Martin Marietta
Environmental
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1984 YEAR CLASS REPORT FOR THE HUDSON RIVER ESTUARY MONITORING PROGRAM

VOLUME I - TEXT

Prepared for

Consolidated Edison Company
of New York, Inc.
4 Irving Place
New York, New York 10003

Jointly financed by

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

MARTIN MARIETTA

May 1986

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FOREWORD

The 1984 Year Class Report was prepared by Martin Marietta Environmental Systems 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 5-09070. The objective of this report is to summarize data collected from the 1984 Hudson River fish sampling surveys, water quality surveys, and the striped bass hatchery/recapture program.

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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] was a summary of 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) differed from previous reports in that there was a focus on 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 evaluation of power plant effects. The 1979 report (TI 1981) was expanded to include the life history and distributional information of an additional nine fish species. Data analysis for this report 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 Schonenhard 1981). The 1980-1981 Year Class Report [Battelle New England Marine Research Laboratory (Battelle) 1983] was the first Year Class Report 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 larval to juvenile stage. The 1982 Year Class Report [Normandeau Associates, Inc. (NAI) 1985a] was similar 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 as required by the Settlement Agreement. The 1983 report also included an evaluation of the relationship between environmental variables and the early life history of striped bass, white perch, and American shad.

The present report adds to the historical data base by describing the results of the 1984 Longitudinal River ichthyoplankton survey and the 1984 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 growth and mortality rates for five of the selected species (striped bass, white perch, Atlantic tomcod, American shad, bay anchovy)

- estimate year class strength (combined standing crop index) for striped bass and white perch

- describe rates and distribution of recaptured striped bass that were released in association with the hatchery program.

The report is organized into 10 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-VIII focus on the objectives outlined above. Within each of these chapters, individual species are discussed separately. Chapter IX discusses some of the assumptions associated with calculation of the estimates presented in this document. Chapter X presents the literature cited.

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*	Egg, YSL, PYS, YOY
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 1984 in order to assess 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 1984 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

Table II-1. Strata sampled by the Longitudinal River and Fall Shoals Programs within the 12 geographic regions of the Hudson River estuary during 1984

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

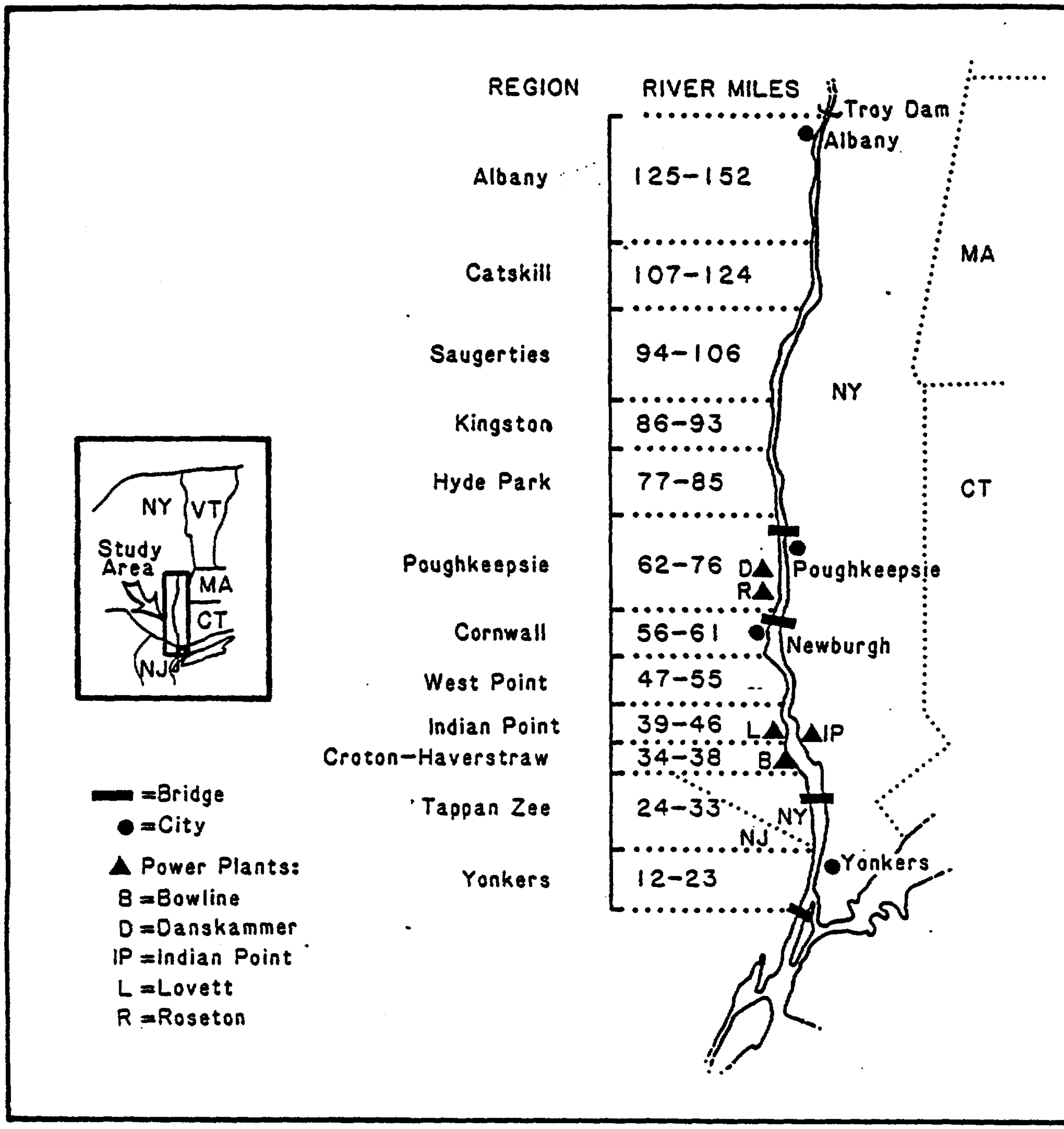
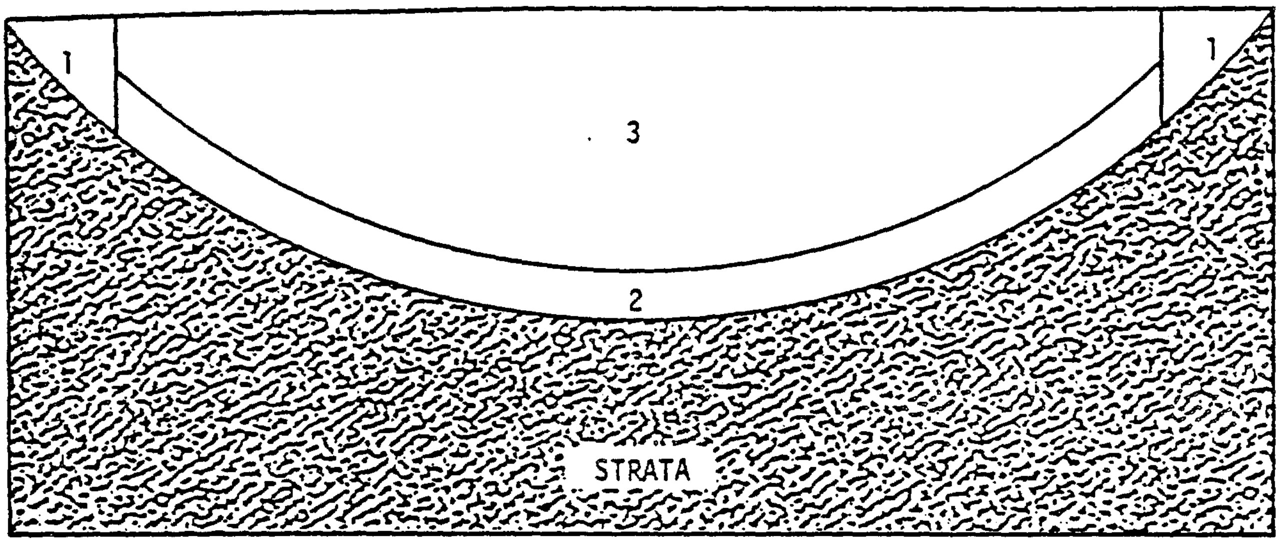


Figure II-1. Location of 12 geographic regions (with river mile boundaries) sampled during 1984 field sampling programs in the Hudson River estuary



1= Shoal [depths ≤ 20 ft (6 m)]
2= Bottom [bottom 10 ft (3 m) of depths > 20 ft (6 m)]
3= Channel [above bottom 10 ft (3 m) of depths > 20 ft (6 m)]

Figure II-2. Cross section of the estuary showing locations of the shoal, bottom and channel strata 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 three 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 was used for collecting samples in the channel, while a 1-m^2 epibenthic sled was used for collections in the bottom and shoal strata. Both gears had 3000-μm mesh nets and were towed against the current. The duration of each tow was 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 1984 sampling surveys in the Hudson River estuary

Name	Starting Date	Ending Date	Number of River Runs	Frequency of River Runs	Number of Samples Per River Run	Strata Sampled	Gear
Longitudinal River	8 May	12 Jul	10	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	16 Jul	25 Oct	8	Biweekly	200	Bottom	1 m^2 epibenthic sled
						Channel	1 m^2 Tucker trawl
						Shoal	1 m^2 epibenthic sled

Table II-2. Continued

Name	Starting Date	Ending Date	Number of River Runs	Frequency of River Runs	Number of Samples Per River Run	Strata Sampled	Gear
Beach Seine[(a)]	24 Jul	1 Nov	8	Biweekly	100	Shore zone	30.5 m beach seine and YSI models 57 and 33
LR/FS Water Quality	9 May	24 Oct	18	Biweekly	164	Shoal	YSI models 57 and 33
						Channel	YSI models 57 and 33

(a) Including beach seine water quality data

Table II-3. Weekly sample allocations for the 1984 Longitudinal River Survey during weeks beginning 30 April[a], 7 May, and 14 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[b]	25[c]	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[d]

[a] No samples were taken during the week of 30 April
[b] Six samples were taken during the week of 7 May
[c] Twenty-six samples were taken during the week of 7 May
[d] All samples were taken during the day

Table II-4. Weekly sample allocations for the 1984 Longitudinal River Survey during weeks beginning 21 May, 28 May, and 4 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	1	6	14	23
West Point	-	-	7	23	30
Cornwall	3	2	9	5	19
Poughkeepsie	-	-	16	22[a]	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[b]

[a] Twenty-three samples were taken during the week of 28 May

[b] All samples were taken at night

Table II-5. Weekly sample allocations for the 1984 Longitudinal River Survey during weeks beginning 11 June, 18 June, 25 June, 2 July, and 9 July

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

(a) Three samples were taken during the week of 9 July
(b) No samples were taken during the week of 11 June
(c) Seven samples were taken during the week of 18 June
(d) Thirteen samples were taken during the week of 18 June
(e) Three samples were taken during the week of 18 June
(f) An additional sample was taken with the epibenthic sled during the week of 18 June
(g) All samples were taken at night

Table II-6. Biweekly sample allocations for the 1984 Fall Shoal Survey during 16 July to 25 October

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

[a] Six samples were taken during the week of 27 August
[b] Two samples were taken during the week of 22 October
[c] Seven samples were taken during the week of 10 September
[d] All samples were taken at night

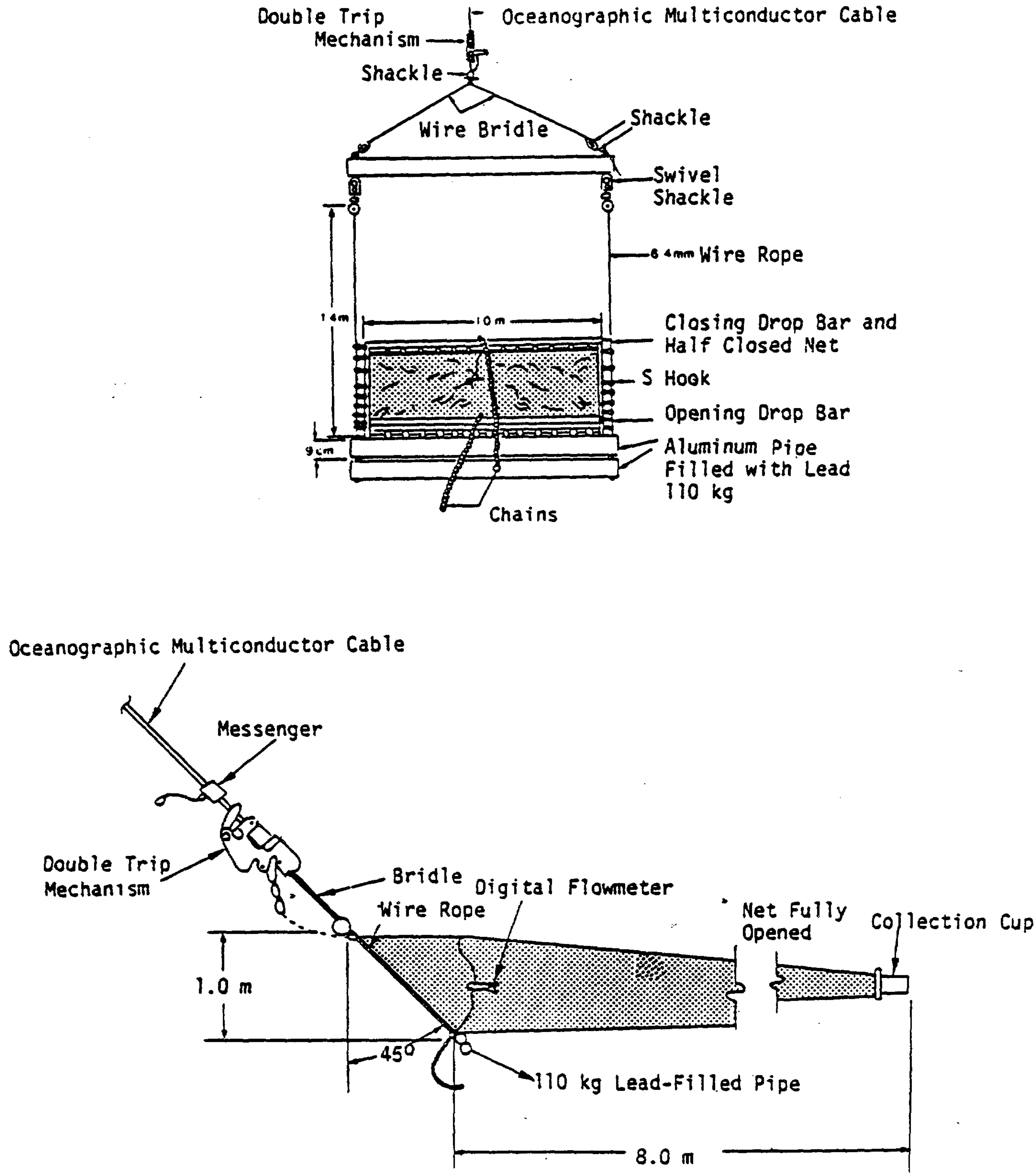
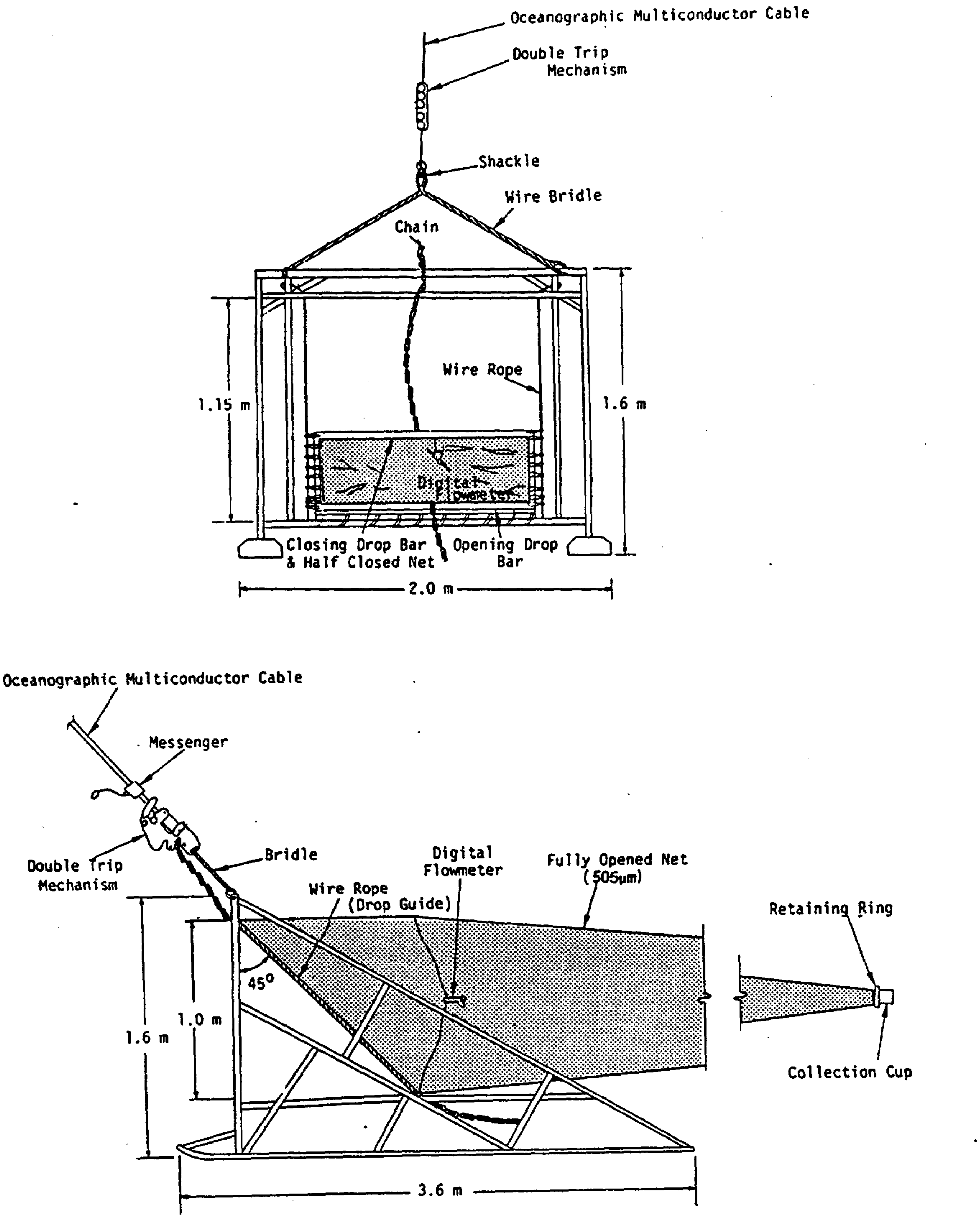
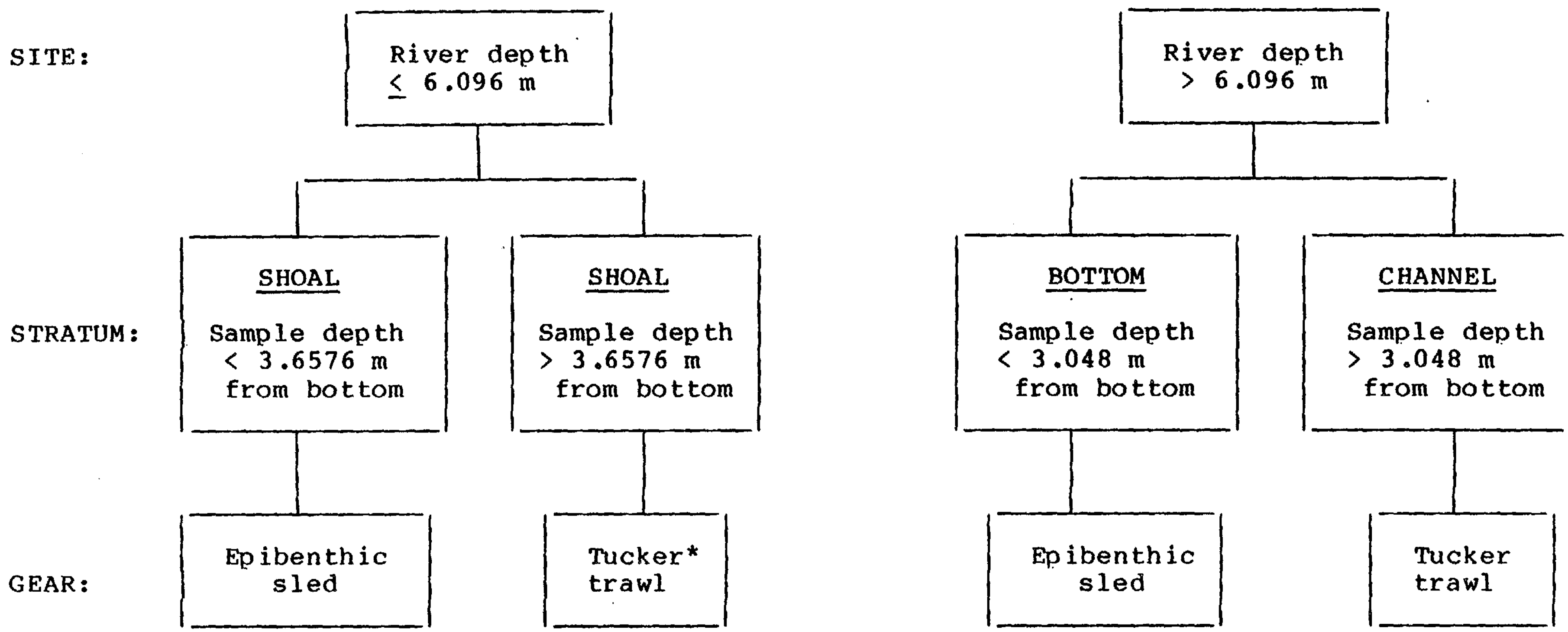


Figure II-3. 1.0 m^2 Tucker trawl (front view, top; side view, bottom) used in the Longitudinal River and Fall Shoals Surveys



II-4. 1.0 m^2 Epibenthic sled (front view, top; side view, bottom) used in the Longitudinal River and Fall Shoals Surveys. For the Fall Shoals Survey the net is fixed to the sled face and remains in an open position.



*FSS uses only the sled in the shoal stratum

Figure II-5. Criteria for gear and strata allocations in the Longitudinal River and Fall Shoals Surveys during 1984

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 with a 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 1984 Beach Seine Survey during 23 July to 1 November

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

[a] Seven samples were taken during the week of 6 August

[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 1984

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 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 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 1984 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 µS/cm, and sampling depth to the nearest 0.1 m.

Table II-10. Fish species for which length measurements (TL) were taken during 1984

Beach Seine and Fall Shoals Surveys

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

Longitudinal River Survey

American shad

striped bass

white perch

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

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

(a) No samples taken on river run 3
(b) No samples taken on river run 10
(c) No samples taken on river run 13
(d) No samples taken on river run 4
Dash indicates that no sample was taken due to limited stratum

E. STRIPED BASS HATCHERY RECAPTURE PROGRAM

During 1984, 147,153 fingerling striped bass were stocked in the Hudson River as part of an ongoing hatchery release program. Fish were stocked in four regions of the river from 6 August to 23 October. Of the total number stocked, 2.3, 42.4, 38.3, and 17.0% were released at the Yonkers, Tappan Zee, Croton-Haverstraw, and Indian Point regions, respectively.

Fish were marked with 1 mm long magnetic coded wire tags. Tags were attached to the cheek of each fish with Northwest Marine Technology tag injectors. During the first few weeks of the stocking program, fish had tags placed horizontally on the cheek, ventral to the eye. Because of poor tag retention, however, subsequent tags were vertically oriented. All fish receiving coded tags also had the dorsal fin clipped for easy identification. Total mortality associated with tagging and fin clipping was estimated to be 17.0% by retaining a subsample of fish for 72 hours after marking (EA Science and Technology 1985).

Each tag had a binary code indicating general time and region of stocking. In most cases, tag codes did not correspond to unique release dates and locations. However, each code generally corresponded to 1- to 3-day release periods.

Recapture information was obtained through the 1984 sampling of the Hudson River Impingement Programs, the Long River Ichthyoplankton and Fall Juvenile Surveys, and the NYSDEC Juvenile Beach Seining Program. Tagged fish were identified either visually in the field by the presence of a clipped dorsal fin or electronically in the laboratory by Northwest Marine Technology metal tag detectors. All marked fish were returned to the laboratory for verification of tag codes and length and weight measurements.

F. 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 volumes, 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).

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

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).

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

where

T = water temperature (°C)

P = pressure (dbar)

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

where

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

$$RT = (0.6765836) + (2.005294)(TD) + (1.11099)(TD^2) - (0.726684)(TD^3) + (0.13587)(TD^4)$$

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

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

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

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 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 additions 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

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

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.

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

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

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

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

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.

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

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)].

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

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).

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

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).

Table II-12. Stratum and region volumes (m^3) and surface areas (m^2) used in analysis of the 1984 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.

$$SC_{rw}{}^{*} = \sum_{k=1}^{3} SC_{krw} \tag{16}$$

where

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

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

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

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).

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

where

SC_w = standing crop estimate for week w

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

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*Unsampled strata were assigned the density of an adjacent stratum according to the rules for stratum volumes listed on page II-25.

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

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)].

$$SC_{rw} = \frac{C_{rw} \; A_r}{A} \qquad (20)$$

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

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

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 by life stage and taxon to facilitate presentation of changes in distribution of individual life stages through time and space. A geographic index which collapses the data over weeks, and a temporal index, which collapses data over regions, were calculated as the relative percentage of the standing crop in a region or a week [Eqs. (22) and (23)]. Thus, the index values range from 0 to 100 with greater values indicating higher standing crops relative to the total standing crop. These indices were calculated only for selected species and life stages when such summaries were necessary to clarify and distinguish patterns observed in the three-dimensional plots presented in Chapter IV.

$$G_r = \frac{\sum_{w=1}^{n} SC_{rw}}{\sum_{r=1}^{12} \sum_{w=1}^{n} SC_{rw}} \; 100 \qquad (22)$$

where

G_r = geographic distribution index for region r

SC_{rw} = regional standing crop calculated in Eq. (16)

n = number of weeks sampled.

$$T_w = \frac{SC_w}{\sum_{w=1}^{n} SC_w} \qquad (23)$$

where

T_w = temporal distribution index for week w

SC_w = weekly standing crop calculated in Eq. (18).

Weekly Combined Standing Crop

The weekly combined standing crop is an estimate of the abundance of white perch and striped bass young-of-year for each week of samples taken in the Hudson River between river miles 12 and 152. During the LRS this was accomplished by adjusting regional standing crop for gear efficiency and summing these values across all regions [Eq. (24)]. Gear efficiency for both the epibenthic sled and Tucker trawl was assigned a value of 0.5. Equation (25) was used for calculating the standard error of weekly combined standing crop during the LRS.

$$CSC_w = \sum_{r=1}^{12} \frac{SC_{rw}}{E_L} \qquad (24)$$

where

CSC_w = combined standing crop for week w during the LRS

SC_{rw} = regional standing crop calculated in Eq. (16)

E_L = gear efficiency adjustment for the LRS (0.5)

$$SE(CSC_w) = \sqrt{\sum_{r=1}^{12} \left[\frac{SE\ (SC_{rw})}{E_L}\right]^2} \qquad (25)$$

where

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

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

E_L = gear efficiency adjustment for the LRS (0.5)

During the fall surveys, weekly combined standing crop was estimated by a six-step process used to combine data from the Fall Shoals and Beach Seine surveys:

- Adjust the standing crop of the shoal stratum for area sampled in the shore zone

- Sum the stratum standing crops within a region for each survey
- Adjust regional standing crop estimates from each survey for gear efficiency
- Sum the regional standing crops for each week for each survey
- Estimate standing crops for unsampled weeks of each survey
- Combine weekly standing crop estimates from the two surveys.

The standing crop 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 reduce 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 shore zone contains 25% of the shoal stratum water if the bottom slopes uniformly from 0 to 6 m.

The regional standing crop estimates were then adjusted for gear efficiency. For Fall Shoals samples, gear efficiency for both the epibenthic sled and the Tucker trawl was assigned a value of 0.5. Species-specific gear efficiency adjustments designed to account for night/day differences between the two fall surveys were used for BSS data. The beach seine catch efficiencies were empirically estimated (TI 1978b, 1979b) as 0.255 for juvenile striped bass and 0.182 for juvenile white perch. The night/day ratios were 2.136 and 1.685 for striped bass and white perch, respectively.

After the Fall Shoals and Beach Seine regional standing crops were adjusted, the 12 regional values were summed to estimate the adjusted standing crop for each week sampled. These four steps are summarized for the BSS and FSS in Eqs. (26 and 27), respectively.

$$SC_{w,B} = \sum_{r=1}^{12} (SC_{rw,B}) \frac{C}{R} \qquad (26)$$

where

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

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

C = catch efficiency of beach seine during the day

R = ratio of night/day beach seine catches.

$$SC_{w,F} = \sum_{r=1}^{12} \left[\frac{1}{E_F} \left[(0.75)(SC_{k=1,r,w}) + \sum_{k=2}^{3} SC_{krw} \right] \right] \quad (27)$$

where

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

E_F = gear efficiency adjustment for the FSS (0.5)

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

k=1 = shoal stratum

k=2 = bottom stratum

k=3 = channel stratum

FSS and BSS sampling was conducted in alternate weeks. Therefore, for weeks when the shore zone was not sampled, the standing crop for that stratum was set equal to that of the previous week. Standing crops missing from the FSS data were assigned the mean of the standing crops for the previous and the following weeks.

The final step in the calculation of weekly combined standing crop was to add the BSS adjusted weekly standing crop to the FSS adjusted weekly standing crop to obtain a weekly estimate incorporating data from both surveys.

Equation (28) was used to estimate the standard error of the adjusted standing crop for the FSS and Eq. (29) was used to estimate the standard error of the BSS adjusted standing crop. The standard error of the weekly combined standing crop was computed as the square root of the sum of the squared estimates [Eq. (30)].

$$SE(SC_{rw,F}) = \sqrt{\left[\frac{(0.75)SE(SC_{k=1,r,w})}{E_F}\right]^2 + \left[\frac{SE(SC_{k=2,r,w})}{E_F}\right]^2 + \left[\frac{SE(SC_{k=3,r,w})}{E_F}\right]^2} \quad (28)$$

where

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

$SE(SC_{krw})$ = standard error of stratum standing crop calculated in Eq. (14)

E_F = gear efficiency adjustment for the FSS (0.5)

k=1 = shoal stratum

k=2 = bottom stratum

k=3 = channel stratum.

$$SE(SC_{rw,B}) = SC_{rw} \quad \frac{VR}{R^2} + \frac{VC}{C^2} + \frac{[SE(SC_{rw})]^2}{SC_{rw}{}^2} \quad (29)$$

where

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

SC_{rw} = regional standing crop calculated in Eq. (20)

VR = variance of night/day catch ratio

R = night/day catch ratio

VC = variance of beach seine catch efficiency

C = catch efficiency of beach seine during the day

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

$$SE(CSC_w) = \sqrt{\sum_{r=1}^{12} \left[SE(SC_{rw,F})^2 + SE(SC_{rw,B})^2 \right]} \quad (30)$$

where

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

$SE(SC_{rw,F})$ = standard error of adjusted standing crop for the FSS calculated in Eq. (28)

$SE(SC_{rw,B})$ = standard error of adjusted standing crop for the BSS calculated in Eq. (29).

Combined Standing Crop Index

The combined standing crop index is a measure of year class strength of juvenile fish which has been calculated for white perch and striped bass since 1976. This index was calculated for 1984 data using the standard analytical methods (Battelle 1983). For striped bass, the calculation involves three steps:

- Weekly combined standing crops for juveniles were plotted and visually inspected to determine the week(s) of peak abundance.
- The geometric mean of the peak abundances was calculated to yield an estimate of the peak abundance for the midpoint of the period of highest weekly combined standing crop.
- This geometric mean was extrapolated using Eq. (31) to estimate abundance on 1 August.

For white perch, the index is calculated similarly, except that all weeks from July to early September are used instead of just the peak week(s). The geometric mean of the combined standing crop from these weeks was calculated and extrapolated to yield an estimate of 1 August abundance using the same procedures as for striped bass [Eq. (31)].

$$CSC_0 = \frac{CSC_t}{e^{-zt}} \tag{31}$$

where

CSC_0 = predicted combined standing crop on day 0 (1 August)

CSC_t = peak combined standing crop on day t

t = time between the midpoint of the peak abundance period and 1 August

z = instantaneous mortality rate.

An instantaneous daily mortality rate (z) of 3.79×10^{-3} was calculated from the annual mortality rate, using Eq. (32).

$$z = \frac{-\ln (1 - A)}{D} \tag{32}$$

where

z = instantaneous mortality rate

A = annual mortality rate = 0.75 (Battelle 1983)

D = number of days in the year.

<u>Summer and Fall Regression Indices</u>

Two alternative methods for calculating a combined standing crop index were developed in the 1982 and 1983 Year Class Reports (NAI 1985a, 1985b). The first index, referred to as the summer regression index, is calculated by regression of weekly combined standing crop data from the week including 1 August to the week including 10 October to estimate standing crop on 1 August. The second method, referred to as the fall index is calculated by regression of weekly combined standing crop data from the first week of September to the first week of October to estimate standing crop on 15 September. When regression is insignificant, the index is calculated as a geometric mean. When the indices are calculated as a geometric mean of weekly combined standing crop data (as they were for 1984 data), the standard error is used to estimate 95% confidence intervals around the geometric mean ($\bar{x} \pm t_{n-2} * SE$).

Beach Seine Index

Another index that has been historically used to assess year class strength of young-of-year striped bass and white perch is the beach seine index (number of fish per 10,000 ft^2 or 929 m^2). This index is based on average catch from the Beach Seine Survey and is calculated using Eq. (33). Only data from samples taken in the Yonkers to Cornwall regions from mid-July through the end of September are used to calculate the index for striped bass, and catch data from all 12 regions between mid-July and mid-October are used to compute the index for white perch.

$$I = \frac{\sum_{w=w_s}^{w_e} \sum_{r=r_s}^{r_e} (C_{rw})(n_{rw})}{(N)(A)} (929) \qquad (33)$$

where

I = beach seine index

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

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).

Growth

Estimates of larval and juvenile growth rates were made from length data collected in the three surveys during 1984. The standard methods that have been used to calculate growth in previous years are described in this section.

For American shad, striped bass, and white perch, two estimates of the average daily growth rate were made: 1) growth rate between hatching and the size at which each species is fully recruited to the beach seine, and 2) growth rate between this recruitment size and 60 mm. Recruitment size has been defined in previous Year Class Reports as 25 and 30 mm for white perch and striped bass, respectively (TI 1980b). Since no estimate for recruitment size of American shad has been identified in previous Year Class Reports, recruitment size for this species was defined as 30 mm, based on 1984 data.

The dates that mean length of the population reached recruitment size and 60 mm were determined for each species by regression in the form of Eq. (34). Weekly mean lengths for young-of-year fish collected during the BSS from the first sampling period in July to the first week when the mean length exceeded 60 mm total length (TL) were used as input to the regression. Once the slope and the intercept were calculated, Eq. (34) was solved to estimate the dates when recruitment size and 60 mm were reached.

$$\ln(L_t) = \ln(L_0) + \beta(T_1) \qquad (34)$$

where

L_t = mean length at time t

L_0 = predicted mean length at time 0 (arbitrarily defined as 1 May)

β = estimated instantaneous growth rate

T_1 = number of days since 1 May at mean length 1.

The date of hatching for striped bass was defined as the midpoint of the week of peak egg abundance. Since the eggs of white perch and American shad are demersal, the peak period of egg abundance in LRS samples may not be a good indicator of actual egg abundances. Therefore, the peak period of yolk-sac larvae abundance (determined by weekly standing crops) was used instead.

Using these dates, the growth rates from hatching to recruitment size were calculated using Eq. (35), and growth rates from recruitment size to 60 mm were calculated using Eq. (36).

$$G_L = \frac{r - L_0}{T_r - T_0} \qquad (35)$$

where

G_L = growth rate of larvae and early juveniles between hatching and recruitment size

r = TL (mm) at which recruitment to the beach seine is complete

L_0 = mean length of yolk-sac larvae (or length at hatching for striped bass)

T_r = number of days since 1 May when length r was reached, estimated using Eq. (35)

T_0 = number of days since 1 May to the midpoint of the week of peak egg (or yolk-sac larvae) standing crop.

$$G_J = \frac{60 - r}{T_{60} - T_r} \qquad (36)$$

where

G_J = growth rate of juveniles between recruitment size and 60 mm TL

T_{60} = number of days since 1 May when 60 mm TL was reached, estimated using Eq. (35).

These methods could not be applied to Atlantic tomcod and bay anchovy. Atlantic tomcod are spawned during winter and mean lengths exceed 60 mm during the entire beach seine and fall shoals surveys. Bay anchovy spawn throughout most of the summer and young-of-year are therefore not fully recruited to the population at the start of the juvenile surveys. For these species, growth rates were estimated as the average change in size per day during the fall surveys [Eq. (37)].

$$G = \frac{L_n - L_0}{T_n - T_0} \qquad (37)$$

where

G = average daily growth rate

L_n = mean length during the last week of sampling

L_0 = mean length during the first week of sampling

T_n = number of days since 1 May for the last week of sampling

T_0 = number of days since 1 May for the first week of sampling.

Mortality

Estimates of daily mortality rate were made for the striped bass, white perch, American shad, Atlantic tomcod, and bay anchovy 1984 year classes. Mortality during the larval stages was estimated for striped bass, white perch, and American shad using LRS data. Juvenile mortality rates were estimated for all five species from BSS and FSS combined standing crop data.

Larval mortality was calculated as the exponential rate of decline of the population from the time of peak combined standing crop during LRS (yolk-sac larvae, post yolk-sac larvae, and young-of-year combined) until the end of that survey [Eq. (38)]. Mortality of young-of-year fish was calculated as the rate of exponential population decline from the time of peak juvenile abundance (CSC) during the FSS and BSS programs until the end of sampling for 1984 [Eq. (38)]. The instantaneous rates of mortality were converted to daily and annual rates using Eqs. (39) and (40), respectively.

$$\ln (CSC_w) = \ln (CSC_0) - (U)(t_w) \qquad (38)$$

where

CSC_w = weekly combined standing crop calculated in Eq. (29)

CSC_0 = predicted weekly combined standing crop for 1 May*

U = instantaneous rate of population decline

t_w = number of days since 1 May* during week w.

* 1 August is used for calculating juvenile mortality

$$z = 1 - e^{-U} \qquad (39)$$

where

z = daily rate of population decline

U = instantaneous rate of population decline calculated in Eq. (38).

$$A = 1 - e^{366z} \qquad (40)$$

where

A = annual mortality rate based on the daily rate of population decline

z = daily rate of population decline calculated in Eq. (39).

G. ASSUMPTIONS ASSOCIATED WITH ANALYSIS OF YEAR CLASS DATA

Throughout this report summary statistics are calculated according to standard methods developed in previous Year Class Reports. In Chapter IV, estimates of mean regional density and standing crop are presented. Estimates of larval and juvenile growth rate and mortality rate are presented in Chapters V and VI, respectively, and indices of juvenile abundance are discussed in Chapter VII.

Each of these summary statistics is designed to provide information about biological processes occurring in the Hudson River. However, proper interpretation of these summary statistics requires that each be an unbiased estimator with known variance. A biased estimator could lead to incorrect conclusions about the population. This section identifies some of the assumptions associated with calculation of summary statistics in this report and discusses how failing to meet these assumptions might lead to bias in the summary statistic or to an error in the estimate of variance.

Estimates of regional density and standing crop are used to identify spatial and temporal changes in the distribution of some Hudson River fish species. There are three major assumptions inherent in these estimates: 1) collection gear in the LRS and FSS are 100% efficient in collecting all sizes and species of concern, 2) the entirety of each stratum in each region was randomly sampled, and 3) the volume and area constants assigned to each stratum and region are correct. Differences in gear efficiency among locations, an inability to sample parts or all of some strata (Table II-1), or incorrect volume and area constants could lead to biased density estimates and incorrect conclusions about population distributions and/or movements.

Growth rate is estimated as the change in weekly mean length of a fish population. Weekly mean lengths for species are determined by calculating the mean length for each life stage and then taking the average of these means weighted by standing crop. Interpretation of growth rate estimates therefore depends on the validity of the assumptions associated with calculation of both standing crop and mean length. The latter calculation assumes that all size classes for which growth estimates are made were captured with equal efficiency. The potential bias associated with this assumption is particularly relevent since different gear were used to collect different life stages.

Weekly combined standing crop is estimated by adjusting standing crop data for gear efficiency and stratum overlap in the BSS and FSS programs. In addition to assumptions associated with the standing crop data the weekly combined standing crop estimates include two additional major assumptions: 1) the gear efficiency adjustments are independent of fish size and geographic region and 2) the shore zone includes 25% of the shoal volume. Unaccounted for variation in gear efficiency due to fish length would affect weekly standing crop estimates differentially among weeks as mean fish size increases. Differences in shore zone surface area among regions could also substantially bias weekly combined standing crop estimates since a large proportion of fish are collected in the shore zone (e.g., Figs. VII-3 and VII-6).

Mortality is estimated from declines in weekly combined standing crop. In addition to the assumptions associated with weekly combined standing crop, mortality estimation assumes that no immigration to or emigration from the study area occurs during the weeks from which mortality is calculated. If fish that are spawned in tributaries move into the Hudson River during the sampling program, mortality rate would be underestimated. In contrast, if fish emigrate from the study area during the sampling program, mortality rates would be overestimated.

Several indices of year class strength for juvenile white perch and striped bass are presented in Chapter VII. For the striped bass CSC index, peak weekly combined standing crop estimates for juveniles are extrapolated to a population size estimate on 1 August. In addition to the assumptions associated with calculation of weekly combined standing crop, calculation of the combined standing crop index assumes that the identified peak value corresponds to the true peak in population abundance. The validity of this assumption depends on two major factors: 1) all young-of-year have reached gear-recruitment size and 2) emigration and gear avoidance have not occurred. If the selected peak is an outlier rather than a true peak, comparison of the index among years could be misleading. The effect of the method used for selecting the period of peak abundance on the estimate was addressed qualitatively by Battelle (1983).

In addition to abundance indices based on weekly combined standing crop, an index based on beach seine catch is also provided. This index is the riverwide average of catch per unit effort. This method assumes that the percentage of the total population occurring in the shore zone is constant among years. Events that caused fish to remain in the channel and bottom strata would lead to an underestimate of abundance. Second, because sampling effort in the BSS is not evenly distributed in the river (Table II-7), and no correction is made for level of effort in a region, this method also assumes that distribution of fish longitudinally along the river does not vary among years. Greater sampling effort in areas where fish concentrations are high could lead to an overestimate of riverwide fish abundance.

The estimates of standard error for each of the summary statistics would also be affected by deviation from the assumptions discussed above. In addition, there are several potential sources of variance that are unaccounted for in the present year class analysis procedures. If, for instance, there is a substantial variance associated with the volume estimate for each ichthyoplankton sample (i.e., differences among flow meters) or there is unmeasured variability associated with the area sampled by the beach seine (i.e., it is not always equal to 450 m^2), then the estimates of standard error associated with standing crop and weekly combined standing crop in this report could be misrepresentative.

It is unlikely that all of the assumptions made in deriving the summary statistics are entirely met. Any violation of assumptions could bias the estimates. Throughout this report the summary statistics are used to describe distribution, infer movement and estimate growth, mortality and abundance. Without detailed examination of the validity of the assumptions and a sensitivity analysis to determine their importance, the degree of bias associated with these estimates remains unknown and the ability to draw conclusions from these data is impaired.

In addition, these summary statistics are compared with similar estimates derived in previous Year Class Reports to describe differences in distribution, growth, mortality, and abundance among years. When appropriate, physicochemical or biological explanations are offered as possible reasons for year-to-year differences in these estimates. However, until the assumptions associated with calculation of these estimates are verified and the year-to-year differences examined in a rigorous analytical manner, the nature of these differences and their statistical validity should be accepted with caution.

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 further interpret water quality patterns in the Hudson River.

A. TEMPERATURE

Mean water temperature measured during the LR/FS water quality survey increased from May to mid-August and then decreased gradually until the end of the sampling program in late October (Table III-1). Peak temperatures occurred during the week beginning 13 August when regional mean values were between 17.5 and 27.1°C (Table A-1). Lowest values occurred during the first week of sampling when mean regional temperatures ranged from 7.8 to 14.3°C.

Comparison of the temporal pattern in 1984 (Fig. III-1) with historical data indicates that the mean temperature in the upper estuary increased above 12°C later in the season than in most previous years (e.g., NAI 1985a, 1985b; TI 1981; Battelle 1983). Historical data indicate that peak temperatures have been observed in August in most previous years, but the 1984 highest weekly mean of 25.4°C was 2-3°C lower than in previous years.

The highest mean regional temperatures (pooled over all dates) were found in the Croton-Haverstraw and Indian Point regions, but there was relatively little difference in mean temperature from the Yonkers to Hyde Park regions (Table III-2). However, from Kingston to Albany there was a downward trend in mean temperature, with the Albany region temperature averaging almost 8°C less than the temperature at Indian Point. The lower temperatures upriver were not a function of anomalously low temperatures during a few weeks; rather, water temperatures measured at Albany were lower than in other regions during every week of the study (Table A-1).

Table III-1. Weekly mean temperature, salinity, and dissolved oxygen measured in the LR/FS water quality survey of the Hudson River in 1984

Week Beginning	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
7 May	13.4	0.4	9.8
14 May	13.3	0.1	9.8
21 May	14.8	1.0	9.7
28 May	14.3	0.6	10.7
4 June	15.3	0.0	10.1
11 June	20.0	1.0	8.7
18 June	21.0	1.3	7.9
25 June	22.2	2.9	8.4
2 July	23.6	1.8	7.5
9 July	23.4	1.0	7.7
16 July	25.0	0.8	7.3
30 July	24.6	2.9	7.1
13 August	26.6	2.8	6.6
27 August	25.0	2.6	7.0
10 September	23.2	3.3	7.7
24 September	21.3	2.8	7.8
8 October	17.0	3.7	8.6
22 October	17.0	4.0	8.5

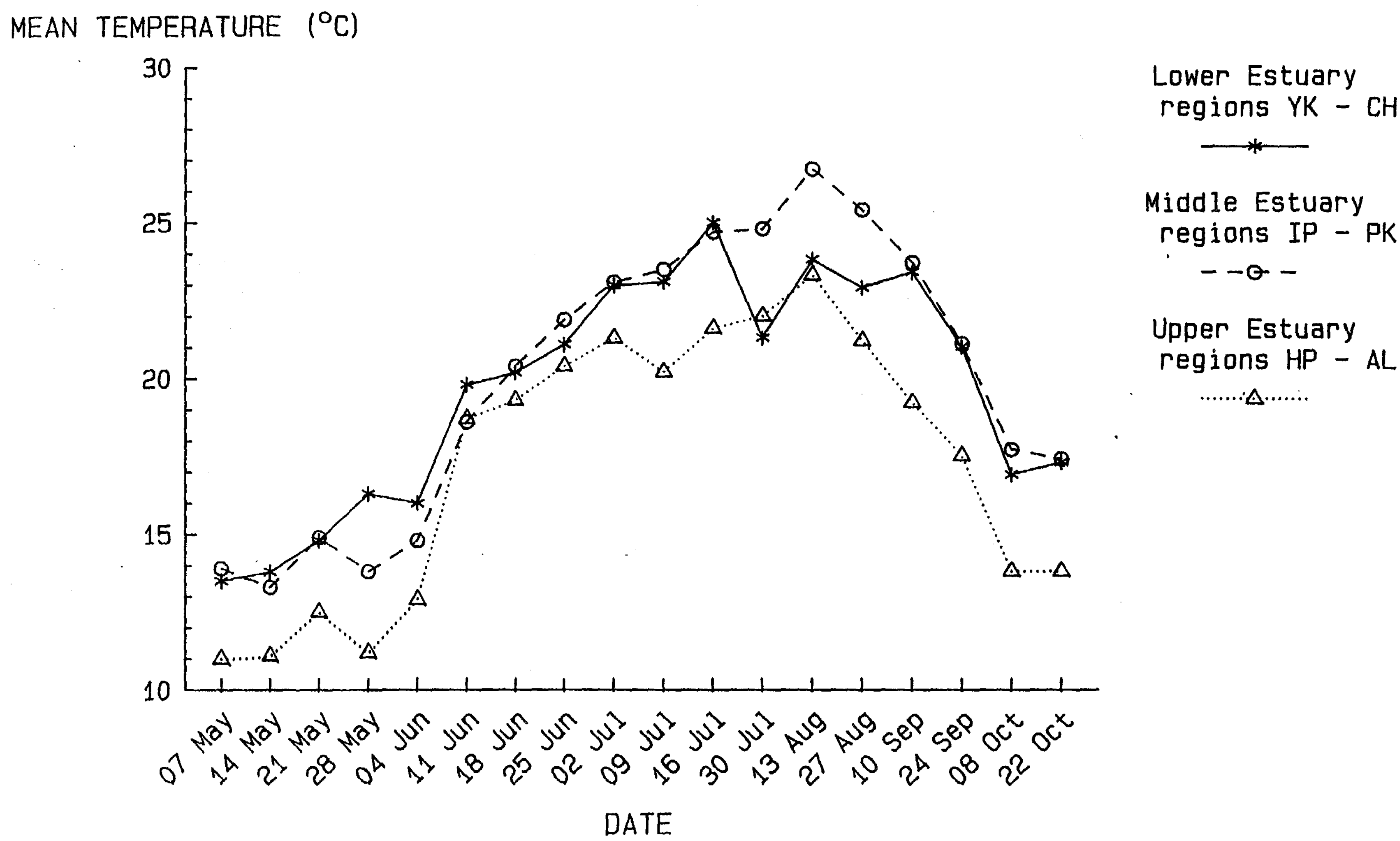

Figure III-1. Weekly mean temperature measured in the LR/FS water quality survey of the Hudson River in 1984

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 1984

Region[a]	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
YK	19.6	8.2	7.5
TZ	20.2	4.0	8.5
CH	20.4	2.6	8.5
IP	20.5	1.7	8.0
WP	19.8	0.8	7.9
CW	20.1	0.4	8.2
PK	19.7	0.0	8.0
HP	19.6	0.0	8.4
KG	18.1	0.0	8.1
SG	17.6	0.0	8.1
CS	15.7	0.0	7.4
AL	12.8	0.0	5.6

[a] See Table II-1 for explanation of region abbreviations.

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 1984

Region[a]	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
YK	19.6	8.2	7.5
TZ	20.2	4.0	8.5
CH	20.4	2.6	8.5
IP	20.5	1.7	8.0
WP	20.1	0.8	8.0
CW	20.1	0.4	8.2
PK	20.1	0.0	8.2
HP	19.9	0.0	8.5
KG	19.9	0.0	8.9
SG	19.9	0.0	9.1
CS	20.0	0.0	9.4
AL	20.0	0.0	8.8

[a] See Table II-1 for explanation of region abbreviations.

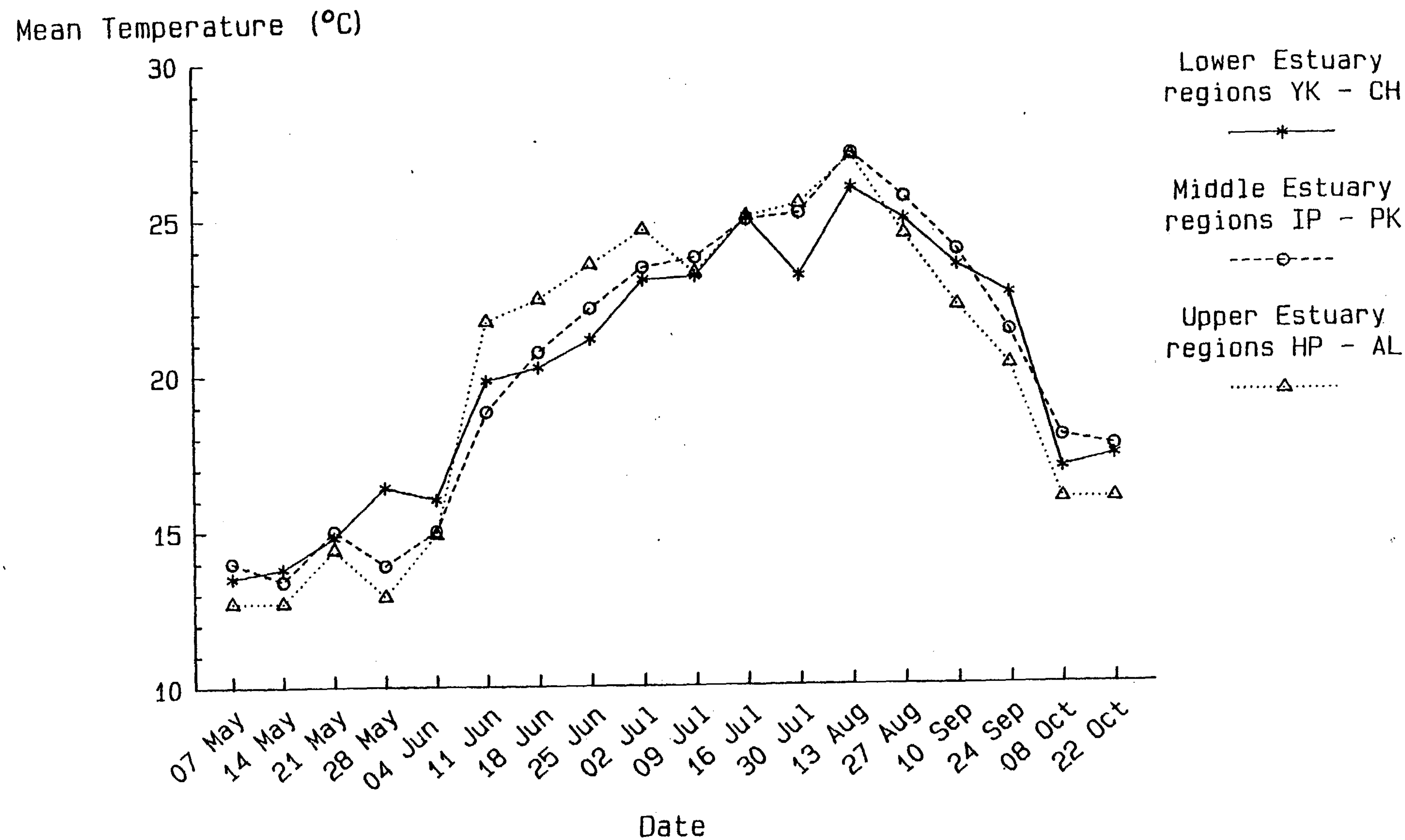

Figure III-1. Weekly mean temperature measured in the LR/FS water quality survey of the Hudson River in 1984

Comparison of the spatial temperature pattern in 1984 with historical spatial patterns can only be made by estuary segment because the data were pooled into upper, middle and lower segments in previous Year Class Reports. Temperatures were consistently lower in the upper estuary than in the middle and lower estuary in 1984 (Fig. III-1). In previous years, temperatures for the upper estuary have been lower than the rest of the river only in the late fall period. However, pooling of data in this manner prevents examination of patterns in a particular region. For example, it is unclear whether temperature at Albany has been lower than in other regions in previous years as it was in 1984.

Vertical temperature patterns within regions were examined by comparing surface and bottom measurements at each sampling station. Surface temperatures were generally higher than bottom temperatures, but differences were not great (Fig. III-2). The greatest difference observed was 3.2°C; however, in 97% of the region-week combinations, the difference was less than 1°C.

Mean temperatures for each region and week sampled in the BSS are presented in Table A-2. Peak temperatures occurred during late July from West Point through Poughkeepsie, and during the beginning of August for all other regions. Mean temperature (pooled over weeks) varied by less than 3°C among regions, with the highest mean in the Indian Point region and the lowest in the Albany region (Table III-3).

Temperatures measured during the BSS were similar to values from the LR/FS water quality survey for all regions except the two farthest upriver (Tables A-1 and A-2). BSS temperatures were within 2°C of LR/FS values for Yonkers through Cornwall regions during the July-October period when the BSS was conducted. From Poughkeepsie through Saugerties, BSS temperatures were within 3°C of LR/FS values. However, in the Catskill and Albany regions, BSS temperatures averaged 6°C higher than LR/FS values, and differed by as much as 9°C.

B. SALINITY

Mean weekly salinity measured during the LR/FS water quality survey generally increased from May through October (Table III-1). The lowest mean salinity in the estuary occurred during the week of 4 June, when the entire sampling area was freshwater (Table A-5). The highest weekly mean value of 4.0 ppt occurred during the final week of the study.

This salinity pattern can be explained, in part, by patterns of freshwater flow (Table III-4). During May, mean flow was 844 m^3/sec. Average flow dropped by more than half in June (to

Table III-3. Regional mean temperature, salinity, and dissolved oxygen values (pooled over all weeks) measured in the Hudson River Beach Seine Survey in 1984

Region[a]	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (ppm)
YK	21.0	8.6	8.2
TZ	21.6	6.0	9.2
CH	22.1	4.5	9.2
IP	22.9	3.7	8.4
WP	22.3	1.3	8.0
CW	21.8	0.4	8.7
PK	22.2	0.1	8.2
HP	21.4	0.0	9.4
KG	21.4	0.0	10.7
SG	20.7	0.0	10.2
CS	21.0	0.0	10.4
AL	20.4	0.0	8.6

[a] See Table II-1 for explanation of region abbreviations

Table III-4. Long-term and 1984 mean freshwater flow (m^3/sec) at Green Island, New York

	Flow (m^3/sec)			
Month	1984	Long-Term Average	Long-Term Minimum	Long-Term Maximum
Jan	308	363	91	961
Feb	742	356	86	885
Mar	465	645	178	1595
Apr	940	887	290	1461
May	844	557	137	1156
Jun	418	275	92	839
Jul	289	193	81	637
Aug	176	158	70	414
Sep	190	181	81	612
Oct	182	238	72	854
Nov	277	353	93	929
Dec	448	404	123	948
ANNUAL AVERAGE	438	384		

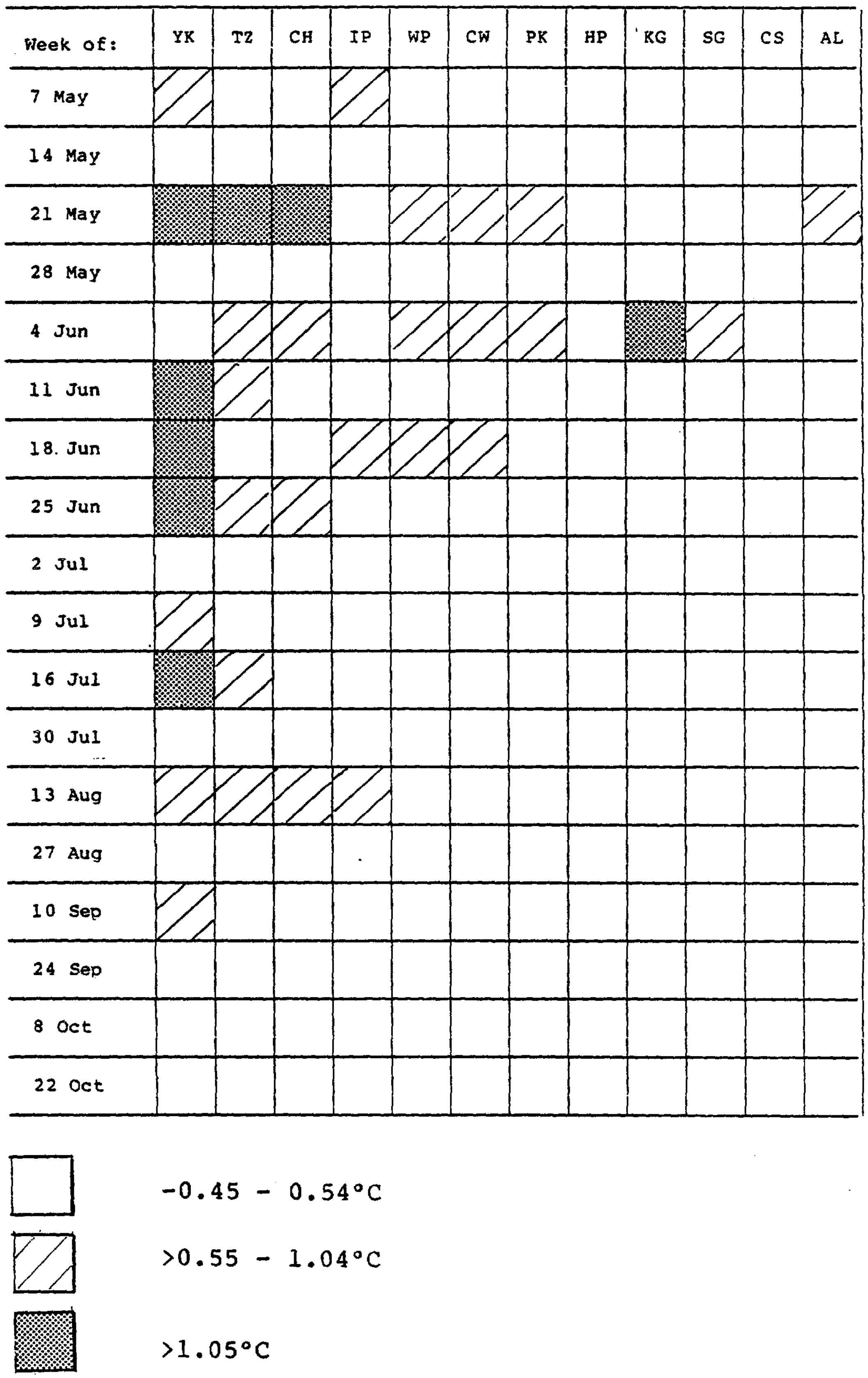

Figure III-2. Surface-to-bottom differences in mean water temperature (°C) from measurements taken during the Longitudinal River/Fall Shoals Water Quality Survey in 1984

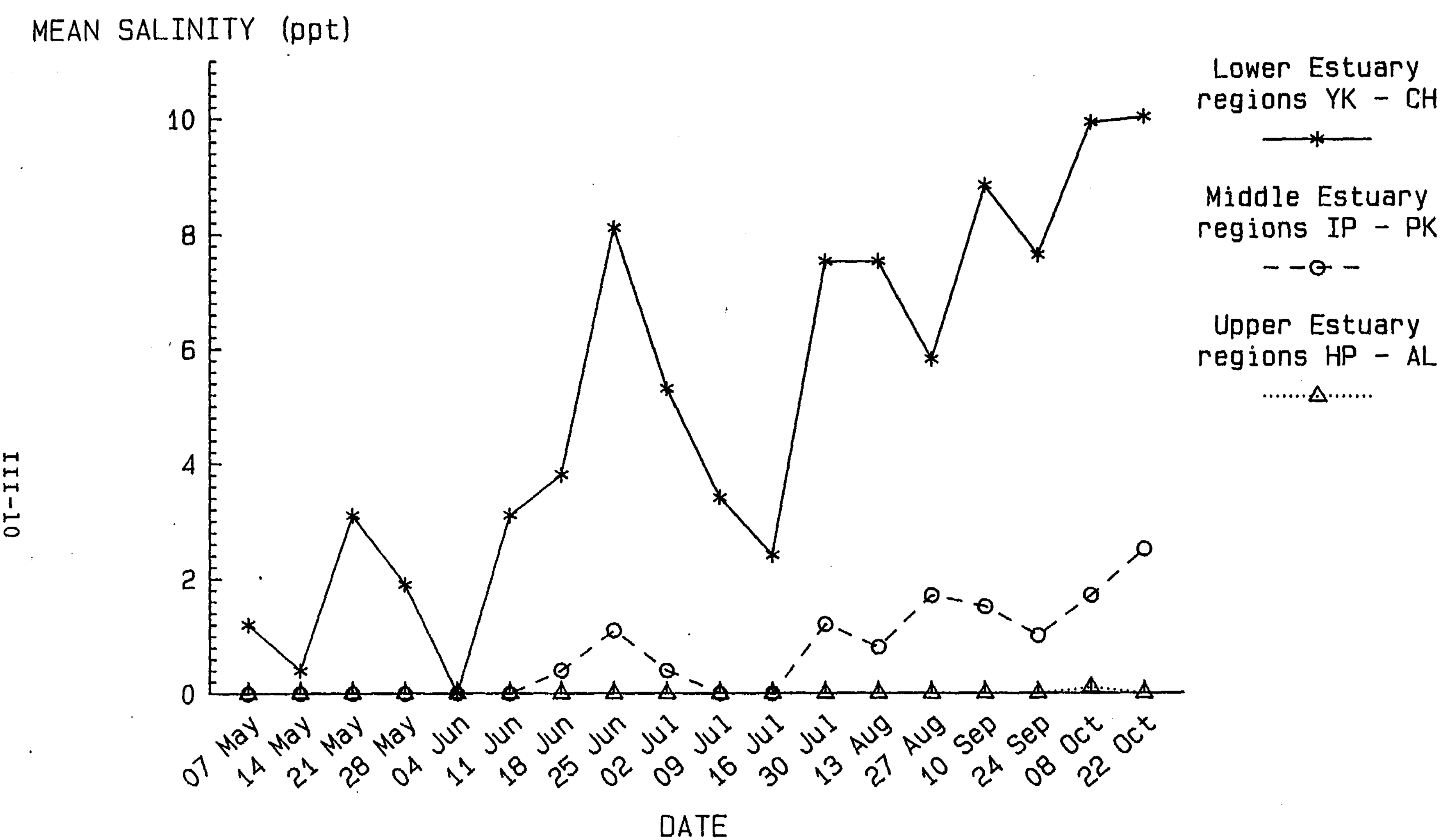

Figure III-3. Weekly mean salinity measured in the LR/FS water quality survey of the Hudson River in 1984

418 m^3/sec) and by another 42% in August (to 176 m^3/sec). Just prior to the incidence of river-wide freshwater in June, flow reached a 1984 maximum of 2945 m^3/sec (30 May).

