Versar INC.

1985 YEAR CLASS REPORT
FOR THE HUDSON RIVER ESTUARY
MONITORING PROGRAM

VOLUME I - TEXT

Prepared for

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FOREWORD

The 1985 Year Class Report was prepared by Versar, Inc., ESM Operations, with the support of Coastal Environmental Services, Inc., for Consolidated Edison Company of New York, Inc., Central Hudson Gas and Electric Corp., New York Power Authority, Niagara Mohawk Power Co., and Orange and Rockland Utilities, Inc., under contract number 6-22160. The objective of this report is to summarize and interpret data collected from the 1985 Hudson River fish sampling surveys.

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I. INTRODUCTION

Since 1973, a series of reports, referred to as Year Class Reports, has been prepared annually for five utilities: Central Hudson Gas and Electric Corp., Consolidated Edison Company of New York, Inc., New York Power Authority, Niagara Mohawk Power Co., and Orange and Rockland Utilities, Inc. The main purpose of the Year Class Reports is to present and analyze data on the distribution and abundance of the early life stages of selected Hudson River fish species.

The first report, "The First Annual Multiplant Report" [Texas Instruments Incorporated (TI) 1975] summarized riverwide data collected to estimate the impact 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). Patterns of abundance and distribution of early life stages were examined in greater detail in the 1975 report, but impacts of plant operations were not estimated (TI 1978a). The 1976 report (TI 1979a) expanded the focus to include ecological relationships of selected fish populations. In the 1977 and 1978 reports (TI 1980a, 1980b), the life histories of selected species were examined in the context of power plant effects. The 1978 report (TI 1980b) was expanded to include the life history and distributional information on nine additional fish species. Data analysis for the 1979 report (TI 1981) was also extended to include predictions of environmental impact based on fish population age structure and age-specific survival. Further statistical analysis of biocharacteristics data available from 1973 to 1979 was included for the three initial key species.

The Hudson River Settlement Agreement among the utilities, the United States Environmental Protection Agency, and other interested parties was announced in 1980, and became effective in May 1981 (Sandler and Schoenhard 1981). The 1980-1981 Year Class Report [Battelle New England Marine Research Laboratory (Battelle) 1983] was the first Year Class Report prepared after execution of the Settlement Agreement and was formatted to continue presentation of life history and population dynamics studies of selected Hudson River fish species. The 1981 study program was also the first in which the length of the sampling season was reduced to focus on the period when most Hudson River fish are maturing from the larval to juvenile stage. The 1982 Year Class Report [Normandeau Associates, Inc. (NAI) 1985a] was similar in content to the 1980-1981 report, but the estimation of year class strength was extended to include a fall index. In addition to the basic survey results, the 1983 report (NAI 1985b) included data on the first recaptures of fish released from a striped bass hatchery which began operation in 1983. The 1983 report also included an examination of the relationship between environmental variables and the early life histories of striped bass, white perch, and American shad. The 1984 Year Class Report contained the types of information presented in the 1982 and 1983 reports, but placed additional emphasis on the indices of year class strength and their interpretation.

The present report adds to the historical data base by describing the results of the 1985 Longitudinal River ichthyoplankton survey and the 1985 Fall Shoals and Beach Seine juvenile surveys. The primary objectives of this Year Class Report are to:

- Present estimates of spatial distribution, temporal distribution, and abundance for 12 selected fish species (Table I-1), and to interpret these findings with respect to life history and environmental variables
- Estimate year class strength using indices that were developed in previous year class reports and develop confidence intervals for these indices
- Identify the major shortcomings associated with previous indices of year class strength and develop a new, statistically reliable, index of year class strength for white perch, striped bass, American shad, and bay anchovy
- Identify factors that may influence year class strength for these four species.

The report is organized into eight chapters. Data collection and data analysis methods are described in Chapter II and a summary of water quality measurements is presented in Chapter III. Chapters IV-VII focus on the objectives outlined above. Within each of these chapters, individual species are discussed separately. Chapter VIII contains the literature cited. An appendix volume contains supporting information.

Table I-1. Fish species selected for presentation in the Hudson River Year Class Report

Common Name[a]	Scientific Name[a]	Life Stages[b]
	Representative and Important Species	
striped bass	*Morone saxatilis*	Egg, YSL, PYS, YOY, YRL
white perch	*Morone americana*	Egg, YSL, PYS, YOY, YRL
Atlantic tomcod	*Microgadus tomcod*	PYS, YOY
alewife	*Alosa pseudoharengus*	YOY, YRL[c]
bay anchovy	*Anchoa mitchilli*	YOY,YRL
weakfish	*Cynoscion regalis*	YOY
white catfish	*Ictalurus catus*	YOY, YRL
spottail shiner	*Notropis hudsonius*	YOY, YRL
Atlantic sturgeon	*Acipenser oxyrhynchus*	YOY, YRL
shortnose sturgeon	*Acipenser brevirostrum*	YOY, YRL
	Ecologically and/or Commercially Important Species	
American shad	*Alosa sapidissima*	PYS, YOY[c]
blueback herring	*Alosa aestivalis*	YOY, YRL[c]

(a)Names recognized by the American Fisheries Society (Robins et al. 1980)
(b)YSL = yolk-sac larvae
PYS = post yolk-sac larvae
YOY = young-of-year
YRL = yearling and older
(c)Egg, yolk-sac larvae, and post yolk-sac larvae of *Alosa* spp. were examined.

II. MATERIALS AND METHODS

A. SAMPLING DESIGN

Three fish surveys were conducted in the Hudson River from spring through fall of 1985 in order to describe riverwide abundances of selected ichthyoplankton and juvenile fish. The Longitudinal River Survey (LRS) was designed to collect pre-juvenile life stages; therefore, sampling was concentrated between spring and midsummer when eggs and larvae of most of the selected species are usually abundant.

The Fall Shoals Survey (FSS) was designed to provide data on juvenile fish. Hence, sampling began when the LRS ended and continued into the fall. The Beach Seine Survey (BSS) was conducted at approximately the same time as the FSS since it too was designed to collect juvenile fish species. Unlike either the FSS or the LRS, samples for the BSS were limited to the shore zone.

Sampling was conducted according to a stratified random design in which the river was divided into 12 regions (Fig. II-1). For the LRS and FSS programs each region was further divided into "strata" on the basis of river depth (Fig. II-2). These strata included:

- Shoal - that portion of the river extending from the shore to a depth of 6 m at mean low tide
- Bottom - that portion of the river extending from the bottom to 3 m above the bottom where river depth is greater than 6 m at mean low tide
- Channel - that portion of the river not considered bottom where river depth is greater than 6 m at mean low tide.

However, not all strata could be sampled in each region. The strata actually sampled in each region during 1985 are given in Table II-1.

Sampling effort within each region and strata for the LRS and FSS programs was determined according to a Neyman allocation procedure based on distributions of fish observed in previous years. For the BSS, the number of beaches sampled in each region was assigned according to the size of the shore zone area in the region. A minimum of three samples was assigned

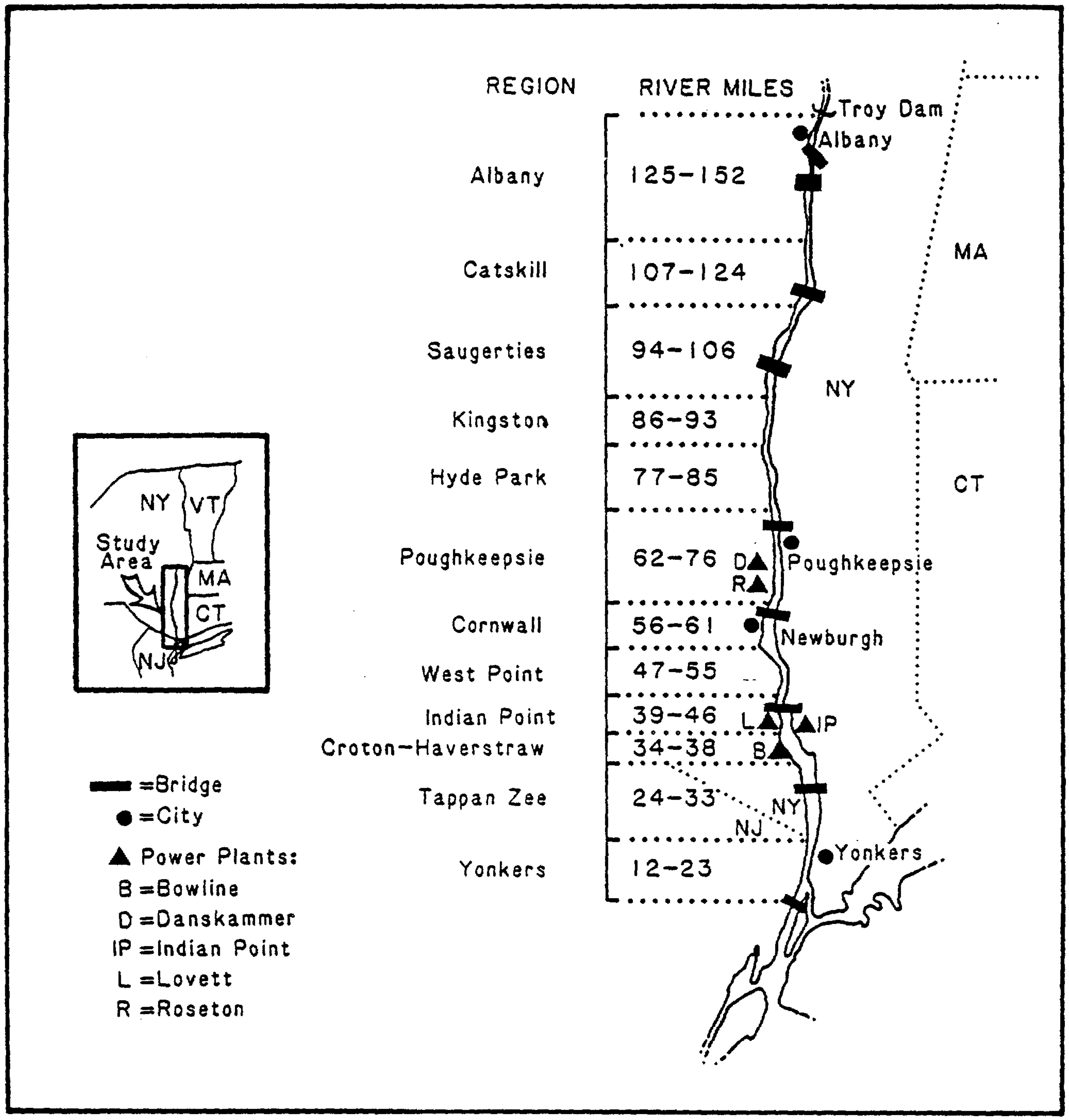
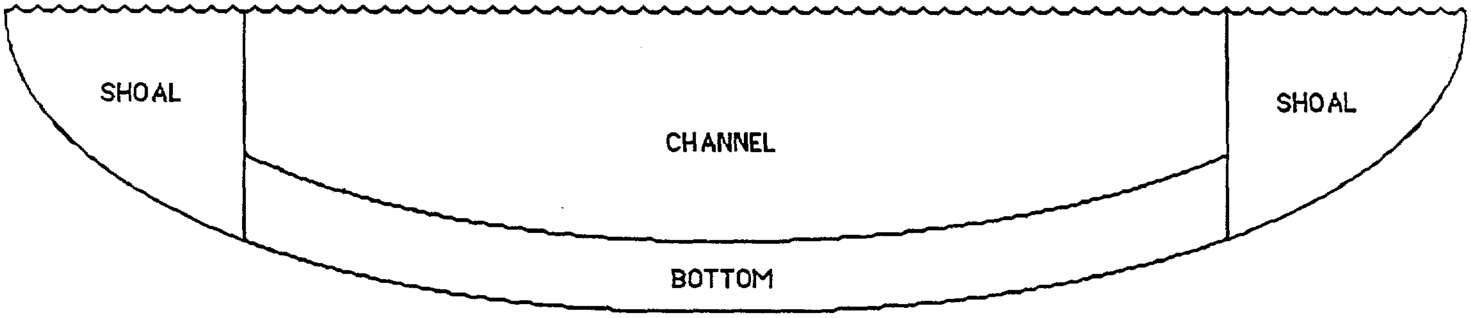


Figure II-1. Location of 12 geographic regions (with river mile boundaries) sampled during 1985 field sampling programs in the Hudson River estuary



Shoal: water of 20 ft (6 m) or less

Bottom: water within 10 ft (3 m) of the river bottom in more than 20 ft (6 m) depth

Channel: water more than 10 ft (3 m) from the river bottom in more than 20 ft (6 m) depth

Figure II-2. Cross section of the estuary showing locations of the shoal, bottom and channel strata

Table II-1. Strata sampled by the Longitudinal River and Fall Shoals Programs within the 12 geographic regions of the Hudson River estuary during 1985

Region	Abbreviation	River Kilometers	Stratum		
			Bottom	Channel	Shoal
Yonkers	(YK)	19-39	*	X	X
Tappan Zee	(TZ)	39-55	X	X	X
Croton-Haverstraw	(CH)	55-63	X	X	X
Indian Point	(IP)	63-76	X	X	X
West Point	(WP)	76-90	X	X	**
Cornwall	(CW)	90-100	X	X	X
Poughkeepsie	(PK)	100-124	X	X	**
Hyde Park	(HP)	124-138	X	X	**
Kingston	(KG)	138-151	X	X	**
Saugerties	(SG)	151-172	X	X	**
Catskill	(CS)	172-201	X	X	**
Albany	(AL)	201-246	X	**	**

X Stratum was sampled in both programs
* Stratum not sampled due to obstructions
** Stratum not sampled - too shallow for sampling gear

to each region for the LRS and FSS programs, and a minimum of five samples was assigned to each region for the BSS. The actual location of samples within each region and/or stratum was randomly assigned.

A summary of general sampling information for each of the surveys is provided in Table II-2. The specific field and laboratory methods used for each survey are discussed below by task and survey.

B. FIELD METHODS

In the LRS, two types of gear were used to sample ichthyoplankton in the shoal, channel, and bottom strata. A Tucker trawl (Fig. II-3) was used to sample the channel, an epibenthic sled (Fig. II-4) was used to sample the bottom, and both gears were used to sample the shoal stratum (Fig. II-5). Each gear had a 1-m^2 opening, a 505-μm mesh net, and was towed against the current. The tow speed (maintained by use of electronic flowmeters mounted along side the vessel) was approximately 1 m/s for the epibenthic sled and 0.9 m/s for the trawl. When an electronic flowmeter failed to operate, tow speed was estimated based on engine RPM. Tow duration for each gear was approximately 5 min. Volume sampled was determined from digital flowmeters mounted in the mouth of the nets. Allocation of effort among regions and strata for the LRS is given in Tables II-3 through II-5. Samples taken during the first five weeks of LRS were collected during the day. All remaining samples were collected at night to decrease gear avoidance by post yolk-sac larvae and juveniles.

In the FSS, two types of gear were used to collect juvenile fish in the shoal, channel, and bottom strata. A 1-m^2 Tucker trawl (3000-μm mesh) was used for collecting samples in the channel, while a 3-m beam trawl with 1.3 cm mesh (Fig. II-6) was used for collections in the bottom and shoal strata. Both gears were towed against the current for approximately 5 min and the tow speed used for each gear was approximately 1.5 m/s (maintained by use of electronic flowmeters deployed along side the sampling vessel). Volume sampled was determined from digital flowmeters mounted in the mouth of the nets. Allocation of effort among regions and strata for the FSS is given in Table II-6. All Fall Shoal samples were collected at night in order to minimize gear avoidance.

Table II-2. Summary of 1985 sampling surveys

Name	Starting Date	Ending Date	Number of River Runs	Frequency of River Runs	Number of Samples Per River Run	Strata Sampled	Gear
Longitudinal River	29 Apr	11 Jul	11	Weekly	186-194	Bottom	1 m^2 epibenthic sled
						Channel	1 m^2 Tucker trawl
						Shoal	1 m^2 epibenthic sled or 1 m^2 Tucker trawl
Fall Shoals	22 Jul	14 Nov	9	Biweekly	200	Bottom	3 m beam trawl
						Channel	1 m^2 Tucker trawl
						Shoal	3 m beam trawl
Beach Seine*	16 Jul	21 Nov	10	Biweekly	100	Shore zone	30.5 m beach seine and YSI models 58 and 33
LR/FS Water Quality	29 Apr	14 Nov	20	Weekly/ Biweekly	164	Shoal	YSI models 57 and 33
						Channel	YSI models 57 and 33

* Including beach seine water quality data

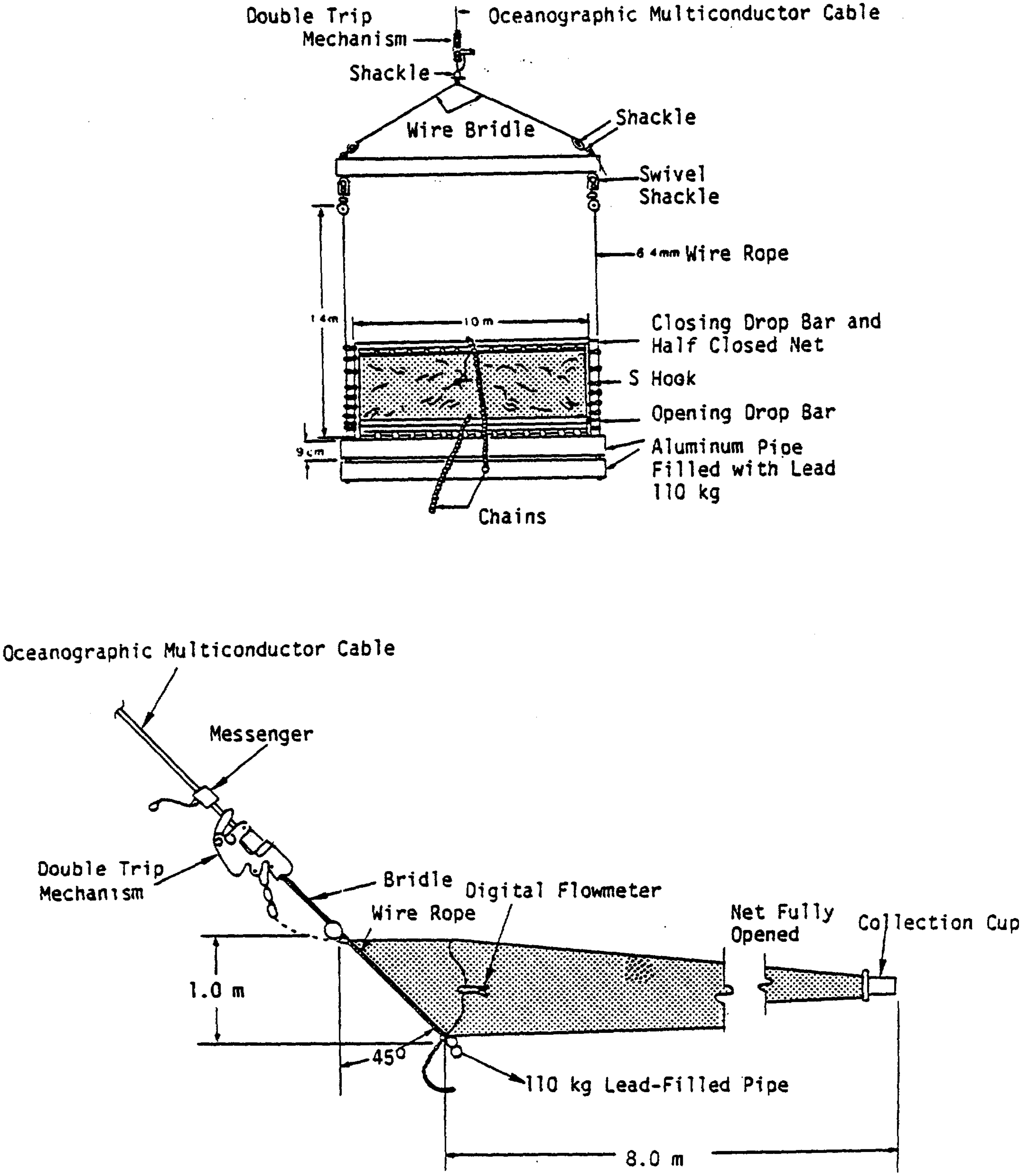


Figure II-3. 1.0 m^2 Tucker trawl (front view, top; side view, bottom) used in the Longitudinal River and Fall Shoals Surveys

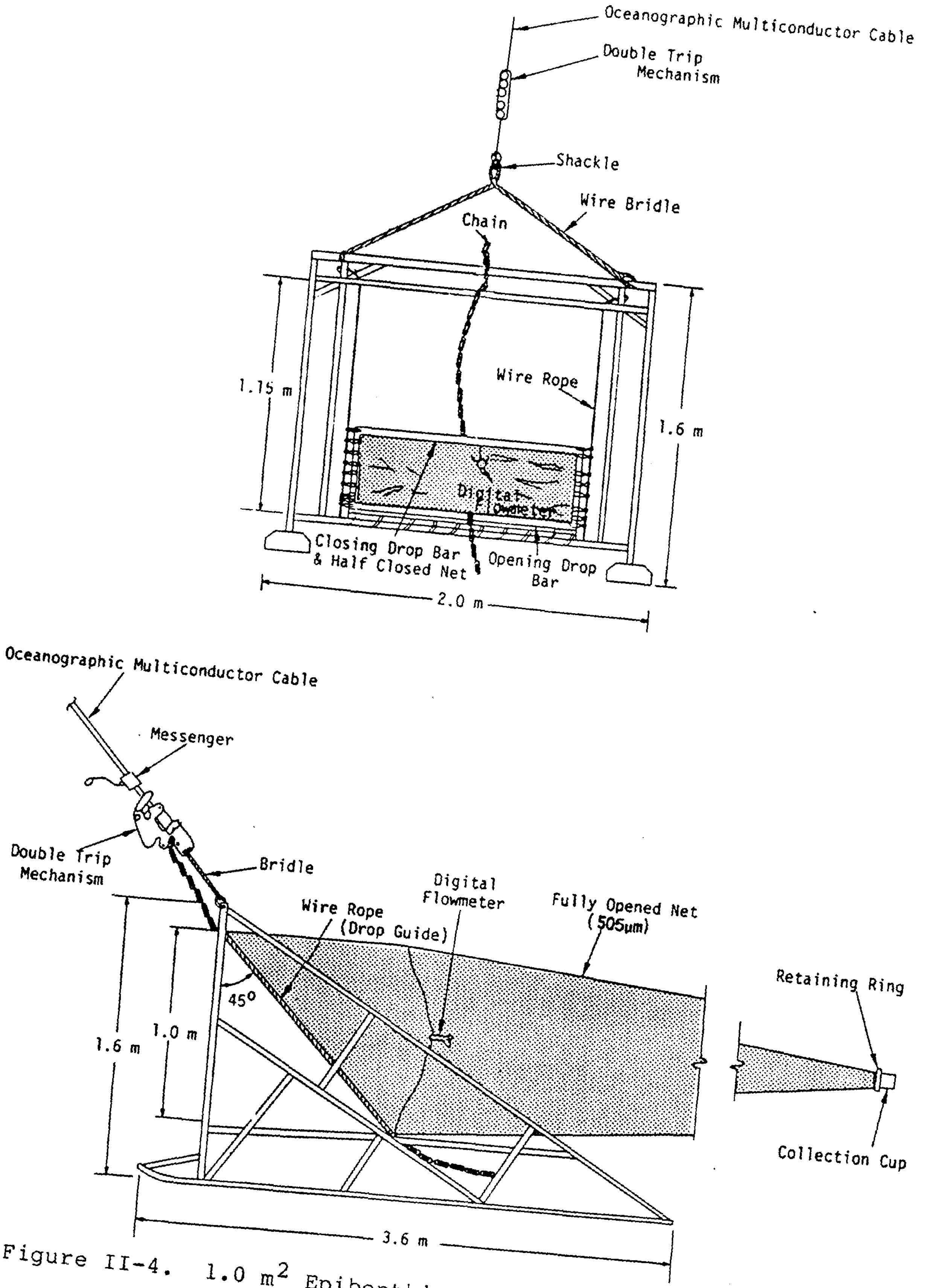


Figure II-4. 1.0 m^2 Epibenthic sled (front view, top; side view, bottom) used in the Longitudinal River Survey.

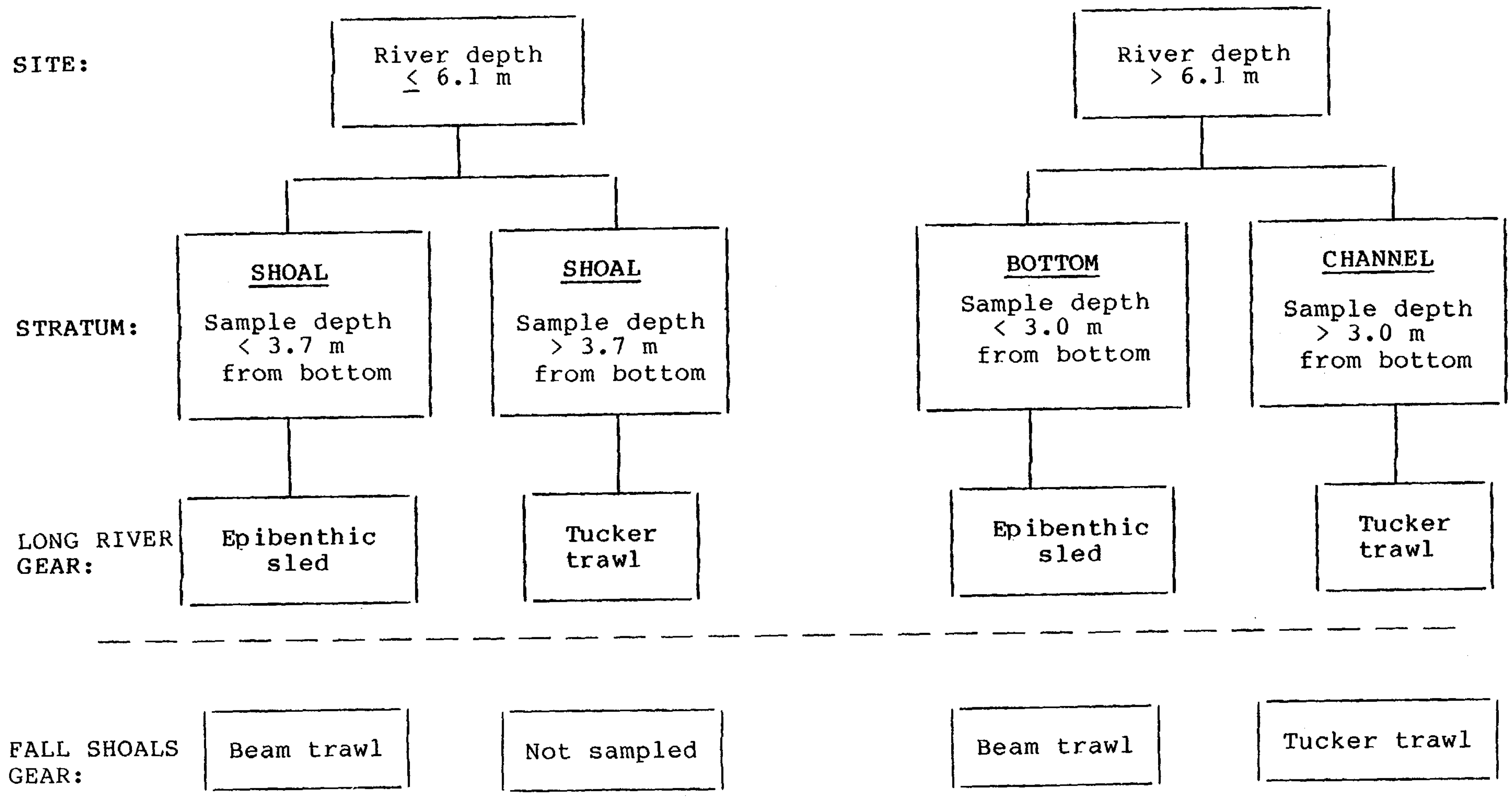


Figure II-5. Criteria for gear and strata allocations in the Longitudinal River and Fall Shoals Surveys during 1985

Table II-3. Weekly sample allocations for the 1985 Longitudinal River Survey during weeks beginning 29 April, 6 May, and 13 May

Region	Shoal (Sled)	Shoal (Trawl)	Bottom (Sled)	Channel (Trawl)	Total
Yonkers	2	1	-	3	6
Tappan Zee	2	1	4	3	10
Croton-Haverstraw	4	2	3	6	15
Indian Point	3	1	7	25	36
West Point	-	-	4	31	35
Cornwall	3	2	12	5	22
Poughkeepsie	-	-	10	10	20
Hyde Park	-	-	9	11	20
Kingston	-	-	6	7	13
Saugerties	-	-	3	3	6
Catskill	-	-	3	3	6
Albany	-	-	5	-	5
TOTAL	14	7	66	107	194*

* All samples were taken during the day.

Table II-4. Weekly sample allocations for the 1985 Longitudinal River Survey during weeks beginning 20 May, 27 May, and 3 June

Region	Shoal (Sled)	Shoal (Trawl)	Bottom (Sled)	Channel (Trawl)	Total
Yonkers	2	1	-	3	6
Tappan Zee	2	1	4	4	11
Croton-Haverstraw	3	2	4	4	13
Indian Point	2[a]	1[a]	6[b]	14[c]	23
West Point	-	-	7	23[d]	30
Cornwall	3	2	9	5[e]	19
Poughkeepsie	-	-	16	22	38
Hyde Park	-	-	7	12	19
Kingston	-	-	4	6	10
Saugerties	-	-	5	3	8
Catskill	-	-	3	3	6
Albany	-	-	3	-	3
TOTAL	12	7	68	99	186[f]

[a] No samples were taken during the week of 27 May.

[b] Seven samples were taken during the weeks of 27 May and 3 June

[c] Twelve and fifteen samples were taken during the weeks of 27 May and 3 June, respectively.

[d] Twenty-four samples were taken during the week of 20 May.

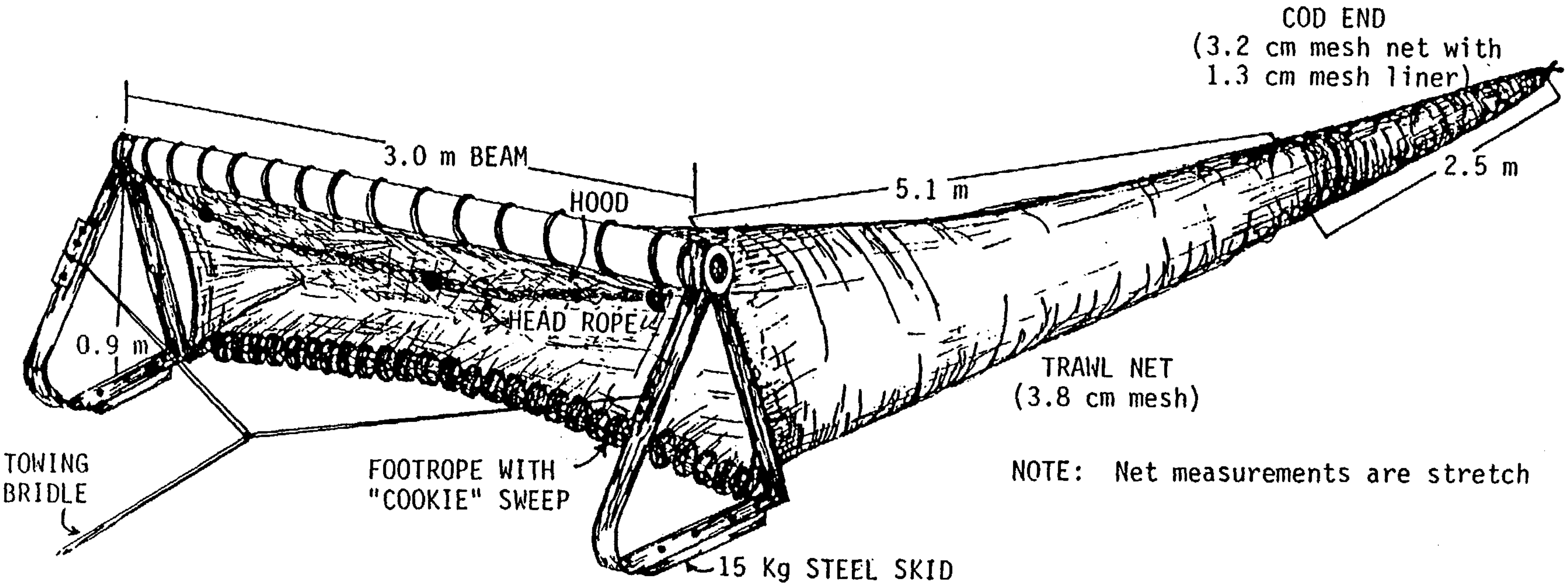
[e] Six samples were taken during the week of 3 June.

[f] Samples taken during the weeks of 20 May and 27 May were taken during the day. Samples taken during the week of 3 June were taken at night.

Table II-5. Weekly sample allocations for the 1985 Longitudinal River Survey during weeks beginning 10 June, 17 June, 24 June, 1 July, and 8 July

Region	Shoal (Sled)	Shoal (Trawl)	Bottom (Sled)	Channel (Trawl)	Total
Yonkers	1	-	-	8	9
Tappan Zee	2	1	5	6	14
Croton-Haverstraw	3	1	6	6	16
Indian Point	3	2	5	16	26
West Point	-	-	8	25	33
Cornwall	2	1	12	13	28
Poughkeepsie	-	-	7	15	22
Hyde Park	-	-	5	9	14
Kingston	-	-	4	6	10
Saugerties	-	-	4	2	6
Catskill	-	-	3	3	6
Albany	-	-	3	-	3
TOTAL	11	5	62	109	187*

* All samples were taken at night.



NOTE: Net measurements are stretch

Figure II-6. Schematic of the 3.0 meter beam trawl used in the Fall Shoals Survey

Table II-6. Biweekly sample allocations for the 1985 Fall Shoal Survey during 22 July to 14 November

	Strata			
Region	Shoal (Sled)	Bottom (Sled)	Channel (Trawl)	Total
Yonkers	7	-	5	12
Tappan Zee	30[a]	8[b]	8	46
Croton-Haverstraw	16	8	3	27
Indian Point	6	5[c]	3	14
West Point	-	5	3	8
Cornwall	5	5	3	13
Poughkeepsie	-	5	3	8
Hyde Park	-	6	4	10
Kingston	-	9[d]	6[e]	15
Saugerties	-	12	6	18
Catskill	-	15[f]	6[g]	21
Albany	-	8	-	8
TOTAL	64	86	50	200[h]

(a) Twenty-eight, thirty-one, and thirty-one samples were taken during the weeks of 22 July, 19 August, and 10 November, respectively.
(b) Seven samples were taken during the week of 10 November.
(c) Eight samples were taken during the week of 10 November.
(d) Ten samples were taken during the week of 22 July.
(e) Five samples were taken during the week of 22 July.
(f) Sixteen samples were taken during the week of 22 July.
(g) Five samples were taken during the week of 22 July.
(h) All samples were taken at night.

In the BSS, a 30.5 m bag beach seine was used to collect juvenile fish in the shore zone of each region. The two wings of the seine are each 2.4 m deep and 12.0 m long, and constructed of 2.0 cm stretch mesh. The 6.1 m bag is 3.0 m deep with 9.5 mm stretch mesh. The net was deployed by holding one end on shore and towing the other end perpendicularly away from the shore by boat. The seine was then hauled into the current in a semicircular path toward shore. The completed tow swept an area of approximately 450 m^2 (TI 1981). Allocation of samples among regions in the BSS are given in Table II-7. All beach seine samples were collected during the day.

For each survey, all yearling and older fish (length classes 2-4, Table II-8) were processed in the field. Fish were sorted by species, and the number in each length class was counted. These fish were then returned to the river. Juvenile fish (also called length class 1 or young-of-year) and earlier life stages were preserved in 10% formalin and sent back to the laboratory for processing.

All sturgeon that were collected were measured to the nearest millimeter and weighed to the nearest gram. Fish that remained alive were returned to the river; those that were dead were frozen and held at the laboratory for the New York State Department of Environmental Conservation (NYSDEC).

C. LABORATORY METHODS

Longitudinal River Survey

Eggs and early life stages were sorted by taxonomic group and life stage (Table II-9), enumerated, and placed in vials containing 5% formalin. For samples of fish eggs or bay anchovy larvae that appeared to contain over 4000 specimens, vials containing these groups were split to one-half, one-fourth, or one-eighth of the original number using a Folsom plankton splitter.

Only American shad, white perch, and striped bass were measured for total length. Whenever possible, 30 individuals of each of these species were measured per sample. When available, at least 10 individuals per life stage were measured. When fewer than 10 specimens of a life stage were encountered, the remainder of the quota was allocated to remaining life stages.

Table II-7. Biweekly sample allocation for the 1985 Beach Seine Survey during 16 July to 21 November

Region	Number of Beaches Sampled
Yonkers	5
Tappan Zee	24
Croton-Haverstraw	14
Indian Point	5
West Point	5
Cornwall	6
Poughkeepsie	5
Hyde Park	5
Kingston	5
Saugerties	9
Catskill	10(a)
Albany	7
TOTAL	100(b)

(a) Eleven samples were taken during the week of 23 September.

(b) All samples were taken during the day.

Table II-8. Length class divisions as defined for fish collected from the Hudson River estuary during 1985

Length Class	Total Length Range (millimeters)
1	0 mm up to Division 1
2	Division 1 + 1 mm up to Division 2
3	Division 2 + 1 mm up to 250 mm
4	251 mm and larger

NOTE: Division 1 and Division 2 represent the upper length limits of young-of-year and yearling age groups, respectively. Division 1 and Division 2 were determined separately for each species as part of the impingement program at the Indian Point power station.

Table II-9. Criteria used for determining life stage of ichthyoplankton

Life Stage	Criterion
Egg	Embryonic stage from spawning to hatching
Yolk-sac larva	From hatching to development of a complete and functional digestive system
Post yolk-sac larva	From development of a complete digestive system to acquisition of a full complement of adult fin rays
Young-of-year (or juvenile)	From stage when the full complement of adult fin rays is acquired to 31 December of the year spawned

Beach Seine and Fall Shoals

All length class 1 fish were identified and counted according to species. In addition, the total length of 12 species was measured to the nearest millimeter (Table II-10).

Up to 10 fish in length class 1 per species were measured for samples taken in the following regions:

Survey	Regions
BSS	Yonkers, Indian Point, West Point, Cornwall, Poughkeepsie
FSS	West Point, Poughkeepsie

For all other regions, up to five fish per species per sample were measured. When more specimens of a species were collected than were needed for length measurements, the fish used to fill the quota were randomly selected.

D. WATER QUALITY

Two sets of water quality measurements were taken during the 1985 sampling period. One set of measurements was taken in conjunction with every beach seine collection. Measurements were taken 0.3 m below the water surface and approximately 15 m from the shoreline.

A separate water quality survey was conducted in association with the LRS and FSS programs. Unlike the BSS, measurements were not taken at the time of each fish collection. Water quality sample locations for this survey were fixed and allocated by region (Table II-11). In the channel locations, samples were taken at surface, bottom, and mid-depth. For shoal samples only surface and bottom samples were collected.

For both water quality surveys, the following parameters were measured *in situ*: temperature to the nearest 0.1°C, dissolved oxygen to the nearest 0.1 mg/l, conductivity to the nearest 10 μS/cm, and sampling depth to the nearest 0.1 m.

Table II-10. Fish species for which length measurements (TL) were taken during 1985

Beach Seine and Fall Shoals Surveys

- alewife
- American shad
- Atlantic sturgeon
- Atlantic tomcod
- bay anchovy
- blueback herring
- shortnose sturgeon
- spottail shiner
- striped bass
- weakfish
- white catfish
- white perch

Longitudinal River Survey

- American shad
- striped bass
- white perch

Table II-11. Sample locations (river mile) for the 1985 Longitudinal River and Fall Shoals Water Quality Survey

Region	Sampling Locations Shoals	Sampling Locations Channel	Number of Samples Per Region
Yonkers	19	14, 17, 19, 22	16
Tappan Zee	29	25, 27, 29, 32	16(a)
Croton-Haverstraw	36	35, 36, 37, 38	16(b)
Indian Point	43	40, 42, 43, 46	16(c)
West Point	--	49, 51, 53, 55	12
Cornwall	59	56, 57, 59, 61	16
Poughkeepsie	--	63, 67, 71, 75	12
Hyde Park	--	78, 80, 82, 84	12
Kingston	--	87, 89, 91, 93	12(d)
Saugerties	--	96, 99, 102, 105	12
Catskill	--	109, 114, 118, 122	12
Albany	--	127, 131, 135, 138	12
TOTAL			164

(a) Thirteen samples were taken during the week of 27 May.

(b) Seventeen, eighteen, and eighteen samples were taken during the weeks of 22 July, 14 October, and 10 November, respectively.

(c) Six and thirteen samples were taken during the weeks of 27 May and 8 July, respectively.

(d) Nine samples were taken during the week of 8 July.

Dash indicates that no samples were taken due to limited stratum.

E. ANALYTICAL METHODS

Water Quality

In order to display the spatial and temporal patterns of temperature, conductivity, salinity, and dissolved oxygen, a mean of each parameter for each region and sampling week, weighted by stratum volume, was calculated. Equation (1) was used to compute these means for the standard water quality stations sampled in conjunction with the LRS and FSS. Equation (2) was used for data taken in conjunction with the BSS. Overall weekly and regional means were computed using Eqs. (3) and (4). The mean of each water quality parameter was calculated for each of three estuary segments that have been defined in previous Year Class Reports: lower estuary (Yonkers to Croton-Haverstraw), middle estuary (Indian Point to Poughkeepsie), and upper estuary (Hyde Park to Albany) using Eq. (5). Salinity data were computed from conductivity data using Eq. (6) (Aanderaa Instruments 1983). The 1985 conductivity had been adjusted to a constant temperature of 25°C. These data were reconverted to raw conductivity for the conversion to salinity.

$$W_{rw} = \sum_{k=1}^{n_{rw}} P_{kr} \left[\frac{1}{n_{krw}} \sum_{d=1}^{n_{krw}} \left(\frac{1}{n_{dkrw}} \sum_{i=1}^{n_{dkrw}} W_{idkrw} \right) \right] \quad (1)$$

where

W_{rw} = weighted mean of a water quality parameter in region r during week w of the LRS and FSS

W_{idkrw} = water quality measurement for location i, at depth d, in stratum k, in region r, during week w

P_{kr} = proportion of the river volume of region r that is contained by stratum k (bottom and channel strata were combined for water quality analysis)

n_{dkrw} = number of sites at which measurements were made at depth d, in stratum k, in region r, during week w

n_{krw} = number of depths sampled in stratum k, in region r, during week w

n_{rw} = number of strata sampled in region r during week w.

$$W_{rw} = \frac{1}{n_{rw}} \sum_{i=1}^{n_{rw}} W_{irw} \qquad (2)$$

where

W_{rw} = mean of a water quality parameter in region r during biweek w of the BSS

W_{irw} = water quality measurement for location i, in region r, during biweek w

n_{rw} = number of water quality measurements taken in region r during biweek w.

$$W_w = \sum_{r=1}^{12} (P_r)(W_{rw}) \qquad (3)$$

where

W_w = mean of a water quality parameter during sampling week w

P_r = proportion of the river volume contained in region r

W_{rw} = weighted mean of a water quality parameter calculated in Eq. (1).

$$W_r = \frac{1}{n_r} \sum_{w}^{n_r} W_{rw} \qquad (4)$$

where

W_r = mean of a water quality parameter in region r

n_r = number of weeks sampled in region r

W_{rw} = weighted mean of a water quality parameter calculated in Eq. (1).

$$W_{sw} = \sum_{r}^{n_s} (P_{rs})(W_{rw}) \qquad (5)$$

where

W_{sw} = mean of a water quality parameter in estuary segment s

P_{rs} = proportion of the estuary segment volume contained in region r

n_s = number of regions sampled in segment s

W_{rw} = weighted mean of a water quality parameter calculated in Eq. (1).

$$\begin{aligned} \text{Salinity} = {} & (-0.08996) + (28.8567)(R) + (12.18882)(R^2) \\ & - (10.61869)(R^3) + (5.98624)(R^4) - (1.32311)(R^5) \\ & + [R(R - 1.0)(0.0442)(T)] - (0.00046)(T^2) - (0.0040)(R)(T) \\ & + [(0.000125 - 0.0000029)(T)(P)] \end{aligned} \qquad (6)$$

where

T = water temperature (°C)

P = pressure (dbar)

$$R = \frac{RST}{RT}$$

where

$$RST = \frac{RSTP}{1.0 + F}$$

$$\begin{aligned} RT = {} & (0.6765836) + (2.005294)(TD) + (1.11099)(TD^2) \\ & - (0.726684)(TD^3) + (0.13587)(TD^4) \end{aligned}$$

$$RSTP = \frac{C}{42.906}$$

$$F = \frac{(1.60836x10^{-5})(P) - (5.4845x10^{-10})(P^2) + (6.166x10^{-15})(P^3)}{(1.0) + (0.030786)(T) + (0.0003169)(T^2)}$$

$$TD = \frac{T}{100.0}$$

C = conductivity (mS/cm).

Density Estimates

Estimates of the population density were made for the LRS and FSS. For these two surveys, the number of fish (by taxon and life stage) in individual samples was first converted to density (number per cubic meter of water sampled) using Eq. (7). The mean density and the standard error of the mean were calculated for each stratum, region, and sampling week using Eqs. (8) and (9). To obtain a mean density and standard error for each region during each sampling week, the stratum densities were weighted by the proportion of the regional river volume found in the stratum [Eq. (10) and (11)]. If a stratum was not sampled, its volume was added to the volume of an adjacent stratum which was sampled. Stratum volume adjustments were made according to the following rules:

If this stratum was missing:	Its volume was added to this stratum:
Shoal	Bottom
Channel	Bottom
Bottom	Channel

$$D_{ikrw} = \frac{C_{ikrw}}{V_{ikrw}} \qquad (7)$$

where

D_{ikrw} = density (for a life stage and a taxon) per cubic meter for sample i, in stratum k, in region r, during week w

C_{ikrw} = number of fish caught in sample i, in stratum k, in region r, during week w

V_{ikrw} = volume sampled (m^3) by sample i, in stratum k, in region r, during week w.

$$D_{krw} = \frac{1}{n_{krw}} \sum_{i=1}^{n_{krw}} D_{ikrw} \qquad (8)$$

where

D_{krw} = average density in stratum k, in region r, during week w

D_{ikrw} = sample density calculated in Eq. (7)

n_{krw} = number of samples taken in stratum k, in region r, during week w.

$$SE(D_{krw}) = \sqrt{\frac{\sum_{i=1}^{n_{krw}} (D_{ikrw} - D_{krw})^2}{(n_{krw})(n_{krw} - 1)}} \qquad (9)$$

where

$SE(D_{krw})$ = standard error of the average density in stratum k, in region r, during week w

D_{ikrw} = sample density calculated in Eq. (7)

D_{krw} = average stratum density calculated in Eq. (8)

$$D_{rw} = \sum_{k=1}^{n_{rw}} (D_{krw})(P_k) \qquad (10)$$

where

D_{rw} = average density in region r during week w

D_{krw} = average stratum density calculated in Eq. (8)

$^*P_k$ = proportion of the regional river volume found in stratum k (see Table II-12)

n_{rw} = number of strata sampled in region r during week w.

$$SE(D_{rw}) = \sqrt{\sum_{k=1}^{n_{rw}} \left[SE(D_{krw})^2 \quad (P_k)^2 \right]} \qquad (11)$$

where

$SE(D_{rw})$ = standard error of the average density in region r during week w

$SE(D_{krw})$ = standard error of the average stratum density calculated in Eq. (9)

Catches from the BSS were reported as number caught per seine haul (CPUE) by life stage and taxon. The average CPUE for a region and its standard error were calculated using Eqs. (12) and (13).

$$C_{rw} = \frac{1}{n_{rw}} \sum_{i=1}^{n_{rw}} C_{irw} \qquad (12)$$

where

C_{rw} = average CPUE in region r during week w

C_{irw} = CPUE for sample i in region r during week w

n_{rw} = number of samples taken in region r during week w.

---

* When a stratum is missing, P_k for the sampled stratum is equal to the sum of the P_k for the sampled stratum and the P_k for the unsampled stratum.

Table II-12. Stratum and region volumes (m^3) and surface areas (m^2) used in analysis of the 1985 Hudson River Year Class data

Geographic Region	Channel Volume	Bottom Volume	Shoal Volume	Region Volume	Shore Zone Surface Area
Yonkers	143,452,543	59,312,978*	26,654,767	229,420,288	3,389,000
Tappan Zee	138,000,768	62,125,705	121,684,992	321,811,465	20,446,000
Croton-Haverstraw	61,309,016	32,517,633	53,910,105	147,736,754	12,101,000
Indian Point	162,269,471	33,418,632	12,648,163	208,336,266	4,147,000
West Point	178,830,022	25,977,862	2,647,885**	207,455,769	1,186,000
Cornwall	94,882,267	36,768,629	8,140,123	139,791,019	4,793,000
Poughkeepsie	228,975,052	63,168,132	5,990,260**	298,133,444	3,193,000
Hyde Park	131,165,041	32,012,000	2,307,625**	165,484,666	558,000
Kingston	93,657,021	35,479,990	12,332,868**	141,469,879	3,874,000
Saugerties	113,143,296	42,845,077	20,307,338**	176,295,711	7,900,000
Catskill	83,924,081	42,281,206	34,526,456**	160,731,743	8,854,000
Albany	32,025,080**	13,517,183	25,606,842**	71,149,105	6,114,000
TOTAL	1,461,633,658	479,425,027	326,757,424	2,267,816,109	76,555,000

*Volume added to channel stratum for analytical purposes.
**Volume added to bottom stratum for analytical purposes.

$$SE(C_{rw}) = \sqrt{\frac{\sum_{i=1}^{n_{rw}} (C_{irw} - C_{rw})^2}{n_{rw}\ (n_{rw} - 1)}} \qquad (13)$$

where

$SE(C_{rw})$ = standard error of average CPUE in region r during week w

C_{rw} = average regional CPUE calculated in Eq. (12)

Standing Crop

Standing crop (the number of fish in an area at a particular time) was estimated by life stage and taxon for each of the three surveys. Standing crop estimates and the associated standard errors were calculated for each stratum in a region by taking the product of the average stratum density (or the standard error) and the volume of water contained in that stratum [Eqs. (14) and (15) for LRS and FSS; Table II-12]. The regional standing crop was then estimated as the sum of the stratum standing crops [Eqs. (16) and (17)]. Similarly, an estimate of the standing crop for the river for each week was calculated by summing the standing crops for the 12 river regions [Eqs. (18) and (19)].

$$SC_{krw} = (V_{kr})(D_{krw}) \qquad (14)$$

where

SC_{krw} = standing crop estimate for stratum k, in region r, during week w

V_{kr} = river volume contained by stratum k in region r

D_{krw} = average stratum density calculated in Eq. (8).

$$SE(SC_{krw}) = (V_{kr})[SE(D_{krw})] \qquad (15)$$

where

$SE(SC_{krw})$ = standard error of the standing crop estimate for stratum k, in region r, during week w

$SE(D_{krw})$ = standard error of average stratum density calculated in Eq. (9).

$$SC_{rw}{}^{*} = \sum_{k=1}^{3} SC_{krw} \qquad (16)$$

where

SC_{rw} = standing crop estimate for region r during week w

SC_{krw} = stratum standing crop estimate calculated in Eq. (14).

$$SE(SC_{rw})^{*} = \sqrt{\sum_{k=1}^{3} [SE(SC_{krw})]^{2}} \qquad (17)$$

where

$SE(SC_{rw})$ = standard error of standing crop estimate for region r during week w

$SE(SC_{krw})$ = standard error of stratum standing crop estimate calculated in Eq. (15).

---

*Volumes of unsampled strata were added to the volumes of an adjacent stratum according to the rules for stratum volumes listed on page II-25.

$$SC_w = \sum_{r=1}^{12} SC_{rw} \tag{18}$$

where

SC_w = standing crop estimate for week w

SC_{rw} = regional standing crop estimate calculated in Eqs. (16) and (20).

$$SE(SC_w) = \sqrt{\sum_{r=1}^{12} [SE(SC_{rw})]^2} \tag{19}$$

where

$SE(SC_w)$ = standard error of standing crop estimate for week w

$SE(SC_{rw})$ = standard error of regional standing crop estimate calculated in Eqs. (17) and (21).

An estimate of regional standing crop (and standard error) for the BSS was obtained by multiplying CPUE and the surface area of the shore zone, and dividing by the empirically derived estimate of the area sampled by the 30.5-m beach seine [Eqs. (20) and (21)]. The weekly estimate of standing crop for the shore zone was calculated as the sum of the 12 regional standing crops [Eqs. (18) and (19)].

$$SC_{rw} = \frac{C_{rw}\ A_r}{A} \tag{20}$$

where

SC_{rw} = standing crop estimate for the shore zone in region r during week w

C_{rw} = average regional CPUE calculated in Eq. (12)

A_r = surface area (m^2) of the shore zone in region r

A = surface area (m^2) sampled by the beach seine (450 m^2, TI 1981).

$$SE(SC_{rw}) = \frac{[SE(C_{rw})](A_r)}{A} \quad (21)$$

where

$SE(SC_{rw})$ = standard error of standing crop estimate for the shore zone in region r during week w

$SE(C_{rw})$ = standard error of average regional CPUE calculated in Eq. (13).

Temporal and Geographic Distribution Indices

Distribution indices were computed to facilitate presentation of changes in distribution of selected species and life stages through time and space. A geographic index which collapse data over weeks was calculated for LRS and BSS data as the relative density in each region (Eq. 22). To allow comparisons of 1985 with historical data, only April through July data were used for LRS and data from weeks 33 to 40 (where week 1 is the first Monday in January) were used for the BSS. In all cases, data were only used when all 12 regions were sampled.

$$G_{ry} = \frac{\sum_{w=1}^{n_y} D_{rwy}}{\sum_{r=1}^{12} \sum_{w=1}^{n_y} D_{rwy}} \quad (22)$$

where

G_{ry} = geographic index for region r in year y

D_{rwy} = regional density for week w in year y calculated in Eq. (10) (or regional CPUE calculated in Eq. (12) for BSS

n_y = number of weeks sampled in year y

A temporal index that collapses data for the entire river was computed for early life stages from LRS standing crops (Eq. 23).

$$T_w = \frac{SC_{wy}}{\sum_{w=1}^{n_y} SC_{wy}} \qquad (23)$$

where

T_{wy} = temporal index for week w in year y

SC_{wy} = weekly standing crop estimate in year y calculated in Eq. 18

n_y = number of weeks sampled in year y

III. WATER QUALITY

Two water quality surveys were conducted in conjunction with fish sampling: the Longitudinal River/Fall Shoals (LR/FS) and the Beach Seine surveys. This chapter emphasizes results from the LR/FS water quality survey since it is the only one to encompass the entire fish sampling period. However, water temperature, salinity (converted from conductivity measurements), and dissolved oxygen data are discussed for both surveys. Freshwater flow data were obtained from the Green Island station at Troy, New York, and are used to assist in further description and interpretation of water quality patterns in the Hudson River.

A. TEMPERATURE

Mean water temperature measured during the LR/FS water quality survey increased from the beginning of sampling in April to the end of July, stayed relatively constant through August, and then decreased gradually from September until the end of the sampling program in early November (Table III-1). Peak temperatures occurred during the week beginning 22 July when the riverwide mean was 25.1°C and regional mean values were between 24.7 and 26.0°C (Table A-1). Lowest values occurred during the last week of sampling when mean riverwide temperature was 12.2°C and regional temperatures ranged from 8.9 to 14.7°C.

Comparison of temperature patterns of 1985 with that in previous years (Appendix D) indicates that peak temperatures in 1985 were lower than in most previous years. No mean weekly regional temperature exceeded 26°C in 1985. In previous years, peak regional values regularly exceeded 27°C and in 1982 even exceeded 30°C.

The highest mean regional temperature (pooled over all dates) was found in the Croton-Haverstraw region (Table III-2). The lowest mean value occurred in the Yonkers region, but the difference between the highest and lowest regional values was less than one degree. The upper estuary was generally warmer than downriver areas during the spring, but was several degrees colder in the fall (Fig. III-1), a pattern also observed in previous years (Appendix D).

Weekly mean temperatures in the BSS were highest in late July and August just after the BSS was first initiated (Table III-3). Temperatures fell rapidly in October from almost 19°C

Table III-1. Weekly mean temperature, salinity, and dissolved oxygen measured in the LR/FS water quality survey of the Hudson River in 1985

Week Beginning	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
29 April	12.7	2.7	10.2
06 May	13.8	2.9	9.8
13 May	16.5	2.4	9.9
20 May	17.5	2.6	9.5
27 May	19.2	2.6	8.9
03 June	20.1	2.5	8.5
10 June	20.5	3.0	7.9
17 June	20.9	2.8	8.1
24 June	21.7	2.6	8.6
01 July	21.6	4.0	7.8
08 July	23.4	3.1	7.4
22 July	25.1	3.8	7.3
05 August	24.6	3.3	8.2
19 August	25.0	4.1	6.4
02 September	23.8	3.8	6.7
16 September	21.5	4.2	7.5
30 September	20.4	2.7	7.7
14 October	17.1	3.0	8.2
28 october	14.6	2.0	9.2
11 November	12.2	4.5	9.1

Table III-2. Regional mean temperature, salinity, and dissolved oxygen values (pooled over all weeks) measured in the LR/FS water quality survey of the Hudson River in 1985

Region*	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
YK	19.2	12.3	7.2
TZ	19.7	7.8	8.5
CH	20.3	5.0	8.4
IP	20.0	3.3	8.0
WP	19.5	1.5	8.1
CW	19.7	0.7	8.4
PK	19.7	0.1	8.0
HP	19.4	0.0	8.3
KG	19.4	0.0	9.2
SG	19.5	0.0	9.6
CS	19.6	0.0	8.9
AL	19.5	0.0	7.7

* See Table II-1 for explanation of region abbreviations

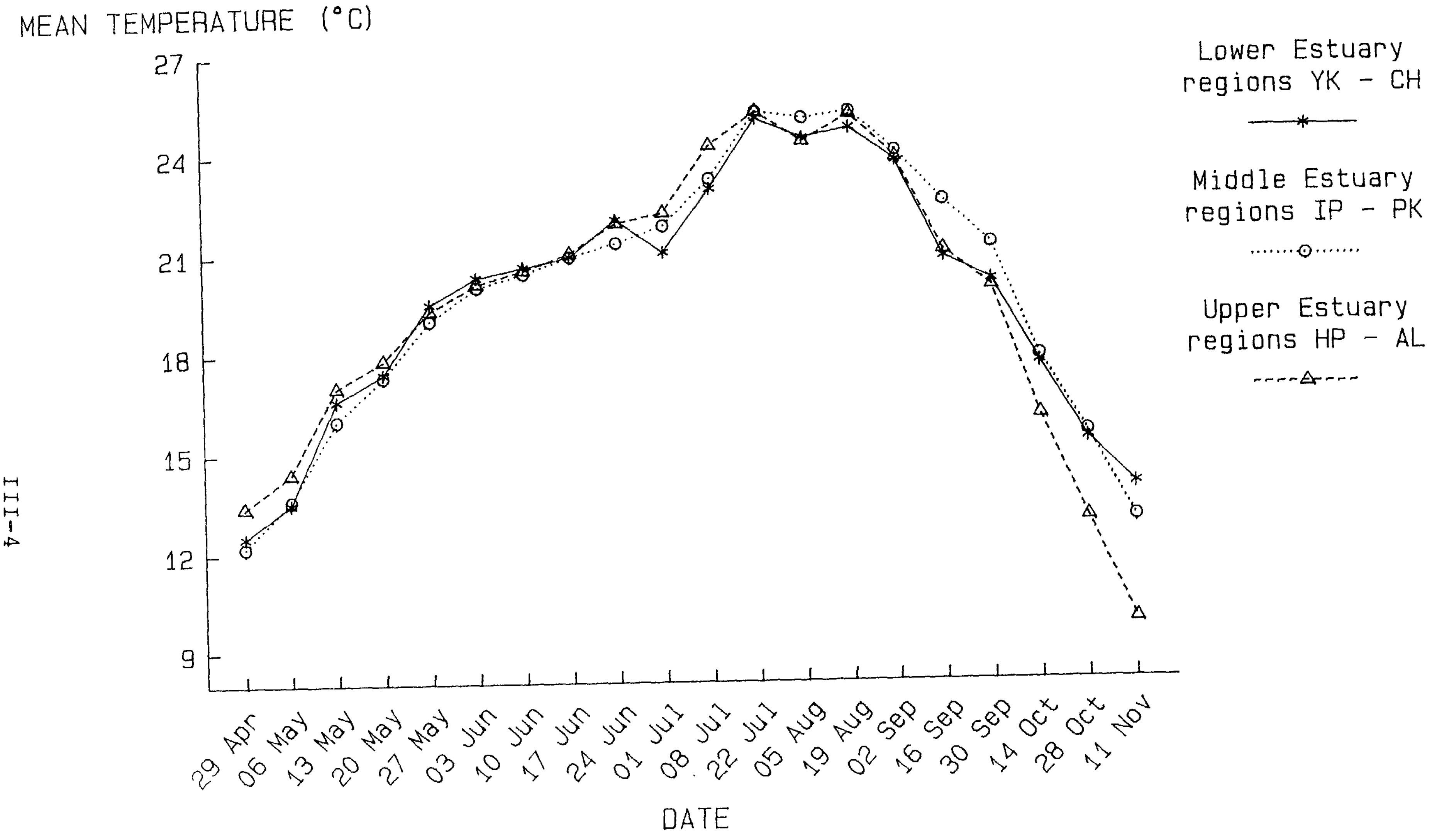


Figure III-1. Weekly mean temperature measured in the LR/FS water quality survey of the Hudson River in 1985

Table III-3. Weekly mean temperature, salinity, and dissolved oxygen measured in the Hudson River Beach Seine Survey in 1985

Week Beginning	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
15 July	26.0	4.3	8.9
29 July	25.2	3.1	7.9
12 August	26.8	3.2	9.7
26 August	25.3	3.7	7.7
09 September	24.0	4.8	7.2
23 September	21.2	6.3	8.5
07 October	18.9	1.9	8.9
21 October	15.3	1.6	9.2
04 November	13.0	4.5	9.7
18 November	9.6	1.4	10.4

during the week of 7 October to less than 10°C by mid-November. Temporal patterns in the BSS temperature data were generally in agreement with LR/FS measurements.

The highest mean regional temperature in the BSS (pooled over all dates) occurred in the Indian Point region and the lowest in the Albany region (Table III-4). Unlike the LR/FS survey, the difference in mean temperature among regions was more than 3°C. However, the BSS focuses primarily on the latter weeks of the LR/FS survey when the upper estuary was also found to be several degrees colder than the lower or middle estuary in the LR/FS survey.

B. SALINITY

Mean salinity in the river was higher in 1985 than in any other year since Year Class studies were undertaken (1974-1984). Mean salinity in the river remained above 2 ppt in every week of the study (Table III-1); in no other year had salinity remained above even 1 ppt in all weeks (Appendix D). In past years, mean salinity has generally been higher in July and August than in the spring. In 1985, the same pattern was also apparent, but the difference in salinity among these periods was less.

As might be anticipated, mean salinity was highest in the Yonkers region and declined with distance upriver (Table III-2). Salinity values in 1985 were consistently high (Fig. III-2), with values in the middle estuary never equal to zero as had been observed in all previous years. The highest weekly mean in the Yonkers region was 10 ppt, but unlike all previous years, no weekly value in that region ever fell below 7 ppt (Appendix D). Similarily, weekly mean salinity in the Tappan Zee region never fell below 5 ppt during the study, even though one or more weekly mean values in this region fell below 1 ppt in every other year of the study.

The salinity patterns observed in the BSS were similar to those observed in the LR/FS water quality survey. Mean salinity was highest in the Yonkers region and decreased upstream (Table III-4); mean weekly salinity never exceeded 0.5 ppt in any region north of Cornwall (Tables A-5 and A-6). Mean weekly salinities for the river exceeded 1 ppt in all weeks, with a high value of 6.3 ppt in late September (Table III-3).

The higher than average salinity in the river can be explained by the low freshwater flow in 1985 (Table III-5). Monthly flows in 1985 were lower than the long-term average in all but two months (January and November). Total freshwater flow for the year was lower than in any year since 1974, except

Table III-4. Regional mean temperature, salinity, and dissolved oxygen values (pooled over all weeks) measured in the Hudson River Beach Seine Survey in 1985

Region*	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
YK	20.9	9.7	8.3
TZ	21.0	6.6	9.6
CH	21.5	4.9	9.5
IP	22.1	3.8	8.7
WP	21.0	1.2	8.4
CW	20.6	0.6	8.7
PK	20.6	0.1	8.2
HP	19.5	0.0	8.3
KG	19.5	0.0	9.3
SG	19.5	0.1	9.4
CS	19.5	0.1	9.1
AL	18.6	0.1	8.2

* See Table II-1 for explanation of region abbreviations

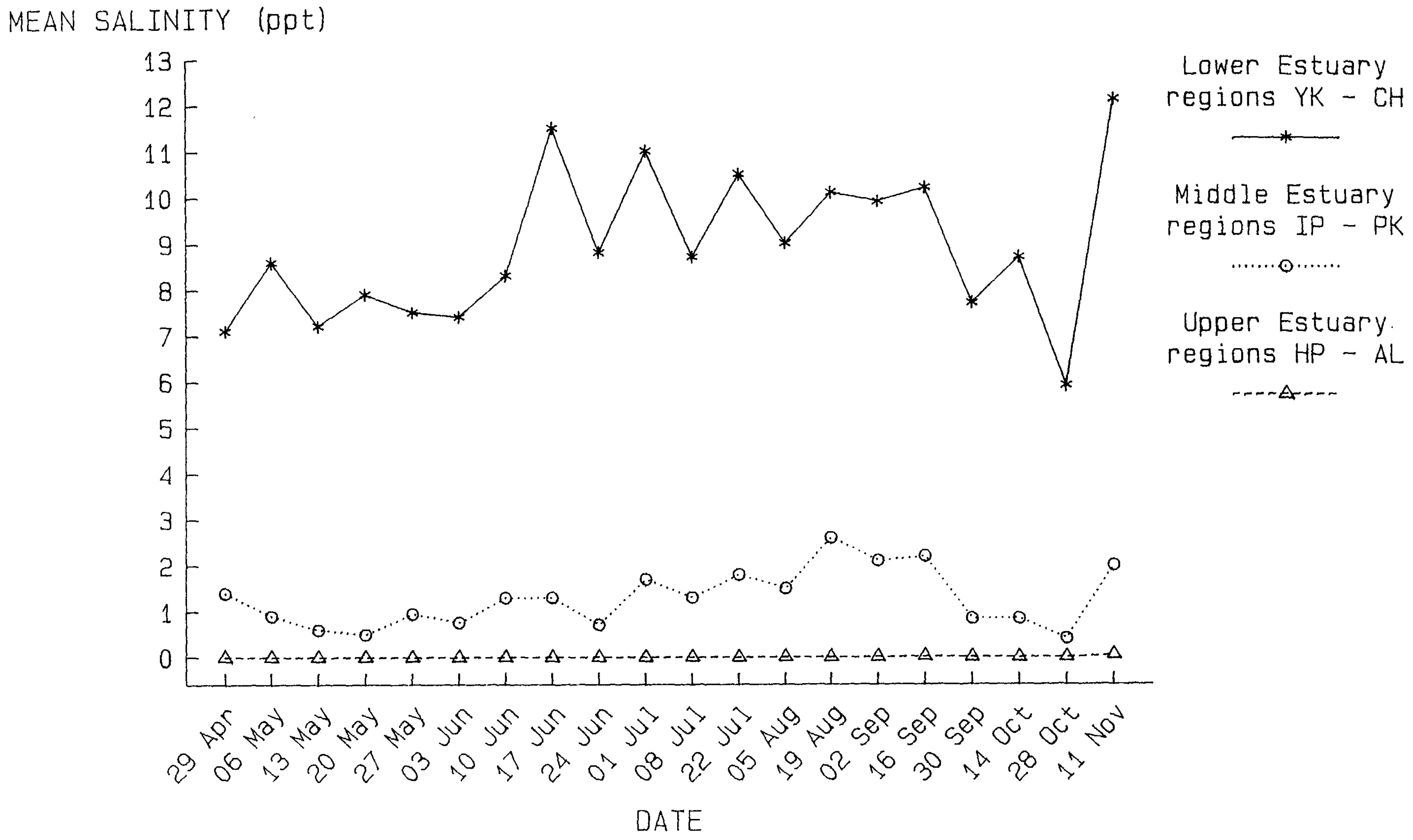


Figure III-2. Weekly mean salinity measured in the LR/FS water quality survey of the Hudson River in 1985

Table III-5. Long-term (1918-1984) and 1985 mean daily freshwater flow (m^3/sec) at Green Island, New York

	Flow (m^3/sec)			
Month	1985 Average	Long-Term Average[a]	Long-Term Minimum	Long-Term Maximum
Jan	440	370	91	961
Feb	319	362	86	885
Mar	581	640	178	1595
Apr	456	887	290	1461
May	232	551	137	1156
Jun	157	279	92	839
Jul	133	195	81	637
Aug	104	158	70	414
Sep	171	180	81	612
Oct	206	240	72	854
Nov	423	353	93	929
Dec	338	402	123	948
Annual Average	296[b]	385		

[a] Simple mean of monthly means (based on Battelle 1983).
[b] Mean of monthly means weighted by number of days/month.

1980. Flow in April was lower than in all years since 1974 except 1980, and in May, June and August was the lowest since 1974 (Table III-6).

C. DISSOLVED OXYGEN

Dissolved oxygen values measured during the LR/FS water quality survey were highest in May with weekly mean values for the river exceeding 8 ppm until mid-June (Table III-1). Dissolved oxygen values were lowest in mid-summer with weekly mean values falling below 7 ppm from mid-August through early September. Dissolved oxygen values increased again in the fall.

This pattern of oxygen decline during summer has been observed in all previous Year Class Reports (Martin Marietta Environmental Systems 1986) and is primarily attributable to the higher temperatures that occur during the warmer months (Fig. III-4). Percent oxygen saturation remained relatively high throughout the sampling period across the entire river, with some decline in the summer (Fig. II-4). The lowest weekly mean dissolved oxygen value observed in 1985 is within the range of historical values. The highest weekly mean oxygen value in 1985 has been exceeded in many years, but these higher historical values were associated with earlier studies when sampling schedules extended into colder months.

Dissolved oxygen (DO) values were generally similar in the different segments of the river (Fig. III-3); however, DO values were several ppm higher in the upper estuary at the end of the surveys (i.e., fall), coincident with the lower temperatures that occurred there at that time. Percent oxygen saturation was also higher in the upper estuary than in the rest of the river in July and August. Highest regional mean dissolved oxygen (pooled over all dates) occurred in the Saugerties region, while the lowest regional mean occurred in Yonkers (Table III-2).

Dissolved oxygen patterns in the BSS were similar to that in the LR/FS survey: highest values occurred in the fall (Table III-3) and there was little longitudinal pattern in mean regional concentrations (Table III-4). Dissolved oxygen values were generally about 1 ppm higher in the BSS survey than in the LR/FS when regional/weekly means are compared (Appendix A). This is consistent with similar comparisons made in previous years and may be related to diel changes in oxygen; the BSS is conducted during the day (when oxygen concentrations are expected to be highest) and the LR/FS survey is conducted during the night.

Table III-6. Monthly mean daily freshwater flow (m^3/sec) at Green Island, New York

	Year											
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
January	623	540	417	225	745	571	256	148	321	259	308	440
February	528	549	885	227	400	336	128	851	361	352	742	319
March	587	671	897	1233	619	1253	634	349	620	581	465	581
April	854	724	1041	1149	950	1080	748	385	1085	1063	940	456
May	650	566	901	454	530	554	274	328	354	1037	844	232
June	249	367	431	207	282	236	192	169	432	358	418	157
July	334	211	433	162	131	132	144	140	182	127	289	133
August	180	254	414	154	169	149	130	134	124	155	176	104
September	294	482	271	408	175	221	118	233	122	133	190	171
October	256	663	658	854	244	314	158	457	124	154	181	206
November	487	637	508	664	227	465	242	395	196	339	277	423
December	549	532	399	750	303	430	273	321	233	799	448	338
Annual	465	516	603	543	398	479	275	322	345	447	438	296

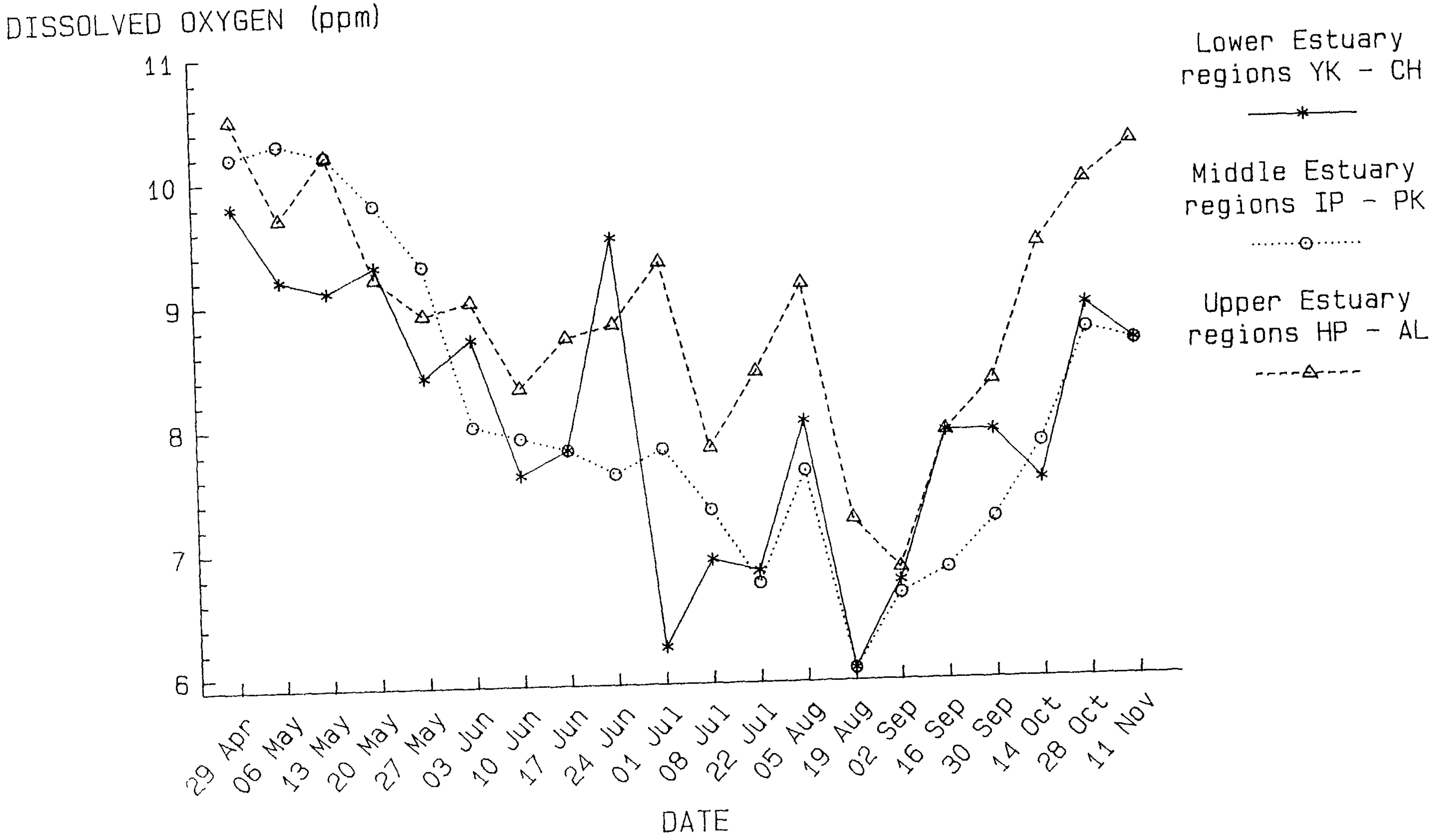


Figure III-3. Weekly mean dissolved oxygen measured in the LR/FS water quality survey of the Hudson River in 1985

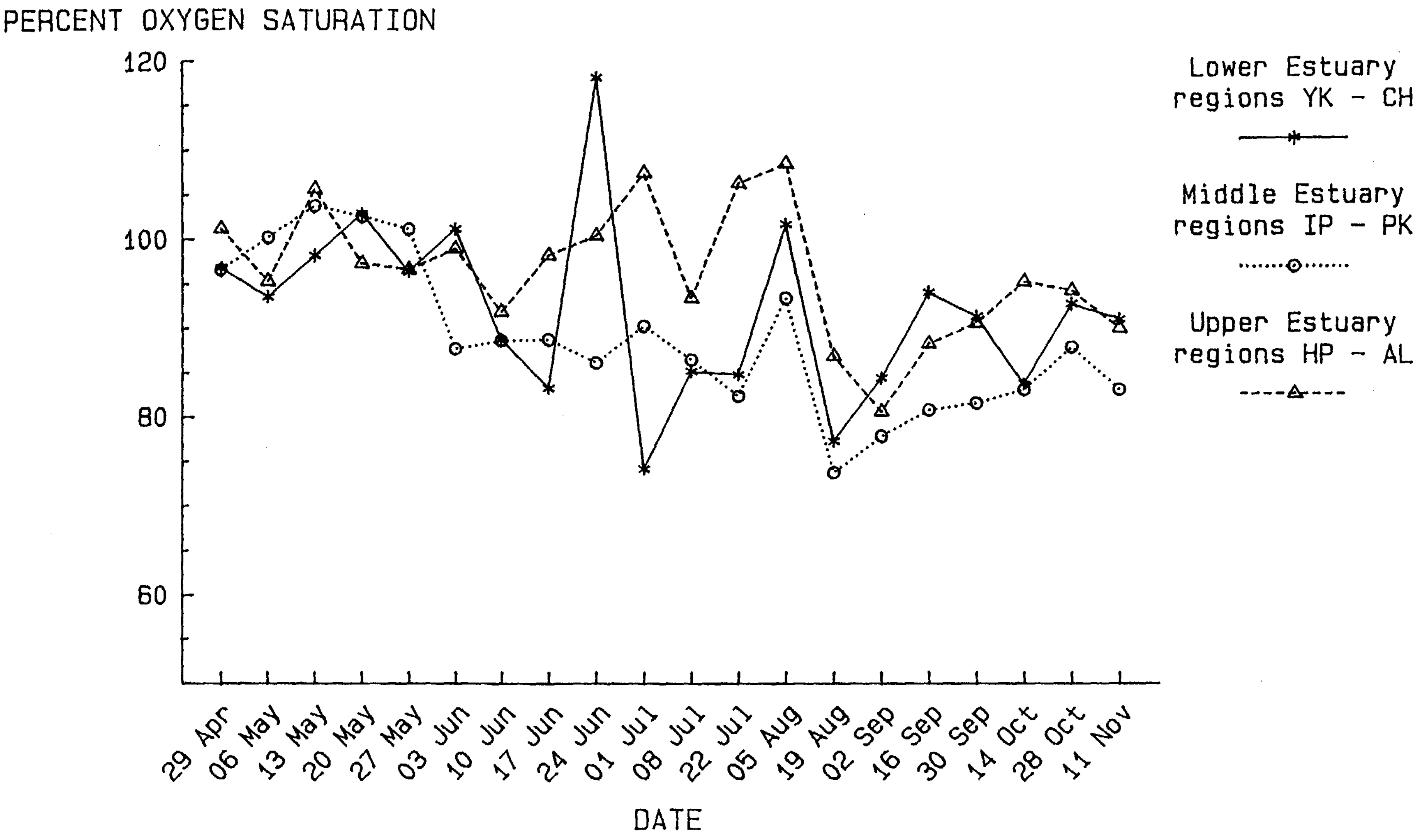


Figure III-4. Weekly mean percent oxygen saturation measured in the LR/FS water quality survey of the Hudson River in 1985

IV. SPATIAL AND TEMPORAL DISTRIBUTION OF SELECTED SPECIES

A. SPECIES COMPOSITION

A total of 84 fish species were captured during the 1985 Hudson River studies (Table IV-1). This constitutes about 66% of the total 128 species recorded during the previous 11 years of the study (Table IV-2) and is slightly above the yearly mean of 79 species (Fig. IV-1). No new species were collected in 1985, however, lookdown, scup, and gray snapper, which had not been reported for several years, were collected. Black crappie and walleye were reported in recent years of the study, but were absent from the 1985 list.

