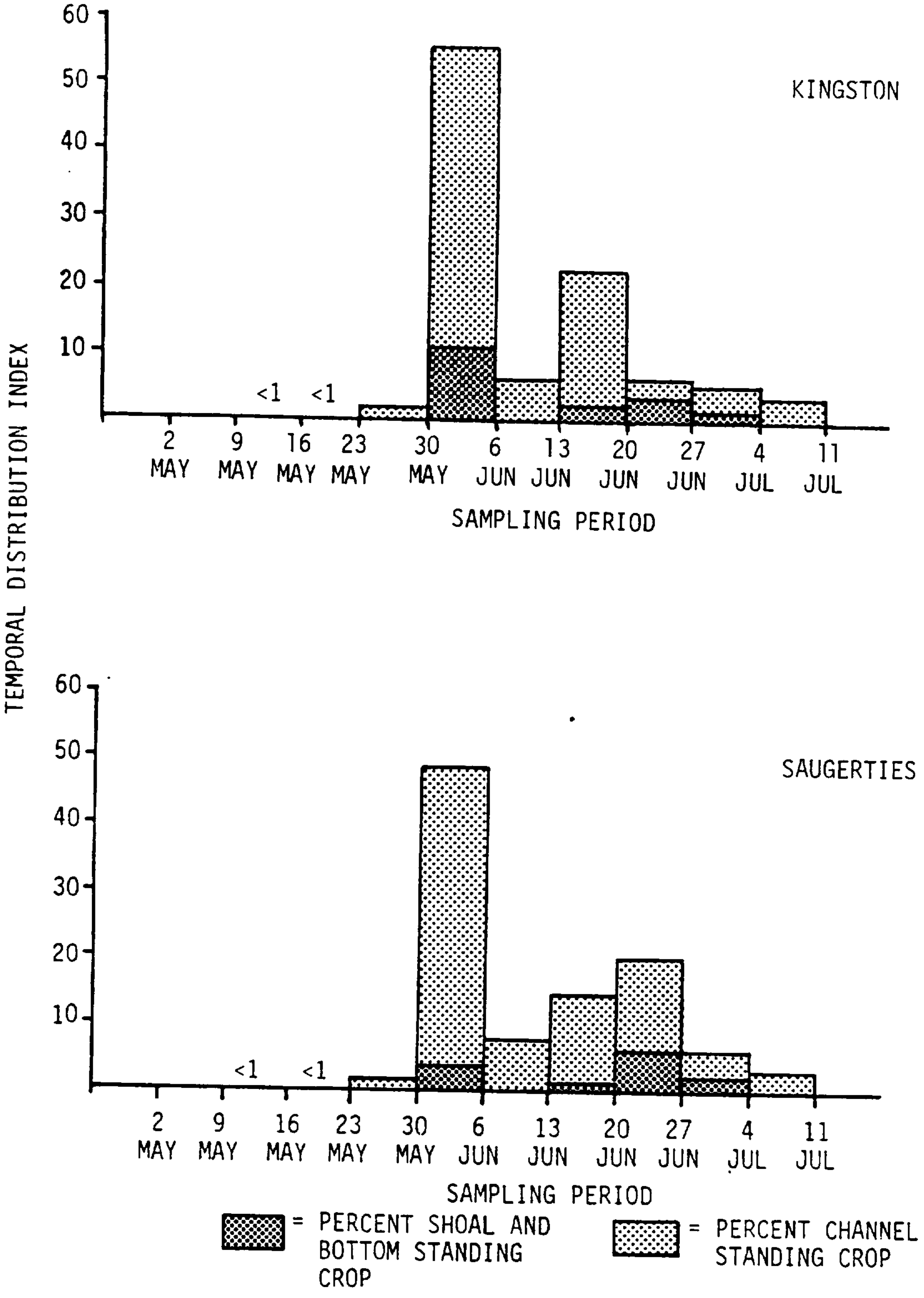

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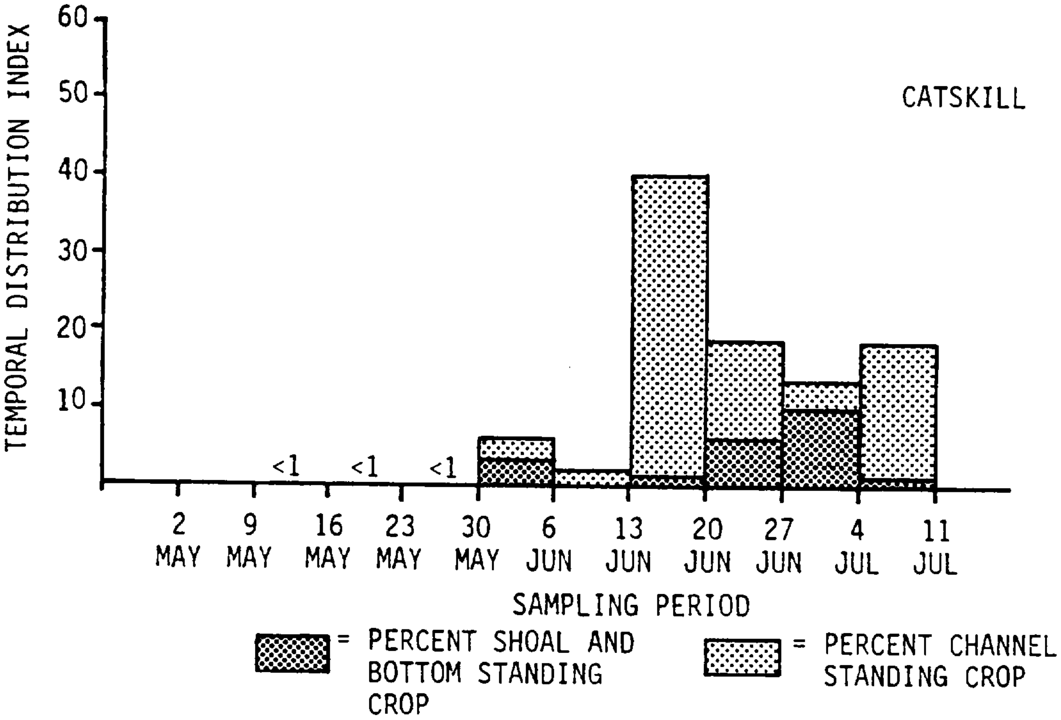
Figure 4.5-6. (Continued).



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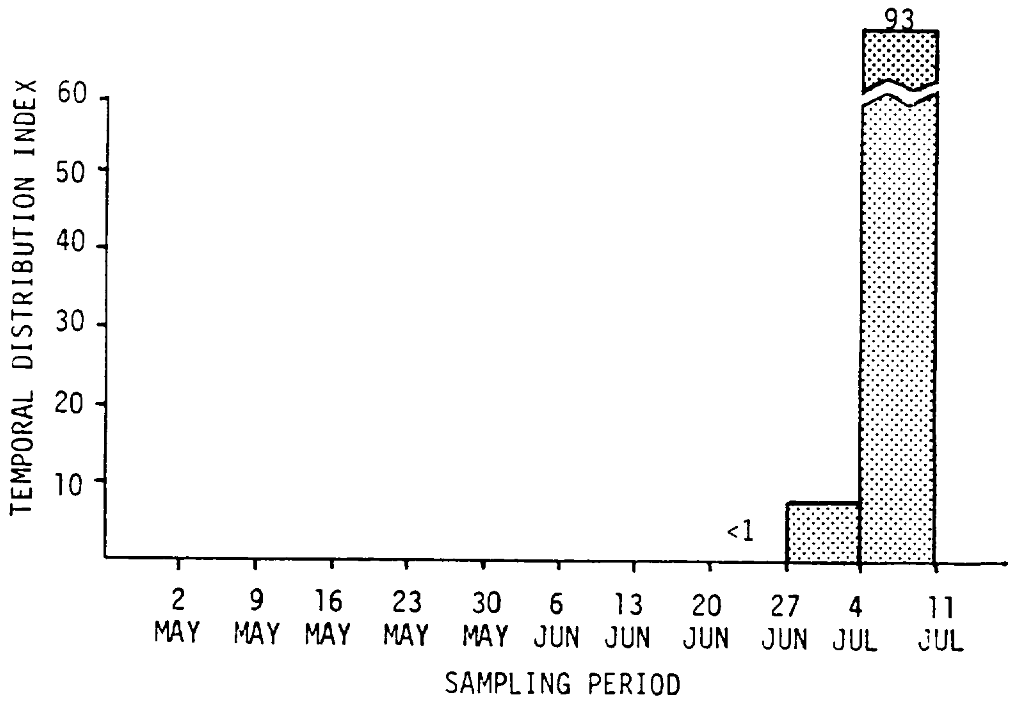


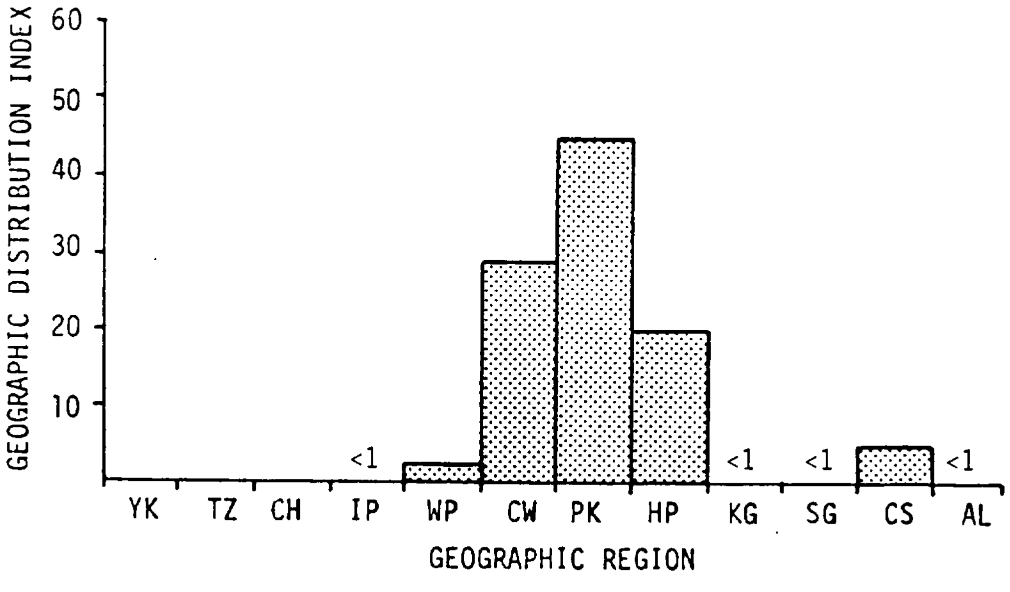


Figure 4.5-7. Temporal and geographic distribution of alewife/blueback herring young-of-the-year based on ichthyoplankton sampling, Hudson River estuary, 1983.

4.6 BLUEBACK HERRING

Blueback herring (*Alosa aestivalis*) are anadromous, occurring in abundance along the east coast from southern New England to Florida (Bigelow and Schroeder, 1953). As noted previously, their peak spawning migration occurs later in the spring than that of the alewife, although some overlap occurs at the end of the alewife spawning run. Blueback herring enter spawning areas when temperatures are as low as 12.8°C and prefer to spawn in fast-moving water over hard substrate (Loesch and Lund, 1977). In large rivers such as the Hudson, they can be found as far upstream as alewives; however, blueback herring do not travel as far up the smaller tributaries as do alewives (Loesch and Lund, 1977). In the Hudson River estuary, most spent adults return to sea by mid-July to mid-August (TI, 1981).

Blueback herring eggs are demersal and somewhat adhesive. Incubation time is 3 to 4 days at 20° to 21°C (Jones *et al.*, 1978). Juvenile blueback herring apparently do not begin to emigrate from the nursery grounds in the Hudson River estuary until mid-October (TI, 1981).

4.6.1 Young-of-the-Year (>35-40 mm)

As noted previously, blueback herring juveniles are indistinguishable from those of alewife until they reach approximately 35-40 mm (total length). In the Fall Shoals Survey, blueback herring juveniles were most abundant at the start of sampling in early August, with decreased abundance by 22 August (Figure 4.6-1). Juveniles were concentrated in the bottom stratum of the upriver regions from Poughkeepsie to Albany, primarily upstream of the average boundary of the salt front. In October, standing crop in the offshore strata increased slightly from levels in late August and late September (Figure 4.6-1).

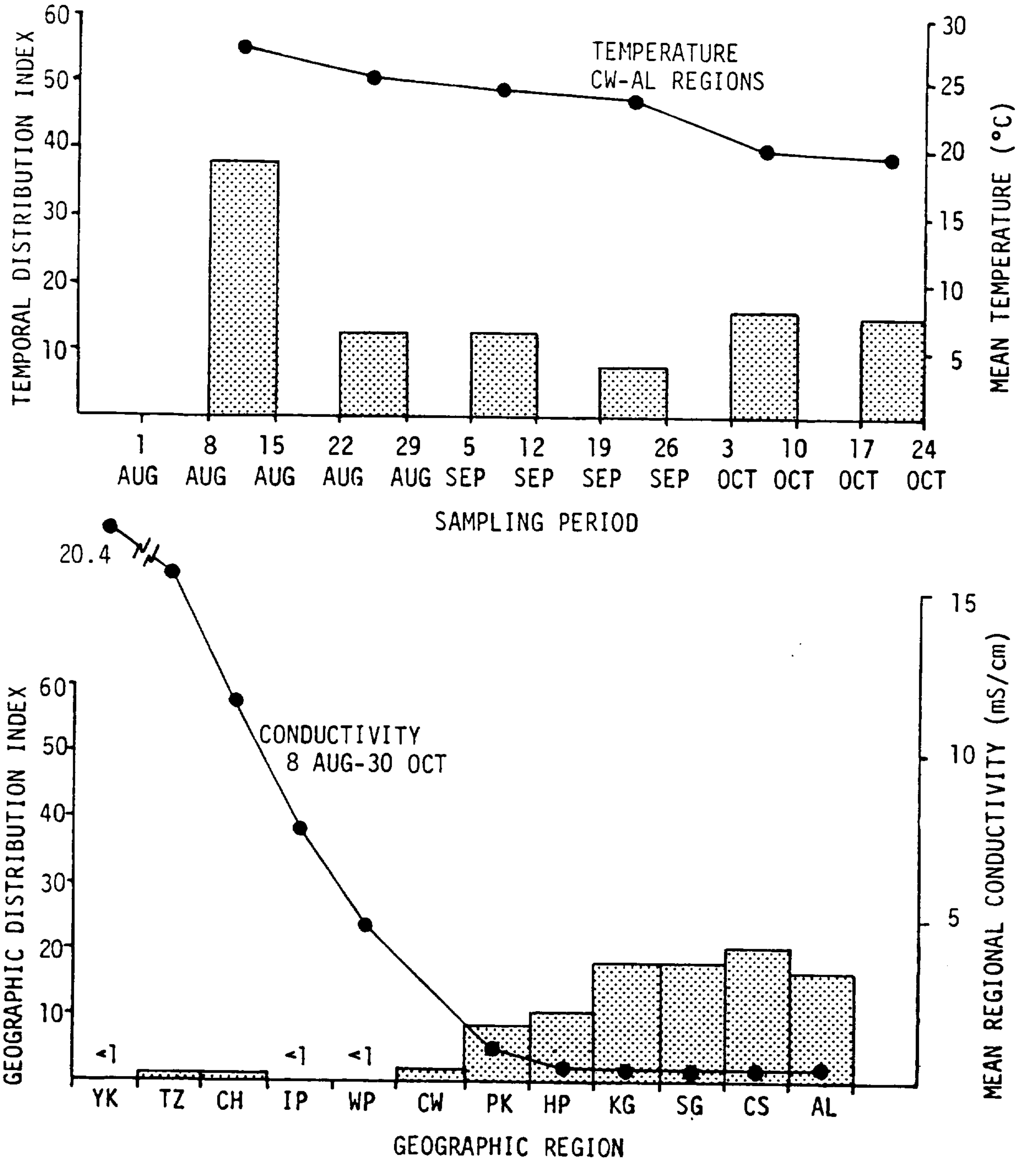


Figure 4.6-1. Temporal and geographic distribution of blueback herring young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.

In the shore zone, blueback herring juveniles were most abundant in August (Figure 4.6-2). Highest standing crop occurred in the middle to upper estuary, again generally upstream of the salt front. By early October, standing crop in the shore zone had also declined from peak levels.

Spatial and temporal distribution of blueback herring juveniles in 1983 was generally similar to that reported in previous years for comparable time periods (TI, 1981; Battelle, 1983; NAI, 1984a). Juveniles had been abundant in the upper and middle estuary throughout the summer. Emigration reportedly does not begin until mid-October; in 1979, emigration occurred when water temperatures dropped below 14°C (TI, 1981). In 1983, when sampling ended in mid-October, water temperatures were above 17°C throughout the estuary.

4.6.2 Yearling and Older Fish

Yearling and older blueback herring were collected sporadically and in low numbers during the 1983 fall juvenile sampling (Appendix B, Tables B-51, B-52 and B-54). Yearlings were also collected in low numbers during the ichthyoplankton program (Appendix B; Table B-50). Older fish were collected throughout most of the ichthyoplankton survey (Figure 4.6-3; Appendix B; Table B-53). Standing crop was highest in the bottom stratum in the upper estuary, with an additional peak in the channel in the Indian Point region.

4.7 ALEWIFE

The alewife, *Alosa pseudoharengus*, is an anadromous fish occurring along the east coast from the Gulf of St. Lawrence south to South Carolina (Leim and Scott, 1966). Spawning migrations occur in spring, with temperature being the most important environmental variable influencing the timing of entrance to the spawning grounds (Richkus, 1974). Alewives prefer to spawn in relatively shallow, sluggish water

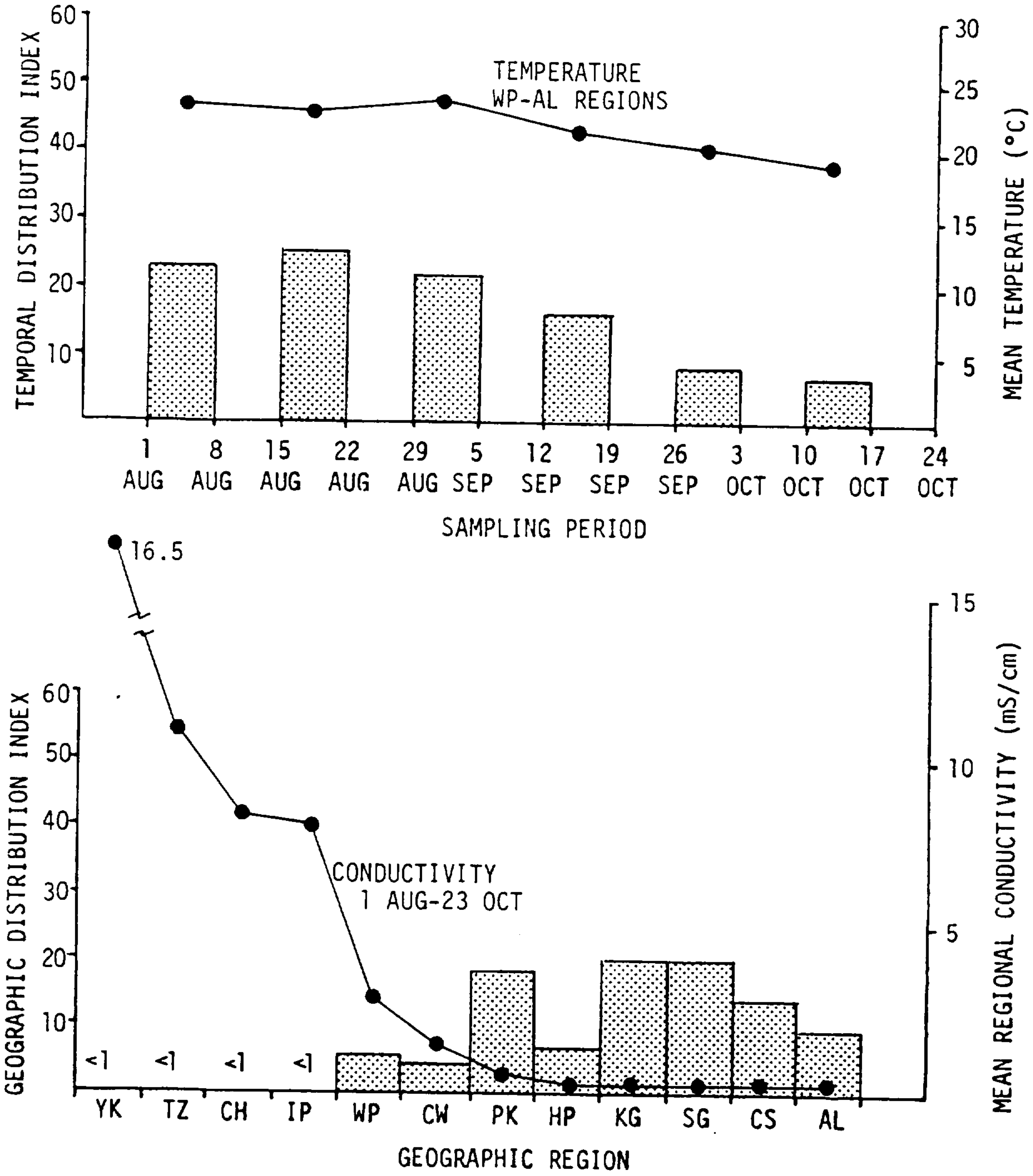


Figure 4.6-2. Temporal and geographic distribution of blueback herring young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

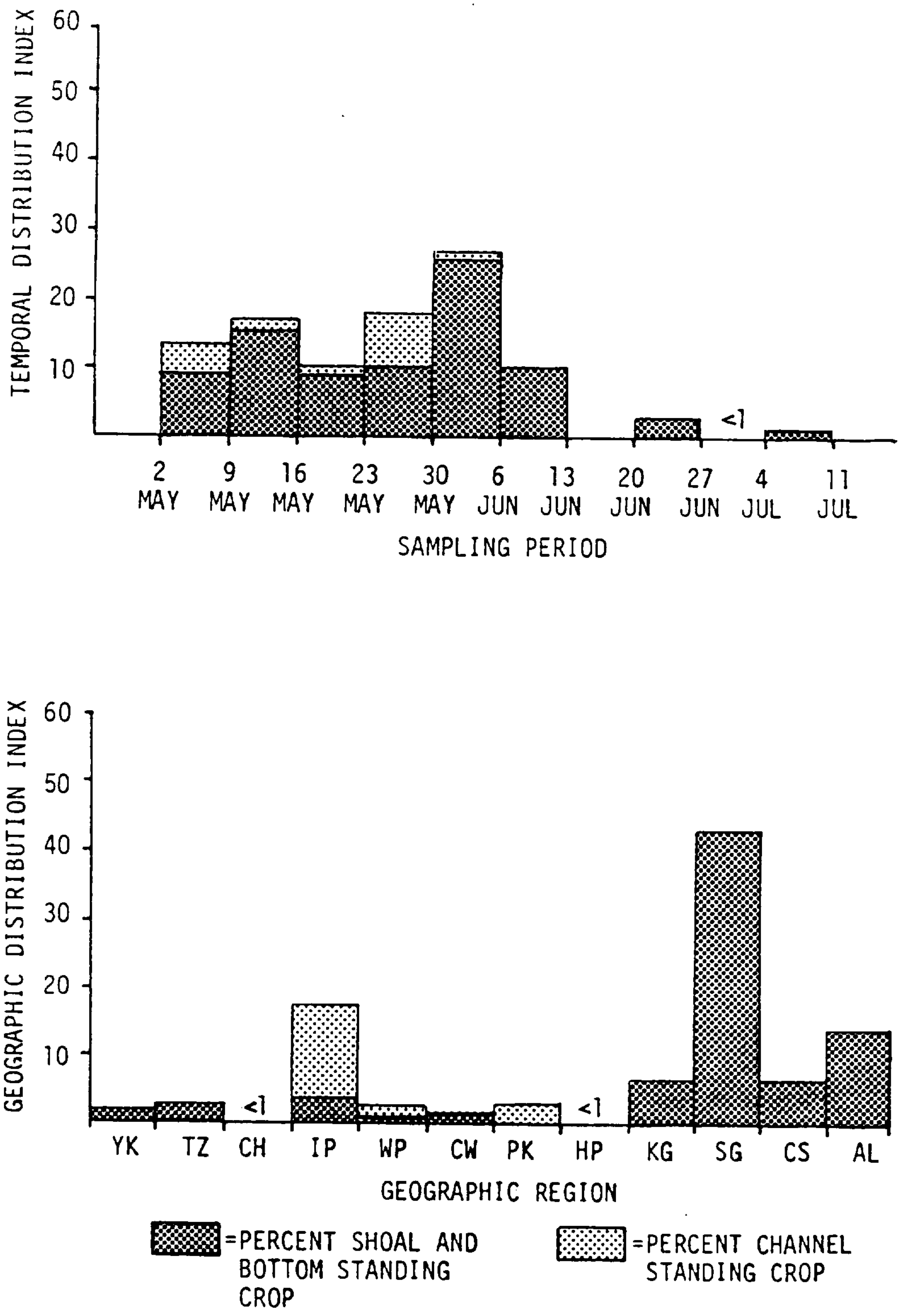


Figure 4.6-3. Temporal and geographic distribution of older blueback herring based on ichthyoplankton sampling, Hudson River estuary, 1983.

over soft substrates (Bigelow and Schroeder, 1953; Kissil, 1974). Following spawning, spent adults apparently emigrate from the Hudson River by mid-June (TI, 1981).

Alewife eggs are demersal and semi-adhesive; hatching occurs in 6 days at 15.6°C (Mansueti and Hardy, 1967). The optimum incubation temperature is 17.8°C (Edsall, 1970). Emigration of juveniles occurs throughout the summer, with the majority of juveniles having left the spawning grounds by autumn (Bigelow and Schroeder, 1953).

4.7.1 Young-of-the-Year (>35-40 mm)

Juvenile alewives collected in the Fall Shoals Survey were most abundant in early August. In late September, standing crop declined to very low levels. In the offshore strata, juveniles were concentrated in the upper and middle estuary upstream of the salt front, with peak standing crop in the Kingston region (Figure 4.7-1). Temporal distribution was variable across regions (Appendix B; Table B-55). In the lower estuary, standing crop peaked in either early August (Croton-Haverstraw), early September (Yonkers) or mid-October (Tappan Zee). Abundance peaks occurred in early August or in mid-October in the middle estuary, and in August or early October in the upper estuary. No consistent downstream movements can be discerned from these distributions.

Shore zone abundances reached a peak in late August followed by a decline through mid-October; abundances were also low in mid-August (Figure 4.7-2). As in the offshore strata, alewife juveniles in the shore zone were more abundant in the upper estuary, primarily in the Saugerties region (Figure 4.7-2). This distribution was consistent throughout the August through October sampling. Alewife juveniles reportedly begin moving downriver into the middle and lower estuary early in the summer, with increased downriver movements evident in October and November coincident with declining water temperatures and

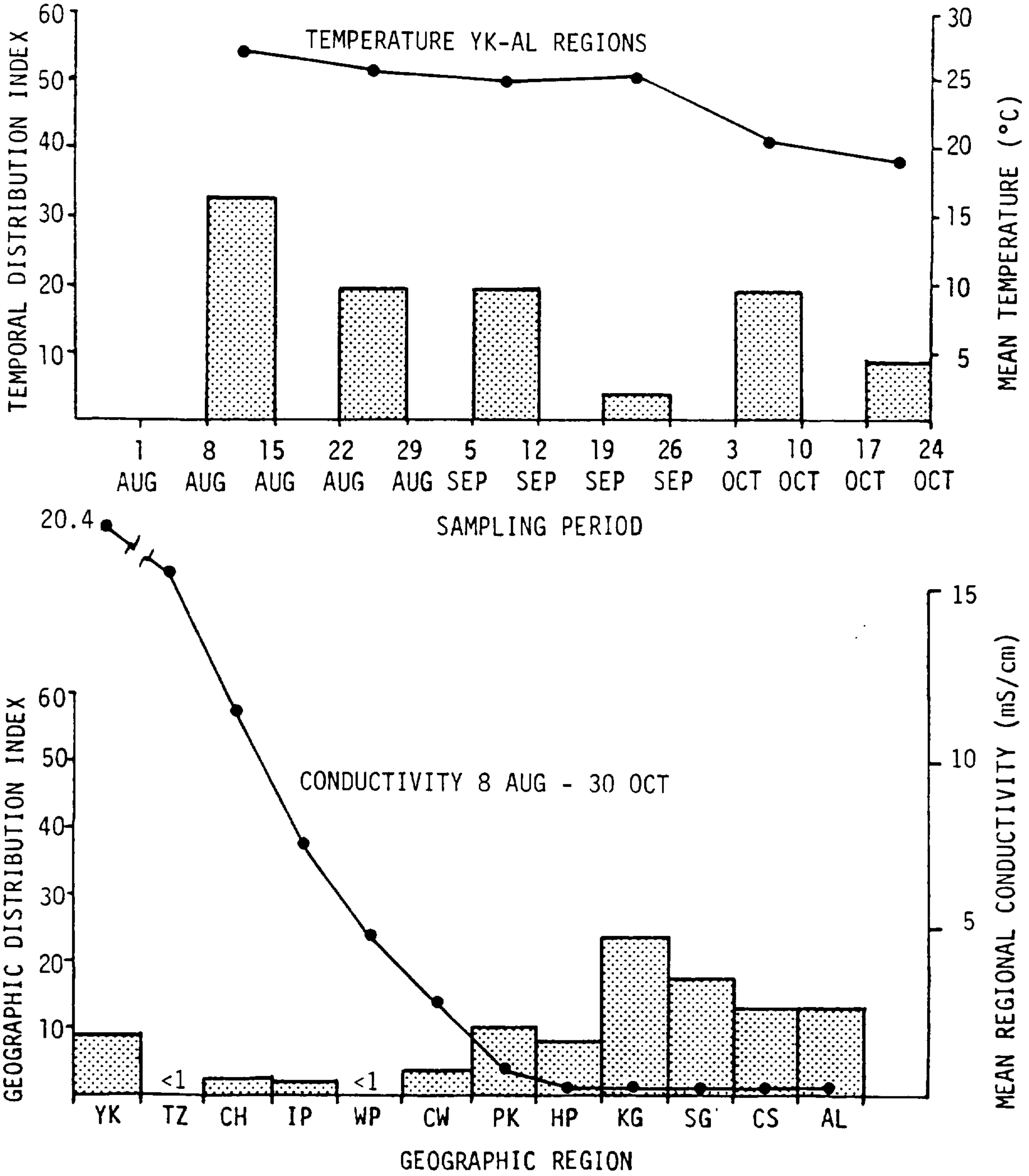


Figure 4.7-1. Temporal and geographic distribution of alewife young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.

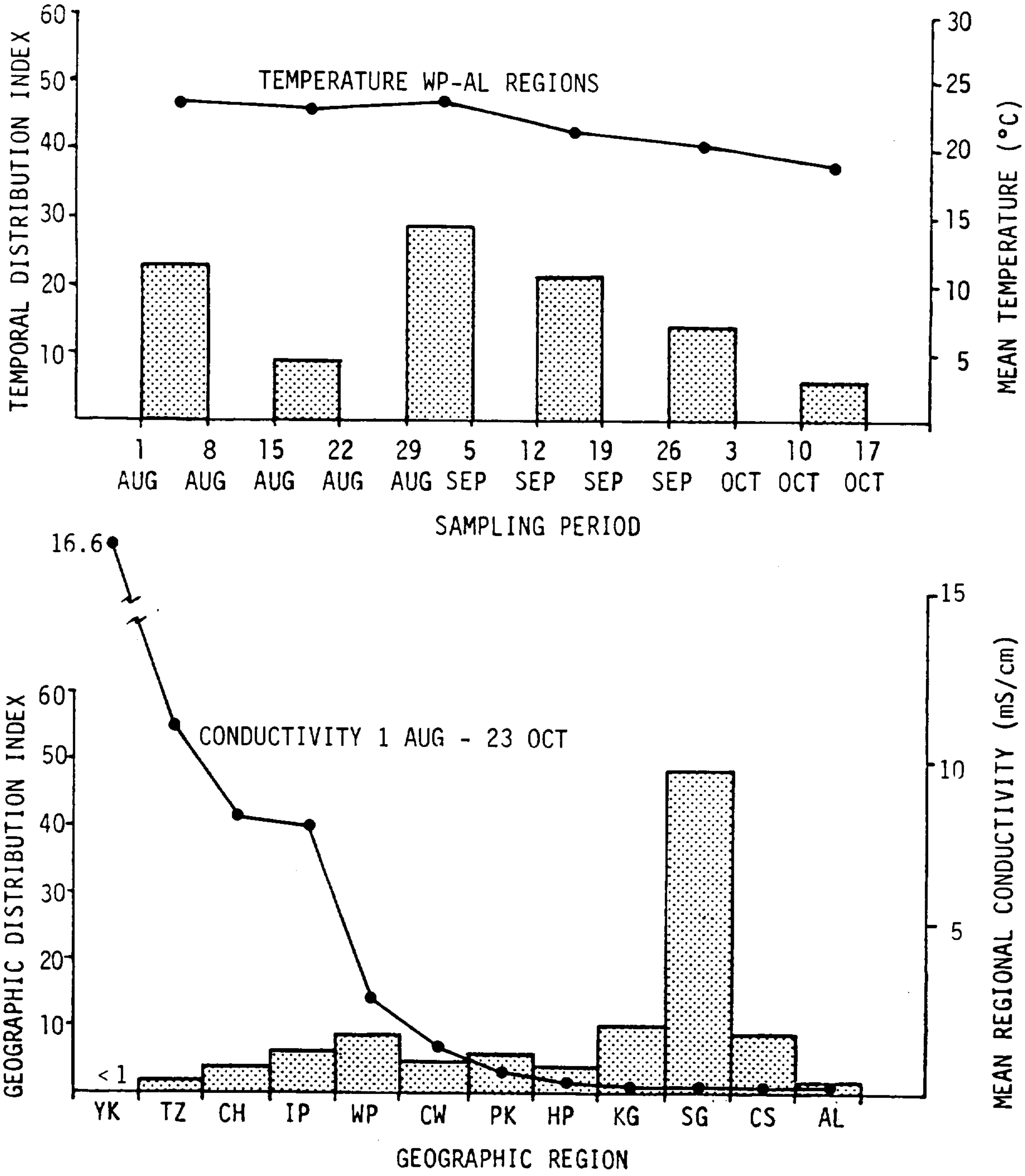


Figure 4.7-2. Temporal and geographic distribution of alewife young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

increasing freshwater flows (TI, 1981). This movement had apparently not begun by the end of the 1983 sampling season.

4.7.2 Yearling and Older Fish

Alewife yearling and older fish were collected in low numbers during the 1983 program (Appendix B; Tables B-57 through B-62). No conclusions can be drawn regarding distribution.

4.8 BAY ANCHOVY

The bay anchovy (*Anchoa mitchilli*) is one of the most abundant fishes of the Atlantic coast (Massman, 1953; Dahlberg, 1972; Derickson and Price, 1973). It occurs in coastal waters from Cape Cod (occasionally into the Gulf of Maine) and southward to Yucatan, Mexico (Hildebrand, 1963). The bay anchovy feeds on mysid shrimp and copepods (Richards, 1963) and in turn is utilized as forage by many fish species including economically important fishes such as white perch, striped bass and bluefish.

Bay anchovies undergo inshore/offshore movements apparently related to spawning and maturation. In the Hudson River estuary, yearling and presumably some older bay anchovies move upstream during May to feed in the brackish waters as far north as Poughkeepsie (TI, 1981). Dovel (1981) has shown that as water temperatures rise above $12^{\circ}C$, mature individuals move back downstream from the low salinity feeding grounds into higher salinity waters (>10 $^{o}/oo$) to spawn. Peak spawning occurs from June-August at temperatures of $20^{\circ}C$ or higher. Spawning is concentrated in the Hudson River from Tappan Zee south to the Narrows (below km 0) as evidenced by peak egg abundance in this location, and particularly in Yonkers (Dovel, 1981; TI, 1981). The newly-hatched larvae are distributed further upstream in the lower salinity waters (<10 $^{o}/oo$) of the Tappan Zee through Indian Point regions. These regions presumably represent the primary nursery area for this species. By early fall, larvae and young-of-the-year move downstream out of the low salinity nursery area. Similar trends were reported for bay anchovy in the Chesapeake area (Dovel, 1971; Lippson *et al.*, 1980) and for the Japanese anchovy (Asami, 1958; Hayusi, 1961) (cited in Dovel, 1981). By late November, anchovies have emigrated from most of the Hudson River estuary to their overwintering grounds (TI, 1981).

Dovel (1981) proposed that bay anchovies require a definite period of exposure to the brackish water environment before reaching maturity and that their downstream movement in spring and fall is related to the onset of maturity. Fish spawned early in the year begin a permanent downstream movement once maturity is reached during early fall and do not return to the upriver nursery area the following spring. Fish spawned late in the year might be forced from the estuary by declining temperatures before maturity was reached. The following spring, these immature yearlings would migrate back to the low salinity nursery area to feed, and once mature, move back downriver to spawn.

4.8.1 Young-of-the-Year

Young-of-the-year bay anchovies were present through the course of the Fall Shoals and Beach Seine Surveys (Figures 4.8-1 and 4.8-2). In both the offshore strata and shore zone, standing crop was highest during late August and early September at temperatures of approximately 26°C. Following these peaks, abundance declined. Earlier surveys reported recruitment to the juvenile stage in late June/early July and peak abudance of juveniles from mid-July through September (TI, 1981; Battelle, 1983). Emigration of juvenile bay anchovies from the estuary has been observed to begin near the end of September with most of the juvenile population absent from the estuary by November (TI, 1981).

Juvenile bay anchovies were present in the offshore strata from Yonkers to Albany (Figure 4.8-1). Abundances were highest in

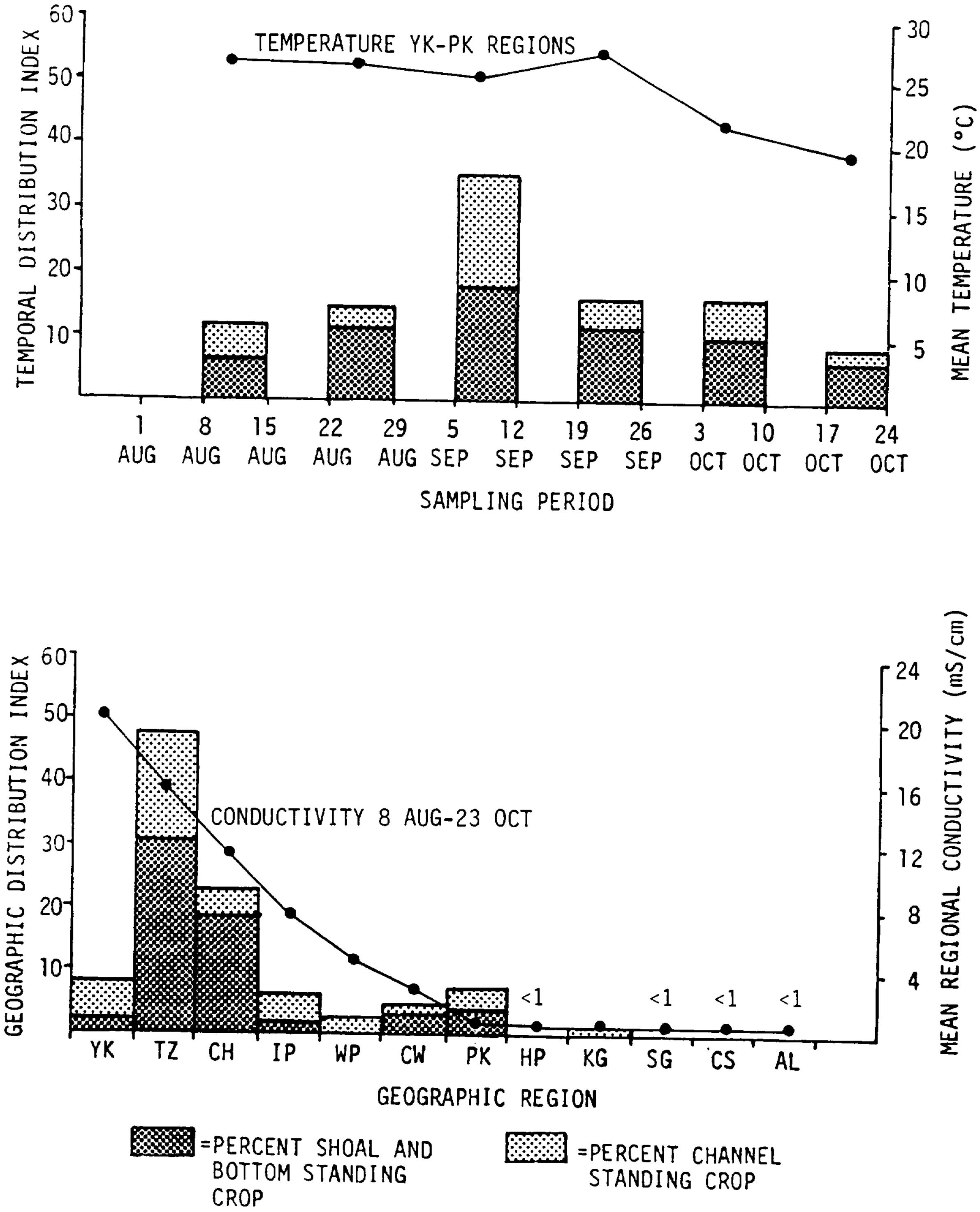


Figure 4.8-1. Temporal and geographic distribution of bay anchovy young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.