As might be anticipated, mean salinity was highest in the Yonkers region and declined quickly with distance upriver (Table III-2). The highest value and the highest weekly mean in the Yonkers region were 18.5 and 14 ppt, respectively (Table A-5). The most upriver region with a mean salinity greater than zero was Cornwall.

Similar to previous years, salinity in the lower estuary during 1984 was consistently higher from May through October than in the middle and upper segments for the same period (Fig. III-3). A large decline in salinity during July, such as that observed in 1984, has not been noted in previous Year Class Reports (1979-1983). The mean salinity in the upper estuary remained at or near zero throughout the study period.

Bottom salinity was higher than surface values at downriver regions (Figure III-4). At Yonkers, mean weekly surface-to-bottom differences averaged 3.2 ppt, and were as high as 9.5 ppt. This pattern is typical of a stratified estuary where more dense, saline water moves upriver along the bottom.

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 (Tables III-2 and III-3); mean weekly salinity never exceeded 0.5 ppt in any region north of Cornwall (Tables A-5 and A-6). In all regions (except Indian Point) where salinity exceeded 0.5 ppt, higher mean salinities were observed in the LR/FS survey (Table A-5) than in the BSS (Table A-6). This difference was less than 1 ppt for every region except Yonkers where BSS salinity was 2.5 ppt lower than that recorded during the LR/FS survey.

C. DISSOLVED OXYGEN

Dissolved oxygen values measured during the LR/FS water quality survey were highest in the spring with weekly mean values for the river exceeding 9 ppm until mid-June (Tables III-1 and A-7). Dissolved oxygen values were lowest in mid-summer with weekly mean values falling below 7 ppm from the end of July through the end of August. Dissolved oxygen values increased again in the fall.

Temporal dissolved oxygen patterns were highly correlated with water temperature ($r^2 = 0.9$, $p < 0.001$; Fig. III-5). This may be partially due to the fact that water is saturated with

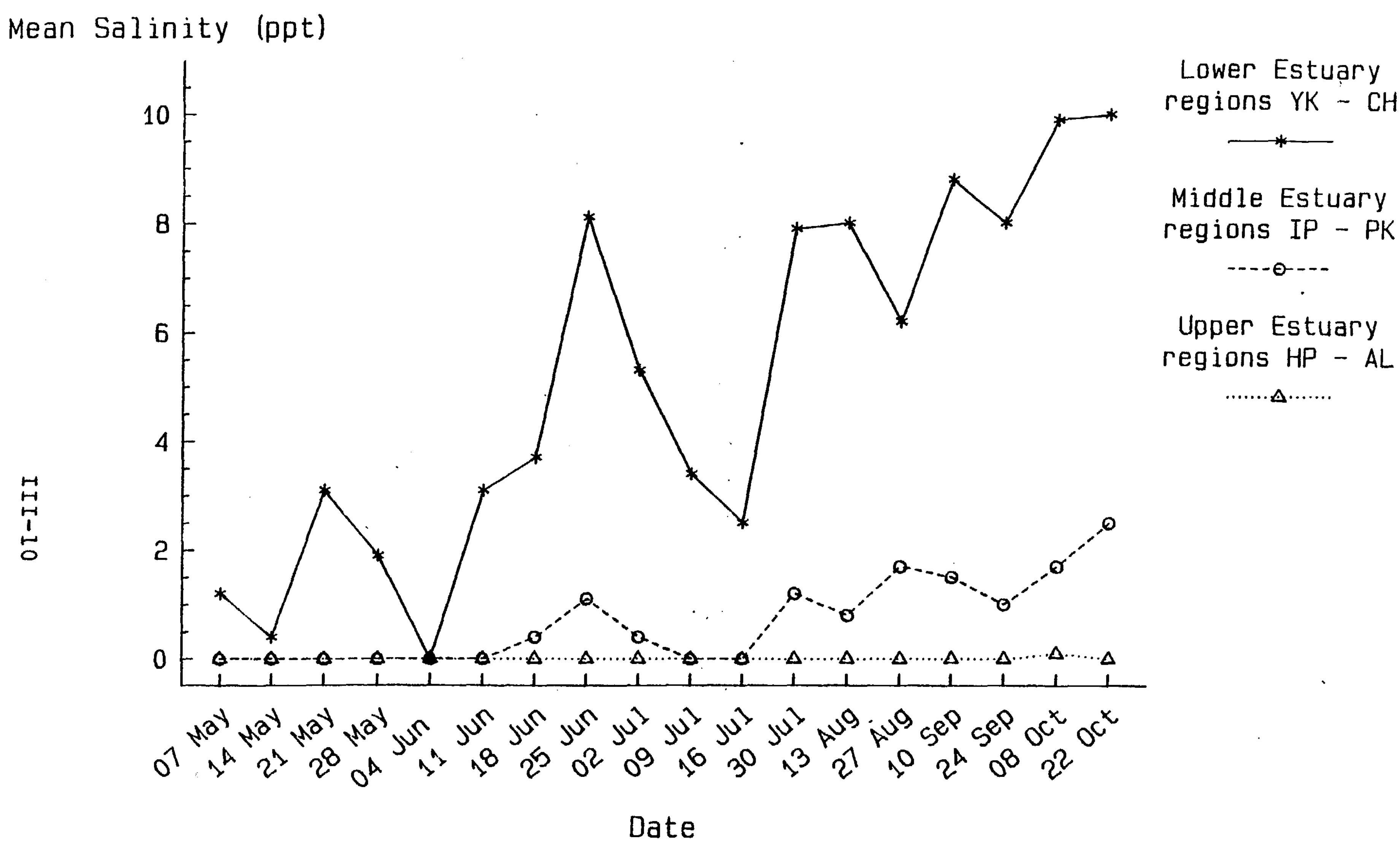

Figure III-3. Weekly mean salinity measured in the LR/FS water quality survey of the Hudson River in 1984

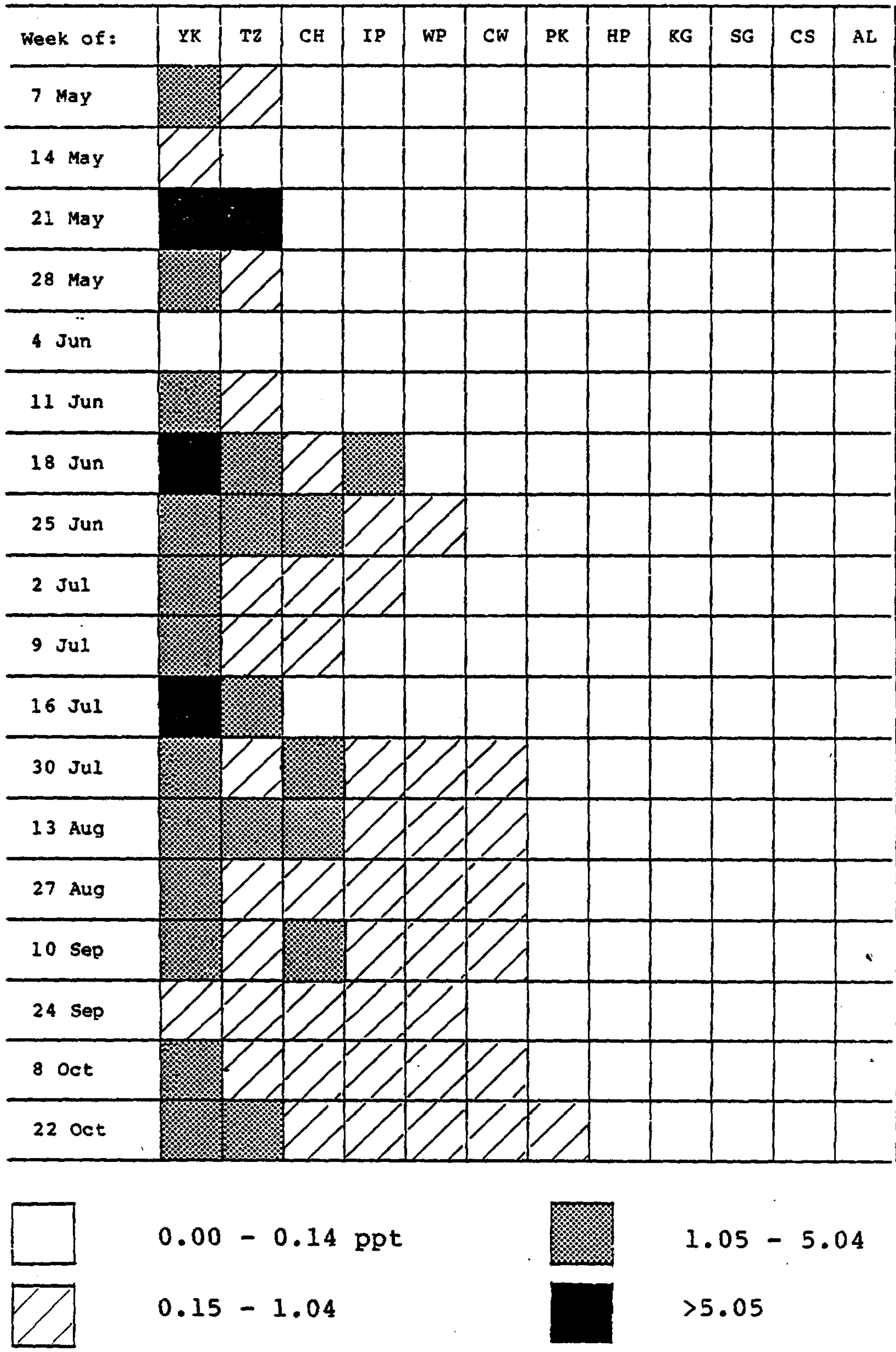

Figure III-4. Surface-to-bottom differences in mean salinity (ppt) from measurements taken during the Longitudinal River/Fall Shoal Water Quality Survey in 1984

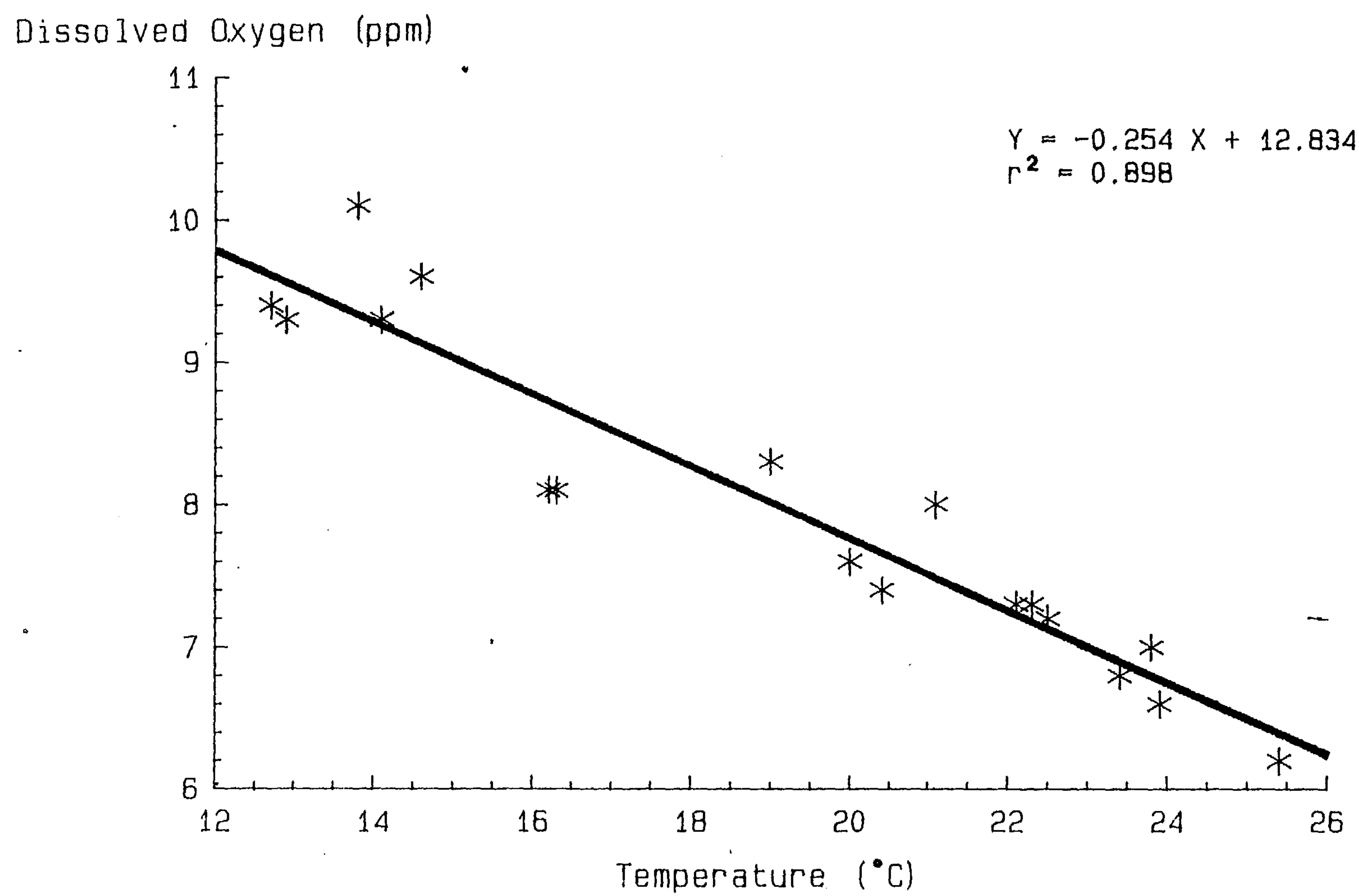

Figure III-5. Relationship between weekly mean temperature (°C) and weekly mean dissolved oxygen (ppm) measured during the Longitudinal River/Fall Shoals Water Quality Survey in 1984

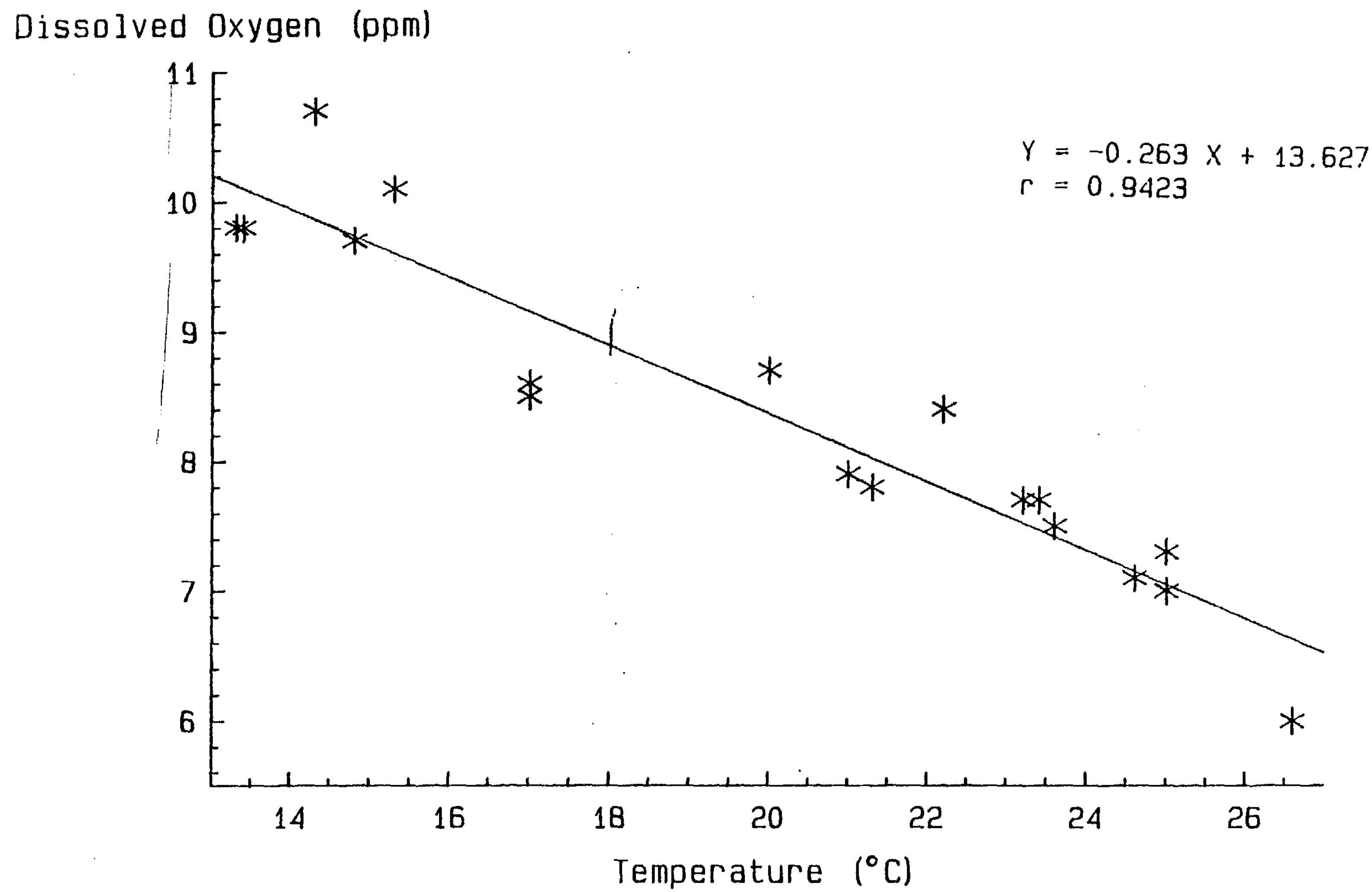

Figure III-5. Relationship between weekly mean temperature (°C) and weekly mean dissolved oxygen (ppm) measured during the Longitudinal River/Fall Shoals Water Quality Survey in 1984 less oxygen at higher temperatures. However, this is not the only explanation; dissolved oxygen values were as low as 49% below saturation levels in midsummer (Table A-9). The higher metabolic activity and associated increased BOD that accompany temperature increases were probably also responsible for declines in oxygen content during the summer.

This pattern of oxygen decline during summer has been observed in all previous Year Class Reports. The lowest weekly mean value observed in 1984 is within the range of historical values. The highest weekly mean oxygen value in 1984 has been exceeded in many years, but these higher historical values were associated with earlier studies when sampling schedules extended into colder months.

There was little spatial gradation in dissolved oxygen content in the Hudson River, with the exception of considerably lower values in the Albany region (Table A-7). The lower dissolved oxygen content (less than 75% saturation) observed at Albany has not been documented in previous Year Class Reports, and it is unclear what caused the lower values to occur in 1984. Mean regional oxygen content was highest in the Tappan Zee and Croton-Haverstraw regions, and was above 7 ppm in all regions except Albany (Table III-2). The mean dissolved oxygen content (pooled over all weeks) at Albany was 5.6 ppm. Dissolved oxygen levels were generally lower in the upper estuary until July and August when oxygen levels were highest in the upper estuary (Fig. III-6).

Surface-to-bottom differences in dissolved oxygen were greatest downriver, and substantial differences occurred primarily in the Yonkers region where surface values averaged 1.3 ppm higher than values on the bottom (Figure III-7). The highest difference observed was 3.6 ppm. The greater surface-to-bottom differences downriver and the lower oxygen content of the bottom waters, were probably due to the influence of warmer, more saline, and less oxygenated water from the New York harbor area moving upriver along the bottom.

Dissolved oxygen for the BSS was consistently 2-6 ppm higher than in the same period during the LR/FS water quality survey (Table A-8). BSS dissolved oxygen values indicated that water in the shore zone was frequently supersaturated even during the summer (Table A-10). This pattern has been observed in the past (e.g., NAI 1985 a and b); however, differences in dissolved oxygen content between the shore zone and other strata have typically been 1 ppm or less.

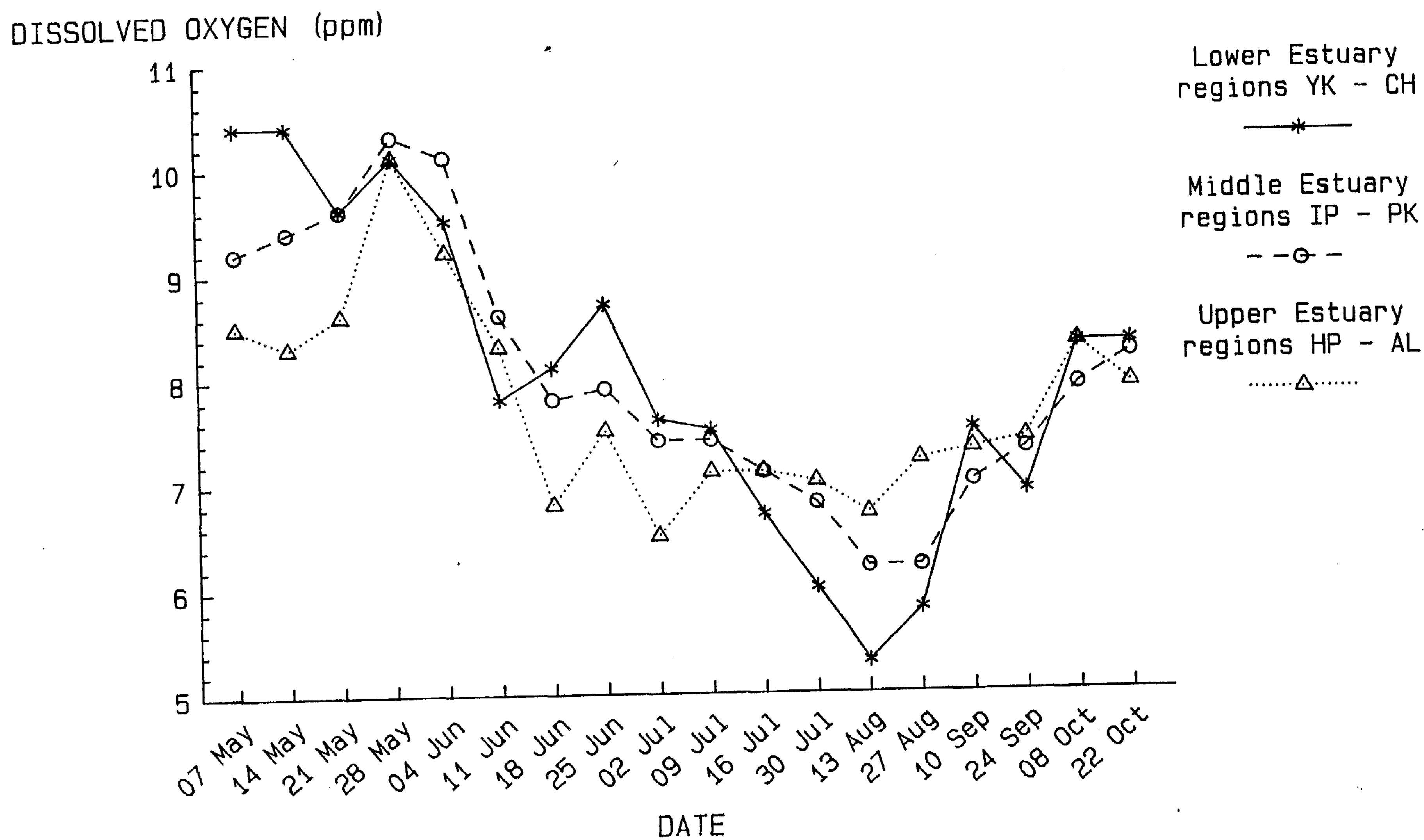

Figure III-6. Weekly mean dissolved oxygen measured in the LR/FS water quality survey of the Hudson River in 1984

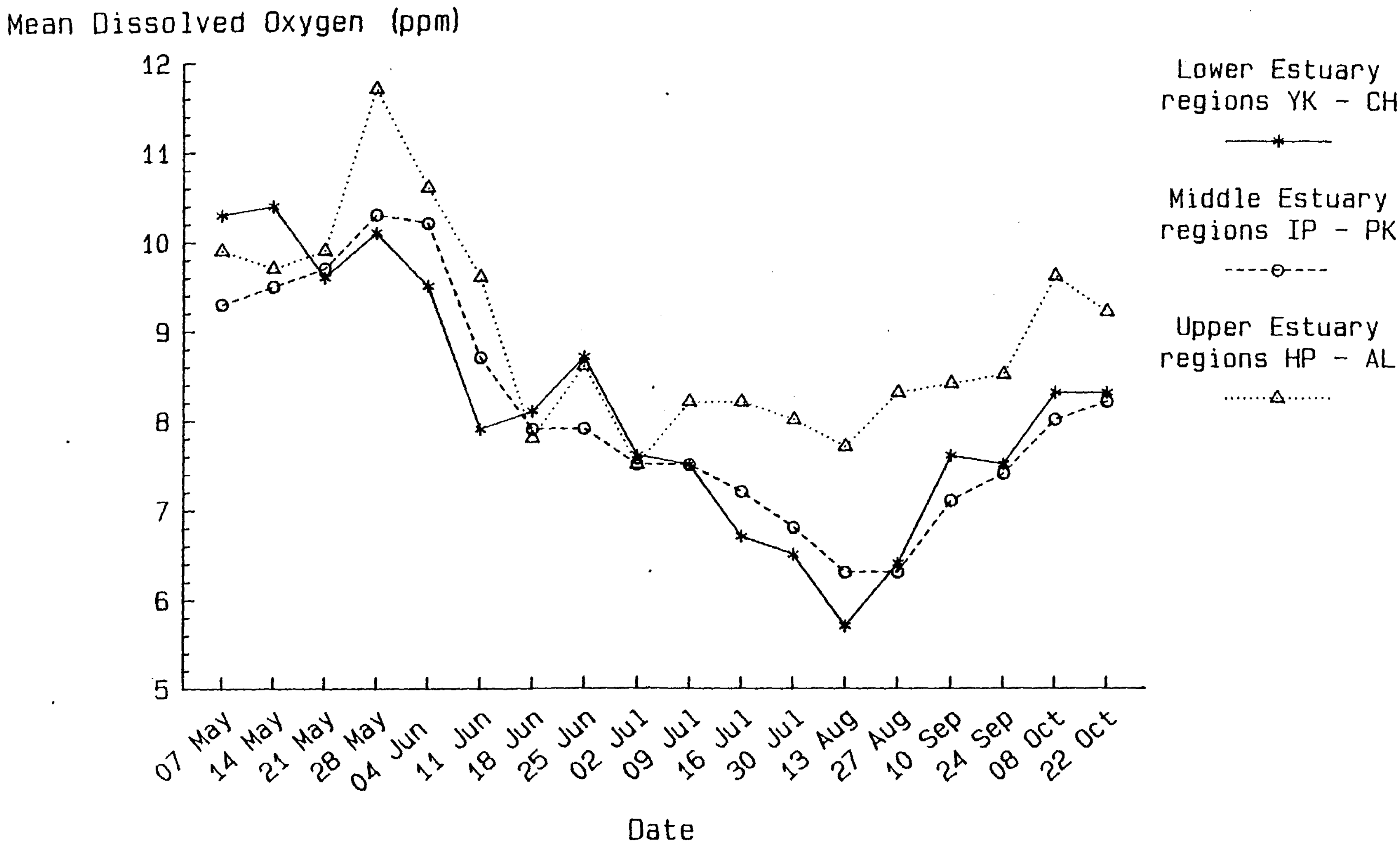

Figure III-6. Weekly mean dissolved oxygen measured in the LR/FS water quality survey of the Hudson River in 1984

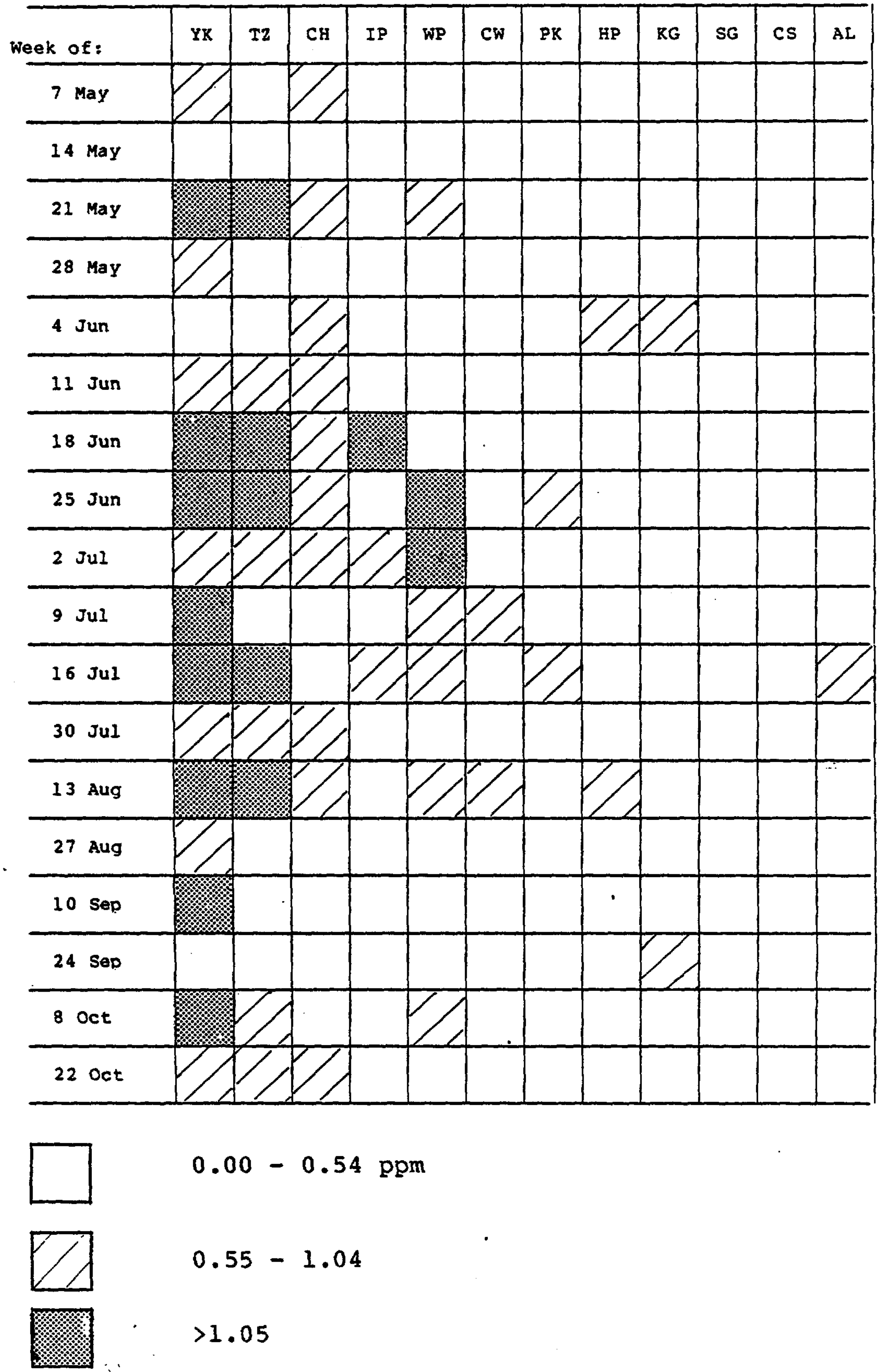

Figure III-7. Surface-to-bottom differences in mean dissolved oxygen (ppm) from measurements taken during the Longitudinal River/Fall Shoals Water Quality Survey in 1984

IV. SPATIAL AND TEMPORAL DISTRIBUTION OF SELECTED SPECIES

A. SPECIES COMPOSITION

A total of 77 fish species were captured in the 1984 Hudson River studies (Table IV-1). More than half of these were captured in only one of the three sampling programs; 21 of the 77 species were collected in all three programs. The species composition reflected a variety of life history groups, including species characteristic of freshwater, estuarine, and marine environments.

A total of 127 species have been reported from the three Hudson River study programs since they were initiated in 1974 (Table IV-2). No new species were added to that list in 1984. However, several species that had not been reported for several years, such as the satinfin shiner, trout perch, and white crappie, were collected in 1984.

B. STRIPED BASS

Striped bass, *Morone saxatilis*, is an 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). Striped bass have also been successfully introduced into numerous reservoirs in the United States (Bailey 1975).

Striped bass enter the Hudson River in early spring to spawn. Spawning generally takes place near the salt front, but may occur throughout the river (Rathjen and Miller 1957, Dovel 1981). After spawning, adults typically remain within the river until fall when water temperature decreases, at which time they migrate to overwintering areas. Young-of-year striped bass spawned in the upper estuary move slowly downriver into higher salinity summer feeding and nursery areas (McFadden et al. 1978). As water temperature decreases during the fall, juveniles move into deep-water overwintering sites in the lower estuary or in adjacent bays or sounds.

Table IV-1. Species composition of fish collected in each of the Hudson River year class surveys during 1984

TAXON	BEACH SEINE	FALL SHOALS	LONG RIVER
ACIPENSER SP.		X	X
ALEWIFE	X	X	X
AMERICAN EEL	X	X	X
AMERICAN SHAD	X	X	X
ATLANTIC MENHADEN	X	X	X
ATLANTIC NEEDLEFISH	X		
ATLANTIC SILVERSIDE	X	X	
ATLANTIC STURGEON		X	X
ATLANTIC TOMCOD	X	X	X
BANDED KILLIFISH	X	X	X
BAY ANCHOVY	X	X	X
BLACK BULLHEAD	X		
BLACK CRAPPIE	X		
BLUEBACK HERRING	X	X	X
BLUEFISH	X	X	X
BLUEGILL	X	X	X
BROWN BULLHEAD	X	X	X
BROWN TROUT	X		
BUTTERFISH	X	X	
CARP	X	X	
CHAIN PICKEREL	X		
CONGER EEL		X	X
CREVALLE JACK	X	X	
CUNNER			X
EMERALD SHINER	X		X
FOURSPINE STICKLEBACK	X	X	X
FOURSPOT FLOUNDER	X	X	
GIZZARD SHAD	X		
GOLDEN SHINER	X		
GOLDFISH	X		
HOGCHOKER	X	X	X
INSHORE LIZARDFISH		X	
LARGEMOUTH BASS	X		
MUMMICHOG	X		
NAKED GOBY		X	
NORTHERN HOG SUCKER	X		
NORTHERN KINGFISH	X		
NORTHERN PIPEFISH	X	X	X
NORTHERN PUFFER	X	X	
NORTHERN SEAROBIN	X		
NORTHERN STARGAZER	X	X	
PUMPKINSEED	X		X
RAINBOW SMELT		X	X
RED HAKE			X
REDBREAST SUNFISH	X		
REDFIN PICKEREL	X		
ROCK BASS	X		
ROUGH SILVERSIDE	X	X	
SATINFIN SHINER	X		

Table IV-1. Continued

TAXON	BEACH SEINE	FALL SHOALS	LONG RIVER
SEA LAMPREY	X		
SHORTNOSE STURGEON		X	X
SILVER PERCH	X	X	
SILVERY MINNOW	X		
SMALLMOUTH BASS	X		
SMALLMOUTH FLOUNDER	X	X	
SPECKLED WORM EEL			X
SPOTFIN SHINER	X		
SPOTTAIL SHINER	X	X	X
SPOTTED HAKE			X
STRIPED BASS	X	X	X
STRIPED MULLET	X		
STRIPED SEAROBIN	X	X	
SUMMER FLOUNDER	X	X	X
TAUTOG			X
TESSELATED DARTER	X	X	X
THREESPINE STICKLEBACK			X
TIDEWATER SILVERSIDE	X	X	
TROUT PERCH			X
WALLEYE			X
WEAKFISH	X	X	X
WHITE CATFISH	X	X	X
WHITE CRAPPIE	X		
WHITE MULLET	X		
WHITE PERCH	X	X	X
WHITE SUCKER	X		X
WINDOWPANE			X
WINTER FLOUNDER	X		X
YELLOW PERCH	X		X

Table IV-2. Species composition of fish collected as part of year class studies from 1974 to 1984

TAXON	74	75	76	77	78	79	80	81	82	83	84
ALEWIFE	X	X	X	X	X	X	X	X	X	X	X
AMERICAN EEL	X	X	X	X	X	X	X	X	X	X	X
AMERICAN SHAD	X	X	X	X	X	X	X	X	X	X	X
AMMODYTES SP.		X	X	X	X	X	X				
ATLANTIC COD							X				
ATLANTIC CROAKER			X	X		X					
ATLANTIC HERRING		X	X		X	X			X		
ATLANTIC MENHADEN	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC NEEDLEFISH	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC SILVERSIDE	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC STURGEON	X	X	X	X	X	X	X	X	X	X	X
ATLANTIC TOMCOD	X	X	X	X	X	X	X	X	X	X	X
BANDED KILLIFISH	X	X	X	X	X	X	X	X	X	X	X
BAY ANCHOVY	X	X	X	X	X	X	X	X	X	X	X
BLACK BULLHEAD				X				X			X
BLACK CRAPPIE	X	X	X	X	X	X	X	X	X	X	X
BLACK SEA BASS					X						
BLACKNOSE DACE	X	X	X	X	X	X	X				
BLUEBACK HERRING	X	X	X	X	X	X	X	X	X	X	X
BLUEFISH	X	X	X	X	X	X	X	X	X	X	X
BLUEGILL	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
BROWN TROUT			X	X	X	X	X				X
BUTTERFISH	X	X	X			X	X	X	X	X	X
CARP	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
CREEK CHUB		X	X	X	X	X	X			X	
CREVALLE JACK	X	X	X	X	X	X	X	X	X	X	X
CUNNER									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
FALL FISH	X	X	X	X	X	X	X	X			
FATHEAD MINNOW	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
FOURSPINE STICKLEBACK	X	X	X	X	X	X	X	X	X	X	X
FOURSPOT FLOUNDER	X						X	X			X
GIZZARD SHAD	X	X	X	X	X	X	X	X		X	X
GOLDEN SHINER	X	X	X	X	X	X	X	X	X	X	X
GOLDFISH	X	X	X	X	X	X	X	X	X	X	X
GRASS PICKEREL	X				X						
GRAY SNAPPER							X				
GREEN SUNFISH		X		X			X				
HICKORY SHAD		X			X	X				X	
HOGCHOKER	X	X	X	X	X	X	X	X	X	X	X
INSHORE LIZARDFISH	X					X	X	X			X
LARGEMOUTH BASS	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		
LOOKDOWN	X	X	X	X		X	X	X			
MIMIC SHINER	X										
MOONFISH			X								
MUMMICHOG	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
NORTHERN PIKE	X	X	X	X	X	X	X		X		
NORTHERN PIPEFISH	X	X	X	X	X	X	X	X	X	X	X
NORTHERN PUFFER		X		X		X	X	X	X	X	X
NORTHERN SEAROBIN			X		X		X	X	X		X
NORTHERN STARGAZER	X						X		X	X	X
POLLACK		X									
PUMPKINSEED	X	X	X	X	X	X	X	X	X	X	X
RAINBOW SMELT	X	X	X	X	X	X	X	X	X	X	X
RAINBOW TROUT						X					
RED HAKE	X		X			X	X	X			X
REDBREAST SUNFISH	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
ROCK GUNNEL			X	X							
ROSYFACE SHINER	X										
ROUGH SILVERSIDE		X	X	X	X	X	X	X	X		X
SATINFIN SHINER	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
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
SILVER HAKE	X	X		X							
SILVER PERCH	X					X					X
SILVERY MINNOW	X	X	X	X	X	X	X	X	X	X	X
SMALLMOUTH BASS	X	X	X	X	X	X	X	X	X	X	X
SMALLMOUTH FLOUNDER						X	X		X		X
SPECKLED WORM EEL					X		X				X
SPOT	X	X	X	X			X		X	X	
SPOTFIN BUTTERFLYFISH									X		
SPOTFIN MOJARRA									X		
SPOTFIN SHINER	X	X	X	X	X	X	X	X			X
SPOTTAIL SHINER	X	X	X	X	X	X	X	X	X	X	X
SPOTTED HAKE							X			X	X
STRIPED ANCHOVY		X				X			X		
STRIPED BASS	X	X	X	X	X	X	X	X	X	X	X
STRIPED CUSKEEL							X				
STRIPED KILLIFISH			X								
STRIPED MULLET	X		X	X		X	X	X	X	X	X
STRIPED SEAROBIN		X			X	X	X	X	X	X	X
SUMMER FLOUNDER	X	X	X	X	X	X	X	X	X		X
TAUTOG		X				X	X	X	X	X	X
TESSELATED DARTER	X	X	X	X	X	X	X	X	X	X	X
THREESPINE STICKLEBACK	X	X	X	X	X	X	X	X	X	X	X
TIDEWATER SILVERSIDE	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
WHITE BASS				X							
WHITE CATFISH	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
WHITE PERCH	X	X	X	X	X	X	X	X	X	X	X
WHITE SUCKER	X	X	X	X	X	X	X	X	X	X	X
WINDOWPANE	X	X		X		X	X	X		X	X
WINTER FLOUNDER	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
YELLOWTAIL FLOUNDER	X										

Eggs

Striped bass eggs were collected from early May through early July (duration of the LRS) from the Tappan Zee to the Albany regions of the Hudson River estuary (Fig. IV-1). Density estimates indicated a bimodal temporal distribution with peaks in mid-May and early June. This bimodal temporal distribution is inconsistent with that presented in any of the previous Year Class Reports; from 1976 through 1983 only single peaks in egg abundance, usually occurring in early May, were observed. Spawning of striped bass is thought to be triggered by rapid warming of water in spring (DiNardo et al. 1985). The 11 June peak of eggs corresponded to a 3-4°C increase in temperature during that week (Table A-1). It is possible that the 14 May peak in egg abundance was associated with temperature increases preceeding initiation of LRS sampling.

Density estimates for eggs were highest in the Croton-Haverstraw through Hyde Park regions, with the highest values occurring in the West Point region during 4 June. No eggs were found in the Yonkers region, and mean regional densities north of Saugerties were always less than 10/1000 m^3. This spatial distribution is consistent with that reported in previous Year Class Reports. Most striped bass eggs were collected in the bottom stratum. Although striped bass eggs are normally semi-buoyant and found in the water column, Albrecht (1964) reported that eggs fall to the bottom in slow-moving water.

Yolk-Sac Larvae

Striped bass yolk-sac larvae were collected every week of the LRS and in all regions except Albany (Fig. IV-2). However, density estimates for yolk-sac larvae exceeded 200/1000 m^3 only in the regions from West Point through Kingston and only during the week of 11 June. One week earlier there was a peak in egg density in the same portion of the estuary (Figs. IV-1 and IV-3). The incubation period for eggs at the temperatures that occurred in the Hudson River during the week of 4 June is less than 1 week (Polgar et al. 1976; Rogers et al. 1977), and thus, the 11 June peak in yolk-sac larval standing crop corresponds to development of eggs found 1 week earlier. Only a very minor peak in yolk-sac larvae standing crop occurred the week after the 14 May peak in egg standing crop. Water temperature in the regions of abundance during the 14 May peak of eggs was about 13°C. Morgan et al. (1981) have shown that hatching success and survival following hatching are less than 50% at that temperature, which might explain the relative absence of a peak in yolk-sac larvae at that time.

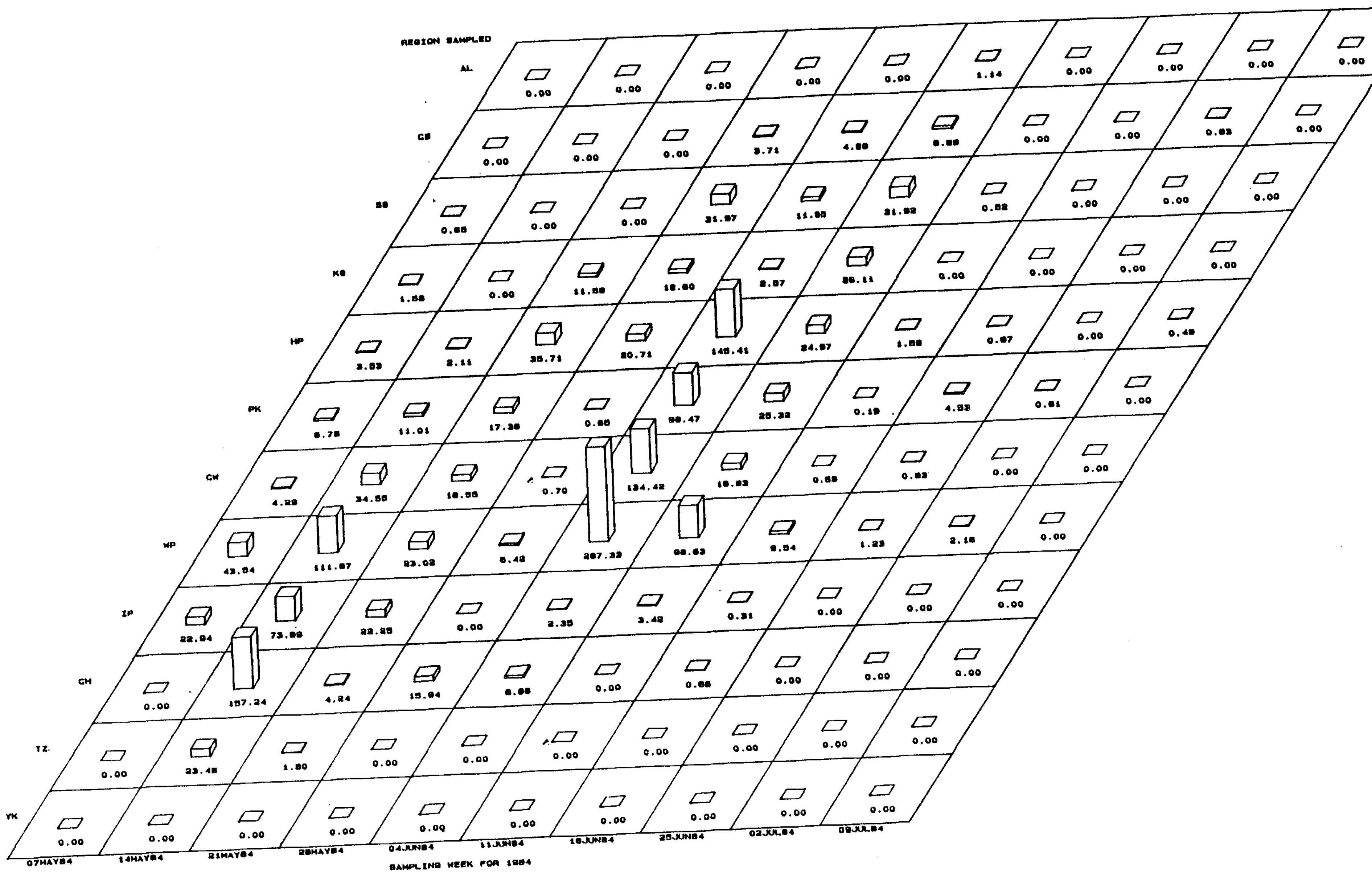

Figure IV-1. Mean regional density (per 1000 m^3) of striped bass eggs collected in the Longitudinal River Survey during 1984

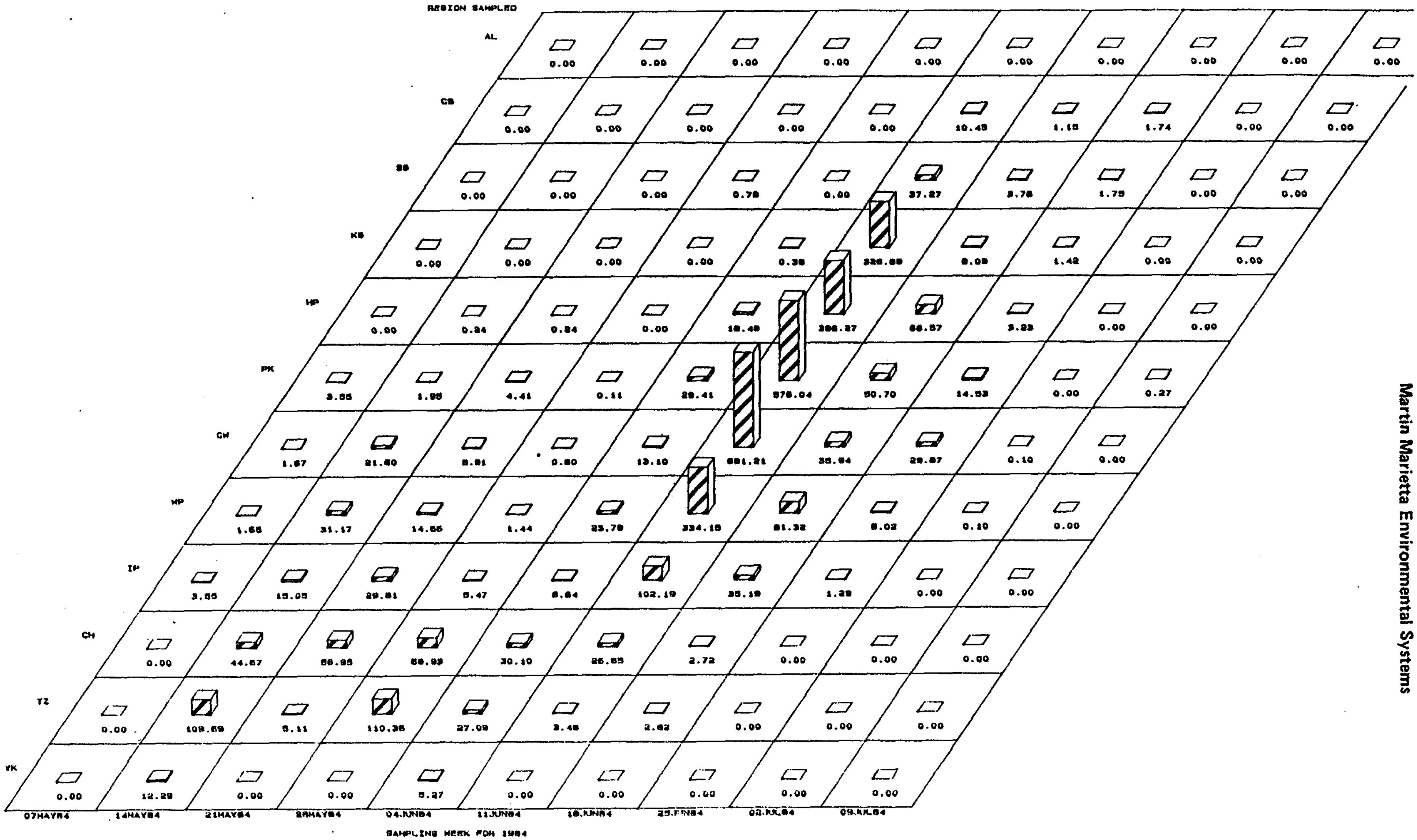

Figure IV-2. Mean regional density (per 1000 m^3) of striped bass yolk-sac larvae collected in the Longitudinal River Survey during 1984

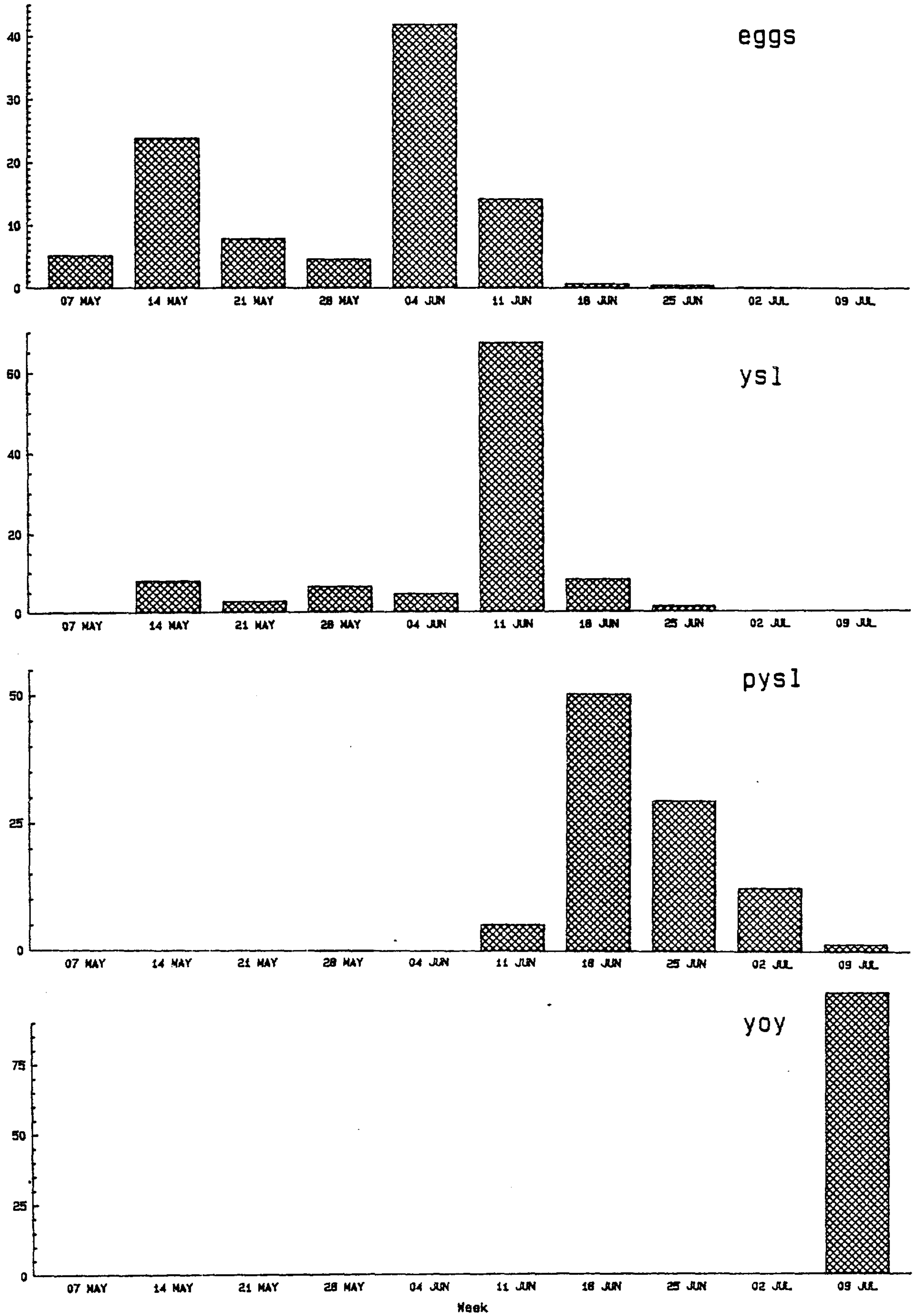

Figure IV-3. Temporal index for striped bass eggs, yolk-sac larvae, post yolk-sac larvae, and young-of-year collected in the Longitudinal River Survey during 1984

The geographic distribution indicated by mean density of yolk-sac larvae in 1984 was similar to that in previous Year Class Reports (TI 1981; Battelle 1983; NAI 1985a and 1985b). Density estimates have usually been highest in the middle regions (Indian Point through Hyde Park), with concentrations decreasing toward the northern and southern ends of the estuary.

The temporal distribution of yolk-sac larvae collected in 1984 indicated that standing crop was greatest in mid-June. This was similar to patterns reported in 1976 and 1983. However, in 1974, 1975, and from 1977 through 1982, peak standing crop of yolk-sac larvae was observed in the latter part of May.

Post Yolk-Sac Larvae

Striped bass post yolk-sac larvae were first collected during the week of 21 May and were collected through the remainder of the LRS (Fig. IV-4). A strong peak, where mean regional densities exceeded 1000/1000 m^3 occurred during the weeks of 18 June and 25 June. Developmental time from the yolk-sac to post yolk-sac stage is approximately 1 week (Setzler et al. 1980) and approximately 1 week before the peak in post yolk-sac density there was a peak in yolk-sac density (Fig. IV-3).

In 1984, density estimates were greatest in mid- to late June. This was similar to patterns reported in 1974, 1976, and 1983. However, in 1975 and between 1977 and 1982 peak concentrations were observed in late May and early June.

Post yolk-sac larvae densities were greatest from the Indian Point to Cornwall regions. Mean density of post yolk-sac larvae never exceeded 50/1000 m^3 in any region north of Hyde Park, or in Yonkers. Similar spatial distributions with peak densities near the Indian Point region have been reported in previous Year Class Reports (e.g., TI 1981; NAI 1985b).

Young-of-Year

Juvenile striped bass were first collected during the final week of the LRS (Fig. IV-5), and were collected in every week of the FSS (Fig. IV-6) and BSS (Fig. IV-7). No large peaks in density were apparent from 1984 data.