The 1985 species composition reflected a variety of taxa from 63 different genera and 40 families. The species listed represent resident cold, cool, and warm freshwater species, resident estuarine and marine species, and migratory estuarine and marine species.

B. STRIPED BASS

Striped bass, Morone saxatilis, is a long lived anadromous species that inhabits coastal waters and tidal rivers. The fish occur naturally along the Atlantic coast of North America from Canada to Florida, and in the Gulf of Mexico from the Appalachicola River in Florida to the Alabama River in Alabama (Brown 1965). The Hudson River is considered the northernmost spawning location for the species, although they range north to the St. Lawrence River. Striped bass have also been successfully introduced into numerous reservoirs and the Pacific coast of the United States (Bailey 1975).

Striped bass enter the estuary in early spring to spawn. Spawning extends from April through June and generally takes place near the salt front, but may occur throughout the river (Rathjen and Miller 1957; Dovel 1971). Females are typically larger, later maturing and less abundant than males, and may carry up to five million eggs (Lewis and Bonner 1966) which are deposited during a near-surface spawning ritual (Werner 1980). The eggs are semibuoyant and drift with the current until they hatch. Incubation time for eggs is temperature dependent, but is generally 2-3 days for the temperatures at which they are

Table IV-1. Species composition of fish collected in each of the Hudson River Year Class surveys during 1985

Table Species composition of fish collected in each of the Hudson River year class surveys during 1985

TAXON CODE	BEACH SEINE	FALL SHOALS	LONG RIVER
ALEWIFE	X	X	X
AMERICAN EEL	X	X	X
AMERICAN SANDLANCE			X
AMERICAN SHAD	X	X	X
ATLANTIC CROAKER		X	X
ATLANTIC MENHADEN	X	X	X
ATLANTIC NEEDLEFISH	X		
ATLANTIC SILVERSIDE	X		
ATLANTIC STURGEON	X	X	X
ATLANTIC TOMCOD	X	X	X
BANDED KILLIFISH	X	X	X
BAY ANCHOVY	X	X	X
BLACK BULLHEAD		X	
BLACKNOSE DACE	X		
BLACK SEA BASS		X	
BLUEBACK HERRING	X	X	X
BLUEFISH	X	X	X
BLUEGILL	X		
BROWN BULLHEAD	X	X	X
BUTTERFISH		X	X
CARP	X	X	
CONGER EEL			X
CREEK CHUB	X		
CREVALLE JACK	X	X	
CUNNER			X
EMERALD SHINER	X		
FATHEAD MINNOW	X		
FOURSPINE STICKLEBACK	X	X	
FOURSPOT FLOUNDER		X	
GIZZARD SHAD	X	X	X
GOLDEN SHINER	X		
GOLDFISH	X		X
GRAY SNAPPER	X		
HOGCHOKER	X	X	X
INSHORE LIZARDFISH		X	
LARGEMOUTH BASS	X		
LONGNOSE DACE	X		
LOOKDOWN	X	X	
MUMMICHOG	X		
NAKED GOBY	X	X	
NORTHERN KINGFISH	X	X	
NORTHERN PIPEFISH	X	X	X
NORTHERN PUFFER	X	X	X

Table IV-1. Continued

TAXON CODE	BEACH SEINE	FALL SHOALS	LONG RIVER
NORTHERN SEAROBIN	X		
NORTHERN STARGAZER	X	X	
PUMPKINSEED	X	X	
RAINBOW SMELT		X	X
RED HAKE		X	
REDBREAST SUNFISH	X	X	
ROCK BASS	X		
ROUGH SILVERSIDE	X	X	
SATINFIN SHINER	X		
SHORTNOSE STURGEON		X	
SILVER PERCH	X		
SILVERY MINNOW	X		
SMALLMOUTH BASS	X		
SMALLMOUTH FLOUNDER	X		
SPOT	X	X	X
SPOTFIN BUTTERFLYFISH		X	
SPOTFIN SHINER	X		
SPOTTAIL SHINER	X	X	X
SPOTTED HAKE		X	X
STRIPED ANCHOVY	X		
STRIPED BASS	X	X	X
STRIPED CUSKEEL		X	
STRIPED MULLET	X		
STRIPED SEAROBIN	X	X	
SUMMER FLOUNDER	X	X	X
TAUTOG	X		X
TESSELATED DARTER	X	X	X
THREESPINE STICKLEBACK	X		
TIDEWATER SILVERSIDE	X		X
WEAKFISH	X	X	X
WHITE CATFISH	X	X	X
WHITE MULLET	X		
WHITE PERCH	X	X	X
WHITE SUCKER	X	X	X
WINDOWPANE		X	X
WINTER FLOUNDER	X	X	X
YELLOW PERCH	X		X

Table IV-2. Species composition of fish collected as part of Year Class studies from 1974 to 1985

TAXON	74	75	76	77	78	79	80	81	82	83	84	85
ALEWIFE	X	X	X	X	X	X	X	X	X	X	X	X
AMERICAN EEL	X	X	X	X	X	X	X	X	X	X	X	X
AMERICAN SHAD	X	X	X	X	X	X	X	X	X	X	X	X
AMMODYTES SP.		X	X	X	X	X	X	X				X
ATLANTIC COD							X					
ATLANTIC CROAKER			X	X		X						X
ATLANTIC HERRING		X	X		X	X			X			
ATLANTIC MENHADEN	X	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC NEEDLEFISH	X	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC SILVERSIDE	X	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC STURGEON	X	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC TOMCOD	X	X	X	X	X	X	X	X	X	X	X	X
BANDED KILLIFISH	X	X	X	X	X	X	X	X	X	X	X	X
BAY ANCHOVY	X	X	X	X	X	X	X	X	X	X	X	X
BLACK BULLHEAD				X				X			X	X
BLACK CRAPPIE	X	X	X	X	X	X	X	X	X	X	X	
BLACK SEA BASS					X							X
BLACKNOSE DACE	X	X	X	X	X	X	X					X
BLUEBACK HERRING	X	X	X	X	X	X	X	X	X	X	X	X
BLUEFISH	X	X	X	X	X	X	X	X	X	X	X	X
BLUEGILL	X	X	X	X	X	X	X	X	X	X	X	X
BLUNTNOSE MINNOW	X	X	X	X	X	X	X					
BRIDLE SHINER	X		X						X			
BROOK STICKLEBACK	X	X	X	X				X				
BROOK TROUT				X	X							
BROWN BULLHEAD	X	X	X	X	X	X	X	X	X	X	X	X
BROWN TROUT			X	X	X	X	X				X	
BUTTERFISH	X	X	X			X	X	X	X	X	X	X
CARP	X	X	X	X	X	X	X	X	X	X	X	X
CENTRAL MUDMINNOW			X				X					
CHAIN PICKEREL	X	X	X	X	X	X	X	X	X		X	
CHANNEL CATFISH	X							X				
COMELY SHINER	X						X					
COMMON SHINER	X	X	X	X	X	X	X	X		X		
CONGER EEL						X		X	X	X	X	X
CREEK CHUB		X	X	X	X	X	X			X		X
CREVALLE JACK	X	X	X	X	X	X	X	X	X	X	X	X
CUNNER									X	X	X	X
CUTLIPS MINNOW	X	X	X	X	X	X						
EAST MUDMINNOW		X					X					
EMERALD SHINER	X	X	X	X	X	X	X	X	X	X	X	X
FALL FISH	X	X	X	X	X	X	X	X				
FATHEAD MINNOW	X	X	X	X	X	X	X					X
FOURBEARD ROCKLING						X	X					

Table IV-2. Continued

TAXON	74	75	76	77	78	79	80	81	82	83	84	85
FOURSPINE STICKLEBACK	X	X	X	X	X	X	X	X	X	X	X	X
FOURSPOT FLOUNDER	X						X	X			X	X
GIZZARD SHAD	X	X	X	X	X	X	X	X		X	X	X
GOLDEN SHINER	X	X	X	X	X	X	X	X	X	X	X	X
GOLDFISH	X	X	X	X	X	X	X	X	X	X	X	X
GRASS PICKEREL	X				X							
GRAY SNAPPER							X					X
GREEN SUNFISH		X		X			X					
HICKORY SHAD		X			X	X				X		
HOGCHOKER	X	X	X	X	X	X	X	X	X	X	X	X
INSHORE LIZARDFISH	X					X	X	X			X	X
LARGEMOUTH BASS	X	X	X	X	X	X	X	X	X	X	X	X
LOGPERCH	X		X	X		X	X			X		
LONGHORN SCULPIN	X	X								X		
LONGNOSE DACE		X	X	X	X				X			X
LOOKDOWN	X	X	X	X		X	X	X				X
MIMIC SHINER	X											
MOONFISH			X									
MUMMICHOG	X	X	X	X	X	X	X	X	X	X	X	X
NAKED GOBY	X		X								X	X
NORTHERN HOG SUCKER	X		X	X	X		X	X			X	
NORTHERN KINGFISH	X	X	X		X	X	X	X	X	X	X	X
NORTHERN PIKE	X	X	X	X	X	X	X		X			
NORTHERN PIPEFISH	X	X	X	X	X	X	X	X	X	X	X	X
NORTHERN PUFFER		X		X		X	X	X	X	X	X	X
NORTHERN SEAROBIN			X		X		X	X	X		X	
NORTHERN STARGAZER	X						X		X	X	X	X
POLLACK		X										
PUMPKINSEED	X	X	X	X	X	X	X	X	X	X	X	X
RAINBOW SMELT	X	X	X	X	X	X	X	X	X	X	X	X
RAINBOW TROUT						X						
RED HAKE	X		X			X	X	X			X	X
REDBREAST SUNFISH	X	X	X	X	X	X	X	X	X	X	X	X
REDFIN PICKEREL	X	X	X	X	X	X	X	X	X		X	
ROCK BASS	X	X	X	X	X	X	X	X	X	X	X	X
ROCK GUNNEL			X	X								
ROSYFACE SHINER	X											
ROUGH SILVERSIDE		X	X	X	X	X	X	X	X		X	X
SATINFIN SHINER	X	X	X	X	X	X	X				X	X
SCUP	X											
SEA LAMPREY	X	X				X	X	X			X	

Table IV-2. Continued

TAXON	74	75	76	77	78	79	80	81	82	83	84	85
SEA RAVEN							X					
SEA ROBIN		X	X		X		X	X				
SEABOARD GOBY		X	X				X					
SHEEPSHEAD								X				
SHIELD DARTER							X					
SHORTNOSE STURGEON	X		X	X		X	X	X	X	X	X	X
SILVER HAKE	X	X		X								
SILVER PERCH	X					X					X	X
SILVERY MINNOW	X	X	X	X	X	X	X	X	X	X	X	X
SMALLMOUTH BASS	X	X	X	X	X	X	X	X	X	X	X	X
SMALLMOUTH FLOUNDER						X	X		X		X	X
SPECKLED WORM EEL					X		X				X	
SPOT	X	X	X	X			X		X	X		X
SPOTFIN BUTTERFLYFISH									X			X
SPOTFIN MOJARRA									X			
SPOTFIN SHINER	X	X	X	X	X	X	X	X			X	X
SPOTTAIL SHINER	X	X	X	X	X	X	X	X	X	X	X	X
SPOTTED HAKE							X			X	X	X
STRIPED ANCHOVY		X				X			X			X
STRIPED BASS	X	X	X	X	X	X	X	X	X	X	X	X
STRIPED CUSKEEL							X					X
STRIPED KILLIFISH			X									
STRIPED MULLET	X		X	X		X	X	X	X	X	X	X
STRIPED SEAROBIN		X			X	X	X	X	X	X	X	X
SUMMER FLOUNDER	X	X	X	X	X	X	X	X	X		X	X
TAUTOG		X				X	X	X	X	X	X	X
TESSELATED DARTER	X	X	X	X	X	X	X	X	X	X	X	X
THREESPINE STICKLEBACK	X	X	X	X	X	X	X	X	X	X	X	X
TIDEWATER SILVERSIDE	X	X	X	X	X	X	X	X	X	X	X	X
TROUT PERCH	X	X	X	X	X	X					X	
WALLEYE			X	X	X	X				X	X	
WEAKFISH	X	X	X	X	X	X	X	X	X	X	X	X
WHITE BASS				X								
WHITE CATFISH	X	X	X	X	X	X	X	X	X	X	X	X
WHITE CRAPPIE	X	X	X	X	X	X	X	X			X	
WHITE MULLET	X	X	X	X	X	X	X		X	X	X	X
WHITE PERCH	X	X	X	X	X	X	X	X	X	X	X	X
WHITE SUCKER	X	X	X	X	X	X	X	X	X	X	X	X
WINDOWPANE	X	X		X		X	X	X		X	X	X
WINTER FLOUNDER	X	X	X	X	X	X	X	X	X	X	X	X
YELLOW BULLHEAD		X						X				
YELLOW PERCH	X	X	X	X	X	X	X	X	X	X	X	X
YELLOWTAIL FLOUNDER	X											

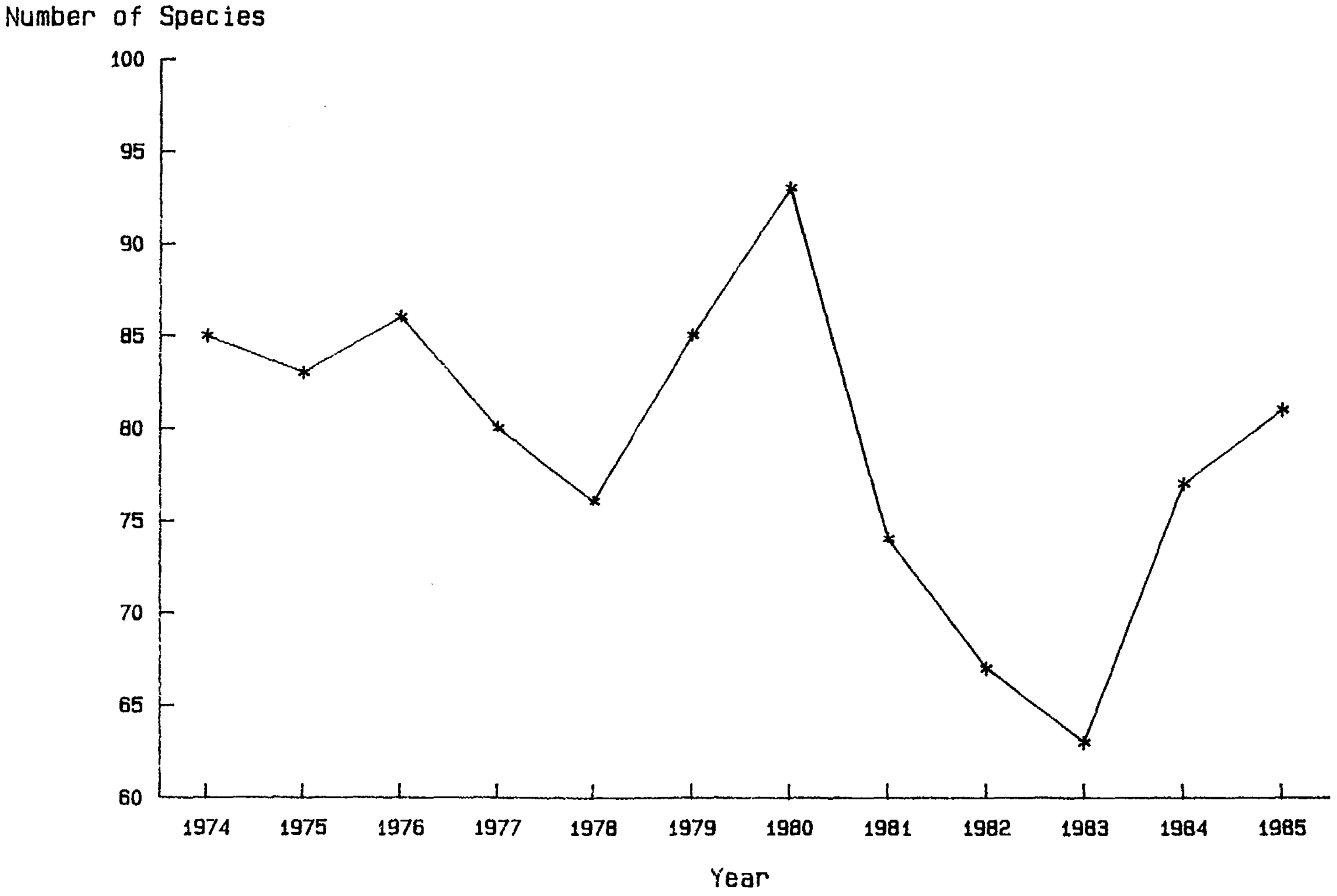


Figure IV-1. Number of species collected in year class studies during 1974-1985 spawned in the Hudson River (Rogers et al. 1977). Early yolk-sac larvae are incapable of sustained swimming and depend on currents to keep them from smothering in silt (Mansueti 1958). Newly hatched larvae retain their yolk-sac for about one week after which time they begin active feeding on small zooplankton (Doroshev 1970). Duration of the post yolk-sac stage is 30-33 days at 18°C (Rogers et al. 1977).

As water temperature decreases during the fall, juveniles move into deep-water overwintering sites in the lower estuary (McFadden et al. 1978) or into adjacent bays or sounds. These fish may remain in the vicinity of the estuary mouth for two or more years before emigration (Kohlenstein 1980, 1981). Older fish may undergo coastal migrations, though for Hudson River populations most fish remain within 50 km of the Hudson or in Long Island Sound (McLaren et al. 1981; Austin and Custer 1977). Hudson River striped bass constitute ~ 10-50% of Atlantic coastal stocks depending on the year (VanWinkle and Kumar 1982), and constitute a higher proportion of the stock in Long Island Sound (Fabrizio and Saila 1986).

Eggs

Striped bass eggs were collected from late April through early July from the Yonkers to the Catskill regions,, but were most abundant in the Cornwall and West Point regions (Fig. IV-2). Peak egg abundance occurred at West Point, but historical records indicate that egg distributions are generally further downstream than were recorded in 1985 (Fig. IV-3). The lower than average freshwater inflows in the spring of 1985 (Table III-5) may have contributed to selection of more upstream spawning areas by striped bass.

Density estimates indicated a single spawning peak during early May, when water temperatures averaged between 13-14°C. This unimodal peak is consistent with most other years, but differs from 1984 when a bimodal temporal distribution was observed. The peak of egg abundance occurred earlier in 1985, and at colder water temperatures than in most other years (Table IV-3). Striped bass eggs were first collected in 1985 when water temperatures were as low as 12°C, and continued to be taken in low numbers until water temperatures rose to approximately 22°C. Spawning of striped bass is thought to be triggered by rapid warming of water in spring (DiNardo et al. 1985). Assuming this is the case, the 0.6-1.6°C mean rise observed in spawning areas between the first and second weeks of LRS was apparently sufficient to induce spawning.

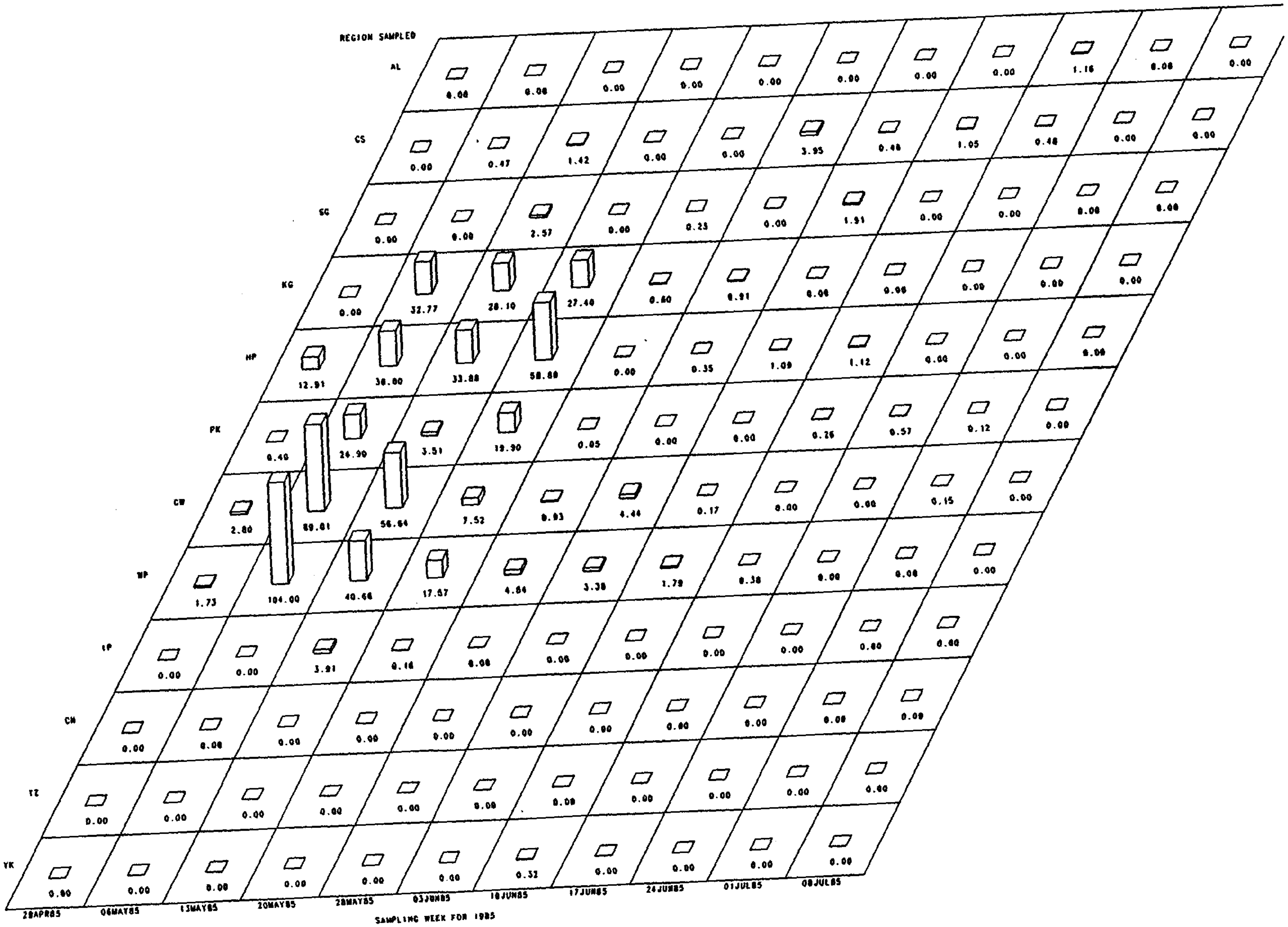


Figure IV-2. Mean regional density (per 1000 m^3) of striped bass eggs collected in the Longitudinal River Survey during 1985

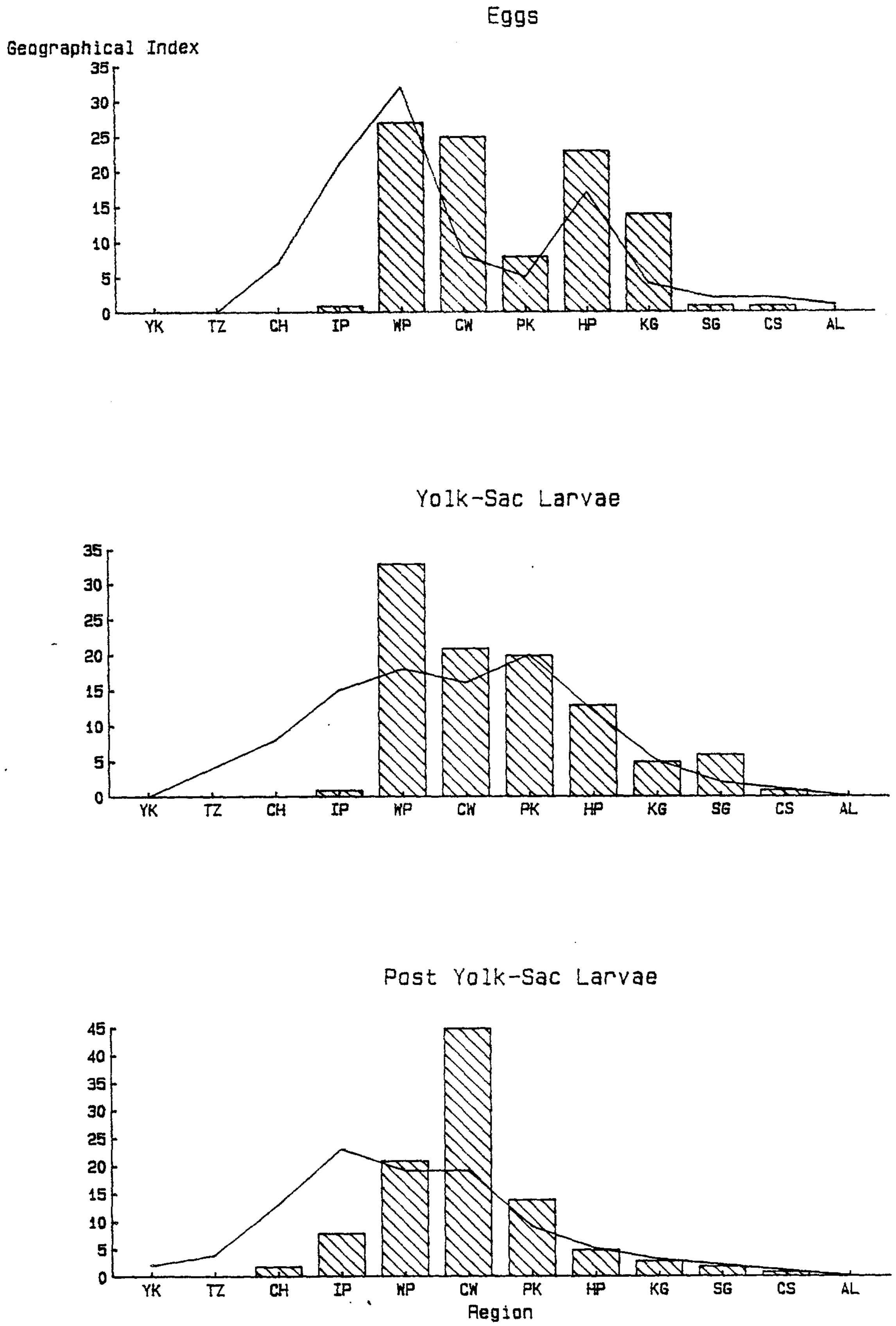


Figure IV-3. Geographic distribution of striped bass eggs, yolk-sac larvae, and post yolk-sac larvae, collected in the Longitudinal River Survey. Bars represent index values for 1985. Lines represent average values for 1974-1984.

Table IV-3. Mean temperature (°C) in regions and periods of peak abundance of striped bass eggs and larvae 1974-1985

	Eggs		Yolk-Sac Larvae		Post Yolk-Sac Larvae	
Year	Peak Period	Mean Temperature	Peak Period	Mean Temperature	Peak Period	Mean Temperature
1974	12 May-25 May	15.4	26 May-08 Jun	17.5	09 Jun-22 Jun	21.5
1975	18 May-31 May	19.0	25 May-07 Jun	19.9	01 Jun-14 Jun	20.6
1976	23 May-05 Jun	15.0	30 May-12 Jun	16.4	06 Jun-19 Jun	18.6
1977	15 May-28 May	14.6	22 May-04 Jun	17.0	29 May-18 Jun	19.3
1978	21 May-27 May	15.7	28 May-10 Jun	20.2	04 Jun-17 Jun	20.7
1979	06 May-19 May	16.2	20 May-02 Jun	18.2	27 May-02 Jun	18.4
1980	19 May-22 May	16.3	27 May-30 May	17.2	02 Jun-13 Jun	18.2
1981	18 May-21 May	15.9	18 May-21 May	15.9	01 Jun-13 Jun	18.0
1982	24 May-28 May	17.1	24 May-28 May	17.1	31 May-09 Jun	18.5
1983	16 May-05 Jun	13.6	06 Jun-19 Jun	19.2	13 Jun-26 Jun	21.7
1984	04 Jun-11 Jun	17.0	11 Jun-18 Jun	20.3	18 Jun-25 Jun	21.2
1985	06 May-20 May	15.5	13 May-20 May	16.9	28 May-03 Jun	19.3

Adapted from NAI (1985b).

Striped bass eggs were most frequently taken from the Hyde Park and West Point regions, with the highest densities observed at West Point during the week of 6 May. Most eggs were taken in water with salinity of 1.5 ppt or less, although one striped bass egg was collected at Yonkers in mid-June in water with a mean salinity of 14.6 ppt.

Most striped bass eggs were collected in the bottom stratum. Although striped bass eggs are considered semi-buoyant and found in the water column, Albrecht (1964) reported that eggs fall to the bottom in slow moving water.

Yolk-Sac Larvae

In 1985, striped bass yolk-sac larvae were collected primarily from mid-May to early June (Fig. IV-4) from Croton-Haverstraw to Albany. As in most previous years, the peak of yolk-sac density occurred between West Point and Poughkeepsie (Fig. IV-3). However, unlike most previous years, very few striped bass yolk-sac larvae were distributed downstream of West Point, probably due to the more upstream location of the salt front in the river in 1985. Some larvae were captured in the Croton-Haverstraw region in water with salinity as high as 5 ppt, but the majority were taken at some distance upstream of the salt front.

The peak of yolk-sac collections occurred one to two weeks earlier in 1985 than in previous Year Class studies (Fig. IV-5) and three weeks earlier than in 1984 (Table IV-3). Although yolk-sac larvae were collected in samples through early July, only small numbers were taken after the end of May. Over 50% of the yolk-sac larvae collected during LRS of 1985 were taken during the week of 20 May; historically, peaks in yolk-sac abundance have been more spread out in time, with the peak week of abundance comprising less than 30% of the total collected for the entire survey. Mean temperature during the period of peak yolk-sac larvae standing crop was between 16-18°C, while the temperature range over which striped bass yolk-sac larvae were taken was 12-22°C.

Post Yolk-Sac Larvae

Striped bass post yolk-sac larvae were first collected during the week of 13 May, with highest densities observed during a 2 week period beginning the week of 28 May (Fig. IV-6). This peak period followed peak yolk-sac larval densities in the same regions by one to two weeks. This is slightly longer than the 6-7 days suggested by Setzler et al. (1980) as

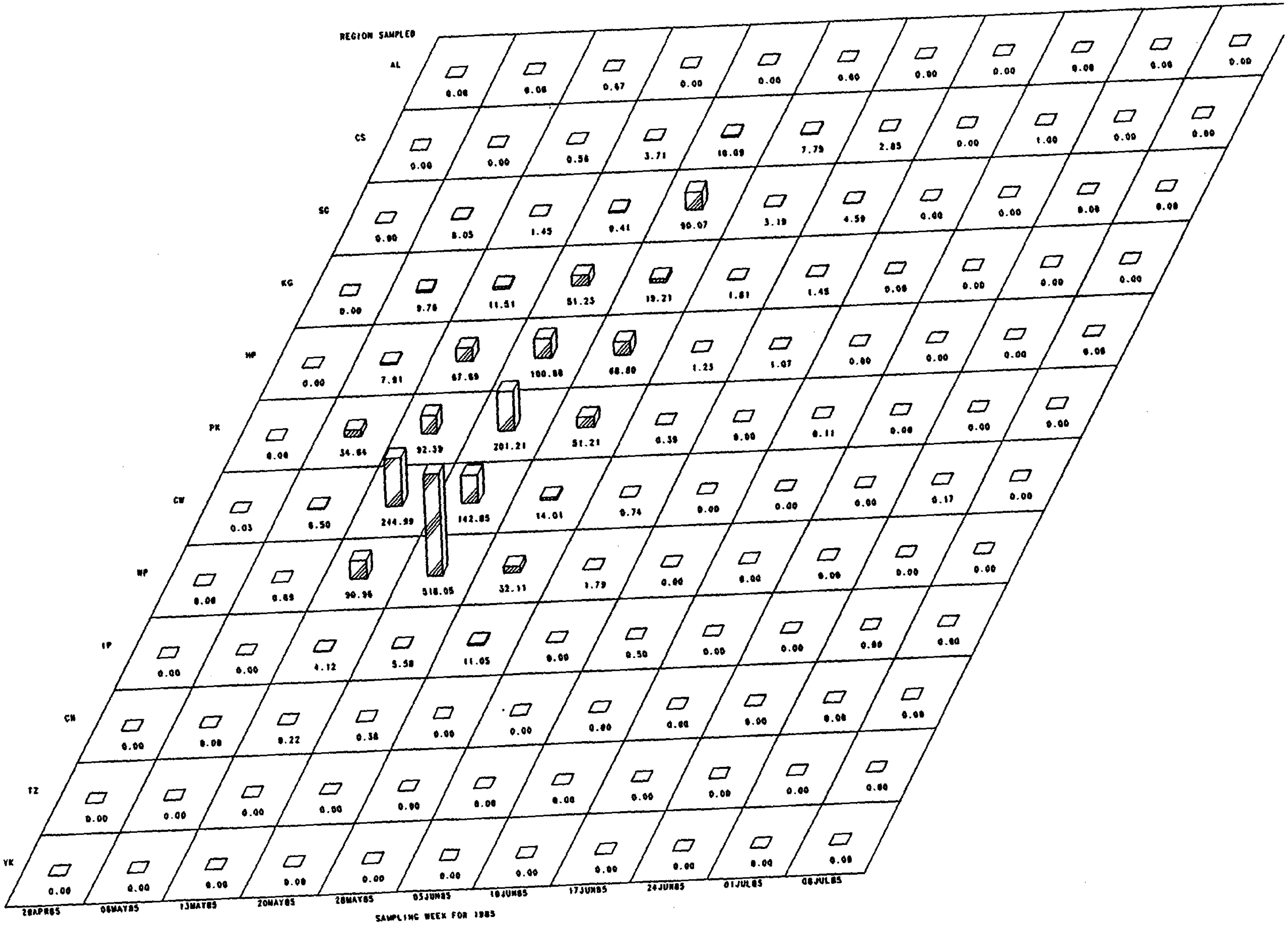


Figure IV-4. Mean regional density (per 1000 m^3) of striped bass yolk-sac larvae collected in the Longitudinal River Survey during 1985

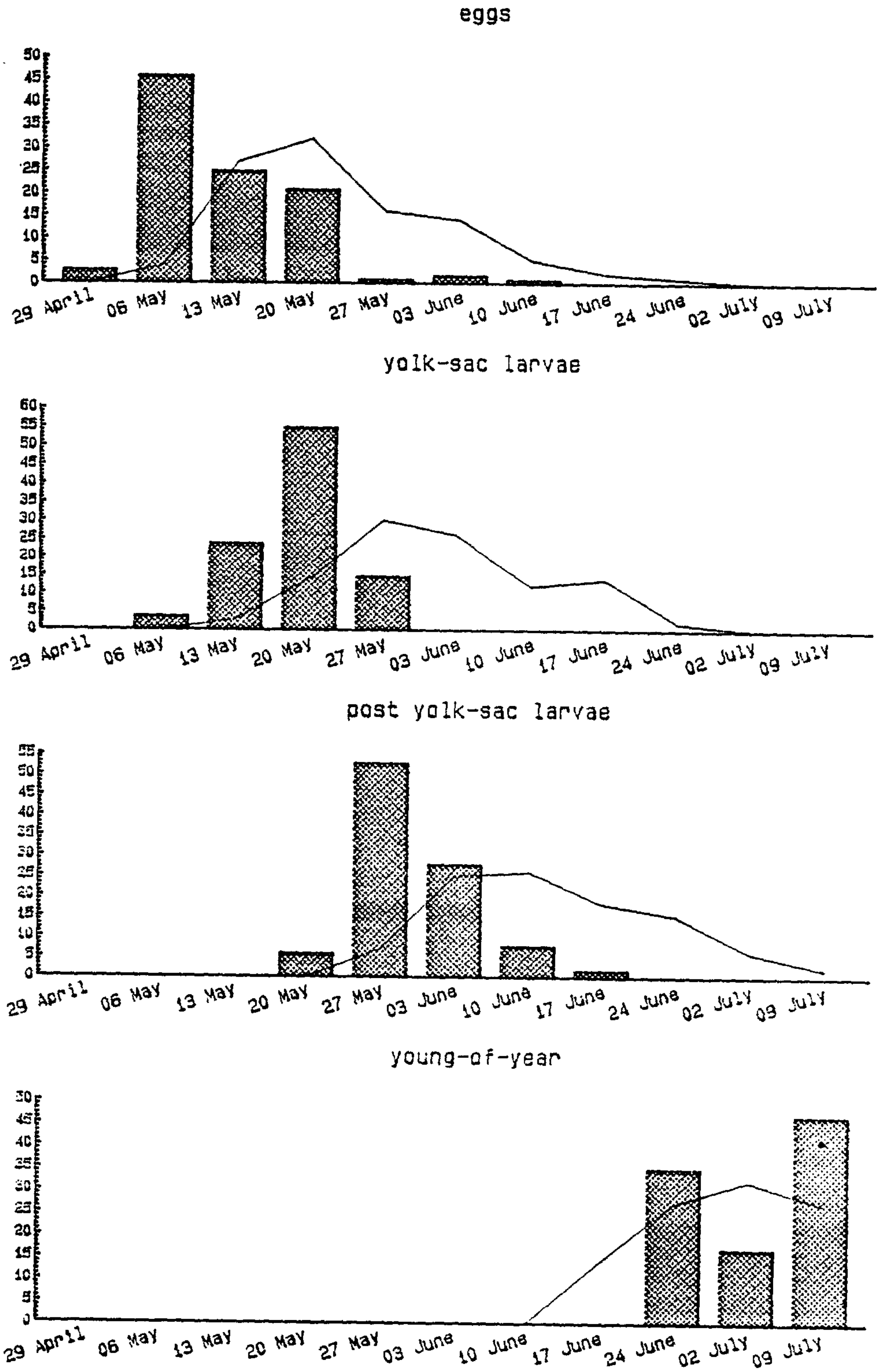


Figure IV-5. Temporal index for striped bass eggs, yolk-sac larvae, post yolk-sac larvae, and young-of-year collected in the Longitudinal River Survey. Bars represent index values for 1985. Lines represent average values for 1974- 1984.

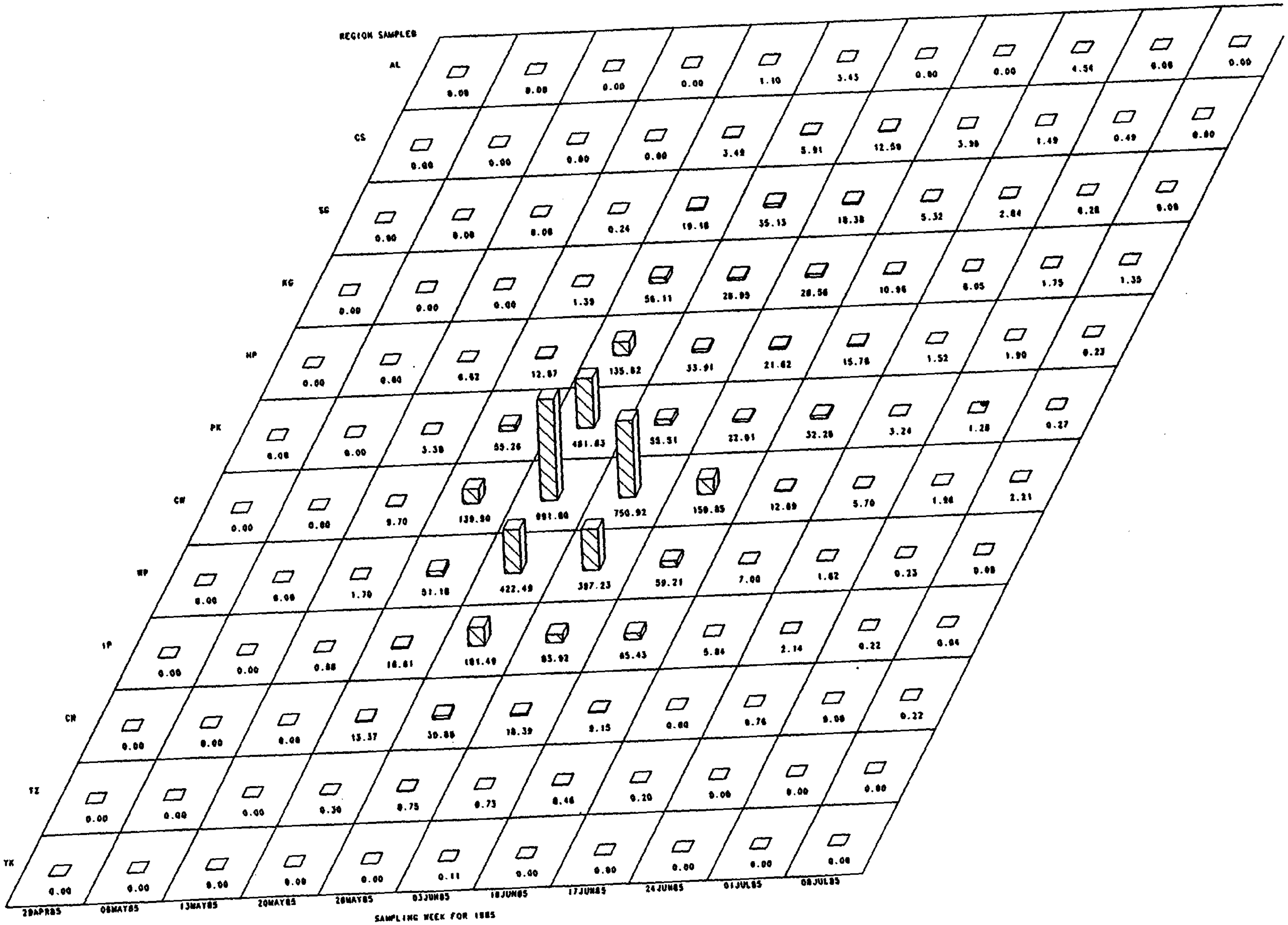


Figure IV-6. Mean regional density (per 1000 m^3) of striped bass post yolk-sac larvae collected in the Longitudinal River Survey during 1985 necessary for development from the yolk-sac to post yolk-sac stage, even though mean water temperatures were not unusually cold during this period (17-19°C). As with yolk-sac larvae, over 50% of striped bass post yolk-sac larvae were taken during a single sampling week (28 May), one to two weeks ahead of the historical LRS mean (Fig. IV-5).

Geographically, post yolk-sac larval densities were highest in the regions bordering the salt front, especially in the Cornwall region. Historically, an average of greater than 60% of striped bass post yolk-sac larvae were taken from regions downstream of Cornwall; whereas, in 1985, about 30% were taken from these regions (Fig. IV-3).

Young-of-Year

Juvenile striped bass were first collected during the LRS in mid June (Fig. IV-7), one of the earliest dates on which juveniles have historically been taken during LRS. All juveniles taken during LRS were from regions upstream of Indian Point, which is in contrast with previous years when an average of over 50% of LRS juvenile striped bass came from below West Point.

Striped bass young-of-year were also taken during every week of the FSS (Fig. IV-8) and BSS (Fig. IV-9). However, none were taken from the Yonkers region until the last week of each survey in November, when temperatures in the upper estuary had fallen below 10°C and may have initiated movement of striped bass to downriver overwintering areas. As in previous years, juveniles were most often taken in 1985 in the lower estuary, although fewer were collected at Yonkers and Tappan Zee where salinity was highest (Fig. IV-10). Juveniles were captured from estuarine waters with a wide range of salinities and temperatures (0-19 ppt and 8-25°C, respectively), although most were collected in regions where salinity was 0-7 ppt and temperature was 15°C or above).

Yearling and Older Fish

Yearling and older striped bass were collected throughout the LRS (Fig. IV-11), FSS (Fig. IV-12), and BSS (Fig. IV-13). They were also collected in all 12 regions, although catches came mainly from the lower estuary, except Yonkers. Catches of yearling and older striped bass were more sporadic in the upper estuary; most were caught between mid-June and mid-August, but some were caught in November when mean temperatures in the region of capture dipped to 7°C.

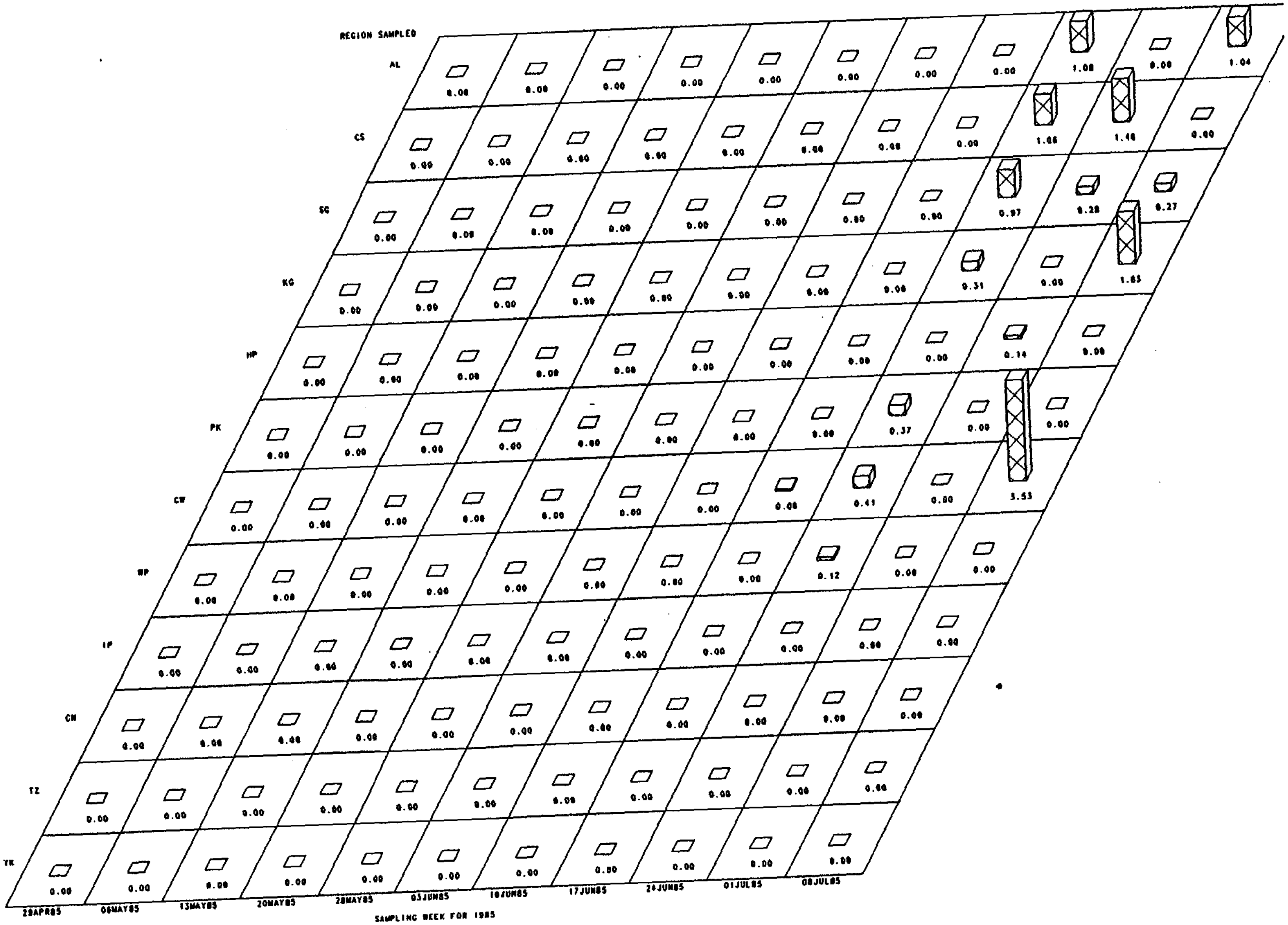


Figure IV-7. Mean regional density (per 1000 m^3) of striped bass young-of-year collected in the Longitudinal River Survey during 1985

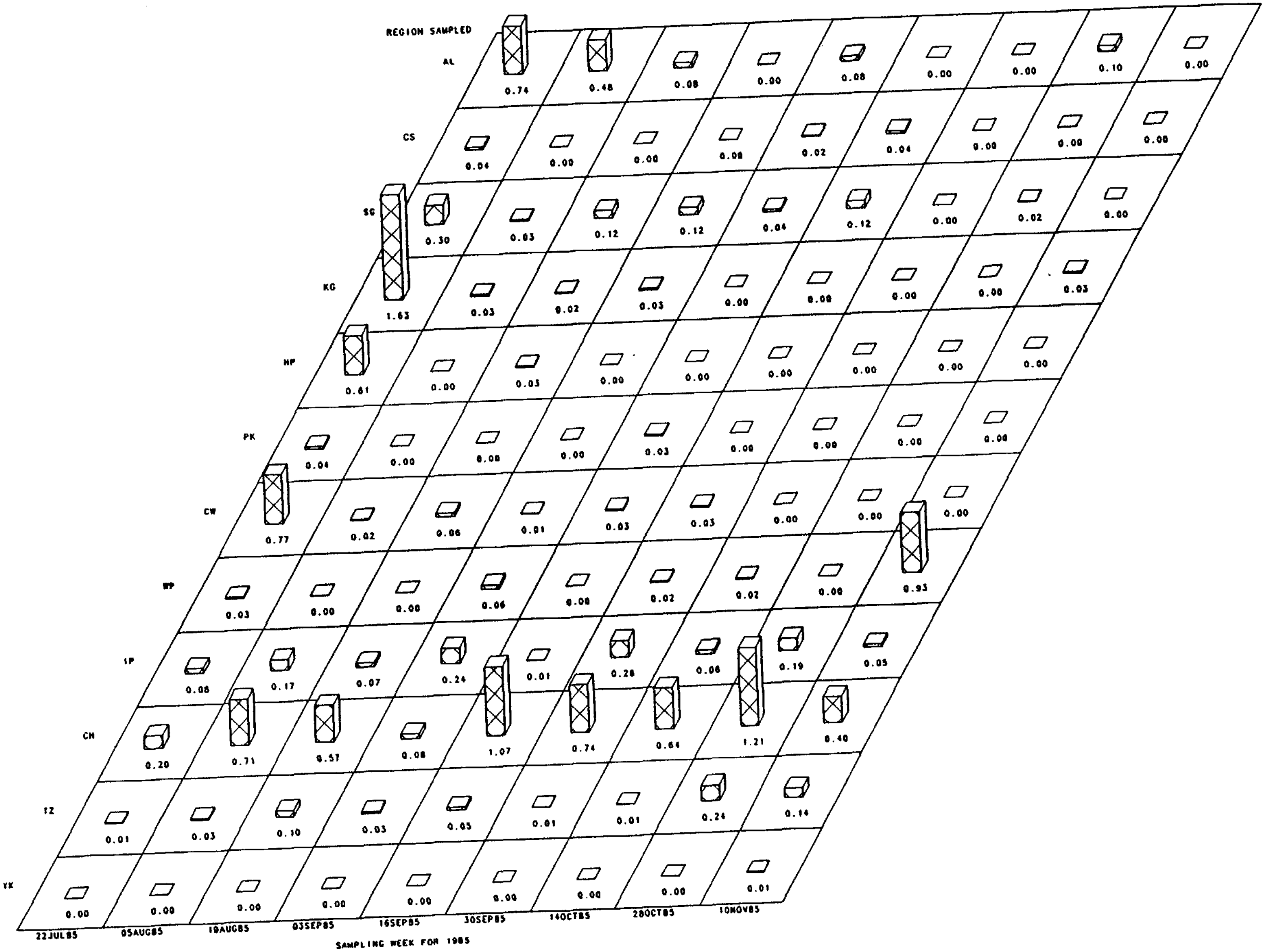


Figure IV-8. Mean regional density (per 1000 m^3) of striped bass young-of-year collected in the Fall Shoals Survey during 1985

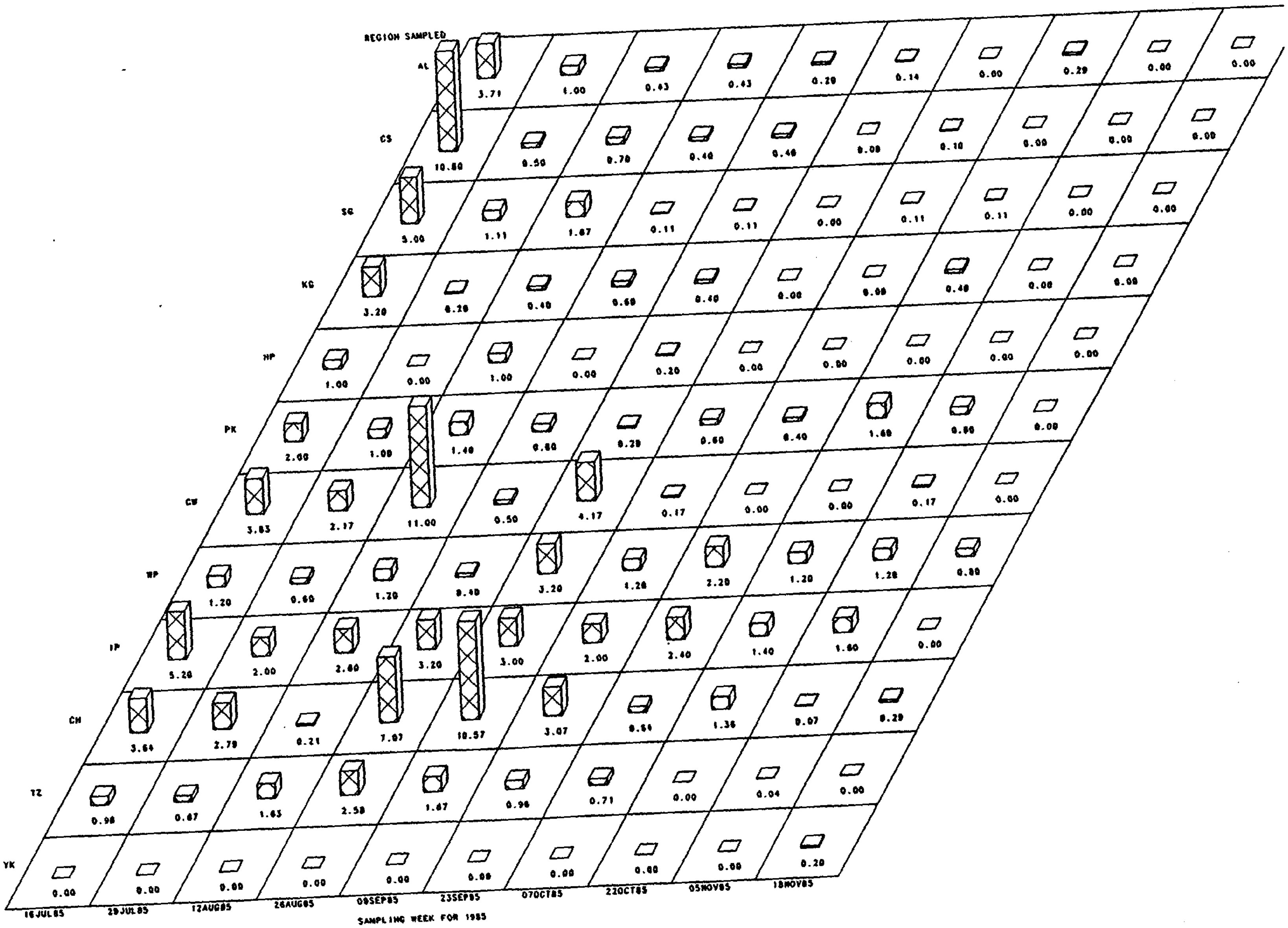


Figure IV-9. Catch per unit effort of striped bass young-of-year collected in the Beach Seine Survey during 1985

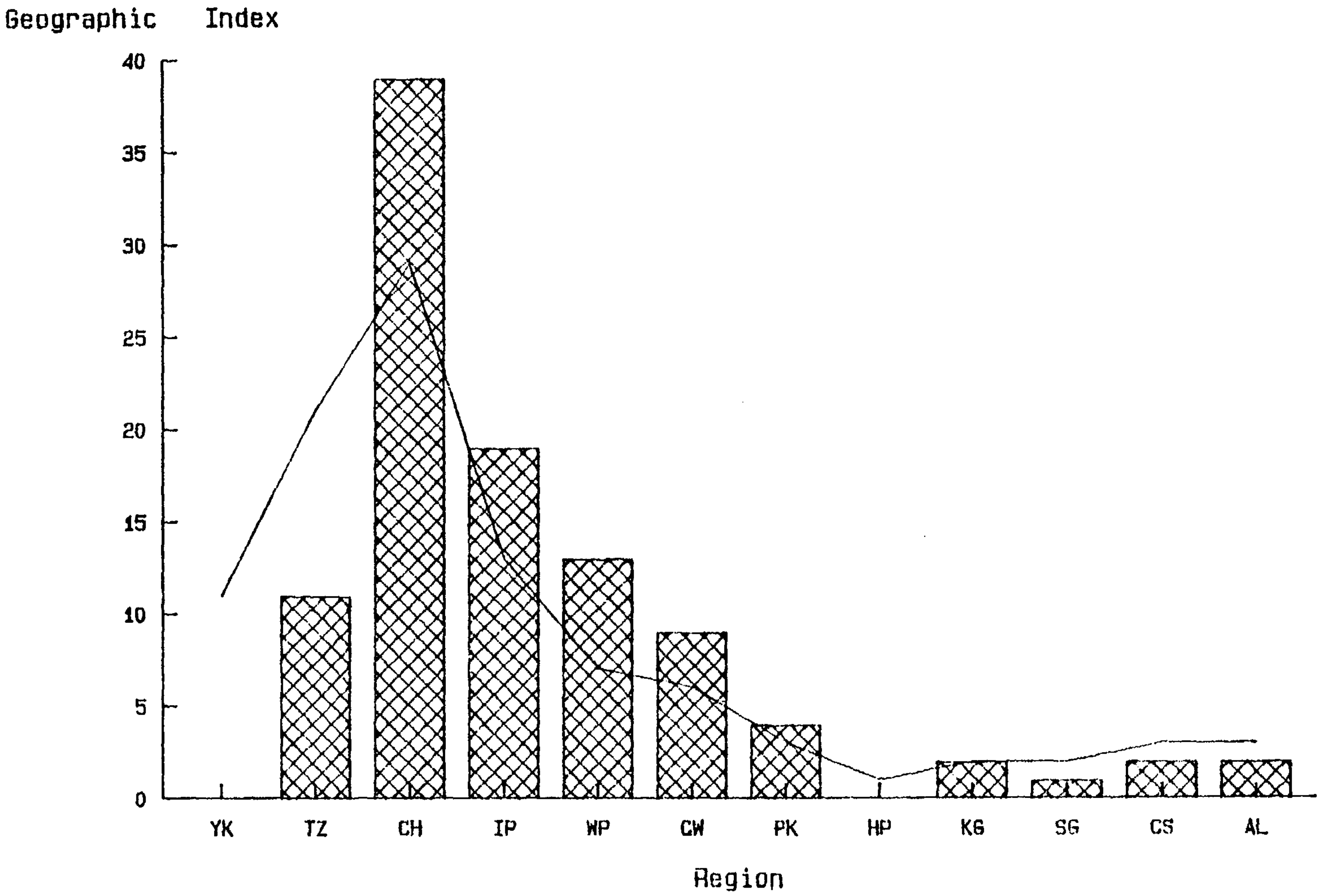


Figure IV-10. Geographic distribution of young-of-year striped bass collected in the Beach Seine Survey. Bars represent index values for 1985. Lines represent average values for 1974-1984.

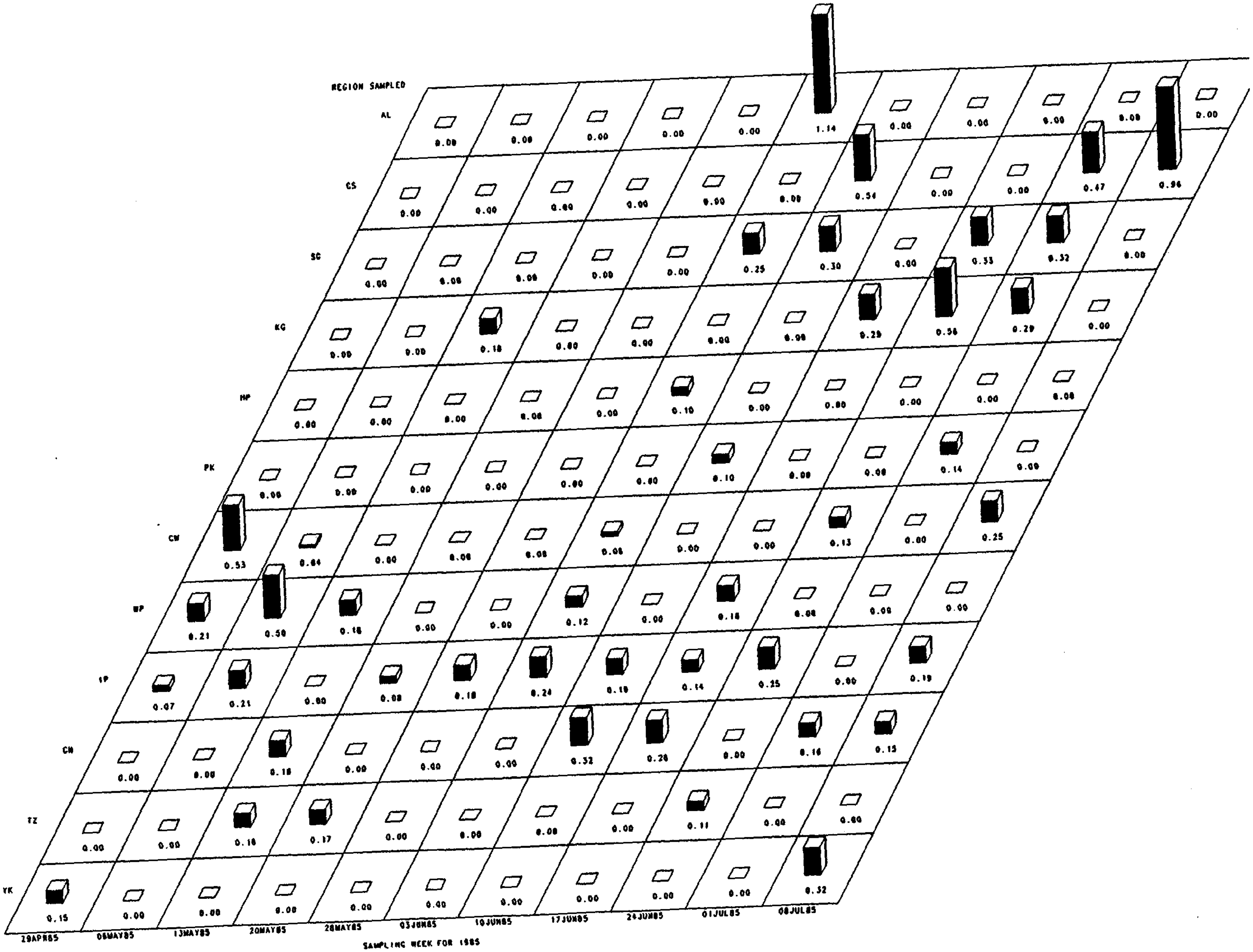


Figure IV-11. Mean regional density (per 1000 m^3) of striped bass yearling and older collected in the Longitudinal River Survey during 1985

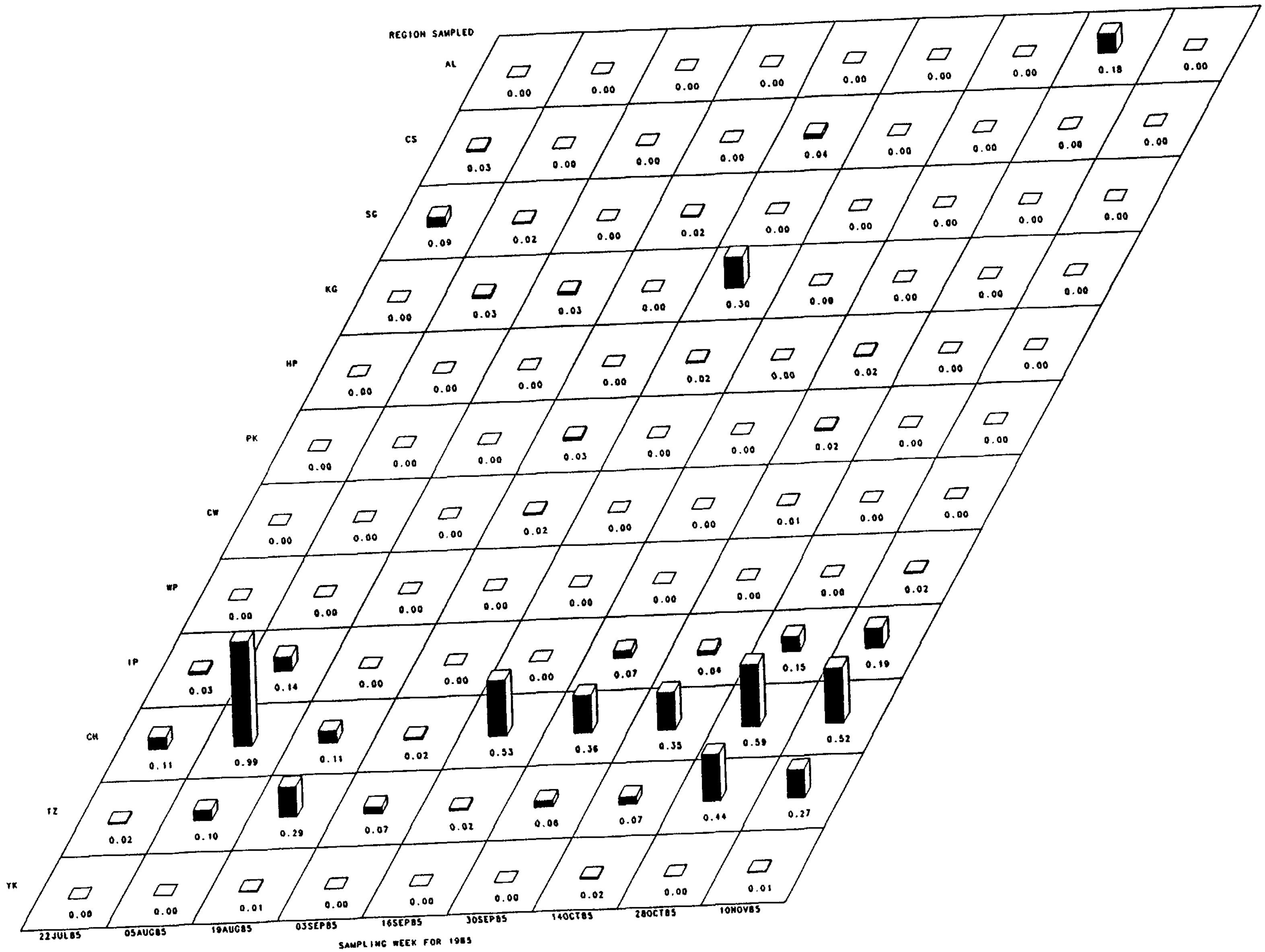


Figure IV-12. Mean regional density (per 1000 m^3) of striped bass yearling and older collected in the Fall Shoals Survey during 1985

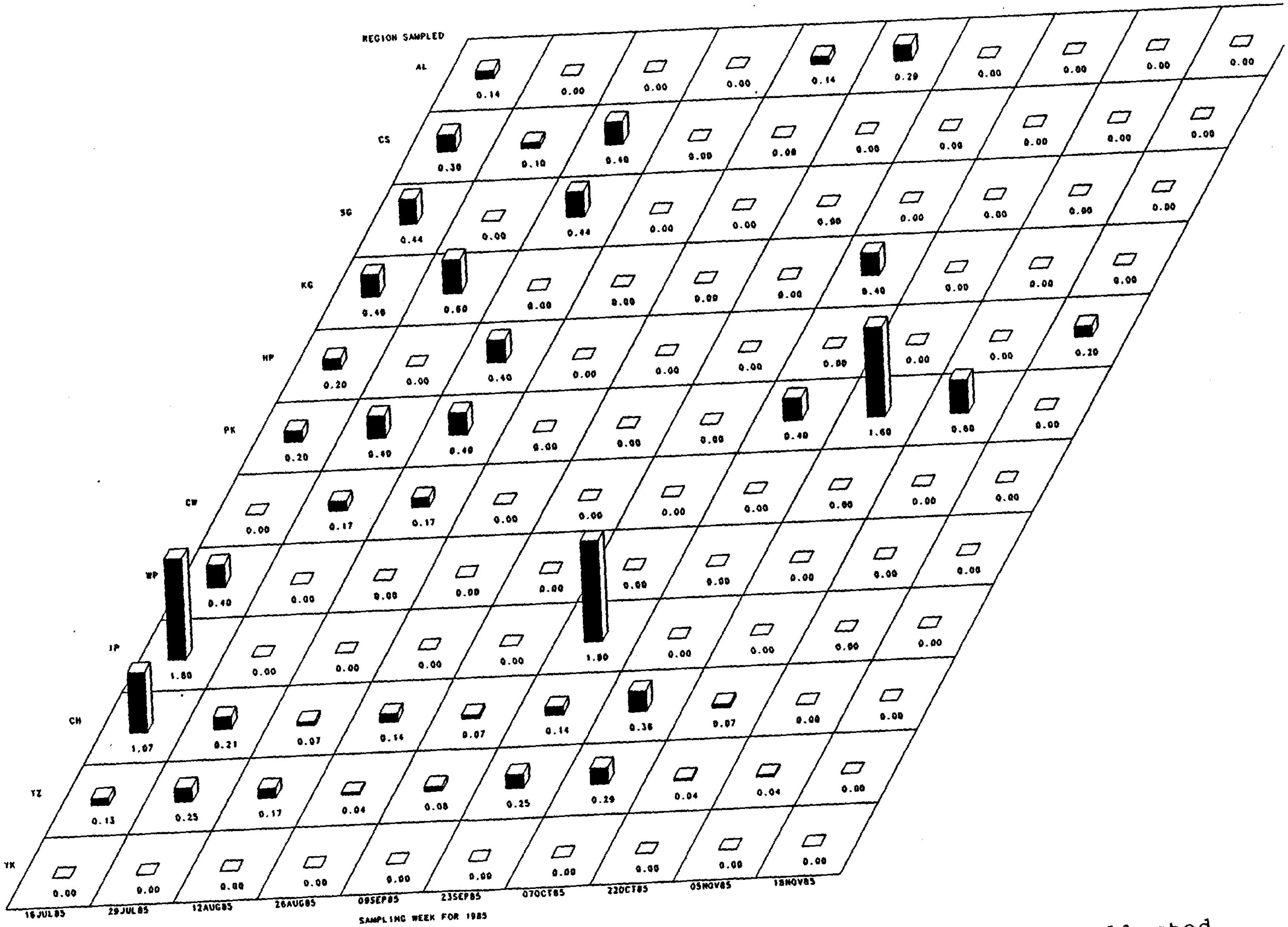


Figure IV-13. Catch per unit effort of striped bass yearling and older collected in the Beach Seine Survey during 1985

C. WHITE PERCH

White perch, Morone americana, are endemic to the east coast of North America, occurring from Nova Scotia to South Carolina. They are primarily estuarine, but also occur in rivers and have been introduced to a number of landlocked impoundments (Woolcott 1962). They invaded the lower Great Lakes during the early 1950s and populations are believed to still be expanding in some areas (Dence 1952; Hergenrader 1980; Werner 1980). Coastal white perch populations are considered semi-anadromous because they show seasonal movement patterns associated with spawning, but movements are generally limited to within an estuary.

White perch are prolific spawners with a mean fecundity of 50,000 eggs per female (Bath and O'Conner 1982). The eggs are demersal, adhesive, apparently scattered in haphazard fashion and are left unprotected (Werner 1980); this spawning behavior may contribute to irregular fluctuations in year class strength noted in some waters (St. Pierre and Hoagman 1975). White perch feed on a variety of prey, including minnows, crustaceans, and insects. They typically travel in schools and forage over broad areas. They are a fairly long lived species, and individuals up to 12 years of age have been recorded.

White perch are found from the mouth of the Hudson River to the base of Troy Dam north of Albany (250 km upstream). They are a dominant species in most portions of the river (Bath and O'Connor 1982), and comprise greater than 50% of total impingement at Hudson River power plants in most years (McFadden et al. 1978). During spring they move upriver to spawn. Spawning generally takes place in freshwater in the Hudson River (Klauda et al. in press), though eggs can survive equally well in salinities up to 10 ppt (Morgan and Rasin 1982). Following spawning, adults gradually move downriver to the overwintering grounds (LMS 1987). In the Hudson River, overwintering generally takes place in deepwater areas from Yonkers to Indian Point (TI 1981).