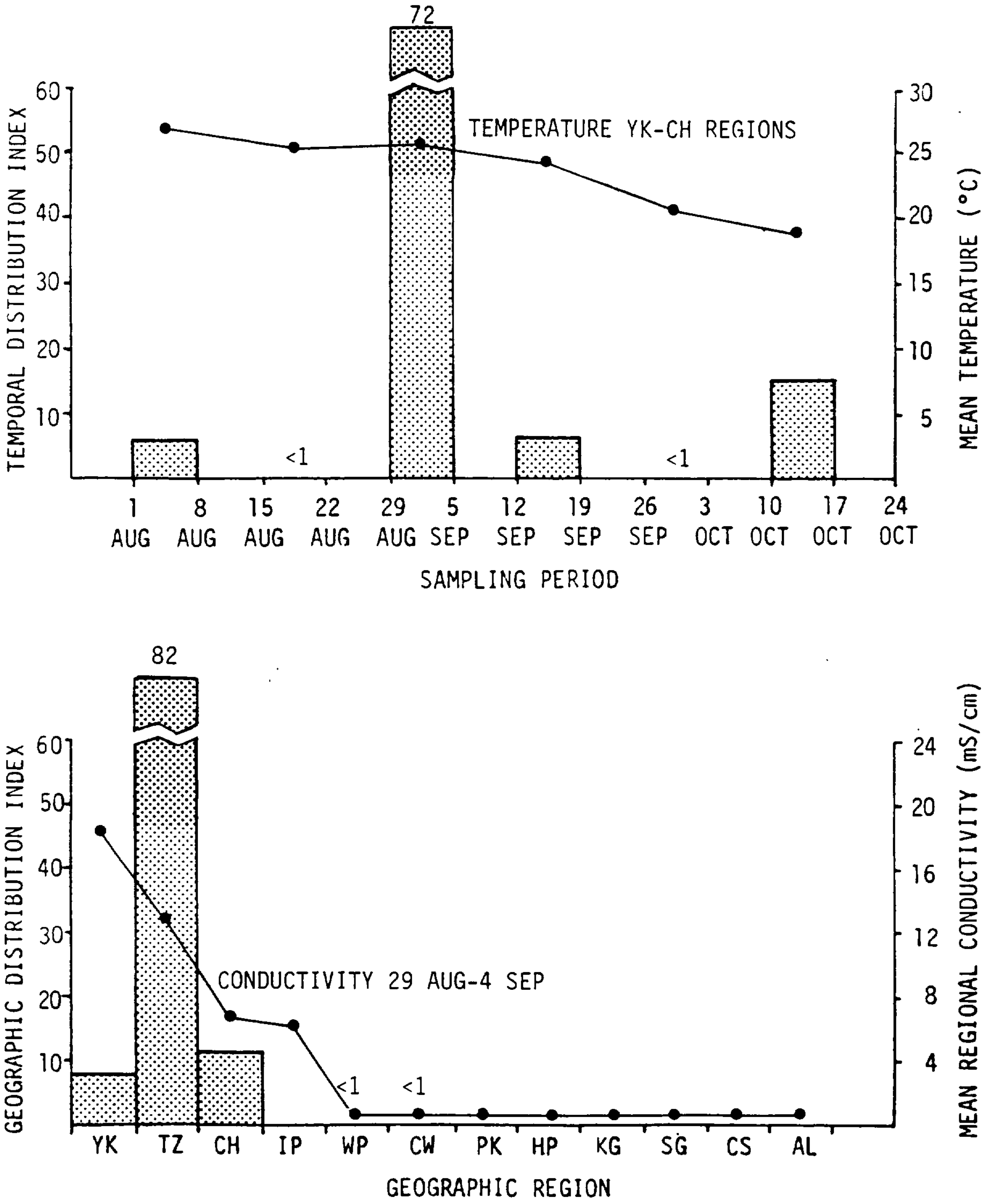


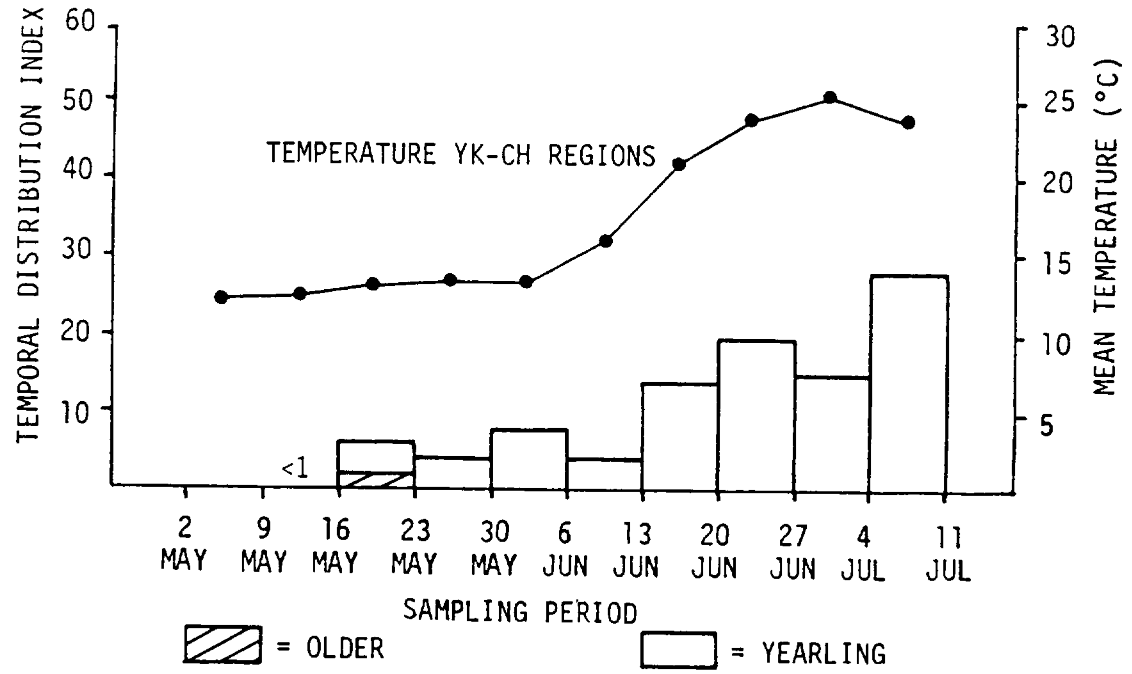
Figure 4.8-2. Temporal and geographic distribution of bay anchovy young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

Tappan Zee where conductivity averaged 16 mS/cm, and decreased upriver from this region with decreasing conductivity values. Juveniles were sparse in waters with a conductivity of less than 0.5 mS/cm. In the shore zone, juveniles were collected almost exclusively in the lower estuary, particularly the Tappan Zee region (Figure 4.8-2). This concentration of juvenile bay anchovies in the shore zone and offshore strata of the lower estuary is consistent with past years' observations.

4.8.2 Yearling and Older Fish

Nearly all of the yearling and older bay anchovies collected during 1983 were yearlings. In the ichthyoplankton sampling program, yearlings steadily increased in abundance from 9 May through 10 July (Figure 4.8-3). Past years' reports described movement of yearling and older bay anchovies into the Hudson River during early to late May, and peak abundances during late May through July (TI, 1981; Battelle, 1983). Peak spawning has been observed to occur during this latter period, primarily from Yonkers downriver to the Narrows (Dovel, 1981; TI, 1981). As expected, abundances during 1983 were highest in the Yonkers region and decreased with distance upriver. Few yearlings were collected upriver of Croton-Haverstraw and none beyond Cornwall. Yearlings were as abundant in the shoal and bottom strata as in the channel stratum.

In the Fall Shoals and Beach Seine Surveys, standing crop of bay anchovy yearlings was greatest during the first sampling period of each survey (i.e., weeks beginning 8 August and 1 August, respectively) (Figures 4.8-4 and 4.8-5). Following these peaks, standing crop dropped to comparatively low levels in both the offshore strata and shore zone. During past years' surveys, yearling bay anchovies began offshore and downstream movements in late July, and by late October most bay anchovies had left the study area (TI, 1981). The geographic distribution of yearling bay anchovies during 1983 was nearly identical to that of juveniles. Yearlings were concentrated in the shore zone and offshore strata of the lower estuary with some extension of yearlings within the offshore strata upriver to Poughkeepsie. Yearlings were absent from or



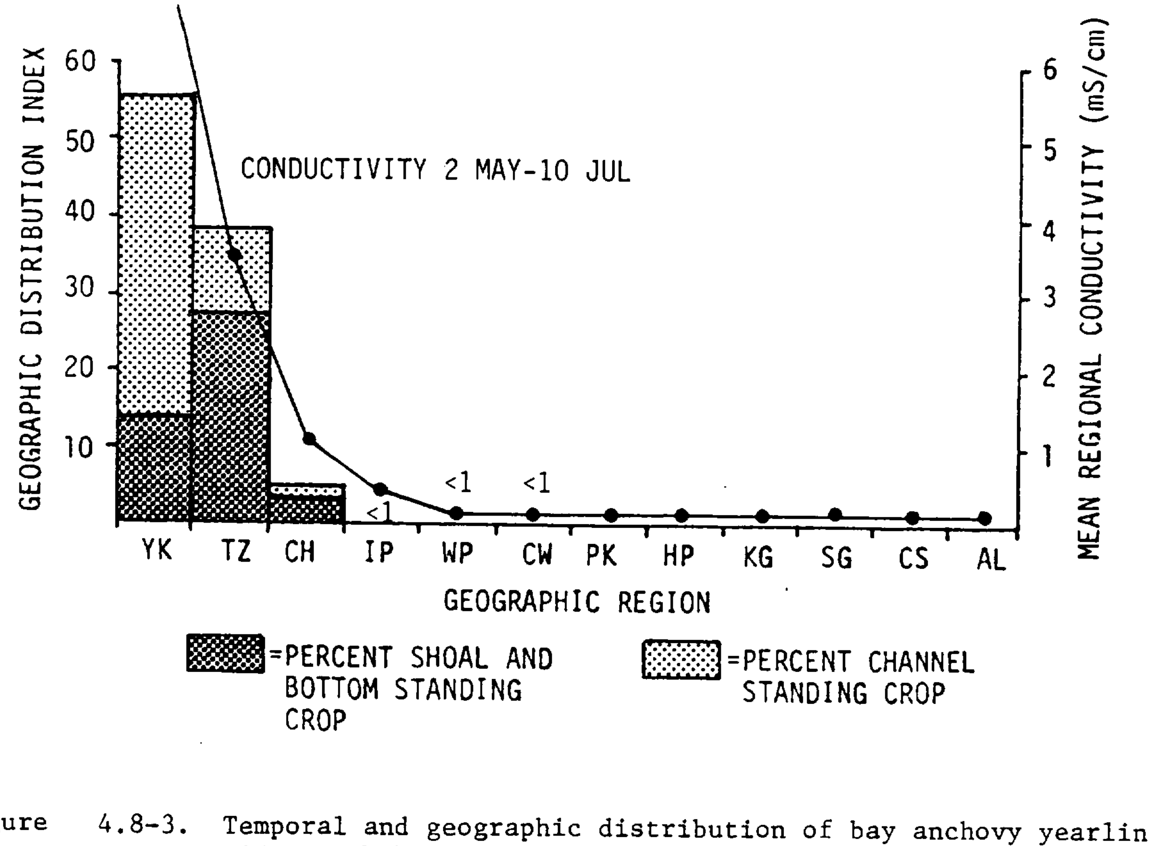


Figure 4.8-3. Temporal and geographic distribution of bay anchovy yearling and older fish based on ichthyoplankton sampling, Hudson River estuary, 1983.

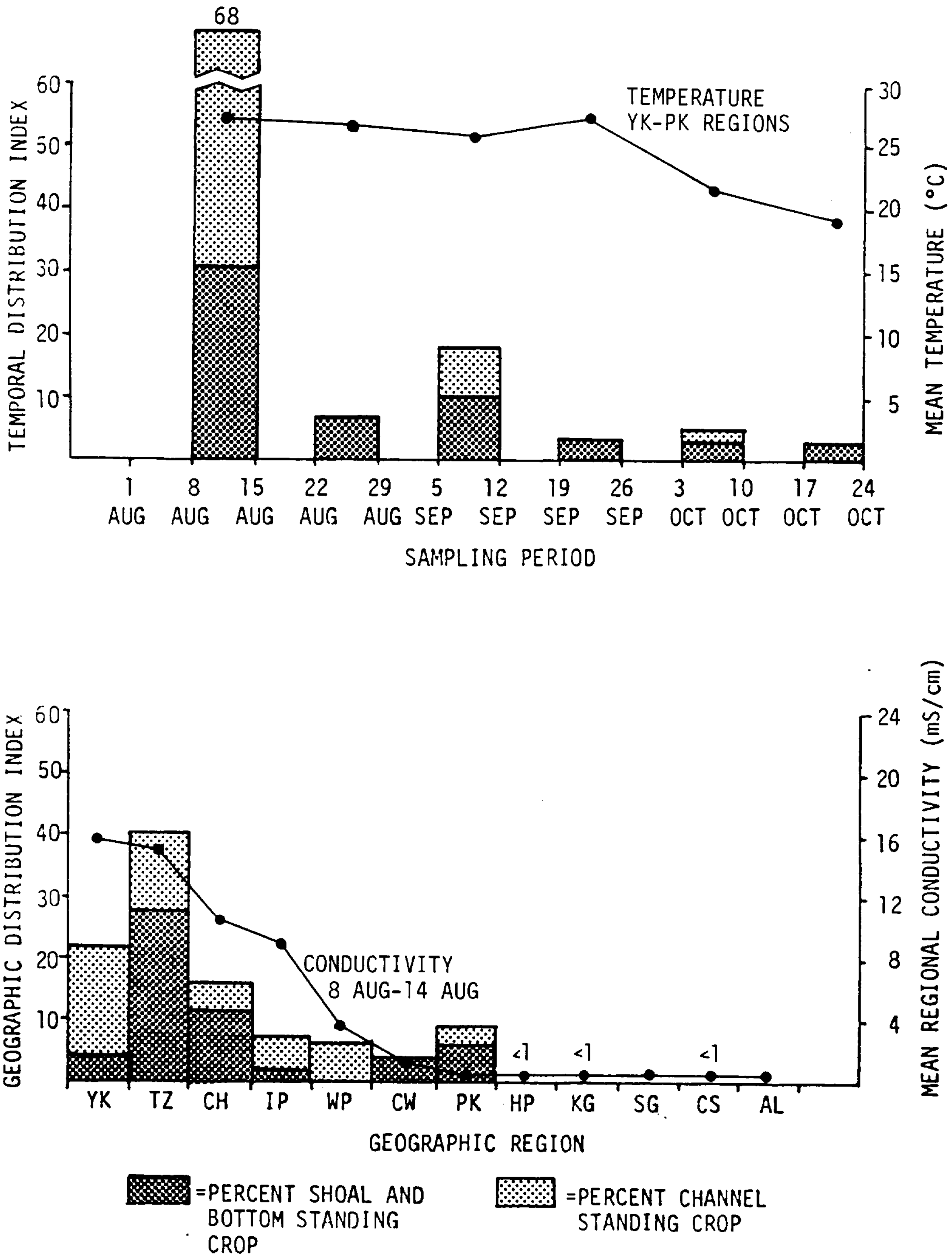


Figure 4.8-4. Temporal and geographic distribution of bay anchovy yearling and older fish based on the Fall Shoals Survey, Hudson River estuary, 1983.

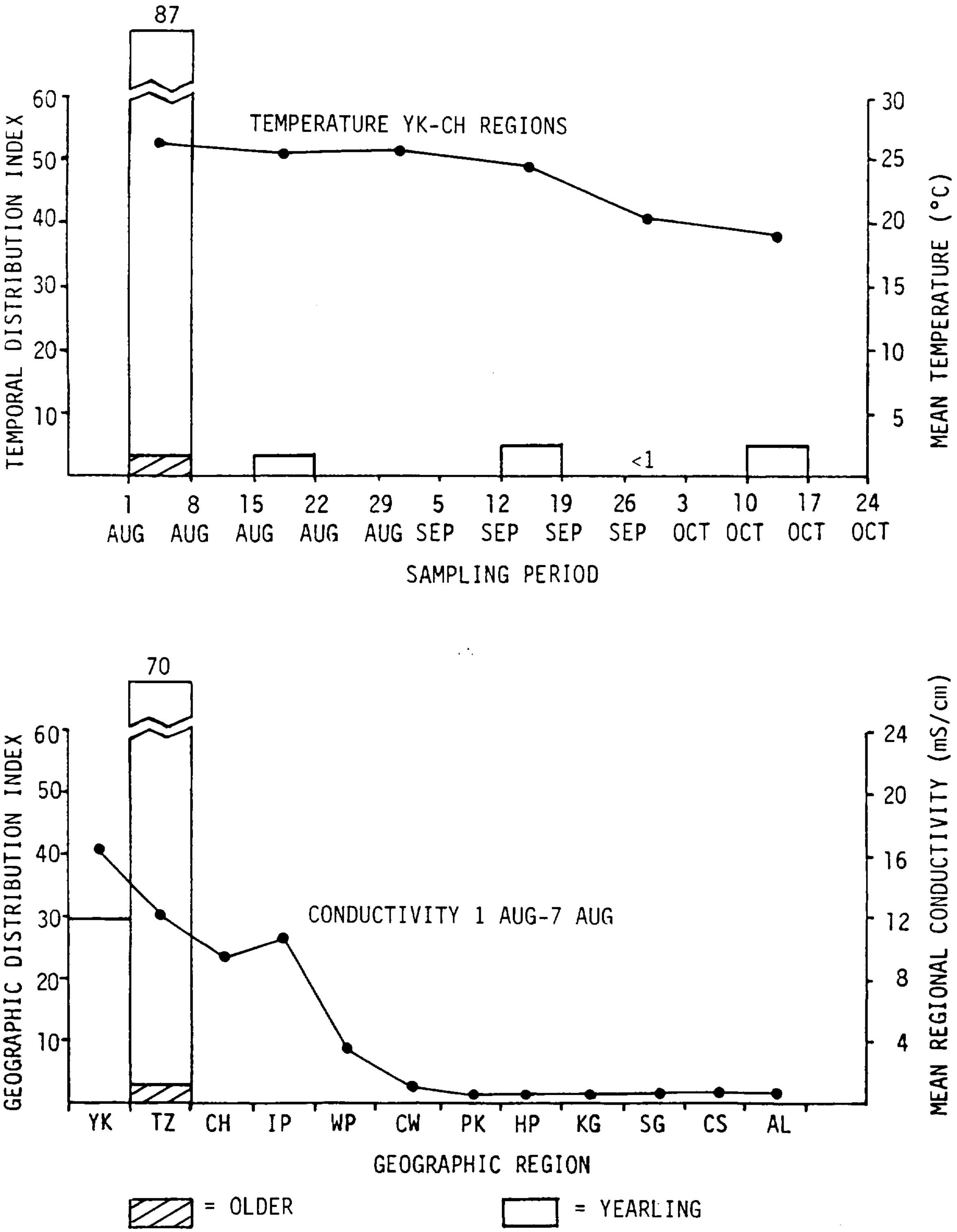


Figure 4.8-5. Temporal and geographic distribution of bay anchovy yearling and older fish based on the Beach Seine Survey, Hudson River estuary, 1983.

collected in relatively low abundances in waters with conductivity values less than 0.5 mS/cm.

4.9 WEAKFISH

The weakfish, *Cynoscion regalis*, a member of the family Sciaenidae, is an important commercial and recreational fish of the Atlantic coast (Wilk, 1979). The weakfish ranges from the east coast of Florida to Massachusetts Bay. At one time large numbers of weakfish were reported as far north as Nova Scotia (Bigelow and Schroeder, 1953), but only a few individuals are present there today. The area of greatest abundance centers around the waters of the Chesapeake Bay region (Thomas, 1971). In the Hudson River, weakfish are found as far upriver as Hyde Park (km 138), with the area of greatest concentration in the lower reaches of the estuary (km 0-89).

Adult weakfish are euryhaline, but only the smaller juveniles have been collected in fresh and low salinity waters (Smith, 1971; Thomas, 1971). Spawning is preceeded by an upriver migration which is triggered by increasing water temperature. Spawning begins during late May and continues through September (Bigelow and Schroeder, 1953; Lippson and Moran, 1974), with major peaks occurring during early June and July (Thomas, 1971; Johnson, 1978). Spawning takes place over a broad temperature range (15^{o}-21^{o}C) in areas where salinity varies between 28 and 31 ^{o}/oo (Lippson and Moran, 1974). Both sexes mature at age III, and larger females may produce several million eggs (TI, 1981). After spawning, weakfish move out of the estuaries and overwinter off the coast of the Carolinas (Bigelow and Schroeder, 1953).

Weakfish eggs are pelagic and highly buoyant (Lippson and Moran, 1974), becoming heavier with development. The eggs are spherical and transparent, with a mean diameter of 0.84-1.3 mm, and tend to be smaller at higher salinities (Johnson, 1978). The eggs are usually found in areas having water temperatures of 17-26.5^{o}C and salinities of 12-31 ^{o}/oo. They hatch in about 40 hrs at 20-21^{o}C (Harmic, 1958). The newly-hatched larvae are 1.5-2.0 mm TL and yolk absorption occurs at approximately 2.2 mm TL. The larvae generally sink to the bottom, allowing the bottom currents to carry them upstream (Thomas, 1971).

Juveniles tend to occupy the deeper shoal and channel waters of the low salinity areas (Smith, 1971). In Delaware Bay, young weakfish were more abundant in the lower salinity waters (3-6 $^{o}/oo$) (Thomas, 1971). Very little information is available on the lower limit of the temperatures preferred by weakfish. They appear to be sensitive to the cold, as the autumn cooling seems to be responsible for their movement out of the estuaries and to the south.

4.9.1 Young-of-the-Year

When the Fall Shoals sampling program began in early August, juvenile weakfish were already at or past the period of maximum abundance (Figure 4.9-1). They occurred primarily in the deeper areas of the lower and middle estuary. Average temperature in the lower and middle estuary during this time period was 27^{o}C (range 26.0^{o}-28.8^{o}C) and conductivity was 9.2 mS/cm (range 1.2-15.6 mS/cm; Appendix C; Tables C-1 and C-5). Most young-of-the-year were collected downriver of Poughkeepsie, where conductivities remained above 0.4 mS/cm (the approximate boundary of the salt front), although one individual was collected in Saugerties (conductivity 0.24 mS/cm). This spatial distribution was similar to those observed in previous years (TI, 1980b, 1981; Battelle, 1983; NAI, 1984a) and appears to be associated with the patterns of conductivity.

The standing crop of juvenile weakfish began decreasing in early September (Figure 4.9-1). This decrease appears to be associated with a decrease in temperature from 27.3^{o} to 19.3^{o}C. Thomas (1971) described a similar decline in abundance in late September to early October in the Delaware River, speculating that the decline was largely associated with mortality rather than with emigration. By the end of

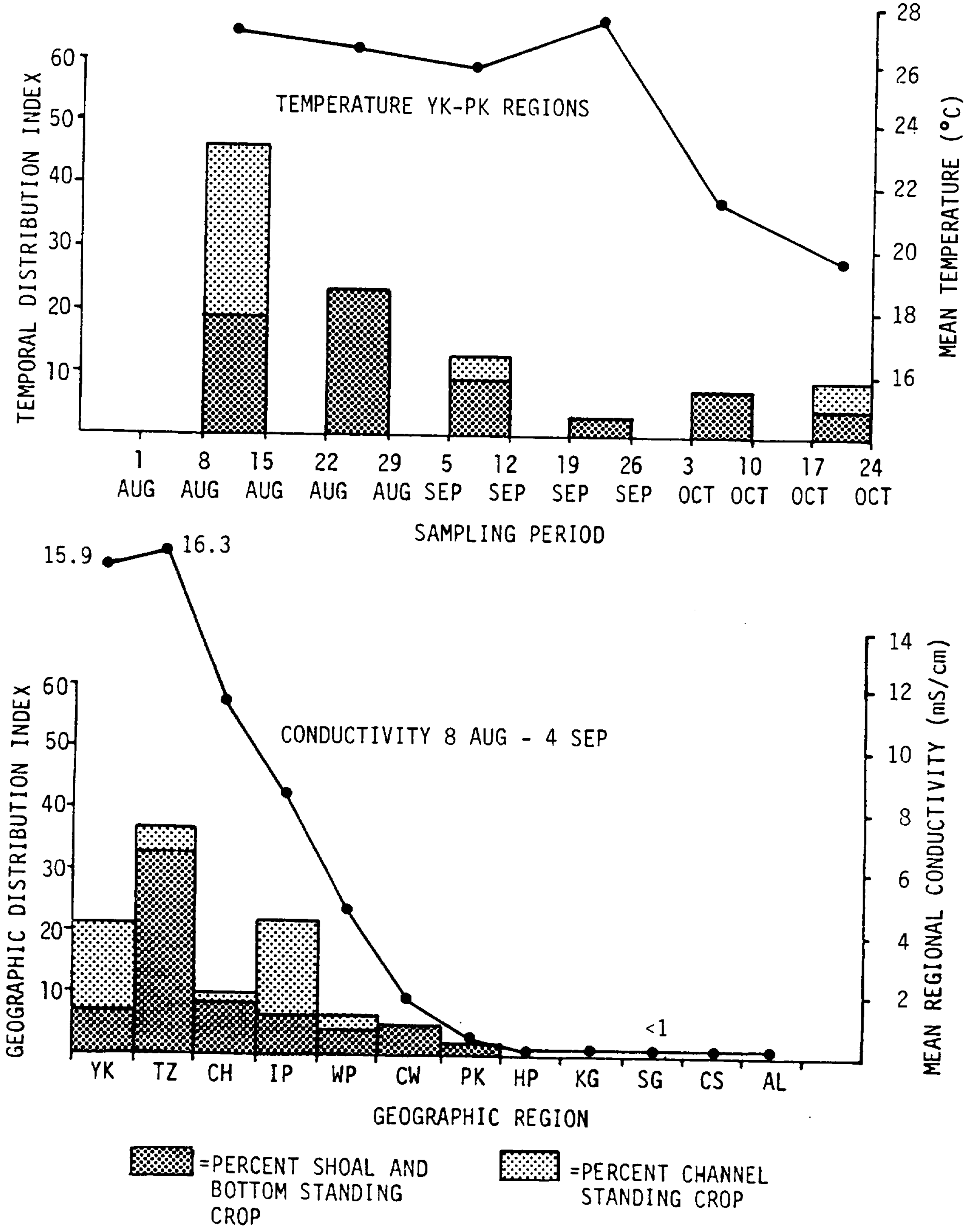


Figure 4.9-1. Temporal and geographic distribution of weakfish young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.

September, most of the juvenile weakfish population had left the offshore strata, although some remained in this area through October.

Weakfish were collected in reduced numbers in the shore zone (Appendix B; Table B-74) through the end of September when they comprised less than four percent of the total standing crop (Figure 4.9-2). Shore zone catches of weakfish were restricted to the lower two regions. No juvenile weakfish were collected in the shore zone after the end of September. In past years, all juvenile weakfish had left the study area by November when water temperature had decreased below 10°C (TI, 1981). Thomas (1971) reported that juvenile weakfish emigrated from the Delaware River estuary when water temperatures dropped below 8°-10°C.

4.10 WHITE CATFISH

The white catfish (*Ictalurus catus*) is a resident of coastal streams along most of the east coast of the United States (Trautman, 1957). It inhabits fresh and brackish waters, and can tolerate salinity concentrations up to 14 °/oo (Kendall and Schwartz, 1968). Catfishes are omnivorous bottom feeders utilizing fish, invertebrates, plant material and carrion, and are generally most active at night. Spawning takes place in fresh or slightly brackish water (2 °/oo or less; Perry and Avault, 1968) during late spring and early summer (Lippson *et al.*, 1980). The eggs are adhesive and the young are attended by the parents (Breder and Rosen, 1966).

In the Hudson River estuary, white catfish move shoreward during spring from their deepwater overwintering areas in the lower and middle estuary (TI, 1981; Battelle, 1983). This shoreward movement during spring was also described for white catfish in the Thames (Schmidt, 1971) and Connecticut (Marcy, 1976b) Rivers. Peak catches of adults in the shore zone of the lower estuary and shoal stratum of the middle and upper estuary in June and July appear to represent the major period of spawning (TI, 1981). Because of the invulnerability of white

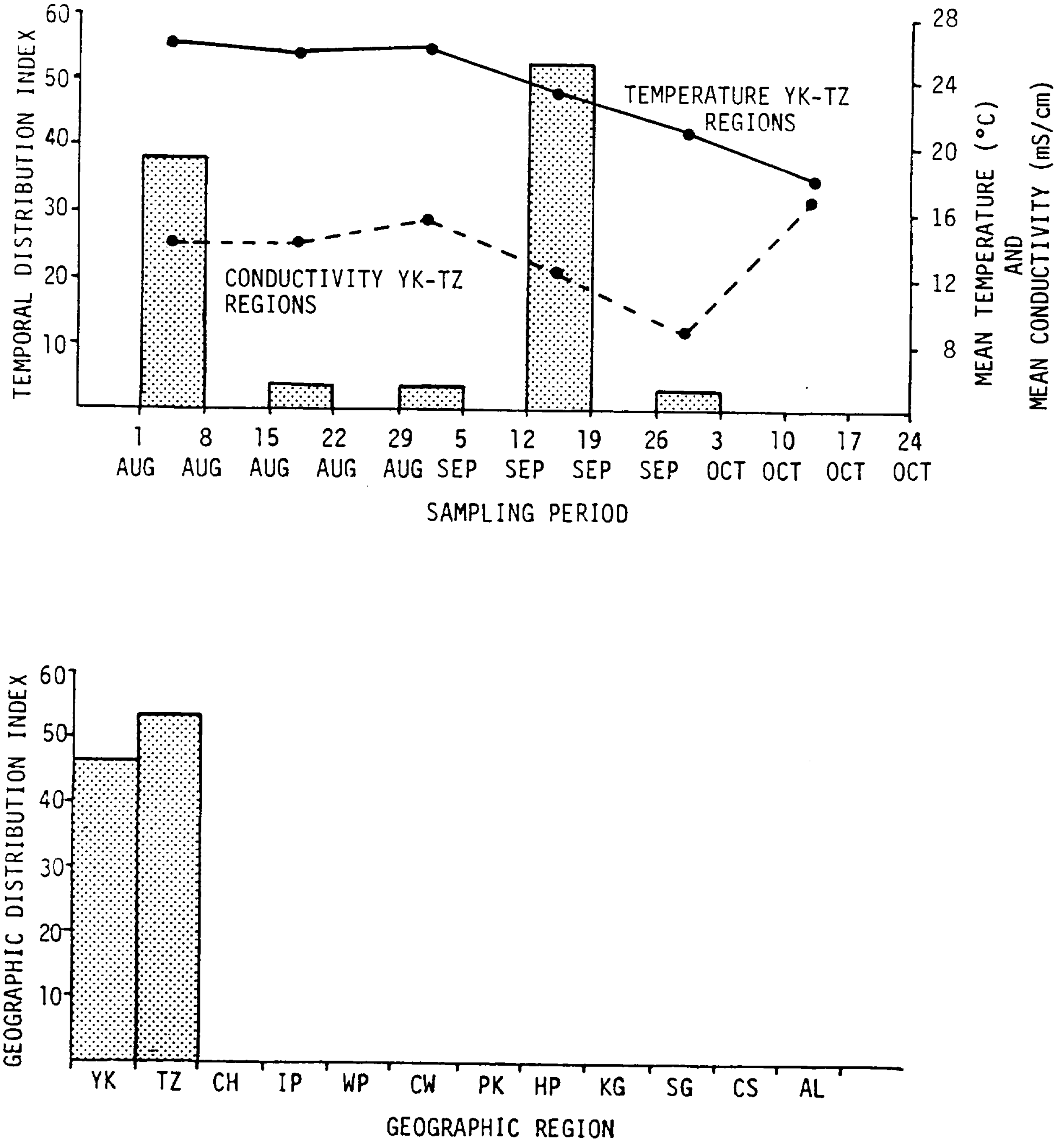


Figure 4.9-2. Temporal and geographic distribution of weakfish young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

catfish eggs and larvae to the sampling gear used in Hudson River sampling programs, no information is available on their distribution in the estuary. However, considering that spawning is unsuccessful at salinities above 2 $^{o}/oo$ (Perry and Avault, 1968) most spawning in the Hudson River estuary probably takes place in the middle and upper segments or in the tributaries.

Juvenile catfish are typically found from Poughkeepsie to Albany in the shoal and bottom strata and are most numerous in the Catskill and Albany regions from late July through early August (TI, 1981). Yearling and older catfish move into the offshore strata during September and October, and begin a downstream migration in late October to the overwintering grounds when shoal temperatures in the upper estuary drop to 14-15°C. Similar fall movements of white catfish to deeper and warmer waters were reported by Mansueti (1950) and Schmidt (1971).

4.10.1 Young-of-the-Year

Young-of-the-year white catfish were collected in low abundances during the last two sampling periods of the ichthyoplankton survey (27 June-10 July 1983) in the West Point and Cornwall Regions (Figure 4.10-1). As in past years, little information was obtained on earlier life stages, as ichthyoplankton sampling detected no eggs or yolk-sac larvae, and only one post yolk-sac larva (week beginning 4 July in the West Point region). During the August through October Fall Shoals Survey, young-of-the-year white catfish were most abundant in the shoal and bottom strata of the West Point through Albany regions (Figure 4.10-2). Few juveniles were collected in the shore zone, and those that were occurred only in the lower half of the estuary (Appendix B; Table B-76). Low juvenile abundance in the shore zone is consistent with past years observations (TI, 1981; Battelle, 1983). The highest abundance of juveniles in the offshore strata occurred during the first sampling period of the Fall Shoals Survey, the week beginning 8 August (Figure 4.10-2). Abundances declined during late August and September,

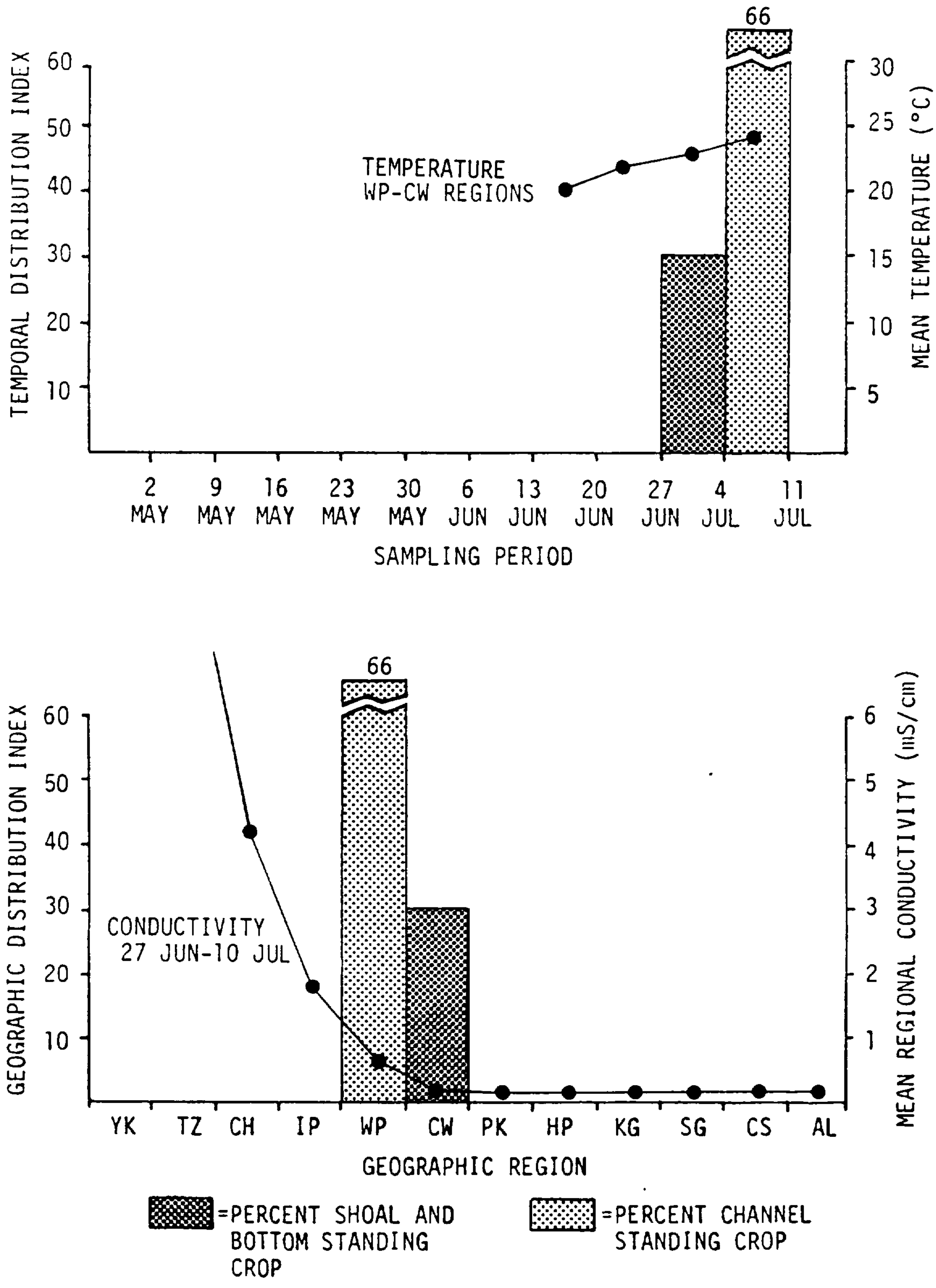


Figure 4.10-1. Temporal and geographic distribution of white catfish young-of-the-year based on ichthyoplankton sampling, Hudson River estuary, 1983.