Juvenile striped bass were collected in all regions of the estuary in both the FSS and BSS. Very few young-of-year striped bass were collected in the channel; more often they were found in shoal and shore-zone areas. Previous Year Class Reports

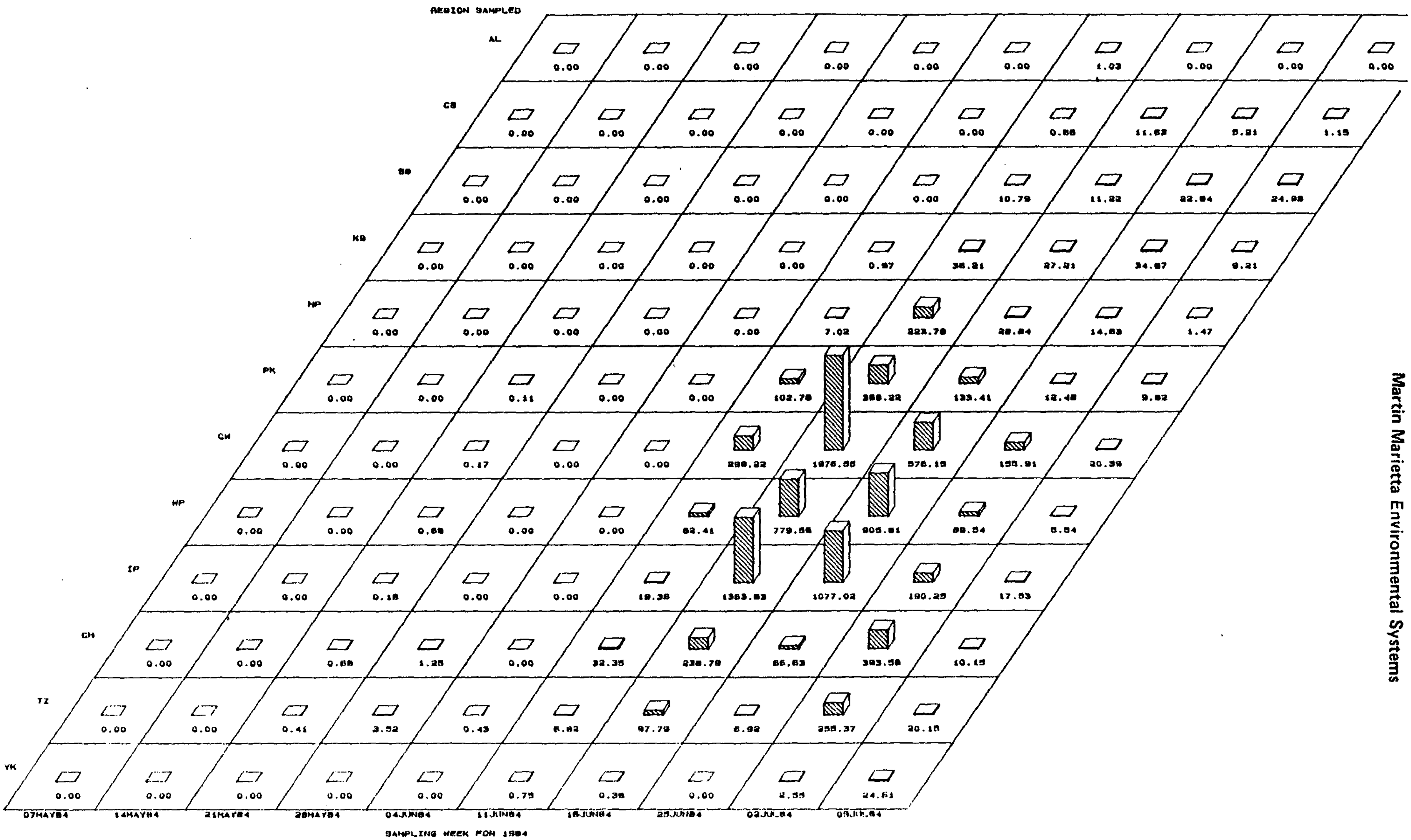

Figure IV-4. Mean regional density (per 1000 m^3) of striped bass post yolk-sac larvae collected in the Longitudinal River Survey during 1984

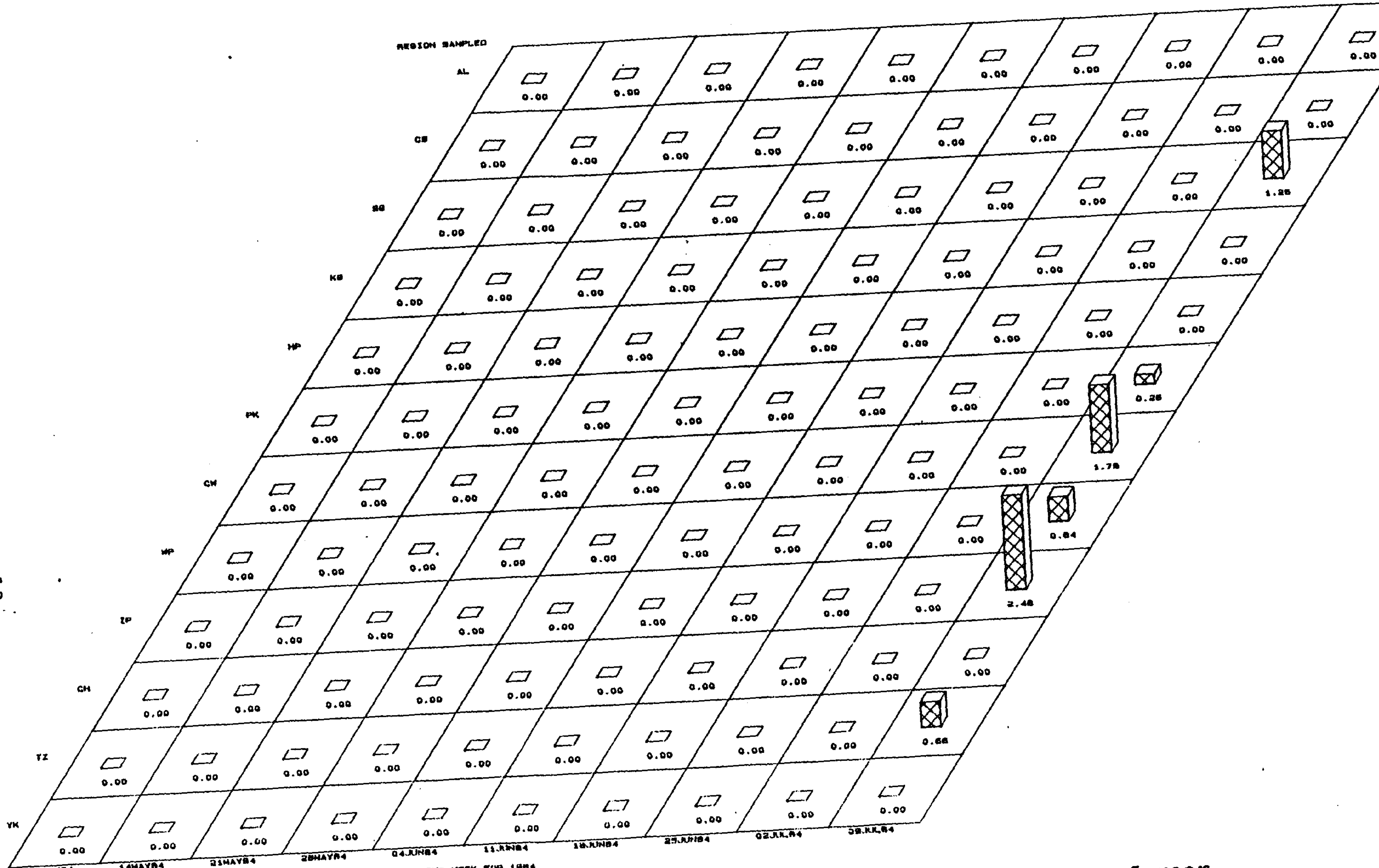

Figure IV-5. Mean regional density (per 1000 m^3) of striped bass young-of-year collected in the Longitudinal River Survey during 1984

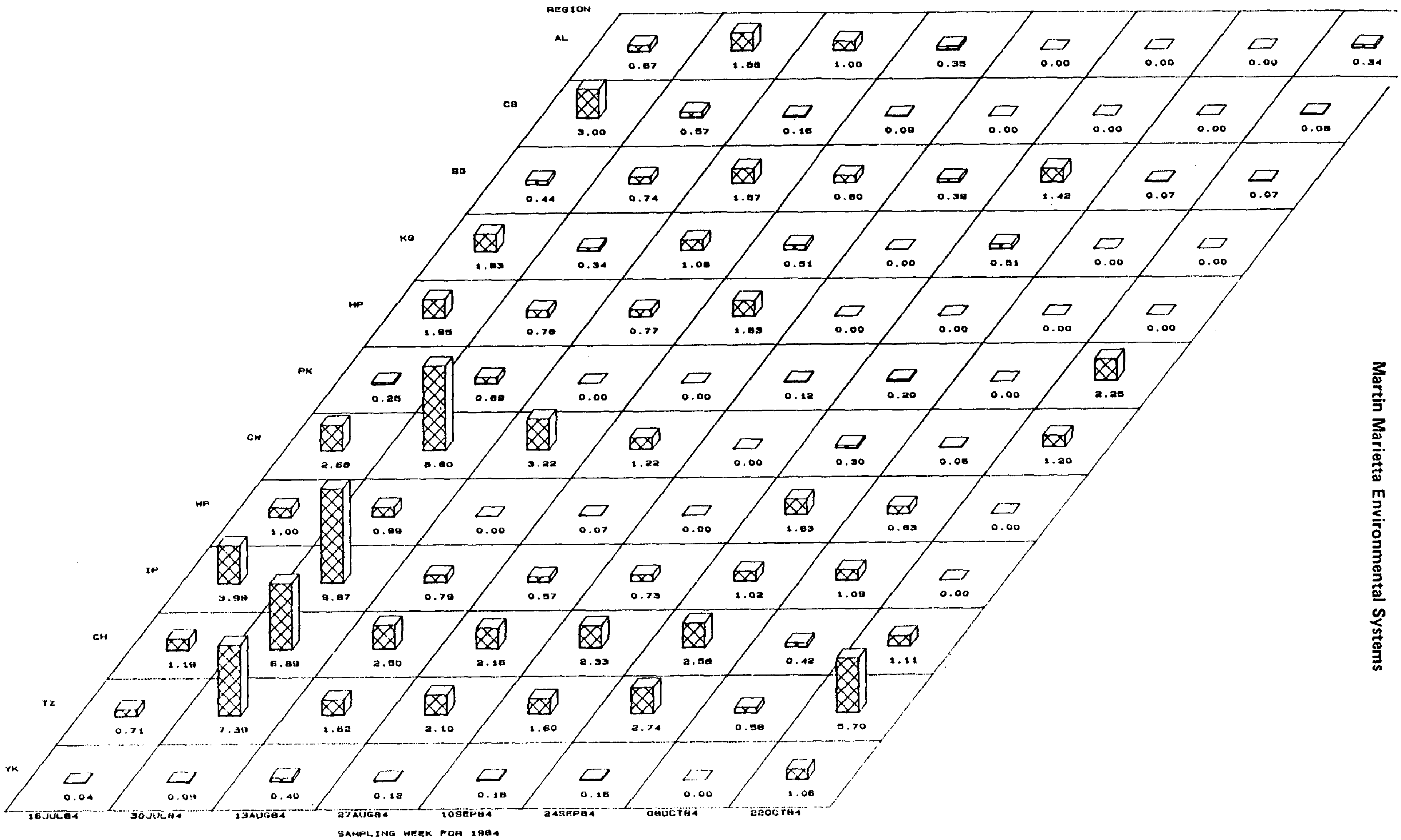

Figure IV-6. Mean regional density (per 1000 m^3) of striped bass young-of-year collected in the Fall Shoals Survey during 1984

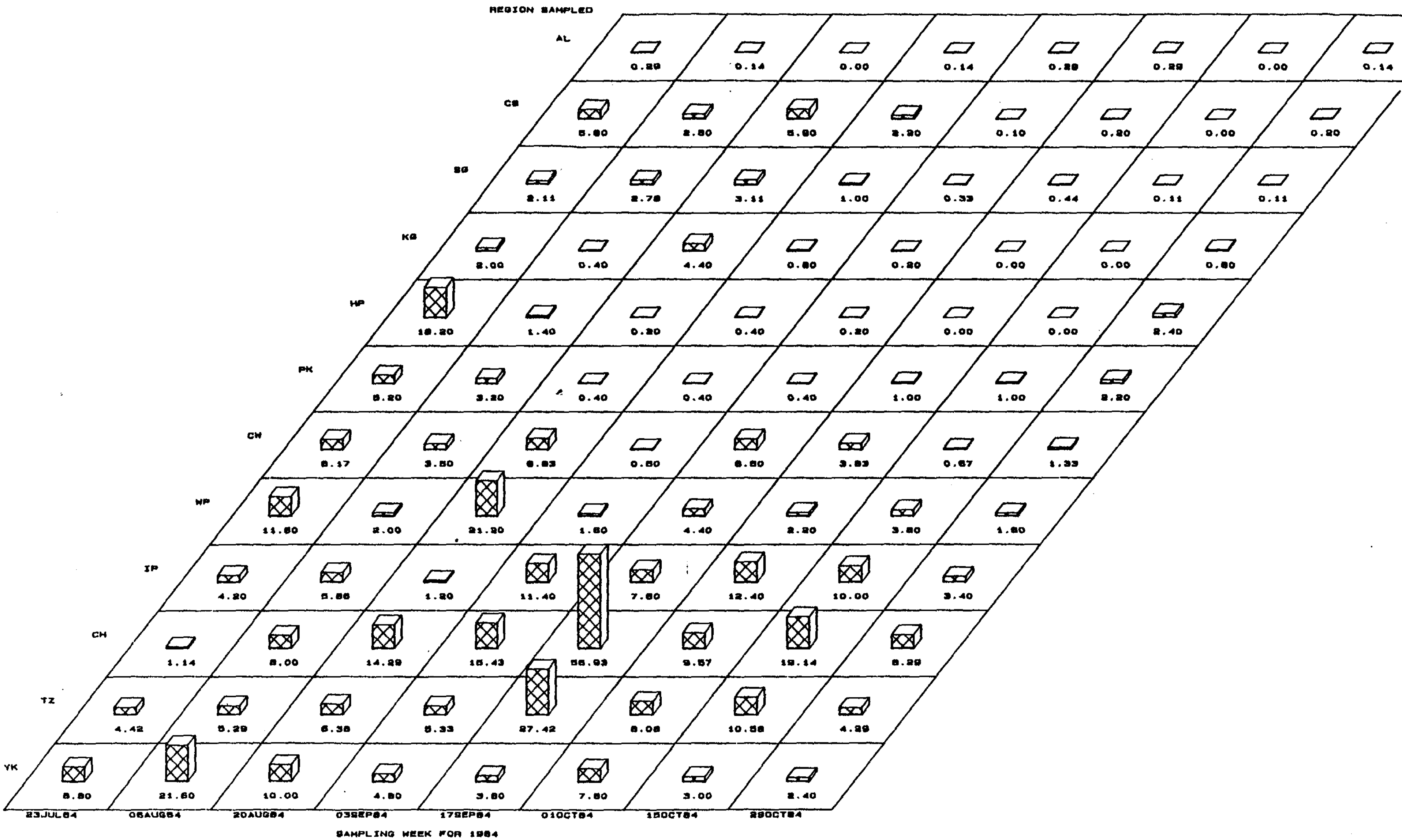

Figure IV-7. Catch per unit effort of striped bass young-of-year collected in the Beach Seine Survey during 1984 have reported movement of juvenile striped bass to downriver overwintering grounds (e.g., TI 1981; NAI 1985a). In 1984, there was a general decline in density of juveniles throughout the river near the end of the fall programs. It is unclear whether this decline reflects movement to overwintering grounds south of the study area or reduced catch efficiency of young-of-year striped bass as they grow. However, the more marked decline in the upper estuary suggests that downriver migration is responsible for at least part of the overall decline in abundance during the fall.

Yearling and Older Fish

Yearling and older striped bass were collected throughout the LRS (Fig. IV-8), FSS (Fig. IV-9), and BSS (Fig. IV-10). They were also collected in all 12 regions, with no gradient in distribution in the river apparent from the data. Presumably the seaward migration that typically occurs for yearling and older striped bass during the fall took place after sampling was terminated in October. However, catches of yearling and older striped bass were sporadic and such migrations might be difficult to detect using the sampling methods employed here.

C. WHITE PERCH

White perch, *Morone americana*, are endemic to the east coast of North America from Nova Scotia to South Carolina, and have also been introduced to a number of landlocked impoundments (Woolcott 1962). White perch are considered semianadromous because they show definite seasonal movement patterns associated with spawning, but movements are generally limited to within an estuary. White perch are found from the mouth of the Hudson River to the base of Troy Dam north of Albany. It is an abundant species in the river, comprising 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, but may occur in saline water up to 5 ppt (Hardy 1978). 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. In the Hudson River, overwintering generally takes place in deepwater areas from Yonkers to Indian Point (TI 1981).

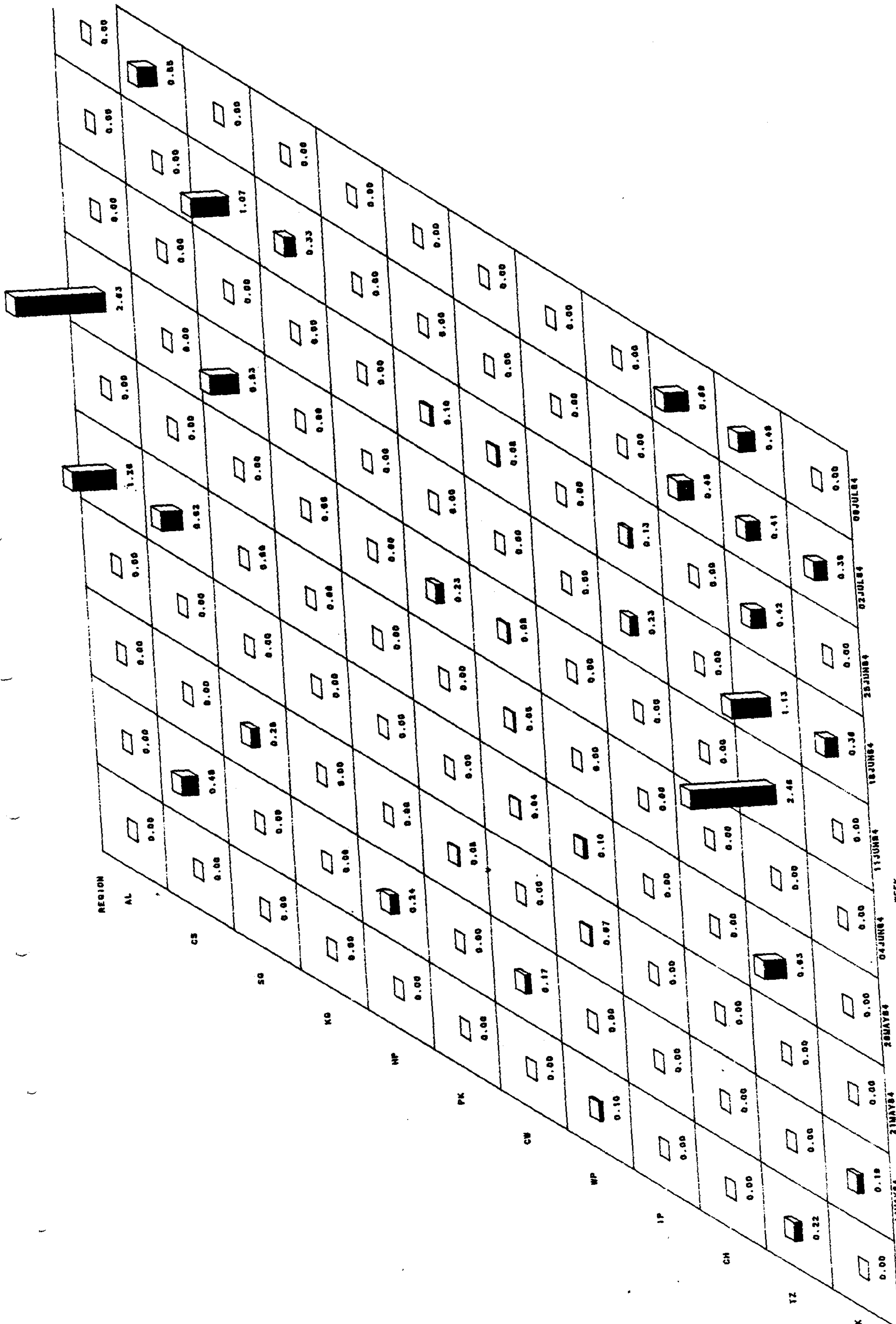

Figure IV-8. Mean regional density (per 1000 m^3) of striped bass yearling and older collected in the Longitudinal River Survey during 1984

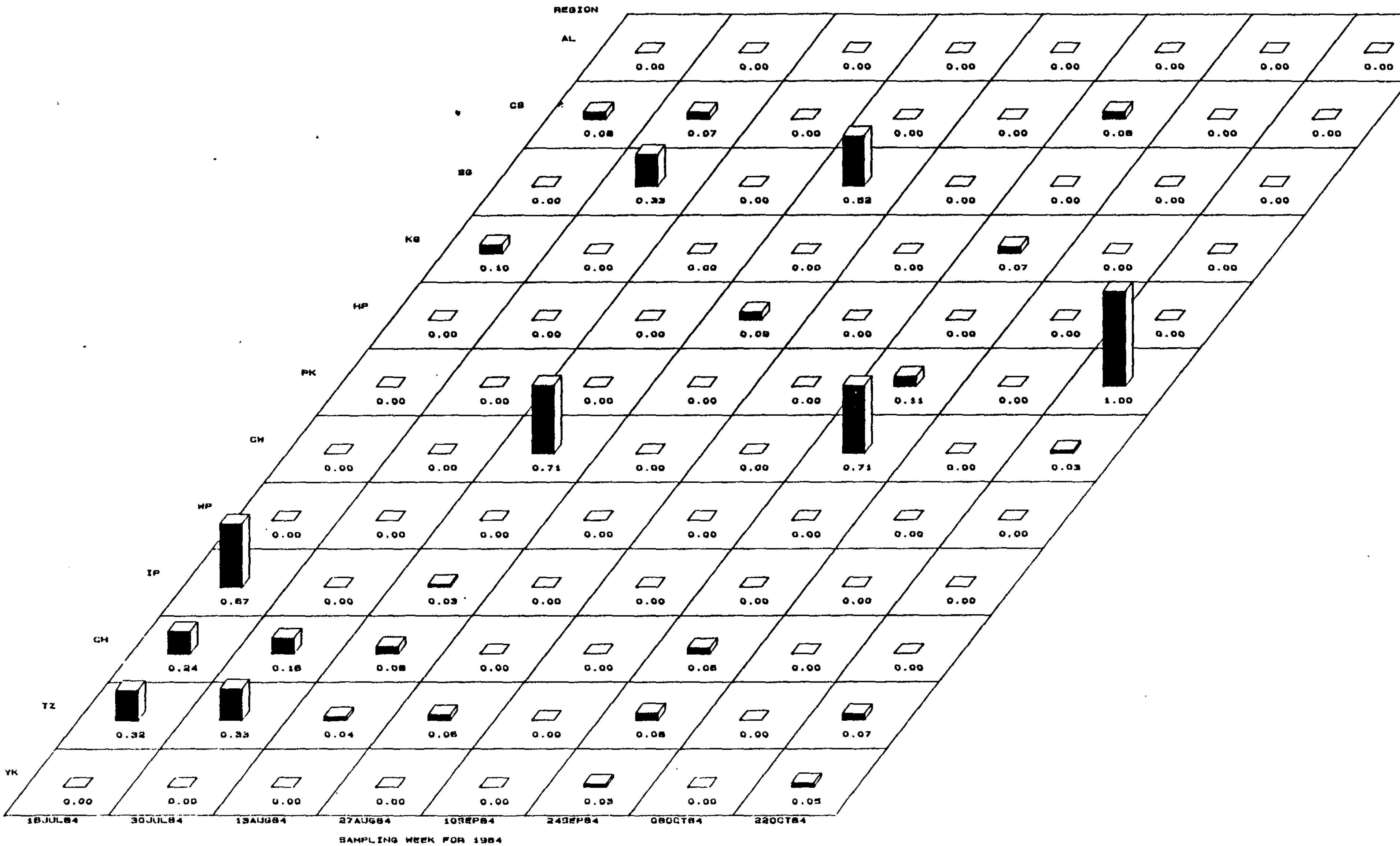

Figure IV-9. Mean regional density (per 1000 m^3) of striped bass yearling and older collected in the Fall Shoals Survey during 1984

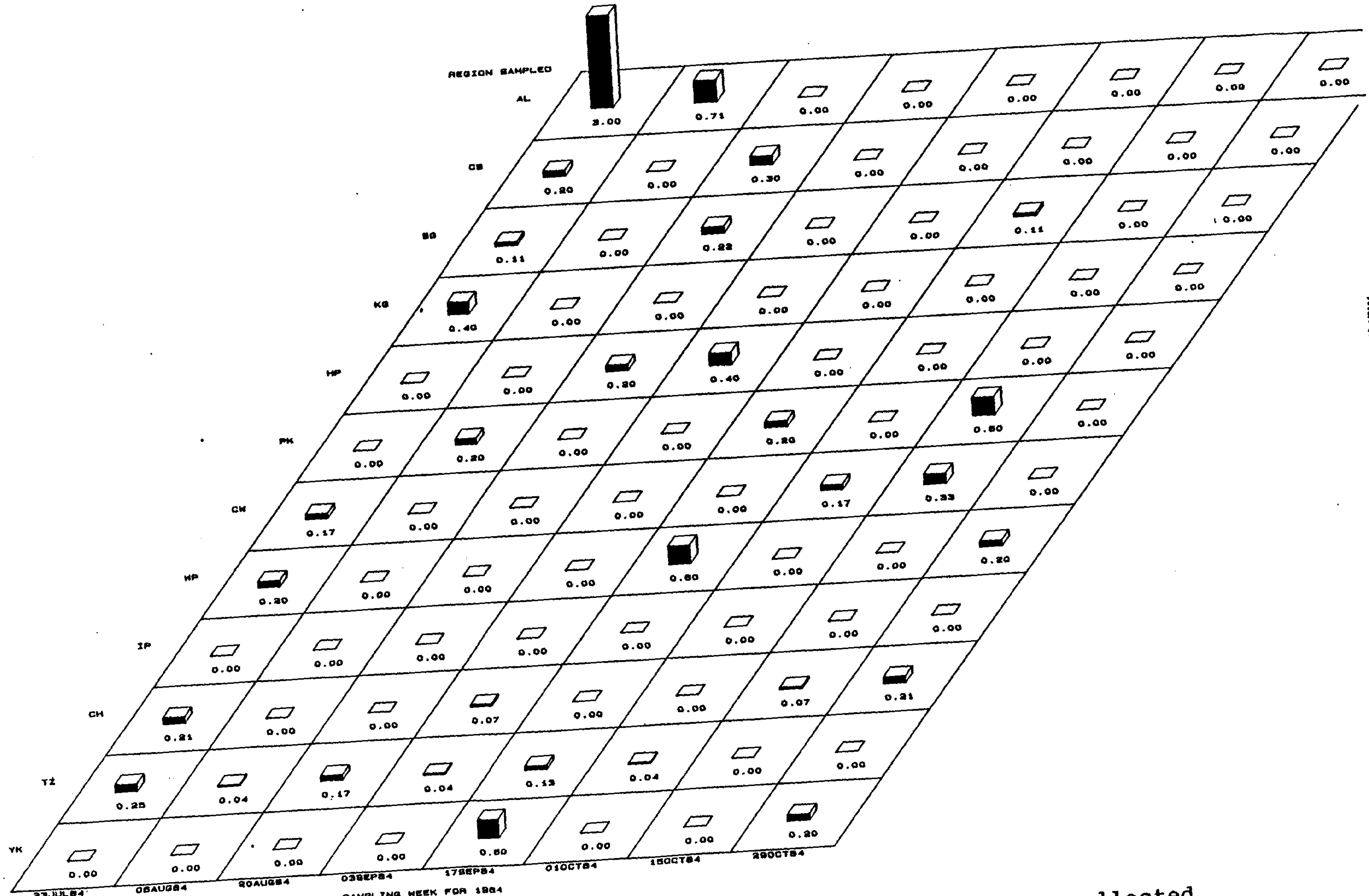

Figure IV-10. Catch per unit effort of striped bass yearling and older collected in the Beach Seine Survey during 1984

Eggs

White perch eggs were found in every region during the LRS, but greatest density estimates occurred for upriver regions (Fig. IV-11). Mean weekly density estimates exceeding 100 eggs per 1000 m^3 were recorded only for regions north of Indian Point, and density estimates exceeding 1000/1000 m^3 were found only in the three most upriver regions. In previous years the peak extended downriver as far as Poughkeepsie, but remained within the preferred freshwater spawning areas of white perch (e.g., TI 1979a, 1980b; NAI 1985b).

White perch eggs were caught every week of the LRS. The largest density estimates for eggs occurred during the week of 11 June, with slightly lower estimates in the previous week. Peak egg abundance has typically been recorded in past Year Class Reports to occur 1-3 weeks earlier (e.g., TI 1980b; Battelle 1983; NAI 1985a).

There are several possible explanations for this late peak in egg density. In 1984, as in previous years, the great majority of white perch eggs were collected from the bottom and shoal strata. White perch eggs are adhesive and demersal, and may not be sufficiently sampled by the methods used in the LRS. NAI (1985a) found a significant correlation between standing crop of eggs and freshwater flow, and suggested that timing of peak egg abundance is as much a function of the degree to which flow dislodges eggs as it is of actual peak standing crop. While high flows might serve to dislodge eggs, they do not seem to have been responsible for the late peak in egg density observed in 1984 (Table IV-3).

Temperature may have been the most important factor influencing egg abundance. Unusually low water temperatures were recorded in the upper estuary during 1984 and may have delayed spawning. Peak spawning has typically occurred in water temperatures of 15-20°C according to previous Year Class Reports (TI 1981; NAI 1985a). However, in 1984, mean water temperature in the upper estuary was still less than 13°C during the week of 4 June (Table A-1). The time of peak egg standing crop (week of 11 June) corresponded to a week in which water temperature rose more than 5°C in every region north of Poughkeepsie, and the sudden increase in temperature may have triggered spawning activity.

Yolk-Sac Larvae

Yolk-sac larvae were collected in every region of the Hudson River and in every week of the LRS (Fig. IV-12), but estimated concentrations were greatest during the week of 11 June in the

Table IV-3. Mean freshwater flow at Green Island USGS station and standing crop of white perch eggs during each week of the 1984 Longitudinal River Survey

Date of Sampling	Mean Flow (m^3/sec)	Standing Crop of Eggs (in Millions)
7 May	25200	262.2
14 May	30700	479.9
21 May	17900	832.7
28 May	56000	54.5
4 June	22900	2036.3
11 June	10100	3451.8
18 June	7700	76.8
25 June	7100	13.3
2 July	10000	2.5
9 July	16900	0.03

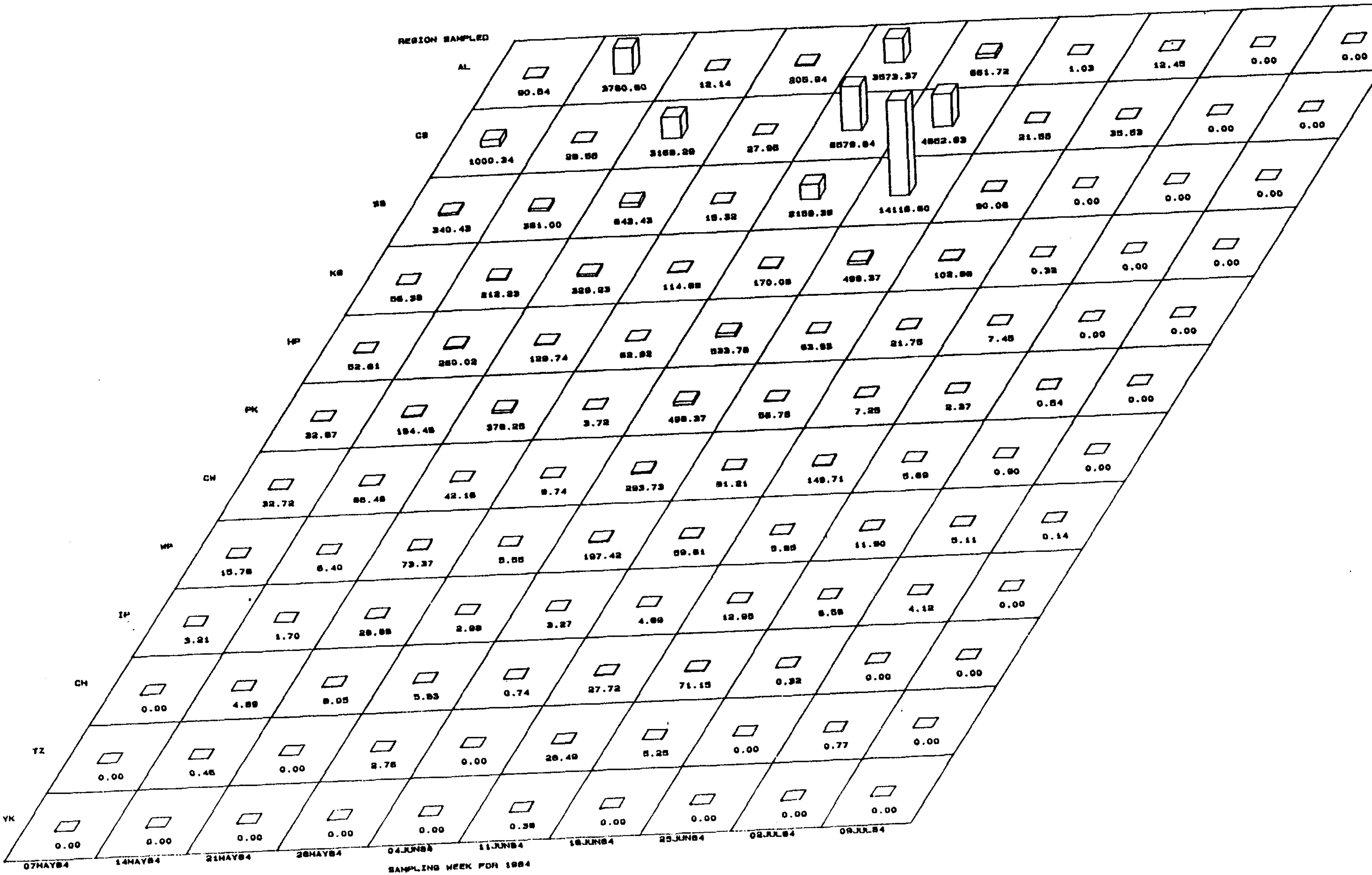

Figure IV-11. Mean regional density (per 1000 m^3) of white perch eggs collected in the Longitudinal River Survey during 1984

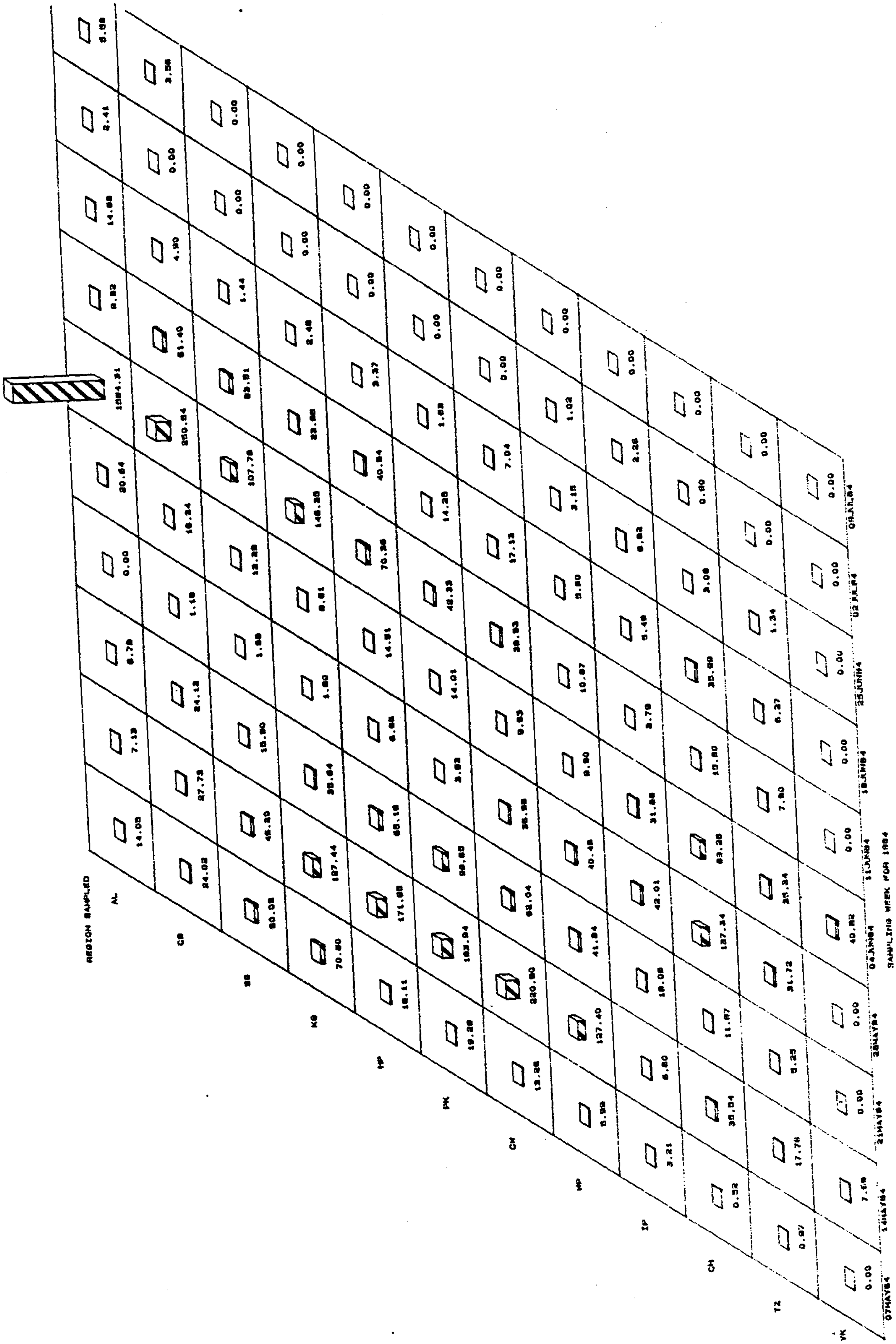

Figure IV-12. Mean regional density (per 1000 m^3) of white perch yolk-sac larvae collected in the Longitudinal River Survey during 1984 upper estuary. This follows by 1 week the initiation of the peak in egg density in the same area (Figs. IV-11 and IV-13). A smaller peak in yolk-sac larval density occurred during the week of 14 May between West Point and Kingston. This second peak did not correspond well with observed egg density and may represent larvae that were hatched from unsampled demersal eggs, or from eggs that were hatched in tributaries and carried downstream to the Hudson River.

In past Year Class Reports the period of peak yolk-sac standing crop generally lasted much longer than it did in 1984 (TI 1981). The period in which yolk-sac density exceeded 1000/1000 m^3 in any region was limited to a single week in 1984. This is probably due to the short period of peak egg density in that year. The yolk-sac stage generally lasts less than 1 week (Mansuetti 1964), and unless spawning occurs for an extended period, the yolk-sac stage will not be present in the water column for long.

Post Yolk-Sac Larvae

Post yolk-sac larvae mean regional densities exceeding 1000/1000 m^3 occurred in the weeks of 11 June, 18 June and 25 June between the Hyde Park and Catskill regions (Fig. IV-14). The period of these high concentrations of post yolk-sac larvae corresponds to that expected based on the peak density estimates of eggs and yolk-sac larvae in the upper estuary during the week of 11 June. However, unlike eggs and yolk-sac larvae, which appeared to be concentrated on the bottom, density estimates of post yolk-sac larvae in the three strata were almost equal, probably facilitating their downstream transport.

Standing crop estimates for post yolk-sac larvae declined substantially during the final 2 weeks of the LRS. This decline followed approximately 2-3 weeks after peak density of the post yolk-sac stage was observed (Fig. IV-14). Development of white perch from the post yolk-sac to juvenile stage generally takes 2-3 weeks at the temperatures that occurred in the Hudson River during late June. Declines in abundance in June to early July are typical of those reported in other Year Class Reports (NAI 1985b; Battelle 1983; TI 1981).

Total standing crop of post yolk-sac larvae (Tables B-31 to B-40) exceeded that of yolk-sac larvae in 1984, suggesting that the latter were not well sampled. Duration of the yolk-sac stage is short (less than 1 week) and it is possible that the weekly sampling of this study was insufficient to collect most white perch between the egg and post yolk-sac stages. Another possibility is that the 500-μm net used in the LRS may not be small enough to retain many of the yolk-sac larvae (Houde and Lovdal 1984). Finally, NAI (1985c) has suggested that many

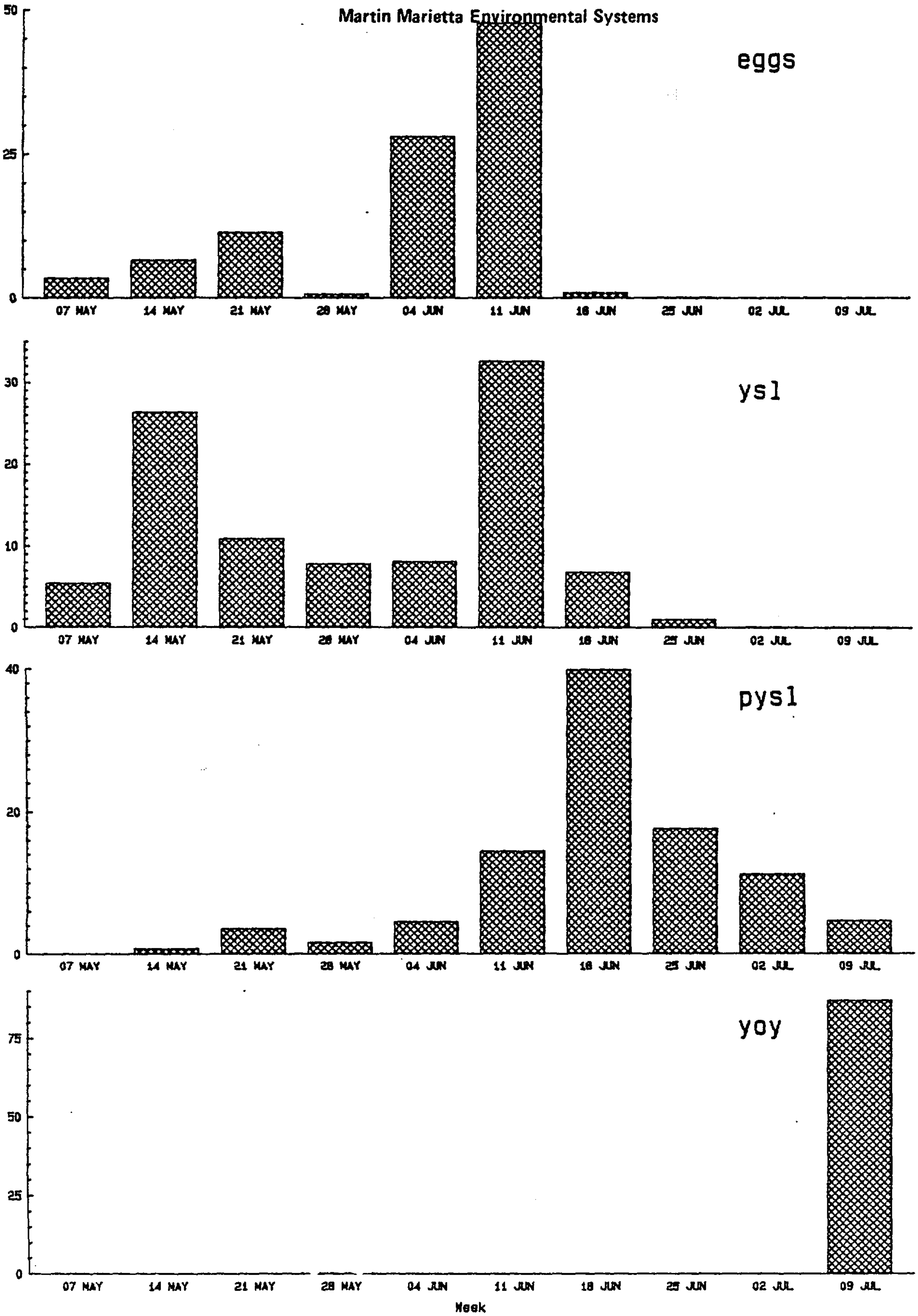

Figure IV-13. Temporal index for white perch eggs, yolk-sac larvae, post yolk-sac larvae, and young-of-year collected in the Longitudinal River Survey during 1984

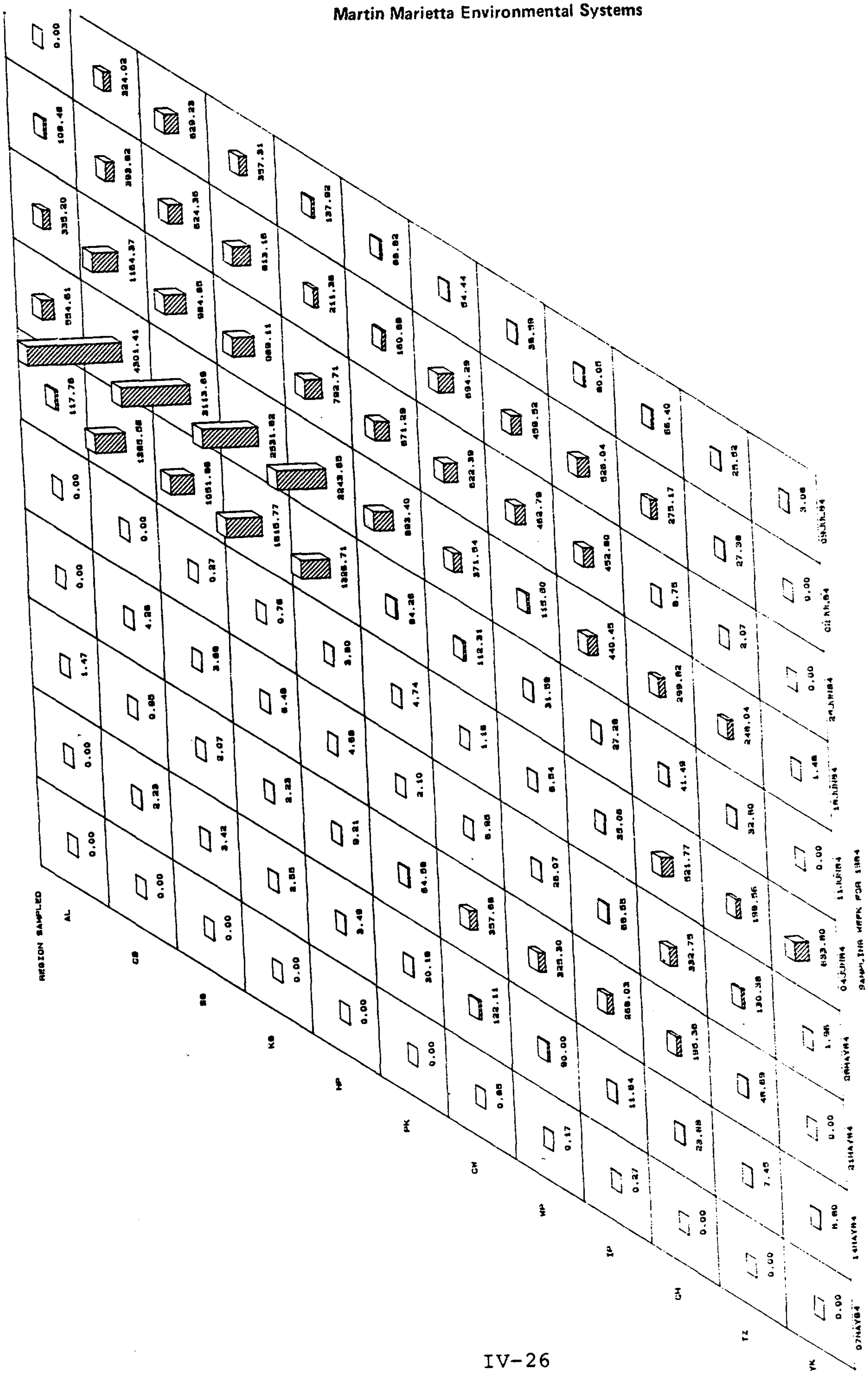

Figure IV-14. Mean regional density (per 1000 m^3) of white perch post yolk-sac larvae collected in the Longitudinal River Survey during 1984 white perch are spawned in tributaries of the Hudson River and may pass through the yolk-sac stage there. Thus, the greater abundance of white perch post-yolk sac larvae in the Hudson River could be due to their immigration into the sampling area.

Young-of-Year

Young-of-year white perch were first collected in the last week of LRS from the Kingston and Saugerties regions (Fig. IV-15). Peak density of post yolk-sac larvae was found 2-3 weeks earlier in these regions, which is consistent with the development time required to reach the juvenile stage. All previous Year Class Reports have reported that juveniles were first collected in late June or early July.

Juvenile white perch were collected throughout the FSS and BSS with most of the catch occurring in the BSS (Figs. IV-16 and IV-17). In the early weeks of these programs, juvenile densities were highest from the Poughkeepsie to Catskill regions, which was also the area of greatest post yolk-sac density. However, later in the fall programs the area containing the greatest concentration of white perch shifted downriver to the Croton-Haverstraw, Indian Point, and West Point regions. Increasing density downstream as the summer progresses accompanied by decreases in shore zone density and increases in channel and bottom density have been noted in previous years and have been attributed to movement of juveniles toward offshore overwintering areas.

Yearling and Older

Yearling and older white perch were collected in every region throughout the entire LRS (Fig. IV-18), FSS (Fig. IV-19), and BSS (Fig. IV-20) programs. Most of these fish were collected in the shoals and shore zone. There appeared to be a bimodal geographic distribution of white perch density in the river. One peak was located downstream between Indian Point and Tappan Zee. The second area of high density was located upstream between Kingston and Albany. Similar bimodal peaks in abundance have been observed in most Year Class Reports (e.g., NAI 1985b; Battelle 1983).

The upstream peak was most pronounced in early to mid-June, during the period of peak egg and larval density. These fish may have been part of the spawning population. It is unclear why abundance was so much less prior to this peak, though NAI (1985c) suggested that many white perch move into tributaries to spawn, and the peak in June might have occurred as these fish returned to the Hudson River.

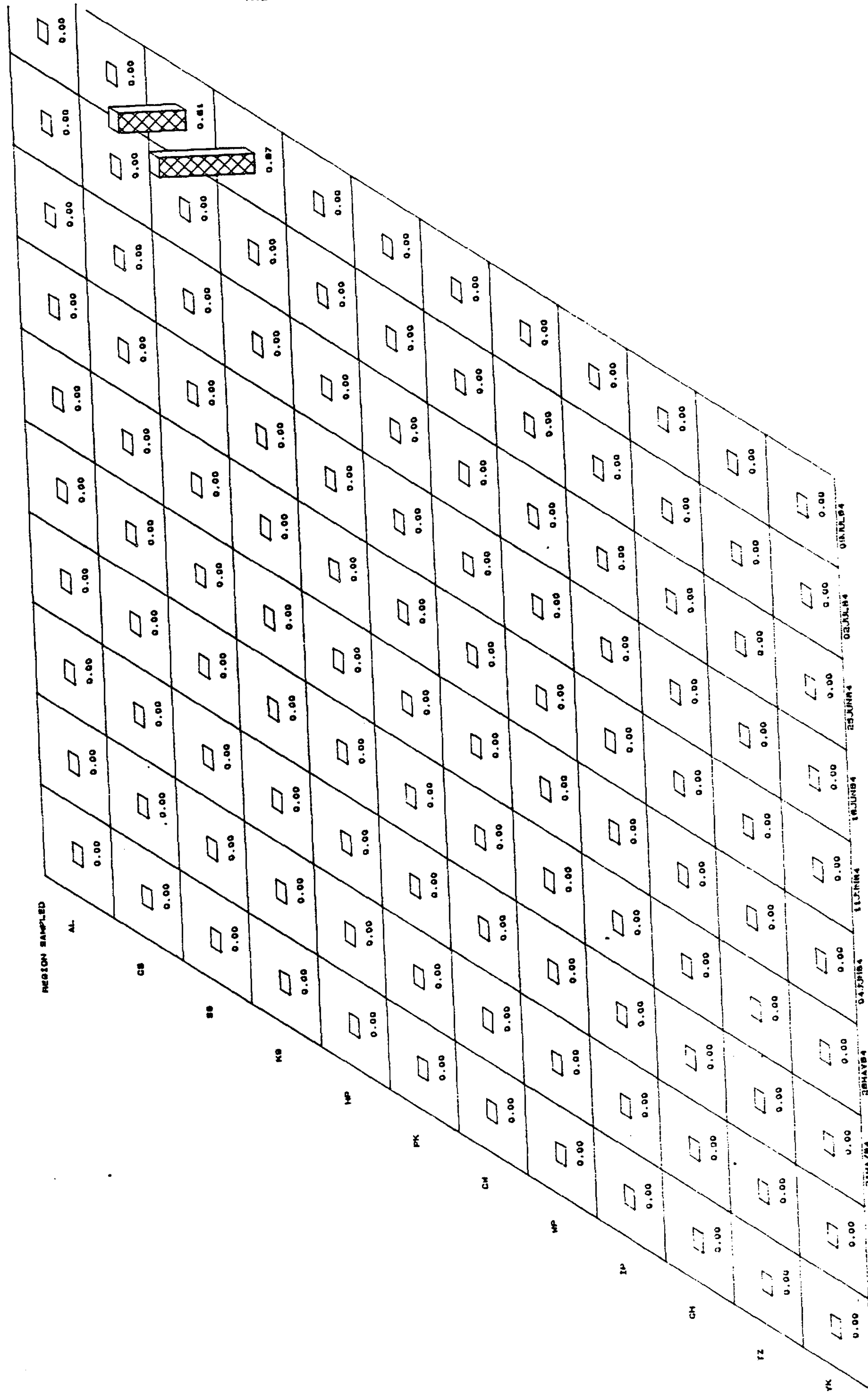

Figure IV-15. Mean regional density (per 1000 m^3) of white perch young-of-year collected in the Longitudinal River Survey during 1984

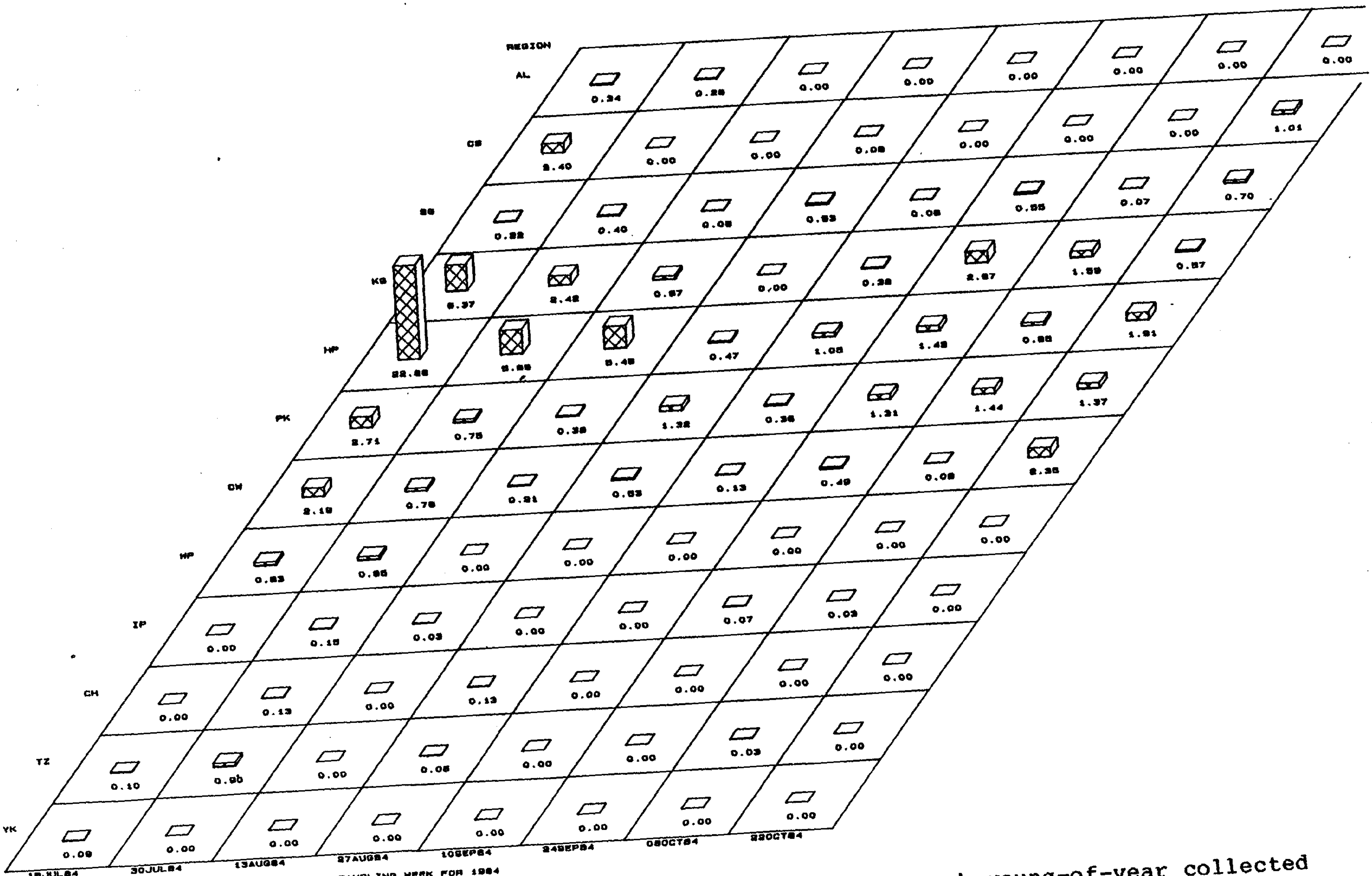

Figure IV-16. Mean regional density (per 1000 m^3) of white perch young-of-year collected in the Fall Shoals Survey during 1984

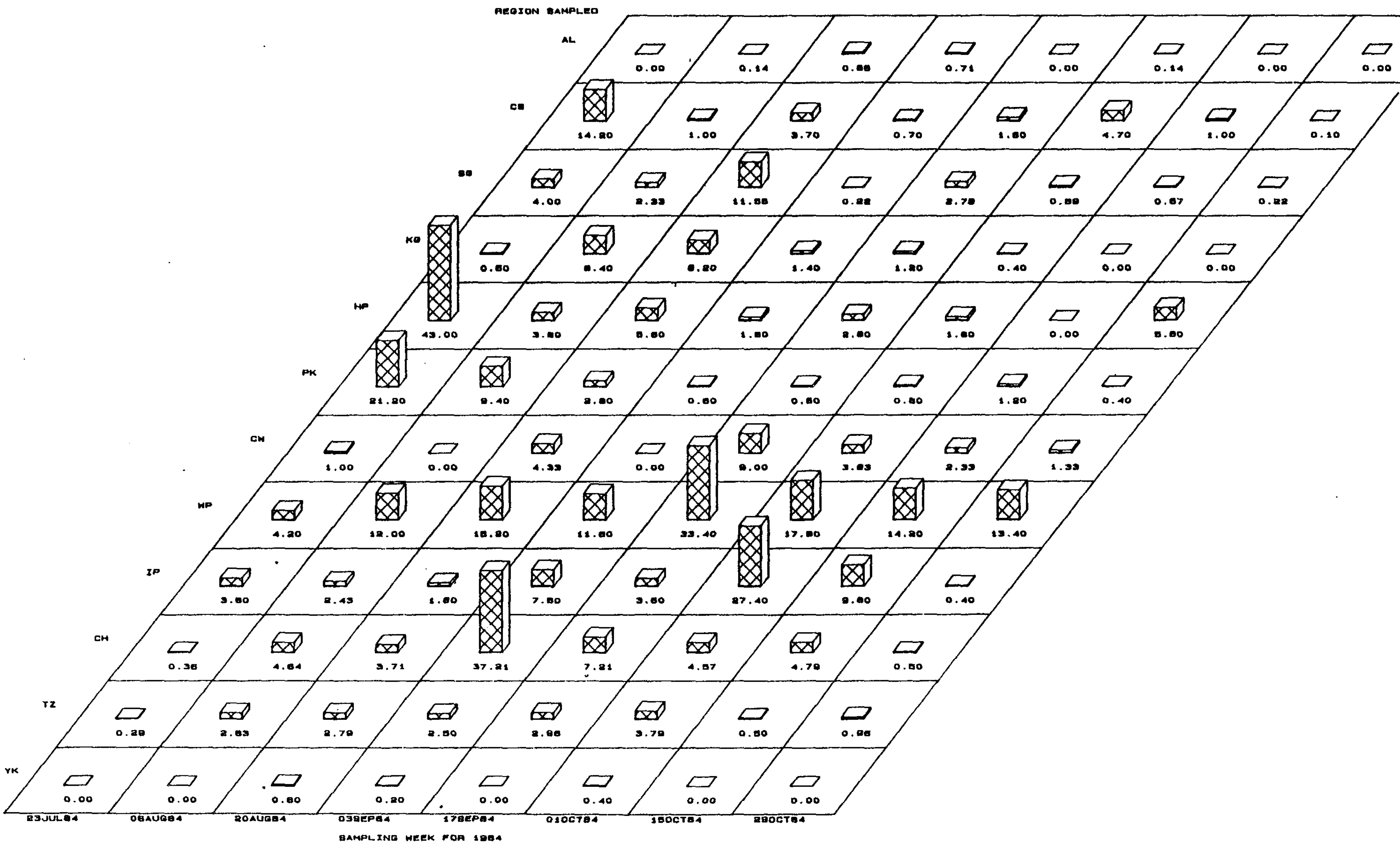

Figure IV-17. Catch per unit effort of white perch young-of-year collected in the Beach Seine Survey during 1984.