Eggs

Although white perch eggs were collected in every region during the LRS, most eggs were found in freshwater with over 50% of the total estimated standing crop occurring in the Saugerties and Catskill regions (Fig. IV-14 and IV-15). In previous Year Class studies, the peak extended downriver as far as Poughkeepsie, but remained within fresh water areas (TI 1979a, 1980b; NAI 1985b; Martin Marietta Environmental Systems

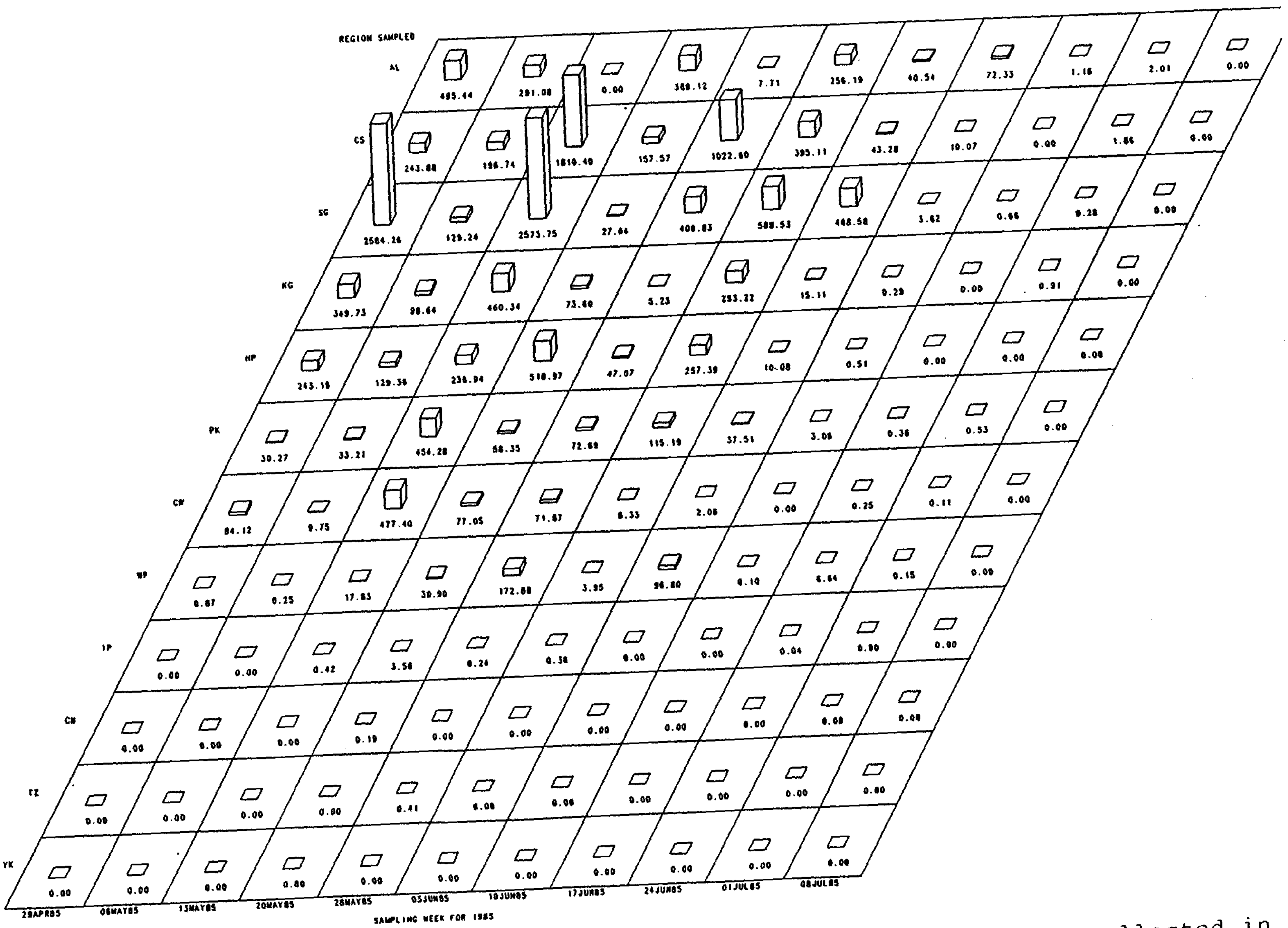


Figure IV-14. Mean regional density (per 1000 m^3) of white perch eggs collected in the Longitudinal River Survey during 1985

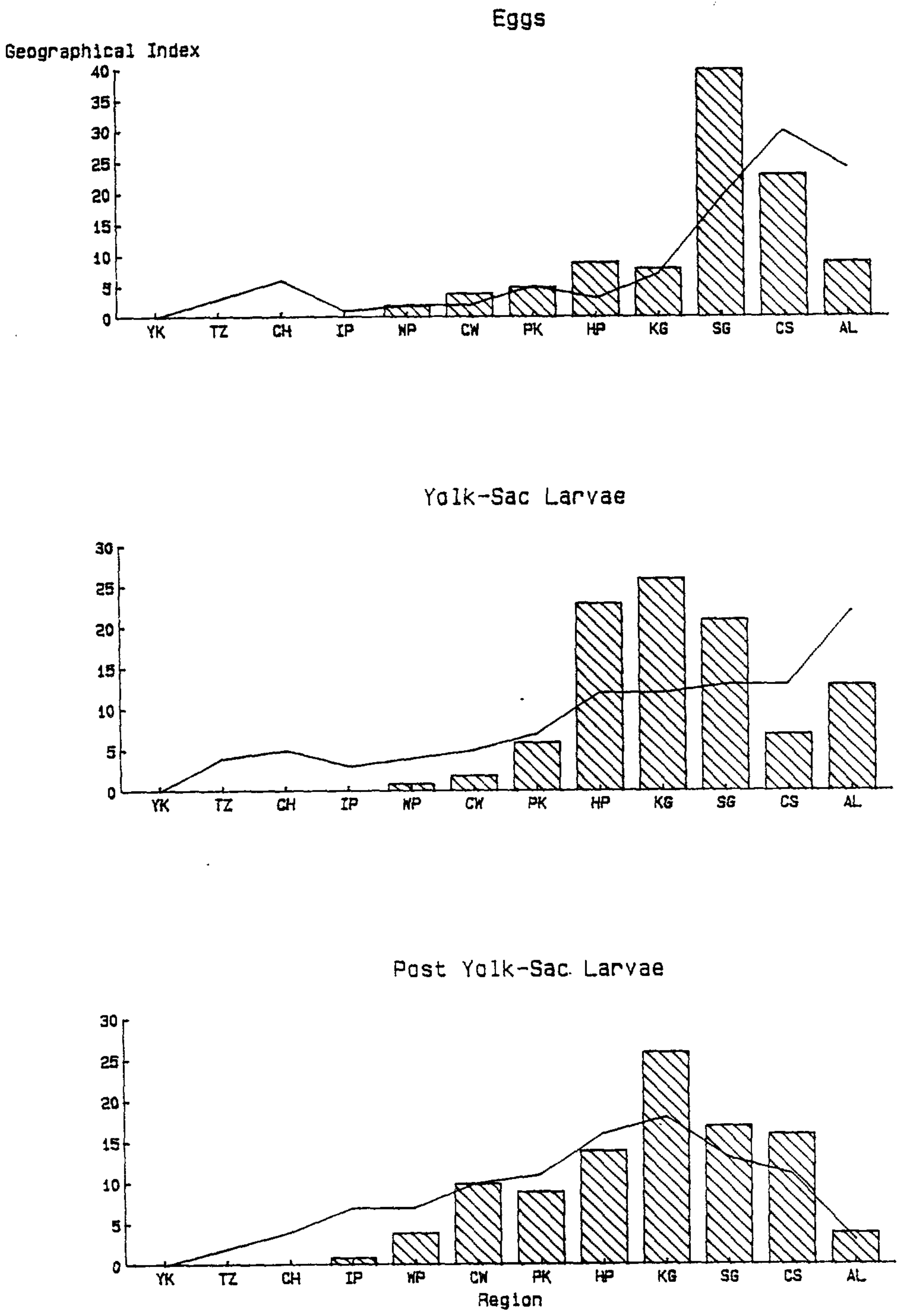


Figure IV-15. Geographic distribution of white perch egg, yolk-sac larvae, and post yolk-sac larvae collected in the Longitudinal River Survey. Bars represent index values for 1985. Lines represent average values for 1974-1984.

1986). In 1985, eggs were taken at salinities as high as 13.5 ppt, but were encountered only sporadically in waters greater than 3 ppt.

White perch eggs were found in samples during all but the last week of the LRS. However, concentrations were highest during the initial two weeks of LRS and densities greater than 100/1000m^3 were not observed after 16 June. Individual peaks were observed during the weeks of 29 April and 13 May; this is 2-4 weeks earlier than peaks observed in most years (Fig. IV-16). However, this conclusion should be viewed cautiously since periods of peak egg abundance may be poorly estimated due to the demersal, adhesive nature of the eggs.

Yolk-Sac Larvae

Yolk-sac larvae were collected as far downstream as Croton-Haverstraw in 5 ppt salinity water (Fig. IV-17). As with eggs, however, concentrations were centered upriver and few yolk-sac larvae were found in water with greater than 3 ppt salinity. This upstream distribution is typical of, but more pronounced than in, previous years (Fig. IV-15). Regional temperatures in which white perch yolk-sac larvae were captured ranged from 12-23°C with a mean of 15°C.

The estimate for peak yolk-sac abundance occurred during the week of 6 May. This is about two weeks earlier than in most previous years (Fig. IV-16). The 6 May peak occurred prior to the highest observed egg density (Fig. IV-16), but this may be based on sampling limitations since the demersal, adhesive nature of white perch eggs may restrict their collection by the sampling gear. White perch yolk-sac larvae continued to be taken until the end of the LRS, but abundance declined sharply beginning in June.

Post Yolk-Sac Larvae

White perch post yolk-sac larvae were captured in all weeks of the LRS, but were most abundant from late May to mid-June (Fig. IV-18), when water temperature averaged 20°C. The peak of post yolk-sac collections followed peak yolk-sac collections by about three weeks, even though development between these stages is thought to be less than one week (Morgan and Rasin 1973). One possible explanation would be an influx of tributary-spawned post yolk-sac larvae to the river during June. Alternatively, some of the earlier spawned larvae may have suffered disproportionately high mortality. Regional densities gradually declined after June, and no regions exceeded

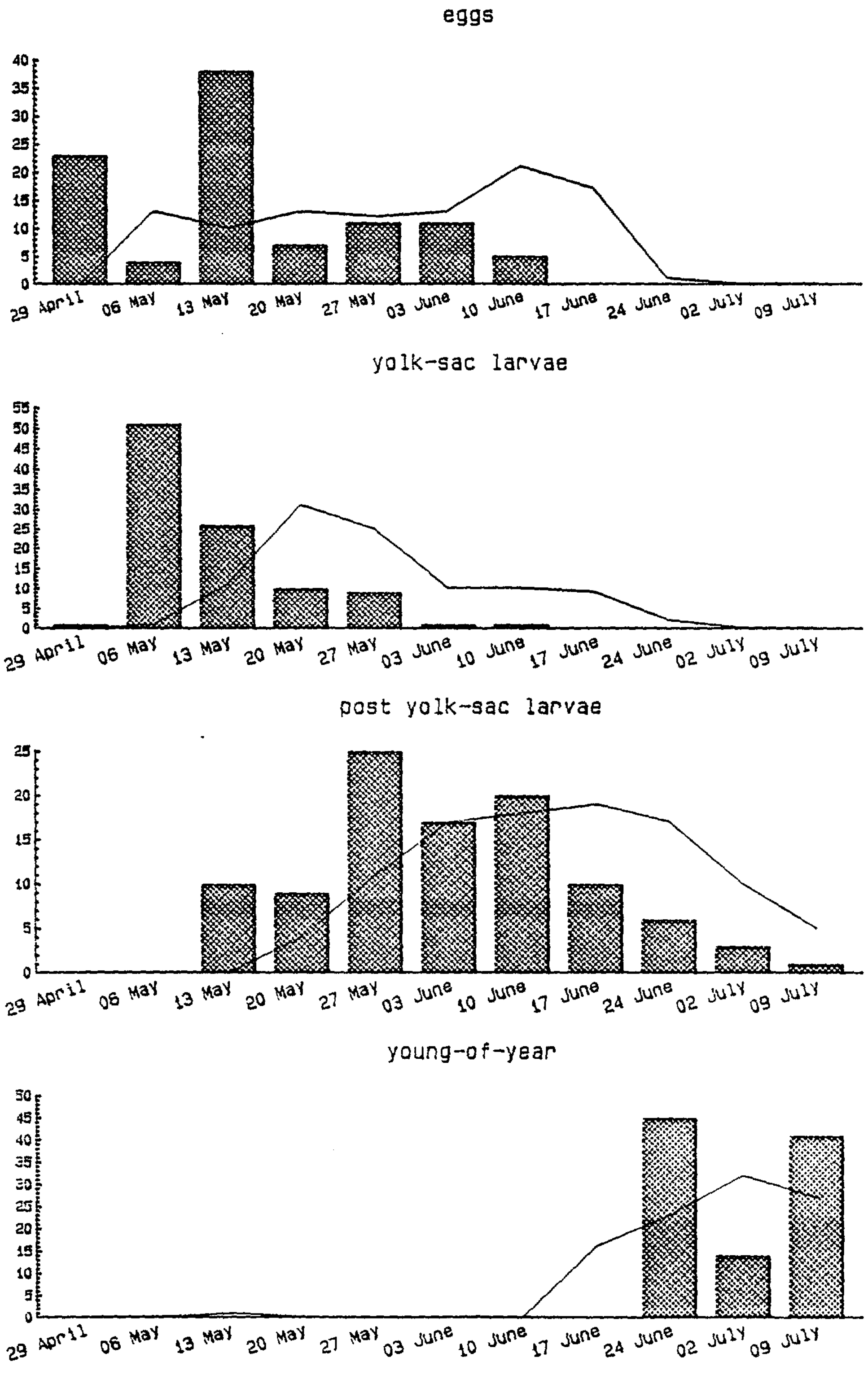


Figure IV-16. Temporal index for white perch eggs, yolk-sac larvae, post yolk-sac larvae, and young-of-year collected in the Longitudinal River Survey. Bars represent index values for 1985. Lines represent the average values for 1974-1984.

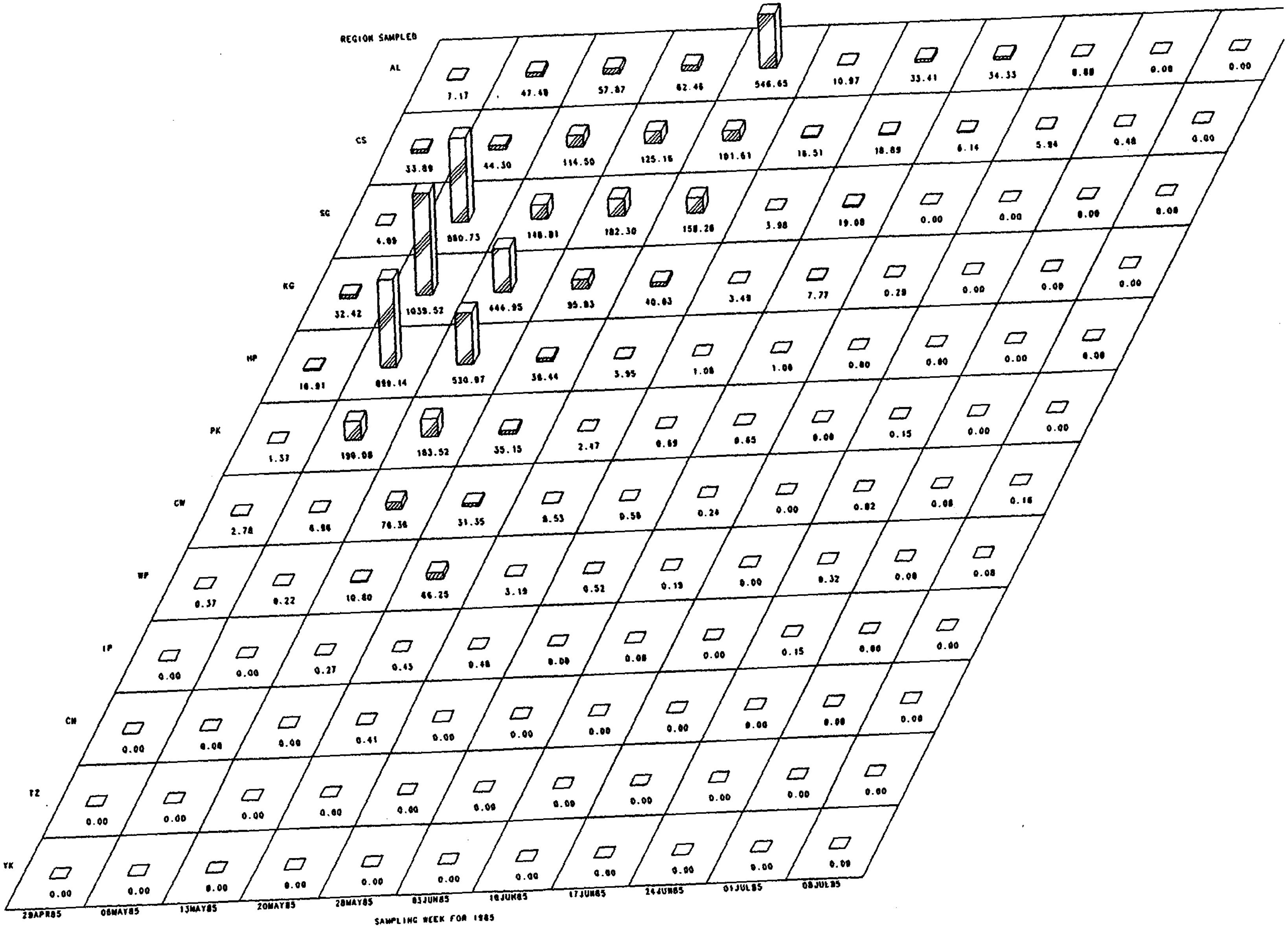


Figure IV-17. Mean regional density (per 1000 m^3) of white perch yolk-sac larvae collected in the Longitudinal River Survey during 1985

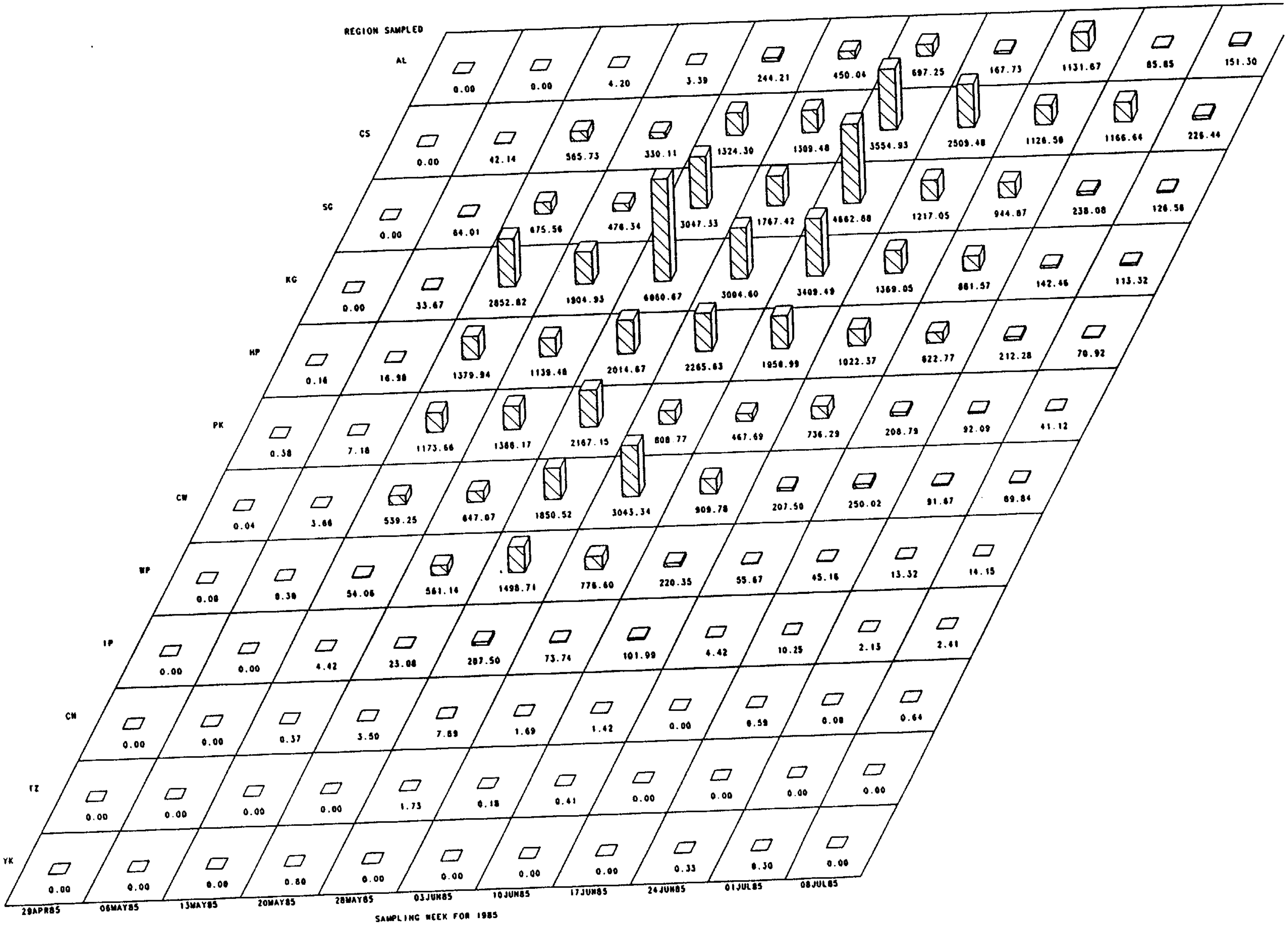


Figure IV-18. Mean regional density (per 1000 m^3) of white perch post yolk-sac larvae collected in the Longitudinal River Survey during 1985

250/1000 m^3 after the first week in July. In many previous years, observed declines have occurred 2-3 weeks later (Fig. IV-16).

Post yolk-sac larvae were caught as far downstream as Yonkers, but consistent catches were recorded only upstream of Croton-Haverstraw, in salinities less than 5 ppt. Dispersal or immigration from tributaries was apparent after mid-May, as post yolk-sac larvae were found in abundance over an increasingly greater portion of the river.

Young-of-Year

Young-of-year white perch were first collected during the LRS on 24 June (Fig. IV-19). Juvenile white perch have been taken as early as late May in some previous Year Class studies, but the date of first capture in 1985 is not atypical of most years (Fig. IV-16). Young-of-year white perch were also taken during all weeks of FSS (Fig. IV-20) and BSS (Fig. IV-21). BSS catches were generally higher in the early fall, and catches in the FSS were higher in the late fall, suggesting that an onshore/offshore movement occurs during the fall. This pattern has also been reported in other Year Class reports.

Young-of-year white perch were taken from all regions but Yonkers. The largest juvenile abundances associated with the BSS occurred at or near the salt front (Fig. IV-21), while peaks found during the LRS and FSS were located between Poughkeepsie and Kingston. Despite this difference, the distribution of juvenile white perch in the shore zone was typical of that in previous Year Class studies (Fig. IV-22).

Yearling and Older

Yearling and older white perch were collected in every region and in every week during the LRS (Fig. IV-23), FSS (Fig. IV-24), and BSS (Fig. IV-25). White perch were least abundant in the higher salinity waters of Yonkers, and there appeared to be a bimodal geographic distribution of fish in the estuary beginning at the start of the FSS and BSS. The downstream peak was located between Tappan Zee and Indian Point, while the upstream peak ranged from Poughkeepsie to Albany on some dates. Similar bimodal abundance peaks have been observed historically.

Prior to the start of the FSS and BSS, a single broad peak, probably representing the spawning population, was observed. This peak period followed peak egg densities by several weeks.

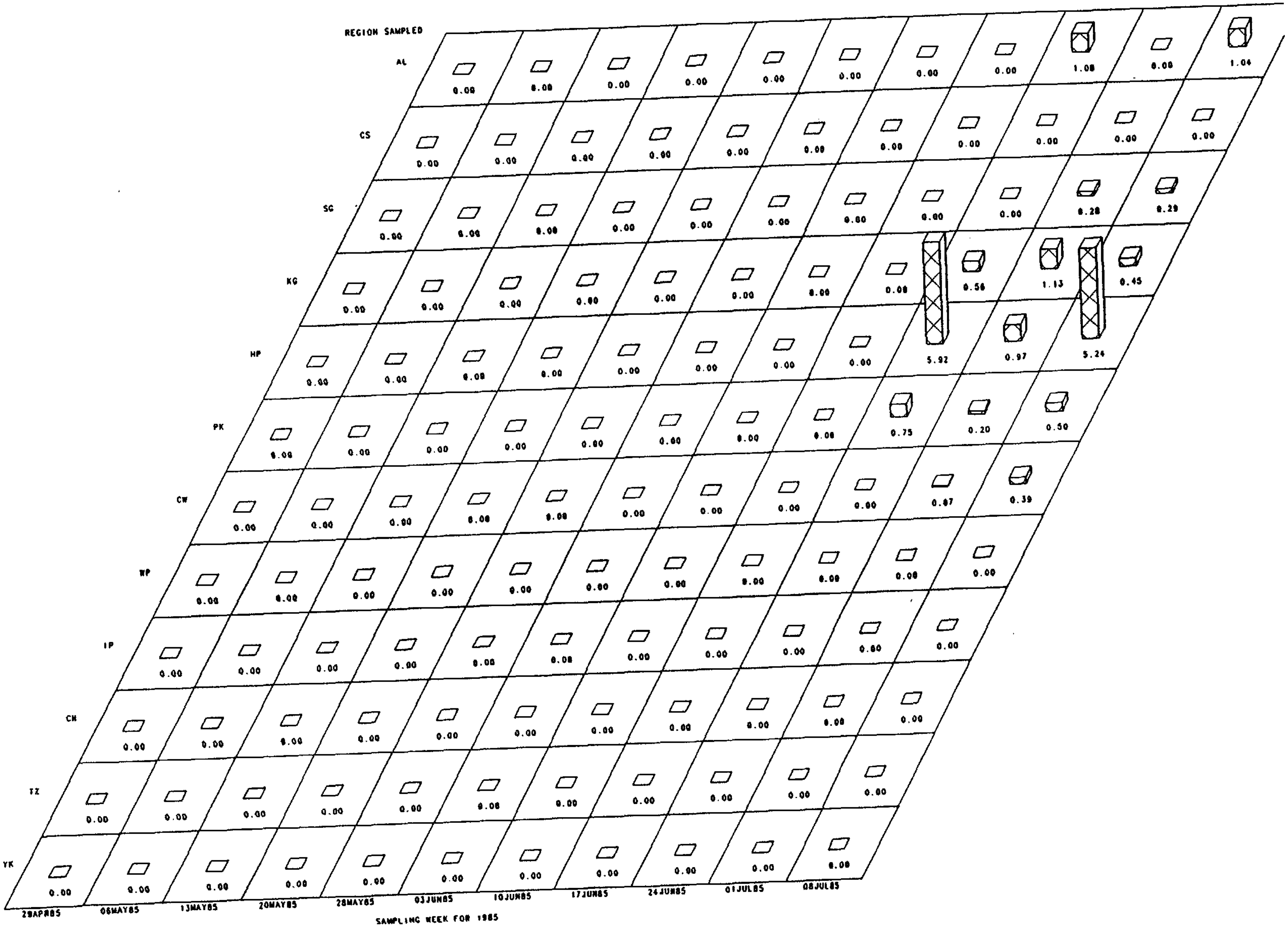


Figure IV-19. Mean regional density (per 1000 m^3) of white perch young-of-year collected in the Longitudinal River Survey during 1985

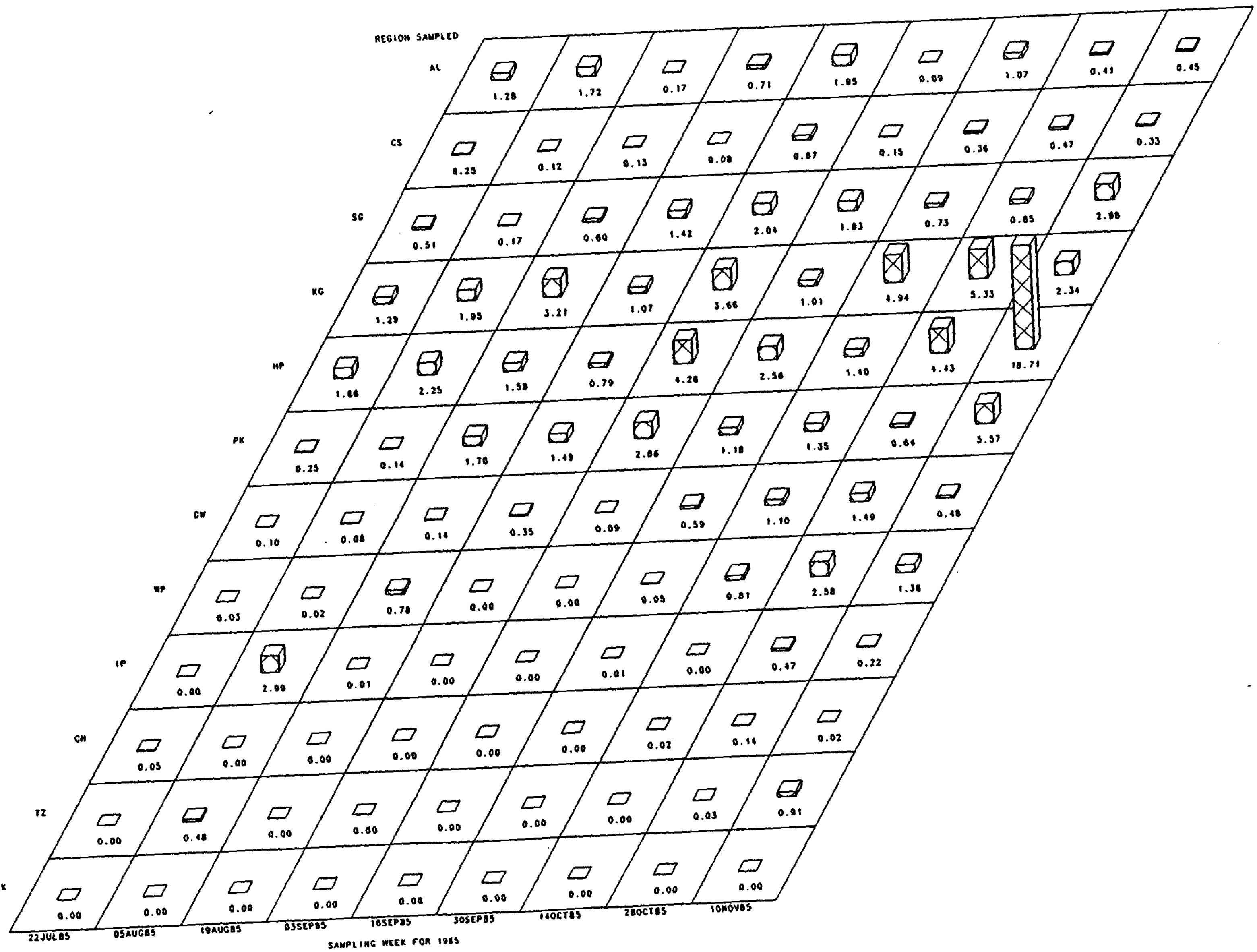


Figure IV-20. Mean regional density (per 1000 m^3) of white perch young-of-year collected in the Fall Shoals Survey during 1985

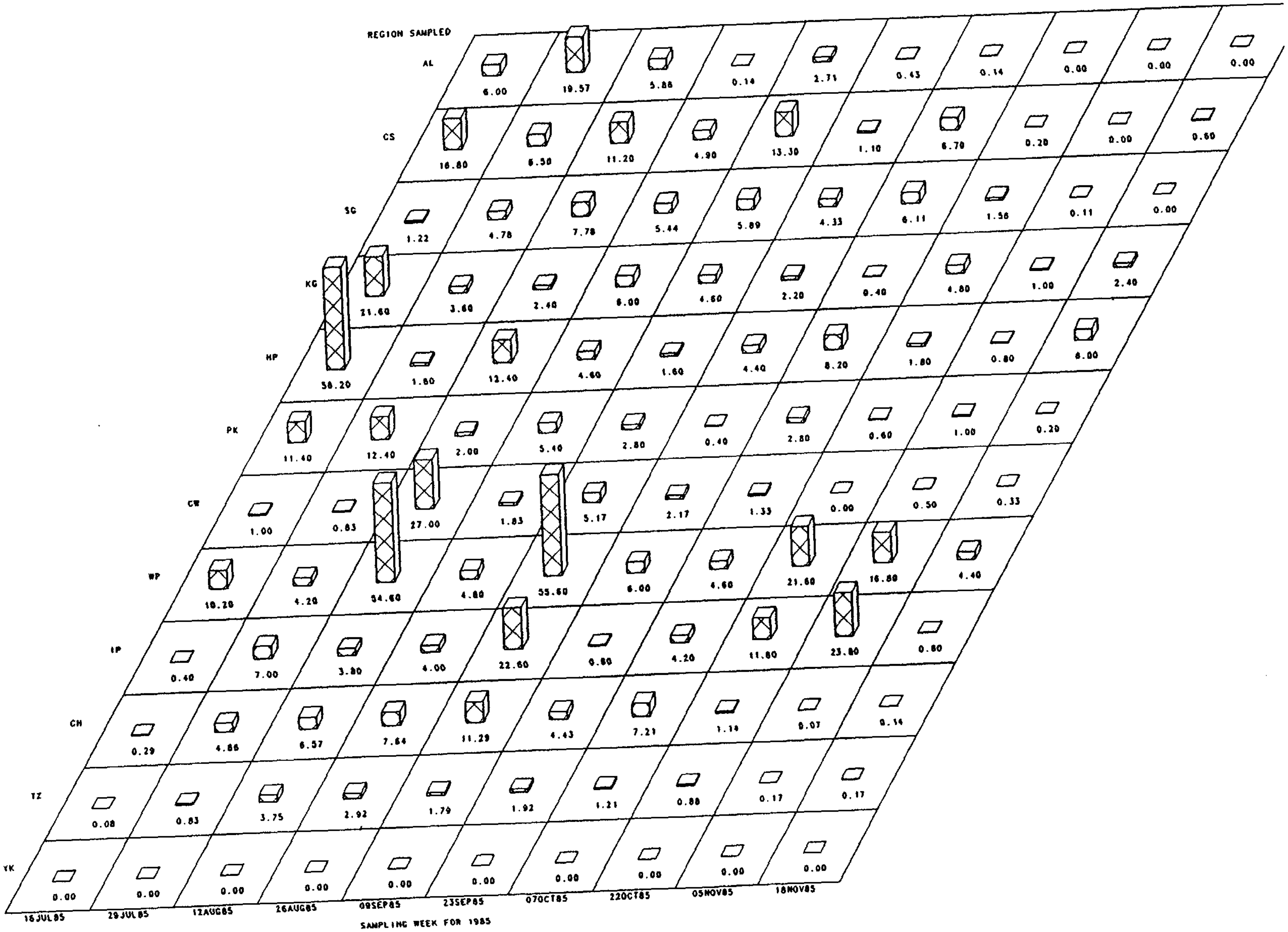


Figure IV-21. Catch per unit effort of white perch young-of-year collected in the Beach Seine Survey during 1985

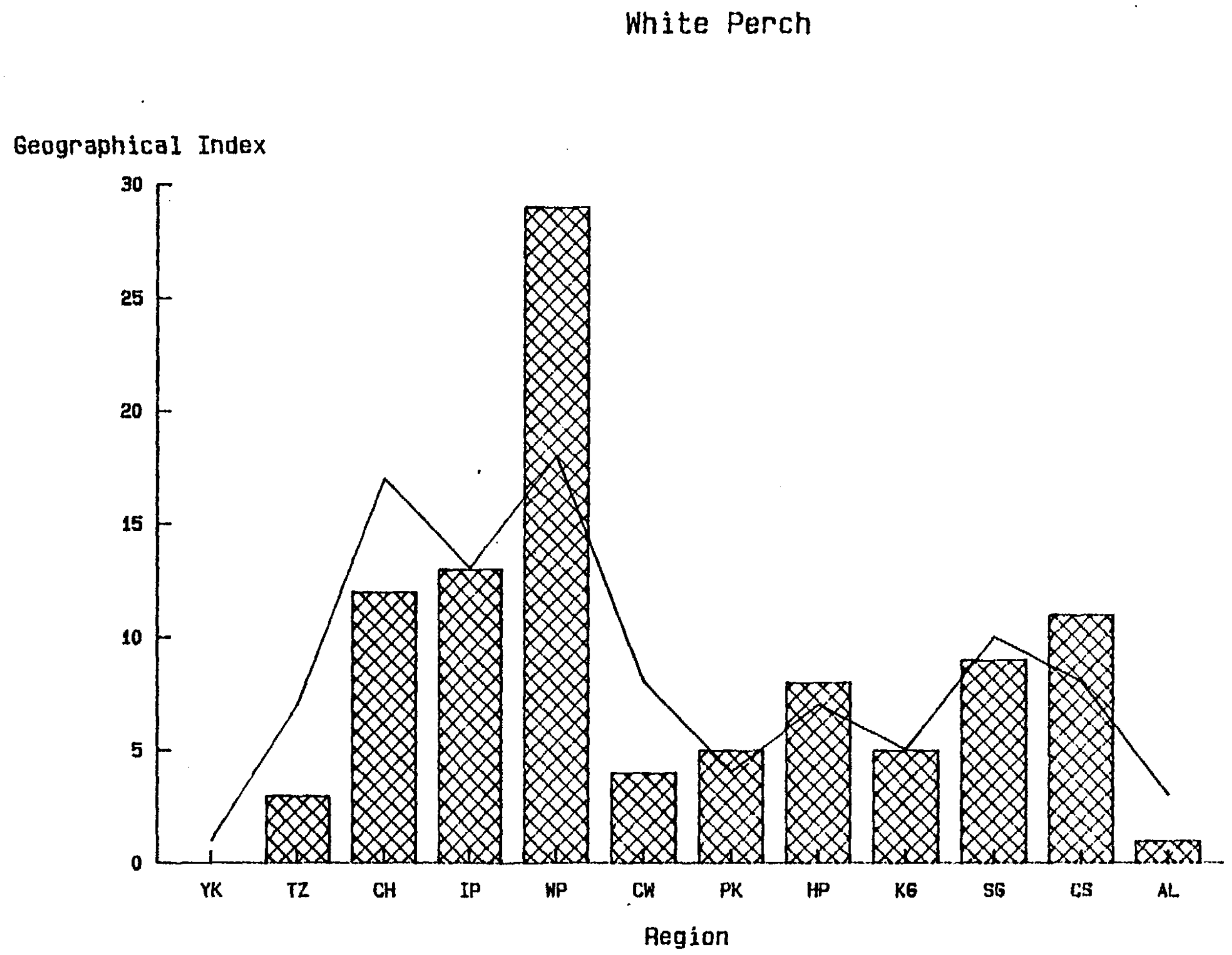


Figure IV-22. Geographic distribution of young-of-year white perch collected in the Beach Seine Survey. Bars represent index values for 1985. The line represents average values for 1974-1984.

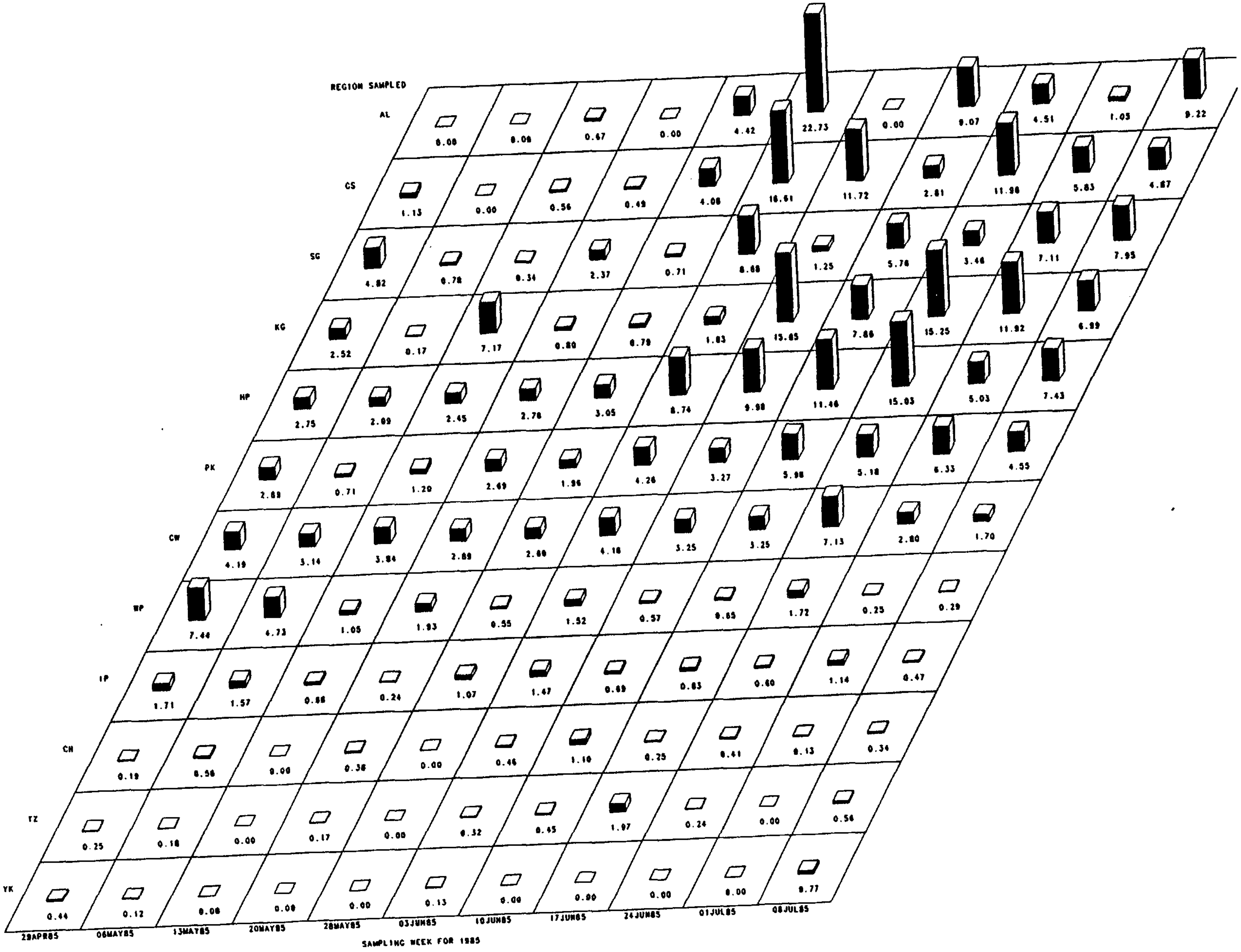


Figure IV-23. Mean regional density (per 1000 m^3) of white perch yearling and older collected in the Longitudinal River Survey during 1985

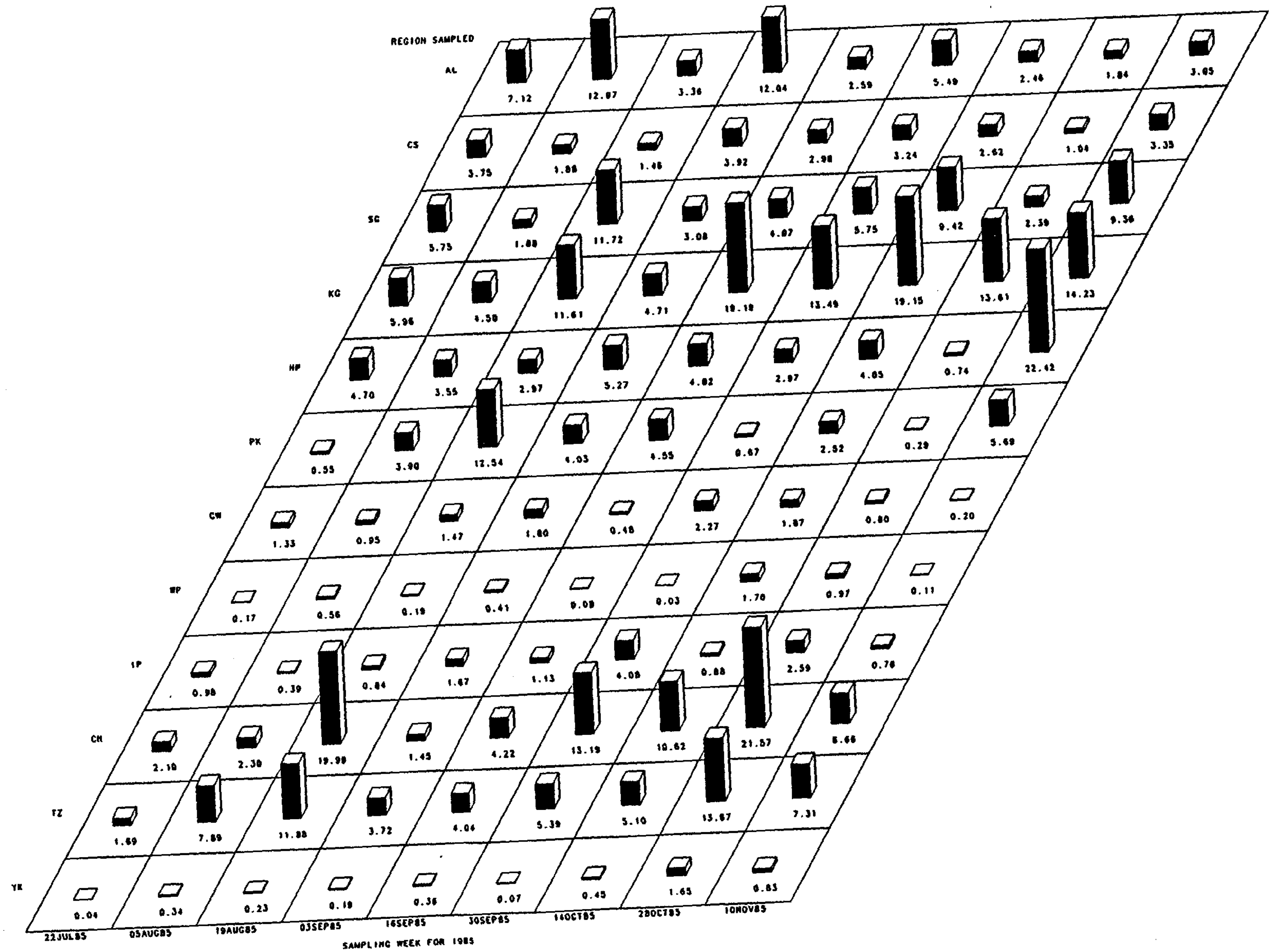


Figure IV-24. Mean regional density (per 1000 m^3) of white perch yearling and older collected in the Fall Shoals Survey during 1985

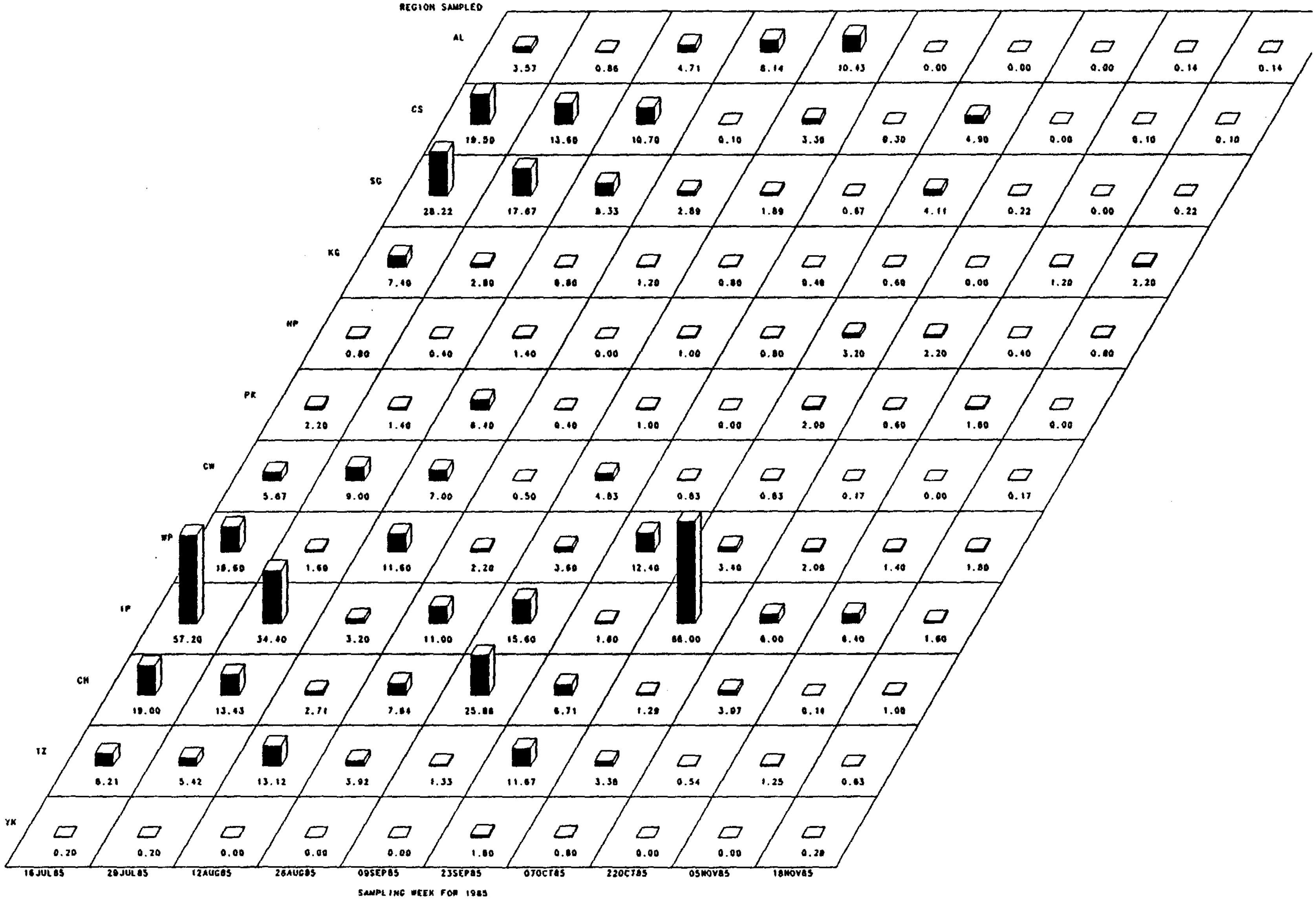


Figure IV-25. Catch per unit effort of white perch yearling and older collected in the Beach Seine Survey during 1985

NAI (1985c) suggested that such peaks in yearling and older white perch density may be associated with the return of tributary spawners to the main river.

During the BSS and FSS, temporal distribution of yearling and older white perch was not well defined, but as water temperatures fell below 15°C, white perch were taken less frequently near shore. Downstream migration may also have begun at the end of FSS, but no clear trend was apparent.

D. ATLANTIC TOMCOD

Atlantic tomcod, *Microgadus tomcod*, is an anadromous species, inhabiting the Atlantic coast from Canada to Virginia (Peterson et al. 1980). Adults normally enter estuaries in November and spawn there in December; however, spawning can occur through February. Spawning typically takes place in freshwater, as sperm cannot fertilize the eggs at salinities greater than 2 ppt (Booth 1967). The eggs, which are demersal and adhesive, hatch in 36-42 days (Hardy and Hudson 1975). After hatching, larvae become buoyant and drift downstream toward the mesohaline environment, where optimal larval development occurs (Peterson et al. 1980).

Post Yolk-Sac Larvae

Consistent with their winter spawning behavior, no Atlantic tomcod eggs or yolk-sac larvae were taken during 1985, and nearly 99% of post yolk-sac larvae taken were captured in the first two weeks of the LRS (Fig. IV-26). Historically, an average of over 85% of all the post yolk-sac larvae collected were taken during the first week of the LRS, but in some years relative few were collected through the first week in July.

Post yolk-sac larval densities were highest at the salt front near West Point, well upstream of Yonkers and Tappan Zee where abundance peaks have occurred in previous years. Larvae were also captured as far upstream as Albany in 1985, which is atypical of previous years. This pattern may be explained by the lack of large freshwater inflows in early 1985. Temperatures during periods in which larvae were collected ranged from 12-18°C.

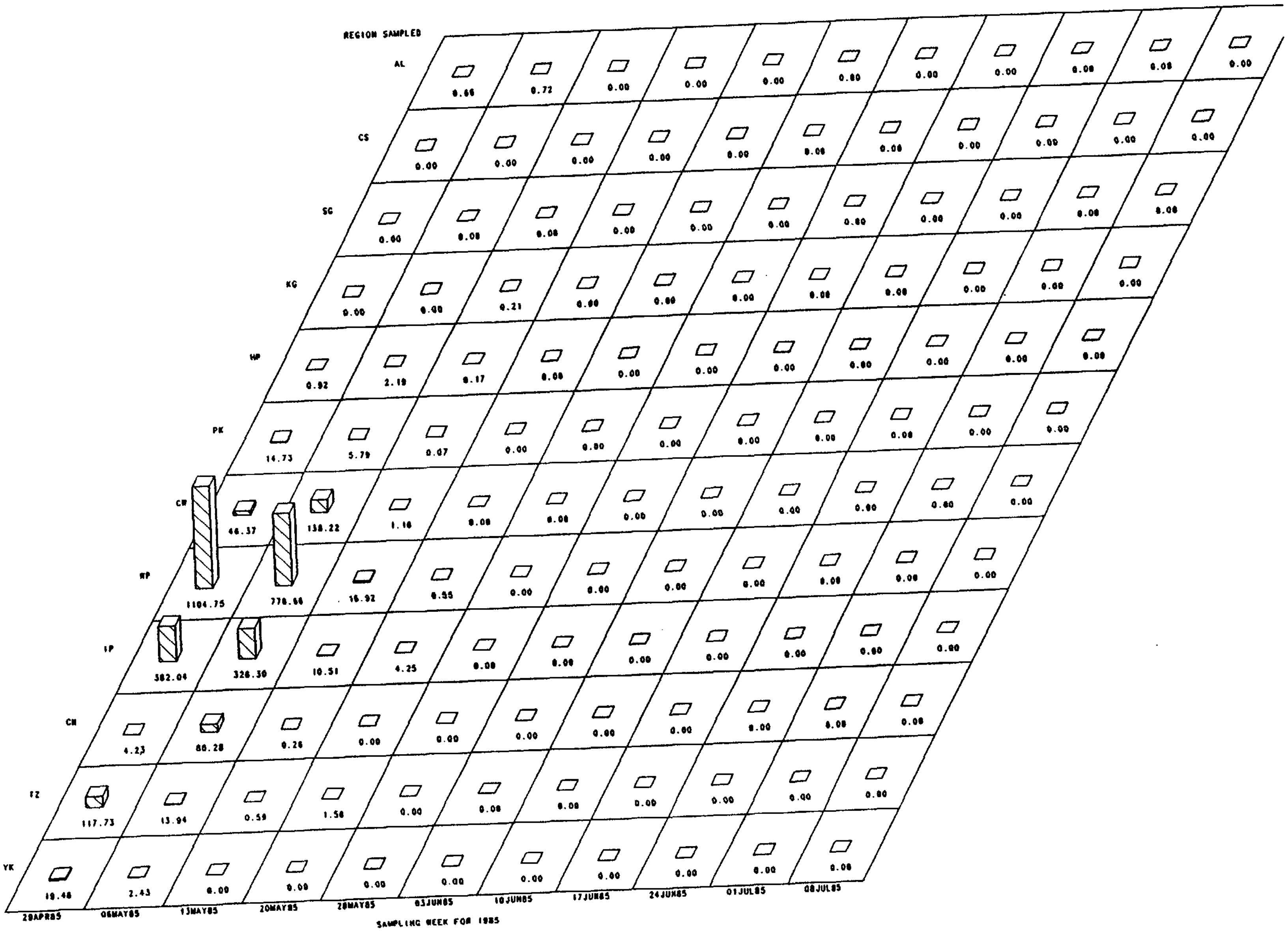


Figure IV-26. Mean regional density (per 1000 m^3) of Atlantic tomcod post yolk-sac larvae collected in the Longitudinal River Survey during 1985

Young-of-Year

Juvenile tomcod were taken throughout the LRS (Fig. IV-27), FSS (Fig IV-28), and BSS (Fig. IV-29). Densities were greatest from late April to mid-June and declined thereafter. During the FSS and BSS, density estimates of juvenile tomcod peaked during the first week of each survey and subsequently declined throughout the surveys.

Atlantic tomcod young-of-year were most abundant between the salt front and areas less than 3 ppt salinity (Croton-Haverstraw to Cornwall) during the LRS and FSS, but some were collected in all regions. As was typical in other years, highest BSS densities were found at Tappan Zee, and no juveniles were taken north of West Point during the BSS (Fig. IV-30).

E. ALOSA SPP.

This taxonomic group comprises the early developmental stages of three anadromous clupeids: American shad (*Alosa sapidissima*), blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*). In previous Year Class Reports American shad has been presented separately.

All three species are anadromous, entering rivers and estuaries along the Atlantic coast in spring to spawn in brackish or freshwater areas. Although the spawning runs of these three species overlap to some extent, peak egg abundance for each of these species can often be identified based on water temperature at time of spawning, water depth, and substrate. Alewife and American shad spawn earliest. Alewife spawning occurs first at temperatures near 13° (Tyus 1974). American shad spawning follows when water temperature is between 13-18 °C (Leggett and Whitney 1972). American shad spawn primarily over sand or pebbly substrates with moderate flow (Marcy 1972; Mansueti 1955). Spawning by alewife generally occurs in lower velocity currents and over a wider range of substrates, including sand, gravel, and detritus-covered bottom (Cooper 1961). Blueback herring may not spawn until temperature exceeds 20 °C and generally spawn on sand or gravel in high flow environments (Loesch and Lund 1977).

All three species are repeat spawners that mature beginning at Age 3 (Chittenden 1975; Tyus 1974; Kissil 1974). All are broadcast spawners, with the number of eggs typically exceeding 50,000 per female (Loesch and Lund 1977; Messieh 1977; Kissil 1974; Leggett 1969). All three species overwinter in coastal

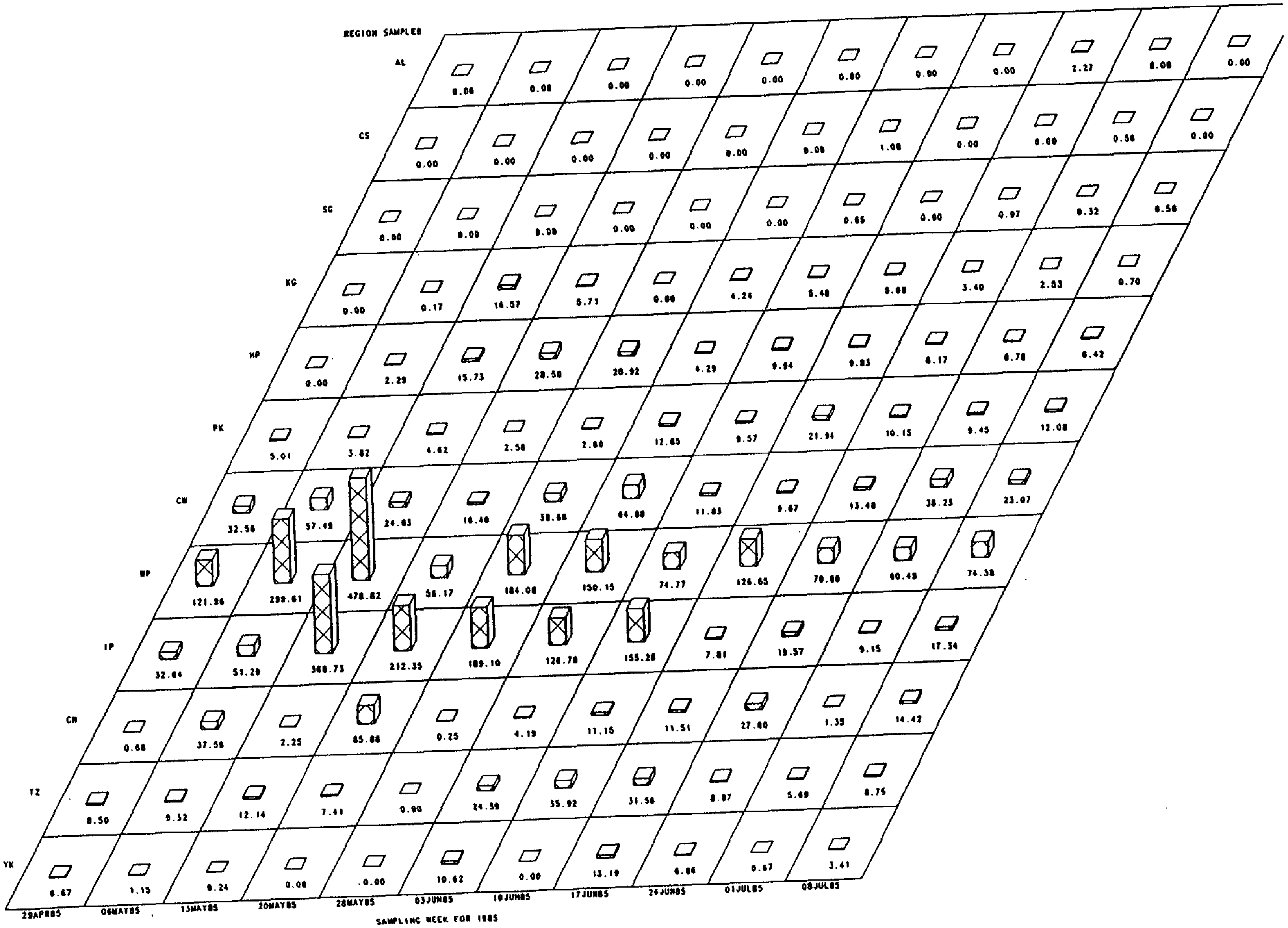


Figure IV-27. Mean regional density (per 1000 m^3) of Atlantic tomcod young-of-year collected in the Longitudinal River Survey during 1985

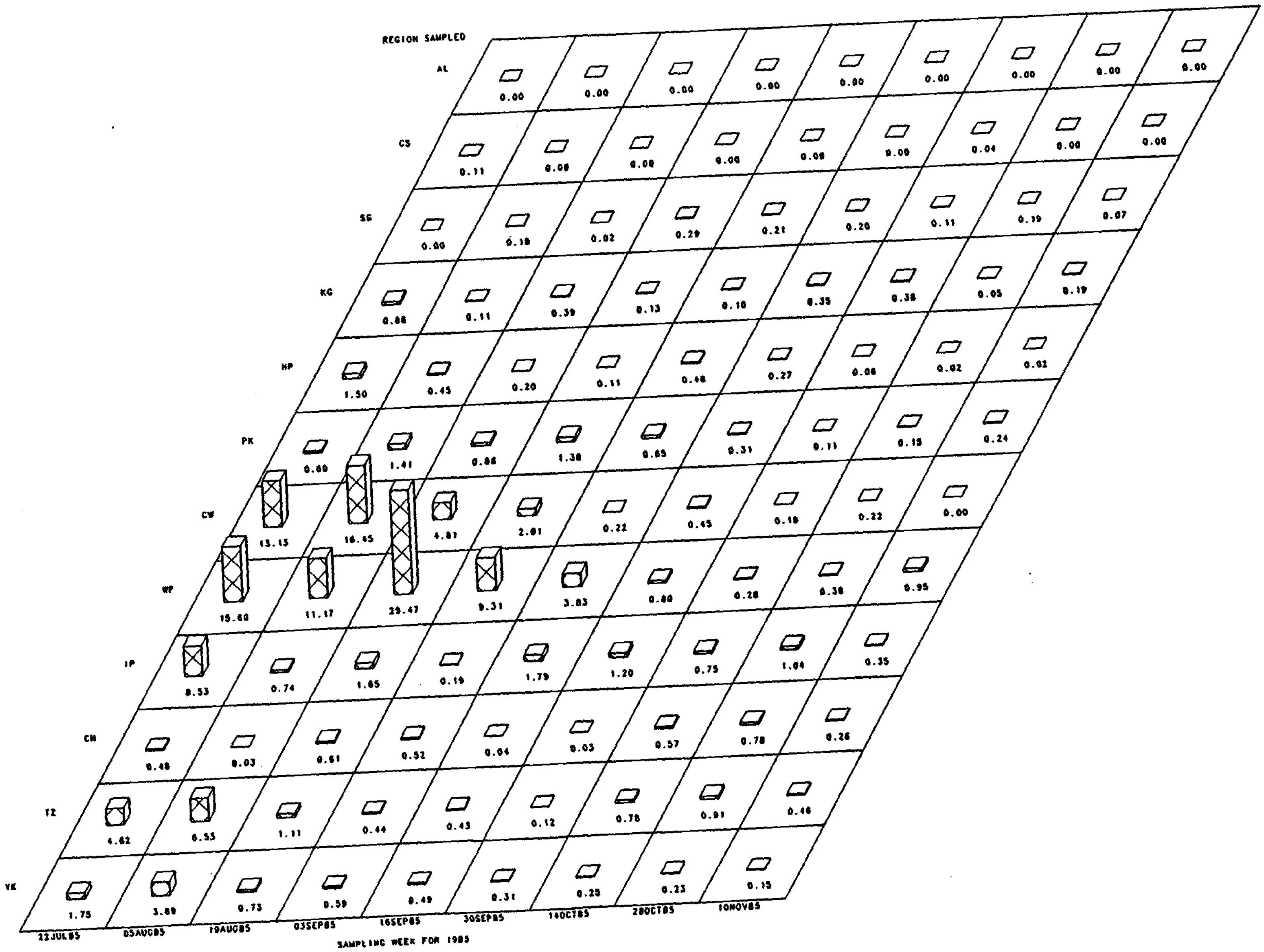


Figure IV-28. Mean regional density (per 1000 m^3) of Atlantic tomcod young-of-year collected in the Fall Shoals Survey during 1985

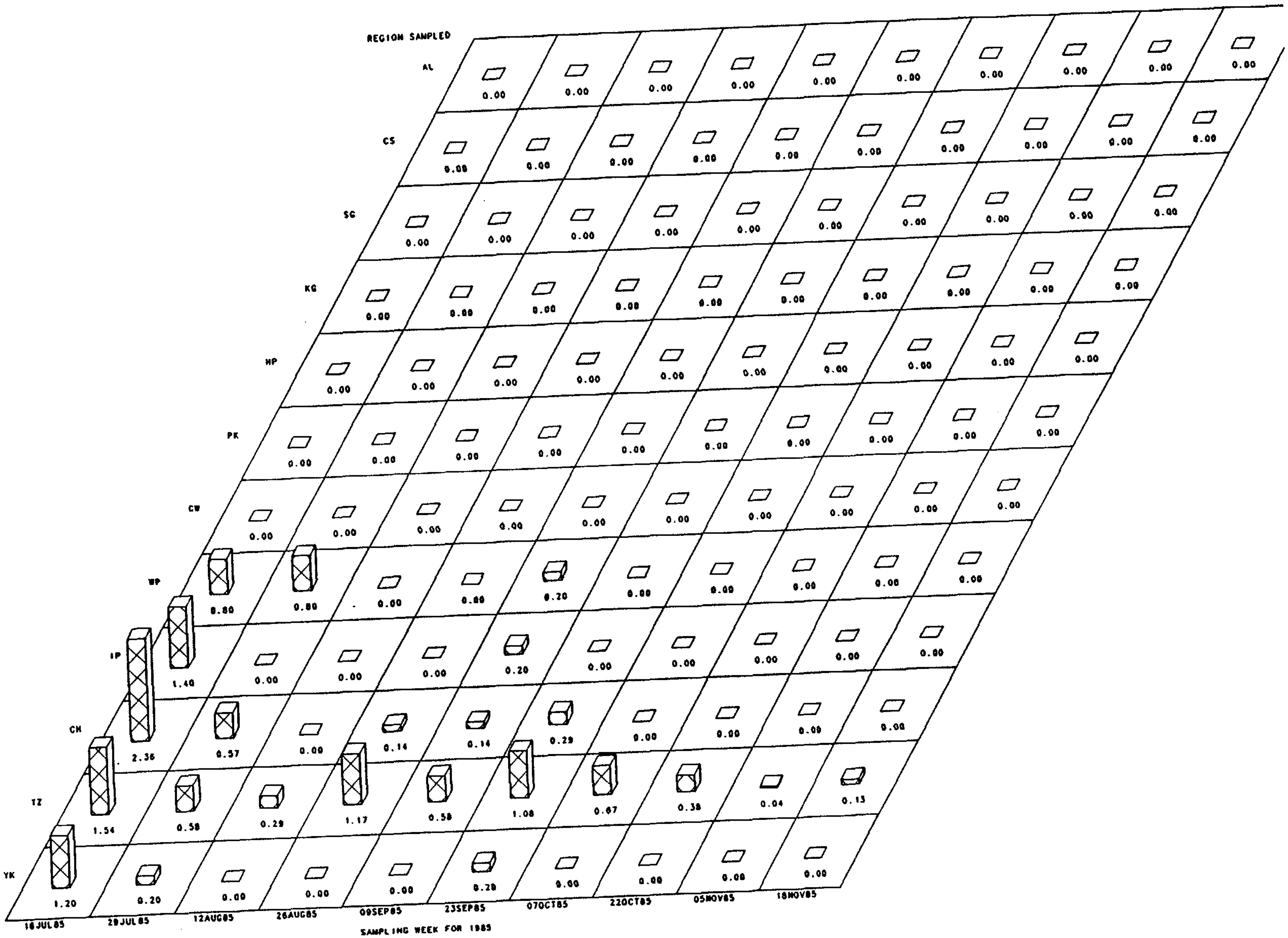


Figure IV-29. Catch per unit effort of Atlantic tomcod young-of-year collected in the Beach Seine Survey during 1985

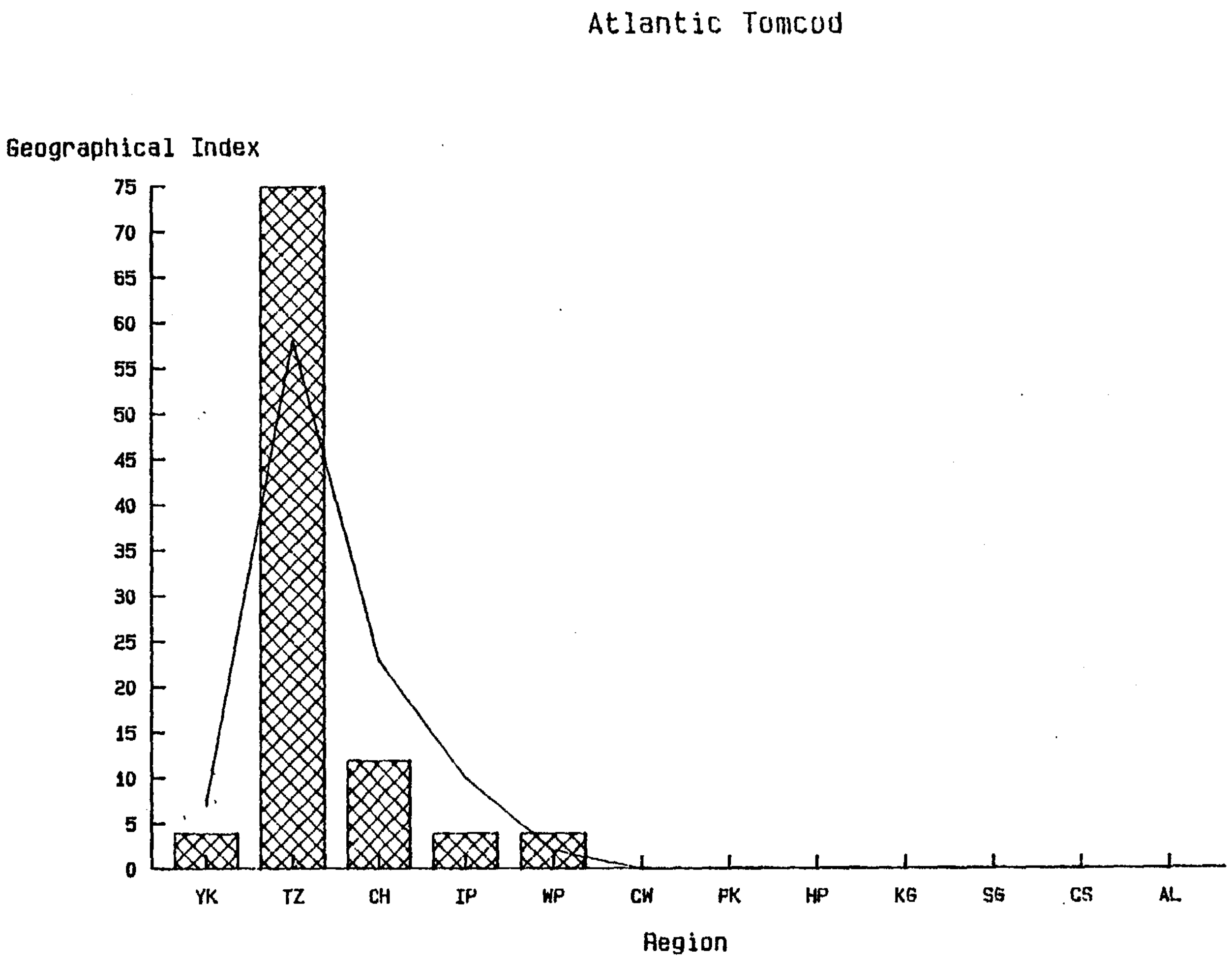

Atlantic Tomcod

Figure IV-30. Geographic distribution of young-of-year Atlantic tomcod collected in the Beach Seine Survey. Bars represent index values for 1985. The line represents average values for 1974-1984.

waters. Juveniles leave the estuary in fall with declining temperature (Kissil 1974; Richkus 1974; Burbidge 1974; Watson 1968) and may not return until they reach spawning age.

Eggs

Alosa spp. were collected during the LRS until late June (Fig. IV-31). However, highest egg densities were observed during the first week of LRS in late April, suggesting that as in previous years, alosid spawning may have peaked prior to initiation of the LRS in April. Although eggs were collected as far downstream as West Point, in the vicinity of the salt front, they were most abundant from Saugerties to Albany. Consistent with historical patterns, Albany was the region containing the greatest density estimates for these species.

Yolk-Sac Larvae

Like *Alosa* eggs, yolk-sac larvae were collected only from regions above Indian Point, with highest densities observed in the Albany Region (Fig. IV-32). Peak density of yolk-sac larvae followed peak egg density by about one week. This is consistent with the less than one week incubation time for eggs at 15°C, which was the temperature observed in the region (Albany) and week (6 May) when peak yolk-sac density was observed. The highest mean temperature observed in regions where yolk-sac larvae were collected was 22.2°C and occurred during the week of 24 June, the last week that yolk-sac larvae were found.

Post Yolk-Sac Larvae

Alosa spp. post yolk-sac larvae were collected in all weeks and from all regions but Yonkers during the LRS (Fig. IV-33). However, few were taken downstream of the salt front, and concentrations were heaviest from Kingston to Saugerties between mid-May and mid-June. Peak densities followed the period of peak yolk-sac abundance by 3-4 weeks. As with eggs and yolk-sac larvae, density estimates for post yolk-sac larvae of this taxonomic group were lower in the lower estuary in 1985 than in many previous years. This may reflect reduced downstream dispersal as a result of low rainfall in 1985.

