1986 AND 1987 YEAR CLASS REPORT

FOR THE HUDSON RIVER ESTUARY

MONITORING PROGRAM

VOLUME I

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CHAPTER 1

INTRODUCTION

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

The first report, First Annual Multiplant Report (Texas Instruments Inc. [TI] 1975), summarized riverwide data collected to estimate the impact of five electric generating stations on striped bass, white perch, and Atlantic tomcod. The multiplant effort was refined and renamed the Year Class Report in 1974 (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 1978). The 1976 report (TI 1979) expanded the focus to include ecological relationships of selected fish populations. In the 1977 and 1978 reports (TI 1980a,b) the life histories of selected species were examined in the context of power plant effects. The 1978 report (TI 1980b) was expanded to include the life history and distributional information on nine additional fish species. Data analysis for the 1979 report (TI 1981) was also extended to include predictions of environmental impact based on fish population age structure and age-specific survival. Further statistical analysis of biocharacteristics data available from 1973 to 1979 was included for the three initial key species.

The Hudson River Settlement Agreement among the utilities, the U.S. Environmental Protection Agency, and other interested parties was announced in 1980 and became effective in May 1981 (Sandler and Schoenhard 1981). The 1980-1981 Year Class Report (Battelle New England Marine Research Laboratory [Battelle]

1983), the first one prepared after execution of the Settlement Agreement, continued the presentation of life history and population dynamics studies of selected Hudson River fish species. The 1981 study program was also the first in which the length of the sampling season was reduced to focus on the period when most Hudson River fish are maturing from the larval to juvenile stage. The 1982 Year Class Report (Normandeau Associates, Inc. [NAI] 1985a) was similar in content to the 1980-1981 report, but the estimation of year class strength was extended to include a fall index. In addition to the basic survey results, the 1983 report (NAI 1985b) included data on the first recaptures of fish released from a striped bass hatchery that began operation in 1983. This report also examined the relationship between environmental variables and the early life histories of striped bass, white perch, and American shad. The 1984 Year Class Report (Martin Marrietta 1986) contained the types of information presented in the 1982 and 1983 reports, but placed additional emphasis on the indices of year class strength and their interpretation.

The 1985 Year Class Report (Versar 1987) described the results from the 1985 Longitudinal River Ichthyoplankton Survey and the 1985 Fall Shoals and Beach Seine Juvenile Surveys. This report focused on (1) the spatiotemporal distributions for 12 fish species with respect to life history and prevailing environmental factors; (2) year class strength indices, including the development of a new index of year class strength for white perch, striped bass, American shad, and bay anchovy; and (3) factors that may influence year class strength for these four species.

The present report adds to the historical data base by describing the results of the Longitudinal River Ichthyoplankton Survey and the Fall Shoals and Beach Seine Juvenile Surveys for 1986 and 1987. The primary objectives of this Year Class Report are to:

- Present estimates of the spatiotemporal distribution and abundance for 12 selected fish species (Table 1-1); interpret these findings with respect to life history and environmental factos.

TABLE 1-1

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, PYSL, YOY, YRL
White perch	Morone americana	Egg, YSL, PYSL, YOY, YRL
Atlantic tomcod	Microgadus tomcod	PYSL, YOY, YRL
Alewife	Alosa pseudoharengus	YOY, YRL[c]
Bay anchovy	Anchoa mitchilli	Egg, YSL, PYSL, YOY, YRL
Weakfish	Cynoscion regalis	PYSL, YOY, YRL
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, PYSL, YOY[c], YRL
Blueback herring	Alosa aestivalis	YOY, YRL[c]

[a]Names recognized by American Fisheries Society (Robins et al. 1980).
[b]YSL - yolk-sac larvae
PYSL - 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.

- Estimate the relative year class strength developed in previous Year Class Reports, including the bivariate index developed in the 1985 Year Class Report.

- Describe the historical patterns of variability in environmental parameters within the Hudson River that may affect fish distribution and abundance, including freshwater flow, temperature, salinity, dissolved oxygen, pH, turbidity, and allochthonous detritus.

- Estimate the influence of the inclusion of previously unsampled regions on abundance and standing crop estimates.

- Describe changes in the fish community of the Hudson River estuary over time and with respect to the influence of environmental factors.

- Describe the growth patterns of larval and juvenile striped bass, white perch, American shad, blueback herring, and alewife during the period 1984-1987. Emphasize the influence of size on the timing of the fall downriver migration of these species.

This report is organized into nine chapters and two volumes: Volume I - Chapters 1 through 9 and References Cited; Volume II - Appendices. Data collection and data analysis methods are described in Chapter 2. Water quality measurements for 1986 and 1987, an analysis of historical patterns of water quality variability and predictability, and a discussion of allochthonous detrital inputs are presented in Chapter 3. Chapter 4 describes the spatiotemporal distribution of the 12 species with reference to environmental factors, sampling methodology, and microhabitat distributions. Chapter 5 describes the unsampled regions' program and results. Chapter 6 describes recruitment trends based on year class strength indices. Community analysis techniques are utilized in Chapter 7 to evaluate the Hudson River estuary fish community. Growth patterns for the major fish taxa are discussed in Chapter 8. Chapter 9 contains an analysis and discussion of size-related distribution and emigration of juvenile striped bass and clupeids. The appendices contain supporting information for the various chapters.

CHAPTER 2

MATERIALS AND METHODS

2.1 SAMPLING DESIGN

Several fishery techniques were employed in three separate sampling programs to obtain comprehensive information on the abundance and distribution of selected larval, juvenile, and adult fish species in the Hudson River estuary. Temporally, the programs covered spring through fall, the period of greatest biological activity in north temperate waters. Program-specific techniques were employed to adequately sample all habitats and permit the determination of spatial distribution patterns. The three programs followed the same general design and employed gear similar to that of previous Hudson River sampling programs.

The three sampling programs that made up the overall program and their objectives were:

- Longitudinal River Survey (LRS). The entire length of the Hudson River estuary was sampled to provide ichthyoplankton data that would allow calculations of standing crop, mortality, and growth rates for selected Hudson River fish species. The primary species were Atlantic tomcod (*Microgadus tomcod*), American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), and white perch (*M. americana*). LRS sampling was concentrated during the spring and midsummer when eggs and larvae of the primary species were usually abundant.

- Fall Shoals Survey (FSS). Samples were collected every other week over the length of the estuary in midsummer and fall. The objective was to provide data on juvenile fish that would allow calculation of standing crop estimates and conditional mortality rates for selected Hudson River fish species. The target species were Atlantic tomcod, American shad, striped bass, and white perch.

- Beach Seine Survey (BSS). Beach seine samples were collected in alternate weeks with the FSS at stations from the George Washington Bridge to the Troy Dam. The objective was to obtain information on juvenile American shad, Atlantic tomcod, striped bass, and white perch while they were concentrated primarily in the shallow, nearshore region. The survey was conducted from mid-June through August, when juveniles of these species were utilizing the shore-zone nursery.

Sampling for all programs was conducted according to a stratified random design in which the river from the George Washington Bridge (RM 12) to the Federal Dam at Troy (RM 152) was divided into 12 regions (Figure 2-1). Each region was further divided into "strata" on the basis of river depth. The strata based on river depth are graphically presented in Figure 2-2 and defined below:

- Shore - that portion of the river extending fron the shore to a depth of 3 m (the stratum defined only for BSS)
- 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

A minimum of three samples were assigned to each stratum in each region for the LRS and FSS; a minimum of five samples were taken in each region for the BSS. The strata actually sampled in each region during the 1986 and 1987 survey periods are given in Table 2-1. Shoal strata samples were not assigned in upriver regions.

A general summary of the three sampling programs for each annual study phase is presented in Table 2-2. The field and laboratory methods used for each survey are described in detail in the following sections.

2.2 LONGITUDINAL RIVER SURVEY (LRS)

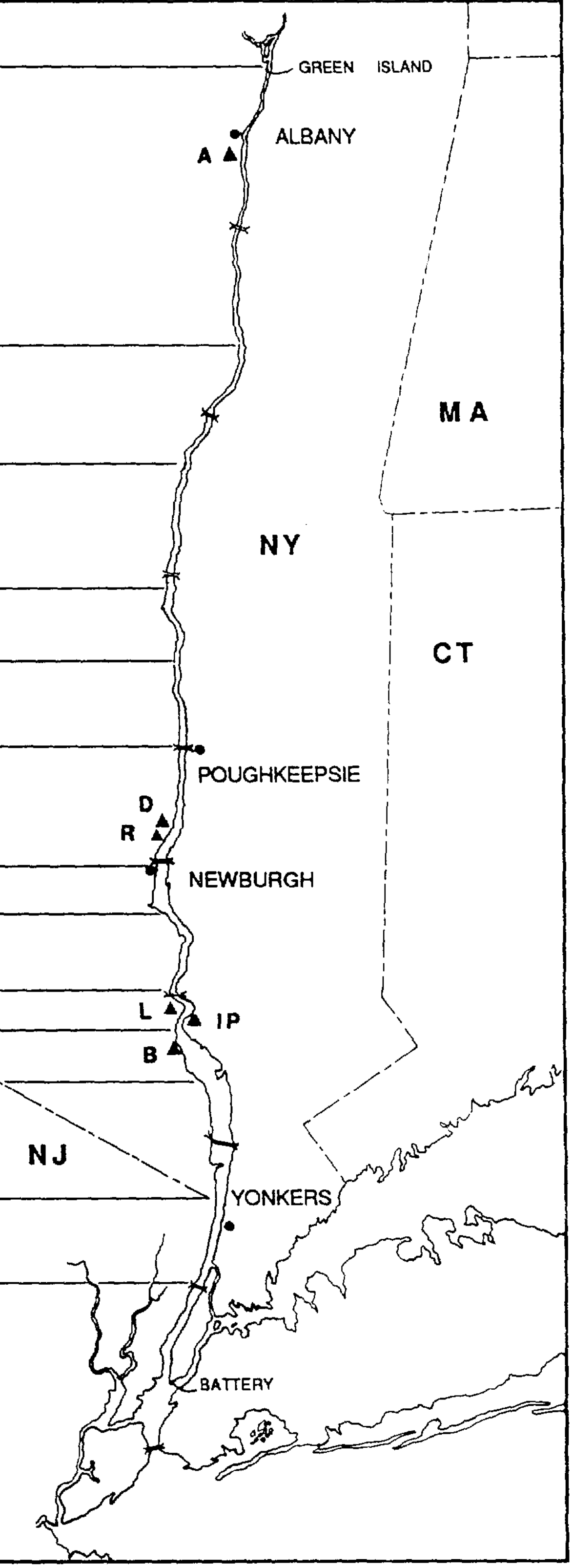
2.2.1 Field Methods

Two gear types were used to sample the shoal, channel, and bottom strata in the LRS: a 1.0-m^2 Tucker trawl (Figure 2-3) to sample the channel strata, an

FIGURE 2-1

GEOGRAPHICAL REGIONS USED DURING FIELD SAMPLING PROGRAMS IN HUDSON RIVER ESTUARY

REGION	RIVER MILES (Kilometers)
ALBANY - AL	125 - 152 (>201.2 - 246.2)
CATSKILL - CS	107 - 124 (>172.2 - 201.2)
SAUGERTIES - SG	94 - 106 (>151.3 - 172.2)
KINGSTON - KG	86 - 93 (>138.4 - 151.3)
HYDE PARK - HP	77 - 85 (>123.9 - 138.4)
POUGHKEEPSIE - PK	62 - 76 (>99.8 - 123.9)
CORNWALL - CW	56 - 61 (>90.1 - 99.8)
WEST POINT - WP	47 - 55 (>75.6 - 90.1)
INDIAN POINT - IP	39 - 46 (>62.8 - 75.6)
CROTON-HAVERSTRAW - CH	34 - 38 (>54.7 - 62.8)
TAPPAN ZEE - TZ	24 - 33 (>38.6 - 54.7)
YONKERS - YK	12 - 23 (>19.3 - 38.6)



LEGEND

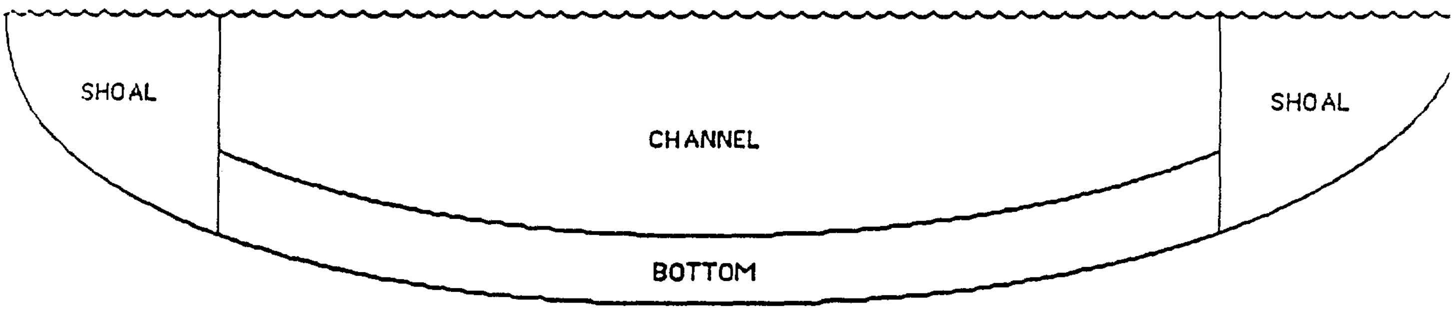
- ● CITY
- ⤫ BRIDGE
- ▲ POWER PLANT

POWER PLANTS

- A - ALBANY
- B - BOWLINE POINT
- D - DANSKAMMER POINT
- IP - INDIAN POINT
- L - LOVETT
- R - ROSETON

FIGURE 2-2

CROSS SECTION OF THE ESTUARY SHOWING LOCATIONS OF THE SHOAL, BOTTOM, AND CHANNEL STRATA



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

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

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

TABLE 2-1

STRATA SAMPLED WITHIN THE 12 GEOGRAPHIC REGIONS OF THE HUDSON RIVER ESTUARY DURING 1986 AND 1987

REGION	ABBREVIATION	RIVER KILOMETERS	1986 SURVEY				1987 SURVEY			
			SHORE	SHOAL	CHANNEL	BOTTOM	SHORE	SHOAL	CHANNEL	BOTTOM
Yonkers	YK	19-39	X	X	X	X	X	X	X	X
Tappan Zee	TZ	39-55	X	X	X	X	X	X	X	X
Croton-Haverstraw	CH	55-63	X	X	X	X	X	X	X	X
Indian Point	IP	63-76	X	X	X	X	X	X	X	X
West Point	WP	76-90	X	-	X	X	X	-	X	X
Cornwall	CW	90-100	X	X	X	X	X	X	X	X
Poughkeepsie	PK	100-124	X	-	X	X	X	-	X	X
Hyde Park	HP	124-138	X	-	X	X	X	-	X	X
Kingston	KG	138-151	X	-	X	X	X	-	X	X
Saugerties	SG	151-172	X	-	X	X	X	-	X	X
Catskill	CS	172-201	X	-	X	X	X	-	X	X
Albany	AL	201-246	X	-	X	X	X	-	X	X

- No samples scheduled.

TABLE 2-2

SUMMARY OF 1986 AND 1987 HUDSON RIVER SAMPLING SURVEY

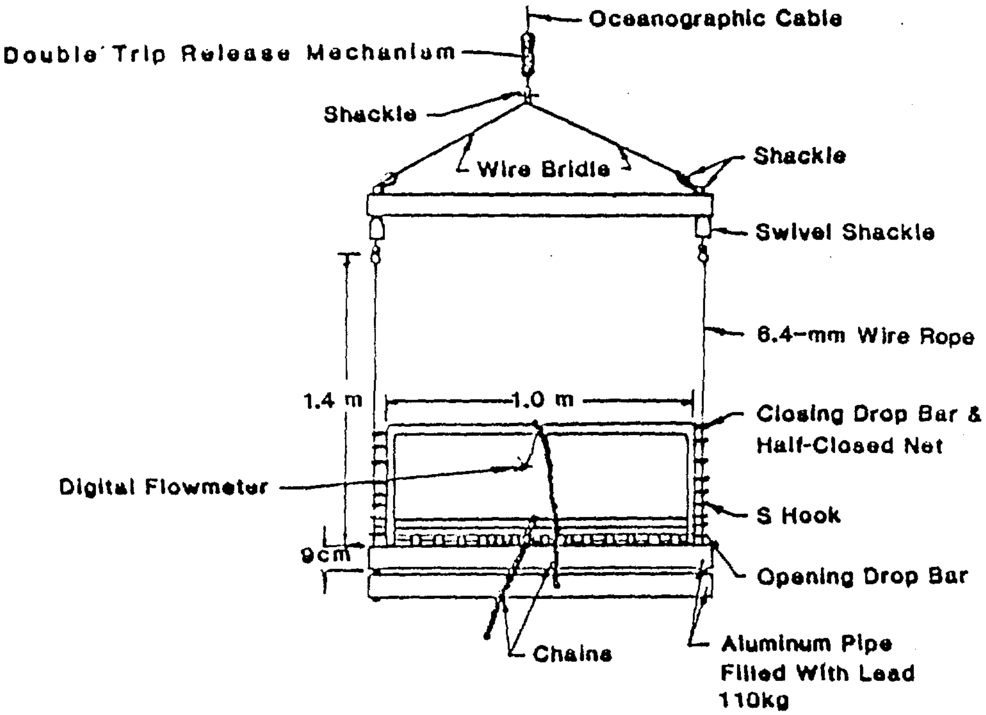
PROGRAM PHASE	SAMPLING SCHEDULE		NUMBER OF	SAMPLING	STRATA	SAMPLE NUMBER		SAMPLE GEAR
	START DATE	END DATE	RIVER RUNS	FREQUENCY	SAMPLED	PROJECTED	ACTUAL	
1986								
Longtitudinal River Ichthyoplankton Survey	29 April	10 July	11	Weekly	Shoal	200	202	1.0-m^2 net on epibenthic sled or 1.0-m^2 Tucker trawl
					Channel	1343[a]	1354	1.0-m^2 Tucker trawl
					Bottom	770	768	1.0-m^2 net on epibenthic sled
Fall Shoals Survey	21 July	2 December	10	Biweekly	Shoal	640	639	3.0-m beam trawl
					Channel	550	549	1.0-m^2 Tucker trawl
					Bottom	910	910	3.0-m beam trawl
Beach Seine Survey	14 July	17 November	10	Biweekly	Shore	1000	1000	30.5-m beach seine
1987								
Longitudinal River Ichthyoplankton Survey	14 April	9 July	13	Weekly	Shoal	260	230	1.0-m^2 net on epibenthic sled or 1.0-m^2 Tucker trawl
					Channel	1543[a]	1515	1.0-m^2 Tucker trawl
					Bottom	896	867	1.0-m^2 net on epibenthic sled
Fall Shoals Survey	13 July	5 November	9	Biweekly	Shoal	576	577	3.0-m beam trawl
					Channel	495	495	1.0-m^2 Tucker trawl
					Bottom	819	819	3.0-m beam trawl
Beach Seine Survey	24 June	13 November	11	Biweekly	Shore	1100	1101	30.5-m beach seine

[a]Includes 141 samples collected for striped bass otolith analysis.

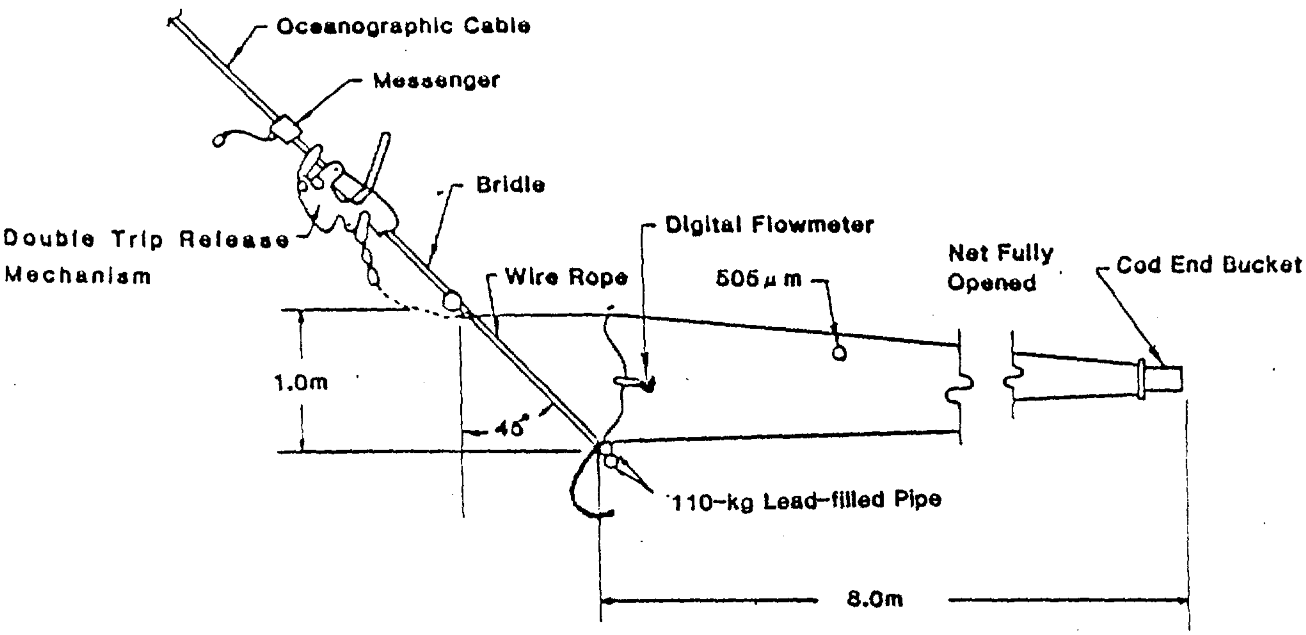
FIGURE 2-3

DESIGN AND DIMENSIONS OF 1.0-m^2 TUCKER TRAWL

FRONT VIEW



SIDE VIEW



epibenthic sled-mounted 1.0-m^2 net similar in design to the Tucker trawl (Figure 2-4) to sample the bottom strata, and both gear types to sample the shoal strata. Table 2-3 presents design specifications for the sampling gear.

Both gear types were towed against the prevailing current for 5 min. The tow started with the remote opening of the net and terminated with its remote closing. The tow speed for the trawl was approximately 90 cm/sec; for the epibenthic sled-mounted net, approximately 100 cm/sec. An electronic flowmeter mounted along the side of the research vessel and equipped with on-deck readout was used to establish and maintain tow speed. A calibrated digital flowmeter (General Oceanics Model 2030) mounted in the center of the net mouth was used to calculate the volume of water filtered for each sample.

The 1986 LRS covered 11 weeks from 29 April to 10 July (Figure 2-5). Sampling was conducted during daylight hours for the first four weeks and at night during the last seven weeks. The midprogram change from diurnal to nocturnal sampling was consistent with sampling protocol for the years 1975 through 1985. A special nocturnal six-week sampling program that incorporated an additional 20 trawl (channel strata) samples per week was conducted between 26 May and 7 July 1986. The samples collected during this survey were scheduled for a special aging study of striped bass larvae using daily otolith rings. The 1987 LRS covered a 13-week period from 14 April through 9 July 1987 (Figure 2-5), with all sampling conducted at night. As noted for the 1986 LRS, a six-week special sampling program to collect samples for striped bass otolith aging was conducted between 25 June and 6 July 1987.

The allocation of sampling effort among river regions and strata was temporally adjusted in response to the projected presence and distribution of target species and life stages. The 1986 and 1987 LRS sampling programs were scheduled as three separate multiweek efforts. The first, which covered the last week of April and the first two weeks of May, was directed toward the collection of eggs of Morone spp. and American shad. The second covered the next three-week period, from the middle of May through the first week of June;

FIGURE 2-4

DESIGN AND DIMENSIONS OF 1.0-m² TUCKER TRAWL MOUNTED ON AN EPIBENTHIC SLED

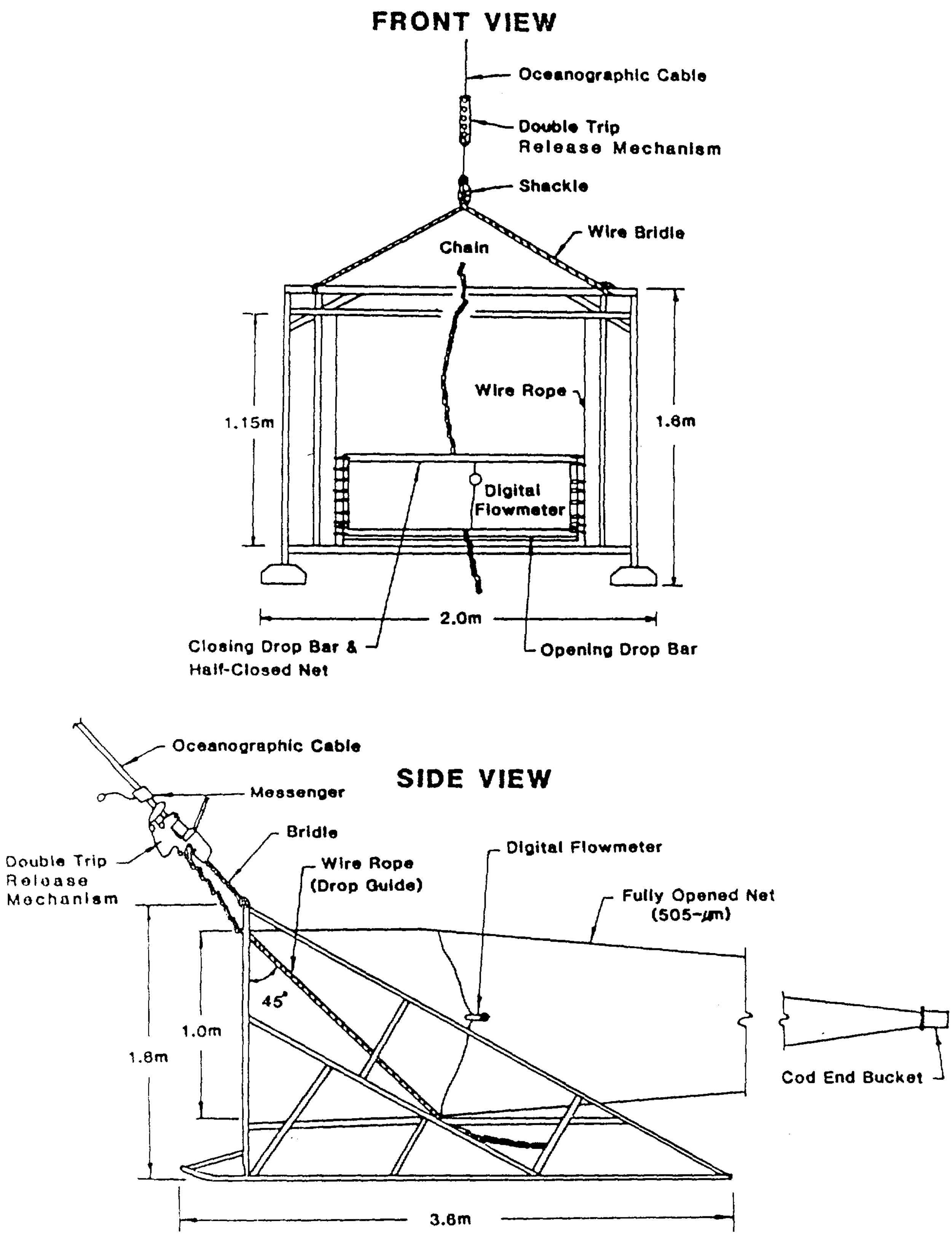


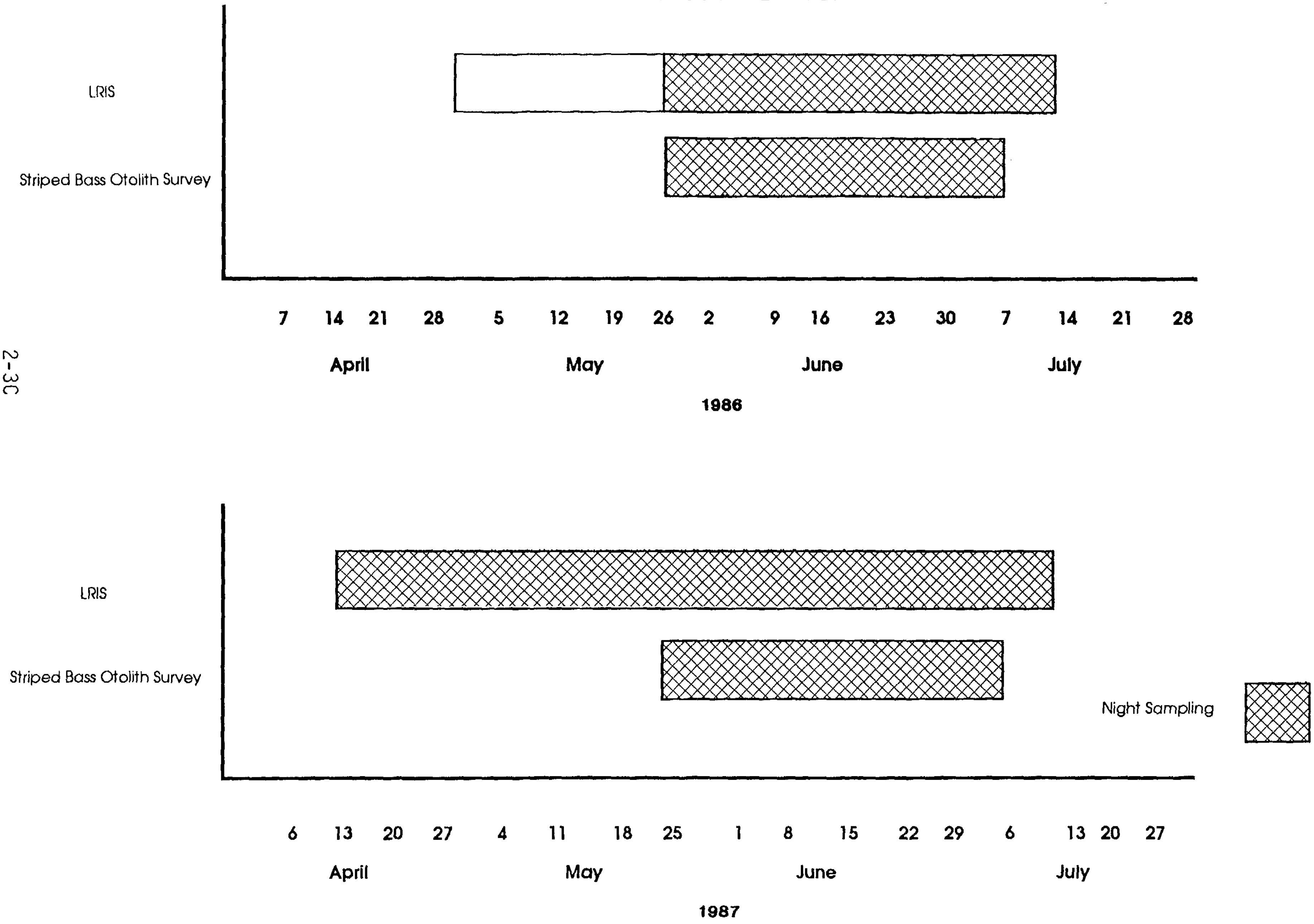
TABLE 2-3

SPECIFICATIONS OF SAMPLING GEAR USED IN
LONGITUDINAL RIVER ICHTHYOPLANKTON SURVEYS - 1986-1987

1.0-m² Tucker Trawl	
Length	8.0 m
Mouth (width)	1.0 m
Mouth (height)	1.4 m
Mesh size	505 μm
Net material	Nytex (monofilament nylon)
Collection cup	30 cm
Length	30 cm
Length with net-retaining ring	37 cm
Mesh size	500 μm
Net material	Nytex (monofilament nylon)
1.0-m² Net Mounted on Epibenthic Sled	
Length	8.0 m
Mouth (width)	1.0 m
Mouth (height)	1.4 m
Mesh size	505 μm
Net material	Nytex (monofilament nylon)
Collection cup	30 cm
Length	30 cm
Length with net-retaining ring	37 cm
Mesh size	500 μm
Net material	Nytex (monofilament nylon)

FIGURE 2-5

LONGITUDINAL RIVER ICHTHYOPLANKTON SURVEY SAMPLE SCHEDULE
1986 AND 1987



this collection targeted Morone spp. and American shad yolk-sac larvae (YSL). The LRS sampling program concluded with a five-week period encompassing the remainder of June and the first part of July. The final sampling effort was designed to collect Morone spp. and American shad post-yolk-sac larvae (PYSL). In addition, two weeks of sampling in 1987, starting in mid-April, was scheduled specifically for the collection of American shad eggs.

The allocation of sampling effort among regions and strata is given in Tables 2-4 and 2-5 for the 1986 and 1987 LRS, respectively. During 1986, 2313 ichthyoplankton samples (including 141 striped bass otolith aging samples) were scheduled for collection; 2324 samples were collected, accounting for 100.5% of the scheduled total. In 1987, 2699 ichthyoplankton samples were scheduled for collection and 2612, or 96.8% of the scheduled number, were collected.

Following net washing and sample concentration in the cod-end bucket, the regularly scheduled LRS samples were examined for yearling and adult fish. All of these fish were identified, enumerated, and returned to the river. Special care was taken for sturgeon and for marked and tagged fish. After yearling and adult fish were removed, the ichthyoplankton sample was placed in a container(s) filled with 10% formalin.

In situ measurements of water temperature (°C), dissolved oxygen (mg/l), and specific conductance (μmhos/cm at 25°C) were taken with calibrated meters at fixed river mile and strata stations. Water quality sampling locations, by river mile and strata, are presented in Table 2-6 for the 1986 and 1987 LRS. Weekly water quality measurements were recorded from surface, middepth, and bottom water strata at channel stations and from the surface and bottom water depth at shoal stations. During the 11 weeks of the 1986 LRS, 1804 samples were scheduled, with 1805 actually collected. In 1987, 1795 of the scheduled 1804 samples were collected during the 11-week program; an additional 200 samples were collected during the two-week extension of the LRS program in mid-April. Ichthyoplankton samples collected for striped bass otolith aging

TABLE 2-4

SUMMARY OF 1986 SAMPLE COLLECTION INFORMATION BY RIVER REGION AND STRATUM

Longitudinal River Ichthyoplankton Survey

RIVER	THREE-WEEK PERIOD FROM 29 APRIL TO 16 MAY 1986[a] ICHTHYOPLANKTON SAMPLE NUMBER					THREE-WEEK PERIOD FROM 19 MAY TO 5 JUNE 1986[b] ICHTHYOPLANKTON SAMPLE NUMBER					FIVE-WEEK PERIOD FROM 9 JUNE TO 10 JULY 1986[c] ICHTHYOPLANKTON SAMPLE NUMBER				
	SHOAL SLED	SHOAL TRAWL	CHANNEL (TRAWL)	BOTTOM (SLED)	TOTAL	SHOAL SLED	SHOAL TRAWL	CHANNEL (TRAWL)	BOTTOM (SLED)	TOTAL	SHOAL SLED	SHOAL TRAWL	CHANNEL (TRAWL)	BOTTOM (SLED)	TOTAL
Yonkers	6	3	9	9	27	6	3	9	9	27	5	-	40	40	85
Tappan Zee	6	3	9	12	30	6	3	11	12	32	10	5	37	25	77
Croton-Haverstraw	12	6	18	9	45	10	6	16	11	43	15	5	40	30	90
Indian Point	9	3	75	21	108	7	3	59	19	88	15	10	100	30	155
West Point	-	-	93	12	105	-	-	87	18	105	-	-	150	40	190
Cornwall	9	6	15	36	66	9	6	19	30	64	10	5	80	60	155
Poughkeepsie	-	-	30	30	60	-	-	64	42	106	-	-	90	35	125
Hyde Park	-	-	33	27	60	-	-	41	23	64	-	-	55	25	80
Kingston	-	-	21	18	39	-	-	19	14	33	-	-	36	20	56
Saugerties	-	-	9	9	18	-	-	9	13	22	-	-	10	20	30
Catskill	-	-	9	9	18	-	-	9	9	18	-	-	15	15	30
Albany	-	-	15	15	30	-	-	13	11	24	-	-	15	15	30
TOTAL	42	21	336	207	606	38	21	356	211	626	55	25	662	350	1092

- No sample scheduled.

[a]All samples collected during daylight period.
[b]Samples from 19-23 May collected during daylight period; samples from 27 May - 5 June collected during nocturnal period.
[c]All samples collected during nocturnal period.

TABLE 2-5

SUMMARY OF 1987 SAMPLE COLLECTION INFORMATION BY RIVER REGION AND STRATUM

Longitudinal River Ichthyoplankton Survey

RIVER	TWO-WEEK PERIOD FROM 14 TO 24 APRIL ICHTHYOPLANKTON SAMPLE NUMBER					THREE-WEEK PERIOD FROM 26 APRIL TO 16 MAY ICHTHYOPLANKTON SAMPLE NUMBER					THREE-WEEK PERIOD FROM 18 MAY TO 4 JUNE ICHTHYOPLANKTON SAMPLE NUMBER					FIVE-WEEK PERIOD FROM 8 JUNE TO 9 JULY ICHTHYOPLANKTON SAMPLE NUMBER				
	SHOAL		CHANNEL	BOTTOM		SHOAL		CHANNEL	BOTTOM		SHOAL		CHANNEL	BOTTOM		SHOAL		CHANNEL	BOTTOM	
	SLED	TRAWL	(TRAWL)	(SLED)	TOTAL	SLED	TRAWL	(TRAWL)	(SLED)	TOTAL	SLED	TRAWL	(TRAWL)	(SLED)	TOTAL	SLED	TRAWL	(TRAWL)	(SLED)	TOTAL
Yonkers	2	2	4	4	12	6	3	10	9	28	6	3	9	9	27	5	-	40	40	85
Tappan Zee	3	6	8	3	20	6	3	9	12	30	6	3	12	12	33	10	5	38	25	78
Croton-Haverstraw	4	4	4	4	16	12	6	18	9	45	9	6	14	12	41	15	5	40	30	90
Indian Point	2	2	3	3	10	9	3	75	21	108	6	3	48	18	75	15	10	100	25	150
West Point	-	-	3	3	6	-	-	93	12	105	-	-	79	21	100	-	-	150	40	190
Cornwall	3	2	3	3	11	9	6	15	36	66	9	6	19	27	61	10	5	80	60	155
Poughkeepsie	-	-	3	3	6	-	-	30	30	60	-	-	76	48	124	-	-	90	35	125
Hyde Park	-	-	7	3	10	-	-	33	27	60	-	-	42	21	63	-	-	55	25	80
Kingston	-	-	13	9	22	-	-	21	18	39	-	-	18	12	30	-	-	30	20	50
Saugerties	-	-	19	12	31	-	-	9	9	18	-	-	9	15	24	-	-	10	20	30
Catskill	-	-	40	20	60	-	-	9	9	18	-	-	9	9	18	-	-	15	15	30
Albany	-	-	64	30	94	-	-	15	15	30	-	-	9	9	18	-	-	15	15	30
TOTAL	14	16	171	97	298	42	21	337	207	607	36	21	344	213	614	55	25	663	350	1093

- No sample scheduled.

TABLE 2-6

WATER QUALITY SAMPLING LOCATIONS (RIVER MILE) IN 1986 AND 1987 LONGITUDINAL RIVER ICHTHYOPLANKTON SURVEYS

RIVER REGION	SAMPLING LOCATIONS (River Mile) SHOALS[a]	CHANNEL	NUMBER OF SAMPLES SCHEDULED PER REGION PER RUN
Yonkers	5	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, 43, 46	16
West Point	-	49, 51, 53, 55	12
Cornwall	59	56, 57, 59, 61	16
Poughkeepsie	-	63, 67, 71, 75	12
Hyde Park	-	78, 80, 82, 84	12
Kingston	-	87, 89, 91, 93	12
Saugerties	-	96, 99, 102, 105	12
Catskill	-	109, 114, 118, 122	12
Albany	-	127, 131, 135, 138	12
TOTAL			164

- No sample scheduled.

[a]Sample collected from east and west shoals at designated river mile.

were handled in the same manner as regularly scheduled LRS samples except that the perservative was 95% ethyl alcohol (ETOH). Following 24 hrs in the initial 95% ETOH, the samples were drained and represerved in 70% ETOH.

2.2.2 Laboratory Methods

Eggs and larvae were separated from detrital material, sorted by major taxonomic group and life stage, counted, and placed in vials containing 5% formalin. The following life stage designations were used in the sorting process:

LIFE STAGE	DESCRIPTION
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 acquisition of a full complement of adult fin rays to 31 December of the year spawned

Vials of samples containing fish eggs or bay anchovy larvae at estimated abundance levels exceeding 4000 were split to one-half, one-fourth, or one-eighth of the original number using a Folsom plankton splitter.

Sorted larval samples were evaluated by a trained technician under magnification and all larvae were identified and enumerated. 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; if fewer than 10 were encountered, the remainder of the quota was allocated to the other life stages in proportion to abundance.

Continuous sampling inspection was employed during the sort and identification procedures to ensure an average outgoing quality (AOQ) of <0.1. Two sampling modes were required in the continuous sampling plan (CSP-1):

Mode 1: The first eight samples sorted or analyzed for larval identification by an individual are subject to 100% quality control (QC) reanalysis. If all eight pass the reanalysis, i.e., if ≤10% of the ichthyoplankton are missed or misidentified per sample, the individual is placed in CSP Mode 2. If any sample fails during Mode 1, then Mode 1 is continued until eight consecutive samples pass. For example, if a sample with QC number 7 fails, then samples with QC numbers 8 through 15 are subject to QC resorting.

Mode 2: Lots of seven consecutive samples per individual are assigned. One sample from each lot is randomly chosen for QC analysis. If a sample fails (>10% of organisms missed or misidentified) during Mode 2, that individual is placed back into Mode 1. For example, if a sample with QC number 6 fails in a lot of seven samples, then samples with QC numbers 7 through 14 are subject to QC reanalysis. If samples 7 through 14 pass, the individual is again placed in Mode 2.

Results of the 1986 and 1987 CSP-1 quality control/quality assurance program are contained in Appendix A.

2.3 FALL SHOALS SURVEY (FSS)

2.3.1 Field Methods

A 1.0-m^2 Tucker trawl and a 3.0-m beam trawl were used to collect juvenile fish in the FSS. The Tucker trawl with 3.0-mm mesh was used to collect samples in the channel strata, while the beam trawl (Figure 2-6) was used to sample the shoal and bottom strata. The latter gear was first used in this capacity in the 1985 FSS; prior to 1985 an epibenthic sled-mounted Tucker trawl was used. (See Table 2-7 for design specifications for both trawl types.)

FIGURE 2-6

DESIGN AND DIMENSIONS OF THE 3.0-m BEAM TRAWL USED IN THE FALL SHOALS SURVEY

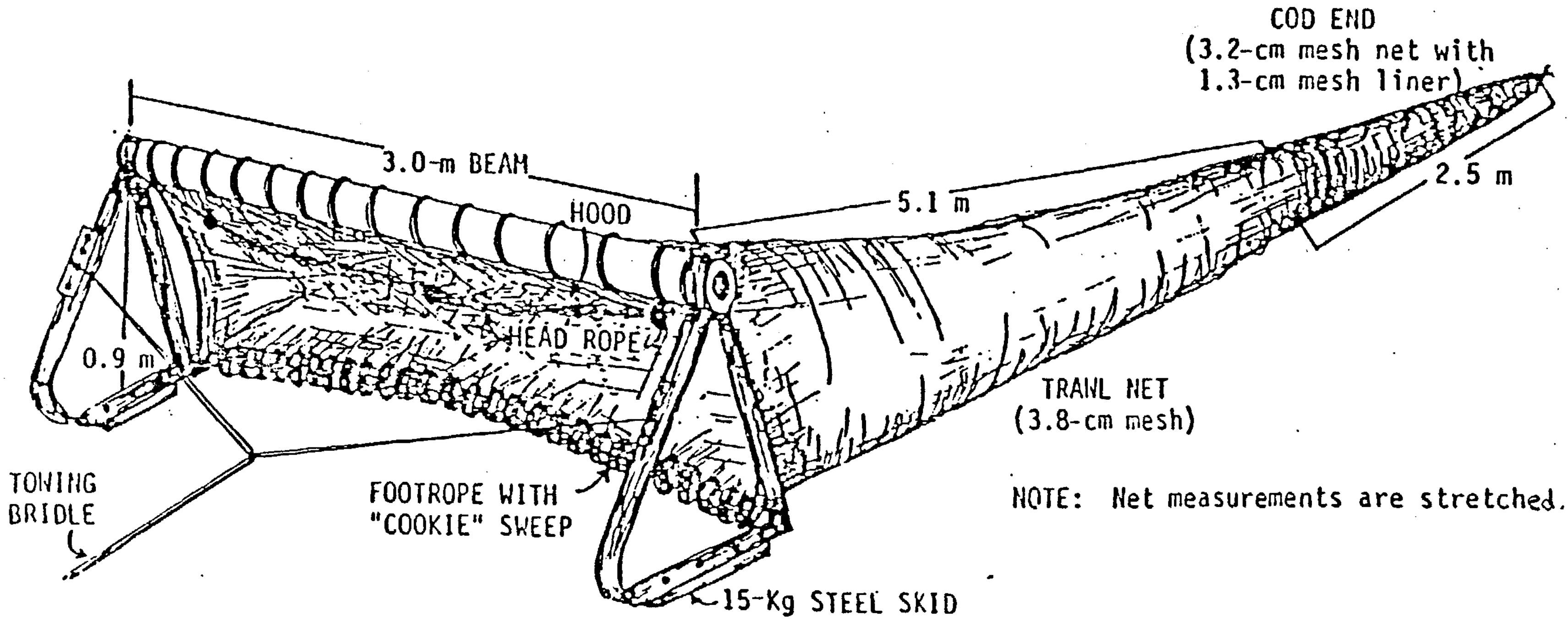


TABLE 2-7

SPECIFICATIONS OF SAMPLING GEAR USED IN FALL SHOALS SURVEYS - 1986-1987

1.0-m^2 Tucker Trawl	
Length	8.0 m
Mouth (width)	1.0 m
Mesh size	3.0 mm
Collection cage (cod end)	
Length	81 cm
Diameter	41 cm
Mesh size	3.0 mm
3.0-m Beam Trawl	
Length	7.6 m
Beam width	3.0 m
Net body	3.8-cm mesh (stretch)
Cod end	3.2-cm mesh (stretch) net with 1.3-cm mesh (stretch) liner
Hood	3.8-cm mesh (stretch)
Footrope	Equipped with 5.1-cm rollers
Headrope	Equipped with three floats
Fish mouth area	2.74 m^2

Both gear types were towed against the prevailing current for approximately 5 min at a tow speed of approximately 150 cm/sec. Tow speed was established and maintained by an electronic flowmeter mounted along the side of the research vessel and equipped with on-deck readout. A calibrated digital flowmeter (General Oceanics Model 2030) mounted in the center of the net mouth was used to calculate the volume of water filtered for each sample.