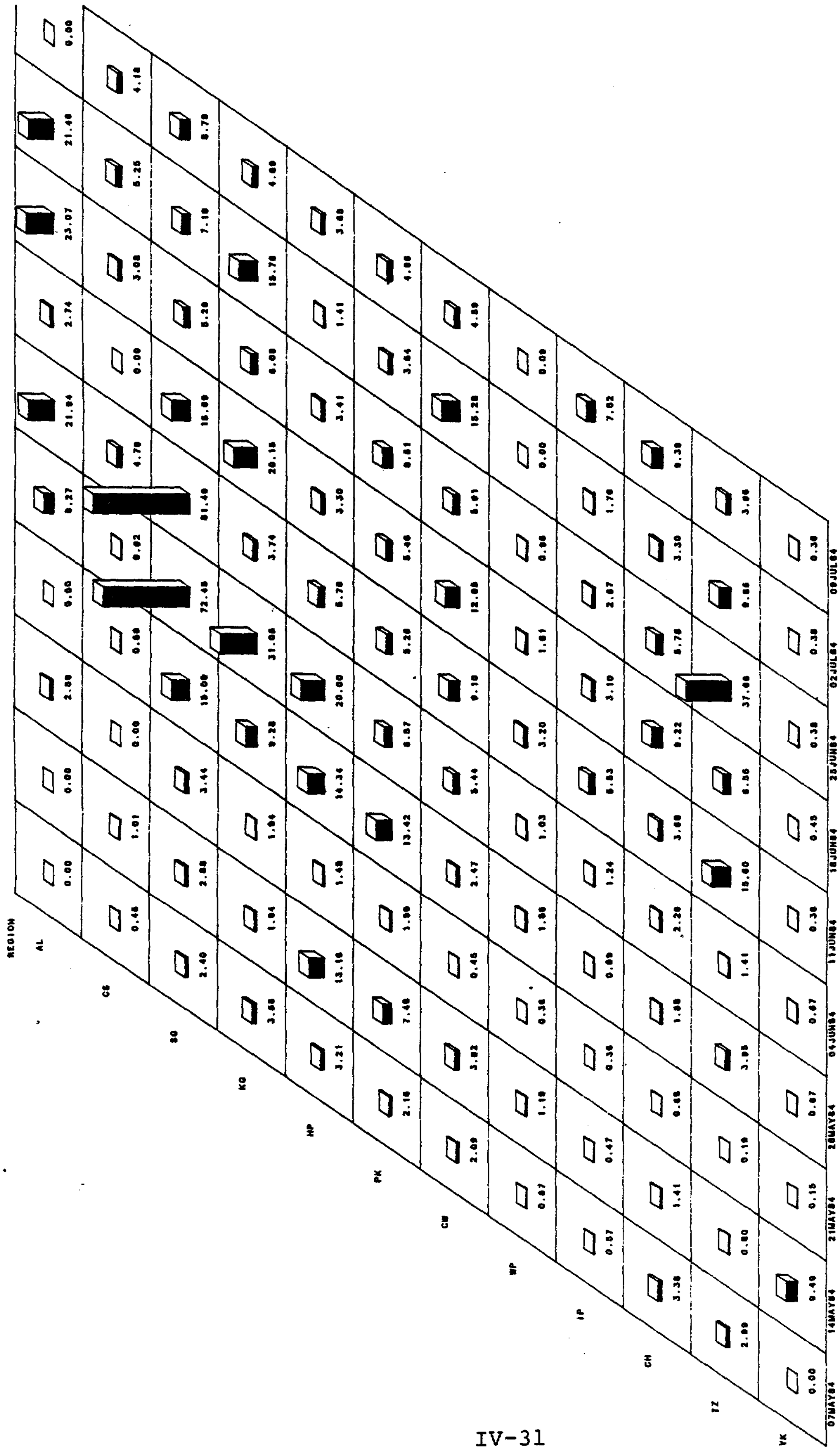

Figure IV-18. Mean regional density (per 1000 m^3) of white perch yearling and older collected in the Longitudinal River Survey during 1984

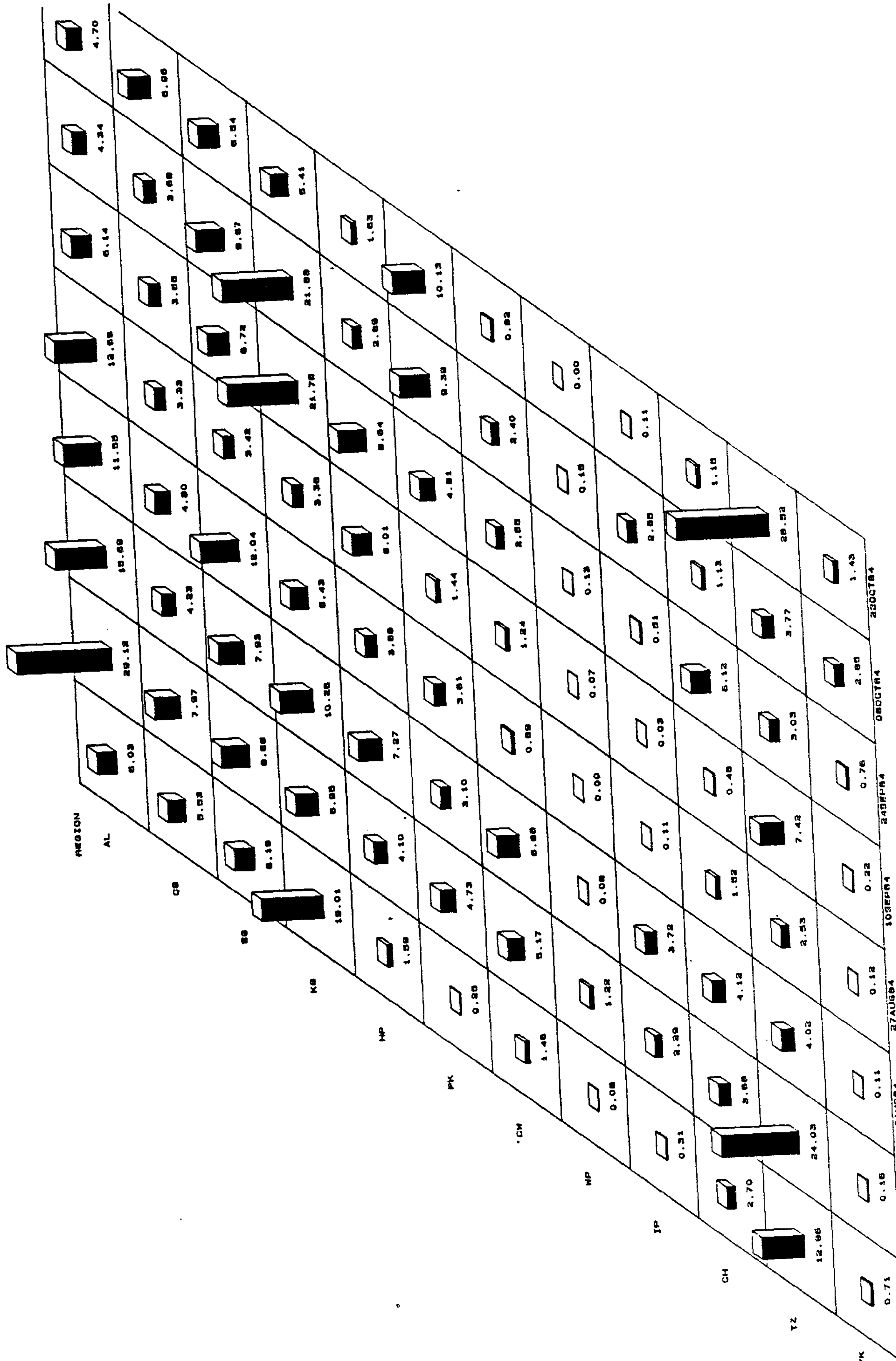

Figure IV-19. Mean regional density (per 1000 m^3) of white perch yearling and older collected in the Fall Shoals Survey during 1984

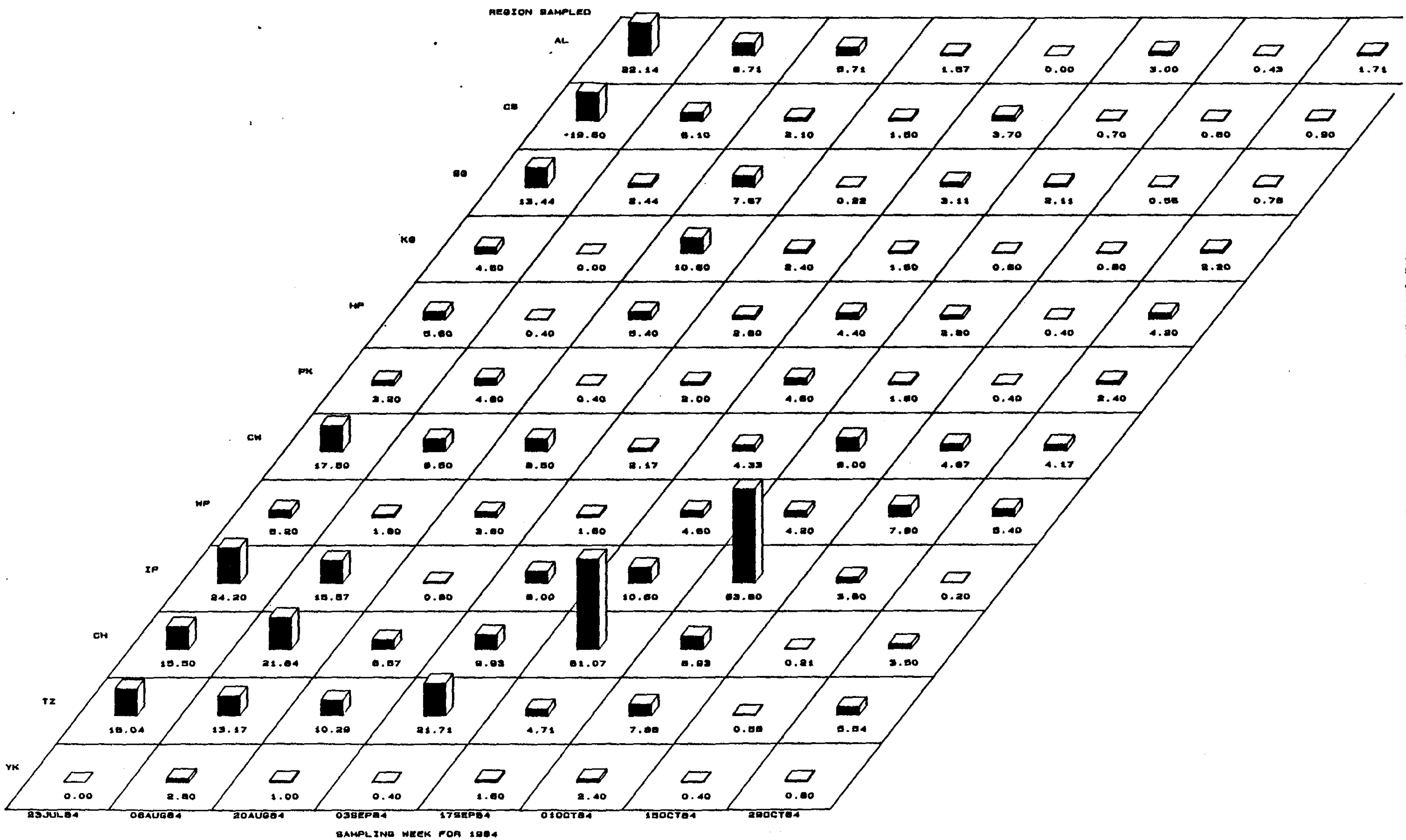

Figure IV-20. Catch per unit effort of white perch yearling and older collected in the Beach Seine Survey during 1984

D. AMERICAN SHAD

American shad, Alosa sapidissima, is an anadromous species which inhabits North American Atlantic waters from the St. Lawrence River in Canada to the St. Johns River in Florida. Spawning occurs in the freshwater reaches of their natal rivers. Stocks north of North Carolina are iteroparous, with the number of repeat spawners increasing with increasing latitude (DiNardo et al. 1985).

Adult shad enter the Hudson River in early spring to spawn in its tributaries and are found as far upstream as the Troy Dam (Sheppard 1976). After spawning, adult shad migrate northward, spending the summer and fall in the Gulf of Maine and Bay of Fundy. As water temperatures decrease, shad migrate southward and offshore, overwintering in the mid-Atlantic region of the east coast. Juveniles remain within the estuary throughout the summer and migrate to the ocean as temperatures decline. The immature shad remain in the ocean until they are mature, approximately 3-5 years, migrating each summer with the adults to the Gulf of Maine (Richkus and DiNardo 1984).

Eggs

American shad eggs were caught in all regions north of Croton-Haverstraw (Fig. IV-21). However, mean regional density estimates exceeding 10/1000 m^3 were found only from Kingston to Albany, with the highest estimates occurring for the Albany region. This distribution is similar to that reported in previous Year Class Reports, except that density estimates were highest for the Saugerties region in 1982 and for the Catskill region from 1976 to 1978. As in previous years, most eggs were collected from the bottom stratum in 1984.

Estimates of shad egg density were greatest during the first week of LRS, and declined rapidly around the third week of May. No shad eggs were caught after the week of 18 June. Previous Year Class Reports have also reported peak egg density for shad to occur during early to mid-May (although bimodal peaks in egg density were reported in the 1976-1978 Year Class Reports).

Eggs were collected only in the freshwater reaches of the river; this pattern is consistent with that expected based on preferred spawning environments for shad (Massmann 1952). Temperatures recorded from the Saugerties through Albany regions during the second and third weeks of May averaged 9.5°C (Table A-1). The reported temperature range for spawning is 7-14°C

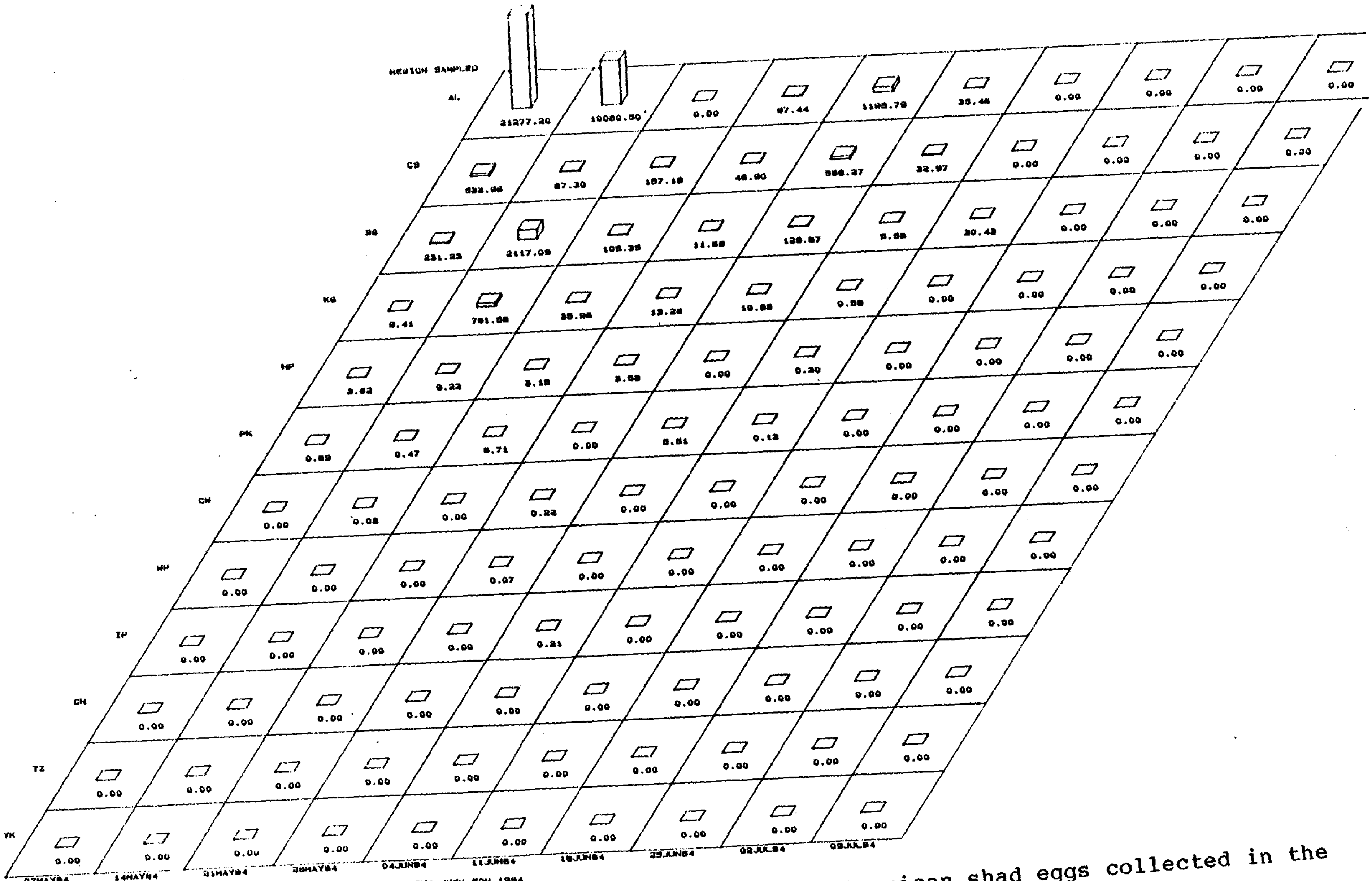

Figure IV-21. Mean regional density (per 1000 m3) of American shad eggs collected in the Longitudinal River Survey during 1984

(Boreman 1981). However, the optimum temperature for egg survival and development is 15.5-26.5°C (Leggett and Whitney 1972). Mean temperatures during maximum egg abundance have approached or exceeded 16°C in only 2 years since 1976 (Table IV-4).

Yolk-sac Larvae

The spatial distribution based on mean regional densities of American shad yolk-sac larvae in 1984 was consistent with that reported in previous Year Class Reports (Battelle 1983; NAI 1985a, 1985b). The larvae were collected from all regions, but were most dense in the upper estuary with highest concentrations estimated for the Albany region (Fig. IV-22). Unlike previous years, however, estimated concentrations of yolk-sac larvae in 1984 exceeded 100/1000 m^3 as far downstream as Indian Point. These downriver concentrations were all observed during the weeks of 28 May and 4 June, following particularly large freshwater inflows to the Hudson River (Table IV-3).

The temporal distribution of yolk-sac density was bimodal with peaks occurring in late May (2 weeks after peak egg density) and early June (4 weeks after peak egg density). This is in contrast with previous studies. From 1976 through 1983, a single peak in yolk-sac larval density was observed and this usually followed peak egg density by 1-2 weeks. The lag between egg and yolk-sac larvae density peaks in 1984 may be due partly to low water temperature during the incubation period. Mansuetti and Hardy (1967) reported incubation times ranging from 2 days at 27°C to 17 days at 12°C. Mean water temperature from Saugerties through Albany was 9.7°C during the period 14 May - 4 June. This is several degrees lower than the mean temperatures reported in previous years for the period of peak yolk-sac standing crop (Table IV-4).

Post Yolk-Sac Larvae

Shad post yolk-sac larvae were collected from mid-May through early July of 1984 (Fig. IV-23) at various times in each region. Post yolk-sac larval densities were highest in the upper estuary, with peak estimated concentrations occurring in the Catskill region in mid-June. A smaller peak in density was found in the Indian Point and West Point regions during the week of 4 June. Yolk-sac larvae primarily occurred upriver of Indian Point in the previous week. The geographic distribution in 1984 was similar to previous years; however, densities at the downriver regions were higher in 1984 than those reported from 1976 through 1983. The temporal distribution indicated that peak densities occurred later than in most previous years, but were not atypical (Table IV-4).

Table IV-4. Mean water temperature (°C) in regions and periods of peak abundance of American shad eggs and larvae, Hudson River estuary, 1976 through 1984[a]

Year	Eggs		Yolk-Sac Larvae		Post Yolk-Sac Larvae	
	Peak Period	Mean Temperature	Peak Period	Mean Temperature	Peak Period	Mean Temperature
1976	2 May - 22 May	13.3	9 May - 12 Jun	15.6	13 Jun - 26 Jun	22.9
1977	1 May - 21 May	13.5	8 May - 28 May	16.6	22 May - 4 Jun	20.5
1978	30 Apr - 27 May	13.1	21 May - 3 Jun	14.8	28 May - 3 Jun	21.4
1979	13 May - 19 May	17.3	13 May - 26 May	18.0	10 Jun - 16 Jun	19.4
1980	5 May - 08 May	15.5	12 May - 15 May	15.5	2 Jun - 13 Jun	20.0
1981	4 May - 09 May	10.0	18 May - 21 May	15.8	18 May - 21 May and	15.8
					8 Jun - 13 Jun	21.0
1982	10 May - 14 May	13.0	17 May - 20 May	16.6	24 May - 3 Jun	18.5
1983	9 May - 18 May	11.9	6 Jun - 9 Jun	16.0	13 Jun - 18 Jun	20.6
1984	7 May - 14 May	12.4	14 May - 4 Jun	13.7	11 Jun - 25 Jun	22.9

[a] Adapted from data presented in NAI (1985b).

Table IV-4. Mean water temperature (°C) in regions and periods of peak abundance of American shad eggs and larvae, Hudson River estuary, 1976 through 1984[a]

Year	Eggs		Yolk-Sac Larvae		Post Yolk-Sac Larvae	
	Peak Period	Mean Temperature	Peak Period	Mean Temperature	Peak Period	Mean Temperature
1976	2 May - 22 May	13.3	9 May - 12 Jun	15.6	13 Jun - 26 Jun	22.9
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1979	13 May - 19 May	17.3	13 May - 26 May	18.0	10 June - 16 Jun	19.4
1980	5 May - 08 May	15.5	12 May - 15 May	15.5	2 June - 13 Jun	20.0
1981	4 May - 09 May	10.0	18 May - 21 May	15.8	18 May - 21 May	15.8
					and	
					8 June - 13 Jun	21.0
1982	10 May - 14 May	13.0	17 May - 20 May	16.6	24 May - 3 Jun	18.5
1983	9 May - 18 May	11.9	6 June - 9 Jun	16.0	13 June - 18 Jun	20.6
1984	7 May - 14 May	9.5	14 May - 4 Jun	9.7	11 June - 25 Jun	18.0

(a)Adapted from data presented in NAI (1985b).

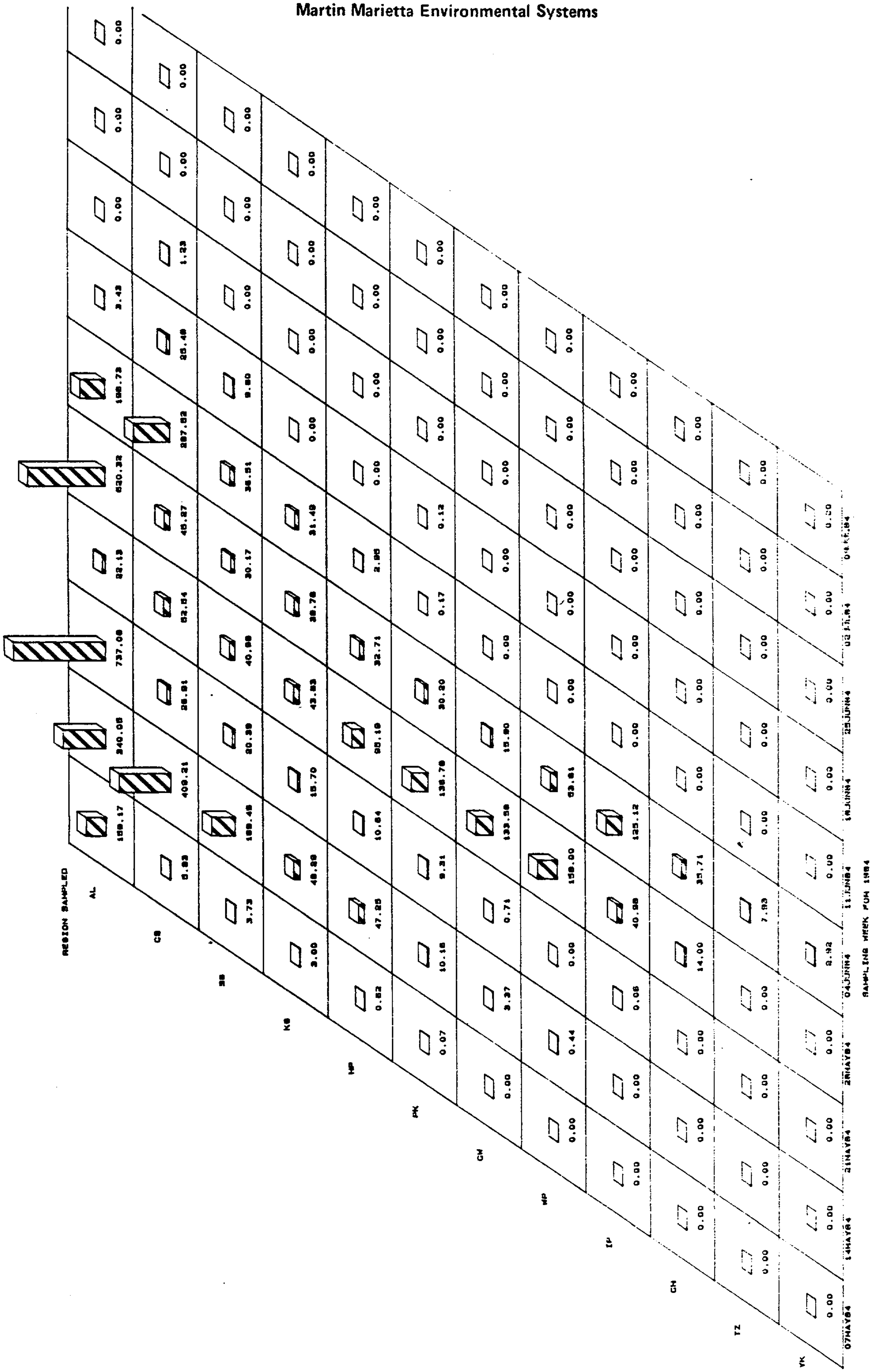

Figure IV-22. Mean regional density (per 1000 m^3) of American shad yolk-sac larvae collected in the Longitudinal River Survey during 1984

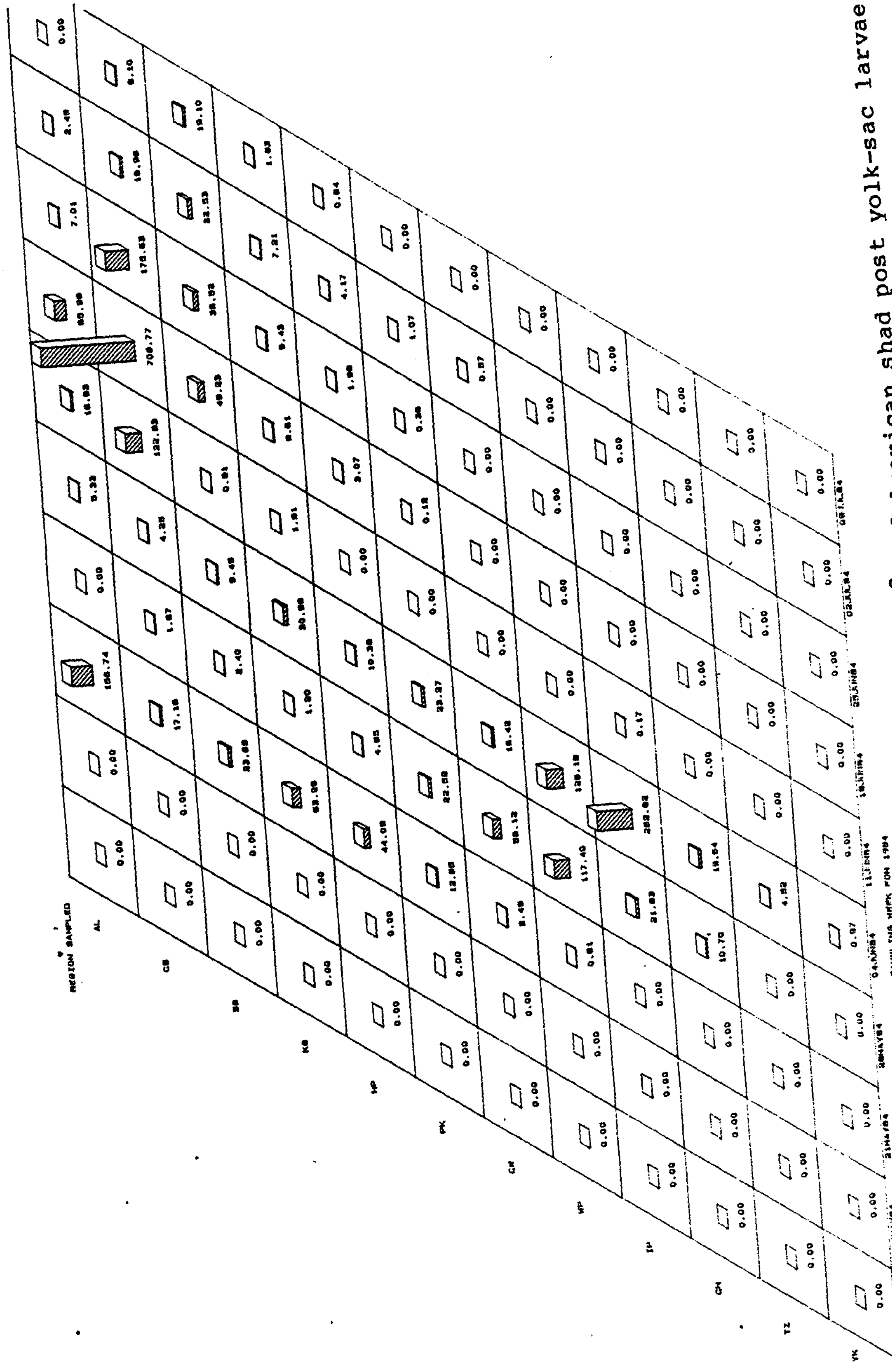

Figure IV-23. Mean regional density (per 1000 m^3) of American shad post yolk-sac larvae collected in the Longitudinal River Survey during 1984

Young-of-Year

Juvenile American shad were collected from the end of the LRS (Fig. IV-24) through the end of the BSS and FSS (Figures IV-25 and IV-26). Peak density of juveniles occurred in mid-July, and followed the highest density of post yolk-sac larvae by about 3 weeks. Similar periods of peak juvenile density have been reported previously (Battelle 1983).

During the LRS, juveniles were most abundant in collections from the upper regions of the estuary where density of the larval stages had been highest. As overall density declined in August and early fall, juveniles became relatively less abundant in samples from the upper estuary. Juvenile shad generally emigrate from Altantic coast rivers after water temperatures drop below 15°C for several days (Leggett and Whitney 1972, Chittenden and Westman 1967). In 1984, temperatures in the Hudson River estuary during fall juvenile surveys were generally above 17°C in the middle estuary (Fig. III-1), and no clear evidence of emigration was observed. Presumably emigration from the estuary occurred after sampling had ended.

E. 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). 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 collected in 1984, and post yolk-sac larvae were only found during the first 2 weeks of the LRS (Fig. IV-27). They were collected south of Poughkeepsie, with the highest densities observed in the Tappan Zee region during the week of 7 May. Density estimates of post yolk-sac larvae in the shoal stratum were greater than those for other strata on all sampling dates.

These patterns of post yolk-sac larval standing crop are similar to that reported in 1975 through 1977 and in 1980, 1981, and 1983. In 1978, 1979, and 1982, post yolk-sac larvae were observed as far north as Poughkeepsie.

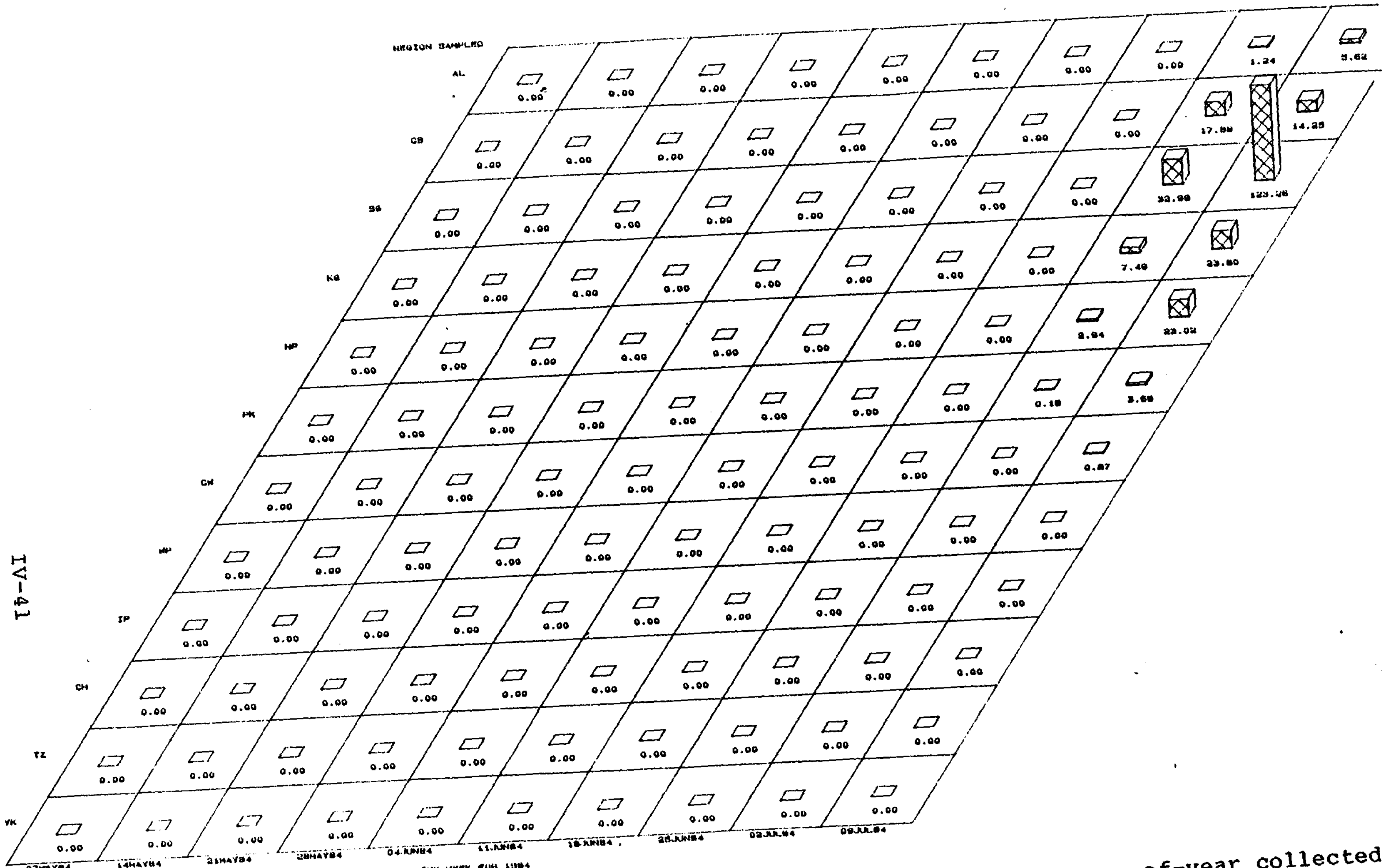

Figure IV-24. Mean regional density (per 1000 m3) of American shad young-of-year collected in the Longitudinal River Survey during 1984

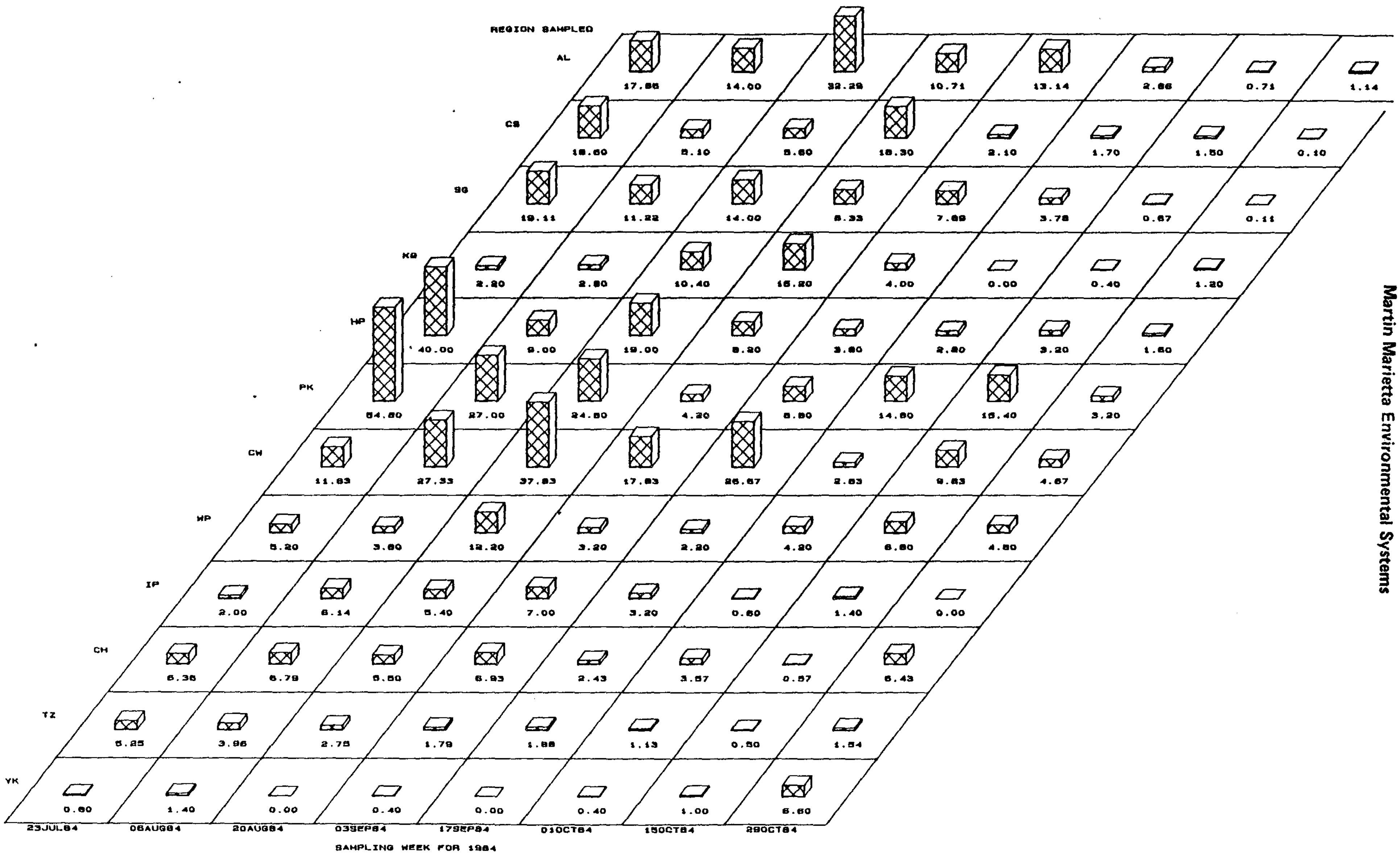

Figure IV-25. Catch per unit effort of American shad young-of-year collected in the Beach Seine Survey during 1984

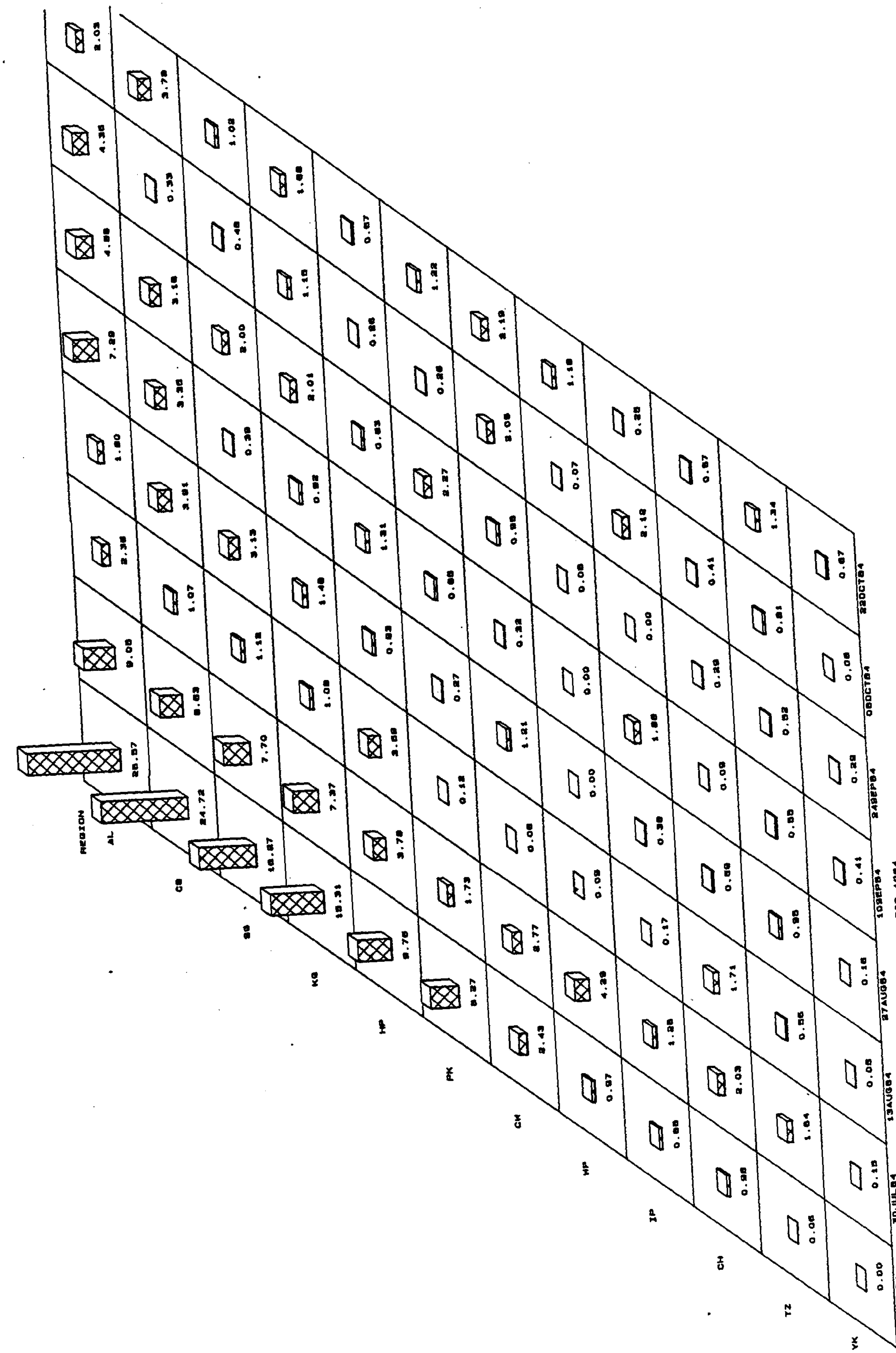

Figure IV-26. Mean regional density (per 1000 m3) of American shad young-of-year collected in the Fall Shoals Survey during 1984

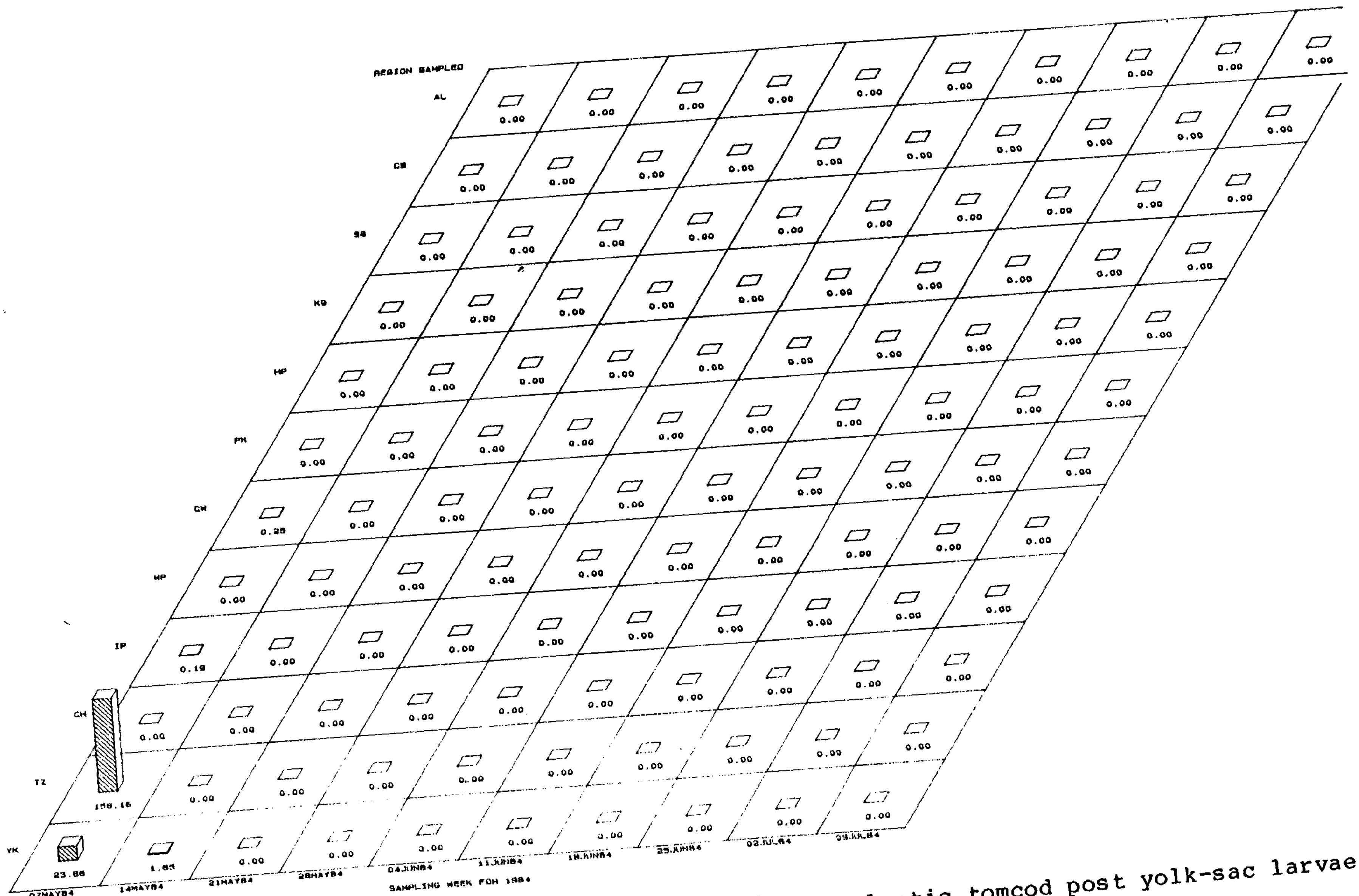

Figure IV-27. Mean regional density (per 1000 m^3) of Atlantic tomcod post yolk-sac larvae collected in the Longitudinal River Survey during 1984

The temporal distribution of tomcod post yolk-sac larvae based on density estimates in 1984 was similar to that reported from 1975 through 1981 and in 1983. In 1980 and 1982, post yolk-sac larvae were observed as late as June.

Young-of-Year

Juvenile tomcod were collected throughout the LRS (Fig. IV-28), BSS (Fig. IV-29), and FSS (Fig. IV-30). Densities were greatest during May and June when mean regional densities regularly exceeded 100/1000 m^3. Density declined steadily after June and mean regional densities were always less than 10/1000 m^3 after August. The May-June peak in juvenile tomcod density is typical of that reported in Year Class Reports from 1979 to 1983. However, in past years, when the LRS began earlier in the year, peak juvenile standing crops were often found in April.

Juvenile tomcod were collected throughout the river, but were most concentrated in samples taken downriver in the Tappan Zee and Yonkers regions. Their distribution has been shown in previous Year Class Reports to be salinity-related. In 1984, very few tomcod were collected during the week of 4 June when the sampling area was completely freshwater. However, juvenile tomcod returned as far upstream as West Point, at a density exceeding 300/1000 m^3 in late June, as salinity in that region increased above 1 ppt. In the BSS, juveniles were never collected north of West Point. This geographic distribution is typical of that presented in all previous Year Class Reports. Also, as in preceding Year Class Reports, juvenile Atlantic tomcod were collected primarily from the bottom stratum in 1984.

F. ALOSA SPP.

This taxonomic group comprises the early developmental stages of two anadromous clupeids, blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*), which are collectively referred to as river herring. These species are difficult to distinguish before the metamorphosed juveniles reach a total length of 35-40 mm (TI 1981). Both species spawn in the spring. Blueback herring spawn somewhat later than alewives, although the blueback spawning migration may overlap the end of the alewife spawning period. This section describes the distribution of eggs, yolk-sac larvae, and post yolk-sac larvae for this category. The young-of-year and yearling and older stages of alewife and blueback herring are presented independently in Sections IV-G and IV-H, respectively.

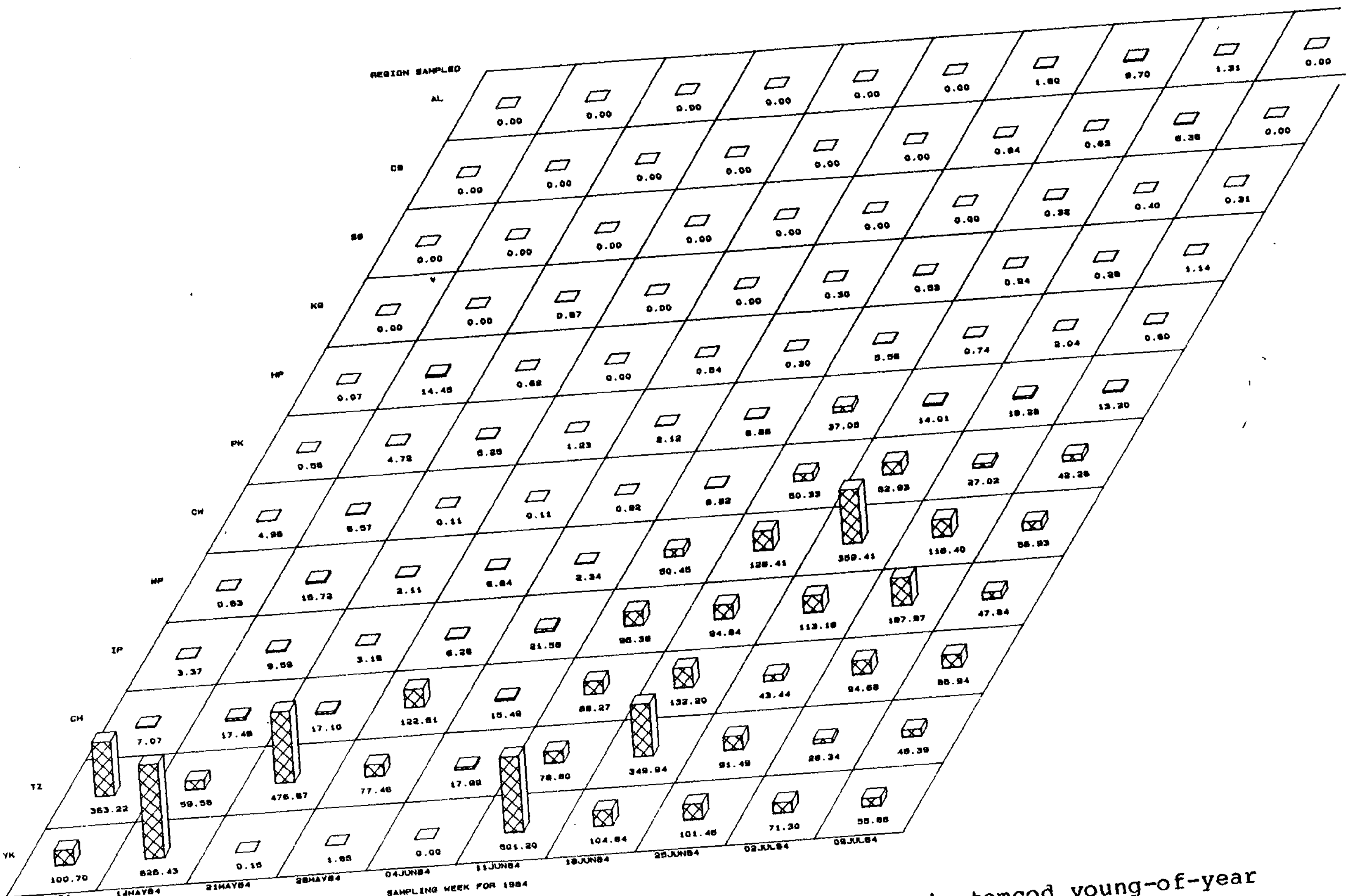

Figure IV-28. Mean regional density (per 1000 m^3) of Atlantic tomcod young-of-year collected in the Longitudinal River Survey during 1984

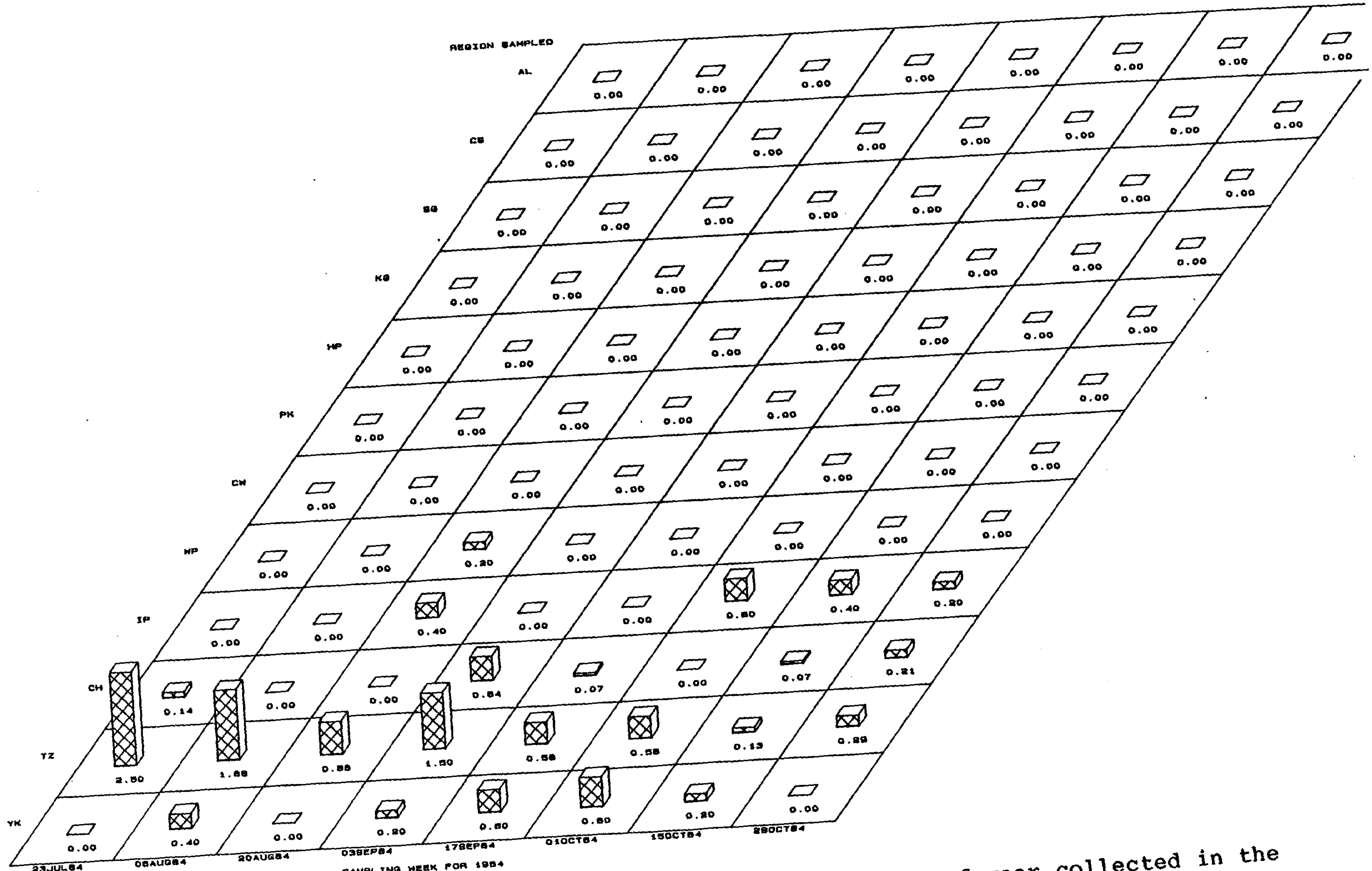

Figure IV-29. Catch per unit effort of Atlantic tomcod young-of-year collected in the Beach Seine Survey during 1984

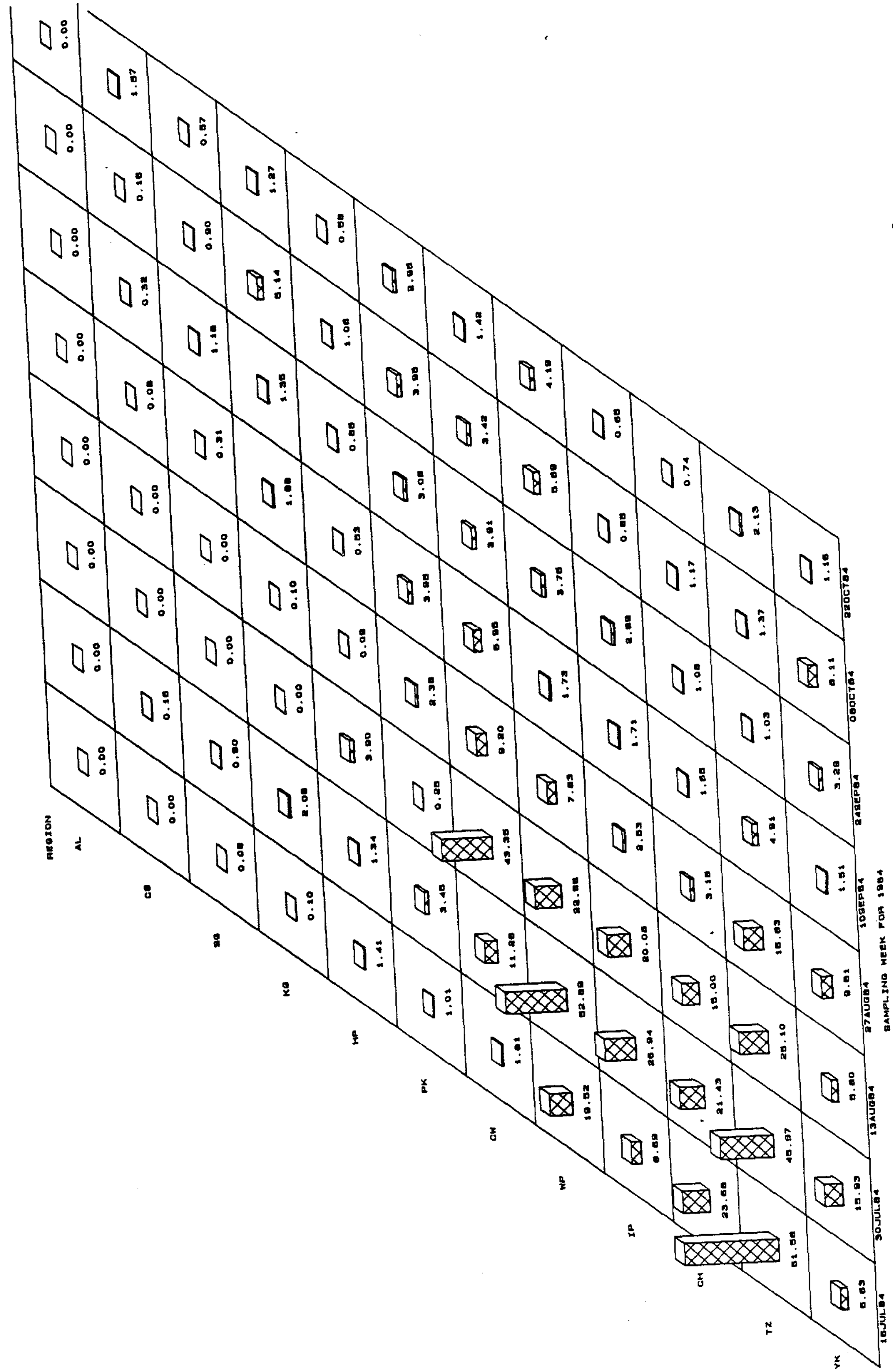

Figure IV-30. Mean regional density (per 1000 m3) of Atlantic tomcod young-of-year collected in the Fall Shoals Survey during 1984

The alewife inhabits coastal waters along the eastern North American coast from Newfoundland to South Carolina (Winters et al. 1973). They spend most of their life at sea, but begin spawning runs to freshwater as temperature increases above 8°C (Richkus 1974). Spawning may take place at temperatures as low as 10°C (Cianci 1969) but peak spawning reportedly occurs between 12 and 15°C (Tyus 1974; Richkus 1974). Once spawning is complete, alewife typically return to sea (Kissil 1974).

The blueback herring inhabits coastal waters from Nova Scotia to Florida. Attempts have been made to introduce this species to reservoirs, but blueback herring have not been found to reproduce when landlocked (Prince and Barwick 1981). Blueback herring return to their natal rivers to spawn in freshwater. Generally they spawn at higher temperatures (21-24°C) than alewife but have been found to spawn at temperatures as low as 14°C (Loesch and Lund 1977).

Eggs

Alosa spp. eggs were collected in all weeks of the LRS except for 9 July (Fig. IV-31). Sample densities exceeded 10,000/1000 m^3 in the first week of the LRS, suggesting that spawning in April, which has been observed in previous years, also occurred in 1984. Two peaks in mean density were observed in 1984: 1) in the week of 14 May, primarily in the Albany region, and 2) in the week of 4 June between Albany and Saugerties. The early peak probably corresponded to spawning by alewife since water temperature at that time was less than 10°C, which is believed to be too low for spawning by blueback herring. The latter peak may have represented spawning by blueback herring.

Although egg distribution was widespread throughout the sampling area, eggs were found in all regions except Tappan Zee. They were most abundant in freshwater areas; mean regional density never exceeded 5/1000 m^3 in any region downriver of Poughkeepsie. The same distribution pattern is typical of that reported in all previous Year Class Reports.

Yolk-Sac Larvae

Alosa spp. yolk-sac larvae were collected in all weeks of the LRS, but two density peaks, one centering around the week of 14 May and a smaller peak occurring during the week of 11 June, were apparent (Fig. IV-32). Each followed a peak in egg density by about 1 week. The presence of yolk-sac larvae in the first week of LRS further suggests that spawning also occurred in April.

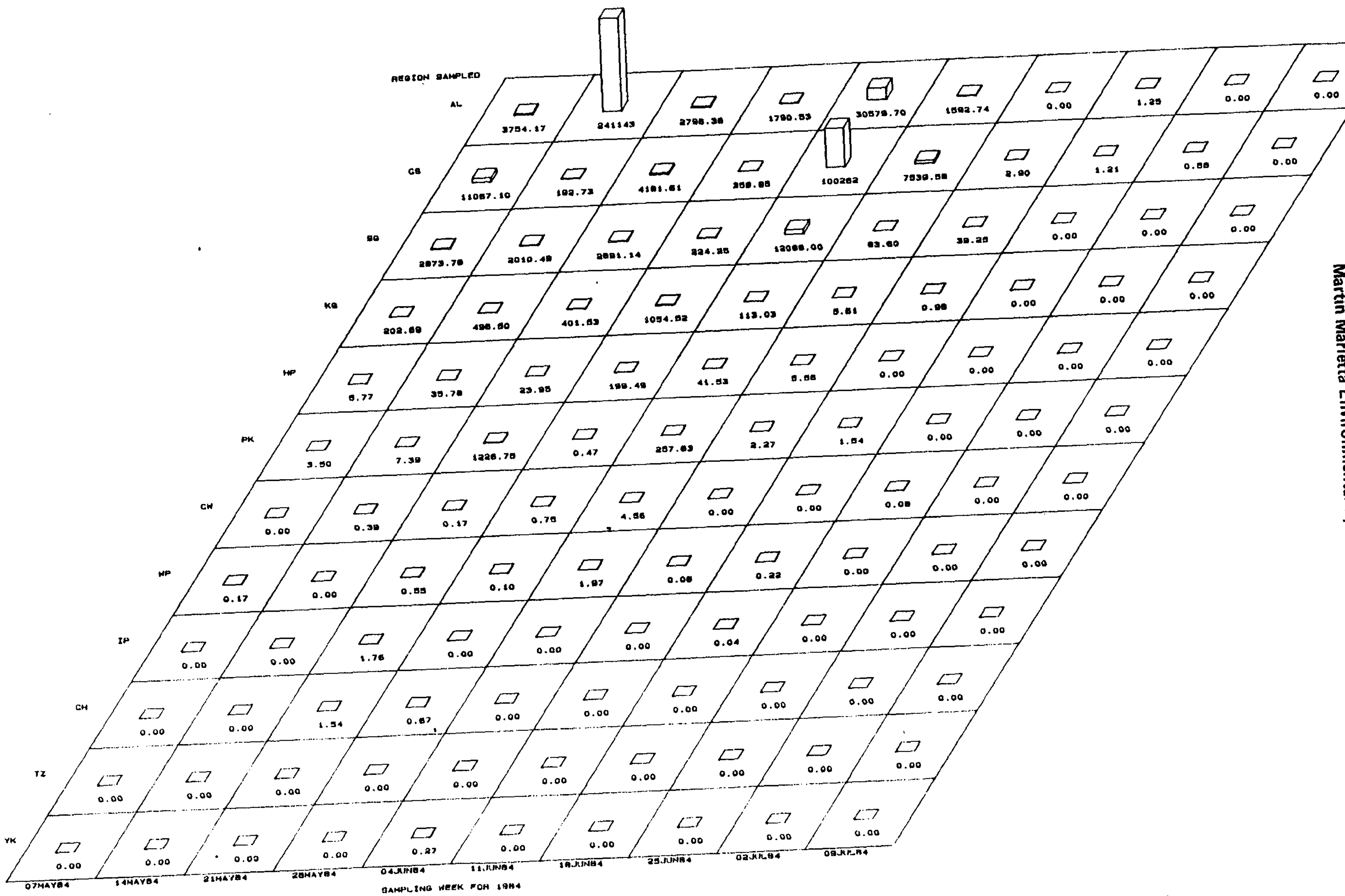

Figure IV-31. Mean regional density (per 1000 m^3) of *Alosa* spp. eggs collected in the Longitudinal River Survey during 1984

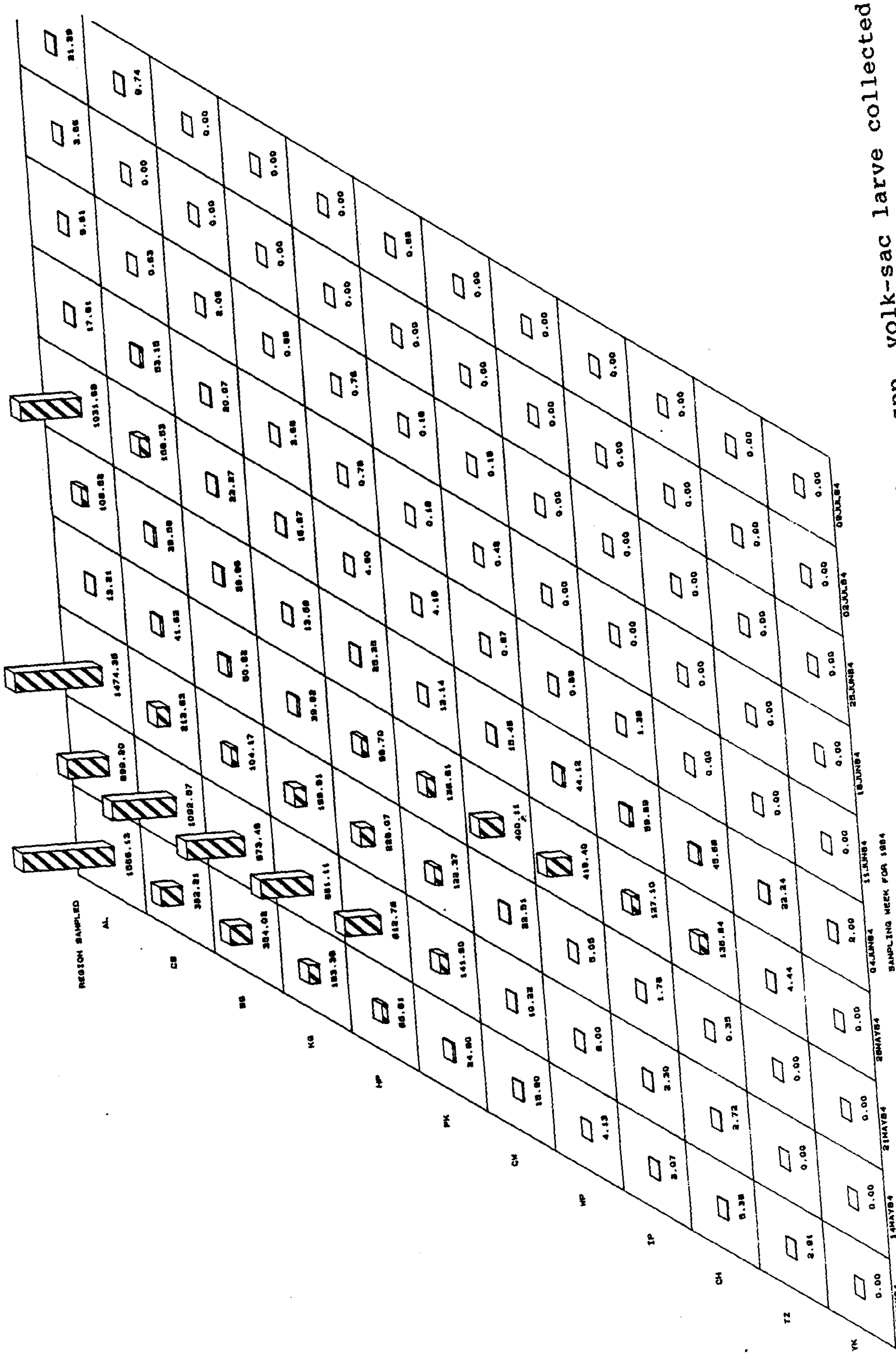

Figure IV-32. Mean regional density (per 1000 m^3) of *Alosa* spp. yolk-sac larve collected in the Longitudinal River Survey during 1984

Like eggs, yolk-sac larvae were collected primarily in freshwater regions. Only in 1 week did densities exceed 100/1000 m^3 as far downriver as Croton-Haverstraw, and this can probably be attributed to exceptionally large freshwater inputs (Table IV-3) that may have transported the larvae downstream.