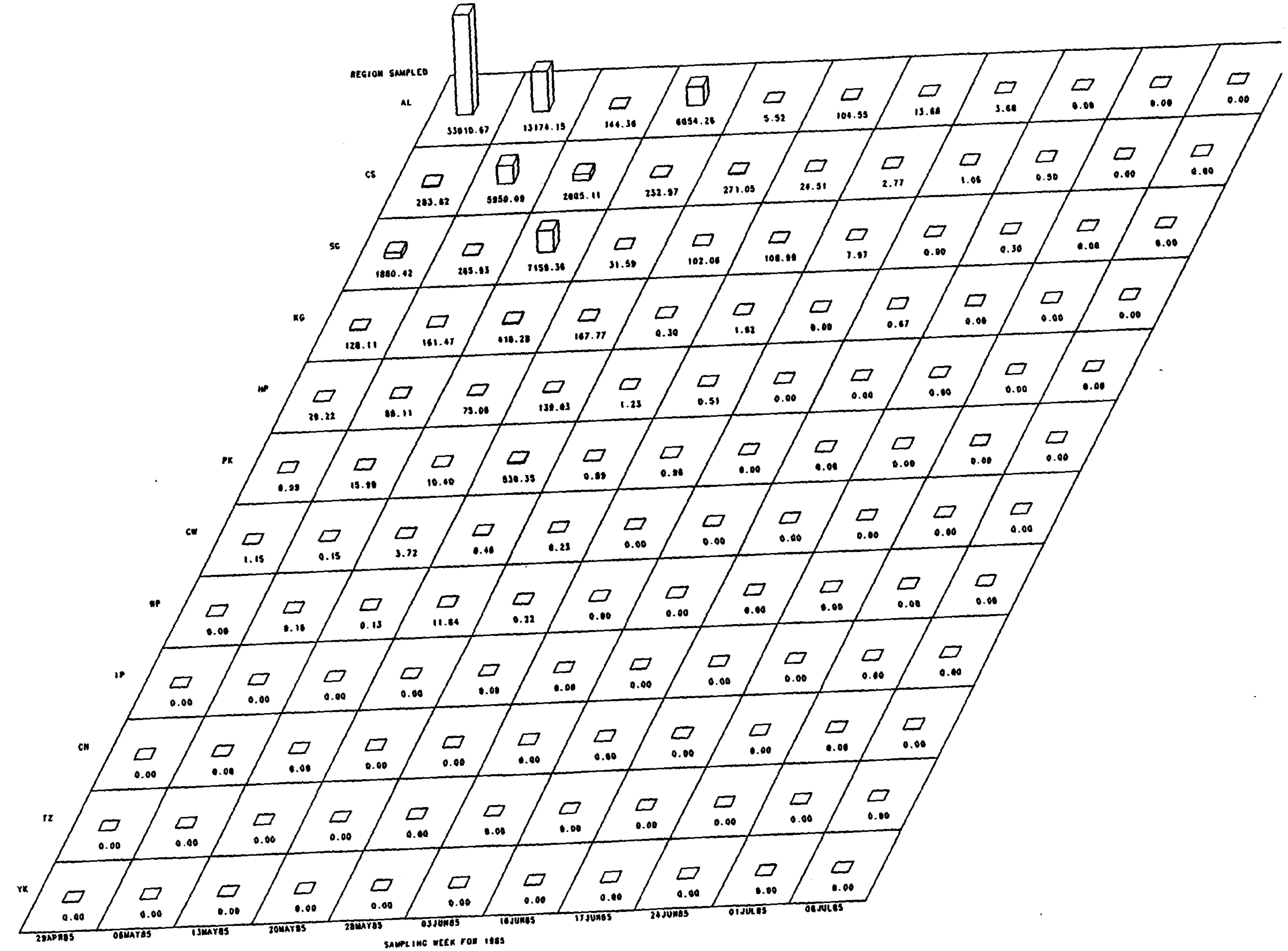


Figure IV-31. Mean regional density (per 1000 m^3) of *Alosa* spp. eggs collected in the Longitudinal River Survey during 1985

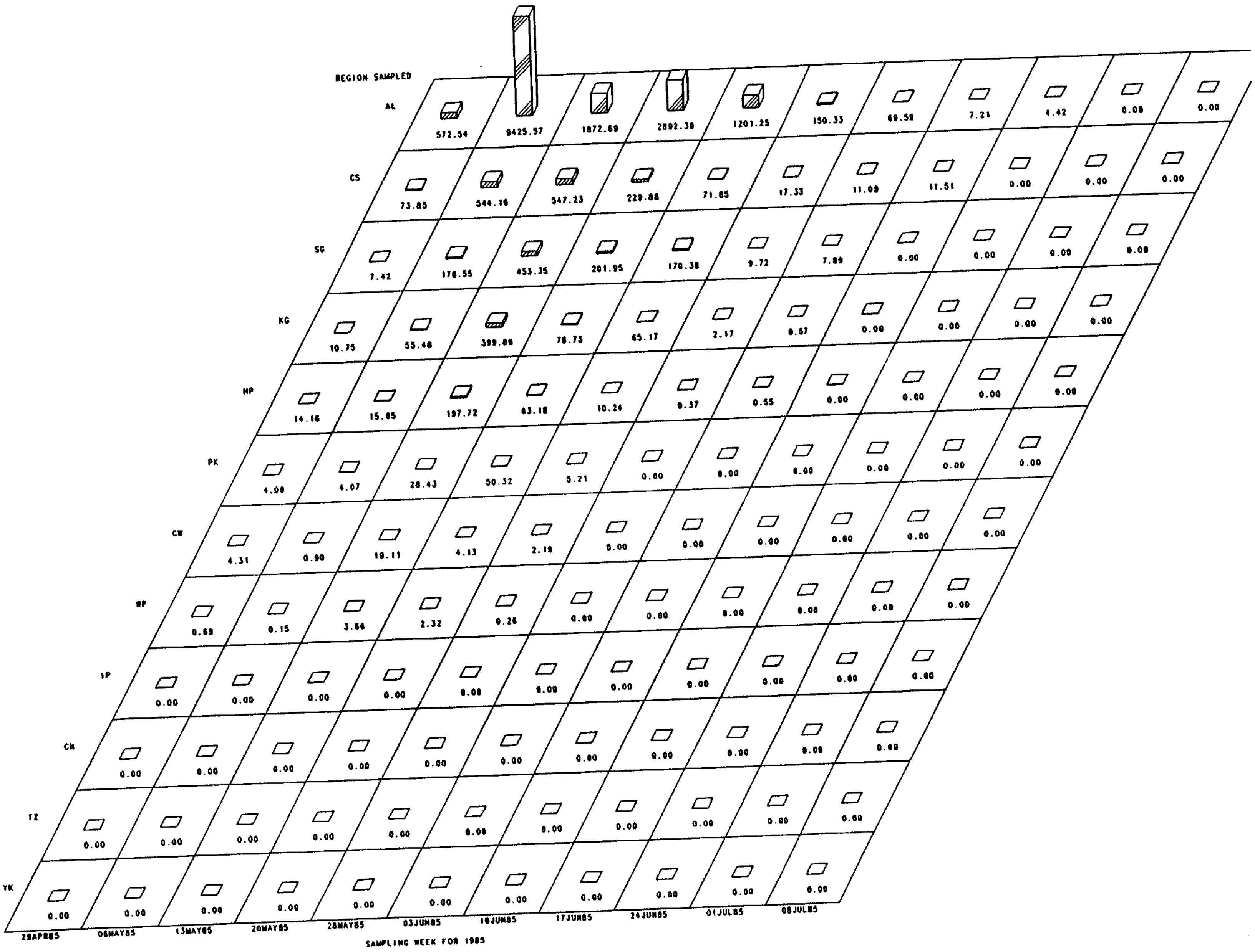


Figure IV-32. Mean regional density (per 1000 m^3) of *Alosa* spp. yolk-sac larvae collected in the Longitudinal River Survey during 1985

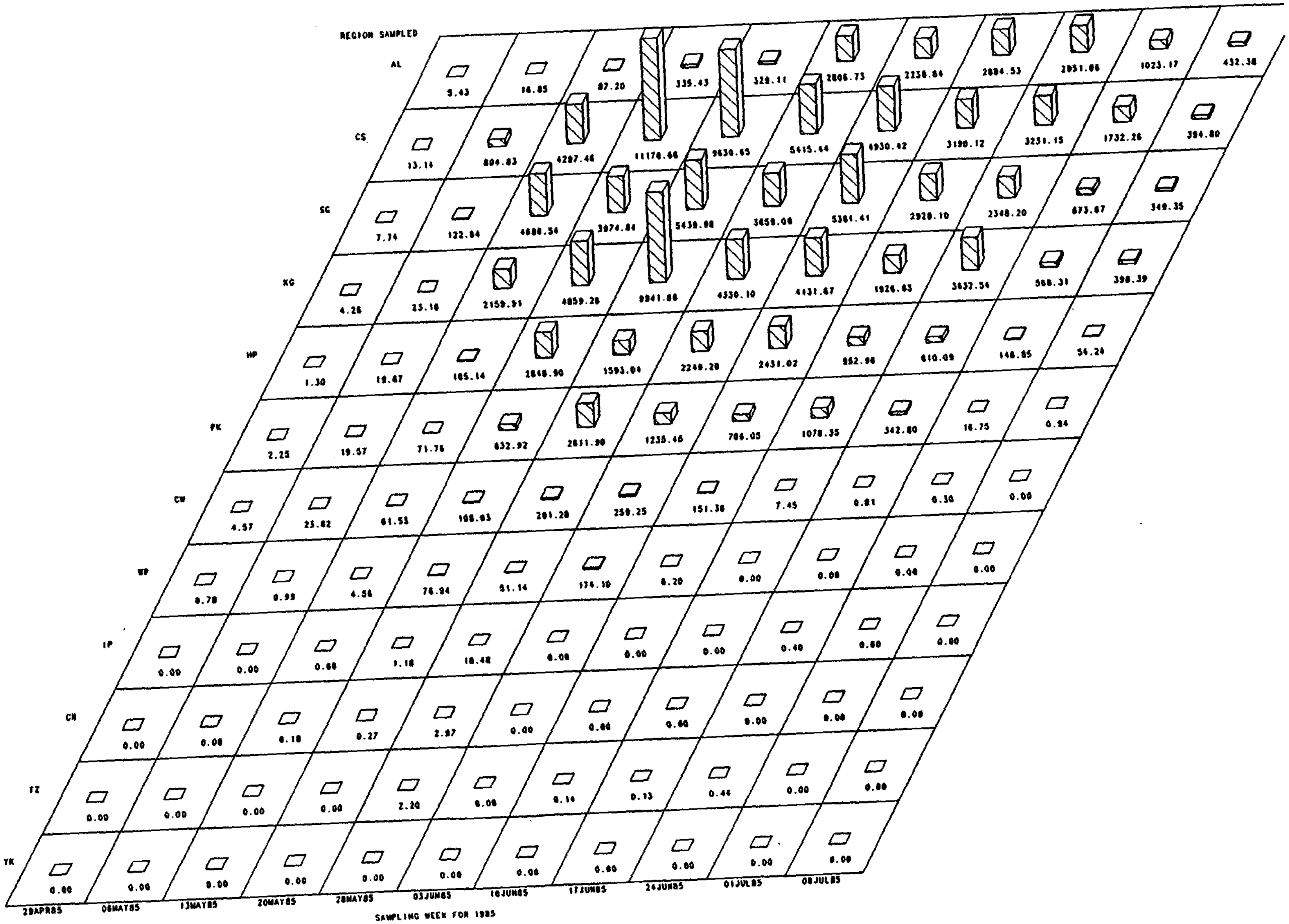


Figure IV-33. Mean regional density (per 1000 m^3) of *Alosa* spp. post yolk-sac larvae collected in the Longitudinal River Survey during 1985

F. AMERICAN SHAD

Post Yolk-Sac Larvae

Nearly 80% of American shad post yolk-sac larvae were caught in the Albany and Catskill regions in 1985, but some post yolk-sac larvae were caught as far south as West Point (Fig. IV-34). Peak estimated concentrations were observed during the weeks of 20 May and 3 June, approximately 1-3 weeks ahead of the mean peak in previous years.

Nearly all post yolk-sac larvae were taken in the freshwater portion of the river and the highest mean regional salinity in which larvae were collected was 2.6 ppt at West Point. Temperature ranged from 15-25°C during the period of time that shad post yolk-sac larvae were taken, with temperatures during peak abundance ranging from about 18-20.5°C.

Young-of-Year

Juvenile American shad were collected from the end of the LRS (Fig. IV-35) through the end of the BSS and FSS (Figs. IV-36 and IV-37). Peak young-of-year density estimates occurred in mid-July and followed post yolk-sac larval density peaks by about 3-5 weeks. Similar periods of peak juvenile density have been reported previously (Battelle 1983; Martin Marietta Environmental Systems 1986).

During the LRS, young-of-year shad were collected in greatest numbers from the upper estuary, where larval stages had been most abundant. During FSS and BSS, young-of-year shad were again most abundant in the upper estuary, but peaks were less pronounced. In previous years, juvenile shad were most frequently collected at Cornwall and Poughkeepsie (Fig. IV-38). The greater upstream concentration in 1985 may have reflected the lesser than average rainfall during the spring. Highest observed densities of juveniles during LRS, BSS, and FSS were during the weeks of 24 June, 16 July and 22 July, respectively. This extended period of abundance roughly corresponds with the duration of post yolk-sac larval abundance. From about the first week in July during LRS, young-of-year shad began dispersing in small numbers from freshwater reaches of the river into mesohaline regions. Juvenile shad were taken least often in the Yonkers region where mean salinities were substantially higher than upstream areas.

A general decline in density estimates of young-of-year shad was evident over the duration of the FSS and BSS. During 1985, juvenile shad apparently emigrated downstream in response

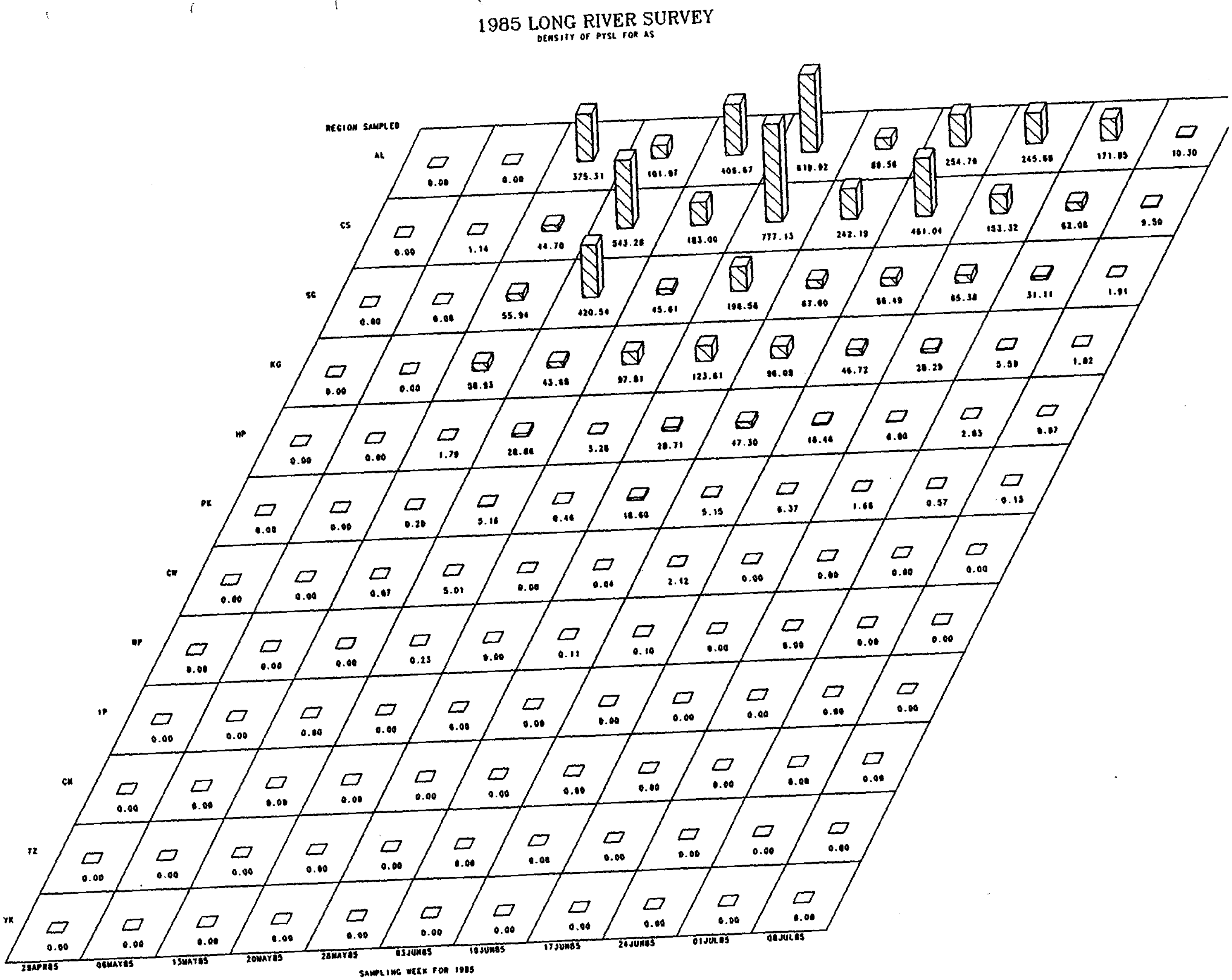


Figure IV-34. Mean regional density (per 1000 m^3) of American shad post yolk-sac larvae collected in the Longitudinal River Survey during 1985

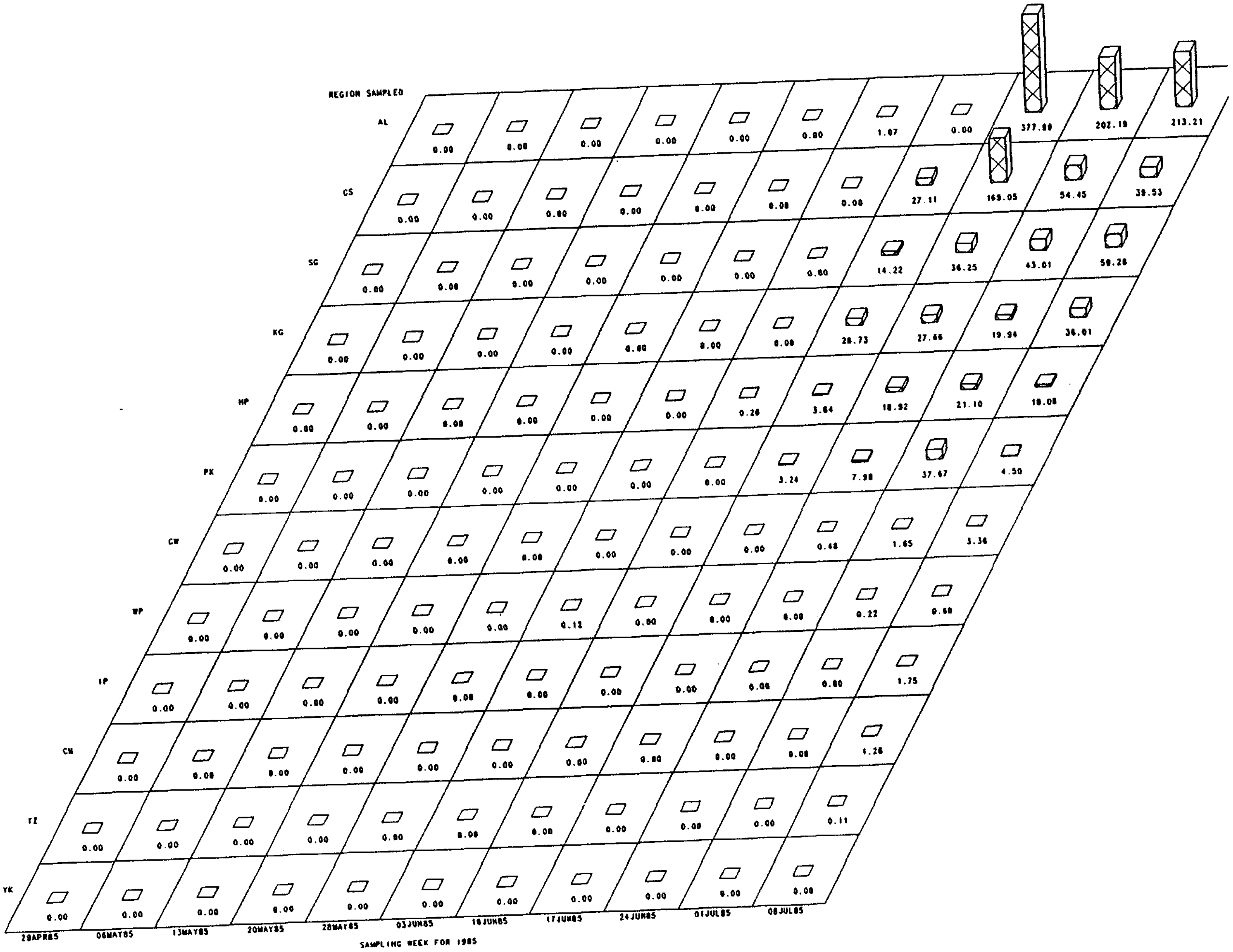


Figure IV-35. Mean regional density (per 1000 m^3) of American shad young-of-year collected in the Longitudinal River Survey during 1985

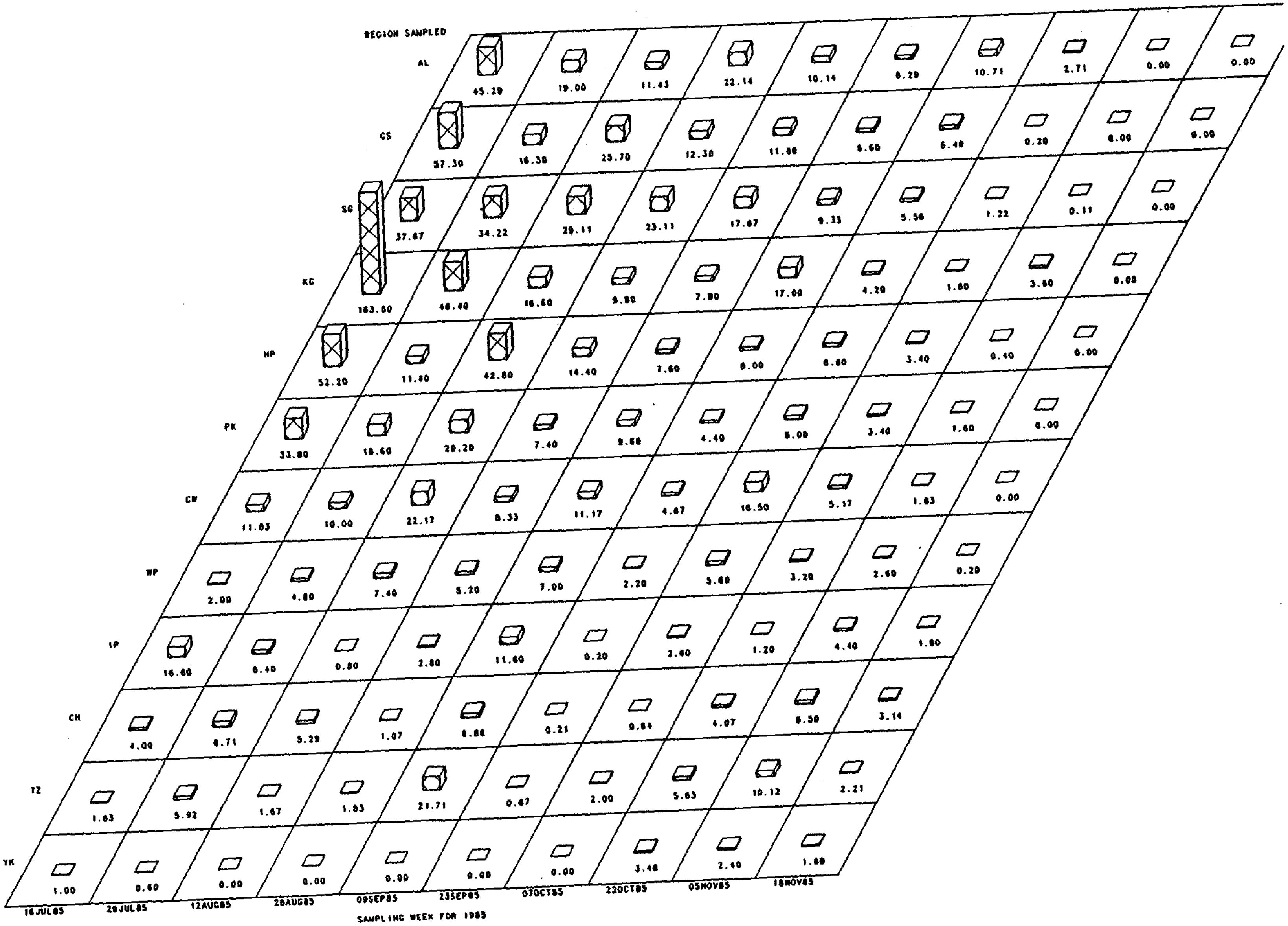


Figure IV-36. Catch per unit effort of American shad young-of-year collected in the Beach Seine Survey during 1985

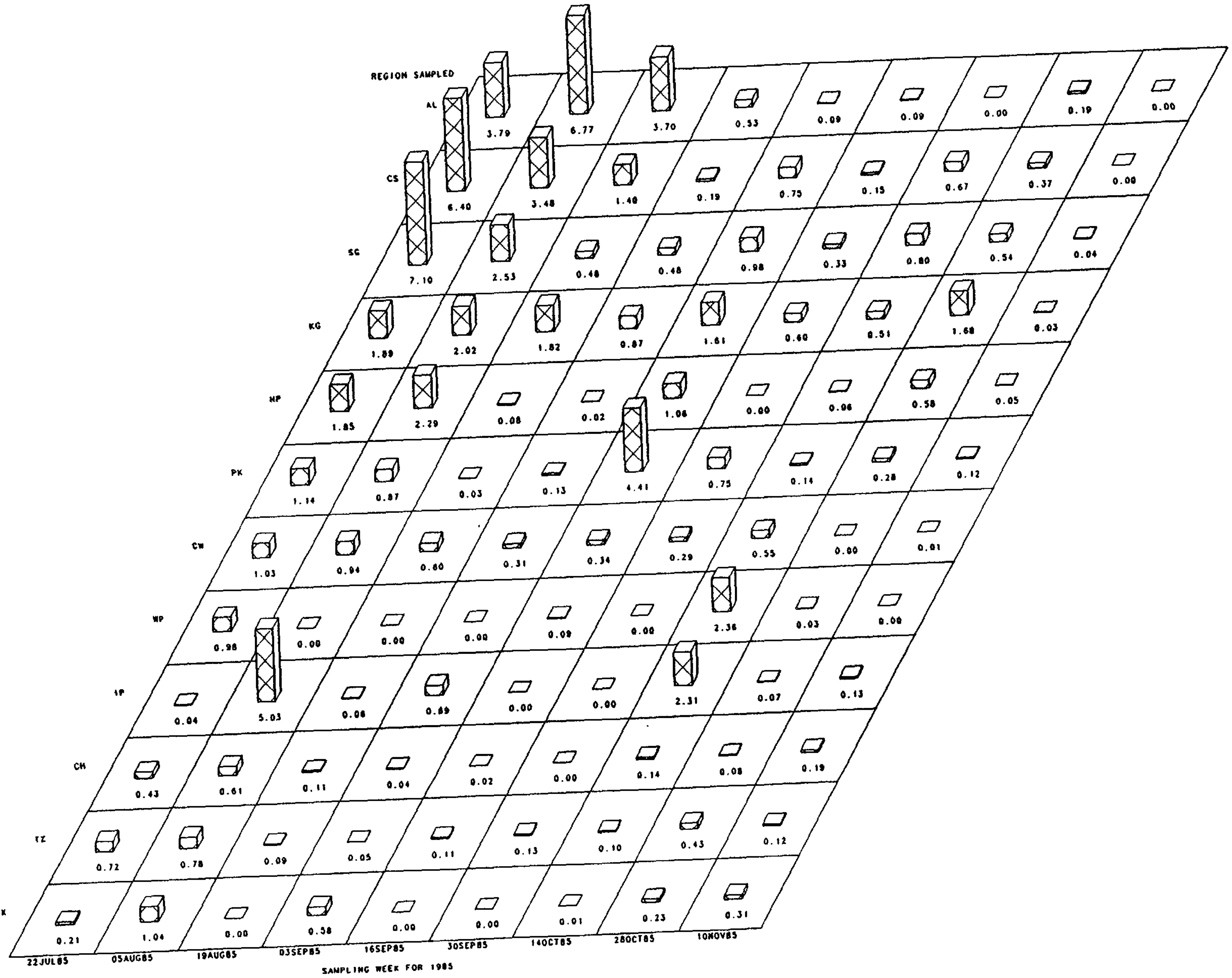


Figure IV-37. Mean regional density (per 1000 m^3) of American shad young-of-year collected in the Fall Shoals Survey during 1985

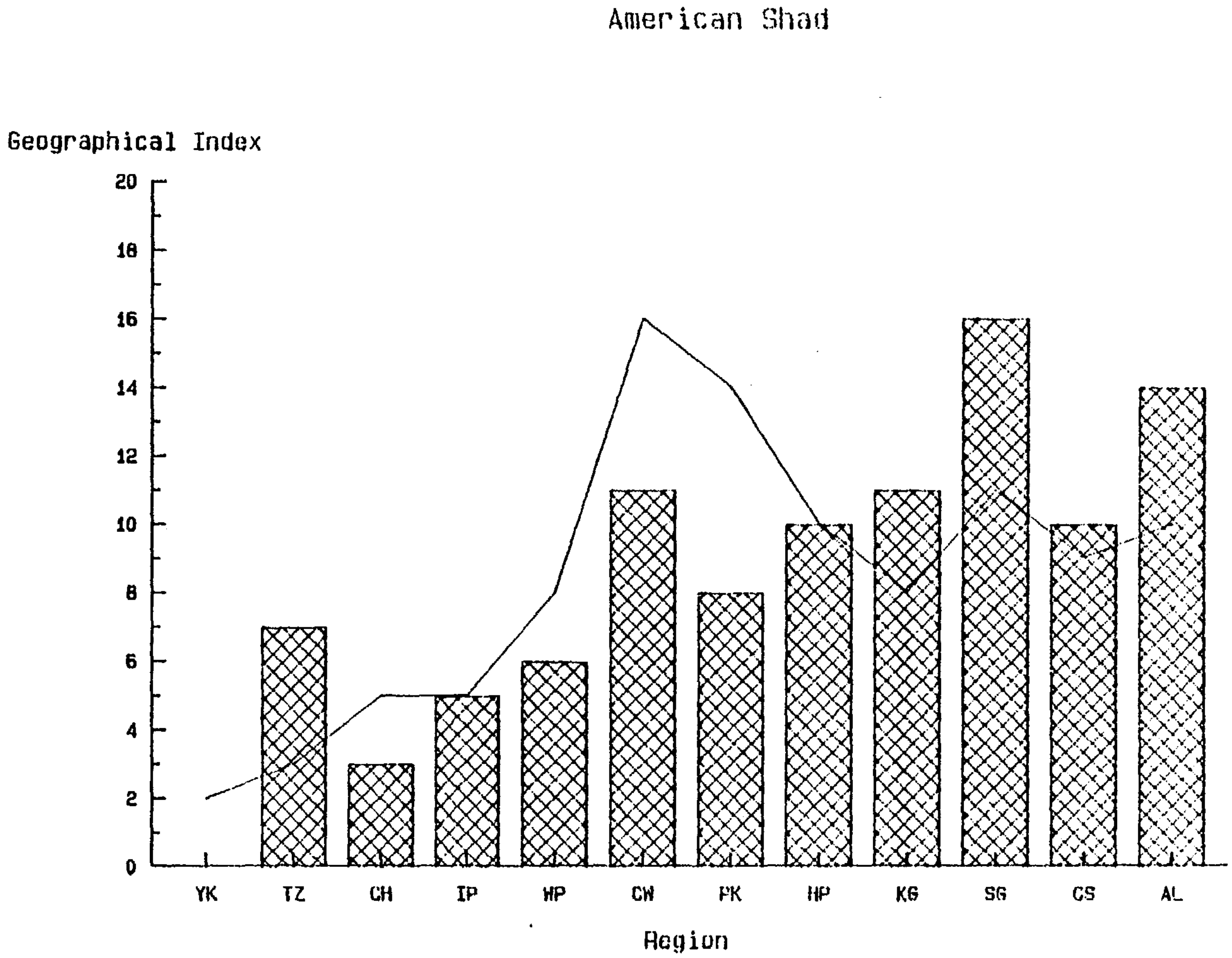


Figure IV-38. Geographic distribution of young-of-year American shad collected in the Beach Seine Survey. Bars represent index values for 1985. The line represents average values for 1974-1984.

to declining fall temperatures; by the last week of BSS no shad were captured in waters below 10°C. Juvenile shad generally leave their natal rivers after water temperatures drop below 15°C for several days (Leggett and Whitney 1972; Chittenden and Westman 1967). In 1985 juvenile shad emigration appeared to more closely follow the 10°C isocline.

G. ALEWIFE

Young-of-Year

Alosids identifiable as juvenile alewife were collected during the LRS in early June, significantly sooner than in most years, but similar to 1980 (Battelle 1983) (Fig. IV-39). As was the case for alosid post yolk-sac larval distribution, early alewife juveniles were most abundant from Kingston to Albany during LRS and a small number were taken from low salinity waters as far south as Croton-Haverstraw.

Juvenile alewives were taken from all regions during the FSS and BSS, in salinities as high as 18 ppt (Fig. IV-40 and Fig. IV-41). Consistent with findings in earlier Year Class studies, greatest catch occurred during July and early August, though density estimates remained high in the FSS until mid-September. A general decline in abundance and possible downstream movement of juveniles below the 10°C isocline was apparent after mid-October; Richkus (1975) suggested that downstream movement of juveniles is associated with rapid declines in water temperature. Results from the last week of the BSS suggest an abandonment of near shore zones throughout the estuary, while limited numbers of alewife were caught in all but the Albany region during the last week of the FSS.

Yearling and Older

Yearling and older alewife were caught infrequently from the first week of LRS (Fig. IV-42), to the end of the FSS (Figs. IV-43 and IV-44). Most capture locations of yearling and older alewife were in the middle and lower estuary but highest regional catches occurred at Albany in May and Kingston in late September.

Collection of yearling and older alewife in previous years was sporadic and a definable fall downriver movement was documented only in the 1982 Year Class Report. It is likely that gear avoidance by yearling and older alewife masks the ability to discern spatio-temporal distributions or movements within the estuary.

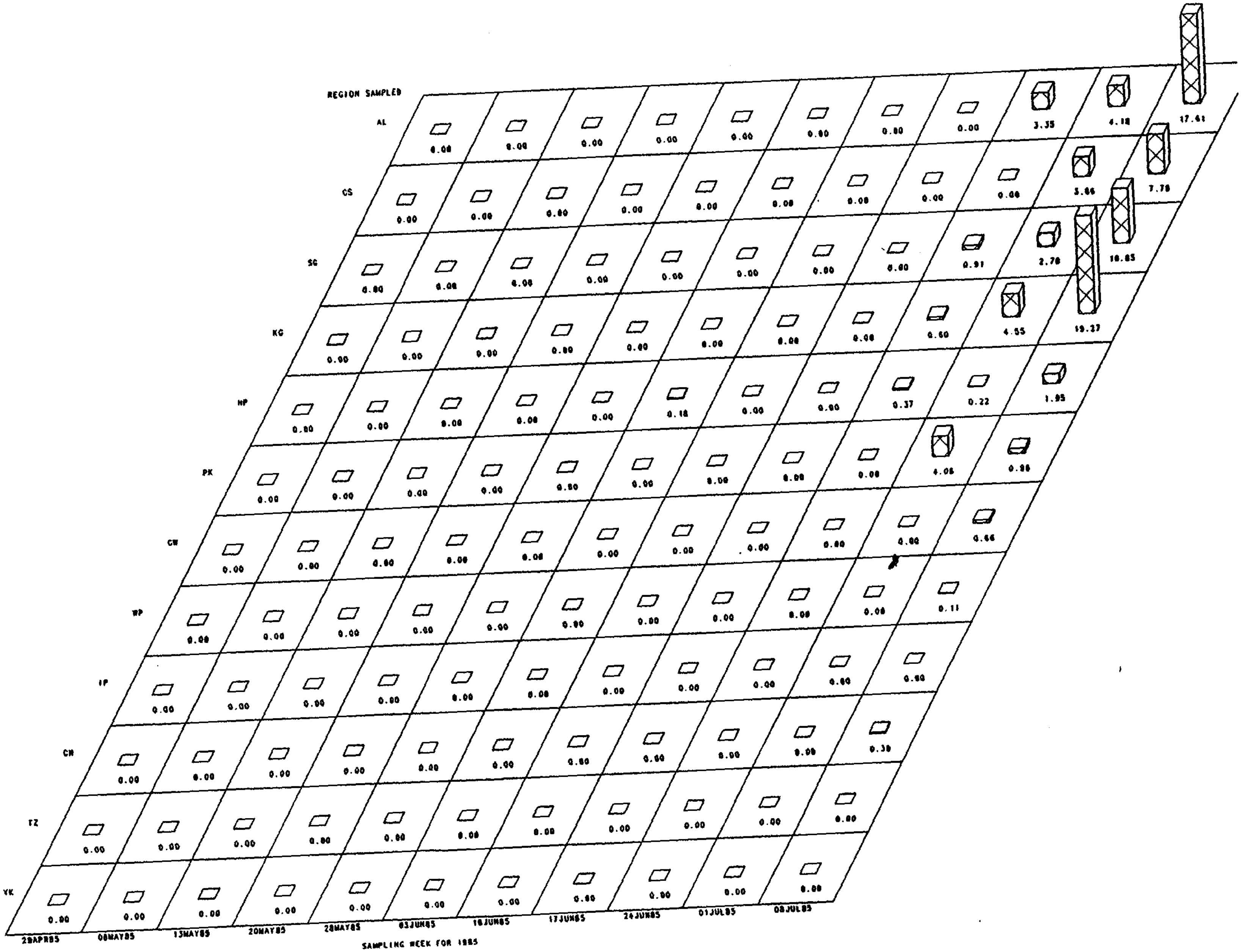


Figure IV-39. Mean regional density (per 1000 m^3) of alewife young-of-year collected in the Longitudinal River Survey during 1985

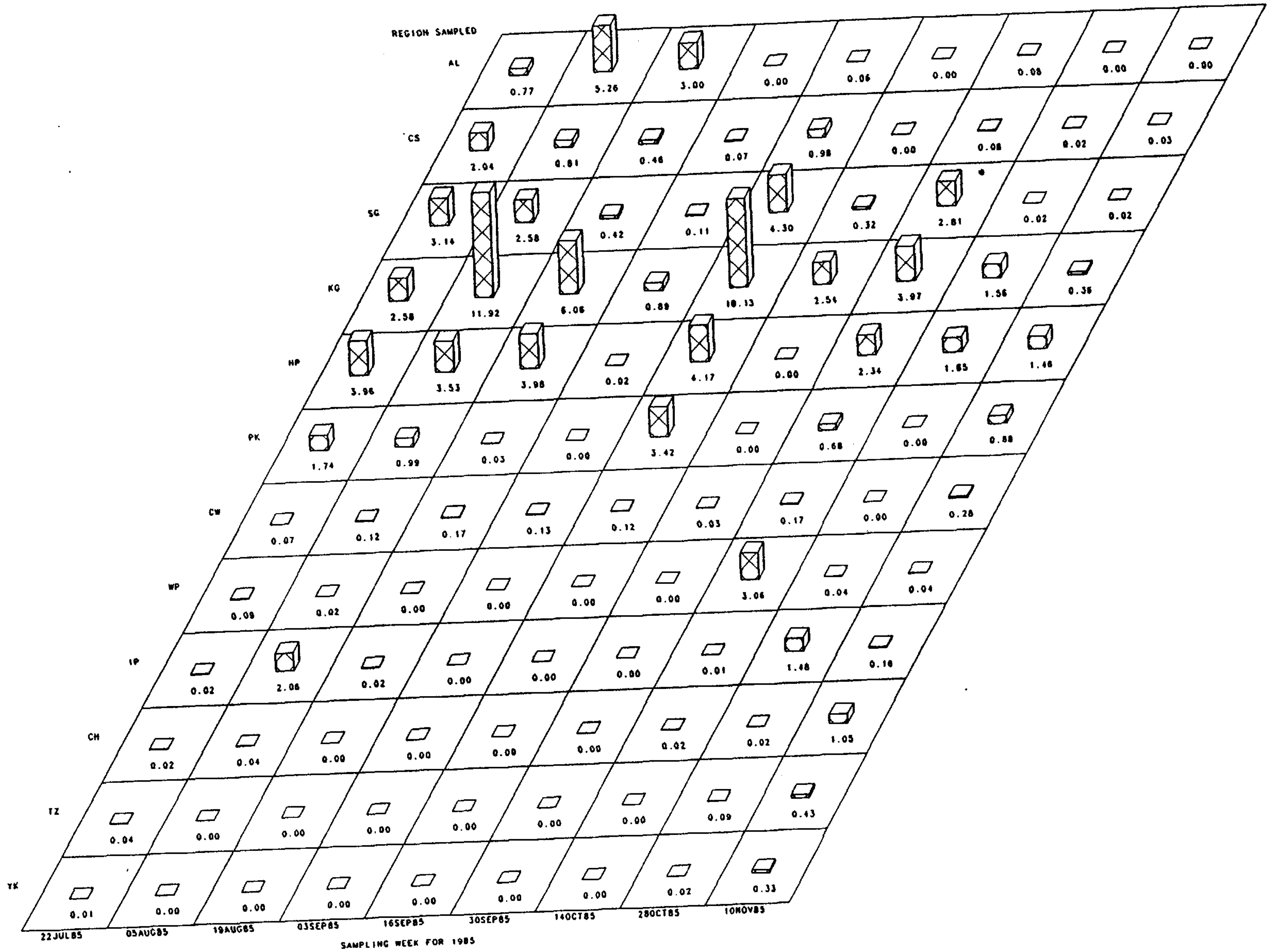


Figure IV-40. Mean regional density (per 1000 m^3) of alewife young-of-year collected in the Fall Shoals Survey during 1985

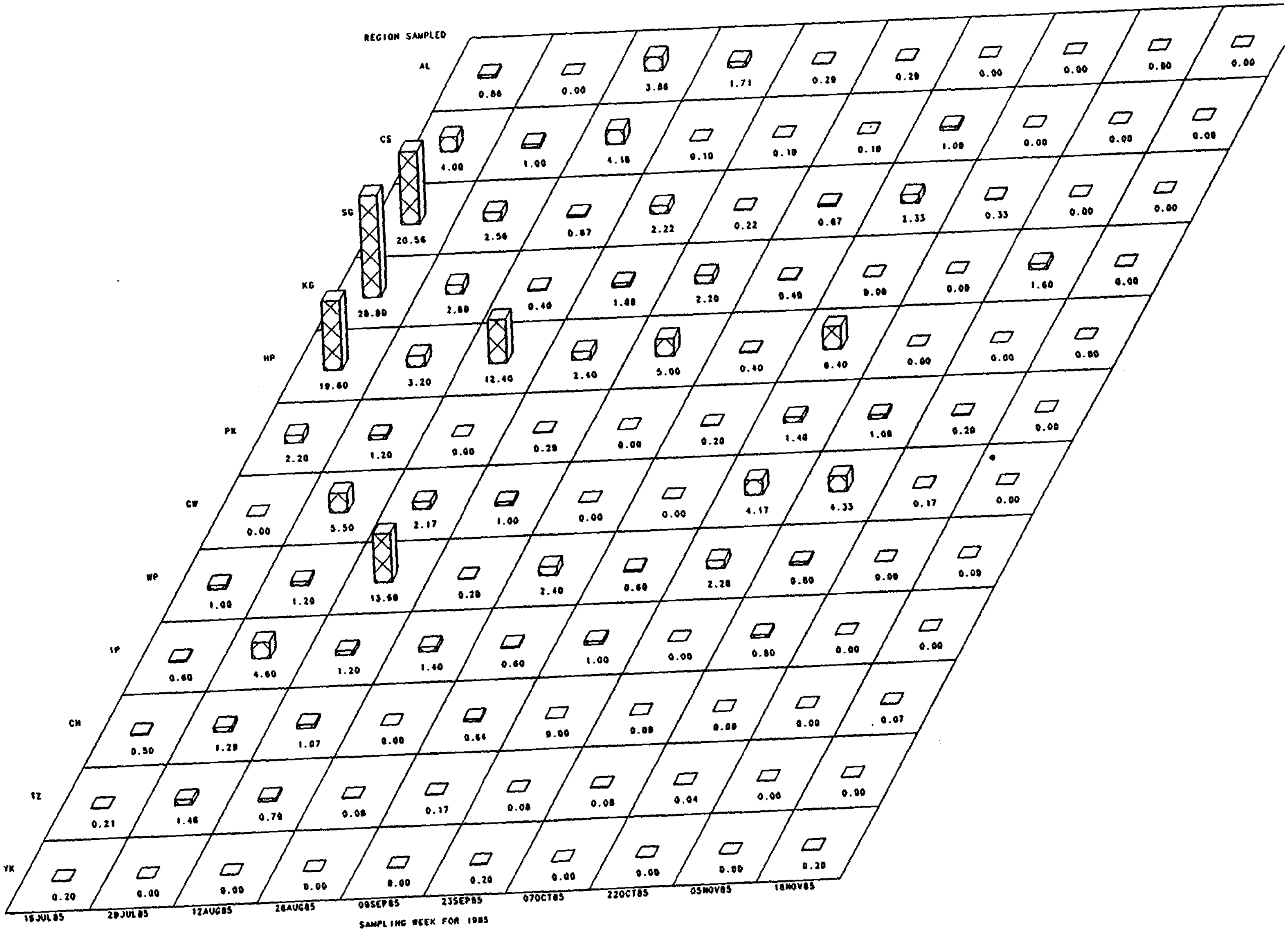


Figure IV-41. Catch per unit effort of alewife young-of-year collected in the Beach Seine Survey during 1985

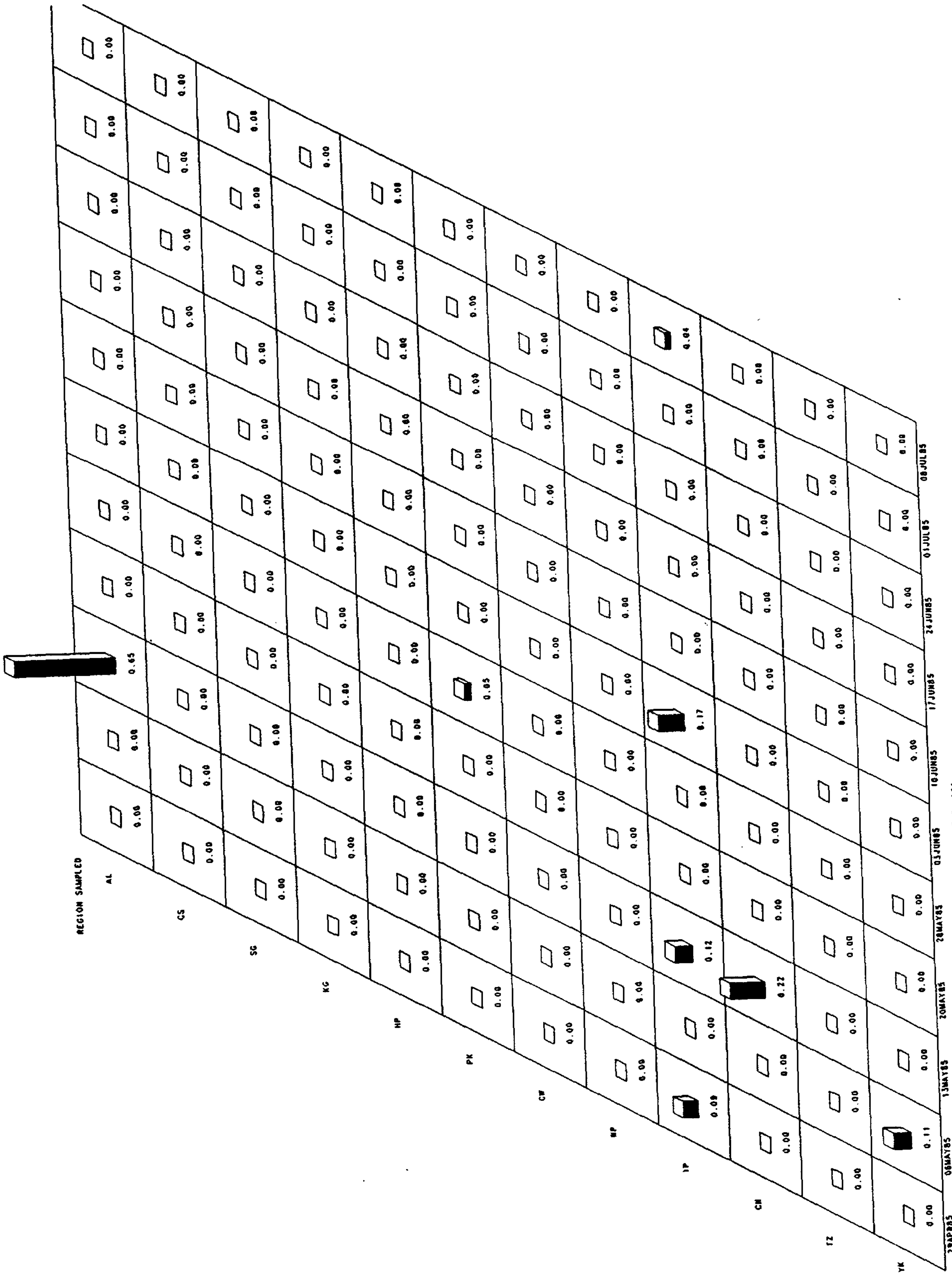


Figure IV-42. Mean regional density (per 1000 m^3) of alewife yearling and older collected in the Longitudinal River Survey during 1985

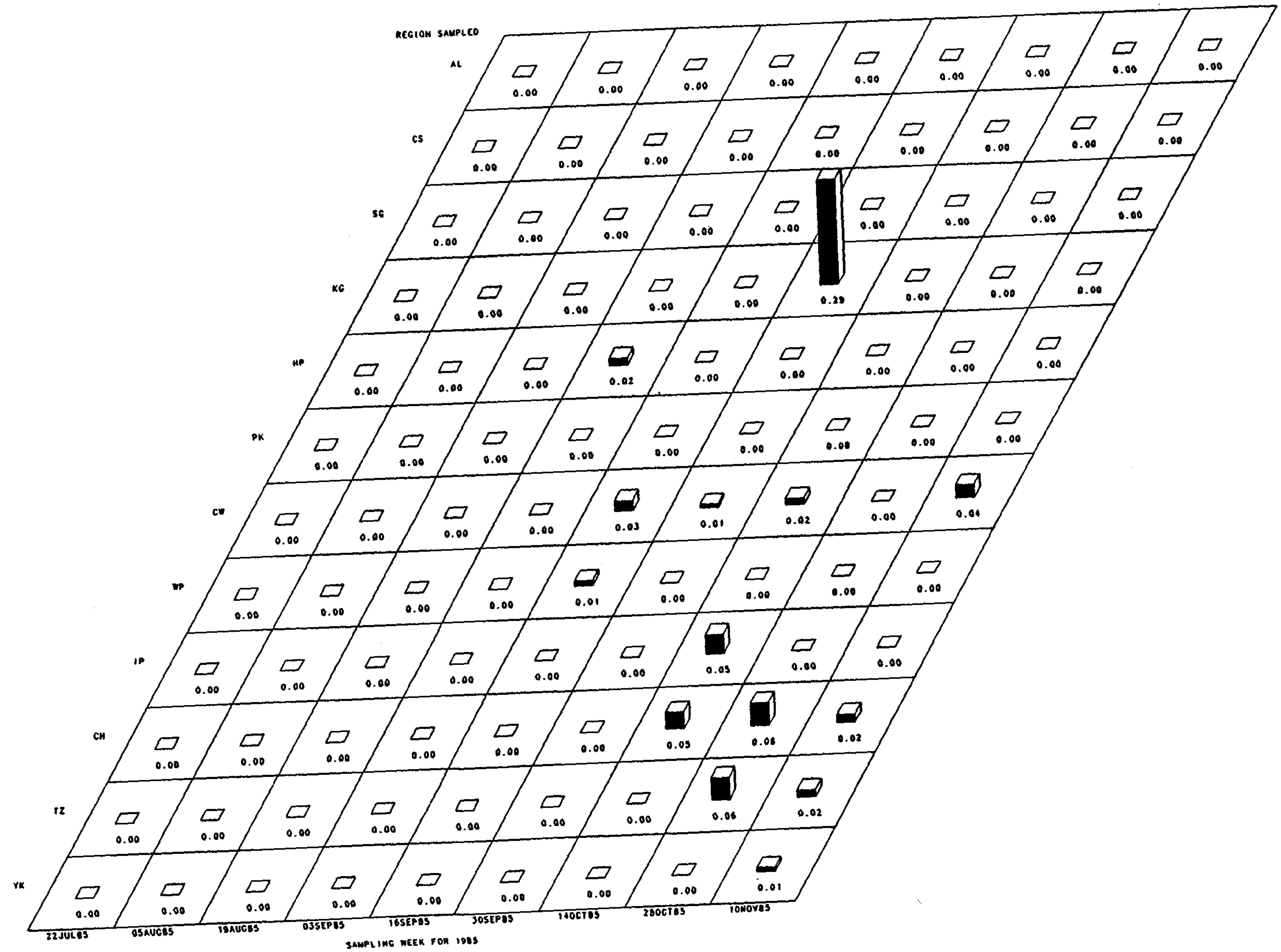


Figure IV-43. Mean regional density (per 1000 m^3) of alewife yearling and older collected in the Fall Shoals Survey during 1985

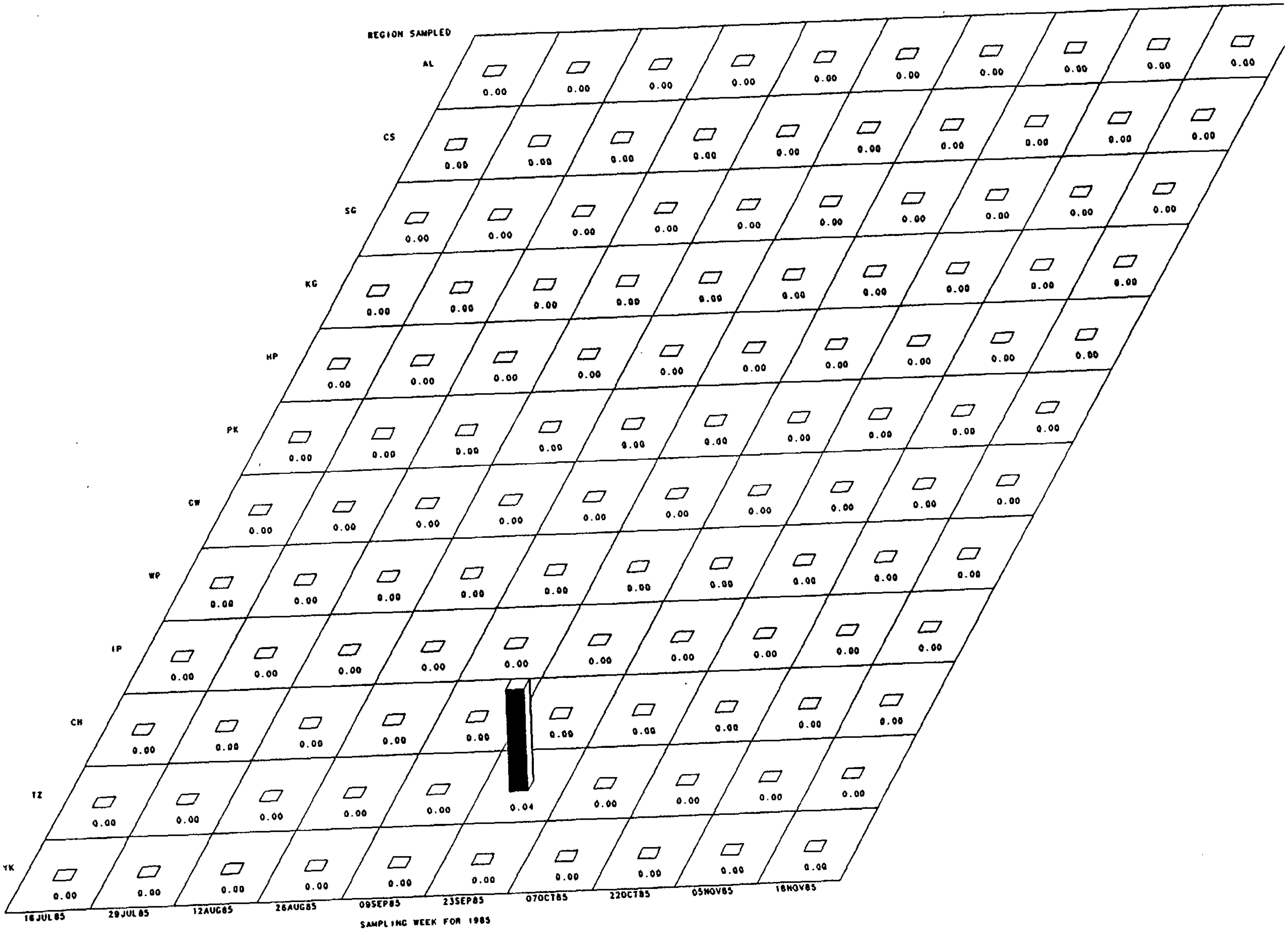


Figure IV-44. Catch per unit effort of alewife yearling and older collected in the Beach Seine Survey during 1985

H. BLUEBACK HERRING

Young-of-Year

Identifiable young-of-year blueback herring were collected from the final week of the LRS (Fig. IV-45) to the end of the FSS (Fig. IV-46) and BSS (Fig. IV-47). After mid-July, juveniles were taken from most regions on a weekly basis, but abundant catches most often came from areas upstream of the salt front. In comparison to alewife, the 1985 distribution of juvenile blueback herring was less restricted to the upper estuary and catches occurred more evenly over many weeks and regions. As in other years, peak densities of juvenile blueback herring in 1985 occurred in early August and gradually declined thereafter. Also, this species was generally absent from the estuary after water temperatures began to decline in the upper estuary in mid-September. Downstream migration was not suggested by the distribution pattern observed in 1985, but has been thought to occur in other years.

Yearling and Older

Yearling and older blueback herring were collected sporadically from the first week of LRS (Fig. IV-48) until the final week of the FSS (Figs. IV-49). Only three yearling and older fish were collected in the BSS. In May, yearling and older blueback herring were taken most regularly from the lower estuary, although an isolated peak was observed at Albany; presumably these fish were spawning adults. After May, no clear trend was apparent, although a downstream fall migration might be implied by the fact that fish were taken only at Yonkers during the last 2 weeks of FSS. As with alewife, gear avoidance by yearling and older fish probably masks the ability to discern true distributional patterns.

I. BAY ANCHOVY

Bay anchovy (Anchoa mitchilli) are abundant fish found along the Atlantic and Gulf coasts of North America from Maine to the Yucatan peninsula. They are primarily estuarine but may be found in environments ranging from freshwater to full-strength seawater. They form an important forage base for many estuarine fish, including bluefish, Atlantic tomcod, white perch and striped bass (Richards 1976; Olney 1983).

Spawning by bay anchovy occurs from May to September (Dovel 1971) at temperatures of 15-30°C (Wang and Kernehan 1979) and

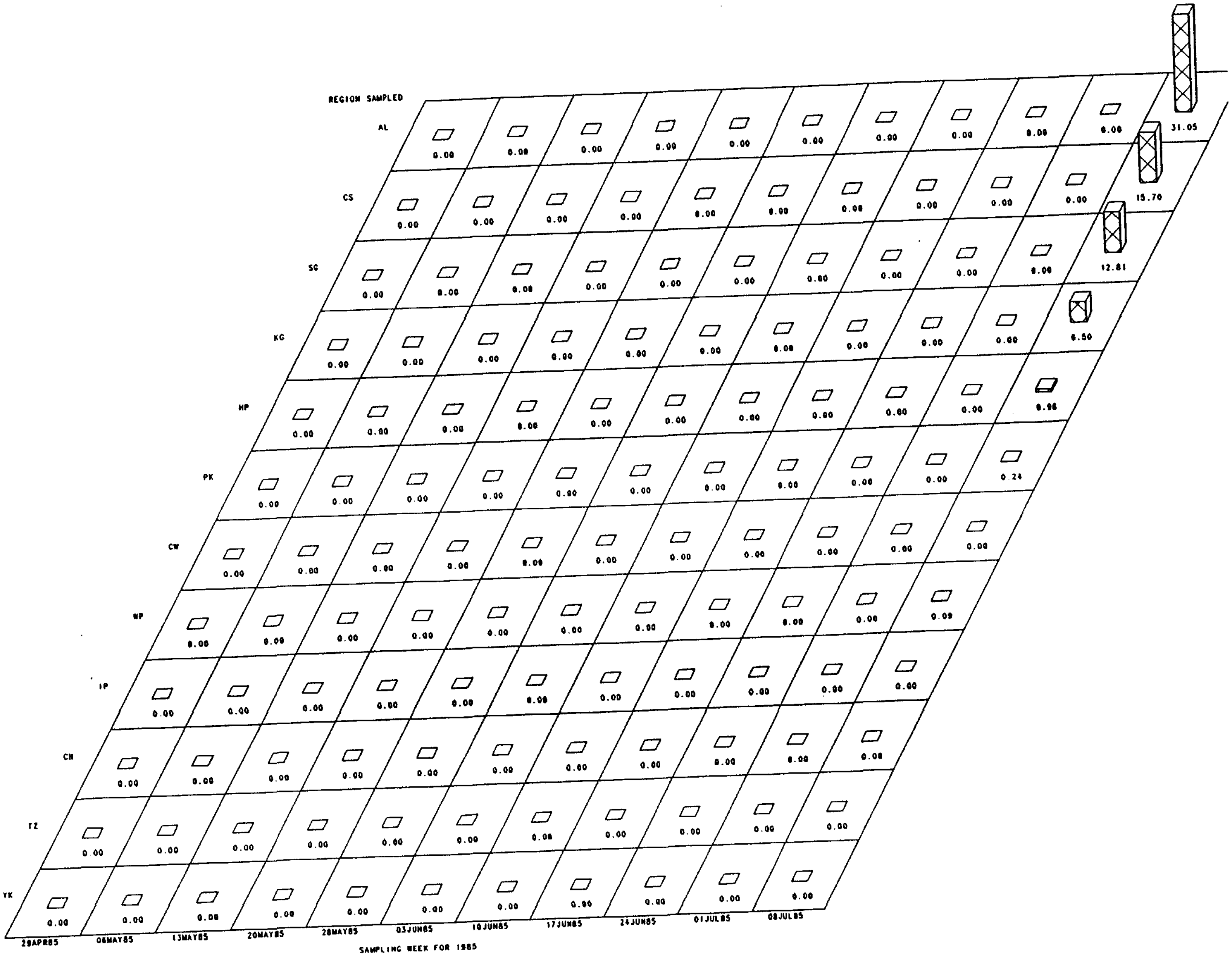


Figure IV-45. Mean regional density (per 1000 m^3) of blueback herring young-of-year collected in the Longitudinal River Survey during 1985

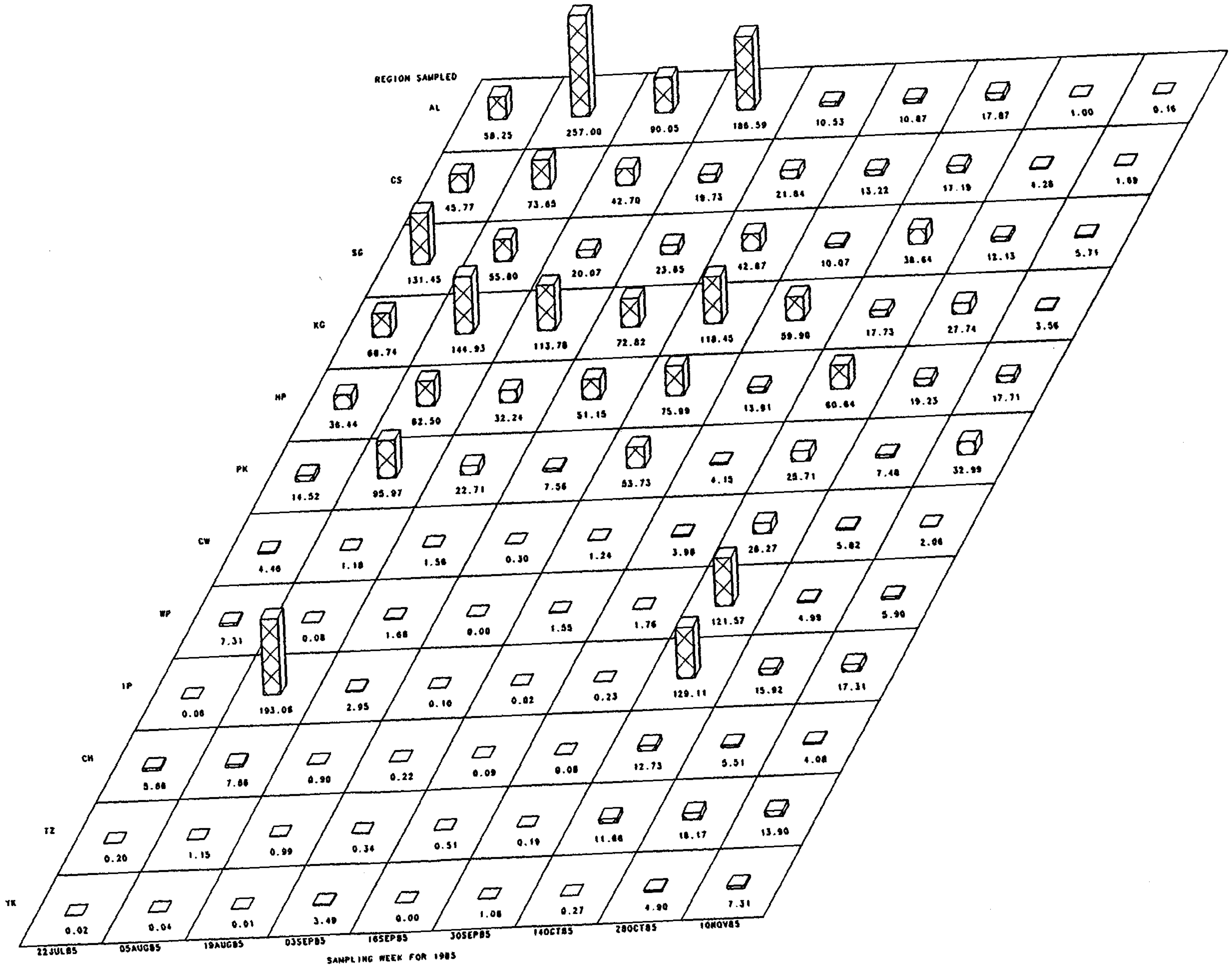


Figure IV-46. Mean regional density (per 1000 m^3) of blueback herring young-of-year collected in the Fall Shoals Survey during 1985

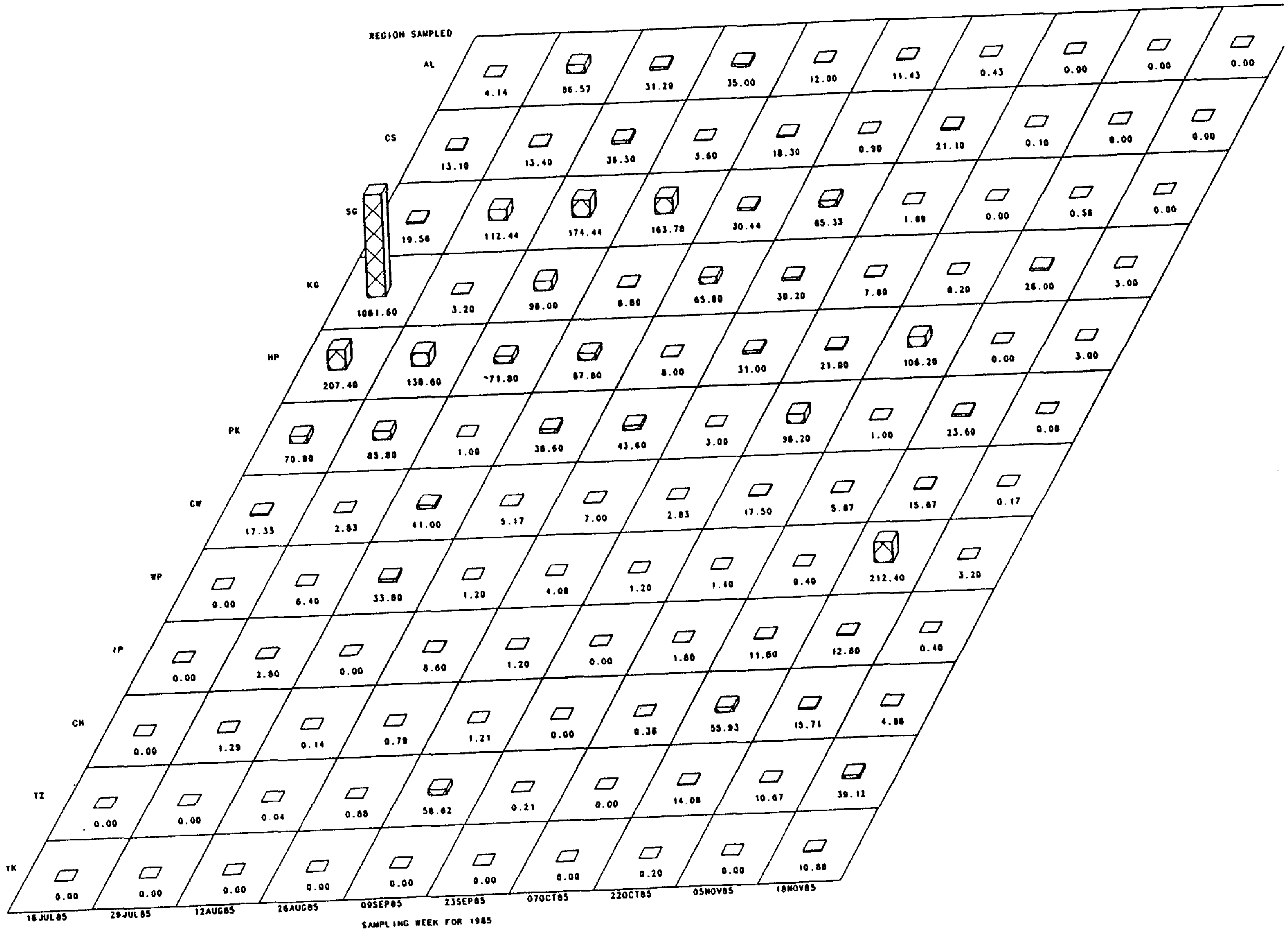


Figure IV-47. Catch per unit effort of blueback herring young-of-year collected in the Beach Seine Survey during 1985

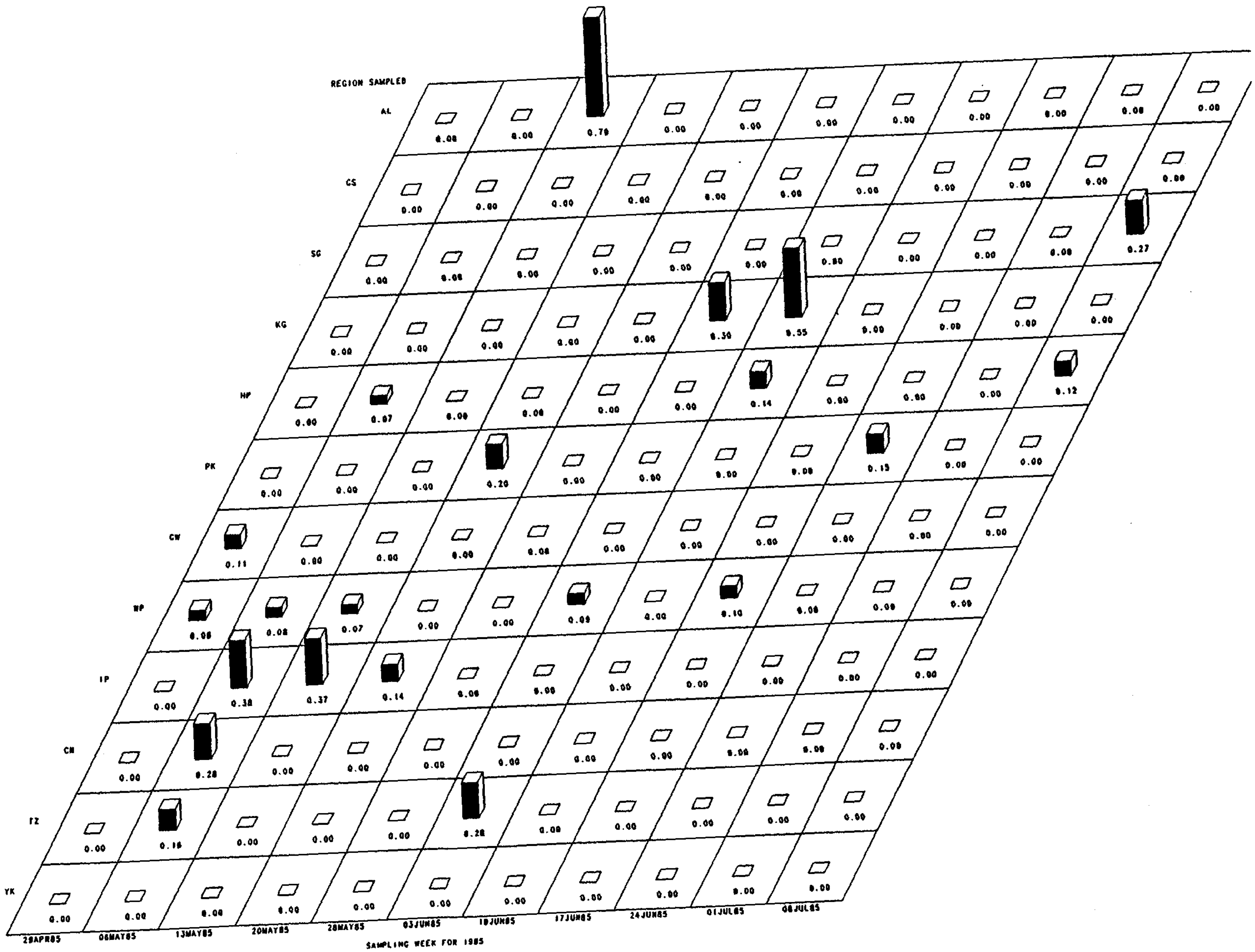


Figure IV-48. Mean regional density (per 1000 m^3) of blueback herring yearling and older collected in the Longitudinal River Survey during 1985

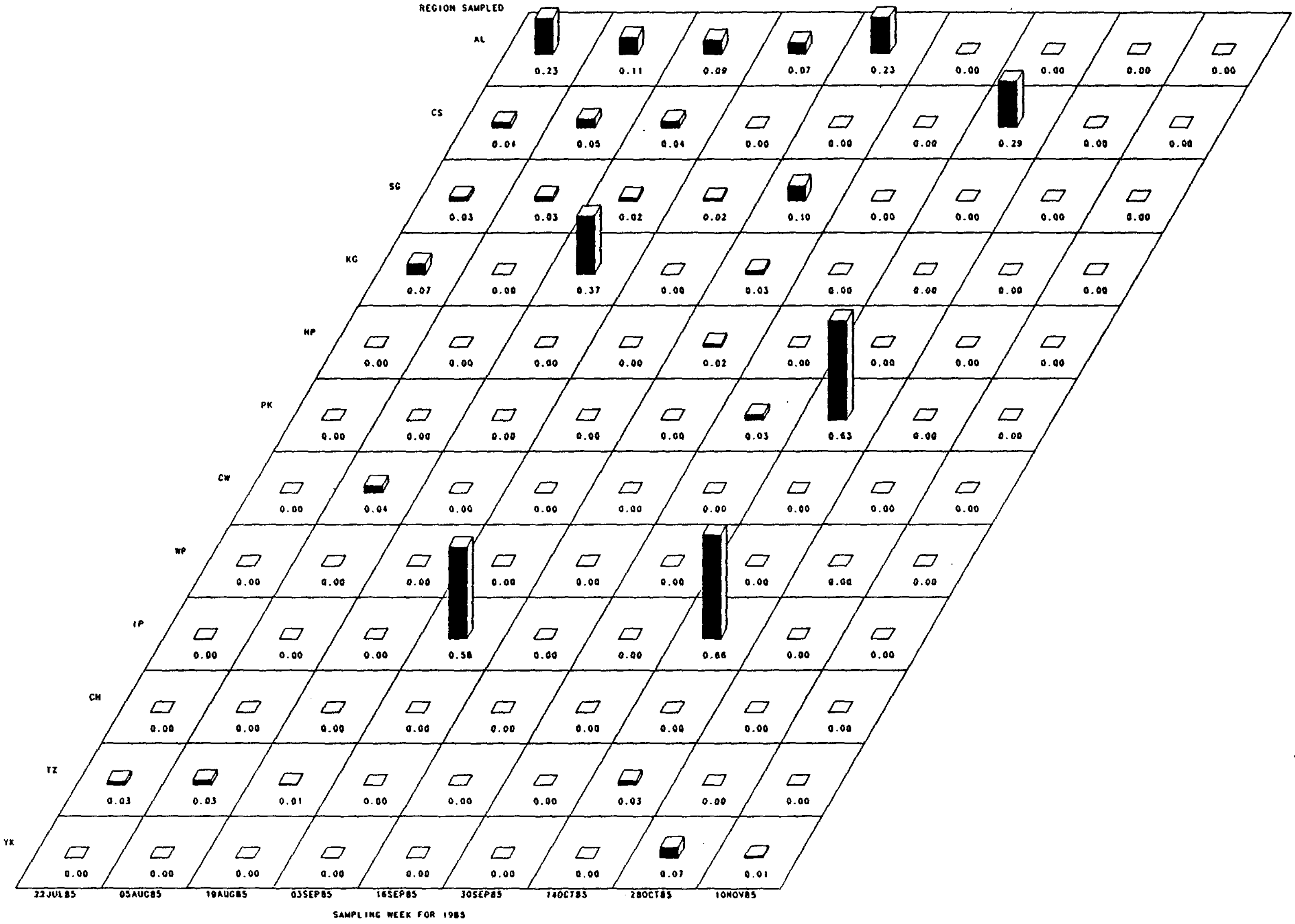


Figure IV-49. Mean regional density (per 1000 m^3) of blueback herring yearling and older collected in the Fall Shoals Survey during 1985 may occur over a wide range of salinities. However, Wang and Kernehan (1979) have suggested that egg mortality is high at salinities less than 5 ppt. Spawning is generally believed to be greatest in mesohaline environments (Dovel 1971), and high egg abundance often occurs in higher salinity environments (Olney 1983).

Young-of-Year

No young-of-year bay anchovy were collected during the LRS in 1985. In previous Year Class studies over 80% of the young-of-year bay anchovy from the LRS were taken during the second week in July, with highest densities in the Tappan Zee, Croton-Haverstraw, and Indian Point regions.

Young-of-year bay anchovies were taken, however, during nearly all of the FSS (Fig. IV-50) and BSS (Fig. IV 51), with the majority of fish taken during FSS. Highest density during the FSS occurred between mid-August and the end of September. This peak is consistent with the peak of juvenile bay anchovy standing crops reported in previous Year Class Reports. As in previous years, young-of-year bay anchovy were most abundant in samples from the mesohaline waters of the lower estuary (Fig. IV-52), but at least some fish were taken in all regions of the river.

Yearling and Older

Yearling and older bay anchovy were captured during every week of sampling except the week of 5 November. Although these fish were caught in all regions, few were caught in regions upstream of the salt front, and most of the catch came from areas with 4 ppt or greater. Estimated regional densities were initially low in the LRS (Fig. IV-53) but increased to 80-200/1000 m^3 in the lower estuary by mid-June. As in previous years, sample densities remained high until mid-August, after which they declined rapidly (Fig. IV-54 and IV-55). The recurrent increase in density during mid-summer each year may be due to upstream movement of bay anchovy from outside of the study area as salinity within the study area increases.