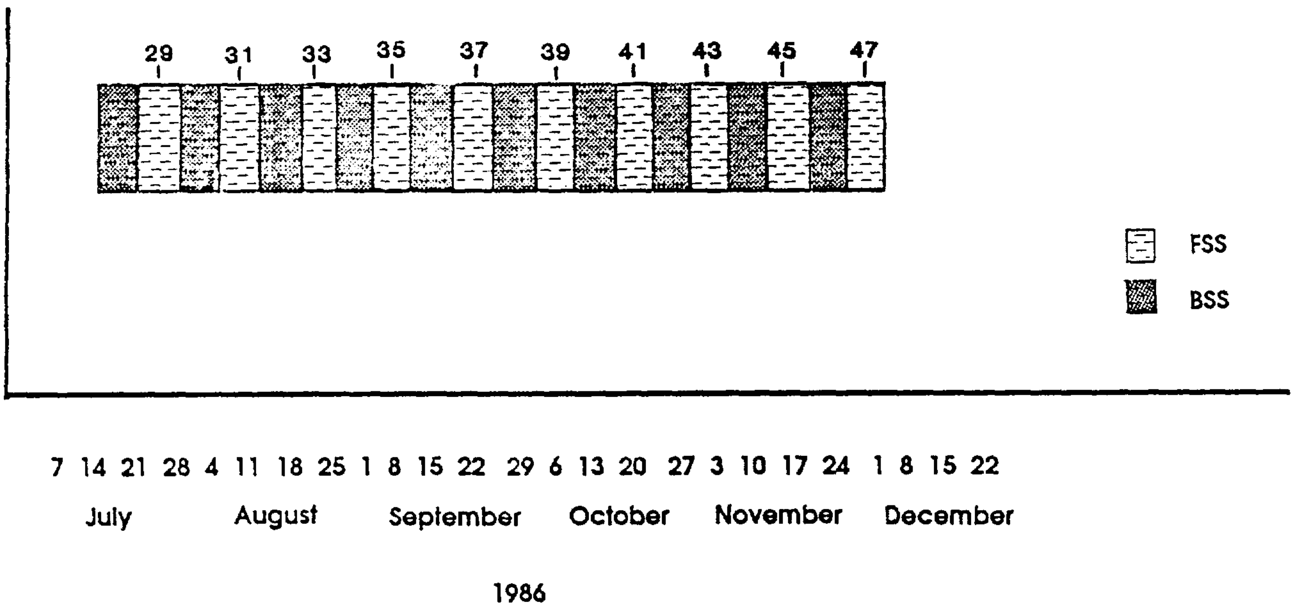
The 1986 FSS biweekly sampling program covered 19 weeks from 21 July to 2 December (Figure 2-7), with all samples collected at night. A nocturnal sampling schedule was also maintained for the biweekly 1987 FSS, which covered 17 weeks from 13 July to 5 November 1987. Tables 2-8 and 2-9 present the distribution of the sampling effort among the 12 river regions by stratum for the 1986 FSS and the 1987 FSS, respectively. In 1986, 2100 samples were scheduled for collection, with 2098 samples, or 99.9% of the scheduled number, actually collected. In 1987, 1891 samples were collected, or 100.1% of the 1890 samples scheduled.

Calibrated meters were used to measure water temperature (°C), dissolved oxygen (mg/l), and specific conductance (μmhos/cm at 25.0°C) at fixed river mile and strata stations. Sampling locations were the same as those used for the LRS sampling program (Table 2-6). Water quality measurements were recorded during each biweekly FSS sampling period from surface, middepth, and bottom water strata at channel stations and from the surface and bottom water depths at shoal stations.

Samples collected during the first two sampling periods (runs 1 and 2) for the 1986 and 1987 FSS programs were preserved with 10% formalin at the time of collection and returned to the laboratory for analysis. Before preservation, samples were examined for sturgeon determined to be yearling or older, based on length categorization; live fish were returned to the river. Samples from the first two runs were returned to the laboratory for analysis because of the difficulty in differentiating some species, especially YOY Morone (striped bass, white perch) and Alosa (alewife, blueback herring). Samples collected

FIGURE 2-7

FALL SHOALS SURVEY AND BEACH SEINE SURVEY SAMPLE SCHEDULE - 1986 AND 1987



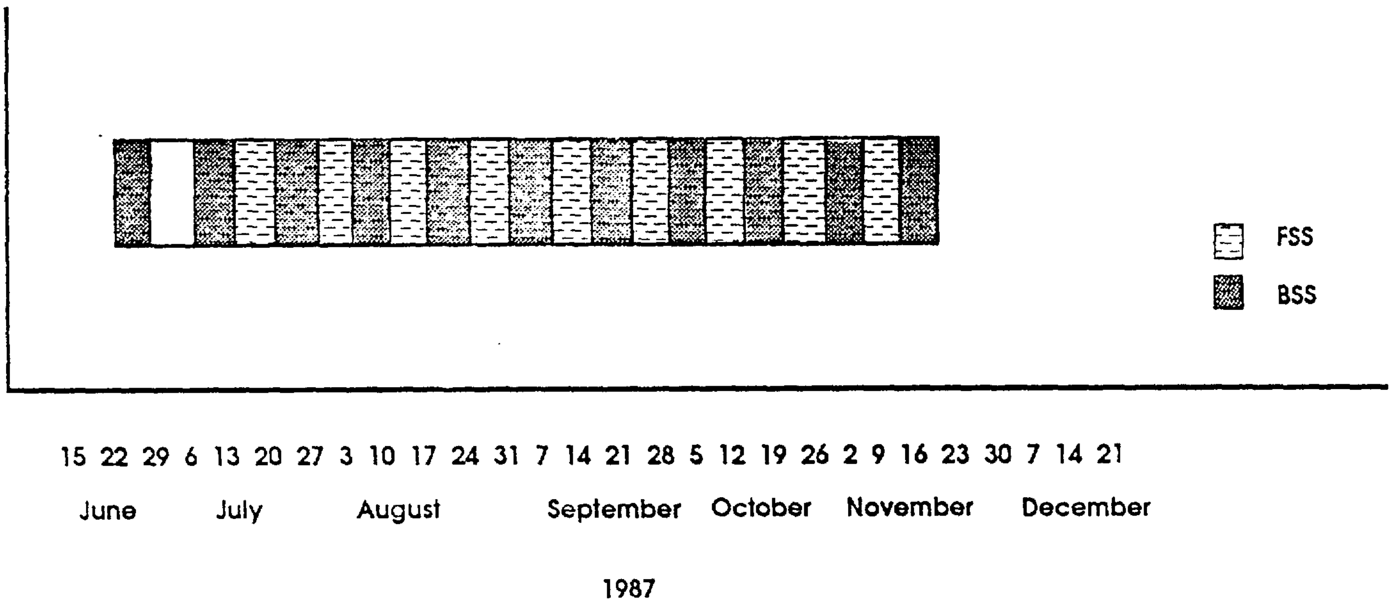


TABLE 2-8

NUMBER OF BIWEEKLY SAMPLES TAKEN IN THE 1986 FALL SHOALS SURVEY

21 July - 2 December

REGION	STRATA: SHOAL (BEAM TRAWL)	CHANNEL (TUCKER TRAWL)	BOTTOM (BEAM TRAWL)	TOTAL
Yonkers	70	50	50	170
Tappan Zee	299	80	80	459
Croton-Haverstraw	160	30	80	270
Indian Point	60	30	50	140
West Point	-	30	50	80
Cornwall	50	30	50	130
Poughkeepsie	-	30	50	80
Hyde Park	-	40	60	100
Kingston	-	59	90	149
Saugerties	-	60	120	180
Catskill	-	60	150	210
Albany	-	50	80	130
TOTAL	639	549	910	2098[a]

- No sample scheduled.

[a]All samples collected at night.

TABLE 2-9

NUMBER OF BIWEEKLY SAMPLES TAKEN IN THE 1987 FALL SHOALS SURVEY

13 July - 5 November

	STRATA			
REGION	SHOAL (BEAM TRAWL)	CHANNEL (TUCKER TRAWL)	BOTTOM (BEAM TRAWL)	TOTAL
Yonkers	63	45	45	153
Tappan Zee	271	72	72	415
Croton-Haverstraw	144	27	72	243
Indian Point	54	27	45	126
West Point	-	27	45	72
Cornwall	45	27	45	117
Poughkeepsie	-	27	45	72
Hyde Park	-	36	54	90
Kingston	-	54	81	135
Saugerties	-	54	108	162
Catskill	-	54	135	189
Albany	-	45	72	117
TOTAL	577	495	819	1891[a]

- No sample scheduled.

[a]All samples collected at night.

following the second biweekly sampling period were evaluated in the field; only fish required to fill length measurement quotas were returned to the laboratory. The quota was to be 20 specimens of a selected species from each river region per run. In river regions where fewer than 10 samples were collected per survey, no more than 10 specimens of each selected species from an individual sample were used to fill the length measurement quota. This criterion was used in the following surveys by river region:

SAMPLING PROGRAM	REGION
Beach Seine Survey	YK, IP, WP, CW, PK
Fall Shoals Survey	WP, PK

In all other regions, when the sample schedule resulted in 10 or more samples per survey, no more than five specimens per species in a sample were used to fill the length measurement quotas. If more specimens of a species were collected than needed, the individuals used to fill the quotas were randomly selected.

2.3.2 Laboratory Methods

Fish from the FSS identified and enumerated in both the field and laboratory were separated into the following length classes:

Length Class 1 - Less than or equal to the YOY length limit ("Division 1"), which was obtained from the Indian Point impingement contractor on a weekly basis for each species

Length Class 2 - Greater than Division 1 and less than or equal to the yearling length limit ("Division 2"; set at 150 mm for most species), also obtained weekly from the impingement contractor. From 1 January through 31 May, Division 2 represents the upper length limit for yearling fish for all species. From 1 June through 31 December, Division 2 is assigned a static value of 150 mm TL for all species except alewife, American shad, blueback herring, striped bass, Atlantic tomcod, and white perch. For these species Division 2 is maintained as a dynamic upper length limit for yearling fish throughout the year.

Length Class 3 - Greater than Division 2 and less than or equal to 250 mm

Length Class 4 - Greater than 250 mm

Twenty specimens of the following selected species collected in each river region were measured for total length (nearest millimeter) in the laboratory:

- Alewife
- American shad
- Atlantic sturgeon
- Atlantic tomcod
- Bay anchovy
- Blueback herring
- Shortnose sturgeon
- Spottail shiner
- Striped bass
- Weakfish
- White catfish
- White perch

2.4 BEACH SEINE SURVEY (BSS)

2.4.1 Field Methods

The BSS utilized a 30.5-m bag beach seine to collect juvenile fish in the shore zone of each region. Table 2-10 presents specifications for the beach seine. One end of the net was held on shore and the other end was towed perpendicularly away from the shore by boat. The seine was then hauled into the current in a semicircular path toward shore. The complete tow swept an area of approximately 450 m^2 (TI 1981). All BSS samples were collected on a diurnal schedule on alternate weeks with the FSS.

The 1986 BSS biweekly sampling program covered 19 weeks. The first samples were collected on 15 July, the last on 21 November 1986 (Figure 2-7), a total

TABLE 2-10

SPECIFICATIONS OF SAMPLING GEAR USED IN BEACH SEINE SURVEYS - 1986-1987

30.5-m Beach Seine	
Number of wings	2
Length of wings	12.0 m
Depth of wings	2.4 m
Wing mesh (stretch)	2.0 cm
Length of bag	6.1 m
Depth of bag	3.0 m
Bag mesh (stretch)	9.5 mm
Sample area	450 m^2

of 10 weekly periods. The alternate-week sampling schedule was used for the 1987 BSS, which covered 21 weeks from 24 June through 13 November 1987; sampling was over 11 weekly periods. Two additional beach seine surveys were conducted during the weeks of 22-26 June and 6-10 July 1987 to collect information on American shad YOY. Allocation of the proposed 100 beach seine samples per river run by river region and the total number collected for the 1986 and 1987 BSS are presented in Table 2-11. All of the scheduled 1000 samples projected for collection in 1986 were collected. Of the 1100 samples scheduled for collection in 1987, 1101 samples were actually collected.

Measurements of water temperature (°C), dissolved oxygen (mg/l), and specific conductance (µmhos/cm at 25°C) were taken with each beach seine sample. Water quality measurements were taken 0.3 m below the water surface and approximately 15.0 m from the shoreline.

Beach seine samples collected during the first three river runs in 1986 and the first four river runs in 1987 were processed in the laboratory because of the difficulty in distinguishing between early juvenile species. All samples collected following run 3 in 1986 and run 4 in 1987 were field processed to yield only 20 specimens of the selected species from each region for length determination in the laboratory. Samples maintained for laboratory analysis were preserved with 10% formalin.

All sturgeon collected under both the FSS and BSS during both years were measured to the nearest millimeter and weighed to the nearest gram. Fish that remained alive were returned to the river; dead fish were frozen and held for the New York State Department of Environmental Conservation (NYSDEC).

2.4.2 Laboratory Methods

All fish returned to the laboratory were measured for total length to the nearest 1.0 mm. Laboratory analysis was conducted in the same manner as described for samples collected under the FSS.

TABLE 2-11

NUMBER OF BIWEEKLY SAMPLES TAKEN IN THE 1986 AND 1987 BEACH SEINE SURVEYS

REGION	NUMBER OF BEACHES SAMPLED 1986	1987
Yonkers	50	55
Tappan Zee	240	265
Croton-Haverstraw	139	153
Indian Point	50	55
West Point	50	55
Cornwall	60	66
Poughkeepsie	50	55
Hyde Park	50	55
Kingston	50	55
Saugerties	90	100
Catskill	100	110
Albany	71	77
TOTAL	1000	1101

2.5 SPECIAL STUDIES

2.5.1 1986 Juvenile Fish Abundance in Previously Unsampled Areas

The objective of the special study conducted during 1986 was to obtain juvenile fish density information from areas of the Hudson River not previously sampled by the FSS and BSS due to obstructions and sampling gear limitations. Except for the addition of a 0.9-m^2 pushnet to sample the beach and shore strata, the special study gear was similar in design and method of deployment to the gear used in the long-term fall juvenile surveys so that fish densities between previously sampled and unsampled areas could be compared.

2.5.1.1 Field Methods. The first phase of the juvenile special study was a general survey to quantify the unsampled areas in all 12 river regions. The areas were categorized based on depth as follows:

STRATA CATEGORY	DEPTH RANGE METERS	DEPTH RANGE FEET
Beach	0.3-1.5	1-5
Shore	1.5-3.0	5-10
Shoal	3.0-6.1	10-20
Bottom	>6.1	>20

A detailed survey was then conducted to determine the extent of the shoal area in the Croton-Haverstraw, West Point, and Poughkeepsie through Albany regions. Fishable areas, defined as a consistent depth contour extending for a minimum distance of 0.2 km with a slope acceptable for net tows, were noted.

Two gear types were used in the 1986 special study: a 2.0-m beam trawl for all depth strata 1.5 m or greater and a 0.9-m^2 pushnet for the beach strata. Design specifications for the two gear types are presented in Table 2-12. Comparative samples utilizing both gear types were conducted in the Catskill region shore strata. Collections using both gear types were approximately 5

TABLE 2-12

SPECIFICATIONS OF SAMPLING GEAR USED IN JUVENILE SPECIAL STUDY - 1986

2.0-m Beam Trawl	
Length	7.0 m
Mouth (width)	2.0 m
Mouth (height)	0.9 m
Mesh size	3.8-m stretch mesh
Cod end	3.2-cm stretch mesh net with 1.3-cm stretch mesh liner
Hood	3.8-cm stretch mesh
Footrope	Equipped with 5.1-cm rollers
Headrope	Equipped with three floats
Fishing mouth area	1.8 m^2
0.9-m^2 Pushnet	
Length	4.7 m
Mouth (width)	1.5 m
Mouth (height)	0.6 m
Mesh size	3.8-cm stretch mesh
Cod end	3.2-cm stretch mesh with 1.3-cm stretch mesh liner
Fishing mouth area	0.9 m^2

min long at a velocity through the water of 150 cm/sec. Tow velocity was established with an electronic flowmeter with on-deck readout mounted alongside the research vessel.

A calibrated digital flowmeter (General Oceanics Model 2030) mounted in the center of each net mouth was used to calculate the volume of water filtered for each sample. The sample volume was estimated to be approximately 850 m^3 for a 5-min beam trawl sample and a minimum of 300 m^3 for a 5-min pushnet sample. All special study sampling was done at night.

Sample allocation and total number of samples among river regions by depth strata and gear type are given in Table 2-13. Special study sampling was conducted in four of the 12 river regions, which were selected based on the projected presence of target species, as follows:

RIVER REGION	TARGET SPECIES
Croton-Haverstraw	Atlantic tomcod Bay anchovy Striped bass
West Point	Atlantic tomcod Striped bass Bay anchovy
Kingston	White perch
Catskill	American shad

A total of 109 pushnet samples were collected from the shore zone in the four river regions: 57 samples off beaches previously sampled under the BSS and 52 off beaches not sampled under the BSS. Twenty pushnet samples were collected from the shore zone in the Catskill region for gear comparison purposes. Eighty-two 2.0-m beam trawl samples were collected: 46 from the 5- to 10-ft-depth shore strata and 36 from the 10- to 20-ft-depth shoal strata. Shore-

TABLE 2-13

SAMPLE ALLOCATION BY RIVER REGION AND GEAR FOR 1986 JUVENILE FISH SPECIAL STUDY

REGION	BEACH (1-5 ft) (0.9-m^2 PUSHNET) PREVIOUSLY SAMPLED	BEACH (1-5 ft) (0.9-m^2 PUSHNET) NON-SAMPLED	SHORE ZONE (5-10 ft) (0.9-m^2 PUSHNET) PREVIOUSLY SAMPLED	SHORE ZONE (5-10 ft) (0.9-m^2 PUSHNET) NON-SAMPLED	SHORE ZONE (5-10 ft) (2.0-m BEAM TRAWL) PREVIOUSLY SAMPLED	SHORE ZONE (5-10 ft) (2.0-m BEAM TRAWL) NON-SAMPLED	SHOAL (10-20 ft) (2.0-m BEAM TRAWL) NONSAMPLED	BOTTOM (>20 ft) (2.0-m BEAM TRAWL) PREVIOUSLY SAMPLED
Yonkers								
Tappan Zee								
Croton-Haverstraw	14	14			6	9		
Indian Point								
West Point	9	3				8	10	10
Cornwall								
Poughkeepsie								
Hyde Park								
Kingston	9	9			4	4	10	10
Saugerties								
Catskill	25	26	10	10	8	7	16	20
Albany								
TOTAL	57	52	10	10	18	28	36	40

zone beam trawl samples were collected in all four selected river regions; no shoal strata samples were collected from the Croton-Haverstraw river region.

All YOY fish taken in the special study samples were placed in unbreakable containers, preserved with 10% formalin, and returned to the laboratory for analysis. All yearling and older fish were sorted by species and counted by length class. All yearling and adult fish were released following field analysis.

Measurements of water temperature (°C), dissolved oxygen (mg/l), and specific conductance (μmhos/cm at 25°C) were taken at each sample location. A single reading for each parameter was recorded for the beach strata samples; surface and bottom readings were recorded for the shore and shoal strata.

2.5.1.2 Laboratory Methods. Thirty YOY fish of each target species were processed per sample for total length to the nearest millimeter.

2.5.2 1987 Special Study to Examine Eggs and Ichthyoplankton Abundance in Unsampled Areas

The objective of the 1987 special study was to obtain information on egg and ichthyoplankton densities from areas of the Hudson River not previously sampled because of obstruction and gear limitations. Sampling gear comparable or identical to that used in the LRS was used to facilitate data evaluation.

2.5.2.1 Field Methods. A 1.0-m^2 Tucker trawl, a 1.0-m^2 net mounted on an epibenthic sled, and a 1.0-m^2 pushnet were used in the 1987 ichthyoplankton special study. (See Table 2-14 for gear specifications.) All nets were equipped with 505-μm mesh. The frame of the epibenthic sled used in 1987 was smaller than the one used for the LRS, which permitted deployment in shallow, confined areas. The bottom water strata (>20 ft) was sampled with the epibenthic sled-mounted net; the shoal strata (10 to 20 ft), with the epibenthic sled-mounted net and the 1.0-m^2 Tucker trawl. The beach strata (1 to 5 ft) were sampled with the 1.0-m^2 pushnet; the shore strata (5 to 10 ft) with

TABLE 2-14

SPECIFICATIONS OF SAMPLING GEAR USED IN ICHTHYOPLANKTON SPECIAL STUDY - 1987

1.0-m^2 Tucker Trawl	
Length	8.0 m
Mouth (width)	1.0 m
Mesh size	505 μm
Net material	Nytex (monofilament nylon)
Collection cup	
Length	30 cm
Length with net retaining ring	37 cm
Mesh size	505 μm
Net material	Nytex (monofilament nylon)
1.0-m^2 Pushnet	
Length	4.7 m
Mouth (width)	1.6 m
Mouth (height)	0.6 m
Mesh size	505 μm
Collection cup	
Length	30 cm
Length with net retaining ring	37 cm
Mesh size	505 μm
Net material	Nytex (monofilament nylon)

both the pushnet and the net-mounted epibenthic sled. All sampling was conducted at night. Sample duration for all gear was 5 min at a tow speed of 90 cm/sec for the Tucker trawl, 100 cm/sec for the epibenthic sled-mounted net, and 90 cm/sec for the pushnet. Tow velocity was established and maintained with an electronic flowmeter with on-deck readout mounted alongside the research vessel.

A calibrated digital flowmeter (General Oceanics Model 2030) mounted in the center of the net mouth was used to calculate the volume of water filtered for each sample.

The pushnet had one velocity meter mounted inside the net mouth and a second outside the net mouth. The difference in meter readings was used to determine net filtration efficiency. The percent difference (P-DIFF) in volume between inside and outside flowmeters was calculated as follows:

$$P\text{-}DIFF = ([\text{outside volume} - \text{inside volume}]/\text{outside volume}) \times 100$$

The mean percent difference (P-DIFF) with its standard deviation and maximum and minimum values is presented below.

STRATA	STRATA CODE	N	PERCENT DIFFERENCE MINIMUM	MAXIMUM	MEAN	STD. DEV.
Beach (1-5 ft)	5	100	-11.25	17.83	2.07	4.19
Shore Zone (5-10 ft)	7	50	- 9.58	21.12	2.94	4.84
Beach and Shore	5+7	150	-11.25	21.12	2.36	4.42

The relatively small differences in percentages between the two flowmeters indicate that the pushnet efficiently filtered the water. The design sample volume for a 5-min tow was a minimum of 300 m^3 for this gear.

Table 2-15 presents the schedule by river region, sampling gear, target species, and life stage. Sample allocation by river region, depth strata, and

TABLE 2-15

SAMPLE DESIGN FOR 1987 ICHTHYOPLANKTON SPECIAL STUDY

REGION	SAMPLE PERIOD	GEAR	STRATUM (ft)	TARGET SPECIES AND LIFE STAGE
Catskill	11-29 May	Pushnet	01-05	American shad eggs and yolk-sac larvae
		Epibenthic sled	05-10	
		Pushnet	05-10	
		Epibenthic sled	10-20	
		Tucker trawl	10-20	
		Epibenthic sled	>20	
Poughkeepsie	8-26 Jun	Pushnet	01-05	Striped bass and white perch post-yolk-sac larvae
		Epibenthic sled	05-10	
		Pushnet	05-10	
		Epibenthic sled	10-20	
		Tucker trawl	10-20	
		Epibenthic sled	>20	
Tappan Zee	8-26 Jun	Pushnet	01-05	Bay anchovy post-yolk-sac larvae
		Epibenthic sled	05-10	
		Pushnet	05-10	
		Epibenthic sled	10-20	
		Tucker trawl	10-20	

gear is presented in Table 2-16. Sampling in the Catskill region was designed to collect information on American shad; in the Poughkeepsie region, striped bass and white perch; in the Tappen Zee region, bay anchovy.

Field processing of the ichthyoplankton samples included the identification, enumeration by length class, and release of all yearling and adult fish. Following examination, the sample was placed in unbreakable containers and preserved with 10% formalin.

2.5.2.2 Laboratory Methods. Samples collected during each week of each sample period were chosen at random and analyzed for abundance of target species. All samples from the week having the greatest abundance of targets were analyzed. Laboratory analysis of the selected ichthyoplankton special study samples included total length and life stage designation for the selected species. All ichthyoplankton were identified and enumerated.

2.5.3 1987 Fall Shoals Special Study

Special study sampling to collect information on juvenile fish was conducted on a limited schedule from the Kingston and Saugerties river regions during 15-18 September 1987. Thirty-three samples were collected from previously sampled bottom strata (>20 ft), 34 from previously unsampled shoal strata (10-20 ft). The samples were evaluated as described for the 1986 juvenile special study (Section 2.5.1).

2.6 ANALYTICAL METHODS

2.6.1 Water Quality Parameters

To display the spatial and temporal patterns of temperature, conductivity, salinity, and dissolved oxygen, a mean of each parameter for each region and sampling week, weighted by stratum volume, was calculated. Equation 1 was used to compute these means for the standard water quality stations sampled in

TABLE 2-16

SAMPLE ALLOCATION BY RIVER REGION AND GEAR FOR 1987 ICHTHYOPLANKTON SPECIAL STUDY

		SHORE (5-10 ft)		SHOAL (10-20 ft)		BOTTOM (>20 ft)
REGION	BEACH (1-5 ft) (1.0-m^2 PUSHNET)	EPIBENTHIC SLED-MOUNTED 1.0-m^2 NET	1.0-m^2 PUSHNET	EPIBENTHIC SLED-MOUNTED 1.0-m^2 NET	1.0-m^2 TUCKER TRAWL	EPIBENTHIC SLED-MOUNTED 1.0-m^2 NET
Yonkers						
Tappan Zee	32	40	25	48	48	
Croton-Haverstraw						
Indian Point						
West Point						
Cornwall						
Poughkeepsie	54	27	27	55	54	30
Hyde Park						
Kingston						
Saugerties						
Catskill	150	75	75	99	201	120
Albany						
TOTAL	236	142	127	202	303	150

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 Equations 3 and 4. The mean of each water quality parameter was calculated using Equation 5 for each of three estuary segments: lower estuary (Yonkers to Croton-Haverstraw), middle estuary (Indian Point to Poughkeepsie), and upper estuary (Hyde Park to Albany). Salinity data were computed from conductivity data (µmhos/cm at 25°C) using Equation 6 (Anaderaa Instruments 1983). These data were reconverted to raw conductivity for the conversion to salinity.

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

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 Equation 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 Equation 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 Equation 1

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

where

T = water temperature (°C)

P = pressure (dbar)

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

where

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

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

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

$$F = \frac{(1.60836\times10^{-5})(P) - (5.4845\times10^{-10})(P^2) + (6.166\times10^{-15})(P^3)}{(1.0) + (0.030786)(T) + (0.0003169)(T^2)}$$

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

C = conductivity (mS/cm)

2.6.2 Density Estimates

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

IF THIS STRATUM WAS NOT SAMPLED	ITS VOLUME WAS ADDED TO THIS STRATUM
Shoal	Bottom
Bottom	Channel

$$D_{ikrw} = \frac{C_{ikrw}}{V_{ikrw}} \tag{7}$$

where

D_{ikrw} = density (for a life stage and species) 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_{krw} = volume sampled (m^3) by sample i, in stratum k, in region r, during week w

$$D_{krw} = \frac{1}{n_{krw}} \sum_{i=1}^{n_{krw}} D_{ikrw} \tag{8}$$

where

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

D_{ikrw} = sample density calculated in Equation 7

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

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

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 Equation 7

D_{krw} = average stratum density calculated in Equation 8

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

where

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

D_{krw} = average stratum density calculated in Equation 8

P_k* = proportion of the regional river volume found in stratum k (see Table 2-17)

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

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

where

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

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

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

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

TABLE 2-17

STRATUM AND REGION VOLUMES (m^3) AND SURFACE AREAS (m^2) USED IN ANALYSIS OF 1986 AND 1987 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

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

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 Equation 12

2.6.3 Annual Abundance Indices

2.6.3.1 Standing Crop Estimates. Standing crop (the number of fish in an area at a particular time) was estimated by life stage and species 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 (Equations 14 and 15 for the LRS and FSS; Table 2-17). The regional standing crop was then estimated as the sum of the stratum standing crops (Equations 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 (Equations 18 and 19).

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

where

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

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

D_{krw} = average stratum density calculated in Equation 8

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

where

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

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

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

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

SC_{krw} = stratum standing crop estimate calculated in Equation 14

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

where

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

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

$$SC_w = \sum_{r=1}^{12} SC_{rw} \qquad (18)$$

where

SC_w = standing crop estimate for week w

SC_{rw} = regional standing crop estimate calculated in Equations 16 and 20

*Volumes of unsampled strata were added to the volumes of an adjacent stratum according to the rules for stratum volumes in Section 2.6.2.

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

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 Equations 17 and 21

An estimate of regional standing crop (and standing 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 (Equations 20 and 21). The weekly estimate of standing crop for the shore zone was calculated as the sum of the 12 regional standing crops (Equations 18 and 19).

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

where

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

C_{rw} = average regional CPUE calculated in Equation 12

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

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

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

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 Equation 13

2.6.3.2. Weekly Combined Standing Crop (CSC). The weekly combined standing crop is an estimate of the abundance of white perch and striped bass YOY for each week of samples taken in the Hudson River between river miles 12 and 152. During the fall surveys, weekly combined standing crop was estimated by a six-step process used to combine data from the Fall Shoals (FSS) and Beach Seine Surveys (BSS):

- 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 under the BSS. 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 FSS 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 1978, 1979) 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.

The epibenthic sled that had been used historically since 1974 was replaced with a beam trawl beginning with the 1985 FSS and was used in the present studies as well. Studies conducted by NAI (1986) in which the two gear were sampled in the same region found statistically significant, species-specific differences in catch between the two sampling devices. Adjustment factors based on these relative catches were developed (Table 2-18) to estimate beam trawl gear efficiency (based on the assumed gear efficiency for the epibenthic sled) so that data collected from 1985 to the present could be compared with data collected prior to 1985. When an adjustment resulted in a revised gear efficiency greater than 100%, gear efficiency was assumed to be 100%.

After the FSS and BSS 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 Equations 22 and 23, respectively.

$$SC_{w,B} = \sum_{r=r_s}^{r_e} (SC_{rw,B}) \frac{R}{C} \tag{22}$$

where

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

$SC_{rw,B}$ = standing crop estimate calculated in Equation 20

C = catch efficiency of beach seine during the day

R = ratio of night/day beach seine catches.

r_s = first region included in the index

r_e = last region included in the index

$$SC_{w,F} = \sum_{r=r_s}^{r_e} \left[\frac{1}{E_F} \left[(0.75)\ (SC_{k_1,r,w}) + \sum_{k=2}^{3} SC_{krw} \right] \right] \tag{23}$$

where

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

TABLE 2-18

ADJUSTMENT FACTORS FOR THE BEAM TRAWL TO STANDARDIZE VALUES WITH THOSE OF THE EPIBENTHIC SLED

SPECIES	ADJUSTMENT FACTOR
Striped bass	4
White perch	13
American shad	0.1
Bay anchovy	0.02

E_F = gear efficiency adjustment for the FSS (0.5)

SC_{krw} = standing crop estimate calculated in Equation 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 24 was used to estimate the standard error of the adjusted standing crop for the FSS; Equation 25 was used to estimate the standard error of the BSS adjusted standing crop (Kendall and Stewart 1977). The standard error of the weekly combined standing crop was computed as the square root of the sum of the squared estimates (Equation 26).

$$SE(SC_{rw,F}) = \sqrt{\left[\frac{(0.75)\ SE(SC_{k_1,r,w})}{E_F}\right]^2 + \left[\frac{SE(SC_{k_2,r,w})}{E_F}\right]^2 + \left[\frac{SE(SC_{k_3,r,w})}{E_F}\right]^2} \qquad (24)$$

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 Equation 14

E_F = gear efficiency adjustment for the FSS (0.5)

k_1 = shoal stratum

k_2 = bottom stratum

k_3 = channel stratum

$$SE(SC_{rw,B}) = SC_{rw,B} \frac{C}{R} \sqrt{\frac{VR}{R^2} + \frac{VC}{C^2} + \frac{[SE(SC_{rw})]^2}{SC_{rw}^2}} \qquad (25)$$

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 Equation 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 Equation 21

$$SE(CSC_w) = \sum_{r=1}^{r_e} \left[SE(SC_{rw,F})^2 + SE(SC_{rw,B})^2 \right] \qquad (26)$$

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 Equation 24

$SE(SC_{rw,B})$ = standard error of adjusted standing crop for the BSS calculated in Equation 25

2.6.3.3 Coordinate Pair Index. Computation of the coordinate pair index involves a two-step process:

- o Calculation of weekly average CPUE values for the BSS and FSS programs
- o Rank transformation of the weekly average CPUE values to calculate the index and test for significant differences among years

Each step in this procedure is detailed below.

Weekly average CPUE for the beach seine component of the index was calculated as the weighted mean of average regional CPUE values. The weighting factor used was the percentage of the 284 sampleable beaches occurring in a region (Table 2-19). The formula for the calculations of the beach seine component of the coordinate pair index is presented in Equation 27.

$$BS_w = \frac{\sum_{r=1}^{12} (B_r)(C_{rw})}{\sum_{r=1}^{12} B_r} \qquad (27)$$

where

BS_w = beach seine average CPUE in week w

B_r = number of sampleable beaches in region r

C_{rw} = average regional CPUE (as calculated in Equation 12)

Weekly CPUE for the offshore component was calculated by first computing weekly strata densities for each stratum of the river using Equation 28:

$$D_{wrk_r} = \frac{\sum_{i=1}^{n_{k_r}} C_{wrk_r i}}{\sum_{i=1}^{n_{k_r}} V_{wrk_r i}} \qquad (28)$$

TABLE 2-19

REVISED VOLUME (m^3) ESTIMATES USED FOR WEIGHTING STRATA MEANS[a] AND NUMBER OF BEACHES USED FOR WEIGHTING REGIONAL MEANS OF ABUNDANCE FOR THE COORDINATE PAIR INDEX

REGION	BOTTOM VOLUME	SHOAL VOLUME	NUMBER OF BEACHES
Yonkers	0	5,784,084	15
Tappan Zee	20,377,231	26,405,643	25
Croton-Haverstraw	10,665,784	11,698,493	25
Indian Point	10,961,311	2,744,651	22
West Point	8,520,739	0	9
Cornwall	12,060,110	1,766,407	15
Poughkeepsie	20,719,147	0	30
Hyde Park	10,499,936	0	17
Kingston	11,637,437	0	11
Saugerties	14,953,185	0	20
Catskill	13,868,236	0	41
Albany	4,433,636	0	54
			284

[a]For bottom and shoal strata.

where

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

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

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

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

Offshore data from 1985-1987 were adjusted for relative gear efficiency since the beam trawl replaced the epibenthic sled for sampling the bottom and shoal habitats during these years. The adjustment factors correspond to modified bottom and shoal strata volume estimates used to correct offshore density estimates for comparison with epibenthic sled data collected in previous years. They were calculated from data presented in the 1985 Year Class Report (NAI 1986) and are presented in Table 2-19.

These strata density estimates were then combined to form a weekly offshore average density estimate (Equation 29). Percent volumes contained in each stratum were used to weight strata density estimates. The volumes used in calculating the coordinate pair index differed from those used in weighting the CSC index values in that only the volume from which random samples were collected was used in these computations. In the CSC calculation bottom volumes used for calculation of standing crop estimates were defined by the portion of the river within 3 m of the bottom. However, since sampling by the epibenthic sled was limited to the volume within 1 m of the bottom, bottom volumes were reduced to reflect this more limited area, which was actually subject to random sampling. Similarly, assumed shoal volumes used to compute the CSC index (the portion of the region between 3 and 6 m in depth) were larger than the volumes actually subject to sampling. In the FSS, sampling was limited to the shoal bottom using an epibenthic sled and inspection of the data indicated that shoal sampling occurred regularly to depths as shallow as 2 m. Therefore, the corrected shoal volumes correspond to that portion of the river between 2 and 6 m in depth and within 1 m of the bottom.

$$D_w = \frac{\sum_{r=r_s}^{r_e} \sum_{k_r=k_{rs}}^{k_{re}} (V_{rk_r})(D_{wrk_r})}{\sum_{r=r_s}^{r_e} \sum_{k_r=k_{rs}}^{k_{re}} V_{rk_r}} \qquad (29)$$

where

D_w = average offshore density estimate for week w

D_{wrk_r} = estimated stratum density calculated in Equation 34

V_{rk_r} = volume weighting factor for stratum k_r in region r

r_s = first region included in the index

r_e = last region included in the index

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

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

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

2.6.4 Temporal and Geographic Distribution Indices

Distribution indices were computed to facilitate presentation of changes in distribution of selected species and life stages through time and space. A geographic index that collapses data over weeks was calculated for LRS and BSS data as the relative density in each region (Equation 30). To allow comparisons of 1986 and 1987 data with historical data, only April through July data were used for LRS; data from weeks 33 to 40 (where week 1 is the first Monday in January) were used for the BSS. In all cases, data were used only when all 12 regions were sampled.

$$G_{ry} = \frac{\sum_{w=1}^{n_y} D_{rwy}}{\sum_{r=1}^{12} \sum_{w=1}^{n_y} D_{rwy}} \tag{30}$$

where

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

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

n_y = number of weeks sampled in year y

A temporal index that collapses data for the entire river was computed for early life stages from LRS standing crops (Equation 31).

$$T_{wy} = \frac{SC_{wy}}{\sum_{w=1}^{n_y} SC_{wy}} \tag{31}$$

where

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

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

n_y = number of weeks sampled in year y

2.6.5 Growth

Growth in length of larval and juvenile fishes has been described using a number of techniques, including successive exponential segments, Gompertz, and logistic growth functions (Zweifel and Lasker 1976; Ricker 1979). Under laboratory conditions early growth of an individual is marked by (1) an initial period of slow growth, (2) a middle period of rapid growth, and (3) a late season period of slow growth. This sigmoid growth pattern results from the function of anabolic and catabolic processes. Early in the season water temperatures are low and nutritional requirements are met solely from absorption of the yolk-sac. At the onset of feeding growth increases rapidly; increased size brings about increased feeding success, increased prey-searching ability through increased swimming speed and sensory capabilities, and increased ration size through an increase in the ability to handle larger prey items (Hunter 1981). Increasing water temperatures during this period serve to increase the metabolic rate. As the season progresses, decreasing temperatures, decreasing day length, and reduced food availability result in slower growth.

Unfortunately, size variability and size-selective sampling makes the description of growth rates from wild populations somewhat difficult to ascertain. Larvae are generally too small to be retained by the relatively coarse mesh size used in beach seines and trawls and must be sampled with fine mesh nets. Due to their increased swimming and sensory capabilities, however, larvae become increasingly less vulnerable to ichthyoplankton sampling gears (Clutter and Anraku 1968; Hunter 1981). Since all larvae are not the same size at any given time, the size selectivity in ichthyoplankton sampling gear results in growth indices that increasingly underestimate the mean size as the season progresses while size selectivity in the beach seine and trawls results in the overestimate of mean size until the smallest individuals have reached recruitment size. The situation is exacerbated by a protracted spawning period since small individuals are added to the population over an extended period of time.

Estimates of population growth rates for larval and juvenile Hudson River fishes were made from mean length data collected during the 1984 through 1987 sampling programs. Two methods were used, one based on successive exponential segments - a log-linear growth model - and another using the logistics growth model. For the log-linear model size-selection bias is minimized by limiting the analysis to the period of presumably full recruitment that occurs after juvenile fish become vulnerable to sampling gear. This has the disadvantage of estimating growth rates from a limited number of observations and it may also be influenced to some degree by size selectivity in the initial observations. The logistics growth model is estimated from a larger number of observations; however, it may also be influenced to some degree by size selectivity in the initial observations.

2.6.5.1 Log-Linear Growth Model. The log-linear growth model assumes exponential or log-linear growth: (1) from hatching to full recruitment to the beach seine, and (2) from full recruitment to 60 mm (Figure 2-8). Previous Year Class Reports have defined full recruitment size for striped bass and white perch as 30 and 25 mm, respectively (TI 1980a,b). Based on 1984 data, the recruitment size of American shad is 30 mm (MMES 1986).

The dates on which the population mean length reached recruitment size and 60 mm were determined from the following relationship:

$$\ln (L_t) = \ln (L_0) + \beta(t) \qquad (32)$$

where

L_t = mean length at time t

L_0 = predicted mean length at time 0

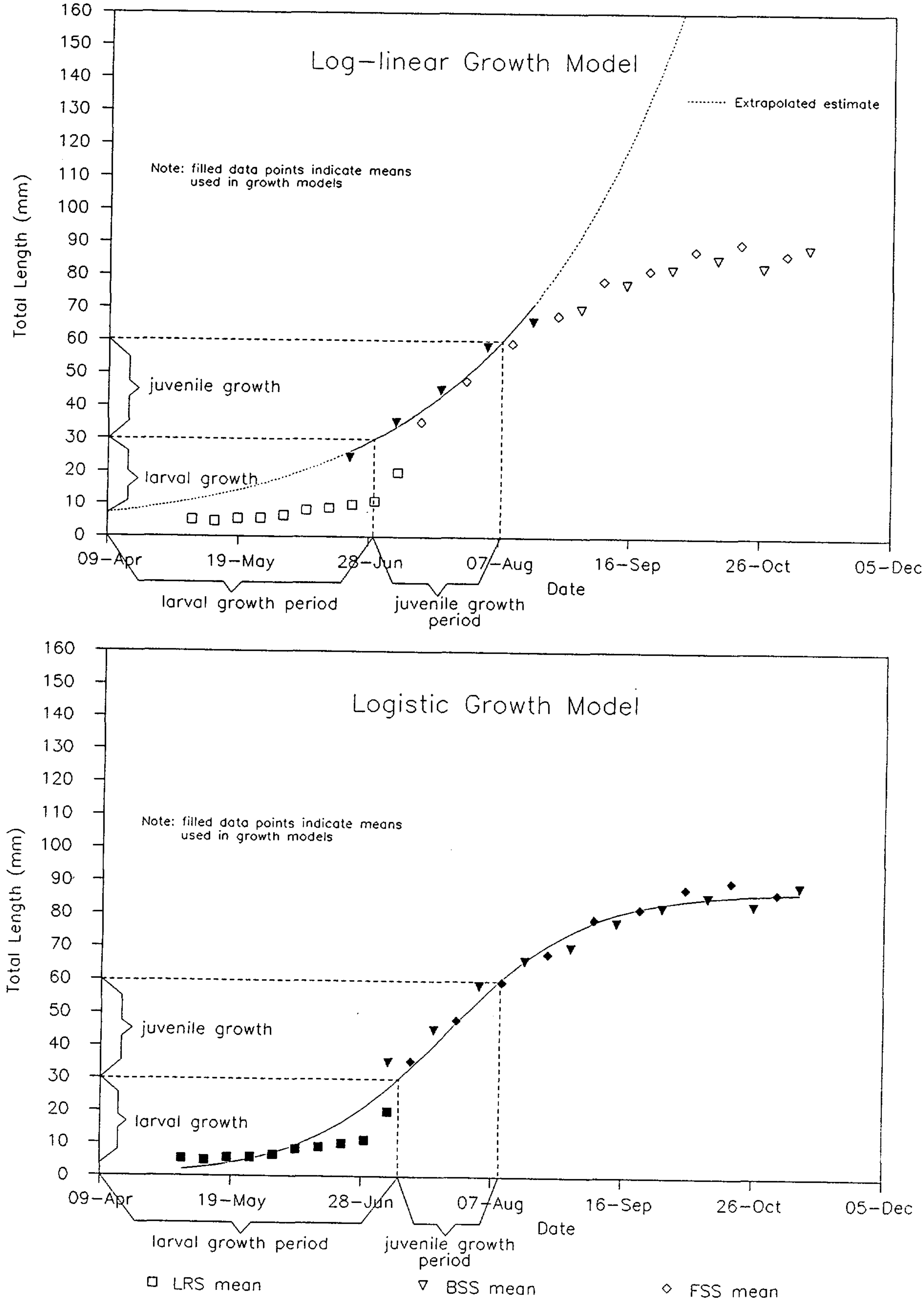
β = instantaneous growth rate

t = number of days since 1 May

The coefficients L_0 and β were estimated using ordinary least-squares regression analysis on log-log transformed BSS data. After solving for L_0 and β,

FIGURE 2-8

MODELS OF FISH POPULATION GROWTH



the equation was rearranged to solve for the dates on which full recruitment and 60 mm TL were reached.

Generally, only the weekly mean lengths from the first sampling period in July to the first week when the mean total length exceeded 60 mm TL were used in the regression analyses. In some cases, however, this criterion left only one to three observations. In order to increase the number of observations in these cases, the mean YSL length from the midweek of peak YSL abundance was included as an additional observation.

The growth rates from hatching to recruitment size were calculated using Equation 33, and the growth rates from recruitment size to 60 mm were calculated using Equation 34.

$$G_L = \frac{r - L_0}{T_r - T_0} \tag{33}$$

where

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

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

L_0 = mean length of YSL (or length at hatching for striped bass)

T_r = number of days since 1 May when length r was reached, estimated using Equation 32

T_0 = number of days since 1 May to the midpoint of the week of YSL (or peak egg for striped bass) standing crop

$$G_J = \frac{60 - r}{T_{60} - T_r} \tag{34}$$

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 was reached, estimated using Equation 32

To determine the growth rate from hatching to recruitment size (G_L), the date of hatching for striped bass was defined as the midpoint of the week of peak egg abundance and mean length at hatching was taken as 4.0 mm. This length selection is based on reports by Westin and Rogers (1978) that mean hatching lengths were between 3.25 and 4.71 mm when hatching was completed at 18°C. The peaks in white perch and American shad egg abundance exhibited by the LRS samples may not accurately reflect peak abundance in the river because of the demersal nature of the eggs of these species. Therefore, the midpoint of the week of peak YSL abundance, rather than eggs peaks, was used in larval growth rate estimates. The larval abundance peaks were determined from the standing crop estimates from the LRS.

2.6.5.2 <u>Logistics Growth Model</u>. Weekly mean lengths (L_t) and the midpoint of the sampling weeks (t) were used to fit the logistics function (Equation 35):

$$L_t = \frac{K}{1 + e^{(A - Rt)}} \qquad (35)$$

The coefficients K, R, and A were derived from the least-squares fit of Equation 35. Equation 35 was rearranged to solve for the dates when recruitment size and 60 mm were reached. Using these dates, the growth rates from hatching to recruitment size and from recruitment size to 60 mm were calculated using the first derivative of the logistic function in the form of Equation 36. The date for hatching for striped bass and peak yolk-sac larvae abundance for white perch and American shad were the same as those estimated for the log-linear model growth estimates.

$$G = \int_{t_0}^{t_1} \left[\frac{RKe^{(A - RT_1)}}{1 + e^{(A - RT_1)^2}}\right] \Big/ \Delta t \qquad (36)$$

where

G = average daily growth rates of larval and early juveniles between hatching and recruitment size or juveniles between recruitment size and 60 mm

t_0 = number of days since 1 April to the midpoint of the week of peak egg (or YSL) standing crop or when recruitment to the beach seine is complete, estimated using Equation 34

t_1 = number of days since 1 April to the date when recruitment to the beach seine is complete or 60 mm is reached, estimated using Equation 34

2.6.6 Center of Abundance Index

To determine relative differences in the movement of size-specific fish distributions over time, an index of the center of abundance was used. Because relative movement of the distribution is the point of interest, it is not necessary for the location of the center of abundance to be the true location of the highest population density. Size-specific population centers were calculated using the following equation:

$$\bar{c}_i = \left(\sum_{j=i}^{n} RM_{ij}\ CPUE_{ij}\right) / \sum_{j=i}^{n} CPUE_{ij} \qquad (37)$$

where

$\bar{c}_i$ = center of abundance for ith size group

RM_{ij} = river mile of capture of ith size group during jth collection

$CPUE_{ij}$ = catch per unit effort for ith size group during jth collection

n = number of collections

The relative changes over time among $\bar{c}_i$ values can be used as an indicator of differences in temporal migration.

CHAPTER 3

WATER QUALITY

Two water quality surveys were conducted in conjunction with fish sampling: the Longitudinal River/Fall Shoals (LRS/FSS) and the Beach Seine (BSS) surveys. This chapter emphasizes results from the LRS/FSS 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 (DO) data are discussed for both surveys. Freshwater flow data obtained from the USGS gauging station at Green Island, New York, were used to assist in further describing and interpreting water quality patterns in the Hudson River. Water quality information from the 1986 and 1987 surveys is presented in Appendix B.

3.1 1986 SURVEY

3.1.1 Temperature

Mean water temperature measured during the LRS/FSS water quality survey increased from the beginning of sampling in April to the end of July, stayed relatively constant through August, and then decreased gradually from September until the end of the sampling program in November (Table 3-1). Peak temperatures occurred during the week beginning 4 August when the riverwide mean was 25.4°C and regional mean values were between 24.5 and 26.1°C (Appendix B). Lowest values occurred during the last week of sampling when mean riverwide temperature was 5.3°C and regional temperatures ranged from 2.6 to 8.6°C.

A comparison of 1986 temperature patterns with those of previous years (Appendix D in Versar 1987) indicates lower peak values in 1986 than in most of the other years. No mean weekly regional temperature exceeded 26.7°C in 1986. Peak regional values regularly exceeded 27°C in previous years and even exceeded 30°C in 1982.