Post Yolk-Sac Larvae

Alosa spp. post yolk-sac larvae were collected in all weeks and in all regions during the LRS (Fig. IV-33). However, two peaks in post yolk-sac density were apparent. Post yolk-sac density estimates exceeded 1000/1000 m^3 between the Croton-Haverstraw and Cornwall regions during the week of 28 May, and from Yonkers to Indian Point the following week. This peak appears to correspond to eggs that were spawned upriver in early May and were washed downriver as yolk-sac larvae during heavy rains that occurred in late May.

The second peak in density occurred north of Poughkeepsie between the weeks of 11 June and 9 July when mean regional densities regularly exceeded 1000/1000 m^3. This peak appears to correspond spatially and temporally to the peaks in egg and yolk-sac larval density that occurred in the upper estuary during the weeks of 4 June and 11 June, respectively.

G. ALEWIFE

Young-of-Year

No young-of-year alosids identifiable as alewife were collected during the LRS, although they were collected throughout the FSS and BSS (Figs. IV-34 and IV-35). In both of these latter programs, the highest regional densities occurred in late July to mid-August, with density declining greatly in October. Young-of-year alewife appeared as early as June in 1980 (Battelle 1983). However, in general, the July-August peak in density during 1984 was very similar to historical patterns.

As in most previous years, juvenile alewife were collected primarily from freshwater regions of the Hudson River during the summer months. No juvenile alewife were found in the Yonkers region in either the FSS or BSS throughout 1984, and collection of this species south of Poughkeepsie was rare. No downstream movement of juvenile alewife was apparent during the fall of 1984. Richkus (1975) has suggested that such downstream movement is associated with rapid declines in water temperature.

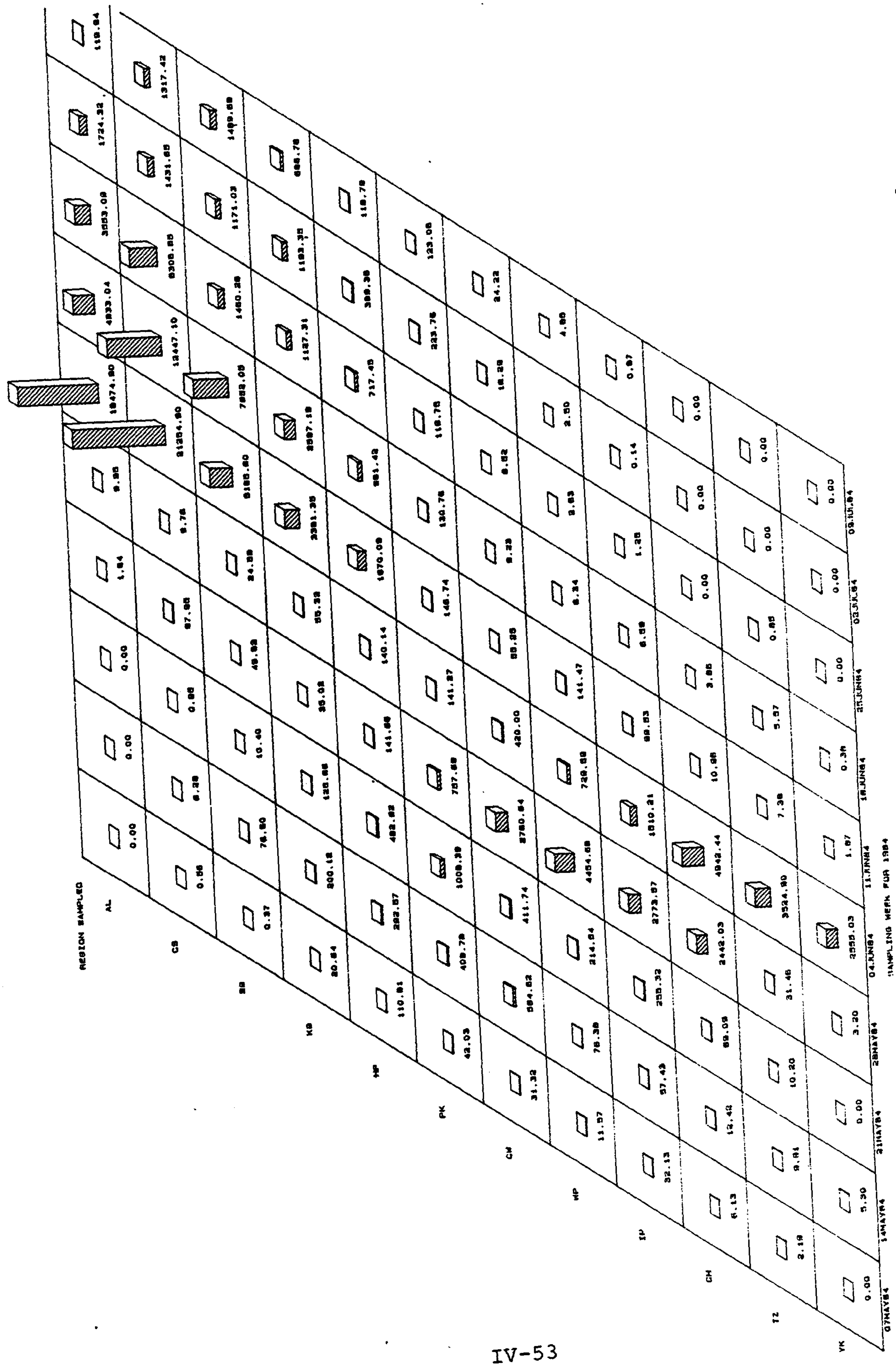

Figure IV-33. Mean regional density (per 1000 m^3) of <u>Alosa spp.</u> post yolk-sac larve collected in the Longitudinal River <u>Survey</u> during 1984

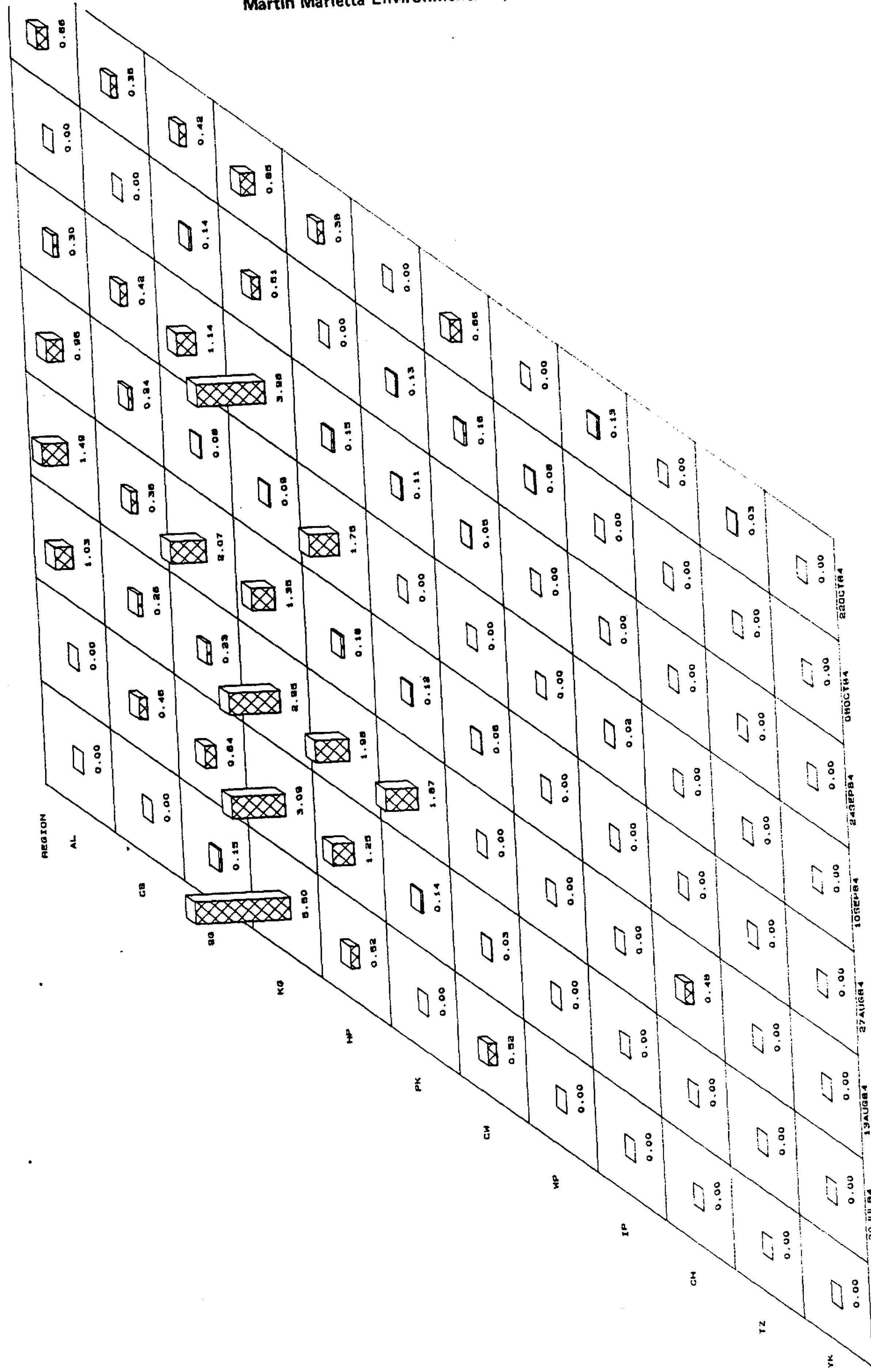

Figure IV-34. Mean regional density (per 1000 m3) of alewife young-of-year collected in the Fall Shoals Survey during 1984

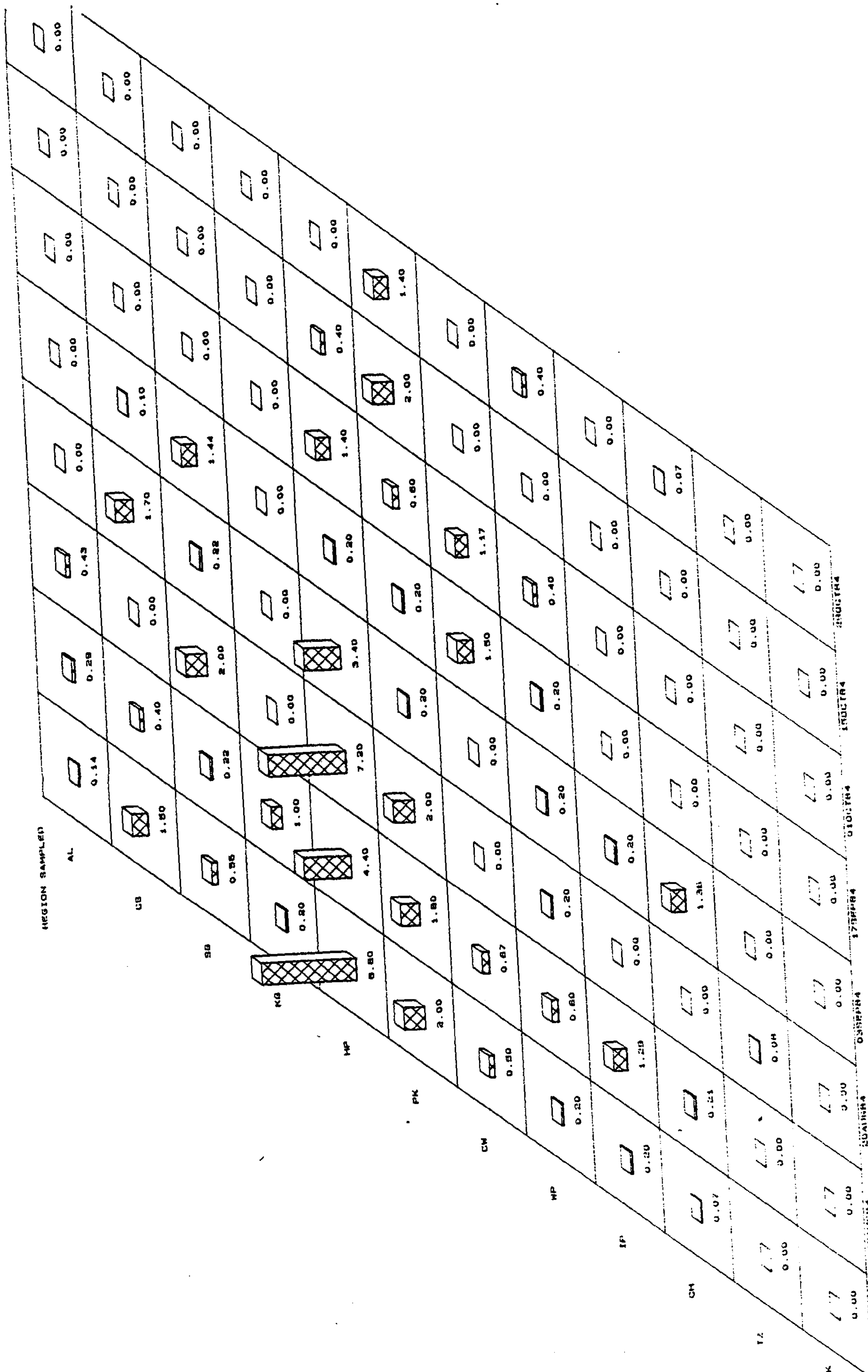

Figure IV-35. Catch per unit effort of alewife young-of-year collected in the Beach Seine Survey during 1984

Water temperature in the Pougkeepsie region still exceeded 17°C during the last week of sampling, and downriver movement probably did not begin until after the FSS and BSS had ended.

Yearling and Older

Yearling and older alewife were caught from the first week of LRS (Fig. IV-36) to the final week of the FSS (Fig. IV-37). During LRS most yearling and older alewife were caught in the upper estuary, whereas in the BSS (Fig. IV-38) and late in the FSS most alewife were caught in the middle and lower estuary. Most yearling and older fish were collected from the bottom stratum, with very few collected in the channel.

Collection of yearling and older alewife in previous years has been sporadic. Downriver movement has only been previously documented in the 1982 Year Class Report. It is likely that swimming ability of yearling and older alewife causes low collection efficiency and may mask any distributional or movement patterns of this species within the Hudson River.

H. BLUEBACK HERRING

Young-of-Year

Identifiable juvenile blueback herring were first collected in very low numbers on 11 June and in slightly greater numbers during the final week of the LRS (Fig. IV-39). However, highest densities of juvenile blueback herring did not occur until late July to early August (Figs. IV-40 and IV-41). After this peak, mean regional densities gradually declined throughout the rest of FSS sampling, but there was no consistent decline in the BSS densities.

June is atypically early for first catch of juvenile blueback herring in the Hudson River. It is even more unusual for juvenile blueback herring to be collected before juvenile alewife are found. However, the period of highest density in 1984 was typical of that reported in many other Year Class Reports.

As with alewife, blueback herring were collected in greatest numbers in freshwater. In the FSS density was greatest north of Poughkeepsie, while in the BSS it was generally highest between Cornwall and Kingston. However, blueback herring catches were more widely distributed than were those of alewife and they occurred farther downriver. No overall downriver migration,

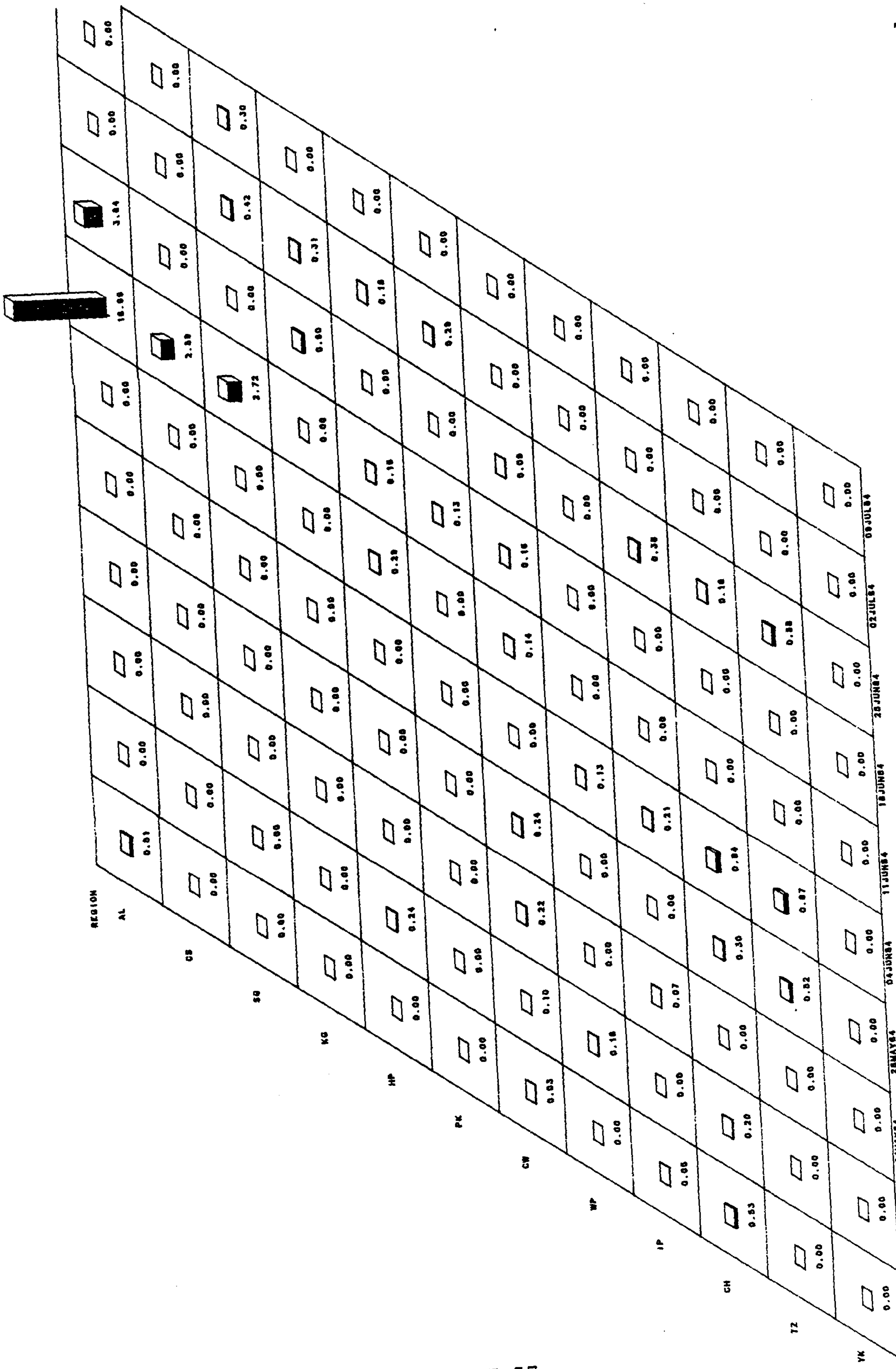

Figure IV-36. Mean regional density (per 1000 m^3) of alewife yearling and older collected in the Longitudinal River Survey during 1984

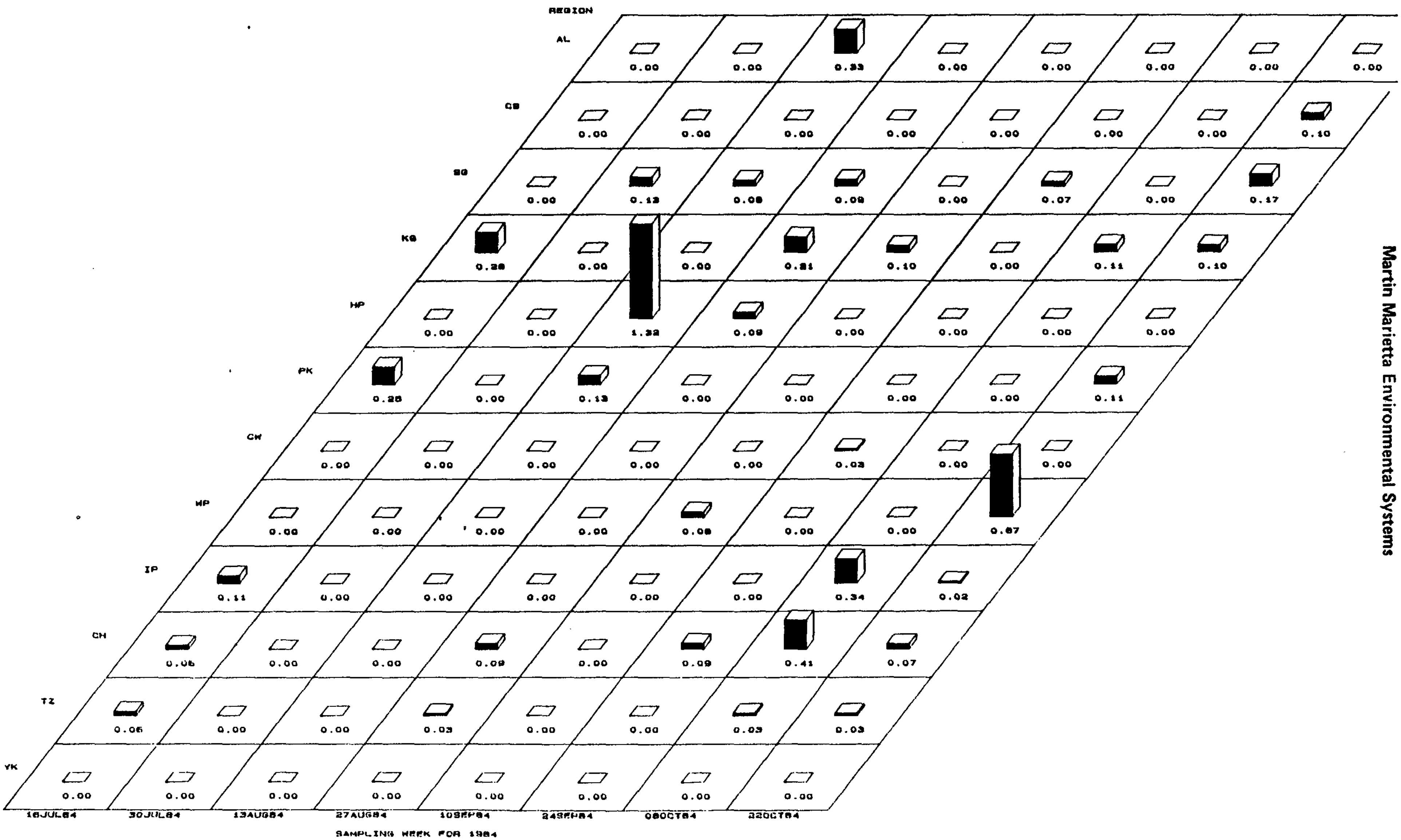

Figure IV-37. Mean regional density (per 1000 m3) of alewife yearling and older collected in the Fall Shoals Survey during 1984

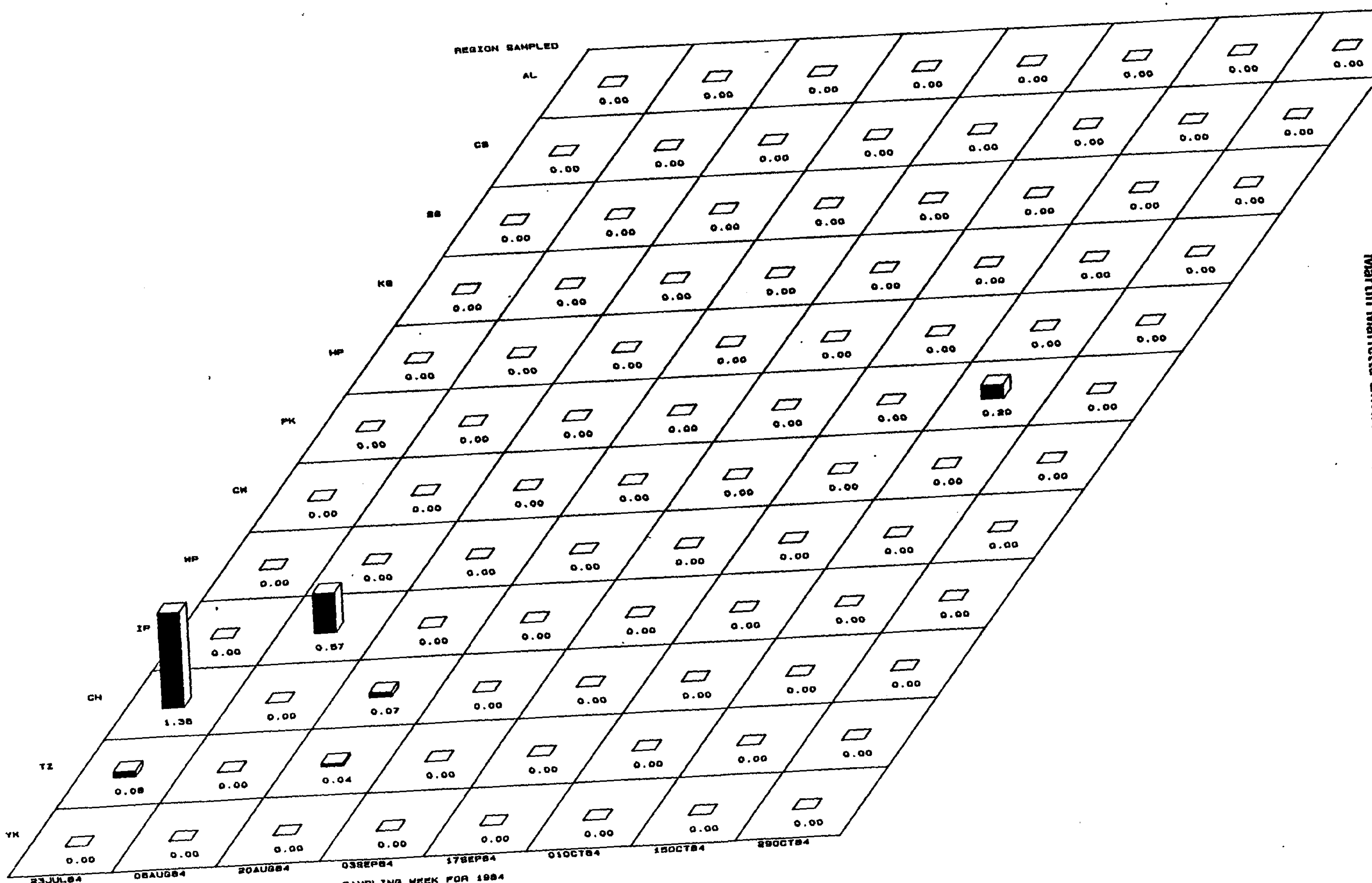

Figure IV-38. Catch per unit effort of alewife yearling and older collected in the Beach Seine Survey during 1984

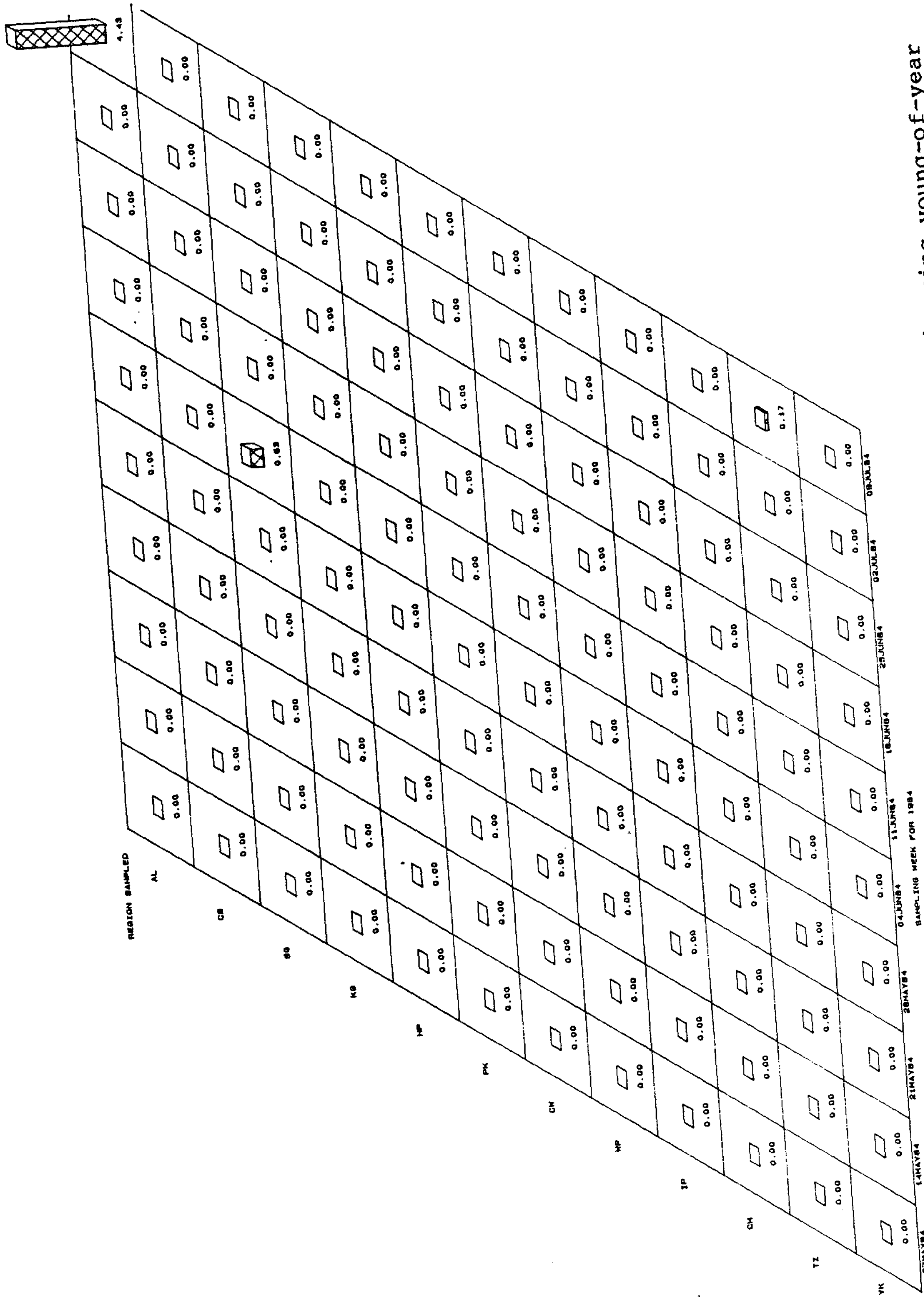

Figure IV-39. Mean regional density (per 1000 m3) of blueback herring young-of-year collected in the Longitudinal River Survey during 1984

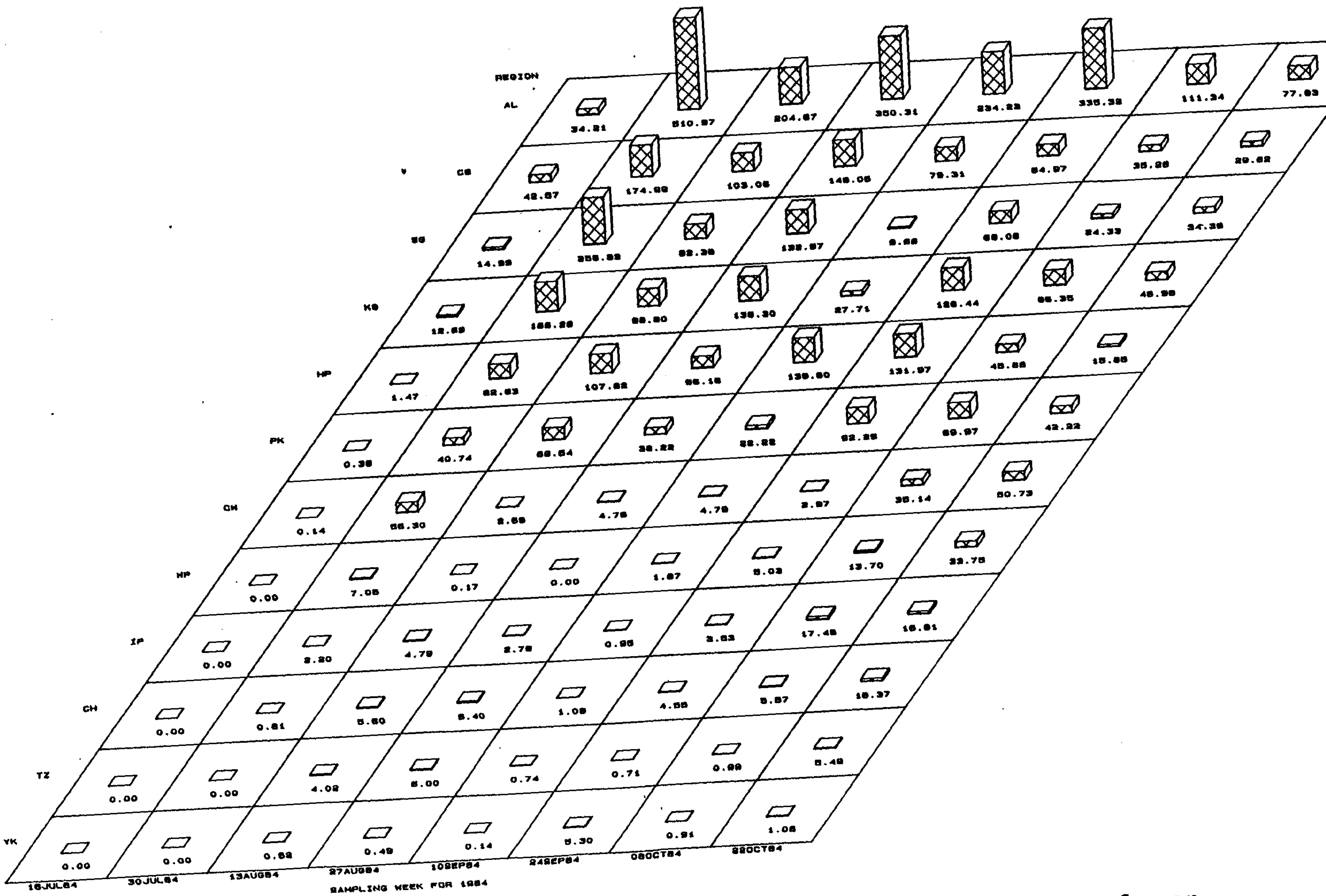

Figure IV-40. Mean regional density (per 1000 m^3) of blueback herring young-of-year collected in the Fall Shoals Survey during 1984

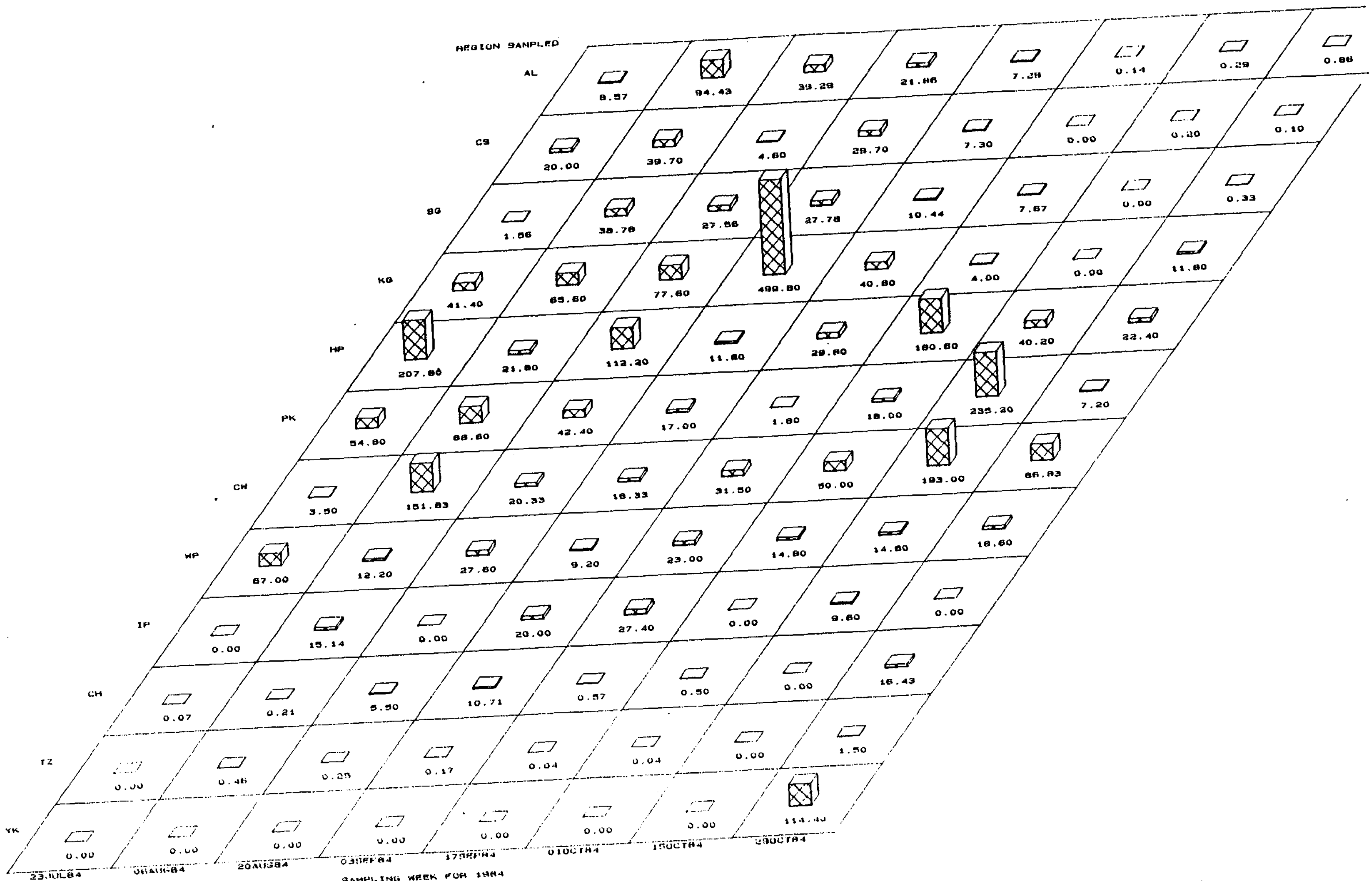

Figure IV-41. Catch per unit effort of blueback herring young-of-year collected in the Beach Seine Survey during 1984 as postulated in previous years, was apparent prior to the end of the study, but a large catch of juvenile blueback herring did occur in the Yonkers region during the final week of the BSS.

Yearling and Older

Yearling and older blueback herring were collected sporadically from the first week of the LRS (Fig. IV-42) until the final week of the FSS (Fig. IV-43). Peak collections occurred during early June in the upriver regions, and corresponded to the time and location of the latter peak of alosid eggs. When yearling and older blueback herring were collected, they were found primarily in the bottom stratum. Only three fish were collected in the shore zone.

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 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 anchovies were collected during the LRS, but they were first collected at the start of the FSS and were collected throughout the remainder of the FSS and BSS (Figs. IV-44 and IV-45). Highest density during the FSS occurred between mid-August and the end of September. This peak is consistent with the peak of juvenile anchovy standing crops reported in previous Year Class Reports (1980 - 1983).

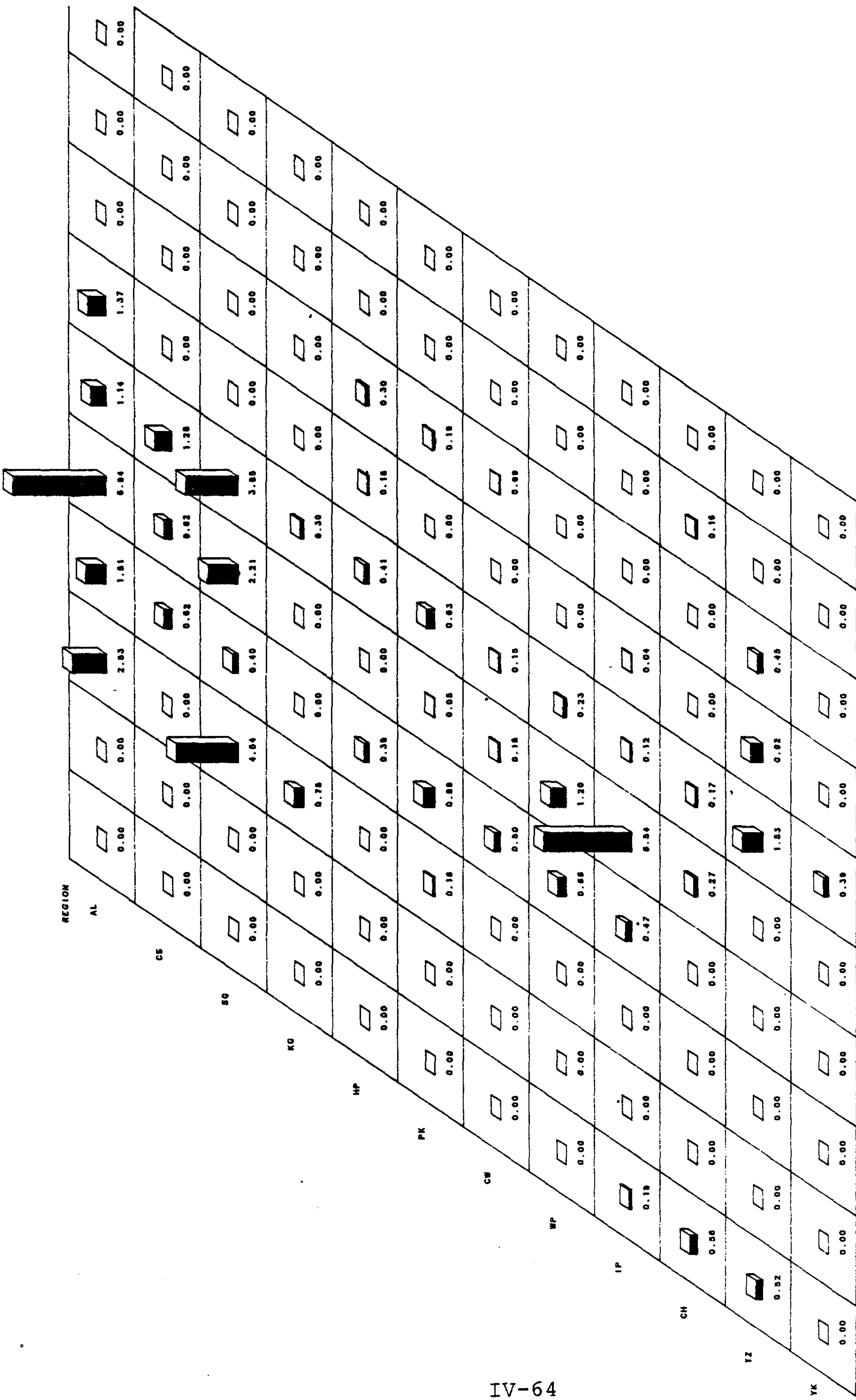

Figure IV-42. Mean regional density (per 1000 m^3) of blueback herring yearling and older collected in the Longitudinal River Survey during 1984

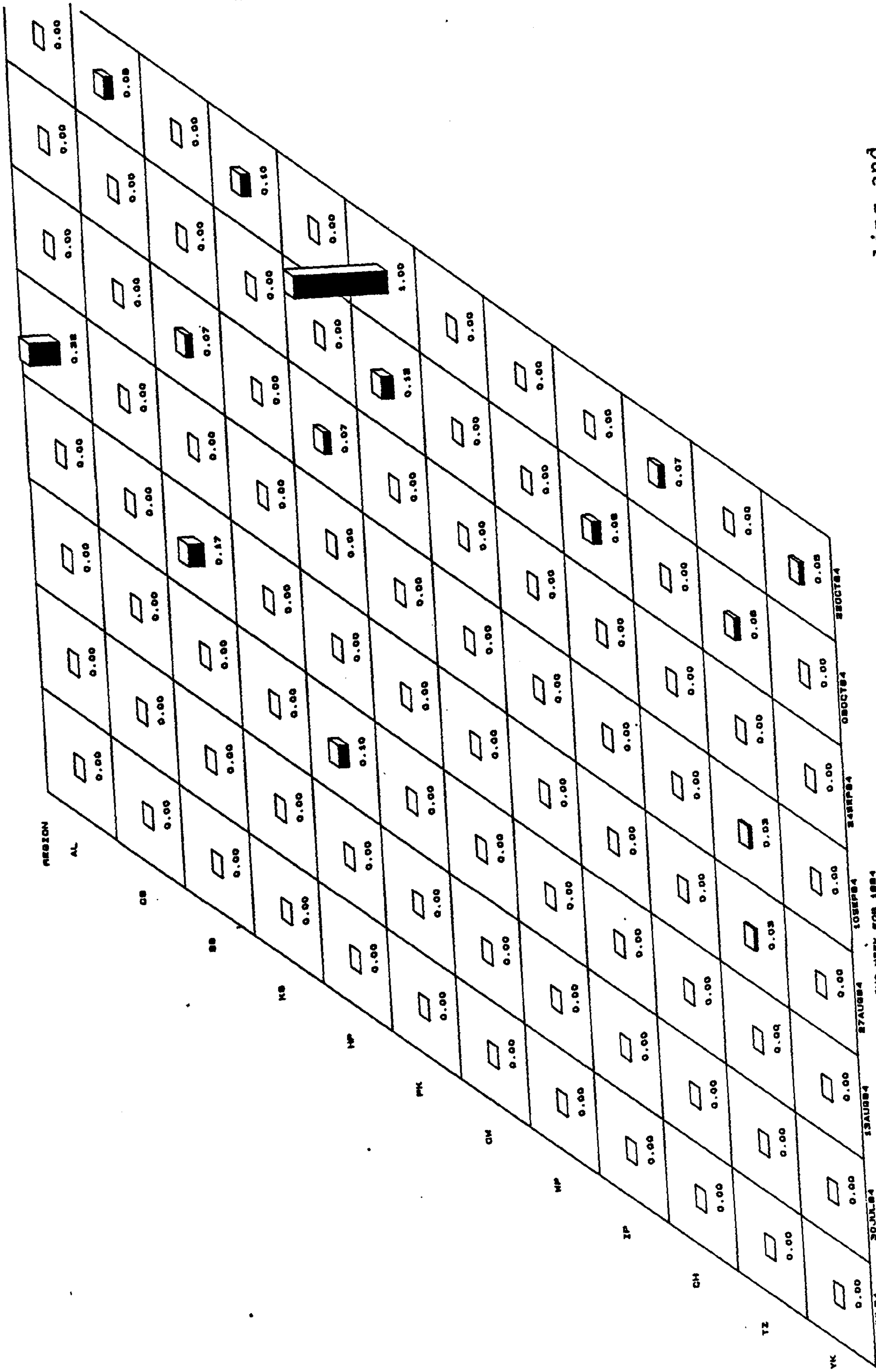

Figure IV-43. Mean regional density (per 1000 m^3) of blueback herring yearling and older collected in the Fall Shoals Survey during 1984

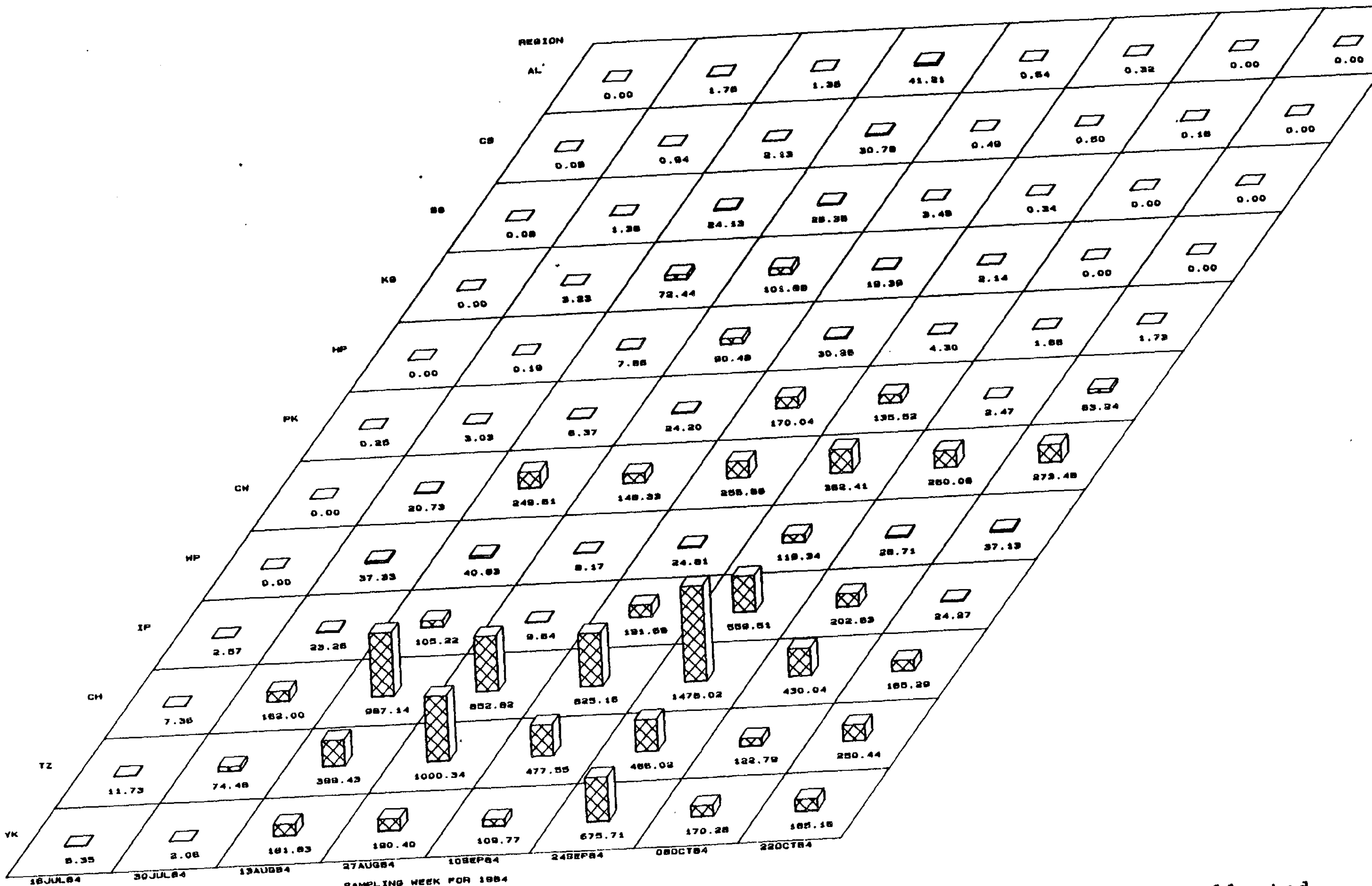

Figure IV-44. Mean regional density (per 1000 m3) of bay anchovy young-of-year collected in the Fall Shoals Survey during 1984

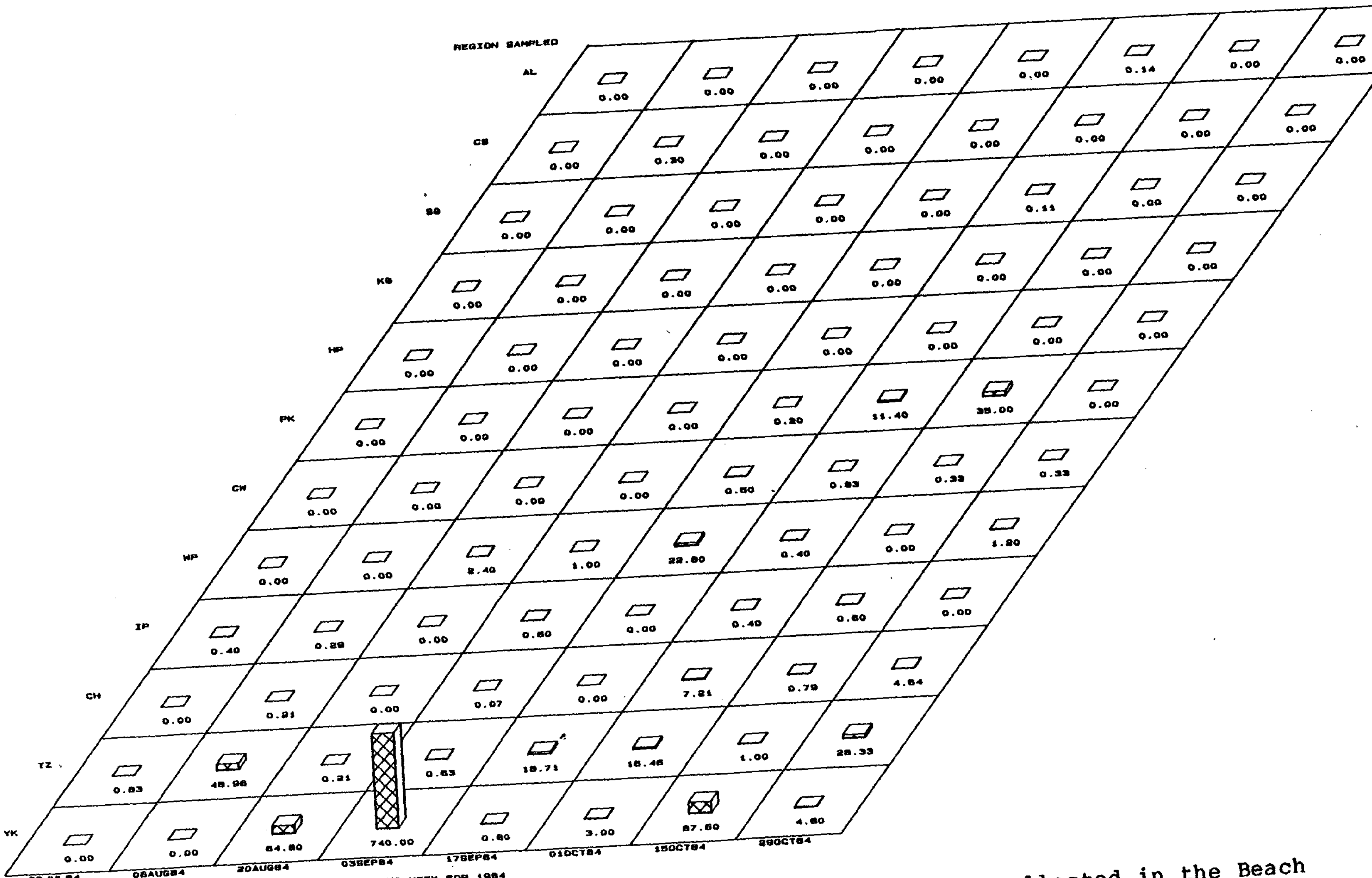

Figure IV-45. Catch per unit effort of bay anchovy young-of-year collected in the Beach Seine Survey during 1984

Juvenile bay anchovy were collected throughout the river, but sample densities were greatest in the oligohaline area between the Cornwall and Yonkers regions. The geographic distribution of juveniles in 1984 was similar to that reported historically.

Yearling and Older

Yearling and older bay anchovy were collected in every week of sampling except the week of 15 October. Mean regional densities were initially low in the LRS (Fig. IV-46) but increased to more than 100/1000 m^3 in the lower estuary by mid-June. Consistent with previous Year Class Reports, density estimates remained high until mid-August, after which they declined rapidly (Figs. IV-47 and IV-48). The increased density of bay anchovy in mid-summer of each year may be a result of upstream movement from outside the study area as freshwater flow decreases and salinity in the lower estuary increases. The decline in density observed in August could have been due to predation mortality, downstream movement, or other environmental factors.

Yearling and older bay anchovy were collected in all regions except Albany, but were primarily collected in the lower three regions of the estuary. However, mean regional densities exceeding 20/1000 m^3 were found as far north as Cornwall when salinity increased in late July. In 1984, sample densities were not markedly different in the shoal, bottom, and channel strata. Substantial numbers of yearling and older bay anchovy were collected only in the shore zone during the first 2 weeks of the BSS.

J. WEAKFISH

Weakfish (Cynoscion regalis) inhabit oceanic and inland tidal waters from Florida to Nova Scotia, but are most abundant from Chesapeake Bay to Long Island Sound (Colton et al. 1979). Weakfish generally spawn in coastal waters and near the mouths of estuaries from April to August (Merriner 1976; Yetman et al. 1985). Larval and juvenile weakfish often move to more brackish areas during early development, but return to deeper offshore water as water temperature declines. Both adults and juveniles from the Hudson River, as well as from other northeastern estuaries, overwinter off the Virginia-Carolina coast (Yetman et al. 1985).