J. WEAKFISH

Weakfish (Cynoscion regalis) inhabit coastal oceanic and inland tidal waters from Florida to Nova Scotia, but are most abundant from Chesapeake Bay to Long Island Sound (Thomas 1971; Colton et al. 1979). Although adults are euryhaline, spawning

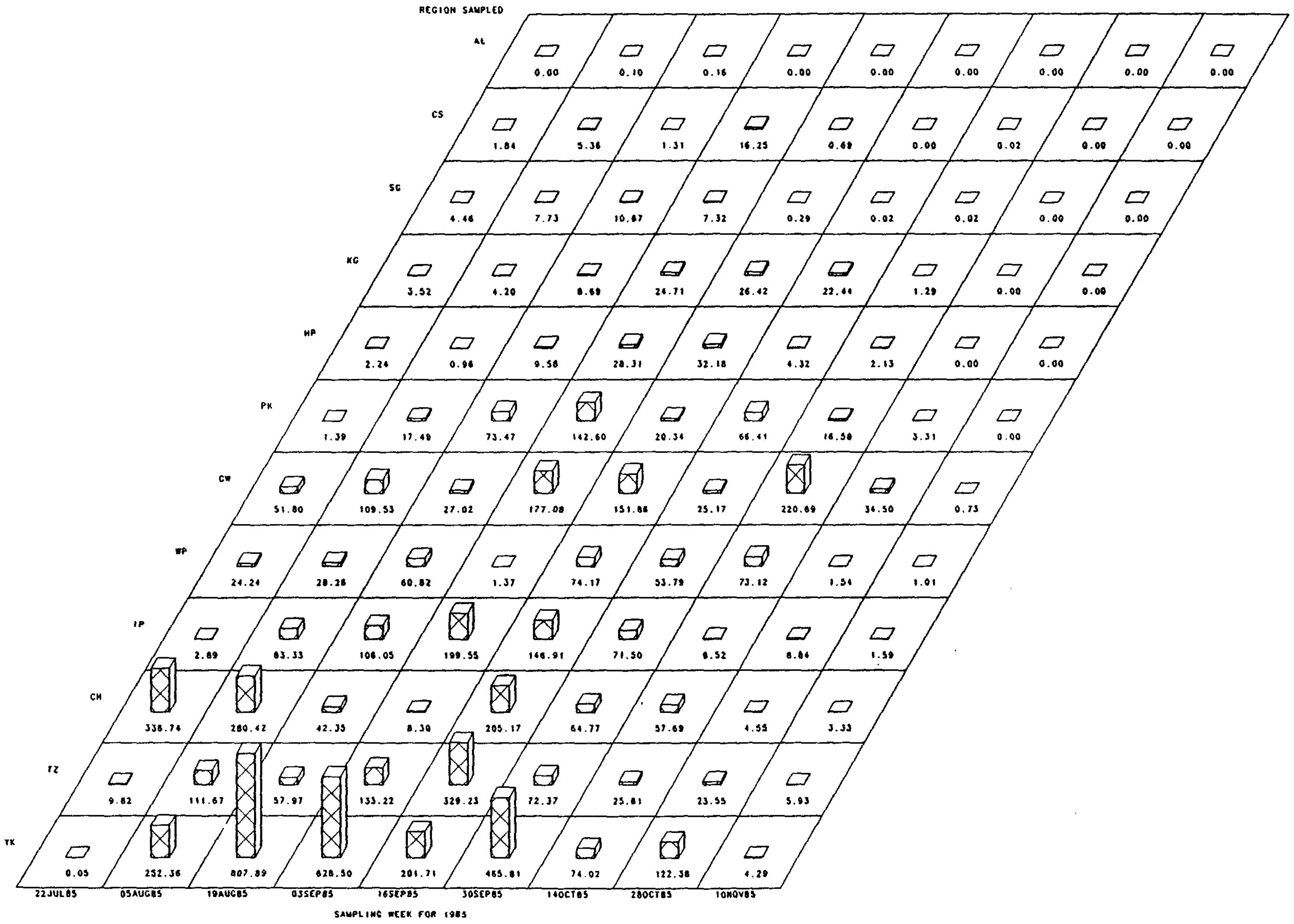


Figure IV-50. Mean regional density (per 1000 m^3) of bay anchovy young-of-year collected in the Fall Shoals Survey during 1985

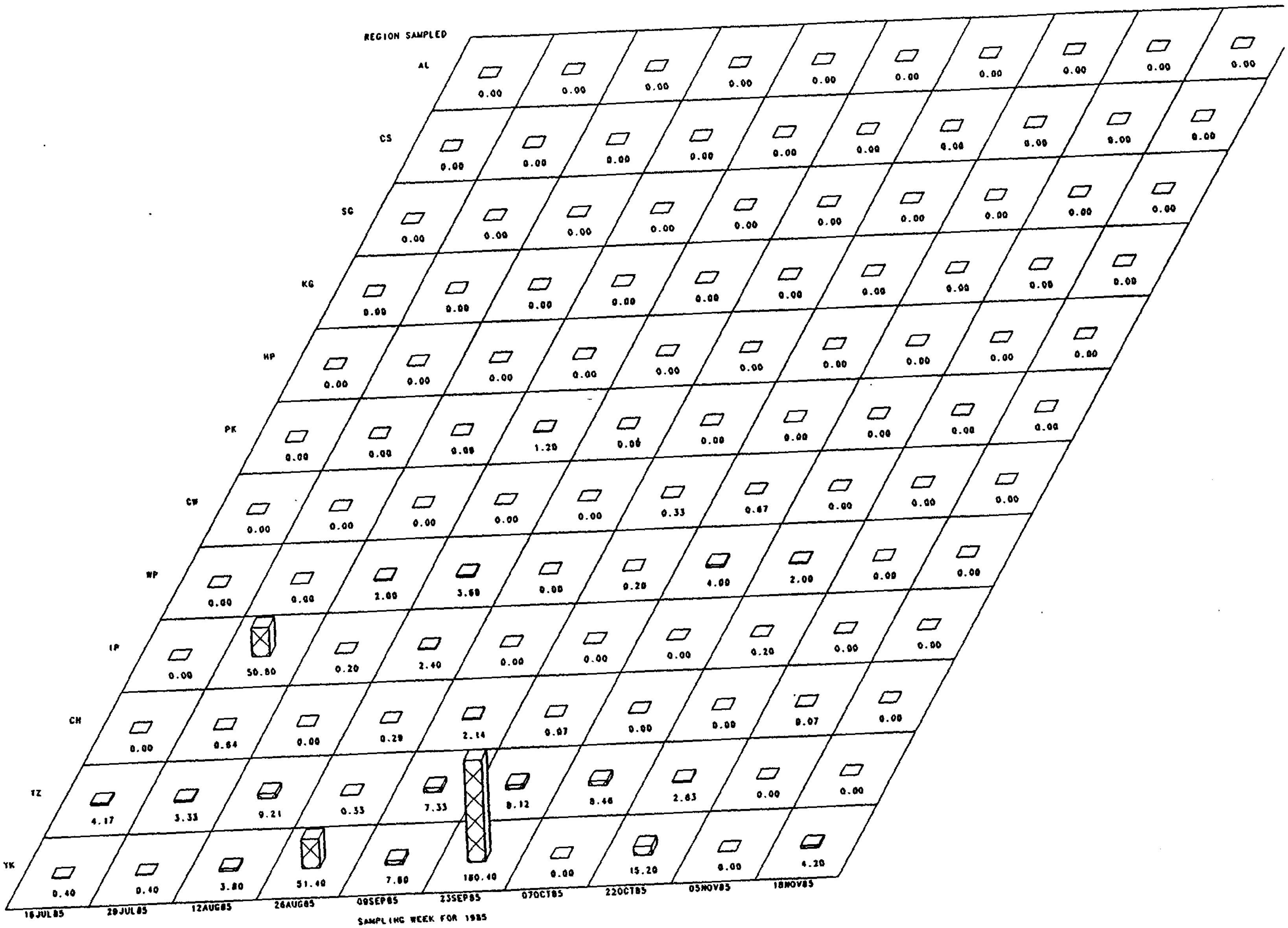


Figure IV-51. Catch per unit effort of bay anchovy young-of-year collected in the Beach Seine Survey during 1985

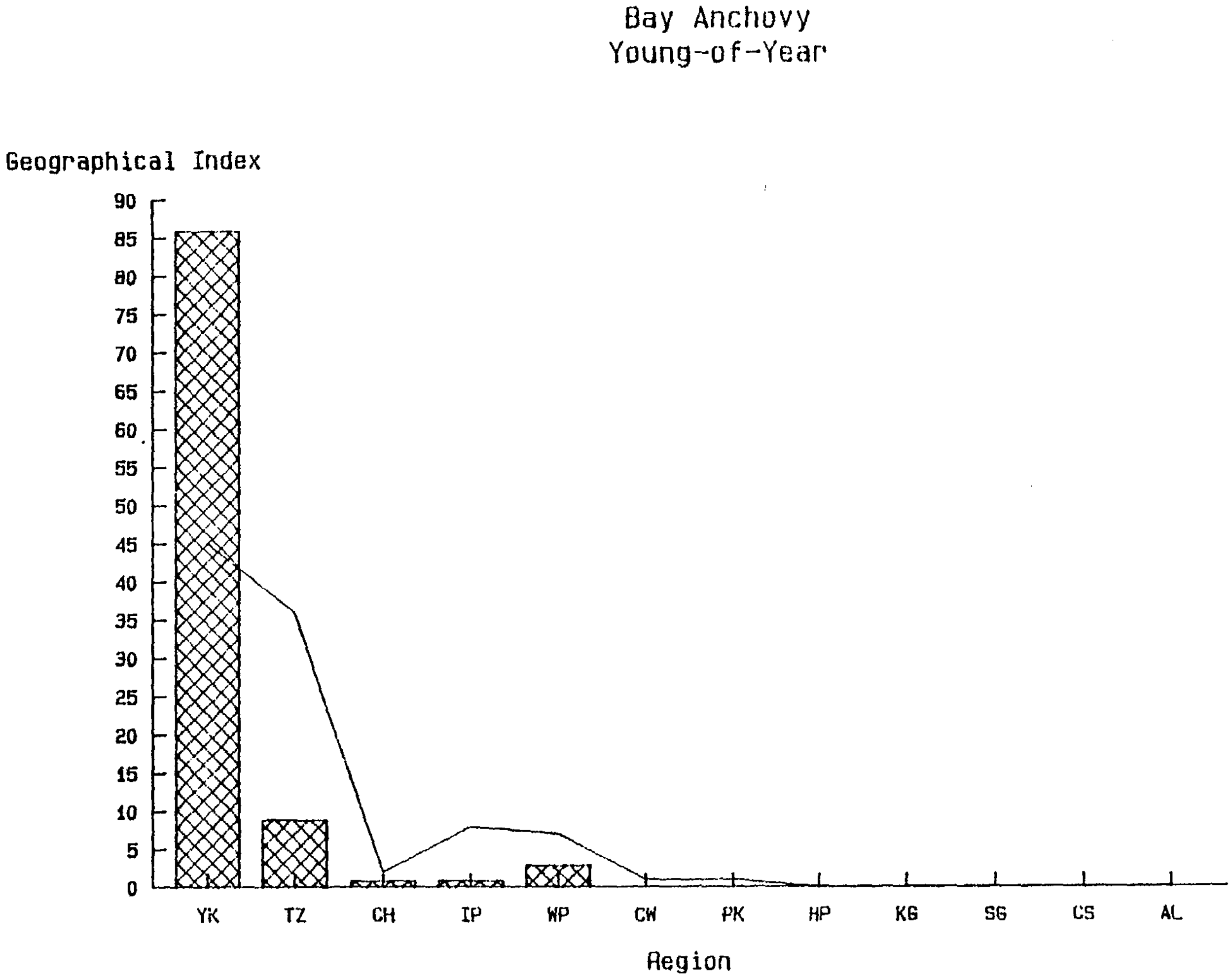


Figure IV-52. Geographic distribution of young-of-year bay anchovy collected in the Beach Seine Survey. Bars represent index values for 1985. The line represents average values for 1974-1984.

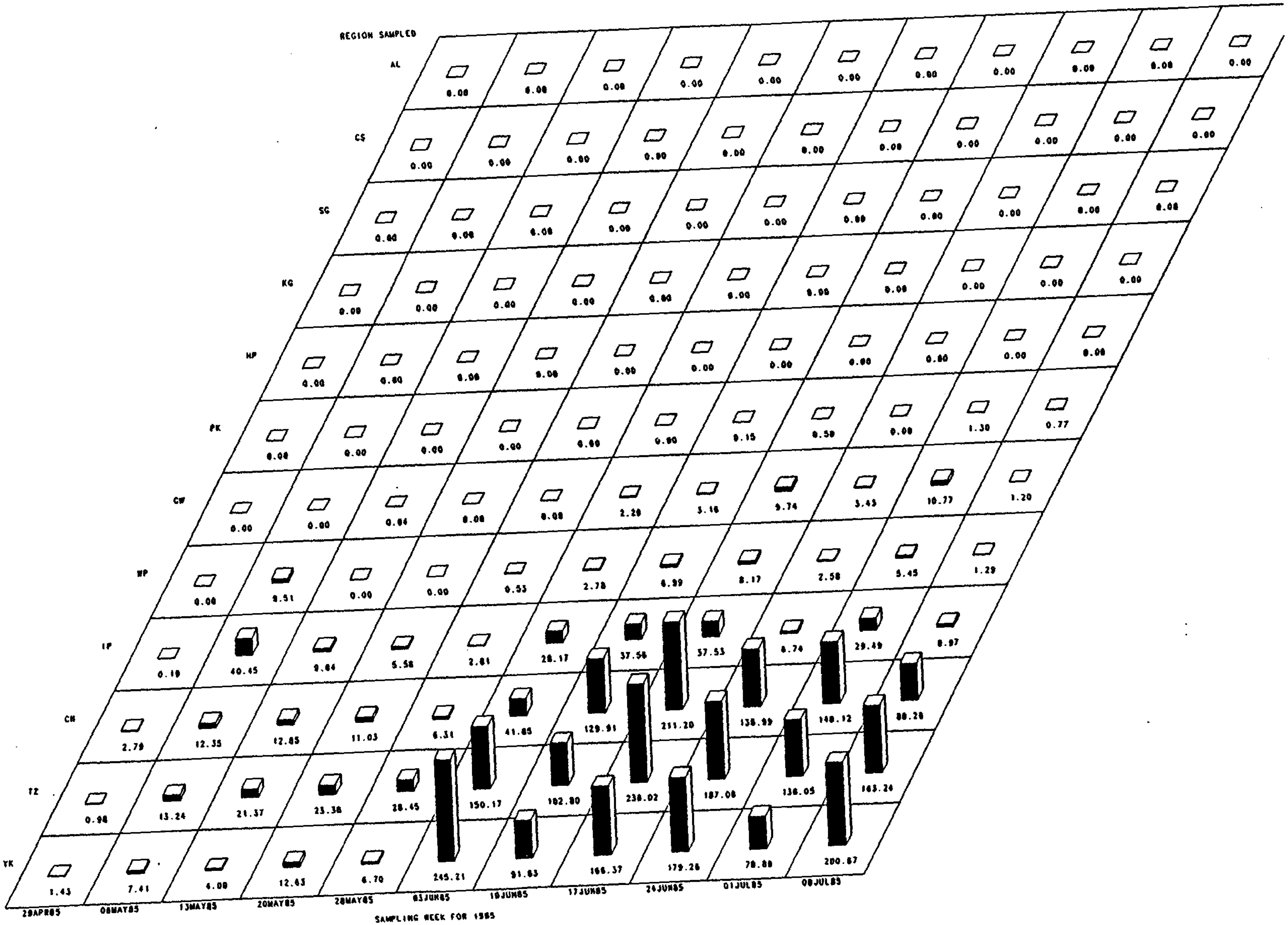


Figure IV-53. Mean regional density (per 1000 m^3) of bay anchovy yearling and older collected in the Longitudinal River Survey during 1985

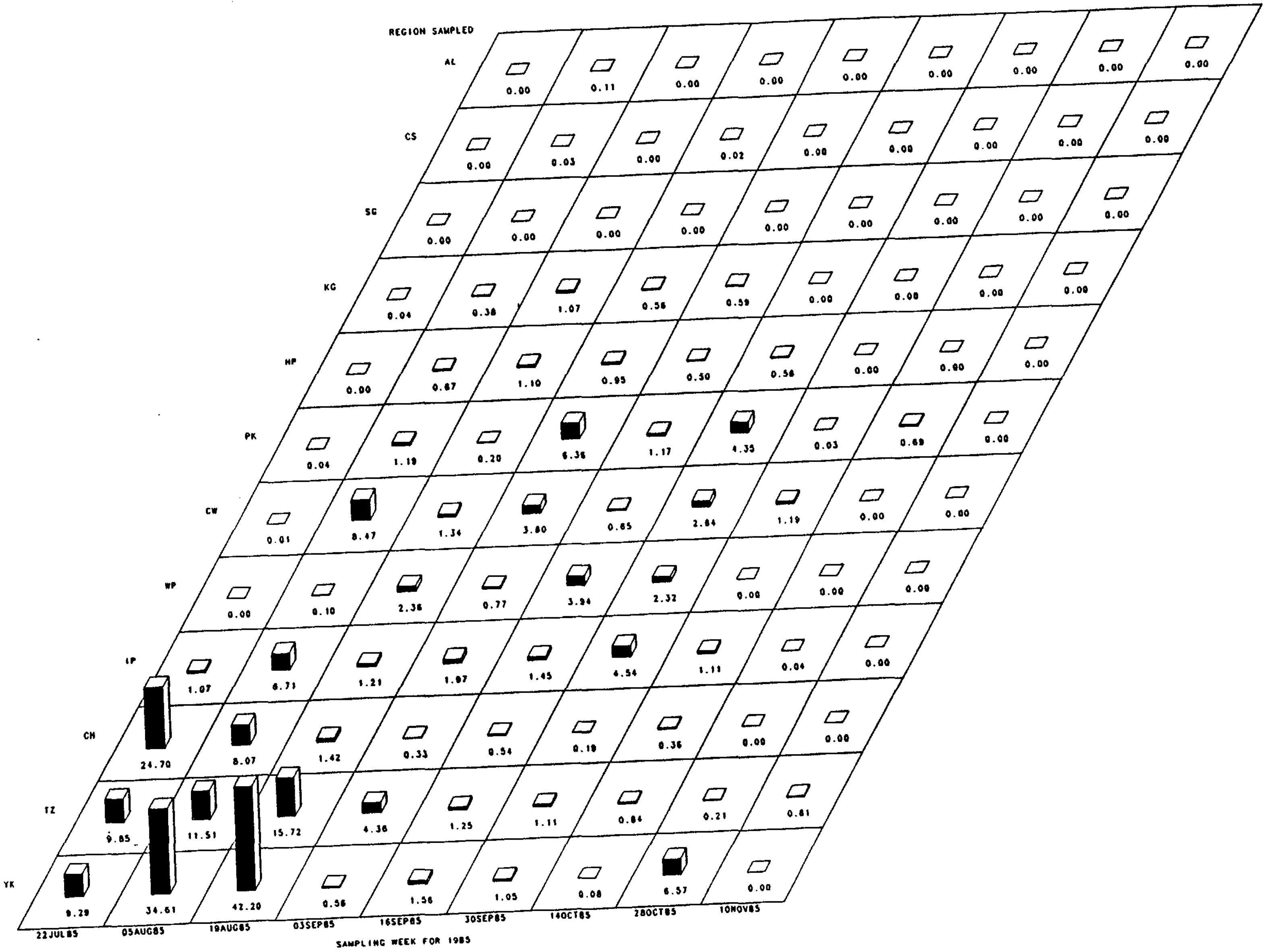


Figure IV-54. Mean regional density (per 1000 m^3) of bay anchovy yearling and older collected in the Fall Shoals Survey during 1985

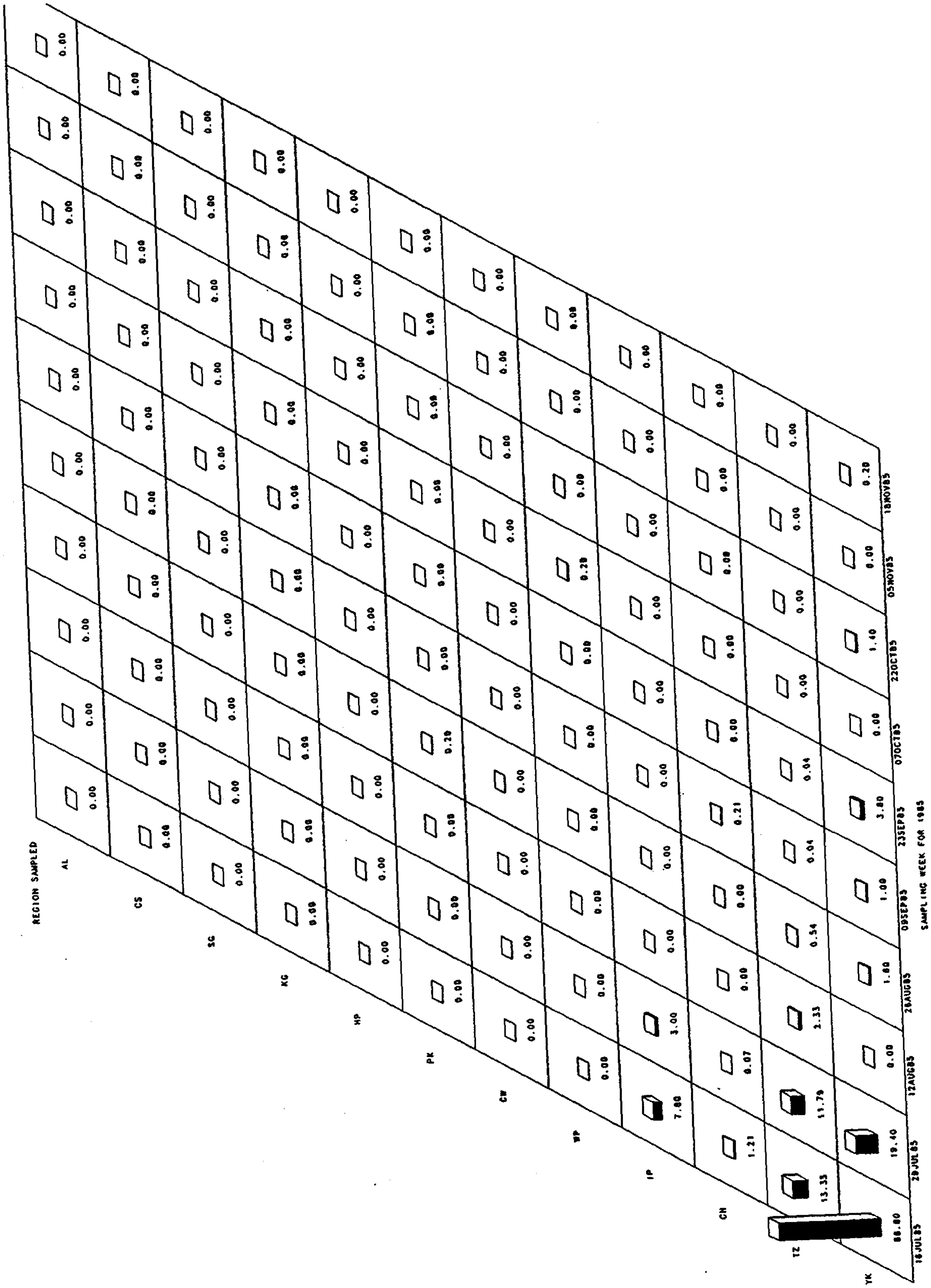


Figure IV-55. Catch per unit effort of bay anchovy yearling and older collected in the Beach Seine Survey during 1985 generally occurs in water with salinities between 28 and 31 ppt (Lippson and Moran 1974) in and near the mouths of estuaries from April to August (Merriner 1976; Yetman et al. 1985). Spawning peaks typically occur during June and July (Thomas 1971; Johnson 1978).

Weakfish eggs, which are pelagic and initially have high bouyancy, lose bouyancy as they develop (Lippson and Moran 1974). They reportedly hatch in 40 hours at temperatures of 20-21°C (Harmic 1958). Newly hatched larvae are carried upstream by bottom currents (Thomas 1971), where early development occurs. As juveniles, weakfish tend to occupy deeper shoal and channel waters with low salinities (Smith 1971). With the decline of water temperatures below 8-10°C in the fall, weakfish from Northeastern regions of the country abandon their estuaries (Thomas 1971; TI 1981) and are believed to overwinter off the Virginia-Carolina coast (Bigelow and Schroeder 1953; Yetman et al. 1985).

Young-of-Year

Juvenile weakfish were collected just downstream of the salt front during the last week of the LRS (Fig. IV-56) and continued to be taken in nonfreshwater areas until the end of FSS in mid-November (Fig. IV-57). As in previous years, standing crop estimates during FSS declined in late summer, but the decline was less evident in the BSS (Fig. IV-58). Spatial distribution of juvenile weakfish collected during the BSS was however, similar to years past in that most fish were captured in the Yonkers and Tappan Zee regions.

K. WHITE CATFISH

The white catfish (Ictalurus catus) is a resident of coastal streams along the eastern U.S. coast (Trautman 1957). They are generally found in fresh or brackish water but can tolerate salinities up to 14 ppt (Kendall and Schwartz 1968). White catfish have been widely introduced in inland waters.

White catfish successfully spawn in waters with 2 ppt or less salinity (Perry and Avault 1968) in late spring or early summer. The eggs, which are adhesive, are laid in a prepared nest; the young are defended until they become free swimming larvae (Breder and Rosen 1966). White catfish are generally found in deep bottom waters, though shoreward movement occurs during spawning periods (Schmidt 1971; Marcy 1976; TI 1981; NAI 1982).

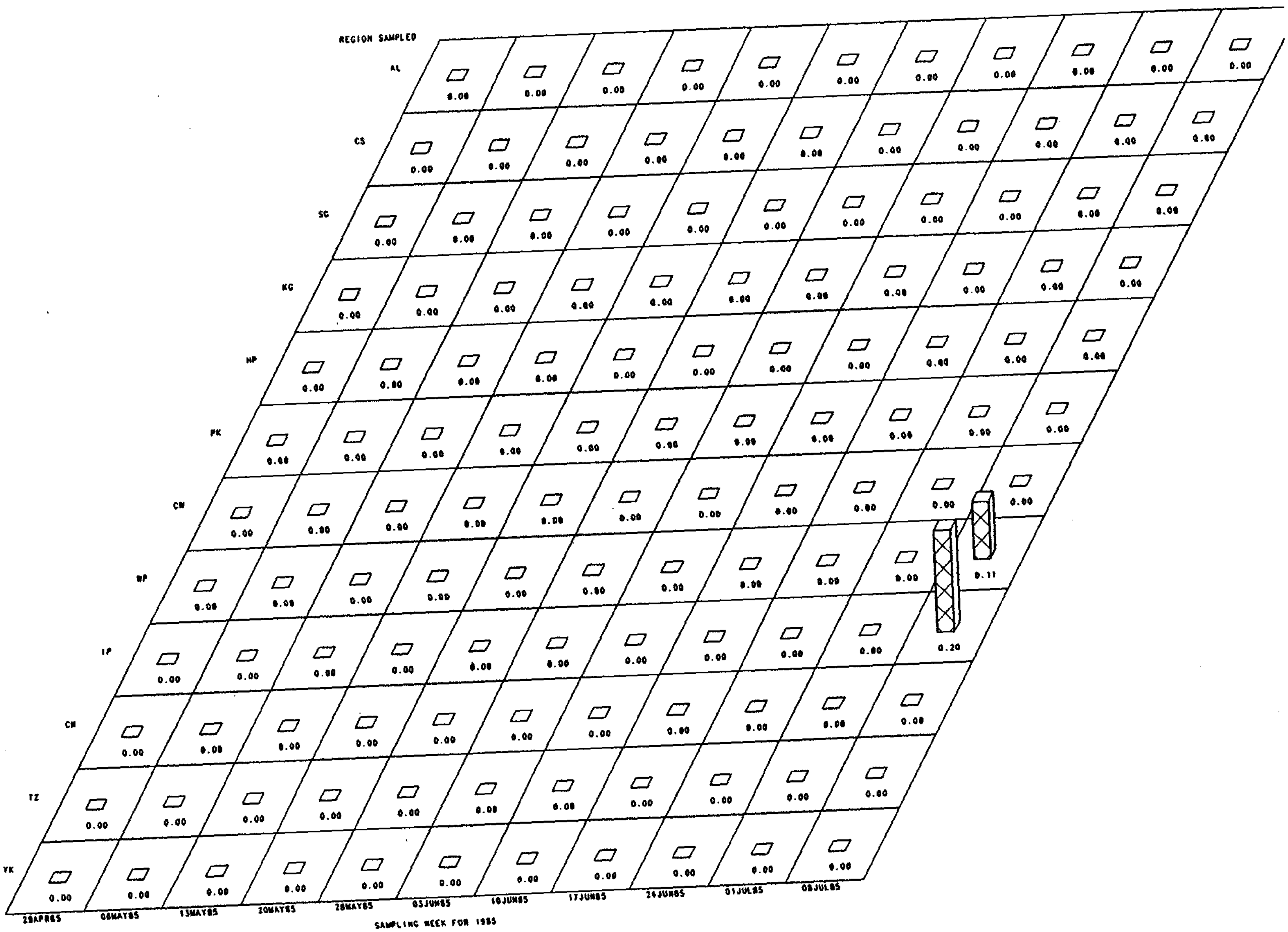


Figure IV-56. Mean regional density (per 1000 m^3) of weakfish young-of-year collected in the Longitudinal River Survey during 1985

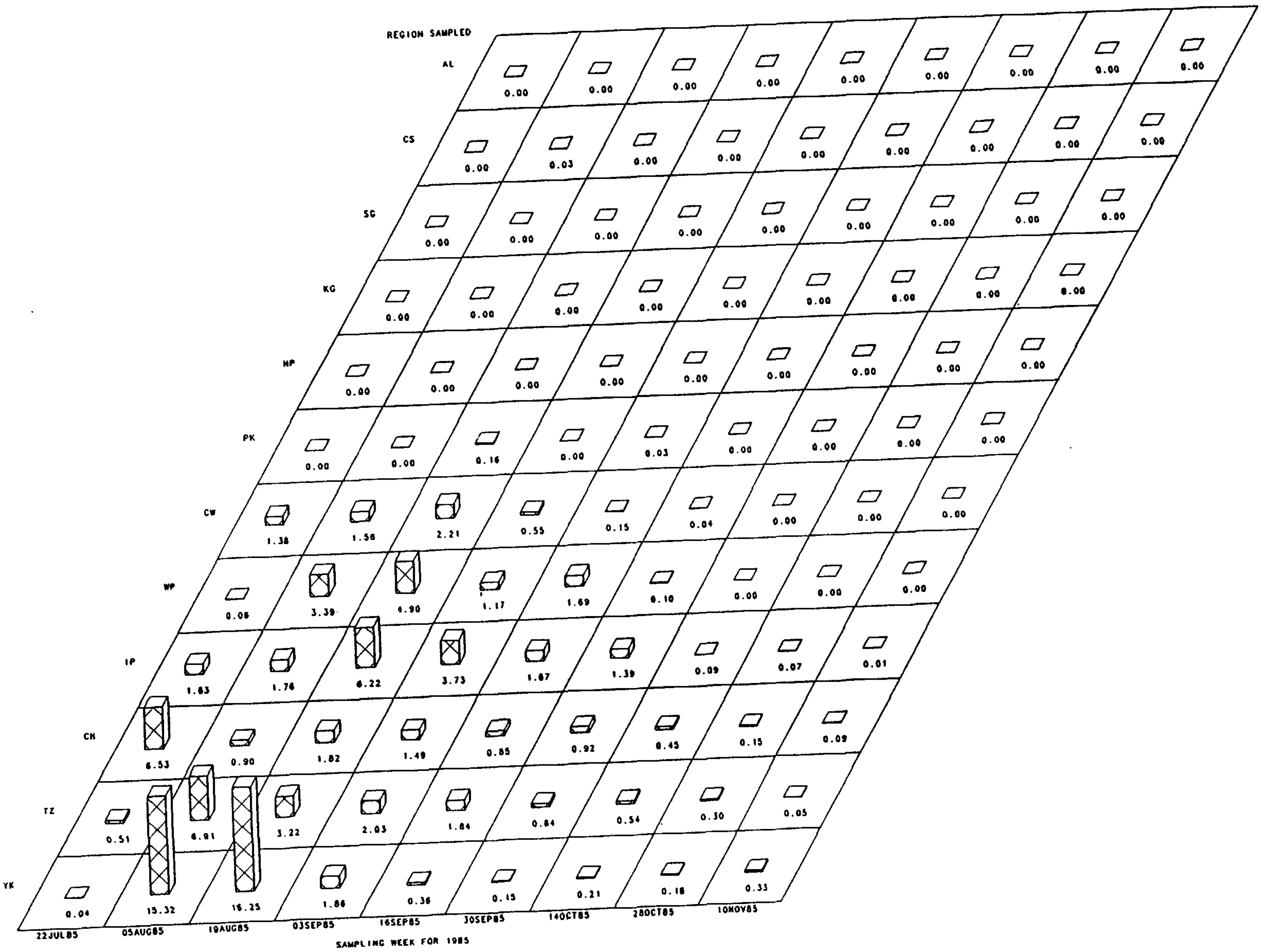


Figure IV-57. Mean regional density (per 1000 m^3) of weakfish young-of-year collected in the Fall Shoals Survey during 1985

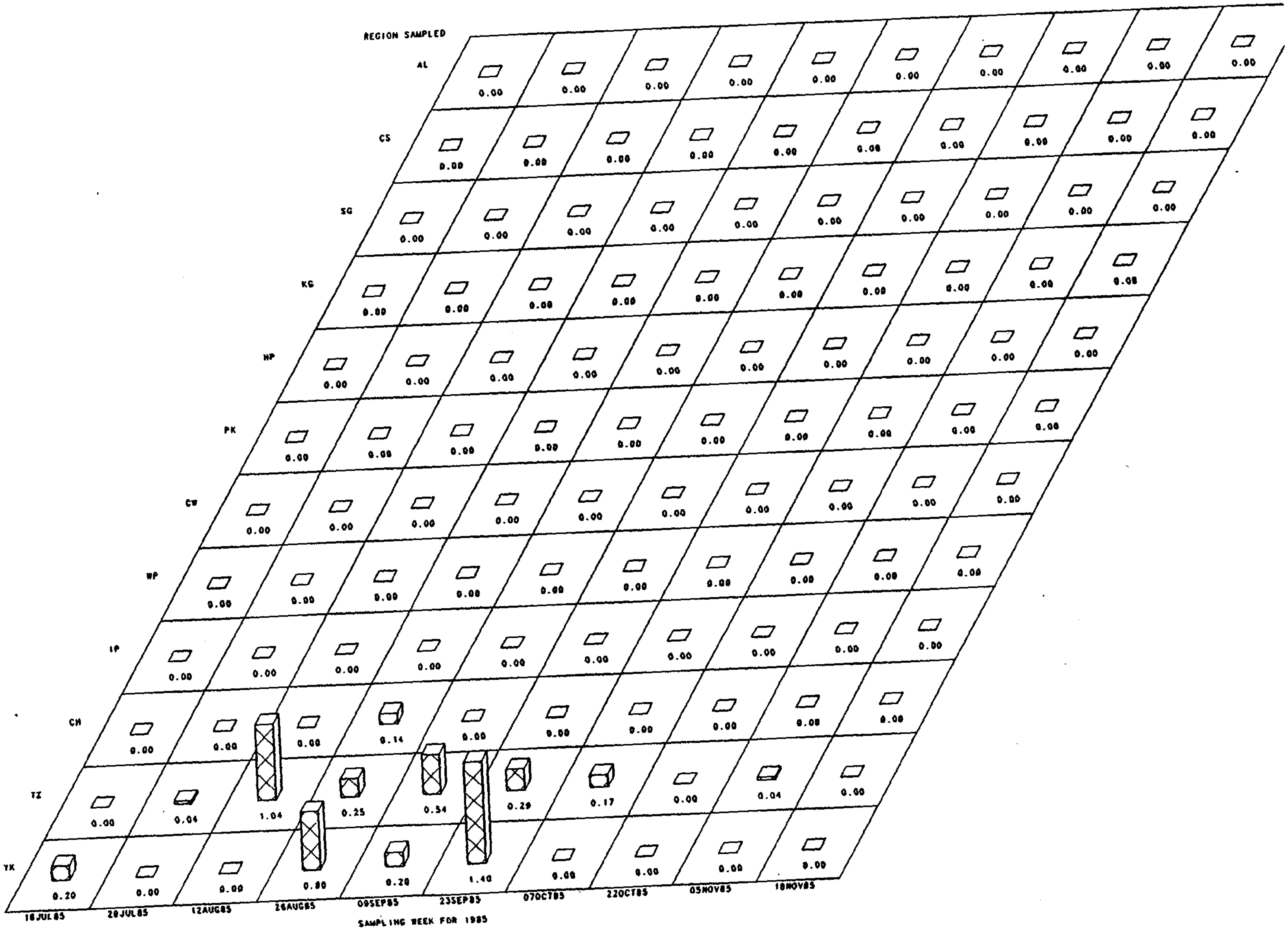


Figure IV-58. Catch per unit effort of weakfish young-of-year collected in the Beach Seine Survey during 1985

Young-of-Year

Prejuvenile stages of white catfish are not sampled well by the sampling gear and strategy used in the LRS. Therefore, no information is available on the spatio-temporal distribution of these eggs and larvae. Standing crop of juveniles was highest from early August to mid-September (Fig. IV-59), which is typical of all previous years except 1984, when peak juvenile density was observed in early July. Juvenile white catfish were collected on only one occasion during the BSS; this paucity of collection by beach seine has been historically observed and is likely due to the preference by white catfish for deeper water.

The majority of juvenile white catfish were captured in the freshwater areas upriver from Kingston. Juvenile white catfish were also taken sporadically in regions just upstream of the salt front. In all but a single instance during 1985, juveniles were taken upstream of the salt front. The single case occurred at Indian Point during the week of 5 August when mean regional salinity was 3.7 ppt.

Yearling and Older

As in most years, yearling and older white catfish were collected throughout the LRS (Fig. IV-60), FSS (Fig. IV-61), and BSS (Fig. IV-62) during 1985. They were collected primarily from bottom and shoal strata, with no apparent temporal peak in abundance. During 29 April to 20 May, white catfish were caught most frequently in the middle estuary. After the beginning of June, the highest catch rates occurred in the upper estuary regions, with fish apparently concentrated in the Albany region.

The early LRS concentration of catfish in the middle estuary may represent an upstream spawning migration, while later occurrence in the upper estuary during June and July may represent fish present at their spawning grounds. NAI (1985b), however, has suggested that while the upstream peak may represent spawning fish, the downstream peak likely reflects those non-spawning catfish that remained within their overwintering area.

L. SPOTTAIL SHINER

Spottail shiner (Notropis hudsonius) is a freshwater species whose distribution extends from the eastern U.S. coast to west of the Mississippi drainage (Trautman 1957). Spottail

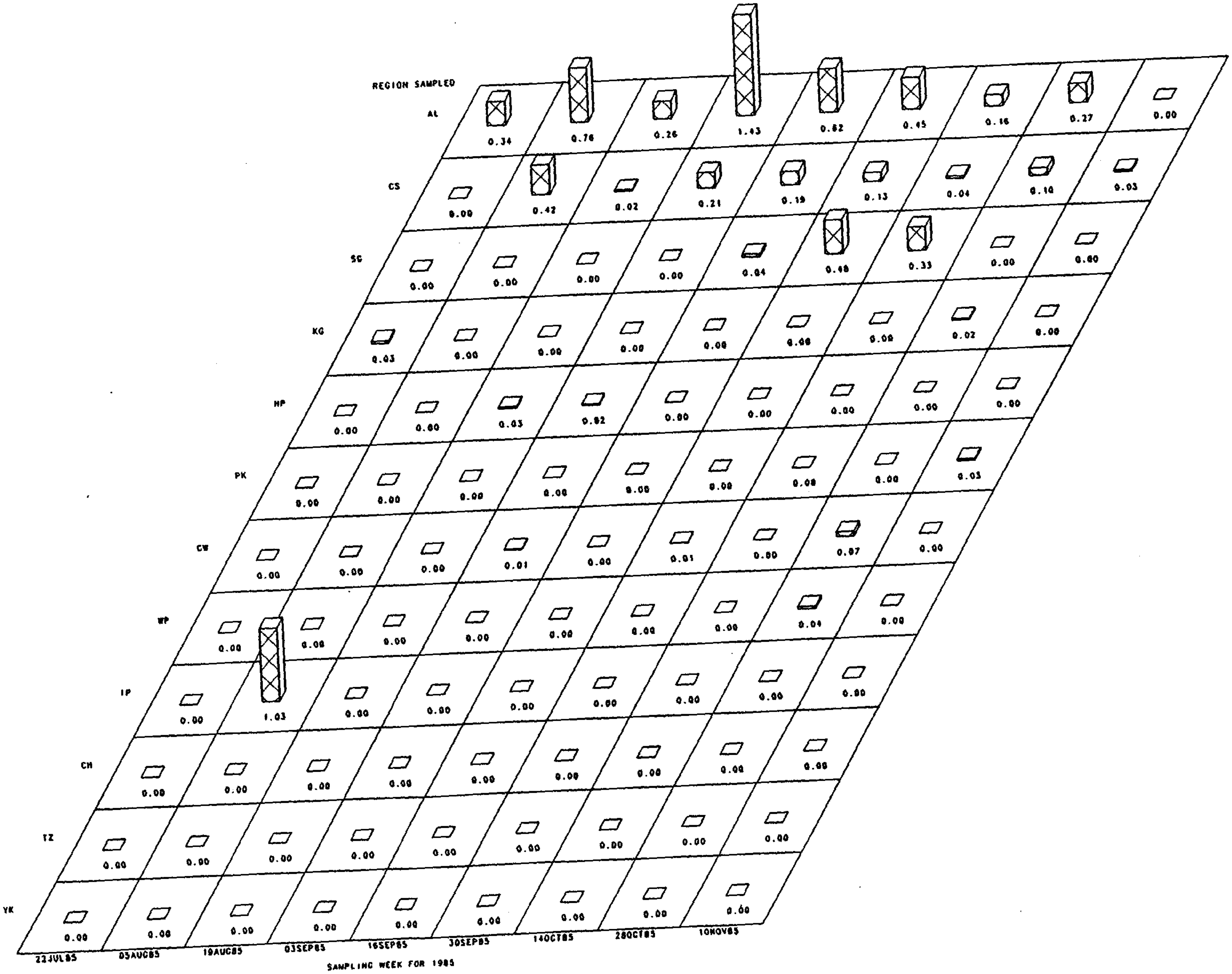


Figure IV-59. Mean regional density (per 1000 m^3) of white catfish young-of-year collected in the Fall Shoals Survey during 1985

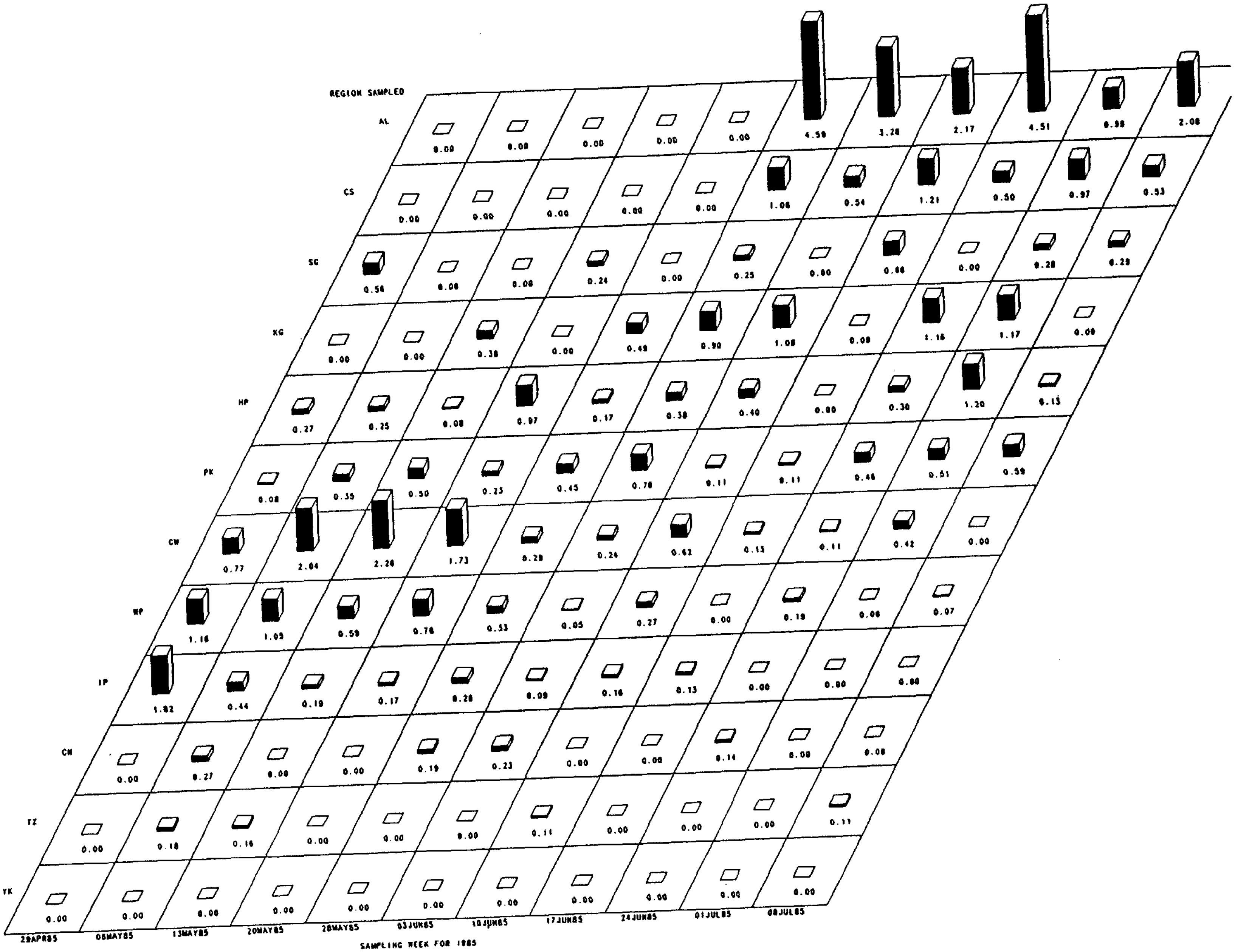


Figure IV-60. Mean regional density (per 1000 m^3) of white catfish yearling and older collected in the Longitudinal River Survey during 1985

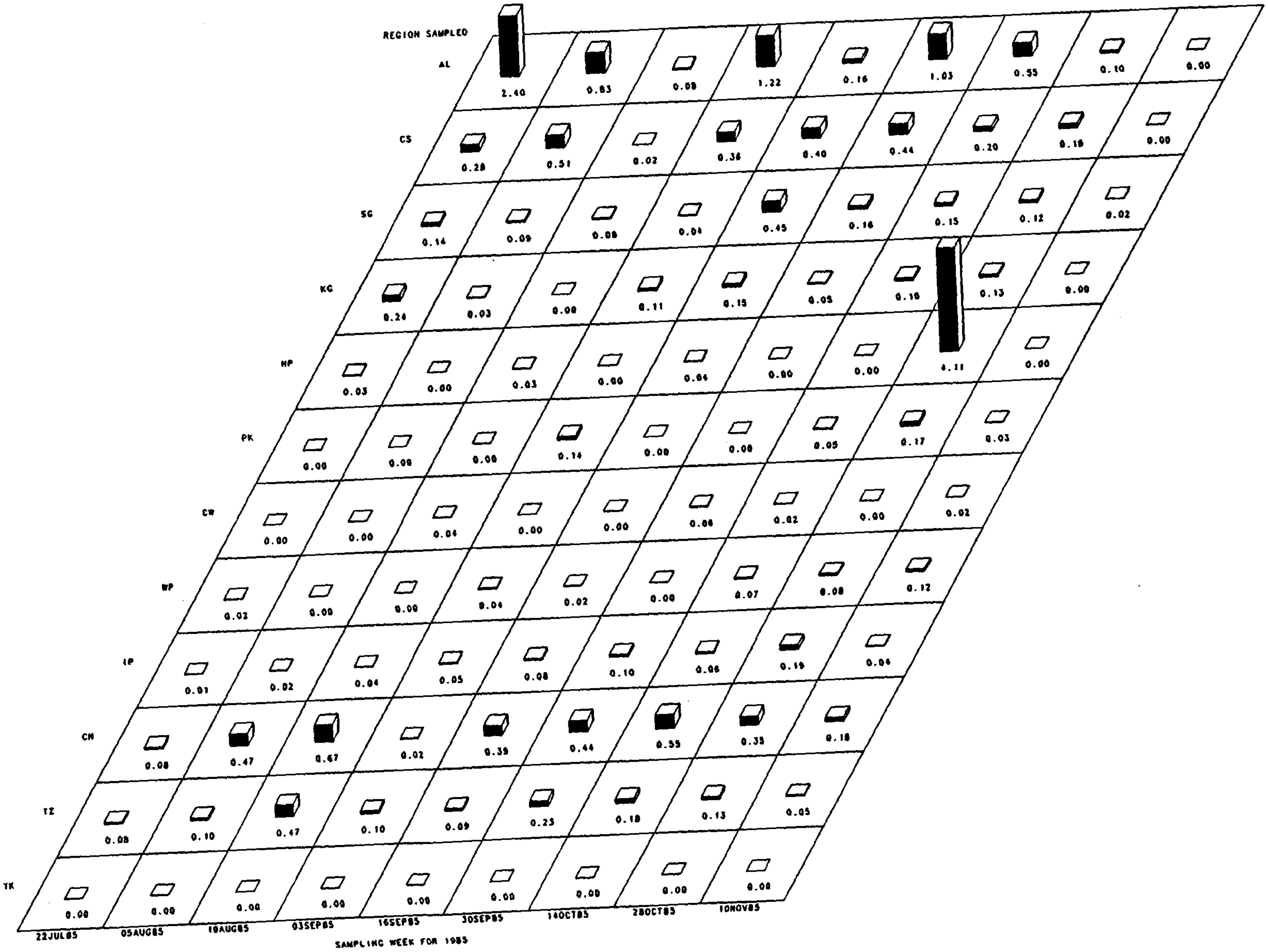


Figure IV-61. Mean regional density (per 1000 m^3) of white catfish yearling and older collected in the Fall Shoals Survey during 1985

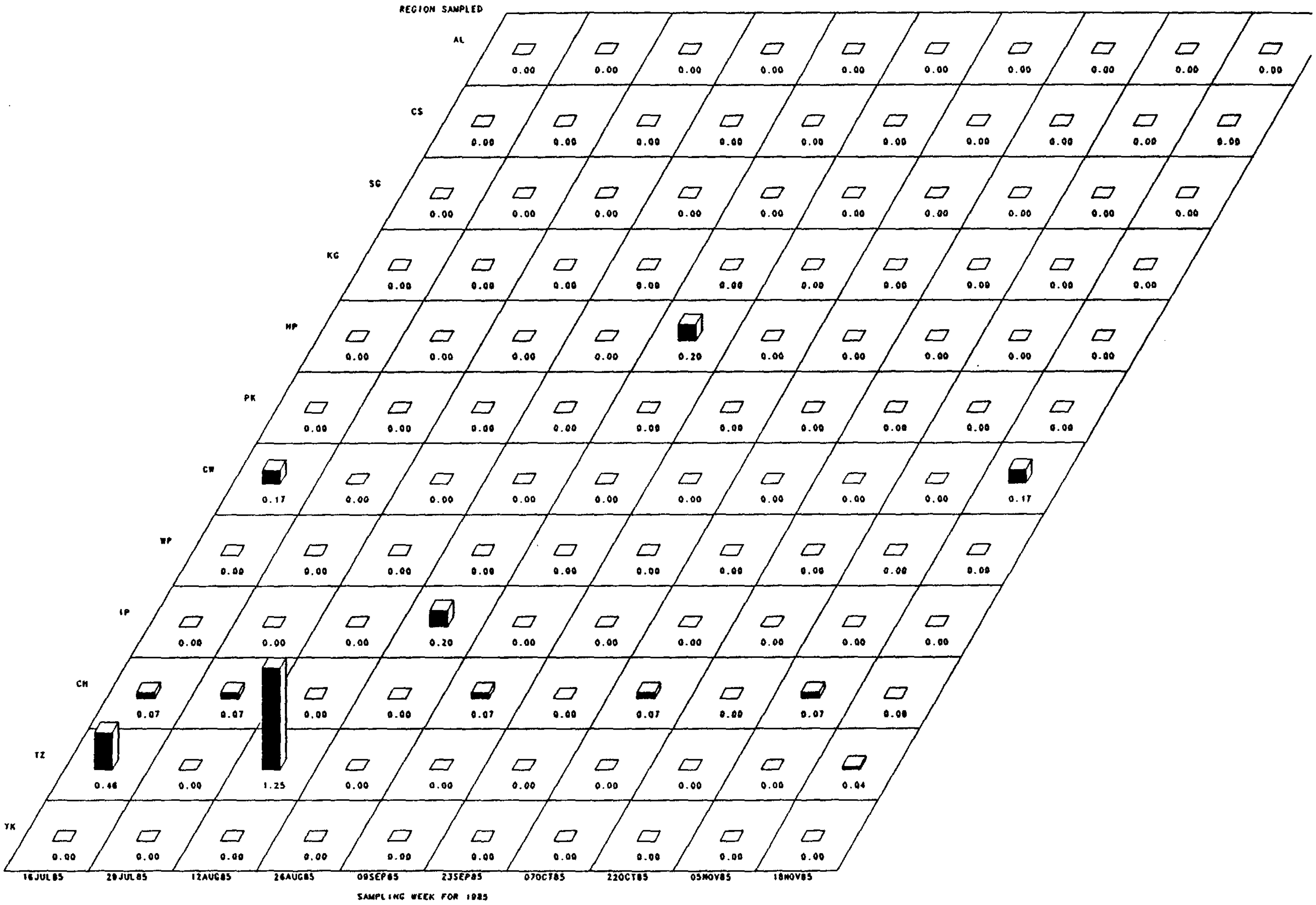


Figure IV-62. Catch per unit effort of white catfish yearling and older collected in the Beach Seine Survey during 1985 shiner is important recreationally as a baitfish and also as forage for piscivorous gamefish. This midwater schooling species prefers clear water with little turbidity and avoids strong currents (Pflieger 1975). Spawning generally takes place in June or July (Werner 1980) over sand or gravel substrate (Jones et al. 1978) and the 1300-2600 demersal eggs deposited by each female are not given parental care (McCann 1959). Eggs hatch in about 4 days at 20°C, and yolk-sac absorption takes place shortly thereafter.

Movement patterns for this species are poorly described outside of the Hudson River. Based on distributional data, TI (1981) has suggested that spottail shiners in the Hudson River move shoreward from deeper water overwintering areas to spawn in the spring and then return to deepwater areas in the fall. Juveniles apparently remain inshore through summer and disperse to deeper areas in fall.

Young-of-Year

No eggs or larvae of spottail shiners were captured during 1985 year class studies; this is likely due to tributary and near-shore spawning habits as well as the fact that eggs are demersal and adhesive. Juveniles were not collected during the LRS but were captured during all weeks of the BSS (Fig. IV-63) and most weeks of the FSS (Fig. IV-64). This pattern is similar to most previous years when spottail shiners were taken with regularity during the BSS and sporadically during FSS. Although some fish were taken from areas with mean regional salinities of near 5 ppt, most were collected upstream of the salt front and densities were highest above Poughkeepsie. As in 1980, peak standing crop of juveniles occurred in July, but a second, smaller peak was observed in early October.

Yearling and Older

Yearling and older spottail shiners were collected beginning in mid-May during the LRS (Fig. IV-65) and during each week of the FSS (Fig. IV-66) and BSS (Fig. IV-67). Highest observed densities occurred during June in the Kingston and Saugerties regions. Spatio-temporal distribution in previous Year Class reports was attributed primarily to the location of the salt front and the magnitude of freshwater flows; in 1985 a relatively low flow and stable temperature pattern restricted spottail shiner distribution primarily to areas north of Indian Point.

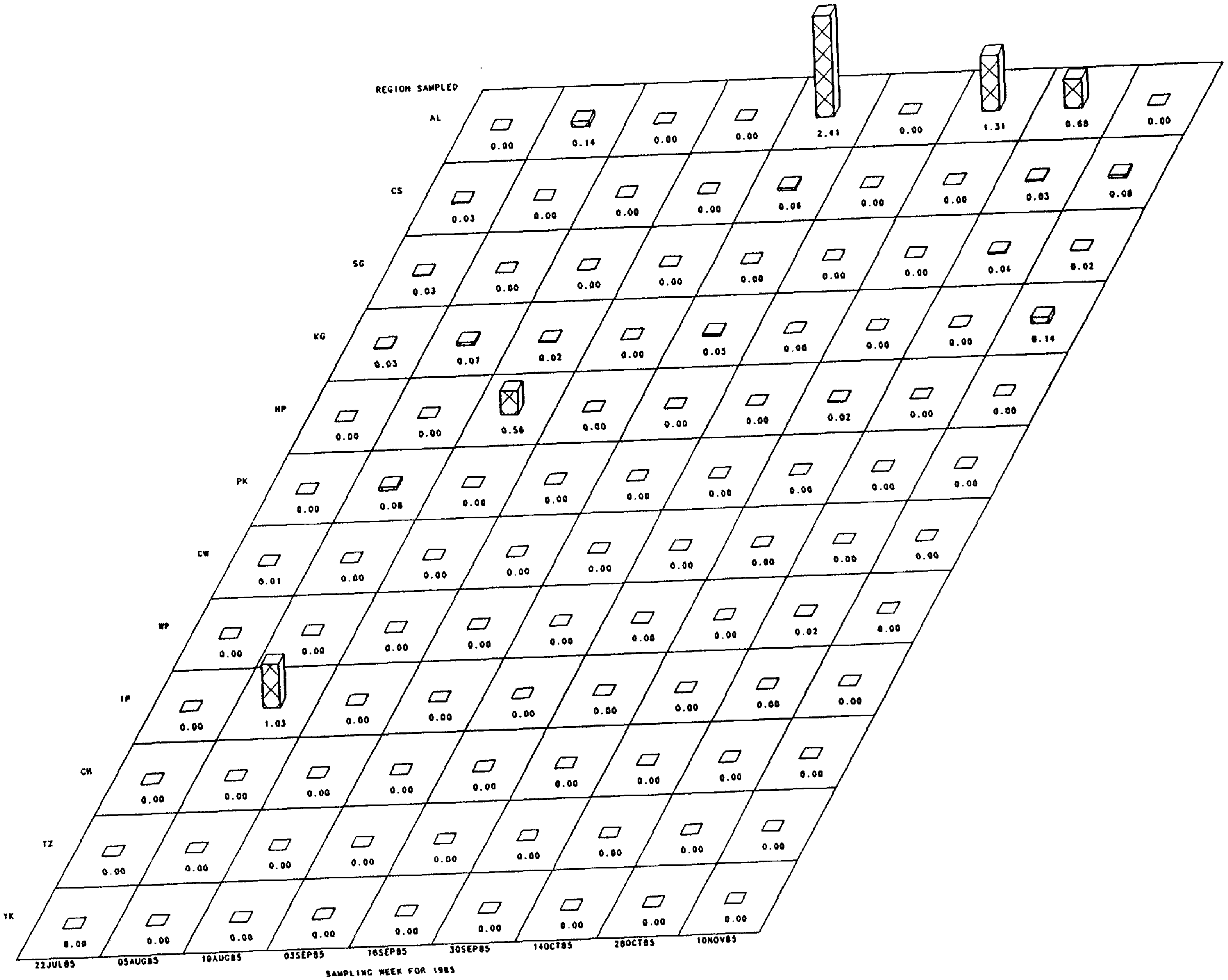


Figure IV-63. Mean regional density (per 1000 m^3) of spottail shiner young-of-year collected in the Fall Shoals Survey during 1985

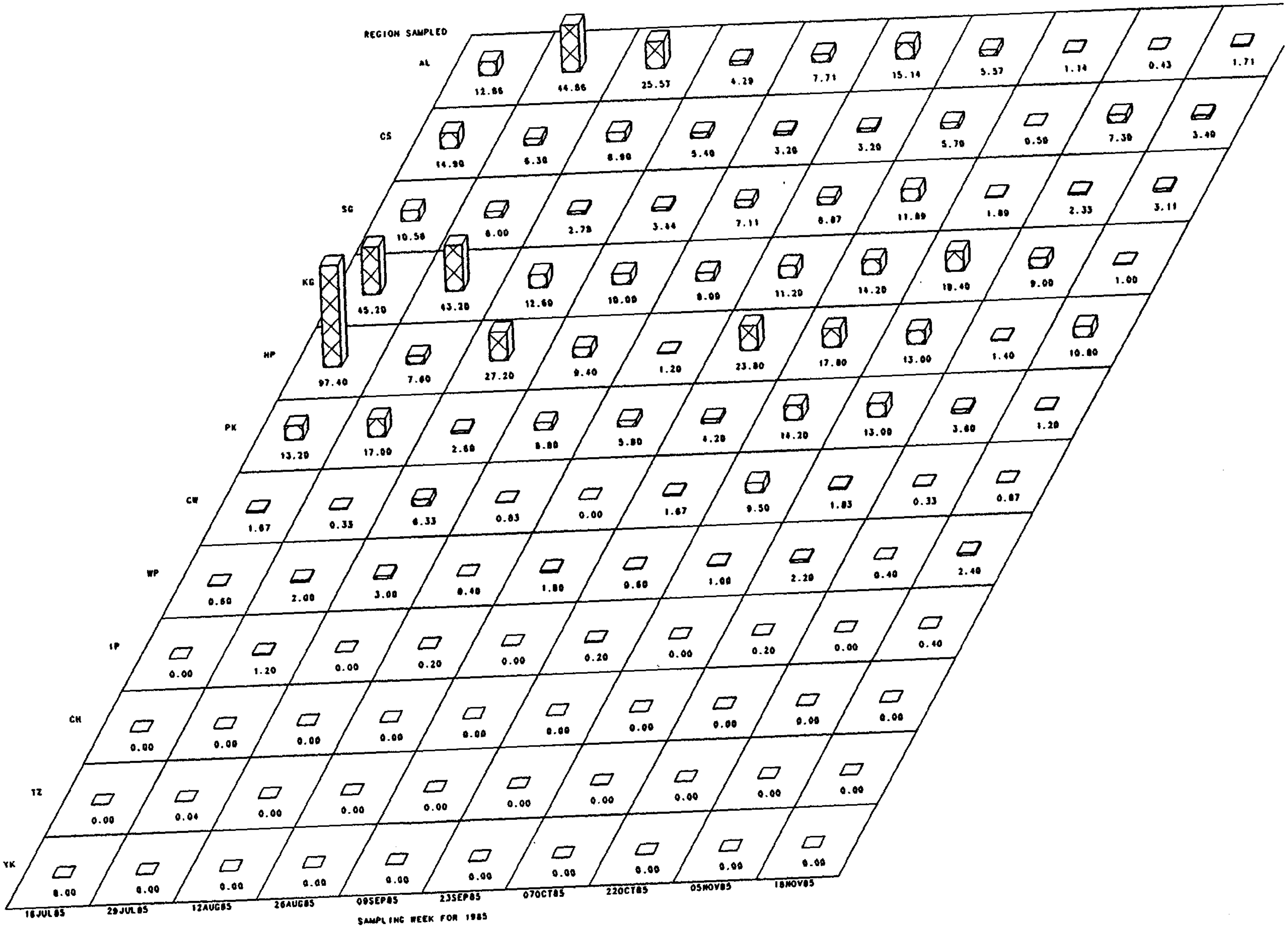


Figure IV-64. Catch per unit effort of spottail shiner young-of-year collected in the Beach Seine Survey during 1985

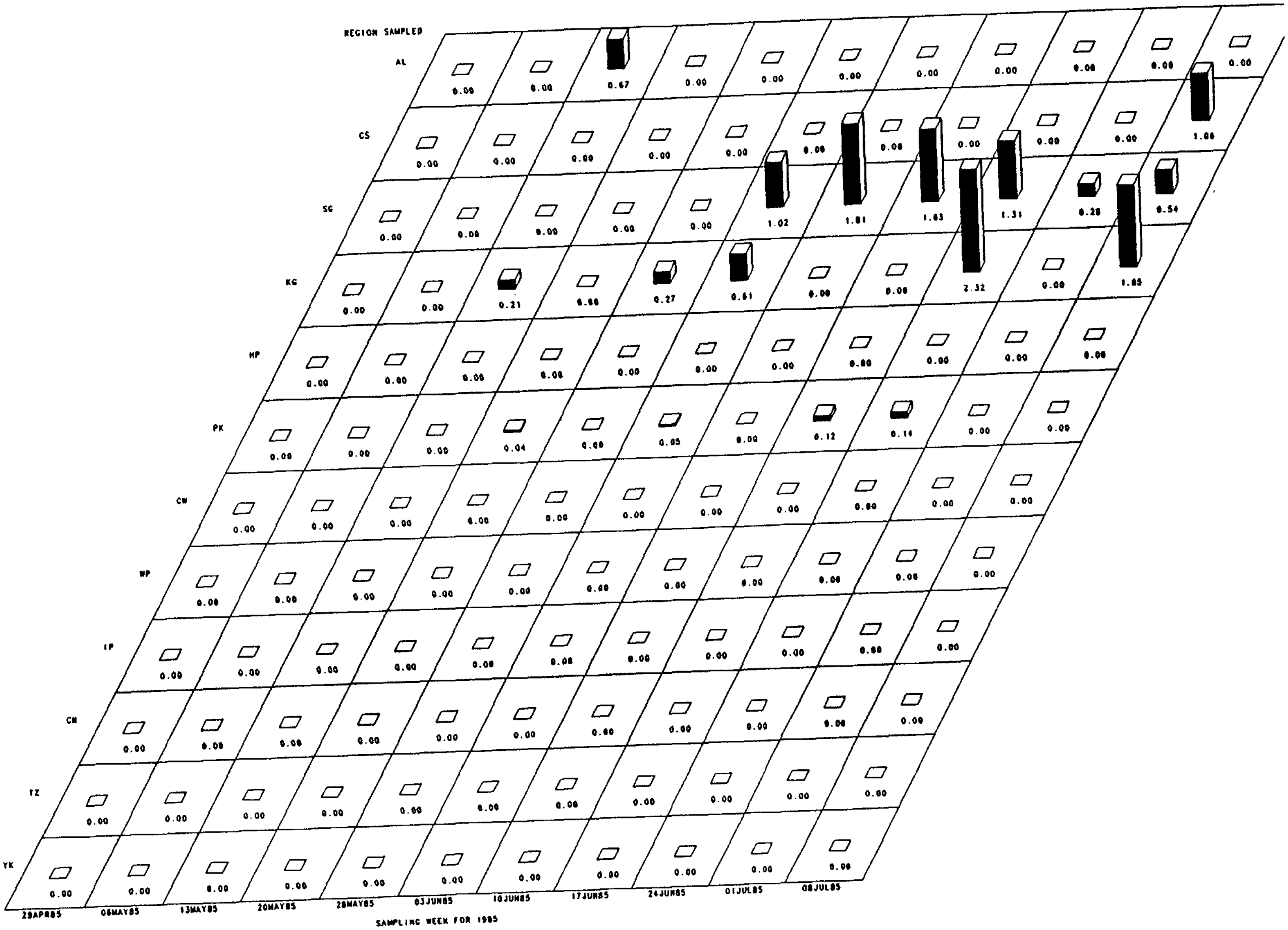


Figure IV-65. Mean regional density (per 1000 m^3) of spottail shiner yearling and older collected in the Longitudinal River Survey during 1985

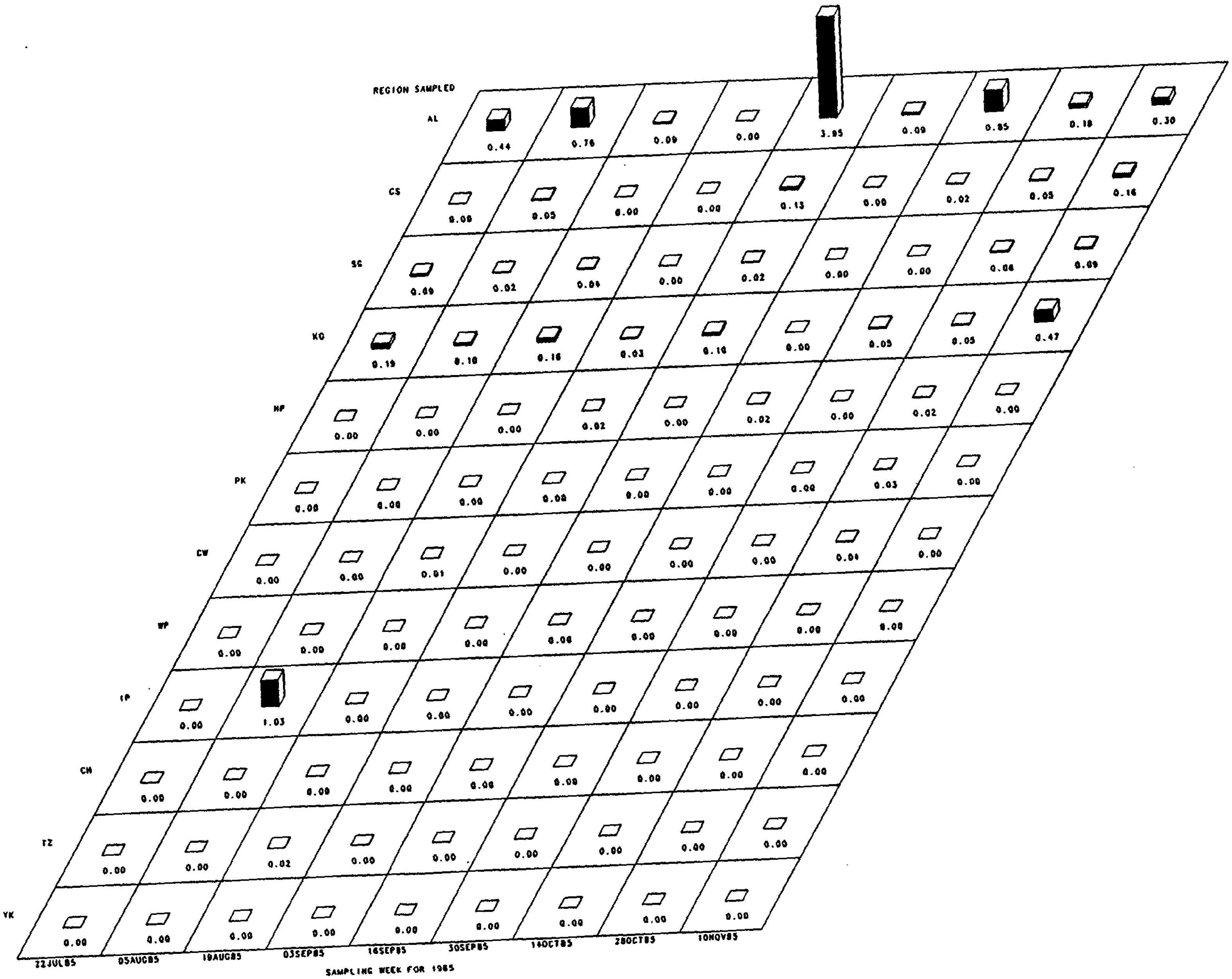


Figure IV-66. Mean regional density (per 1000 m^3) of spottail shiner yearling and older collected in the Fall Shoals Survey during 1985

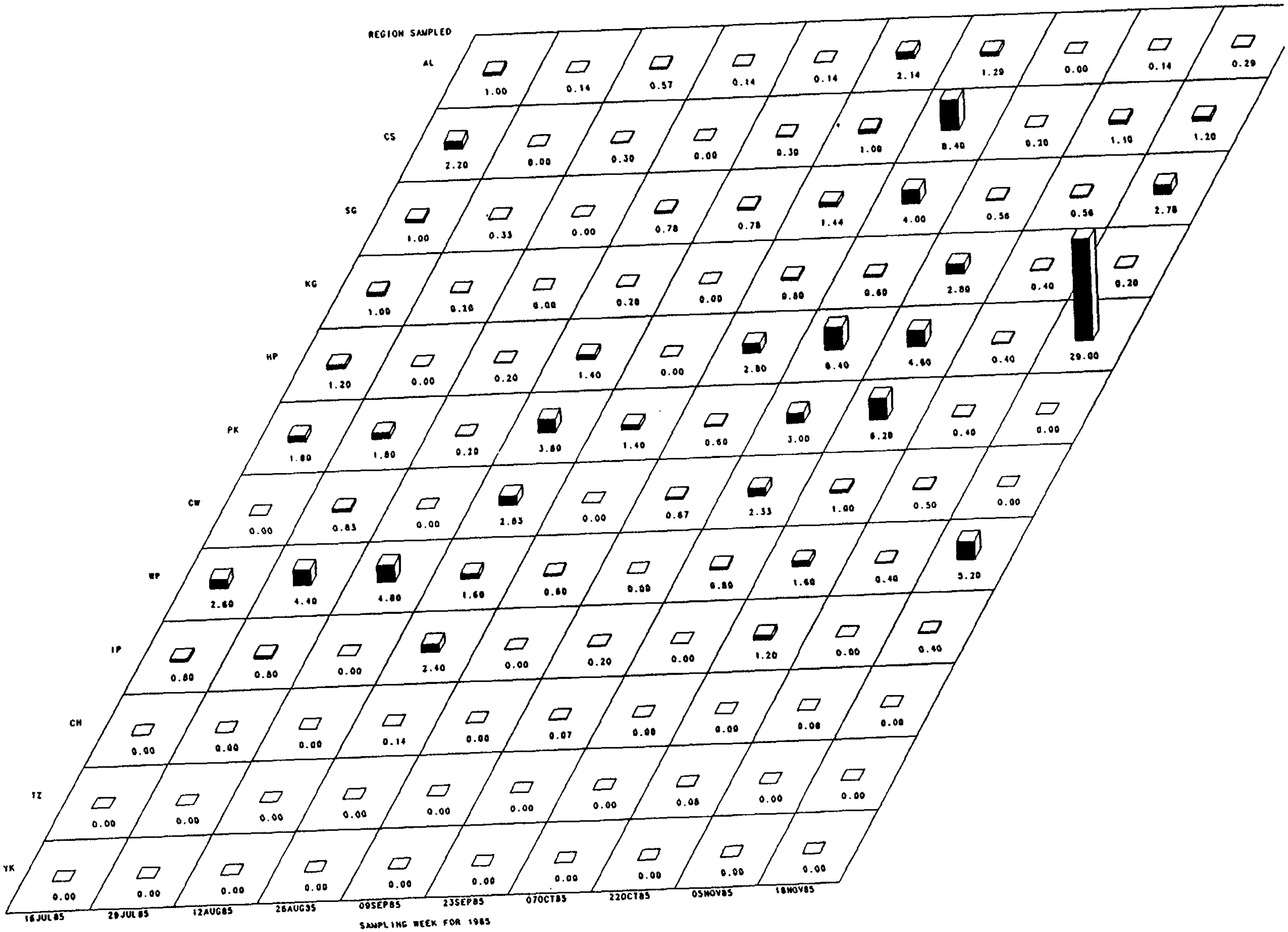


Figure IV-67. Catch per unit effort of spottail shiner yearling and older collected in the Beach Seine Survey during 1985

M. ATLANTIC STURGEON

Atlantic sturgeon (Acipenser oxyrhynchus) is a very long lived, slow growing anadromous species that inhabits estuarine and offshore waters from Labrador to South America; although the range of the more abundant northern subspecies (A. oxyrhynchus oxyrhynchus) extends only as far south as Florida (Vladykov and Greeley 1963; Smith 1985). Adults generally reside in coastal waters near their natal estuary, but are occassionally collected offshore (Murawski and Pacheco 1977).

Individual sturgeon may spawn as infrequently as once every 3-6 years (Scott and Crossman 1973; Smith 1985). Spawning takes place in spring on hard bottomed shoal areas (Borodin 1925). Large females may carry several million eggs each, but may take more than 20 years before first reproducing (TI 1981). Eggs are demersal, adhesive, and hatch in 4-7 days when water temperature is 18-20°C (Jones et al. 1978). Yolk-sac absorbtion is thought to occur within one week. As juveniles, Atlantic sturgeon tend to remain in their natal estuary for 3-5 years (Huff 1975), but do not overwinter in the upper estuary (Brundage and Meadows 1982; Lazzari et al. 1986). Adults may remain in the estuary through summer, but generally overwinter outside of the estuary.

Young-of-Year

No juvenile or earlier life stages of Atlantic sturgeon were collected during 1985 year class studies. The last year young-of-year were captured was 1980 when 37 individuals were collected.

Yearling and Older

As in previous years, collections of yearling and older Atlantic sturgeon in 1985 were sporadic (Figs. IV-68 and IV-69). Only one fish was taken in the BSS. Most were taken from the bottom stratum at or above the salt front. Atlantic sturgeon were collected from mid-May until mid-November, and in all regions except Yonkers.