TABLE 3-1

WEEKLY MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES MEASURED IN THE HUDSON RIVER LRS/FSS WATER QUALITY SURVEY IN 1986

WEEK BEGINNING	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
28 Apr	12.4	1.6	9.7
05 May	13.4	2.2	9.9
12	15.3	2.2	10.1
19	17.8	2.3	9.9
26	20.0	0.7	8.5
02 Jun	20.7	1.4	8.1
09	21.0	1.3	8.4
16	21.4	1.6	7.8
23	21.7	0.4	8.3
30	22.3	1.5	8.2
07 Jul	23.7	2.6	8.3
21	25.0	2.5	7.1
04 Aug	25.4	2.2	6.8
18	25.4	1.2	6.8
01 Sep	22.3	3.0	6.9
15	20.7	2.7	7.4
29	20.0	3.0	7.7
13 Oct	16.1	2.6	8.7
27	14.0	3.3	9.1
10 Nov	9.8	1.5	9.7
17	5.3	0.2	11.1

The highest mean regional temperature (pooled over all dates) was found in the Croton-Haverstraw region (Table 3-2), the lowest in the Albany region, but the difference between the two values was less than 1.5°C. The upper estuary was generally warmer than downriver areas during the spring, but was several degrees colder in the fall (Figure 3-1), a pattern also observed in previous years (Appendix D in Versar 1987).

Weekly mean temperatures in the BSS were highest in late July and August just after the program started (Table 3-3). Temperatures fell rapidly in October from 18.0°C during the week of 6 October to 7.2°C by mid-November. Temporal patterns in the BSS temperature data were generally in agreement with LRS/FSS measurements.

The highest mean regional temperature in the BSS (pooled over all dates) occurred in the Indian Point region, the lowest in the Albany region (Table 3-4). Unlike the LRS/FSS, the difference in mean temperature among regions was more than 3°C. The BSS, however, focuses primarily on the last weeks of the LRS/FSS, when the upper estuary was several degrees colder than the lower or middle estuary.

3.1.2 <u>Salinity</u>

Mean weekly salinity measured during the LRS/FSS water quality survey generally increased from late April through October (Table 3-1). The lowest mean salinity in the estuary occurred during the week of 23 June, when the water was fresh in all regions from Indian Point through Albany. The highest weekly mean value, 3.3 ppt, occurred during the week of 27 October.

This salinity pattern can be explained in part by patterns of freshwater flow (Tables 3-5 and 3-6). During April-May, mean flow was 512 m^3/sec. Average flow dropped by 38% in June-July (to 316 m^3/sec) and by another 17% in August-September (to 262 m^3/sec). Flow nearly tripled (320-365 m^3/sec) on 23 and 24

TABLE 3-2

REGIONAL MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES (POOLED OVER ALL WEEKS) MEASURED IN THE HUDSON RIVER WATER QUALITY SURVEY IN 1986

REGIONAL	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
YK	18.5	9.0	7.7
TZ	19.0	4.5	8.5
CH	19.5	2.6	8.4
IP	19.3	1.4	8.1
WP	19.0	0.5	8.1
CW	19.0	0.1	8.4
PK	18.7	0.0	8.4
HP	18.3	0.0	8.7
KG	18.3	0.0	9.2
SG	18.4	0.0	9.5
CS	18.3	0.0	9.1
AL	18.2	0.0	8.7

Note: See Figure 2-1 for explanation of region abbreviations.

FIGURE 3-1

Weekly mean temperature measured in the LRS/FSS water quality survey of the Hudson River in 1986

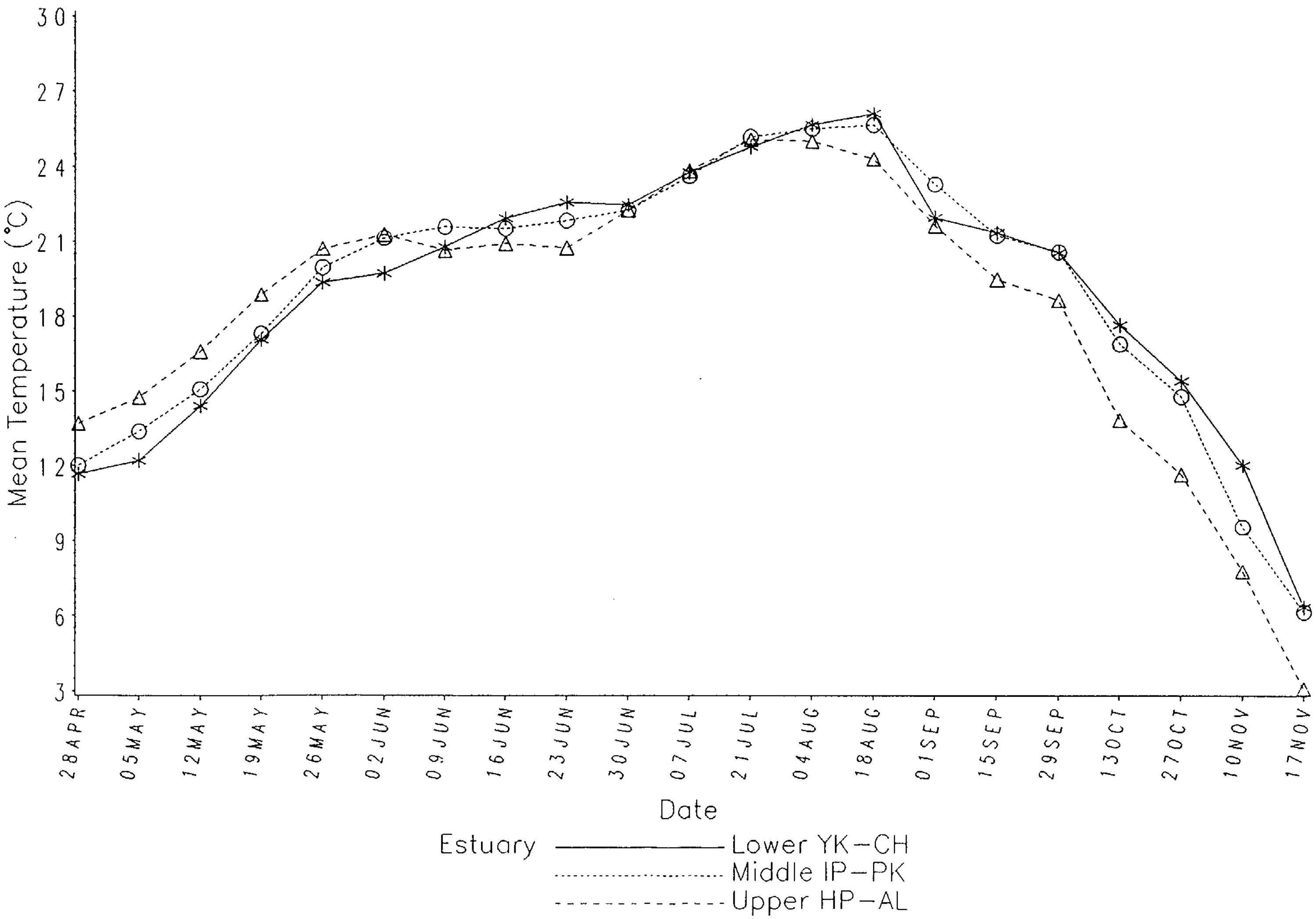


TABLE 3-3

WEEKLY MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES MEASURED IN THE HUDSON RIVER BSS IN 1986

WEEK BEGINNING	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
14 Jul	24.6	2.5	8.5
28	25.5	1.5	7.0
11 Aug	25.8	1.2	8.7
25	24.0	0.9	8.6
08 Sep	22.2	2.5	8.1
22	20.2	2.4	7.8
06 Oct	18.0	1.8	8.9
20	15.3	0.7	9.5
03 Nov	12.0	2.8	9.5
17	7.2	1.0	11.0

TABLE 3-4

REGIONAL MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES (POOLED OVER ALL WEEKS) MEASURED IN THE HUDSON RIVER BSS IN 1986

REGIONAL	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
YK	20.2	8.1	7.6
TZ	19.8	4.3	9.0
CH	20.2	2.5	8.5
IP	20.8	1.6	8.2
WP	20.1	0.4	8.0
CW	19.9	0.2	9.5
PK	19.7	0.0	8.5
HP	18.6	0.0	8.8
KG	18.0	0.0	9.1
SG	18.2	0.0	9.6
CS	18.6	0.0	10.2
AL	17.3	0.0	9.0

Note: See Figure 2-1 for explanation of region abbreviations.

TABLE 3-5

LONG-TERM (1918-1985) AND 1986 MEAN DAILY FRESHWATER FLOW (m^3/sec) RECORDED AT GREEN ISLAND, NEW YORK

MONTH	FLOW (m^3/sec) 1986 AVERAGE	LONG-TERM AVERAGE[a]	LONG-TERM MINIMUM	LONG-TERM MAXIMUM
Jan	308	371	91	961
Feb	358	361	86	885
Mar	1,011	639	178	1,595
Apr	683	881	290	1,461
May	342	546	137	1,156
Jun	404	277	92	839
Jul	228	194	81	637
Aug	307	157	70	414
Sep	218	180	81	612
Oct	337	240	72	854
Nov	545	354	93	929
Dec	524	401	123	948
Annual Average	439[b]	384		

[a]Simple mean of monthly means.
[b]Mean of monthly means weighted by number of days/month.

TABLE 3-6

MONTHLY MEAN DAILY FRESHWATER FLOW (m^3/sec) RECORDED AT GREEN ISLAND, NEW YORK

MONTH	1974	1975	1976	1977	YEAR 1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Jan	623	540	417	225	745	571	256	148	321	259	308	440	308	263
Feb	528	549	885	227	400	336	128	851	361	352	742	319	358	201
Mar	587	671	897	1,233	619	1,253	634	349	620	581	465	581	1,011	596
Apr	854	724	1,041	1,149	950	1,080	748	385	1,085	1,063	940	456	683	897
May	650	566	901	454	530	554	274	328	354	1,037	844	232	342	122
Jun	249	367	431	207	282	236	192	169	432	358	418	157	404	175
Jul	334	211	433	162	131	132	144	140	182	127	289	133	228	162
Aug	180	254	414	154	169	149	130	134	124	155	176	104	307	118
Sep	294	482	271	408	175	221	118	233	122	133	190	171	218	341
Oct	256	663	658	854	244	314	158	457	124	154	181	203	337	466
Nov	487	637	508	664	227	465	242	395	196	339	277	419	545	415
Dec	549	532	399	750	303	430	273	321	233	799	448	330	524	412
Annual	465	516	603	543	398	479	275	322	345	447	438	295	439	347

June, the period of lowest mean salinity, from its average of 118 m^3/sec during the previous week.

As might be anticipated, mean salinity was highest in the Yonkers region and declined quickly with distance upriver (Table 3-2). The highest weekly mean value in this region was 13.8 ppt (Appendix B). The region farthest upriver that had a mean salinity greater than zero was Cornwall.

Similar to previous years, salinity in 1986 was consistently higher in the lower estuary from May through October than in the middle and upper segments for the same period (Figure 3-2). Mean salinity in the upper estuary remained at or near zero throughout the study period.

The salinity patterns observed in the BSS were similar to those observed in the LRS/FSS water quality survey. Mean salinity was highest in the Yonkers region and decreased upstream (Table 3-4); mean weekly salinity never exceeded 0.5 ppt in any region north of Cornwall. Mean weekly salinities for the river exceeded 0.7 ppt in all weeks, with a high value of 2.8 ppt in early November (Table 3-3).

3.1.3 Dissolved Oxygen

DO values measured during the LRS/FSS water quality survey were highest in May and November, with weekly mean values for the river exceeding 8 mg/l until mid-June (Table 3-1). DO values were lowest in midsummer, with more than half the weekly mean values falling below 7 mg/l from early August through mid-September. DO values increased again in the fall.

This pattern of oxygen decline during summer has been observed in all previous Year Class Reports (MMES 1986) and is primarily attributable to the higher temperatures during the warmer months (Figure 3-3). The lowest weekly mean DO value observed in 1986 is within the range of historical values. The highest has been exceeded in many years, but these higher historical values were

FIGURE 3-2

Weekly mean salinity measured in the LRS/FSS water quality survey of the Hudson River in 1986

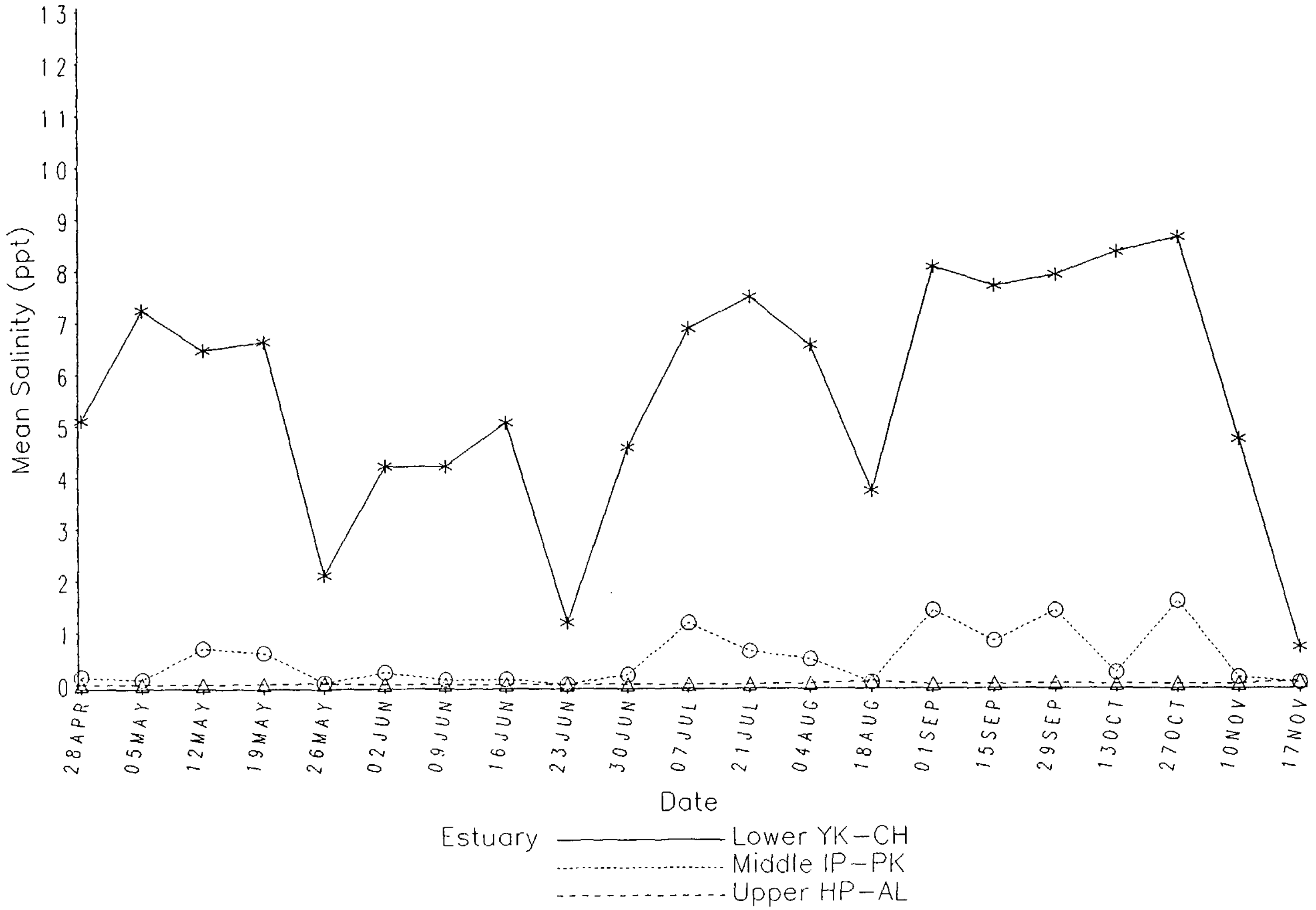
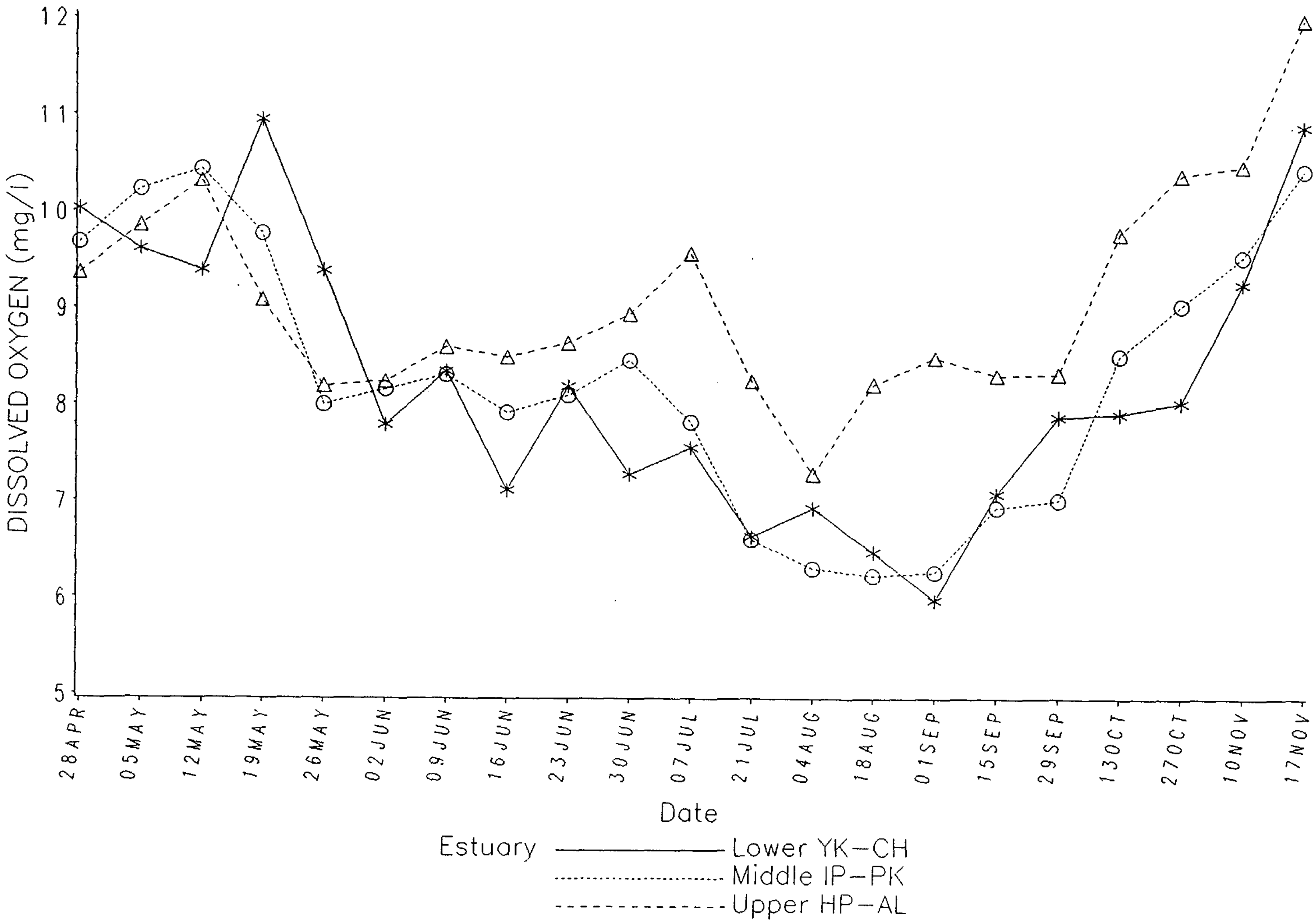


FIGURE 3-3

Weekly mean dissolved oxygen measured in the LRS/FSS water quality survey of the Hudson River in 1986



associated with earlier studies when sampling schedules extended into colder months.

DO values were generally similar in the different segments of the river, varying by about 2 mg/l (Figure 3-3), and were several milligrams per liter higher at the end of the surveys (i.e., fall) than in midsummer, coincident with lower temperatures at that time. Percent oxygen saturation was higher in the upper estuary than in the rest of the river in June, July, and August (Figure 3-4). Highest regional mean DO (pooled over all dates) occurred in the Saugerties region, the lowest in Yonkers (Table 3-2).

DO patterns in the BSS were similar to those in the LRS/FSS: highest values in the fall (Table 3-3) and no consistent regional longitudinal pattern (Table 3-4). DO values were generally about 1 mg/l higher in the BSS than in the LRS/FSS when regional/weekly means are compared. This is consistent with similar comparisons made in previous years and may be related to diel changes in oxygen; the BSS is conducted during the day (when oxygen concentrations are expected to be highest), the LRS/FSS at night.

3.2 1987 SURVEY

3.2.1 Temperature

Mean water temperature measured during the LRS/FSS water quality survey generally increased from the beginning of sampling in April to the end of July and then decreased from September until the program's end in early November (Table 3-7). Peak temperatures occurred during the week beginning 27 July when the riverwide mean was 26.9°C and regional mean values were between 26.4 and 27.9°C (Appendix B). Lowest values occurred during the last week of sampling when mean riverwide temperature was 9.5°C and regional temperatures ranged from 8.9 to 10.1°C.

FIGURE 3-4

Weekly mean percent oxygen saturation measured in the LRS/FSS water quality survey of the Hudson River in 1986

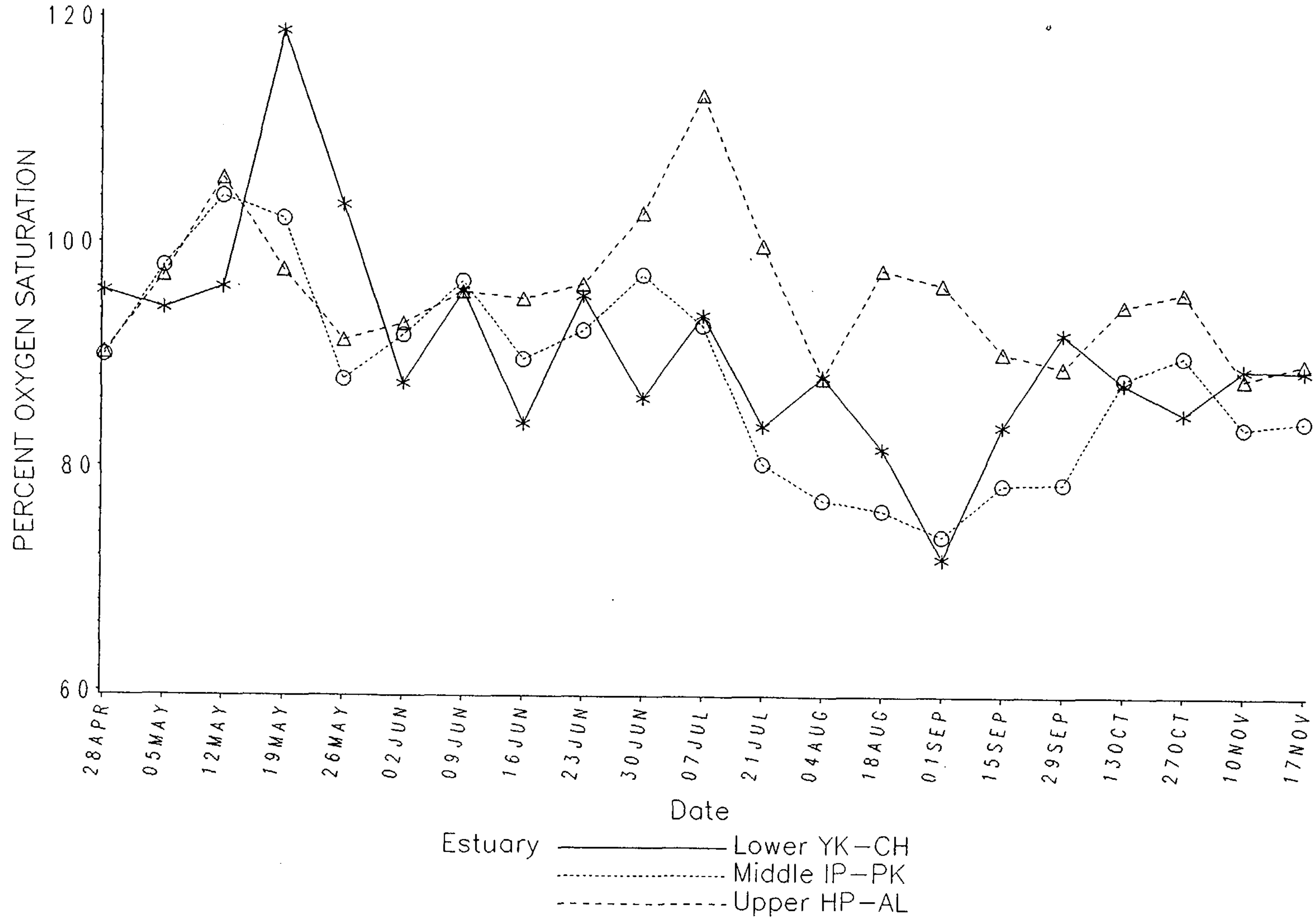


TABLE 3-7

WEEKLY MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES MEASURED IN THE HUDSON RIVER LRS/FSS WATER QUALITY SURVEY IN 1987

WEEK BEGINNING	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
13 Apr	9.5	1.1	10.7
20	12.0[a]	0.0[a]	10.1[a]
27	11.4	1.8	9.5
04 May	12.1	1.2	9.4
11	14.4	2.9	9.7
18	16.0	2.6	9.0
25	17.4	2.7	8.7
01 Jun	19.9	2.6	9.0
08	19.7	3.5	7.9
15	21.7	2.9	7.6
22	22.8	3.3	6.8
29	23.2	3.1	6.7
06 Jul	23.9	3.4	7.6
13	25.8	2.8	7.7
27	26.9	3.3	8.3
10 Aug	25.3	3.3	6.5
24	24.4	3.7	6.7
07 Sep	22.5	2.7	6.8
21	20.0	1.9	7.3
05 Oct	15.4	1.0	9.6
19	12.5	2.9	9.8
02 Nov	10.9	0.3	10.3

[a]Yonkers and Tappan Zee regions not sampled during this week.

A comparison of 1987 temperature patterns with those of previous years (Appendix D in Versar 1987) indicates that riverwide peak temperatures occurred earlier than in most of the other years. In previous years peak values regularly occurred in August except in 1975, 1976, 1979, and 1985.

The highest mean regional temperature (pooled over all dates) was found in the Croton-Haverstraw region (Table 3-8), the lowest in the Kingston region, but the difference between the two values was less than 1.6°C. The upper estuary was generally warmer than downriver areas during the spring, but was several degrees colder in the fall (Figure 3-5), a pattern also observed in previous years (Appendix D in Versar 1987).

Weekly mean temperatures in the BSS were highest in late July and August (Table 3-9). Temperatures fell rapidly in late September, from 18.9°C during the week of 28 September to 7.4°C by early November. Temporal patterns in the BSS temperature data were generally in agreement with LRS/FSS measurements.

The highest mean regional temperature in the BSS (pooled over all dates) occurred in the Croton-Haverstraw region, the lowest in the Albany region (Table 3-10). Unlike the LRS/FSS, the difference in mean temperature among regions was more than 2.5°C. The BSS, however, focuses primarily on the last weeks of the LRS/FSS, when the upper estuary was several degrees colder than the lower or middle estuary.

3.2.2 Salinity

Mean weekly salinity measured during the LRS/FSS water quality survey generally increased from April through August and decreased from September to November (Table 3-7). The lowest mean salinity in the estuary occurred during the week of 2 November, when the water in all regions from Croton-Haverstraw through Albany was fresh. The highest weekly mean value, 3.7 ppt, occurred during the week of 24 August.

TABLE 3-8

REGIONAL MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES (POOLED OVER ALL WEEKS) MEASURED IN THE HUDSON RIVER LRS/FSS WATER QUALITY SURVEY IN 1987

REGIONAL	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
YK	18.7	9.9	7.4
TZ	19.2	5.9	8.2
CH	19.7	3.8	8.2
IP	19.4	2.7	8.0
WP	18.9	1.3	8.4
CW	18.9	0.5	8.7
PK	18.7	0.1	8.3
HP	18.6	0.0	8.4
KG	18.1	0.0	9.0
SG	18.2	0.0	9.1
CS	18.5	0.0	9.2
AL	18.6	0.0	8.5

Note: See Figure 2-1 for explanation of region abbreviations.

FIGURE 3-5
Weekly mean temperature measured in the LRS/FSS water quality survey of the Hudson River in 1987

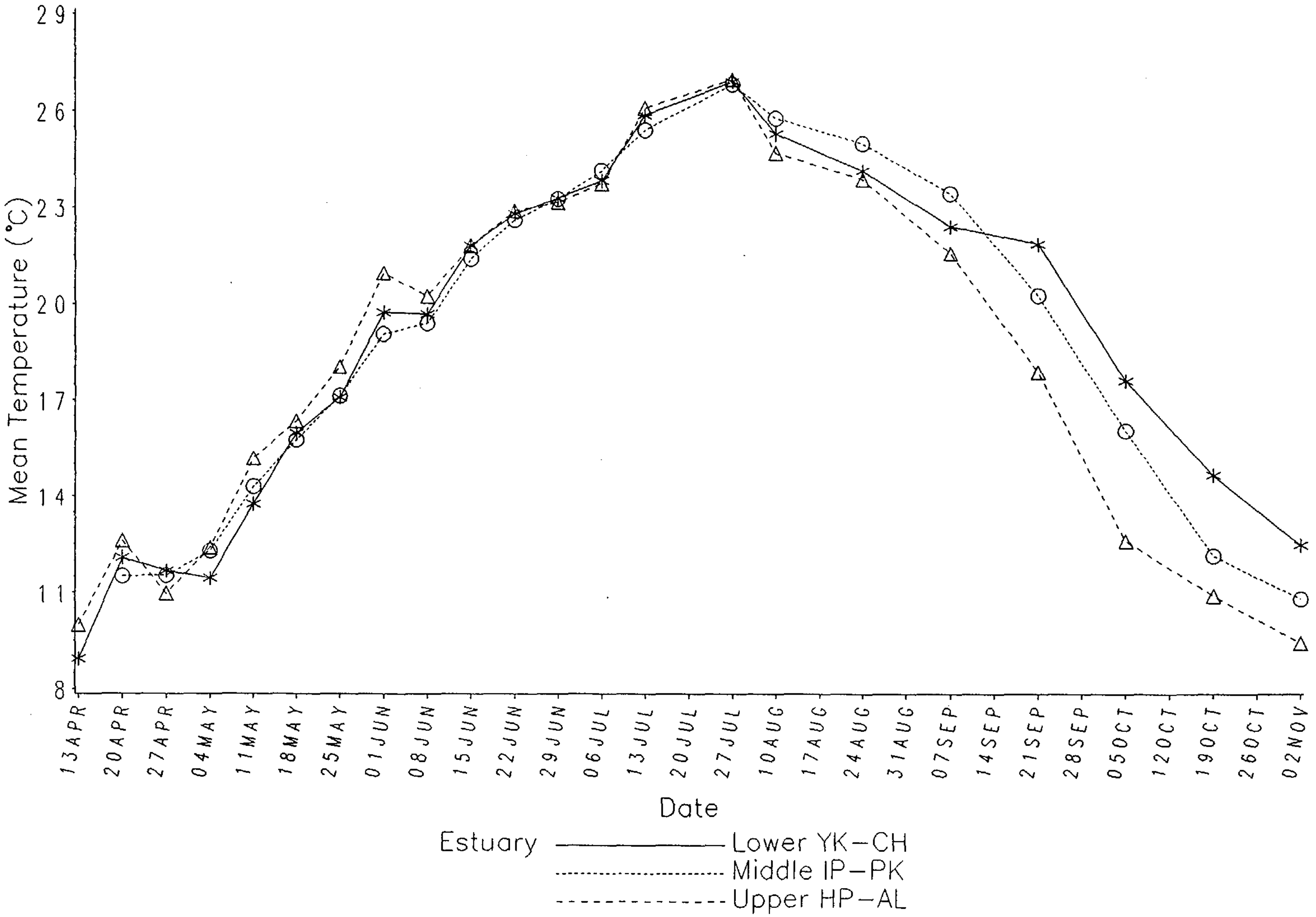


TABLE 3-9

WEEKLY MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES MEASURED IN THE HUDSON RIVER BSS IN 1987

WEEK BEGINNING	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
22 Jun	24.8	3.1	8.5
06 Jul	24.2	2.2	8.0
20	27.6	2.1	8.4
03 Aug	27.2	2.8	8.3
17	27.7	2.7	9.3
31	23.0	3.0	7.9
14 Sep	22.5	1.4	8.3
28	18.9	1.0	8.7
12 Oct	13.0	0.3	10.6
26	12.0	1.8	10.2
09 Nov	7.4	0.4	12.2

TABLE 3-10

REGIONAL MEAN TEMPERATURE, SALINITY, AND DISSOLVED OXYGEN VALUES (POOLED OVER ALL WEEKS) MEASURED IN THE HUDSON RIVER BSS IN 1987

REGIONAL	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
YK	21.6	6.8	8.6
TZ	21.5	4.5	9.7
CH	22.0	3.1	9.4
IP	21.8	2.4	8.7
WP	20.3	0.7	8.2
CW	20.3	0.5	9.3
PK	20.4	0.0	8.7
HP	20.5	0.0	9.2
KG	20.0	0.0	9.7
SG	19.6	0.0	9.7
CS	20.0	0.0	9.8
AL	19.4	0.0	9.2

Note: See Figure 2-1 for explanation of region abbreviations.

This salinity pattern can be explained in part by patterns of freshwater flow (Tables 3-6 and 3-11). During April, mean flow was 897 m^3/sec. Average flow dropped by 83% in May-June (to 149 m^3/sec) and by another 6% in July-August (to 140 m^3/sec). The flow then tripled to 403 m^3/sec during September-October, which caused the salinity to decline over this two-month period.

As might be anticipated, mean salinity was highest in the Yonkers region and declined quickly with distance upriver (Table 3-8). The highest weekly mean value in this region was 13.5 ppt (Appendix B). The region farthest upriver that had a mean salinity greater than zero was Poughkeepsie.

Similar to previous years, salinity in 1987 was consistently higher in the lower estuary from May through October than in the middle and upper segments for the same period (Figure 3-6). Mean salinity in the upper estuary remained at or near zero throughout the study period.

The salinity patterns observed in the BSS were similar to those observed in the LRS/FSS water quality survey. Mean salinity was highest in the Yonkers region and decreased upstream (Table 3-10); mean weekly salinity never exceeded 0.5 ppt in any region north of Cornwall. Mean weekly salinities for the river exceeded 0.3 ppt in all weeks, with a high value of 3.1 ppt in late June (Table 3-9).

3.2.3 Dissolved Oxygen

DO values measured during the LRS/FSS water quality survey were highest in April and November, with weekly mean values for the river exceeding 8 mg/l until early June (Table 3-7). DO values were lowest in midsummer, with more than half of the weekly mean values falling below 7 mg/l from late June through mid-September. DO values increased again in the fall.

This pattern of oxygen decline during summer has been observed in all previous Year Class Reports (MMES 1986) and is primarily attributable to the higher

TABLE 3-11

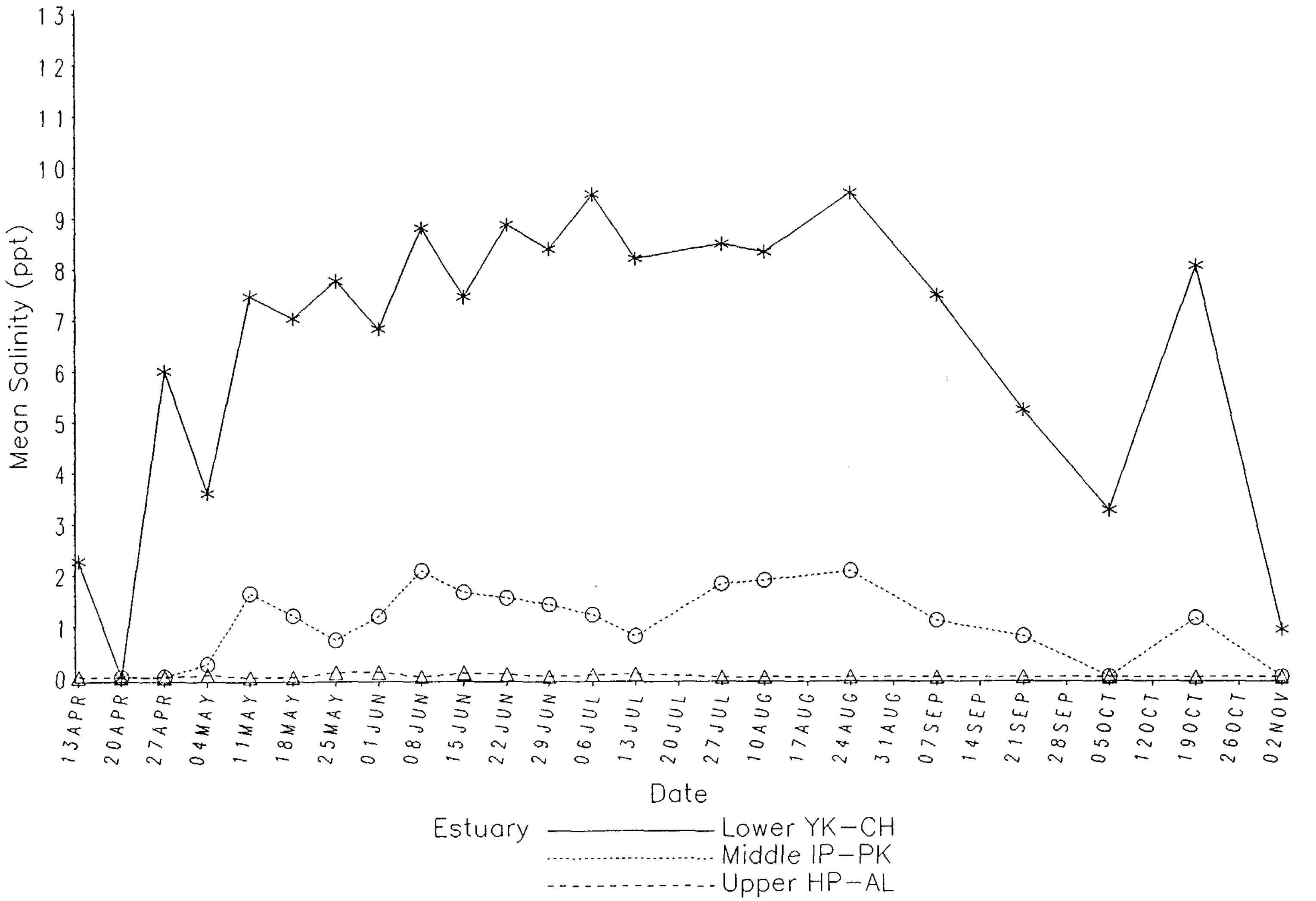
LONG-TERM (1918-1986) AND 1987 MEAN DAILY FRESHWATER FLOW (m^3/sec) RECORDED AT GREEN ISLAND, NEW YORK

MONTH	FLOW (m^3/sec) 1987[a] AVERAGE	LONG-TERM AVERAGE[b]	LONG-TERM MINIMUM	LONG-TERM MAXIMUM
Jan	263	364	91	961
Feb	201	361	86	885
Mar	596	648	178	1,595
Apr	897	878	290	1,461
May	122	544	137	1,156
Jun	175	279	92	839
Jul	162	195	81	637
Aug	118	160	70	414
Sep	341	181	81	612
Oct	466	241	72	854
Nov	415	357	93	929
Dec	412	403	123	948
Annual Average	347[a]	384		

[a]Provisional data.
[b]Mean of monthly means weighted by number of days/month.

FIGURE 3-6

Weekly mean salinity measured in the LRS/FSS water quality survey of the Hudson River in 1987



temperatures that occur during the warmer months (Figure 3-7). The lowest weekly mean DO value observed in 1987 is within the range of historical values. The highest has been exceeded in many years, but these higher historical values were associated with earlier studies when sampling schedules extended into colder months.

DO values were generally similar in the different segments of the river, varying by about 1-3 mg/l (Figure 3-7), and were several milligrams per liter higher at the end of the surveys (i.e., fall) than in midsummer, coincident with lower temperatures at that time. Percent oxygen saturation was usually higher in the upper estuary than in the rest of the river in June, July, and August (Figure 3-8). Highest regional mean DO (pooled over all dates) occurred in the Coxsackie region, the lowest in Yonkers (Table 3-8).

DO patterns in the BSS were similar to those in the LRS/FSS: highest values in the fall (Table 3-9) and no consistent longitudinal pattern (Table 3-10). DO values were generally about 1 mg/l higher in the BSS than in the LRS/FSS when regional/weekly means are compared. This is consistent with similar comparisons made in previous years and may be related to diel changes in oxygen, especially in the shore zone which has higher concentrations of rooted aquatic growth; the BSS is conducted during the day (when oxygen concentrations are expected to be highest), the LRS/FSS at night.

3.3 VARIABILITY AND PREDICTABILITY OF ENVIRONMENTAL PARAMETERS

3.3.1 Temperature

3.3.1.1 Temporal Patterns. One of the primary factors influencing reproduction, migration, distribution, growth, and survival of fishes in estuaries is water temperature. To assess variability and predictability of water temperature in the Hudson River, the long-term records from the Poughkeepsie Water Works (PWW), located just north of the City of Poughkeepsie, New York, at Rkm 122 (RM 76) were analyzed. Mean river temperatures from 1951 to 1987 were

FIGURE 3-7

Weekly mean dissolved oxygen measured in the LRS/FSS water quality survey of the Hudson River in 1987

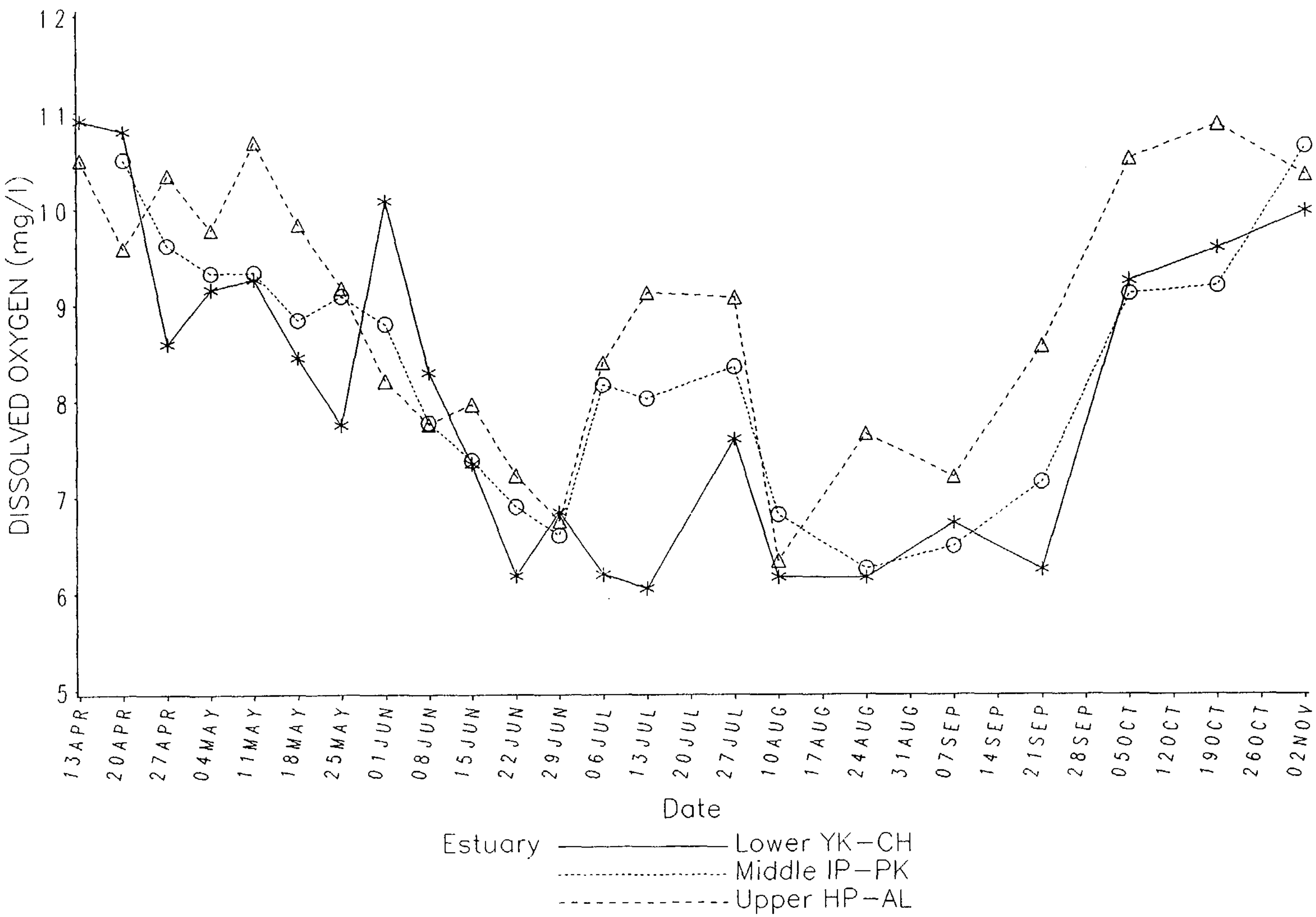
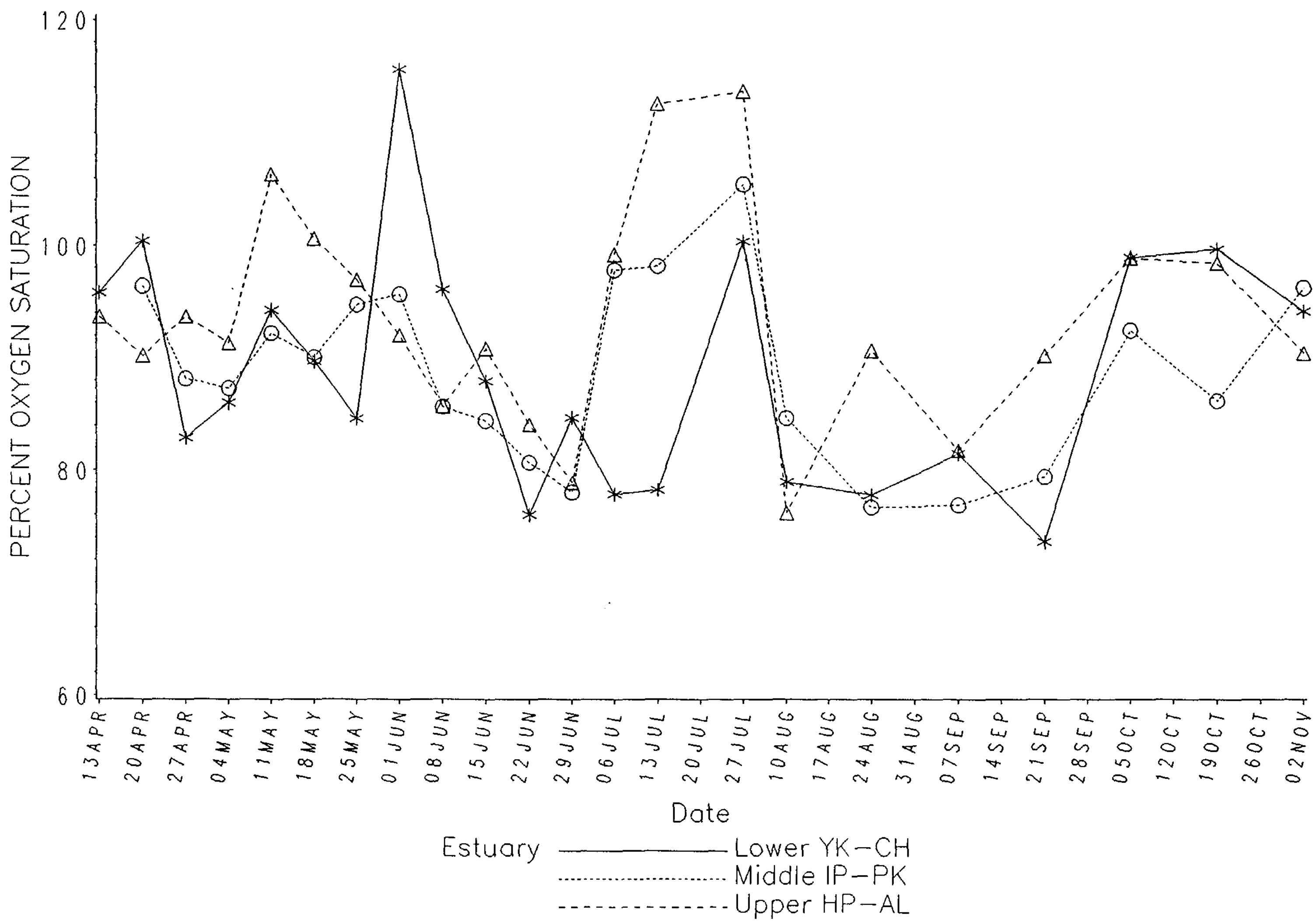


FIGURE 3-8
Weekly mean percent oxygen saturation measured in the LRS/FSS water quality survey of the Hudson River in 1987



available for analysis. Although temperatures were recorded daily for most of this period, beginning in June 1982 they were not recorded on weekends or major holidays. To fill in the missing values, the temperature from the nearest preceding day was substituted for the missing points.