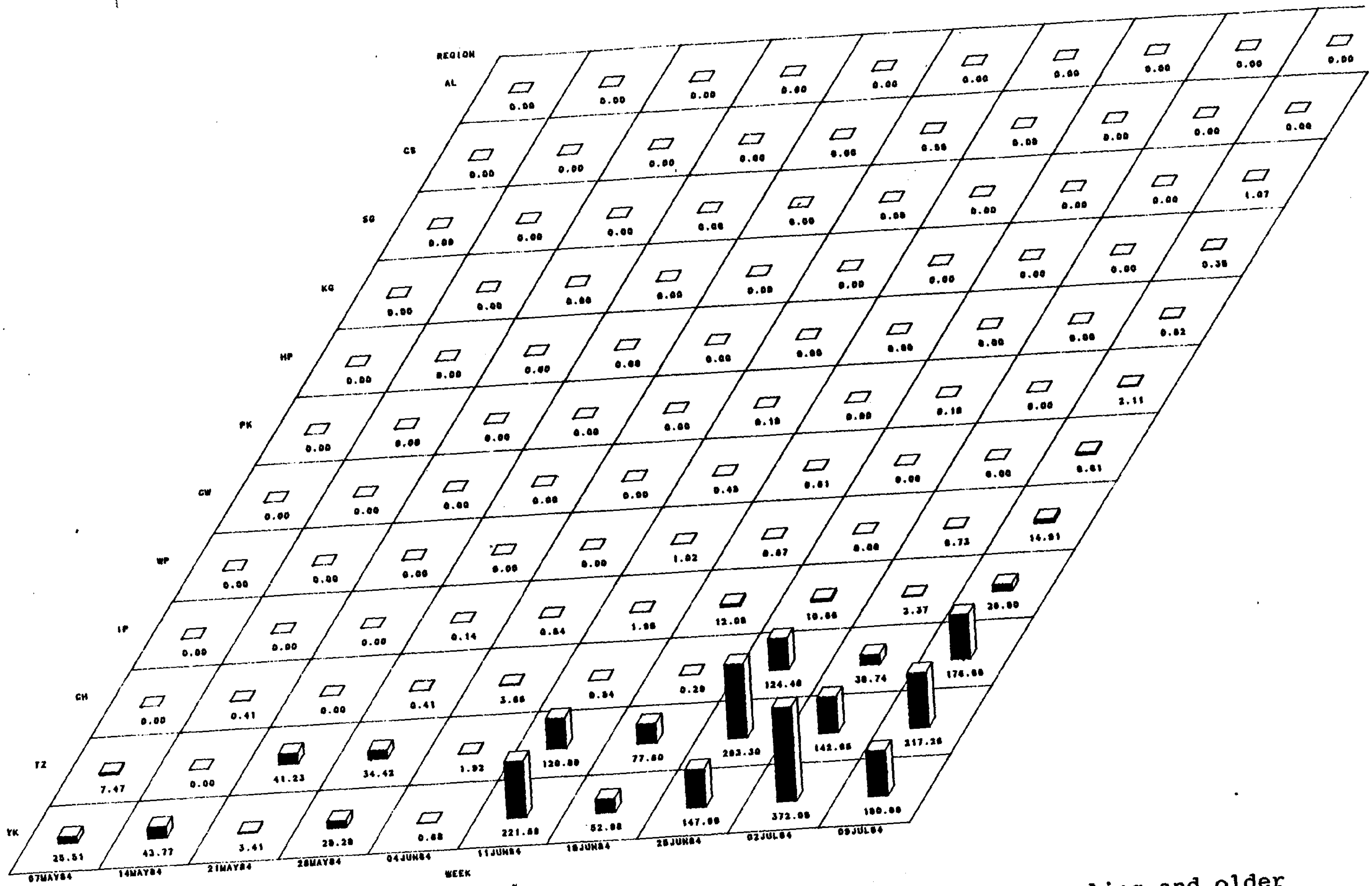

Figure IV-46. Mean regional density (per 1000 m^3) of bay anchovy yearling and older collected in the in the Longitudinal River Survey during 1984

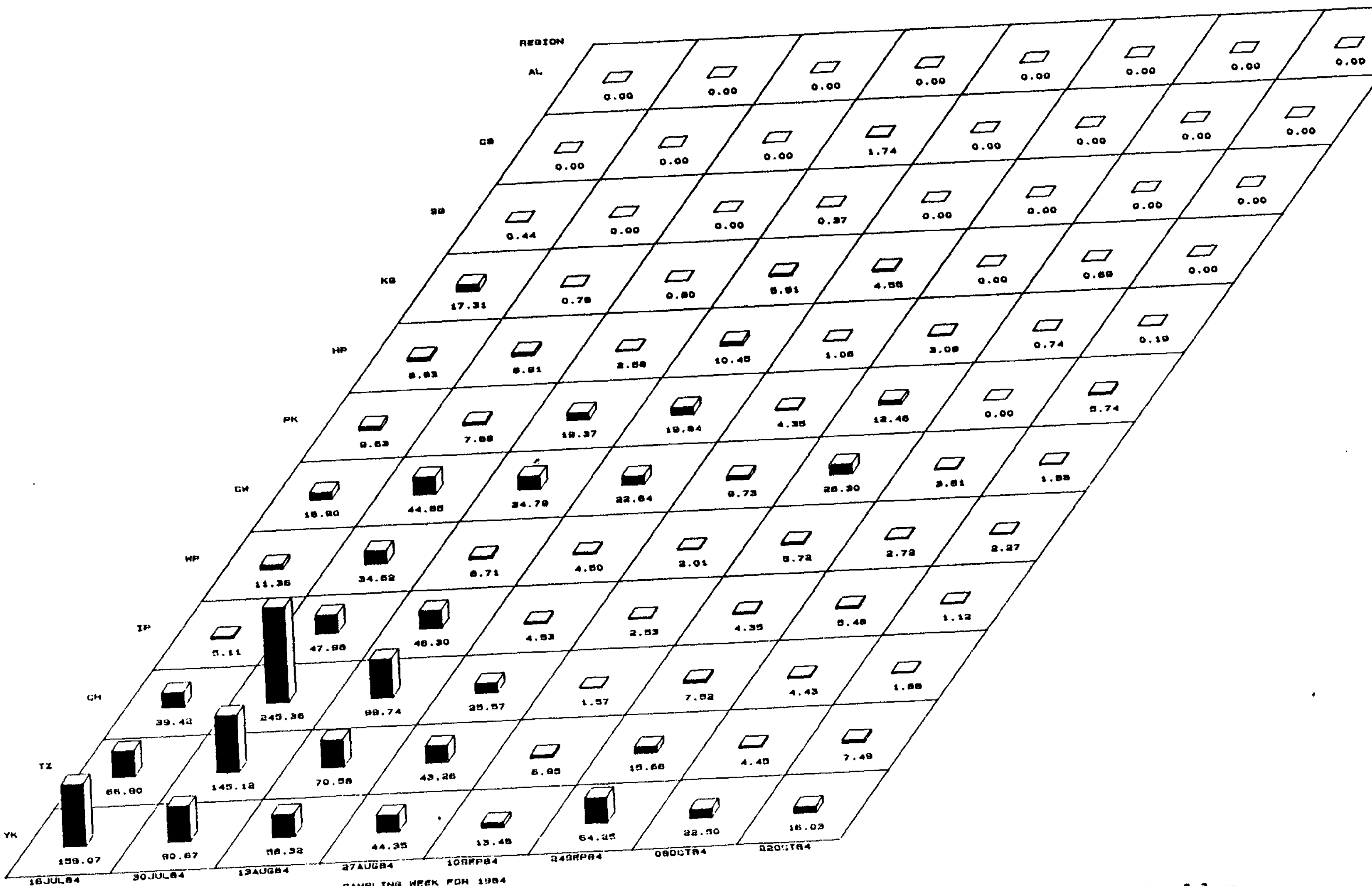

Figure IV-47. Mean regional density (per 1000 m3) of bay anchovy yearling and older collected in the in the Fall Shoals Survey during 1984

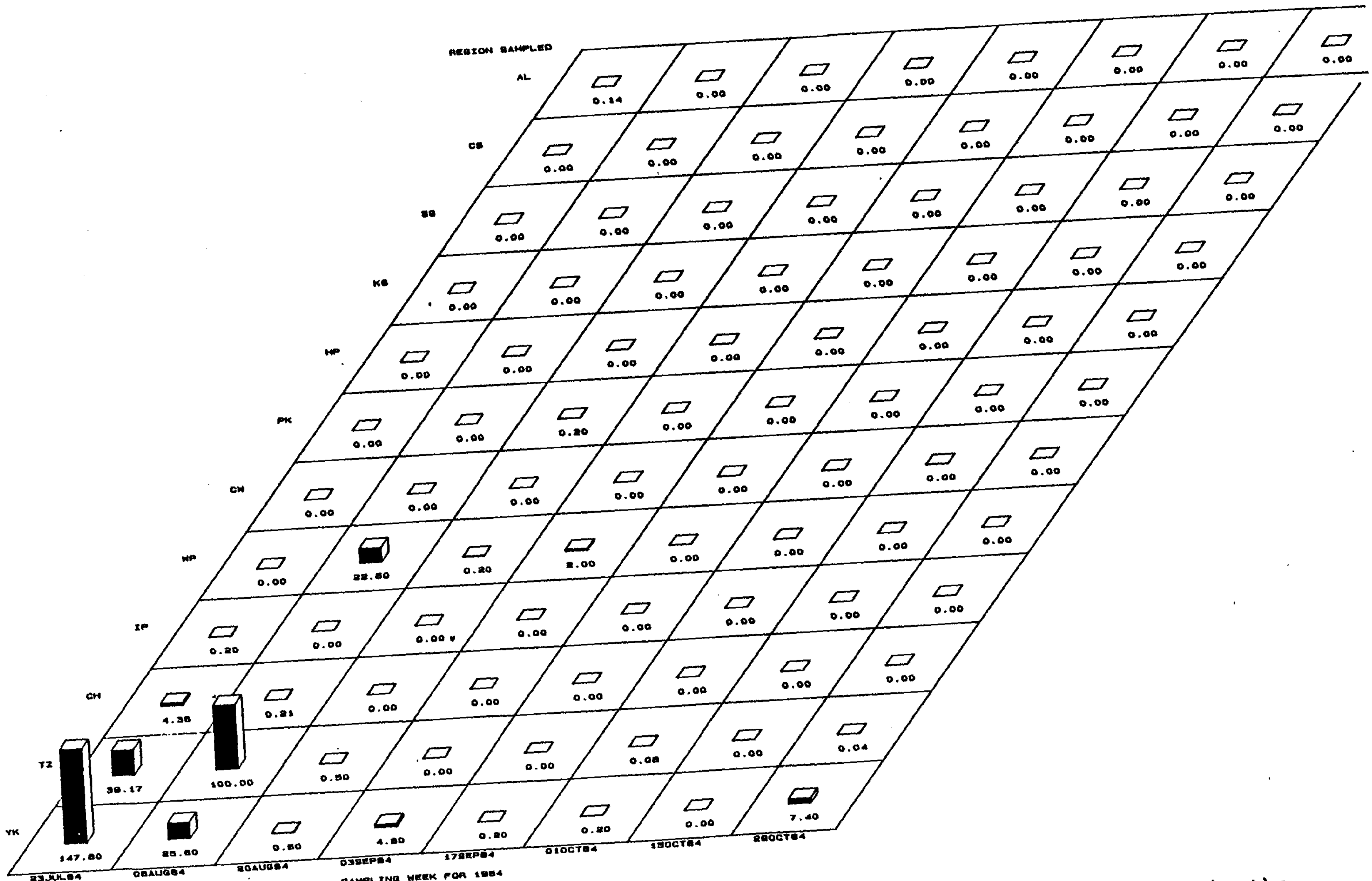

Figure IV-48. Catch per unit effort of bay anchovy yearling and older collected in the Beach Seine Survey during 1984

Young-of-Year

No juvenile weakfish were collected during LRS, though they were captured in every week of the FSS. Estimated density of juveniles was initially low in July, but rose sharply at the end of July (Figs. IV-49 and IV-50). Standing crop estimates declined greatly by mid-September when water temperature began to fall. This pattern of weakfish abundance rapidly increasing and then declining steadily through September has been reported in previous years (Battelle 1983; NAI 1985a, 1985b).

Juvenile weakfish were primarily collected in regions where salinity exceeded 1 ppt. None were collected north of Poughkeepsie in the FSS and none were collected upriver of Tappan Zee in the BSS. Similar distributions have been reported in previous years (Battelle 1983; NAI 1985a, 1985b).

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). Eggs of white catfish are restricted to water with salinity less than 2 ppt (Perry and Avault 1968). Spawning takes place in late spring or early summer. White catfish eggs are adhesive and attended by the parents. White catfish are generally found in deep bottom waters, though movement toward the shore zone is typical during spawning season (TI 1981).

Young-of-Year

Juvenile white catfish were collected from the eighth week (25 June) of the LRS until the end of the FSS (Figs. IV-51 and IV-52). Peak density was found in early July. Since white catfish eggs are adhesive, none were collected during the LRS, and the data cannot indicate how long after peak egg abundance young-of-year were first collected. However, the period of peak juvenile density in 1984 was much earlier than that presented in previous Year Class Reports (Battelle 1983; NAI 1985a, 1985b).

Juvenile white catfish were found primarily in freshwater areas of the upper estuary; no juvenile white catfish were collected below the Cornwall region, and densities exceeding 2/1000 m^3 were only found in the Albany and Catskill regions. Most juvenile catfish were found in the bottom stratum. Only

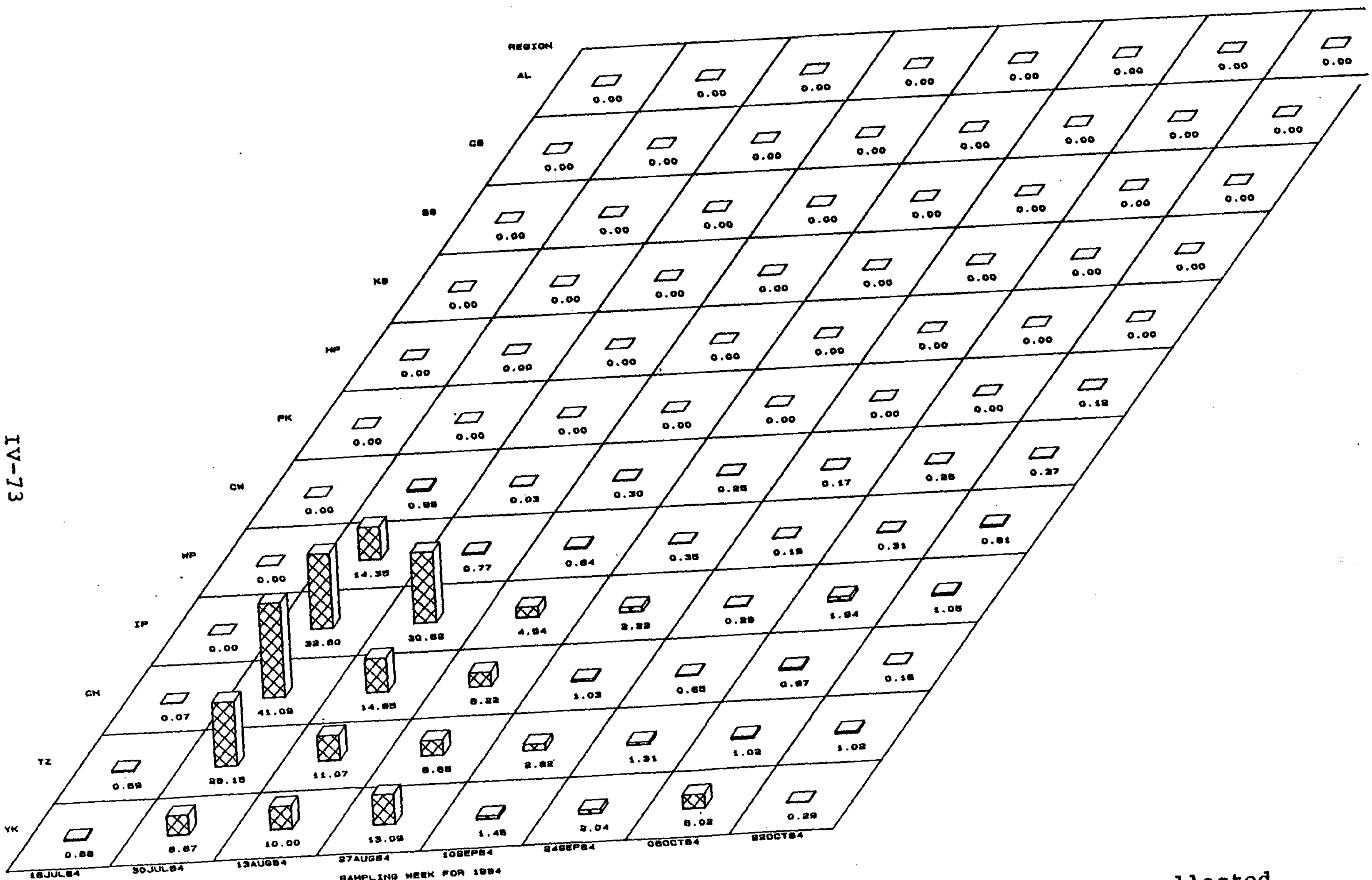

Figure IV-49. Mean regional density (per 1000 m3) of weakfish young-of-year collected in the in the Fall Shoals Survey during 1984

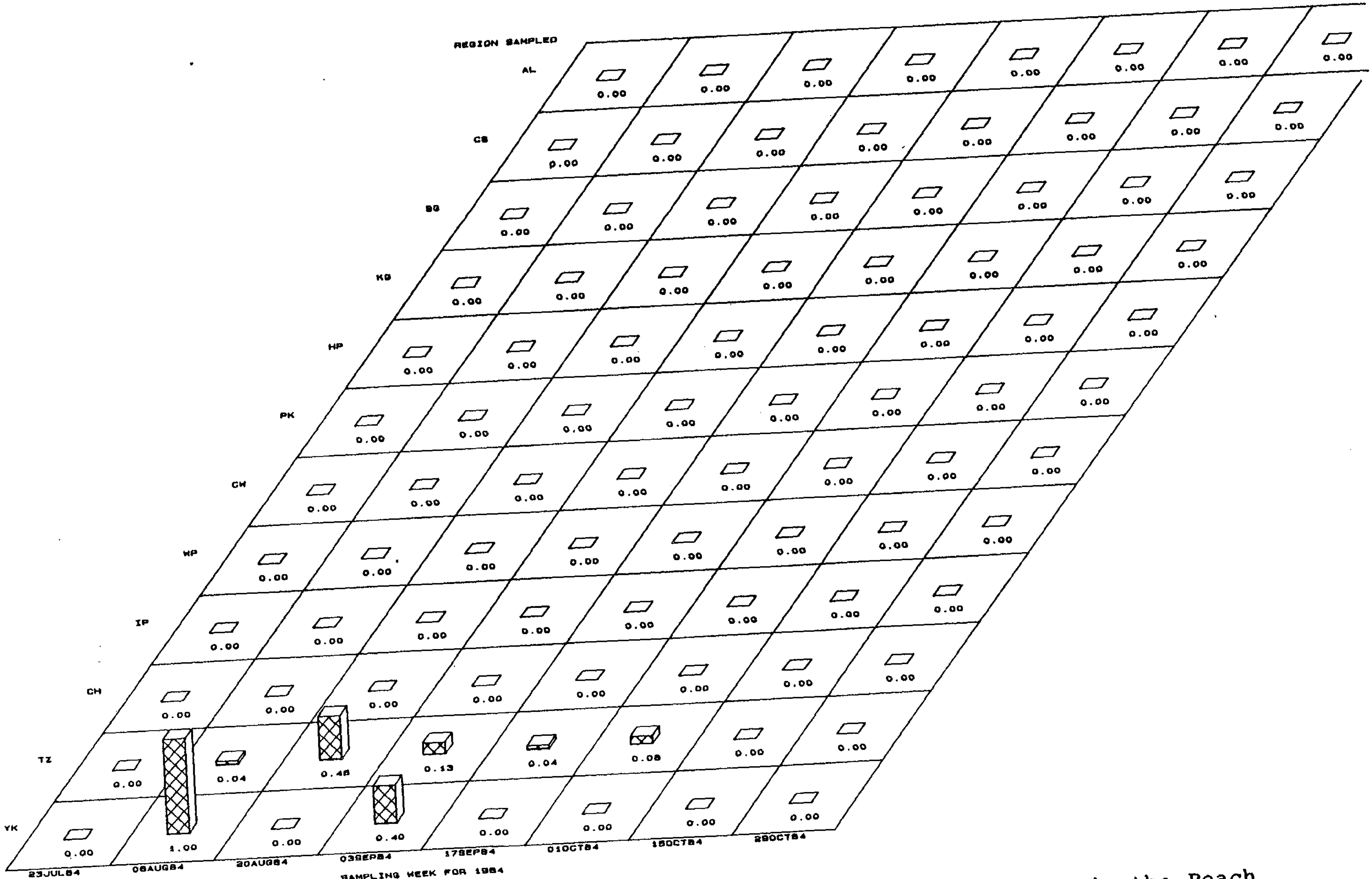

Figure IV-50. Catch per unit effort of weakfish young-of-year collected in the Beach Seine Survey during 1984

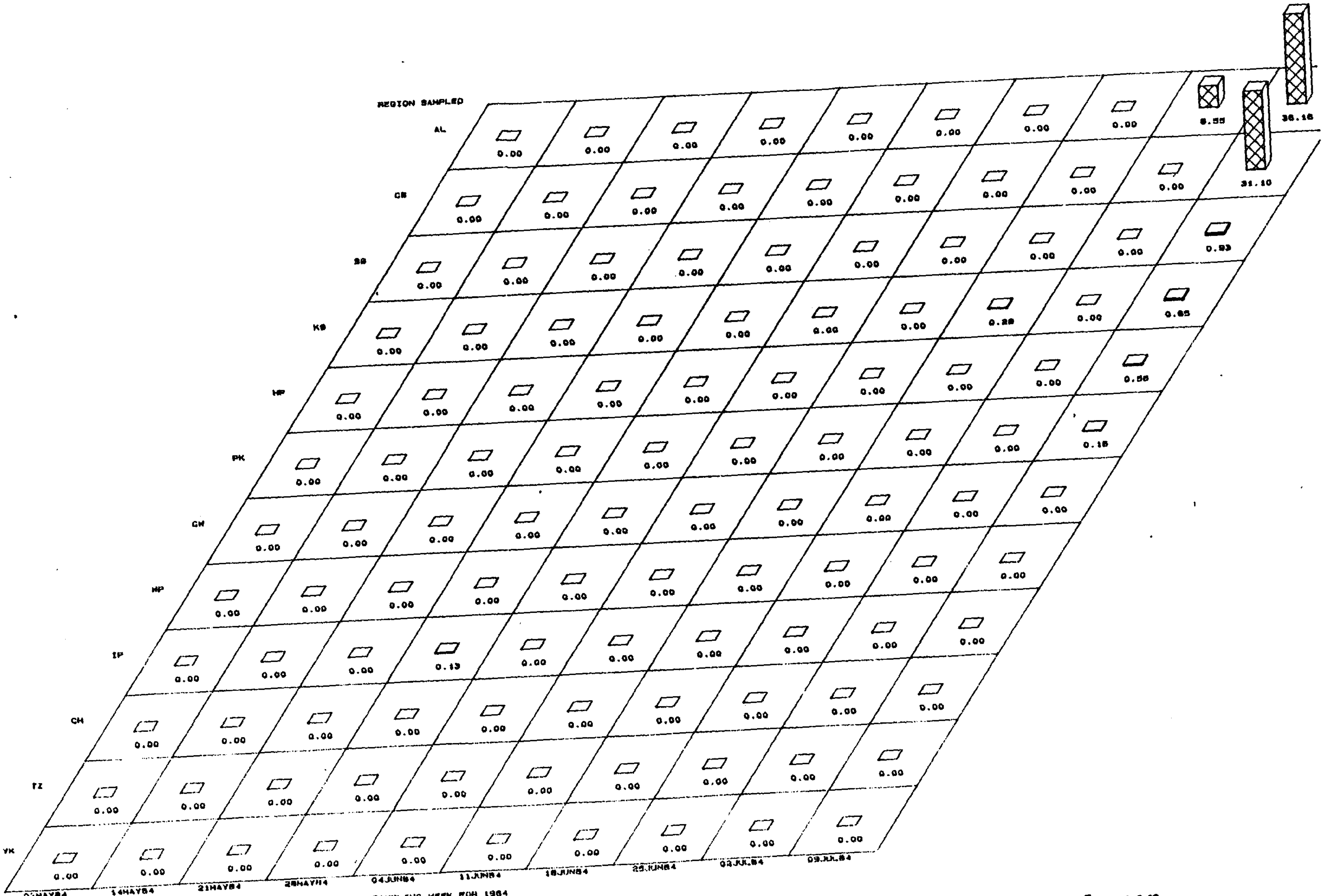

Figure IV-51. Mean regional density (per 1000 m^3) of white catfish young-of-year collected in the Longitudinal River Survey during 1984

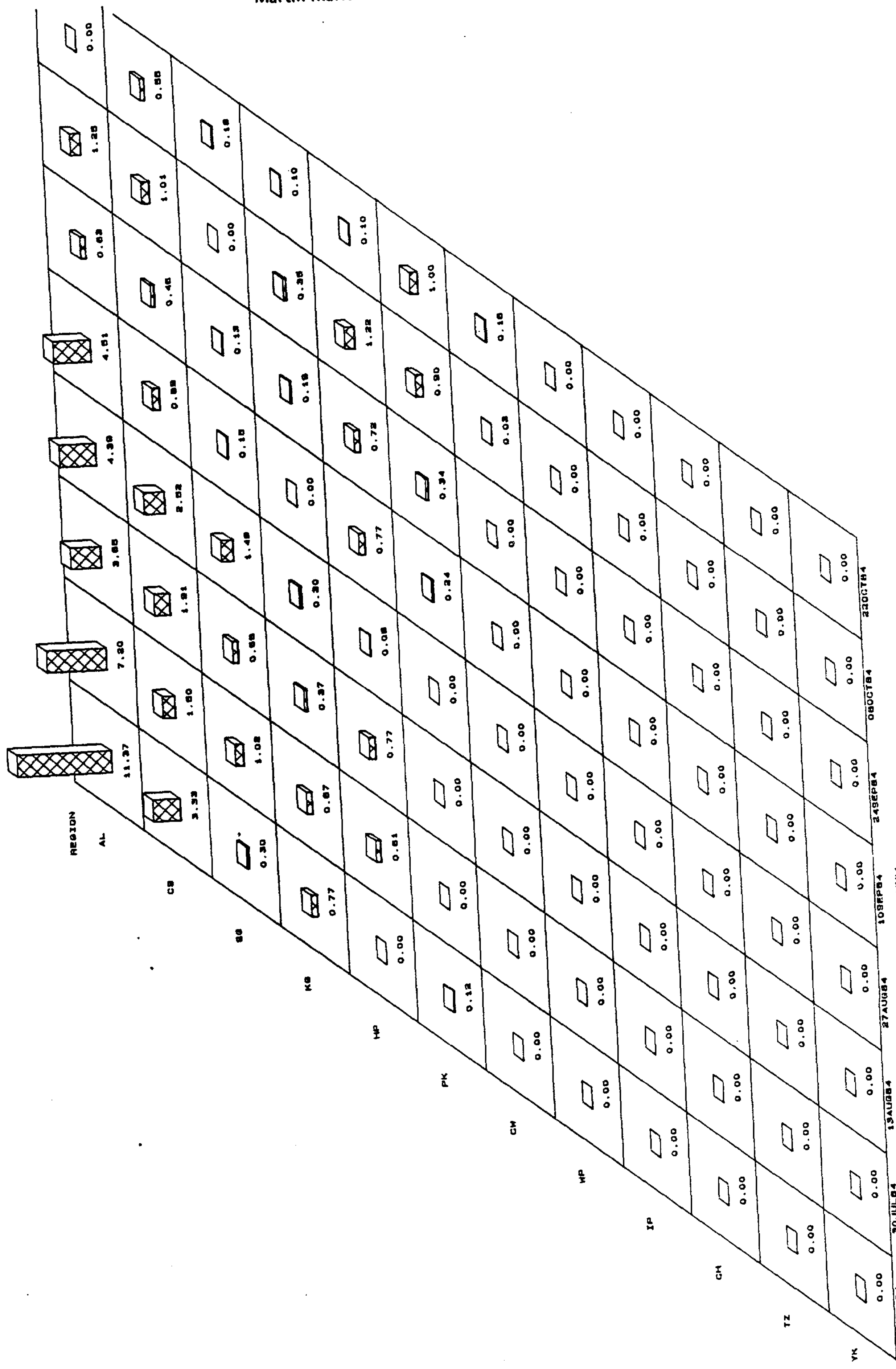

Figure IV-52. Mean regional density (per 1000 m3) of white catfish young-of-year collected in the Fall Shoals Survey during 1984 two individuals, both from the Saugerties region, were collected from the shore zone. This spatial distribution, both within regions and among regions, is typical of that reported for the FSS in previous years.

Yearling and Older

Yearling and older white catfish were collected throughout the LRS (Fig. IV-53), FSS (Fig. IV-54), and BSS (Fig. IV-55), with no apparent temporal peak in abundance. Historically recorded temporal peaks in density have occurred only sporadically.

Yearling and older catfish were collected primarily from the bottom and shoal strata. There was a bimodal peak in their geographic distribution, with mean regional fish densities exceeding $2/1000\ m^3$ only in the upper estuary from Saugerties to Albany and in the lower estuary in Tappan Zee. NAI (1985b) has suggested that the upper estuary peak consists of catfish spawning in the required low-salinity environment, while the downstream peak reflects those 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). The eggs are demersal and are spawned from April to September, generally in sand and gravel habitat (Jones et al. 1978). 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.

Young-of-Year

Young-of-year spottail shiner were first collected during the final week of LRS when two individuals were taken from the Catskill region. While spottail shiner eggs were not identified in this study, juveniles first appeared about 1 month after a peak in abundance of unidentified cyprinid eggs was observed. No spottail shiner were collected during the first week of the FSS, but they were found from the first week of BSS until the end of the fall programs (Figs. IV-56 and IV-57), with no

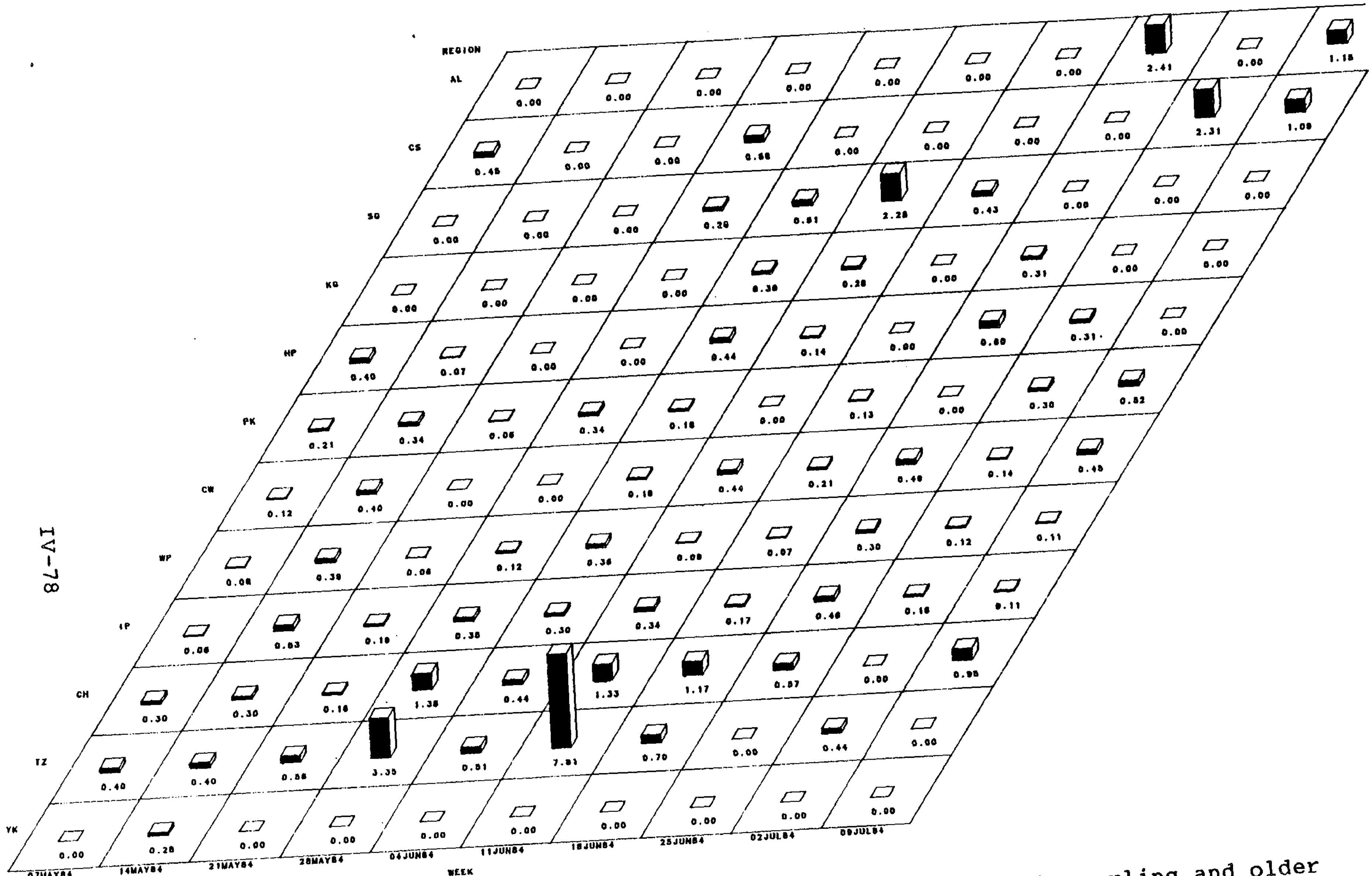

Figure IV-53. Mean regional density (per 1000 m^3) of white catfish yearling and older collected in the Longitudinal River Survey during 1984

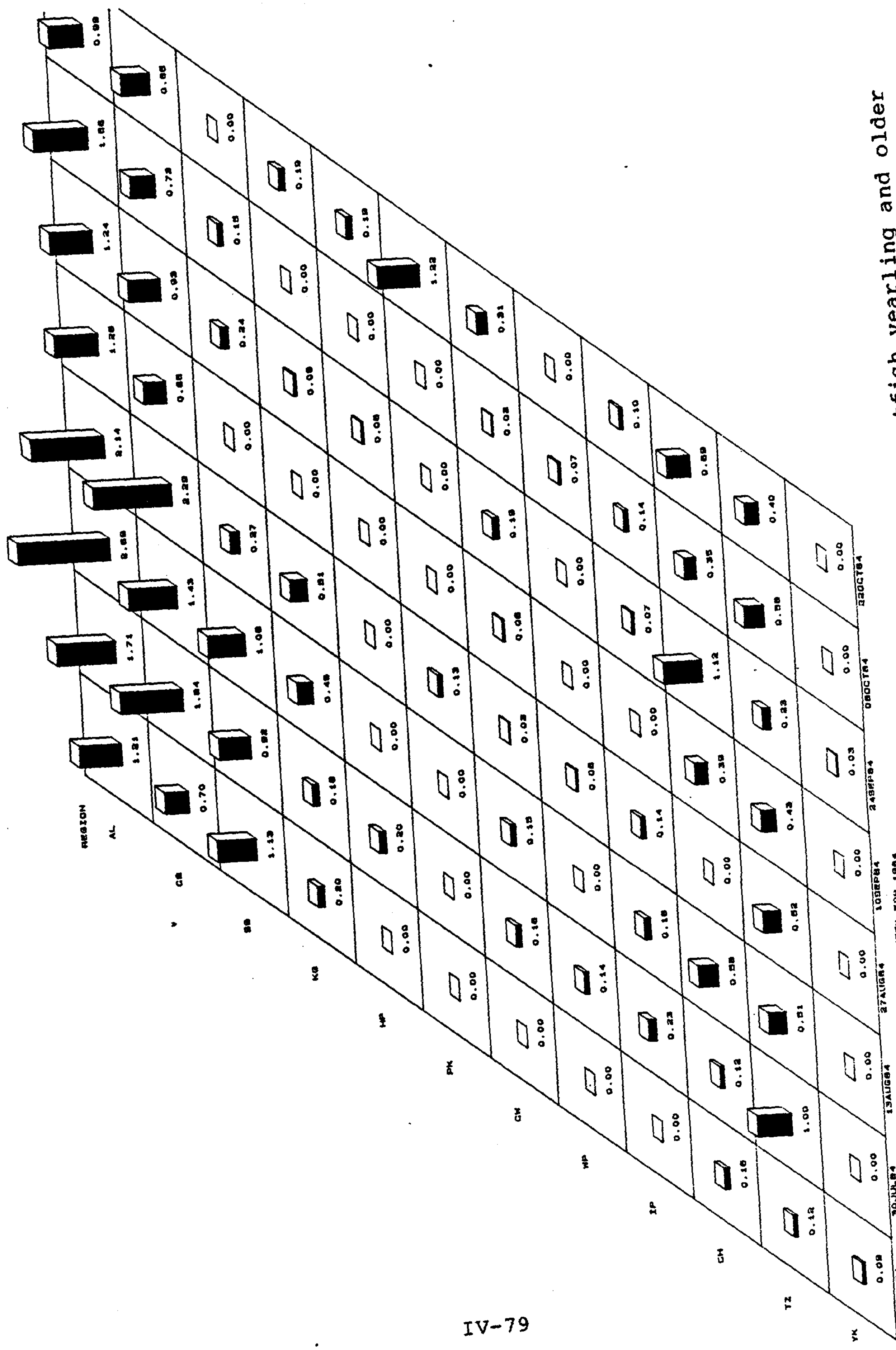

Figure IV-54. Mean regional density (per 1000 m3) of white catfish yearling and older collected in the Fall Shoals Survey during 1984

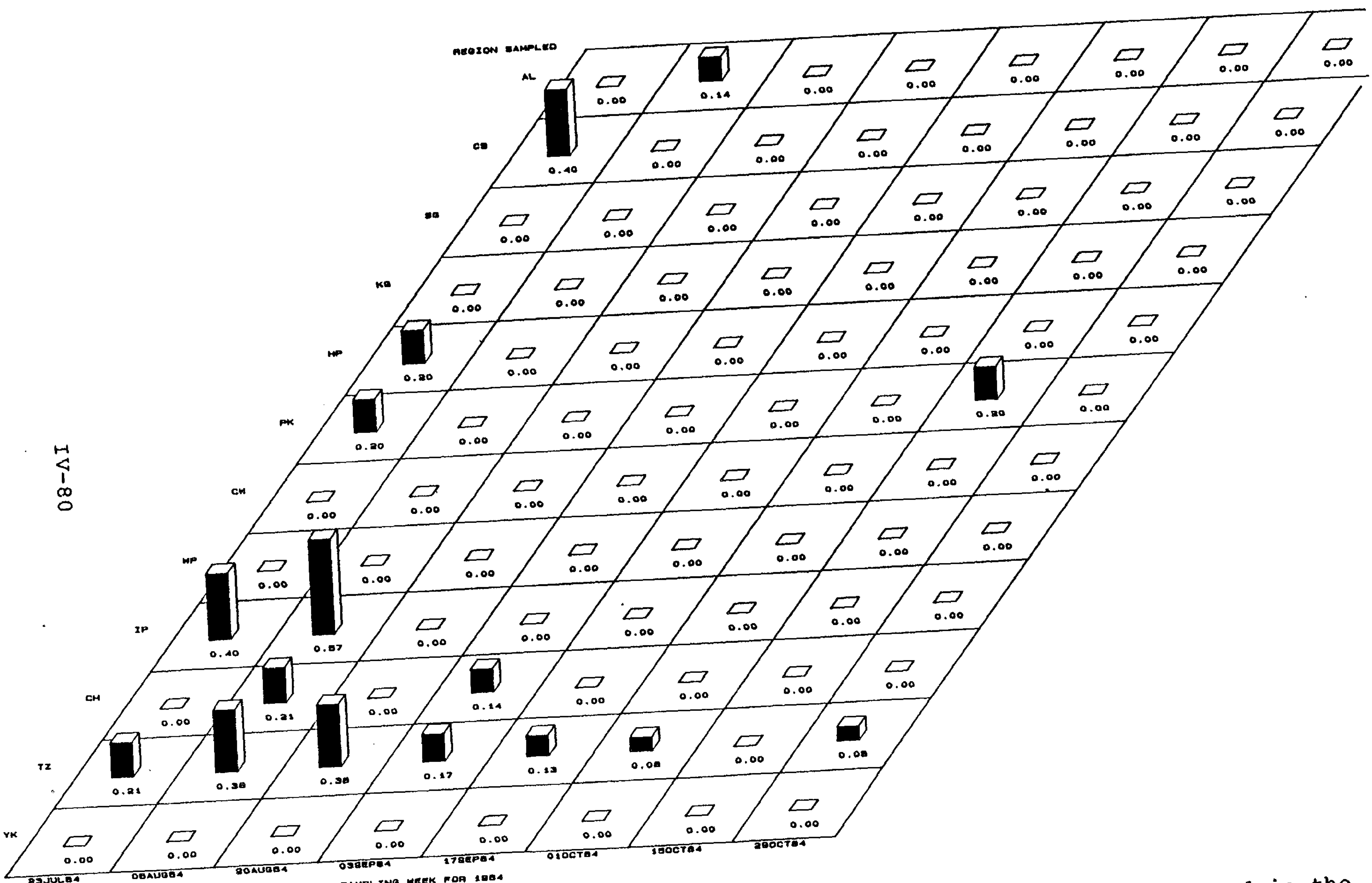

Figure IV-55. Catch per unit effort of white catfish yearling and older collected in the Beach Seine Survey during 1984

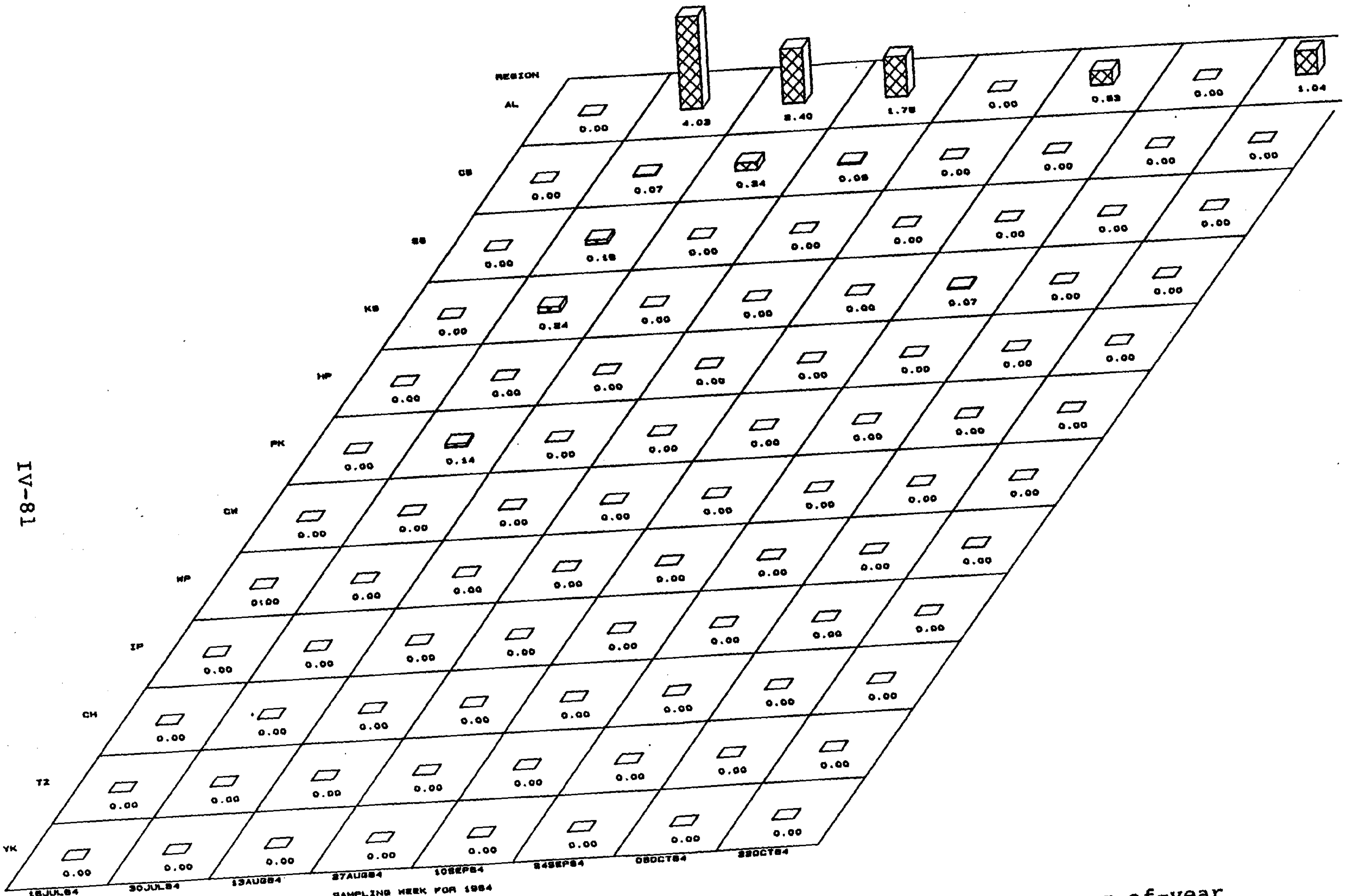

Figure IV-56. Mean regional density (per 1000 m3) of spottail shiner young-of-year collected in the Fall Shoals Survey during 1984

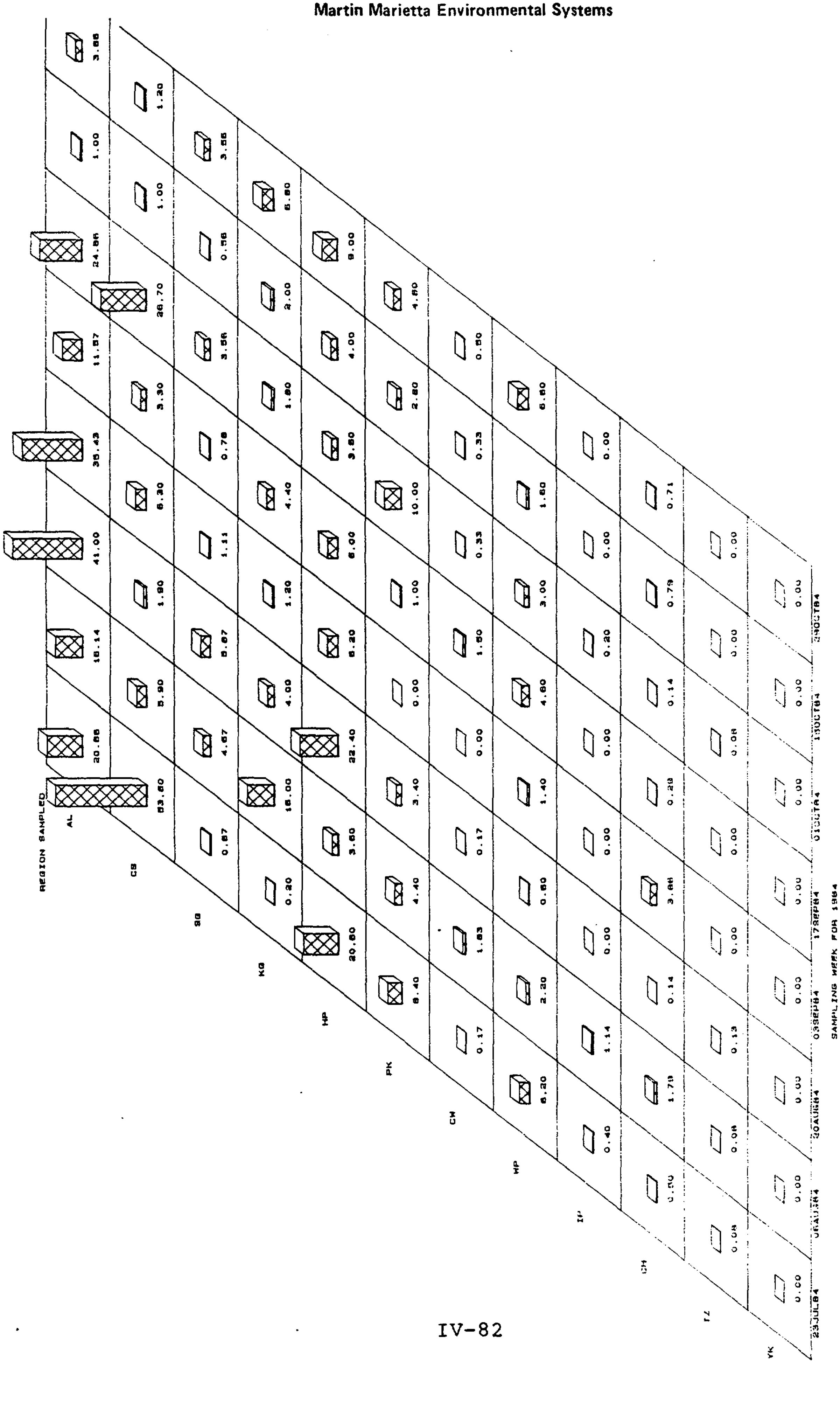

Figure IV-57. Catch per unit effort of spottail shiner young-of-year collected in the Beach Seine Survey during 1984 apparent peak. The peak reported in other Year Class Reports has been variable, occurring as early as July (1980) or as late as September (1982), with very broad peaks in some years (1981).

Young-of-year spottail shiner were collected in all regions except Yonkers, but highest densities were found in the upper estuary. In the FSS, only a single individual was collected south of Kingston; in the BSS mean catches exceeding 25 per haul were found only in the Albany and Catskill regions. Considerably more (over an order of magnitude) juvenile spottail shiner were collected in the BSS survey than in the FSS. Spottail shiner collected during the FSS were collected almost exclusively from the bottom and shoal strata.

Yearling and Older

Yearling and older spottail shiner were collected from the beginning of the LRS (Fig. IV-58) to the end of the BSS (Fig. IV-59). Density estimates sporadically exceeded one fish per 1000 m^3 from late May through October, with no obvious peak in abundance. Peaks in standing crop have been reported to have occurred primarily in May and June in previous years (TI 1981; NAI 1985b).

Spottail shiner were collected almost exclusively in freshwater and from the bottom stratum. None were found in the Yonkers and Tappan Zee regions, and highest regional densities were found north of Poughkeepsie. This concentration of spottail shiner upriver was more pronounced in the FSS (Fig. IV-60) than in the BSS, a pattern which has been observed in past Year Class Reports.

M. ATLANTIC STURGEON

Atlantic sturgeon (Acipenser oxyrhynchus) is an anadromous species that inhabits estuarine and offshore waters from Labrador to South America; thought the range of the more abundant northern subspecies (A. oxyrhynchus oxyrhynchus) extends only as far south as Florida (Smith, 1985). Adults generally reside in coastal waters near their natal estuary, but are occassionally collected offshore (Murawski and Pacheco 1977). These fish move into estuarine and freshwater areas in the spring to spawn when water temperature reaches 13-18°C (Borodin 1925). Adults leave the estuary from October to December, but juveniles generally remain for 3-5 years before migrating (Huff 1975). In the Hudson River, females may not become reproductively mature until age 20 and will spawn at intervals of 3-5 years following maturity (Smith 1985).

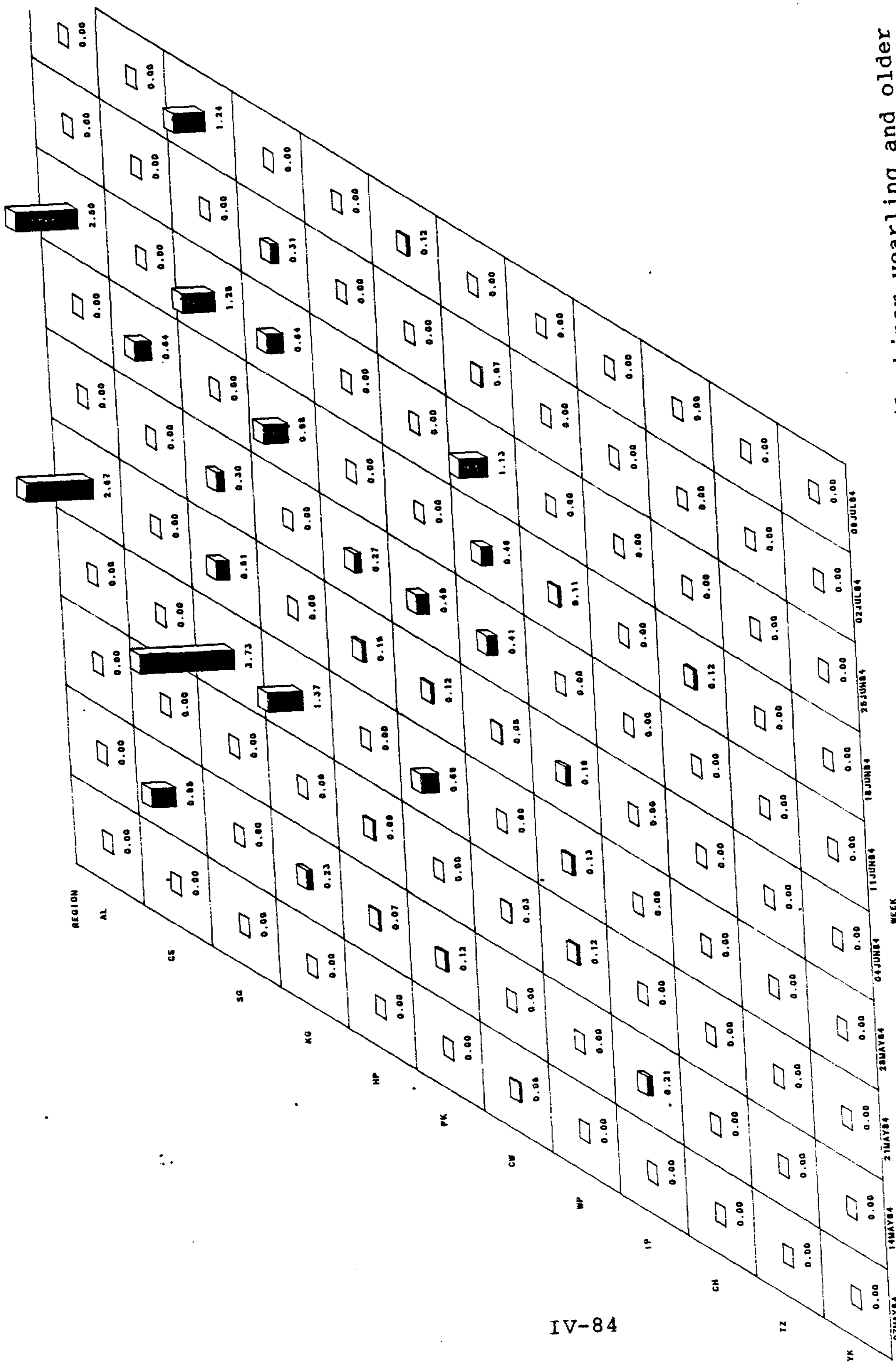

Figure IV-58. Mean regional density (per 1000 m3) of spottail shiner yearling and older collected in the Longitudinal River Survey during 1984

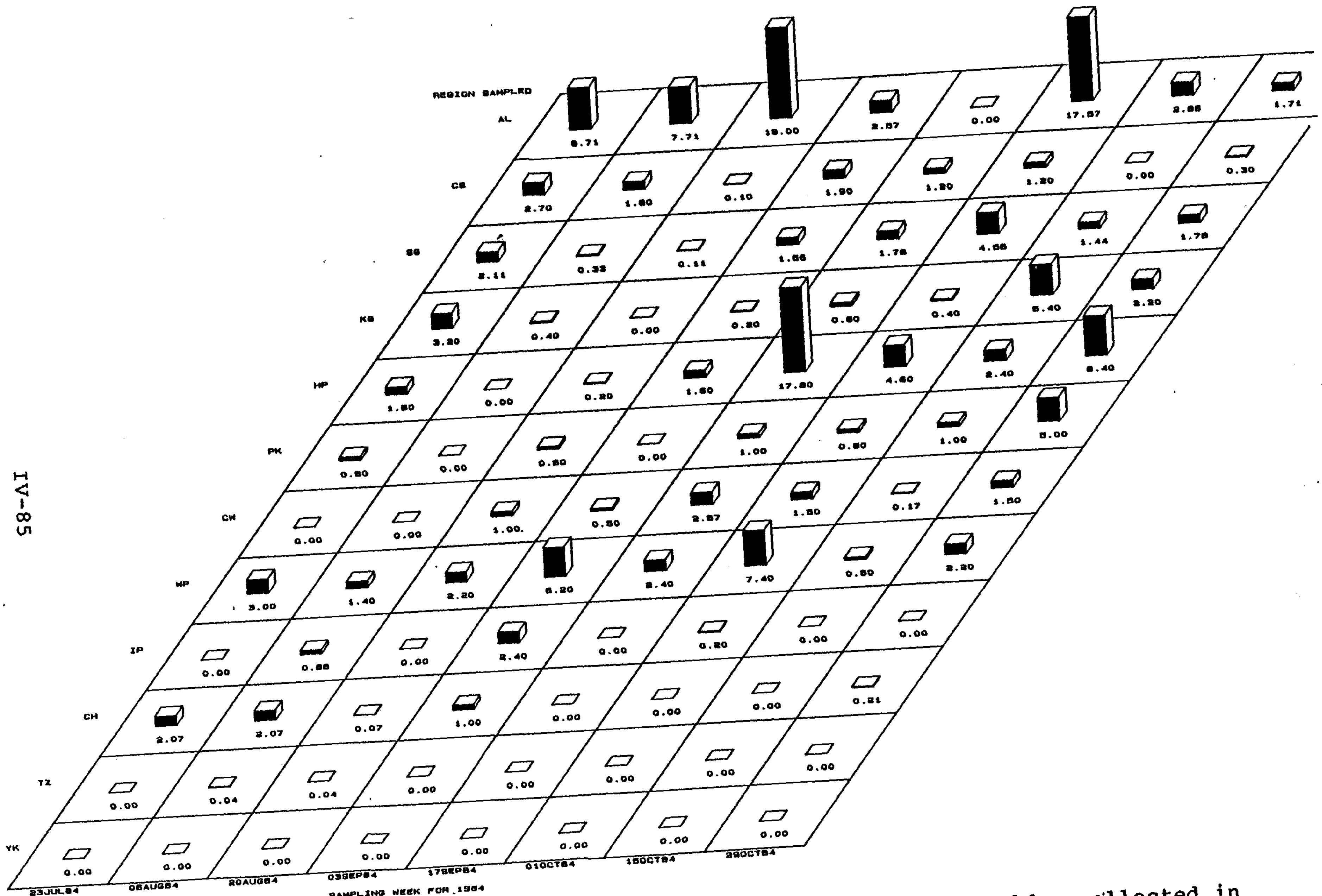

Figure IV-59. Catch per unit effort of spottail shiner yearling and older collected in the Beach Seine Survey during 1984

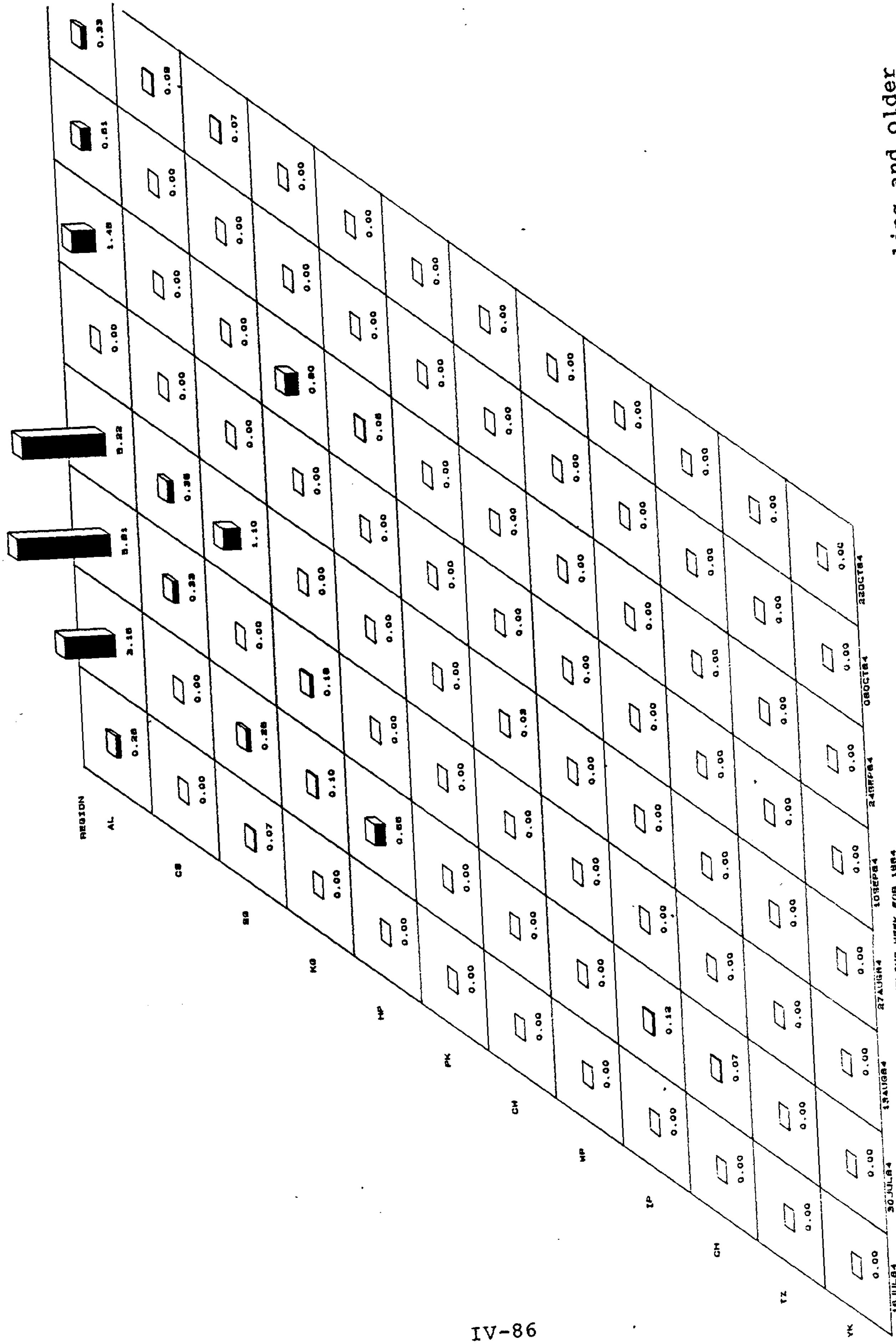

Figure IV-60. Mean regional density (per 1000 m3) of spottail shiner yearling and older collected in the Fall Shoals Survey during 1984

Young-of-Year

No young-of-year Atlantic sturgeon were collected in any of the year class studies during 1984. No juveniles have been captured in these programs since 1980, when 37 were collected.

Yearling and Older

A total of 34 yearling and older Atlantic sturgeon were collected in 1984. They were collected from the first week of the LRS (Fig. IV-61) to the last week of the FSS (Fig. IV-62), and were collected in all regions except Indian Point, Tappan Zee, and Yonkers. Consistent with historical reports, collection was sporadic throughout the estuary. However, their distribution among strata was well defined. Two fish were captured in the shoals with the remainder caught in the bottom stratum. None were collected from the channel stratum or the shore zone.

N. SHORTNOSE STURGEON

The shortnose sturgeon (Acipenser brevirostrum) is an endangered species that inhabits estuaries and near-shore waters from Canada to Florida. Spawning is less frequent than for the Atlantic sturgeon, with only one or two spawns occurring during a lifetime (Taubert 1980). First spawning generally does not occur until they have reached at least eight years of age (Taubert 1980), and generally occurs in freshwater areas during the 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 nine shortnose sturgeon were collected in 1984 Year Class studies (Table IV-5). Two of these were post yolk-sac collected from freshwater areas during early June. The remainder were yearling and older fish collected mostly from the bottom stratum during the LRS and the FSS. No shortnose sturgeon were collected during the BSS.