N. SHORTNOSE STURGEON

The shortnose sturgeon (Acipenser brevirostrum) is an endangered species (Dadswell 1979) that inhabits near shore and estuarine waters from the St. John River in New Brunswick to

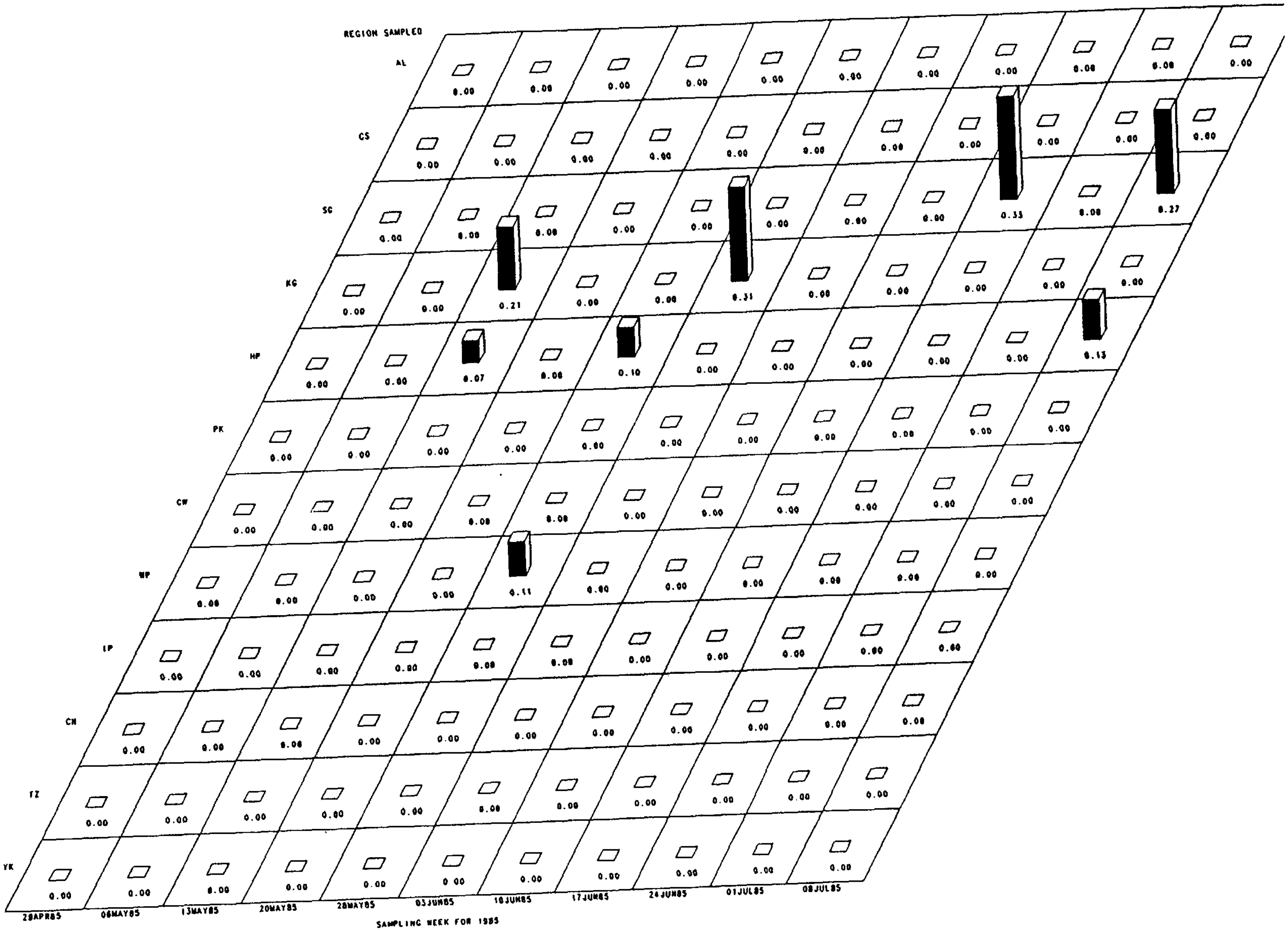


Figure IV-68. Mean regional density (per 1000 m^3) of Atlantic sturgeon yearling and older collected in the Longitudinal River Survey during 1985

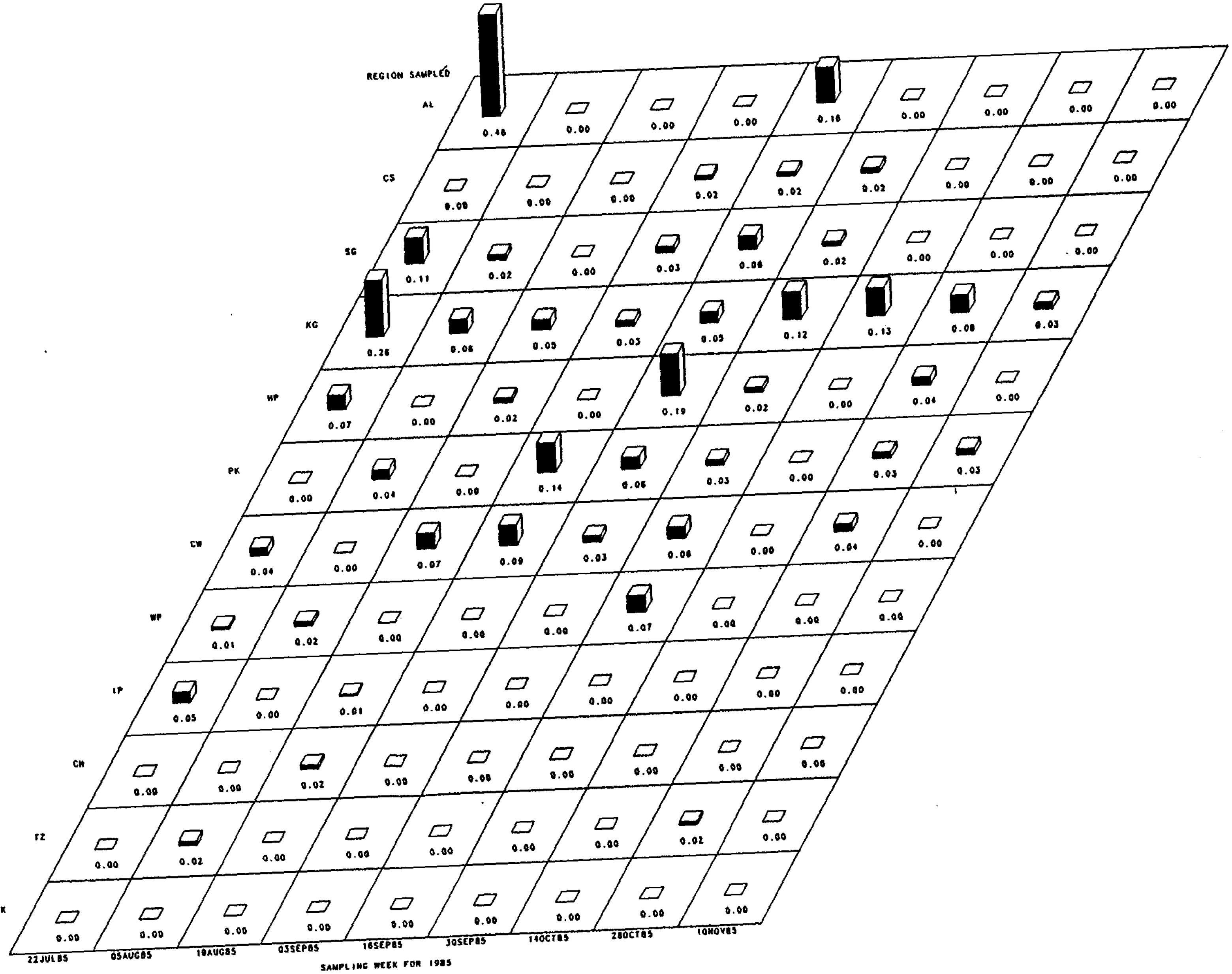


Figure IV-69. Mean regional density (per 1000 m^3) of Atlantic sturgeon yearling and older collected in the Fall Shoals Survey during 1985 the St. Johns River in Florida (Vladykov and Greeley 1963). Historically, shortnose sturgeon were abundant in large estuaries from the Connecticut to the Potomac Rivers (Scott and Crossman 1973), and a landlocked population exists in the Connecticut River (Taubert 1980).

As with other species of Acipenser, the shortnose is long lived, has slow growth and sexual maturity rates, and individuals spawn aperiodically. Age at first spawning may be 8-17 years (Scott and Crossman 1973; Jones et al. 1978; Taubert 1980), and spawning may occur only 1-2 times per lifetime, with as much as 20 years between spawns (Taubert 1980). Spawning is thought to occur mostly in freshwater during spring (DiNardo et al. 1985).

Unlike the Atlantic sturgeon, shortnose sturgeon tend to remain within an estuary during most of their life. However, extensive movement (as much as 20 km/day) within estuaries has been noted (McCleave et al. 1977; Buckley and Kynard 1985). In the Hudson River, shortnose sturgeon are thought to overwinter in the middle estuary, move upriver to spawn and return to overwintering areas following spawning (TI 1981).

Only 15 shortnose sturgeon were collected during 1985; all were yearlings or older and all were collected during the FSS (Table IV-4) from regions with salinities of 5 ppt or less. Most of the shortnose sturgeon captured were taken from the bottom stratum during September, when temperatures were between 17-22°C.

Table IV-4. Collections of shortnose sturgeon during 1985 Year Class studies

Date	Region	Stratum	Number Collected
22 August	Hyde Park	Bottom	1
18 September	Kingston	Bottom	5
19 September	Poughkeepsie	Bottom	1
01 October	Kingston	Bottom	2
01 October	Saugerties	Bottom	1
02 October	Hyde Park	Bottom	2
03 October	West Point	Bottom	1
15 October	Kingston	Bottom	1
29 October	Croton-Haverstraw	Channel	1
29 October	Saugerties	Bottom	1

V. HISTORICAL ABUNDANCE INDICES

A. INTRODUCTION

Indices of annual year class strength for white perch and striped bass in the Hudson River have historically been calculated using FSS and BSS data. Two basic types of abundance indices have been used: indices based only on beach seine data and those based on combined standing crop (CSC). Combined standing crop is an estimate of the number of fish in the river at a given point in time. It is calculated as the sum of the standing crop estimate for the offshore areas (volumetrically expanded FSS density estimates) and the standing crop estimate for the shore zone region (from areally expanded BSS density estimates). The first use of a CSC index was in the 1974 report (Table V-1). This index has developed over the years into three different types of indices for striped bass and white perch:

- Summer and fall regression indices for both species
- The peak method index for striped bass
- The geometric mean method index for white perch.

The purpose of this chapter is to present results of these previously developed indices, to present confidence intervals for these indices where possible, and to evaluate the methods used for calculating indices of year class strength. For presentation of these indices, methods were standardized to eliminate minor differences that existed in calculation of the indices among years. Generally, the values computed were close to previously reported values, although some differences resulted when methods were standardized. Confidence intervals were also determined for annual values of the historical indices. This was done to provide a means for assessing the significance of annual differences and for identifying apparent trends in year class strength.

Section B of this chapter outlines characteristics which are desirable in any useful index of abundance. These characteristics form the basis for evaluating each of the historical indices. Section C discusses the historical beach seine index. Section D discusses the calculation of weekly combined standing crop as it pertains to the historical indices. The three CSC index methods: the peak method for striped bass, the geometric

Table V-1. Indices of relative year class strength presented in Hudson River Year Class Reports (1973-1985)

Index	First Applied In:	First Applied To:	Citation
Beach seine catch per unit area	1973	striped bass, white perch, bluefish	TI (1975)
Combined standing crop -- peak and no extrapolation	1974	striped bass, white perch, Atlantic tomcod	TI (1977)
Combined standing crop -- peak and extrapolation	1979	striped bass	TI (1981)
Combined standing crop -- geometric mean and extrapolation	1979	white perch	TI (1981)*
Combined standing crop -- summer and fall regression	1982	striped bass, white perch	NAI (1985a)
Coordinate pair	1985	striped bass, white perch, American shad	MMES (1987)

mean method for white perch, and the summer and fall regression methods, are discussed in Sections E, F and G, respectively. Section H summarizes the major limitations associated with each of these previously developed indices.

B. DESIRABLE CHARACTERISTICS OF AN INDEX OF ABUNDANCE

Two conditions must be met if an index of abundance is to accurately reflect year class strength of fish in the Hudson River:

- The index must accurately estimate relative abundance among years in the areas from which sample sites are selected
- The proportion of the population in the sampled areas must be constant among years.

The first condition requires that the expected catch per unit effort for samples collected in the area subject to sampling is a constant fraction of the number of fish present in this area. This condition implies that gear efficiency must remain the same among years. Differences in gear efficiency among years could, for instance, lead to an erroneous conclusion that the number of fish in a sampled area had changed when, in fact, only the ability to collect them had changed.

The second condition is necessary if inferences about the Hudson River population as a whole are to be drawn from the sampled population. If a larger proportion of the population occurs in areas subject to sampling in one year relative to another, then differences in the index would be attributable to the change in distribution of the fish and not to a difference in year class strength. The importance of satisfying this requirement is low if a high percentage of the population occurs in the area subject to sampling. However, inferences to the Hudson River population can be grossly incorrect if only a small proportion of the population inhabits the area subject to sampling and their use of the area is transient (i.e., fish move into and out of the area). Furthermore, erroneous inferences would be highly likely if the area subject to sampling is not the same in all years.

C. BEACH SEINE INDEX

Methods

The beach seine index is expressed as the average number of fish caught per 10,000 ft^2 (929 m^2) sampled [Eq. (24)]. Only data from the Yonkers to Cornwall regions from mid-July to mid-September are used to calculate this index for striped bass, and data taken from all regions from mid-July to mid-October are used to compute this index for white perch.

$$I_{BS} = \frac{\sum_{w=w_s}^{w_e} \sum_{r=r_s}^{r_e} (C_{rw})\ (n_{rw})}{(N)(A)} (929) \qquad (24)$$

where

I_{BS} = beach seine index

C_{rw} = average CPUE in region r during week w (as calculated in Eq. (12), Chapter II

n_{rw} = number of samples taken in region r during week w

r_s = first region included in the index

r_e = last region included in the index

w_s = first week included in the index

w_e = last week included in the index

N = total number of samples used to calculate the index

A = surface area (m^2) sampled by the 30.5 m beach seine (450 m^2).

The standard error of the beach seine index is given in Eq. (25).

$$SE\ (I_{BS}) = \sqrt{\frac{\sum_{w=w_s}^{w_e} \sum_{r=r_s}^{r_e} \left(SE(C_{rw})^2 \quad (n_{rw})^2 \right)}{(N^2)\ (A^2)} (929^2)} \qquad (25)$$

where

$SE(I_{BS})$ = standard error of the beach seine index

$SE(C_{rw})$ = standard error of the average CPUE in region r and week w (as calculated in Eq. (13), Chapter II).

The beach seine index is the simple mean CPUE for all samples taken within the relevant temporal and geographic window. Confidence intervals for this index have not been previously calculated but can be approximated by invoking the Central Limit Theorem. This theorem states that the distribution of a sample mean (e.g., the beach seine index) approaches a normal distribution as sample size increases (Walpole and Myers 1978). A sample size of 30 is usually sufficient to generate reliable results. This implies that a 95% confidence interval can be established for each yearly value of the beach seine index using normal theory techniques. A 95% confidence interval for the beach seine index value would therefore be approximated as plus/minus two standard errors of the index value. This confidence interval provides a means for making hypothesis tests concerning yearly values of the beach seine index. A significant difference in the values of the index for the two years can be assumed to exist (at $\alpha \approx 0.05$) if the beach seine index confidence intervals for two years do not overlap.

Results

Beach seine index values and their associated confidence intervals do not suggest a trend in year class strength for striped bass during the years 1974-1985 (Fig. V-1). There are instances of isolated high index years (e.g., the index for 1981 is significantly higher than all other years except 1978 and 1983) and low index years (e.g., 1979 is significantly lower than 1975, 1977, 1978, 1981, 1983, and 1984). However, it is notable that the index value for 1985, which is almost one-third of the next smallest value observed in 1979, is significantly lower than the index value for every other year in the study.

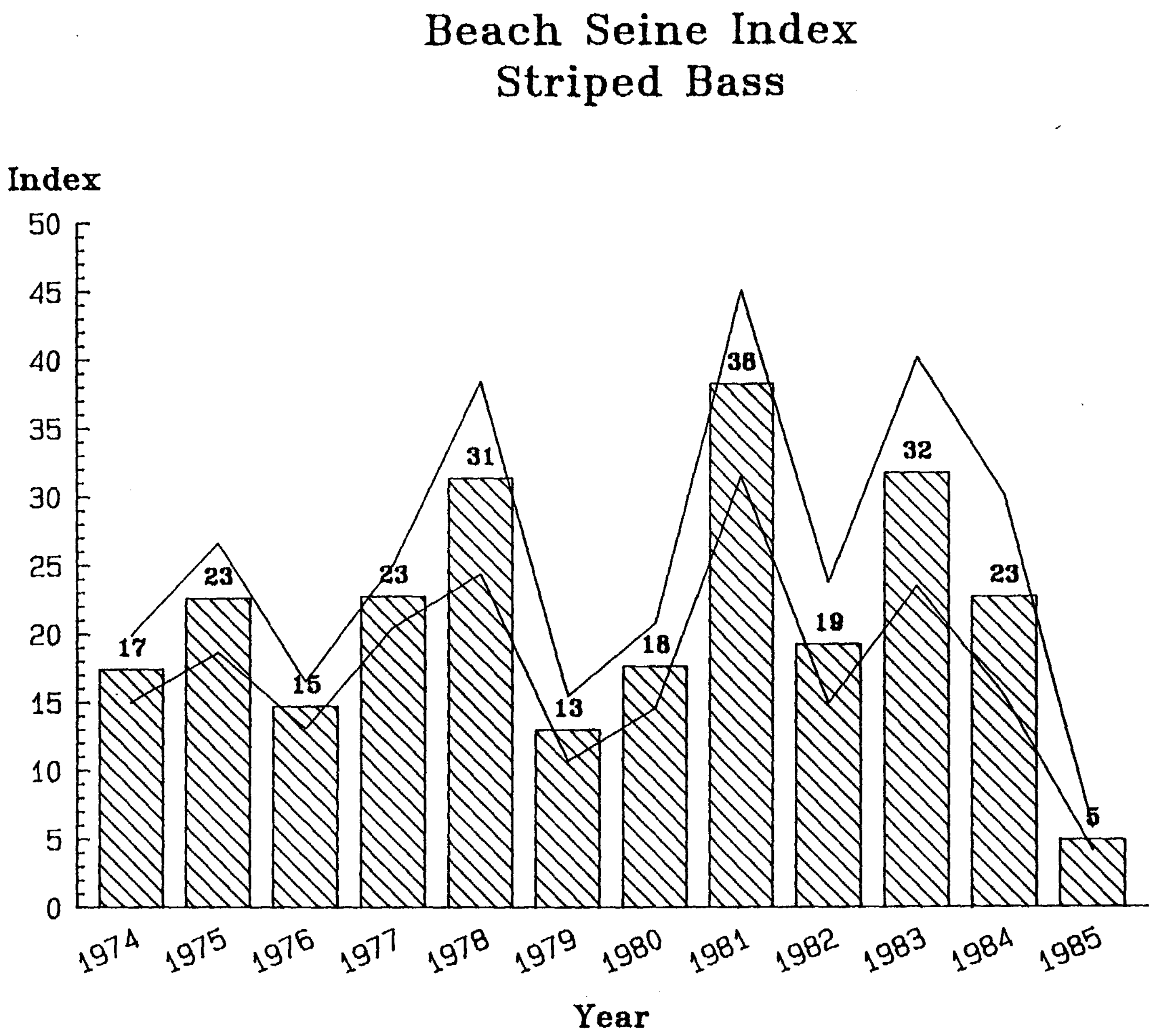


Figure V-1. Beach seine index and associated 95% confidence intervals for striped bass collected in the Hudson River since 1974

For white perch, the beach seine index and associated confidence intervals do not suggest a clearly defined long-term trend in year class strength during 1974 to 1985 (Fig. V-2). However, this index suggests two separate groupings (relatively high and relatively low index values) of years. The average index value from 1975 through 1983 was 24, while only 1979 was significantly higher than any other years in that span of time. The years 1974, 1984 and 1985 form a second grouping of years. Average index value in this group is less than one half of the average value for the years 1975-1983. No significant differences could be detected among years in the second grouping, but each was significantly lower than any year in the first group.

Assumptions and Limitations

The historically developed beach seine index does not appear to meet either of the criteria discussed in Section B of this chapter. The estimate of mean CPUE for the 284 beach locations from which weekly sample sites are selected is biased. This problem is relatively minor and could be corrected by using an alternative method for calculating mean CPUE. However, there are considerable problems associated with making inferences to the Hudson River population that are generic to any index based solely on beach seine data. The problems related to both criteria are discussed below.

The beach seine index, as historically calculated, does not provide an unbiased estimate of relative population size within the areas subject to sampling. The weekly average CPUE is calculated as the simple mean of all samples in the week. However, sampling effort is allocated on a stratified basis such that some beaches have a higher probability of being sampled than others. Should fish be concentrated in a region where the number of beaches sampled is disproportionately high (e.g., 24 of the 100 samples in a week are allocated to the Tappan Zee region), a disproportionately high index value will be calculated. In contrast, if the same population of fish was concentrated in a region where fewer samples are taken (e.g., only 5 out of 100 samples are allocated to the Yonkers region), the index would be disproportionately low. Thus, the index could confound true differences in abundance among years with distributional differences among years.

Furthermore, relative gear efficiency may not be the same among years because the temporal period over which the index was historically calculated varied among years. Both the striped bass and white perch index are calculated for the period beginning mid-July (week 29). However, the beach seine sampling program did not begin until as late as week 33 in one year

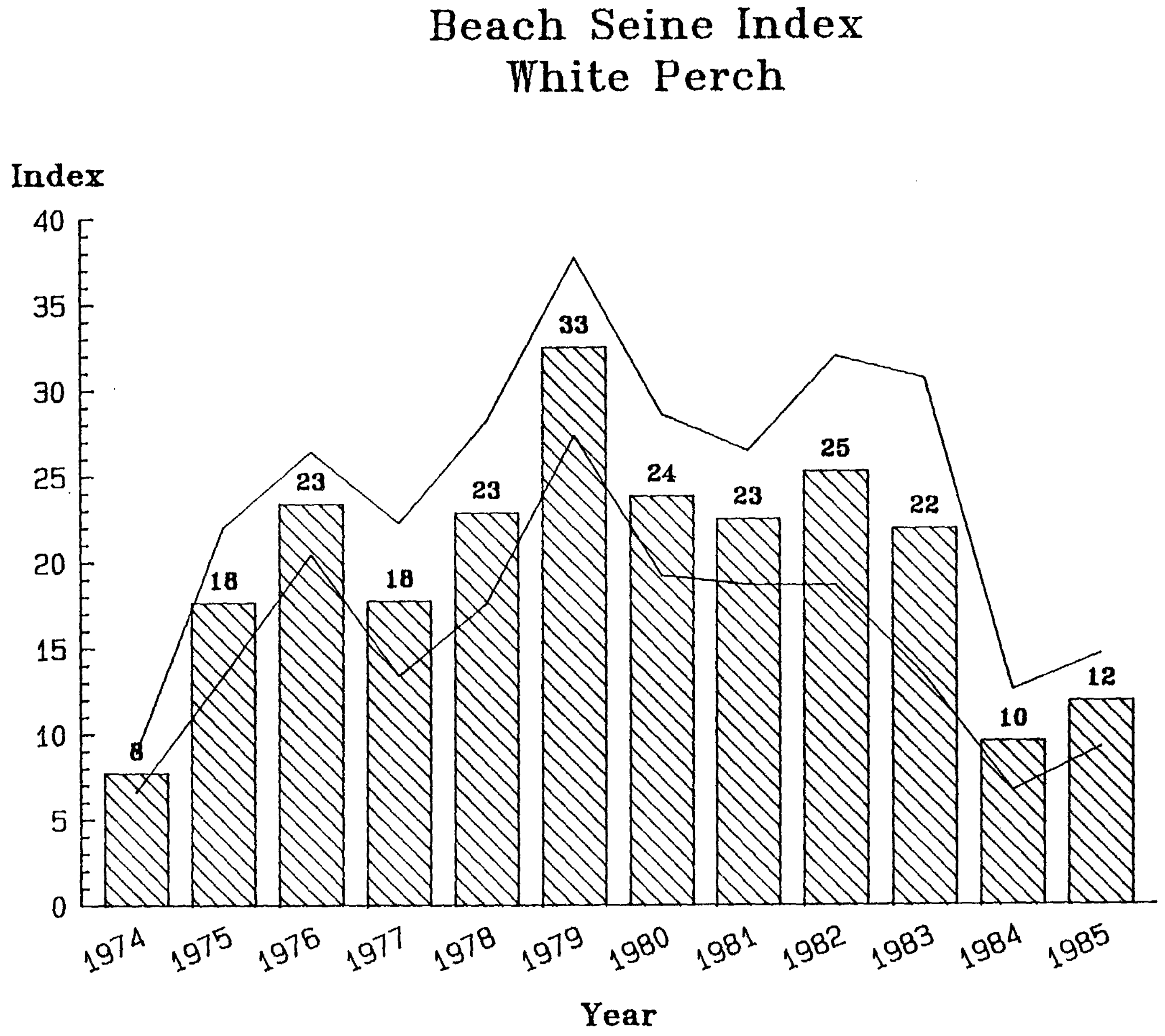


Figure V-2. Beach seine index and associated 95% confidence intervals for white perch collected in the Hudson River since 1974

(Fig. V-3). Since gear efficiency is likely to be a function of fish size and water temperature, both of which vary with time of year, relative gear efficiency among years may differ when these different temporal periods are used for comparison of beach seine catch among years.

The larger problem, however, is that only limited conclusions about Hudson River fish populations can be inferred from the beach seine index because the proportion of the population occurring in the areas subject to sampling is unlikely to remain constant from year to year. The beach seine index is particularly sensitive to this assumption since the areas subject to sampling are limited to 284 beaches which constitute no more than 2% of the total shoreline of the river. Therefore, small differences in distribution between sampled and unsampled shore zone areas among years could severely affect year to year comparisons using the index. Further, differences in distribution of fish between the shore zone and the rest of the river may confound the results of this index, since these offshore data are not included in the beach seine index. To examine the importance of this type of movement, the ratio of nearshore/offshore catch (i.e., BSS/FSS) was compared among years. Data from a common set of weeks (weeks 33-40) and for a common set of regions (Yonkers to Poughkeepsie) were used to calculate the ratio of mean catch per unit effort in offshore sampling to mean catch per unit effort in nearshore sampling. Data from 1985 were not included because the beam trawl was used in place of the epibenthic sled in that year. This ratio differed by as much as 12 fold among certain years for striped bass and white perch (Figs. V-4 and V-5). This result suggests that the proportion of these populations that is subject to sampling by the beach seine may differ substantially among years.

D. WEEKLY COMBINED STANDING CROP

Methods

The weekly combined standing crop method has been used to estimate the abundance of white perch and striped bass young-of-year for each week of sampling in the Hudson River between river miles 12 and 152. For the LRS, this is accomplished by adjusting regional standing crop estimates for gear efficiency and summing these values across all regions [Eq. (26)]. Equation (27) was used for calculating the standard error of weekly combined standing crop estimates based on data from the LRS.

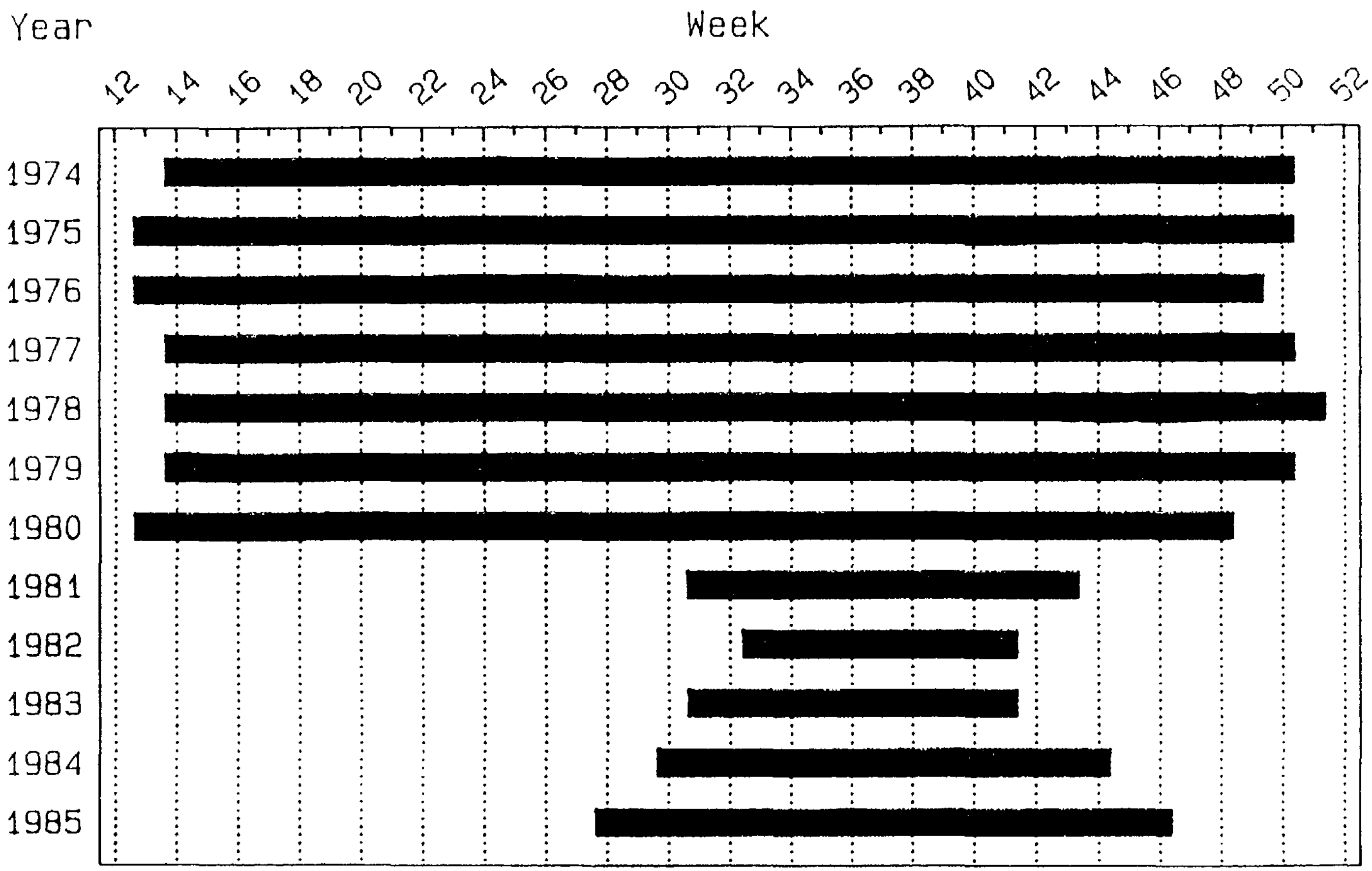


Figure V-3. Range of weeks over which Beach Seine Survey sampling was conducted on the Hudson River from 1974-1985. Week number designations are based on the number of Mondays in the year prior to the date of sampling.

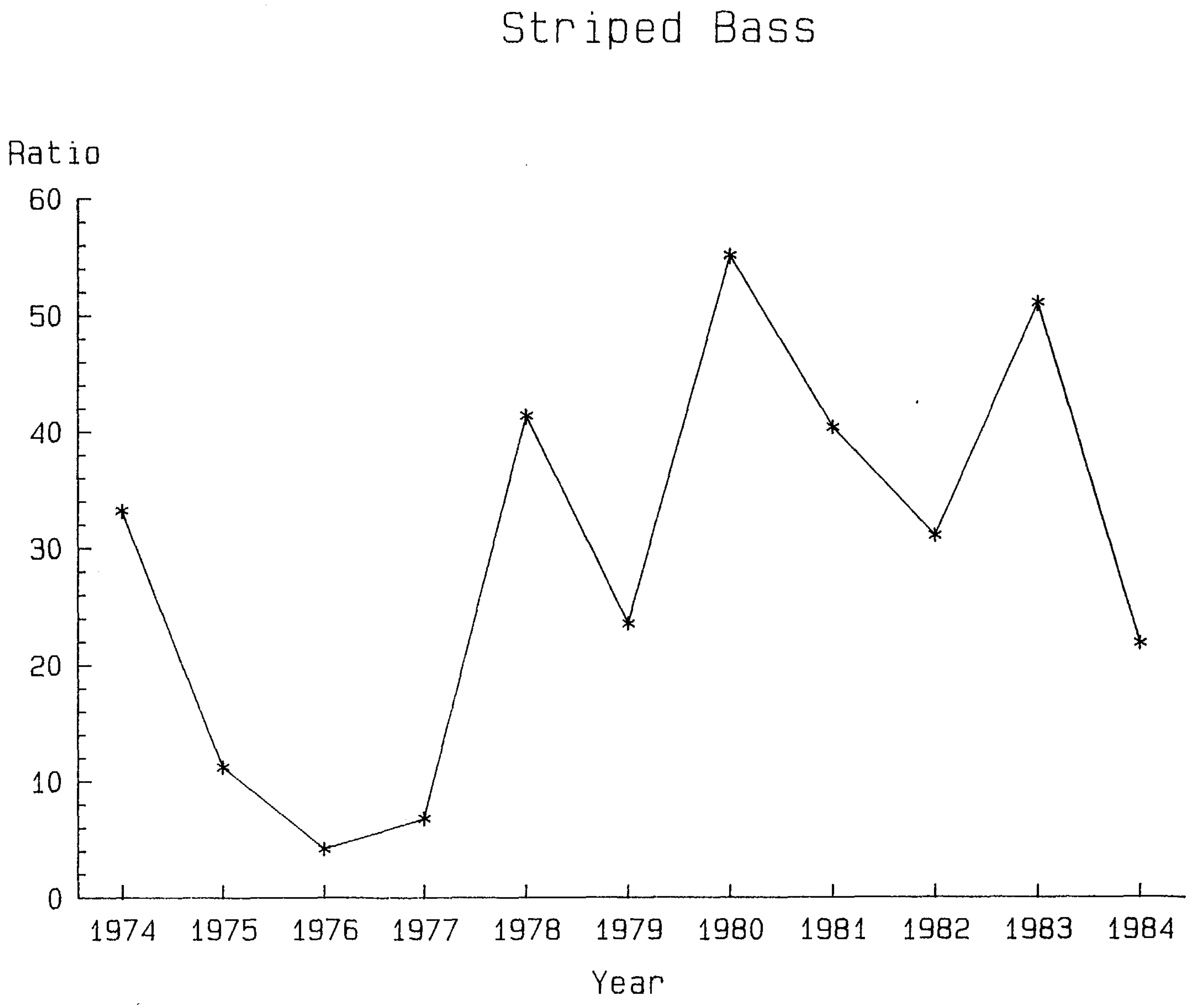


Figure V-4. Ratio of mean beach seine catch per unit effort to Fall Shoals catch per 100 m^3 for striped bass

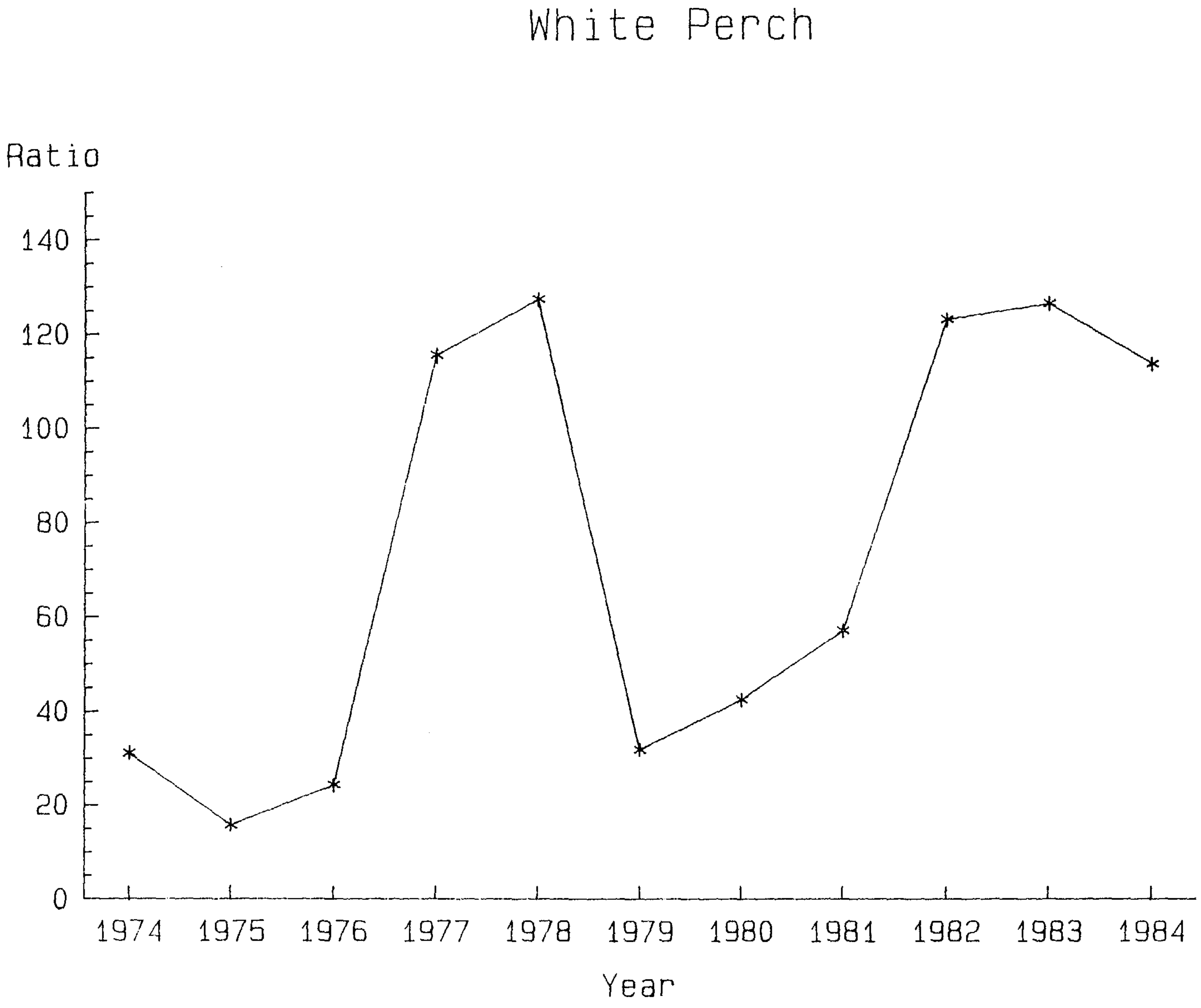


Figure V-5. Ratio of mean beach seine catch per unit effort to Fall Shoals catch per 100 m^3 for white perch

$$CSC_w = \sum_{r=1}^{12} \frac{SC_{rw}}{E_L} \qquad (26)$$

where

CSC_w = combined standing crop estimate for week w

SC_{rw} = regional standing crop (as calculated in Eq. (16), Chapter II)

E_L = gear efficiency adjustment for the LRS, where gear efficiency is assumed to be 50%

$$SE(CSC_w) = \sqrt{\sum_{r=1}^{12} \left[\frac{SE\ (SC_{rw})}{E_L}\right]^2} \qquad (27)$$

where

$SE(CSC_w)$ = standard error of weekly CSC estimate

$SE(SC_{rw})$ = standard error of the regional standing crop estimate (as calculated in Eq. (17), Chapter II).

During the fall surveys, weekly combined standing crop estimates were computed in six-steps that combined data from the Fall Shoals and Beach Seine surveys:

- Adjust the standing crop estimate of the shoal stratum for area sampled in the shore zone
- Sum the stratum standing crop estimates within a region for each survey
- Adjust regional standing crop estimates from each survey for gear efficiency
- Sum the regional standing crop estimates for each week for each survey
- Predict standing crop estimates for unsampled weeks of each survey
- Combine weekly standing crop estimates from the two surveys.

The standing crop estimate of the shoal stratum was reduced by 25% prior to summation of the three strata standing crop estimates for each region. This adjustment was made in order to eliminate overlap between the shoal stratum (0-6 m) sampled in the FSS and the shore zone (0-3 m) sampled with the beach seine. It was based on the assumption that the bottom slopes uniformly from 0 to 6 m.

After summing the stratum standing crop estimates in each region for each survey, the regional standing crop estimates were adjusted for gear efficiency. For Fall Shoals samples, gear efficiency for the epibenthic sled and the Tucker trawl was assumed to be 50%. The beach seine catch efficiencies were estimated (TI 1978b; 1979b) as 0.255 for juvenile striped bass and 0.182 for juvenile white perch. Since FSS sampling takes place at night and BSS sampling takes place during the day, species-specific gear efficiency adjustments (designed to account for night/day differences between the two fall surveys) were applied to standing crop estimates from the BSS. Texas Instruments (1978b; 1979) estimated night/day ratios of 2.136 and 1.685 for striped bass and white perch, respectively.

As described in Chapter II, the epibenthic sled that had been used historically since 1974 was replaced with a beam trawl for the 1985 FSS. Studies conducted by NAI (1986) in which the two gear were sampled in the same region found statistically significant, species-specific differences in catch between the two sampling devices. Adjustment factors, based on these relative catches, were developed in this report to estimate beam trawl gear efficiency (based on the assumed gear efficiency for epibenthic sled) so that data collected in 1985 could be compared to data collected prior to 1985 (Table V-2). When an adjustment resulted in a revised gear efficiency greater than 100%, gear efficiency was assumed to be 100%.

After the Fall Shoals and Beach Seine regional standing crop estimates were adjusted, the regional values were summed to estimate the adjusted standing crop for each week sampled. These steps are summarized for the BSS and FSS in Eqs. (28) and (29), respectively.

$$SC_{w,B} = \sum_{r=r_s}^{r_e} (SC_{rw,B}) \left(\frac{R}{C} \right) \tag{28}$$

where

$SC_{w,B}$ = adjusted standing crop estimate for week w of the BSS

Table V-2. Adjustment factors by which gear efficiency of the beam trawl were divided to standardize values with that of the epibenthic sled (NAI 1986)

Species	Adjustment Factor
Striped bass	4
White perch	13
American shad	0.1
Bay anchovy	0.02

$SC_{rw,B}$ = standing crop estimate (as calculated in Eq. (20), Chapter II)

C = catch efficiency of the beach seine

R = night/day adjustment factor for beach seine catches

r_s = first region included in the index

r_e = last region included in the index.

$$SC_{w,F} = \sum_{r=r_s}^{r_e} \left[\frac{1}{E_F} \left[(0.75)(SC_{k=1,r,w}) + \sum_{k=2}^{3} SC_{krw} \right] \right] \quad (29)$$

where

$SC_{w,F}$ = adjusted standing crop estimate for week w of the FSS

E_F = gear efficiency adjustment for the FSS

SC_{krw} = standing crop estimate (as calculated in Eq. (14), Chapter II)

k = (1 = shoal stratum
2 = bottom stratum
3 = channel stratum).

Only regions 1-7 were sampled during the FSS from 1975 to 1978 so only FSS and BSS data from those regions were included in the CSC indices for these years. However, data from all regions were used in the calculation of CSC indices for 1979-1985 (as was done for the 1979-1984 year class reports).

The final step in the calculation of weekly combined standing crop was to add the BSS and FSS adjusted weekly standing crop estimates to obtain a weekly estimate incorporating data from both surveys. In most years, FSS and BSS sampling were conducted in alternate weeks. Therefore, for weeks when no FSS sampling was conducted, the weekly FSS standing crop estimate was set equal to the mean of the FSS standing crop estimates for the two adjacent weeks. In weeks when no BSS sampling was conducted, the BSS standing crop estimate was set equal to the BSS estimate of the previous week.

Formulae for estimating the standard error for the combined standing crop estimates are presented below. Equation (30) was used to estimate the standard error of the adjusted standing crop estimates for the FSS, and Eq. (31) was used to estimate the standard error of the BSS adjusted standing crop estimates (Kendall and Stewart 1977). The standard error of the weekly combined standing crop estimate was computed as the square root of the sum of the squared estimates of standard errors for the BSS and FSS estimates [Eq. (32)].

$$SE(SC_{rw,F}) = \sqrt{\left[\frac{(0.75)SE(SC_{k=1,r,w})}{E_F}\right]^2 + \left[\frac{SE(SC_{k=2,r,w})}{E_F}\right]^2 + \left[\frac{SE(SC_{k=3,r,w})}{E_F}\right]^2} \qquad (30)$$

where

$SE(SC_{rw,F})$ = standard error of adjusted standing crop estimate for region r, during week w of the FSS

$SE(SC_{krw})$ = standard error of stratum standing crop estimate (as calculated in Eq. (15), Chapter II)

$$SE(SC_{rw,B}) = SC_{rw,B}\,\frac{C}{R}\sqrt{\frac{VR}{R^2} + \frac{VC}{C^2} + \frac{[SE(SC_{rw})]^2}{SC_{rw}^{\;2}}} \qquad (31)$$

where

$SE(SC_{rw,B})$ = standard error of adjusted standing crop estimate for region r, during week w of the BSS

SC_{rw} = regional standing crop estimate (as calculated in Eq. (20), Chapter II)

VR = estimated variance of night/day catch ratio

VC = estimated variance of beach seine catch efficiency

$SE(SC_{rw})$ = standard error of regional standing crop estimate (as calculated in Eq. (21), Chapter II).

$$SE(CSC_w) = \sqrt{\sum_{r=1}^{r_e} \left[SE(SC_{rw,F})^2 + SE(SC_{rw,B})^2 \right]} \qquad (32)$$

where

$SE(CSC_w)$ = standard error of weekly CSC estimate

$SE(SC_{rw,F})$ = standard error of adjusted standing crop estimate for the FSS calculated in Eq. (30)

$SE(SC_{rw,B})$ = standard error of adjusted standing crop estimate for the BSS calculated in Eq. (31).

Assumptions and Limitations

The CSC index approach improves upon the beach seine index by increasing the proportion of the total river subject to sampling. However, the weekly CSC value appears to be a poor estimator of relative abundance within the area subject to sampling because it is sensitive to the weighting system used to combine FSS and BSS data which has not been empirically estimated. Furthermore, the proportion of the population within the sampling area varies among years because of changes to the number of strata and regions sampled since 1974.

The principal concern with the estimate of relative abundance in the sampled area is that the CSC assumes a relative importance weighting for the offshore trawl sampling and the nearshore beach seine sampling that has not been empirically estimated. The weighting is based on a set of areas and volumes for each survey that do not correspond to the areas and volumes actually subject to random sampling and on a set of estimated gear efficiencies. The result is that the FSS component of the CSC is weighted over ten times more heavily than the BSS component. If the proportion of the population that is sampled by each survey changes from year to year (as was indicated by the pronounced differences in onshore/offshore distribution patterns among years), and the weighting factors for the two surveys are incorrect, year-to-year differences in the combined standing crop estimates may simply reflect changes in distribution patterns rather than changes in abundance.

For the beach seine component of CSC, the area that is actually subject to sampling consists of 284 beaches that are about 30 m in length and extend <30 m from shore. In weighting the beach seine catch, it is assumed that these sampled beaches represent the entire shoreline in the river to a depth of 3.1 m.

For offshore gear, the volume used for weighting is more representative of the actual area subject to sampling; although there are still many areas, such as upstream shoals which are not sampled but whose volumes are included in the weighting factors. However, unlike the beach seine efficiency value which is based on empirical observations, the gear efficiency value of 50% for the offshore gear was selected to conservatively estimate the size of fish populations. Use of this gear efficiency for combining BSS and FSS data for year-to-year comparisons appears to be inappropriate. Most studies of trawl gear would suggest that efficiency is considerably lower than 50% (Kjelson and Colby 1977). In addition, when the beam trawl and the epibenthic sled were deployed in the same regions and weeks to measure relative gear efficiency, the beam trawl collected ten times as many white perch and four times as many striped bass for the same volume filtered (NAI 1986). Thus, it appears that gear efficiency for the epibenthic sled can be no higher than 10% for white perch and 25% for striped bass, at least in those regions and weeks where the comparisons were made. Gear efficiency for the epibenthic sled may be considerably lower than even these values since the gear efficiency of a beam trawl has been reported to be as low as 10% (Kjelson and Colby 1977).

The estimate of relative abundance within the area subject to sampling is also confounded by the fact that the same gear has not been used to sample the bottom habitat in all years. The epibenthic sled was replaced by the beam trawl in 1985. While relative gear efficiency adjustment factors are available, they are based on only one month of sampling, conducted primarily in a single region and in the shoal stratum. For striped bass, this adjustment was based on more than 500 fish collected with each gear. However, for white perch the adjustment factor was based on less than 25 fish caught in the epibenthic sled.

The ability to draw inferences about the river as a whole from collections made in the area subject to sampling is limited because the area subject to sampling has not been the same in all years. With the exception of one region sampled in 1974, the channel has only been sampled since 1979 (Fig. V-6). The bottom stratum has been sampled in all years, but from 1974-1978 bottom sampling only occurred as far upriver as region 7 (Fig. V-7). The shoal stratum has been consistently sampled in all years except in 1975 and 1976, when region 6 went unsampled (Fig. V-8). These differences in sampling among years will affect different species differentially. The lack of upriver sampling will be a more important factor for species like American shad which is generally distributed in the upriver regions (Figs. IV-36 and IV-37). Striped bass and white perch are distributed more downriver (Figs. IV-10 and IV-22) and indices for these species would not be as sensitive to the lack of upriver sampling in some years. The lack of channel data

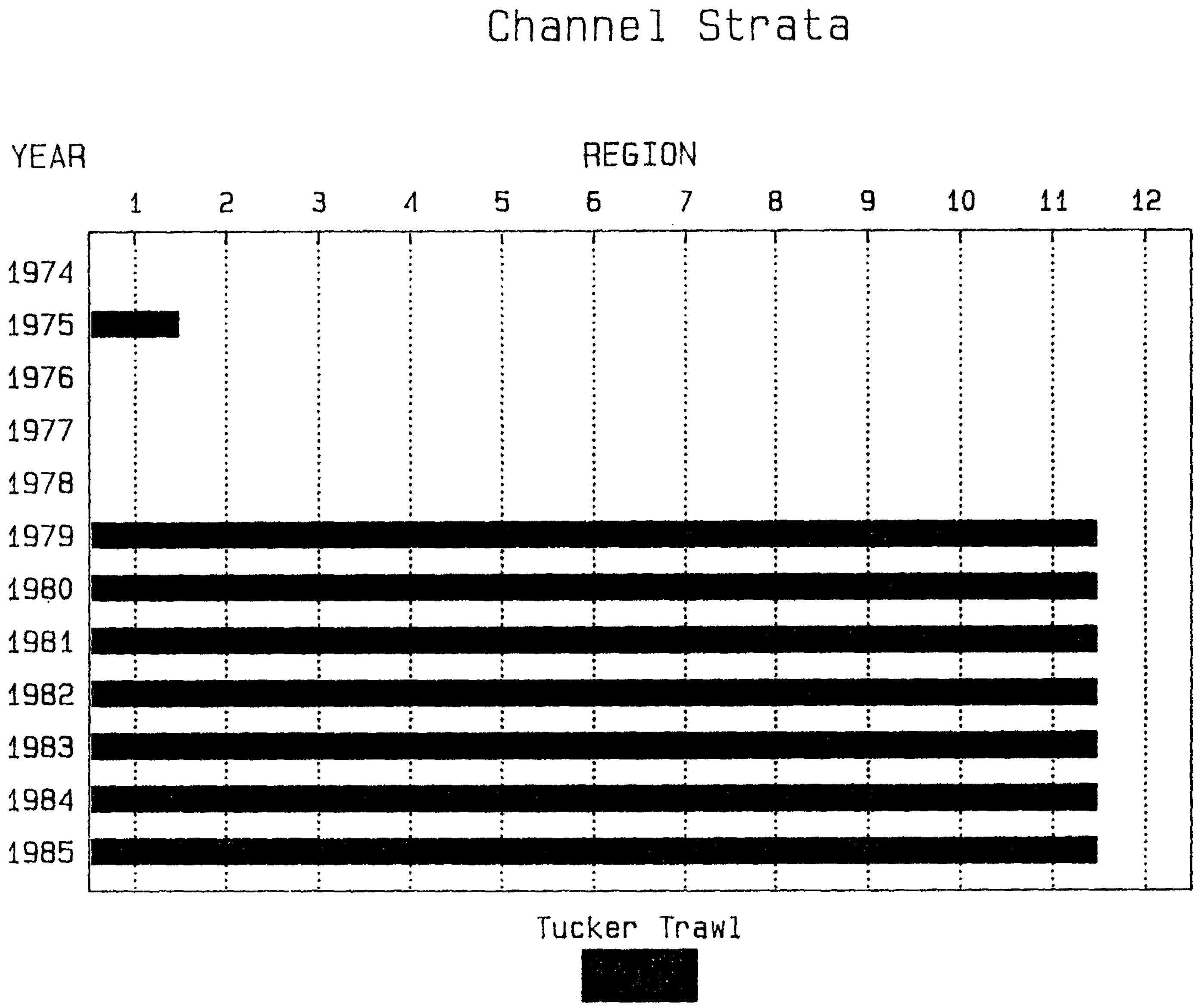


Figure V-6. Regions in which the channel stratum was sampled by the Fall Shoals Survey program from 1974-1985

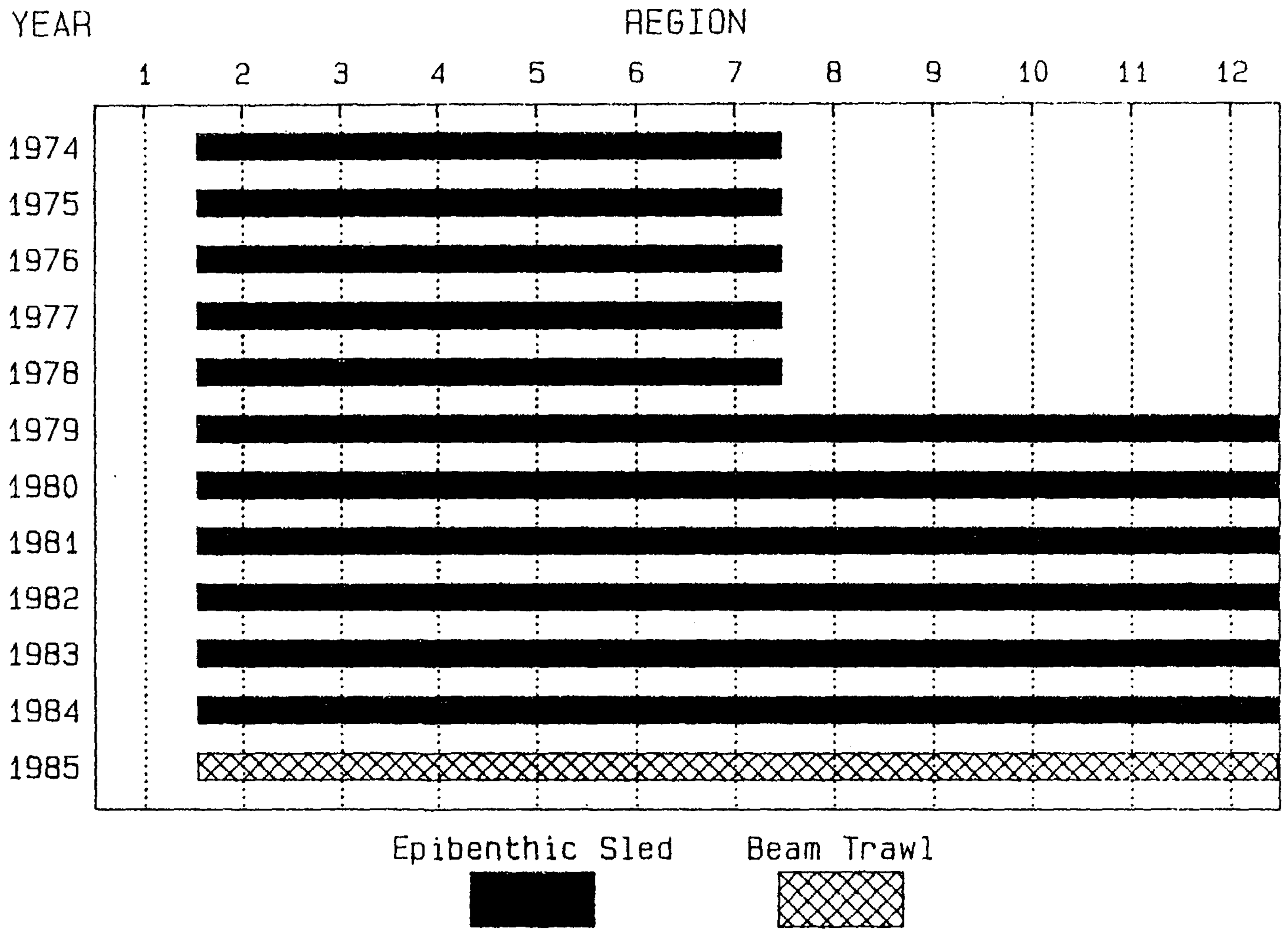


Figure V-7. Regions in which the bottom stratum was sampled by the Fall Shoals Survey program from 1974-1985

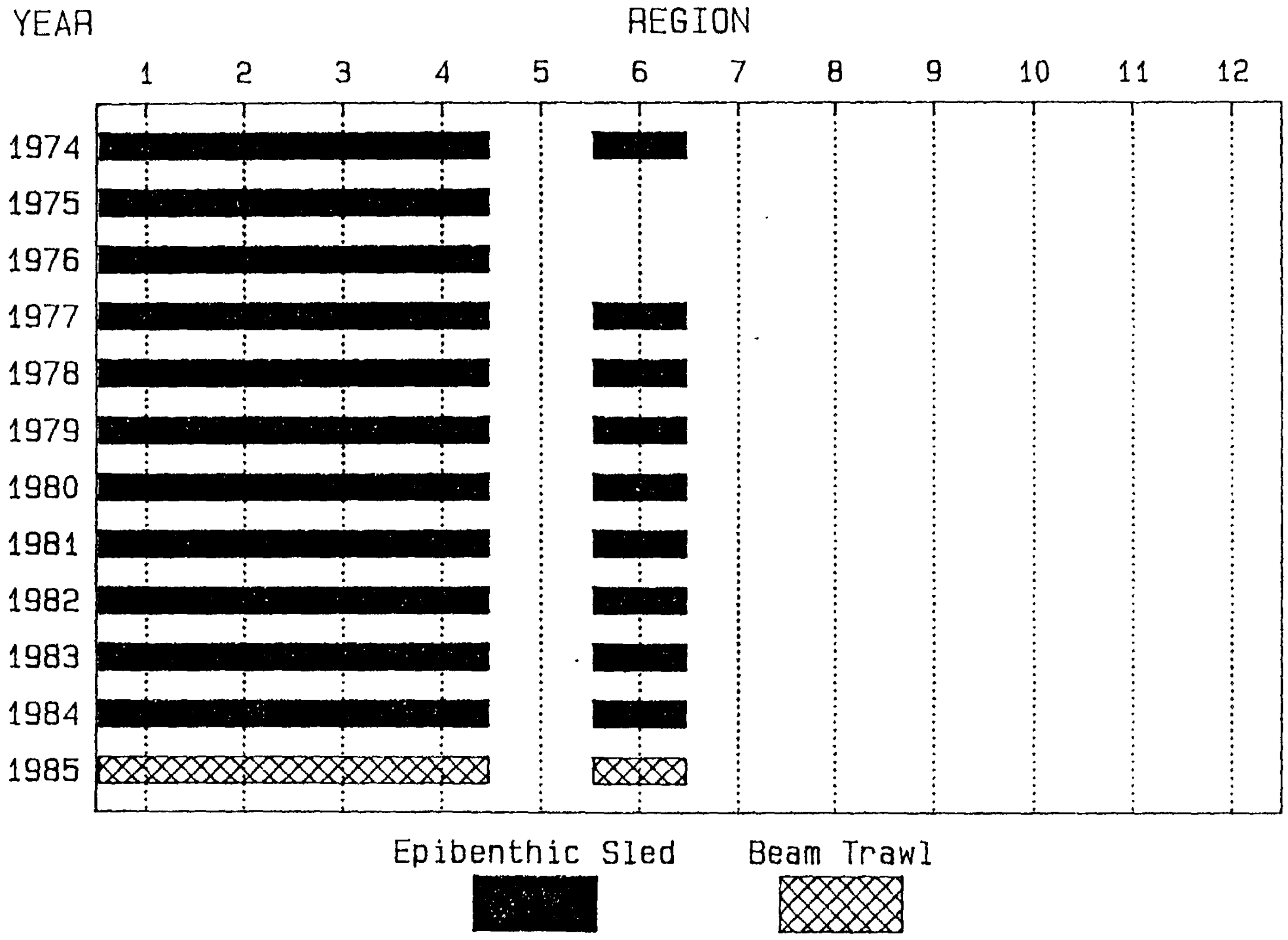


Figure V-8. Regions in which the shoal stratum was sampled by the Fall Shoals Survey program from 1974-1985 is likely to be less important for striped bass and white perch than for American shad because these fish generally feed on the bottom whereas shad are filter feeders and are more likely to be found in the water column.

E. PEAK METHOD INDEX FOR STRIPED BASS

Method

The peak method CSC index has been calculated for striped bass since 1976. This method is calculated in the following manner:

- Weekly CSC values are plotted and visually inspected to determine the week of peak abundance
- The abundance on 1 August is predicted using the peak abundance value and an assumed rate of mortality [Eq. (33)].

$$CSC_O = \frac{CSC_W}{e^{-zt}} \tag{33}$$

where

CSC_O = predicted CSC on day 0 (1 August)

CSC_W = CSC estimate for peak week w

t = number of days between midpoint of the peak abundance week and 1 August

z = instantaneous (daily) mortality rate corresponding to an annual mortality rate of 0.75 ($z = 3.79 * 10^{-3}$) (Battelle 1983).

A simplified estimate of the standard error of the peak CSC method index is given in Eq. (34):

$$SE(CSC_O) = \frac{SE(CSC_W)}{e^{-zt}} \tag{34}$$

where

$SE(CSC_O)$ = the standard error of the predicted CSC on 1 August

$SE(CSC_w)$ = the standard error of the weekly CSC value for peak week w [Eq. (27)].

Confidence intervals for the peak method index could be calculated by first assuming an underlying distribution of the estimate of peak weekly CSC. However, there are no data to examine the distribution directly because there is only one estimate of the peak. It is also not possible to determine the distribution of the peak estimate indirectly from weekly CSC values because these observations are too few and are not independent (recall that they are linear combinations of each other). Therefore, rather than assuming an underlying distribution for which there is no evidence, confidence intervals could be calculated using Chebycher's Theoren (Walpole and Myers 1978) which does not require any information on the distribution. This approach is conservative and yields large confidence intervals, and therefore tends to minimize Type I errors for year to year comparisons. An approximate 95% confidence interval for the real value of the peak method index can be calculated as the index plus or minus 4.5 times the standard error of the peak week as calculated in Eq. (34). A confidence interval computed in this manner can be determined for each year of the peak CSC method index to determine whether significant differences existed among years.

Results

CSC values could not be calculated for 1974 because a large number of strata and regions were not sampled in that year. Peak CSC index values and associated confidence intervals for striped bass from 1975-1985 are given in Fig. V-9. No trends in year class strength are apparent. The highest index value using the peak method occurred in 1978 and the lowest in 1985. However, 1985 could not be distinguished statistically from any year other than 1980. The confidence intervals with this method are very wide and the lower limit in many years overlaps zero. This was due, in part, to the conservative procedure used for calculating the confidence interval.

Assumptions and Limitations

In addition to the limitations associated with the weekly CSC values, the peak method index has further disadvantages as an estimator of relative abundance in the area subject to sampling. First, the time of year of the peak differs among years. This occurred because the peak CSC values were observed at different times in different years, and because the starting and ending dates for the BSS (Fig. V-5) and FSS (Fig. V-10)

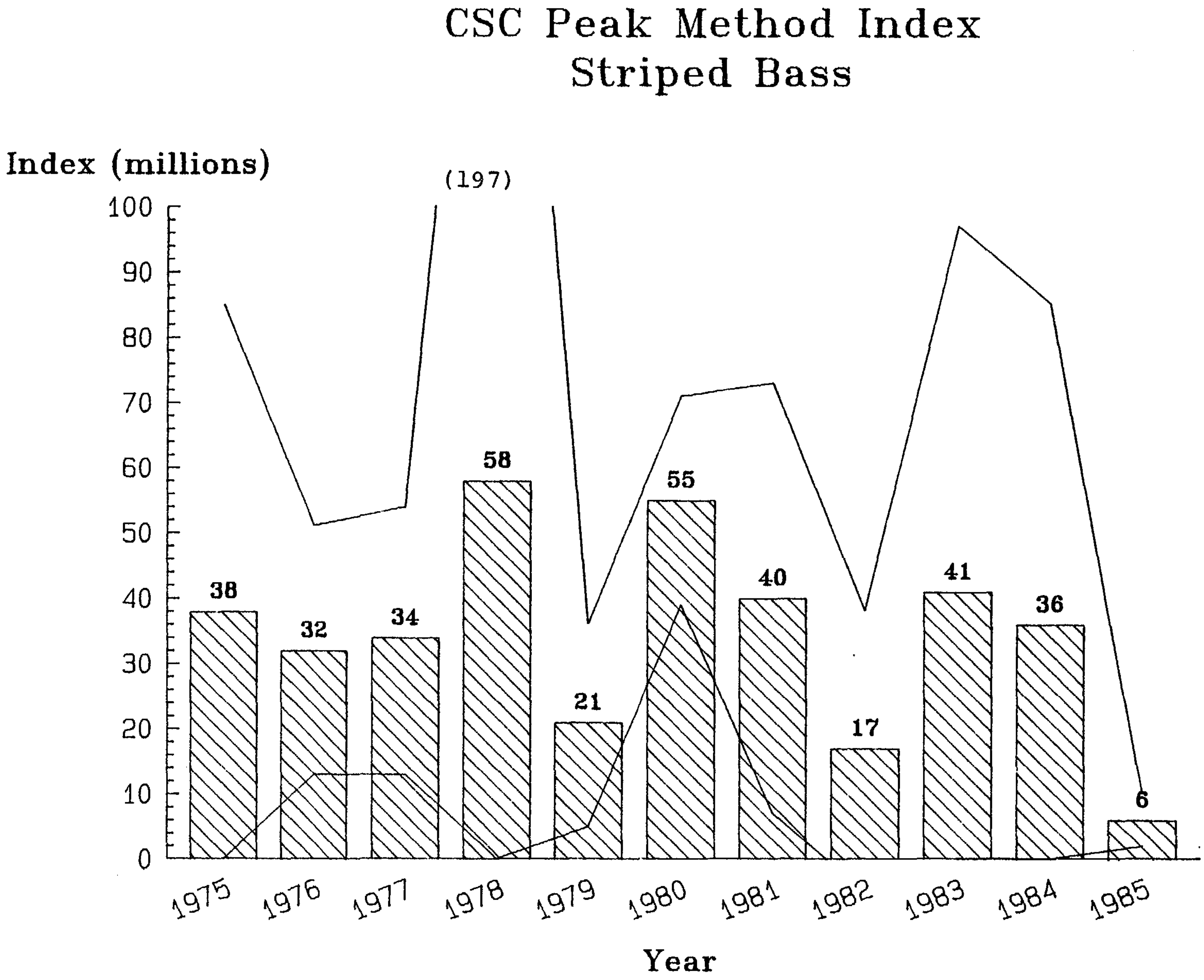


Figure V-9. Peak method combined standing crop index and associated 95% confidence intervals for striped bass collected in the Hudson River since 1975

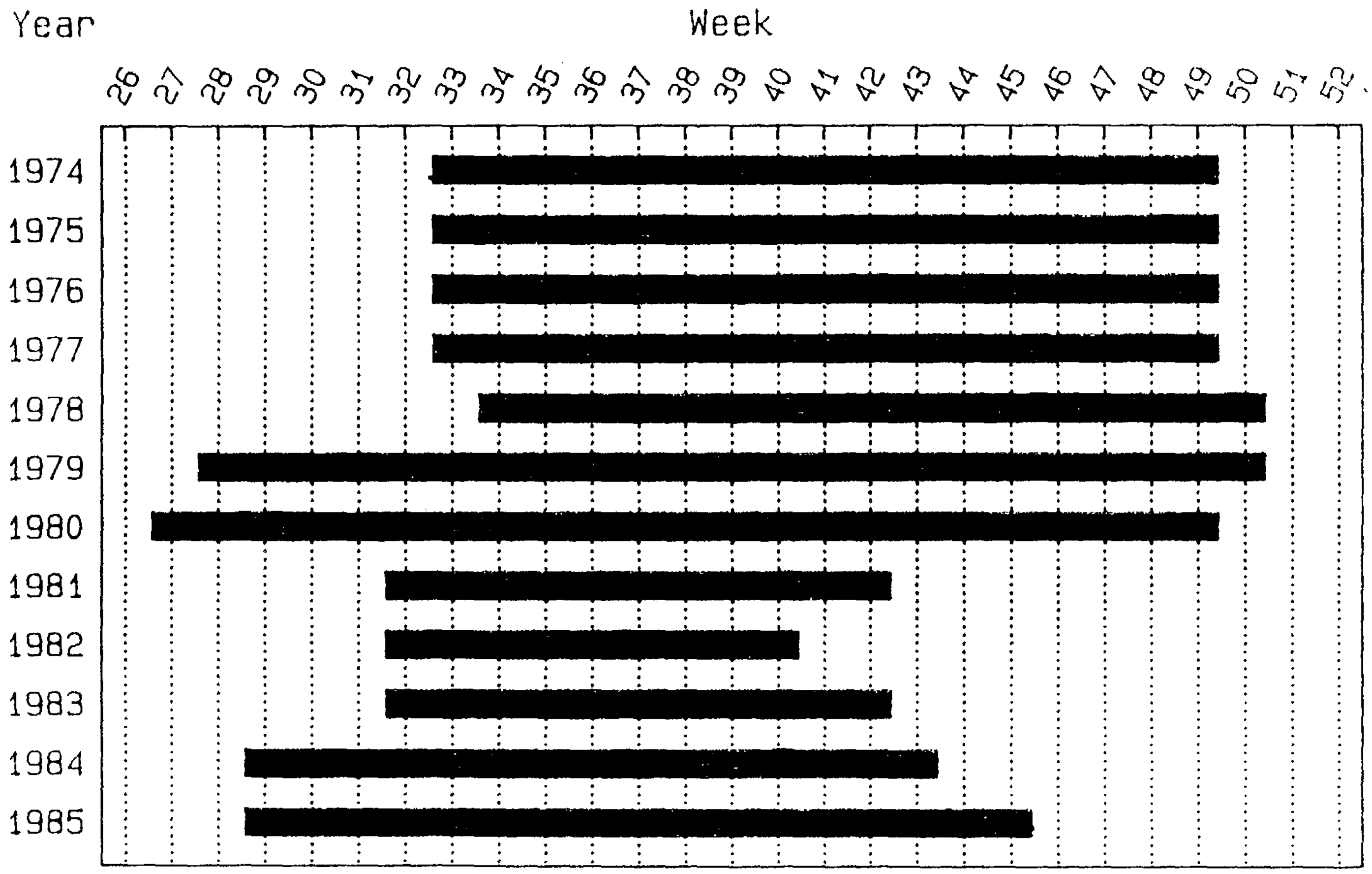


Figure V-10. Range of weeks over which Fall Shoals Survey sampling was conducted on the Hudson River from 1974-1985. Weeks are based on the number of Mondays in the year prior to the date of sampling.

differed among years. Second, because these samples were taken at different times of the year, gear efficiency may have been different in different years. Third, the index is based on the highest value, which also generally is the most variable value. Hence, the variance of the peak method index is generally high and differences in year class strength may be masked.

The peak method also assumes a fixed mortality rate after 1 August that is common to all years. This mortality rate is not estimated from the yearly data, but is taken as a fixed constant for all years of interest. If the true mortality rate fluctuates from year to year, these estimates of relative abundance would not be comparable among years.

In addition, the standard error of this index is a biased estimate because it is assumed to be equal to the product of the standard error of the peak CSC and the extrapolation term. This only includes the variation in the peak week CSC value; it does not include the variation caused by choosing the peak CSC from a group of CSC values. Inclusion of this source of variation in the estimate of the standard error of the peak would necessitate an assumption regarding the distribution of the weekly CSC values, which as stated earlier can not be based on available data.

F. GEOMETRIC MEAN METHOD FOR WHITE PERCH

Method

The geometric mean index is based on the geometric mean of all weekly CSC values for white perch from July to early September. The projected mean value for 1 August is then computed in a manner identical to that used for the peak method index [Eq (35)]:

$$GM = \frac{e^{\overline{\ln(CSC)}}}{e^{-zt}} \qquad (35)$$

where

GM = geometric mean CSC index

$\overline{\ln(CSC)}$ = mean of the natural log of the CSC values from July to early September t = time from the midpoint of sampling period (July to early September) to 1 August

z = instantaneous (daily) mortality rate ($z = 3.79 \times 10^{-3}$).

Confidence intervals for these index values were developed historically and are determined in the following manner:

- A 95% confidence interval is determined for the arithmetic mean of the logarithms of the observations using the student's t-distribution
- An exponent function is used to identify the 95% confidence interval for the geometric mean
- The endpoints of the geometric mean confidence interval are extrapolated to 1 August using the instaneous mortality rate above to obtain a 95% confidence interval for the index value.

Results

Values of the geometric mean CSC index for white perch and associated confidence intervals are given in Fig. V-11. Significantly lower index values were found for 1977, 1984, and 1985 than for all other years except 1978. A downward trend in the index value occurs from 1979 through 1985, though no significant difference in the index value can be distinguished for any pair of years between 1979-1983.

Assumptions and Limitations

Other than limitations associated with the CSC weekly values, the principal concern with the geometric mean index is that the temporal period used in the index varies among years, which, as discussed earlier, may affect relative gear efficiency among years. The index is supposed to be calculated from July (week 27) to early September (week 36). However, the fall sampling programs have not begun until as late as week 33 in some years (Figs. V-3 and V-10).

The development of confidence intervals for this index requires that weekly CSC values be independent and identically distributed. CSC values that are adjacent in time are not independent of each other due to the interpolation scheme that is used to determine weekly Fall Shoals standing crops and weekly Beach Seine standing crops.

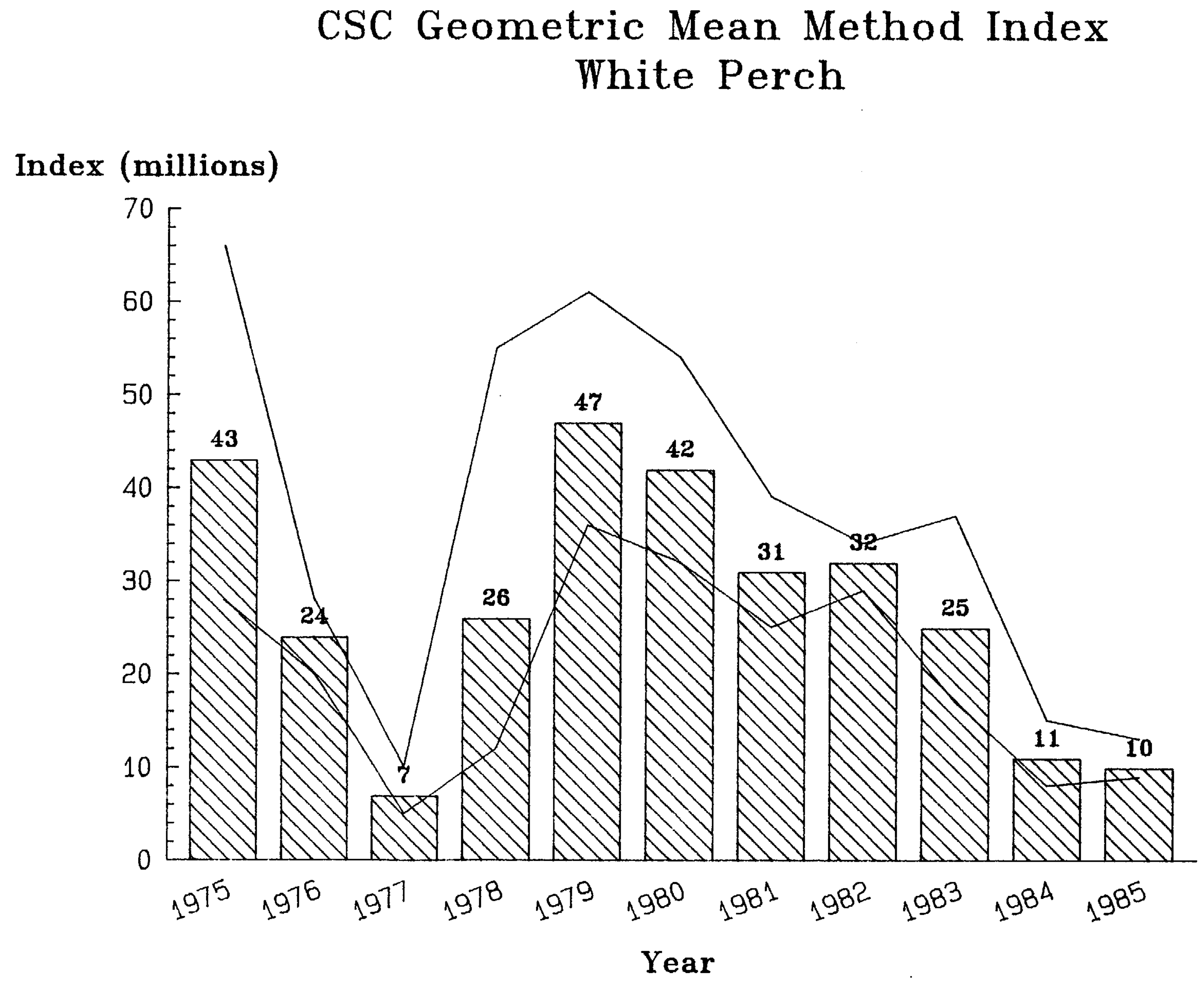


Figure V-11. Geometric mean combined standing crop index and associated 95% confidence intervals for white perch collected in the Hudson River since 1975

G. REGRESSION METHODS (SUMMER AND FALL)

Methods

The two regression methods of calculating a CSC index for striped bass and white perch were developed in the 1982 Year Class Report (NAI 1985a). The first index, referred to as the summer regression index is an estimate of the standing crop on 1 August. It is calculated by regression of the natural logarithms of weekly CSC on date (from the week including 1 August to the week including 10 October):

$$\ln[CSC_t] = \ln[CSC_o] - bt \tag{36}$$

where

CSC_t = combined standing crop at time t

CSC_o = combined standing crop at time 0 (1 August)

b = estimated instantaneous mortality rate

t = time from the midpoint of sampling period to 1 August.