Daily variability over the 37-year period of record (1951-1987) is summarized in Figure 3-9 and detailed in Appendix C. Water temperatures cycle on an annual basis, with the low, averaging approximately 1.0°C, occurring in January and February, the high, averaging approximately 25°C, in August. From April through June temperatures increase at an average rate of approximately 0.2°C per day; from mid-September through mid-December temperatures fall at the same rate. On corresponding days over the 37-year period the daily January and February temperatures ranged from a low of 0°C to a high of 5°C; August temperatures ranged from a low of 21.7°C to a high of 27.8°C.

The observed range in temperature variability suggests that if temperature was the only factor controlling the timing of such biological processes as spawning or migration, then considerable year-to-year differences would be expected. For example, striped bass spawning typically occurs when spring temperatures reach approximately 15°C (TI 1981). Therefore, spawning may be expected as early as 4 May or as late as 5 June. The actual periods of peak spawning correspond closely to this range. TI (1981) cites the period of peak spawning as from 6 May through 5 June during 1974-1979.

During the period of record the average annual temperature was 12.38°C (SD=0.51). On the basis of values greater than ± one standard deviation from the mean, the years 1951, 1960, 1962, 1963, 1972, 1974, and 1976 were cooler than average; 1957, 1959, 1964, 1968, 1983, 1984, and 1985 were warmer than average (Figure 3-10).

To further quantify the predictability and variability of Hudson River water temperatures, a Box-Jenkins (Box and Jenkins 1976) model was fit to weekly average temperatures (Figure 3-11). The water temperature series was found to

FIGURE 3-9

HUDSON RIVER WATER TEMPERATURE

Daily Variation

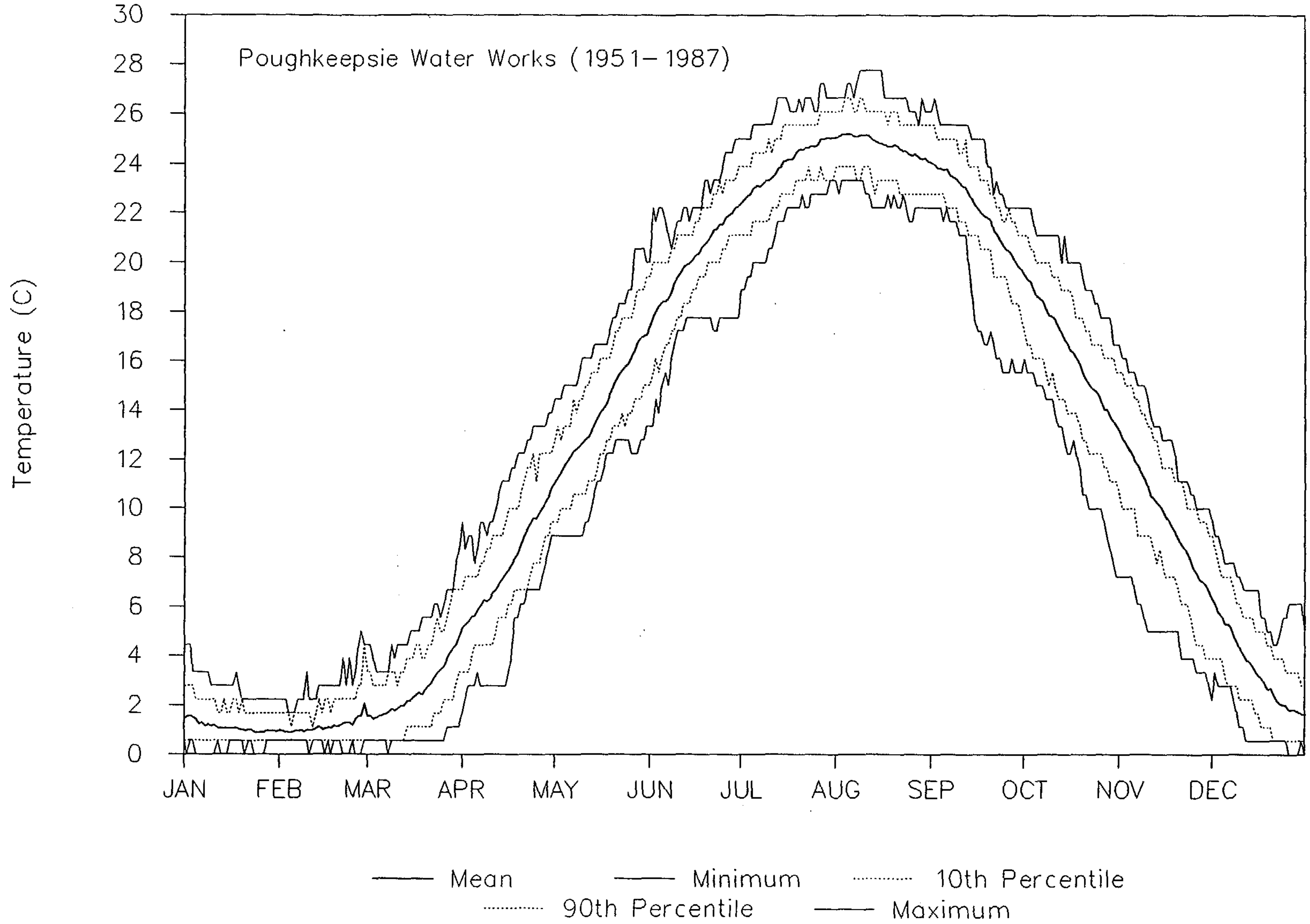


FIGURE 3-10
HUDSON RIVER WATER TEMPERATURE

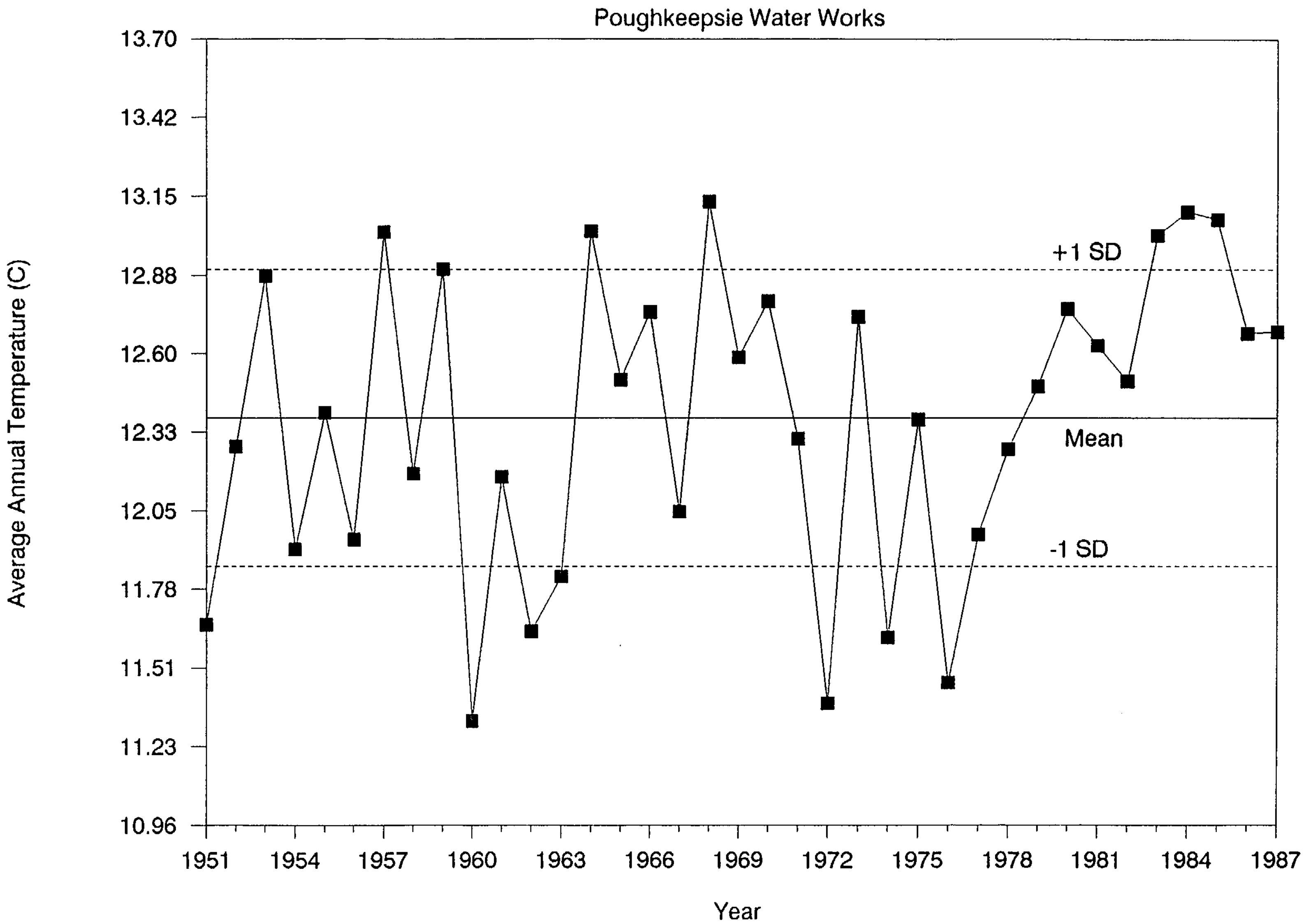
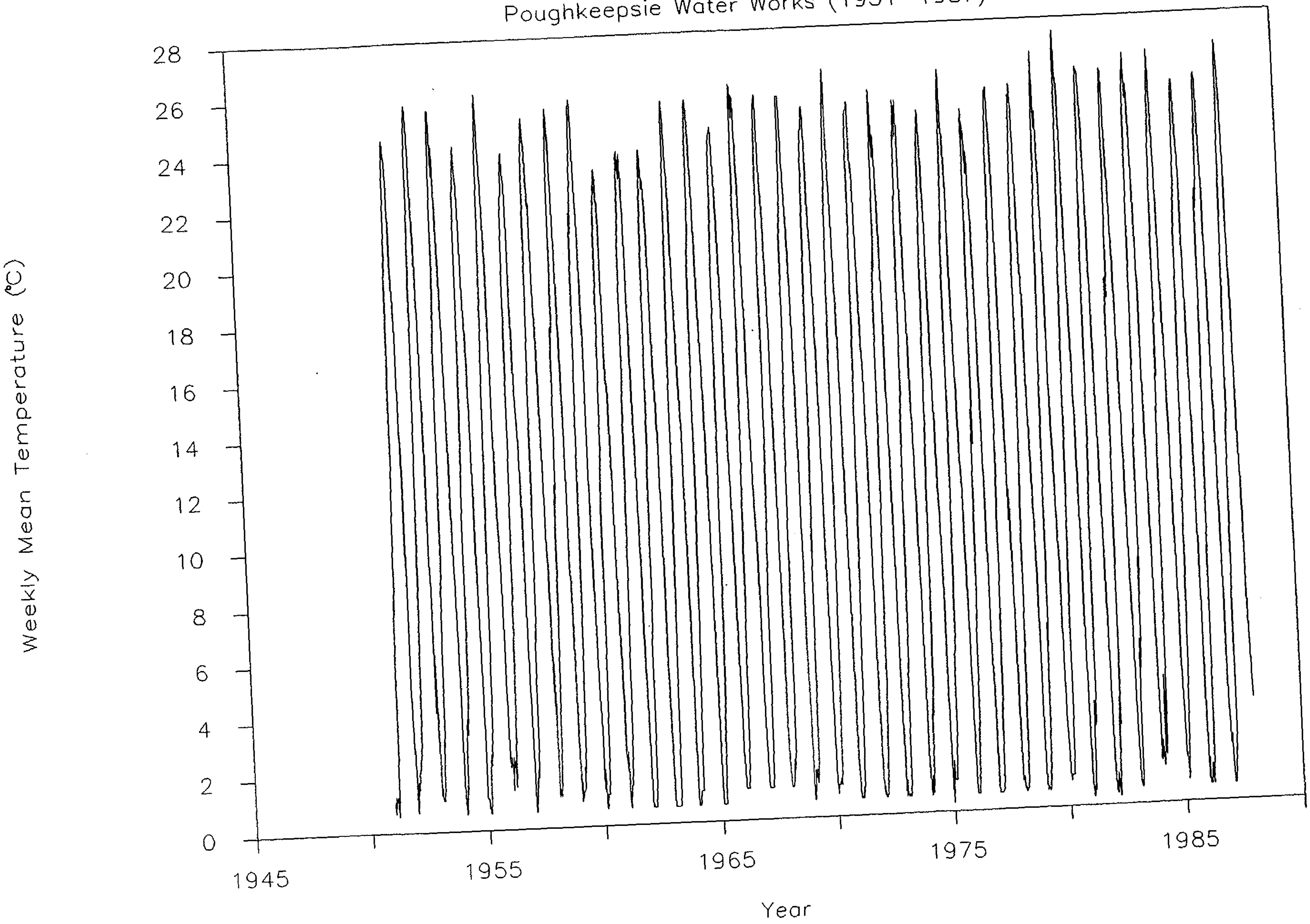


FIGURE 3-11

HUDSON RIVER WATER TEMPERATURE

Poughkeepsie Water Works (1951–1987)



be adequately modeled by a second-order autoregressive process (AR2) after seasonal decomposition and removal of a linear trend. The dominant source of variation in Hudson River water temperatures was the seasonal cycle, accounting for over 99% of the total variation (Table 3-12). Autocorrelation analysis indicated a very high degree of correlation among observations at 52-week, i.e., one-year, intervals. The weekly coefficients describing this seasonal cycle are presented in Table 3-13.

The linear trend is described by the relationship $x_i = 12.15141 + 0.0002631i$, where i is weeks since 1 January 1951. Although this component accounts for only a small proportion of the total variance, less than 0.01%, it compares favorably with other assessments of recent climatic trends. The coefficient for this component, 0.0002631 per week, indicates that the average water temperature has increased 0.51°C over the 37-year period. Hansen and Lebedeff (1987) indicate an approximate 0.7°C rise in temperature over the last 100 years in the northern hemisphere. This equates to a rise of 0.007°C per year compared to our estimate for the Hudson River estuary of 0.014°C per year. (We emphasize that this analysis describes past trends. It is not intended to be used as the basis for predicting future trends.)

After removal of the seasonal and linear trends, a significant amount of the remaining variation was explained by the high degree of autocorrelation among observations, i.e., higher than average temperatures during one week tend to be followed by higher than average temperatures in subsequent weeks; lower than average temperatures are followed by lower than average temperatures in subsequent weeks. The autocorrelation function of the series indicated an exponential dampening, with significant correlations at numerous lag periods; the partial autocorrelation function indicated significant correlations at only the first two lag periods, suggesting a second-order autoregressive model. This conclusion was further supported by examination of the residual mean sum of squares from various alternative models. The final maximum likelihood solution was:

TABLE 3-12

COEFFICIENT OF DETERMINATION (r^2) AND CUMULATIVE VARIANCE EXPLAINED FOR POUGHKEEPSIE WATER WORKS TEMPERATURE (1951-1987) AND GREEN ISLAND FRESHWATER DISCHARGE (1947-1987) TIME SERIES MODELS

STEP	SOURCE	r^2	VARIANCE EXPLAINED
Water Temperature			
1	Seasonal cycle	0.9980	799.037
2	Linear trend	0.9980	799.058
3	AR2	0.9995	800.202
Freshwater Discharge			
1	Seasonal cycle	0.3739	799.037
2	Linear trend	0.3742	799.058
3	AR2	0.5776	800.202

TABLE 3-13

SEASONAL COEFFICIENTS FOR WATER TEMPERATURE AND FRESHWATER DISCHARGE MODELS

WEEK	TEMPERATURE	FLOW	WEEK	TEMPERATURE	FLOW
1	-10.93	1690.7	27	10.47	-3651.8
2	-11.23	2897.4	28	11.19	-4055.0
3	-11.33	913.8	29	11.95	-3825.1
4	-11.45	-102.3	30	12.43	-4312.0
5	-11.46	919.5	31	12.73	-5558.5
6	-11.44	-521.7	32	12.78	-6177.6
7	-11.34	-337.9	33	12.47	-7503.7
8	-11.18	-617.1	34	12.18	-7595.8
9	-10.86	203.0	35	11.81	-7908.2
10	-10.63	511.4	36	11.32	-7843.2
11	-10.15	92.8	37	10.45	-7982.3
12	-9.51	1801.4	38	9.26	-7813.7
13	-8.12	3938.8	39	7.94	-7878.2
14	-6.69	7802.1	40	6.68	-7715.5
15	-5.69	7198.9	41	5.34	-7986.5
16	-4.15	16616.3	42	3.83	-7444.4
17	-2.51	13851.5	43	2.31	-6351.3
18	-0.92	15425.8	44	0.87	-6030.3
19	0.32	16509.1	45	-0.77	-5262.0
20	1.74	13446.2	46	-2.38	-4053.2
21	3.41	12270.2	47	-3.93	-3079.9
22	4.89	7672.2	48	-5.61	-3055.2
23	6.23	7777.8	49	-7.15	-2728.4
24	7.54	5209.2	50	-8.64	-90.0
25	8.68	1843.4	51	-9.82	100.9
26	9.63	-1293.6	52	-10.57	82.2

$$x_t = 1.0395\, x_{t-1} - 0.2376\, x_{t-2} + Z_t$$

where

x_{t-1} = detrended and deseasonalized temperature at time t-1

x_{t-2} = detrended and deseasonalized temperature at time t-2

Z_t = random shock

The second-order autoregressive model successfully reduced the residual variation to randomness, or white noise (Portmanteau test $\chi^2_{18} = 16.83$, $P>0.05$). The small size of the residual variance, 0.4388 (from an initial variance of 800.6413), indicates that average weekly water temperatures are highly predictable from the time-series model.

To determine periods of unusually high or low temperature, deviations from weekly average temperatures were examined. A plot of smoothed (5-point moving average) residuals indicates a period of cooler than average temperatures during the early to mid-1960s and late 1970s (Figure 3-12). Warmer than average temperatures occurred during the mid- to late 1960s and mid-1980s.

Seasonal variability was examined from the standard deviations of the weekly temperature residuals. A plot of these values (Figure 3-13) indicates that variability is lowest, SD≈0.4°C, during January and February (weeks 1-8). Greatest variability, SD>1.3°C, occurred from April through early June (weeks 13-23) and again from late September through early December (weeks 39-49). Peak variability, SD=1.8°C, occurred during early June. Temperatures are moderately variable during the summer (weeks 24-38).

3.3.1.2 Spatial Patterns. Although the PWW data set provides a relatively extensive temporal description of Hudson River water temperatures, it does so for only a single location along the river's length. Since fish generally have free access to most of the river below the Troy Dam, it is essential to have an understanding of the predictability and variability throughout the river. The most complete data set for riverwide temperatures is from the

FIGURE 3-12

HUDSON RIVER WATER TEMPERATURE

Poughkeepsie Water Works (1951-1987)

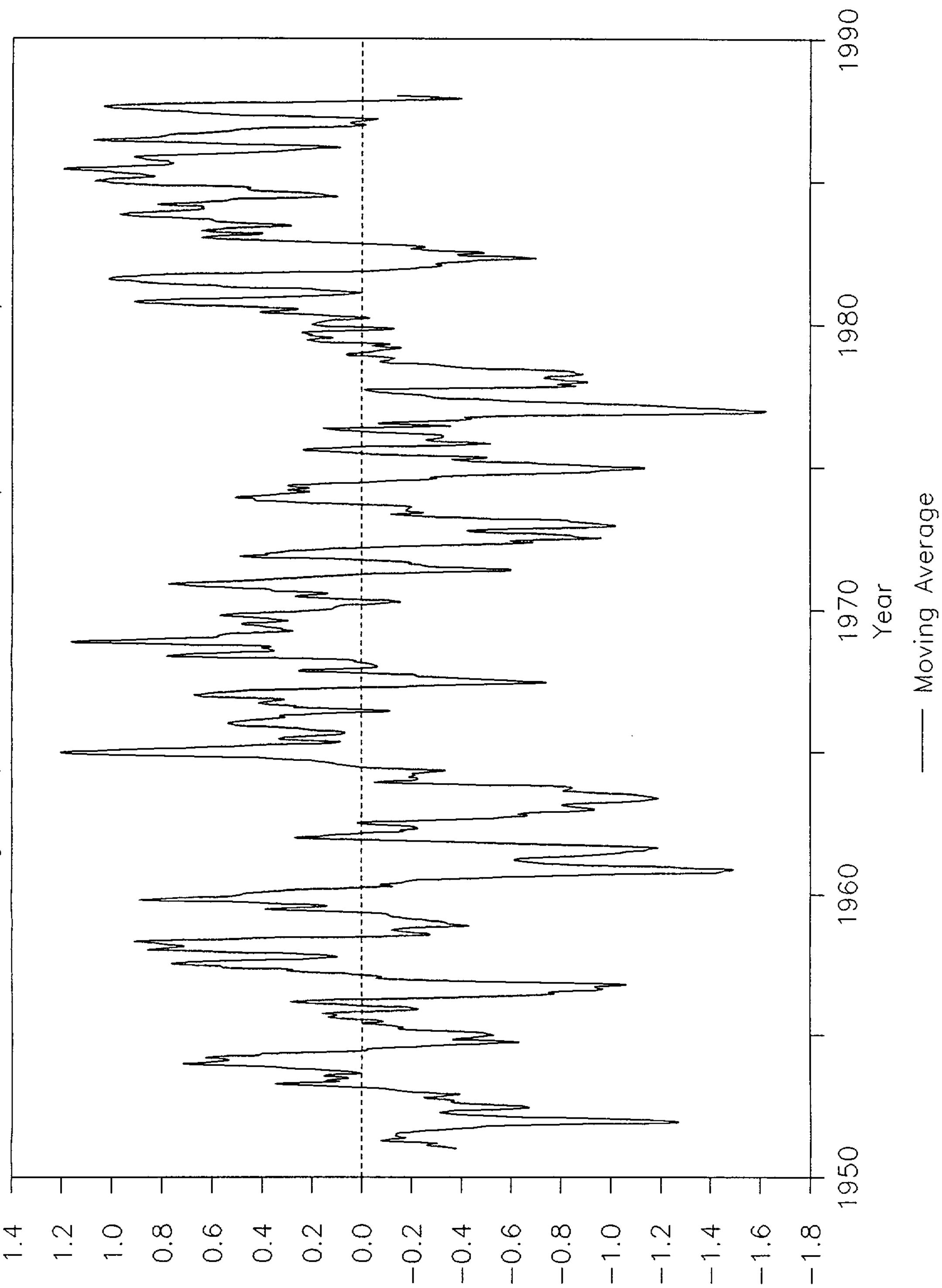
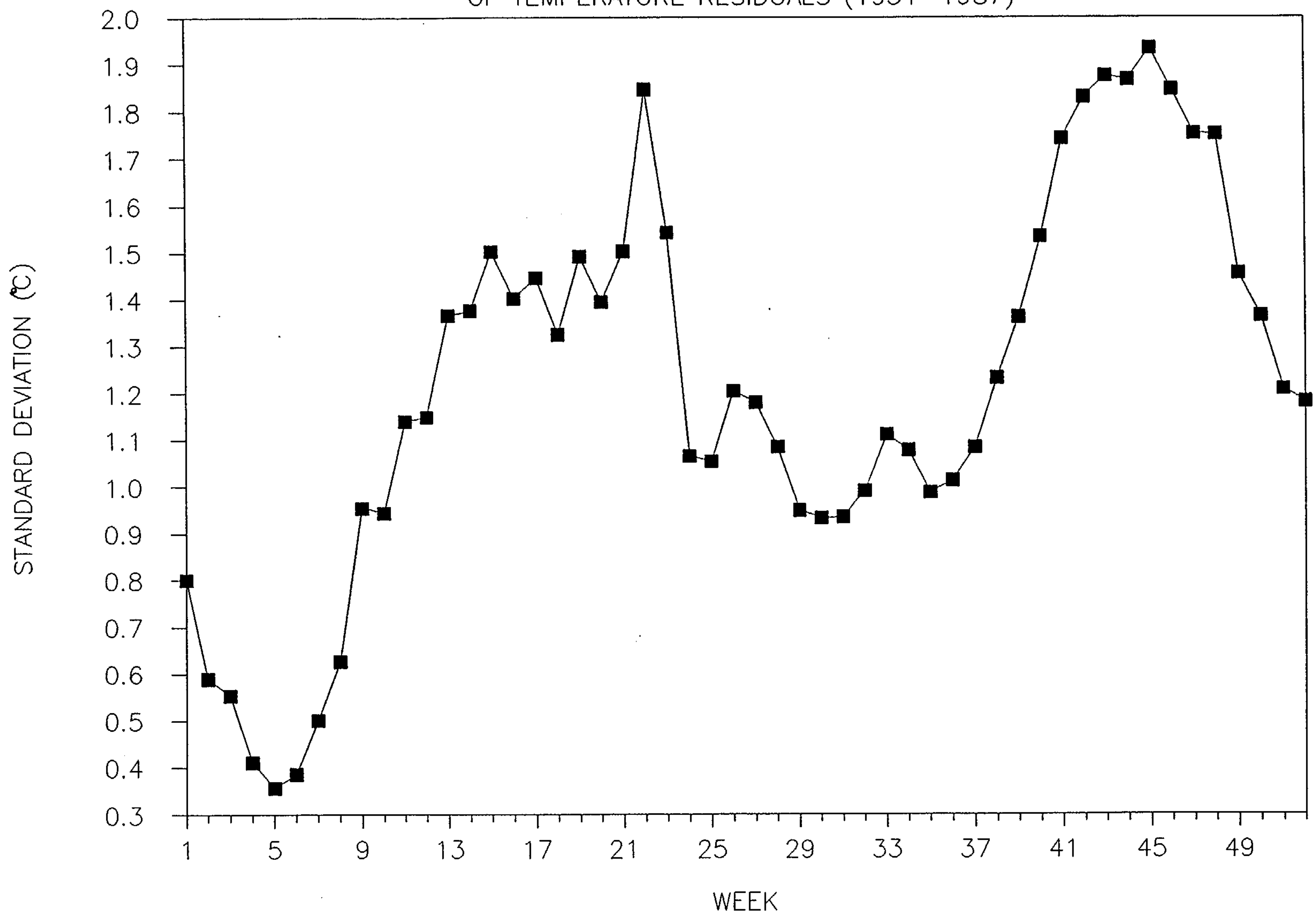


FIGURE 3-13

STANDARD DEVIATION

OF TEMPERATURE RESIDUALS (1951-1987)



Hudson River Utilities (HRU) LRS, FSS, and BSS sampling programs conducted from 1974 through 1987. The relationship between the PWW and the weekly average regional water temperature for the 12 regions of the HRU sampling program was examined through regression and correlation analysis as well as through graphical analysis.

Regression and correlation analysis results indicate a high degree of similarity in temperature values between the 12 regions and the PWW. Correlation coefficients are all positive and highly significant ($P<0.001$), ranging from a high of 0.9762 for Hyde Park to a low of 0.9607 for Yonkers (Table 3-14). Similarity in temperature between the PWW (Rkm 122; RM 76) and the Hyde Park region (Rkm 124-137; RM 77-85) would be expected to be the greatest, based on location. The least similarity in temperature would be expected for the Yonkers region, based on the marine influence in the lower estuary. In fact, correlation analysis indicates a high degree of similarity among all regions, 0.9286 to 0.9946 (Table 3-15), but a greater degree of similarity between spatially proximal regions.

Further investigation of the regression results indicates a nearly consistent decrease in intercepts and an increase in slopes of the regressions as one moves upriver (Table 3-14). The slope of the relationship would be expected to be 1.0 and the intercept 0.0 if the regional mean water temperature is the same as the PWW temperature. As with the correlation coefficients, the PWW temperatures most closely resemble those from the Hyde Park region. The Hyde Park slope and intercept values of 0.994 and -0.334, respectively, come closest to expected and are not statistically different from 1.0 and 0.0 ($P>0.05$).

The nearly consistent trends in slope and intercept values suggest a systematic departure of temperatures from the PWW temperatures. The nature of this departure is evident in plots of the average weekly PWW temperature over the period 1951-1987 compared to the average regional temperature over the period 1974-1987 (Figure 3-14). All regions appear to closely track the PWW temper-

TABLE 3-14

COMPARISON BETWEEN POUGHKEEPSIE WATER WORKS AND REGIONAL WEEKLY MEAN WATER TEMPERATURE, 1974-1987

REGION	n	INTERCEPT	SLOPE	SE SLOPE	RMSE	CORRELATION COEFFICIENT r	F-RATIO	PROBABILITY >F
YK	304	2.343	0.874	0.015	1.630	0.9607	3613.15	<0.001**
TZ	304	2.037	0.906	0.014	1.527	0.9675	4427.33	<0.001**
CH	305	1.931	0.925	0.014	1.584	0.9670	4368.99	<0.001**
IP	306	1.677	0.935	0.015	1.710	0.9627	3851.05	<0.001**
WP	302	1.464	0.927	0.014	1.576	0.9661	4198.86	<0.001**
CW	302	1.234	0.943	0.013	1.417	0.9732	5371.34	<0.001**
PK	302	0.816	0.959	0.013	1.380	0.9751	5797.00	<0.001**
HP	249	-0.334	0.994	0.014	1.097	0.9762	4995.63	<0.001**
KG	251	-0.737	1.013	0.014	1.174	0.9747	4727.37	<0.001**
SG	248	-0.721	1.010	0.016	1.260	0.9710	4058.53	<0.001**
CS	248	-1.115	1.034	0.017	1.368	0.9692	3826.49	<0.001**
AL	245	-1.805	1.068	0.019	1.494	0.9627	3076.13	<0.001**

Note: See Figure 2-1 for explanation of region abbreviations.
n - sample size; RMSE - root mean square error.
**Highly significant, P<0.01.

TABLE 3-15

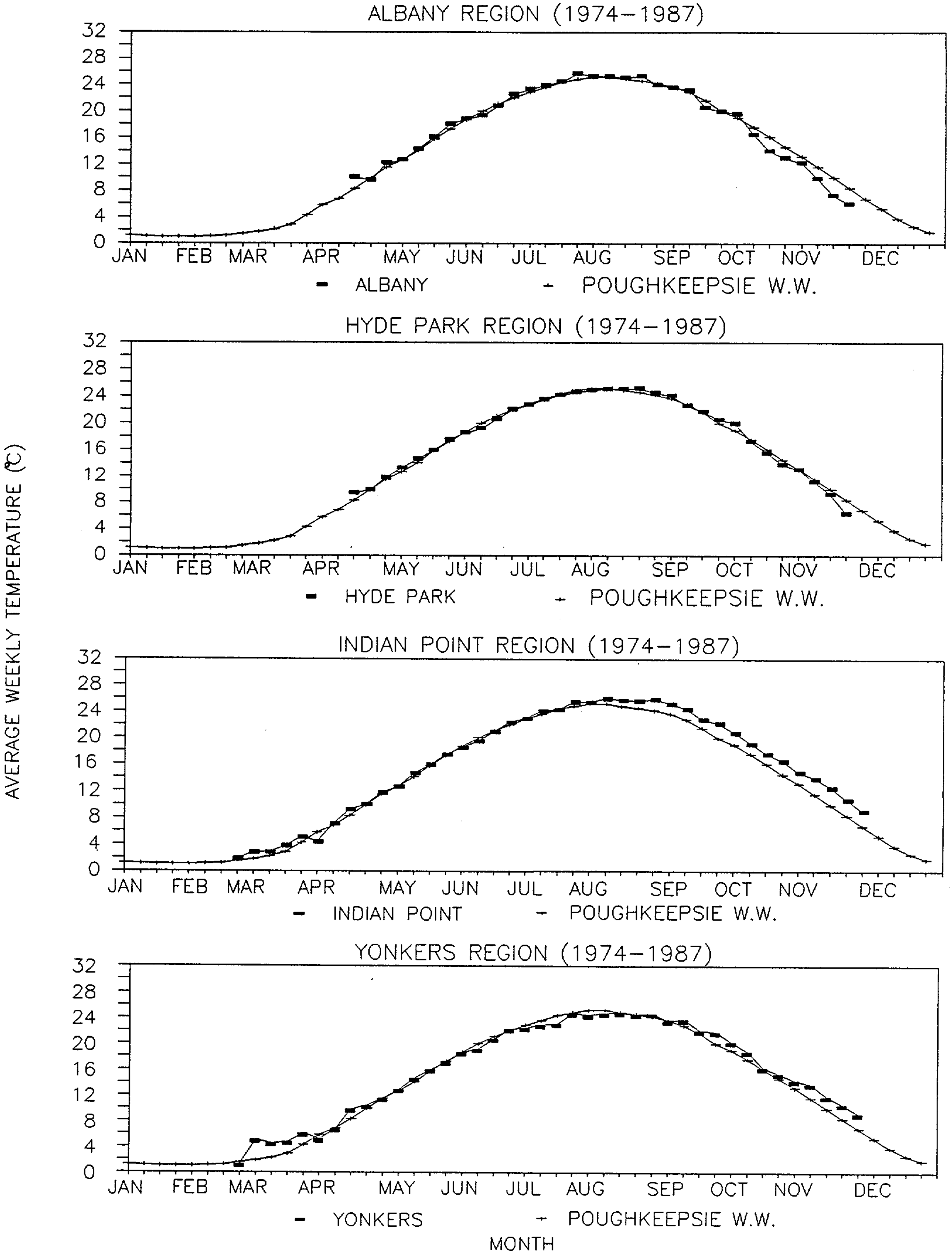
COMPARISON AMONG REGIONAL WEEKLY MEAN HUDSON RIVER WATER TEMPERATURES, 1974-1987

	CORRELATION COEFFICIENT										
	YK	TZ	CH	IP	WP	CW	PK	HP	KG	SG	CS
TZ	0.9921										
CH	0.9845	0.9921									
IP	0.9803	0.9839	0.9902								
WP	0.9783	0.9819	0.9857	0.9926							
CW	0.9776	0.9823	0.9846	0.9882	0.9940						
PK	0.9739	0.9784	0.9796	0.9837	0.9888	0.9946					
HP	0.9526	0.9638	0.9639	0.9655	0.9733	0.9822	0.9892				
KG	0.9477	0.9599	0.9575	0.9533	0.9628	0.9715	0.9774	0.9927			
SG	0.9401	0.9538	0.9487	0.9448	0.9541	0.9609	0.9670	0.9830	0.9915		
CS	0.9378	0.9504	0.9464	0.9430	0.9474	0.9532	0.9614	0.9804	0.9882	0.9934	
AL	0.9286	0.9419	0.9405	0.9378	0.9422	0.9460	0.9531	0.9726	0.9809	0.9865	0.9942

Note: See Figure 2-1 for explanation of region abbreviations.

FIGURE 3-14

AVERAGE WEEKLY TEMPERATURE VS. TIME



atures from spring through July when freshwater inflow approaches its annual minimum. Beginning in about mid-August, however, temperatures in upriver regions begin to cool; regions farther downriver remain near the summer maximum temperature. This earlier cooling is due to the cooler temperatures in the Adirondack Mountain headwaters and to the smaller cross-sectional area of the northern river regions (Cooper et al. 1988) that results in a reduced residence time. Thus, high-flow, low-temperature events, which become more common in the fall, tend to rapidly drive warmer waters downstream out of the regions above Hyde Park (Texas Instruments 1976). Regions downstream from Hyde Park tend to have higher temperatures than at PWW during the late summer and fall. Their larger cross-sectional areas cause a longer residence time, which makes the southern regions less influenced by short-duration high-flow events. Additionally, temperatures in lower regions are stabilized by the intrusion of marine waters and to some extent by the heat discharged by generating stations between Rkm 68 and 107 (RM 42-55).

Regional variability was assessed from the deseasonalized data. This was accomplished by first computing the average regional temperature for each week, then subtracting the weekly mean from each observation taken during that week. The standard deviation of the residuals then yields a measure of variability without the influence of the seasonal cycle. The regional standard deviations (Figure 3-15) were consistent with the observations in the previous analysis; the more downriver regions, Yonkers through Kingston, tend to display less variability than do the upriver regions of Saugerties through Albany. The larger volume and influence of marine waters stabilized the downriver regions and reduced variability.

Plots of the residuals by region, Figures 3-16 and 3-17, suggest that spring temperatures in 1974 and 1975, summer temperatures in 1983 and 1984, and fall temperatures in 1980, 1981, and 1986 were cooler than average in all regions. Temperatures during the fall of 1983 were 5 to 6°C warmer than average. Overall, however, water temperatures were within ±2°C of the seasonal average within each region.

FIGURE 3-15

STANDARD DEVIATION OF TEMPERATURE RESIDUALS

1974 – 1987

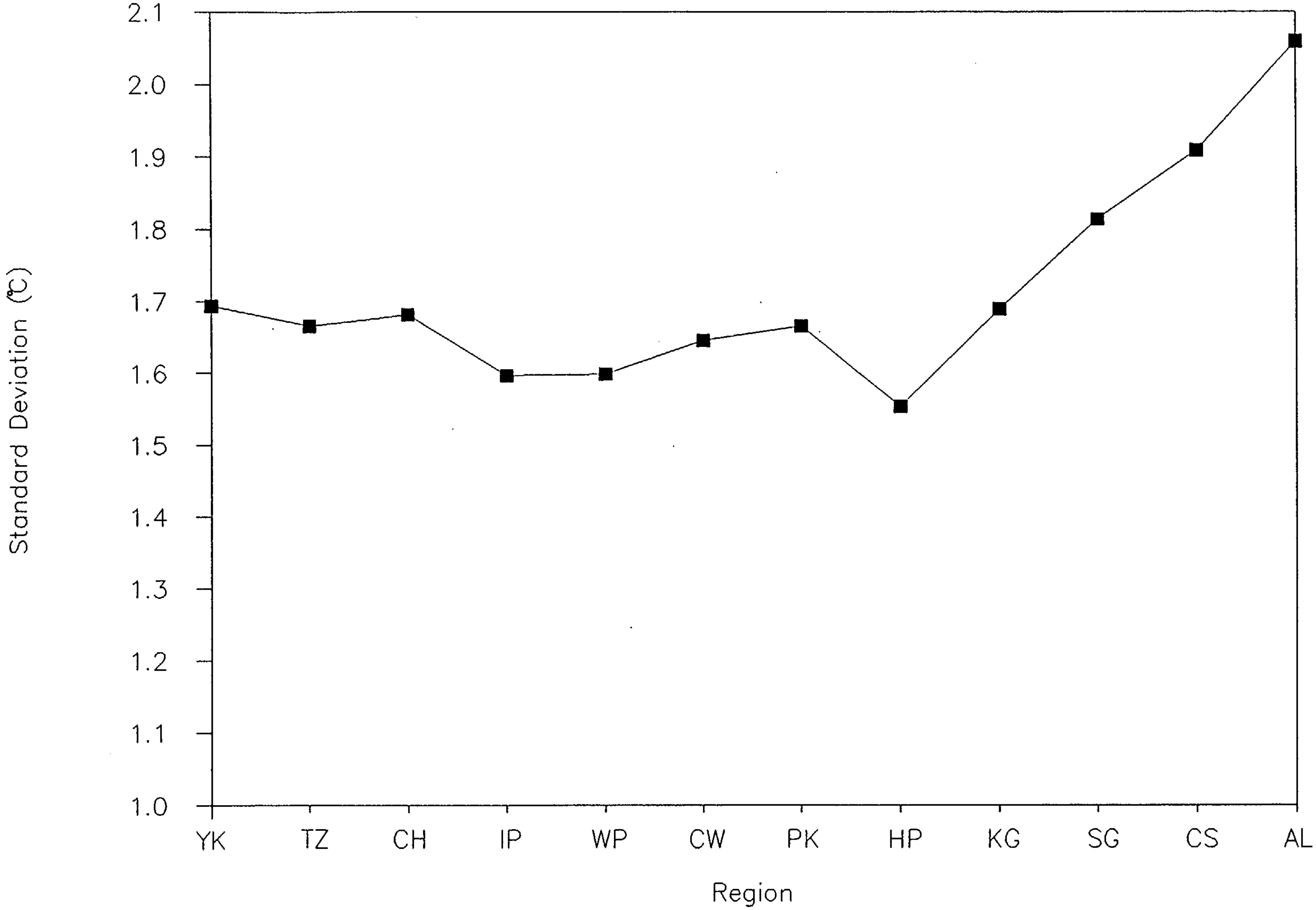
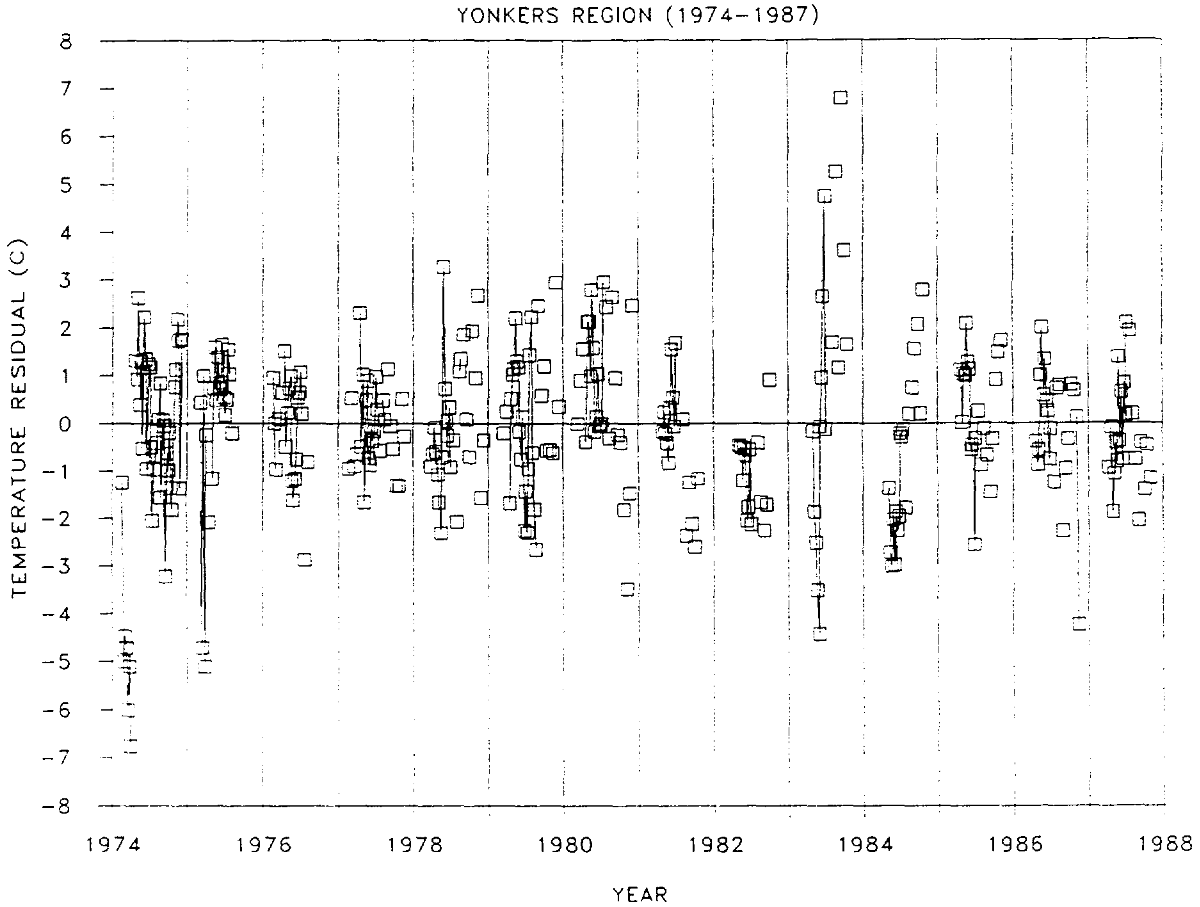


FIGURE 3-16

TEMPERATURE RESIDUAL VS TIME



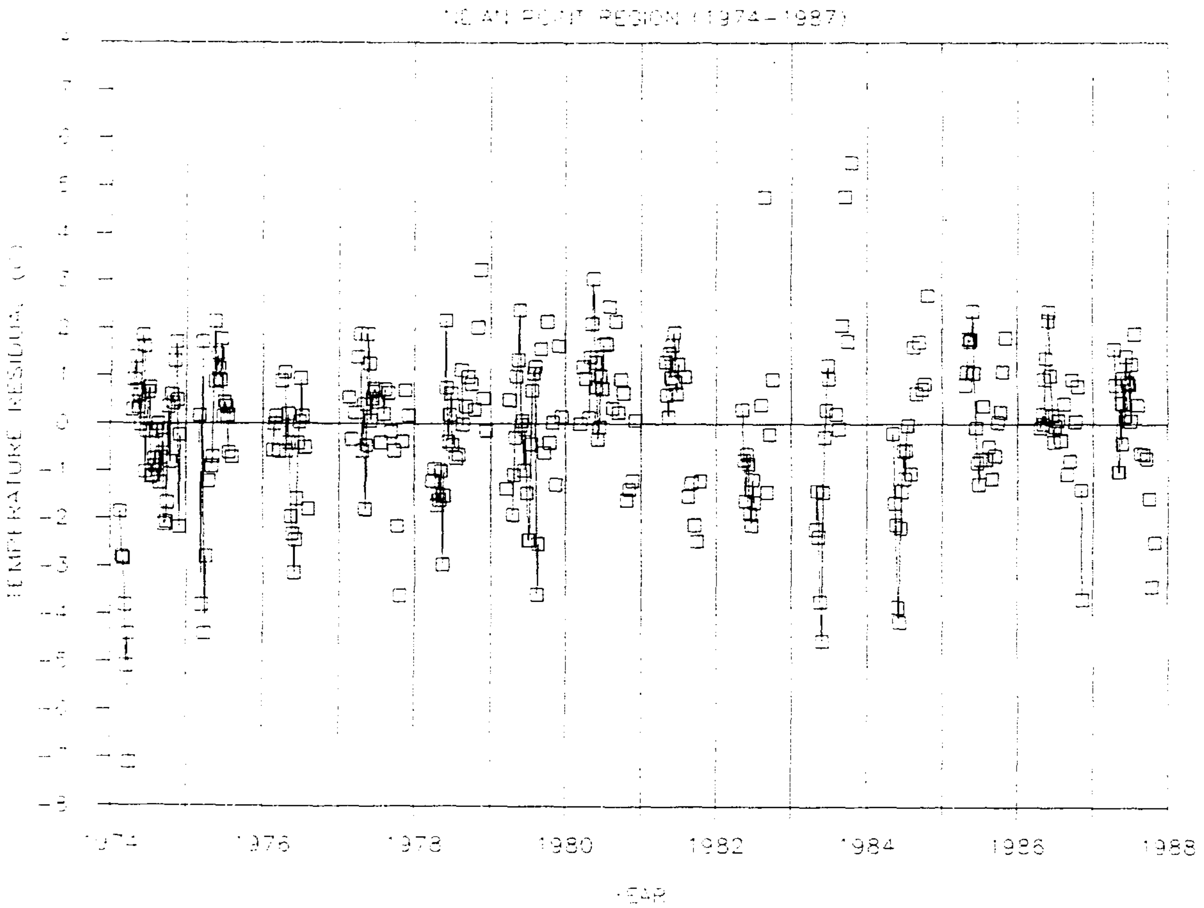
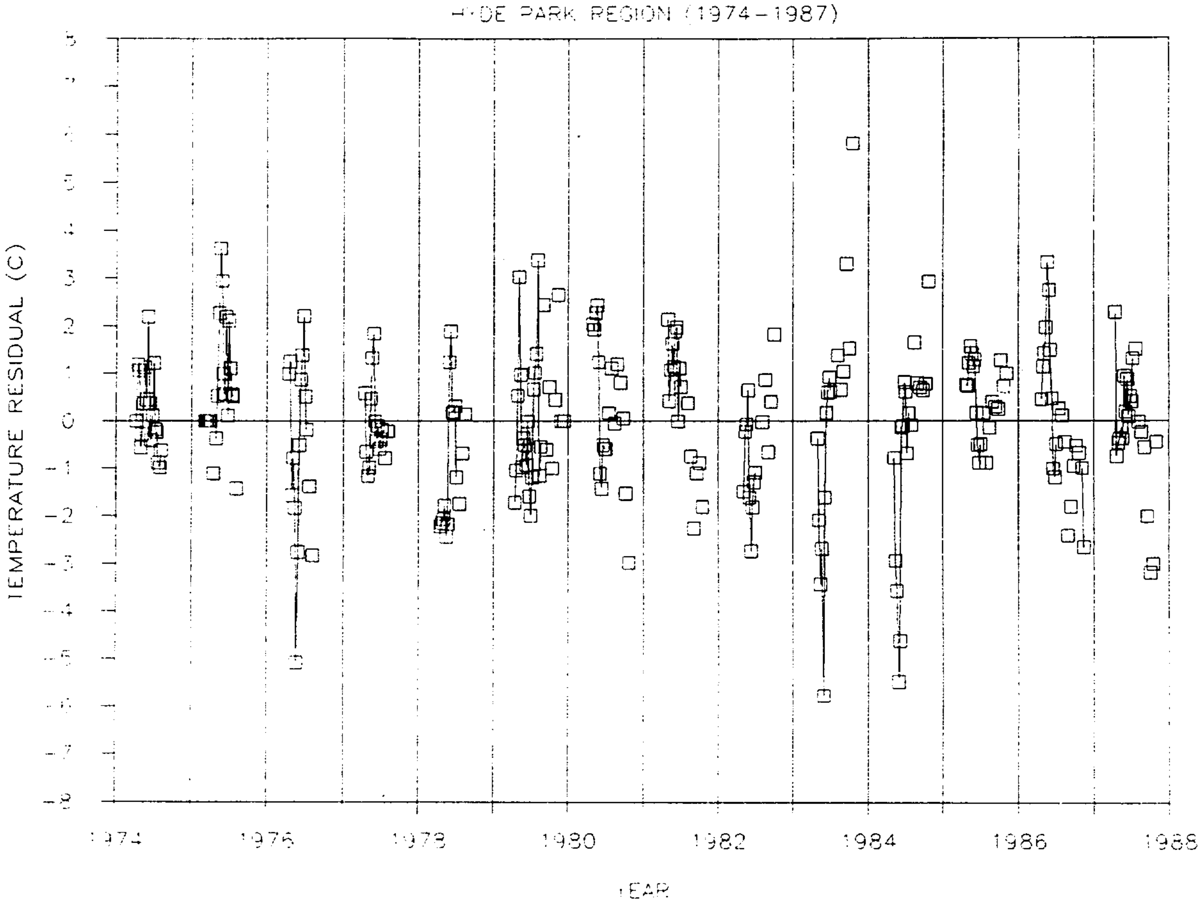
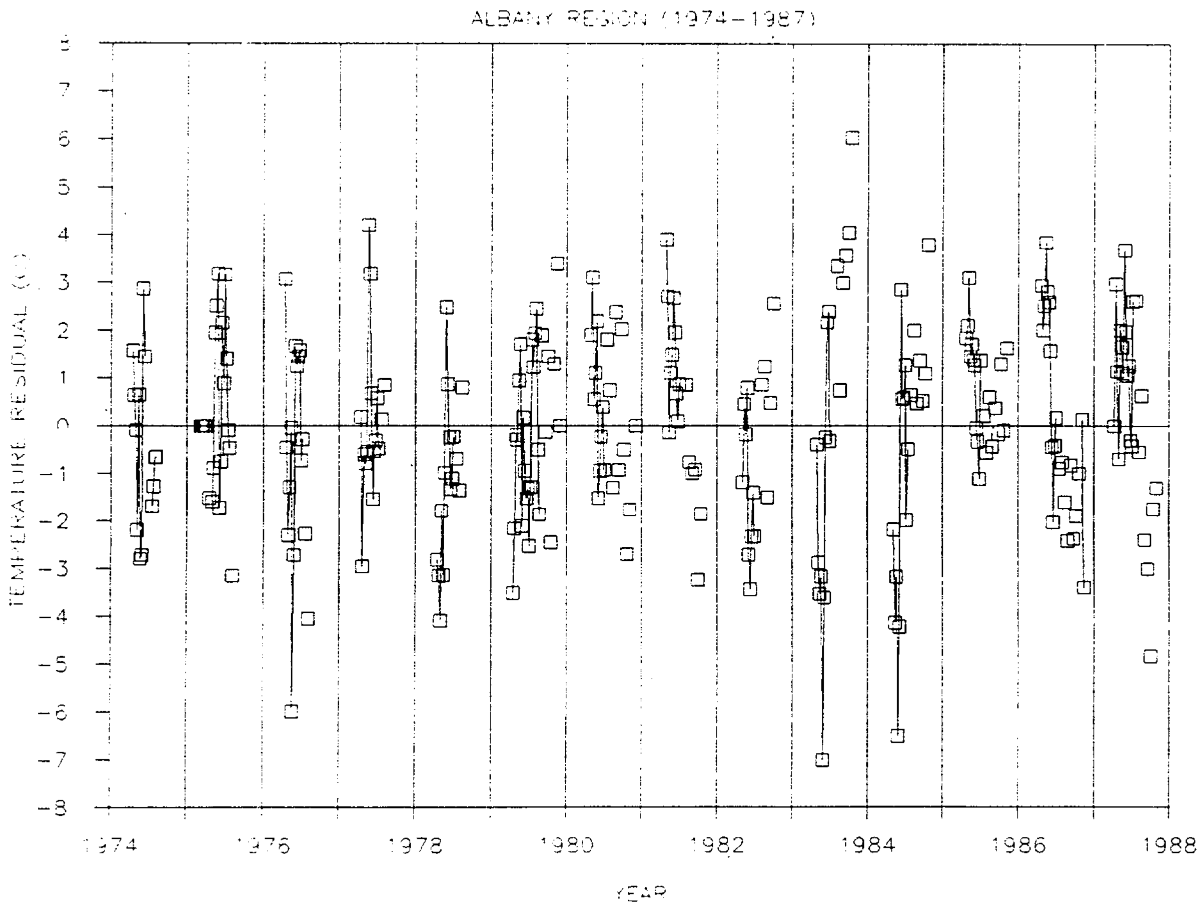


FIGURE 3-17

TEMPERATURE RESIDUAL VS TIME





3.3.2 Freshwater Discharge

Predictability and variability of Hudson River freshwater discharge rates were assessed from the records of two USGS gauging stations, Green Island and Wappinger Creek. The Green Island gauging station (No. 01358000) is located on the Hudson River at Green Island in Albany County, just upstream from the Troy lock and dam, and 0.8 km (0.5 miles) downstream from the 5th branch Mohawk River (42°45'08"N, 73°41'22"W). The drainage area monitored by this station is approximately 20,953 km^2 (8090 mi^2). The accuracy of discharge records is considered fair above 425 m^3/sec (15,000 cfs) and poor below this level (Lumia et al. 1984).