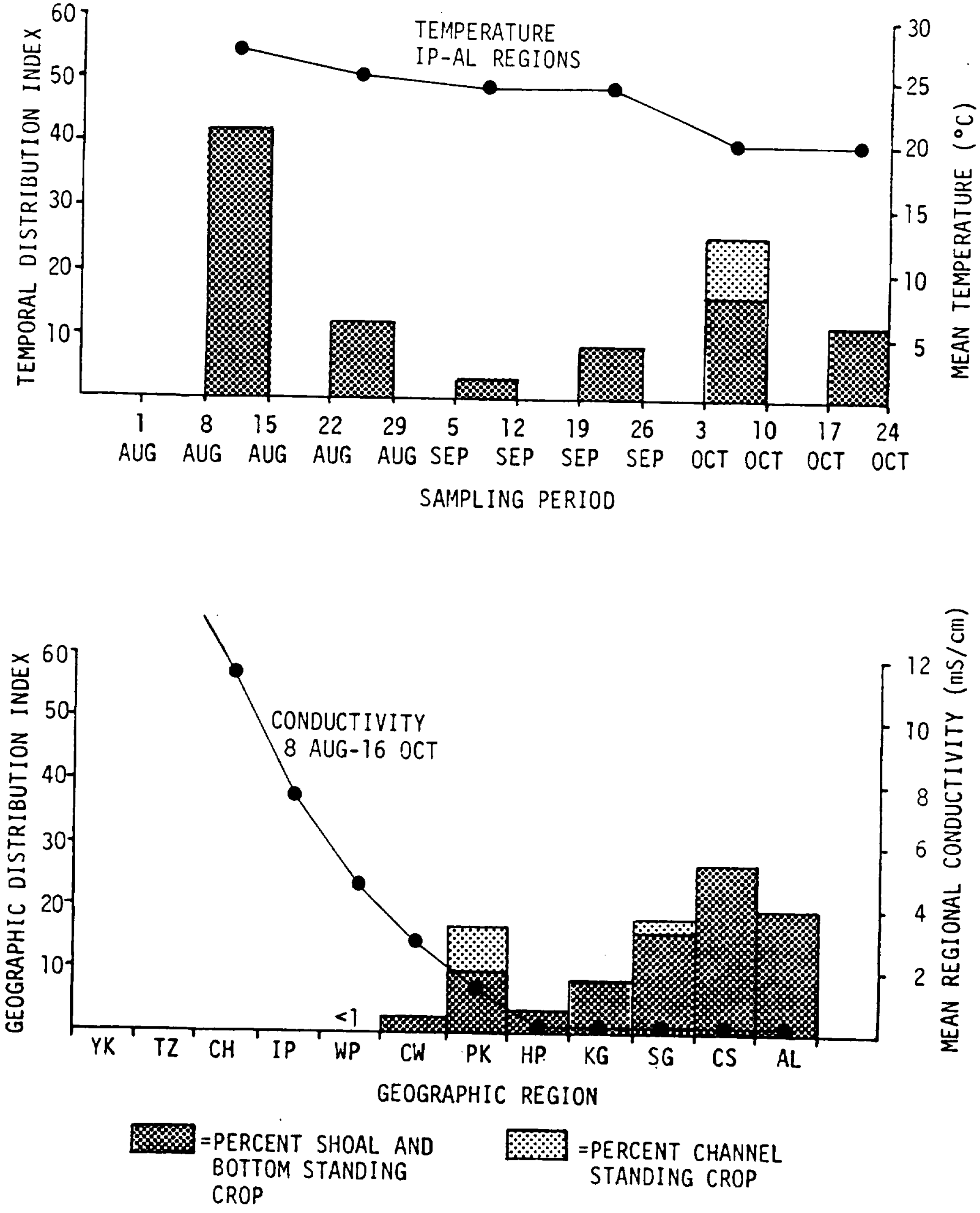


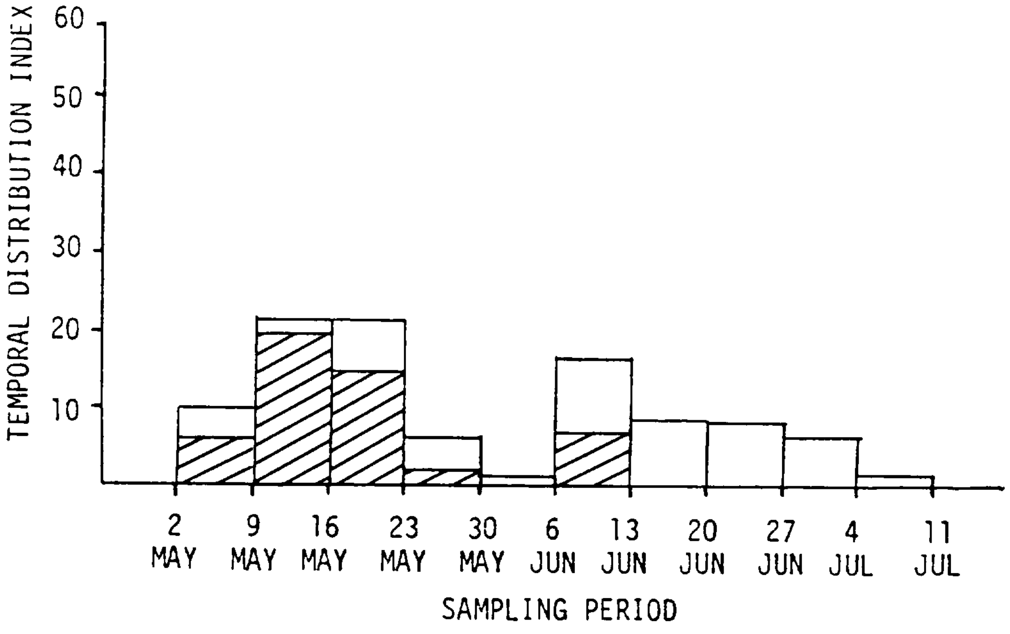
Figure 4.10-2. Temporal and geographic distribution of white catfish young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.

increased to moderate levels in early October and subsequently declined by the end of the survey. Past years' data have shown a great deal of variability in the timing of peak juvenile abundance. Peaks were recorded from late July through early August in 1979, during late September and October in 1980 and 1981, and during early September in 1982.

4.10.2 Yearling and Older Fish

Yearling and older white catfish were collected throughout the ichthyoplankton survey, 2 May through 10 July (Figure 4.10-3). Older catfish were most numerous during May, whereas yearlings, though present throughout the survey, were most numerous during June. During the period of ichthyoplankton sampling, yearling and older white catfish were collected in all regions except Saugerties and Albany in the upper estuary. Highest abundances occurred in the Croton-Haverstraw and Indian Point regions. This concentration of yearling and older white catfish in the lower and middle estuary is consistent with the distribution reported in the 1979 Year Class Report (TI, 1981). Catfish abundance as estimated by ichthyoplankton sampling declined through early July, when few yearlings and no older fish were collected.

Low catches of yearling and older fish also occurred in August when few individuals were collected by either the Fall Shoals or the Beach Seine Surveys (Figures 4.10-4 and 4.10-5). This distribution suggests that a major portion of the yearling and older population had, by July and August, moved out of the main stem of the estuary and perhaps into the tributaries and other areas of the river that are relatively inaccessable to sampling. The extent to which white catfish utilize the tributaries in the Hudson River estuary is uncertain. In the Potomac River adult white catfish seemed to prefer brackish and freshwater tributaries over freshwater areas of the main stem for spawning sites (Lippson *et al.*, 1980). In the Hudson, return movements during fall to the deeper waters of the main stem were indicated by increasing catches first in the shore zone and then in the



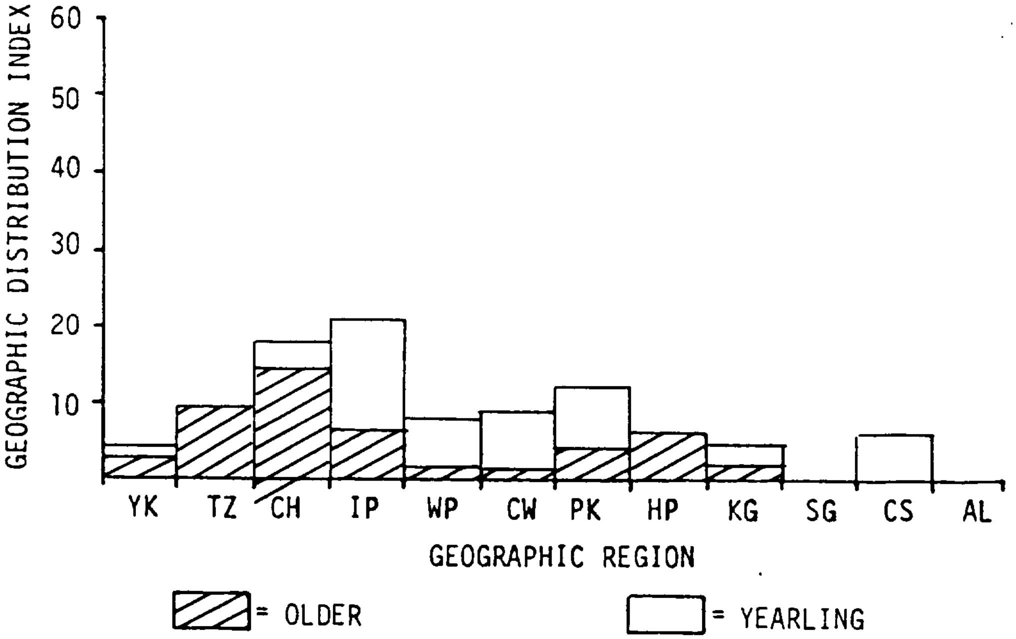


Figure 4.10-3. Temporal and geographic distribution of white catfish yearling and older fish based on ichthyoplankton sampling, Hudson River estuary, 1983.

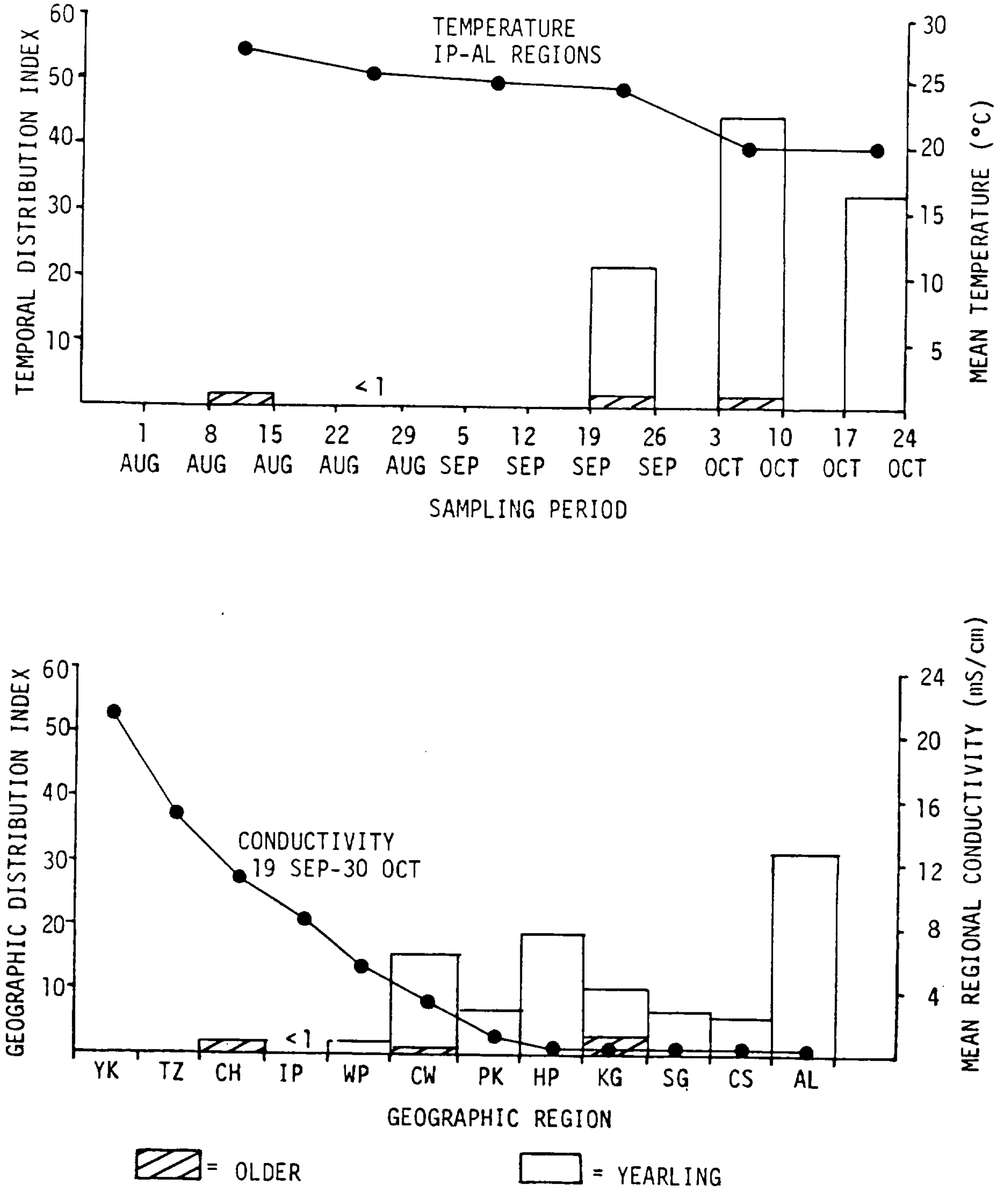


Figure 4.10-4. Temporal and geographic distribution of white catfish yearling and older fish based on the Fall Shoals Survey, Hudson River estuary, 1983.

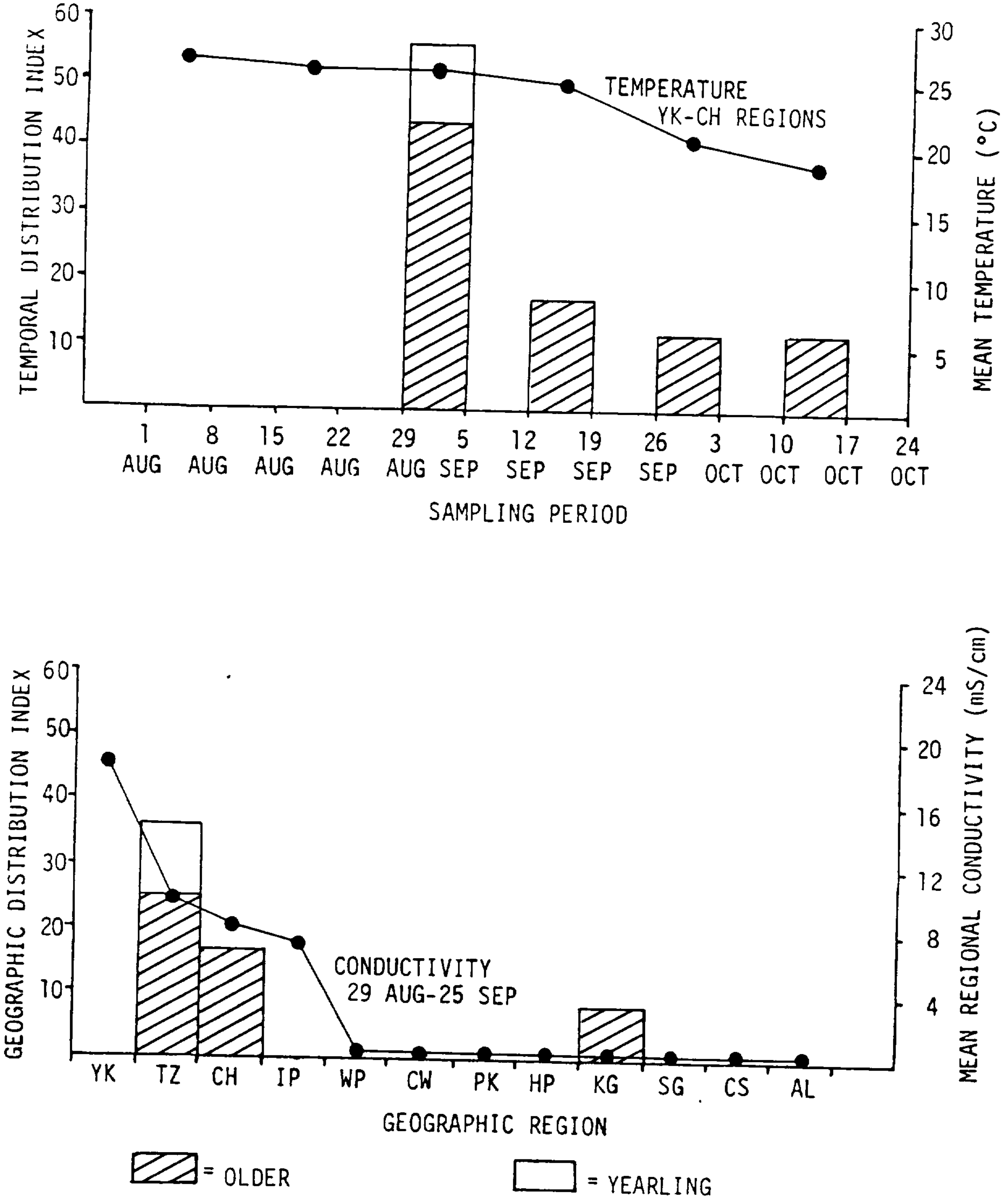


Figure 4.10-5. Temporal and geographic distribution of white catfish yearling and older fish based on the Beach Seine Survey, Hudson River estuary, 1983.

offshore strata (Figures 4.10-4 and 4.10-5). Similar movements where described in the 1979 Year Class Report (TI, 1981). Yearling and older fish presumably moved shoreward during June, July and early August, and offshore beginning in early September. Downriver movements from the upper to the lower estuary have occurred during late October (TI, 1981).

4.11 SPOTTAIL SHINER

The spottail shiner, *Notropis hudsonius*, occurs in freshwater rivers and lakes in North America from Canada south to Georgia in the east, and from Iowa south to Missouri in the west (Scott and Crossman, 1973). It is a small midwater schooling fish and has a variable diet which includes insects, small crustaceans, water mites, eggs and larvae of their own young, and plant material. Spottail shiners appear to prefer habitats with sand and gravel bottoms and avoid strong currents (Pflieger, 1975). They are important forage fish throughout their range. Spawning occurs over sandy shoals during spring and early summer, depending on climate and latitude (Scott and Crossman, 1973).

In the Hudson River estuary, spottail shiners overwinter in the bottom and shoal strata of the middle and upper estuary (TI, 1981). During late April, yearling and older fish move inshore and by May are most abundant in the shore zone of the upper estuary. Concentrations of spottail shiners in this area presumably reflect spawning. Cyprinid eggs and larvae, very likely including those of the spottail shiner, have been collected in the Hudson River during late May through mid-August, thus supporting this position (TI, 1981). After spawning is complete in late June, adults disperse throughout the offshore areas. Juveniles remain concentrated in the shore zone through August and then begin to move offshore in September. Peak catches of juveniles in the bottom and shoal strata of the middle and upper estuary have been recorded from late October into winter. Abundance of yearling and older fish increases in the shore zone during early fall; in November, spottail shiners move back offshore to their deepwater overwintering areas in the middle and upper estuary.

4.11.1 Young-of-the-Year

Juvenile spottail shiners were concentrated in the shore zone throughout the August through October sampling season (Figure 4.11-1). Few juveniles were collected in the offshore strata during the Fall Shoals Survey and none were found in ichthyoplankton collections during the May through July sampling season. Juvenile spottail shiners were collected by beach seine sampling in increasing numbers from the Tappan Zee to Albany regions. This spatial pattern was similar to the distribution reported prior to 1979, and in 1980 and 1981. During 1979 and 1982, juveniles were more evenly distributed between the middle and upper estuary (TI, 1981; NAI, 1984a). The highest shore zone standing crop of the survey occurred during the first week of August; thereafter, abundances generally declined. In past surveys, juveniles were found concentrated in the shore zone during July, and evidence of an offshore movement into the shoals was observed in September (TI, 1981). Though few individuals were collected in the offshore strata, standing crops began to increase during late September through October suggesting that an offshore movement had begun (Figure 4.11-2). Peak offshore movement of juveniles typically occurs from October through mid-December (TI, 1981).

4.11.2 Yearling and Older Fish

The majority of yearling and older spottail shiners collected in the ichthyoplankton, Fall Shoals and Beach Seine Surveys were yearlings. In the ichthyoplankton survey, yearling and older fish peaked at different times (Figure 4.11-3). Older fish were collected only during mid-May, and yearlings primarily during June. Both abundance peaks occurred during the primary period of spawning reported for spottail shiners in the Hudson River, May and June (TI, 1981). It is conceivable

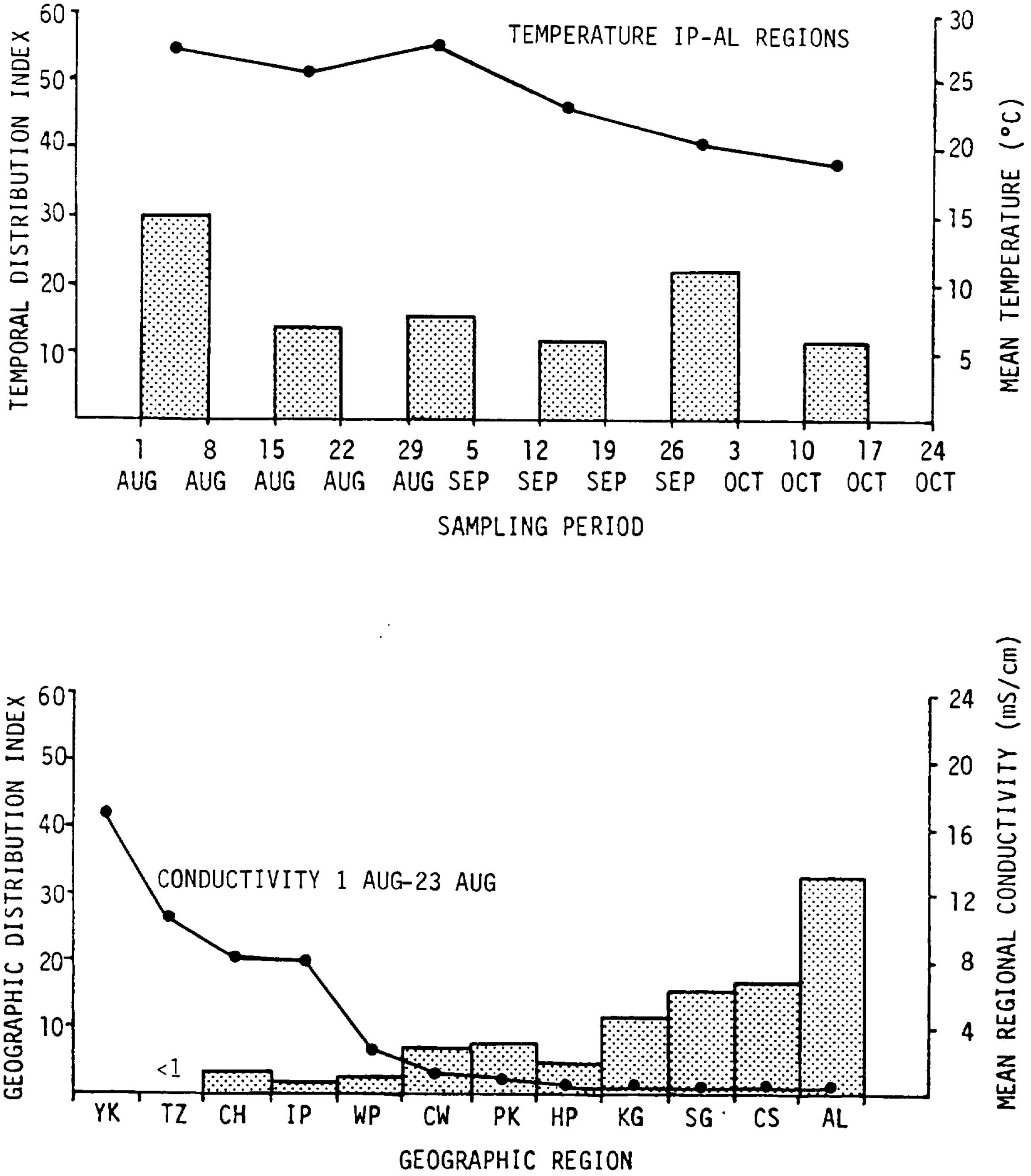


Figure 4.11-1. Temporal and geographic distribution of spottial shiner young-of-the-year based on the Beach Seine Survey, Hudson River estuary, 1983.

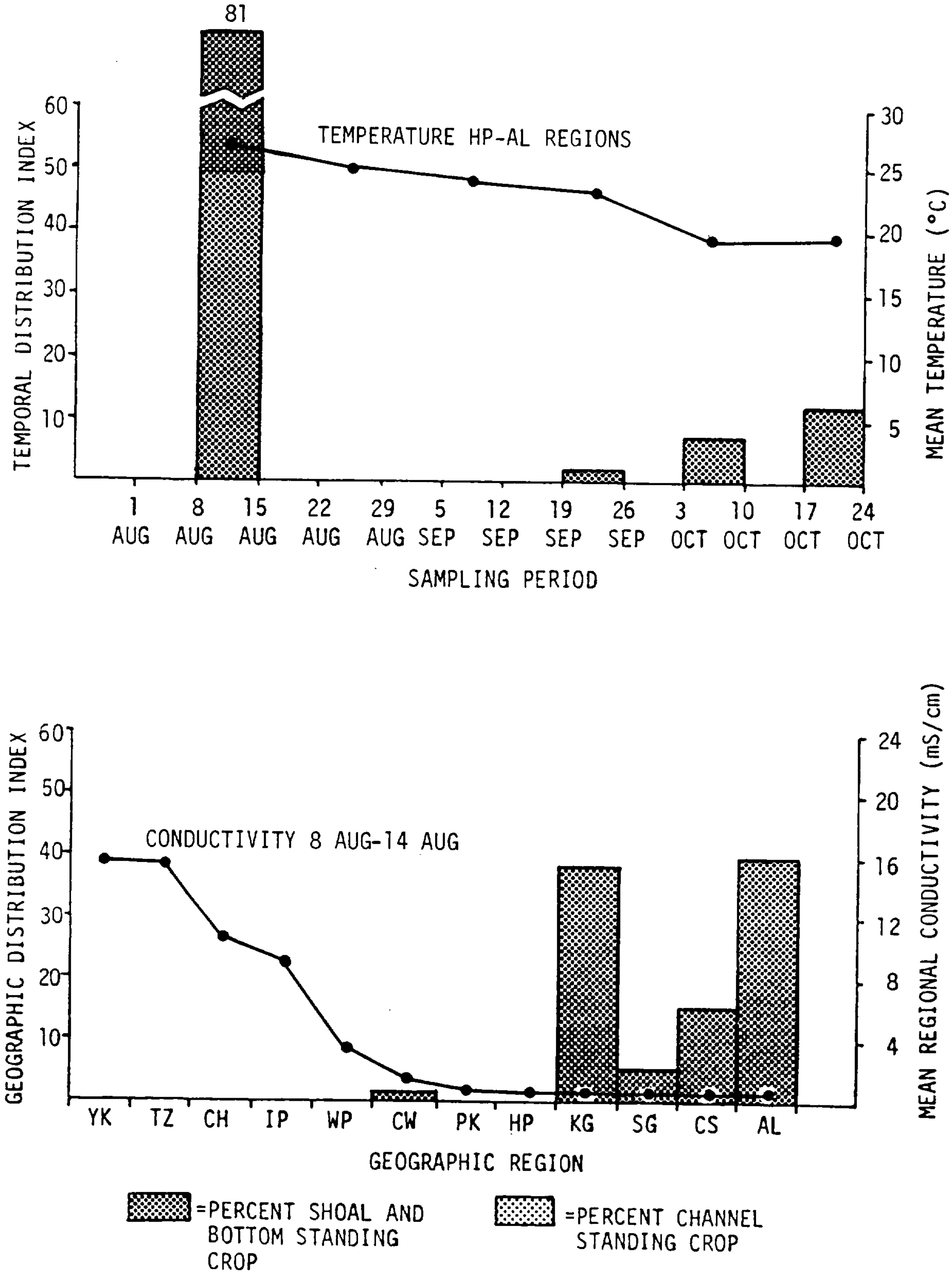


Figure 4.11-2. Temporal and geographic distribution of spottail shiner young-of-the-year based on the Fall Shoals Survey, Hudson River estuary, 1983.

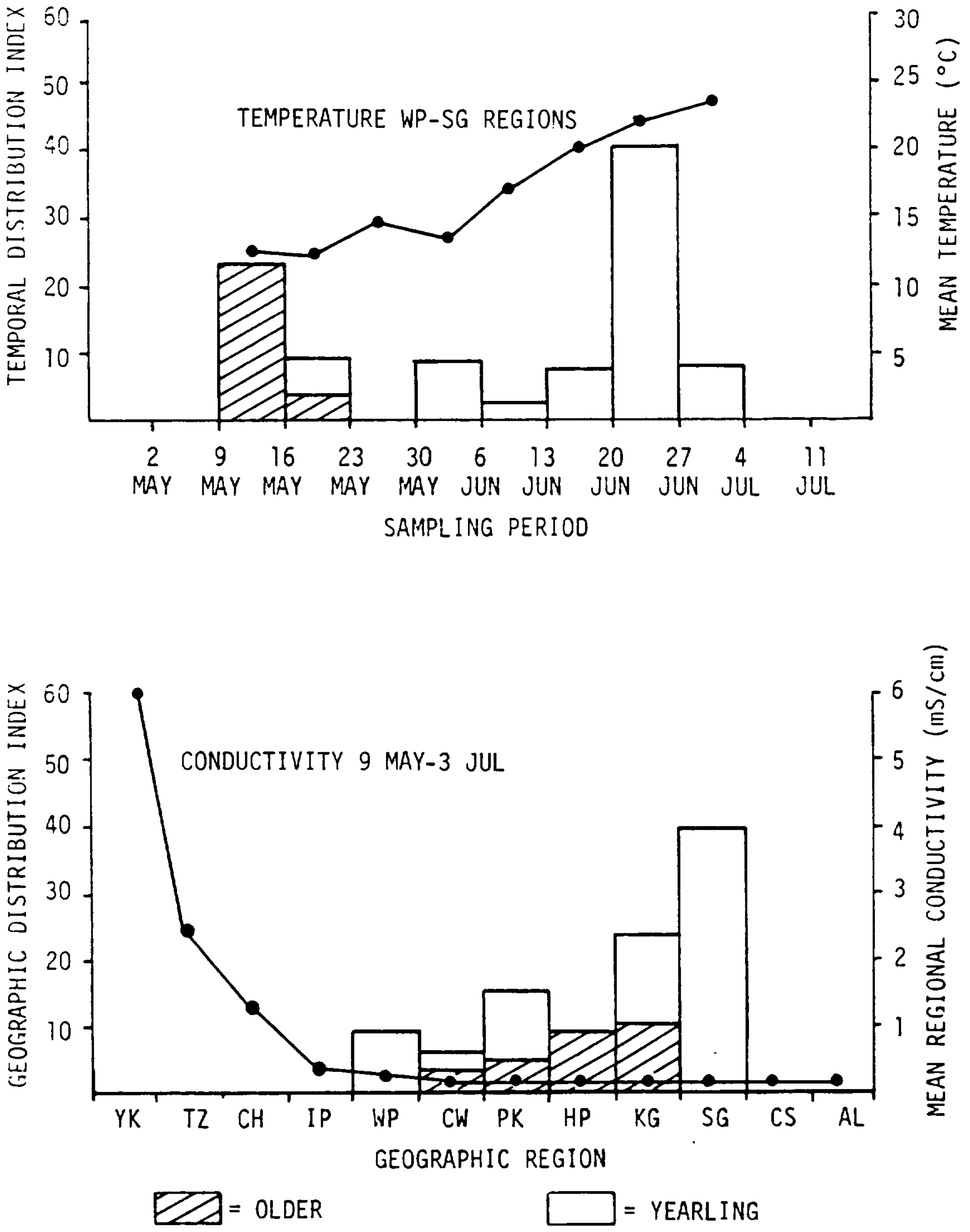


Figure 4.11-3. Temporal and geographic distribution of spottail shiner yearling and older fish based on ichthyoplankton sampling, Hudson River estuary, 1983.

that this segregation reflects a difference in the time of spawning of yearling vs. older fish. Spatially, yearling and older fish were concentrated in the freshwater regions from West Point to Saugerties during the May and June sampling period.

During the August through October Fall Shoals and Beach Seine Surveys, spottail shiner yearlings were most abundant in the shore zone and offshore strata of the upper estuary, though small concentrations were encountered in the shore zone as far down river as the Tappan Zee region (Figures 4.11-4 and 4.11-5). Only three shiners older than yearling were encountered during both surveys. In the shore zone, where standing crop estimates were highest, yearling abundance peaked during late August-early September, and after decreasing slightly, remained fairly constant through October. In the offshore strata, abundances generally declined through early October and then, during the final sampling period of the Fall Shoals Survey, abundance increased to moderate levels. Though not explicitly clear, this distribution might be interpreted as reflecting an onshore movement of yearlings during the period August through October followed by an offshore movement during late October. Similar onshore/offshore movements during this period were reported for yearling and older spottail shiners in past years (TI, 1981). Spottail shiners apparently overwinter in the offshore area of the middle and upper estuary and major offshore movements of yearling and older fish from the shore zone to the bottom and shoal strata have been reported to occur during November (TI, 1981).

4.12 ATLANTIC STURGEON

The Atlantic sturgeon, *Acipenser oxyrhynchus*, is a member of the family Acipenseridae. It is an anadromous species, spending the majority of its life in coastal waters, ascending estuaries only to spawn. Atlantic sturgeon range from Labrador and the Gulf of St. Lawrence to eastern Florida. In the Hudson River estuary, Atlantic sturgeon may be found from Croton-Haverstraw (km 55) north to Catskill (km 200).

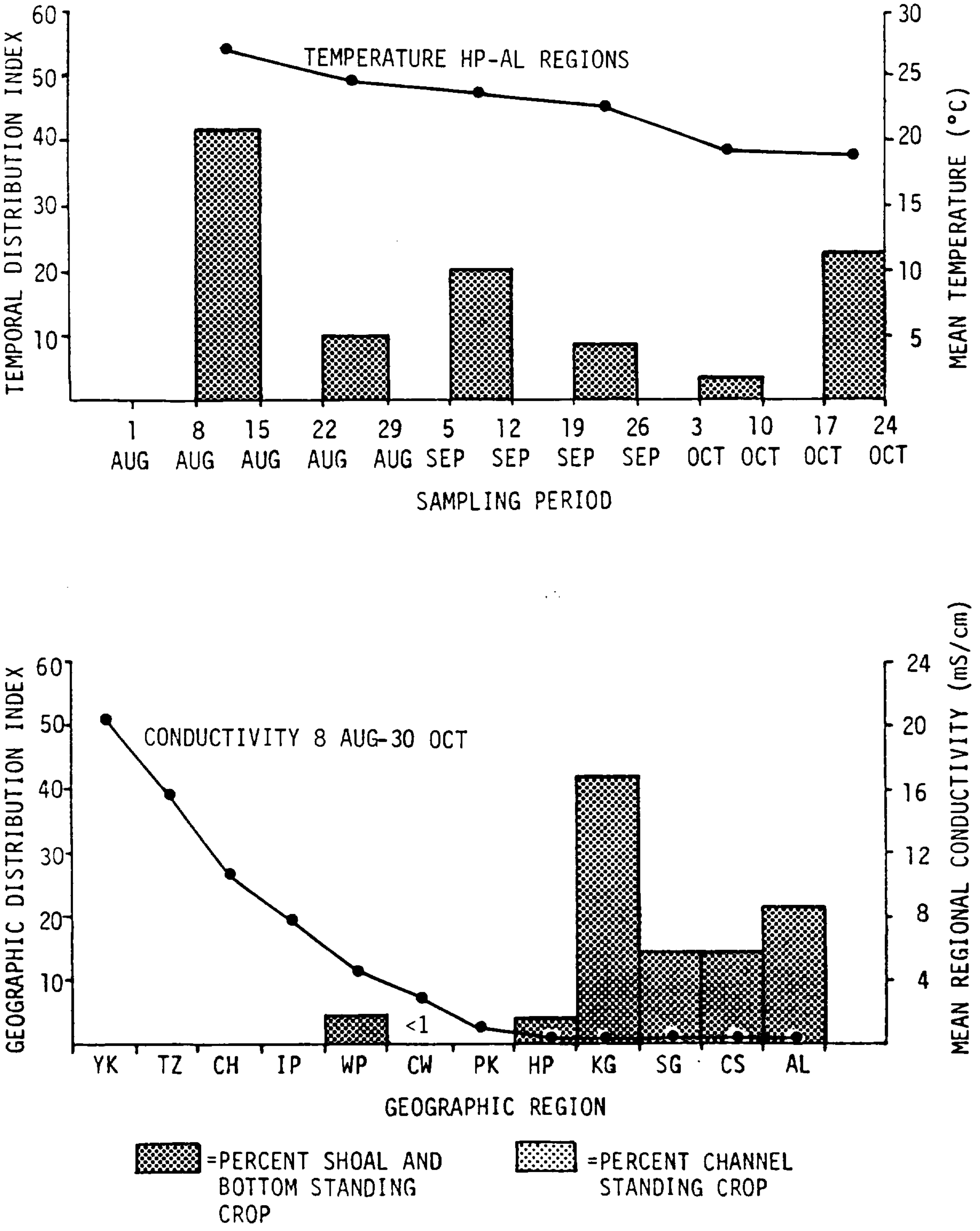


Figure 4.11-4. Temporal and geographic distribution of yearling spottail shiner based on the Fall Shoals Survey, Hudson River estuary, 1983.

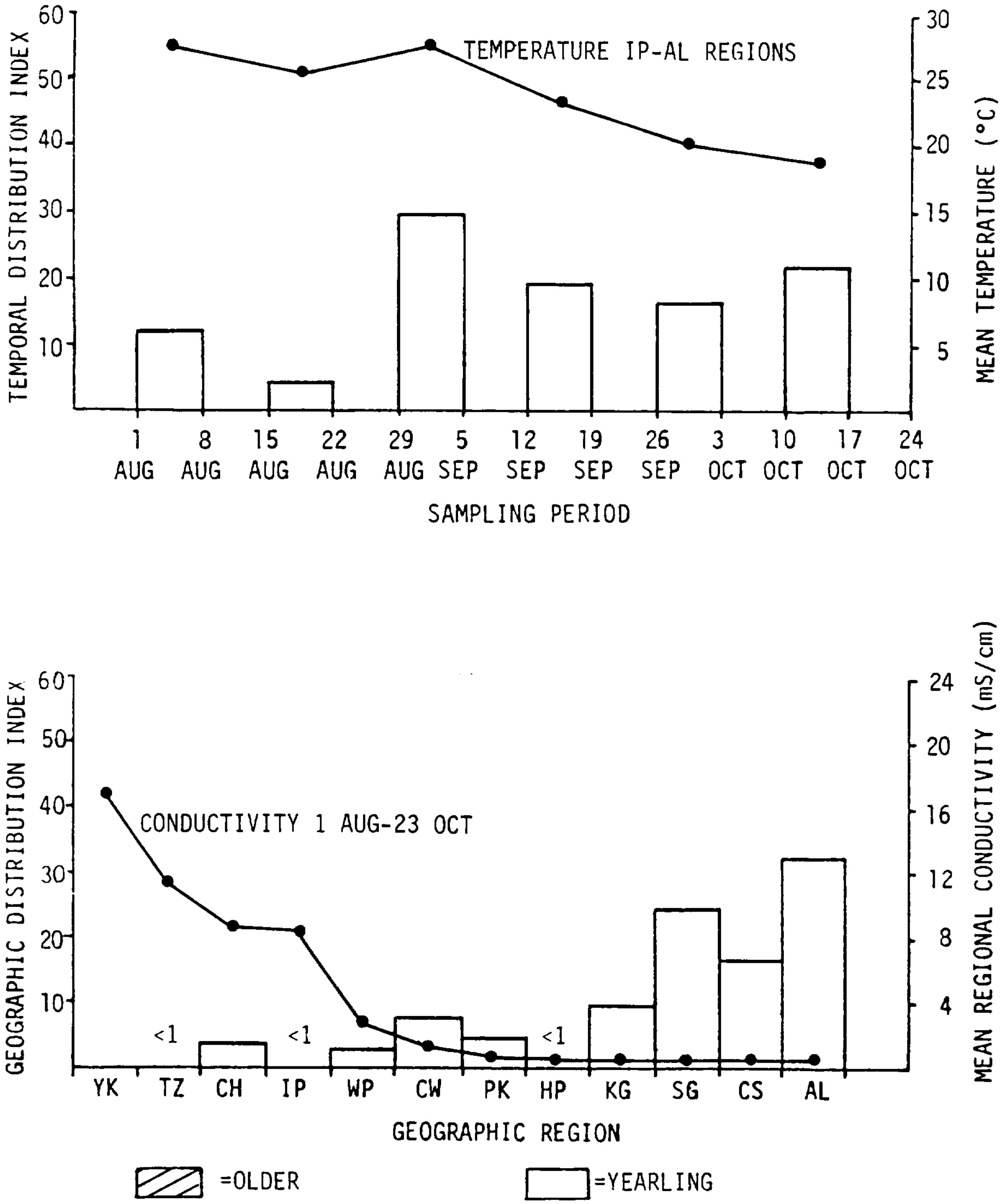


Figure 4.11-5. Temporal and geographic distribution of spottail shiner yearling and older fish based on the Beach Seine Survey, Hudson River estuary, 1983.