A similar method known as the fall regression method was performed on weekly standing crop data from the first week of September to the first week of October to estimate standing crop on 15 September.

Confidence intervals for the two methods were developed historically and were based on the confidence limits for estimates from the linear regression of the natural logarithms of the CSC values. The confidence limits for the index were computed by exponentiating the confidence limits for the natural logarithms of CSC. For both indices, if the regression was not significant at the 0.05 level of significance, a geometric mean of the weekly CSC values was determined and a confidence interval similar to that for the geometric mean CSC method was calculated.

Results

For striped bass, regression using the summer index method was insignificant in 1975, 1978, 1983, and 1984, while for white perch, it was insignificant in 1975, 1977, 1983, and

1984. The fall regression was only significant for striped bass in 1976, 1981, and 1982. For white perch it was only significant in 1976 and 1982.

The striped bass summer regression index values for the years 1982-1985 were lower than for most other years and significantly lower than in the two previous years (Fig. V-12). In addition, the value for 1985 was significantly lower than for all other years and more than twenty times lower than in 1981. The fall regression index for striped bass was not higher in 1980 and 1981 than in the later years, but the value for 1985 was lower than in any other year and significantly lower than in all years except 1979 (Fig. V-13).

The summer regression index for white perch was significantly lower in 1977, 1984, and 1985 than in any other years (Fig. V-14). In addition there was a downward trend in the index from 1979 to 1985, with the values from 1983-1985 significantly lower than any of the values from 1979-1982. For the white perch fall regression index the downward trend since 1979 was less apparent, though the values for 1977, 1984, and 1985 were still significantly lower than for all other years (Fig. V-15).

Assumptions and Limitations

Both regression methods require the assumption that the logarithms of the weekly CSC values are normally distributed and that the errors are independent. Because sampling effort is staggered among weeks and interpolation is necessary to combine the beach seine and fall shoals data, weekly values of CSC are linear combinations of each other. This implies that the error terms associated with the CSC values are not independent; therefore, the least squares procedure is unreliable in estimation of the parameters of the regression equation (Draper and Smith 1981).

H. SUMMARY OF MAJOR LIMITATIONS OF PREVIOUSLY DEVELOPED INDICES OF YEAR CLASS STRENGTH

The previously developed indices of abundance all have two basic flaws that limit their usefulness as indicators of trends in year class strength:

- They either fail to consider information collected in the offshore survey or they combine data from the offshore sampling and the nearshore beach seine sampling using non-empirical correction factors.

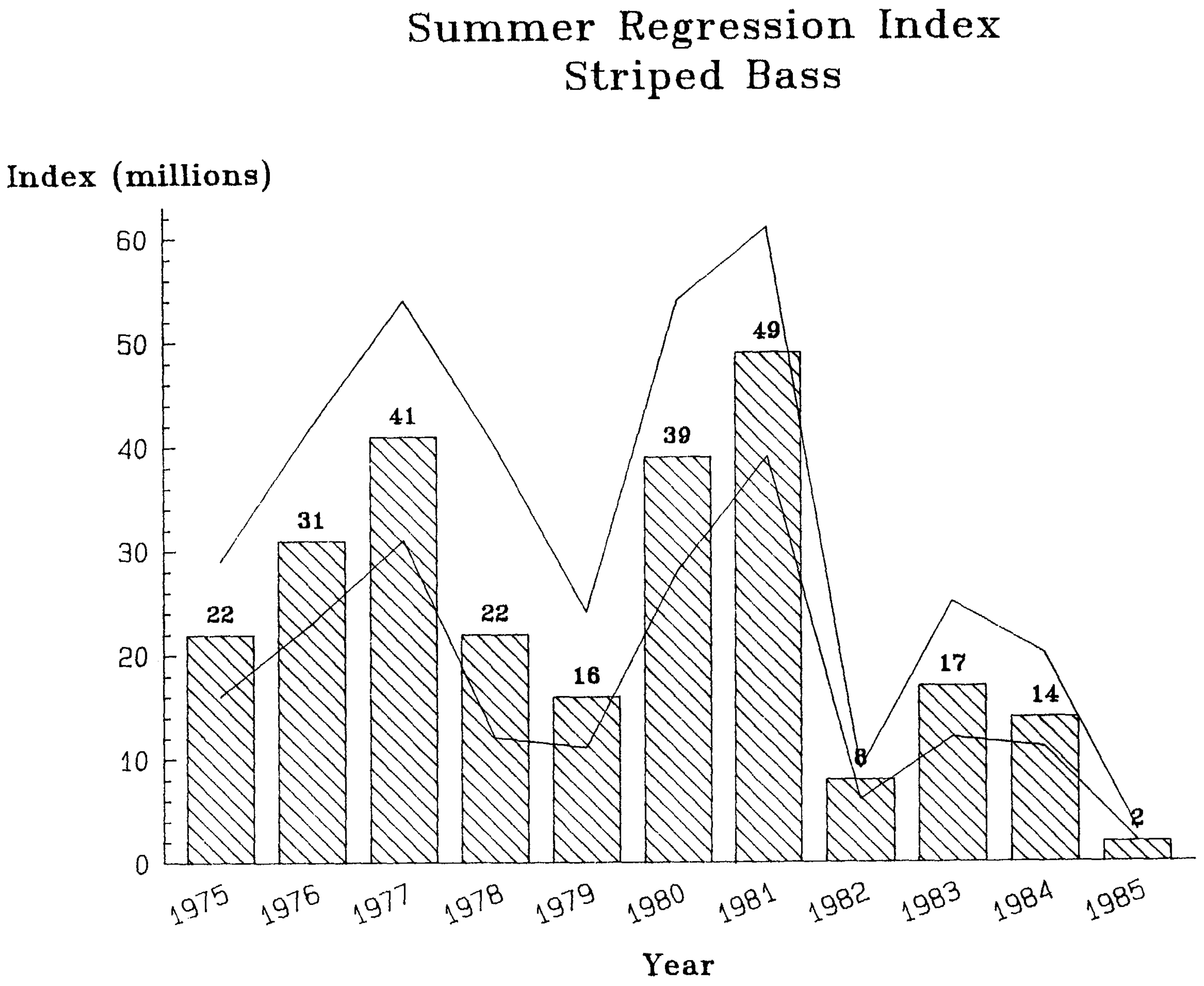
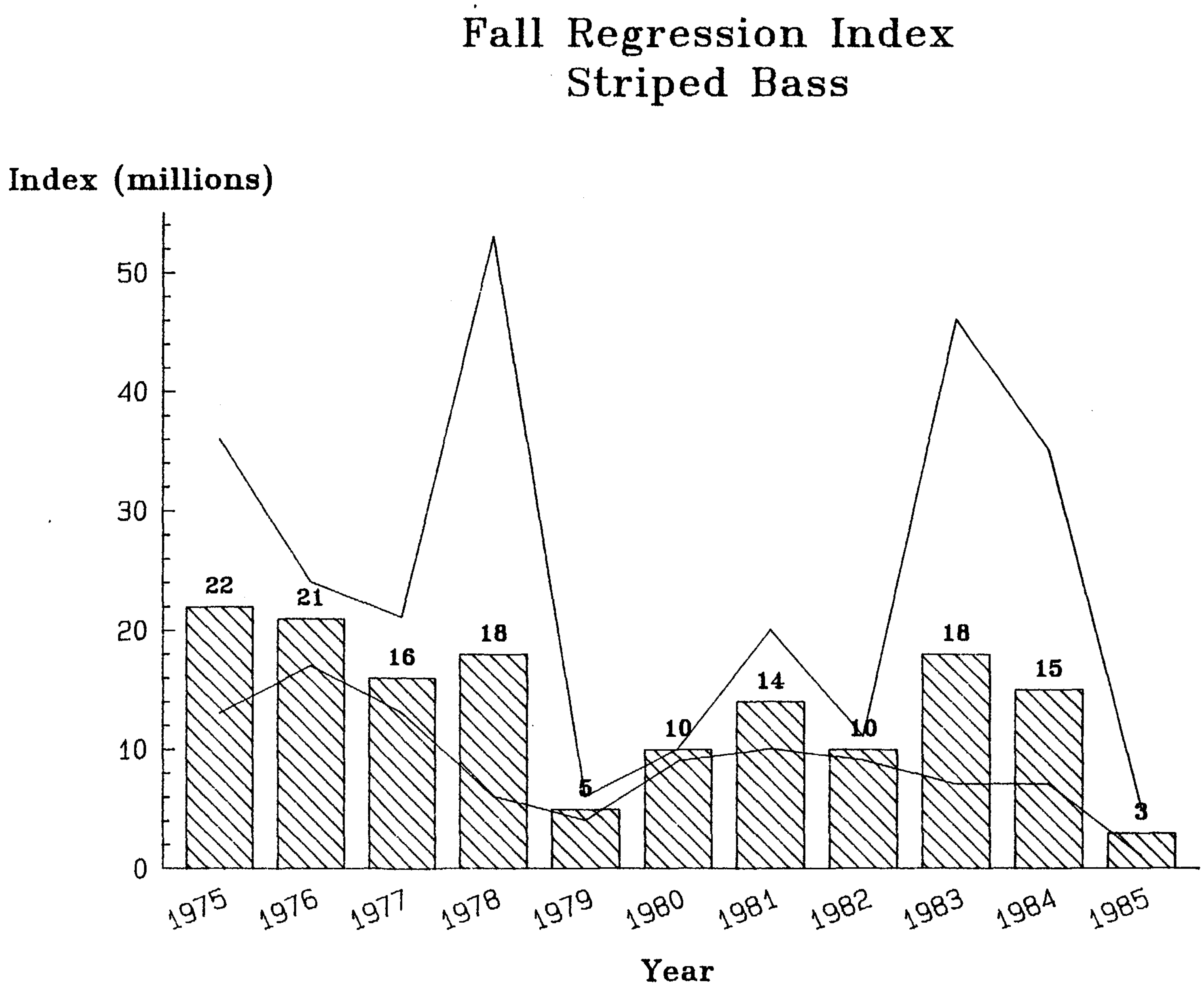


Figure V-12. Summer regression method index and associated 95% confidence intervals for striped bass collected in the Hudson River since 1975



Fall Regression Index
Striped Bass

Figure V-13. Fall regression method index and associated 95% confidence intervals for striped bass collected in the Hudson River since 1975

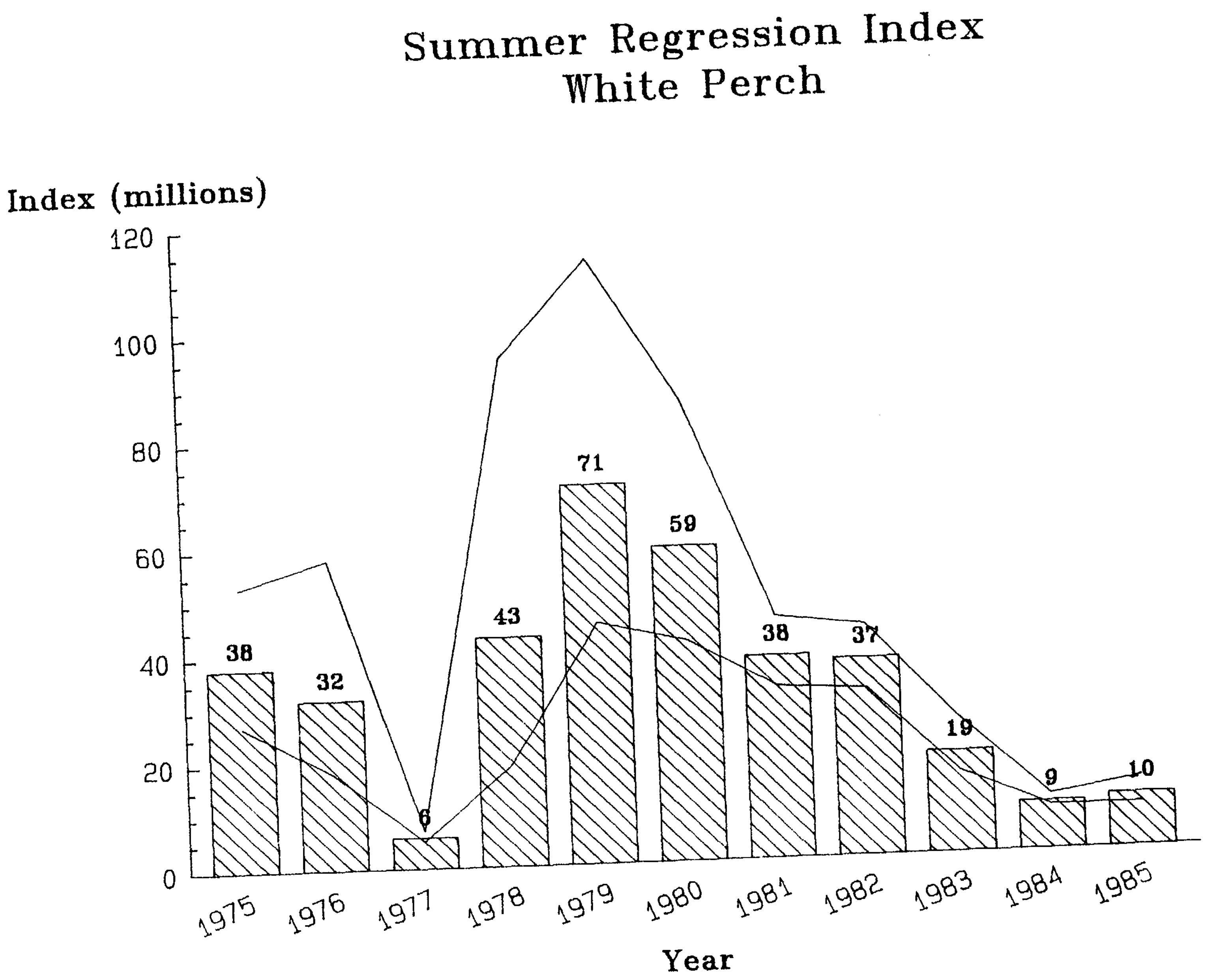


Figure V-14. Summer regression method index and associated 95% confidence intervals for white perch collected in the Hudson River since 1975

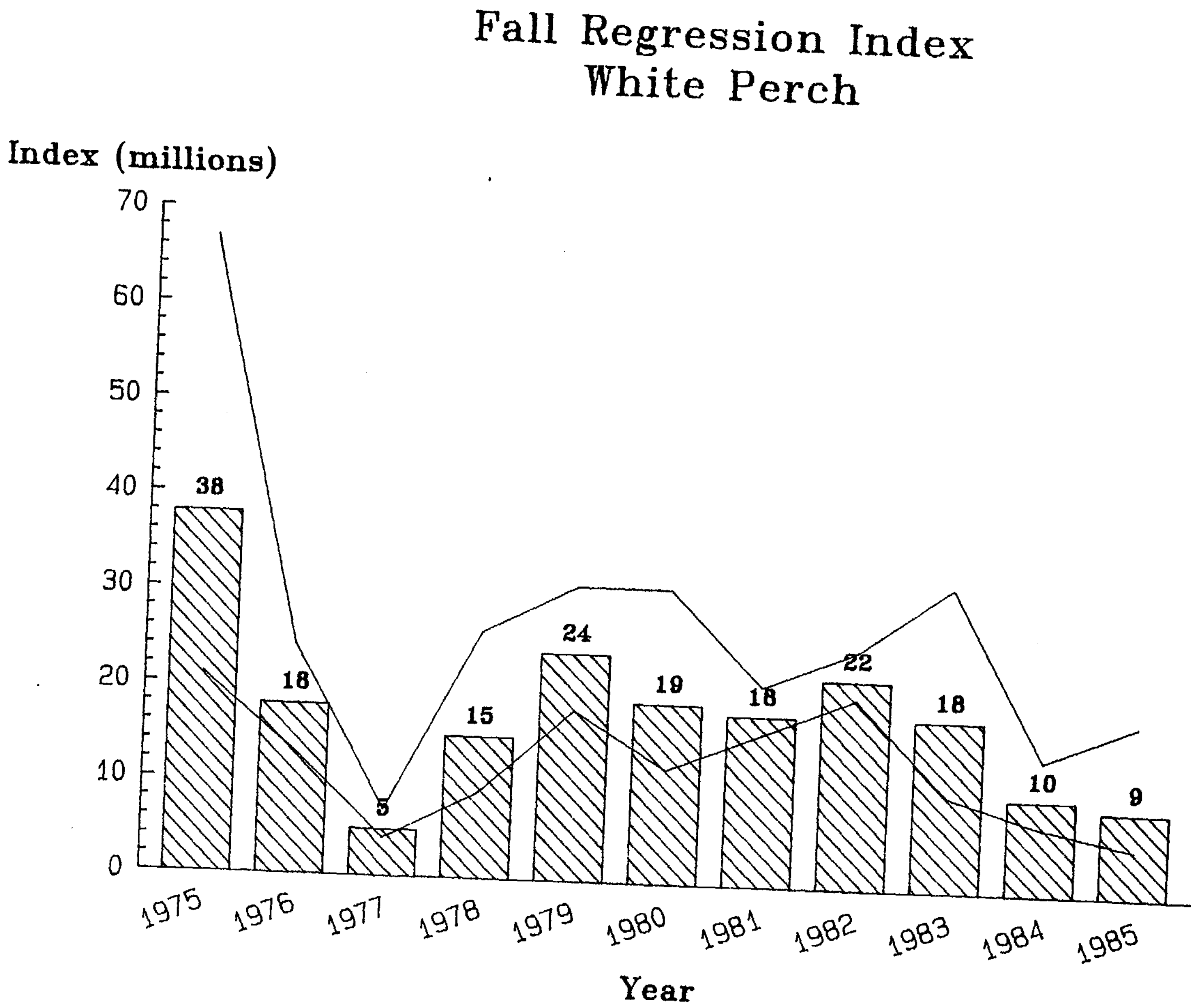


Figure V-15. Fall regression method index and associated 95% confidence intervals for white perch collected in the Hudson River since 1975

- They use data from dissimilar temporal and geographic windows among years, thus comparing populations with different characteristics (other than abundance) in different years.

Indices based on weekly CSC estimates assume a relative weighting of importance for catch per unit effort information from two forms of sampling (beach seine and offshore sampling). The weight given to the offshore CPUE is more than ten fold higher than that given to the beach seine CPUE. Unless these weighting factors reflect true relative probability of capture for the two sampling programs, actual among year differences in abundance will be confounded by among year differences in onshore/offshore distribution patterns. The beach seine index ignores data from offshore and consequently also suffers from confounding of abundance differences among years and differences in distribution patterns.

In addition, the historically developed indices do not use comparable sets of data for among year comparisons. The temporal and spatial windows during which sampling was conducted differ among years. Geographic differences among years may hinder inferences to the larger population because the fraction of the larger population occurring within the sampled area may have varied among years. Temporal differences in sampling among years may have affected relative gear efficiency and may also have affected the proportion of the Hudson River population at risk to the gear because movement patterns into and out of the sampled areas are season specific.

VI. COORDINATE PAIR INDEX OF RELATIVE YEAR CLASS STRENGTH

A. INTRODUCTION

One of the objectives of the 1985 Year Class Report was to examine whether a new, statistically reliable index of year class strength could be developed for striped bass, white perch, American shad, and bay anchovy. This chapter presents an alternative index that overcomes the two major shortcomings of the previously developed indices described in Chapter V (Section H). Section B of this chapter presents an overview of, and rationale for the new index, while the method of calculating the new index is presented in Section C. Results of analysis based on this index for the four key species are presented in Section D. Assumptions and limitations of the new index are presented in Section E.

B. OVERVIEW OF THE COORDINATE PAIR INDEX

The index we propose is one that is based on a coordinate pair, with one axis of the pair corresponding to a weighted average CPUE from the BSS and the other axis corresponding to a weighted average CPUE from the FSS. As opposed to a scalar index, the coordinate pair approach treats the two data sets independently and does not place a relative weighting on the two axes. Conclusions concerning relative year class strength are drawn when one year is superior to another on both the BSS and FSS axes. This approach is conservative in that it identifies a more limited set of among-year differences in year class strength than does a scalar index that allows for a superior value on one axis to mask an inferior value on the other. However, the coordinate pair approach is more useful since it uses information from both sets of available data without basing conclusions on assumed weightings for the two axes.

The coordinate pair approach uses a ranking procedure to assign a value to each axis for each year. A weighted catch per unit effort is first calculated for each week of sampling in each year. Then all weeks in all years are ranked and a mean rank for each year is calculated. The ranking procedure is used in preference to using a mean CPUE among weeks in a year because of the decided non-normality of the data; over 90% of the offshore samples in most years contain no striped bass or white perch. Nevertheless, mean CPUE is also presented to depict the magnitude of difference among years. Statistical inferences, however, are based on nonparametric analyses of the ranks.

The index is based on data collected in a spatial and temporal window held in common among all years. The temporal window used for both axes is weeks 33-40. The geographic extent for the BSS axis includes all 12 regions since these have been sampled in all years (Fig. VI-1). Geographic extent used in the offshore component varied among species. For each species, a sensitivity analysis (Section D) was used to determine whether inclusion of the regions and strata not sampled consistently in all years substantially altered the relative index value. For those species affected by addition of the more recent (post-1979) data, the index was calculated only for 1979-1985 using the larger geographic extent sampled in those years.

C. METHODS

Computation of the coordinate pair index involves a three step process:

- Calculation of weekly average CPUE values for the BSS and FSS programs
- Recalculation of the FSS values using additional strata collected only since 1979, and conducting a sensitivity analysis to determine whether the index should be limited to the data set collected only in the later years
- Rank transformation of the weekly average CPUE values to calculate the index and test for significant differences among years.

Each step in this procedure is detailed below.

Weekly average CPUE for the beach seine component of the index was calculated as the weighted mean of average regional CPUE values [Eq. (37)]. The weighting factor used was the percent of the 284 sampleable beaches occurring in a region (Table VI-1). This differs from the CSC indices discussed in Chapter V, total shore zone surface area in each region was used as the weighting factor.

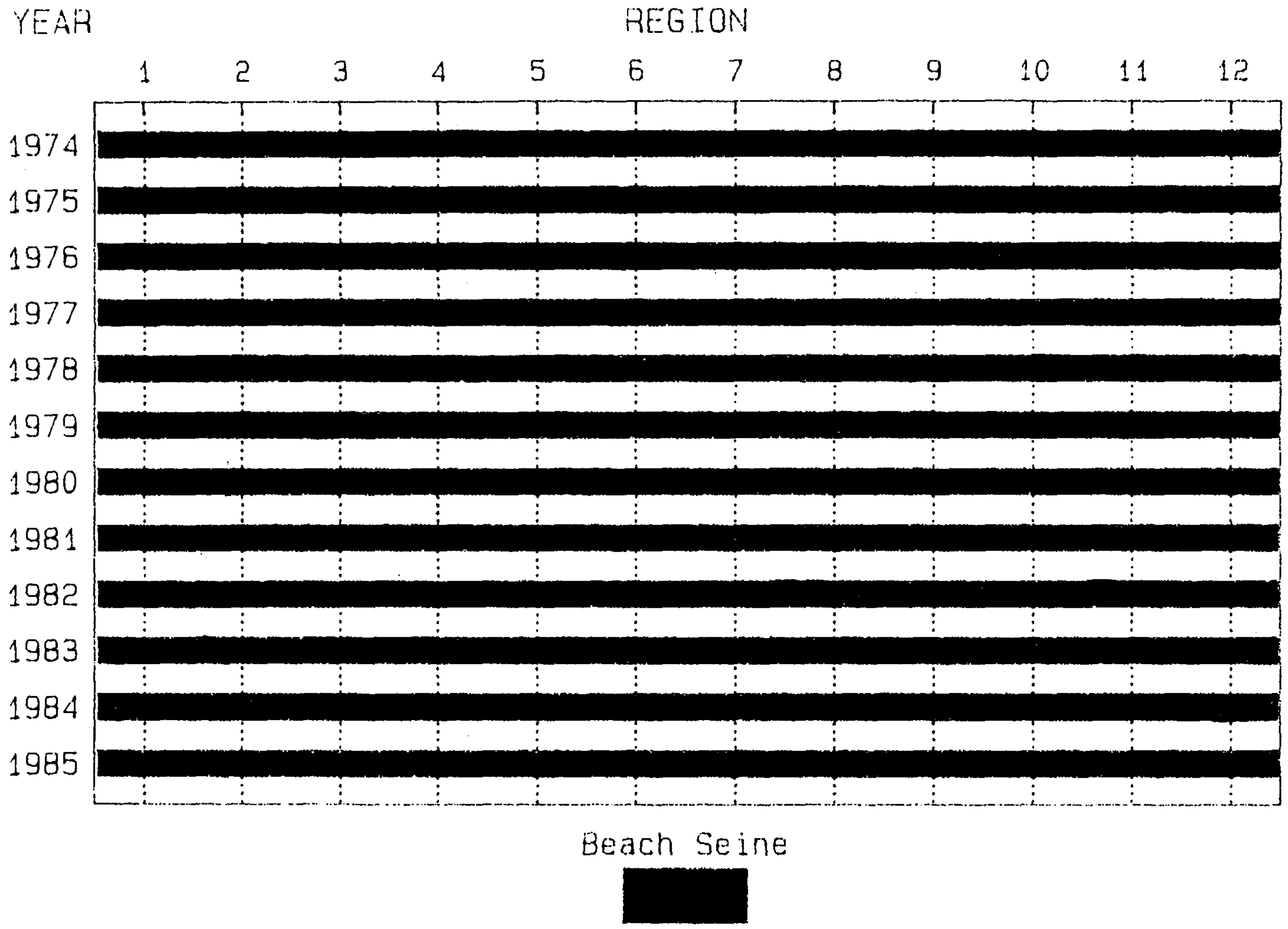


Figure VI-1. Regions of the Hudson River in which beach seine survey sampling was conducted from 1974-1985

Table VI-1. Revised volume estimates used for weighting strata means for bottom and shoal strata, and number of beaches used for weighting regional means in calculation of riverwide relative abundance for the coordinate pair index. Channel volume weightings remain the same as in Table II-12.

Region	Bottom Volume	Shoal Volume	Number of Beaches
1	---	5,784,084	15
2	20,377,231	26,405,643	25
3	10,665,784	11,698,493	25
4	10,961,311	2,744,651	22
5	8,520,739	---	9
6	12,060,110	1,766,407	15
7	20,719,147	---	30
8	10,499,936	---	17
9	11,637,437	---	11
10	14,053,185	---	20
11	13,868,236	---	41
12	4,433,636	---	54

$$BS_w = \frac{\sum_{r=1}^{12} (B_r)(C_{rw})}{\sum_{r=1}^{12} B_r} \qquad (37)$$

where

BS_w = beach seine average CPUE in week w

B_r = number of sampleable beaches in region r

C_{rw} = average regional CPUE (as calculated in Eq. (12), Chapter II).

Weekly CPUE for the offshore component was calculated by first computing weekly strata densities for each stratum of the river using Equation (38):

$$D_{wrk_r} = \frac{\sum_{i=1}^{n_{k_r}} C_{wrk_r i}}{\sum_{i=1}^{n_{k_r}} V_{wrk_r i}} \qquad (38)$$

where

D_{wrk_r} = estimated density in stratum k_r of region r during week w

n_{k_r} = number of samples taken in stratum k_r of region r

$C_{wrk_r i}$ = number of fish caught in sample i in stratum k_r of region r during week w

$V_{wrk_r i}$ = volume of sample i in stratum k_r of region r during week w.

Offshore data from 1985 had to be adjusted for relative gear efficiency since the beam trawl replaced the epibenthic sled for sampling the bottom and shoal habitats in that year. Adjustment factors used to correct 1985 offshore density estimates for comparison with epibenthic sled data collected in previous years were calculated from data presented in NAI (1986), and are given in Table V-1.

These strata density estimates were then combined to form a weekly offshore average density estimate [Eq. (39)]. Percent volumes contained in each stratum were used to weight strata density estimates. These volumes differed from those used in weighting of CSC values in that only the volume from which random samples were collected was used in these computations (Table VI-1). In the CSC calculation, bottom volumes used for calculation of standing crop estimates were defined by the portion of the river that is within 3 m of the bottom. However, since sampling by the epibenthic sled was limited to the volume within one meter of the bottom, bottom volumes were reduced to reflect this more limited area which was actually subject to random sampling. Similarly, assumed shoal volumes used to compute the CSC index (the portion of the region that was between 3 m and 6 m in depth) were larger than the volumes actually subject to sampling. In the FSS, sampling was limited to the shoal bottom using an epibenthic sled and inspection of the data indicated that shoal sampling occurred regularly to depths as shallow as two meters. Therefore, our corrected shoal volumes correspond to the portion of the river between 2 m and 6 m in depth, and within 1 m of the bottom.

$$D_w = \frac{\sum_{r=r_s}^{r_e} \sum_{k_r=k_{rs}}^{k_{re}} (V_{rk_r})(D_{wrk_r})}{\sum_{r=r_s}^{r_e} \sum_{k_r=k_{rs}}^{k_{re}} V_{rk_r}} \qquad (39)$$

where

D_w = average offshore density estimate for week w

D_{wrk_r} = estimated stratum density calculated in Eq. (38)

V_{rk_r} = volume weighting factor for stratum k_r in region r (Table VI-1)

r_s = first region included in the index

r_e = last region included in the index

k_{rs} = first stratum included from region r in the index

k_{re} = last stratum included from region r in the index.

Sensitivity of Index to Data from Areas Not Sampled: 1974-1978

Since the goal was to develop an index for all years between 1974 and 1985, the procedure for computing average CPUE for the offshore axis was initially applied only to those regions and strata which were sampled in all years. This baseline set of data consisted of observations only from the shoal stratum in regions 1-4 (Yonkers to Indian Point) and the bottom stratum from regions 2-7 (Tappan Zee to Poughkeepsie)

Starting in 1979, the channel stratum in regions 1-11 and the upriver bottom stratum in regions 8-12 were added to the sampling regime. The shoal stratum in region 6 was sampled in every year after 1975. These strata are potentially important in determining year class strength, since they constitute a large fraction of total river volume. A sensitivity analysis was conducted to assess their importance. First, the offshore weekly average density estimates were recalculated for years 1979 to 1985 using an extended set of data consisting of observations from the shoal stratum for regions 1-4 and 6, the bottom stratum for regions 2-12, and channel stratum for regions 1-11. However, channel data were excluded from the extended data set if ten fish of the species were never caught in a region-week during the 12 years of sampling (ten fish corresponds to the 95% confidence limit for a catch of zero assuming a Poisson sampling distribution). Then the average annual CPUE for the initial and extended data sets were compared by correlation analysis. If the correlation was significant ($\alpha = 0.05$) then the index was based on only the data common to years 1974 to 1985. However, If the correlation was not significant, indicating that the additional data altered conclusions concerning year class strength, the index was redefined to include only the years 1979 to 1985 using the extended data set.

Rank Transformation

After weekly average CPUE values were computed for an axis, all weeks in all years were ranked, and the mean rank for each year was computed. A Kruskal-Wallis nonparametric analysis of variance was performed on the rank transformed data to test for among year differences (Conover 1971). A nonparametric multiple comparison procedure was then performed on the mean ranks for each year to assess particular differences between years (Daniel 1978). These procedures were conducted independently on each of the two axes of the index.

D. RESULTS

Striped Bass

Based on results of the sensitivity analysis, only strata in which data were collected in all years since 1974 were included in the FSS axis for striped bass. No information was added from the channel sampling since only 21 young-of-year striped bass were collected in the channel during seven years of sampling. Also, a Pearson correlation coefficient of 0.99 was obtained when offshore yearly mean density estimates from the baseline set of data (shoal regions 1-4, bottom regions 2-7) were compared to the yearly mean density estimates for the extended data set.

The Kruskal-Wallis test on weekly ranks of densities showed statistically significant differences among years for both the beach seine and offshore components of the index. Results from multiple comparison procedures, applied to determine specific between year differences (Table VI-2), showed that the only pairwise yearly comparisons that were significant ($\alpha = 0.05$) on both dimensions of the index involved 1985. Many preceeding years (1974, 1975, 1977, 1978, 1981, 1984) had significantly higher values than 1985 on both dimensions of the index. For most of these comparisons the index value in 1985 was more than an order of magnitude smaller on both axes (Fig. VI-2) and corresponded to a similar magnitude of difference in CPUE (Fig. VI-3).

White Perch

Only the data collected in all years since 1974 were included in the index of abundance for white perch. Very few white perch were collected in channel sampling; on only two occasions were an acceptably large number of perch caught to consider use of channel data in the index. However, in each of these instances, the catch was the result of a single haul in which the depth of the sample indicated that the Tucker trawl had been inadvertently deployed in the bottom stratum. The upstream bottom and shoal areas sampled since 1979 were not included in the index, because the Pearson correlation coefficient between the yearly mean density estimates from the baseline and extended data sets was 0.93.

Results from the Kruskal-Wallis test indicated there were significant differences in mean rank among years on both the BSS and FSS axes. The index indicates that 1974, 1984 and 1985 were relatively poor years (Fig. VI-4). The index for

Table VI-2. Probability levels for significant differences in striped bass relative abundances between two years. The upper triangle (above Xs) refers to the beach seine density estimates. The lower triangle (below Xs) refers to the offshore density estimates.

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1974	X	0.60	0.14	0.43	0.16	0.27	0.80	0.43	0.26	0.67	0.69	<0.01
1975	0.13	X	0.38	0.21	0.07	0.58	0.46	0.22	0.54	0.38	0.93	0.03
1976	0.01	0.40	X	0.03	<0.01	0.77	0.10	0.04	0.85	0.08	0.36	0.16
1977	0.01	0.39	0.98	X	0.57	0.07	0.61	0.96	0.07	0.75	0.27	<0.01
1978	0.77	0.29	0.06	0.06	X	0.02	0.28	0.62	0.02	0.39	0.10	<0.01
1979	0.75	0.11	0.02	0.01	0.59	X	0.20	0.08	0.93	0.16	0.54	0.11
1980	0.37	0.04	<0.01	<0.01	0.30	0.62	X	0.60	0.19	0.86	0.54	<0.01
1981	0.91	0.16	0.03	0.02	0.73	0.85	0.50	X	0.08	0.73	0.28	<0.01
1982	0.48	0.06	<0.01	<0.01	0.39	0.74	0.87	0.61	X	0.16	0.51	0.15
1983	0.55	0.07	<0.01	<0.01	0.44	0.82	0.80	0.67	0.93	X	0.46	<0.01
1984	0.52	0.46	0.11	0.11	0.76	0.40	0.18	0.51	0.24	0.28	X	0.03
1985	0.02	<0.01	<0.01	<0.01	0.02	0.08	0.20	0.05	0.15	0.12	<0.01	X

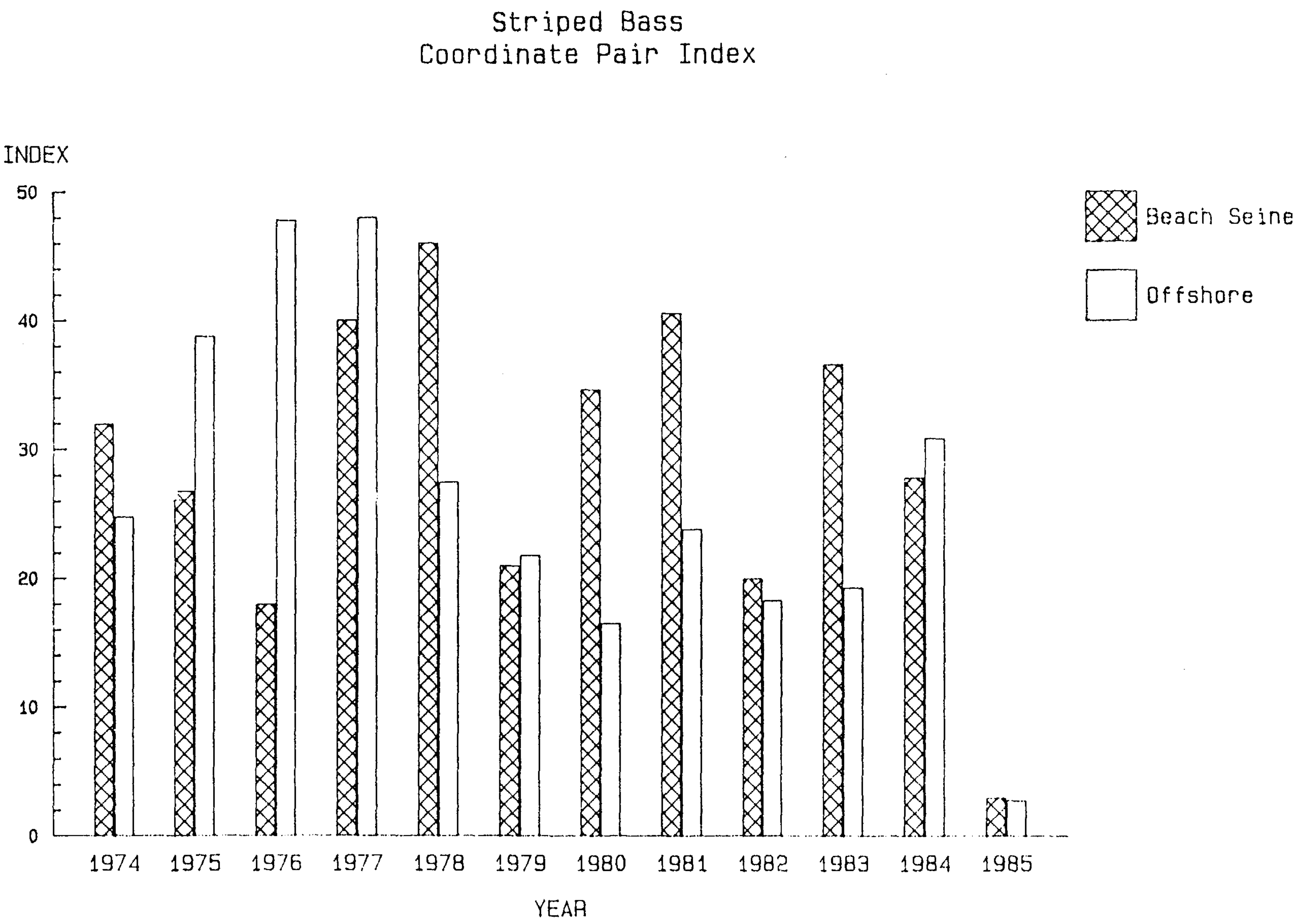


Figure VI-2. Coordinate pair index for striped bass collected in the Hudson River since 1974

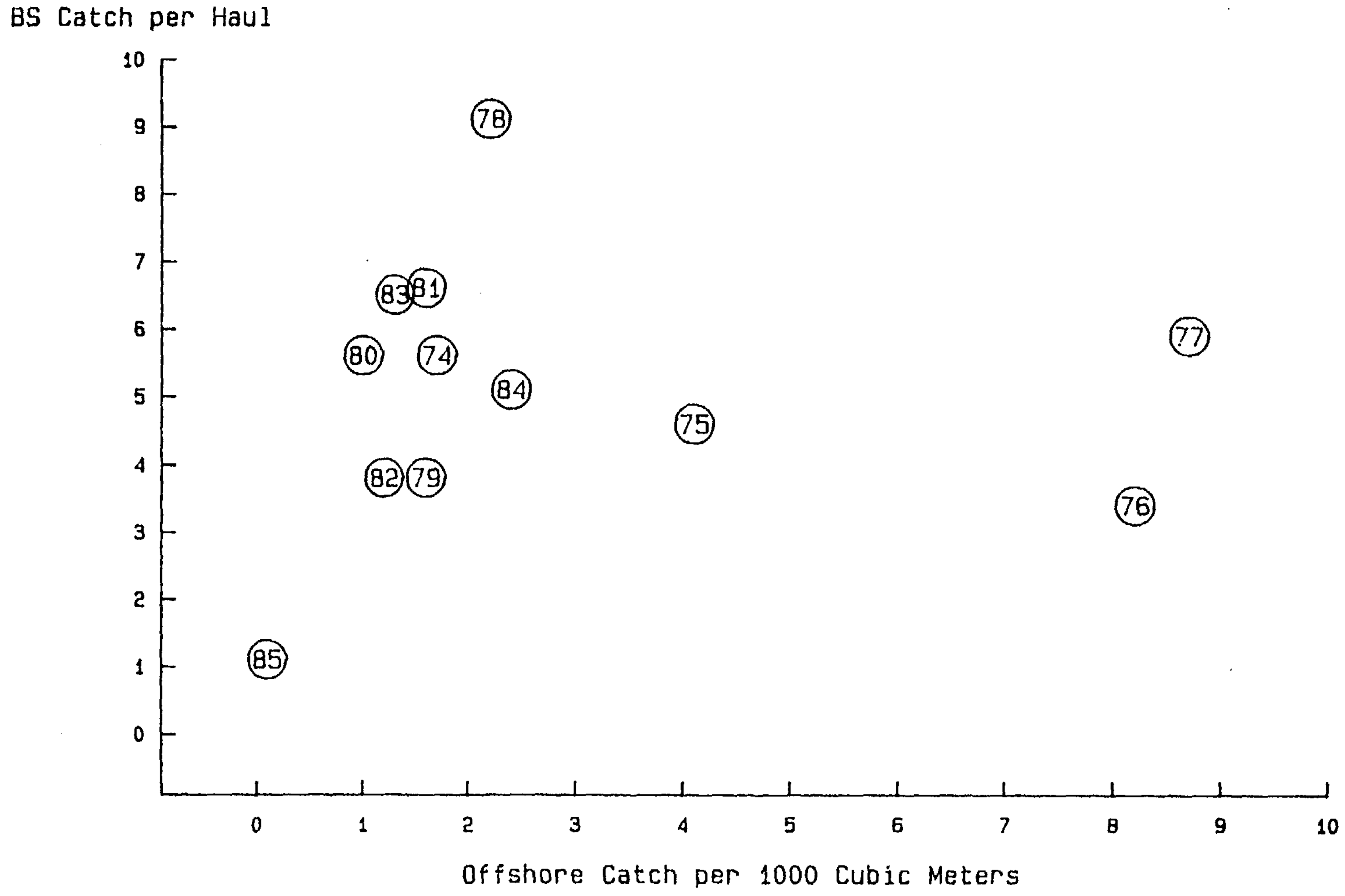


Figure VI-3. Average weekly offshore density estimate and beach seine catch per unit effort for striped bass collected in the Hudson River, 1974-1985

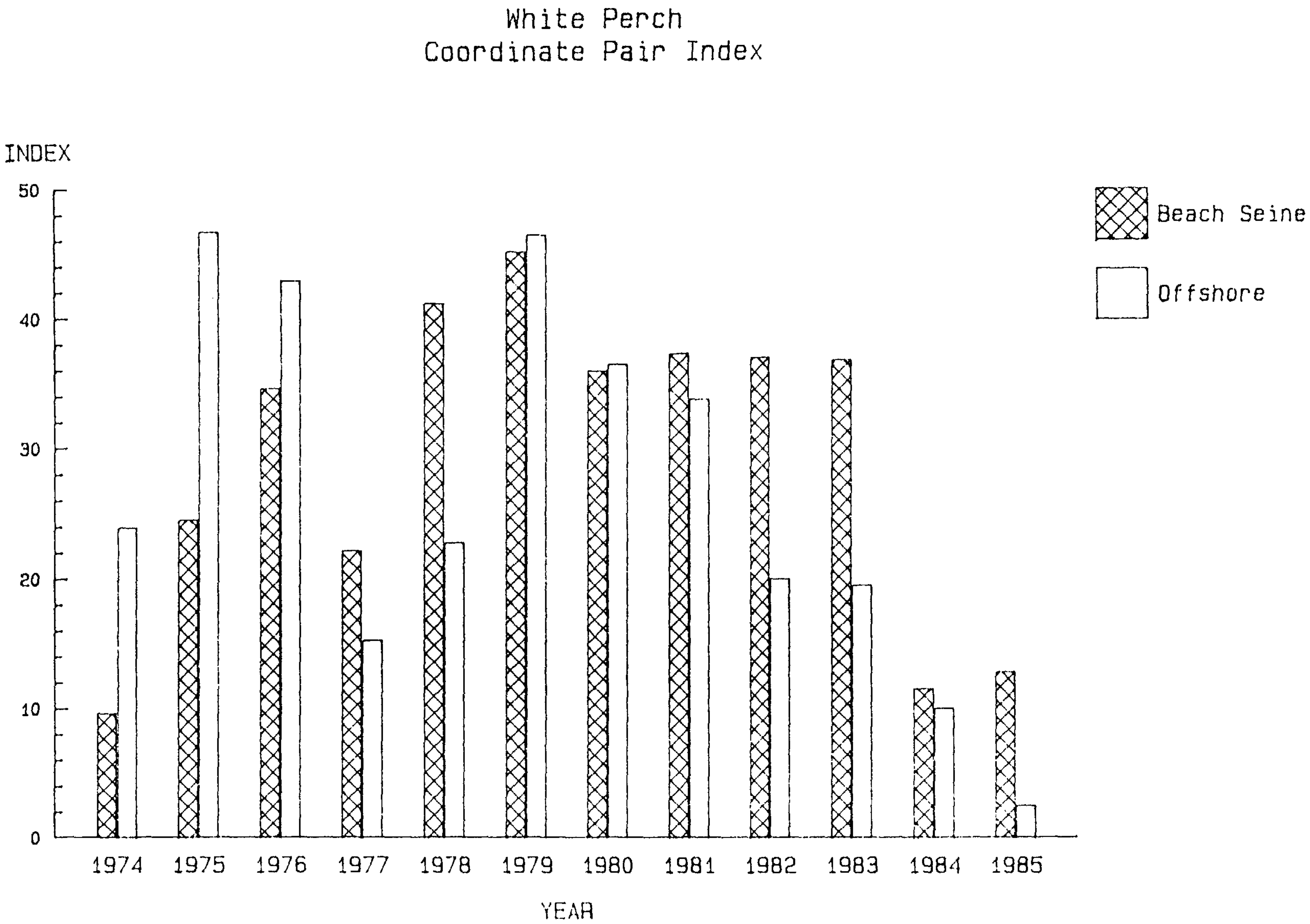


Figure VI-4. Coordinate pair index for white perch collected in the Hudson River since 1974

1974 was significantly less than that for 1976 and 1979, and the indices for 1984 and 1985 were significantly less than those for 1976, 1979, 1980, and 1981 in both dimensions at the α =0.05 level of significance (Table VI-3).

The data also suggest that year class strength of white perch has declined since 1979. Mean rank for the offshore axis falls monotonically from 1979 to 1985 (Fig. VI-4) with mean CPUE differences exceeding an order of magnitude over this period (Fig. VI-5). Mean ranks on the BSS axis also declined from 1979 to 1985, but the decline occurred as a step function, with all years between 1979-1983 statistically distinguishable from 1984 and 1985, but not from each other. Although a decline since 1979 is apparent, such a decline may only be part of a cyclical pattern; the low years in that decline, 1984 and 1985, could not be statistically distinguished from 1974 or 1977 on either axis.

American Shad

Unlike striped bass and white perch, the index for American shad was calculated only for 1979-1985 using data from the greater geographical extent sampled in those years. The Pearson correlation coefficient between the yearly mean density estimates from the baseline and the extended data sets was 0.28 and not significant, indicating that the channel and upriver data sampled only since 1979 are important to the determination of an index for American shad (Fig. VI-6). The importance of the upriver data is attested to by the geographic index for American shad (Fig. IV-38) which shows that a large segment of the population is found in the upriver regions.

No significant differences in year class strength among years were detected for American shad (Fig. VI-7). For the offshore axis the Kruskal-Wallis test indicated no significant differences in mean ranks among years. This is supported by the fact that the range in mean CPUE between 1979-1985 was less than four-fold (Fig. VI-8). Significant differences were detected on the BSS axis of the index (Table VI-4), but these differences were small in magnitude (corresponding to only about two-fold differences in CPUE).

Bay Anchovy

The Pearson correlation between yearly average offshore density estimates of young-of-year bay anchovies from the baseline and extended sets of data for years 1979 to 1985 was not significant ($r = 0.8$) (Fig. VI-9). This low correlation

Table VI-3. Probability levels for significant differences in white perch relative abundances between two years. The upper triangle (above Xs) refers to the beach seine density estimates. The lower triangle (below Xs) refers to the offshore density estimates.

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1974	X	0.14	<0.01	0.21	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.86	0.77
1975	0.01	X	0.32	0.82	0.11	0.05	0.28	0.26	0.27	0.28	0.24	0.29
1976	0.04	0.73	X	0.21	0.52	0.29	0.89	0.81	0.83	0.85	0.03	0.04
1977	0.35	<0.01	<0.01	X	0.07	0.03	0.19	0.18	0.18	0.19	0.34	0.40
1978	0.89	0.03	<0.06	0.48	X	0.70	0.62	0.72	0.71	0.69	<0.01	0.01
1979	0.02	0.98	0.74	<0.01	0.03	X	0.38	0.48	0.46	0.45	<0.01	<0.01
1980	0.18	0.34	0.54	0.05	0.20	0.35	X	0.91	0.93	0.95	0.03	0.04
1981	0.29	0.23	0.39	0.08	0.30	0.23	0.80	X	0.98	0.97	0.03	0.04
1982	0.67	0.01	0.03	0.66	0.80	0.01	0.12	0.20	X	0.98	0.03	0.04
1983	0.63	0.01	0.03	0.69	0.76	0.01	0.11	0.18	0.96	X	0.03	0.04
1984	0.13	<0.01	<0.01	0.62	0.23	<0.01	0.01	0.03	0.35	0.38	X	0.92
1985	0.02	<0.01	<0.01	0.23	0.06	<0.01	<0.01	<0.01	0.10	0.11	0.48	X

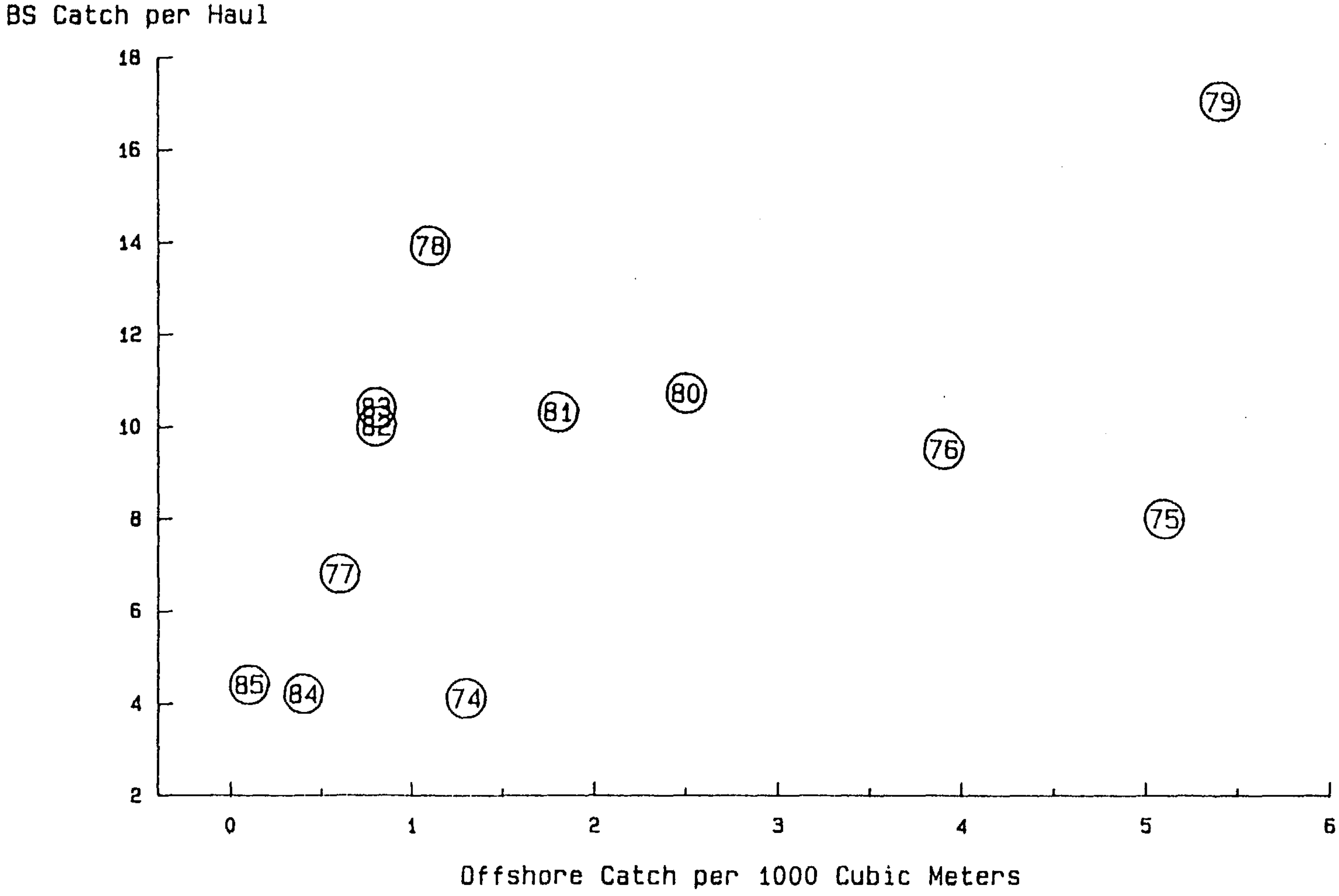


Figure VI-5. Average weekly offshore density estimate and beach seine catch per unit effort for white perch collected in the Hudson River, 1974-1985

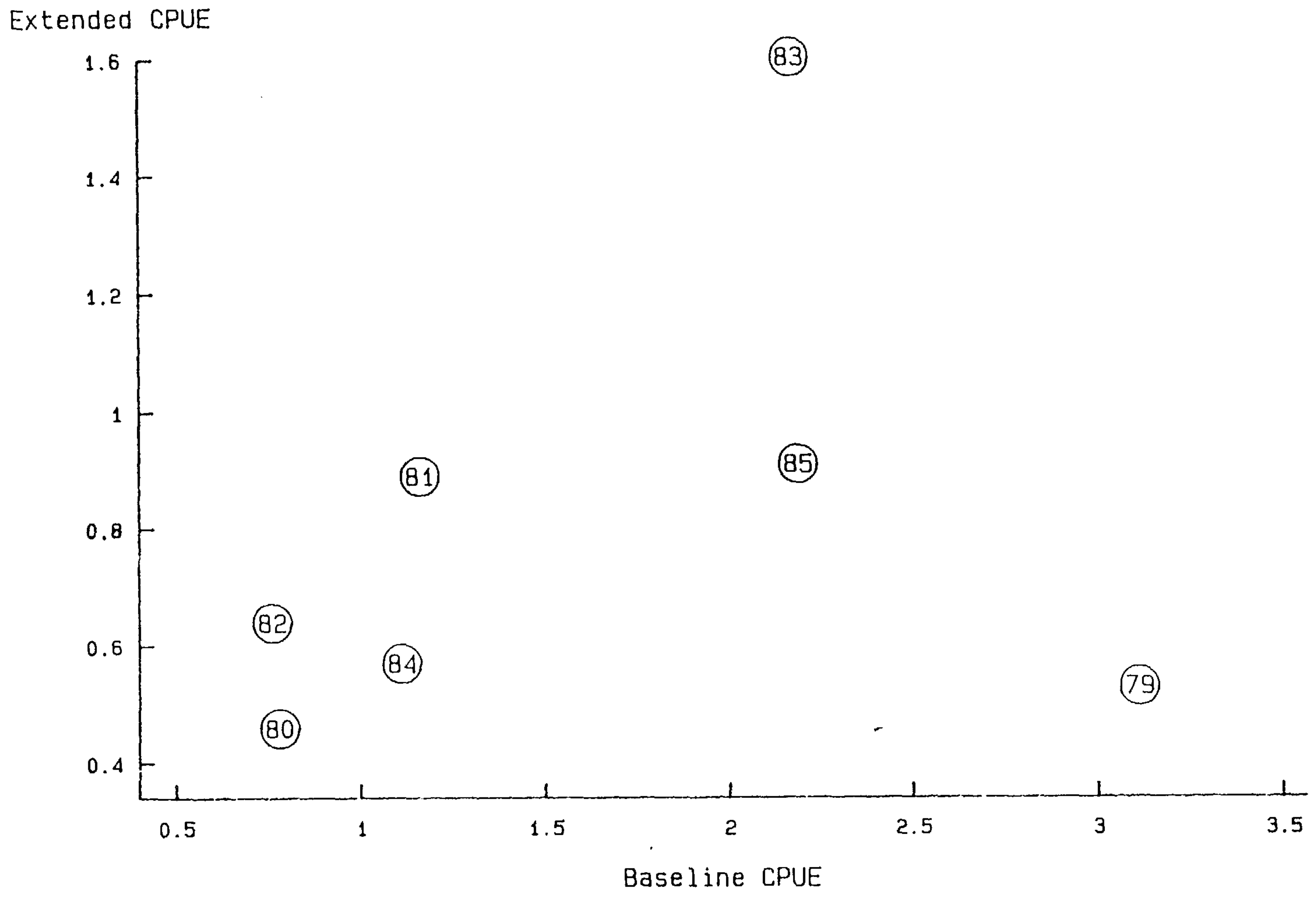


Figure VI-6. Comparison of baseline to extended average catch per unit effort (CPUE) for American shad in the Fall Shoals Survey, 1979 to 1985

- Baseline CPUE:

  Includes data from the common set of strata sampled in all years 1974-1985

- Extended CPUE:

  Includes data from the common set of regions and strata sampled in the later years 1979-1985

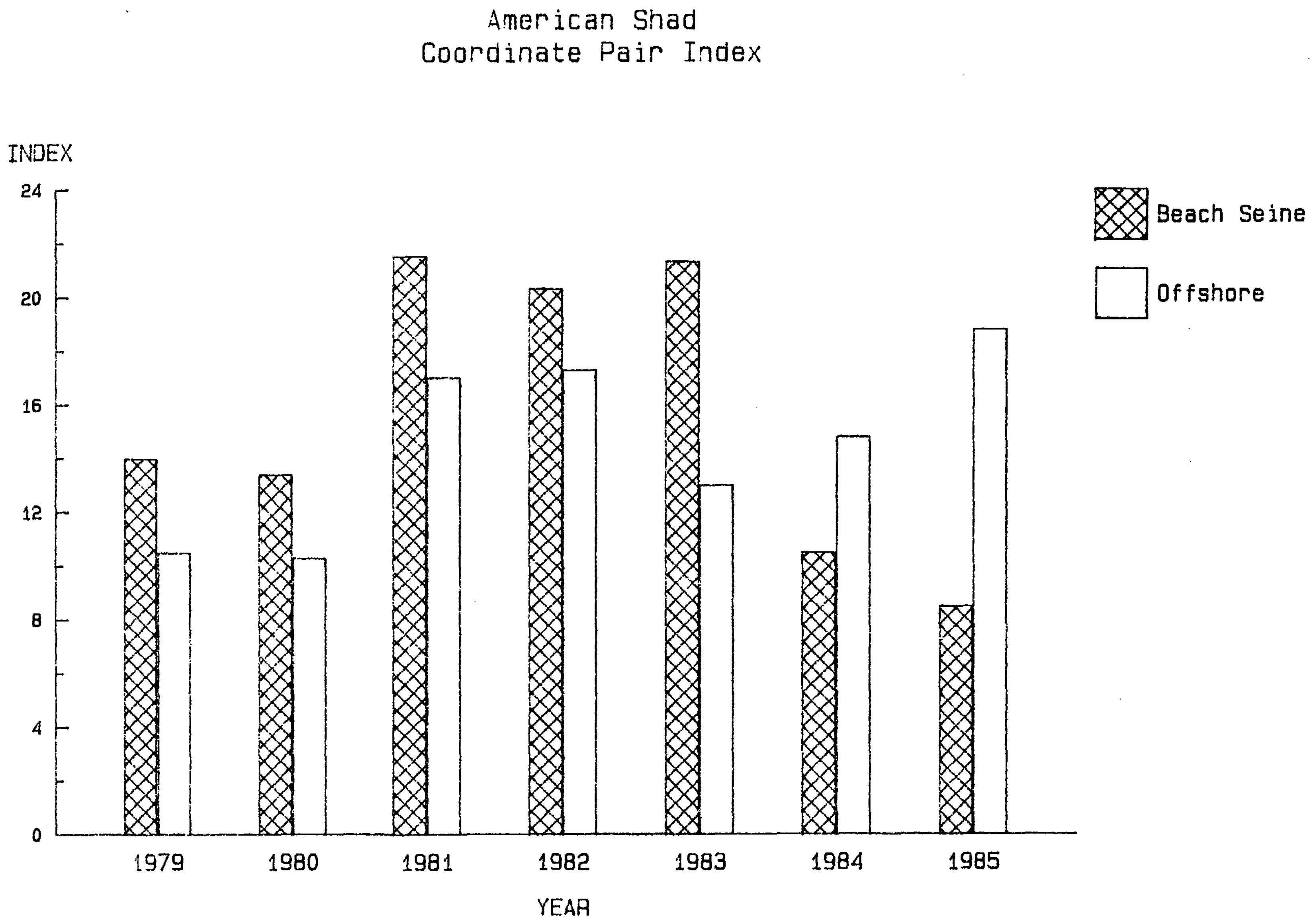


Figure VI-7. Coordinate pair index for American shad collected in the Hudson River, 1979 to 1985

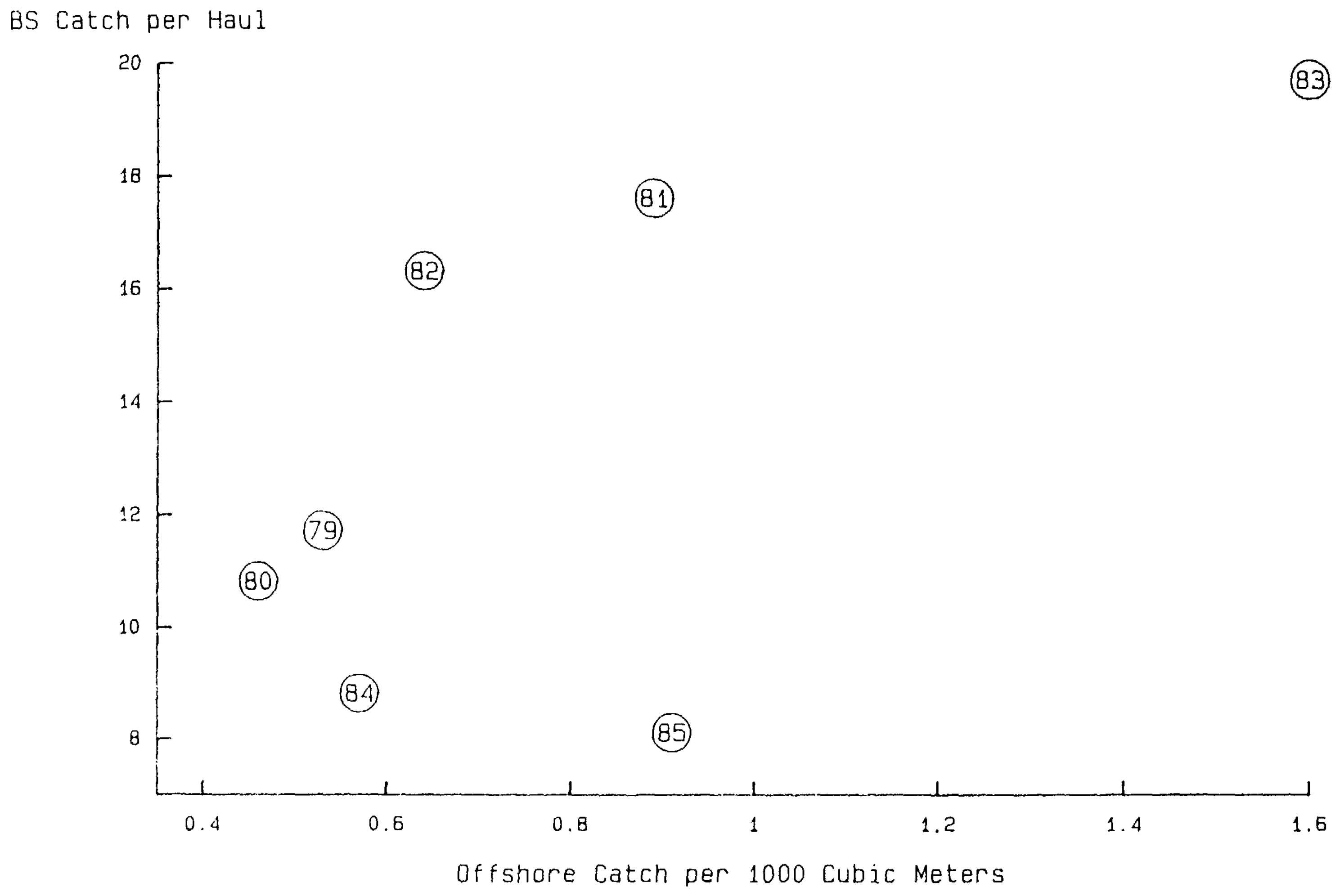


Figure VI-8. Average weekly offshore density estimates and beach seine catch per unit effort for American shad collected in the Hudson River, 1979-1985

Table VI-4. Probability levels for significant differences in American shad relative abundances between two years. The upper triangle (above Xs) refers to the beach seine density estimates. The lower triangle (below Xs) refers to the offshore density estimates.

	1979	1980	1981	1982	1983	1984	1985
1979	X	0.91	0.20	0.29	0.22	0.55	0.35
1980	0.97	X	0.17	0.24	0.18	0.62	0.41
1981	0.26	0.25	X	0.84	0.97	0.08	0.04
1982	0.25	0.23	0.97	X	0.87	0.12	0.06
1983	0.67	0.64	0.49	0.46	X	0.08	0.04
1984	0.46	0.44	0.70	0.67	0.76	X	0.75
1985	0.16	0.14	0.76	0.80	0.32	0.49	X

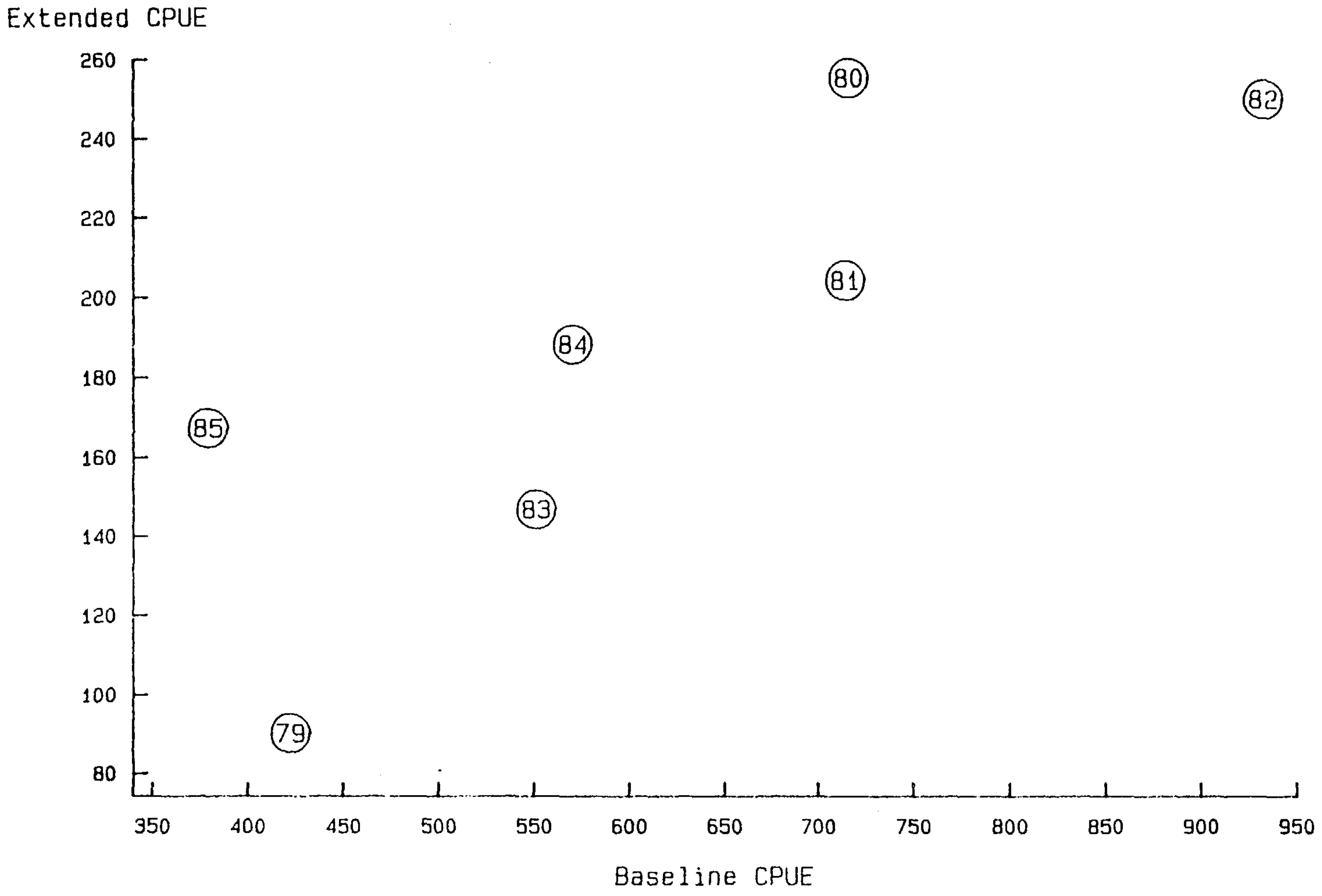


Figure VI-9. Comparison of baseline to extended catch per unit effort (CPUE) for bay anchovy in the Fall Shoals Survey, 1979 to 1985.

- Baseline CPUE:

  Includes data from the common set of strata sampled in all years 1974-1985

- Extended CPUE:

  Includes data from the common set of regions and strata sampled in the later years 1979-1985 indicated that an index based only on offshore data common to all years (1974 to 1985) could be unreliable. Thus, an index for young-of-year bay anchovy was developed only for the years 1979 to 1985 using the extended data set.

The Kruskal-Wallis test indicates significant differences among years in both the beach seine and offshore components of the index. However, no year had a significantly higher value than any other year on both axes (Table VI-5). On the offshore axis, 1985 was significantly higher than all preceeding years except 1982, at the 0.08 level of significance. However, 1985 was only an average year on the beach seine axis (Fig. VI-10) and could not be distinguished statistically from any other year. Mean beach seine CPUE ranged from 0.9 CPUE in 1983 to 12.2 CPUE in 1984 (Fig. VI-11). Offshore density estimates ranged from 90 fish/1000 m^3 in 1979 to 254 fish/1000 m^3 in 1980.

E. ASSUMPTIONS AND LIMITATIONS

Limitations on the usefulness of the coordinate pair index can be grouped into two categories: those dealing with gear efficiency and those dealing with unsampled areas. These same limitations were also found for the historically developed indices of abundance, but for the coordinate pair index these limitations have been minimized. They cannot be eliminated entirely because in part they represent limitations imposed by the historic sampling protocol. For some species or in some years, these limitations may hinder inferences about year class strength. This section examines these limitations to determine the degree to which they reduce reliability of conclusions based on the coordinate pair index.

Gear Efficiency

The coordinate pair index uses species-specific adjustment factors to correct for differences in relative gear efficiency between the beam trawl (used in 1985) and the epibenthic sled (used in all other years). For striped bass, the adjustment factor is based on a reasonably large sample size (NAI 1986), but was limited to studies conducted only in the shoal stratum and conducted primarily in a single region. For white perch and American shad, the same limitation holds true but is compounded by small sample sizes (an average of less than 0.5 fish per haul and less than 50 fish total) for at least one of the gears. Because CPUE values are multiplied directly by the adjustment factor, an error in the adjustment factor could substantially bias the comparison of 1985 with all other years.

Table VI-5. Probability levels for significant differences in bay anchovy relative abundances between two years. The upper triangle (above Xs) refers to the beach seine density estimates. The lower triangle (below Xs) refers to the offshore density estimates.