The Wappinger Creek station (No. 01372500) is located on Wappinger Creek, in Dutchess County, New York (41°39'11"N, 73°52'23"W), approximately 213 m (700 ft) downstream from Red Oak Mill dam and 7.2 km (4.5 miles) northeast of the Village of Wappingers Falls. The station gauges a drainage area of approximately 469 km^2 (181 mi^2) and has been in operation since August 1928. The accuracy of the records is considered fair except for the winter period, which is considered poor (Lumia et al. 1984). The Wappinger Creek station was selected primarily because of its extensive temporal coverage. However, this location is likely more indicative of discharges of the smaller drainage tributaries along the length of the Hudson River (Table 3-16). These drainage systems may demonstrate a more immediate response to precipitation than the larger upriver drainage area monitored by the Green Island station.

3.3.2.1 Temporal Patterns. Over the period 1947-1987 the peak daily discharge rate measured at Green Island was 5125 m^3/sec (181,000 cfs) recorded on 31 December 1948. The minimum daily discharge was 25 m^3/sec (882 cfs) recorded on 2 September 1968. Over the period of record the daily average discharge is approximately 391 m^3/sec (13,800 cfs). Daily flows for the years 1974-1987 are presented in Appendix D.

TABLE 3-16

FRESHWATER TRIBUTARIES TO THE HUDSON RIVER BELOW TROY, NEW YORK

TRIBUTARY	RIVER MILE (km)	SHORE	DRAINAGE AREA (mi^2)	MEAN FLOW (cfs)
Green Brook	16.0 (26)	West		
Crumkill Creek	24.0 (39)	West		
Sparkill Creek	24.5 (39)	West		
Croton River	34.0 (55)	East	378	
Cedar Pond Brook	39.0 (63)	West		
Peekskill Creek	44.0 (71)	East		
Popelopen Creek	47.0 (76)	West		
Arden Brook	51.0 (82)	East		
Indian Brook	53.0 (85)	East		
Foundry Brook	55.0 (89)	East		
Moodna Creek	58.0 (93)	West		
Fishkill Creek	60.0 (97)	East		
Wappinger Creek	67.0 (108)	East	208	254
Casper Creek	70.0 (113)	East		
Maritje Kill	79.0 (127)	East		
Crum Elbow Creek	82.0 (132)	East		
Black Creek	84.0 (135)	West		
Indian Kill	85.0 (137)	East		
Fallsburg Creek	88.0 (142)	East		
Landsman Kill	89.0 (143)	East		
Rondout Crk.(+Wallkill R.)	92.0 (148)	West	1197	
Stony Creek	101.0 (163)	East		
Esopus Creek	103.0 (166)	West	425	588
Post Creek	110.0 (177)	West		
Roeliff Jansen Kill	111.0 (179)	East	208	
Foxes Creek	111.5 (179)	East		
Bargett Creek	112.0 (180)	West		
Dubois Creek	113.0 (182)	West		
Catskill Creek	113.0 (182)	West	417	
Mineral Spring Brook	113.0 (182)	West		
Corlaer Kill	115.5 (186)	West		
Murderers Creek	120.0 (193)	West		
Kinderhook Creek	122.0 (196)	East	512	
Coxsackie Creek	128.0 (206)	West		
Mill Creek	129.0 (208)	East		
Hannacroix Creek	132.5 (213)	West		
Coeymans Creek	134.5 (216)	West		
Schodack Creek	136.0 (219)	East		
Muitzes Kill	136.5 (220)	East		
Baker Creek	137.0 (220)	West		
Vlockie Kill	137.5 (221)	East		
Binnen Kill	138.0 (222)	West		
Moordener Kill	138.5 (223)	East	33	38
Vloman Kill	139.0 (224)	West		
Vierda Kill	140.0 (225)	East		
Cooper Kill	142.5 (229)	East		
Papscanee Creek	143.0 (230)	East		
Island Creek	143.5 (231)	West		
Normans Kill	144.0 (232)	West	168	145
Mill Creek	145.5 (234)	East		

Daily average discharge values for Green Island from 1947 through 1987 are displayed in Figure 3-18. Typically, discharges peak from late April to early May, averaging approximately 850 m^3/sec (30,000 cfs). Low flows, averaging approximately 170 m^3/sec (6000 cfs), prevail from July through September. Flows increase in October and remain relatively constant at approximately 425 m^3/sec (15,000 cfs) until April.

As with the PWW water temperature data, weekly average Green Island flow data (Figure 3-19) were analyzed using the Box-Jenkins (Box and Jenkins 1976) method. The time-series modeling procedure indicated that the data series required deseasonalization, linear trend removal, and a first-order autoregressive component to reduce the data to white noise. The final model indicates that the discharge patterns are far less predictable than water temperature; the total explained variance was 57.76% for the flow data as compared to 99.95% for the temperature data. As with water temperature, autocorrelation analysis indicated a high degree of correlation among observations separated by 52 weeks, indicating an annual cycle. The weekly coefficients describing this seasonal cycle, expressed as deviations from annual mean flow, are presented in Table 3-13. The linear trend is described by the relationship $x_i = -377.6 + 0.354i$. The positive slope suggests that flow has increased at an average rate of 0.5 m^3/sec (18 cfs) per year over the period of record.

After removal of the seasonal and linear trends, a significant amount of the remaining variation was explained by a first-order autoregressive (AR1) process:

$$x_t = 0.570x_{t-1} + Z_t$$

where

x_{t-1} = detrended and deseasonalized flow at time t-1

Z_t = random shock

This AR1 model successfully reduced the remaining variation to white noise (Portmanteau test $\chi^2_{19} = 22.81$, P>0.05).

FIGURE 3-18

DAILY FLOW

GREEN ISLAND 1947-1987

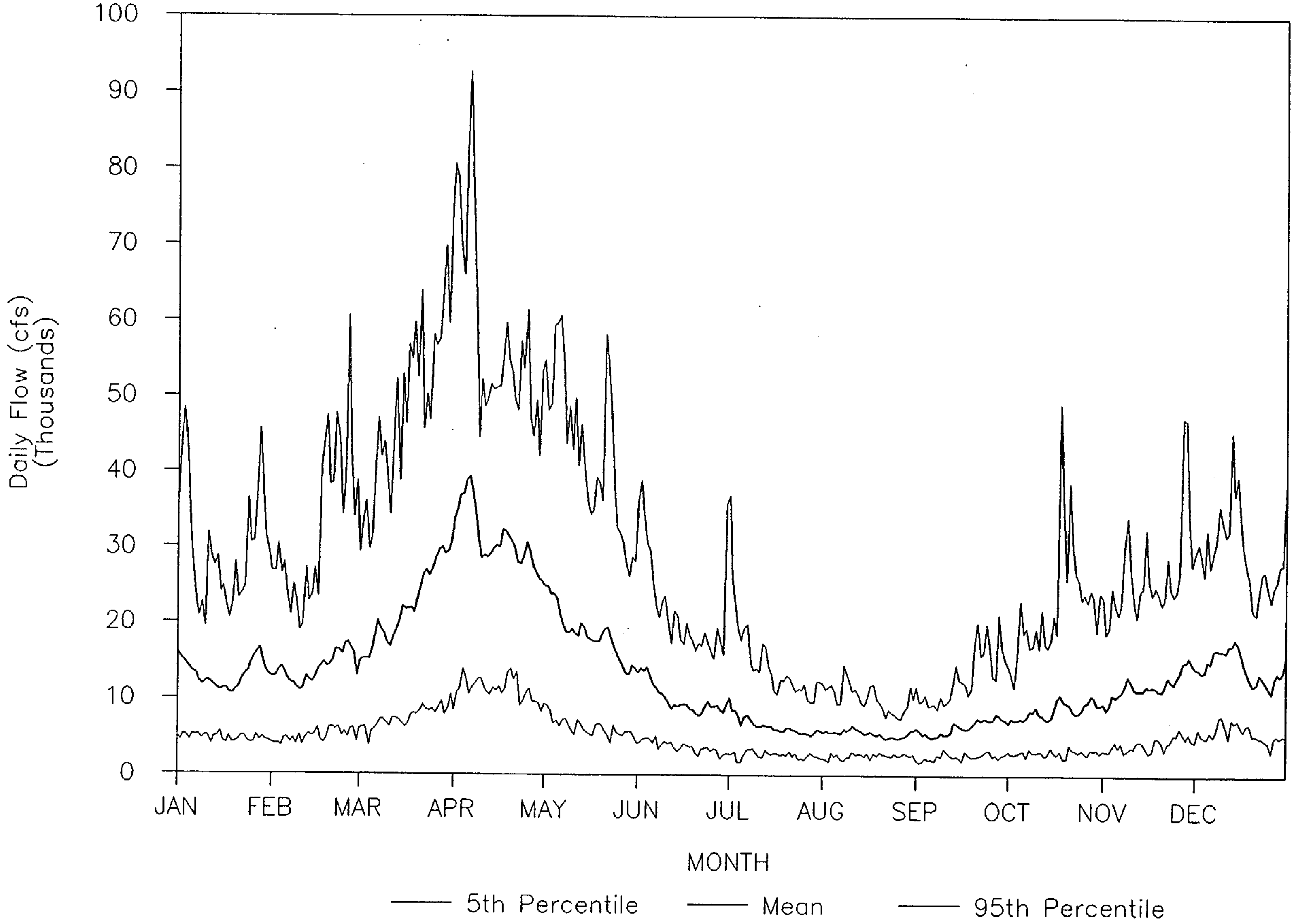
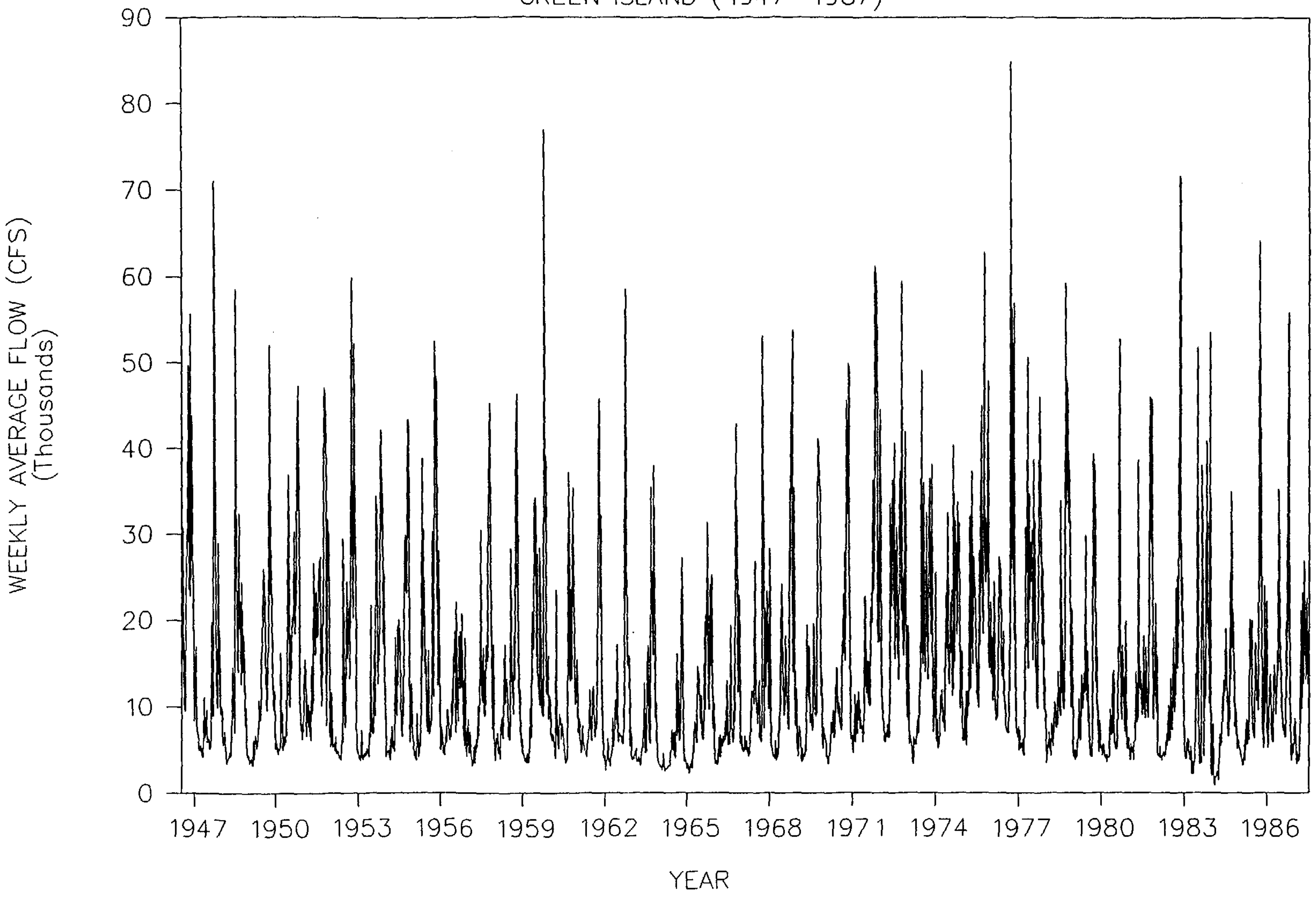


FIGURE 3-19

WEEKLY AVERAGE FLOW VS TIME

GREEN ISLAND (1947-1987)



To determine periods of unusual discharge rates, i.e., periods of abnormally high or low flow rates, the residual flows, or deviations from weekly average flows, were computed. These were obtained by calculating the mean flow over the entire 41-year period for each week, then subtracting the weekly mean from each observation during the given week (Figure 3-20). After smoothing (9-point moving average), several distinct periods of high and low flow became apparent (Figure 3-21). The most pronounced period was from approximately 1960 through 1970, a period of severe drought. This was followed, from 1972 through 1980, by a period of above-average discharges. The period 1980-1987 has seen a return to drought conditions, but not of the same severity as the 1960-1970 period.

Cross-correlation analysis (Davis 1973) of weekly average water temperature and discharge residuals indicates a significant, but weak, negative correlation between the two series (Figure 3-22). The maximum correlation, $r=-0.2686$ ($P<0.01$), occurred when water temperature residuals led discharge residuals by one week. This relationship indicates that, in general, higher than normal temperatures are associated with lower than normal flows the following week, while lower than normal temperatures (likely associated with precipitation) are associated with higher than normal discharges the following week.

To determine if Green Island flows are indicative of flows in the lower Hudson River similarity between Green Island and Wappinger Creek discharge records was compared using cross-correlation analysis, with a $\pm$50-day lag period. Over the period of record for the Wappinger Creek station the peak daily discharge rate was 527 m^3/sec (18,600 cfs) on 19 August 1955 and the minimum flow was 0.025 m/sec (0.9 cfs) on 20 and 21 September 1964. The average discharge was approximately 7.1 m^3/sec (250 cfs). The results of the correlation analysis (Figure 3-23) indicate a relatively strong association between the two series, with a maximum correlation, $r=0.6397$ ($P<0.01$), at the zero lag period. This indicates that increases and decreases in flow are recorded at the two stations at approximately the same time (at least within one

FIGURE 3-20

DEVIATIONS OF WEEKLY AVERAGE FLOWS

FLOW VS TIME – GREEN ISLAND (1947–1987)

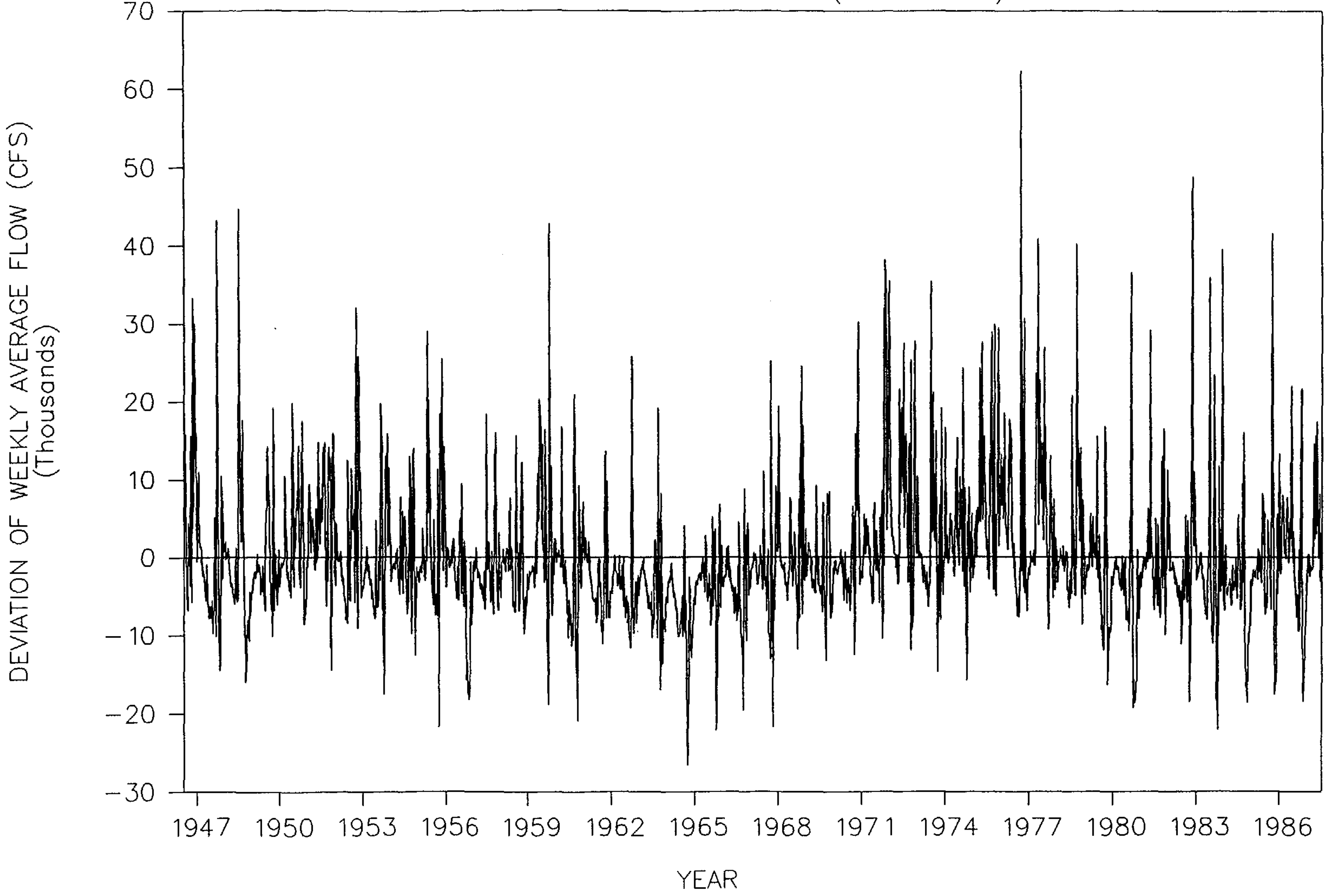


FIGURE 3-21

DEVIATIONS OF WEEKLY AVERAGE FLOWS

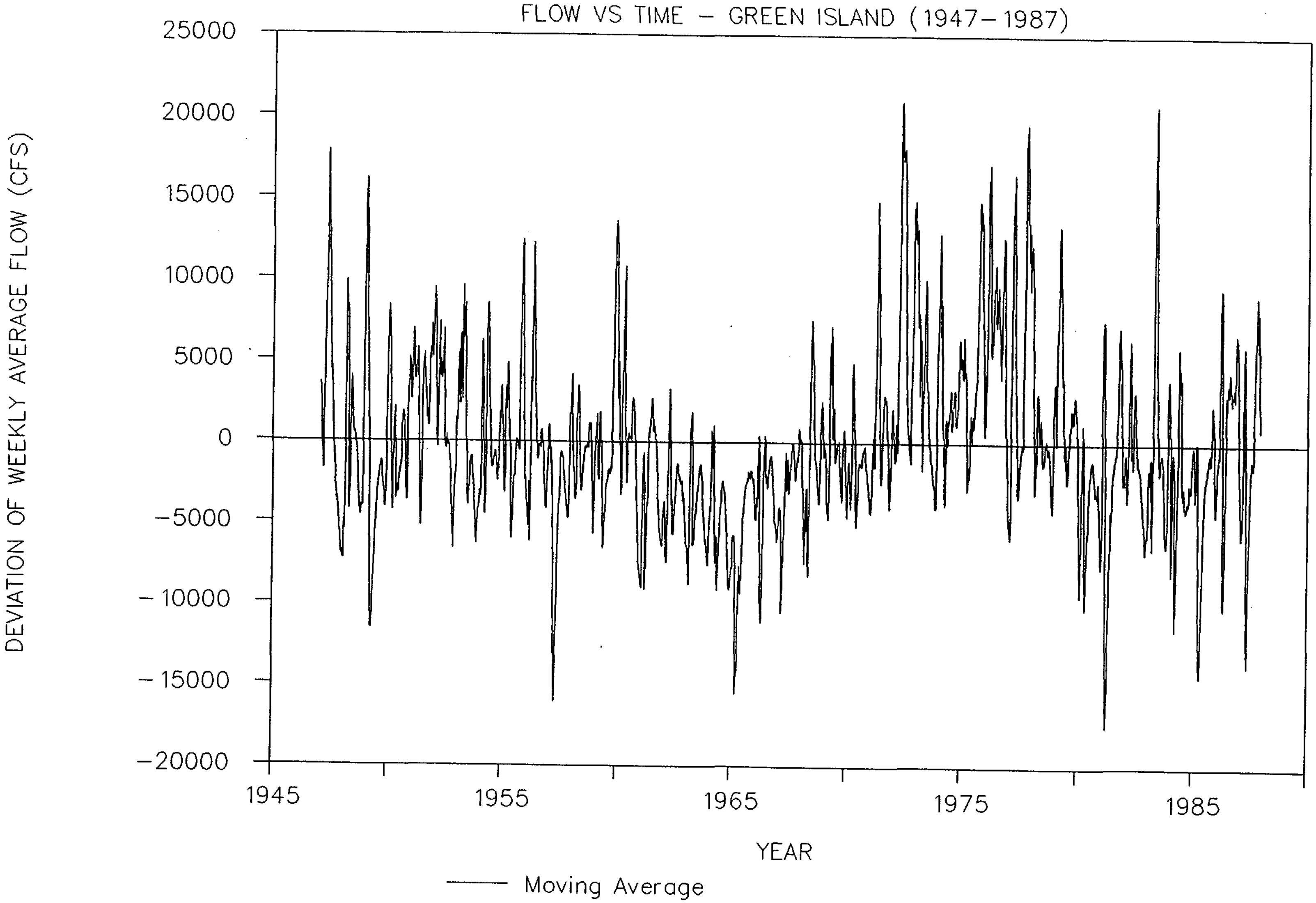


FIGURE 3-22

WEEKLY MEAN FLOW vs WATER TEMPERATURE

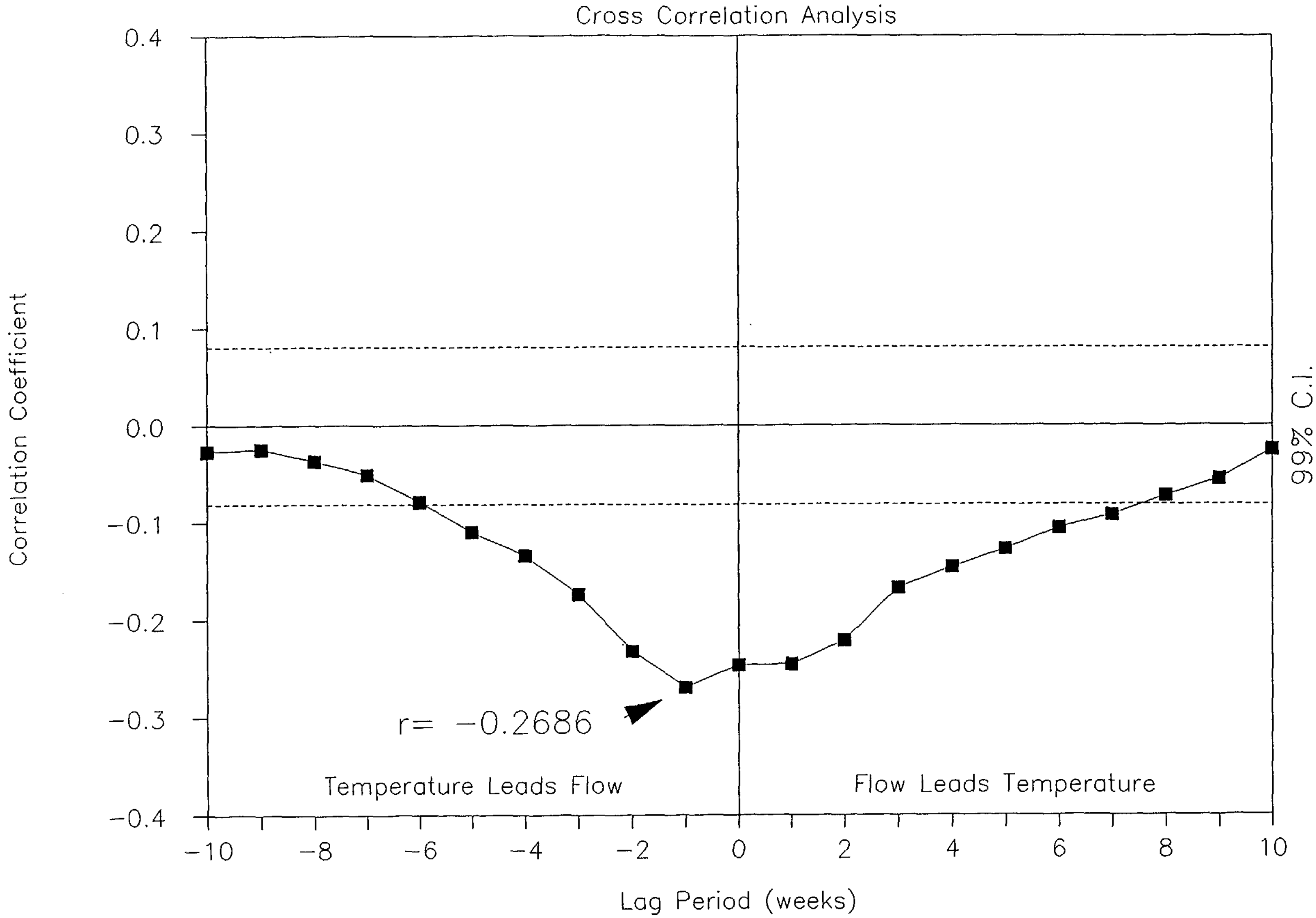
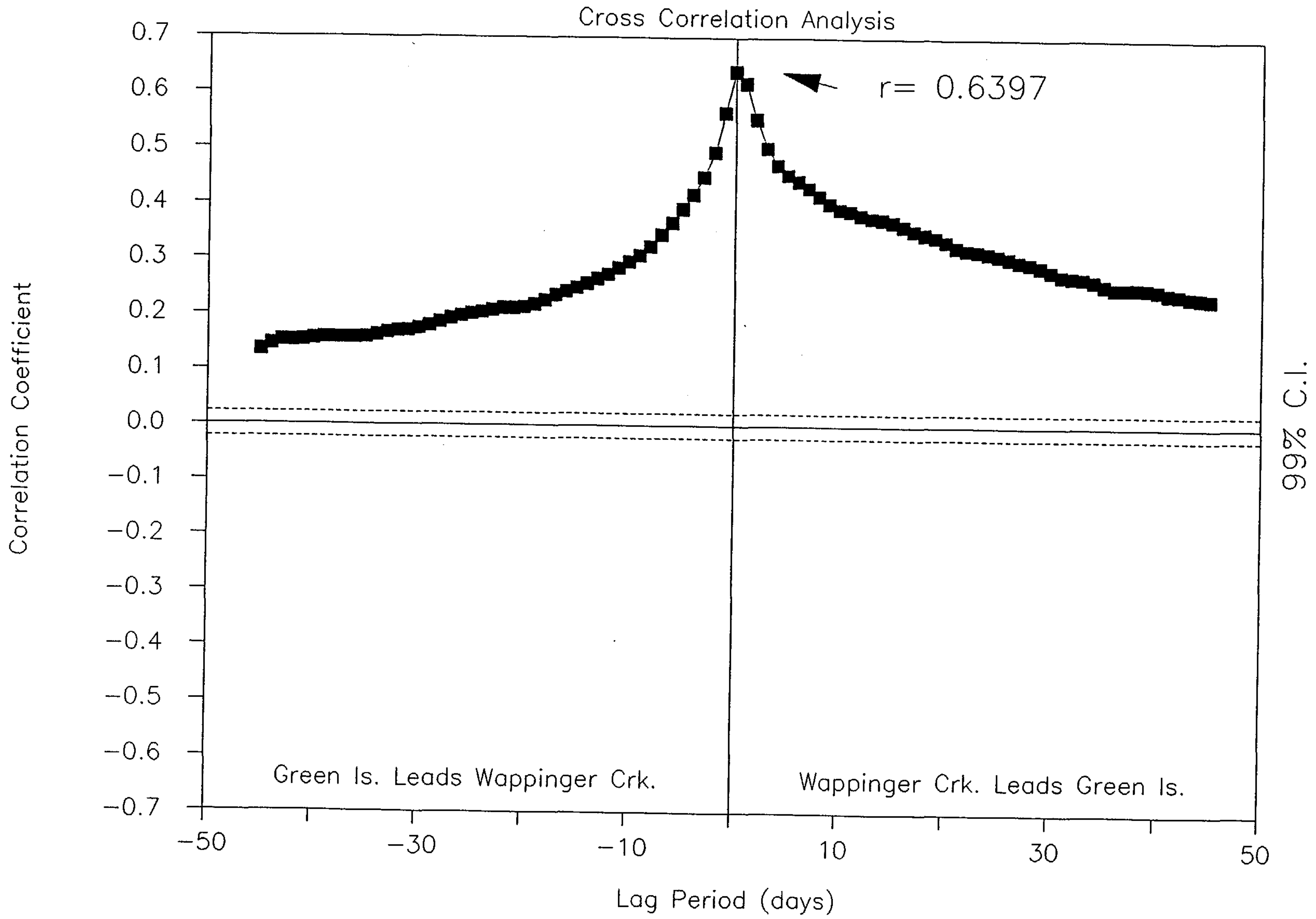


FIGURE 3-23

Wappinger Creek vs Green Island Daily Flow



day). However, it is also apparent that correlations at positive lag periods, i.e., where Wappinger Creek records led Green Island records, tend to be higher at corresponding lags than when Green Island records led Wappinger Creek records. This suggests that the Green Island flows respond to change more slowly than flows recorded at the Wappinger Creek station. This type of response would be expected, considering the 45-fold larger drainage area gauged by the Green Island station. The analysis suggests that the Wappinger Creek flow information is not a good indicator of Hudson River flow patterns.

3.3.2.2 Seasonal Patterns. Seasonal patterns of variability were examined from the standard deviations of the Green Island weekly flow residuals. A plot of these values (Figure 3-24) indicates that the greatest variability occurs from late March through late June (weeks 12-25); the least, from mid-August through mid-October (weeks 33-42).

3.3.3 Salinity

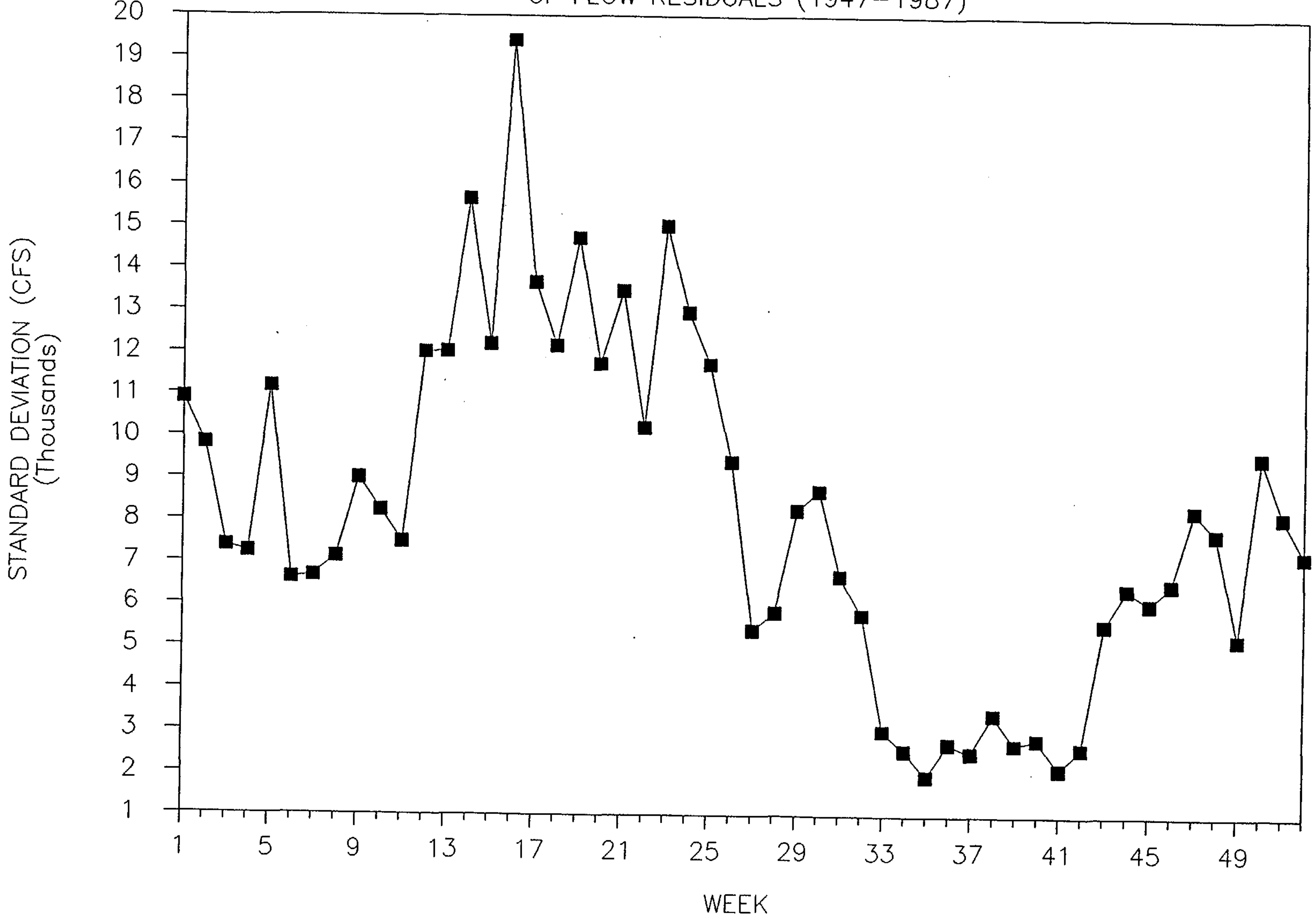
The lower Hudson River is a partially stratified estuary (Abood 1974, 1977). Less dense fresh water enters the estuary at the head and flows downstream above the denser marine waters entering the mouth of the river. Tidally induced turbulent eddies tend to mix the lighter fresh water downward and the heavier salt water upward, with a net result of producing a gradient of increasing salinity as one nears the mouth of the river. This mixing process results in a two-layered circulation pattern with a net downstream flow of fresh water near the surface and a net upstream flow of salt water near the bottom. Generally, as freshwater flows increase, the magnitude of the tidal velocity and the duration of the tidal phases decrease. The net result is a decrease in marine intrusion.

Abood (1974, 1977) demonstrated a close relationship between flow and salinity in the lower Hudson River. The position of the salt front, defined as the 0.1 ppt isosal, may be estimated from the relationships:

FIGURE 3-24

STANDARD DEVIATION

OF FLOW RESIDUALS (1947-1987)



$$L = 135\, Q_f^{-0.38} \text{ for } Q_f \leq 27$$

$$L = 1948\, Q_f^{-1.19} \text{ for } Q_f > 27$$

where

L = location of 0.1 ppt isosal in miles from the Battery, New York City

Q_f = freshwater flow in the lower Hudson River measured in 1000 cfs

3.3.3.1 Temporal Patterns. The freshwater flow in the lower Hudson River includes the discharges from tributaries such as Kinderhook, Wallkill, Rondout, Fishkill, and Wappinger creeks as well as that from the upper Hudson River measured by the Green Island station. Since most of the these tributaries are ungauged, their contributions to total discharge must be estimated.

Abood et al. (1990, In prep.) estimated, via regression analysis, the following contributions:

$Q_f = 1.477\, Q_{GI}$ for January
$Q_f = 1.600\, Q_{GI}$ for February
$Q_f = 1.319\, Q_{GI}$ for March
$Q_f = 1.311\, Q_{GI}$ for April
$Q_f = 1.356\, Q_{GI}$ for May
$Q_f = 1.231\, Q_{GI}$ for June
$Q_f = 1.228\, Q_{GI}$ for July
$Q_f = 1.358\, Q_{GI}$ for August
$Q_f = 1.237\, Q_{GI}$ for September
$Q_f = 1.569\, Q_{GI}$ for October
$Q_f = 1.516\, Q_{GI}$ for November
$Q_f = 1.421\, Q_{GI}$ for December

where

QGI = Green Island flow in cfs

Abood (1974, 1977) also noted that a lag period of five to 10 days was required before changes in flow were reflected as changes in salt front position. More precisely, the lag period (t) was best described by the relationship:

$$t = (256.14/Q_f)^{0.4}$$

Applying the relationships described by Abood (1974, 1977) to the average Green Island flow during 1947-1987, the salt front typically resides within the Tappan Zee to Poughkeepsie regions (Figure 3-25). During the spring highflow period the salt front is typically near Rkm 42 (RM 26); during the summer lowflow period it typically moves upriver to a position near Rkm 105 (RM 65). Estimated salt front positions for 1986 and 1987 are presented in Figures 3-26 and 3-27.

3.3.3.2 Spatial Patterns. Empirical measures of regional and seasonal changes in salinity were determined from the combined LRS, FSS, and BSS physical-chemical parameter sampling programs over the period 1974-1987. Procedures for determining salinity from conductivity are given in Section 2.6.1.

During the period 1974-1987 average salinity was highest in the most downriver region, Yonkers, ranging from a low of near 0 to over 18 ppt. Average salinity decreased regularly in an upriver direction (Figures 3-28 through 3-31) until, by the Poughkeepsie region, values greater than 0 ppt were rarely recorded.

Variability, as measured by the standard deviations of the residual salinity, i.e., the difference between the weekly salinity and the 1974-1987 average salinity for that week, decreases in an upriver direction (Figure 3-32). In the Yonkers region, the region of greatest variability, 95% of the observations fell within 7.4 ppt of the 1974-1987 weekly average; in the Poughkeepsie region 95% of the observations fell within 0.4 ppt of this long-term average.