The adults usually remain in coastal waters near their natal estuarine system, but will occasionally be collected offshore (Murawski and Pacheco, 1977). In the spring, adults begin to move towards fresh water to spawn. Spawning occurs over hard bottoms in shoal areas when water temperatures are 13-18°C (Jones *et al.*, 1978). Spawning appears to occur only once during the season (Scott and Crossman, 1973), with individual sturgeon possibly requiring a 3-6 year resting stage prior to spawning again. Males reach sexual maturity by age XXII and females by age XXVIII. Fecundity estimates are 500,000 to several million eggs per female (TI, 1981).

The demersal, adhesive eggs are 2-3 mm in diameter and hatch in 4-7 days at temperatures of 18-20°C (Jones *et al.*, 1978). Upon hatching, larvae are 11 mm TL and absorb the yolk sac in 6 days.

Juveniles usually remain within the estuary for up to six years, at which time they have reached 760-915 mm in length. While still in the estuary, juveniles are demersal, consuming chironomid larvae, small crustaceans, and plant material (TI, 1981). After emigration from the estuary, juveniles occasionally make oceanic excursions of up to 1450 km (Magnin and Beaulieu, 1963). The Atlantic sturgeon is slow-growing, reaching a length of 1650-1900 mm and a weight of 68 kg.

4.12.1 Young-of-the-Year

No young-of-the-year Atlantic sturgeon were collected in the Hudson River estuary in 1983.

4.12.2 Yearling and Older Fish

A total of 37 immature Atlantic sturgeon were collected during the 1983 Hudson River monitoring program. Three yearling fish were taken on the bottom with the epibenthic sled (Appendix B; Tables B-90 and B-91). Two of these were collected in West Point (km 84) on 15 June (ichthyoplankton survey) and one individual was taken during the Fall Shoals program on 10 August in Hyde Park (km 125).

Seven older individuals were collected during the ichthyoplankton survey (Appendix B; Table B-92). All were taken with the epibenthic sled in the West Point region (km 76-90). Four were taken during the week of 16 May, two during the week of 20 June, and one during the first week of July.

Twenty-seven older individuals were collected during the Fall Shoals Survey (Appendix B; Table B-93). Ninety-six percent of these were collected during the week of 22 August between Poughkeepsie and Albany (Figure 4.12-1).

4.13 SHORTNOSE STURGEON

The shortnose sturgeon, *Acipenser brevirostrum*, a member of the family Acipenseridae, is a rare and endangered species (Dadswell, 1979). The shortnose sturgeon occurs along the eastern Atlantic coast, from the St. John River in New Brunswick south to the St. Johns River in Florida (Vladykov and Greenley, 1963). At one time the shortnose sturgeon was an abundant species in tidal waters from Connecticut to the Potomac River (Scott and Crossman, 1973). This species is most often seen in large tidal rivers, but may also occur in the inshore marine waters. A landlocked population is present in the Connecticut River (Taubert, 1980).

The shortnose sturgeon is a slow growing species, with a maximum size of 1357 mm TL and 16.5 kg (Jones *et al.*, 1978), but probably only reaches about 885 mm TL and 4.1 kg in the Hudson River (Scott and Crossman, 1973). Lifespan is at least 14 years in the Hudson River, and as long as 27 years in the Saint John River, N.B. (Scott and Crossman, 1973). Sexual maturity is reached at approximately 500 mm TL for males and 600 mm TL for females (Scott and Crossman, 1973), with

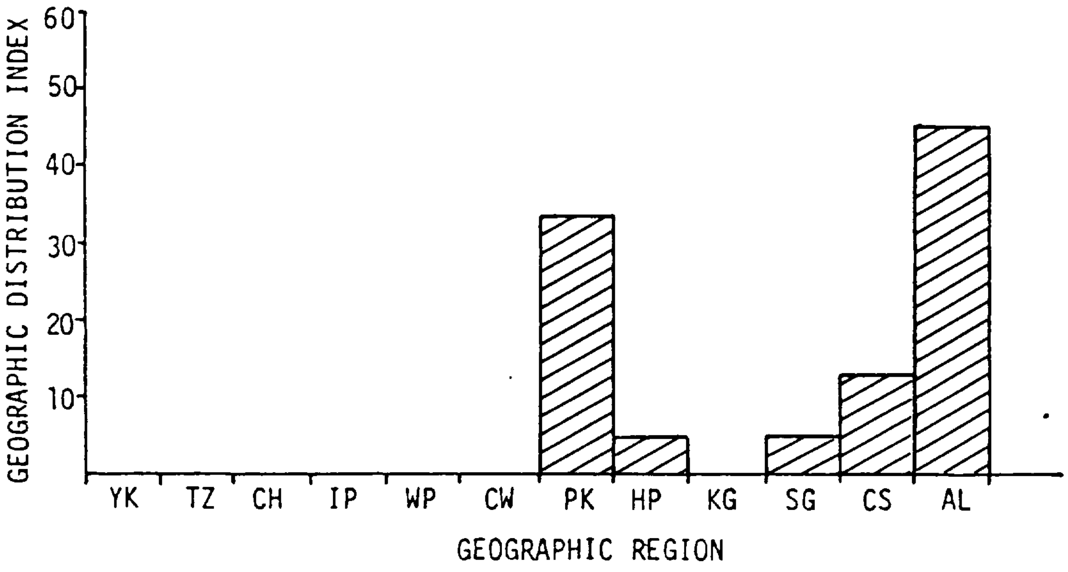


Figure 4.12-1. Geographic distribution of older Atlantic sturgeon based on the Fall Shoals Survey, Hudson River estuary, 1983.

first spawning occurring at about 8-17 years of age (Jones *et al.*, 1978; Taubert, 1980). Shortnose sturgeon only spawn once or twice in their lifetime, with the second spawning occurring at 14-20 years of age (Taubert, 1980).

In the Hudson River, immature shortnose sturgeon and adults in resting condition (which will not spawn the next spring) overwinter in the upper reaches of the lower estuary, while those approaching spawning condition overwinter in the lower part of the upper estuary (TI, 1981). The latter move upriver in spring as water temperatures rise above 5°C, and spawn in late April and early May in the uppermost part of the estuary, when temperatures range from 6 to 17°C (TI, 1981). Females produce between 48,000 and 99,000 eggs (Jones *et al.*, 1978).

Mature ovarian eggs average 3.0 mm in diameter. The eggs are demersal and strongly adhesive at first, becoming essentially nonadhesive after 2 hr. They are half brown and half greyish white and hatch in 4-13 days (Jones *et al.*, 1978) Larvae are about 8-10 mm at hatching and are heavily pigmented (Taubert and Dadswell, 1980). The yolk is nearly absorbed at 13-15 mm TL at approximately two weeks of age (Taubert and Dadswell, 1980). Larvae remain on the bottom for several days after hatching (Jones *et al.*, 1978). Relatively few sturgeon larvae or young-of-the-year have been collected in the Hudson River (TI, 1981), and since shortnose sturgeon larvae have only recently been described (Taubert and Dadswell, 1980; Bath *et al.*, 1981) little is known about how their abundance and distribution in the Hudson compares with that of the Atlantic sturgeon.

4.13.1 Post Yolk-sac Larvae and Young-of-the-Year

Six post yolk-sac larvae and two juvenile shortnose sturgeon were collected during the 1983 ichthyoplankton survey. The post yolk-sac larvae were collected on 31 May in the Albany region (km 201-208). The juveniles were collected in the Hyde Park region on 7 June (km 132) and 28 June (km 124) (Appendix B; Table B-94). All specimens were taken with the epibenthic sled in depths greater than 12 meters.

Few larvae and young-of-the-year sturgeon (*Acipenser* spp.) have been collected in the Hudson River. From 1977 to 1979, only four larvae and one young-of-the-year were taken (TI, 1981). None were collected during the 1980 through 1982 sampling periods. With these limited data, little can be discussed regarding larval or young-of-the-year sturgeon distributional patterns.

4.13.2 Yearling and Older Fish

Five immature shortnose sturgeon were collected in 1983. Two yearlings were taken during the Fall Shoals Survey (Appendix B; Table B-95). One individual was collected on 4 October (km 153) and the other on 17 October (km 169). Three older specimens (Appendix B; Tables B-96 and B-97) were taken during the ichthyoplankton (two specimens; 24 May, km 122) and Fall Shoals surveys (one specimen; 22 August, km 204). All shortnose sturgeon were collected with the epibenthic sled in depths greater than 10 meters. Due to the limited number of shortnose sturgeon collected, distributional trends cannot be adequately discussed.

5.0 GROWTH AND MORTALITY

Estimates of growth and mortality of larval and juvenile fishes are important tools in understanding the population dynamics of a particular stock. Mortality in the early life stages is considered to be a key factor influencing adult population levels (Gulland, 1965). Because mortality rates are high during the early life stages, small changes in mortality rate can result in large changes in the number of fish ultimately recruited to the adult stock. Growth data can indicate when recruitment size is reached, and they can also indicate changes in mortality. Both growth and mortality data reflect the influence of various environmental factors upon a population, and can therefore provide some insight regarding fluctuations in abundance among year classes.

The purpose of this section is to present estimates of growth and mortality rates during the larval and juvenile stages of five key species in 1983, and compare those estimates to data from previous years. The species discussed are striped bass, white perch, American shad, Atlantic tomcod, and bay anchovy.

For the period 1973-1979, estimates of striped bass and white perch growth during the late larval through early juvenile period were based on length data collected mainly in July (TI, 1981). Beginning in 1981, sampling was not conducted during most of July, so corresponding estimates could not be calculated the same way as for previous years. To compensate for the missing data, larval and early juvenile growth for the 1983 year class was inferred by extrapolating backward the mean length data from August-October, and extrapolating forward the mean length data from late June-early July, by the procedure developed in the 1982 Year Class Report (NAI, 1984a). In doing this, certain assumptions were made about recruitment, gear avoidance, and the shape of the growth curve. This approach and its underlying rationale are described in Section 5.1.1.1 using the striped bass data as an example. An independant estimate of growth based on maximum length data was also calculated, in order to corroborate the results based on mean length. Growth estimates for white perch and American shad (Sections 5.2.1.1 and 5.3.1.1) were calculated by the same method.

Mortality was calculated for previous year class reports by two methods (TI, 1981). Late larval and early juvenile mortality of striped bass for the years 1976-1979 was calculated by the method of Sette (1943), which is based on length-frequency data. Mortality of late larval/early juvenile white perch and mortality of larger young-of-the-year for both striped bass and white perch was estimated by the population decline method based on standing crop data (Section 2.2.3.3). In 1983, because no ichthyoplankton samples were collected after early July, sufficient data were not available for using the length-frequency method (this point is further discussed in Section 5.1.2.1). Therefore, all 1983 mortality estimates were calculated by the population decline method as was done for 1982 (NAI, 1984a).

5.1 STRIPED BASS

5.1.1 Growth

5.1.1.1 Larvae and Early Young-of-the-Year

Growth of larval and early juvenile striped bass was examined in previous years in two ways: (1) observation of changes in mean lengths and length-frequency distributions from week to week, and (2) estimation of average growth rate during the intervals from hatching to 30 mm and from 30 mm to 60 mm (TI, 1981). Growth rates for 1973-1979 were calculated from weekly estimates of mean length, primarily during July (TI, 1981). The method was reviewed in the 1980-81 Year Class Report (Battelle, 1983), but no data or growth estimates were presented for those two years. Beginning in 1981, a three- or four-week gap occurred each year between ichthyoplankton sampling and juvenile sampling. This was during the period of early summer rapid growth when the mean length increased roughly from 10 to 60 mm.

To compensate for the missing data, an alternate method of estimating growth during that period was developed (NAI, 1984a). The new method produced growth estimates for the intervals from hatching to 30 mm and 30 mm to 60 mm that differed substantially from those of previous years, because the earlier method had failed to account for fish below recruitment size during July (NAI, 1984a). Growth estimates presented in this section for 1983 were calculated the same way as in the 1982 Year Class Report.

Mean length of larval and early juvenile striped bass in ichthyoplankton samples followed the same pattern from week to week as observed in previous years: there was no substantial increase in mean length until early July (Figure 5.1-1). This apparent lack of growth during the eight-week period in May and June was the result of (1) a decrease or interruption in growth around the time of yolk absorption, which typically lasts 1-3 weeks (Rogers *et al.*, 1977), and (2) continuous recruitment of newly hatched larvae occurring while the numbers of older larvae were rapidly diminished by high mortality rates. In 1983, recruitment was essentially completed by the week of 13 June, which was the last week that eggs or early yolk-sac larvae accounted for a substantial proportion of the 1983 year class of striped bass (Table 5.1-1). After yolk absorption, striped bass growth rate begins to increase rapidly, becoming exponential above 7 mm (Rogers *et al.*, 1977). In 1983 this exponential growth phase lasted from late June until early August, when the growth rate began to decrease (Figure 5.1-1).

TABLE 5.1-1. EGGS AND RECENTLY HATCHED LARVAE (<5 mm TL) AS A PERCENTAGE OF STRIPED BASS ICHTHYOPLANKTON STANDING CROP, HUDSON RIVER ESTUARY, 1983.

2-8 May	None Caught	6-12 Jun	45%
9-15 May	96%	13-19 Jun	15%
16-22 May	86%	20-26 Jun	3%
23-29 May	54%	27 Jun-3 Jul	1%
30 May-5 Jun	87%	4-10 Jul	1%

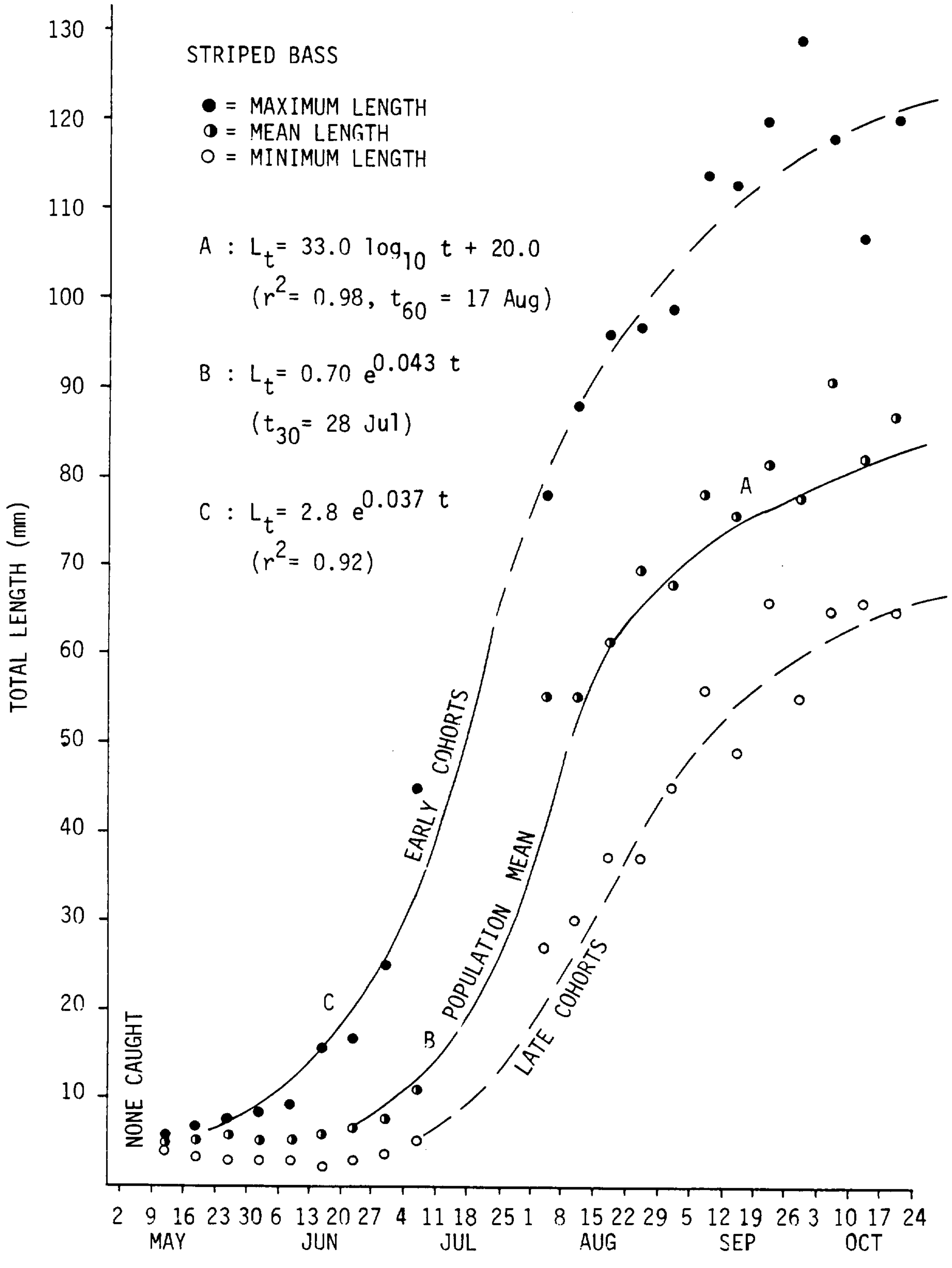


Figure 5.1-1. Growth of striped bass larvae and early juveniles (mm TL) estimated from ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983. Solid lines are exponential and logarithmic curves fit by linear regression; dashed lines were drawn by eye.

To compare growth in 1983 with growth in previous years, estimates were needed of the dates when the population mean reached 30 and 60 mm. Since (1) these could not be generated by linear regression of mean length data between those two sizes as they had been prior to 1980 because of the missing data, and (2) juvenile length data for July could not provide an unbiased estimate of the mean length for the population even if they were available because juveniles under 30 mm were not effectively sampled by the gear, the dates were estimated by extrapolating from the available data. The date when 60 mm mean length was reached was estimated by extrapolating back the mean lengths from the Beach Seine survey. Fall Shoals (epibenthic sled and Tucker trawl) data were excluded because (1) these data were less representative of the population than Beach Seine data, since most of the fish were in the shore zone during these fall juvenile surveys (60-99% based on combined standing crop, Appendix B, Table B-7), and (2) Fall Shoals data had considerably higher variability, both among weeks and (as shown by larger standard errors) within weeks. Based on an assumed recruitment length of 30 mm (TI, 1981), the week of 1 August was also excluded, because the population was not fully recruited to the sampling gear until about mid-August when the youngest and slowest growing fish reached this length (Figure 5.1-1). Recruitment to a gear refers to the time when all members of a population have attained sufficient size to be effectively collected by that particular sampling gear. A logarithmic growth curve (Equation 15, Appendix A) was used because the growth rate was decreasing during this period. The resulting equation fitted the data very well (curve A, $r^2 = 0.98$, Figure 5.1-1) and also closely resembled the eye-fitted curve used to describe growth in previous years (TI, 1981). It produced the estimate that the mean length reached 60 mm on 17 August (Equation 16, Appendix A). The 17 August estimate indicates that striped bass reached 60 mm later in 1983 than in previous years: 30 July-12 August in 1973-1979 (TI, 1981) and 10 August in 1982 (NAI, 1984a).

The pattern of mean lengths of juvenile striped bass in 1983, as well as in previous years, indicates that growth rate begins to decrease (i.e., the exponential growth phase ends) at about 50 mm. This size was reached in 1983 on approximately 9 August as estimated from the logarithmic growth curve (curve A, Figure 5.1-1). The beginning of exponential growth for the population mean was estimated as the week of 20 June, and an exponential curve (Equation 17, Appendix A) was generated from those two points (curve B, Figure 5.1-1). The latter date was selected for three reasons. (1) The presence of larvae over 20 mm in later weeks suggests the possibility of substantial gear avoidance, potentially causing an underestimate of the true population mean. TI (1981) observed that the relative abundance declined precipitously above that size. (2) Mean length data prior to 13 June were affected by ongoing recruitment, so they are not an accurate indication of growth. (3) The mean length in the week of 13 June was 6.0 mm, whereas exponential growth does not begin until about 7 mm. This was estimated by fitting a curve by eye to the data from three replicates at 18°C presented by Rogers *et al*. (1977), and then plotting that curve on a logarithmic scale. Above 7 mm the plot was a straight line, indicating an exponential relationship. From these two points, 50 mm on 9 August (from the logarithmic equation) and 6.7 mm on 23 June based on the assumption stated above that growth is exponential from roughly 7 to 50 mm, an exponential growth curve was calculated (Equation 17, Appendix A). This exponential relationship (curve B, Figure 5.1-1) represents a growth rate of 4.4% per day for larvae and juveniles between 7 and 50 mm.

The time when the mean length reached 30 mm was estimated from the exponential growth curve as 28 July (Equation 18, Appendix A), essentially the same as the 26 July estimate for 1982 (NAI, 1984a). Estimates for 1973-1979 of 27 June to 10 July (TI, 1981) are not comparable because they were derived by a different method. Those estimates were biased by the use of mean length data from July and early August when the population was not fully recruited to the gear, causing the estimated dates for 30 mm to be too early (NAI, 1984a). As a result, growth estimates for 1973-1979 were usually higher between hatching and 30 mm (0.49-0.84 mm/day) and lower between 30 and 60 mm (0.87-1.10 mm/day) than these 1983 estimates (0.5 and 1.5 mm/day, respectively; Equation 19, Appendix A). The average growth rate of juveniles between 30 and 60 mm in 1983 of 1.5 mm per day was slower than the 2.1 mm per day observed in 1982 (NAI, 1984a). If the average hatching date was about 2 June (the mid-point of the week of peak egg standing crop), and the average size at hatching was 3.1 mm (Mansueti, 1964), then the average growth rate from hatching to 30 mm was 0.5 mm per day and the average growth rate from hatching to 60 mm was 0.7 mm per day.

The rate of increase of mean length of a population may not always accurately reflect the same growth rate exhibited by individual larvae, so this estimate of striped bass growth was evaluated by comparing it to the growth inferred from maximum lengths. Because the maximum length data are not means they are unaffected by recruitment or age-specific mortality, and are considered to be a reasonable approximation of growth of certain individual fish, i.e., the faster growing individuals among the cohorts which hatched in the early part of the season. Also, gear avoidance does not introduce a serious bias, as long as at least a few of the large fish are caught. To verify this assumption, log-transformed maximum lengths from the ichthyoplankton sampling periods were plotted against time (sampling week). The data approximated a straight line, due to exponential growth, and the points late in the sampling season did not fall below the line (they would if they seriously underestimated the true maximum length for the population). This lack of bias in maximum length data in contrast to mean length data is due to the fact that the proportion of large fish in the samples, which may substantially underestimate the true proportion, does not affect the maximum length value, whereas it does affect the estimate of the mean. Since neither recruitment nor gear avoidance biases the maximum length data, all of the ichthyoplankton sampling periods can be used to estimate growth of early cohorts. This made it unnecessary to include Beach Seine or Fall Shoals data to provide a sufficient number of data points to establish the exponential growth curve, so a logarithmic curve was not calculated from maximum lengths. An exponential curve was estimated directly from the nine weekly values of maximum length from the ichthyoplankton sampling, using Equation 17 (Appendix A). The resulting equation (curve C, Figure 5.1-1) fitted the data well (r^2 =

0.92). The growth patterns inferred from the mean and the maximum length data were in close agreement with each other (Figure 5.1-1).

5.1.1.2 Young-of-the-Year

Juvenile striped bass growth data for 1983 are available for the period from early August to mid-October (Figure 5.1-2). Fish collected in the shore zone, which represent the bulk of the population in the summer, grew from 61 mm mean length to 82 mm mean length in an eight-week period (week of 15 August to week of 10 October), an average growth of 0.4 mm per day. The growth rate decreased somewhat during this period, as the fish were no longer in the exponential phase of growth. These lengths were 7-9 mm lower than the means for the corresponding weeks in 1982 (NAI, 1984a).

Except for early August, the average sized striped bass juveniles which were collected in Fall Shoals samples were generally larger than those in the shore zone. This may indicate that the faster growing (or older) individuals prefer deeper water or that fish which have moved into shallow areas do not grow as fast. In 1982 this trend did not become established until October (NAI, 1984a). This size difference may indicate that the larger fish are the earliest ones to enter deeper water as they begin migrating down the estuary. This pattern is consistent with previous observations, when the difference between Fall Shoals and Beach Seine mean lengths increased in November and December (TI, 1981). There were no substantial size differences among river regions.

5.1.2 Mortality

5.1.2.1 Larvae and Early Young-of-the-Year

Mortality of striped bass from 6 to 20 mm in 1983 could not be calculated by the length-frequency method used for 1976-1979, because

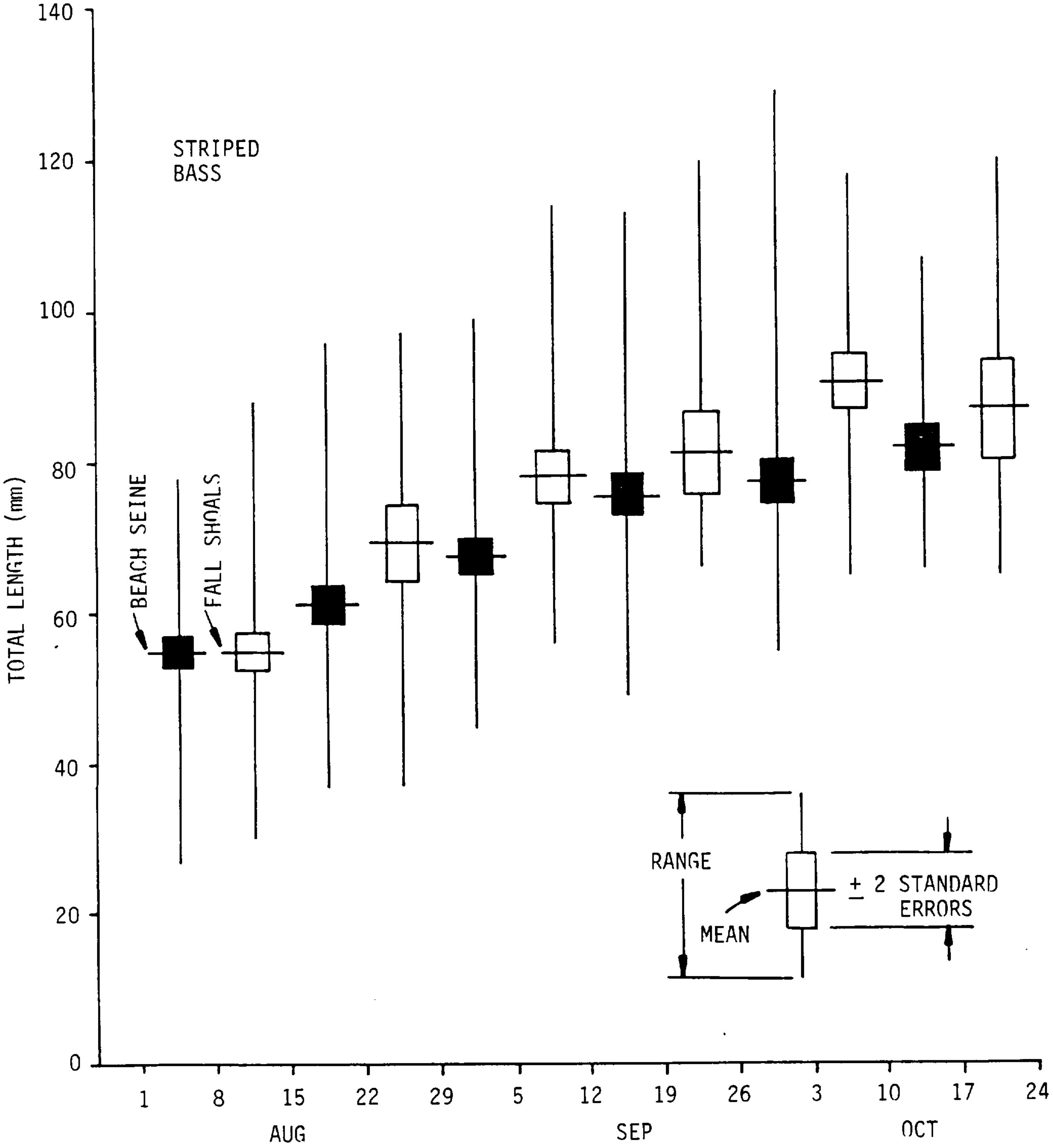


Figure 5.1-2. Growth of striped bass juveniles (mm TL) estimated from Fall Shoals and Beach Seine Surveys, Hudson River estuary, 1983.

ichthyoplankton sampling ended with the week of 4 July, when there were still small larvae present (<5 mm). The length-frequency method requires sampling until all larvae have grown larger than the maximum size under consideration (20 mm in this case) because it uses an estimate of the total number of fish which survive to each size interval during the entire year. If sampling ends before the maximum size is reached, as it did in 1983, then the total number of larvae that reach a certain size (e.g., 15-16 mm) during that year is underestimated. This is because those individuals that were smaller than that when sampling ended are not sampled when they eventually reach that size. The extent to which any particular size class is underestimated increases with increasing size. For example, only a small percentage of the larvae hatched in 1983 had not yet reached 7 mm by the end of sampling, so the 6-7 mm size interval would only be slightly underestimated. In contrast, probably less than half of the striped bass that would survive to 20 mm in 1983 had reached that size by the end of sampling, based on the observation that the mean length for the population did not reach 20 mm until about a week and a half after sampling ended (Figure 5.1-1). A mortality estimate based on the length-frequency method in 1983 would therefore substantially overestimate actual mortality because of not accounting for many of the fish which would survive to the larger size intervals. Mortality was estimated instead by the population decline method.

Mortality of striped bass from the week of peak standing crop (week of 13 June) through the last week of ichthyoplankton sampling, calculated by the population decline method (Equations 20 and 21, Appendix A), was 13% per day (Figure 5.1-3). The assumption that recruitment was complete by the peak week was supported by the low proportion of eggs and small yolk-sac larvae in subsequent weeks (Table 5.1-1). Standing crop could be underestimated for a week or so after the peak, however, if small yolk-sac larvae are not fully recruited to the 505-μm mesh. This would cause mortality to be underestimated.

Larval mortality appeared to be somewhat greater in 1983 than in 1982 when it was estimated to be 9% per day (NAI, 1984a). Mortalities of 16 to 19% per day were reported for 1976-1979 (TI, 1981),

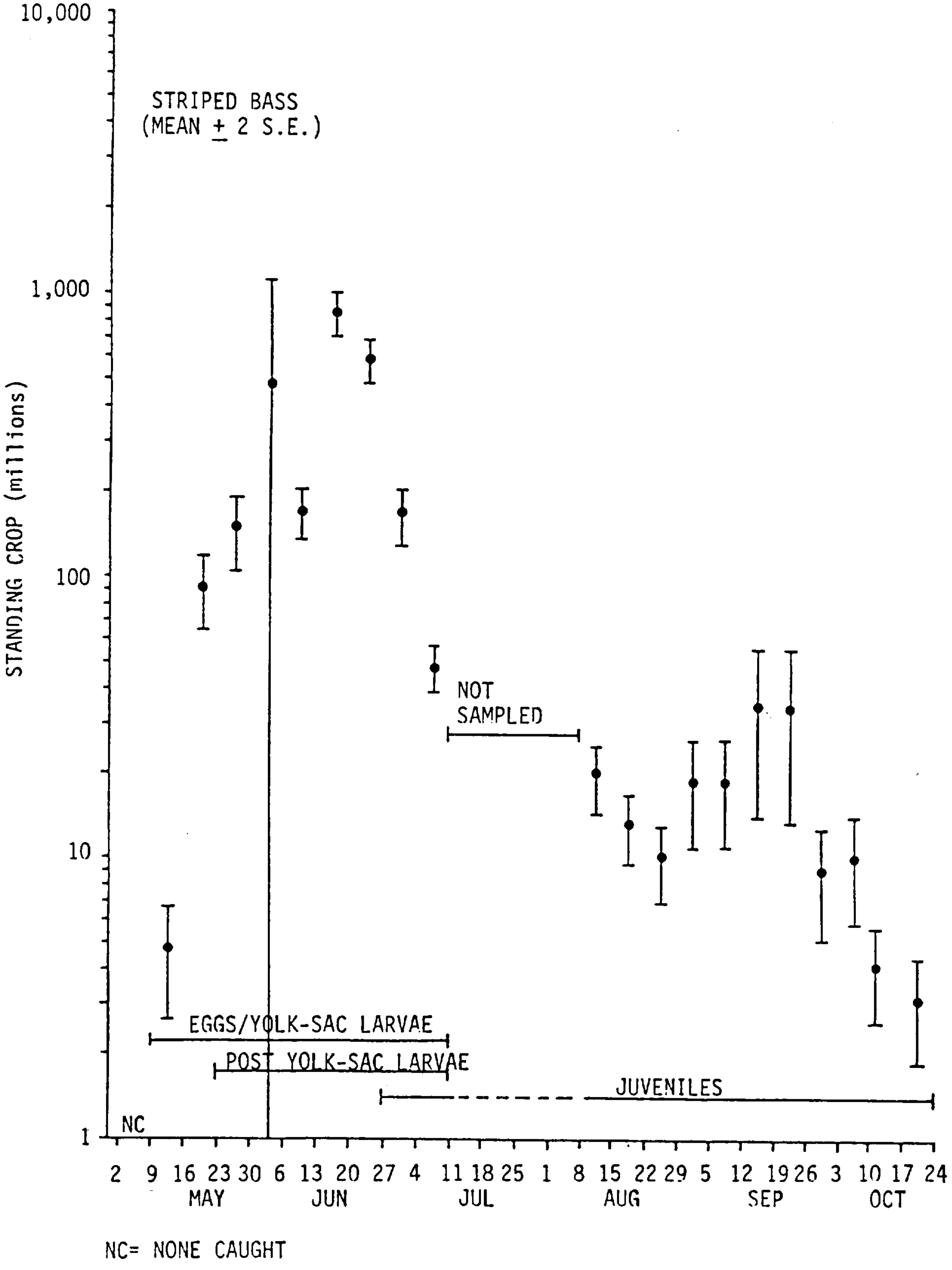


Figure 5.1-3. Standing crop of striped bass early life stages based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983.

using the length-frequency method of Sette (1943), which could not be used for the 1982 and 1983 data because samples were not collected over a long enough period (NAI, 1984a).

During 1976, 1978, and 1979, mortality rate decreased as larvae attained a length of approximately 10 mm, based on an assessment of mortality by the length-frequency method (TI, 1981). In 1983, however, it could not be determined whether this length-related decrease occurred, because of the wide range in ages present during any one week.

5.1.2.2 Young-of-the-Year

Mortality of striped bass young-of-the-year over 30 mm in length was estimated in previous years by using the weekly combined standing crop data from the Fall Shoals and Beach Seine Surveys as a measure of population decline. Estimates for 1975-1979 ranged from 0.3 to 1.8% per day (TI, 1981). During 1976-1981 the typical pattern of the standing crop survival curve was (1) a period of moderate mortality around July and August (less than in the larval and early juvenile stages) followed by (2) a period of reduced mortality rate during September and sometimes the latter part of August, and then (3) reduced standing crops in the fall attributed to dispersal from the sampling area in addition to mortality (TI, 1979, 1980a, 1980b, 1981; Battelle, 1983).

In 1983, the population of young-of-the-year striped bass, as estimated by combined standing crop (CSC), did not decline steadily. It fluctuated between 10 and 35 million in August and September, and then began to decline in October (Figure 5.1-3). This pattern is difficult to interpret in terms of mortality. It appears that either (1) mortality was too small to detect during August and September in relation to the variation in the catch data, or (2) there was an increase in the population from late August to mid-September due to immigration from somewhere outside the sampling area, such as tributary streams. The former explanation is probably more likely because of the relatively wide confidence intervals associated with the weekly CSC values (Section 6.0). In 1982, there was no appreciable mortality observed during a similar sampling season (NAI, 1984a).

An approximation of the average mortality rate from early July to mid-August can be made from the standing crop estimates for the last week of ichthyoplankton sampling and the first week when juvenile abundance estimates were available for both the shore zone and the offshore strata. Based on a standing crop reduction from 48.3 million to 20.4 million over a five-week period, the mortality was about 2.4% per day (Equation 20, Appendix A, with $N_o = 48.3 \times 10^6$, $N_t = 20.4 \times 10^6$, $t = 35$ days; Equation 21, Appendix A). A comparable estimate of 2.9% per day was obtained for 1982 (NAI, 1984a). These can only be considered approximate because only two data points were used for each, and those were from different sampling gears. The mortality represented by these estimates includes some which occurred during the post yolk-sac stage, since much of the population had not yet reached the juvenile stage in early July. These mortality estimates may be somewhat low because of gear avoidance by older (i.e., larger) fish of the year class by early July.

Juvenile striped bass mortality estimates for 1975-1979 varied widely, with the high estimates for 1977 and 1979 attributed to emigration from the sampling area in the early fall (TI, 1981). The period used for those estimates was not consistent, however, beginning as early as 9 July in one year and as late as 27 August in another. It appears from the combined standing crop data of several years that the period from roughly early July to mid-August is one in which the mortality is variable and transitional between the high larval mortalities and the low juvenile mortalities of late summer. Another difficulty in assessing early summer mortality is that even if samples were collected prior to August, as they were before 1981, the population was undergoing recruitment to the sampling gear then. Assuming that recruitment occurs at around 30 mm, in 1983 it began in early July and continued through mid-August (Figure 5.1-1), which was similar to the recruitment period in 1982 (NAI, 1984a). Estimates of the juvenile standing crop before mid-August are therefore too low, making the mortality estimates for the July-October period of previous years too low as well.

5.2 WHITE PERCH

5.2.1 Growth

5.2.1.1 Larvae and Early Young-of-the-Year

Growth of larval and early juvenile white perch in 1983 was examined by the same method as for striped bass. Mean length was relatively stable during the ichthyoplankton sampling season. Recruitment to the yolk-sac stage was essentially complete by the week of 13 June, after which substantially fewer eggs and recently hatched larvae were collected (Table 5.2-1). When Fall Shoals and Beach Seine sampling began in August, recruitment to the sampling gear was not complete. The recruitment size of 25 mm (TI, 1981) was not reached by all young-of-the-year until about mid-August (Figure 5.2-1).