	1979	1980	1981	1982	1983	1984	1985
1979	X	0.24	0.36	0.36	0.07	0.85	0.63
1980	0.01	X	0.84	0.84	<0.01	0.36	0.11
1981	0.04	0.67	X	>0.99	0.01	0.49	0.19
1982	<0.01	0.76	0.46	X	0.01	0.49	0.19
1983	0.25	0.18	0.37	0.10	X	0.06	0.21
1984	0.04	0.67	>0.99	0.46	0.37	X	0.52
1985	0.08	0.46	0.76	0.30	0.55	0.76	X

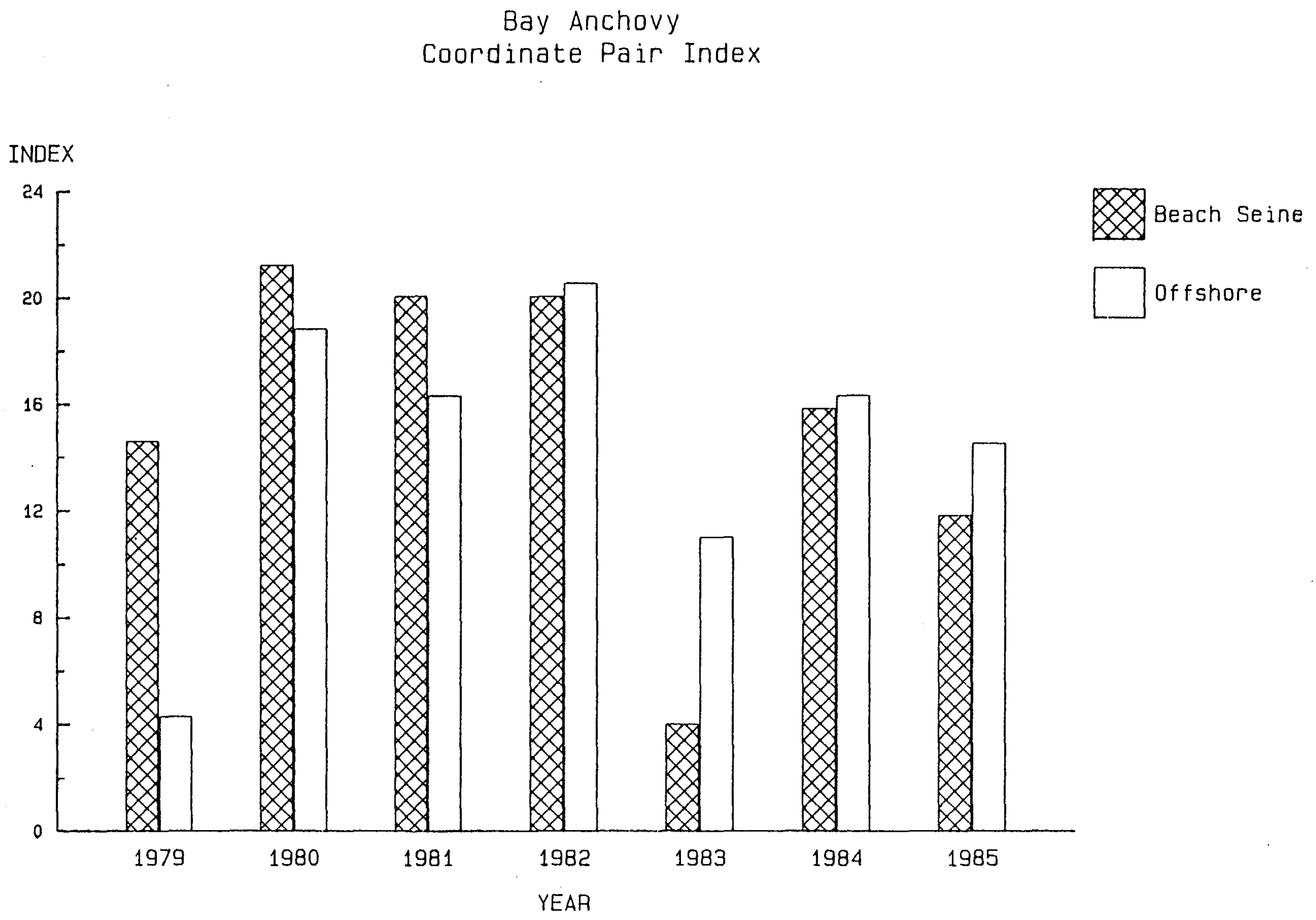


Figure VI-10. Coordinate pair index for bay anchovy collected in the Hudson River, 1979 to 1985

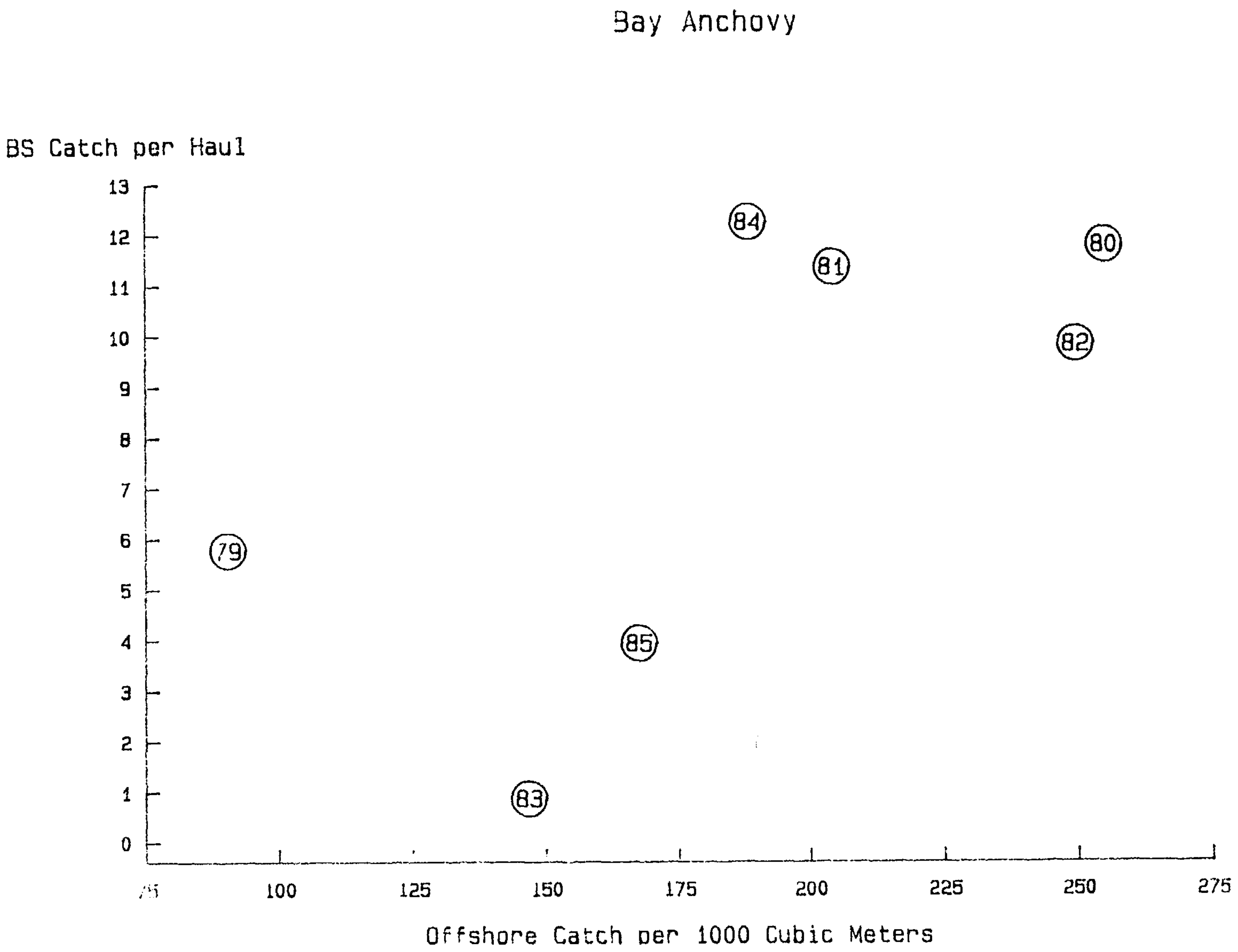


Figure VI-11. Average weekly offshore density estimates and beach seine catch per unit effort for bay anchovy collected in the Hudson River, 1979-1985

In addition, the coordiante pair index assumes an equal gear efficiency for the epibenthic sled and the Tucker trawl so that channel data can be included in the offshore axis of the index for American shad and bay anchovy. This assumption could be eliminated by treating the channel data as a third axis, but doing so would further reduce ability to detect differences among years. While there are no data to support the assumed equality in gear efficiency between the Tucker trawl and epibenthic sled, the two gears have equal mesh size, equally sized net openings and are towed at the same speed during collections.

Unsampled Areas

Inferences from the coordinate pair index to the Hudson River populations are still limited by the assumption that the fraction of the larger population that occurs within the areas subject to sampling remains the same from year to year. The index is sensitive to this because a sizable area of the Hudson River system remains unsampled and includes:

- The Hudson River downstream of river mile 12. (No similar concern exists for the upstream area because the Troy Dam provides an upstream limit to young-of-year fish movement)
- Unsampled strata within the sampled regions (primarily the shoal in regions 5 and 7-12, but also including the bottom in region 1 and the channel in region 12)
- Shore zone area not included in the 284 sampled beaches.

Index values for all four species are sensitive to the possibility of a large fraction of the riverwide population inhabiting the unsampled shore zone areas. As discussed earlier, the beaches subject to sampling constitute less than 2% of the total shoreline. In addition, the sampled shore zone includes only those areas less than 30 m from the shore and shoal stratum sampling was limited to depths exceeding 2 m. Consequently, there exists a substantial amount of "shore zone" area less than 2 m in depth but more than 30 m from shore that was not sampled. Finally, the beaches actually sampled in the BSS are probably not representative of the remaining shore zone because the sampled beaches are generally, flat areas that have been cleared of obstructions that might serve as refuge.

Sensitivity of the index to the unsampled areas is species-specific. The index for striped bass appears to be the least sensitive to the unsampled areas. Striped bass generally do not spawn or develop in small tributaries of rivers, and there are no large tributaries to the Hudson River below the Troy Dam. Downstream distribution (below the George Washington Bridge) is of minor concern because striped bass young-of-year generally develop at or above the salt front (Fig. IV-10) and mark-recapture studies conducted in the 1970's indicated that the downstream migration of young-of-year striped bass to overwintering grounds doesn't begin until after week 40 (TI 1981). The fact that the upriver shoal areas have gone unsampled is also of little concern, as striped bass are generally distributed downstream of Poughkeepsie.

The white perch index is even less sensitive than striped bass to the unsampled downstream areas because white perch are distributed further upstream than striped bass (Fig. IV-22) and mark-recapture studies also indicate that white perch remain within the region they were marked during weeks 33-40 (TI 1981). However, because they are distributed further upstream, the white perch index is more sensitive to the unsampled shoal area in regions 7-12. In addition, white perch are more likely to spawn in tributaries than are striped bass, but the young-of-year are still likely to be concentrated in the mainstem of the river, rather than in the tributaries.

American shad are distributed even further upriver than white perch (Fig. IV-38) and their index is therefore insensitive to the unsampled downstream areas. However, shad are concentrated in the regions where the shoal is unsampled and where the number of beaches available to be sampled is small. Thus, the American shad index will be sensitive to this unsampled area, if the proportion within the area subject to sampling changes among years. In addition, American shad are likely to spawn in tributaries, although most young-of-year are likely to develop in the river.

The index for bay anchovy is likely to be a very poor indicator of year class strength. Bay anchovy spawn primarily in mesohaline areas and move upstream as they develop. The majority of the population is likely to occur downstream of the study area, as is suggested by the distribution pattern observed in Year Class studies (Fig. IV-52). Thus, the index value may be determined primarily by longitudinal distribution patterns, which may be heavily influenced by rainfall and salinity patterns within the river, rather than by abundance of the bay anchovy population.

There is an additional problem with the bay anchovy index: recruitment of young-of-year anchovy to the gear may not be complete by week 33 (the first week included in the index). Bay anchovy may continue to spawn this late and the smaller juvenile bay anchovy may not be captured by the large mesh gear being used in these sampling programs. This problem could be overcome by developing an index for yearling bay anchovy. However, classification of anchovy into age classes on the basis of size alone after the first year is difficult, because their protacted spawning season does not lead to clear age-size class peaks. In addition, an index based on yearling anchovy would still be unreliable because of the same downstream distribution problem that occurs for the juveniles.

VII. FACTORS INFLUENCING YEAR CLASS STRENGTH

A. INTRODUCTION

Interpretation of patterns in year class strength, such as those identified in Chapter VI, can be improved by understanding the factors that influence year class strength. Available water quality data interpreted in conjunction with relative abundance estimates and distribution patterns of early life stages can provide such an understanding. This chapter identifies and examines factors that may have affected year class strength of striped bass and white perch between 1974 and 1985. Bay anchovy was not considered in this chapter because a reliable index of their year class strength could not be developed. American shad were not included because no differences in their year class strength were detected in Chapter VI.

Previous Year Class Reports have attempted to correlate year class strength with environmental variables. The approach used in these previous reports was primarily to correlate environmental variables with indices of year class strength for all years. However, factors affecting year class strength, particularly those responsible for causing a poor year class, may differ from year to year and among lifestages. Thus, in our approach we have taken a more mechanistic approach, examining survival at each lifestage individually.

The ultimate objective of this chapter is to identify how (i.e., which environmental factors) and when (i.e., at what point in the life cycle) year class strength has been determined in the Hudson River since 1974. This was conducted as a two step process. The first step was to identify those environmental factors that led to low survival of individual life stages. The second step was to examine survival data and identify the principal life stage at which year class strength is determined.

The approach used in the first step was to identify years when survival of particular lifestages was poor and to independently identify years when potentially adverse environmental conditions occurred. Then a determination was made as to whether any of these environmental conditions occurred during periods of low survival and whether they were also absent in years of high survival.

However, identification of factors affecting survival of individual lifestages is not by itself sufficient to identify the factors most affecting year class strength. Year class strength is a function of both the number of eggs deposited and the survival of those eggs to the young-of-year stage. Thus, as a second step following identification of low survival events and their potential causes, relative year class strength was examined to see whether poor survival, low egg abundance, or a combination of both factors were responsible for years of low year class strength.

The remainder of this chapter is organized into two sections. Section B describes the methods that were used to identify factors that may have influenced year class strength for each of the species of interest; the last section presents results from these analyses for each species.

B. METHODS

The first step, identification of factors affecting lifestage survival, consisted of four elements:

- Calculation of relative abundance indices for each lifestage
- Calculation of relative survival indices for each lifestage
- Identification of unusual environmental conditions and what lifestages were abundant when they occurred
- Assessment of whether years with low survival at various lifestages were also years with unusual environmental conditions.

Methods used in performing each of these elements are described below. The second step, integration of survival data to determine whether years of low year class strength were primarily attributable to low survival at particular lifestages or to low egg abundance, was accomplished by comparing year class strength with survival at each lifestage.

1. <u>Relative Abundance Index</u>

An index of relative abundance was calculated for each lifestage and species (egg to young-of-year). Coordinate pair indices were developed for juvenile striped bass, white perch, and American shad in Chapter VI. Because a single scalar value could not be associated with each year, the years were classified as having high, low, or unknown year class strength in this chapter. For eggs, yolk-sac larvae, and post yolk-sac larvae, scalar indices of relative abundance were developed.

Young-of-Year

The protocol for classification of annual young-of-year abundance consisted of three steps:

- Identification of years with high mean ranks on the beach seine axis and years with low mean ranks on the beach seine axis
- Identification of years with high mean ranks on the offshore axis and years with low mean ranks on the offshore axis
- Concatenation of these findings to identify years which had high mean ranks on both axes and years which had low mean ranks on both axes.

Years with high mean ranks on both axes were classified as having high year class strength, and years with low mean ranks on both axes were classified as having low year class strength.

The selection of high and low years on each axis was accomplished in two steps. First, Duncan's underscore method was used to summarize which years had mean ranks that were significantly different ($\alpha = 0.05$) from each other. The year with the highest mean rank and the year with the lowest mean rank were identified. If the mean ranks were significantly different ($\alpha = 0.05$) in these two years, the year with the high mean rank was classified as a good year on that axis, and the year with the low mean rank was classified as a poor year on that axis. The years with next highest and next lowest mean ranks, for each axis, were then identified and retained as good and poor years, respectively, if their mean ranks were significantly different. This procedure was repeated until no additional pair of years that were significantly different from each other were found.

After completion of this exercise, the years classified as low for both axes, and the years classified as high for both axes were identified. Years classified as low for both axes were defined as years with low year class strength. Years classified as high for both axes were defined as years with high year class strength.

If at least one year could not be defined as being a good year on both axes, or at least one year could not be identified as a poor year on both axes, the level of significance was increased (up to 0.10) and the process repeated until each of the two categories contained at least one year. Unclassified years were defined as having had unknown year class strengths. They may have been years with a high mean rank on one axis but an intermediate or low mean rank on the other. Without knowing the relative weighting for the two axes, such years can only be classified as years with unknown year class strength. This approach is conservative in that many years may fall into the "unknown" category, and misclassification of intermediate years as low or high is improbable.

Eggs and Larvae

Relative abundance indices for eggs and larvae were computed using weekly standing crop estimates (Eq. 18) for each year for striped bass and white perch. The index was calculated as the total standing crop of each lifestage for the year, normalized (by dividing by the maximum value) to a relative index among years for each lifestage. An index of relative abundance was computed for eggs, yolk-sac larvae and post yolk-sac larvae for striped bass and only for yolk-sac and post-yolk sac larvae for white perch. An index for white perch eggs was not calculated since white perch eggs are adhesive and demersal (Mansueti 1964) and therefore, may not be sampled well by gear used in the LRS.

This index of early lifestage abundance is independent of sampling effort if the entire temporal event of the lifestage is sampled. This assumption appears to have been met in all but one year. In 1982, 20% of the total standing crop of striped bass eggs was collected in the first week of sampling. This suggests that in 1982, when sampling did not begin until 10 May, a substantial number of striped bass eggs may have occurred prior to initiation of sampling. Thus, the relative egg abundance index for 1982 may be an underestimate for striped bass. For white perch, the standing crop estimate of yolk-sac or post yolk-sac larvae collected in the first or last week of sampling never exceeded 10% of the total standing crop for the year, suggesting that relative larval abundance of white perch was not underestimated to a large extent in any year.

2. Relative Survival Index

Survival can be simply expressed by the ratio of abundances of one lifestage to another. For instance, egg survival is equal to the number of yolk-sac larvae produced divided by the number of eggs spawned. Similarly, post yolk-sac survival is equal to the number of young-of-year divided by the number of post yolk-sac. For eggs and yolk-sac larvae, relative survival was approximated by dividing the total standing crop for the year of the second lifestage by the total standing crop for the first lifestage. Absolute survival can not be inferred from this approximation of relative survival using total standing crop, since different lifestages have different durations. Therefore, this ratio was normalized to a 0 to 1 scale in the same manner as the relative abundance index.

Survival of post yolk-sac could not be quantified in the same way as egg and yolk-sac survival because a single estimate of young-of-year abundance was not available. Therefore, an alternative approach based on categorization was developed. This approach was based on the classification scheme already described for year class strength (low, unknown, and high) and three categories for post yolk-sac abundance (low, medium, and high).

Years with low post yolk-sac survival were identified by comparing relative year class strength (i.e., high, low, or unknown) to the relative abundance of post yolk-sac larvae. Years with relatively high post yolk-sac abundance and low year class strength were classified as having low ichthyoplankton survival. Conversely, years with relatively low post yolk-sac abundance and high year class strength are classified as having high post yolk-sac survival.

To be consistent with the categorical representation of year class strength, relative post yolk-sac abundances were classified as high, medium, and low. Thus the comparisons used to identify years of high and low ichthyoplankton survival can be depicted graphically in terms of a simple 3 x 3 matrix (Fig. VII-1). Years with low ichthyoplankton survival are represented by the cells in the upper left hand corner of the matrix. Similarly, years with high ichthyoplankton survival are represented by the cells in the lower right hand corner of the matrix. It should be reiterated that years with unknown year class strength are not necessarily years of medium year class strength. A year classified as unknown could have had

- Medium year class strength
- High year class strength with a high value on one axis of the index but a low value on the other axis
- Low year class strength with a high value on one axis of the index but a low value on the other axis.

Years of low, medium, and high post yolk-sac abundance were categorized using the index of relative abundance described above. Years of low abundance were defined as those with index values more than one median absolute deviation (Mosteller and Tukey 1977) below the median index value. Years of high abundance were defined as those with index values more than one median absolute deviation above the median index value.

RELATIVE ABUNDANCE	Low	Unknown	High
High	VERY LOW	UNKNOWN	AVERAGE
Medium	LOW	UNKNOWN	HIGH
Low	AVERAGE	UNKNOWN	VERY HIGH

RELATIVE YEAR CLASS STRENGTH

Figure VII-1. Relative ichthyoplankton survival deduced from relative post yolk-sac abundance and relative year class strength

3. Identification of Unusual Environmental Conditions

The objective of this element is to identify the periods of unusual environmental conditions that may have led to low survival of eggs or larvae. The variables selected for examination were based on known or anticipated effects of these variables on striped bass larvae and includes the variables considered in previous Year Class Reports. However, the list of variables selected was limited by available data. A number of factors that could affect survival and year class strength, such as food availability (Eldridge et al. 1981), contaminant levels (Hall et al. 1984, 1985), fishing pressure (Goodyear 1985) or predation, could not be considered because data were unavailable. Unusual conditions for the variables selected were defined by examining patterns over the 12 year period and identifying deviations from the average.

Eight different environmental variables were examined as potentially affecting survival of eggs or larvae of striped bass and white perch:

- Large flow events
- Sudden temperature declines or increases
- Above or below average temperature during peak abundance periods
- Above or below average salinity during peak abundance periods
- High or low salinity encroachment
- Occurrences of low dissolved oxygen
- High vulnerability to entrainment for ichthyoplankton
- Long juvenile exposure period.

Six of these are measures of physical variables. The seventh is a measure of spatial distribution relative to potential entrainment through power plants. The eighth is a measure of temporal distribution.

For some of the environmental variables selected, an unusual condition could be defined based on laboratory studies identifying tolerance levels for these fish. For other variables, however, unusual conditions could only be defined by examining patterns over the 12 year period and identifying deviations from the average. In such circumstances, an attempt was made to establish criteria such that 3-6 events were identified as unusual. The rationale for this arbitrary selection was that after about 6 events in a 12 year period, an event ceased to be unusual; if fewer than 3 events were identified, meaningful analysis could not be conducted. The data sources and definition of unusual conditions for each variable is given below.

Large flow events can displace larvae downstream and potentially affect their survival. United States Geological Survey daily freshwater flow data (1974 to 1985) from the Green Island, New York station were used to identify large flow events. Large flow events were defined, based on deviation from average conditions, as daily discharge volumes greater than 2,000 m^3 sec^{-1} that were observed between the last week in April and 15 June, and discharge volumes greater than 600 m^3 sec^{-1} observed between 16 June and the end of July. The two-tiered criteria for defining unusual flow was required because of large differences in base flow during the two periods.

Water temperature (°C), salinity (ppt), and dissolved oxygen (ppm) data were obtained from the LR/FS water quality program for each year (see Appendix D for methods and data summaries). Weekly means by region, weighted by stratum volumes, were calculated for each of these water quality parameters.

The hatching success and survival of larval white perch and striped bass have been shown in laboratory studies to be temperature-dependent (Morgan and Rasin 1982; Morgan et al. 1981). Therefore, years in which water temperature at the time and place of peak abundance for each lifestage varied from the average were identified using the median absolute deviation technique described earlier. In addition, Kernehan et al. (1981) and Dey (1981) have suggested that rapid temperature declines of 2 °C can lead to mortality of striped bass larvae and therefore all declines of 2 °C or more were identified as anomolous events. Eggs and larvae are less sensitive to rapid increases in temperature (Schubel and Auld 1974), but will respond with developmental difficulties (Koo and Johnston 1978). All temperature increases of 4 °C within a one week period were identified as unusual events.

Criteria for unusual salinity conditions were examined in two ways. First, years in which the average salinity in the regions and weeks during peak abundance was significantly above or below average for that lifestage were identified using the median absolute deviation procedure. Second, years of unusual salinity conditions were also defined based on degree of salinity encroachment. Years of high salinity encroachment were defined as those when mean salinity exceeded 2 ppt in the Cornwall region. Years when the mean salinity in the West Point region did not reach 2 ppt were defined as low salinity encroachment years.

Dissolved oxygen levels below 3 ppm have been shown to substantially stress many estuarine fish species including striped bass (Harrell and Bayless 1981; Thornton 1975). Generally, mean dissolved oxygen in the Hudson River is well above 3 ppm (Appendix D); however, dissolved oxygen occasionally dropped below this value, and all such occurrences were noted as unusual conditions.

Entrainment through power plants has been suggested as a factor that increases ichthyoplankton mortality in the Hudson River. Since estimates of entrainment abundance for the three largest plants (Indian Point, Bowline, and Roseton) are not available for all years between 1974-1985, an index of entrainment vulnerability based on geographic distribution of entrainable lifestages and plant withdrawal rates was computed. This index was calculated by lifestage, and is intended to reflect the proportion of the riverwide standing crop that may have been at risk to entrainment by the three plants. The index is based on Eq. (40) but is presented in terms of values normalized to range from 0 to 1.

$$E_y = \frac{\sum_{p=1}^{3} \sum_{w=1}^{n_{wy}} \sum_{r=1}^{12} SC_{rwy} \left[\frac{(F_{pwy})(P_{pr})}{V_r} \right]}{\sum_{w=1}^{n_{wy}} \sum_{r=1}^{12} SC_{rwy}} \quad (40)$$

where

E_y = relative entrainment vulnerability index for year y

SC_{rwy} = standing crop estimate in region r duing week w of year y (as calculated in Eq. (16), Chapter II)

F_{pwy} = flow through plant p during week w of year y (m^3)

P_{pr} = proportion of the flow through plant p that is withdrawn from region r

V_r = volume of region r (m^3)

n_{wy} = number of weeks sampled in year y.

The estimates for the proportion of each plant's water withdrawal that comes from each region (P_{pr}) were taken from Lawler, Matusky and Skelly, Engineeers (1983) (Table VII-1).

Table VII-1. Proportion of power plant cooling water flows withdrawn from each longitudinal region of the Hudson River (from Lawler, Matusky and Skelly Engineers 1983)

	Power Plant		
Region	Roseton	Indian Point	Bowline Point
YK	0	0	0
TZ	0	0	0.271
CH	0	0.298	0.358
IP	0	0.562	0.371
WP	0	0.140	0
CW	0.273	0	0
PK	0.727	0	0
HP	0	0	0
KG	0	0	0
SG	0	0	0
CS	0	0	0
AL	0	0	0

Monthly withdrawal rates for each plant for May, June, and July of each year were provided by Consolidated Edison. Volumes of the longitudinal regions are given in Table II-12.

Years of high and low entrainment vulnerability were defined according to the following procedure. For each life stage, each year was assigned a rank from 1 to 12 based on the value of the entrainment vulnerability index. A mean rank for each year was then computed by averaging the ranks for the three life stages (egg, yolk-sac larvae, and post yolk-sac larvae). The three years with the highest mean ranks and the three years with the lowest mean ranks were defined as years with high and low entrainment vulnerability, respectively.

The juvenile exposure index represents a measure of potentially decreased survival that might occur in those years when eggs are spawned early and young-of-year are exposed to an extended period of risk prior to the time from which the young-of-year index is calculated (week 33). The length of time between the peak of the post yolk-sac stage and week 33 (the first week of data used in the index of year class strength) was examined by computing the "mean" week of post yolk-sac abundance:

$$P_y = \frac{\sum_{w=1}^{n_{wy}} WK_y \quad SC_{wy}}{\overset{n_{wy}}{\underset{w=1}{}} \quad SC_{wy}} \tag{41}$$

where

P_y = mean week of post yolk-sac larvae abundance for year y

SC_{wy} = standing crop estimate for week w of year y (as calculated in Eq. (18), Chapter II)

WK_y = week number in year y where week 1 begins with the first Sunday in January

n_{wy} = number of weeks sampled in year y.

Years of extended or shortened post yolk-sac/young-of-year exposure periods were defined as those in which the mean week was at least 1 week earlier or later than the average of mean weeks for all years. Early peak periods of post yolk-sac larvae suggest that the risk of these fish to mortality (i.e., prior to week 33) was higher since they were exposed to risks for a longer period of time. Similarily, late post yolk-sac peaks suggest that the time period of risk was less in those years.

4. Concordance Between Ichthyoplankton Survival and Environmental Conditions

Identification of factors that may have influenced egg or larval survival was conducted in three steps. The first step was to determine which, if any, unusual environmental conditions occurred in each of the years identified as having low ichthyoplankton survival. This step produced initial hypotheses about possible factors affecting ichthyoplankton survival. The second step was to determine whether these initial hypotheses were consistent across all years. If an unusual event was associated with low survival of a lifestage in a single year, but with high or average survival in other years, then that event was dismissed as an important unifying factor.

If an unusual environmental event corresponded only with years of low survival, the final step was to examine data on temporal distribution patterns (of each life stage) for evidence of the loss of organisms. For example, a large peak of yolk-sac larvae observed in week t might be expected to be followed by a peak of post yolk-sac larvae in week t+1. No post yolk-sac larvae observed in week t+1 would be evidence of high mortality during the period from t to t+1. This was done to corroborate hypotheses on unusual conditions that were thought to have caused high mortality.

C. RESULTS

1. Relative Abundance Index

Young-of-Year

Year class strength for striped bass was classified according to the procedures described in Section B as low in 1982 and 1985, and as high in 1977 (Fig. VII-2). For striped bass this classification was conducted with a significance level of $\alpha = 0.08$. For white perch, 1984 and 1985 were classified as having had low year class strength, and 1979 was classified as having had high year class strength (Fig. VII-2). This classification was conducted with a significance level of $\alpha = 0.05$.

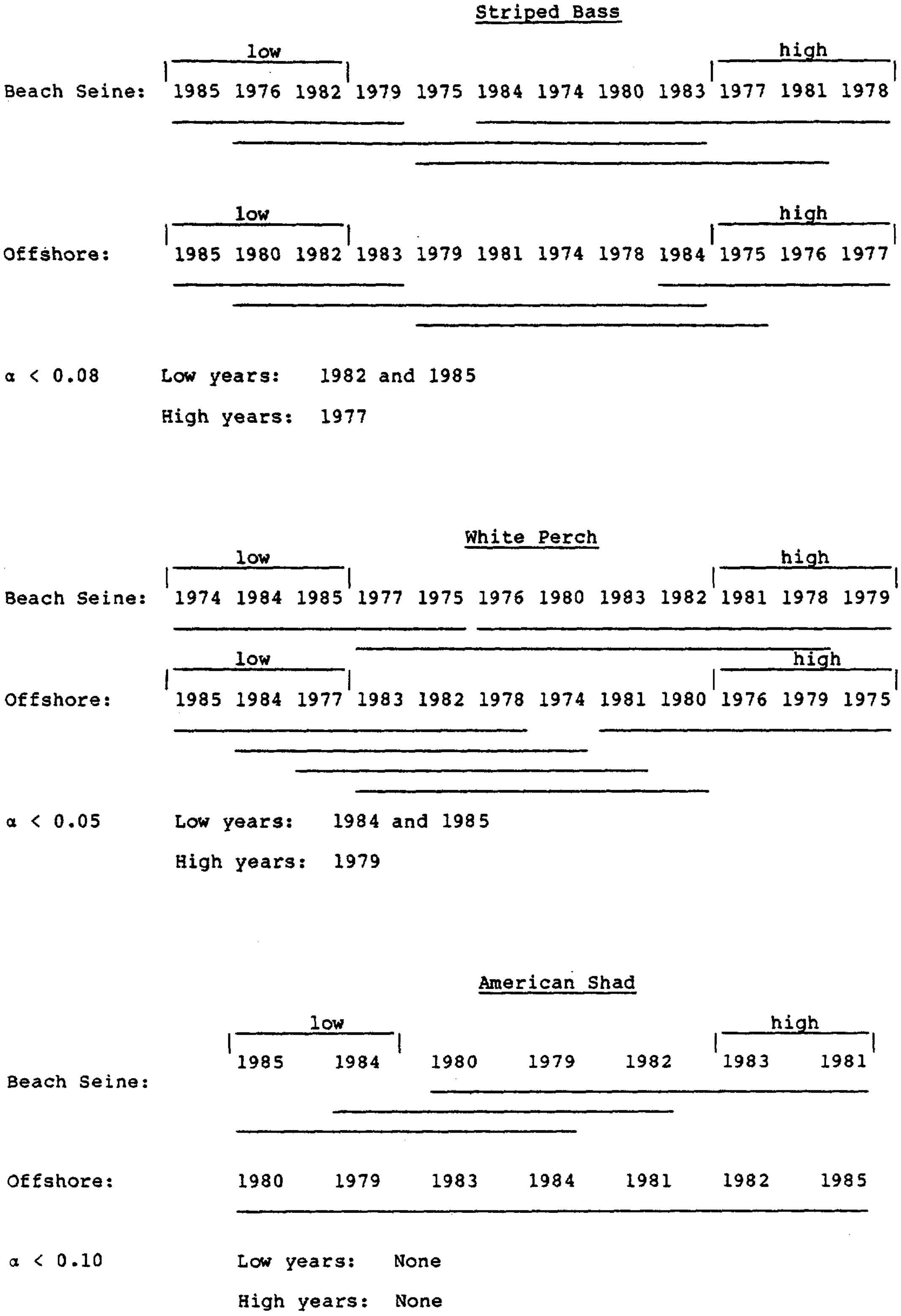


Figure VII-2. Classification of years of high and low year class strengths for striped bass, white perch, and American shad in the Hudson River. Underscores indicate years not significantly different from each other.

For American shad, no years could be classified as having had high or low year class strength when the classification was conducted with a significance level of 0.10 (Fig. VII-2). The level of significance had to be dropped to unacceptably low levels ($\alpha \geq 0.25$) before high and low years could be identified. This finding is consistent with the discussion in Chapter VI for American shad. Because no years of high or low year class strength were identified, no effort was made to establish relationships between environmental variables and young-of-year abundance.

Eggs and Larvae

An index of relative abundance was calculated for striped bass eggs, yolk-sac larvae, and post yolk-sac larvae (Fig. VII-3) and for white perch yolk-sac and post yolk-sac larvae (Fig. VII-4). Striped bass egg abundance was lowest in 1985 and highest in 1983. However, the 1983 value should be viewed cautiously because the extraordinary high egg abundance was primarily the result of a single sample containing over 10,000 eggs that almost equalled the total number of striped bass eggs in the nearly 2,000 remaining samples from that year. Years 1974 and 1977 also had relatively high egg abundances. Relative abundance of yolk-sac larvae was lowest in 1974, 1976, and 1985 and highest in 1975, 1977, and 1982. The year of lowest post yolk-sac abundance of striped bass occurred in 1976; highest abundance was observed in 1981.

Relative yolk-sac larvae abundance for white perch was higher in 1982 and 1983 than in all other years and post yolk-sac larvae were most abundant in 1982 and 1985. The lowest relative abundances of both larval stages were observed for 1974 and 1975.

2. Relative Survival Index

Egg and Yolk-Sac Larvae

Striped bass egg survival based on the ratio of yolk-sac abundance to egg abundance was higher in 1975 and 1982 than in other years and was lowest in 1974 and 1983 (Fig. VII-5). Survival of yolk-sac larvae was high in 1981 and low in 1976 and 1977 (Fig. VII-5). For white perch, the highest yolk-sac survival occurred in 1978 and the lowest in 1983 (Fig. VII-6).

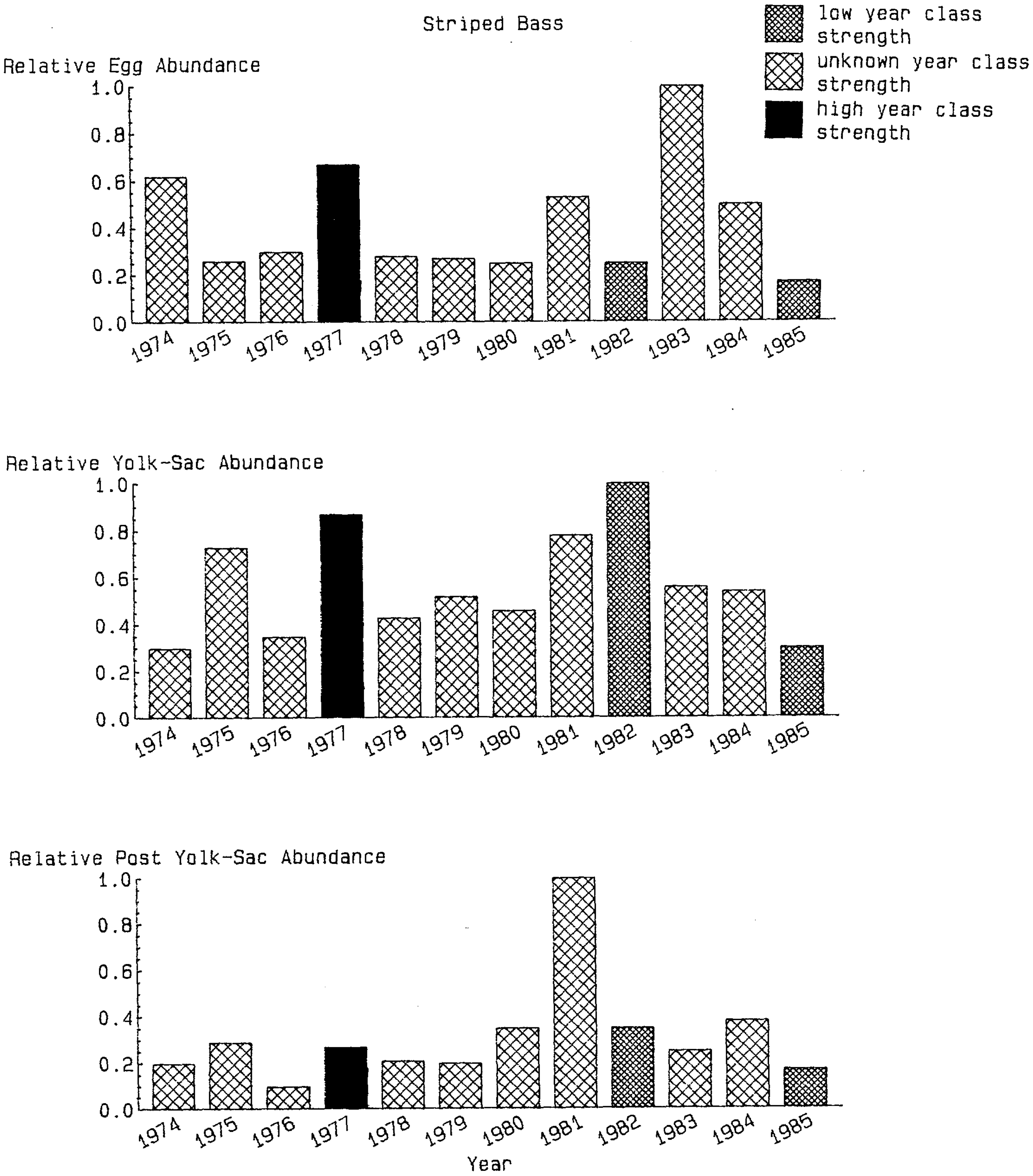


Figure VII-3. Relative striped bass egg, yolk-sac, and post yolk-sac abundance in the Hudson River, 1974 to 1985

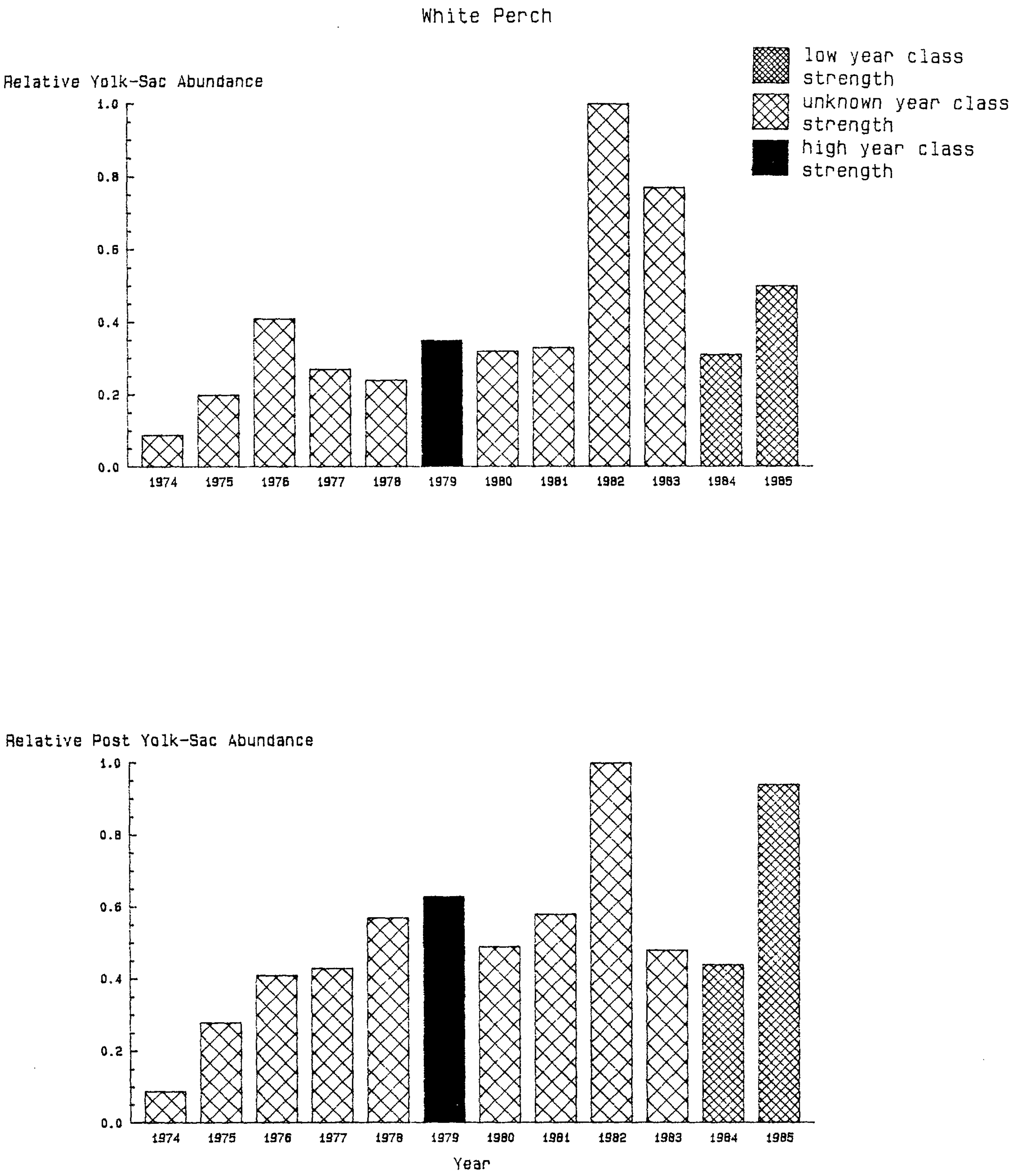


Figure VII-4. Relative white perch yolk-sac and post yolk-sac larvae abundances in the Hudson River, 1974 to 1985

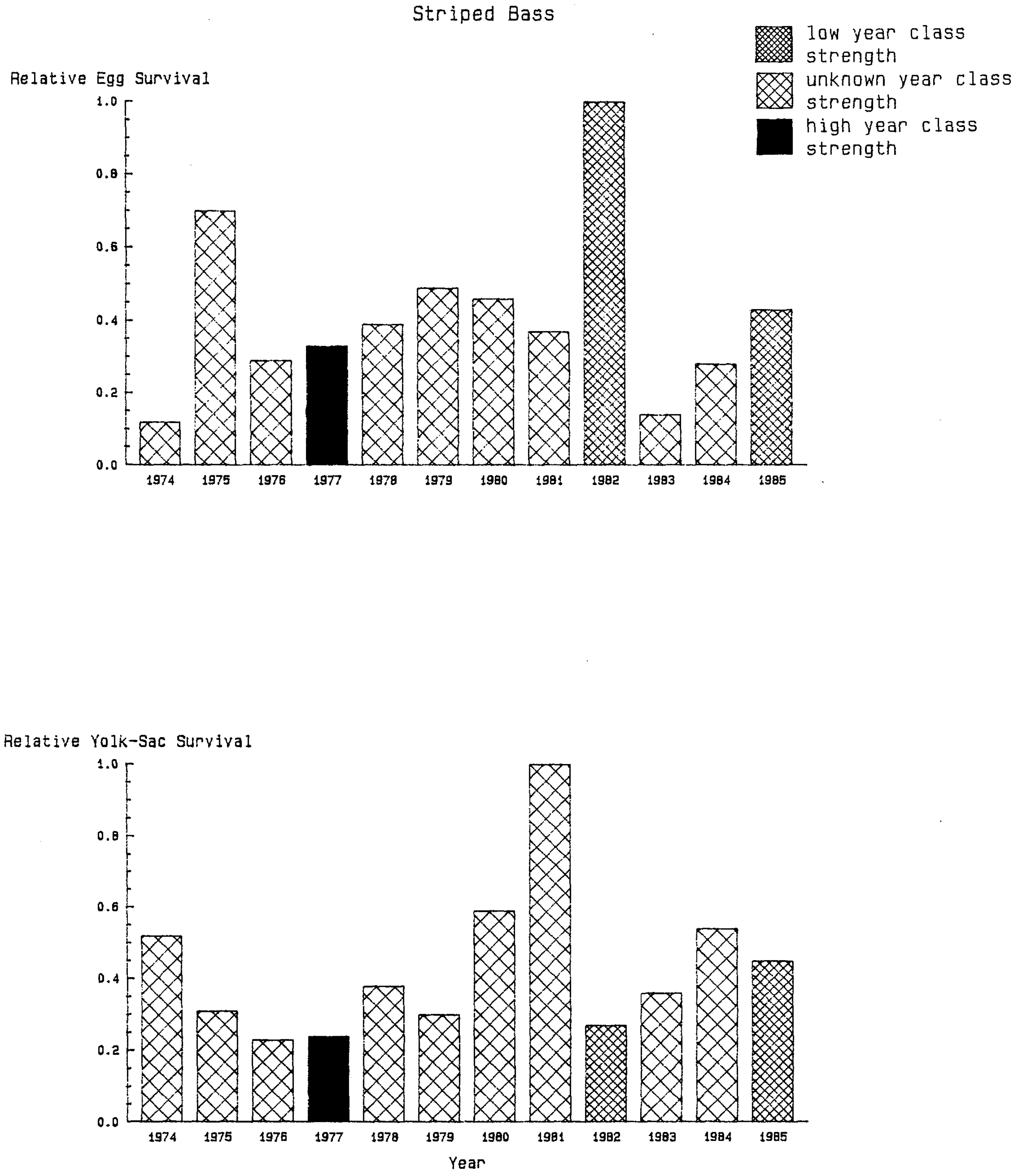


Figure VII-5. Relative egg and yolk-sac larvae survival of striped bass in the Hudson River, 1974 to 1985

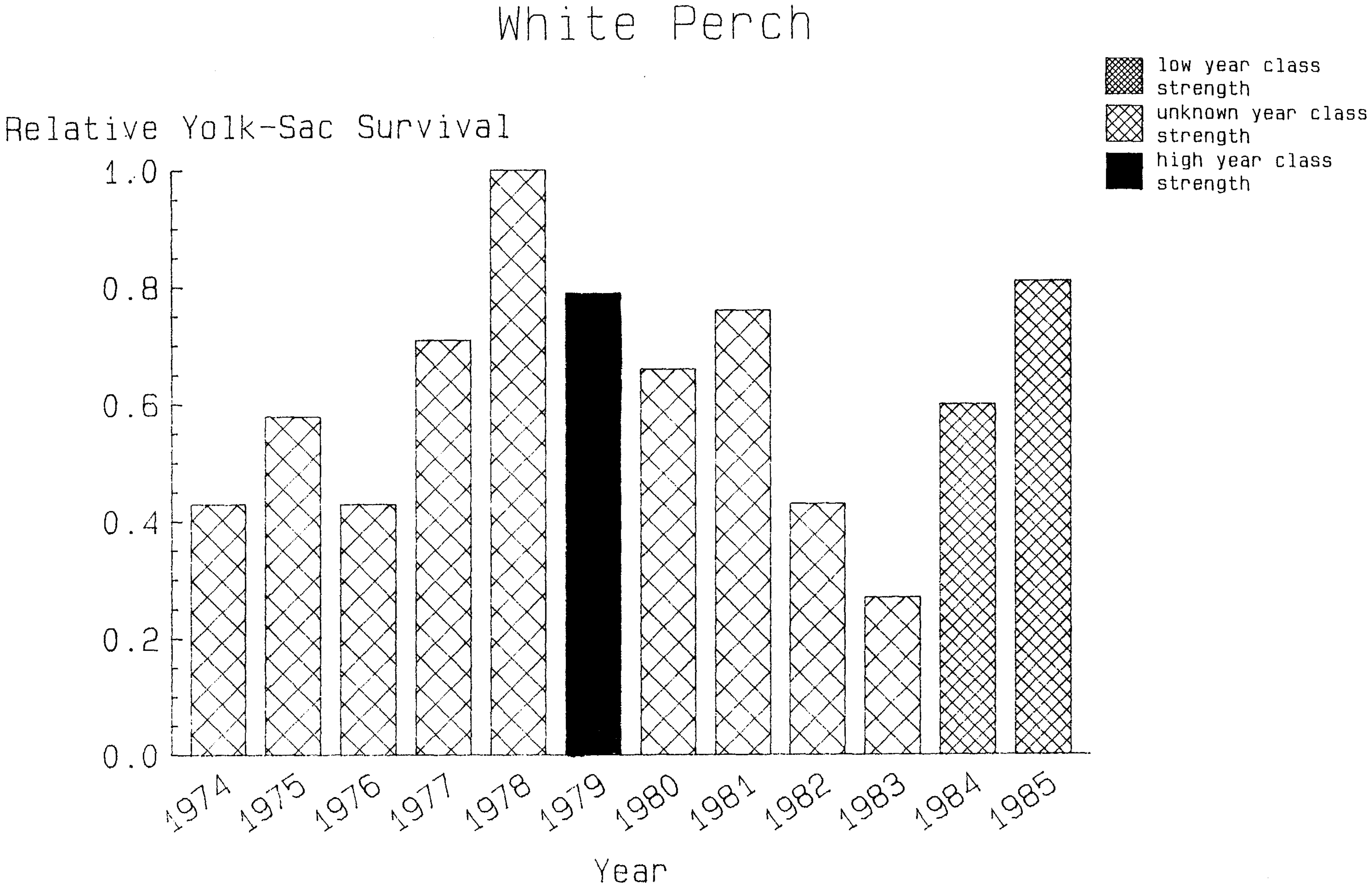


Figure VII-6. Relative yolk-sac larvae survival of white perch in the Hudson River, 1974 to 1985

Post Yolk-Sac Larvae

Since scalar annual values for post yolk-sac larvae survival were unavailable, a matrix approach was used to categorize survival. The relative abundances of striped bass post yolk-sac larvae and young-of-year suggest that post yolk-sac survival must have been low in 1982, was probably high in 1977, and was not high enough in 1985 to prevent a low abundance of post yolk-sac from resulting in a weak year class (Fig. VII-7). For white perch, post yolk-sac survival appeared to be very low in 1985 when a large number of post yolk-sac larvae resulted in relatively poor year class strength. Post yolk-sac survival was also low in 1984. In 1979, survival of white perch larvae (high abundance) was sufficient to maintain a strong year class. All other years (for striped bass and white perch) had unknown year class strength and therefore no conclusions about post yolk-sac survival could be drawn.

3. Identification of Unusual Environmental Conditions

Large temperature declines, as defined in Section B, occurred in eight of the 12 years (Table VII-2). Three of these declines occurred immediately after mean water temperature reached 15°C (1976, 1983, and 1984) which corresponds to the onset of peak spawning for striped bass in most years (Table IV-3). The remainder of the declines occurred after the mean temperature reached 20-22°C, and the temperature did not drop below 15°C. None of these drops in temperature were observed below region 6 (Cornwall). Sharp temperature increases of more than 4°C within one week were observed in 1974, 1977, 1978, and 1984. An increase as high as 8°C in one week was recorded for early June in 1984.

The average temperature during the periods and in the regions of peak abundance of each lifestage are given in Figures VII-8 and VII-9, for striped bass and white perch, respectively. Most years had at least one lifestage where the temperature deviated from average (exceptions were 1974 and 1977 for striped bass and 1980 and 1981 for white perch). In 1985, peak abundances of all three lifestages of striped bass occurred at below average temperature. In 1984, peak abundance of all three lifestages for white perch occurred at above average temperature.

Periods of high freshwater flow, as defined in Section B, occurred in seven years. In 1974, 1975, 1982, and 1984, relatively high flows occurred in late June and early July. In 1976, 1977, 1983, and 1984 high flows were recorded on at least one day in April or May (Table VII-2). The wettest year based on total April to July flow was 1976.

(a) Striped Bass

Relative Post Yolk-Sac Abundance

	Low	Unknown	High
High	82	80 81 84	
Medium		74 75 78 79 83	77
Low	85	76	

Young-of-Year Index

(b) White Perch

Relative Post Yolk-Sac Abundance

	Low	Unknown	High
High	85	81 82	79
Medium	84	76 77 78 83	
Low		74 75	

Young-of-Year Index

Figure VII-7. Relative post yolk-sac larvae abundance and relative year class strength of striped bass (a) and white perch (b) in the Hudson River, 1974 to 1985

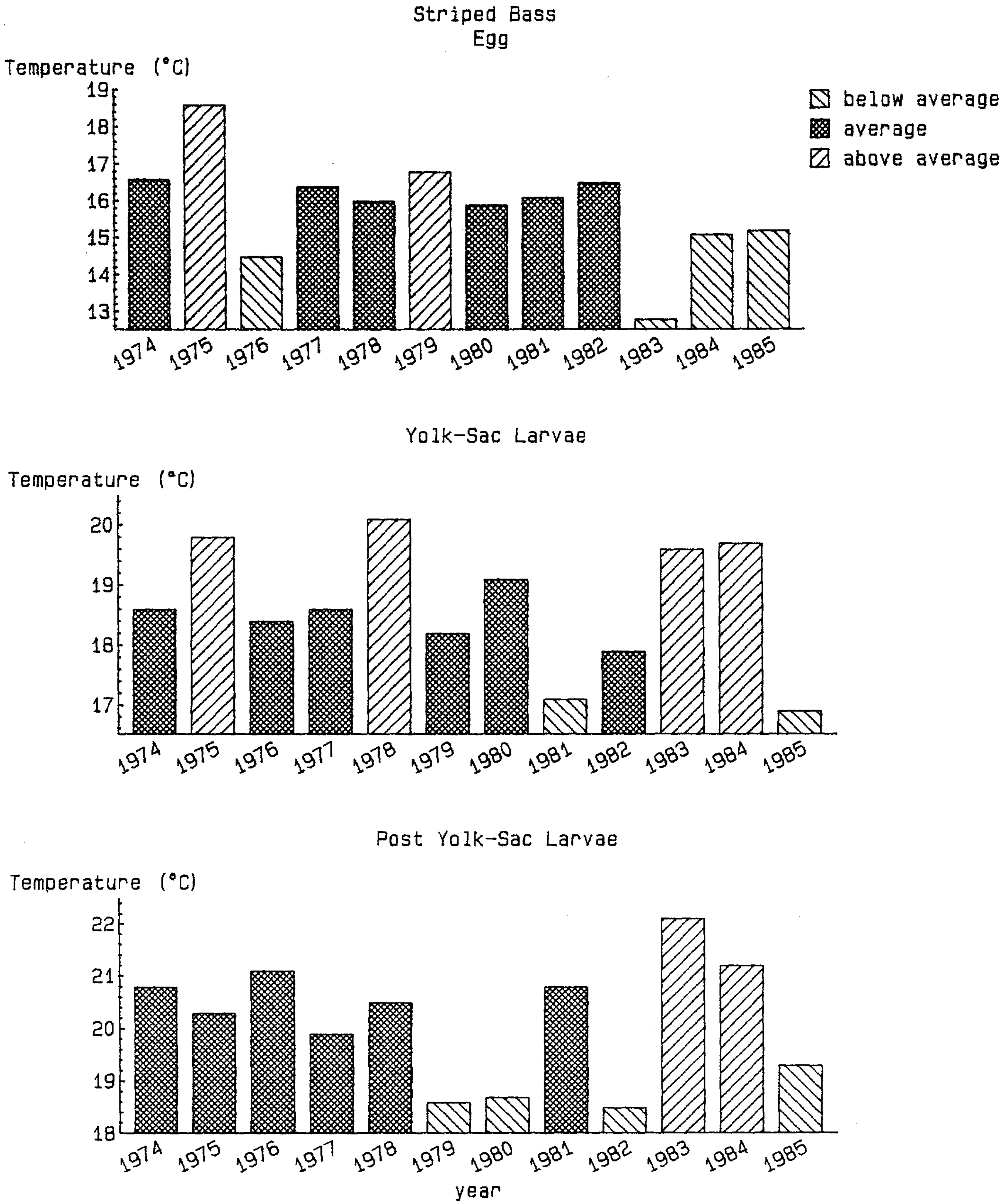
Table VII-2. Summary of unusual environmental conditions that may have influenced year class strength of striped bass or white perch in the Hudson River

Year	Sharp Temperature Decline	Sharp Temperature Rise	High Freshwater Flow	Salinity Encroachment	Low Dissolved Oxygen
1974	-	04-14 June	03-07 July	Low	<3 ppm(a)
1975	02-13 June	-	13-14 June	-	-
1976	17-26 May(b)	-	20-21 May 01-03 July 13-14 July	Low	-
1977	31 May-09 June	16-26 May	01, 25,26 April	-	-
1978	-	22 May-02 June	-	-	-
1979	21 May-02 June	-	-	Low	<3 ppm
1980	02-13 June	-	-	High	<3 ppm
1981	-	-	-	-	-
1982	01-09 June	-	19 April 30 June-01 July	-	-
1983	23 May-02 June(b)	-	25-27 April 02-05 May	High	-
1984	21 May-03 June(b)	04-15 June	30-31 May 07- 09 July	-	-
1985	-	-	-	High	-

(a) Data suggest that dissolved oxygen data for 1974 may contain errors.
(b) Temperature dropped below 15°C.

Table VII-3. Mean salinity during peak abundance periods of striped bass and white perch eggs and larvae in the Hudson River, 1974 to 1985

	Striped Bass			White Perch		
Year	Egg	Yolk-Sac Larvae	Post Yolk-Sac Larvae	Egg	Yolk-Sac Larvae	Post Yolk-Sac Larvae
1974	0.0	0.2	0.2	0.4	0.0	0.0
1975	0.0	0.1	0.7	0.1	0.1	0.3
1976	0.0	0.0	0.1	0.0	0.0	0.0
1977	0.0	0.3	0.8	0.2	0.0	0.0
1978	0.0	0.0	0.6	0.0	0.0	0.0
1979	0.0	0.0	0.3	0.0	0.0	0.0
1980	0.0	0.1	1.4	0.0	0.0	0.0
1981	0.2	0.2	0.3	0.0	0.0	0.0
1982	0.1	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	0.2	0.0	0.0	0.0
1984	0.0	0.0	0.8	0.0	0.0	0.0
1985	0.3	0.1	0.4	0.0	0.0	0.0


Striped Bass
Egg

Yolk-Sac Larvae

Post Yolk-Sac Larvae

Figure VII-8. Mean temperature during peak abundance periods of striped bass eggs, yolk-sac, and post yolk-sac in the Hudson River, 1974 to 1985

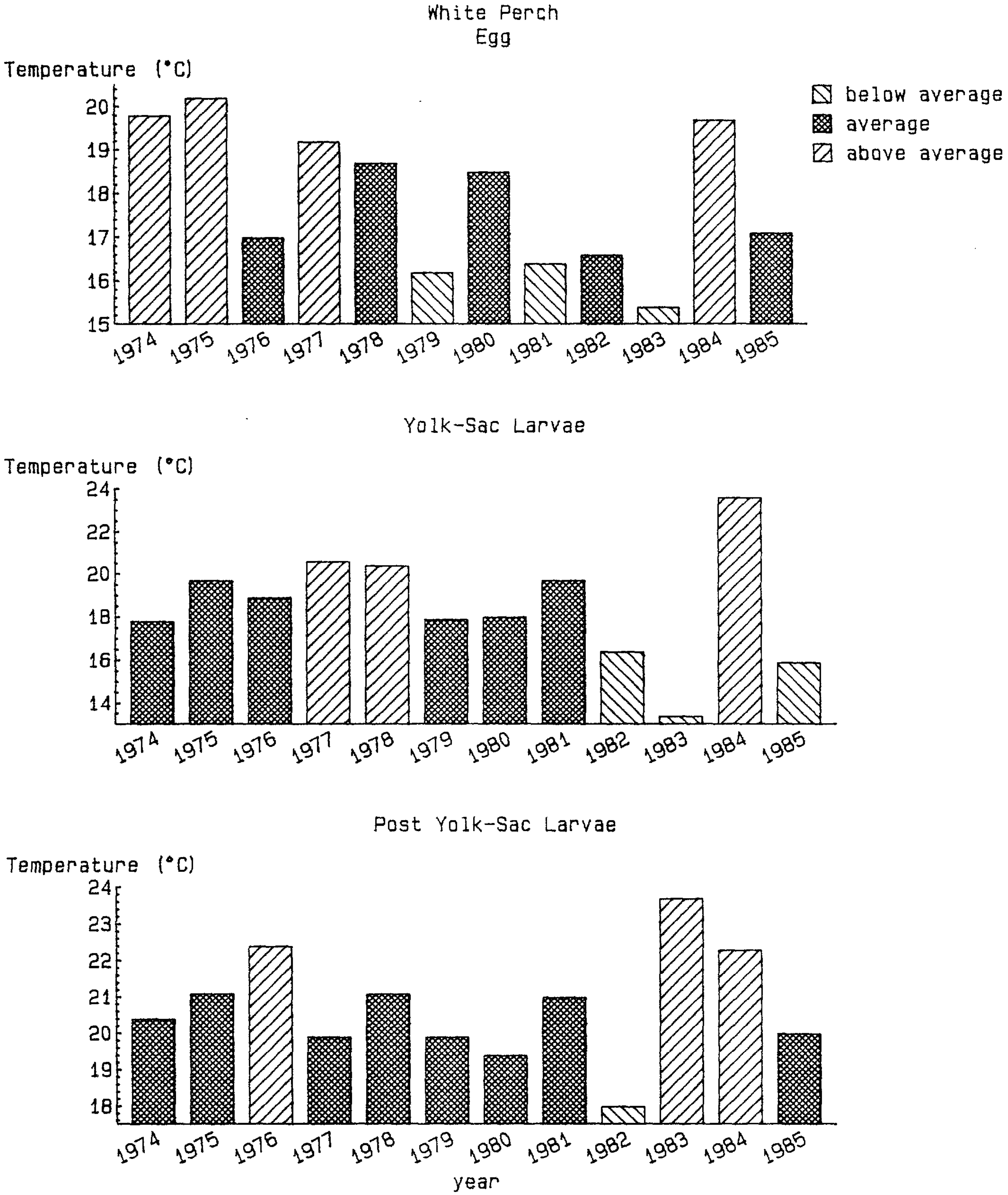


Figure VII-9. Mean temperature during peak abundance periods of white perch eggs, yolk-sac, and post yolk-sac in the Hudson River, 1974 to 1985

The three years of high salinity encroachment (1980, 1983, and 1985) were the only years when mean salinity exceeded 2 ppt in region 6 (Cornwall). The three lowest salinity encroachment years (1974, 1976, and 1979) were the only years when the mean salinity in region 5 (West Point) did not reach 2 ppt in any week (Table VII-2).

Peak abundance of striped bass eggs occurred at locations with above average salinity in 1981, 1982, and 1985 (Table VII-3). In 1974 and 1977, peak abundance of yolk-sac larvae occurred at above average salinity. No years could be identified as ones in which the peak abundance of eggs or yolk-sac occurred in an area of low salinity since in most years these lifestages developed in fresh water (Table VII-3). Peak post yolk-sac abundance of striped bass occurred at above-average salinities in 1975, 1980 and 1984. Lowest salinities for post yolk-sac occurred in 1976 and 1982. White perch eggs and larvae were generally found in freshwater. Average salinity during peak abundance of white perch only exceeded 0.1 ppt in 1974 and 1977 for eggs, and 1975 for post yolk-sac larvae.

Mean dissolved oxygen values below 3 ppm have been recorded in three years (1974, 1979, and 1980). In 1974, zero values were recorded for the entire region of West Point and Cornwall during one week in September. Since it is unlikely that dissolved oxygen concentration in all samples (including samples collected at the surface) was zero, the dissolved oxygen data for 1974 are suspect. The lowest values in 1979 and 1980 were 2.5 and 2.9, respectively.

The index of vulnerability to entrainment, as measured by the procedure described in Section B, varied considerably among years (Table VII-4). For striped bass, the three years of highest vulnerability were 1975, 1977, and 1979; the three lowest years of vulnerability were 1974, 1982, and 1985. For white perch, the two years of highest vulnerability were 1975 and 1977; 1979 and 1983 were tied for the third highest value of entrainment vulnerability index. The year of lowest vulnerability was 1985 followed by 1981 and 1982 (Table VII-5).

The mean week statistic for post yolk-sac abundance ranged from 21.5 in 1985 to 25.5 in 1984 for striped bass and from 21.9 in 1985 to 25.1 in 1984 for white perch. For striped bass, only 1985 had a "mean week" more than a week before the average "mean week" for all years. For white perch, the "mean week" in 1981 and in 1985 was more than a week before the average for all years. Thus, juvenile striped bass were at risk to mortality for an extended period (prior to week 33) in 1985 and juvenile white perch experienced an extended exposure period in 1981 and 1985.

Table VII-4. Entrainment vulnerability index for striped bass in the Hudson River. Mean rank is the mean of the ranks of the index values for the three life stages. High rank indicates high entrainment vulnerability.

	Entrainment Vulnerability Index			
Year	Egg	Yolk-Sac	Post Yolk-Sac	Mean Rank
1974	0.43	0.34	0.52	2.3
1975	0.58	0.79	0.91	9.2
1976	0.40	0.70	0.82	6.0
1977	0.63	1.00	0.96	11.3
1978	1.00	0.77	0.78	8.7
1979	0.58	0.90	1.00	10.8
1980	0.51	0.57	0.71	5.7
1981	0.56	0.68	0.60	5.8
1982	0.21	0.41	0.58	1.7
1983	0.27	0.82	0.91	7.3
1984	0.49	0.53	0.91	6.3
1985	0.25	0.46	0.60	2.8

Table VII-5. Entrainment vulnerability index for white perch in the Hudson River. Mean rank is the mean of the ranks of the index values for the three life stages. High rank indicates high vulnerability to entrainment.

	Relative Entrainment Vulnerability Index			
Year	Egg	Yolk-Sac	Post Yolk-Sac	Mean Rank
1974	1.00	0.38	0.63	8.3
1975	0.48	0.76	1.00	10.3
1976	0.21	0.59	0.48	6.0
1977	0.38	0.79	0.63	9.0
1978	0.13	1.00	0.59	8.0
1979	0.12	0.65	0.96	7.8
1980	0.10	0.28	0.47	3.0
1981	0.02	0.33	0.61	3.7
1982	0.04	0.22	0.63	4.0
1983	0.14	0.84	0.87	9.5
1984	0.07	0.84	0.58	5.8
1985	0.12	0.19	0.34	2.5

4. Concordance Between Ichthyoplankton Survival and Environmental Conditions

Striped Bass

Striped bass egg survival was low in 1974 and 1983 (Fig. VII-5) but there were no environmental factors that were well correlated with egg survival. Only three of the potentially adverse environmental conditions we examined did not occur in years of high egg survival (1975 and 1982): a sudden temperature decline, below average temperatures during peak egg abundance, and large freshwater flow events (Table VII-6). Of the variables, no unusual conditions occurred in 1974 that might explain why relatively few eggs survived. In 1983, there was a 2° temperature decline to 12.8° during the peak period for eggs. Temperature this low can reduce the frequency of hatching to less than 50% (Morgan et al. 1981). However, the egg survival estimate for 1983 may be an artifact of a single large value as discussed earlier and therefore any correlation of temperature leading to low survival in 1983 should be viewed with caution.

Survival of striped bass yolk-sac larvae was low in 1976 and 1977 (Fig. VII-5) and several potentially adverse conditions occurred in these years (Table VII-6). In 1976, a bimodal temporal distribution of yolk-sac larvae was observed. The early peak occurred during the week of 17 May, and was followed by a second peak during the weeks of 7 and 14 June. Apparently most of the yolk-sac larvae collected in late May died, since substantial numbers of post yolk-sac larvae were not collected until the week of 14 June. Dey (1981) has previously suggested that this mortality was the result of a 2° temperature drop during the week of 24 May. However, the Year Class data suggest that this temperature drop was limited to those regions north of Cornwall (Table D-4) and that no such drop occurred south of Cornwall where over 90% of the yolk-sac larvae were found in that week. It is possible that the weekly measurements used in the Year Class sampling program are too infrequent to detect a temperature drop as Dey (1981) used daily data from the Poughkeepsie water works plant to reach his conclusion. However, it is also possible that in the lower estuary the drop was ameliorated by mixing with warmer water from the New York harbor area. Daily water intake temperature data available from the Indian Point generating station indicated a temperature drop in late May but to a lesser extent than at Poughkeepsie water works. An alternative hypothesis for the high yolk-sac mortality in 1976 could be that the high flows which occurred during 20-21 May washed the yolk-sac larvae out of the study area. During the week of 24 May salinity in the lower most region of the study area was less than 0.5 ppt, and peak abundance of striped bass post yolk-sac larvae in the Hudson River have often been observed at salinities above that level (Table VII-3).

Table VII-6. Summary of striped bass egg and larval survival and environmental factors that may have influenced that survival in the Hudson River, 1974 to 1985

Survival				Temperature				Salinity								
Egg	Yolk-sac	Post Yolk-sac	Year	Drop	Rise	Below Average	Above Average	Low Encroachment	High Encroachment	Below Average	Above Average	Low Dissolved Oxygen	Large Flow Events	Long Exposure Duration	High Entrainment Vulnerability	Year
Low	Average		1974	—	Y,P	—	—	X	—	—	Y	—	—	—	—	1974
High	Average		1975	Y,P	—	—	E,Y	-	—	—	P	—	P	—	—	1975
Average	Low		1976	E,Y	—	E	—	X	—	P	—	—	Y	—	—	1976
Average	Low	High	1977	Y,P	E,Y	—	—	-	—	—	—	—	—	—	E,Y,P	1977
Average	Average		1978	—	E,Y	—	Y	-	—	—	—	—	—	—	E	1978
Average	Average		1979	E,Y,P	—	P	E	X	—	—	—	P	—	—	Y,P	1979
Average	Average		1980	Y,P	—	P	—	-	X	—	P	—	—	—	—	1980
Average	High		1981	—	—	Y	—	-	—	—	E	—	—	—	—	1981
High	Average	Very low	1982	Y,P	—	P	—	-	—	P	E	—	—	—	—	1982
Low	Average		1983	E,Y	—	E	Y,P	-	X	—	—	—	—	—	—	1983
Average	Average		1984	E,Y	E,Y	E	Y,P	-	—	—	P	—	E,Y,P	—	—	1984
Average	Average	Average	1985	—	—	E,Y,P	—	-	X	—	E	—	—	X	—	1985

E = Event occurred when eggs were present.
Y = Event occurred when yolk-sac larvae were present.
P = Event occurred when post yolk-sac larvae were present.
X = Condition occurred in that year.
— = The condition did not occur when eggs or larvae of striped bass were present in that year.

In 1977, the peak of yolk-sac larvae did not seem to disappear as in 1976. These larvae experienced a sharp temperature rise followed by a sudden decline during the week of peak abundance, and the entrainment vulnerability index was high for this lifestage in 1977. None of these factors occurred in years of high yolk-sac survival (Table VII-6), and may have influenced the mortality of striped bass yolk-sac larvae in 1977.

Relative survival of post yolk-sac could not be directly estimated since a scalar index of abundance was not available for young-of-year. Hence, most years were classifed as having unknown survival because their relative yearclass strength was unknown. Three of the twelve years were classified as to their survival: 1977 striped bass post yolk-sac larvae had high survival, 1982 larvae had low survival and 1985 larvae probably had average survival (Fig. VII-7), since a relatively low abundance of post yolk-sac larvae led to a relatively low young-of-year abundance.

Sharp temperature drops don't appear to have been an important factor in determining post yolk-sac survival since a sharp drop occurred in 1977 when survival was high. The only unusual conditions that occurred in 1982 and not in 1977 were below average temperature and below average salinity during peak abundance. Bayless (1972) reported better survival of larval striped bass in water exceeding 3 ppt than in freshwater and Lal et al. (1977) reported that optimal salinity increased with age of the larvae. Post yolk-sac were found further down river on the average in 1982 than in any other year of the study. These conditions may have exposed post yolk-sac larvae in 1982 to different predators, such as juvenile weakfish and bluefish, which are more typically found in oligohaline rather than freshwater environments.

White Perch

Several of the environmental factors we examined were found to be relatively unimportant in determining yolk-sac larvae survival (Table VII-7). Below average temperature during peak abundance was inconsistently associated with yolk-sac survival. Low temperatures occurred in 1981 when survival was lowest, but also occurred in 1985, which was the second highest year for yolk-sac survival (Fig. VII-6). Similarly, high salinity encroachment occurred in years of low (1983), intermediate (1980), and high (1985) survival. The index of entrainment vulnerability was highest in 1978, the year of highest survival. In addition, average salinity during peak abundance, dissolved oxygen, and sharp temperature rises did not occur in years of high or low survival, suggesting that these factors, at least in the ranges that occurred during the study period, do not greatly influence yolk-sac survival.

Table VII-7. Summary of white perch larval survival and environmental factors that may have influenced that survival in the Hudson River, 1974 to 1985

Survival		Temperature					Salinity							
Yolk-sac	Post Yolk-sac	Year	Drop	Rise	Below Average	Above Average	Low Encroachment	High Encroachment	Below Average	Above Average	Low Dissolved Oxygen	Large Flow Events	Long Exposure Duration	High Entrainment Vulnerability	Year
Average		1974	—	E,Y,P	—	E	X	—	—	E	—	—	—	E	1974
Average		1975	E,Y,P	—	—	E	—	—	—	P	—	E,P	—	E,P	1975
Average		1976	E,Y	—	—	P	X	—	—	—	—	E,Y	—	E	1976
Average		1977	E,Y,P	E,Y	—	Y	—	—	—	E	—	—	—	E	1977
High		1978	—	E	—	Y	—	—	—	—	—	—	—	Y	1978
Average	Average	1979	E,Y,P	—	E	—	X	—	—	—	P	—	—	P	1979
Average		1980	E,Y,P	—	—	—	—	X	—	—	—	—	—	—	1980
Average		1981	—	—	—	—	—	—	—	—	—	—	X	—	1981
Average		1982	E,Y,P	—	P	—	—	—	—	—	—	—	—	—	1982
Low		1983	E,Y	—	E,Y	P	—	X	—	—	—	E	—	P	1983
Average	Low	1984	E	E,Y	—	E,Y,P	—	—	—	—	—	E	—	—	1984
Average	Very low	1985	—	—	Y	—	—	X	—	—	—	—	X	—	1985

E = Event occurred when eggs were present.
Y = Event occurred when yolk-sac larvae were present.
P = Event occurred when post yolk-sac larvae were present.
X = Condition occurred in that year.
— = The condition did not occur when eggs or larvae of white perch were present in that year.

The environmental factors remaining that may adversely influence yolk-sac survival are temperature declines, and high flow events (Table VII-7). In 1983, the year of lowest survival, white perch yolk-sac exhibited a large, broad peak from 9-23 May and then a secondary, smaller peak in early June. Catches of post yolk-sac suggest that survival was greater for the second peak of yolk-sac larvae. The higher mortality for the earlier yolk-sac larvae may be attributable to the temperature decline (from around 15° C to about 12° C) that occurred in late May. This temperature change did not appear to decimate the early cohort, but may have reduced their survival, perhaps by increasing their lifestage duration and hence, their risk to predation. A similar pattern of a dual temporal peak occurred in 1976 in which the first peak of yolk-sac larvae appears to have had extremely low survival. However, in 1976 the mortality of the first peak corresponded to both a temperature drop and to large freshwater flows.

The year of low post yolk-sac survival (1985) was a year of high salinity encroachment and a long post yolk-sac/juvenile exposure duration (Table VII-7). In 1984, when survival was also low, the only unusual condition occurring during the period was above average temperature. Since no years of high survival were identified, it is not possible to further eliminate some of these potential factors affecting post yolk-sac survival.

Summary

The approach we used to identify environmental factors potentially leading to low survival of individual lifestages is limited in two ways. First, one must assume that the relative survival estimates accurately portray differences is survival among years. Since the lifestage duration of the eggs and yolk-sac larvae is shorter than the one week interval between sampling runs (Rogers et al. 1977), it is possible that relative abundance of a lifestage will be poorly estimated in years when many eggs are released over a very short time period. However, since a high abundance of striped bass and white perch eggs appears to occur over at least a three week period in most years (Figs. IV-5 and IV-16), it is unlikely that a single large spawn between sampling periods will highly influence relative between-lifestage survival estimates among years.

The second shortcoming is that inferences about environmental factors drawn from this approach are merely the result of correlation. They do not necessarily imply cause and effect nor do they eliminate other potential causes of mortality that could not be investigated with available data. However, it is interesting that two environmental factors, freshwater flow and temperature declines, were consistently found to be associated with low survival. High freshwater flows may wash the eggs or larvae downstream and into the water column where they may be more vulnerable to predators. Alternatively, high flows may increase turbidity, which at high levels can affect survival of striped bass and white perch larvae (Auld and Schubel 1978). No laboratory studies have directly tested the effects of temperature decline on larval survival, but survival of early life stages of both species has been shown in the laboratory to be temperature sensitive (Morgan and Rasin 1982; Morgan et al. 1981). Low temperatures or temperature declines have also been suggested to inhibit feeding and thereby affect survival (Dey 1981; Eldridge et al. 1981) though the importance of a temporary cessation in feeding has yet to be fully established (Boreman 1983; Rogers and Westin 1981).

The approach used here also allows us to identify those environmental factors that are unlikely to be significantly affecting mortality. This can be accomplished by identifying those factors which are consistently associated with years of average or high survival. Several variables, including high salinity, salinity encroachment, temperature increases, entrainment vulnerability, and exposure duration, appeared to fit in this category.

5. Concordance Between Ichthyoplankton Survival, Egg Abundance, and Year Class Strength

The objective of this chapter is to relate environmental variables to year class strength. In the previous section, relative survival of each lifestage was examined in relation to a list of environmental variables that may potentially affect survival of any particular lifestage. However, the strength of a year class is determined by both the number of individuals entering the population and the survival of those individuals in the first year. Therefore, the last step in the process is to determine at what lifestage(s) year class strength of striped bass and white perch have been determined in the Hudson River since 1974. Although, definitive conclusions can not be drawn since only three years for each species were classified as having high or low year class strength, several observations can be made.

Striped Bass

Striped bass year class strength seems to be related to two factors primarily: survival of post yolk-sac larvae and relative egg abundance. Of the three lifestages, survival of the post yolk-sac larvae appears to be most important (Fig. VII-5). Egg survival was high in 1982, a year of low year class strength. In 1977, a year of high year class strength, yolk-sac larvae survival was low. Therefore, relative survival of eggs and yolk-sac larvae does not consistently lead to lower year class strength. On the other hand, 1977 had high post yolk-sac survival and 1982 and 1985 had low post yolk-sac survival.

The relative abundance of eggs was also consistently related to year class strength for the three years that could be examined (Fig. VII-3). The second highest year of egg abundance occurred in 1977 while the lowest two years for egg abundance were 1982 and 1985, the two years classified as having low year class strength.

White Perch

For the three years in which relative year class strength of white perch could be determined, there seemed to be little correlation with larval abundance (Fig. VII-4). For example, the 1985 year class was poor, yet the relative abundance indices for yolk-sac and post yolk-sac larvae were high. On the other hand, low survival of post-yolk-sac corresponded to low year class strength of white perch. This was not always the case for yolk-sac larvae (e.g., 1985). Thus, for white perch in the Hudson River, environmental factors affecting the post yolk-sac stage appear to be of primary importance in determining year class strength for the three years for which such a determination can be made.

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