Over the season, regional salinity values reflect the diminished flows of the summer months (Figure 3-33). In the Yonkers region salinity averaged approxi-

FIGURE 3-25

SALT FRONT LOCATION VS. TIME

BASED ON GREEN ISLAND FLOWS, 1947-1987

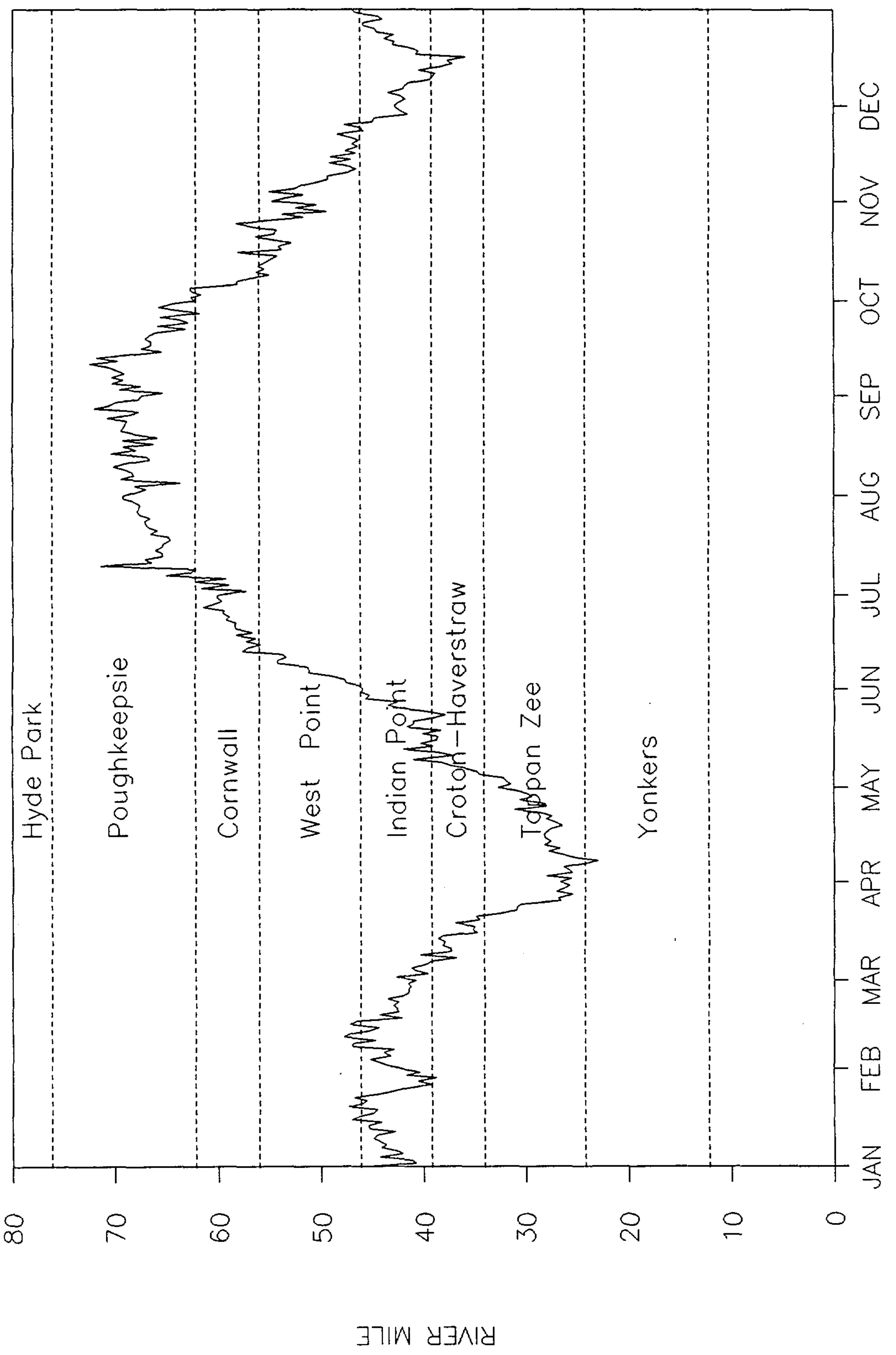


FIGURE 3-26

SALT FRONT LOCATION VS. TIME

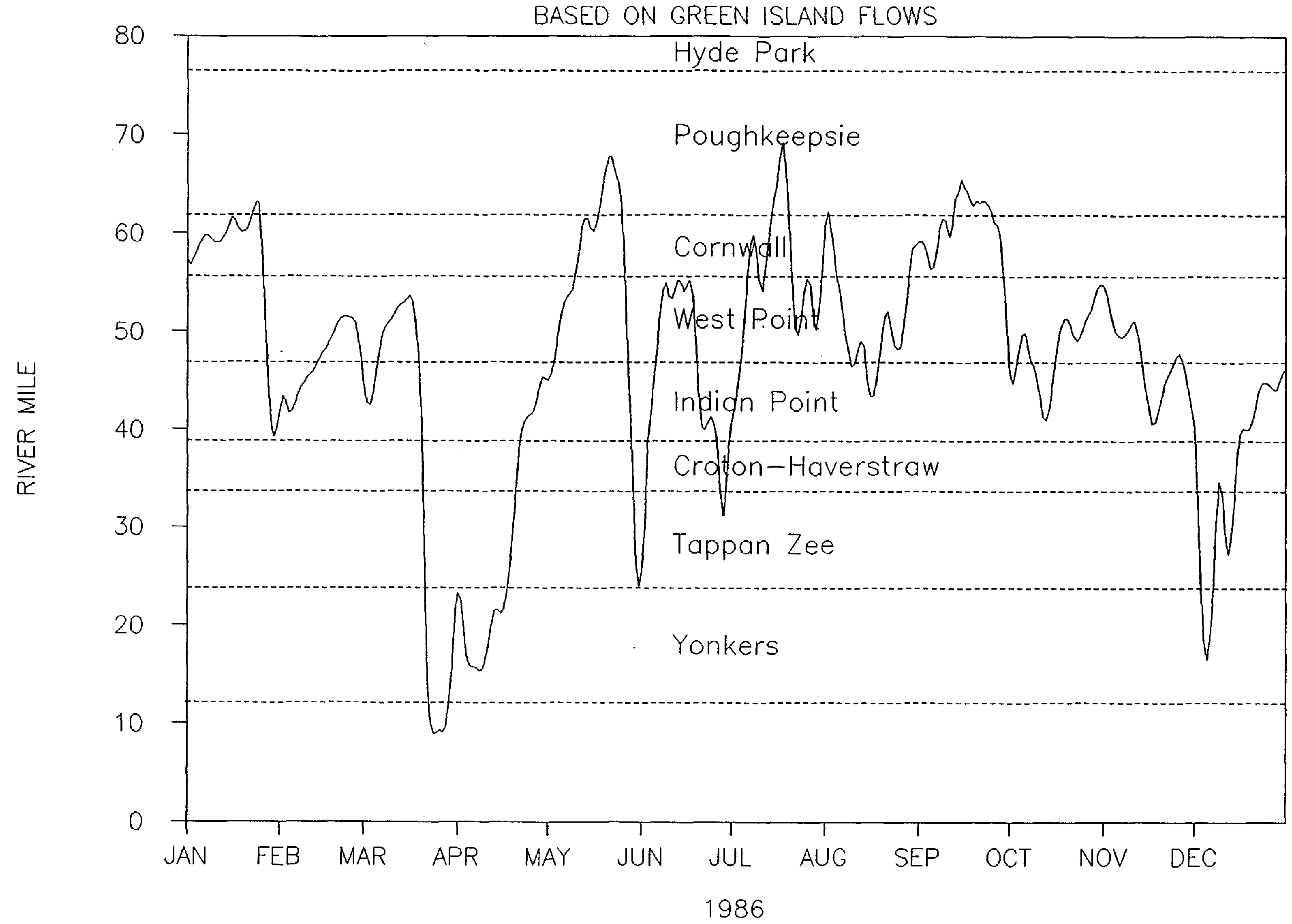


FIGURE 3-27

SALT FRONT LOCATION VS. TIME

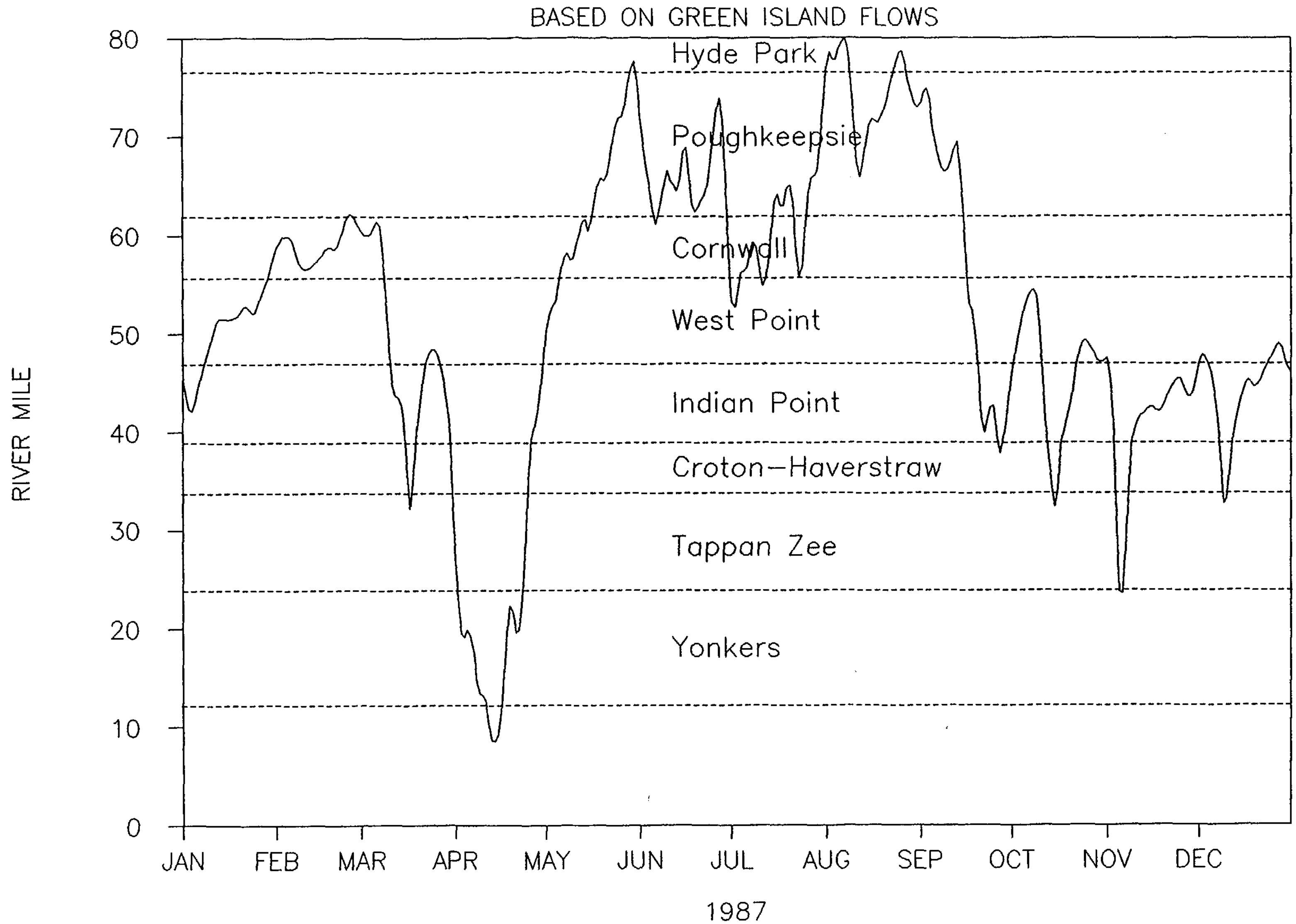
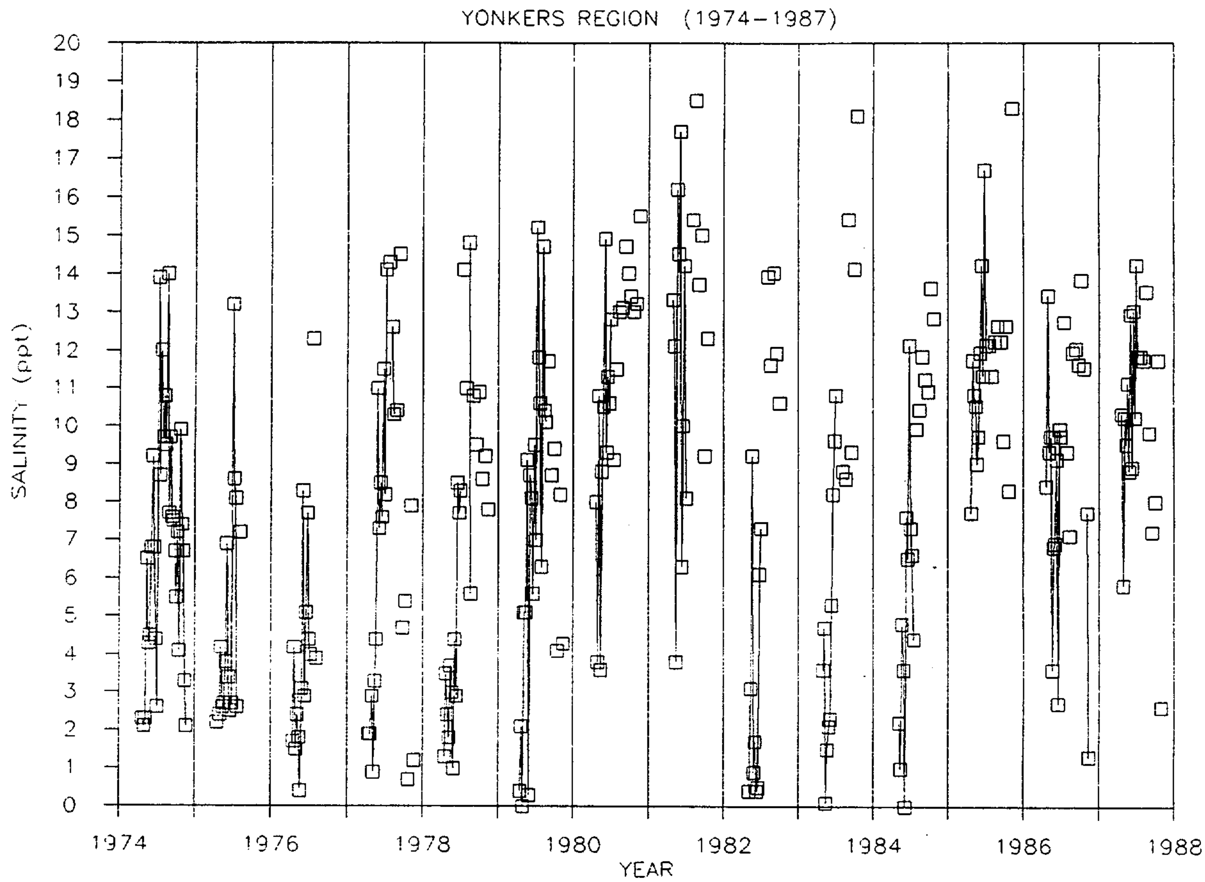


FIGURE 3-28
SALINITY VS. TIME



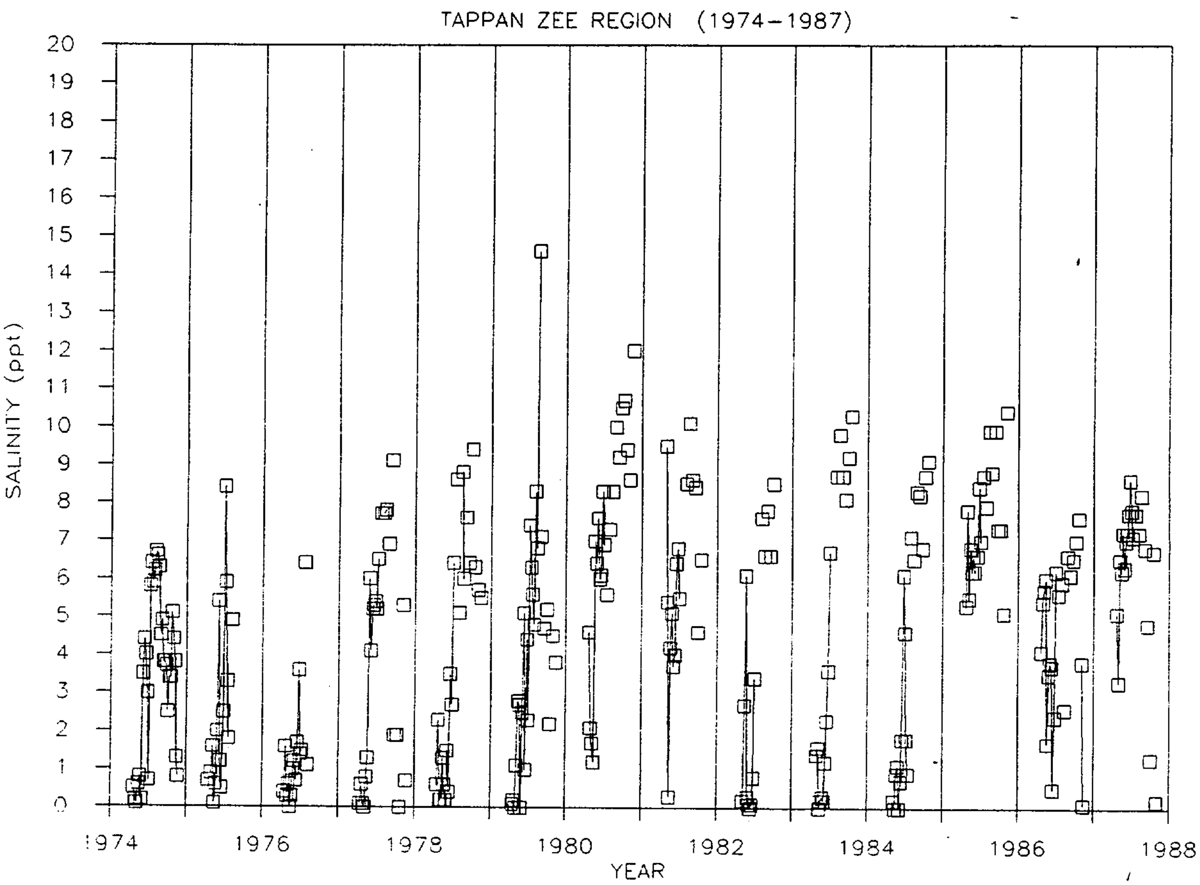
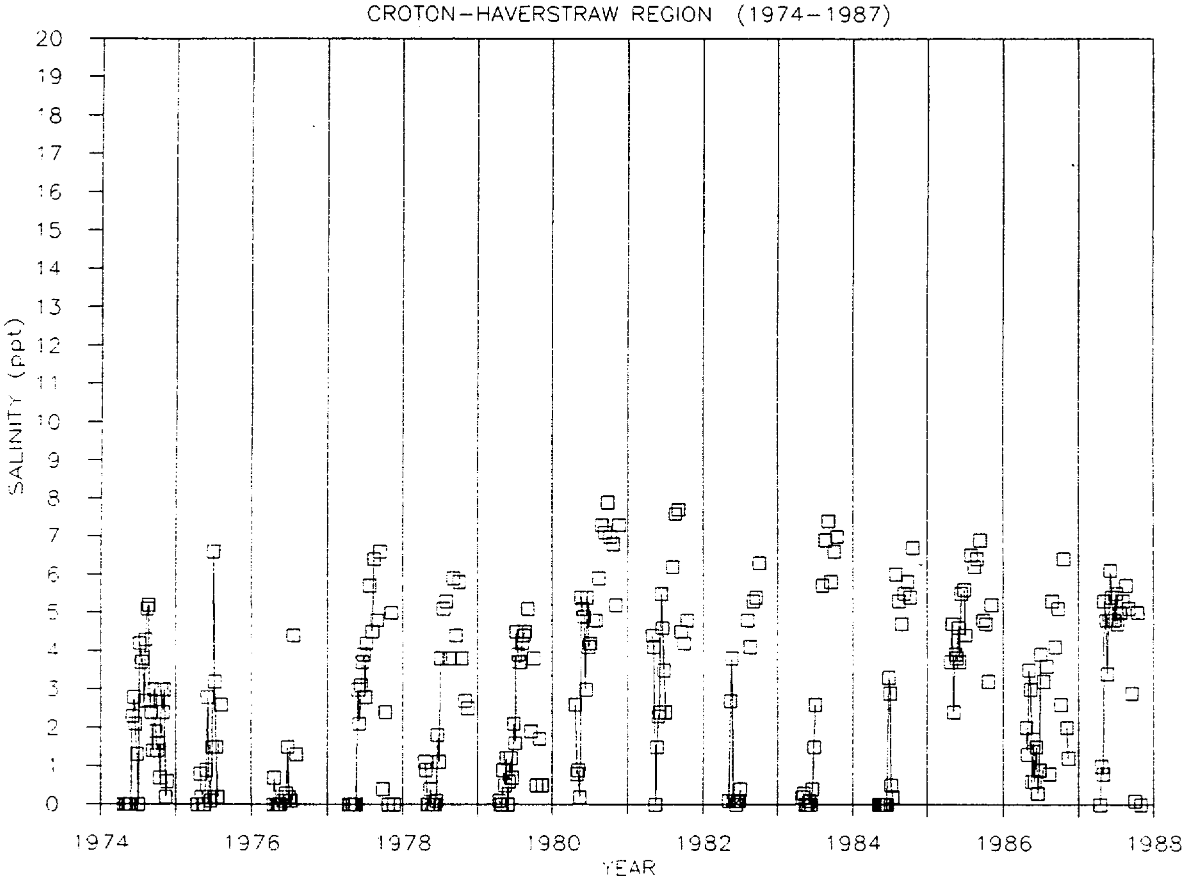


FIGURE 3-29

SALINITY VS. TIME



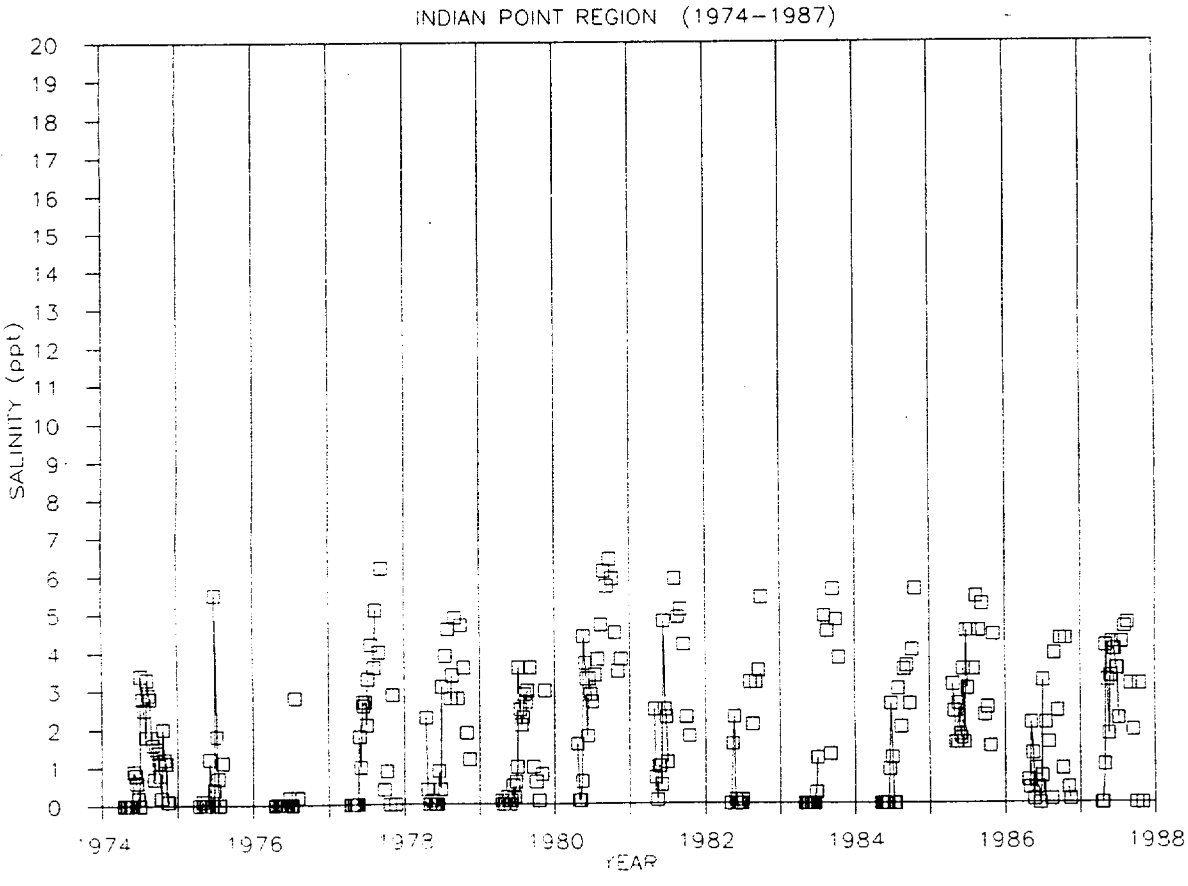
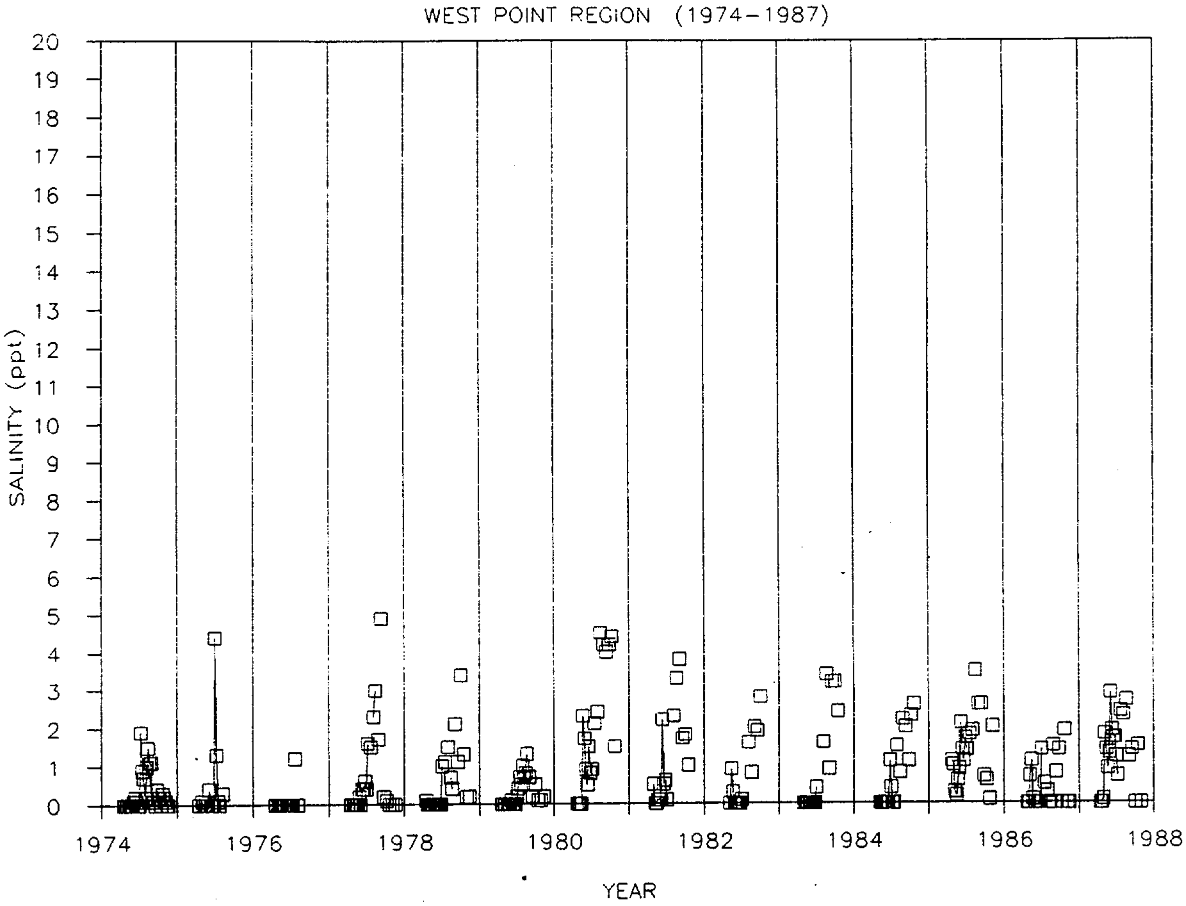


FIGURE 3-30

SALINITY VS. TIME



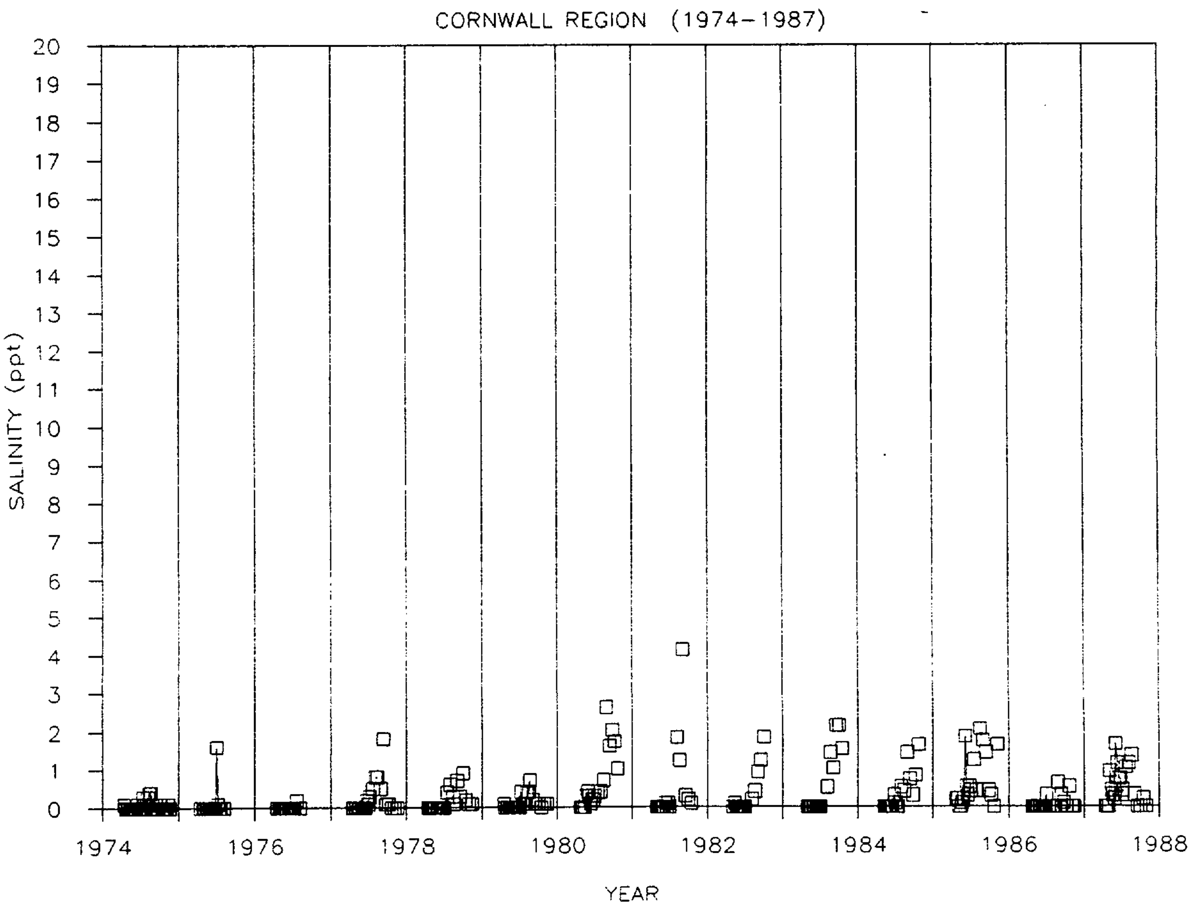


FIGURE 3-31
SALINITY VS. TIME

POUGHKEEPSIE REGION (1974–1987)

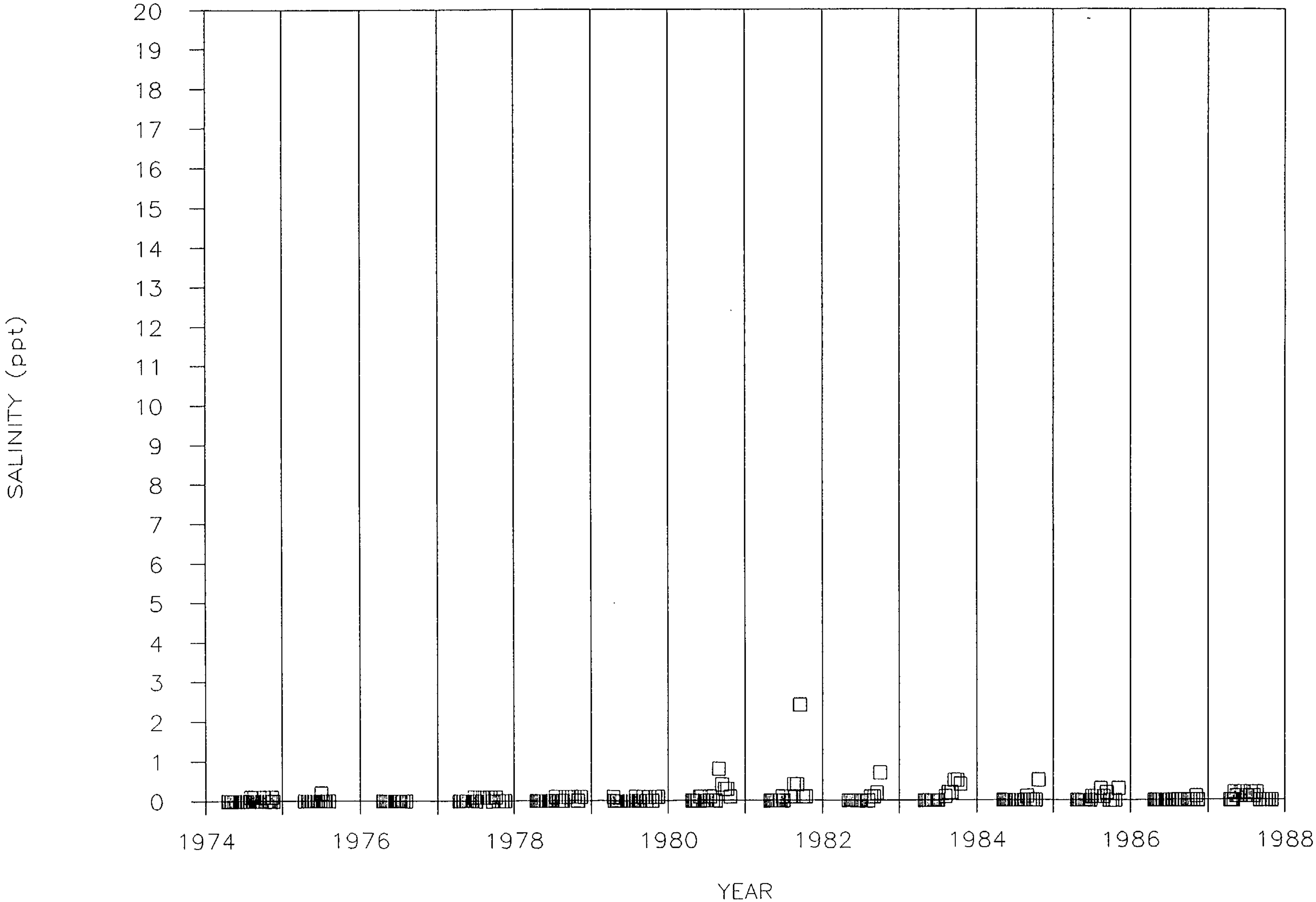


FIGURE 3-32

STANDARD DEVIATION OF SALINITY RESIDUALS
1974 - 1987

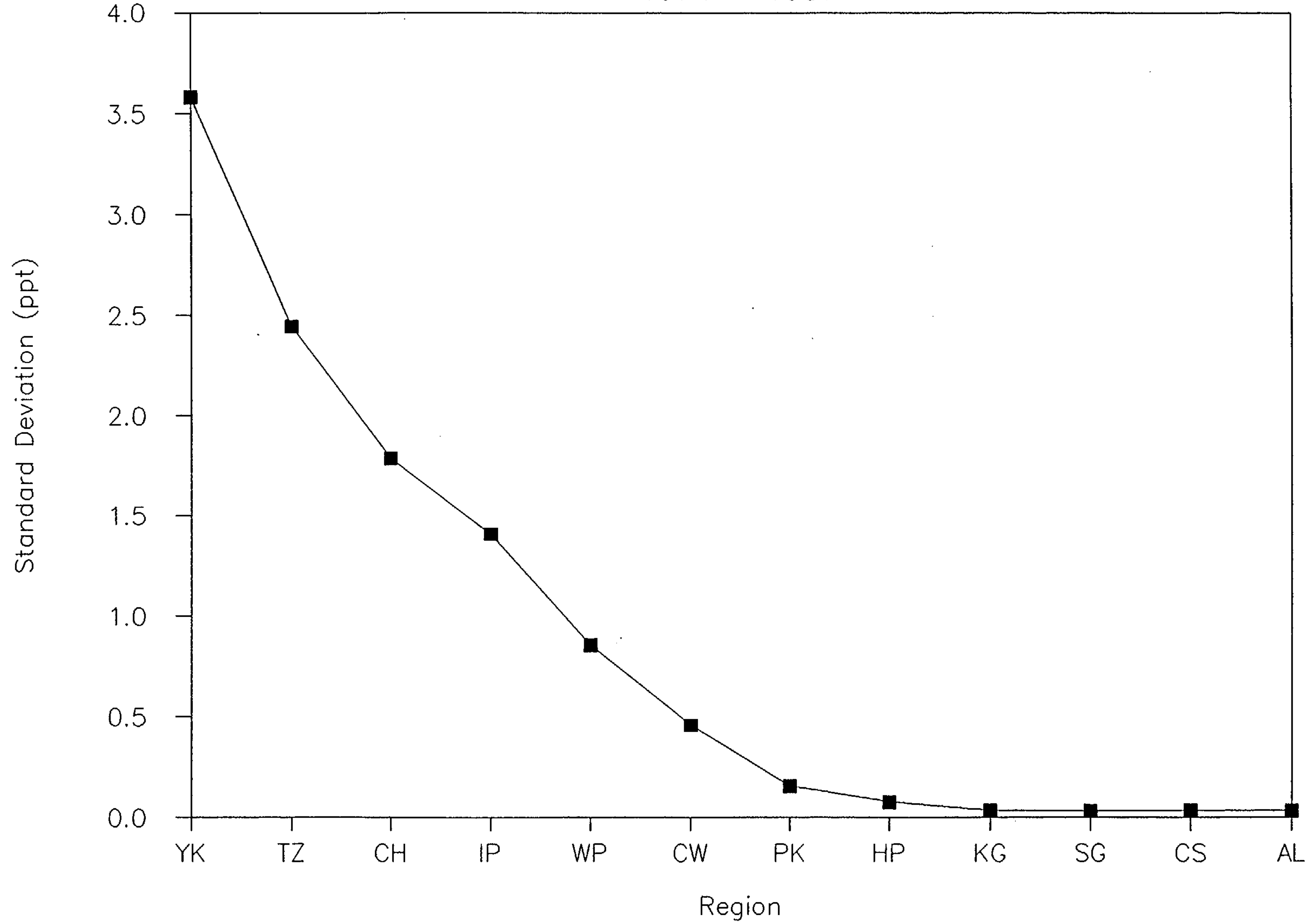
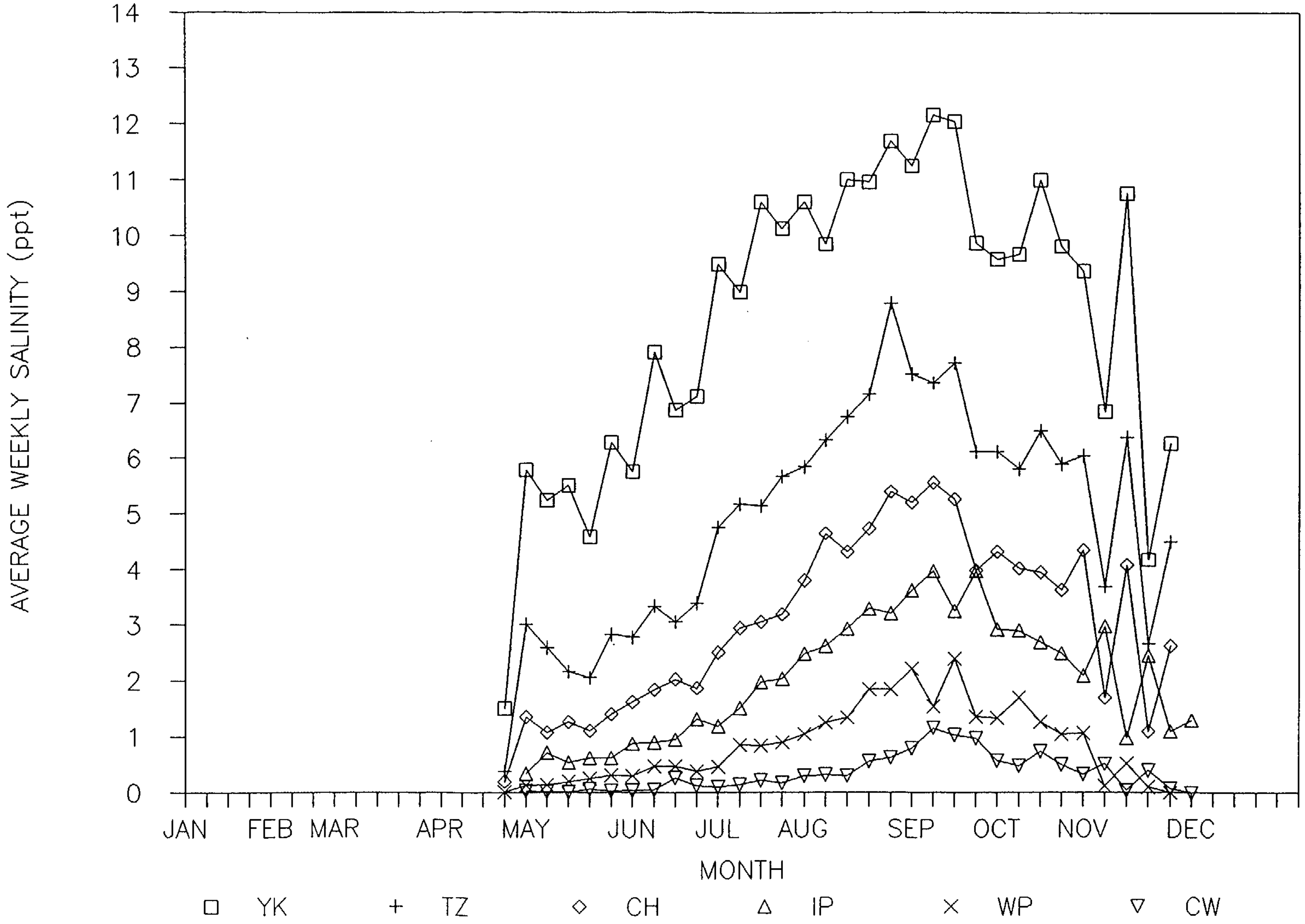


FIGURE 3-33

AVERAGE WEEKLY HUDSON RIVER SALINITY

1974–1987



mately 6 ppt in May and gradually increased to approximately 12 ppt in August and September before decreasing to about 6 ppt in late November through December. The Tappan Zee region displays a similar pattern, but at somewhat lower salinity values: spring salinity is near 3 ppt, peaks to approximately 7 ppt in the summer, then decreases to about 4 ppt in the fall. The same pattern is repeated in all the upriver regions as far as Hyde Park, but at decreasing average salinity. Regions above Poughkeepsie are typically fresh water, and therefore display no seasonal pattern in salinity.

The longitudinal relationship between freshwater inflow (average for preceding week) and salinity, as measured by the Hudson River Utilities' program, is evident in Figure 3-34. At flows near 793 m^3/sec (28,000 cfs), near the median spring flow, salinities in the Yonkers region average approximately 2 ppt and drop to less than 0.1 ppt by the Croton-Haverstraw region. At low summer flows of 130 m^3/sec (4600 cfs), salinities at Yonkers average approximately 11 ppt and drop to less than 0.1 ppt by the Poughkeepsie region.

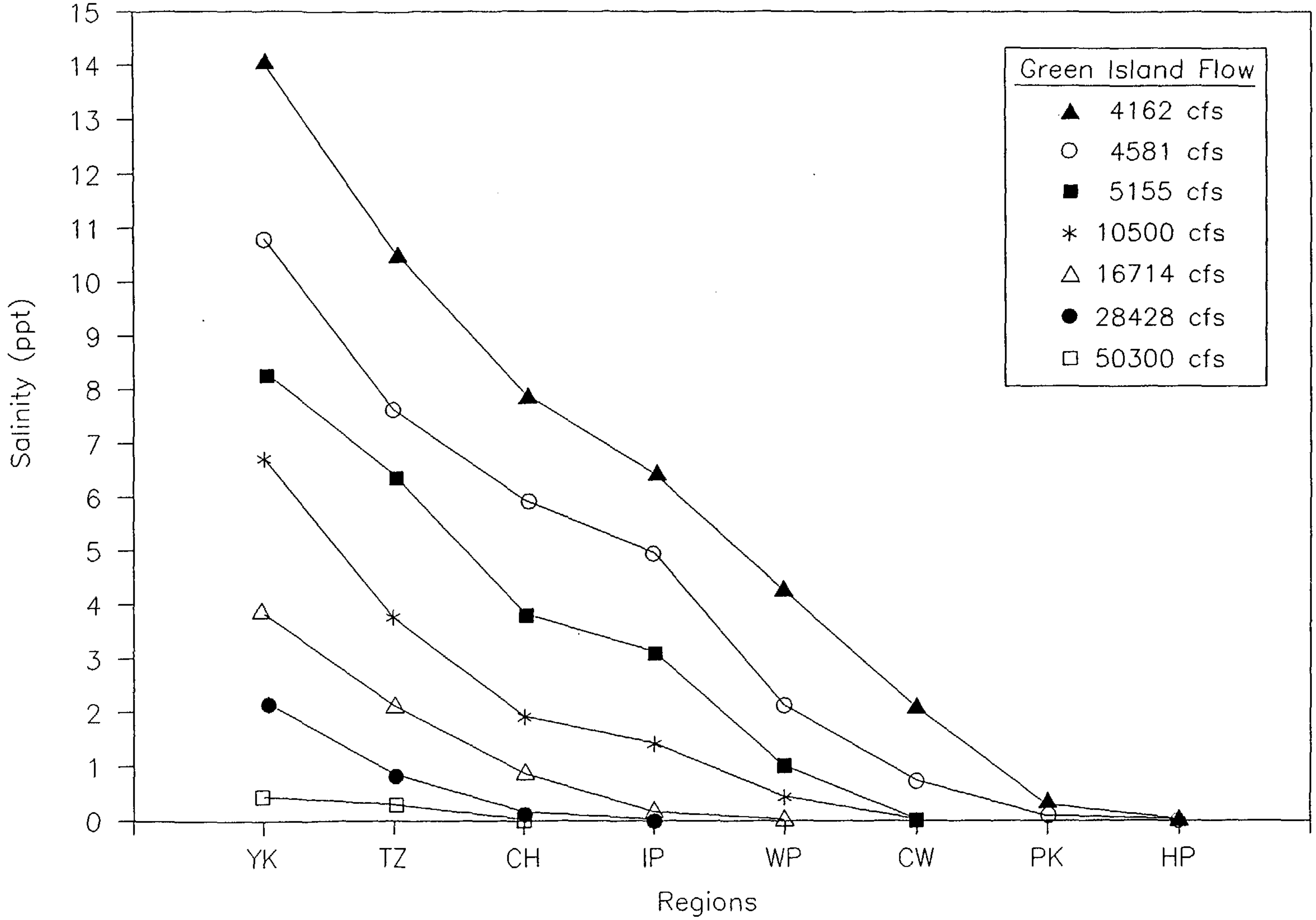
3.3.4 Dissolved Oxygen

Dissolved oxygen is one of the most important factors in the survival of nearly all aquatic organisms; the lower limit for normal respiration of aquatic animals appears to be 1-2 mg/l (Emery and Stevenson 1957). The concentration of DO is determined by the interaction of several biological and physical processes: photosynthesis, tidal mixing, low temperatures, low salinity, and high atmospheric pressure increase oxygen concentrations; respiration, microbial decomposition of organic material, chemical oxidation, high temperatures, high salinity, and low atmospheric pressure decrease oxygen concentrations. The interaction among these factors typically results in a seasonal pattern of highest DO concentrations during the winter and lowest during the summer and a diel pattern of highest DO during daylight and lowest during darkness. In highly stratified estuaries a gradient of decreasing DO with depth may develop due to the reduced interchange between the turbulent mixing of enriched surface fresh water and the more stagnant bottom seawater.

FIGURE 3-34

HUDSON RIVER REGIONAL SALINITY

Effects of Variable Freshwater Flow Rates



Leslie et al. (1988), using DO as an indicator of pollution, reviewed Hudson River trends in dissolved oxygen for the period 1967-1980. Two regions of low DO were identified: Albany (Rkm 193-242; RM 120-150) and New York City (Rkm 0-16; RM 0-10). In the Albany region, prior to 1974, summer DO levels were below the New York State standard of 4 mg/l and even approached 0 mg/l during 1970-1972. In 1974 two waste treatment plants came on line, which treated approximately 80% of these cities' domestic wastes. Records of dissolved oxygen at Glenmont, New York (Rkm 228; RM 142), indicate that DO levels improved after 1974. In the New York City area DO concentrations consistently fell below 4 mg/l during the summer for all surveys. However, the authors noted that for most of the year DO in the New York City area is well above the state standard and transient fish do frequent the area in the noncritical months.