To estimate the date when 60 mm mean length was reached, a logarithmic curve was fitted to both Fall Shoals and Beach Seine data beginning with the week of 15 August (curve A, Figure 5.2-1), because white perch juveniles were present in large numbers in both the shore zone and the offshore strata during the juvenile sampling programs.

TABLE 5.2-1. EGGS AND RECENTLY HATCHED LARVAE (<3.5 mm TL) AS A PERCENTAGE OF WHITE PERCH ICHTHYOPLANKTON STANDING CROP, HUDSON RIVER ESTUARY, 1983.

2-8 May	89%	6-12 Jun	42%
9-15 May	77%	13-19 Jun	29%
16-22 May	54%	20-26 Jun	3%
23-29 May	30%	27 Jun-3 Jul	<1%
30 May-5 Jun	44%	4-10 Jul	<1%

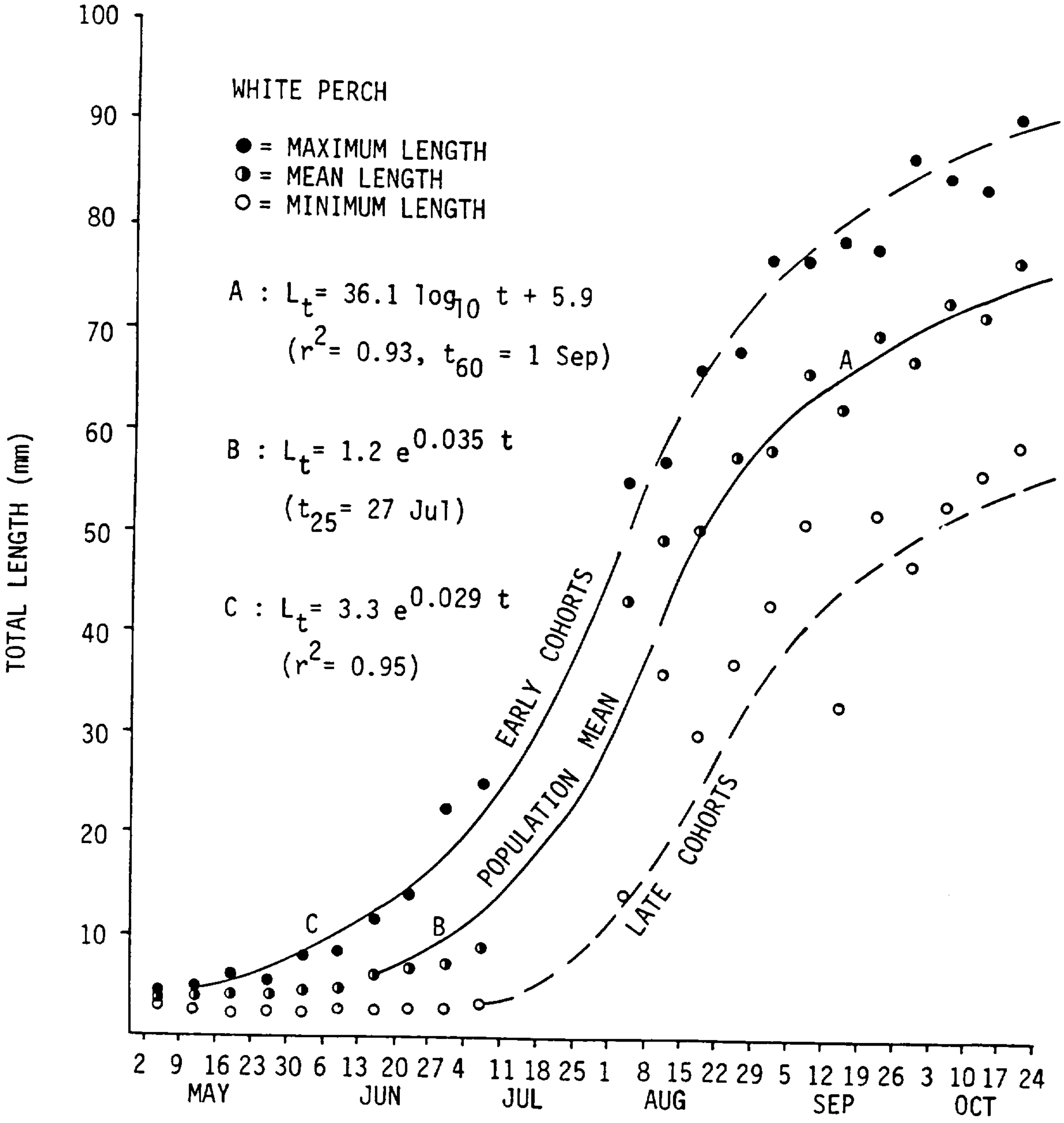


Figure 5.2-1. Growth of white perch larvae and early juveniles (mm TL) estimated from ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983. Solid lines are exponential and logarithmic curves fit by linear regression; dashed lines were drawn by eye.

This growth curve fitted the late summer-early fall data well (r^2 = .93), and estimated that 60 mm was reached on 1 September. This was well after the phase of rapid exponential growth, which ended in early August. Examination of the mean length plot estimated the end of the exponential growth phase to be 40 mm. Two points, 5.9 mm during the week of 13 June (when recruitment was approximately complete) and 40 mm on 10 August (from the logarithmic curve), were then used to estimate the growth curve for the period of exponential growth (curve B, Figure 5.2-1). This in turn provided an estimate of 27 July as the date when the recruitment length of 25 mm (TI, 1981) was attained, and an average growth rate between 25 and 60 mm of 1.0 mm per day. Growth rate for the same length interval was estimated at 0.57 to 0.77 mm per day during 1973-1979 (TI, 1981), and 0.8 mm per day during 1982 (NAI, 1984a).

The time of peak hatching for white perch in 1983 was approximately mid-May, based on the numbers of eggs and yolk-sac larvae present (Section 4.2). In previous years, post yolk-sac larvae usually reached their peak abundance about one week after the peak of yolk-sac larvae, but in 1983 they were most abundant five weeks later, during the week of 20 June. This suggests that either (1) duration of the yolk-sac stage was unusually long in 1983, or (2) mortality of the yolk-sac stage was very high until early to mid-June, and the observed peak of post yolk-sac larvae was predominantly composed of larvae which hatched late in the spawning season. The five-week period between the peaks of yolk-sac and post yolk-sac larvae was too long to be accounted for by slow development, because the maximum reported stage duration for white perch yolk-sac larvae is only 13 days (Hardy, 1978). The second explanation is more plausible, because similar occurrences have been observed for other species. Mortality of early hatching cohorts of rock gunnel (*Pholis gunnellus*) was found to be much higher than for larvae which hatched several weeks later in the season, this being attributed to absence of suitable food organisms during the early hatching (Townsend, 1983). White perch in 1983 continued to hatch from the beginning of May until well into June (Table 5.2-1), but water temperatures were unusually cold from mid-May through the first week of June (Section 3.1). This delayed warming could have delayed the production of the prey species upon which the survival and growth of white perch larvae depend. If this is true, and if 6-mm larvae are roughly three weeks old as assumed in 1982 (NAI, 1984a), then larvae captured during the week of 13 June, which averaged 5.9 mm in length, probably hatched during the week of 23 May rather than a week or two earlier when hatching peaked. This estimate of hatching date, together with the estimated exponential growth curve (curve B, Figure 5.2-1) and an estimated hatching length of 2.6 mm (Hardy, 1978), implies an average growth rate from hatching to 25 mm of 0.36 mm per day. This is similar to the 0.34 mm per day estimated for 1982 (NAI, 1984a). For the 1973-1979 period, the estimates of mean hatching date ranged between 16 May and 13 June, and growth estimates from hatching up to 25 mm ranged from 0.45 to 0.85 mm per day (TI, 1981).

As seen for the 1982 year class of white perch (NAI, 1984a), the estimated times of hatching and reaching 60 mm in 1983 were fairly close to previous estimates, but the estimate of when recruitment length was reached was substantially later than earlier estimates. This can be attributed to overestimating the mean population length during July of earlier years by using sampling gear to which the population was not yet fully recruited. The estimate of the 1983 growth rate based on the maximum lengths, representing the faster growing individuals among the early cohorts (curve C, Figure 5.2-1), closely resembled the estimate produced from the mean lengths.

5.2.1.2 Young-of-the-Year

Juvenile white perch growth was approximately linear during early August through early October, with growth rate decreasing slightly during that period (Figure 5.2-2), although incomplete recruitment in early August caused means for the first two weeks to be overestimated somewhat. Both Fall Shoals and Beach Seine Survey data indicated growth of 0.4 mm per day. During the late summer-early fall period, mean lengths in the shore zone lagged a week or more behind those in the offshore strata, suggesting a slight preference by larger fish for

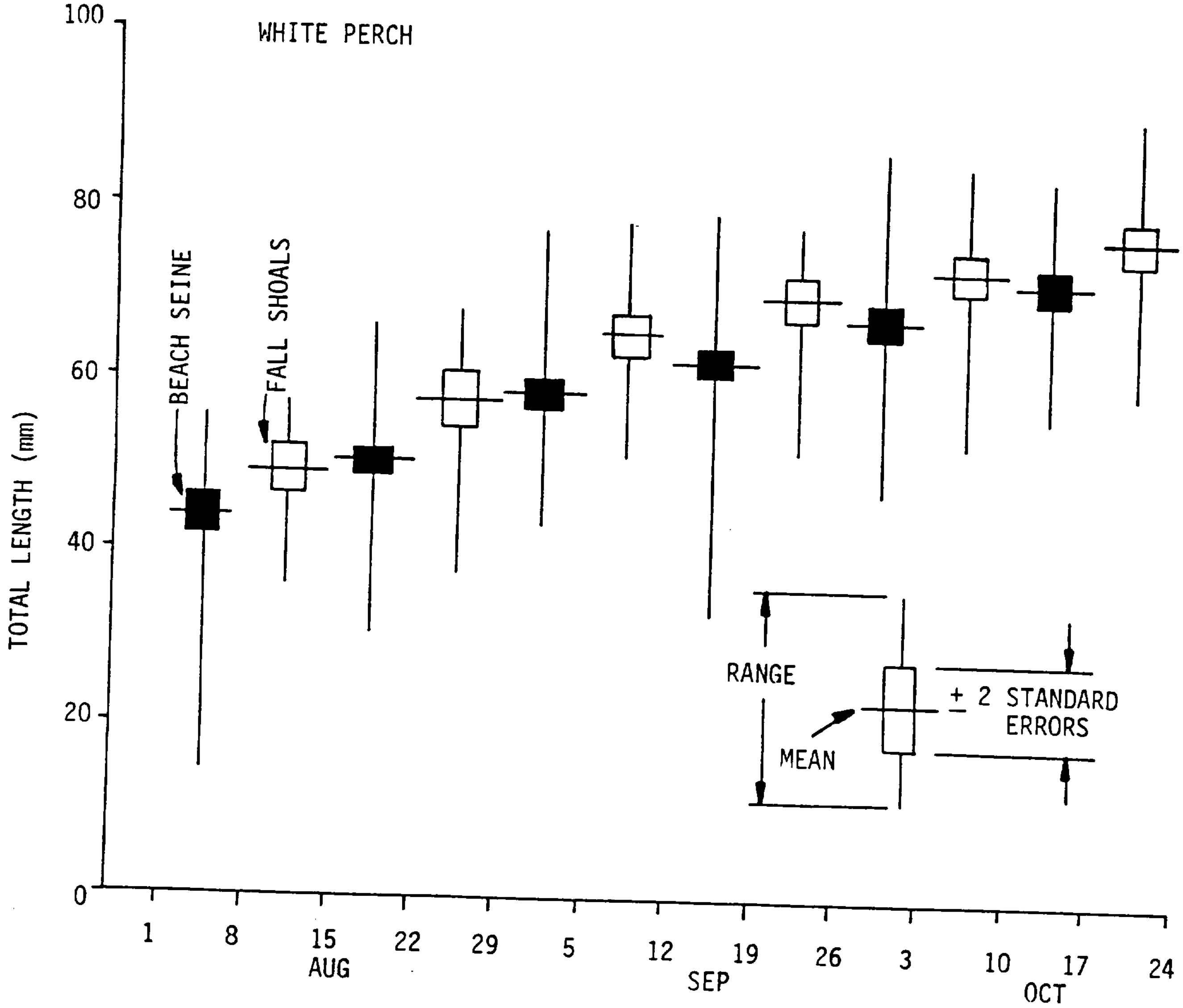


Figure 5.2-2. Growth of white perch juveniles (mm TL) estimated from Fall Shoals and Beach Seine Surveys, Hudson River estuary, 1983.

deeper water. Mean lengths in 1983 were slightly higher than in corresponding weeks of 1982 (NAI, 1984a).

5.2.2 Mortality

5.2.2.1 Larvae and Early Young-of-the-Year

Recruitment to the yolk-sac stage was virtually complete by the week of 13 June (Table 5.2-1), corresponding to the week with the highest standing crop of early life stages of white perch (Figure 5.2-3). Using this week of peak standing crop plus the remaining three sampling weeks for estimating mortality by the population decline method, the resulting estimate is 5% per day. The standing crop did not appear to decrease from the week of 13 June to the following week. This may be due to underestimating abundance of the smallest larvae due to the mesh size (505 µm) of the sampling gear. Without including the week of 13 June, the mortality estimate would be 7% per day. These estimates are similar to the 1982 estimate (5% per day; NAI, 1984a), but much lower than the 10-14% per day estimated for 1976-1979 (TI, 1981). The estimates for those earlier years were based on a longer sampling season. The abundance in July of those years was probably underestimated because early juveniles are under sampled by the ichthyoplankton gear (as avoidance increases with growth), and by the Fall Shoals and Beach Seine gears (until fully recruited in mid-August). This is also suggested by the dip in the combined standing crop in late July (TI, 1981). The effect of these abundance underestimates is to increase the mortality estimate relative to an estimate (such as 1983) lacking July data. Probably 10% per day is a more realistic figure for post yolk-sac larval mortality, although it is most likely an overestimate for somewhat later (mid- through late July).

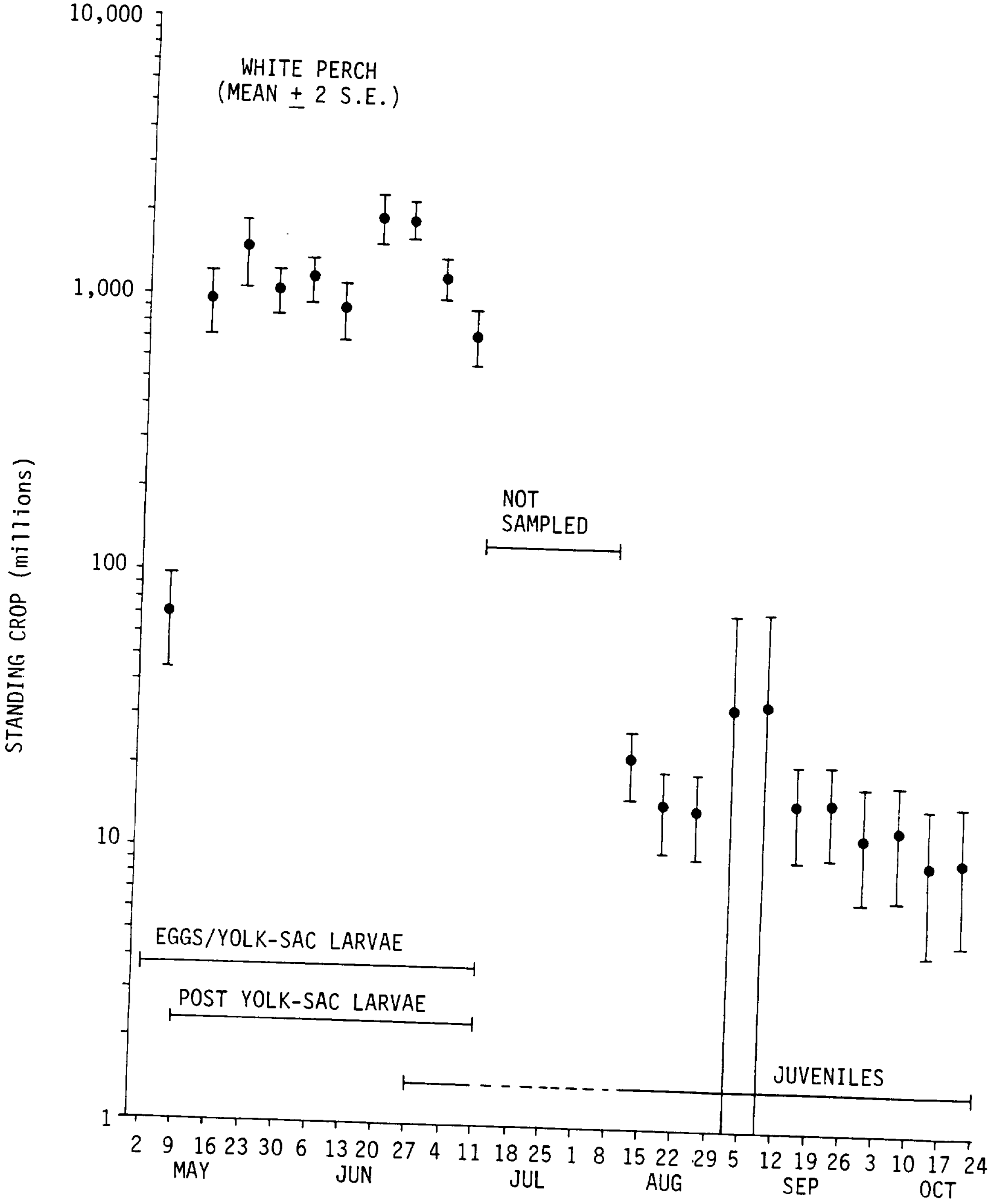


Figure 5.2-3. Standing crop of white perch early life stages based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983.

5.2.2.2 Young-of-the-Year

Mortality of white perch juveniles from early August to mid-October was 1.1% per day, based on the rate of decline in the weekly combined standing crop estimates. This was higher than the estimates for 1976-1979, which ranged from 0.2 to 0.9% per day, with 0.6% per day (1979) judged as the best estimate because of the expanded sampling program and revised gear efficiency data introduced that year (TI, 1981). Although the time intervals represented by those earlier estimates were not consistent, the results were in agreement in that mortality is substantially reduced from the larval stages. The 1983 mortality estimate was slightly lower than the 1982 estimate of 1.3% per day (NAI, 1984a). Similar to striped bass, white perch mortality had reached the phase of low and consistent mortality by the time juvenile sampling began in 1983.

5.3 AMERICAN SHAD

5.3.1 Growth

Growth of larval and early juvenile American shad was estimated by the same method as for striped bass and white perch. Recruitment to the plankton appeared to be complete by the week of 6 June when mean length was 11.5 mm, based on substantial reductions in the abundance of eggs and (particularly) yolk-sac larvae (Appendix B, Tables B-27 and B-28) as well as a reduction in the proportion of these stages in the total standing crop (Table 5.3-1) in subsequent weeks. Growth was assumed to be exponential from then until a length of 45 mm, the inflection point estimated by inspection of the mean length plot, was reached (Figure 5.3-1). The date the mean length reached 45 mm was estimated as 19 July from a logarithmic growth curve fitted to Fall Shoals and Beach Seine data (curve A, Figure 5.3-1). Because the exponential phase of growth ended in July, the logarithmic equation estimating subsequent growth (Appendix A, Equation 15) could not use t = days after 1 August. Instead, t = days after 1 June was used. Besides

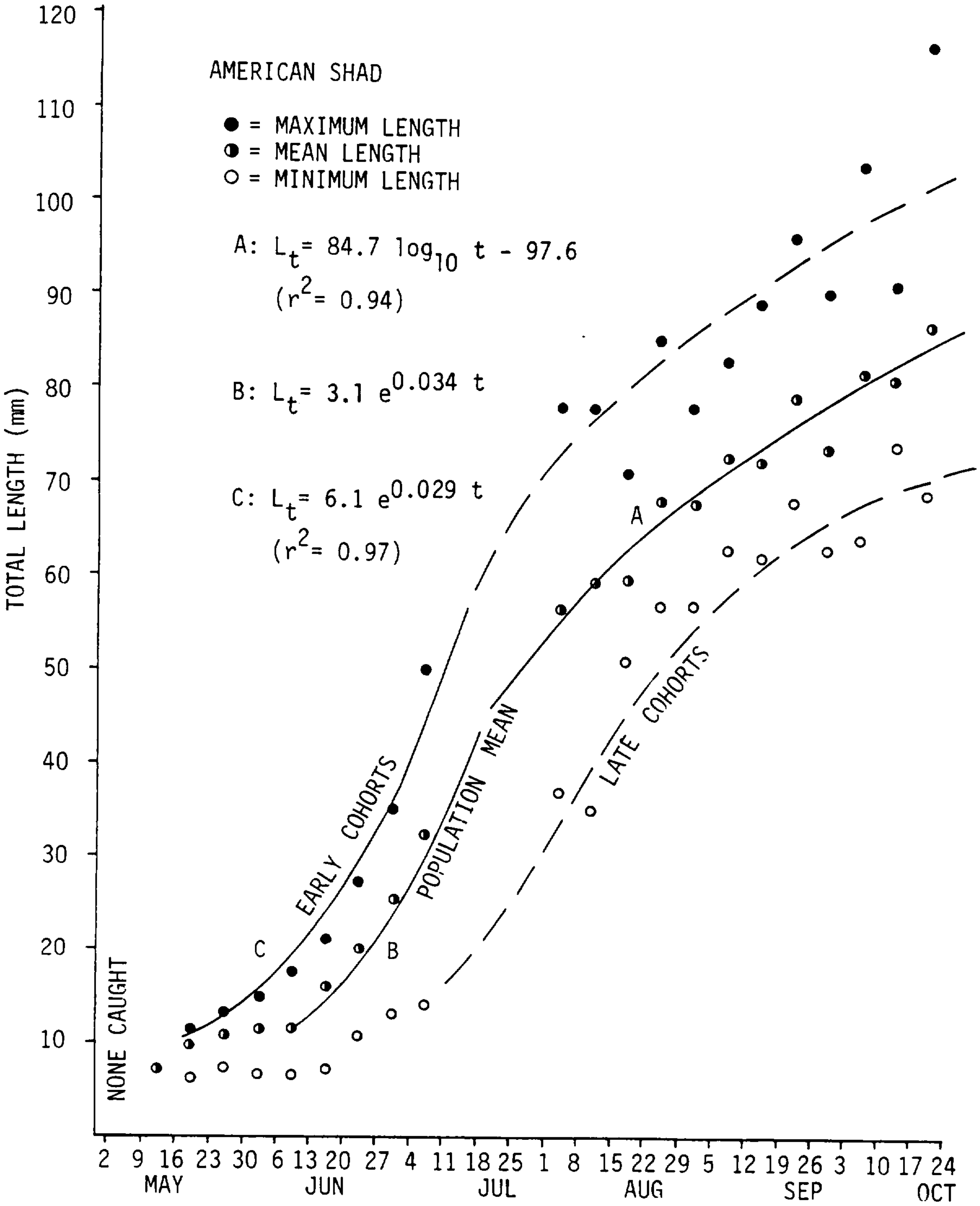


Figure 5.3-1. Growth of American shad larvae and early juveniles (mm TL) estimated from ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983. Solid lines are exponential and logarithmic curves fit by linear regression; dashed lines were drawn by eye.

TABLE 5.3-1. EGGS AND RECENTLY HATCHED LARVAE (<10 mm TL) AS A PERCENTAGE OF AMERICAN SHAD ICHTHYOPLANKTON STANDING CROP, HUDSON RIVER ESTUARY, 1983.

2-8 May	100%	6-12 Jun	20%
9-15 May	100%	13-19 Jun	4%
16-22 May	>99%	20-26 Jun	0%
23-29 May	79%	27 Jun-3 Jul	0%
30 May-5 Jun	27%	4-10 Jul	0%

allowing estimation of lengths prior to August, this also produced a better fit to the data ($r^2 = 0.94$ vs. $r^2 = 0.82$).

Exponential growth, estimated at 3.4% per day from 11.5 to 45 mm, closely followed the observed mean lengths during the four remaining weeks of ichthyoplankton sampling (curve B, Figure 5.3-1). This growth estimate (1) agreed well with the rate of increase in maximum lengths, which was 3.0% per day (curve C, Figure 5.3-1), and (2) was somewhat higher than the growth estimate of 2.2% per day for 1982 (NAI, 1984a). In 1983, the mean length of American shad larvae reached 11.5 mm about three weeks later than in 1982 (NAI, 1984a). However, because of the higher growth rate in 1983, by early July the mean lengths were roughly comparable to those in 1982. In contrast to American shad, observed mean lengths of white perch and, to a lesser extent, striped bass lagged behind the estimated exponential growth in the last weeks of ichthyoplankton sampling. This suggests that either gear avoidance by shad may not be as strong as for striped bass and white perch, or growth of shad larvae is not interrupted by a phase of reduced growth.

During early August to mid-October, American shad juveniles grew about 0.4 mm per day in the shore zone and the offshore strata (Figure 5.3-2). As in 1982, the average length was consistently greater in Fall Shoals collections than in the Beach Seine Survey, suggesting differences in either depth preference or gear efficiency related to size. Lengths in 1983 were consistently lower than lengths during the corresponding weeks in 1982 (NAI, 1984a).

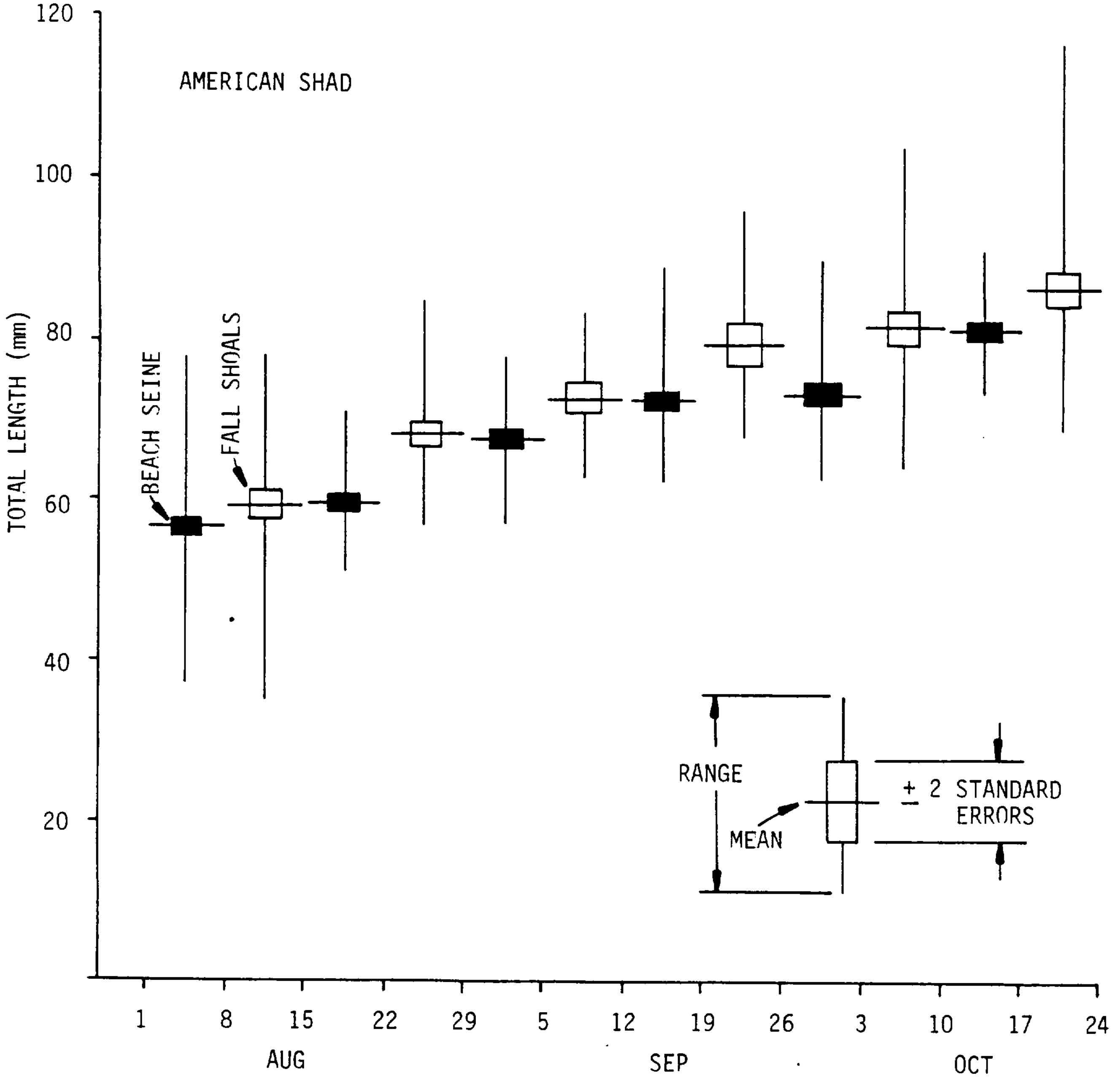


Figure 5.3-2. Growth of American shad juveniles (mm TL) estimated from Fall Shoals and Beach Seine Surveys, Hudson River estuary, 1983.

American shad larvae in the Connecticut River, aged by otoliths, showed a decrease in growth rate as they approached 25 mm, the length at metamorphosis to the juvenile stage, followed by an increase in growth rate after metamorphosis (Crecco *et al.*, 1983). This was not evident in the present study, which related mean length to capture date rather than to age. In the Hudson River, growth from 25 to 80 mm took about 63 days in 1983 (2 July-3 September), compared to 69 days in 1982 (26 June-3 September; NAI, 1984a) and 45 to 50 days in the Connecticut River (1979-1982 data; Crecco *et al.*, 1983).

5.3.2 Mortality

Larval and early juvenile mortality cannot be estimated for American shad by the length-frequency method because sampling ended before larval and early juvenile growth was complete. Standing crop estimates were used for estimating mortality. From the week of 6 June, when recruitment was essentially complete (Table 5.3-1), through the last week of ichthyoplankton sampling, the population declined at a rate of 7% per day (Figure 5.3-3), similar to the 6% per day estimated for 1982 (NAI, 1984a). These estimates can only be considered approximate, because in both years (1) the time of recruitment was not sharply defined by the standing crop data, (2) the standing crop estimates did not produce a consistent pattern of decline during that period, and (3) some of the values were associated with relatively high standard errors.

Summer and early fall mortality was estimated from weekly combined standing crop data. Gear efficiency values were not incorporated in these data because they are not available, but the distribution of American shad between the shore zone and the offshore strata was fairly consistent. Thus, even though abundance may be underestimated because no gear efficiency correction was used, the pattern of weekly CSC should be valid. Recruitment to the juvenile surveys appeared to be complete by the week of 22 August when the standing crop was highest (Figure 5.3-3). Estimated mortality from the peak week through the last sampling week was 4% per day. Virtually all of the decrease in standing

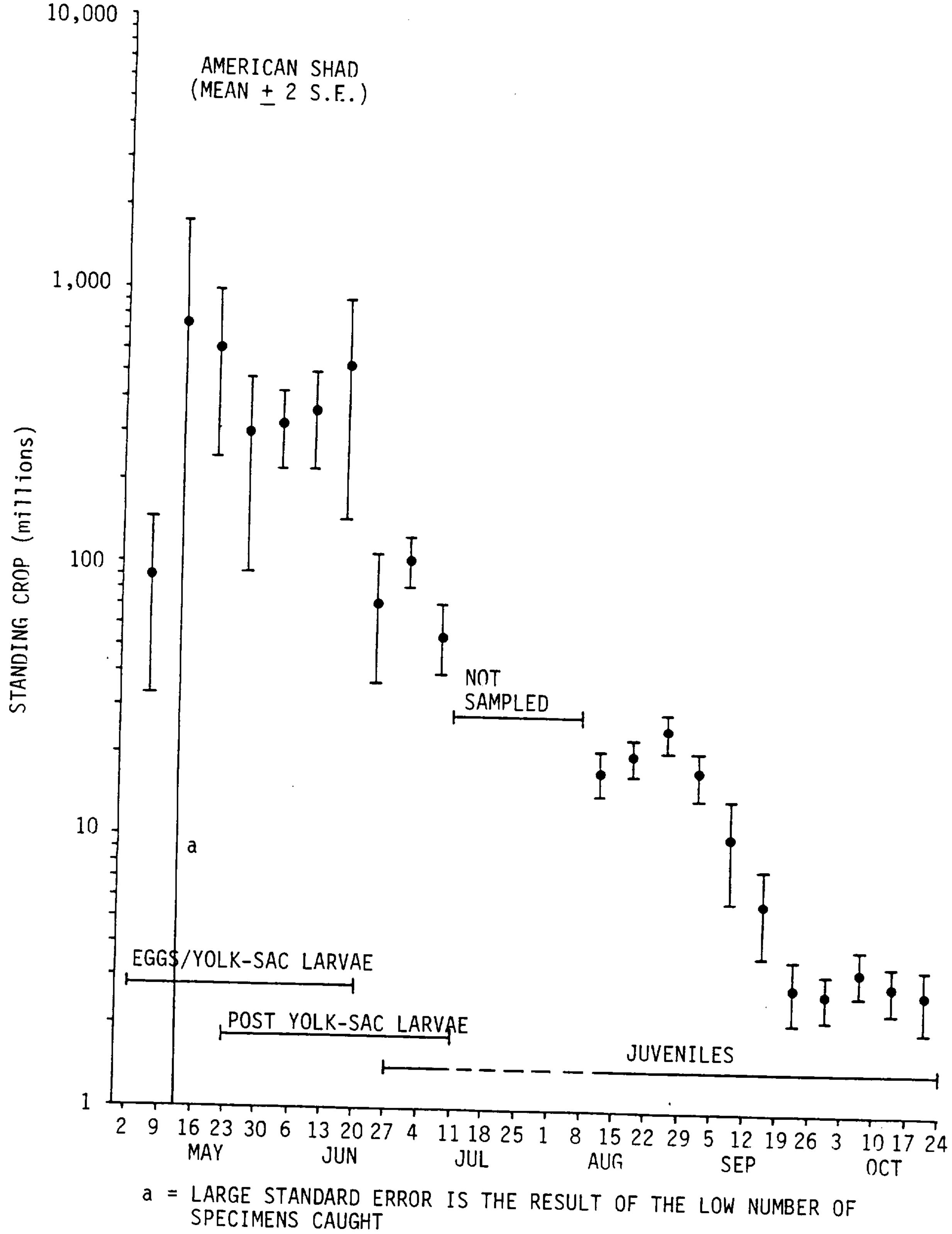


Figure 5.3-3. Standing crop of American shad early life stages based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983.

crop occurred during the first half of this period. The estimated population of American shad went from 25 million in the week of 22 August to three million in the week of 19 September, a decrease of 8% per day. Then there was no further decrease for the remaining four weeks of the sampling season. The pattern in 1982 was very different: the standing crop was relatively stable between 4 and 5 million from mid-August through the end of September, dropping a little in October to around 3 million (NAI, 1984a).

Part of the decrease observed in 1983 may be due not only to mortality, but also to emigration from the estuary. The distribution of shad within the river did not show a downstream shift in their concentration (Section 4.3), so movement seems to account for only a small part of the decrease. Mortality of American shad in the Connecticut River decreased from 20-26% per day at 10-13 mm to 4.3-6.5% per day at 21-23 mm, and juvenile mortality was 1.8-2.0% per day at 40-80 mm, based on the length-frequency method (Crecco *et al.*, 1983).

5.4 ATLANTIC TOMCOD

5.4.1 Growth

Because the Atlantic tomcod is a winter spawner, growth of larvae and early juveniles occurred prior to ichthyoplankton sampling. During the late summer-early fall, mean length of young-of-the-year tomcod in the offshore strata (representing the vast majority of the standing crop; Appendix B, Table B-43) increased from 72 to 95 mm (Figure 5.4-1). Each mean length was 8-15 mm smaller than in the corresponding week of 1982 (NAI, 1984a). In the Fall Shoals collections, mean length increased 0.3 mm per day. Mean lengths in the shore zone, though variable, tended to be higher than in the offshore strata. This pattern is the reverse of that seen for striped bass, white perch, and American shad, which were usually larger in the offshore strata. Tomcod were mostly located in the bottom stratum. Larger individuals may move over greater distances, more often venturing into the shore

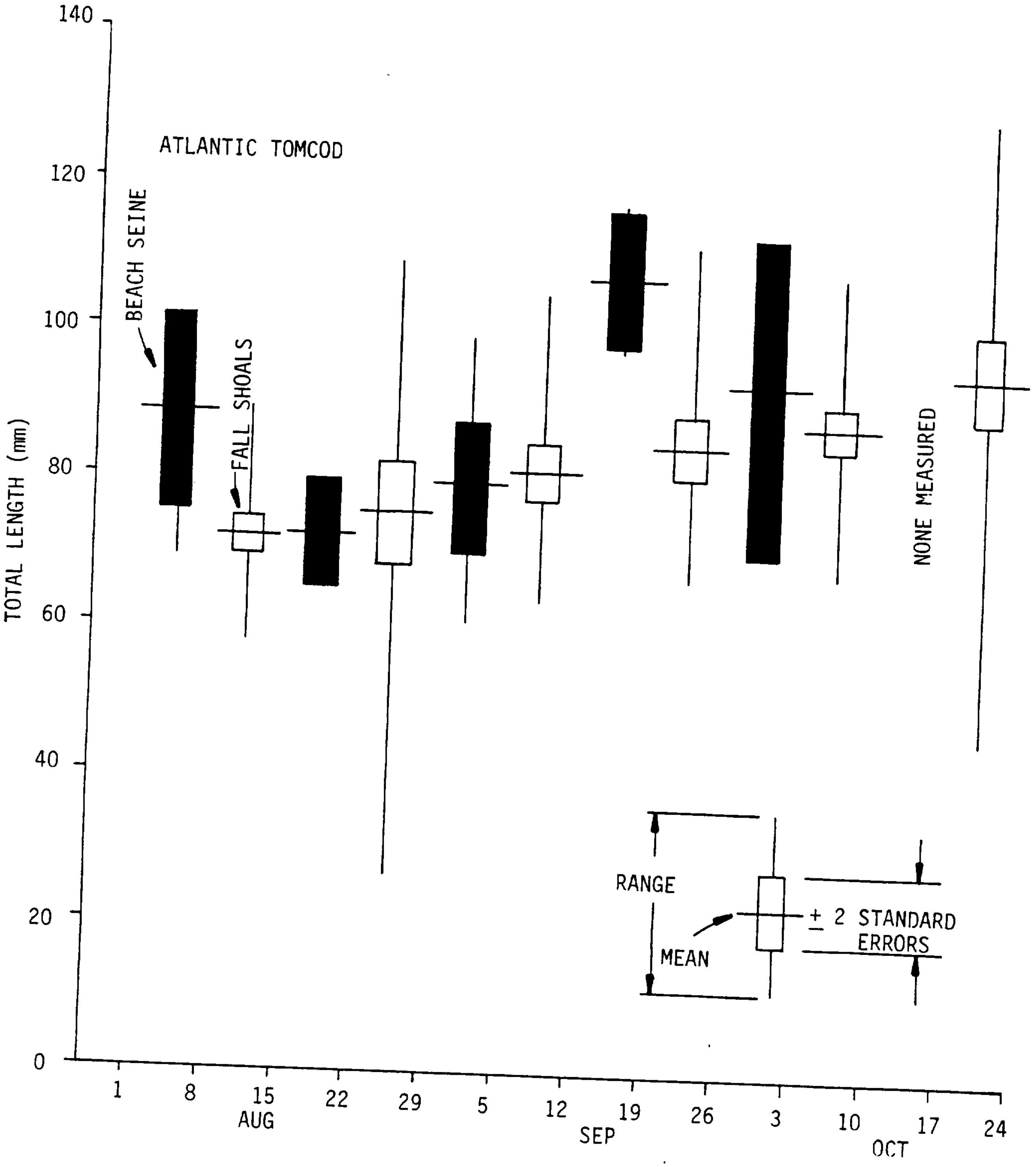


Figure 5.4-1. Growth of Atlantic tomcod juveniles (mm TL) estimated from Fall Shoals and Beach Seine Surveys, Hudson River estuary, 1983.

zone than smaller fish, or larger tomcod may have an advantage over smaller ones enabling them to more successfully utilize those areas.