Table IV-5. Collections of shortnose sturgeon during the 1984 year class studies

Week	Region	Strata	Life Stage
	Long River Survey		
4 June	Kingston	Bottom	Post yolk-sac
11 June	Hyde Park	Bottom	Post yolk-sac
25 June	Croton-Haverstraw	Bottom	Yearling and older
2 July	Cornwall	Bottom	Yearling and older
	Fall Shoals Survey		
16 July	Tappan Zee	Shoal	Yearling and older
13 August	Saugerties	Bottom	Yearling and older
10 Sept	Kingston	Bottom	Yearling and older
24 Sept	Cornwall	Bottom	Yearling and older
8 Oct	Kingston	Channel	Yearling and older

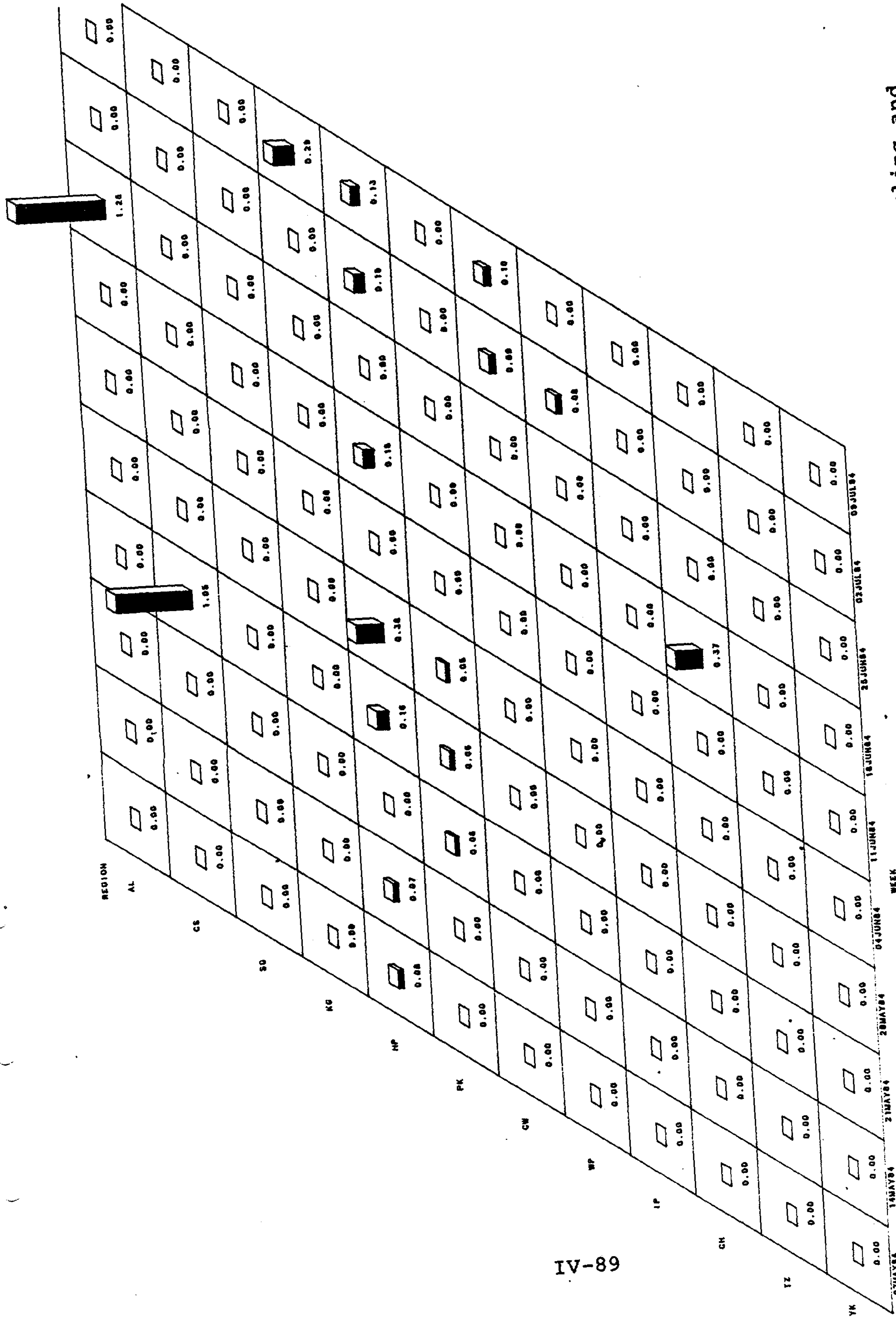

Figure IV-61. Mean regional density (per 1000 m^3) of Atlantic sturgeon yearling and older collected in the Longitudinal River Survey during 1984

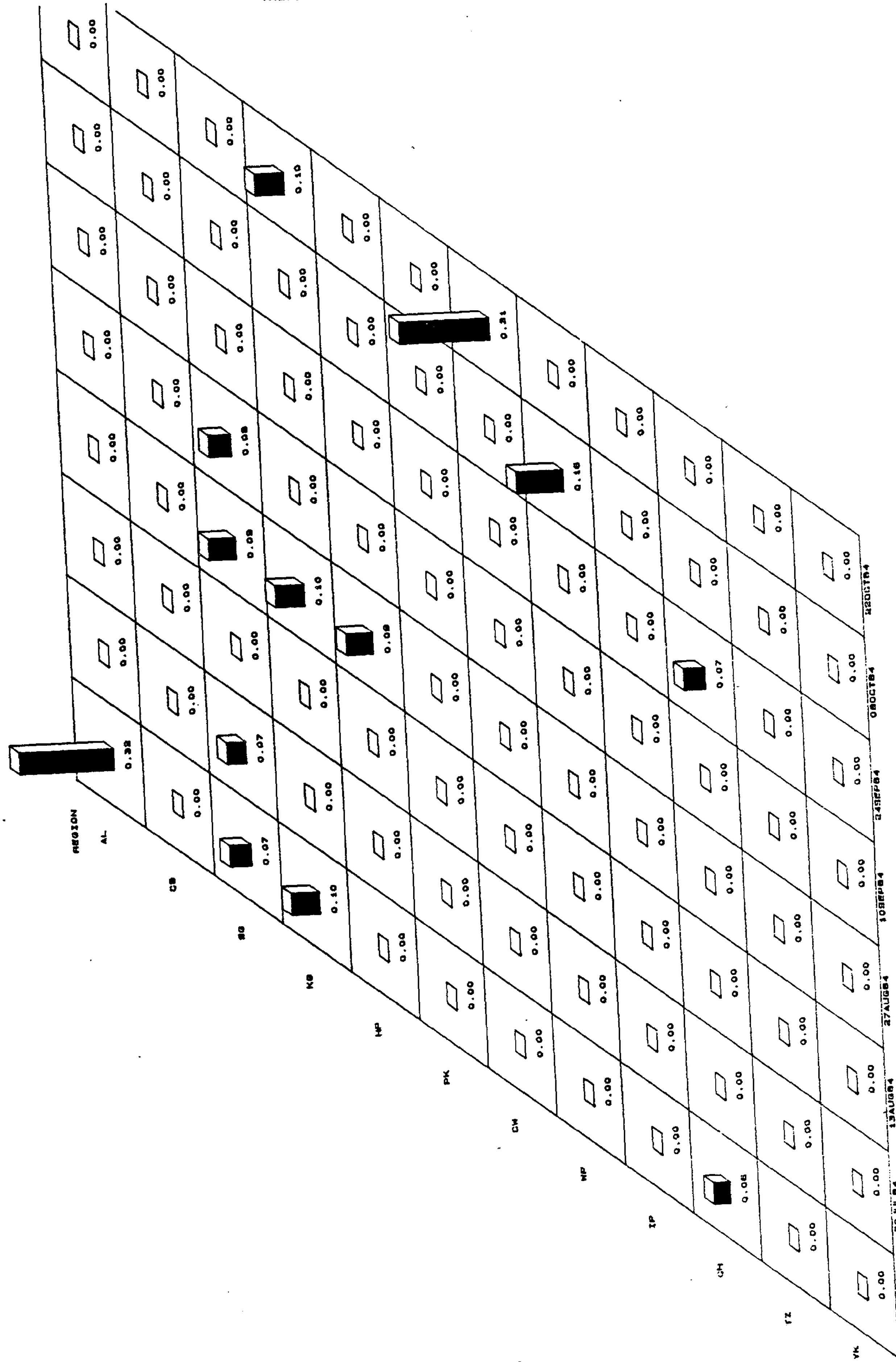

Figure IV-62. Mean regional density (per 1000 m3) of Atlantic sturgeon yearling and older collected in the Fall Shoals Survey during 1984

V. GROWTH

This chapter presents estimates of larval and juvenile growth rates for striped bass, white perch, American shad, Atlantic tomcod, and bay anchovy for 1984. In addition, these estimates are compared with growth rates reported in previous Year Class Reports. Methods for calculating growth rates are described in Section II-F of this report.

A. STRIPED BASS

A log-linear regression ($\ln Y = 0.01935x + 1.9525$, $r^2 = 0.999$), based on mean length data from 23 July to 20 August of the BSS, was used to determine that the Hudson River striped bass population reached a mean length of 30 mm (TL) on 14 July, and reached 60 mm on 19 August (Fig. V-1). Peak egg abundance occurred during the week of 4 June (Table B-4). Using these data, the larval and juvenile growth rates were calculated to be 0.7 and 0.8 mm/day, respectively.

The date when mean length of striped bass reached 30 mm was late in the year compared to that reported in other Year Class Reports (excluding 1982 and 1983 when a 4-week gap between ichthyoplankton and juvenile sampling precluded use of the standard regression methods). Similarly, the date when striped bass length reached 60 mm was the latest ever recorded (Table V-1).

The 1984 estimate of juvenile growth rate is the lowest value recorded for striped bass since initiation of the Year Class Reports in 1973. In contrast the 1984 larval growth rate estimate was the second highest value ever recorded (Table V-1). This discrepency in relative growth rates is due to the date chosen for calculating peak egg abundance. Striped bass egg abundance showed a bimodal peak in 1984, (Fig. IV-1). The latter of the two peaks was used for estimating egg abundance since this peak was larger and the earlier peak appeared to contribute little to the juvenile population, (Fig. IV-3). If the earlier date (16 May) had been chosen, the larval growth rate would have been 0.4 mm/day which, like the juvenile growth rate, would be the lowest value recorded in any Year Class Report.

TI (1981) suggested that two environmental variables that best correlate with growth of striped bass in the Hudson River are temperature and freshwater flow. However, temperature does not seem to be responsible for the low growth rate of striped

Table V-1. Estimates of larval and early juvenile (4-30 mm TL) and juvenile (30-60 mm TL) growth rates of striped bass collected from the Hudson River estuary since 1973[a]

Year	Larvae and Early Juveniles		Juveniles	
	Time Period	Rate (mm/day)	Time Period	Rate (mm/day)
1973	16 May - 9 Jul	0.5	09 Jul - 5 Aug	1.1
1974	16 May - 6 Jul	0.5	16 Jul - 9 Aug	0.9
1975	21 May - 28 Jun	0.7	28 Jun - 30 Jul	0.9
1976	08 Jun - 10 Jul	0.8	10 Jul - 12 Aug	0.9
1977	18 May - 6 Jul	0.5	06 Jul - 5 Aug	1.0
1978	24 May - 3 Jul	0.7	03 Jul - 2 Aug	1.0
1979	09 May - 27 Jun	0.5	27 Jun - 1 Aug	0.9
1982[b]	04 Jun - 26 Jul	0.5	26 Jul - 10 Aug	2.0
1983[b]	02 Jun - 28 Jul	0.5	28 Jul - 17 Aug	1.5
1984	06 Jun - 14 Jul	0.7	14 Jul - 19 Aug	0.8

[a] Growth rates were not estimated from 1980 or 1981 data.
[b] Methods different from those described in Section II-F were used (NAI 1985a, 1985b).

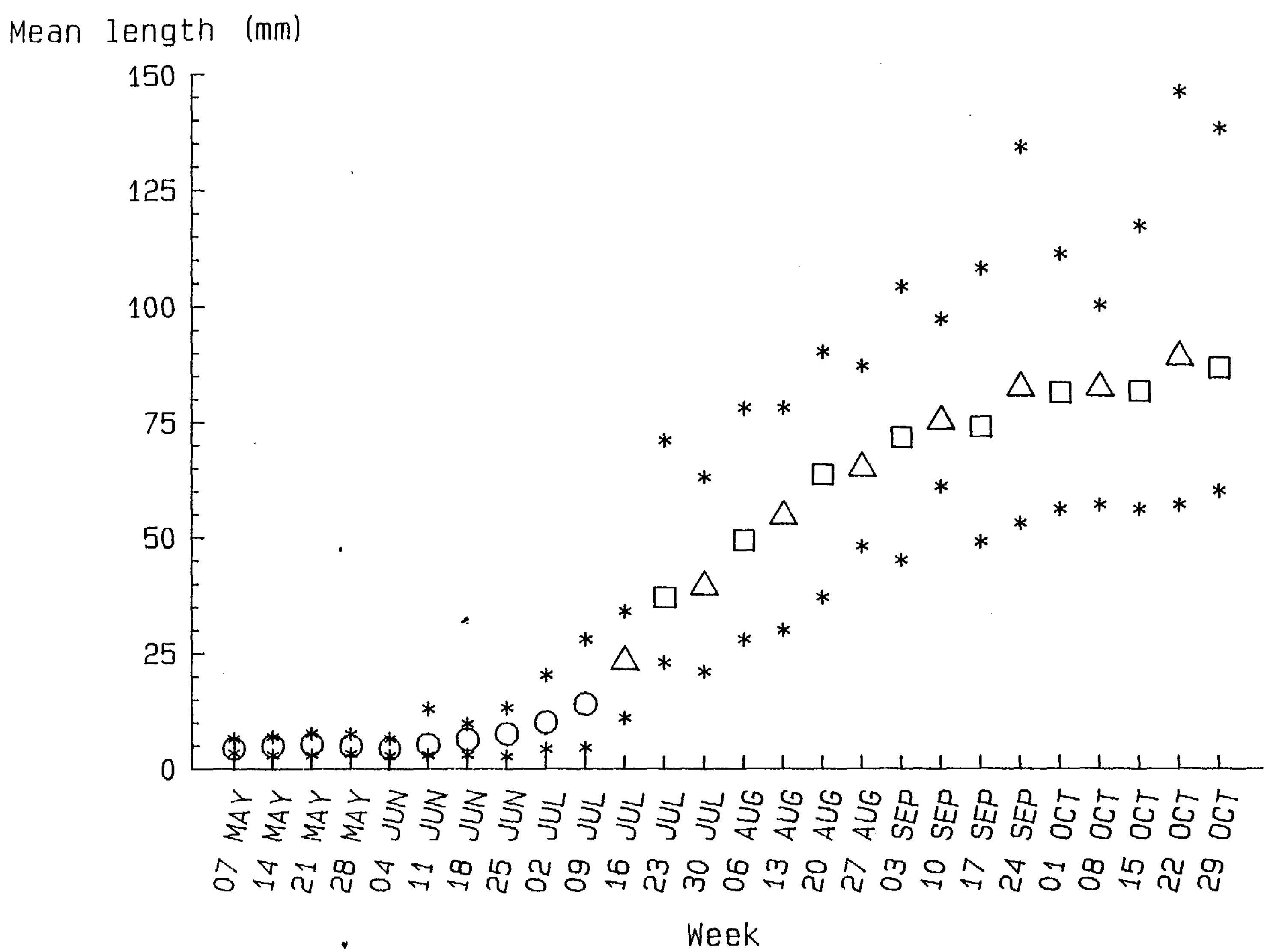

Figure V-1. Mean length of young-of-year striped bass collected from the Hudson River during 1984
O - LRS
Δ - FSS
□ - BSS
* - minimum and maximum length

bass in 1984. Optimal temperature for growth of larval striped bass has been reported as 15-22°C (Davies 1973) and 18-24°C (Rogers et al. 1977); Hudson River temperatures were well within these ranges in the regions where striped bass larvae were abundant. Similarly, water temperature during peak juvenile abundance was within the range described as optimal by both Bowker et al. (1969) and Cox and Coutant (1981). Further, river temperatures during periods of peak striped bass abundance in 1984 were within the range observed in previous Year Class Reports (Table V-2).

Freshwater flow may have had a greater effect than temperature on growth of striped bass. The optimal salinity for growth of larval striped bass is 3.5-14 ppt (Lal et al. 1977). Freshwater flow in the Hudson River from May to July was about 50% above the historical average (Table III-4), and resulted in salinities of zero in the spawning area during most of the period for larval and early juvenile growth (Tables A-5 and A-6). Further, the conductivity values (salinity data were not presented in most previous Year Class Reports) in regions of peak larval and juvenile abundance was considerably higher in previous years than in 1984.

B. WHITE PERCH

The Hudson River white perch population was estimated to have reached average lengths of 25 and 60 mm TL on 7 July and 8 September 1984, respectively (Fig. V-2). This estimate was based on a log-linear regression ($\ln Y = 0.138X + 2.277$, $r^2 = 0.946$) of BSS data collected from 23 July to 17 September. The week of peak yolk-sac larvae abundance was identified as 11 June. Larval white perch growth was estimated as 0.9 mm/day and juvenile growth was estimated as 0.6 mm/day.

The date when the white perch population was estimated to reach a mean length of 60 mm in 1984 was equal to that predicted for 1982, but at least a week later than dates reported in all other Year Class Reports (Table V-3). In contrast, the date when mean population size was estimated to reach 25 mm (July 7) falls within the range of dates reported in previous years (28 June and 27 July; Table V-3).

The 1984 larval growth estimate is the highest value ever recorded from the Hudson River. Larval growth rate estimates for white perch between 1973 and 1984 range from 0.3 to 0.9 mm/day (Table V-3). The estimate for juvenile growth in 1984 was low, being equal to that of the 3 years with the lowest growth rates, 1976, 1978, and 1979.

Table V-2. Mean temperature (°C) in regions and periods of peak abundance of striped bass eggs and larvae

	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	9 Jun-22 Jun	21.5
1975	18 May-31 May	19.0	25 May-07 Jun	19.9	1 Jun-14 Jun	20.6
1976	23 May-05 Jun	15.0	30 May-12 Jun	16.4	6 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	4 Jun-17 Jun	20.7
1979	6 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	2 Jun-13 Jun	18.2
1981	18 May-21 May	15.9	18 May-21 May	15.9	1 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-6 Jun	13.6	6 Jun-19 Jun	19.2	13 Jun-26 Jun	21.7
1984	4 Jun-11 Jun	17.0	11 Jun-18 Jun	20.3	18 Jun-25 Jun	21.2

Adapted from NAI (1985b).

Table V-2. Mean temperature (°C) in regions and periods of peak abundance of striped bass eggs and larvae

Year	Eggs		Yolk-Sac Larvae		Post Yolk-Sac Larvae	
	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	9 Jun-22 Jun	21.5
1975	18 May-31 May	19.0	25 May-07 Jun	19.9	1 Jun-14 Jun	20.6
1976	23 May-05 Jun	15.0	30 May-12 Jun	16.4	6 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	4 Jun-17 Jun	20.7
1979	6 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	2 Jun-13 Jun	18.2
1981	18 May-21 May	15.9	18 May-21 May	15.9	1 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	6 Jun-19 Jun	19.2	13 Jun-26 Jun	21.7
1984	4 Jun-10 Jun	14.7	11 Jun-17 Jun	19.0	18 Jun-25 Jun	21.1

Adapted from NAI (1985b)

Table V-3. Estimates of larval (3-25 mm TL) and juvenile (25-60 mm TL) growth rates of white perch collected from the Hudson River estuary since 1973[a]

Year	Larvae and Early Juveniles		Juveniles	
	Time Period	Rate (mm/day)	Time Period	Rate (mm/day)
1973	13 Jun - 10 Jul	0.8	10 Jul - 24 Aug	0.8
1974	22 May - 10 Jul	0.5	10 Jul - 27 Aug	0.7
1975	24 May - 26 Jun	0.7	26 Jun - 17 Aug	0.7
1976	12 Jun - 8 Jul	0.8	8 Jul - 2 Sep	0.6
1977	24 May - 1 Jul	0.6	1 Jul - 23 Aug	0.7
1978	31 May - 28 Jun	0.8	28 Jun - 22 Aug	0.6
1979	16 May - 28 Jun	0.5	28 Jun - 30 Aug	0.6
1982[b]	19 May - 25 Jul	0.3	25 Jul - 8 Sep	0.8
1983[b]	25 May - 27 Jul	0.4	27 Jul - 1 Sep	1.0
1984	16 May - 7 Jul	0.9	7 Jul - 8 Sep	0.6

(a) Growth rates were not available for 1980 or 1981
(b) Methods different from those described in Section II-F were used (NAI 1985a, 1985b)

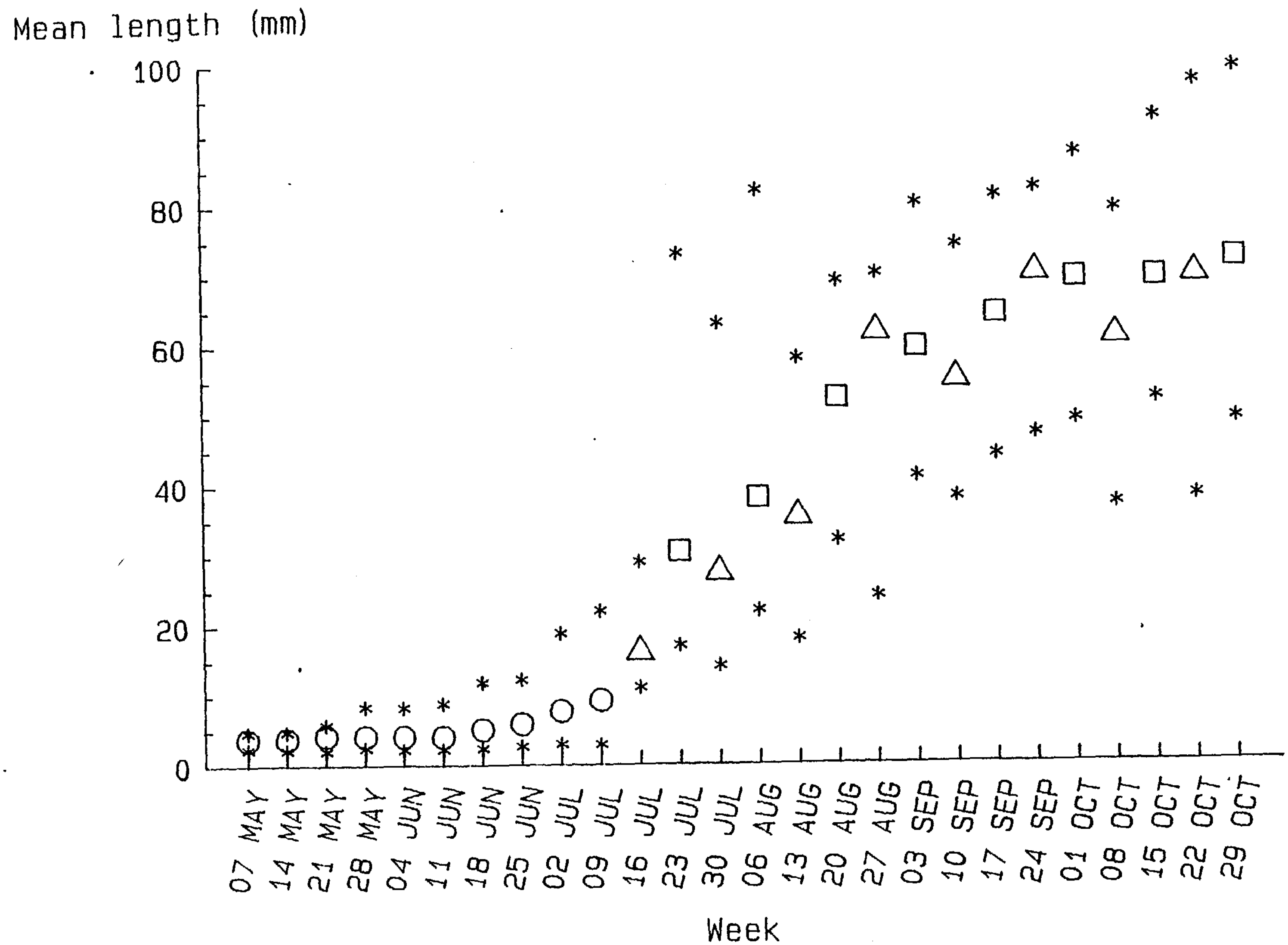

Figure V-2. Mean length of young-of-year white perch collected from the Hudson River during 1984
O - LRS
Δ - FSS
□ - BSS
* - minimum and maximum length

It is difficult to identify factors that might have led to the relatively high growth rate of larval white perch in 1984. Unlike striped bass, the optimal temperature and salinity for white perch growth have not been established.

C. AMERICAN SHAD

The American shad population was estimated to reach a mean length of 60 mm TL on 31 July based on log-linear regression ($\ln Y = 0.038x + 0.783$, $r^2 = 1.00$) of mean length data from BSS sampling on 23 July and 6 August (Fig. V-3). The date that American shad reached recruitment size (30 mm) could not be interpolated from BSS data, since mean length already exceeded 50 mm during the first week of beach seine sampling. In previous years (NAI 1985a, 1985b) similar gaps in data were filled by assuming an exponential rate of growth from the time spawning was completed until the time fish reached 60 mm TL. This technique was applied for American shad during 1984. Using these data, the mean length of the population was calculated to have reached 30 mm TL on 9 July. Yolk-sac standing crop was estimated as having reached peak abundance during the week of 28 May. Using these data the larval and juvenile growth rates were calculated as 0.5 and 1.3 mm/day, respectively.

Comparisons of American shad growth rates among years are not presented since the method used for 1984 data had not been applied to shad data in previous Year Class Reports. Only in 1982 and 1983 were growth estimates for shad calculated, and these were limited to fish greater than 60 mm (NAI 1985a, 1985b). However, the growth rate for juvenile shad of 1.3 mm/day is considerably higher than that reported for shad in other river systems (Williams and Bruger 1972; Watson 1968; Marcy 1976).

D. ATLANTIC TOMCOD

No larval growth estimates were made for Atlantic tomcod since it spawns during winter, and length data were not collected for this species during the LRS. In addition, no growth measurements could be obtained for the 30-60 mm size group since the mean size of Atlantic tomcod during the first week of the fall surveys already exceeded 60 mm (Fig. V-4). However, a daily growth rate for young-of-year Atlantic tomcod was estimated to be 0.4 mm/day based on the change in mean length from 70 to 106 mm which occurred during the FSS (BSS data were not used because most Atlantic tomcod were captured in the FSS).

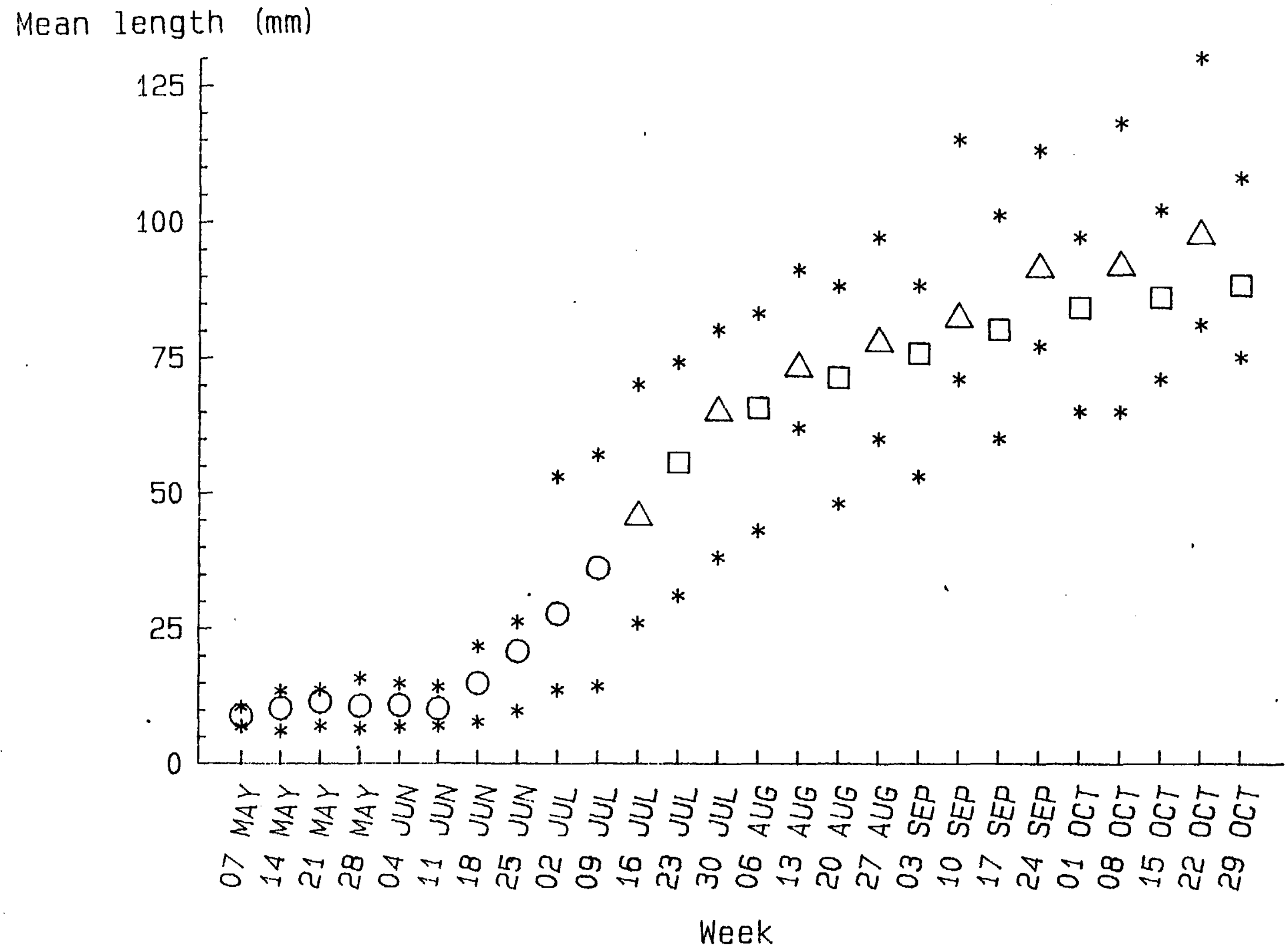

Figure V-3. Mean length of young-of-year American shad collected from the Hudson River during 1984
O - LRS
Δ - FSS
□ - BSS
* - minimum and maximum length

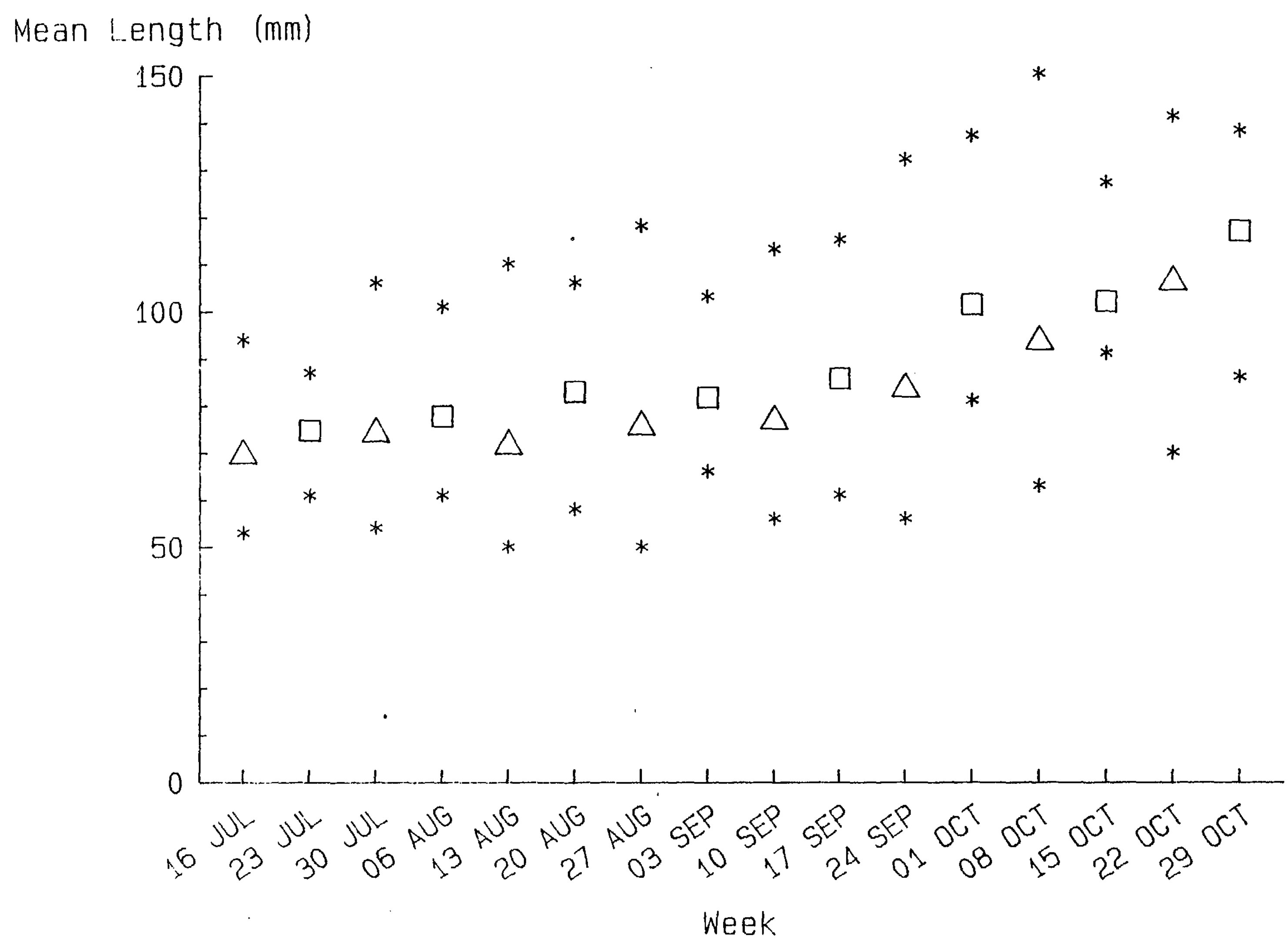

Figure V-4. Mean length of young-of-year Atlantic tomcod collected from the Hudson River during 1984
Δ - FSS
□ - BSS
* - minimum and maximum length

Growth rate for this species has been calculated for only two previous years: growth rate was estimated as 0.2 mm/day in 1982 and as 0.3 mm/day in 1983. Direct comparison of these growth rates with the 1984 value is not advisable, however, because the 1984 FSS began in mid-July while the 1982 and 1983 FSS began in early August.

E. BAY ANCHOVY

Mean length of bay anchovy increased from 16.4 to 42.0 mm during the FSS, and from 26.9 to 49.7 mm in the BSS (Fig. V-5). These changes in mean size correspond to growth rates of 0.2 and 0.3 mm/day for the BSS and FSS, respectively. These rates are similar to those found in previous years (NAI 1985a, 1985b) and are within the range of growth rates (0.15-0.43 mm/day) reported for juvenile bay anchovies in other river systems (Perlmutter 1939; Stevenson 1958; Marcellus 1972). However, these figures may be under-estimates of true growth rate because bay anchovy typically spawns in the Hudson River throughout the period when the 1984 Fall Shoals and Beach Seine surveys took place (Dovel 1981). Thus, young individuals are continually being recruited and lowering the population mean length.

Mean size of young-of-year bay anchovy was smaller for the FSS than for the BSS in 1984; the same pattern was also observed in the summer of 1982 (NAI 1985a) and 1983 (NAI 1985b). Recruitment of recently spawned individuals to the channel areas would reduce mean size in that stratum. In addition, movement of larger individuals to the shore zone and differential collection efficiency of gear used in the two surveys might possibly explain this pattern.

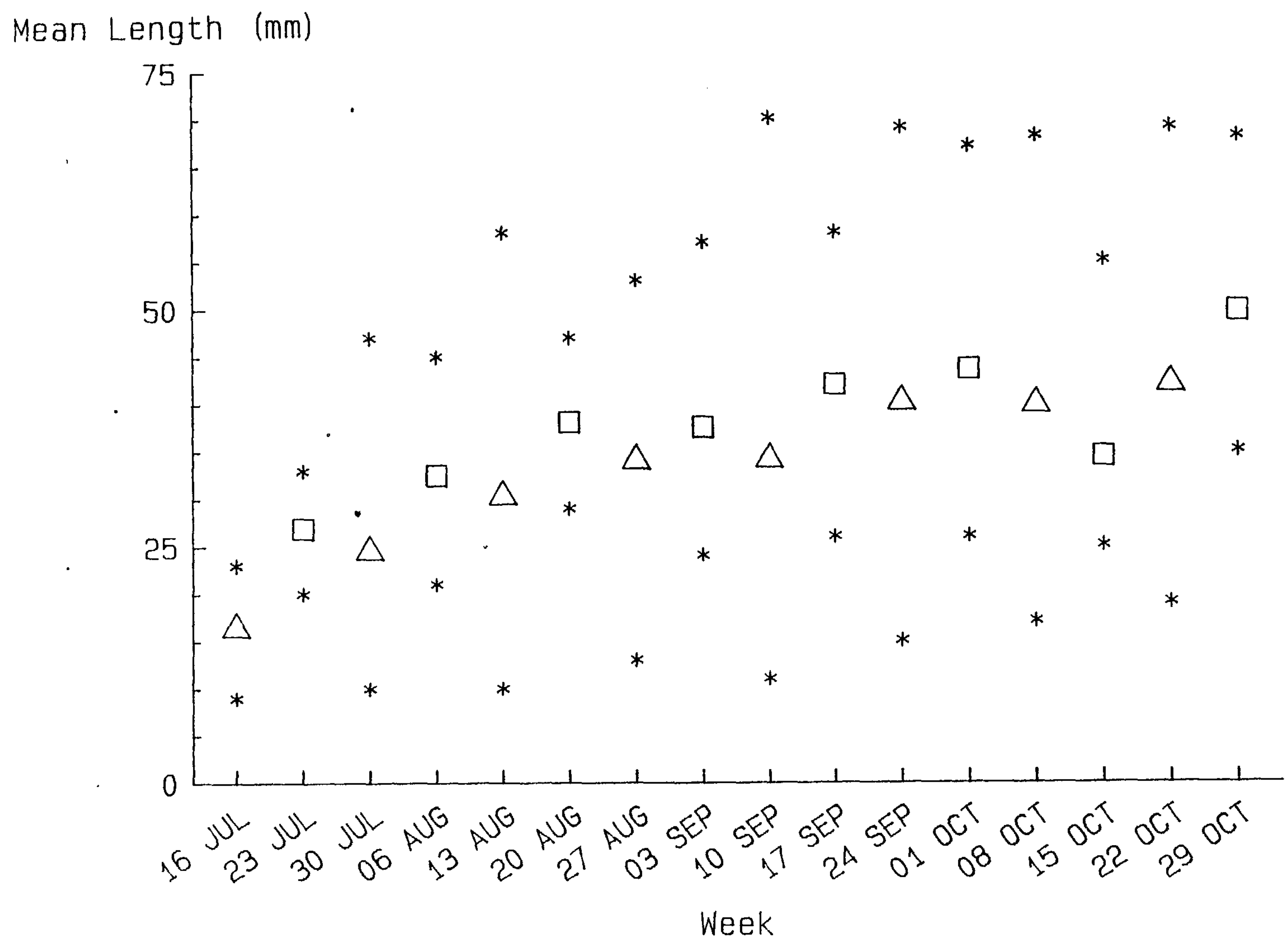

Figure V-5. Mean length of young-of-year bay anchovy collected from the Hudson River during 1984
Δ - FSS
□ - BSS
* - minimum and maximum length

VI. MORTALITY

Mortality rates were estimated for three species of larval fish (striped bass, white perch, American shad) and five species of juvenile fish (striped bass, white perch, American shad, Atlantic tomcod, bay anchovy) collected from the Hudson River in 1984 using the population decline method described in Section II-F. In these calculations species-specific estimates of gear efficiency were unavailable, and weekly combined standing crop for American shad, Atlantic tomcod, and bay anchovy were unadjusted for collection efficiency.

In previous Year Class Reports, the Sette (1943) method was used to estimate mortality of larval and early juvenile (<20 mm) striped bass. This was not used to calculate mortality in 1984 since a key assumption of the method is that all fish have reached the designated cutoff (in this case, 20 mm in length) by termination of sampling. At the end of the LRS in 1984, more than 90% of the striped bass standing crop were less than 20 mm in length.

A. STRIPED BASS

Striped bass larval mortality rate, based on the decline of weekly combined standing crop from 18 June (the week of peak standing crop), until the end of LRS sampling in the week of 9 July (Fig. VI-1), was 17.4% per day (or greater than 99.9% when extrapolated to an annual rate). Although the estimate for daily mortality rate has varied among years (Table VI-1), when extrapolated to an annual rate, larval mortality has exceeded 99% in every previous year. The 1984 daily rate was higher than in either 1982 or 1983 when the population decline method was used, and was within the range found from 1976 to 1979, when the Sette method was used. The 1984 daily mortality rate was also within the range of 7-32% daily larval mortality observed for striped bass in the Potomac River (Polgar 1977).

Juvenile mortality rate could not be determined for striped bass in 1984. Weekly combined standing crop of juvenile striped bass did not decline continuously during the fall surveys (Fig. VI-1) but exhibited several peaks in standing crop during the weeks of 30 July, 17 September, and 24 September. No estimate of juvenile mortality from 1984 data is provided because the regression of combined standing crop and sampling date was not significant. Calculation of mortality based on a subset of the data (e.g., just August data) would not produce estimates comparable with other years and would not, therefore, contribute to the design and purpose of the Year Class Reports.

Table VI-1. Estimates of larval mortality rates for striped bass in the Hudson River estuary.

Year[a]	Peak Standing Crop (millions)	Period of Peak Standing Crop	Method	Daily Mortality Rate
1976[b]	700	NA[c]	Sette	15.6
1977	1475	NA	Sette	15.5
1978	1135	NA	Sette	19.0
1979	1546	NA	Sette	14.4
1982[d]	~ 1100	31 May-05 Jul	Population Decline	9.0
1983[e]	~ 840	13 Jun-04 Jul	Population Decline	13.0
1984	2015	18 Jun-09 Jul	Population Decline	17.4

(a) No mortality estimates were available for 1980 or 1981
(b) 1976-1979 data were taken from TI (1981)
(c) NA - not applicable
(d) 1982 data were taken from NAI (1985a)
(e) 1983 data were taken from NAI (1985b)

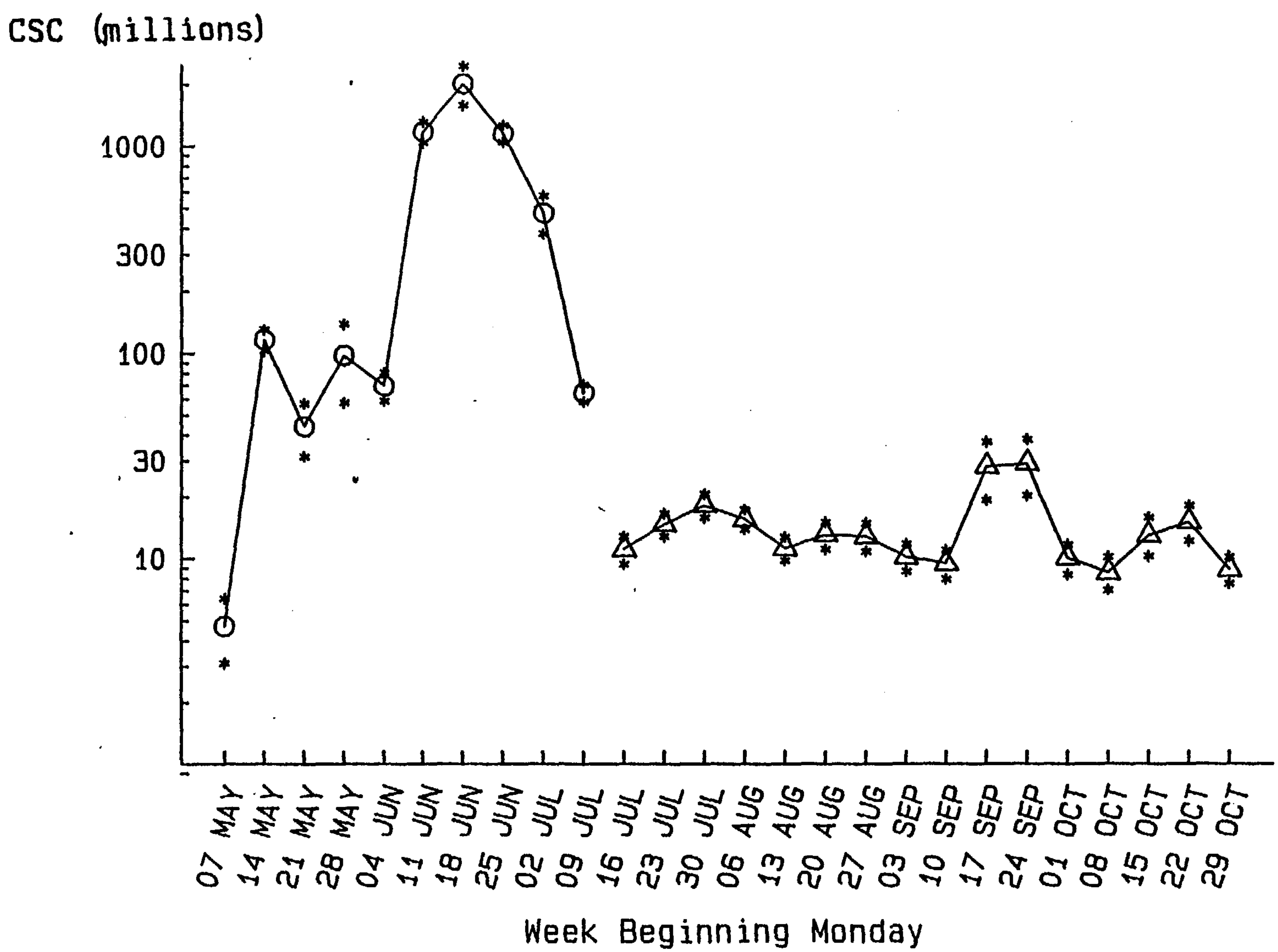

Figure VI-1. Weekly combined standing crop of larval and young-of-year striped bass collected in the Hudson River during 1984.
O - LRS
Δ - FSS and BSS
* - plus/minus one standard error

B. WHITE PERCH

Combined standing crop during the LRS peaked during the week of 18 June at 5.23 x 10^9 and declined exponentially thereafter (Fig. VI-2). Larval mortality calculated from that peak until the end of the LRS yielded a daily mortality rate of 10.2% (annual mortality rate exceeding 99%). This rate is higher than in the previous 2 years, but falls within the range of historical values reported for the Hudson River (Table VI-2).

Weekly combined standing crop of young-of-year white perch generally declined from the first week of sampling (16 July) through the remainder of the fall surveys, although a minor secondary peak occurred in September. Calculation of juvenile mortality from weekly combined standing crop estimates for the entire sampling period yielded a daily rate of 0.9% (equal to an annual rate of 96%). This value is at the upper end of the range observed in past years (Table VI-3).

C. AMERICAN SHAD

Based on regression of weekly combined standing crop from the peak on 4 June until the end of the LRS (Fig. VI-3), the estimate for daily mortality rate of larval American shad was 6.2%. Larval mortality of American shad has only been calculated in two previous years: mortality rates of 6 and 7% were determined for 1982 and 1983, respectively (NAI 1985a, 1985b).

Peak abundance for juvenile American shad (2.9 x 10^7) occurred during the final week of LRS sampling (9 July). The juvenile mortality estimate based on regression from the week of highest young-of-year abundance during 1984 resulted in a daily mortality rate of 1.8%. When only the Beach Seine Survey (BSS) and Fall Shoals Survey (FSS) data were used, the juvenile mortality rate was 1.5%.

The 1984 juvenile mortality rate for American shad fell between the estimates of 0.85 and 4.0% reported in 1982 and 1983, respectively. Mortality estimates for American shad have not been presented in other Year Class Reports. Juvenile daily mortality rates of 1.8 to 2.0% have been reported for the Connecticut River (Crecco et al. 1983).

D. ATLANTIC TOMCOD

Since Atlantic tomcod are winter spawners, relatively few larvae were caught during the LRS. Therefore, larval mortality could not be estimated. However, juvenile mortality was estimated using data from the peak abundance during the fall surveys

Table VI-2. Estimates of larval mortality rates for white perch in the Hudson River estuary.

Year[a]	Period	Daily Rate of Population Decline
1976[b]	20 June - 31 July	12.6
1977	6 June - 13 August	10.7
1978	12 June - 30 June	12.8
1979	11 June - 28 July	10.0
1982[c]	7 June - 5 July	5.0
1983[d]	20 June - 4 July	7.0
1984	18 June - 9 July	10.2

(a) No mortality estimates were available for 1980 or 1981
(b) 1976 - 1979 data were taken from TI (1981)
(c) 1982 data were taken from NAI (1985a)
(d) 1983 data were taken from NAI (1985b)

Table VI-3. Estimates of juvenile mortality rates for white perch in the Hudson River estuary

Year[a]	Period	Daily Rate of Population Decline
1976[b]	1 August - 11 December	0.5
1977	14 August - 29 October	0.7
1978	27 August - 23 September	0.2
	24 September - 23 October	0.7
	22 October - 18 November	0.9
1979	29 July - 15 December	0.6
1982[c]	16 August - 11 October	1.3
1983[d]	8 August - 17 October	1.1
1984	16 July - 29 October	0.9

(a) No mortality estimates were available for 1980 or 1981
(b) 1976 - 1979 data were taken from TI (1981)
(c) 1982 data were taken from NAI (1985a)
(d) 1983 data were taken from NAI (1985b)

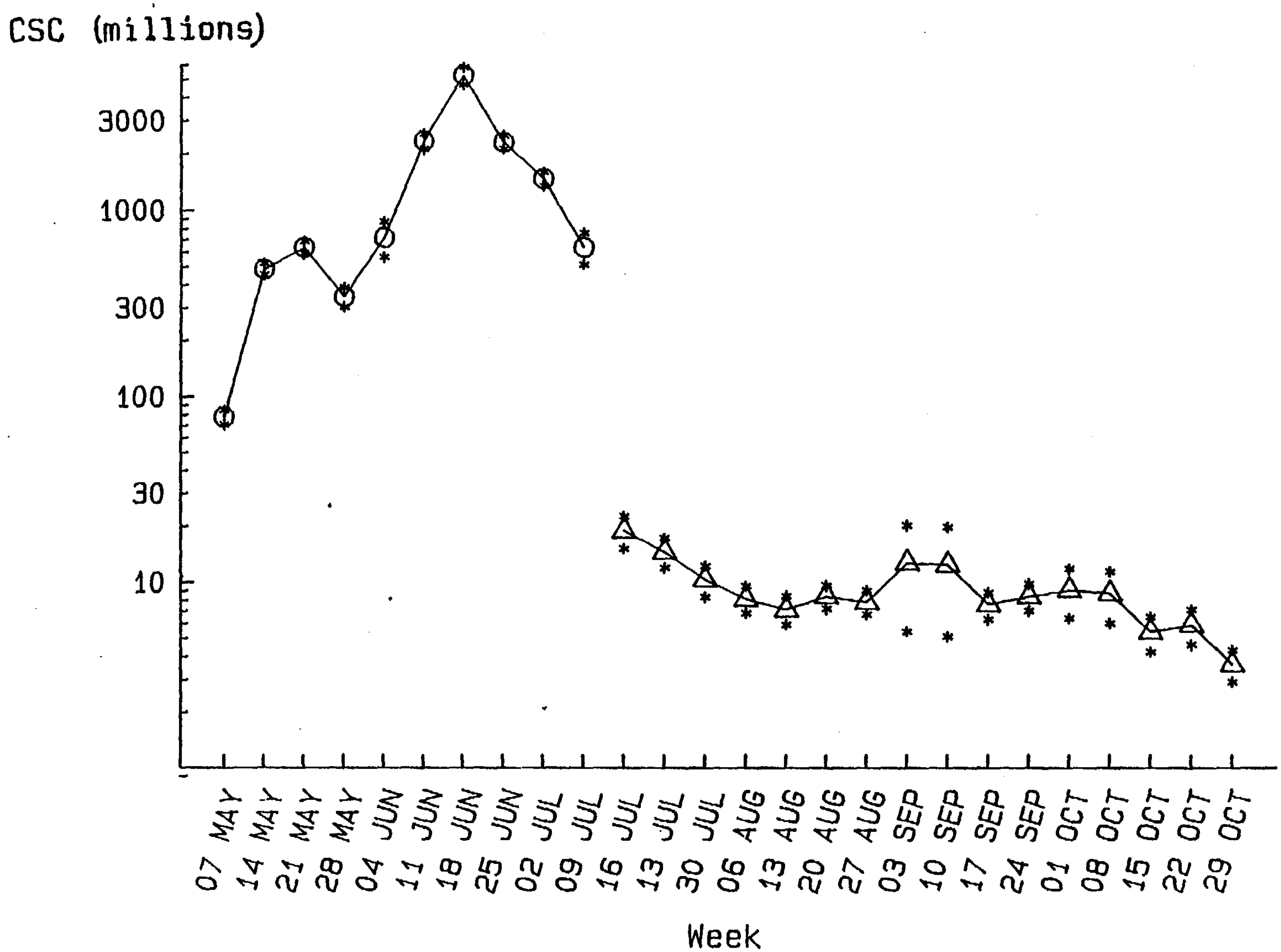

Figure VI-2. Weekly combined standing crop of larval and young-of-year white perch collected in the Hudson River during 1984.
O - LRS
Δ - FSS and BSS
* - plus/minus one standard error

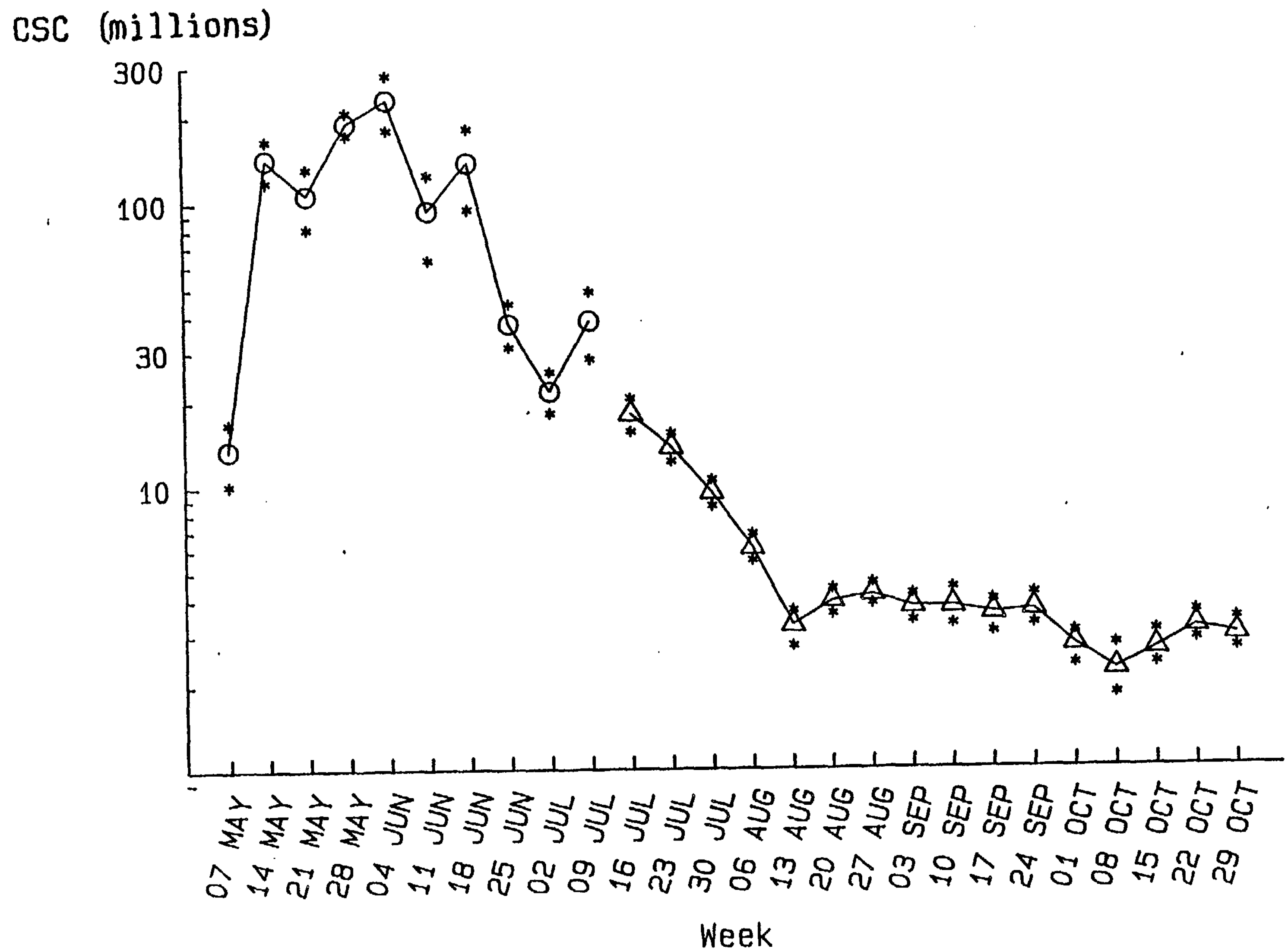

Figure VI-3. Weekly combined standing crop of larval and young-of-year American shad collected in the Hudson River during 1984.
O - LRS
Δ - FSS and BSS
* - plus/minus one standard error

(first week of collection) until the end of sampling (Fig. VI-4). The 1984 daily mortality rate of 2.6% was within the range of 2.4-3.0% reported for other years (1982 and 1983 only).

E. BAY ANCHOVY

Bay anchovy spawn continuously throughout most of the study period. Therefore, estimation of mortality based on population decline can be misleading. Larval mortality has not been calculated in previous years and was not calculated in 1984. However, juvenile mortality was calculated based on decline in abundance from the week of 24 September, presumably after recruitment had ceased (Fig. VI-5). The daily mortality rate for bay anchovy based on this 1 month of data was 3.6%. This rate is very similar to the rate of 3.0% found in both 1982 and 1983 when September peaks were also used.

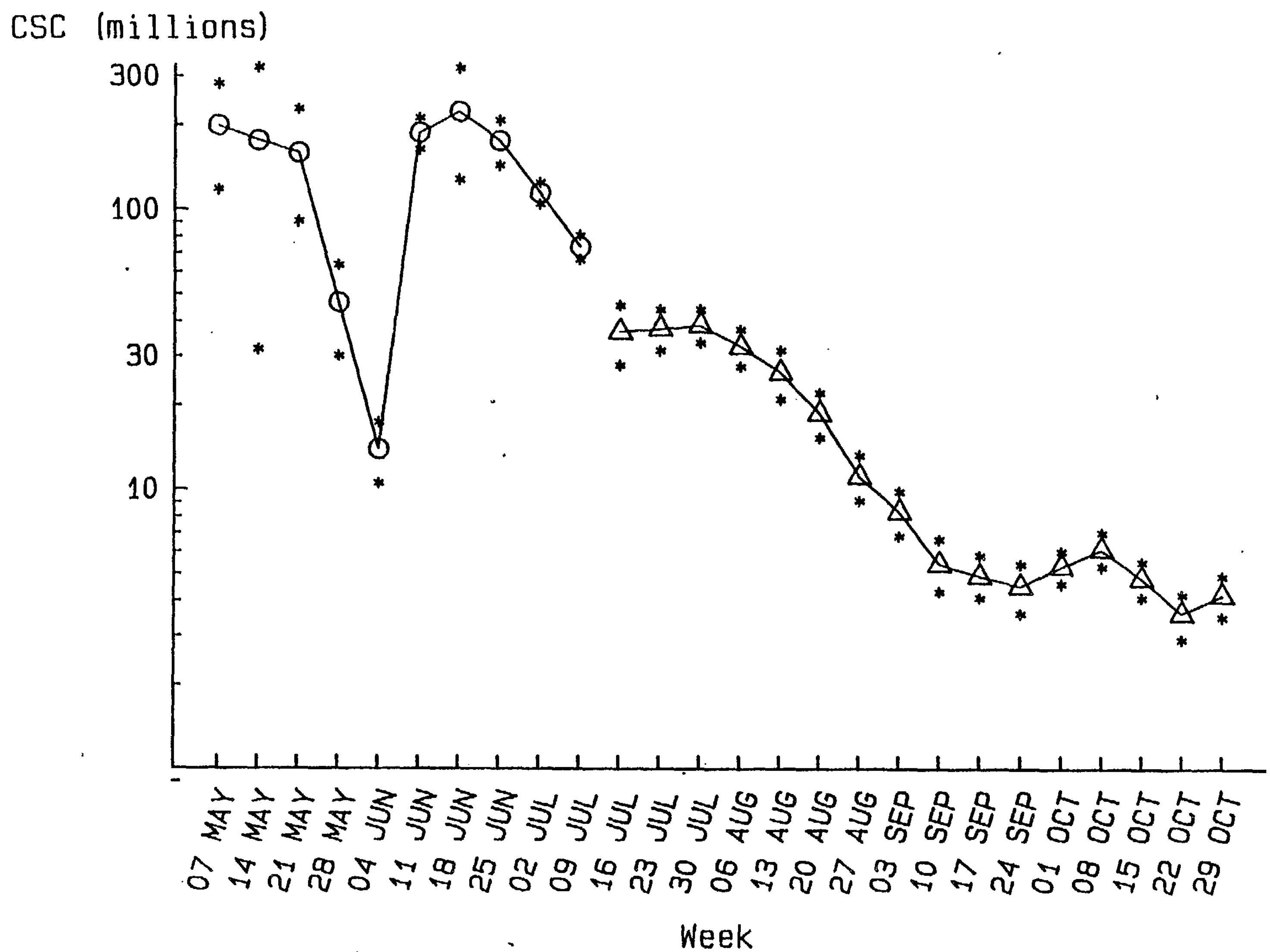

Figure VI-4. Weekly combined standing crop of larval and young-of-year Atlantic tomcod collected in the Hudson River during 1984.
O - LRS
Δ - FSS and BSS
* - plus/minus one standard error

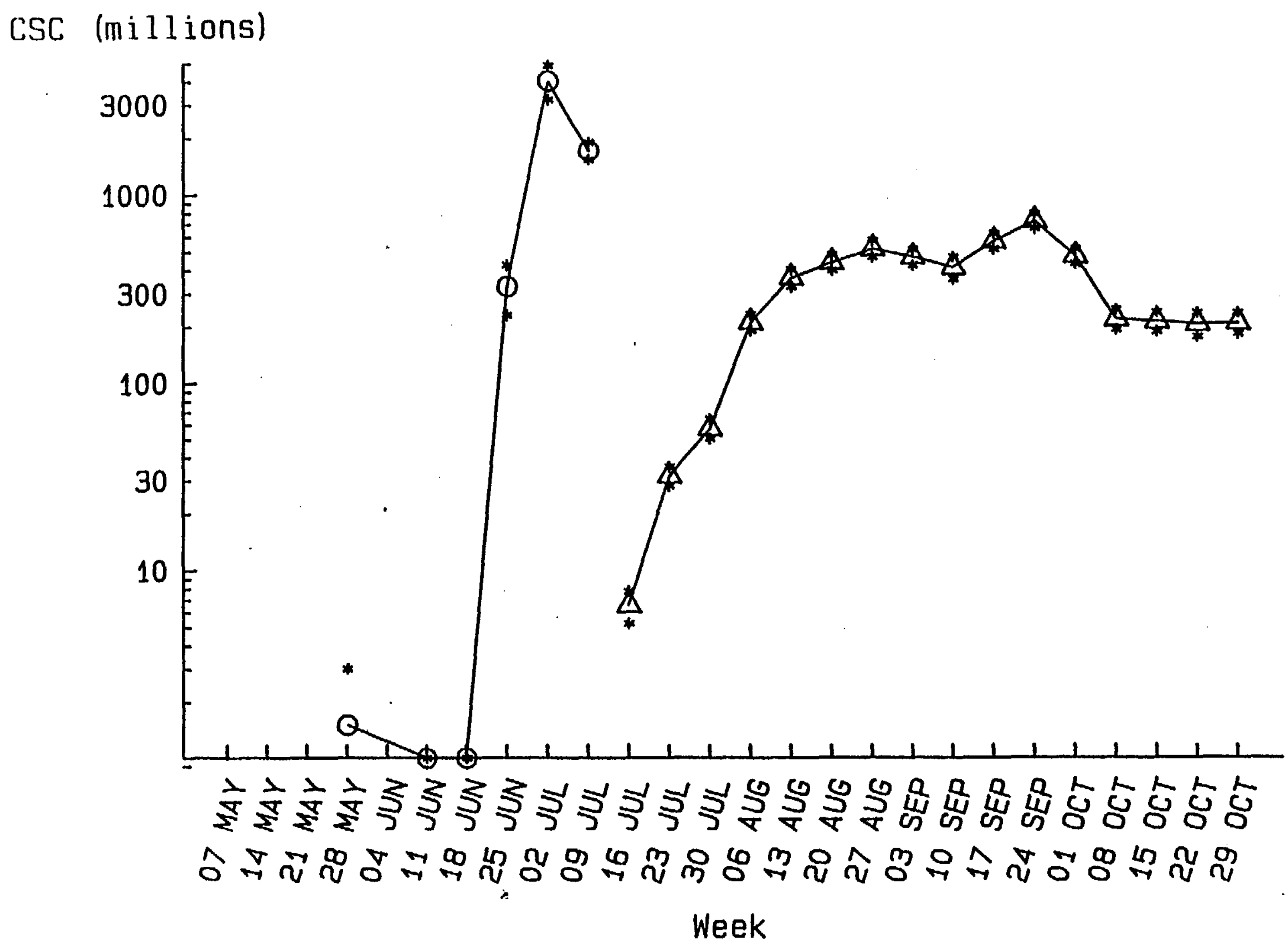

Figure VI-5. Weekly combined standing crop of larval and young-of-year bay anchovy collected in the Hudson River during 1984.
O - LRS
Δ - FSS and BSS
* - plus/minus one standard error

VII. ANNUAL ABUNDANCE INDICES

Several indices of year class strength have historically been calculated for Hudson River white perch and striped bass using data from the LRS, FSS and BSS programs and have provided year-to-year comparisons of riverwide abundance. The combined standing crop (CSC) index has been the most frequently presented index in previous Year Class Reports (TI 1981; Battelle 1983), but was replaced by the summer and fall regression indices in 1982 and 1983 when the sampling period did not fully reflect the time periods during which juvenile fish were most abundant*. The beach seine index has been used to provide information on young-of-year abundance in those years prior to standardization of the ichthyoplankton and fall juvenile surveys (1969-1973)*. The beach seine index has not been presented since the 1979 Year Class Report.

In this chapter, the 1984 CSC index is presented and results obtained from the three alternative indices (summer regression, fall regression, and beach seine) are compared to it. To provide uniformity for historical comparisons, the beach seine index was calculated for the intermediate years when it was not reported (1980 through 1983) and the CSC index was calculated for 1982 and 1983 data.