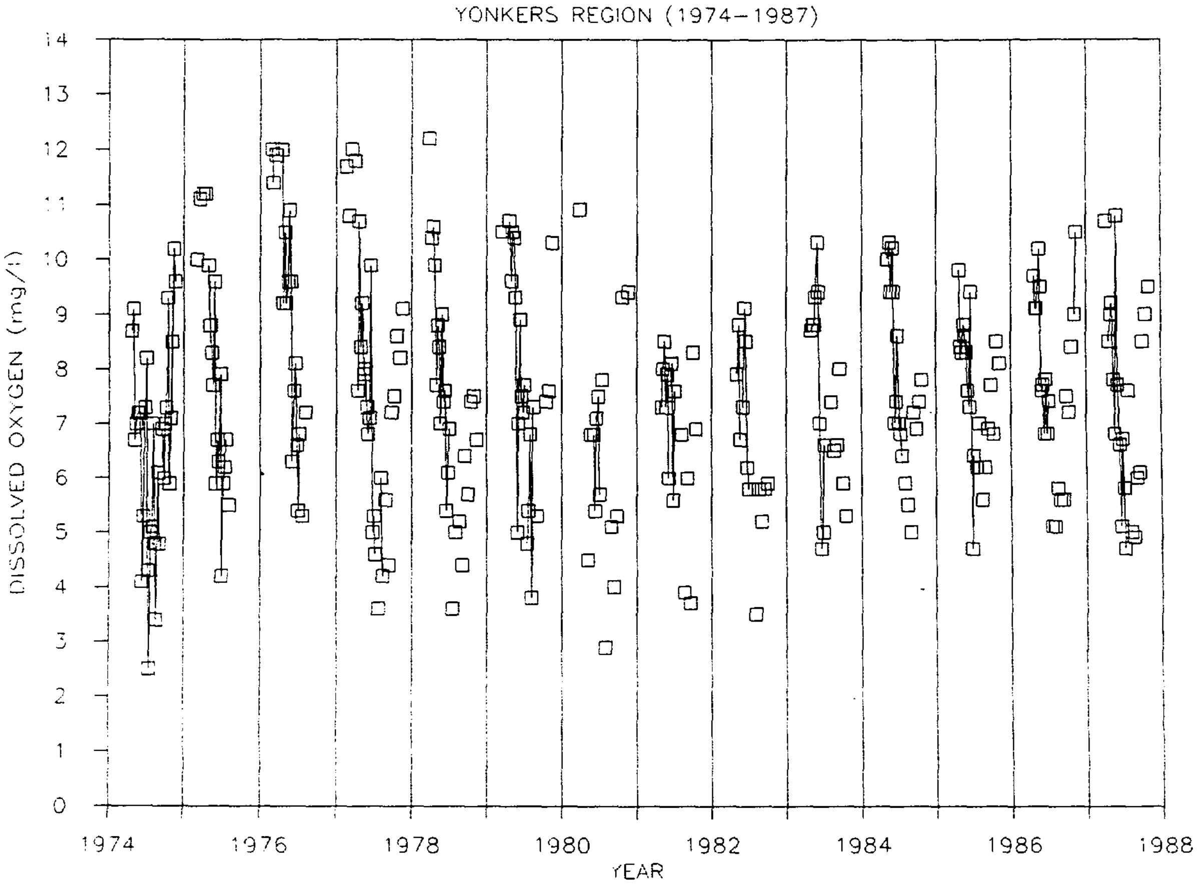
Analysis of the DO data collected in the LRS and FSS reveals similar findings. Average regional DO values over the period 1974-1987 indicate lowest average DO concentrations in the Albany region (Rkm 201-244; RM 125-152) and the Yonkers region (Rkm 19-37; RM 12-23). Only the Yonkers region, however, yielded summer DO values regularly below 4 mg/l and then only prior to 1983 (Figures 3-35 and 3-36). Highest average DO concentrations were observed in the regions from Kingston through Catskill.

Over the sampling year average DO concentrations were generally highest in February and April and lowest in July through September. In the Yonkers region peak DO concentrations averaged approximately 12 mg/l and decreased to about 5 mg/l in the summer. Peak DO concentrations remained relatively constant at 12-13 mg/l throughout the river. Summer DO values tended to increase in an upriver direction from approximately 7 mg/l in the Tappan Zee region to about 8.5 mg/l in the Catskill region before decreasing to about 6.5 mg/l in the Albany region (Figures 3-37 and 3-38).

Analysis of residual DO values, i.e., the difference between the average weekly DO concentration for the region over the period 1974-1987 and each indi-

FIGURE 3-35

DISSOLVED OXYGEN VS. TIME



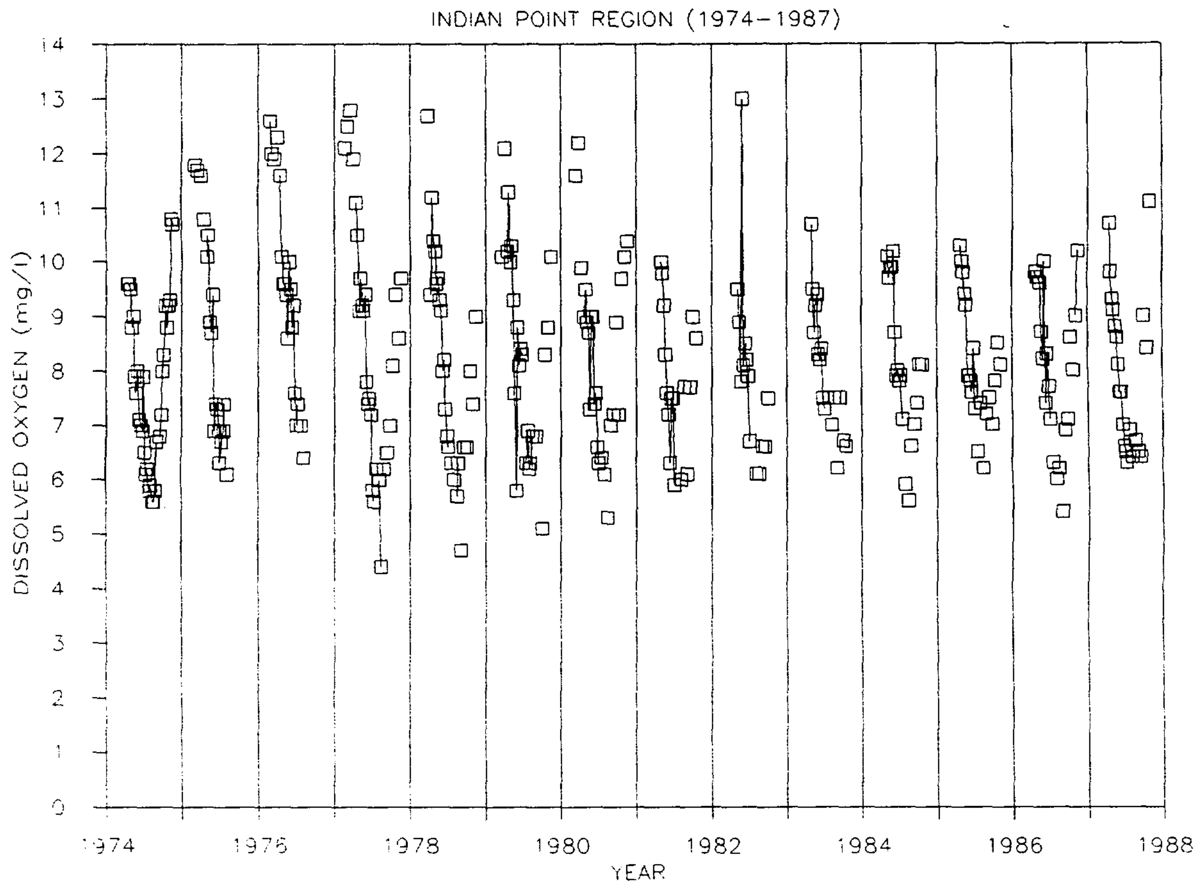
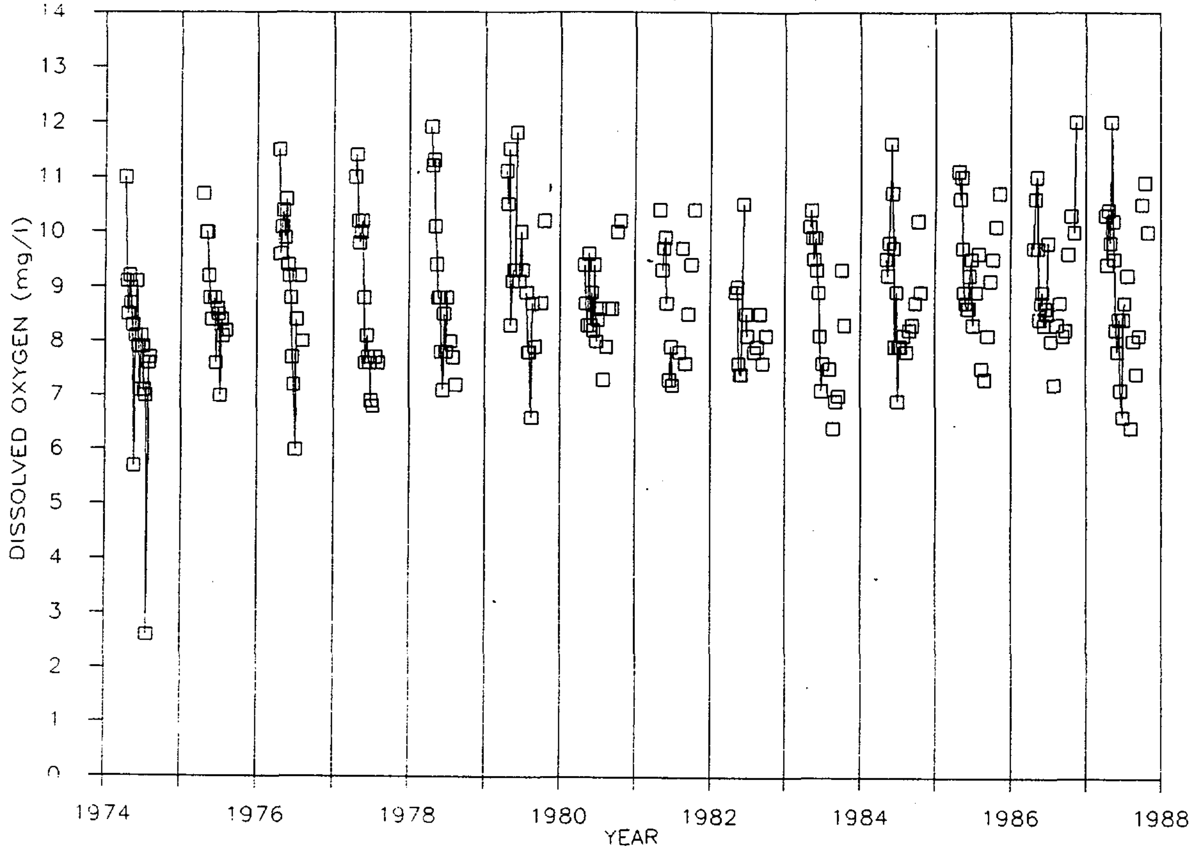


FIGURE 3-36

DISSOLVED OXYGEN VS. TIME

KINGSTON REGION (1974–1987)



ALBANY REGION (1974–1987)

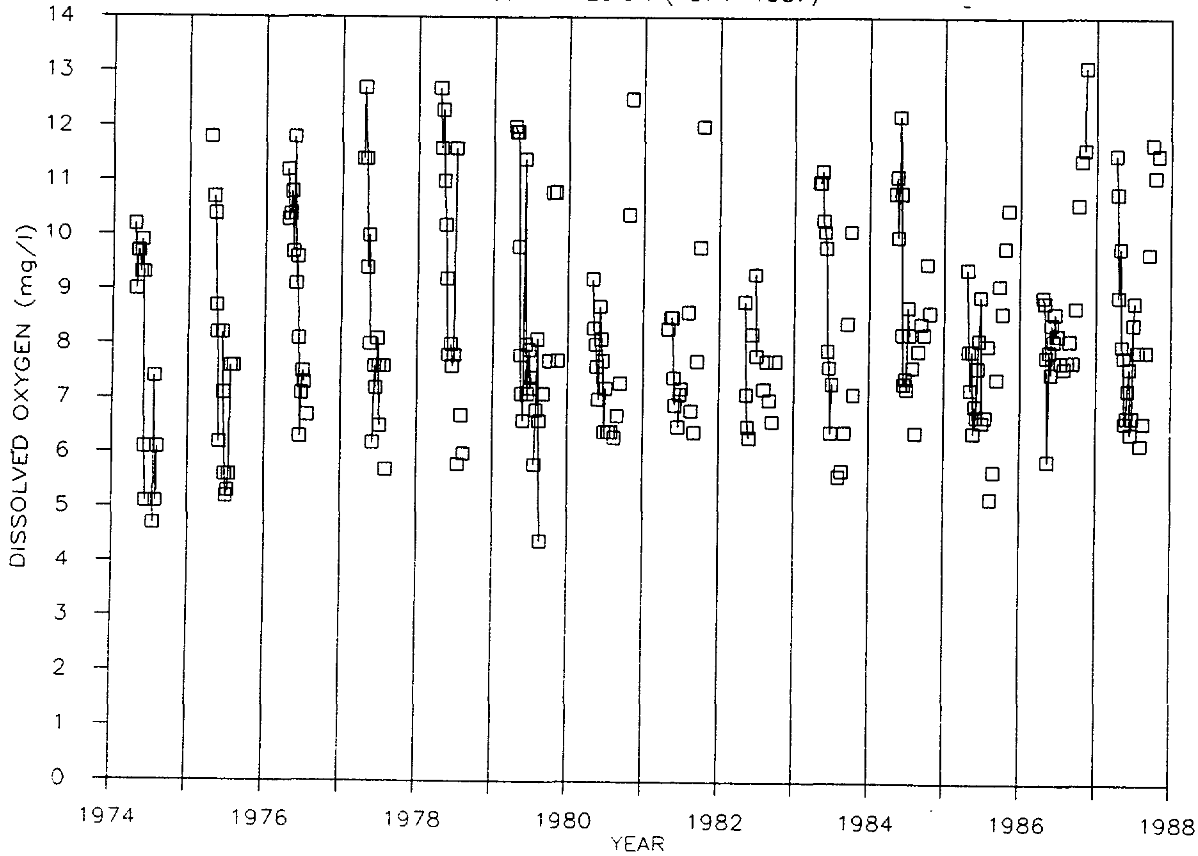
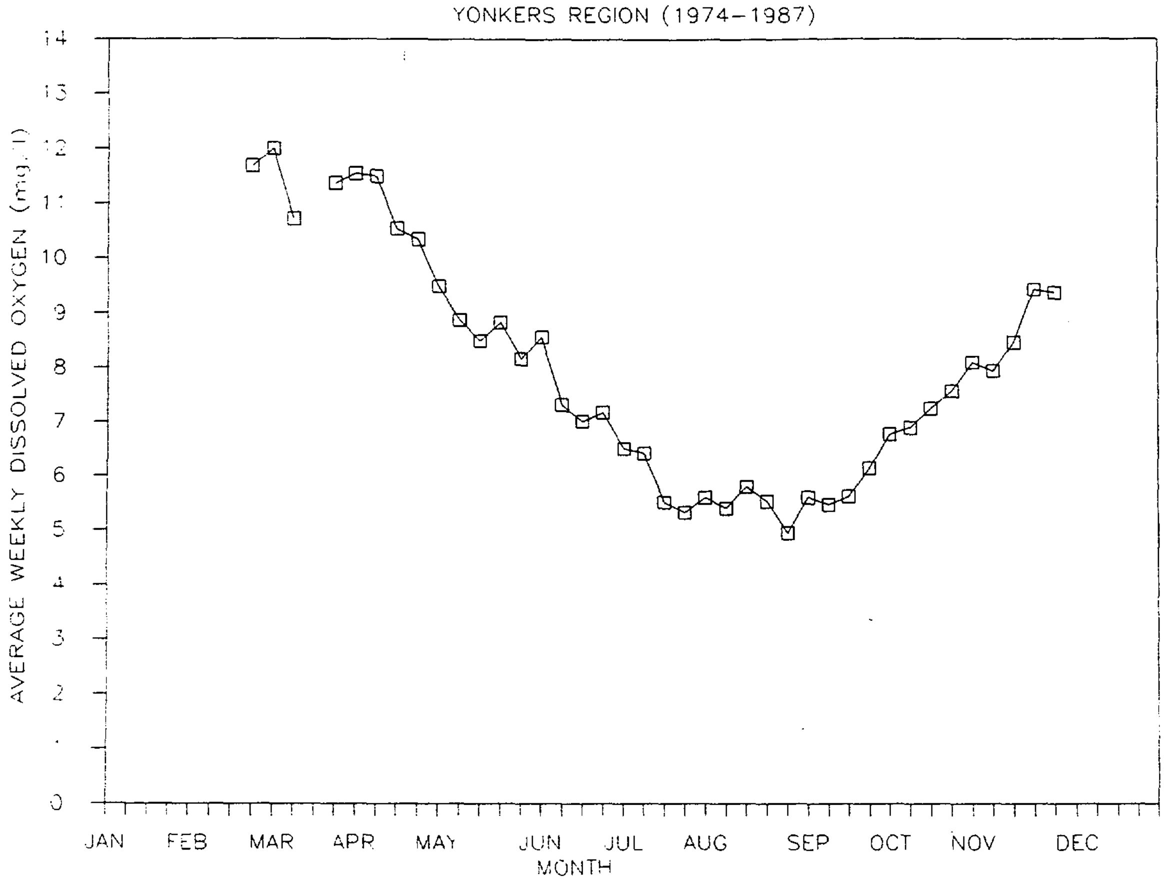


FIGURE 3-37

AVERAGE WEEKLY DISSOLVED OXYGEN VS TIME



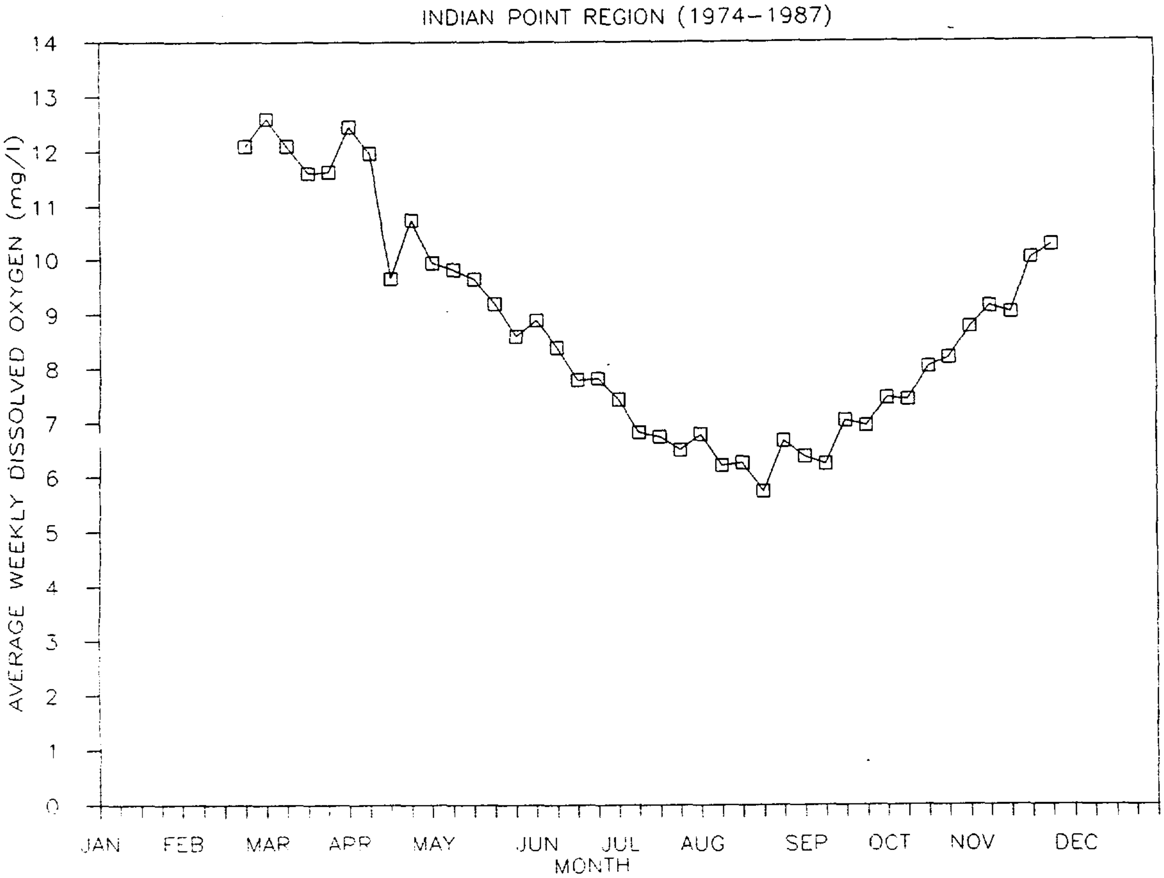
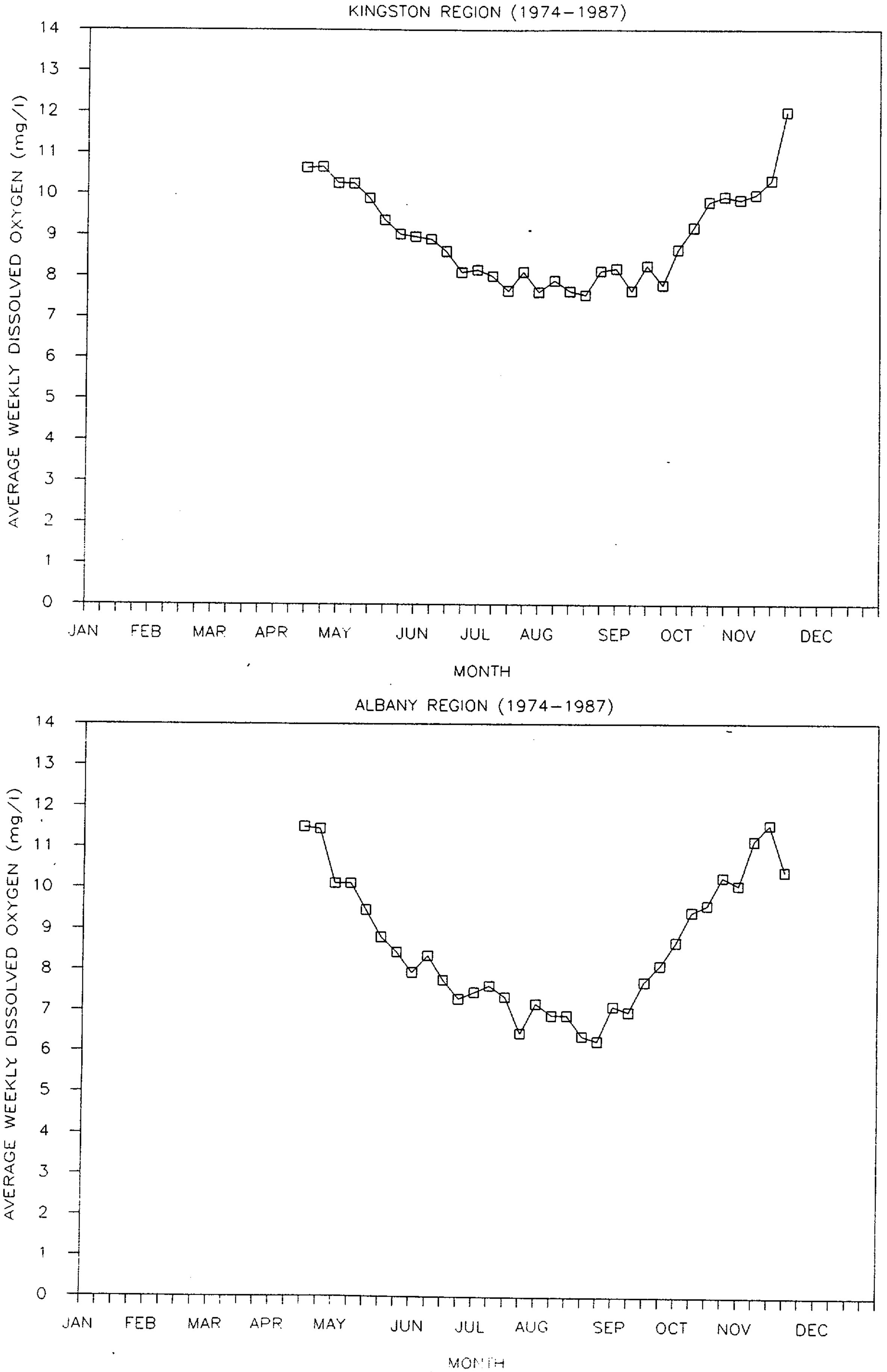


FIGURE 3-38

AVERAGE WEEKLY DISSOLVED OXYGEN VS TIME



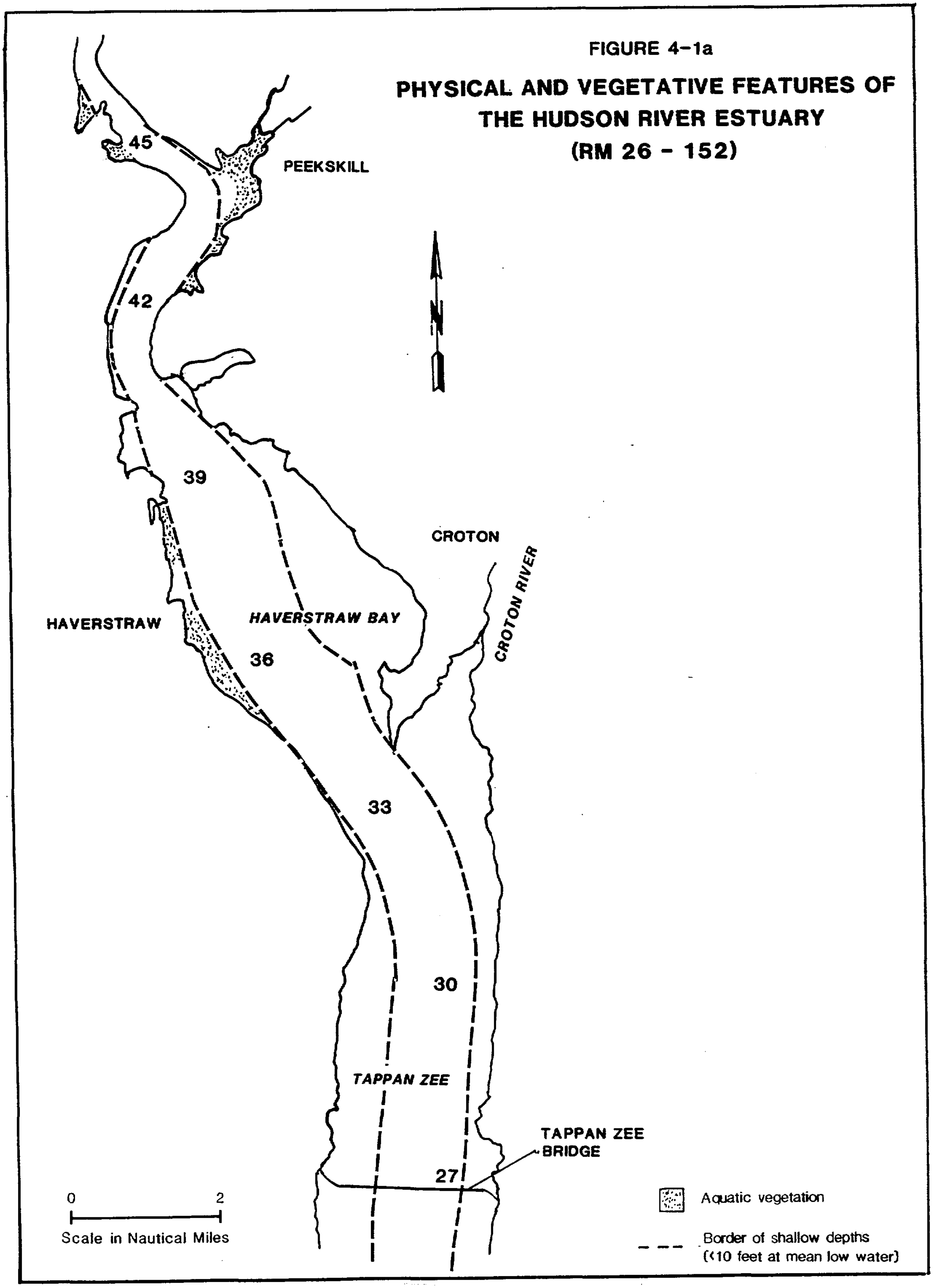


FIGURE 4-1a
PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)

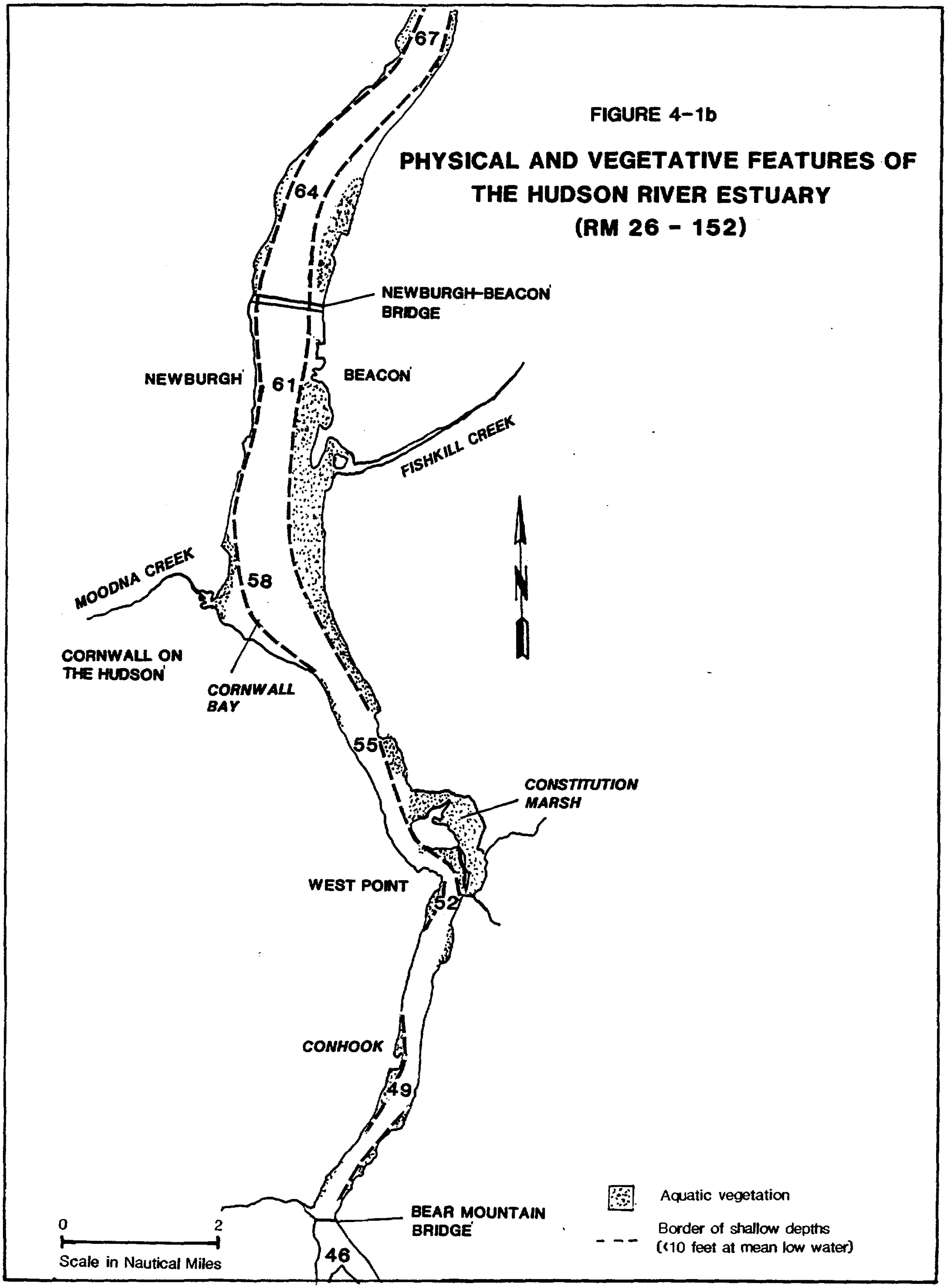
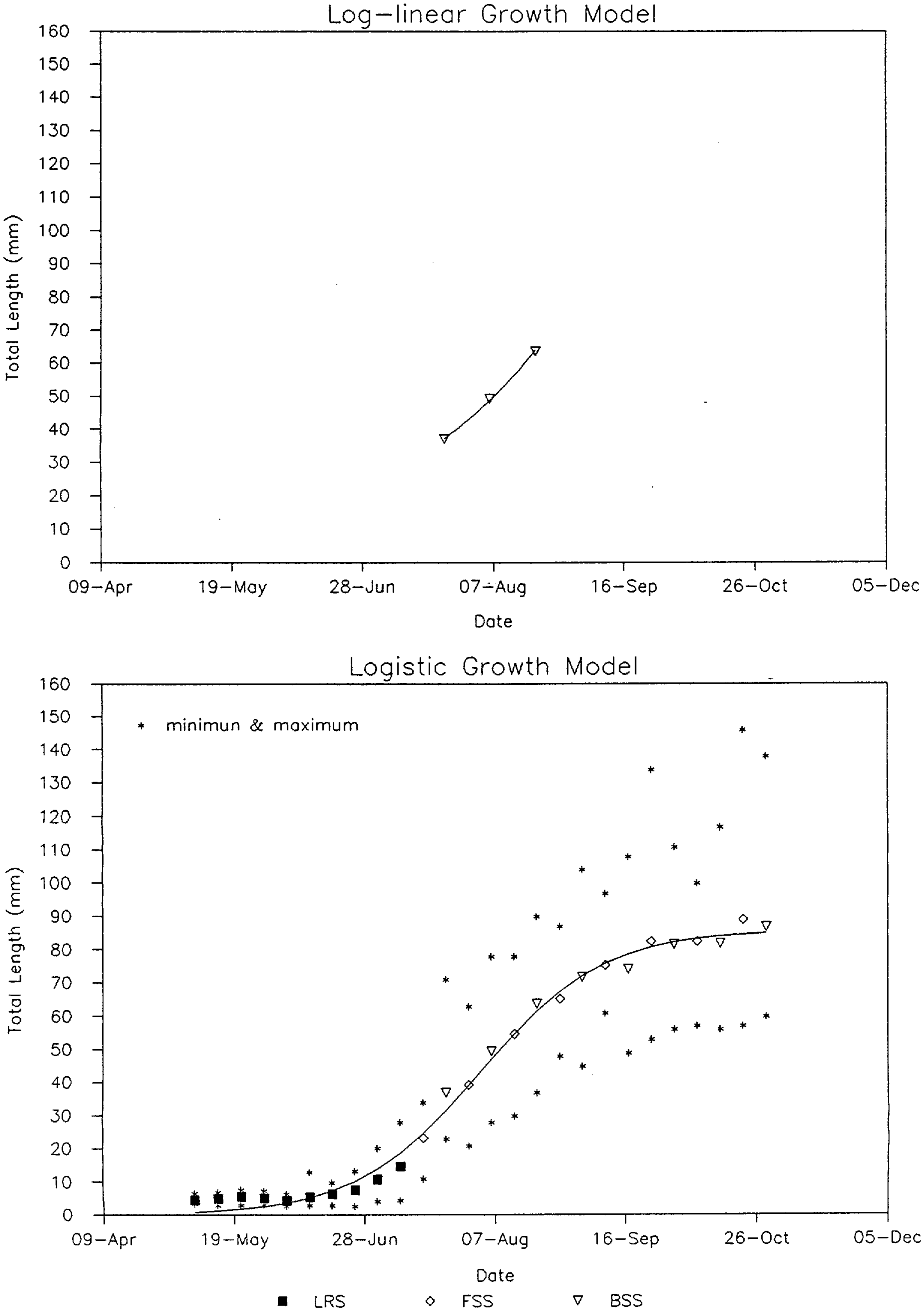


FIGURE 4-1b

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)

FIGURE 8-3

STRIPED BASS GROWTH - 1984



Egg abundance distribution was bimodal in 1984. The first cohort appeared to contribute little to the juvenile population; this is likely due to mortality of the early cohort. Cold water temperatures (Figure 8-1) and high freshwater flows (Figure 8-2) during late May and early June 1984 were primarily responsible for the mortality. Because the logistic model includes mean length data prior to 1 June sampling, there is a possible discrepancy in growth rates between the two models. The logistic equation was therefore recalculated using only the larval mean lengths from collections after 1 June so as not to include information on the nonrecruited cohorts. Using the new equation (K = 85.117706, R = 0.054522, A = 6.705854, r^2 = 0.9353), it was determined that the striped bass population reached a mean length of 30 and 60 mm (TL), respectively, on 21 July and 18 August, the same dates as determined previously using larval mean lengths from all sample collections (Figure 8-4); thus, growth rates also remain the same.

Mean temperatures during peak egg, YSL, and PYSL abundance were within the range observed in other years (Table 8-2). Compared to other years (1974-1987), peak egg, YSL, and PYSL abundance occurred approximately two weeks later in the season (Table 8-2). This resulted in a later growing season, evidenced by the shift toward the right in the sigmoid growth curve as compared to years 1985-1987 (Figure 8-5); growth achieved during the fall period also appears to be smaller. However, larval and juvenile growth rates are similar to striped bass 1985-1987 values (Table 8-1), which have earlier egg abundance dates.

8.1.2 1985 Survey

8.1.2.1 Log-Linear Estimates. The striped bass population in 1985 reached mean total lengths of 30 and 60 mm on 6 and 25 July, respectively (Table 8-1). These dates were estimated from the log-linear regression (ln Y = 0.035909x + 1.011067, r^2 = 0.9838) of striped bass mean lengths from the 15 and 29 July BSS and the 20 May LRS sampling periods (Figure 8-6). Because of the small sample size in the 12 and 26 August BSS samples and the small number of regression points, the 20 May LRS sample period, midpoint of peak striped

FIGURE 8-4

STRIPED BASS GROWTH – 1984

Logistic Growth Model

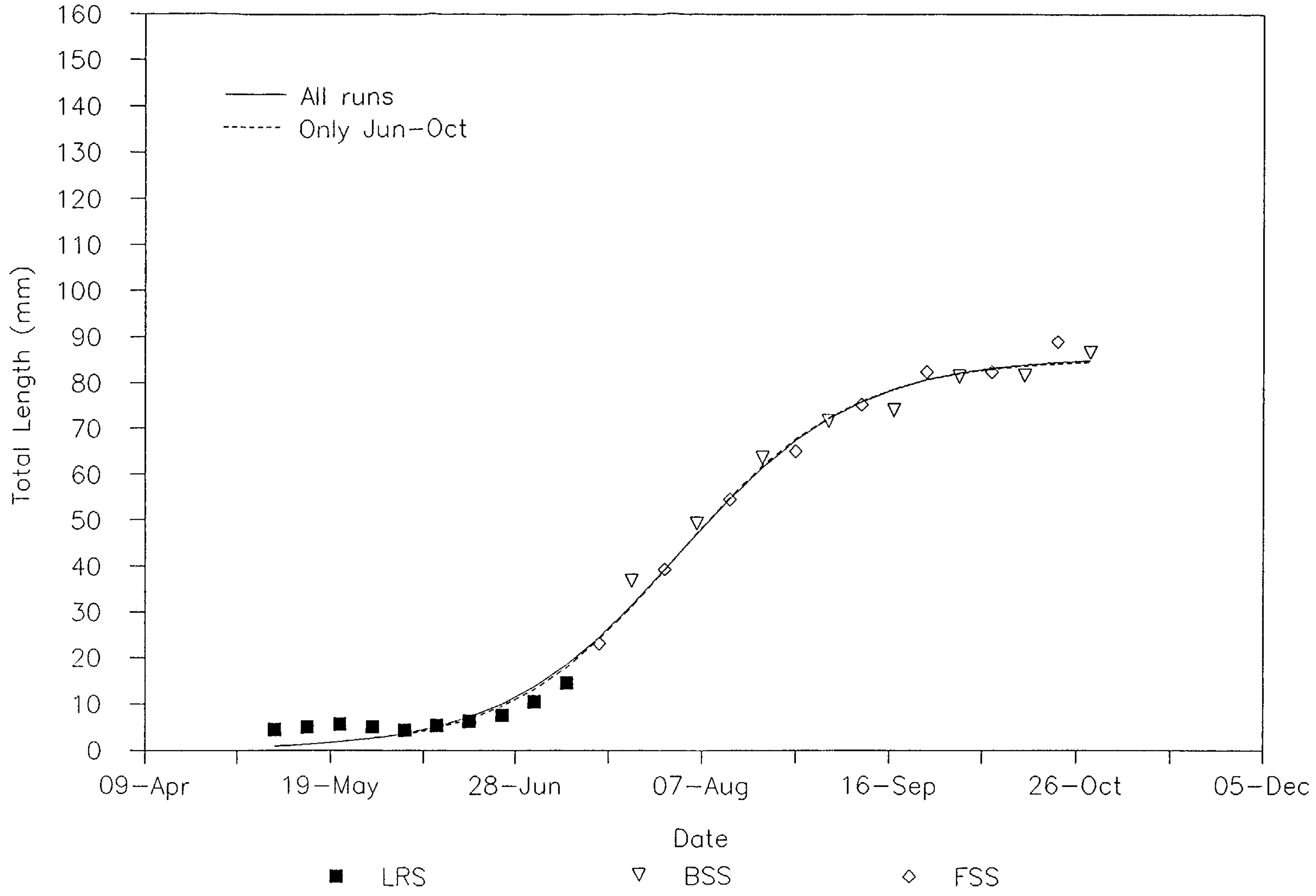


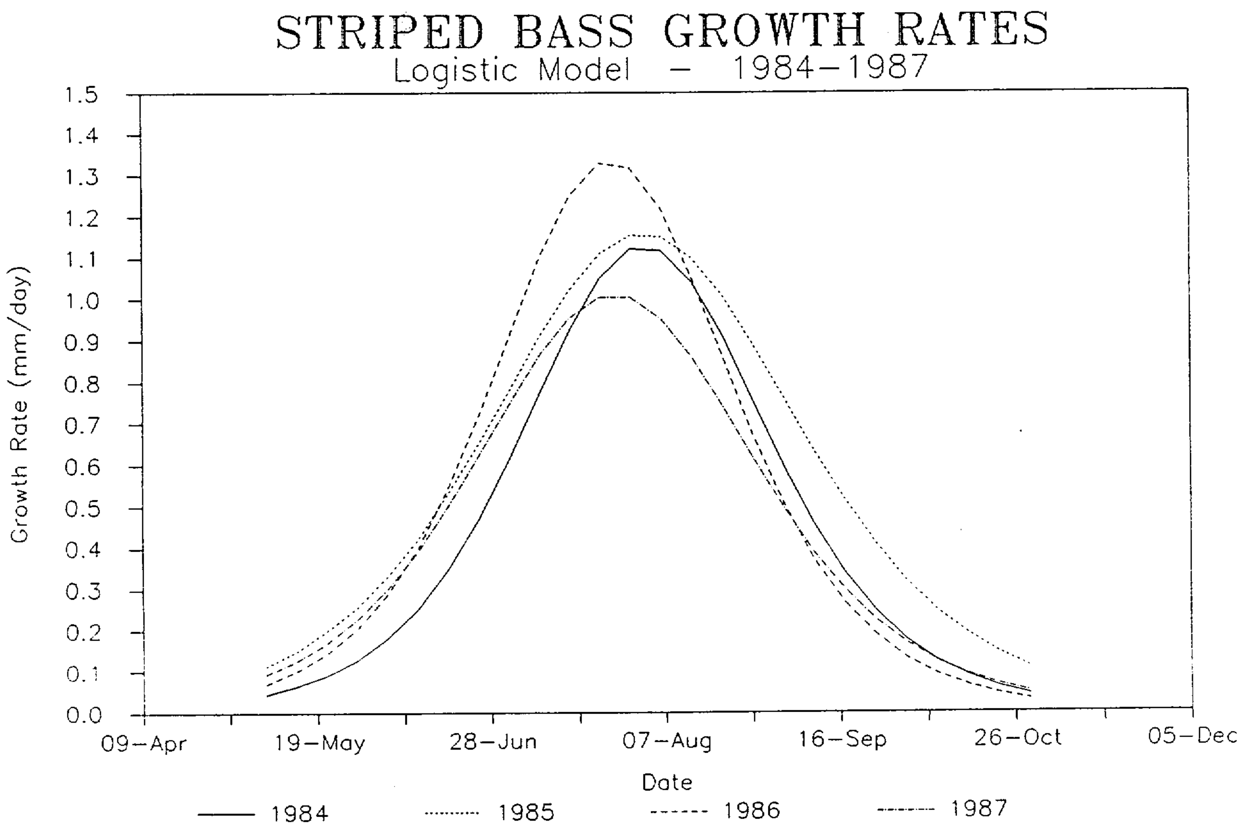
TABLE 8-2

MEAN WATER TEMPERATURE (C°) IN REGIONS AND PERIODS OF PEAK ABUNDANCE OF STRIPED BASS EGGS AND LARVAE, HUDSON RIVER ESTUARY, 1974-1987[a]

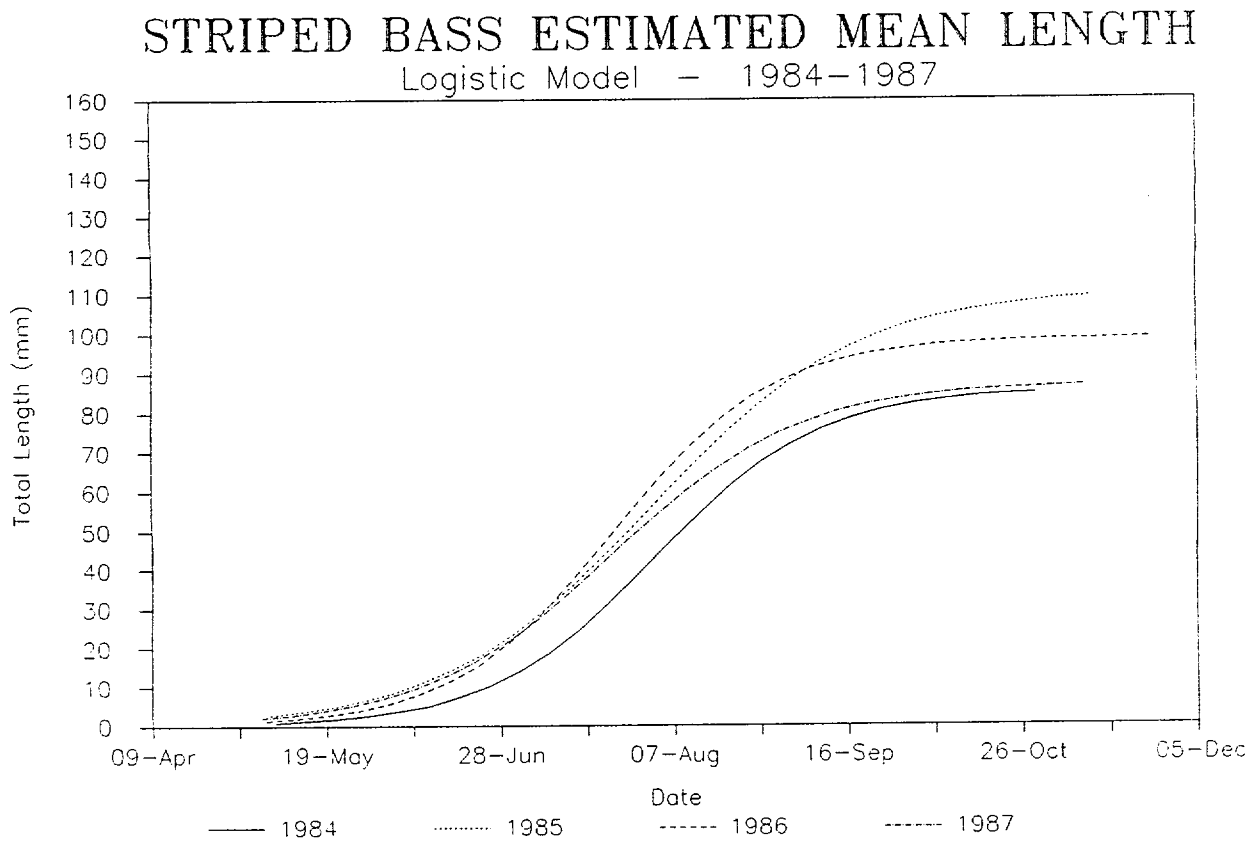
	EGGS		YOLK-SAC LARVAE		POST-YOLK-SAC LARVAE	
YEAR	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE
1974	12 May - 25 May	15.4	26 May - 08 Jun	17.5	09 Jun - 22 Jun	21.5
1975	18 May - 31 May	19.0	25 May - 07 Jun	19.9	01 Jun - 14 Jun	20.6
1976	23 May - 05 Jun	15.0	30 May - 12 Jun	16.4	06 Jun - 19 Jun	18.6
1977	15 May - 28 May	14.36	22 May - 04 Jun	17.0	29 May - 18 Jun	19.3
1978	21 May - 27 May	15.7	28 May - 10 Jun	20.2	04 Jun - 17 Jun	20.7
1979	06 May - 19 May	16.2	20 May - 02 Jun	18.2	27 May - 02 Jun	18.4
1980	19 May - 22 May	16.3	27 May - 30 May	17.2	02 Jun - 13 Jun	18.2
1981	18 May - 21 May	15.9	18 May - 21 May	15.9	01 Jun - 13 Jun	18.0
1982	24 May - 28 May	17.1	24 May - 28 Jun	17.1	31 May - 09 Jun	18.5
1983	16 May - 05 Jun	13.6	06 Jun - 19 Jun	19.2	13 Jun - 26 Jun	21.7
1984	04 Jun - 10 Jun	14.7	11 Jun - 17 Jun	19.0	18 Jun - 25 Jun	21.1
1985	06 May - 20 May	15.5	13 May - 20 May	16.9	28 May - 03 Jun	19.3
1986	12 May - 18 May	17.9	26 May - 01 Jun	20.9	02 Jun - 08 Jun	21.0
1987	11 May - 17 May	14.2	18 May - 24 May	15.5	25 May - 07 Jun	18.2

[a]Adapted from MMES (1986).