5.4.2 Mortality

Ichthyoplankton sampling in 1983 began after most Atlantic tomcod had entered the juvenile stage, so larval and early juvenile mortality cannot be estimated. Combined standing crop estimates, unadjusted for gear efficiencies (because they are not available), were utilized to examine the rate of decline of the population. The standing crop estimate dropped from 3 million in early August to 0.8 million in late September, a decrease of 3.0% per day, and then rose slowly to 1.3 million in late October (Figure 5.4-2). However, these changes in the standing crop estimate do not appear to be significant, judging by the error bars overlapping among all dates. The apparent increase in October may indicate a gradual movement into the sampling area from more saline waters downriver as lower temperatures signal the approach of the spawning season. In 1982 standing crop estimates were higher than those of 1983, but the mortality rate (2.4% per day) was fairly similar (NAI, 1984a).

5.5 BAY ANCHOVY

5.5.1 Growth

The 1983 ichthyoplankton season ended before the bay anchovy spawning season did, and length data were not collected. Bay anchovy spawning extends over a relatively long period of time, lasting from late May to late August in the Hudson River (Dovel, 1981). Growth is rapid, with some individuals of early cohorts reaching sexual maturity the same summer in which they hatched (Hildebrand and Cable, 1930; Hildebrand, 1963). Because of this protracted spawning and rapid growth, there is a large variation in age and size among individuals at any particular time. This would complicate efforts to estimate growth

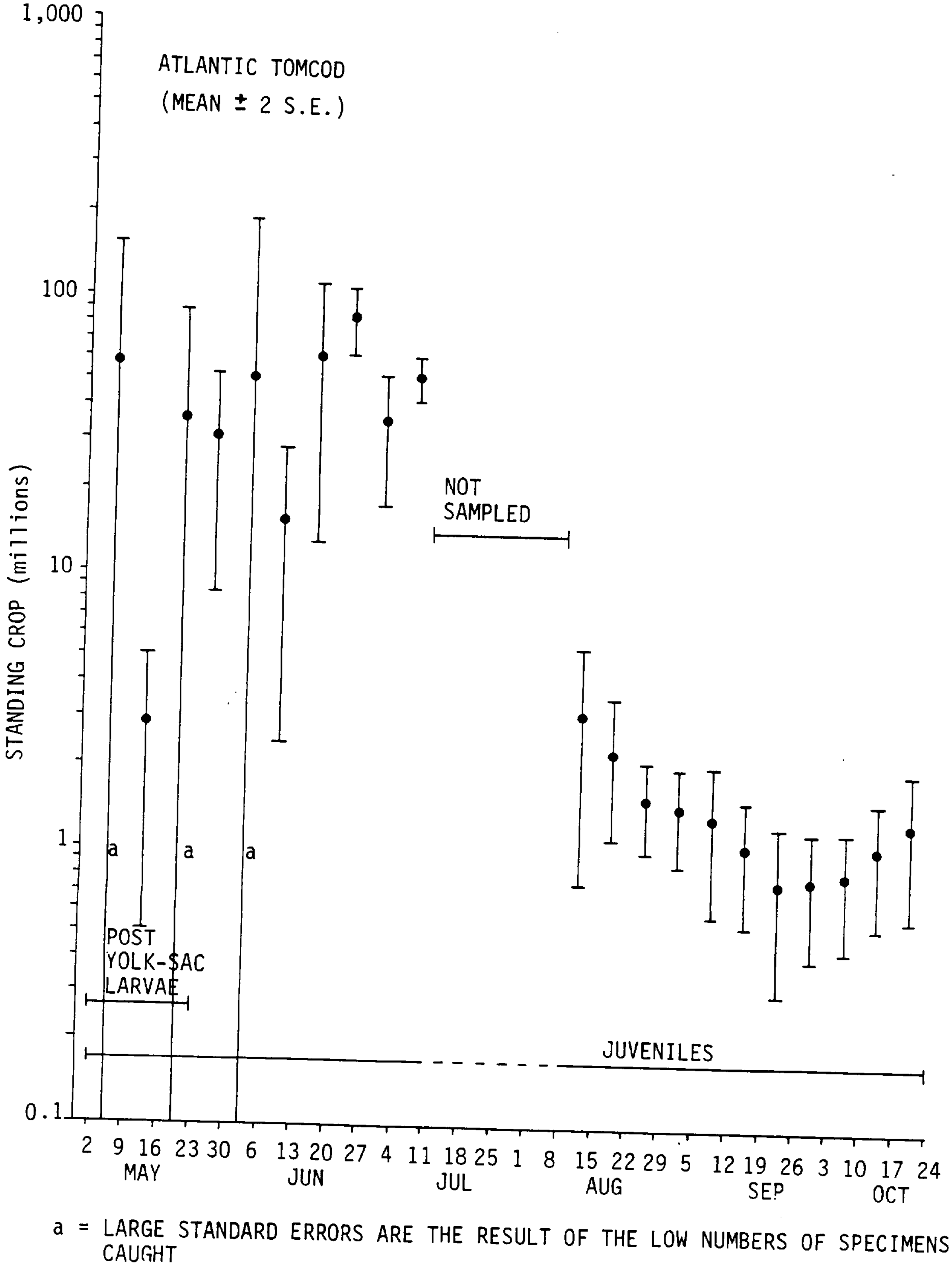


Figure 5.4-2. Standing crop of Atlantic tomcod early life stages, based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983.

rates for the phase of rapid growth during the larval and early juvenile stages even if length data were available.

Length data from the Fall Shoals and Beach Seine sampling show relatively little growth from early August to late October in terms of the population mean (Figure 5.5-1). This suggests that substantial recruitment was still occurring during August, also indicated by the weekly combined standing crops, which peaked in the second week of September (Figure 5.5-2). Based on Fall Shoals samples, representing the majority of the standing crop, growth from early August to late October averaged 0.2 mm per day. These results were similar to those reported for 1982 (NAI, 1984a).

In the shore zone, growth was not consistent from week to week. Mean length in the shore zone was usually higher than in the deeper strata. This may indicate that bay anchovy tend to congregate in the shore zone only after they have reached a certain size.

5.5.2 Mortality

Because of the heterogeneity in age structure of the bay anchovy population, estimation of larval and early juvenile mortality would be difficult. After recruitment was complete in early September, the standing crop began to decline steadily, allowing an estimate of mortality to be calculated for the older fish (Figure 5.5-2). Although there would still be a substantial range of ages represented, those age differences would become proportionately less as the fish became older. Also, most if not all of the fish would have reached a point where mortality could be expected to be stabilized at a moderate level compared to the high mortality characteristic of the early stages of many fishes. The bay anchovy population in 1983 declined from early September to late October at a rate of 3% per day. In 1982 a similar mortality rate was observed, but the standing crop estimates were higher than in 1983 (NAI, 1984a).

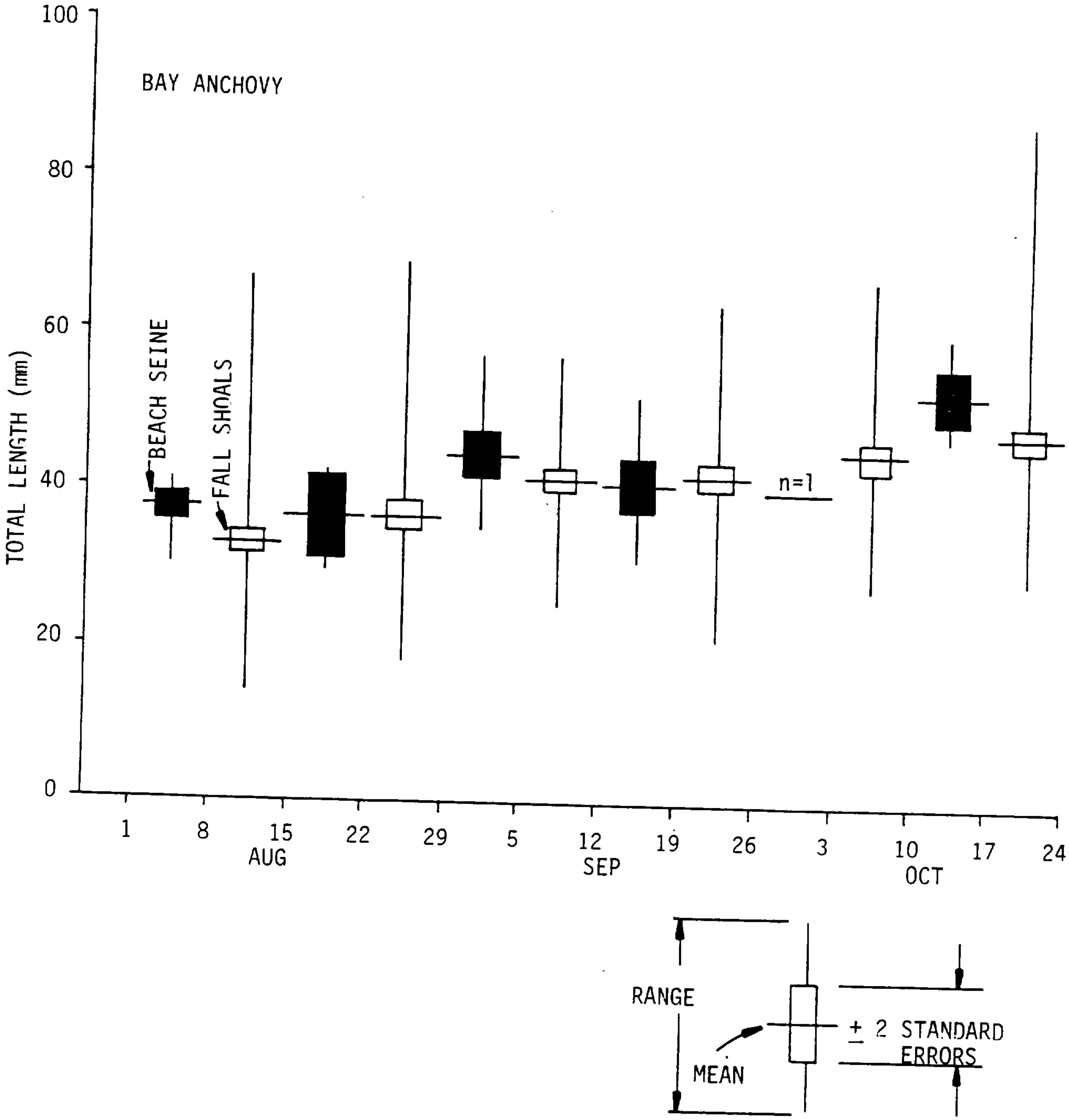


Figure 5.5-1. Growth of bay anchovy juveniles (mm TL) estimated from Fall Shoals and Beach Seine Surveys, Hudson River estuary, 1983.

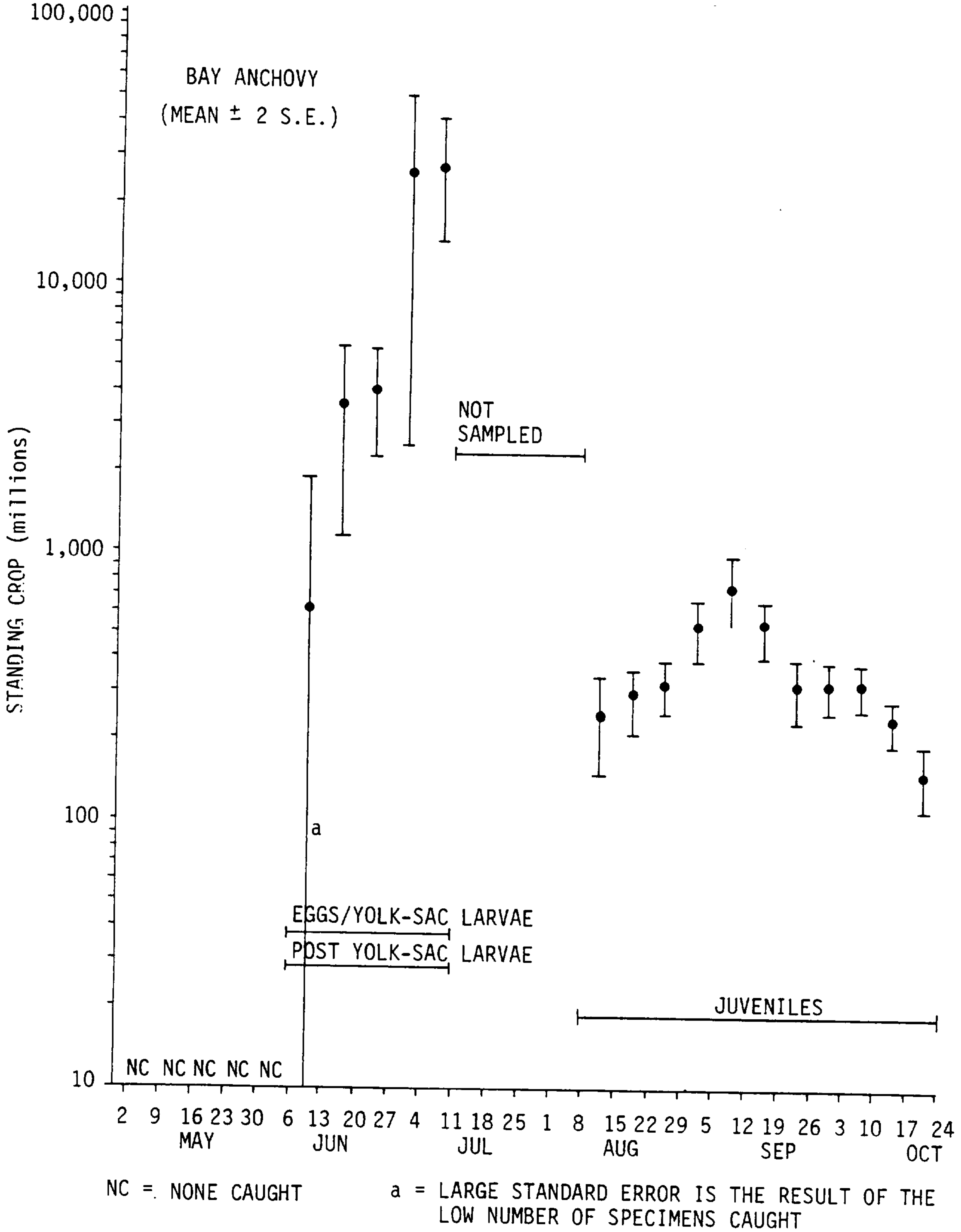


Figure 5.5-2. Standing crop of bay anchovy early life stages based on ichthyoplankton and fall juvenile surveys, Hudson River estuary, 1983.

6.0 ANNUAL ABUNDANCE ESTIMATES

Year class strength, or the number of fish produced in a single year's spawning season relative to those spawned in other years, can vary widely from year to year for a given species (Hjort, 1926). For example, abundance of striped bass in Maryland waters increased six-fold when the dominant year class of 1934 entered the fishery (Koo, 1970). Year class strength is believed to be established during the early life stages (Marr, 1956; Gulland, 1965; May, 1974; Crecco and Savoy, 1984). Since a dominant year class can make up a substantial proportion of the spawning stock over a period of several years, e.g., the 1973 striped bass year class (TI, 1981), detection of year class strength at an early age is an important contribution to the study of population dynamics and can be a useful management tool.

Year class strength has been evaluated in previous year class reports by the combined standing crop (CSC) estimate. The CSC estimate is an estimate of the population size of young-of-the-year fish present in the Hudson River estuary on a standard date, based on combining estimates derived from both the Fall Shoals and Beach Seine Surveys. Ichthyoplankton data were also included in calculating the CSC for 1979 and earlier years, but in 1980-1983 ichthyoplankton sampling ended in early July, before recruitment to the juvenile stage was complete, and thus before the period used in calculating the 1 August CSC estimate. The effect of this change on the comparability of CSC before and after 1979 is negligible, because the contribution of the ichthyoplankton to the total standing crop of young-of-the-year was very small in August, based on the data from 1979 and earlier. A summer CSC estimate, estimating the population on 1 August, has been presented in year class reports since 1979 (TI, 1981; Battelle, 1983; NAI, 1984a). This date was chosen because it was estimated that (1) virtually all striped bass have been recruited to the juvenile stage by that time, and (2) no substantial dispersal of juveniles from the estuary has occurred by that date (TI, 1981). The method of calculating the 1 August estimate from the weekly CSC data was modified in the 1982 Year Class Report in an attempt to reduce the subjectivity involved (NAI, 1984a). This alternate procedure, which uses regression of several weeks of CSC values instead of extrapolation from only the peak week(s), was found to produce results consistent with the previously used method. The regression procedure was followed for deriving the 1 August estimates for 1983 presented in this section but modifications were necessary for the striped bass summer estimate. The summer CSC estimate is discussed for striped bass and for white perch for comparison with summer values reported for earlier years.

A fall CSC estimate corresponding to 15 September was introduced in the 1982 Year Class Report (NAI, 1984a). The fall CSC estimate was found to be more precise than the summer estimate because the late summer-early fall population levels were more stable than those earlier in the summer. The extent to which early emigration from the sampling area might affect the fall estimate is unknown. This was attributed to lower and less variable mortality rates in the fall (NAI, 1984a). A 15 September estimate for striped bass and white perch is presented and discussed in this section.

6.1 STRIPED BASS

The procedure proposed in the 1982 Year Class Report to provide a 1 August estimate was to calculate a regression from weekly CSC estimates during the 10-week period beginning with the week containing 1 August (NAI, 1984a). This approach assumed that emigration from the estuary would not cause a substantial decrease in CSC during that period. However, the 1 August estimate for striped bass in 1982 could not be calculated because the regression procedure assumes mortality is occurring at that time, and the 1982 data didn't show significant mortality. Difficulties were also encountered in forming an estimate for 1983 for several reasons: (1) there was an atypically erratic pattern among weeks, rather than the expected consistent decline after the completion of recruitment; (2) several weekly estimates had unusually wide confidence intervals; (3) extrapolating data from mid-August through early October back through a period (early August) when mortality was undoubtedly higher would underestimate the 1 August population (this last consideration is not limited to 1983 data).

In 1983, the nine-week period from 8 August through 9 October was used to calculate a regression from weekly CSC estimates. The CSC during the subsequent two weeks (weeks of 10 and 17 October) was lower than in previous weeks (Figure 6.1-1), possibly due to emigration, and those two weeks were therefore excluded from the calculation of the 1 August estimate, which was consistent with the approach used for 1982. There was no CSC estimate for the week of 1-7 August because Fall Shoals sampling did not begin until the following week, thus there was no estimate of standing crop in the offshore strata during 1-7 August.

Regression of weekly CSC estimates of the nine-week period was non-significant (there was not a significant change in CSC over that time interval). In cases of non-significant regressions, the geometric mean has been used instead of a regression estimate (NAI, 1984a). This would result in an estimate for 1 August of 16.8 million. It has previously been assumed in calculations of the 1 August estimate that there is significant mortality during the early part of August. It is reasonable to expect that that was true in 1983, and the actual standing crop on 1 August was higher than estimated by this method.

The CSC estimates for the weeks of 12 and 19 September did not fit well into the pattern established by the other weeks. They were substantially higher than in the previous five weeks, which would not be expected if recruitment of the population to the juvenile sampling gear were complete by mid-August (assuming no immigration). The 95% confidence intervals for those two weeks, calculated using $t_{.05} = 4.303$ (NAI, 1984a), were much wider than in the other weeks and indicate that the apparent increase was not statistically significant. Those two weeks were therefore eliminated from the data set to see whether they were responsible for the non-significance of the regression. However, the

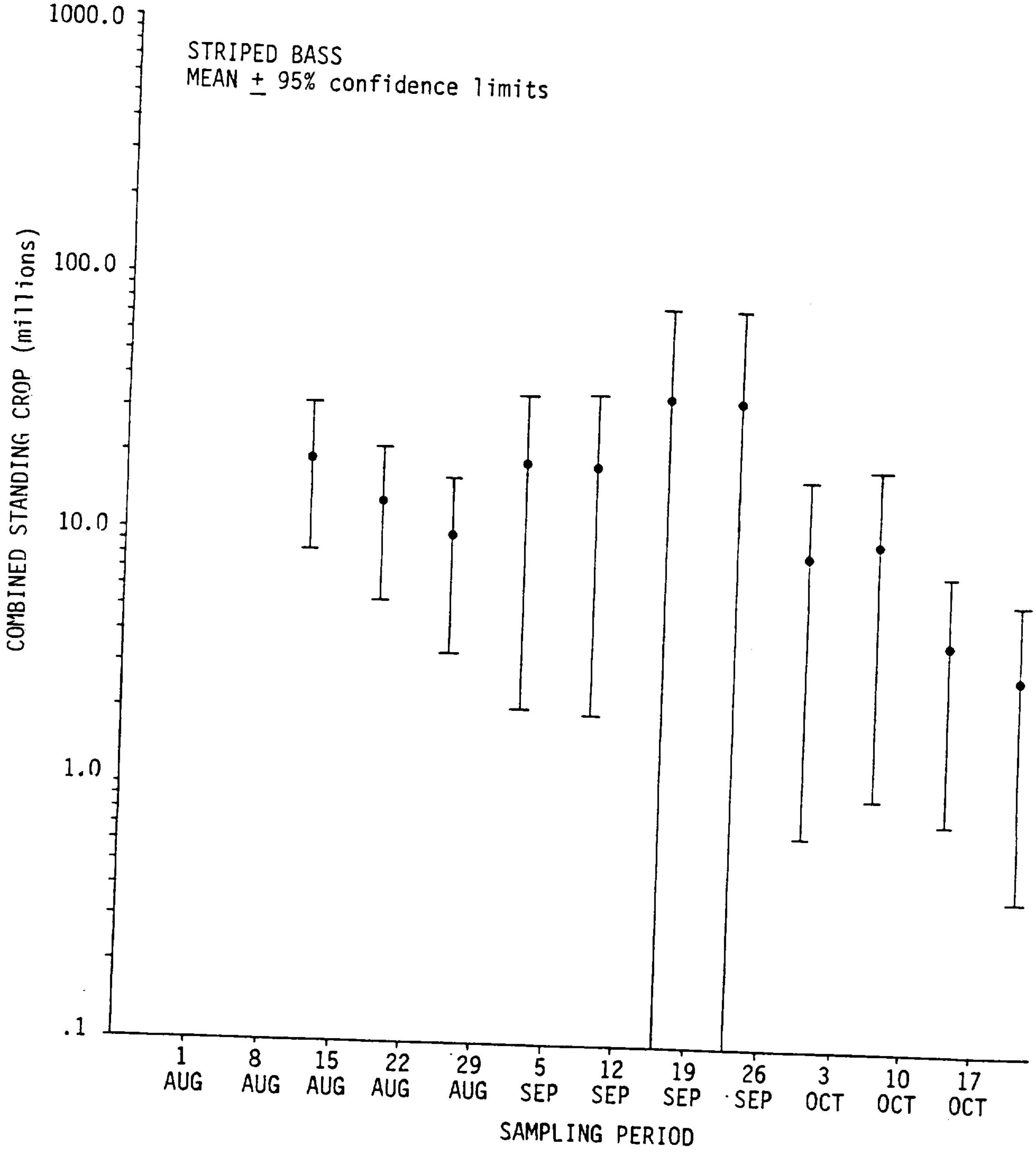
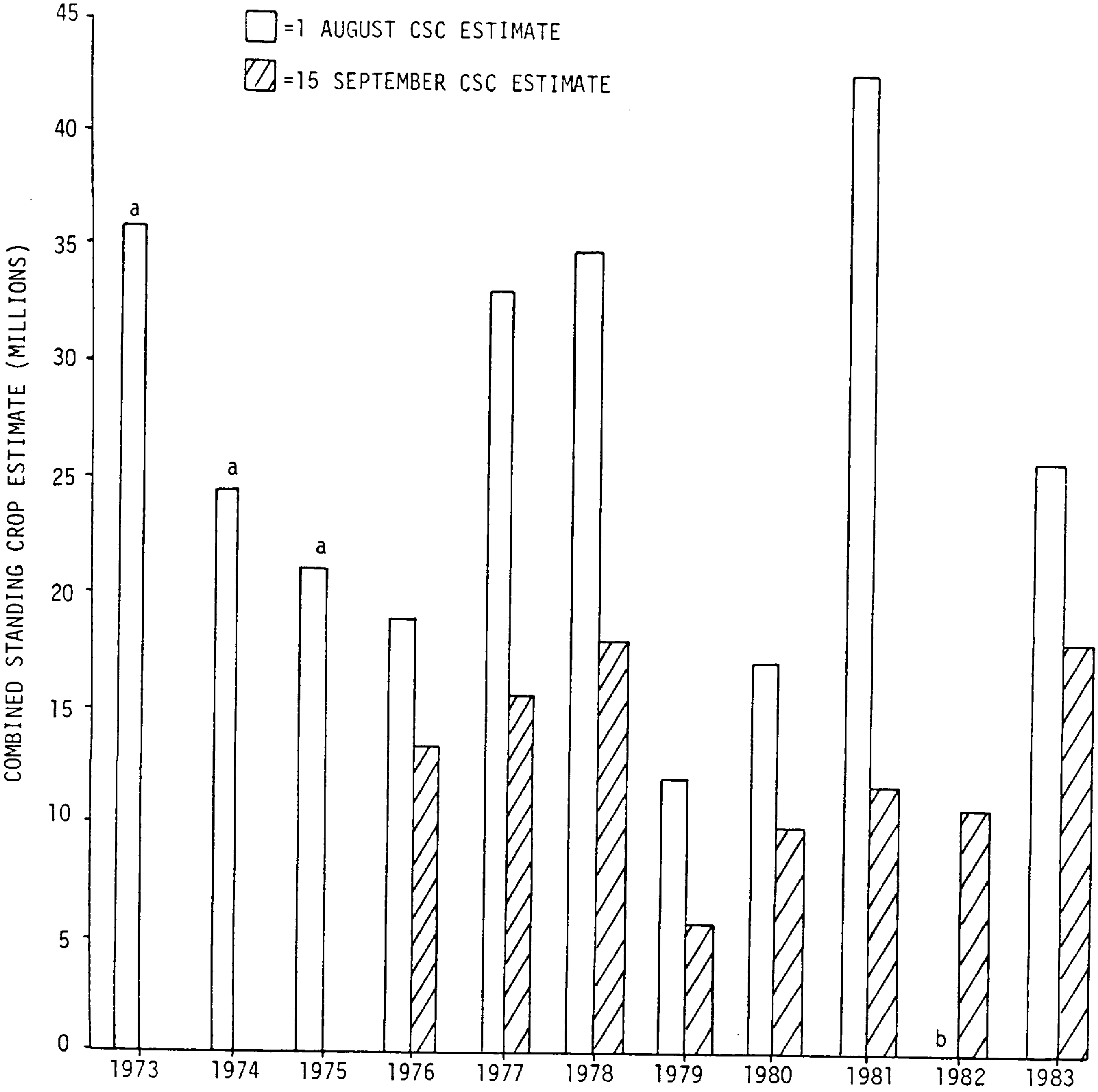


Figure 6.1-1. Weekly combined standing crop estimates (± 95% confidence limits) of striped bass young-of-the-year, Hudson River estuary, 1983.

results were still non-significant without those two points, (the geometric mean without them was 13.7 million for the 8 August - 9 October period).

Because of the non-significance of the regression, and the liklihood that extrapolation of the 1983 striped bass data back to 1 August would underestimate the actual population, another approach was investigated. Mortality between early July and mid-August was estimated to be roughly 2.9% per day in 1982 (NAI, 1984a) and 2.4% per day in 1983 (Section 5.1.2.2). Assuming the mortality in early August to be on the order of 2% per day (it should be decreasing during the July-August period), and estimating the standing crop to be 20.4 million on 11 August (midpoint of sampling week; Appendix B, Table B-7), then a reasonable estimate for the 1 August standing crop would be 25.0 million (Equations 20 and 21, Appendix A). Since the 95% confidence limits for the 11 August CSC estimate were 8.4 million and 32.3 million, confidence limits for the 1 August estimate derived from it would be somewhat wider, due to the additional uncertainty introduced by the mortality estimate. Based on this 1 August estimate of 25 million young-of-the-year striped bass, the 1983 year class strength was moderate in comparison to previous years (Figure 6.1-2).

A fall (15 September) estimate of year class strength was calculated by regressing the five-week period beginning with the week containing 1 September as was done for previous years (NAI, 1984a). A non-significant regression model was obtained. Therefore, a simple geometric mean of these five weeks was calculated, resulting in a fall CSC estimate of 20.8 million fish with 95% confidence limits (NAI, 1984a) of 10.4 million to 41.5 million (Table 6.1-1). Due to the unusually wide 95% confidence limits associated with the weeks of 12 September and 19 September, the fall CSC estimate was also calculated without those two weeks. The resultant estimate was 14.8 million fish (Table 6.1-1). Therefore, the best estimate of a fall CSC estimate for striped bass would probably be between 14 and 21 million fish ($\bar{x} = 17.5 \times 10^6$). Based on this value for the CSC estimate, the 1983 striped



a = 1973-1975 CALCULATED BY PEAK METHOD (TI, 1981), 15 SEPTEMBER ESTIMATE NOT AVAILABLE.

b = 1 AUGUST ESTIMATE FOR 1982 NOT CALCULABLE (NAI, 1984a)

Figure 6.1-2. Combined standing crop (CSC) estimate of juvenile striped bass, summer (1 August) and fall (15 September) 1973-1983, Hudson River estuary.

TABLE 6.1-1. FALL COMBINED STANDING CROP ESTIMATE AND 95% CONFIDENCE LIMITS (MILLIONS) FOR STRIPED BASS YOUNG-OF-THE-YEAR, HUDSON RIVER ESTUARY, 1983.

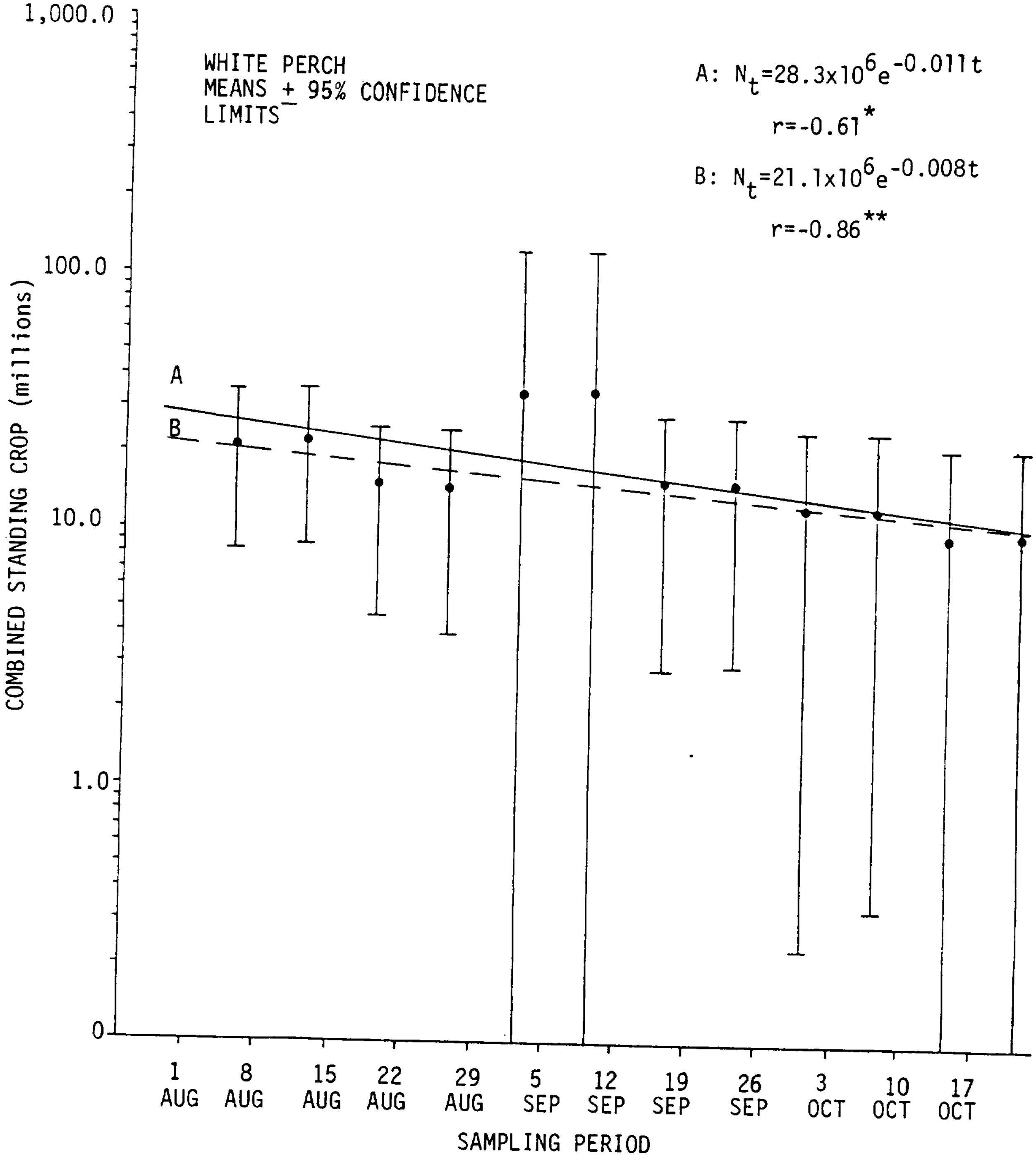
WEEKS[a]	df	LOWER CONFIDENCE LIMIT	CSC ESTIMATE	UPPER CONFIDENCE LIMIT
29 Aug-26 Sep	4	10.4	20.8	41.5
29 Aug-26 Sep minus 5-12 Sep	2	5.2	14.8	42.2

[a] In both cases a non-significant regression model was obtained; therefore, a geometric mean was calculated.

bass year class is at least as strong as the previous year classes of 1977 and 1978, and may possibly be the strongest year class reported since 1976 (Figure 6.1-2).

6.2 WHITE PERCH

A summer combined standing crop (CSC) estimate was calculated to evaluate juvenile white perch year class strength as of 1 August, in order to give a relative assessment of the number of fish available for recruitment to the adult stock compared to previous years. The 1983 data suggest that recruitment was virtually complete by mid-August (Figure 5.2-1). Substantial emigration from the estuary did not appear to have begun until after the completion of the fall juvenile sampling programs (Section 4.2.4). Although Beach Seine sampling began in the week of 1 August, there are no data from the offshore strata to calculate a CSC for that week, as Fall Shoals sampling began the following week. Therefore, the eleven-week period from 8 August to 23 October was used to calculate the summer CSC estimate (Figure 6.2-1). From these weekly data, white perch year class strength was estimated to be 28.3 million fish (Table 6.2-1).



A) Represents the weeks between 8 August - 17 October

B) Represents the weeks between 8 August - 17 October minus the weeks of 29 August and 5 September

$* = P \leq 0.05$

$** = P \leq 0.01$

Figure 6.2-1. Weekly combined standing crop estimates (± 95% confidence limits) and the predicted summer CSC estimate (1 August) of white perch young-of-the-year, Hudson River estuary, 1983.

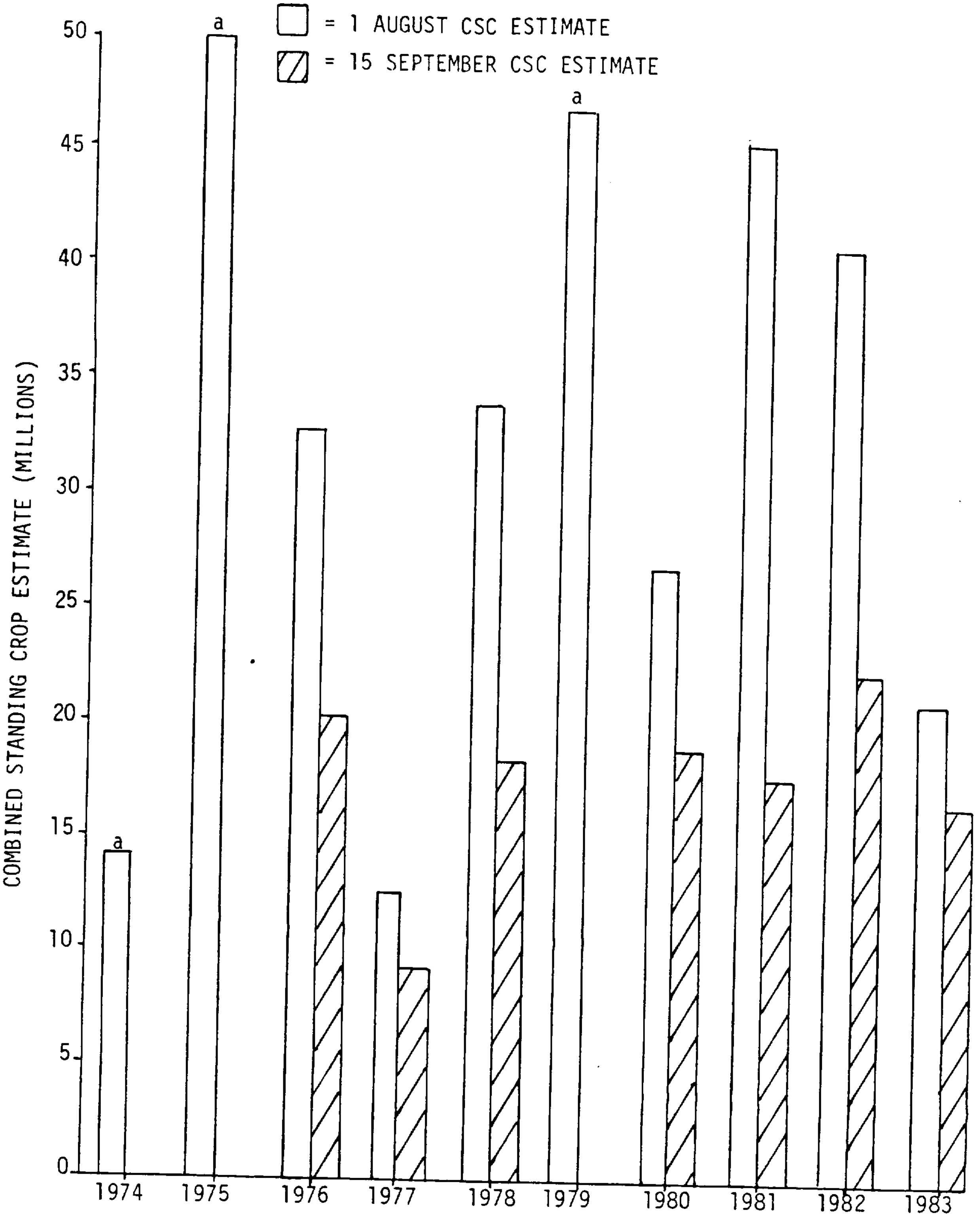
TABLE 6.2-1. COMBINED STANDING CROP ESTIMATES AND 95% CONFIDENCE LIMITS (MILLIONS) FOR WHITE PERCH YOUNG-OF-THE-YEAR, HUDSON RIVER ESTUARY, 1983.

ESTIMATE	df	LOWER CONFIDENCE LIMIT	CSC ESTIMATE	UPPER CONFIDENCE LIMIT
Summer[a]	9	16.2	28.3	49.7
Summer[b]	7	16.7	21.2	26.9
Fall	4	14.4	16.8	19.7

[a] regression using weeks 8 August-17 October

[b] regression using weeks 8 August-17 October minus the weeks of 29 August and 5 September.