A. STRIPED BASS

CSC Index

Peak abundance in 1984 was estimated to occur during the weeks of 17 and 24 September (Fig. VII-1). Based on this period of peak abundance, the 1984 CSC index for young-of-year striped bass was computed to be 34.9 million, a value which has only been exceeded in 1981 and 1983 (Fig. VII-2).

The CSC index includes a correction factor for mortality that occurs between 1 August and the week of peak abundance.

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*Personal Communication with Consolidated Edison; telephone conversation between F. Jacobs and J. Waxman, May 12, 1986.

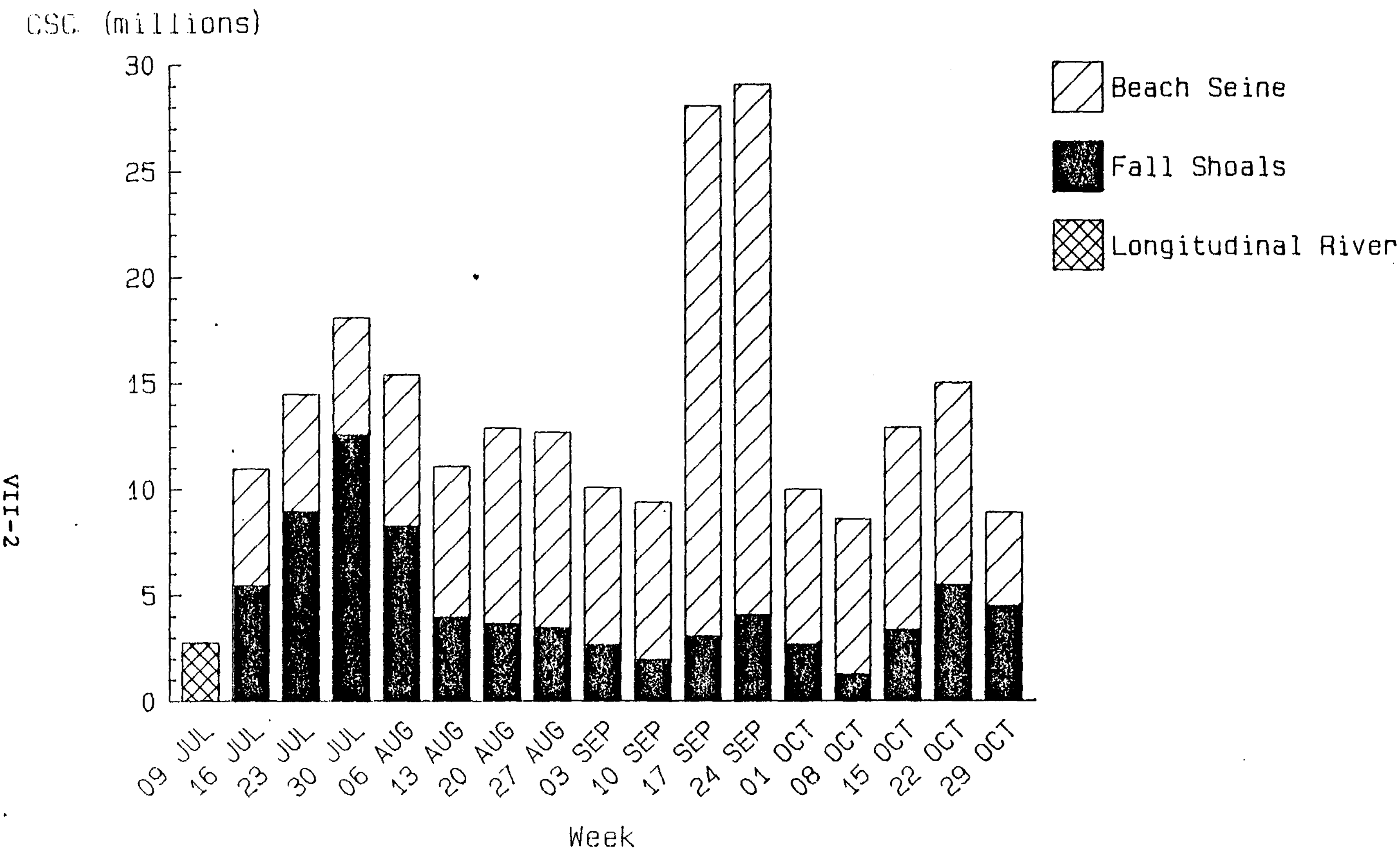
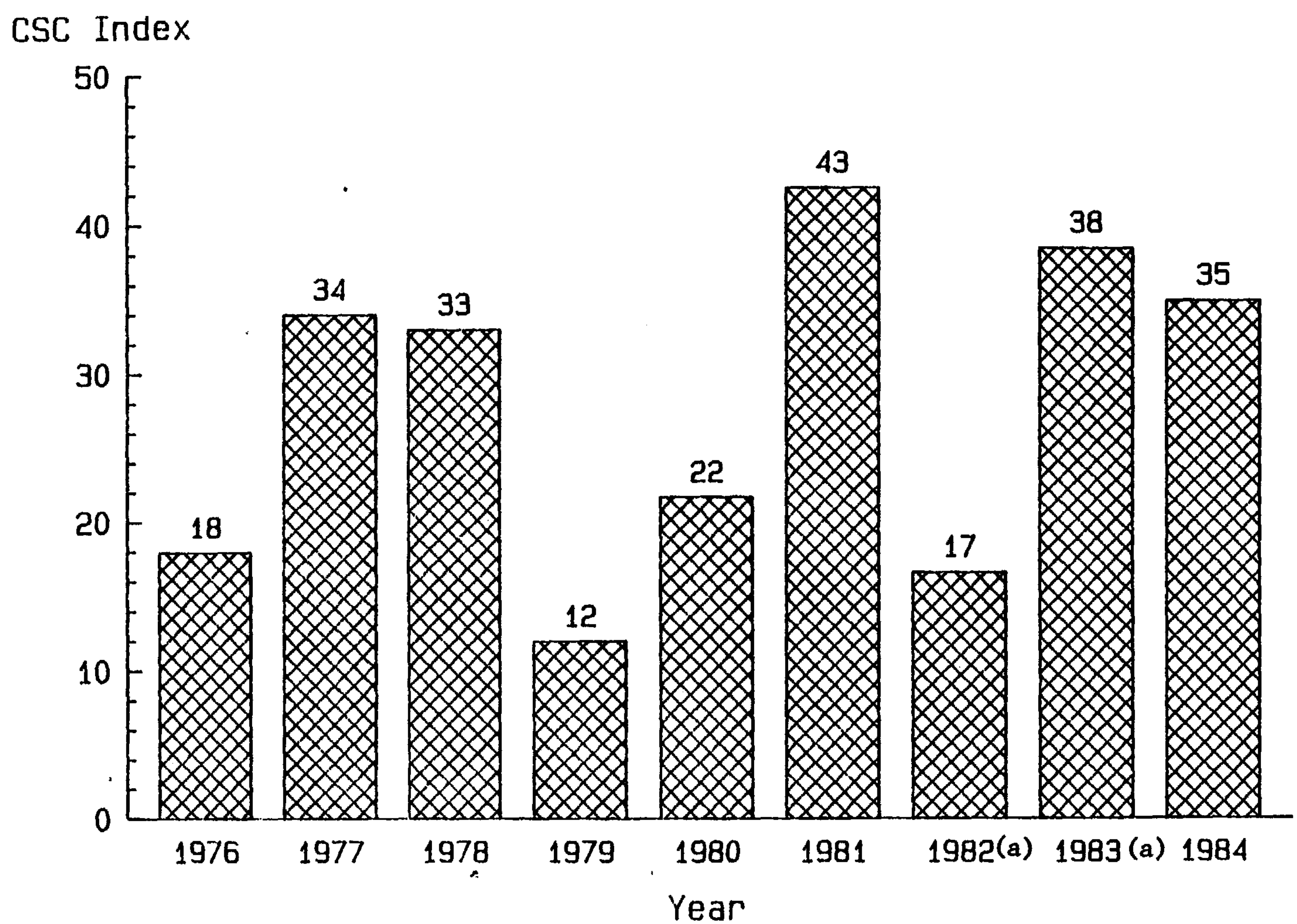


Figure VII-1. Combined standing crop of young-of-year striped bass collected in the Hudson River during 1984



(a) 1982 and 1983 indices were recalculated using the methods described in Section II-F

Figure VII-2. Combined standing crop index for young-of-year striped bass in the Hudson River estuary, 1976 to 1984 occurs, the greater the correction factor will be. Peaks in weekly estimated striped bass abundance have typically occurred in August in previous years, whereas the peak occurred much later in 1984. However, this correction does not seem to be responsible for the higher-than-average index in 1984. If no correction for mortality had been applied, the CSC index would have been 30 instead of 35. Late peaks have occurred previously (1982 and 1983) and there seems to be little relation between when the peak occurs and the value of the index.

There is little evidence in the water quality data to suggest why 1984 would exhibit above-average striped bass abundance. Water temperature at the time of hatching was slightly lower and temperature during larval development was slightly higher than in most previous years (Table V-2). However, these facts may be inconsequential since, historically, the relationship between water temperature during these life stages and the index of year class abundance has been weak (Fig. VII-3). Salinity during hatching and development was less than that typically observed in previous years, and was outside the optimal range for hatching and growth. The lower-than-average growth rate estimate for juvenile striped bass (Table V-1), and the higher-than-average mortality rate estimate for larval striped bass (Table VI-1) further suggest that optimal water quality conditions that would lead to a strong year class of striped bass did not occur in the Hudson River in 1984.

Although the CSC index suggests that 1984 was an above-average year for striped bass year class strength, this conclusion should not be unequivocally accepted. There are no error estimates associated with the CSC index. There are, however, error estimates associated with the weekly combined standing crop values that indicate a high degree of variability. For example, the 95% confidence intervals around the CSC for the peak weeks in 1982, 1983, and 1984 suggest that these three peaks (ranging from about 13 to 32 million) would be statistically indistinguishable. Given such high variability of the weekly CSC estimates it seems likely that the CSC indices would also have large confidence intervals.

Year-to-year comparisons of the CSC index are also hampered by the possibility that the peak week could represent an outlier rather than a true peak. In 1984, the peak was generated almost entirely from large catches in the BSS during the week of 17 September (the 24 September peak is based on BSS data from the previous week since beach seine sampling collections are only made in alternate weeks), primarily on a few beaches in the Croton-Haverstraw and Tappan-Zee regions. While these large catches could be representative of a concentration of striped bass in these regions during that week, they could also have resulted from anomolously large catches on beaches containing a locally dense population. Further development of analytical techniques to consider such possibilities would enhance comparison of the CSC index among years.

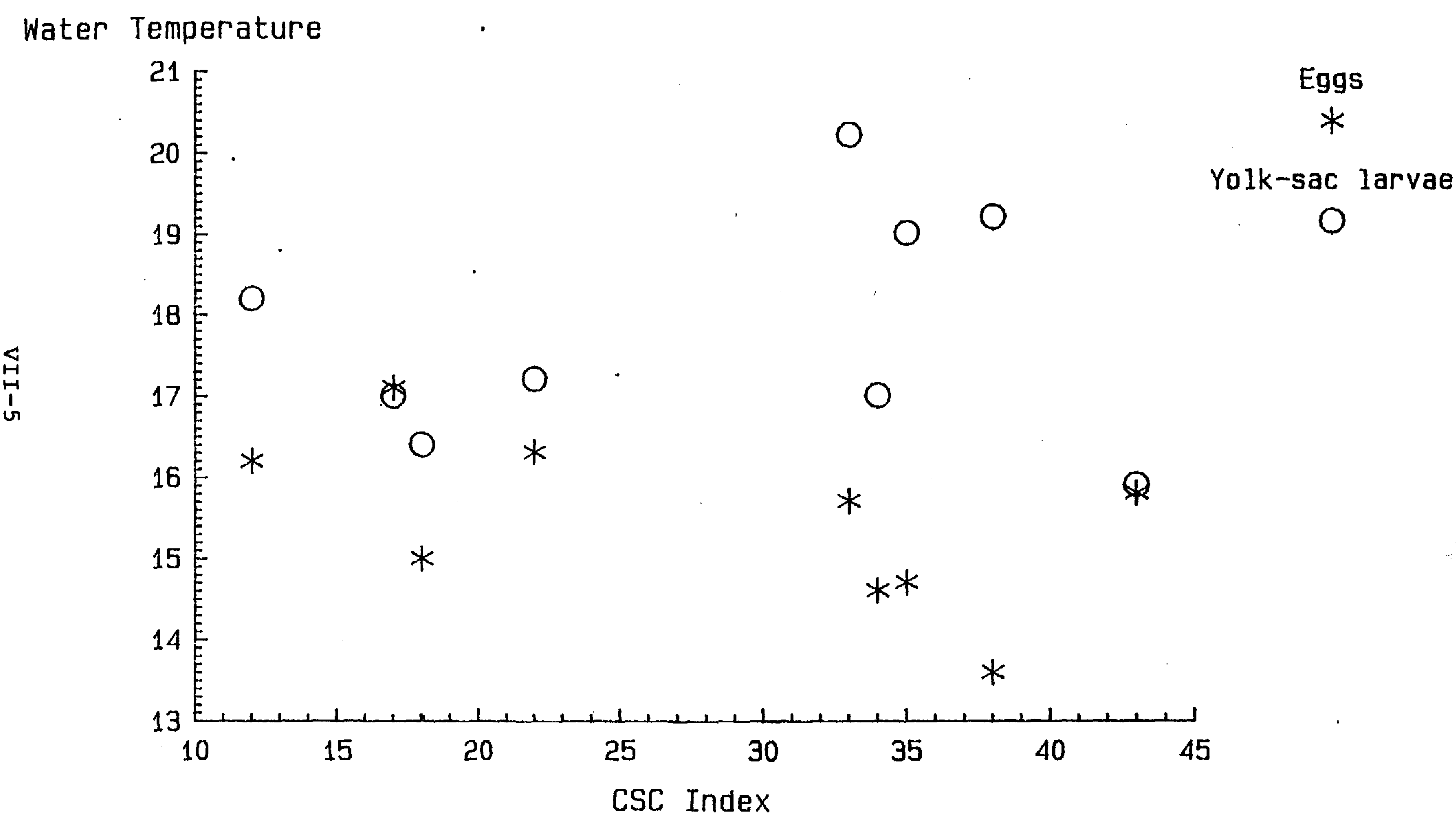


Figure VII-3. Relationship between water temperature during periods of maximum egg and larval abundance and the combined standing crop index for striped bass since 1976

Summer Regression Index

When methods developed by NAI (1985a) for calculating the summer index were applied to 1984 data, the regression was not found to be significant. When a geometric mean of the 1984 data was calculated, the index was 14.4 million (95% confidence limits: 10.8 - 19.3 million), exceeding only the value recorded for 1979.

Figure VII-4 shows the historical relationship between the CSC and summer regression indices. Although these indices disagree considerably on strength of the striped bass year class in 1984, historically they appear to track each other reasonably well. In 1984, the difference between the peak weekly CSC and the other weekly CSCs was greater than that difference in previous years. The influence of the peak weeks on the index of yearclass strength is great for the CSC method and is much less for the regression method.

Fall Regression Index

The regression of weekly combined standing crop values for calculation of the fall index was also not significant. When calculated by geometric mean this index was 15.1 million (95% confidence limits: 6.6 - 34.5 million). Similar to the CSC index, comparison of the fall index with that from previous years would suggest that 1984 was an above-average year for abundance of striped bass young-of-year (Fig. VII-5).

Beach Seine Index

The striped bass beach seine index for 1984 was 22.9 per 929 m^2, which is an intermediate value in comparison to previous years (Fig. VII-6). An additional index of striped bass year class strength in the Hudson River is calculated annually by the New York State Department of Environmental Conservation (NYSDEC) and is based on their own beach seine survey data. This survey is conducted between river miles 22 and 37 during late August through early November (Young 1984). Comparison of the 1984 NYSDEC index with that from previous years suggests that 1984 was an intermediate to above-average year for juvenile striped bass abundance in the Hudson River (Fig. VII-6).

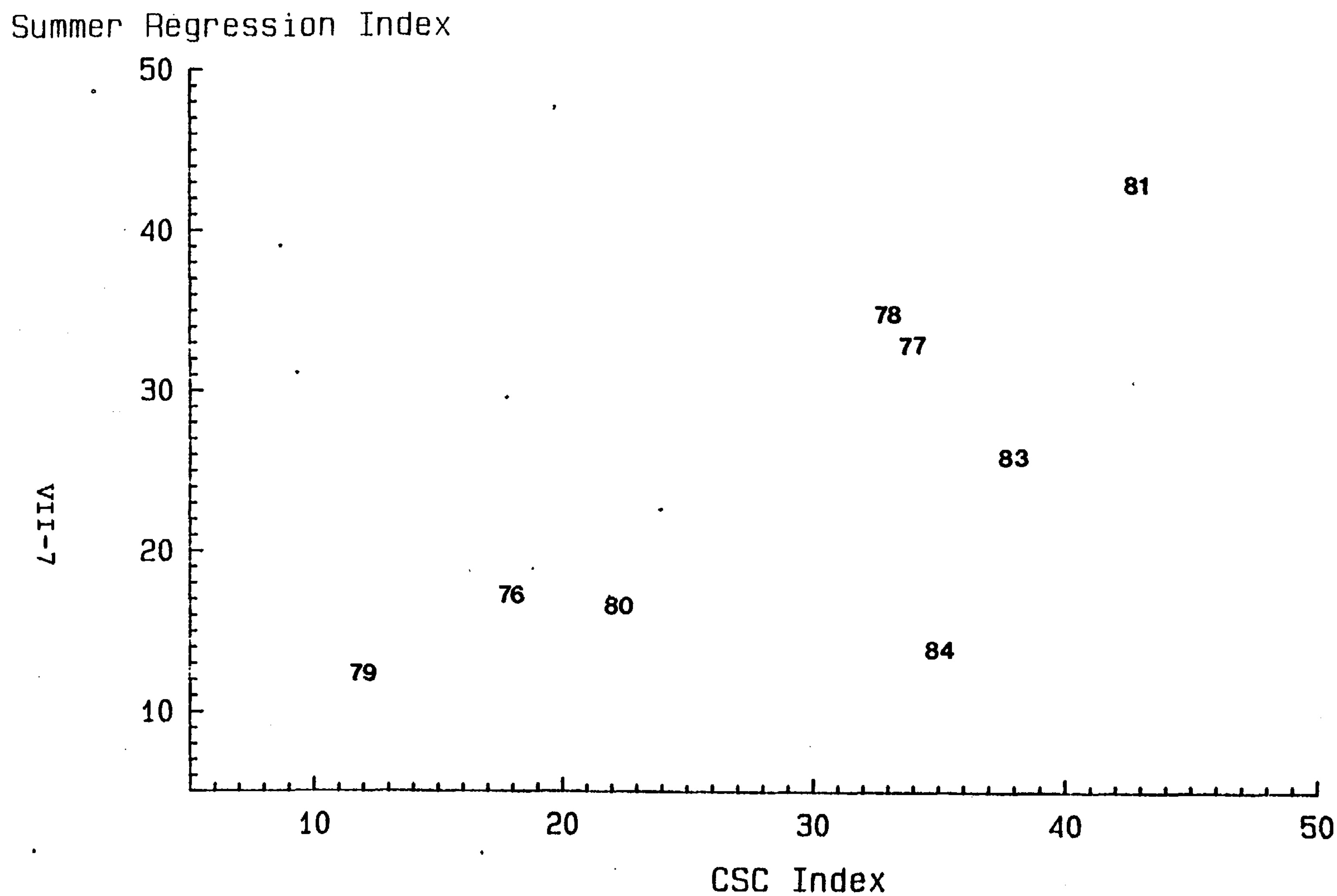


Figure VII-4. Comparison of peak CSC index and summer index for striped bass since 1976. Numbers indicate the year which each point represents. No data are available for 1982.

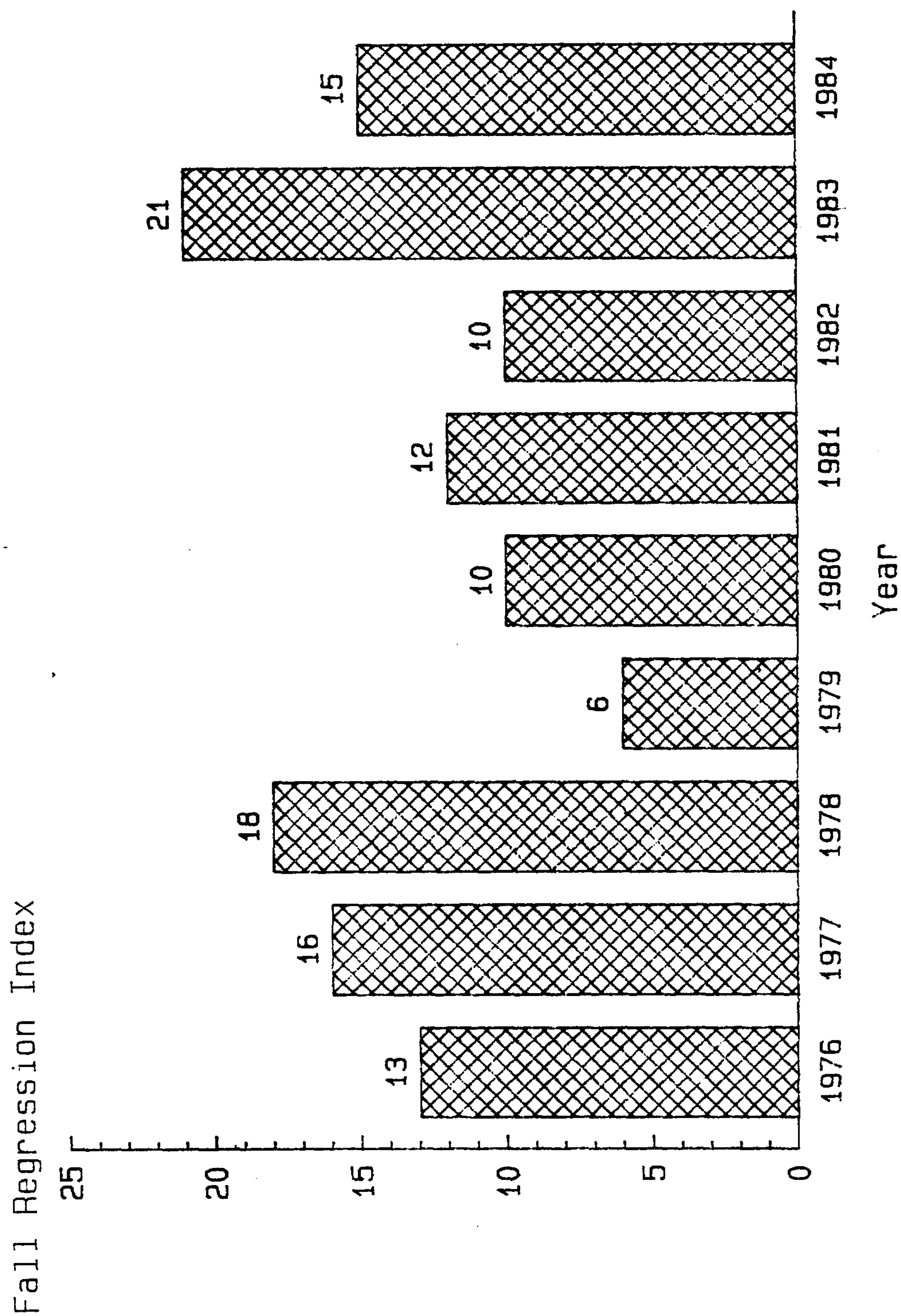


Figure VII-5. Fall index for young-of-year striped bass abundance in the Hudson River since 1976

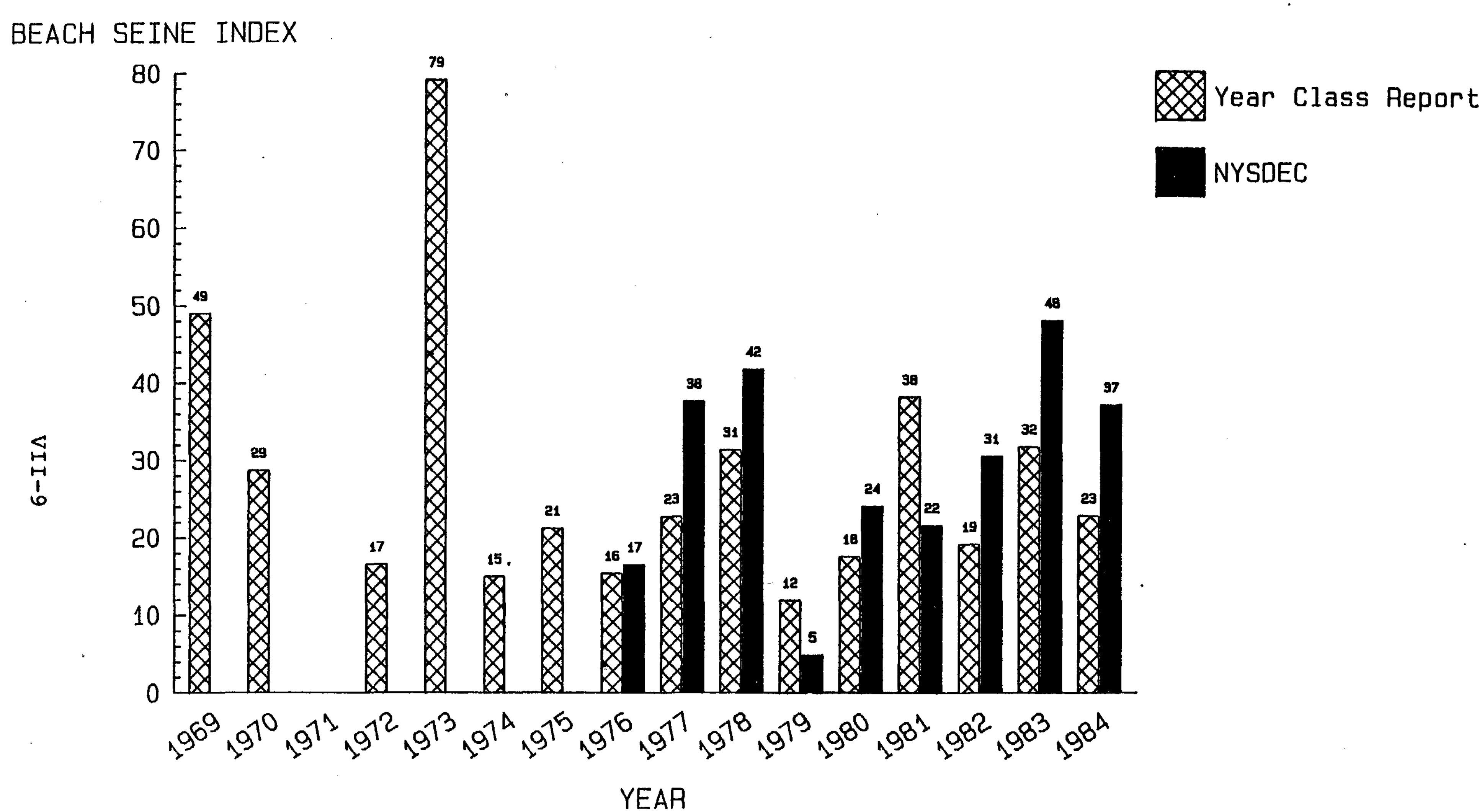


Figure VII-6. Beach seine index for young-of-year striped bass collected in the Hudson River since 1969. Insufficient data were available for 1971.

B. WHITE PERCH

CSC Index

The 1984 CSC index for young-of-year white perch was 10.9 million. This is the lowest value yet reported for white perch and is consistent with a downward trend in the CSC index which began in 1982 (Fig. VII-7). This decline is also consistent with reductions in white perch impingement rates observed during the same period at some Hudson River power plants (Martin Marietta Environmental Systems 1985; Lawler, Matusky and Skelly Engineers 1985).

The reasons for this downward trend and the low 1984 CSC index for white perch are not apparent from the water quality data collected as part of the year class studies. Water temperature, dissolved oxygen, and salinity during the period when early life stages were abundant in 1984 were similar to values observed during early life stages in previous years. Moreover, NAI (1985c) found that there was little relationship between these water quality variables and white perch abundance. Further, the estimates of growth rate for larval and early juvenile white perch were higher in 1984 than in previous years (Table V-3), further suggesting that water quality was adequate and not responsible for the low abundance estimate.

Mortality estimates for larval (Table VI-2) and juvenile (Table VI-3) white perch in 1984 were close to the median for all years for which it has been calculated, suggesting that mortality of early life stages was not responsible for the low abundance estimate for young-of-year white perch in 1984. Mortality estimates developed in the Year Class Reports are sensitive to a number of assumptions (see Section II.G) that might confound year-to-year comparisons. Still, NAI's (1985c) mortality estimates for Hudson River white perch also indicate that 1984 was an average year, suggesting that increased mortality in early life stages is not a good explanation for the low CSC index in 1984.

If mortality in early life stages has not increased over the last several years, a decline in abundance would most likely be due to a reduction in number of eggs spawned. In 1984, the period of peak white perch egg collections occurred late and lasted only two weeks. Cold water temperatures that persisted until June may have reduced the length of the spawning period and the total number of eggs released. However, this would not account for the gradual decline in abundance observed since 1981. An alternative explanation for a gradual decline in egg abundance is that failure of juveniles to reach spawning age, or an increase in mortality of older individuals, has led

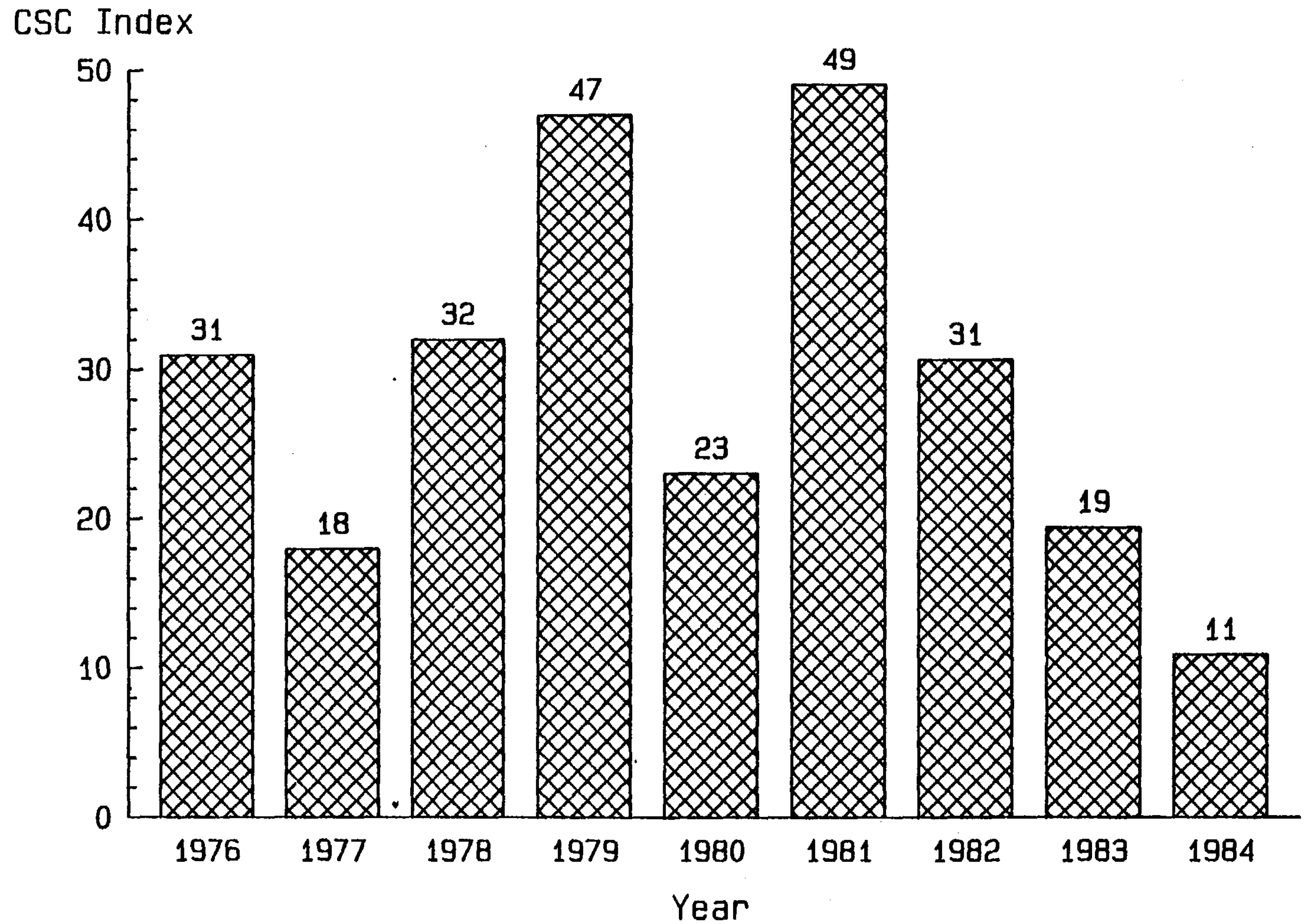


Figure VII-7. Combined standing crop index for white perch collected during Hudson River year class studies from 1976 to 1984 to a gradual decline in population size of sexually mature white perch. Unfortunately, gear efficiency for collection of yearling and older white perch is too low to address this possibility with available year class data.

Finally, it is possible that the decline in the index of white perch abundance may not represent an actual decline in the abundance of white perch in the Hudson River. There are many assumptions associated with calculation of the CSC index (see Section II.G) that may have been met to varying degrees in different years, thus leading to inconsistent biases in the index. Further, there are no error estimates associated with the CSC index and the apparent year-to-year differences in the index may not be statistically valid. Potential biases associated with calculation of the CSC index need to be addressed, and error estimates associated with the index need to be derived, before year-to-year patterns in year class strength can be inferred with reasonable certainty from the CSC index.

Summer and Fall Regression Indices

When the seasonal regression methods developed by NAI (1985a) were applied to the 1984 white perch data, neither regression was found to be significant. When calculated as geometric means, the summer index was 9.0 million (95% confidence limit: 7.8 - 10.4 million) and the fall index was 9.8 million (95% confidence limit: 7.1 - 13.7 million). When compared to the respective indices in previous years, both of these values suggest that year class strength for white perch in the Hudson River in 1984 was among the lowest recorded since initiation of year class studies (Fig. VII-8).

The summer and fall regression indices appear to corroborate the finding of the CSC index that white perch abundance was low in 1984. However, the similarity among these indices should not be overstated because they may result from use of the same data set to calculate all three indices. The CSC index for white perch is calculated as the average weekly combined standing crop from July to September. When the regressions for the summer and fall indices are not significant, these indices are also calculated from an average of weekly combined standing crop data. There is considerable overlap in the weeks that are used in calculation of the CSC and the summer and fall regression indices of white perch year class strength, which could lead to similarities in patterns of the indices.

The summer and fall regression indices have 95% confidence limits that suggest the reductions in white perch year class strength were statistically valid. However, these variance formulations were derived in previous Year Class Reports and

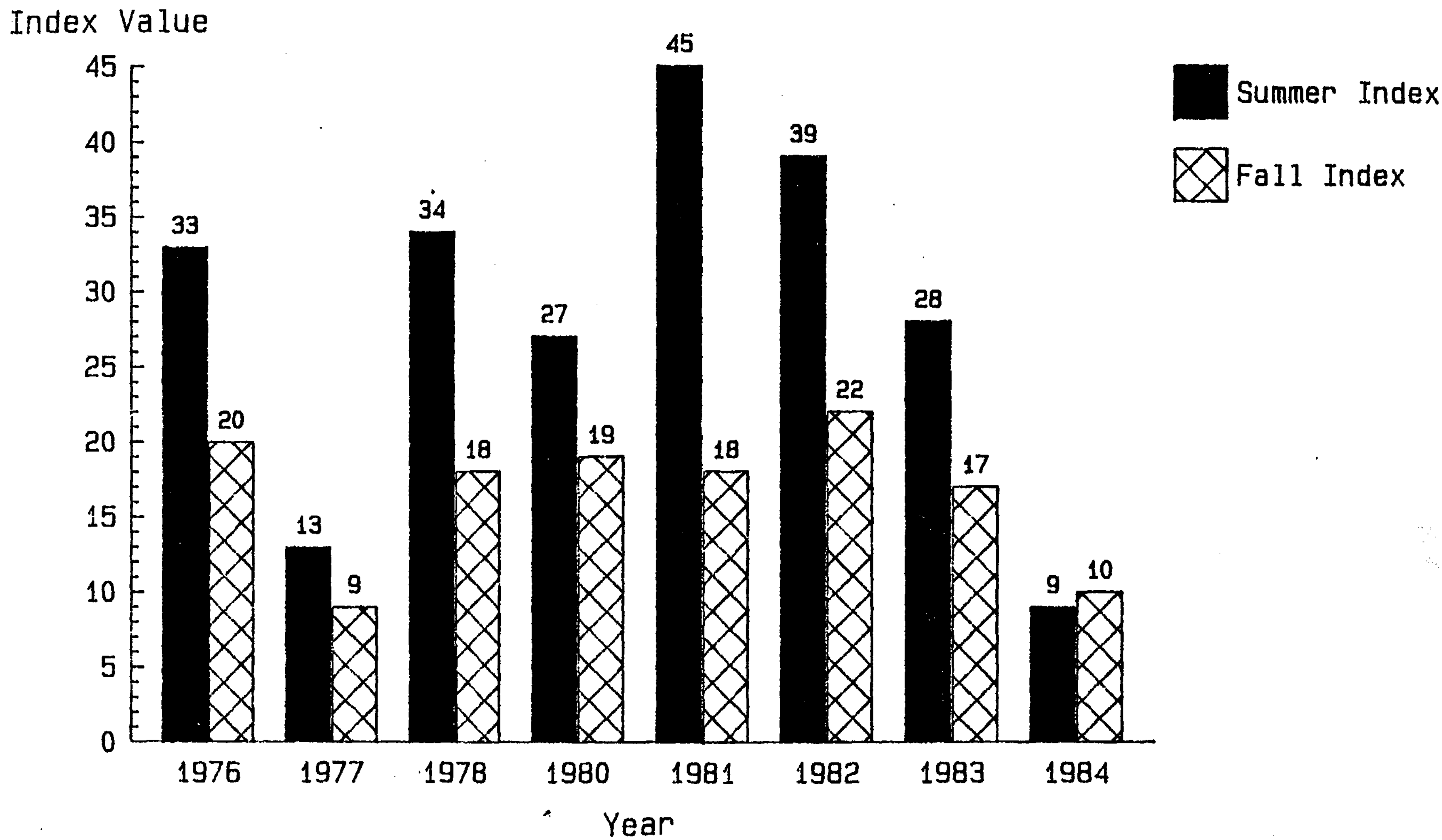


Figure VII-8. Summer and fall regression indices of juvenile white perch abundance in the Hudson River since 1976. No data were available for 1979.

may be inappropriate because they represent only the variability in density estimates among weeks, and do not represent sampling error among replicate samples within a week. Reformulation of their calculation to include this additional source of variability will be necessary before they can be used to assess statistical validity of the white perch declines.

Beach Seine Index

The 1984 beach seine index for white perch was 10.4 fish per 929 m^2, which is the lowest value for this index since 1974 (Fig. VII-9). Unlike the CSC index, the beach seine index suggests a sudden decline of white perch abundance in 1984, rather than a gradual decline since 1981.

The different rates of decline in the beach seine and CSC indices may be an artifact of variance; neither index has an associated estimate of error with which to address this possibility. However, it is also possible that the less gradual decline in the beach seine index may result from differences in the sampling dates among years. Beach seine sampling began in early August in 1981 and 1983, mid-August in 1982, but started in July in 1984 (Fig. VII-10). The white perch beach seine index is calculated as an unweighted average of all beach seine hauls throughout the river from July to mid-October. Data from previous Year Class Reports suggest that most juvenile white perch move from the channel and bottom to the shore zone of the Hudson River in August, which results in much lower catch per effort for hauls taken in July compared to those taken in August and September. By not sampling in July of 1981-1983 when one would expect catch to be low, the indices for these years may have been artifically inflated.

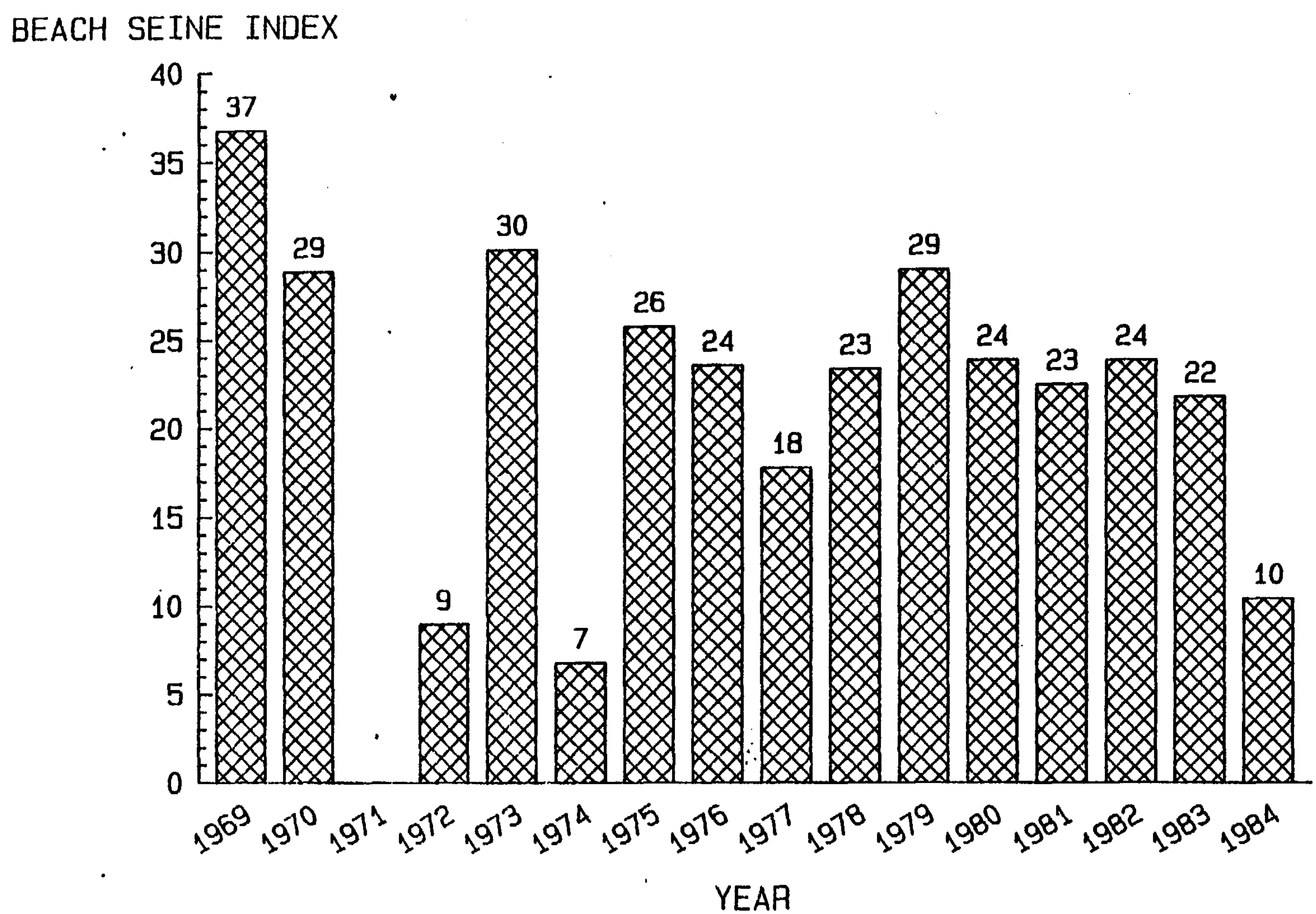


Figure VII-9. Beach seine index for white perch collected in the Hudson River since 1969. No data were available for 1971.

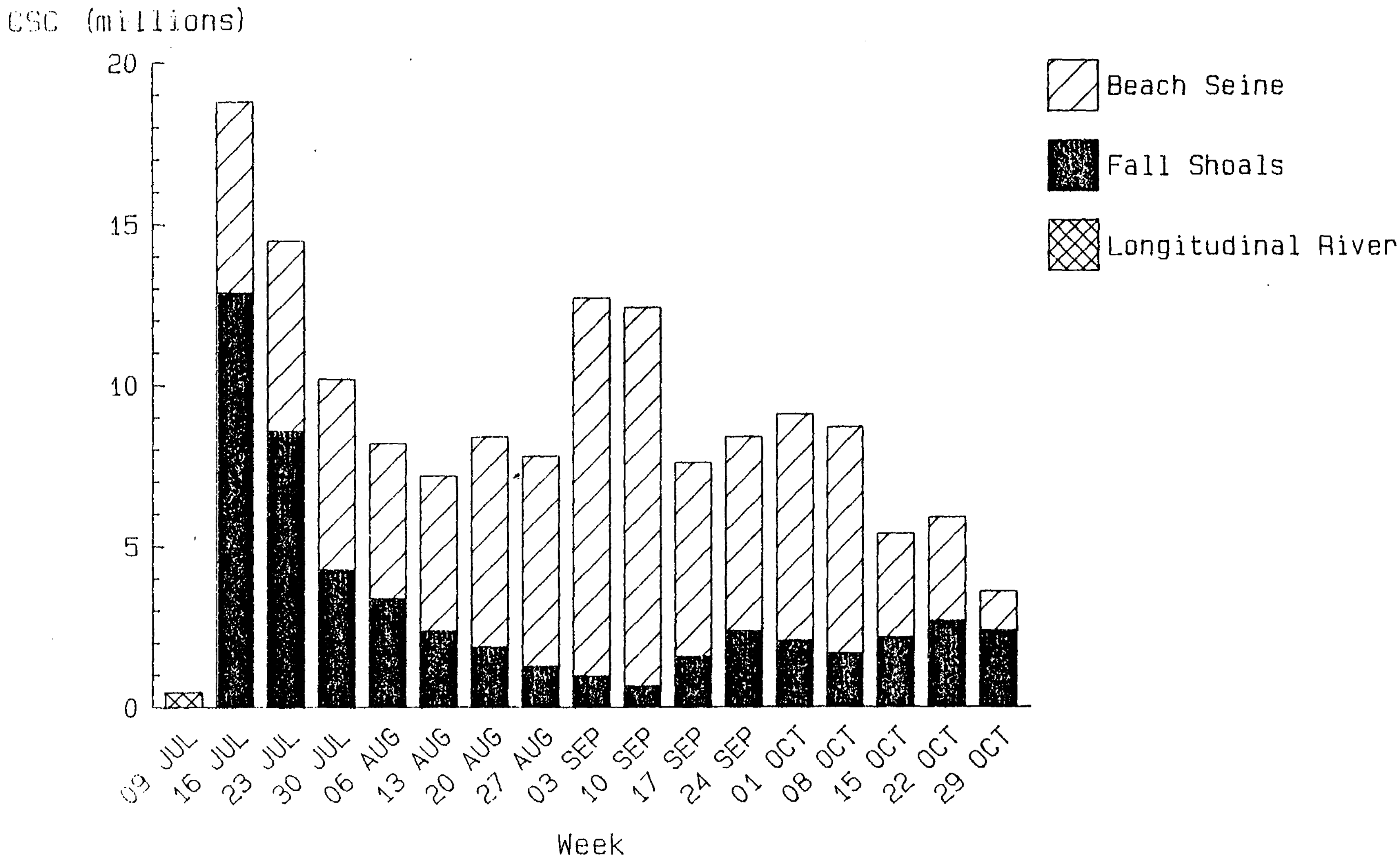


Figure VII-10. Combined standing crop of young-of-year white perch collected in the Hudson River during 1984

VIII. STRIPED BASS HATCHERY RECAPTURE PROGRAM

Hatchery reared striped bass were recaptured during the regular 1984 samplings of the Hudson River Impingement Programs, the Long River Ichthyoplankton and Fall Juvenile Surveys, and the New York State Department of Environmental Conservation (NYSDEC) Juvenile Seining Program. During these programs, 186 of the 147,153 striped bass released as part of the 1984 hatchery program were recaptured (Table D-2).

Stocking distribution of hatchery fish was intended to approximate the expected distribution of wild striped bass in the Hudson River. Figure VIII-1 shows the planned stocking proportions by region, the actual stocking distribution (which differed slightly from planned because of boat malfunction), and the distribution of wild striped bass (based on FSS standing crop data for the period of hatchery releases). The percentage of fish stocks in the Yonkers and Tappan Zee regions mimics closely the percentage of fish naturally occuring there (44.4 vs 44.7). However, the number of fish released in the Croton-Haverstraw and Indian Point regions was disproportionately high compared to the percentage of the natural population occurring in these regions. Further, no fish were stocked north of Indian Point despite the fact that one-third of the natural population standing crop was estimated to inhabit those areas at the time of stocking.

Recapture locations ranged from river mile (RM) 23 to RM 95 (Fig. VIII-2). The majority of fish were recaptured at RM 42 (51%) and RM 66 (16%) which are the locations of the Indian Point and Roseton power plants, respectively. All marked striped bass from RM 42 and 66 were collected during impingement sampling. Nine percent of the total recaptures were taken at RM 35, and 5% were taken at RM 27. No other location accounted for more than 2% of the total recaptures.

The tags used in the recapture program did not correspond to a unique date and location of release. To estimate the amount of time that each fish was at large, the assumption was made that release occurred on the latest date that fish with that tag code were released. To estimate distance traveled, the river mile of release was assumed to be the river mile closest to the recapture location from which fish with that tag code were released. While these assumptions should result in an underestimation of number of days at large and of river miles traveled, they should not lead to excessive bias since unique tag types were usually released over a period of 3 days or less, and release locations were usually confined to within 3 miles.

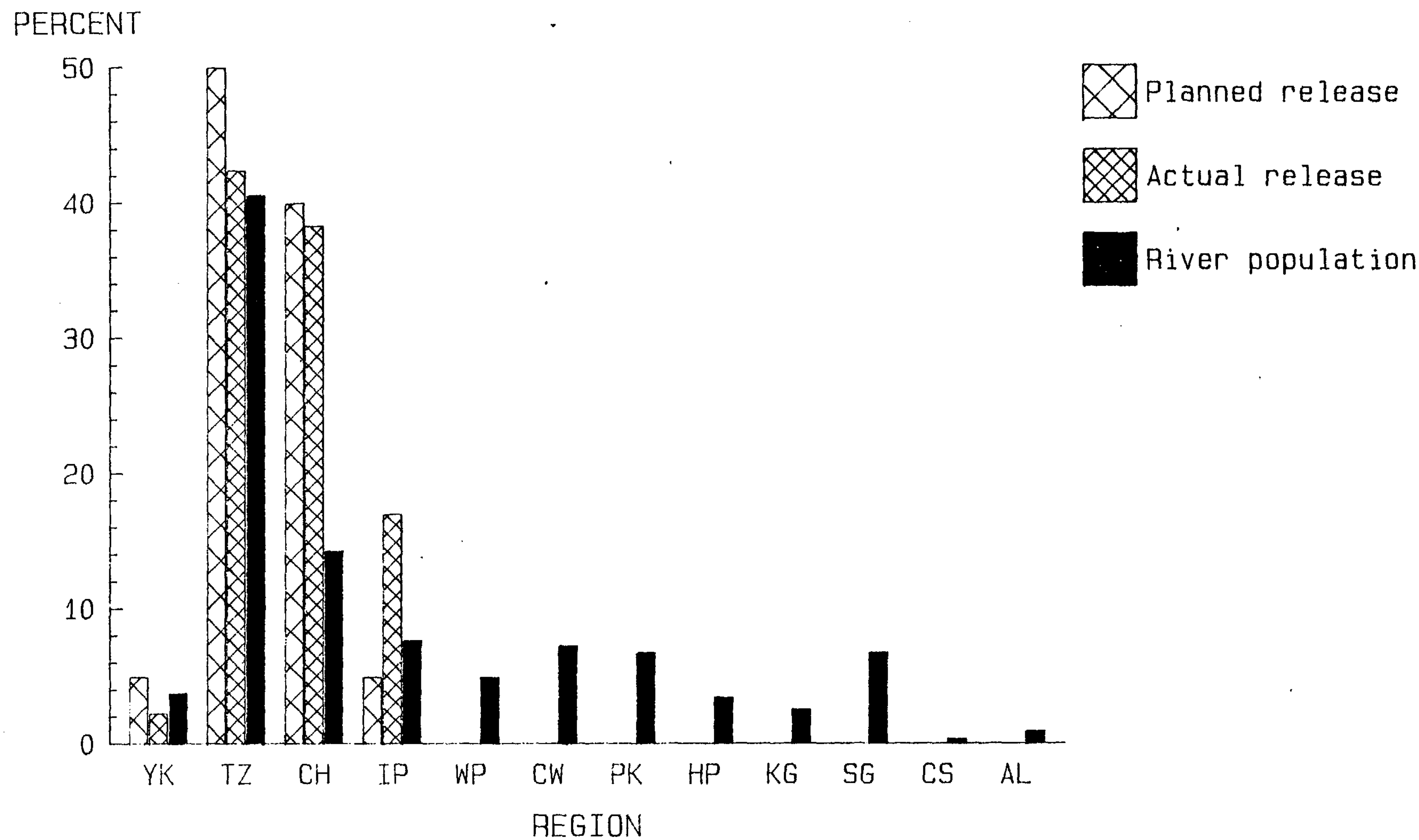


Figure VIII-1. Planned and actual stocking distribution of marked striped bass released in 1984 and the 1984 distribution of wild striped bass during the period of hatchery releases

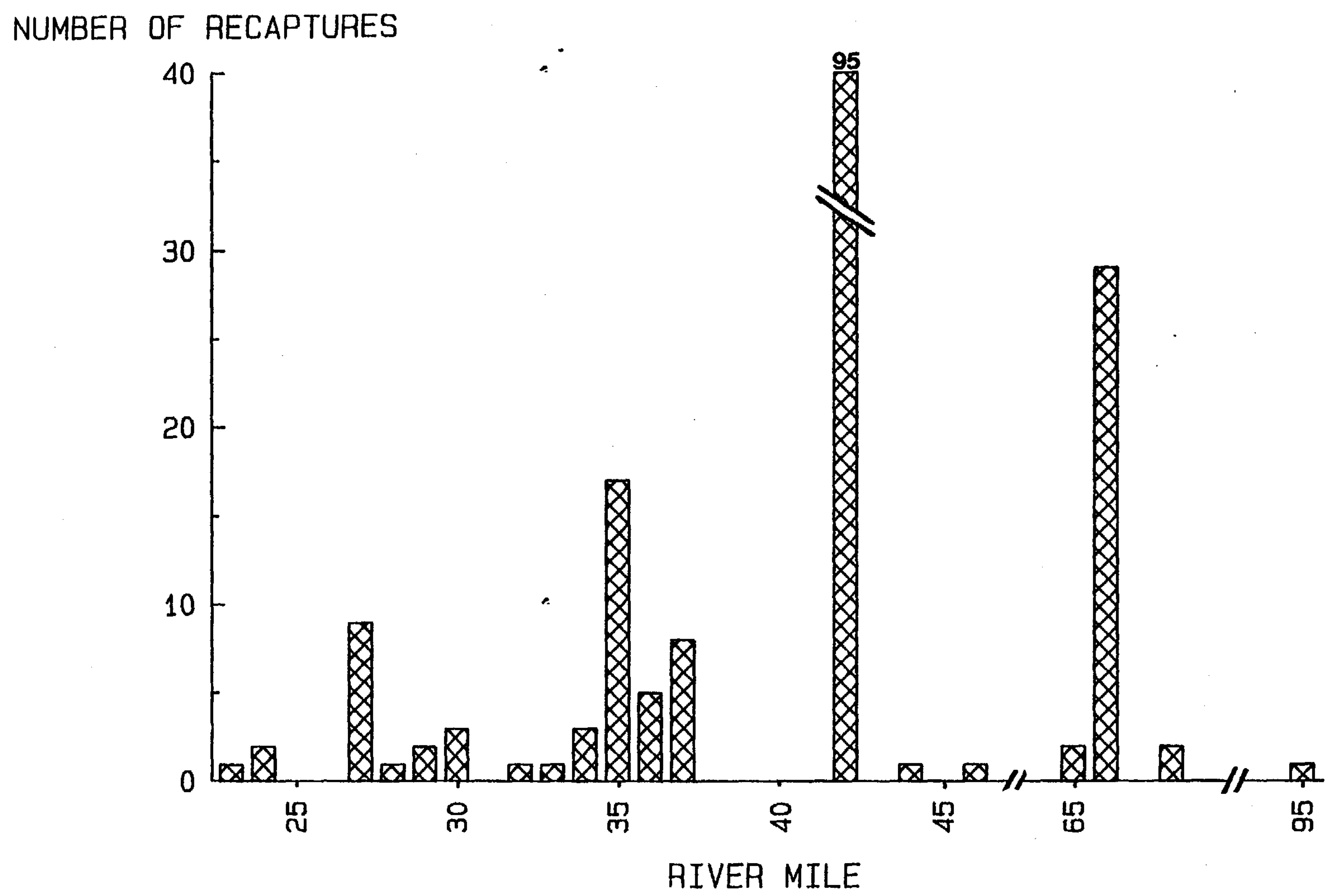


Figure VIII-2. Recapture frequency of hatchery fish as a function of river mile

The number of days between release and recapture ranged from 0 to 57, but most fish were recaptured within 2 days of release (Fig. VIII-3). The majority of fish recaptured after the first few days at large were impinged at Indian Point on 10-13 September. These recaptures corresponded to large releases of hatchery fish one mile downstream (during a flood tide) from the plant between 9 and 11 September. When Indian Point data were excluded, the rate of recapture of hatchery fish was fairly constant for the first 30 days following release.

It is difficult to tell whether there was any net population movement by the hatchery fish following their release because recapture effort was not spread evenly up- and downstream along the river. Many fish were recaptured within 1 mile of where they were released even though they had been at large for more than 2 weeks; one fish was recaptured within 1 mile of its release location 6 weeks after being released. On the other hand, another fish was recaptured 57 miles upriver only 9 days after its release; this corresponds to a net movement rate of 1.2 body lengths per second, or close to the maximum sustainable speed for striped bass (Freadman 1979). In general, when fish were recaptured more than 2 miles from their release point, they were recaptured upstream. This may have occurred because recapture effort was greater upstream. However, only one fish was collected in the downstream Yonkers region despite the regular sampling that was done there as part of the year class study.

Some of the data suggest that the stocked fish constituted a very large part of the local striped bass population near their release point. During the 3 days in September when marked fish were recaptured at Indian Point, 70 of the 83 fish captured in scheduled Indian Point impingement samples were found to be marked (Table VIII-1). However, fifty-five of the marked fish were part of a group of 23,000 fish that had been stocked 1 mile downstream during that week. Therefore, it is not possible with available data to differentiate whether the high ratio of marked recaptures at that time is indicative of low ambient population in the local area or if hatchery reared fish soon after their release are more susceptible to impingement than are fish from the natural population.

When considered on a riverwide basis, the hatchery fish seem to have constituted only a very small fraction of the natural population of striped bass. From the time that stocking began, 4089 young-of-year striped bass were collected as part of the Fall Shoals and Beach Seine surveys and only 21 were identified as hatchery fish.

Table VIII-1. Dates and total number of marked and unmarked striped bass collected in impingement samples at Indian Point, 10-13 September 1984

Date	Marked	Unmarked
10 September	49	3
11 September	2	6
13 September	19	4
TOTAL	70	13

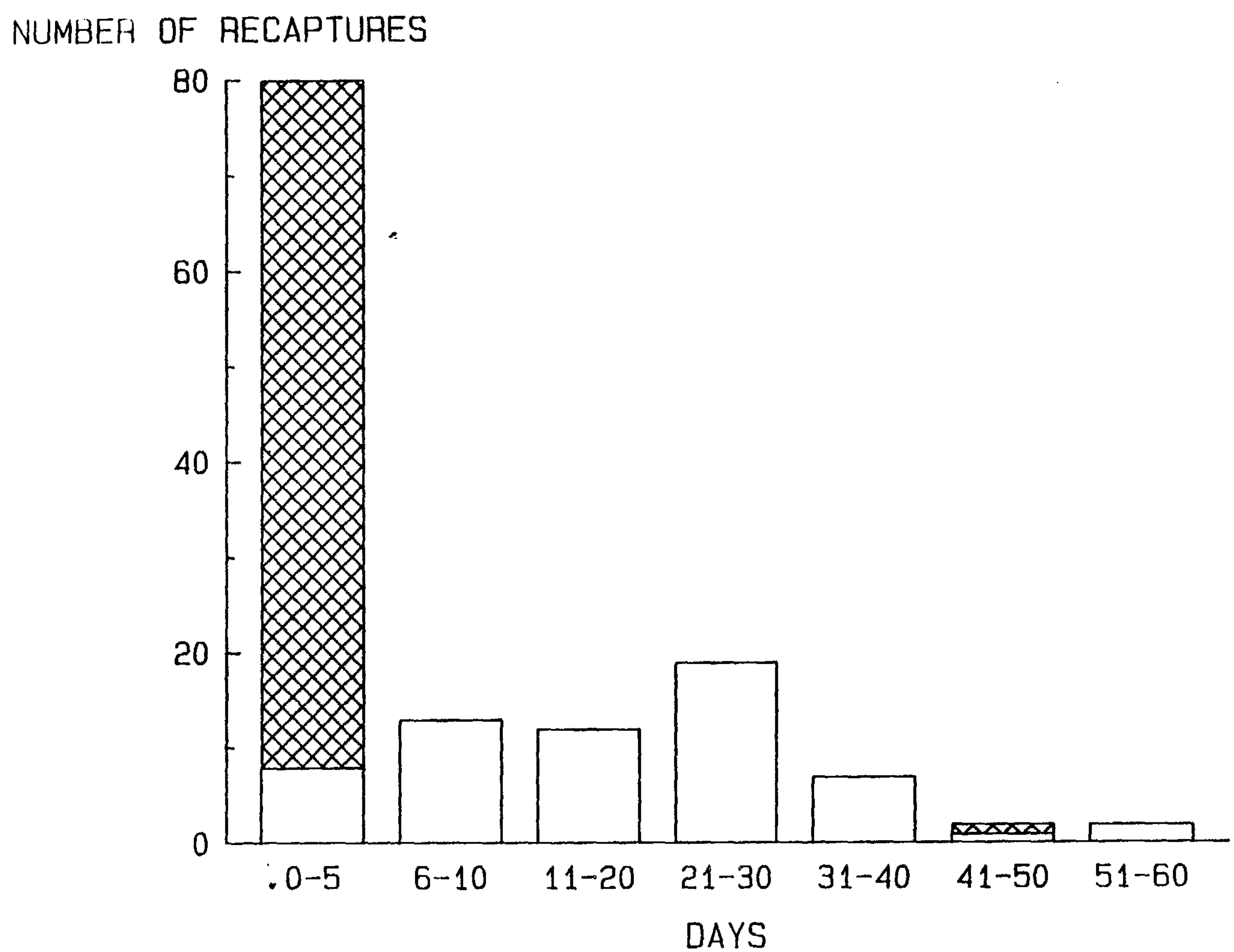


Figure VIII-3. Recapture frequency as a function of number of days following release

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