During the weeks of 29 August and 5 September, an increase in combined standing crop was observed. This increase was possibly due to (1) immigration into the sampling area, (2) movements among strata affecting the estimate because of inaccuracies in gear efficiency factors or seasonal changes in gear efficiency, or (3) some other factor(s). By incorporating these points, the subsequent estimate could possibly be overestimated. Due to the large confidence intervals associated with these weeks the estimate was also calculated omitting these two weeks. The comparison of the two best-fit lines through the weekly combined standing crop estimates is shown in Figure 6.2-1. Regardless of which weeks were used, a significant regression model was achieved and the estimate of white perch year class strength appears to be between 21.2 and 28.3 million fish (Table 6.2-1). In comparison with previous year class reports, this estimate places the 1983 year class well below the observed average (NAI, 1984a), with only the 1974 and 1977 year classes being lower (Figure 6.2-2).



a = 1974-1975 and 1979 CALCULATED BY PEAK METHOD (TI, 1981), 15 SEPTEMBER ESTIMATE NOT AVAILABLE.

Figure 6.2-2. Combined standing crop (CSC) estimate of juvenile white perch, summer (1 August) and fall (15 September) 1974-1983, Hudson River estuary.

A fall CSC estimate (15 September) was estimated from the period when the juvenile population appears to be stable with respect to mortality and movements. For 1983 this time incorporated the weeks beginning 12 September and continuing through 23 October (Figure 6.2-1). The fall estimate, calculated by the regression method, was 16.8 million fish (Figure 6.2-2; Table 6.2-1). The 1983 fall CSC estimate compares favorably with the summer estimate, again estimating the 1983 white perch year class strength to be below the observed average.

7.0 ENVIRONMENTAL EFFECTS ON GROWTH, MORTALITY, AND ABUNDANCE

Control of year class strength by the action of environmental factors on early life stages of many fish species is a currently favored hypothesis in fisheries biology. This section examines that assumption by testing for relationships between selected environmental variables and the mortality and growth of larval and juvenile striped bass, white perch, and American shad. Rationale supporting the importance of environmental factors and the selection of factors to be tested in this analysis are presented in subsection 7.1. Data reduction procedures, the statistical analyses that were used in this section, and the way in which they were applied, are described in subsection 7.2. Results of the analysis are presented in subsection 7.3.

7.1 RATIONALE

Striped bass, white perch, and American shad, which broadcast their eggs into an unprotected environment, produce surplus numbers of their early life stages. Year class strength is more likely to be a function of extrinsic (e.g., environmental) factors influencing survival of early life stages than the initial abundance of eggs or size of the the adult stock, unless they are extremely scarce. Evidence of this is based largely on the striped bass literature. No relationship could be demonstrated between the abundance of eggs or larvae and the abundance of young-of-the-year striped bass in the Hudson River during 1976-1979 (TI, 1981), or the Chesapeake and Delaware Canal region during 1970-1977, or the Nanticoke River during 1963-1977 (Kernehan *et al.*, 1981). Van Winkle *et al.* (1979) found no simple periodicity (i.e., consistent cycles in abundance) among time series of striped bass commercial catch data. Ulanowicz and Polgar (1980) could not explain striped bass year class success from an analysis of spatial and temporal abundance patterns of ichthyoplankton. All these authors felt that year class strength was determined by density-independent environmental variables, but their analyses of environmental data were inconclusive.

The Hudson River Monitoring Program provides the best available data to test these hypotheses because data have been collected in a fairly consistent format since 1975.

The environmental factors of temperature, conductivity, dissolved oxygen, and freshwater flow were tested for their effects on growth and mortality. Any of these factors may act singly or in combination with others to affect growth, mortality, or abundance. Water temperature is certainly the most important abiotic factor in the Hudson River estuary because it directly controls metabolic rates of aquatic plants, invertebrates and fishes (essentially the entire community). Within the range of tolerance of each species, temperature controls consumption, metabolism and therefore growth rates. Depletion of dissolved oxygen may limit growth or increase mortality rate. The difference between maximum or minimum dissolved oxygen concentration and the saturation level of dissolved oxygen at a particular temperature is an index of nutrient loading. Conductivity is directly related to salinity, and thus serves as a measure of the freshwater-seawater mix occupied by a population. As is the case with temperature, each estuarine species has an optimal salinity at which it grows and survives best, and a range of tolerance. Freshwater flow is the main source of nutrient input to the estuary. Population size at the beginning of a weekly or biweekly sampling period was also included in the analyses to test for density-dependent effects.

7.2 DATA MANIPULATION AND STATISTICAL TECHNIQUES

Data used for this analysis were from the 1975-1983 ichthyoplankton (Longitudinal River Survey) and the 1976-1983 juvenile samples (Fall Shoals and Beach Seine Survey). One observation in this analysis corresponds to the exposure of a population to environmental conditions during the interval between one weekly or biweekly set of samples and the next. Growth or mortality during that one- or two-week interval are the dependent (or response) variables. Estimates of mortality would also include the effects of any emigration from the sampling area, as mortality was calculated from the decreases in population estimates. The independent (or predictive) variables of temperature, dissolved oxygen, and conductivity that are associated with an individual observation are the averages of the values for the two sampling periods that define the interval represented by that observation. The independent variable standing crop is the abundance estimate for the sampling period beginning the interval represented by that observation. Standing crop at the beginning of an observation was considered as an independent variable in this analysis because the magnitude of population response to any environmental variable is often mediated by the abundance, or density, of the population. Because nutrients carried into the estuary require time to cycle through the ecosystem, an essentially infinite number of time periods of freshwater flow might be considered. In this case, only the flow during the weekly, (in the case of post yolk-sac larvae) or biweekly (in the case of young-of-the-year) interval preceeding each observation was considered.

The sampling frequencies of the programs described in this and previous year class reports place certain limitations on analyses. Weekly or biweekly sampling frequencies made the sampling programs relatively insensitive to acute (short-term) phenomena, such as local depletion of dissolved oxygen over a few days, or sudden changes in temperature. These programs would be expected to be much more sensitive to factors operating over larger scales because the entire estuary was included in sampling design, and sampling continued over several weeks. Meaningful analyses could be performed on post yolk-sac larvae and young-of-the-year, but durations of the egg and yolk-sac larvae stages for these species are typically less than the sampling frequency.

Sample size (number of observations) also limited the types of analyses that could be performed. Mortality and growth rates of a given species and life-stage were calculated from the date of the peak in standing crop to the date when sampling ceased (the usual case with juveniles), or standing crop was zero in most river regions (the usual case with post yolk-sac larvae). This resulted in only about five observations in each year for each life stage. Because of these small sample sizes, time series plots of growth and mortality, and bivariate plots of their relationships to pairs of environmental variables, did not show any clear patterns. Within this set of samples, there were no regional average temperatures or dissolved oxygen concentrations within the ranges that would be expected to produce high levels of mortality (Otwell and Merriner, 1975; TI, 1981).

Each analysis of these data is a specific application of the general linear model that was calculated with the SAS GLM procedure (SAS, 1982). Specific applications of the GLM procedure are more commonly known by other names, e.g., multiple regression, analysis of variance, analysis of covariance. Multiple regression is an analysis of the effect that continuous predictive variables (which all may have any value along continuous scales) have on another continuous variable (growth or mortality rate in this case). When the predictive variables are of the class type, their values correspond to distinct categories (e.g. before vs. after), and their analysis is strictly an analysis of variance (ANOVA). Analysis of covariance (ANCOVA) involves a combination of continuous and class variables. An example of this is the analysis of the response of mortality rate to standing crop (a continuous variable) before and after the Fall Shoals Survey was expanded into river regions above Poughkeepsie (a class variable). The test of whether a model is significant is analagous to the F-test for the complete model in ANOVA or ANCOVA. Tests of whether regression coefficients for individual variables or interaction terms are significantly different from zero are equivalent to tests of those terms in ANOVA.

River regions above Poughkeepsie were sampled in the Fall Shoals program only from 1979 onward. To include data from 1976 through 1978 in the analyses, a class variable YEARTYPE was included. Growth, mortality, and all environmental parameters are continuous variables, but analysis of covariance had to be applied to analyses of young-of-the-year because of the class variable resulting from this discontinuity in the sampling program. Therefore, effects of environmental variables were tested only after adjustment for expanding the program, i.e., YEARTYPE was always first in the variable list. Two predictive equations were produced; coefficients for environmental variables were the same, but there were different intercepts for periods before (1976-1978) and after (1979-1983) river regions above Poughkeepsie were included in Fall Shoals samples. This approach assumed that population responses to environmental variables were similar in all years, but a larger population of young-of-the-year was sampled after the upriver stations were added.

The order of presentation is another important consideration when more than one predictive variable is used. When analyzing the effects of several variables in one predictive model, it is usually most useful to test the effects of each variable after adjusting for the other variables that are being considered. This method produces partial, or Type III F-tests that are equivalent to tests of whether regression coefficients of individual variables are significantly different from zero. Sometimes, however the effects of one variable mask the effects of another variable, so that when all variables are considered simultaneously, important variables will produce nonsignificant results in Type III tests. This is usually the result of correlation among predictive variables, e.g. temperature and dissolved oxygen in this analysis. Predictive variables that are correlated with each other will each appear to "account for" variation in a response variable in a similar fashion. Thus, when a new predictive variable is added to a model, it can only "explain" variation in the response variable that is not correlated to predictive variables that were previously considered in the same model. For example, if dissolved oxygen were considered before temperature in an analysis, variation in a response variable could be spuriously "explained" by variation in dissolved oxygen in water that was always at 100% saturation. Even though temperature would be the real causative factor (affecting both the response variable and dissolved oxygen), it would not be a significant factor after adjustment for variation in dissolved oxygen (Type III test). Temperature-related changes in dissolved oxygen concentration would have already been incorporated in the variation in the response variable that was "explained" by dissolved oxygen alone. Any effects of a new predictive variable that are similar to effects of previously considered variables, even if the new variable amplifies those effects, will be attributed to the variables considered previously. Correlated predictive variables may be "unmasked" by applying sequential, or Type I tests that analyze the incremental contribution of each variable as it is added to the model. Type I tests of variables later in the sequence will be adjusted for those tested previously, but not vice versa. Thus, variables that an investigator feels are important but are being masked by the effects of other variables (which are often interrelated in biological systems), may be included early in the sequence. Specific examples are discussed in subsection 7.3.

The models used for this analysis were applied by a three-step process. The first step was pairwise testing to identify which variables and interactions appeared to be significant. Then, significant variables and interactions were combined in an intermediate model for each species and life stage. The third step was to produce a final model that included terms that were significant in both the pairwise and intermediate models. Investigation of synergistic effects of the variables was limited to pairwise combinations because sample sizes were limited. A model that included the predictive variables of temperature, dissolved oxygen, conductivity, freshwater flow, and standing crop, plus all possible two-, three-, four-, and five-way interactions would have 30 terms. Such an analysis would require about 60 or 80 data points to provide the 30 degrees of freedom used by the model plus sufficient error degrees of freedom to detect statistical differences. Even if only two-way interactions were considered, 45 to 65 data points would be required. Sample sizes available from this data set ranged from 24 to 53 observations for a given species and life-stage. This pairwise approach (as opposed to a multifactor analysis) gained error degrees of freedom (statistical power) at the expense of increased Type I error: the overall probability of concluding a significant effect just from chance when none really exists is 5% times the number of models run, given that 5% is the minimum level for accepting significance of any model. The pairwise approach required running ten models per species and life stage instead of one, so the random probability of Type I error was 50%. Therefore, any variables that were significant or played a part in any significant interaction in the preliminary analyses were included in an intermediate model for each species and life stage. Exclusion of factors that were not significant in pairwise tests reduced the number of terms to a quantity that could be tested in one model with the available data. Only those terms that were significant in the intermediate model were included in a final model.

7.3 RESULTS

Discussion of the results of the analyses is divided into generalities which applied to all three species (subsection 7.3.1), and specific results for individual species: striped bass (7.3.2), white perch (7.3.3), and American shad (7.3.4).

7.3.1 General Results

Several generalities are apparent in the results of this study (Table 7.3-1). Temperature is obviously the most important of the environmental variables tested. It was part of all the final models that resulted from these analyses, except for the analysis of factors contributing to mortality of young-of-the-year white perch. The reason why white perch were different is unknown, except for the general resilience of this species. Adjustment was made for seasonal trends in all environmental factors by placing temperature before these other factors in the models because seasonal differences are primarily defined by temperature. Temperature is known to be a controlling factor for the saturation level of dissolved oxygen. Several variables were masked by other terms, i.e. they were significant in Type I tests, but not in Type III tests. Dissolved oxygen and conductivity were masking variables for temperature for striped bass and white perch post yolk-sac larvae (Table 7.3-2), and freshwater flow had a slight masking effect due to seasonal patterns, e.g. with dissolved oxygen for striped bass and white perch post yolk-sac larvae. Standing crop had a masking effect on the influence of temperature on growth of striped bass young-of-the-year

TABLE 7.3-1. STATISTICALLY SIGNIFICANT EFFECTS OF TEMPERATURE (T), DISSOLVED OXYGEN (D), CONDUCTIVITY (C), FRESHWATER FLOW (F), STANDING CROP (N), AND TWO-WAY INTERACTIONS (PAIRS OF VARIABLES) ON SURVIVAL AND GROWTH OF EARLY LIFE STAGES OF STRIPED BASS, WHITE PERCH, AND AMERICAN SHAD IN THE HUDSON RIVER ESTUARY, 1975-1983.

SPECIES AND LIFESTAGE	PREDICTIVE EQUATION	MODEL TEST	R^2
EFFECTS ON INSTANTANEOUS MORTALITY RATE			
Striped bass			
post yolk-sac larvae	$-0.5550 + 0.0319T$	0.0016	0.213
young-of-the-year		0.0001	0.474
1976-1978	$0.0052 - 0.0023T$ $+ 1.0478 \times 10^{-5}N - 3.1403 \times 10^{-7}TN$		
1979-1983	$0.0258 - 0.0023T$ $+ 1.0478 \times 10^{-5}N - 3.1403 \times 10^{-7}TN$		
White perch			
post yolk-sac larvae	$-0.3768 + 0.0195T + 0.0838C$	0.0001	0.395
young-of-the-year		0.0005	0.334
1976-1978	$-0.0257 + 2.2782 \times 10^{-6}N$		
1979-1983	$-0.0367 + 2.2782 \times 10^{-6}N$		
American shad			
young-of-the-year	$-1.7043 + 0.0732T + 0.1860D$ $- 0.0079TD$	0.0003	0.547
EFFECTS ON INSTANTANEOUS GROWTH RATE OF YOUNG-OF-THE-YEAR			
Striped bass		0.0001	0.606
1976-1978	$-0.0064 + 5.6512 \times 10^{-4}T$		
1979-1983	$-0.0042 + 5.6512 \times 10^{-4}T$		
White perch		0.0001	0.991
1976-1978	$e^{-17.1621 + 0.3016T + 0.7448D}$		
1979-1983	$e^{-17.4568 + 0.3016T + 0.7448D}$		

TABLE 7.3-2. PRELIMINARY ANALYSES TO IDENTIFY SIGNIFICANT MAIN EFFECTS AND TWO-WAY INTERACTIONS OF FIVE ENVIRONMENTAL VARIABLES ON INSTANTANEOUS MORTALITY RATES OF POST YOLK-SAC LARVAE AND YOUNG-OF-THE-YEAR STRIPED BASS, WHITE PERCH, AND AMERICAN SHAD IN THE HUDSON RIVER, 1975-1983.

		VARIABLES[b]				TYPE I TESTS[c]			TYPE III TESTS		
SPECIES	LIFESTAGE[a]	A	B	N	TEST OF MODEL	A	B	AB	A	B	AB
Striped	PYSL	TEMP	DO	43	0.01	0.01	NS[d]	NS	NS	NS	NS
bass	YOY			53	NS						
White	PYSL			47	0.01	0.01	NS	NS	NS	NS	NS
perch	YOY			46	NS						
Amer.	PYSL			24	NS						
shad	YOY			30	0.01	NS	NS	0.01	0.01	0.01	0.01
Striped	PYSL	TEMP	COND	44	0.01	0.01	NS	NS	NS	NS	NS
bass	YOY			53	0.03	NS	NS	NS	NS	NS	NS
White	PYSL			47	0.01	0.01	0.02	NS	NS	NS	NS
perch	YOY			46	NS						
Amer.	PYSL			24	NS						
shad	YOY			30	0.01	0.04	NS	0.01	0.01	0.01	0.01
Striped	PYSL	TEMP	FWflow	44	0.01	0.01	NS	NS	0.02	NS	NS
bass	YOY			53	NS						
White	PYSL			47	0.01	0.01	NS	NS	0.01	NS	NS
perch	YOY			46	NS						
Amer.	PYSL			24	NS						
shad	YOY			30	0.01	NS	NS	NS	NS	NS	NS
Striped	PYSL	TEMP	STcrop	44	0.01	0.01	NS	NS	0.01	NS	NS
bass	YOY			53	0.01	NS	0.01	0.01	NS	0.01	0.01
White	PYSL			47	0.01	0.01	NS	NS	0.01	NS	NS
perch	YOY			46	0.01	NS	0.01	NS	NS	0.01	NS
Amer.	PYSL			24	NS						
shad	YOY			30	0.01	NS	NS	NS	0.04	NS	NS

(Continued)

TABLE 7.3-2. (Continued).

		VARIABLES[b]			TEST OF	TYPE I TESTS[c]			TYPE III TESTS		
SPECIES	LIFESTAGE[a]	A	B	N	MODEL	A	B	AB	A	B	AB
Striped bass	PYSL	DO	COND	43	0.03	0.01	NS	NS	NS	NS	NS
	YOY			53	0.05	NS	NS	NS	NS	NS	NS
White perch	PYSL			47	0.01	0.01	0.01	NS	NS	NS	NS
	YOY			46	NS						
Amer. shad	PYSL			24	NS						
	YOY			30	0.01	NS	0.04	0.01	NS	0.01	0.01
Striped bass	PYSL	DO	FWflow	43	0.04	0.01	NS	NS	NS	NS	NS
	YOY			53	NS						
White perch	PYSL			47	0.01	0.01	0.01	NS	NS	NS	NS
	YOY			46	NS						
Amer. shad	PYSL			24	NS						
	YOY			30	0.01	NS	NS	0.03	NS	0.03	0.03
Striped bass	PYSL	DO	STcrop	43	0.04	0.01	NS	NS	0.02	NS	NS
	YOY			53	0.01	NS	0.01	0.03	NS	NS	0.03
White perch	PYSL			47	0.01	0.01	NS	NS	0.04	NS	NS
	YOY			46	0.01	NS	0.01	NS	NS	NS	NS
Amer. shad	PYSL			24	NS						
	YOY			30	0.01	NS	NS	0.04	0.02	0.04	0.04
Striped bass	PYSL	COND	FWflow	44	NS						
	YOY			53	NS						
White perch	PYSL			47	0.01	0.01	NS	NS	NS	NS	NS
	YOY			46	NS						
Amer. shad	PYSL			24	NS						
	YOY			30	0.01	0.03	NS	NS	NS	NS	NS
Striped bass	PYSL	COND	STcrop	44	NS						
	YOY			53	0.01	NS	0.01	NS	NS	NS	NS
White perch	PYSL			47	0.01	0.01	NS	NS	0.01	NS	NS
	YOY			46	0.01	NS	0.01	NS	NS	0.05	NS

(Continued)

TABLE 7.3-2. (Continued).

						TYPE I TESTS[c]			TYPE III TESTS		
SPECIES	LIFESTAGE[a]	VARIABLES[b] A	B	N	TEST OF MODEL	A	B	AB	A	B	AB
Amer. shad	PYSL	COND	STcrop	24	NS[d]						
	YOY			30	0.01	0.02	NS	NS	0.01	0.04	NS
Striped bass	PYSL	FWflow	STcrop	44	NS						
	YOY			53	0.01	NS	0.01	NS	NS	NS	NS
White perch	PYSL			47	0.01	0.01	0.02	0.01	0.01	0.01	0.01
	YOY			46	0.01	NS	0.01	NS	NS	NS	NS
Amer. shad	PYSL			24	NS						
	YOY			30	0.02	NS	NS	NS	NS	NS	NS

---

[a] PYSL=post yolk-sac larvae, YOY=young-of-the-year

[b] TEMP=temperature, DO=dissolved oxygen, COND=conductivity, FWflow=freshwater flow, STcrop=standing crop

[c] Two types of statistical tests were applied to variables in significant models. Type I probability levels are based on entering each variable sequentially (A, B, and the interaction of A and B) into the model. Type III probability levels are based on partial sums of squares, in which the effect of each variable on mortality is considered after adjustment for the effects of the other two variables.

[d] Non-significant results (probabilities >0.05).

(Table 7.3-3), but it generally did not influence the significance level of the temperature effect on mortality (Table 7.3-2). A number of spurious correlations appeared in pairwise analyses not involving temperature because of the relationship of other abiotic variables to temperature. Temperature was listed first in the intermediate models, and only those terms that were significant in combination with temperature in the pairwise tests remained significant. Three terms that were significant after adjustment for temperature in the pairwise tests were not significant in the intermediate models: the effects of conductivity and the temperature-conductivity interaction on instantaneous mortality rate of American shad young-of-the-year, and the effect of the temperature-freshwater flow interaction on instantaneous growth rate of white perch young-ofthe-year. These variables were significant after adjustment for temperature, but were not significant after adjustment for both temperature and dissolved oxygen. All variables that were significant in intermediate models were significant in final models, or contributed to a significant interaction. This is an example of one of the hazards of correlation-type analyses. Variables that are statistically significant predictors may not cause an effect, but may instead be correlated with the true causative factor.

7.3.2 Striped Bass

Temperature was the only variable significantly correlated with instantaneous mortality rate of post yolk-sac larvae (Table 7.3-4, Figure 7.3-1). During this critical period, when exogenous feeding must begin but the size range of potential prey is narrowest (Werner, 1974), increases in metabolic rate resulting from increases in temperature make survival more tenuous.

No abiotic variables by themselves had a significant effect on the instantaneous mortality rate of young-of-the-year striped bass (Table 7.3-5). There was a positive relationship between standing crop and mortality (Figure 7.3-2). Temperature alone did not have a significant effect, but it played a role in a significant interaction with

TABLE 7.3-3. PRELIMINARY ANALYSES TO IDENTIFY SIGNIFICANT MAIN EFFECTS AND TWO-WAY INTERACTIONS OF FIVE ENVIRONMENTAL VARIABLES ON INSTANTANEOUS GROWTH RATES OF YOUNG-OF-THE-YEAR STRIPED BASS AND WHITE PERCH IN THE HUDSON RIVER ESTUARY, 1976-1979 AND 1982-1983.[a]

					TYPE I TESTS[c]			TYPE III TESTS		
SPECIES	VARIABLES[b] A	B	N	TEST OF MODEL	A	B	AB	A	B	AB
striped bass	TEMP	DO	41	0.01	0.01	NS[d]	NS	NS	NS	NS
white perch			31	0.01	0.01	0.01	NS	0.01	0.01	NS
striped bass	TEMP	COND	41	0.01	0.01	NS	NS	0.04	NS	NS
white perch			31	0.01	0.01	NS	NS	0.04	NS	NS
striped bass	TEMP	FWflow	41	0.01	0.01	NS	NS	NS	NS	NS
white perch			31	0.01	0.01	NS	0.02	0.01	0.02	0.02
striped bass	TEMP	STcrop	41	0.01	0.01	NS	NS	NS	NS	NS
white perch			31	0.01	0.01	NS	NS	0.02	NS	NS
striped bass	DO	COND	41	0.01	0.01	NS	NS	0.05	NS	NS
white perch			31	0.01	0.01	NS	NS	NS	NS	NS
striped bass	DO	FWflow	41	0.01	0.01	NS	NS	NS	NS	NS
white perch			31	0.01	0.01	NS	0.02	0.01	0.02	0.02
striped bass	DO	STcrop	41	0.01	0.01	NS	NS	NS	NS	NS
white perch			31	0.01	0.01	NS	NS	NS	NS	NS

(Continued)

TABLE 7.3-3. (Continued).

SPECIES	VARIABLES[b] A	B	N	TEST OF MODEL	TYPE I TESTS[c] A	B	AB	TYPE III TESTS A	B	AB
striped bass	COND	FWflow	41	0.01	NS[d]	NS	NS	NS	NS	NS
white perch			31	0.01	NS	0.03	NS	NS	NS	NS
striped bass	COND	STcrop	41	0.01	0.05	NS	0.03	0.04	0.01	0.03
white perch			31	0.01	NS	NS	NS	NS	NS	NS
striped bass	FWflow	STcrop	41	0.01	NS	NS	NS	NS	NS	NS
white perch			31	0.01	0.02	NS	NS	NS	NS	NS

[a] No growth data were reported for 1980 or 1981 (Battelle 1983).

[b] TEMP=temperature, DO=dissolved oxygen, COND=conductivity, FWflow=freshwater flow, STcrop=standing crop

[c] Two types of statistical tests were applied to variables in significant models. Type I probability levels are based on entering each variable sequentially (A, B, and the interaction of A and B) into the model. Type III probability levels are based on partial sums of squares, in which the effect of each variable on mortality is considered after adjustment for the effects of the other two variables.

[d] Non-significant results (probabilities >0.05).

TABLE 7.3-4. STATISTICAL ANALYSIS OF THE FINAL MODEL FOR THE EFFECTS OF TEMPERATURE ON INSTANTANEOUS MORTALITY RATE OF STRIPED BASS POST YOLK-SAC LARVAE. OVERALL SIGNIFICANCE LEVEL OF THE MODEL WAS α=0.0016.

		TESTS OF SIGNIFICANCE	
PARAMETER	ESTIMATE	TEST OF PARAMETER=0[a]	TYPE I F-TEST[b]
Intercept	-0.5550	0.0116	
Temperature Coefficient	0.0319	0.0016	0.0016

[a] Probabilities that coefficients were equal to zero were equal to Type III F-tests based on partial sums of squares, that test the effect of each variable after adjustment for the effects of all other variables in the model.

[b] Type I probability levels are based on entering each variable sequentially into the model.

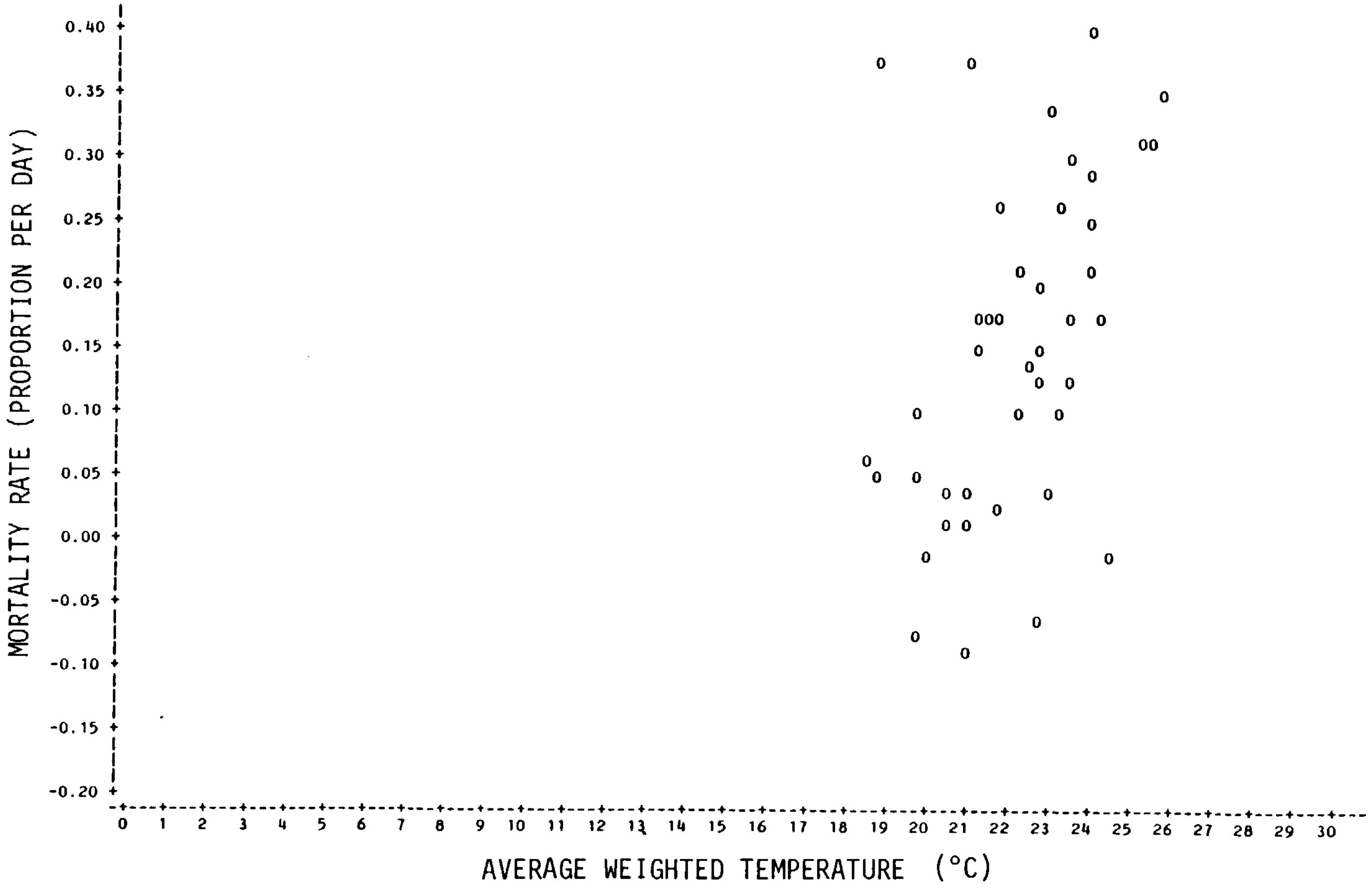


Figure 7.3-1. The relationship between average water temperature weighted by population distribution and average daily instantaneous mortality rate between weekly standing crop estimates of striped bass post yolk-sac larvae.

TABLE 7.3-5. STATISTICAL ANALYSIS OF THE FINAL MODEL FOR THE EFFECTS OF TEMPERATURE, STANDING CROP AND THEIR INTERACTION ON INSTANTANEOUS MORTALITY RATE OF STRIPED BASS YOUNG-OF-THE-YEAR. OVERALL SIGNIFICANCE LEVEL OF THE MODEL WAS $\alpha=0.0001$.

		TESTS OF SIGNIFICANCE	
PARAMETER	ESTIMATE	TEST OF PARAMETER=0[a]	TYPE I F-TEST[b]
Intercept[c]			0.0011
1976-1978	0.0052	0.8617	
1979-1983	0.0258	0.4464	
Coefficients			
Temperature	-0.0023	0.1922	0.4686
Standing crop	1.0478×10^{-5}	0.0007	0.0001
Interaction	-3.1403×10^{-7}	0.0133	0.0133

[a] Probabilities that coefficients were equal to zero were equal to Type III F-tests based on partial sums of squares, that test the effect of each variable after adjustment for the effects of all other variables in the model.

[b] Type I probability levels are based on entering each variable sequentially into the model.

[c] Separate intercepts were calculated for years before and after the Fall Shoals program was expanded.

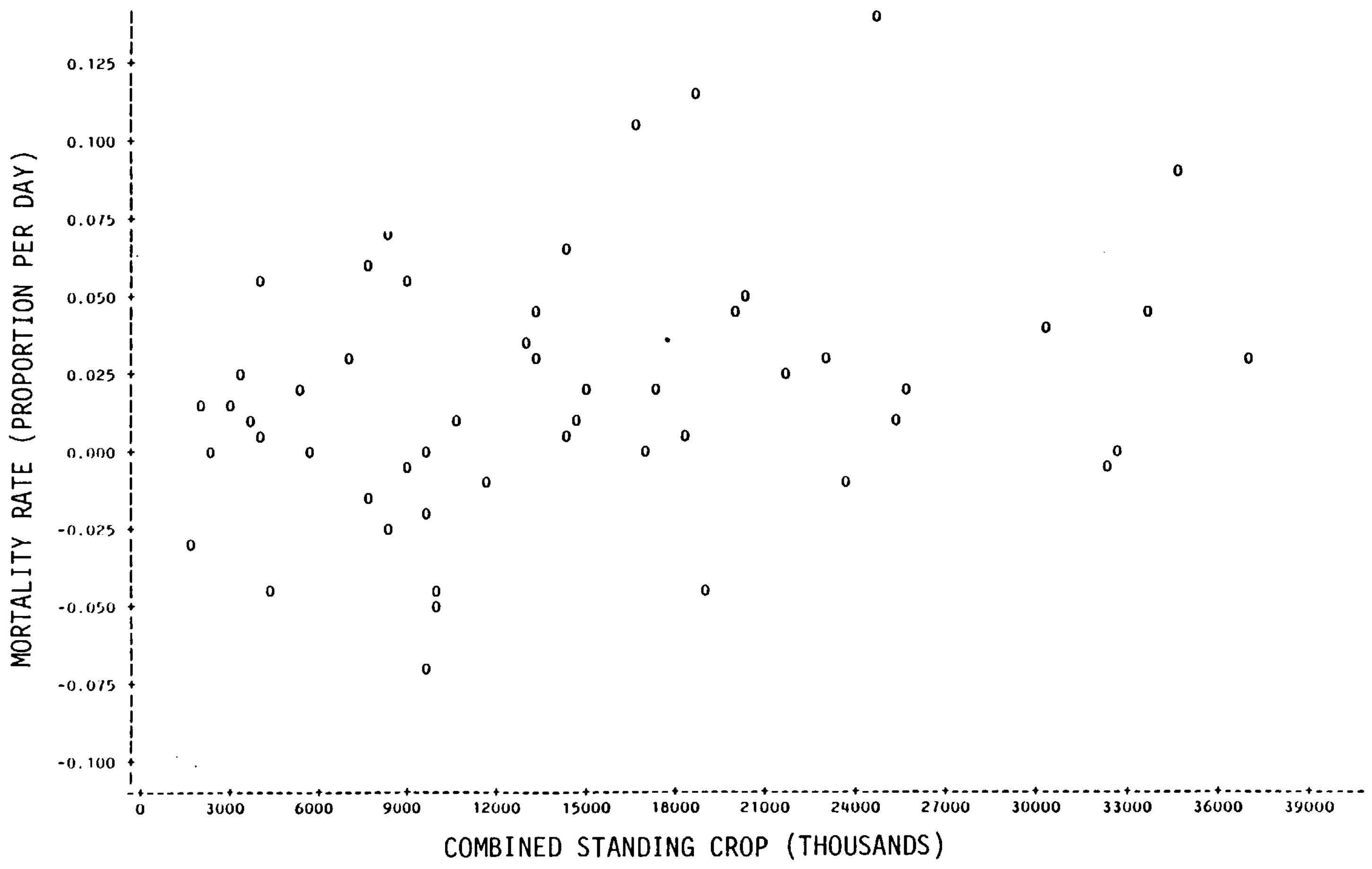


Figure 7.3-2. The relationship between initial standing crop and average daily instantaneous mortality rate between biweekly standing crop estimates of striped bass young-of-the-year.

standing crop. The negative coefficient for this interaction indicated that the effect of standing crop on mortality was less at higher temperatures, reflecting the higher variation in mortality rate observed in early summer compared to late summer (Section 5.0). If emigration from the sampling area contributed an appreciable amount to the observed population decline, then it may also be more variable earlier in the year. Inclusion of the interaction in the model provided a better predictor than temperature alone, and increased R^2 from 0.265 to 0.547.

Temperature was also the only variable significantly correlated with instantaneous growth rate of young-of-the-year striped bass (Table 7.3-6). A direct relationship between temperature and growth rate (Figure 7.3-3) is to be expected over the range of temperatures encountered in this analysis, providing that food is not severely limited (Kellogg and Gift, 1983).

A previous analysis (TI, 1981) was not comparable to this one. They found no relationship between growth rate of young-of-the-year and water temperature, and a significant correlation with juvenile abundance, but juvenile abundance was the combined standing crop estimate of abundance on August 1, and water temperature was the mean over the entire period when striped bass grew from 30 to 60 mm TL. The analysis in this report should be much more sensitive and reliable because of increased sample size and specificity of data. The previous analysis was based on only seven data points (annual means), and annual data are not as suitable for analysis of factors influencing growth as are data representing periods of a few weeks (Rice and Cochran, 1984).

The relationship between mortality and standing crop in the absence of a similar relationship to growth suggests extrinsic (e.g., predation, abiotic variables) rather than intrinsic (e.g., disease, nutrition) causes of mortality. Factors intrinsic to the striped bass themselves would be expected to be expressed as effects on growth as well as mortality. Predation is a likely cause, because predation rate might be expected to be more severe when prey are more abundant.

TABLE 7.3-6. STATISTICAL ANALYSIS OF THE FINAL MODEL FOR THE EFFECTS OF TEMPERATURE ON INSTANTANEOUS GROWTH RATE OF STRIPED BASS YOUNG-OF-THE-YEAR. OVEARLL SIGNIFICANCE LEVEL OF THE MODEL WAS $\alpha=0.0001$.

		TESTS OF SIGNIFICANCE	
PARAMETER	ESTIMATE	TEST OF PARAMETER=0[a]	TYPE I F-TEST[b]
Intercept[c]			0.0001
1976-1978	-0.0065	0.0794	
1979-1983	-0.0042	0.3331	
Temperature coefficient	5.6512×10^{-4}	0.0030	0.0030

[a] Probabilities that coefficients were equal to zero were equal to Type III F-tests based on partial sums of squares, that test the effect of each variable after adjustment for the effects of all other variables in the model.

[b] Type I probability levels are based on entering each variable sequentially into the model.

[c] Separate intercepts were calculated for years before and after the Fall Shoals program was expanded.

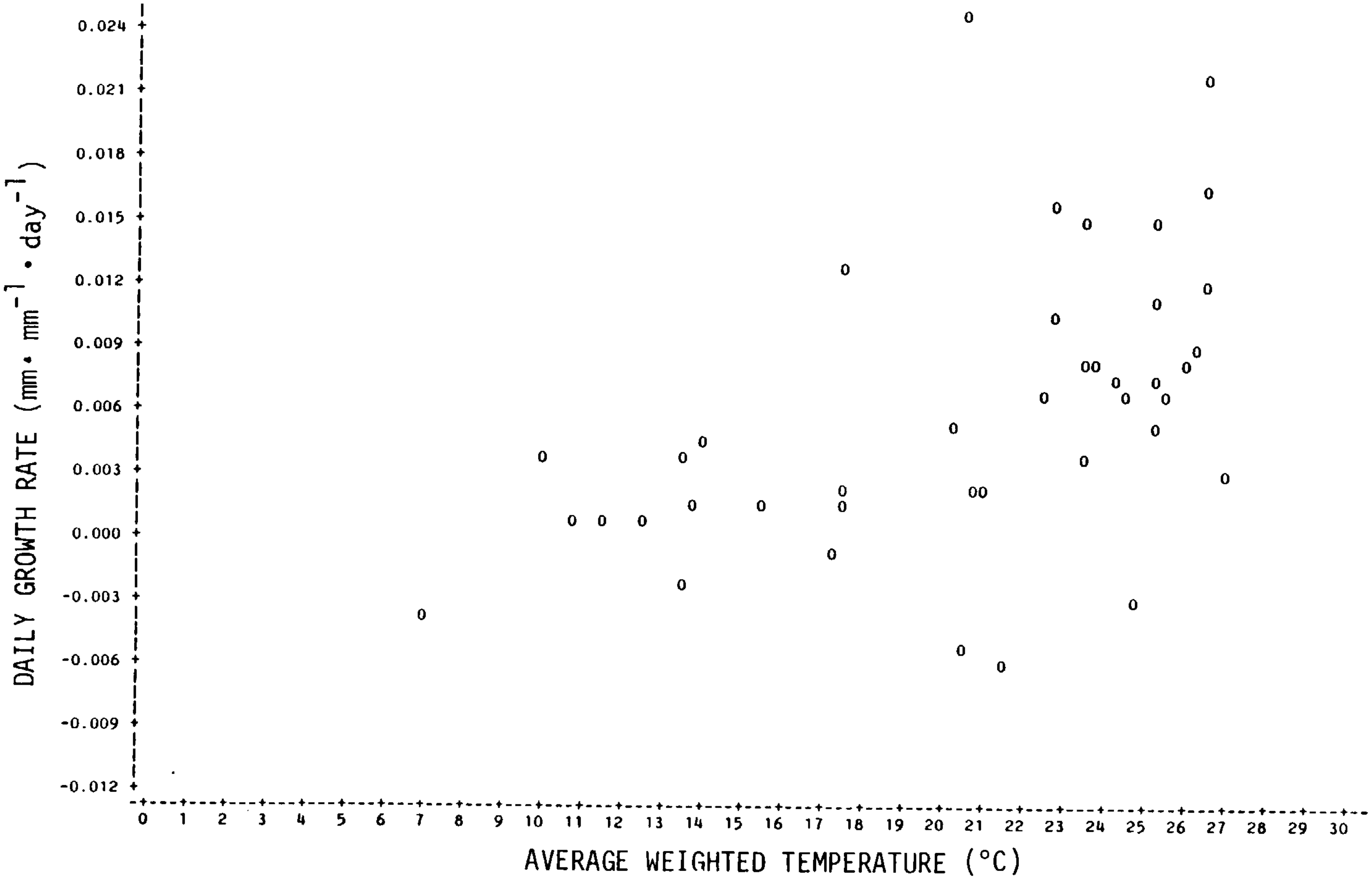


Figure 7.3-3. The relationship between average water temperature weighted by population distribution and average daily instantaneous growth rate between biweekly standing crop estimates of striped bass young-of-the-year.

Predators such as bluefish are usually more abundant in late summer and fall when temperatures are lower than during midsummer. This would result in a negative relationship between mortality and temperature, and a negative temperature-standing crop interaction.

7.3.3 White Perch

Results of the analyses on white perch were very similar to those for striped bass. Mortality rate of post yolk-sac larvae was positively correlated with temperature (Table 7.3-7, Figure 7.3-4), mortality rate of young-of-the-year was density-dependent (Table 7.3-8, Figure 7.3-5), and young-of-the-year growth rate was greater at higher temperatures (Table 7.3-9, Figure 7.3-6). However, conductivity played a major role in the mortality rate of post yolk-sac larvae (Table 7.3-7, Figure 7.3-7). Temperature had no significant effect on mortality rate of young-of-the-year, and dissolved oxygen concentrations positively affected their growth rate (Table 7.3-9). The saturation level of dissolved oxygen is inversely related to temperature, and thus growth rate (Figure 7.3-8) but the coefficient was positive after adjustment for temperature (Table 7.3-9), indicating that growth rate was enhanced by better-than-average dissolved oxygen concentration at a given temperature. This effect was similar over the entire range of temperatures, because the temperature-dissolved oxygen interaction term was not significant.

The response of growth rate to temperature appeared to be curvilinear (Figure 7.3-9), so the model was fit by natural log-transforming instantaneous growth rate. A linear response to temperature for growth by striped bass and a curvilinear response by white perch were also noted by Kellogg and Gift (1983).

TABLE 7.3-7. STATISTICAL ANALYSIS OF THE FINAL MODEL FOR THE EFFECTS OF TEMPERATURE AND CONDUCTIVITY ON INSTANTANEOUS MORTALITY RATE OF WHITE PERCH POST YOLK-SAC LARVAE. OVERALL SIGNIFICANCE LEVEL OF THE MODEL WAS $\alpha=0.0001$.

		TESTS OF SIGNIFICANCE	
PARAMETER	ESTIMATE	TEST OF PARAMETER=0[a]	TYPE I F-TEST[b]
Intercept	-0.3768	0.0099	
Coefficients[c]			
Temperature	0.0195	0.0049	0.0001
Conductivity	0.0838	0.0144	0.0144

---

[a] Probabilities that coefficients were equal to zero were equal to Type III F-tests based on partial sums of squares, that test the effect of each variable after adjustment for the effects of all other variables in the model.

[b] Type I probability levels are based on entering each variable sequentially into the model.

[c] The temperature-conductivity interaction was not significant.

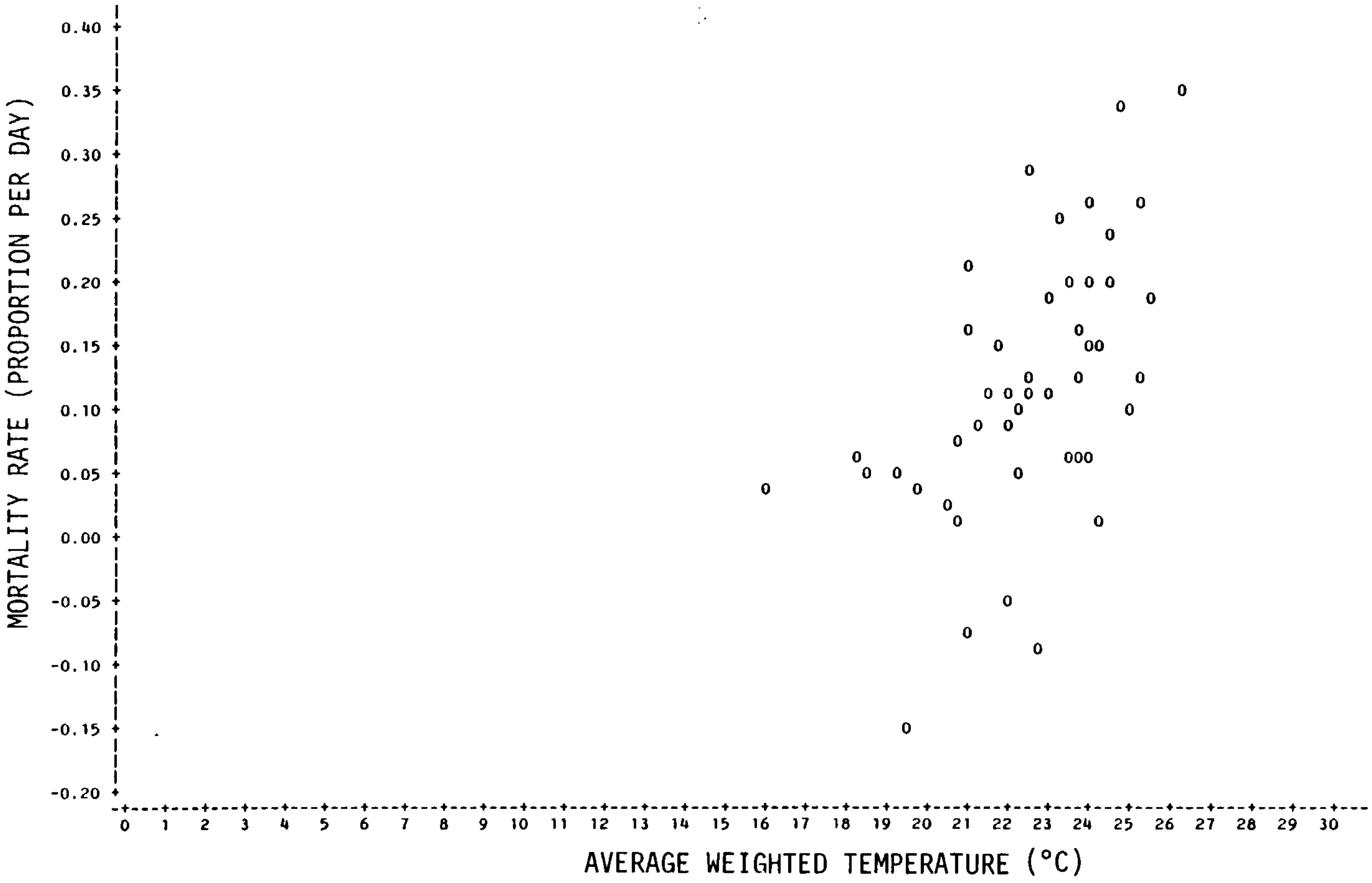


Figure 7.3-4. The relationship between average water temperature weighted by population distribution and average daily instantaneous mortality rate between weekly standing crop estimates of white perch post yolk-sac larvae.

TABLE 7.3-8. STATISTICAL ANALYSIS OF THE FINAL MODEL FOR THE EFFECTS OF STANDING CROP ON INSTANTANEOUS MORTALITY RATE OF WHITE PERCH YOUNG-OF-THE-YEAR. OVERALL SIGNIFICANCE LEVEL OF THE MODEL WAS α=0.0005.

		TESTS OF SIGNIFICANCE	
PARAMETER	ESTIMATE	TEST OF PARAMETER=0[a]	TYPE I F-TEST[b]
Intercept[c]			0.0937
1976-1978	-0.0257	0.0110	
1979-1983	-0.0367	0.0113	
Standing crop coefficient	2.2782×10^{-6}	0.0002	0.0002

[a] Probabilities that coefficients were equal to zero were equal to Type III F-tests based on partial sums of squares, that test the effect of each variable after adjustment for the effects of all other variables in the model.

[b] Type I probability levels are based on entering each variable sequentially into the model.

[c] Separate intercepts were calculated for years before and after the Fall Shoals program was expanded.

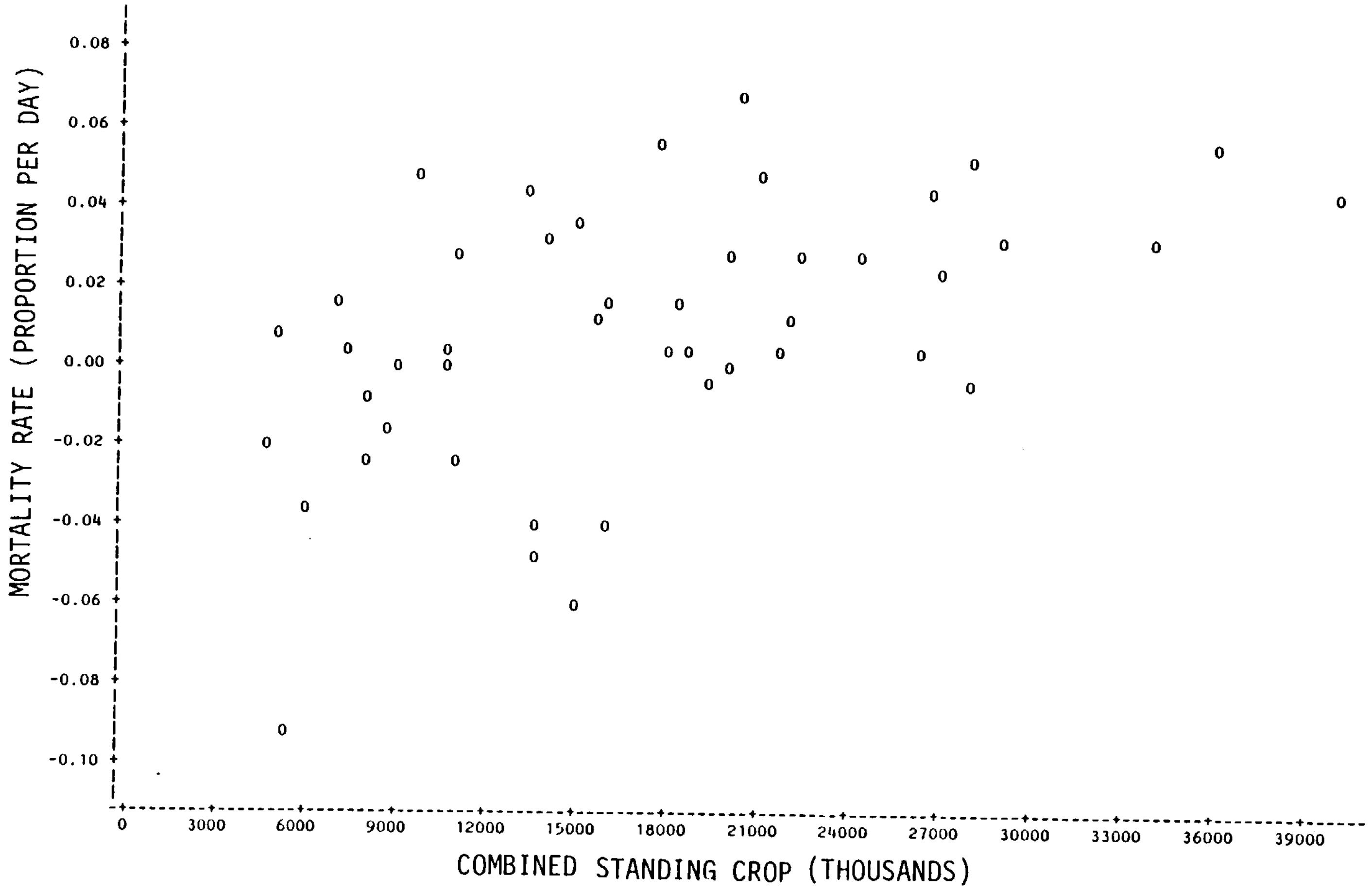


Figure 7.3-5. The relationship between initial standing crop and average daily instantaneous mortality rate between biweekly standing crop estimates of white perch young-of-the-year.

TABLE 7.3-9. STATISTICAL ANALYSIS OF THE FINAL MODEL FOR THE EFFECTS OF TEMPERATURE AND DISSOLVED OXYGEN ON THE LOGARITHM OF INSTANTANEOUS GROWTH RATE OF WHITE PERCH YOUNG-OF-THE-YEAR. OVERALL SIGNIFICANCE LEVEL OF THE MODEL WAS $\alpha=0.0001$.

		TESTS OF SIGNIFICANCE	
PARAMETER	ESTIMATE	TEST OF PARAMETER=0[a]	TYPE I F-TEST[b]
Intercept[c]			0.0001
1976-1978	-17.1621	0.0001	
1979-1983	-17.4568	0.0001	
Coefficients[d]			
Temperature	0.3016	0.0001	0.0001
Dissolved oxygen	0.7448	0.0206	0.0206

[a] Probabilities that coefficients were equal to zero were equal to Type III F-tests based on partial sums of squares, that test the effect of each variable after adjustment for the effects of all other variables in the model.

[b] Type I probability levels are based on entering each variable sequentially into the model.

[c] Separate intercepts were calculated for years before and after the Fall Shoals program was expanded.

[d] The temperature-dissolved oxygen interaction was not significant.

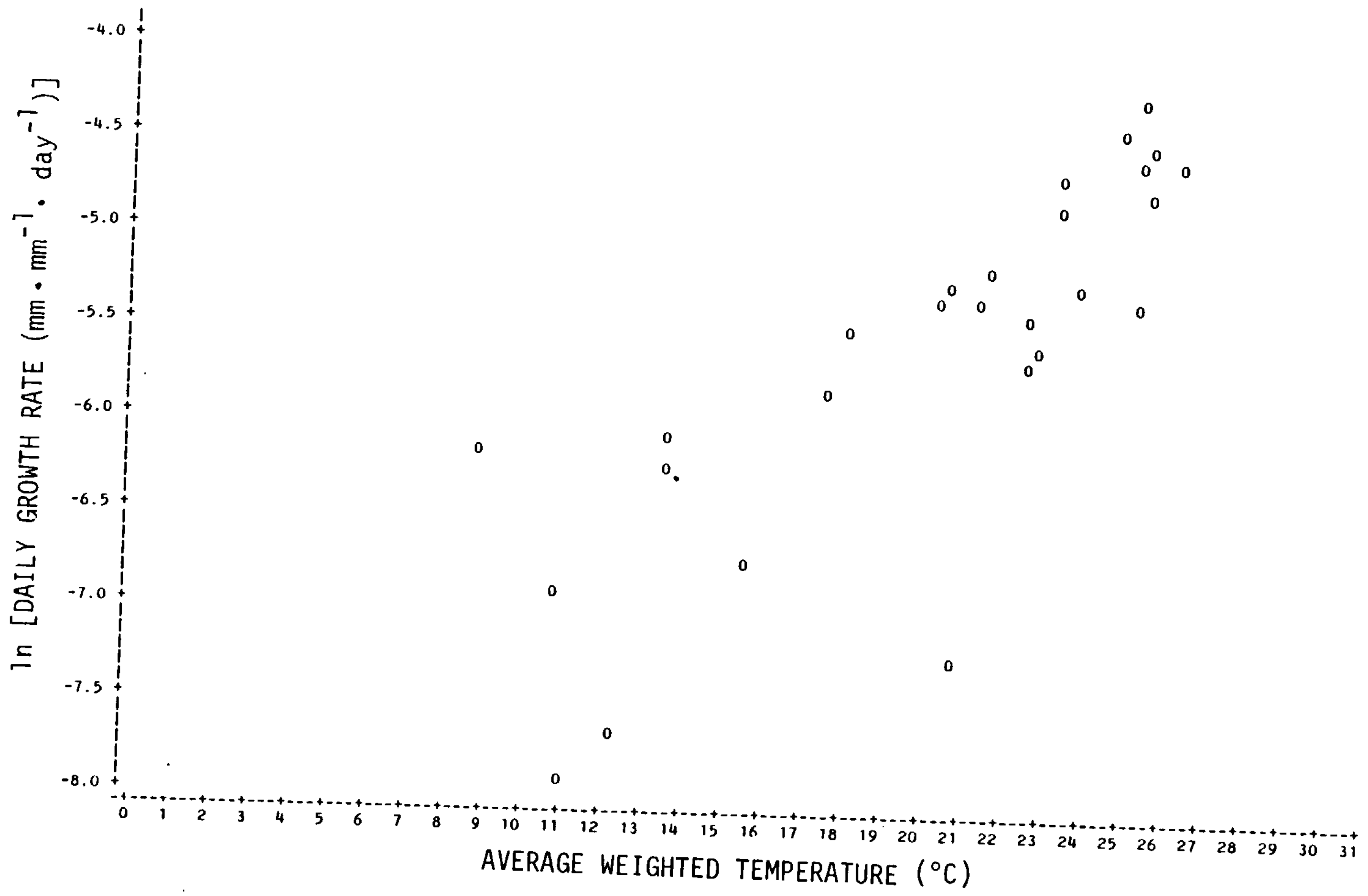


Figure 7.3-6. The relationship between average water temperature weighted by population distribution and the natural logarithm of average daily instantaneous growth rate between biweekly standing crop estimates of white perch young-of-the-year.

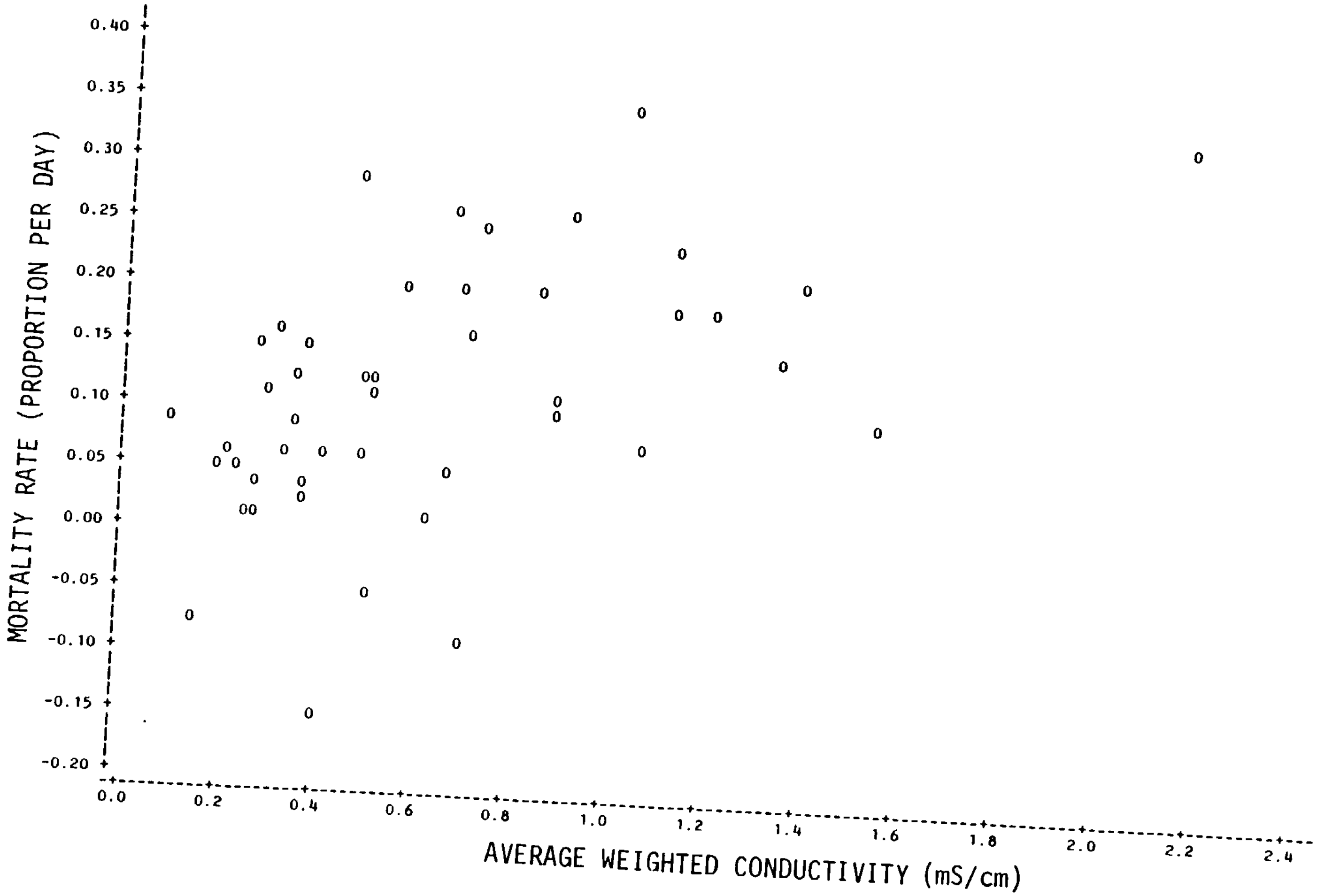


Figure 7.3-7. The relationship between average conductivity weighted by population distribution and average daily instantaneous mortality rate between weekly standing crop estimates of white perch post yolk-sac larvae.

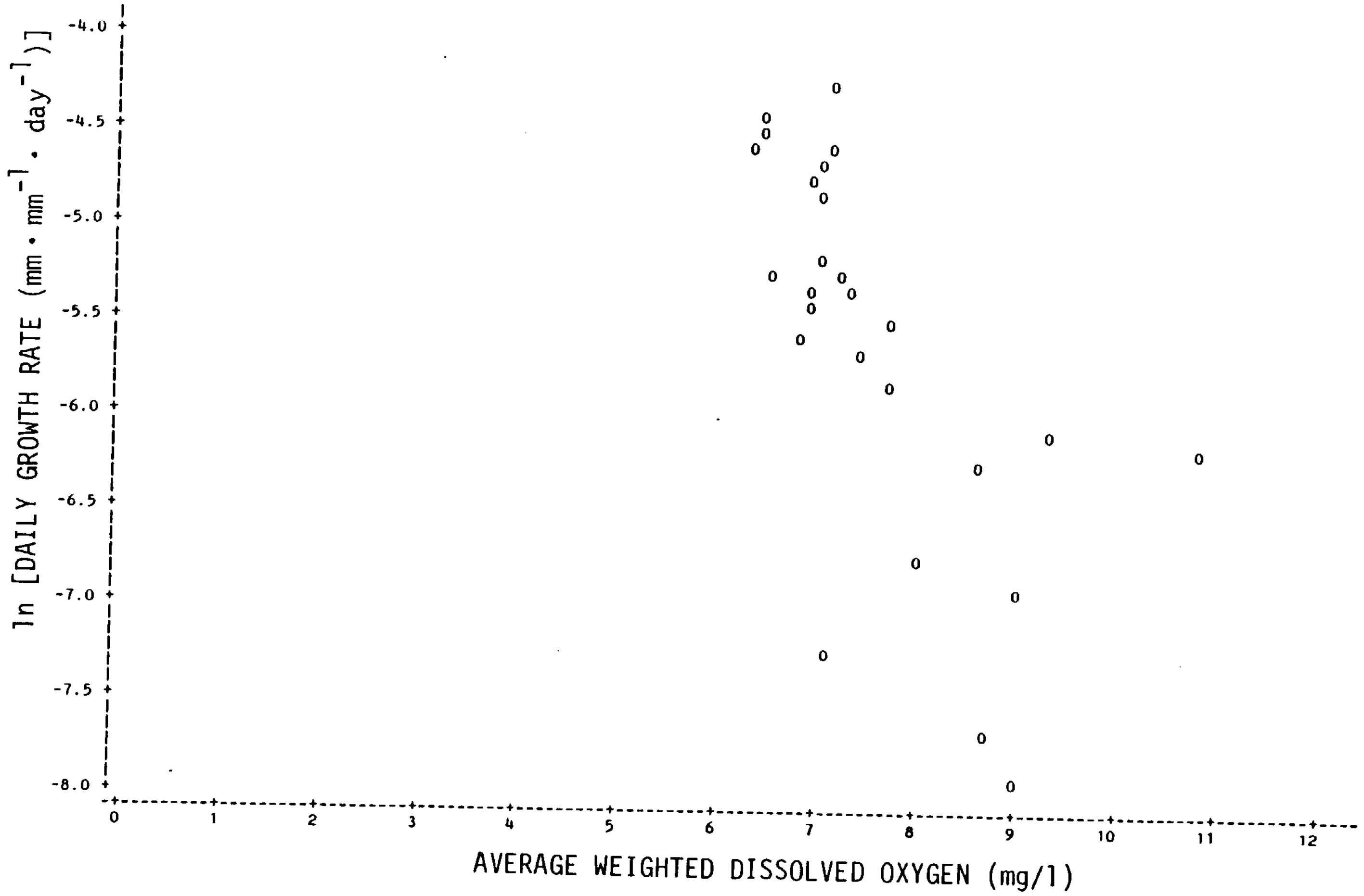


Figure 7.3-8. The relationship between average dissolved oxygen concentration weighted by population distribution and the natural logarithm of average daily instantaneous growth rate between biweekly standing crop estimates of white perch young-of-the-year.

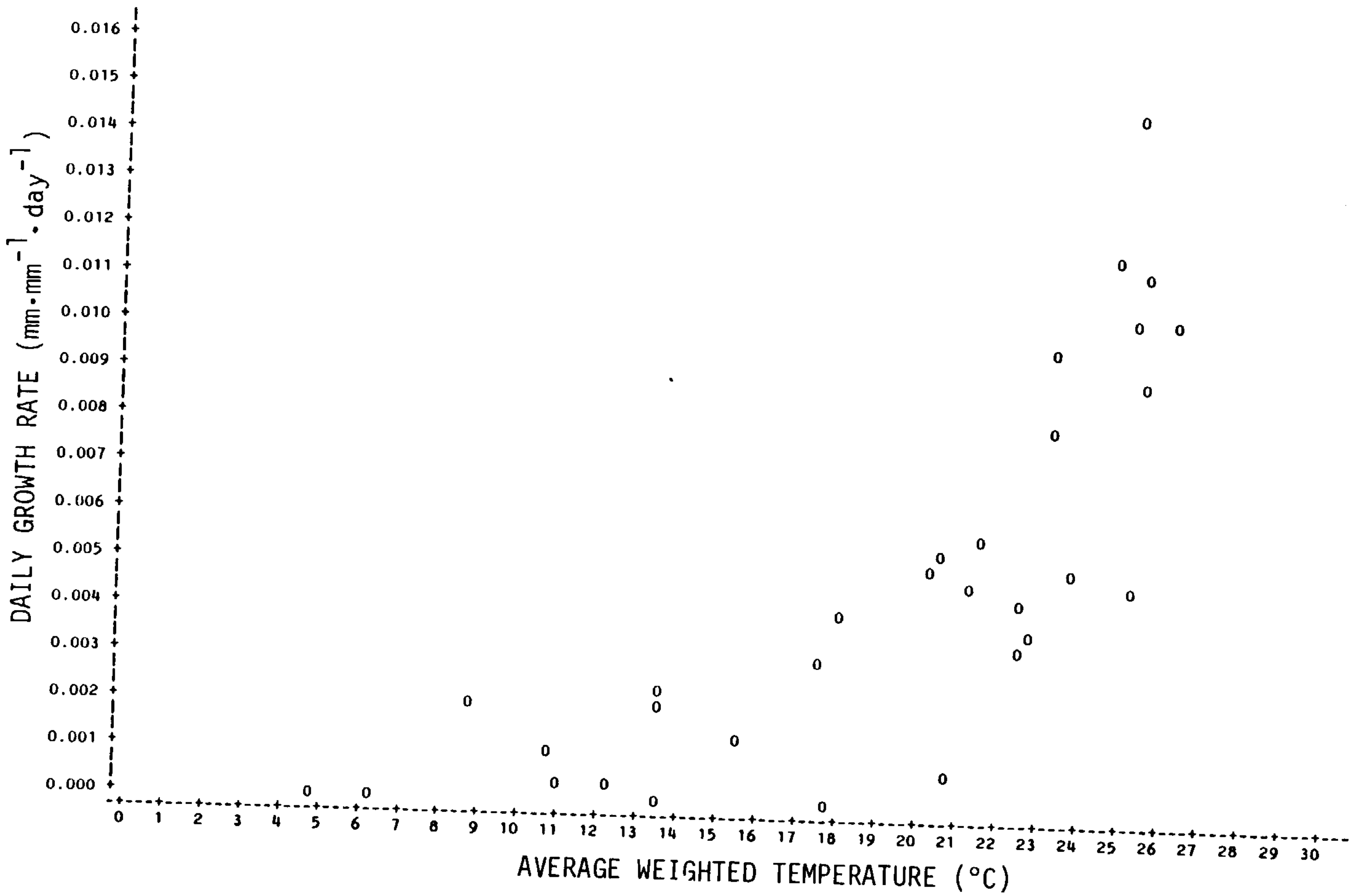


Figure 7.3-9. The curvilinear relationship between average water temperature weighted by population distribution and average daily instantaneous growth rate between biweekly standing crop estimates of white perch young-of-the-year.

7.3.4 American Shad

None of the variables that were considered had a significant effect on instantaneous mortality rate of post yolk-sac larvae of American shad (Table 7.3-2). Although the highest mortality rates for young-of-the-year were observed at cooler temperatures, there was a significant trend for mortality rate to increase with temperature (Table 7.3-10, Figure 7.3-10). The inclusion of dissolved oxygen concentration in the model significantly improved its predictive ability (Figure 7.3-11), but most of the effect was attributable to its negative interaction with temperature. Thus, high dissolved oxygen concentrations for a given temperature tended to buffer the effect of temperature on mortality rate.

TABLE 7.3-10. STATISTICAL ANALYSIS OF THE FINAL MODEL FOR THE EFFECTS OF TEMPERATURE, DISSOLVED OXYGEN, AND THEIR INTERACTION OF INSTANTANEOUS MORTALITY RATE OF AMERICAN SHAD YOUNG-OF-THE-YEAR. OVERALL SIGNIFICANCE LEVEL OF THE MODEL WAS $\alpha=0.0003$.

		TESTS OF SIGNIFICANCE	
PARAMETER	ESTIMATE	TEST OF PARAMETER=0[a]	TYPE I F-TEST[b]
Intercept[c]	-1.7043	0.0032	
Coefficients			
Temperature	0.0732	0.0027	0.0505
Dissolved oxygen	0.1860	0.0020	0.7193
Interaction	-0.0079	0.0020	0.0020

---

[a] Probabilities that coefficients were equal to zero were equal to Type III F-tests based on partial sums of squares, that test the effect of each variable after adjustment for the effects of all other variables in the model.

[b] Type I probability levels are based on entering each variable sequentially into the model.

[c] Data were available only for years after the Fall Shoals program was expanded.

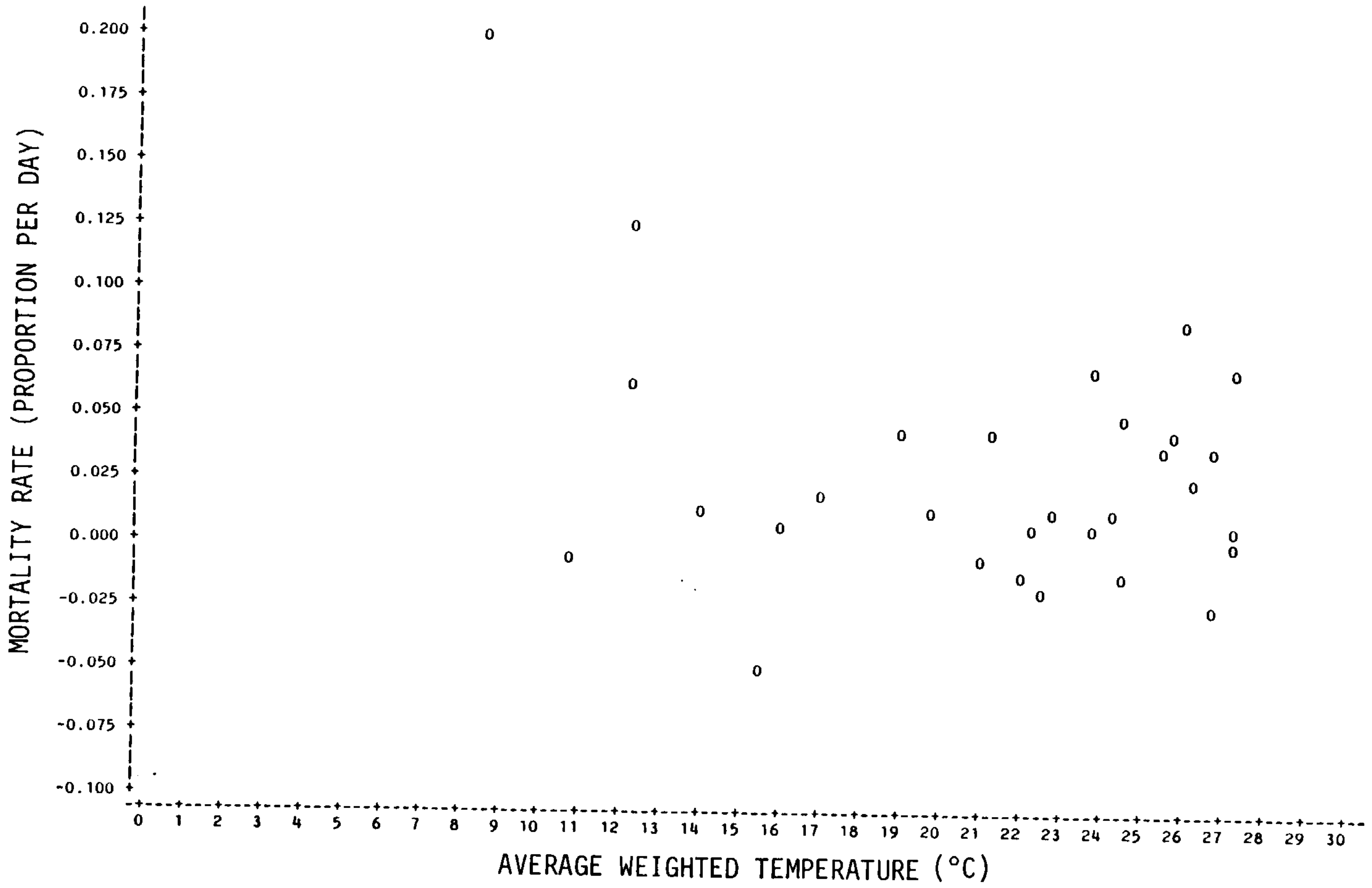


Figure 7.3-10. The relationship between average water temperature weighted by population distribution and average daily instantaneous mortality rate between biweekly standing crop estimates of American shad young-of-the-year.

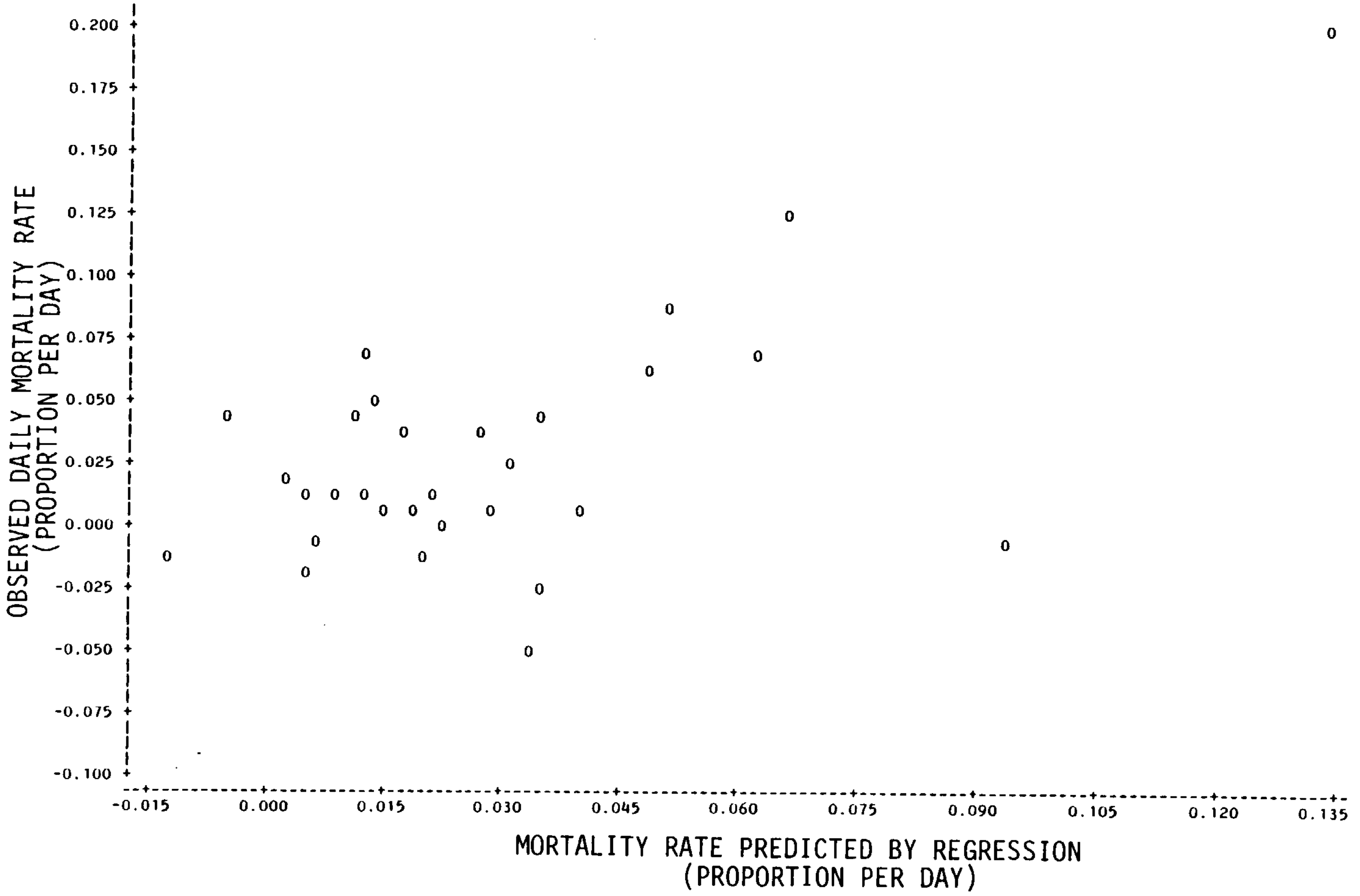


Figure 7.3-11. Comparison of the observed daily instantaneous mortality rates of American shad young-of-the-year and instantaneous mortality rates predicted from a regression model including temperature, dissolved oxygen, and their interaction.

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