FIGURE 8-5



STRIPED BASS GROWTH RATES
Logistic Model – 1984–1987
Growth Rate (mm/day)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
09–Apr
19–May
28–Jun
07–Aug
16–Sep
26–Oct
05–Dec
Date
1984
1985
1986
1987

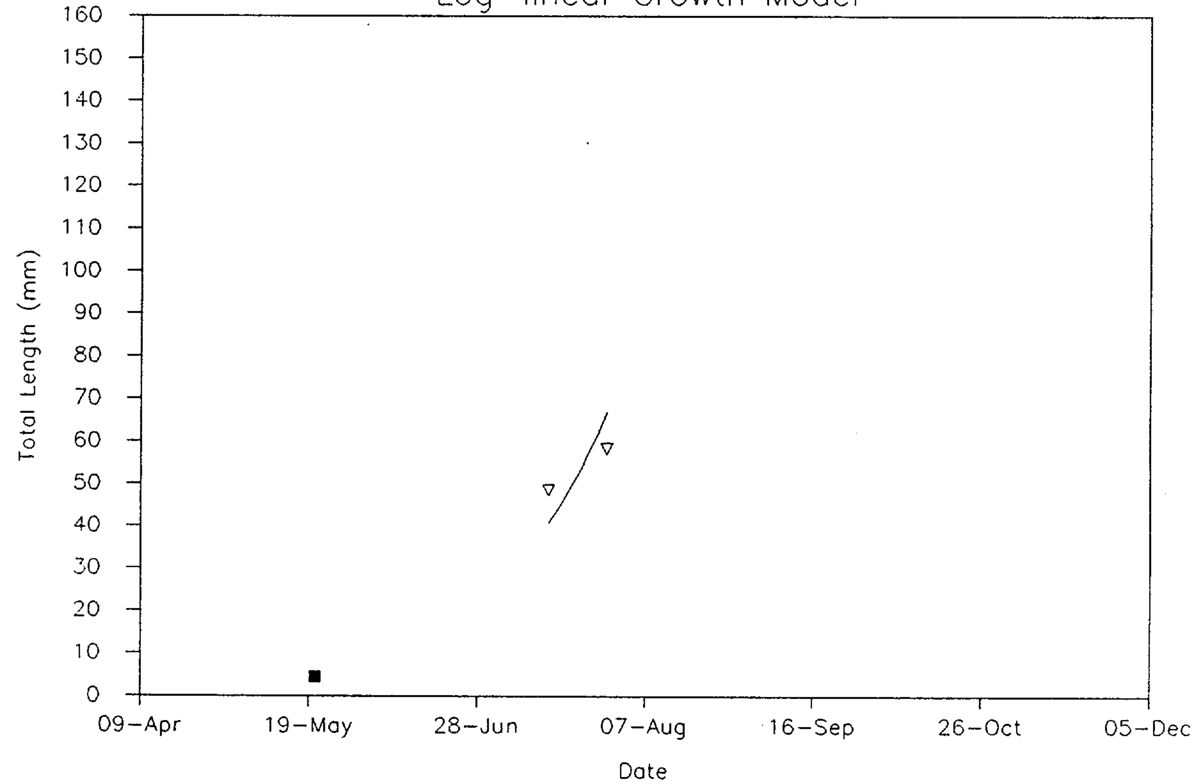


STRIPED BASS ESTIMATED MEAN LENGTH
Logistic Model – 1984–1987
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09–Apr
19–May
28–Jun
07–Aug
16–Sep
26–Oct
05–Dec
Date
1984
1985
1986
1987

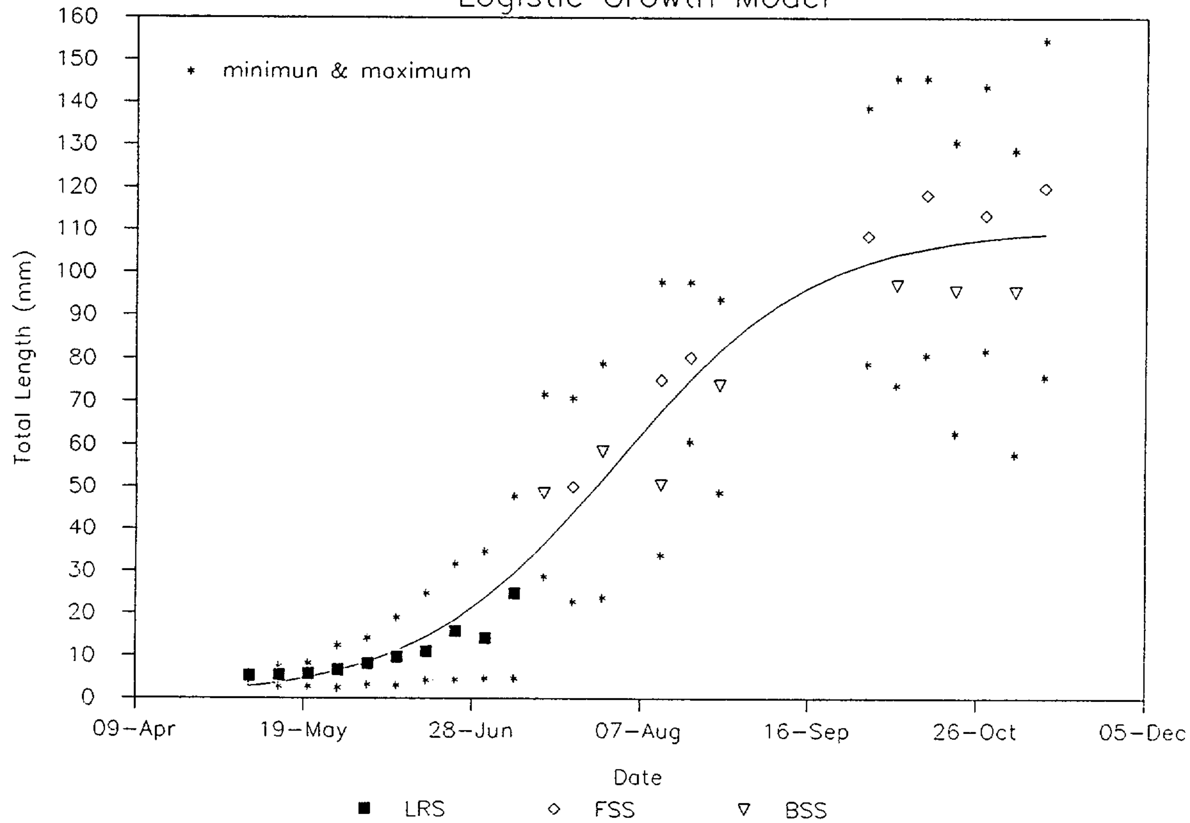
FIGURE 8-6

STRIPED BASS GROWTH – 1985

Log–linear Growth Model



Logistic Growth Model



vidual observation from the corresponding week, indicates that the middle estuary regions are least variable in DO concentration (Figure 3-39). In the regions from Indian Point through Hyde Park 95% of the DO values fell within approximately 1.6 mg/l of the weekly average. In the more variable Yonkers and Albany regions 95% of the observations fell within 2.3 and 2.5 mg/l of the weekly average.

Reasonably accurate estimates of DO concentrations can be obtained from the prevailing water temperature by using the equations given in Table 3-17. The lowest correlation coefficient of -0.6615 was determined for the Saugerties region while six of the 12 regions had correlation coefficient determinations greater than -0.8. Comparison of the regressions indicates significant differences ($F_{11, 3154} = 38.01$, $P<0.01$); therefore, a separate equation should be used for each region.

3.3.5 pH

The pH of an aquatic system, a measure of hydrogen ion concentration, is an important biological parameter since many internal bodily functions (primarily respiration) are directly influenced by it (Odum 1971). Chemically, pH controls the distribution of many trace metals through its effects on solubility, adsorption, and complexation (Culberson and Sharp 1983). Though pH is a critical parameter, biological populations exhibit a high tolerance to naturally occurring pH conditions. Long-term lower Hudson River water quality monitoring programs indicate a mean pH range between 6.4 and 8.2, with no predictable temporal or spatial patterns evident (Cooper et al. 1988). The lower Hudson River is well buffered (Moran and Limburg 1986; Cooper et al. 1988), which acts to stabilize the pH and minimize the potential damaging effects to plants and animals of acid rain and point and nonpoint source discharges.

In aquatic ecosystems the seasonal, diel, and spatial patterns of pH are often directly correlated with carbon dioxide (CO_2) and inversely correlated with DO

FIGURE 3-39

STANDARD DEVIATION OF

DISSOLVED OXYGEN RESIDUALS (1974–1987)

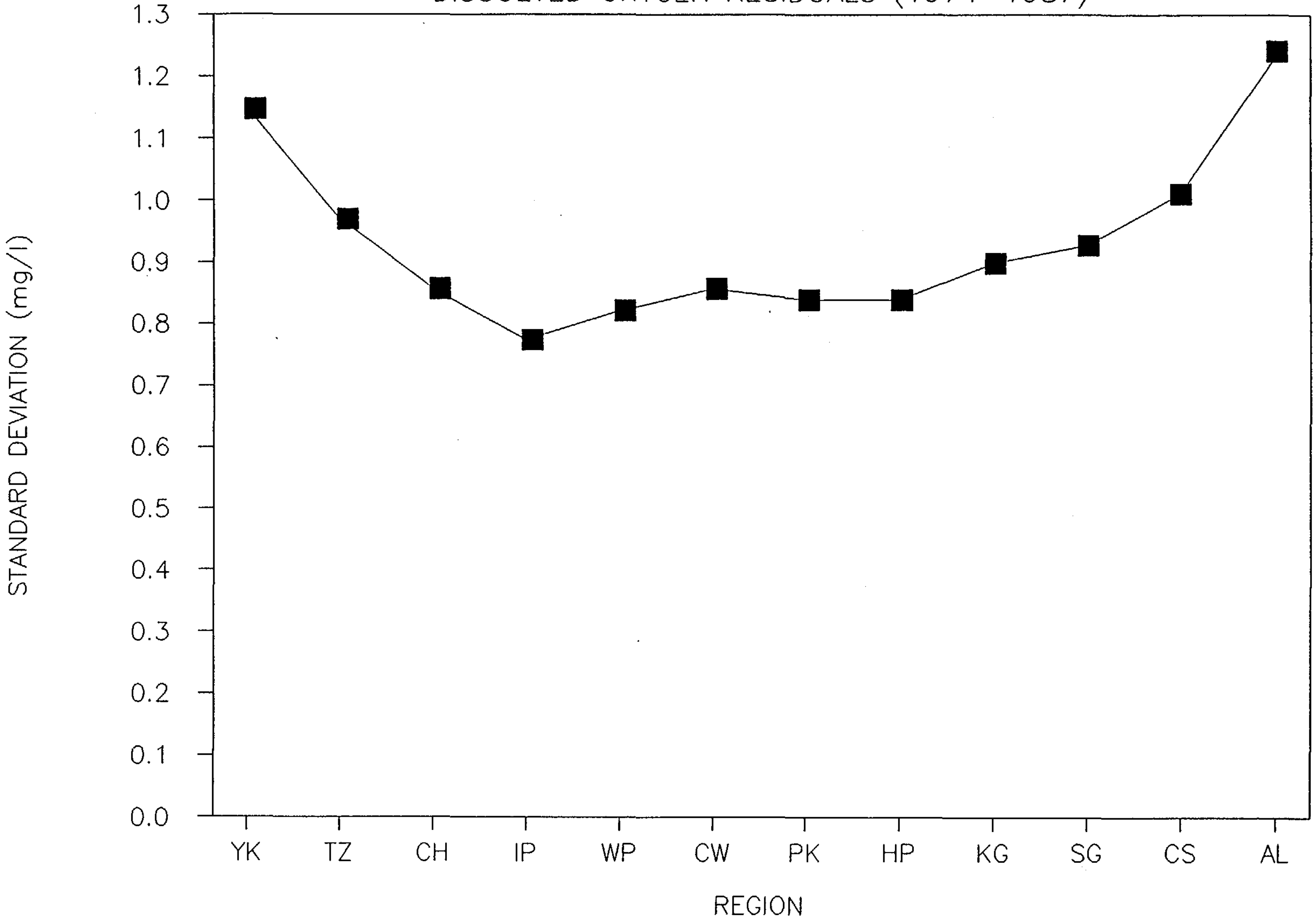


TABLE 3-17

COMPARISON BETWEEN REGIONAL WEEKLY MEAN WATER TEMPERATURE AND DISSOLVED OXYGEN (mg/l), 1974-1987

REGION	n	INTERCEPT	SLOPE	SE SLOPE	RMSE	CORRELATION COEFFICIENT r	F-RATIO	PROBABILITY >F
YK	276	12.51	-0.274	0.014	1.284	-0.7629	381.48	<0.001**
TZ	287	12.54	-0.221	0.011	1.054	-0.7747	427.91	<0.001**
CH	290	12.62	-0.221	0.009	0.932	-0.8154	571.52	<0.001**
IP	292	12.99	-0.254	0.008	0.776	-0.8934	1146.49	<0.001**
WP	284	13.06	-0.256	0.008	0.787	-0.8887	1059.60	<0.001**
CW	283	12.77	-0.228	0.008	0.807	-0.8614	807.95	<0.001**
PK	284	12.83	-0.240	0.009	0.840	-0.8656	842.89	<0.001**
HP	232	12.71	-0.226	0.012	0.867	-0.7897	381.14	<0.001**
KG	237	12.49	-0.191	0.011	0.886	-0.7378	280.72	<0.001**
SG	236	12.16	-0.165	0.012	0.966	-0.6615	182.10	<0.001**
CS	234	12.42	-0.180	0.012	0.957	-0.7100	235.87	<0.001**
AL	232	13.01	-0.275	0.013	1.081	-0.8144	453.07	<0.001**
Pooled	3167	12.68	-0.228	0.003	1.060	-0.7734	4710.94	<0.001**

Note: See Figure 2-1 for explanation of region abbreviations.
n - sample size; RMSE - root mean square error.
**Highly significant, P<0.01.

through respiration and photosynthesis. During sunlight hours plants use CO_2 and produce oxygen; during periods of darkness respiration reverses the process, using oxygen and producing CO_2. The pH cycle closely follows the CO_2 concentration since CO_2 reacts with water to form carbonic acid, which can lower pH. Diel variations of 0.2 to 1.0 pH units have been recorded for bays and lagoons (Emery and Stevenson 1957), areas subject to greater photosynthetic activity; estuaries generally exhibit lower diel variability, approximately 0.05 pH units.

The Hudson River Utilities have recorded pH during a number of sampling programs, including the LRS, FSS, BSS, Interregional Trawl Survey, and Mark-Recapture Program. It was recorded consistently, estuarywide, only during 1974-1978, however. Additionally, at least three different types of meters (IL175 Portamatic, Hydrolab 6D, and Sergeant-Welch PBL) were used, although usage was generally consistent within a program. Because of potential differences among meters and the difficulties in calibrating and maintaining them, it is best not to mix data from programs utilizing different meters. For this reason, and because they offer the most continuous data source, only the data from the LRS and FSS programs were analyzed in detail (Appendix E).

Over the five-year period 1974-1978, pH averaged 7.33, but with significant differences among years (ANOVA $F_{4,643} = 51.91$, $P<0.001$) and among regions (ANOVA $F_{11,636} = 3.89$, $P<0.001$) (Table 3-18). Average pH values by year for the lower, middle, and upper estuary are given in Figures 3-40 through 3-44. The year 1974 yielded the highest average pH value, 7.49; 1976, the lowest, 7.06. Although the overall mean for 1976 is biased by the lack of data from the Hyde Park through Albany regions, pH measurements from the Yonkers through Poughkeepsie regions were often the lowest among the five years (Table 3-19). Although the difference among years is highly significant, the actual difference among years is minimal, basically patternless, and probably does not reflect changes in the aquatic environment, but rather year-to-year variations in the calibration of pH meters.

TABLE 3-18

ANALYSIS OF VARIANCE (ANOVA) FOR pH MEASURED IN THE LOWER HUDSON RIVER LRS/FSS, 1974-1978

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-VALUE	PROBABILITY >F
Yearly Comparison					
Year	4	13.137	3.2843	51.91	0.00000**
Error	643	40.679	0.0633		
Total	647	53.816			
Regional Comparison					
Region	11	2.735	0.2486	3.89	0.00002**
Error	636	40.628	0.0639		
Total	647	43.363			

**Significant at $p \leq 0.01$.

FIGURE 3-40

WEEKLY MEAN pH

LRS/FSS WATER QUALITY SURVEY 1974

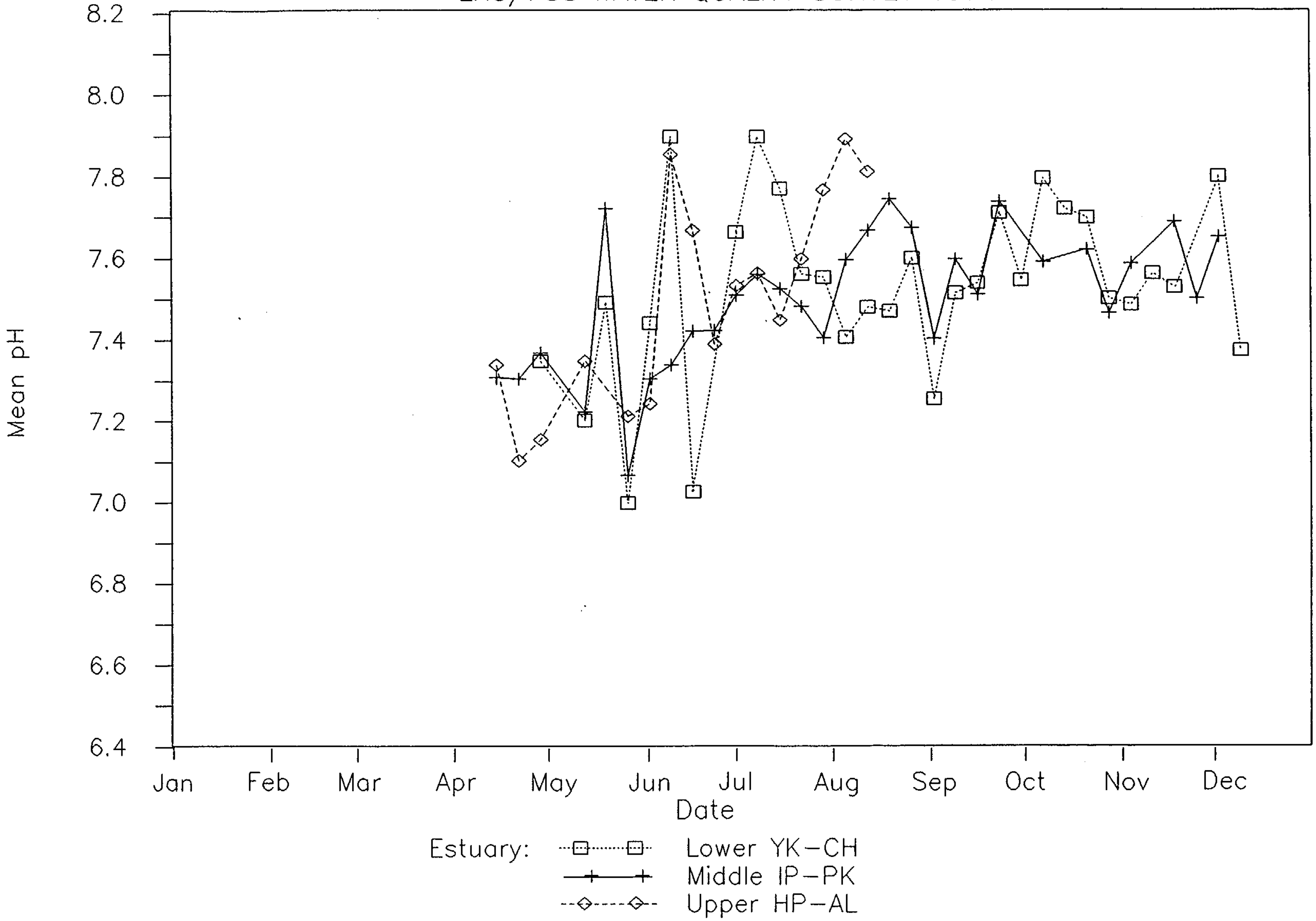


FIGURE 3-41

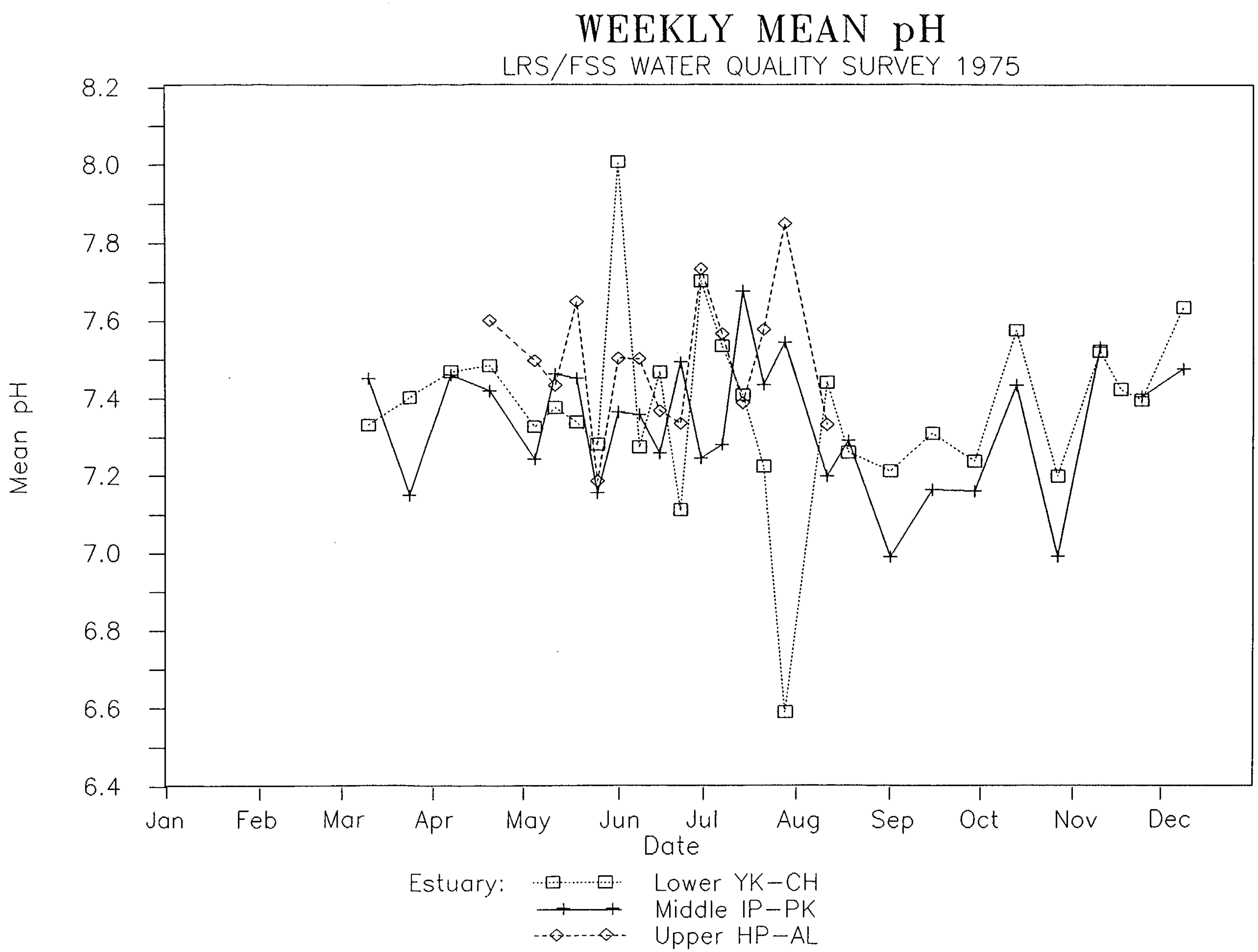

WEEKLY MEAN pH
LRS/FSS WATER QUALITY SURVEY 1975
Mean pH
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Date
Estuary:
Lower YK–CH
Middle IP–PK
Upper HP–AL

FIGURE 3-42

WEEKLY MEAN pH

LRS/FSS WATER QUALITY SURVEY 1976

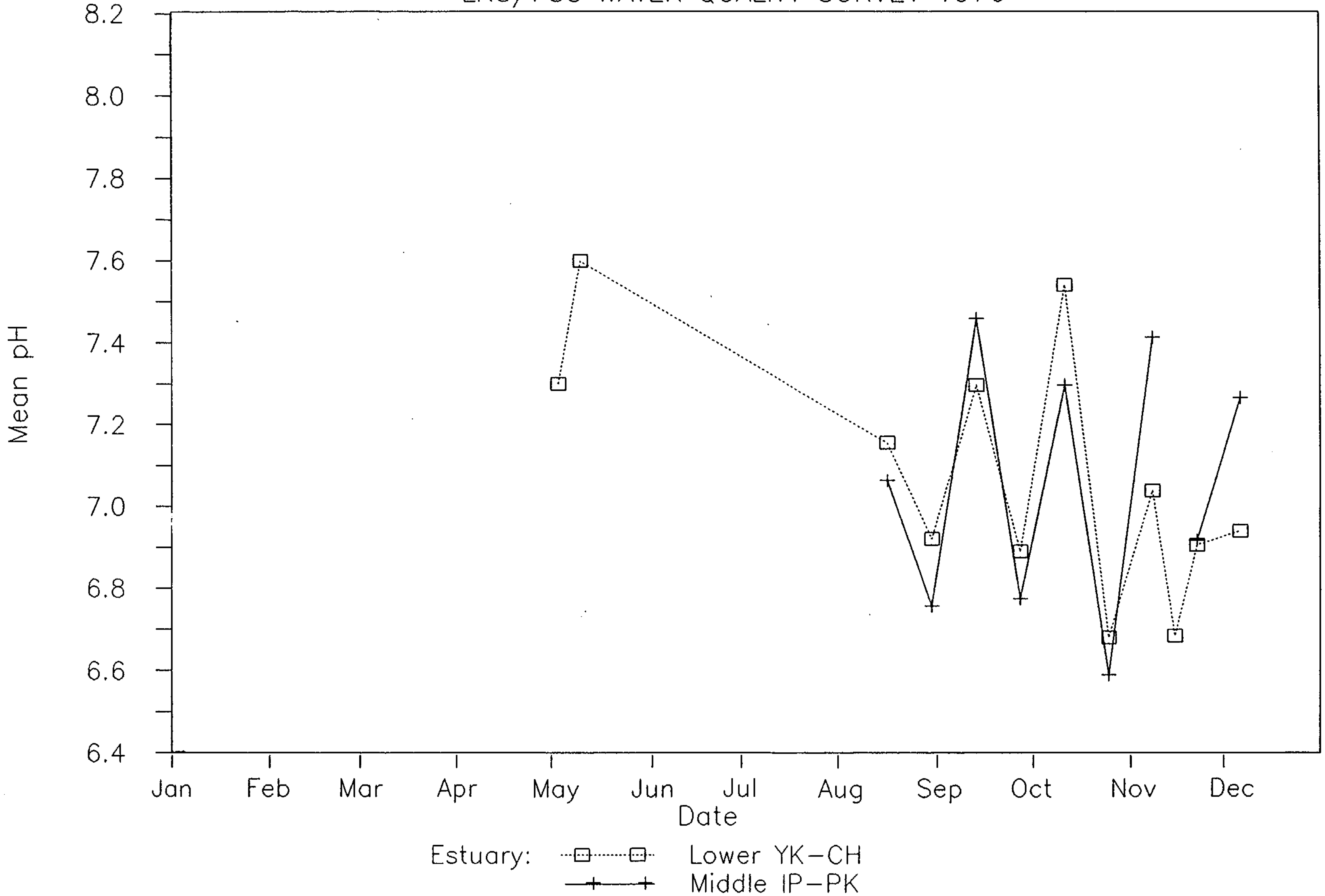


FIGURE 3-43

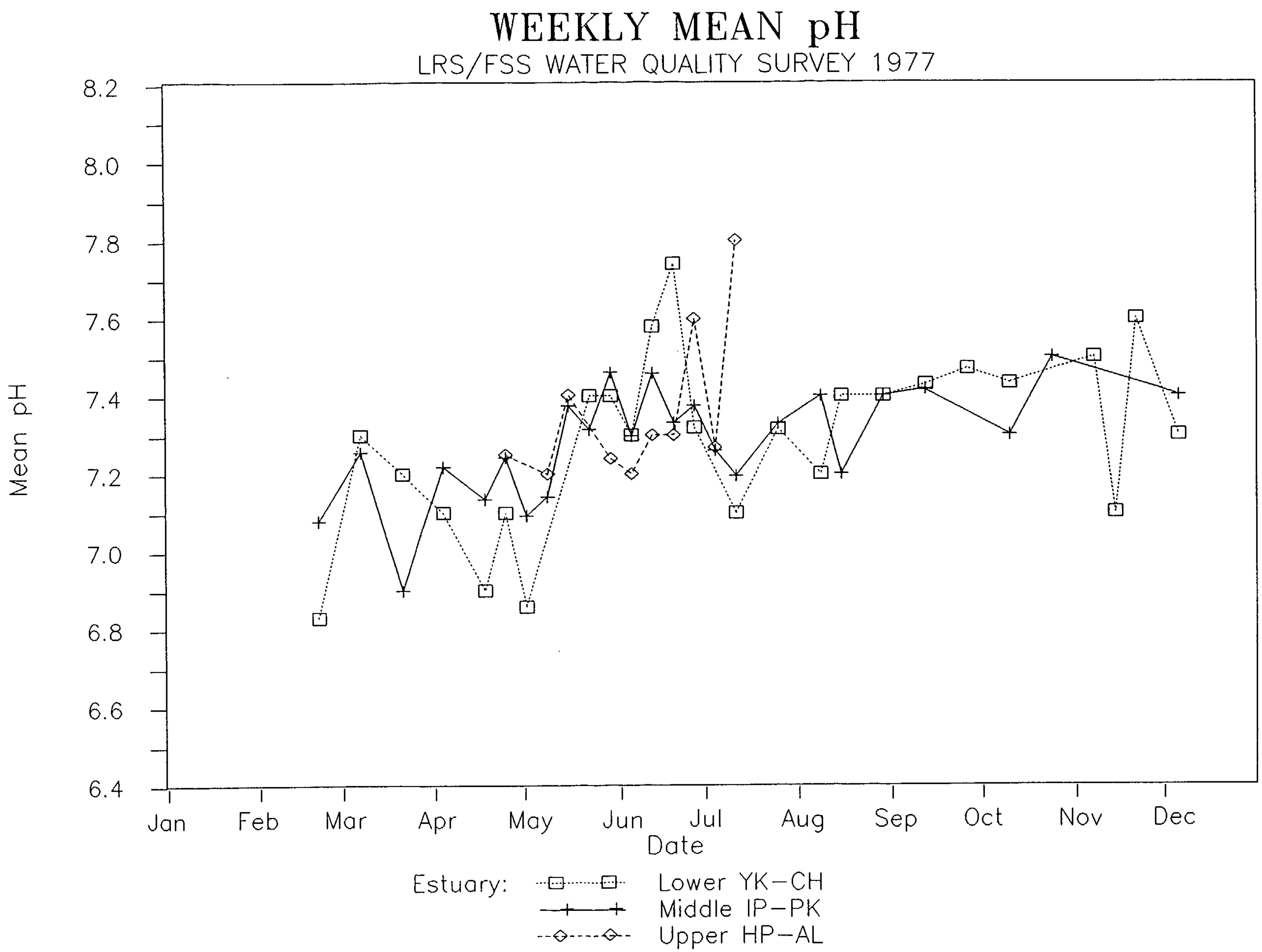

WEEKLY MEAN pH
LRS/FSS WATER QUALITY SURVEY 1977
Mean pH
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Date
Estuary:
Lower YK–CH
Middle IP–PK
Upper HP–AL

FIGURE 3-44

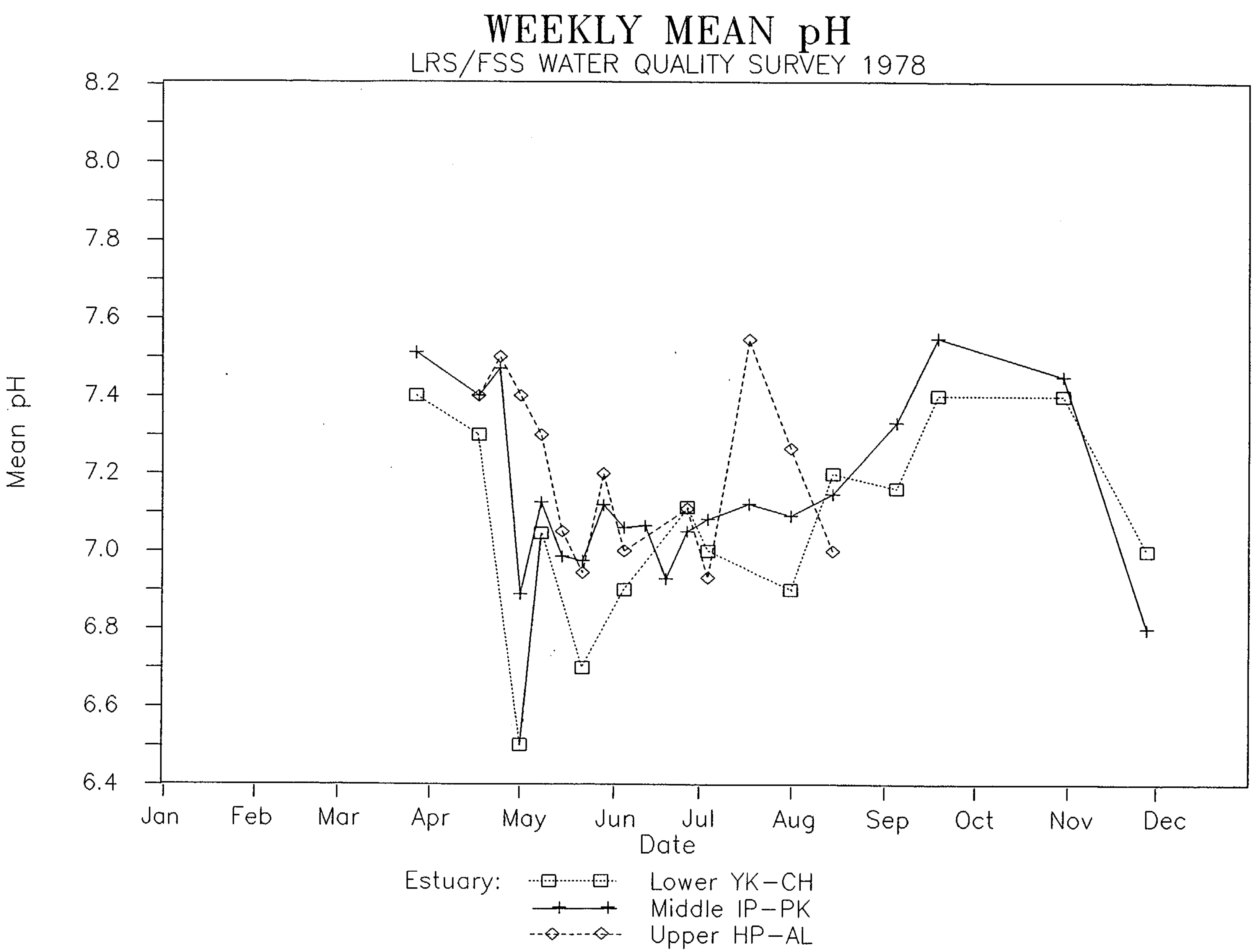

WEEKLY MEAN pH
LRS/FSS WATER QUALITY SURVEY 1978
Mean pH
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Date
Estuary:
Lower YK-CH
Middle IP-PK
Upper HP-AL

TABLE 3-19

AVERAGE REGIONAL pH FOR HUDSON RIVER, 1974-1978
(LRS/FSS)

RIVER REGION	1974	1975	1976	1977	1978	MEAN	SD	n
YK	7.51	7.37	6.96	7.15	6.85	7.32	0.33	58
TZ	7.54	7.37	7.04	7.35	7.12	7.36	0.25	83
CH	7.49	7.34	7.19	7.29	7.11	7.32	0.25	77
IP	7.52	7.28	7.01	7.23	7.21	7.29	0.23	89
WP	7.50	7.35	7.12	7.29	7.16	7.30	0.23	79
CW	7.52	7.35	7.10	7.33	7.14	7.35	0.26	56
PK	7.45	7.33	7.04	7.29	7.09[a]	7.28	0.20	78
HP	7.48	7.38	b	7.27	7.18	7.37	0.21	37
KG	7.60	7.63	b	7.25	7.17	7.49	0.28	29
SG	7.39	7.55	b	7.49	7.43	7.48	0.36	29
CS	7.29	7.44	b	7.50	7.13	7.34	0.28	19
AL	7.02	7.25	b	7.20	7.02	7.11	0.21	14
Mean	7.49	7.37	7.06	7.29	7.14	7.33	0.25	648
SD	0.26	0.24	0.32	0.19	0.28			
n	186	194	65	113	90			

Note: See Figure 2-1 for explanation of region abbreviations.
SD - Standard deviation; n - sample size.

[a]One 31 July reading of 2.4 likely erroneous, not included.
[b]No sample data recorded.

3.3.6 Turbidity

Turbidity is a measure of the suspended material in the water column, such as small colloidal particles, phytoplankton, algae, organic detritus, clays, silts, and sands (Biggs et al. 1983). These materials are important in that they affect geochemical processes (such as trace metal and pollutant transport), the extent of the photic zone (the region of photosynthetic activity), sedimentation rates, and visually related processes (such as feeding in fish).

The rate of introduction of suspended sediments into the estuary depends primarily on the land usage around the watershed. Urbanization removes natural vegetation, while construction of impervious surfaces, such as buildings, parking lots, and roads, reduces natural ground absorptivity. The overall result is a tendency for greater storm runoff, increased peak flows, and higher erosion from surface land and streambanks (Lippson et al. 1979). Storms and the resultant runoff also increase turbidity by resuspending bottom sediments. The degree of resuspension is influenced by the types of sediments, circulation patterns, and settling characteristics of the material. Typically, highest sediment loads are in the shallow, nearshore regions. Sediment loads often increase in a downriver direction until regions of concentrated seawater are encountered. At high saline levels sediments tend to be removed from the water column by flocculation (Emery and Stevenson 1957).

The Hudson River Utilities have recorded turbidity during a number of sampling programs, including the LRS, FSS, BSS, Interregional Trawl Survey, and Mark-Recapture Program. However, it was recorded consistently, estuarywide, only during 1974-1978 (Appendix F).

Over the five-year period 1974-1978, turbidity averaged 13.6 FTUs, but with significant differences among years (ANOVA $F_{4,1107} = 17.06$, $P<0.001$) and among regions (ANOVA $F_{11,1100} = 7.98$, $P<0.001$) (Table 3-20). Average turbidity values by year for the lower, middle, and upper estuary are given in Figures 3-45 through 3-49. The year 1977 yielded the highest average turbid-

TABLE 3-20

ANALYSIS OF VARIANCE (ANOVA) FOR TURBIDITY (FTU) MEASURED IN THE LOWER HUDSON RIVER LRS/FSS, 1974-1978

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-VALUE	PROBABILITY >F
Yearly Comparison					
Year	4	8436.9	2109.2	17.06	0.00000**
Error	1107	136840.0	123.6		
Total	1111	145280.0			
Regional Comparison					
Region	11	10927.0	993.4	7.98	0.00000**
Error	1100	136840.0	124.4		
Total	1111	147770.0			

**Significant at $p \leq 0.01$.

FIGURE 3-45

WEEKLY MEAN TURBIDITY

LRS/FSS WATER QUALITY SURVEY 1974

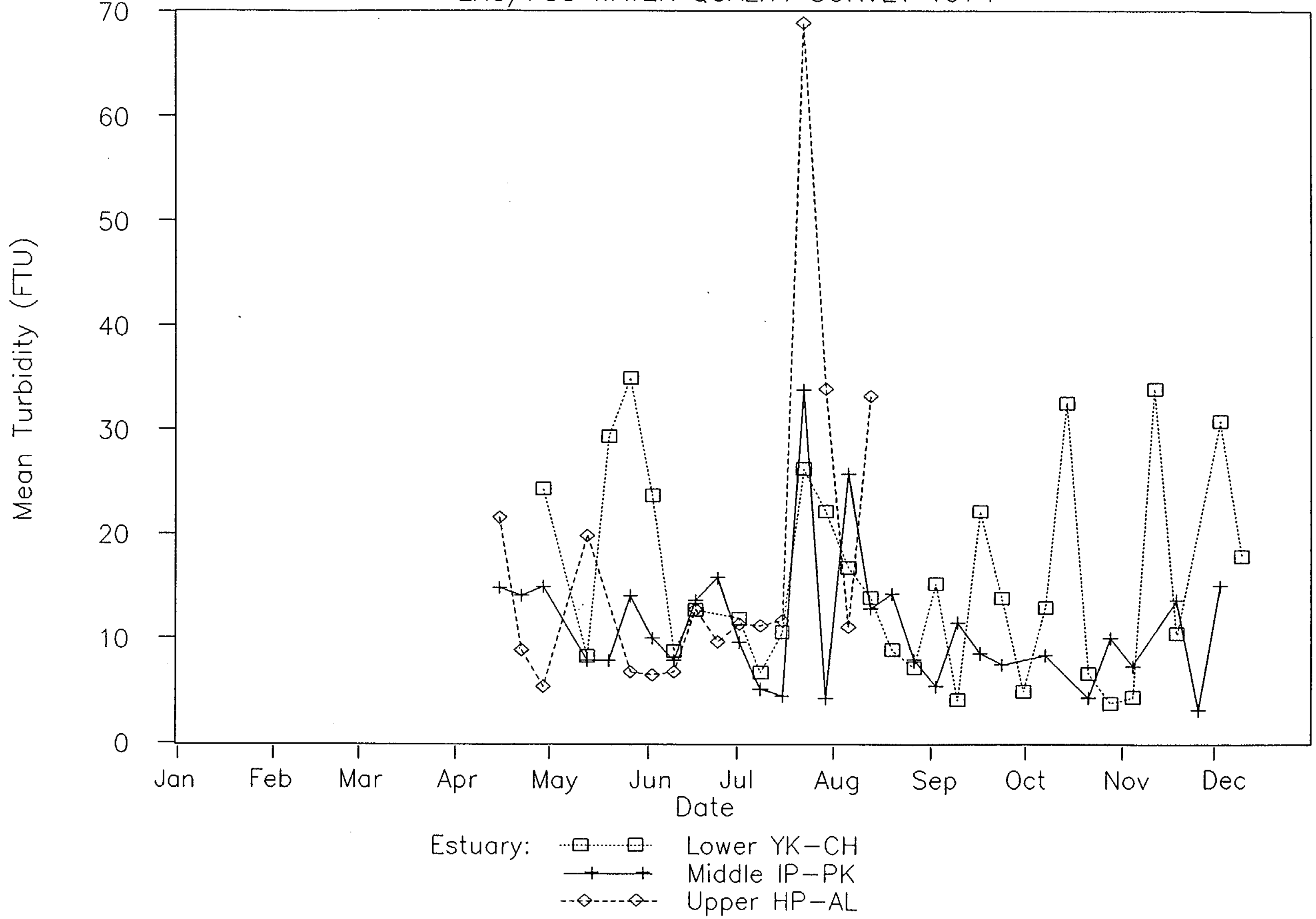


FIGURE 3-46

WEEKLY MEAN TURBIDITY

LRS/FSS WATER QUALITY SURVEY 1975

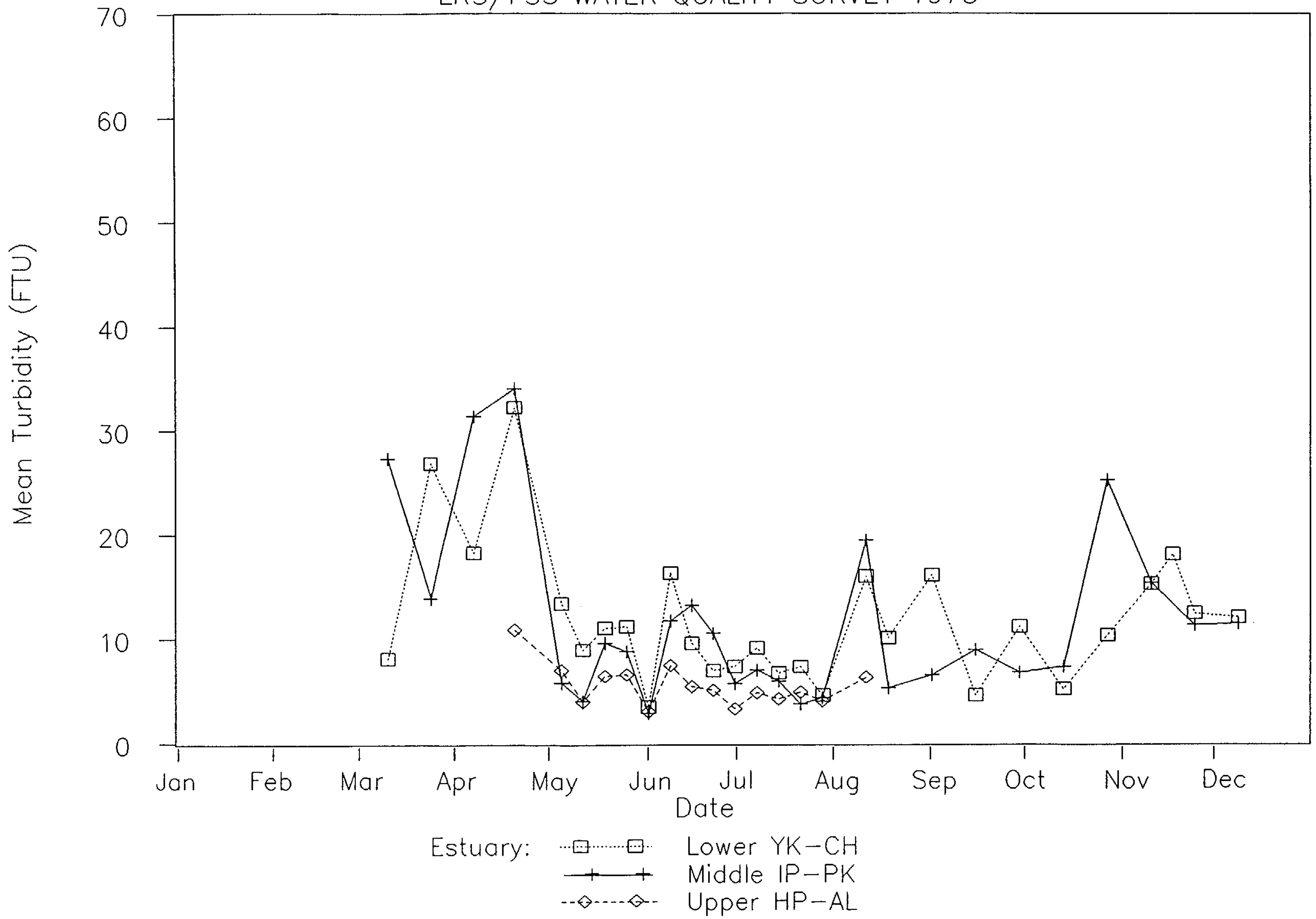


FIGURE 3-47

WEEKLY MEAN TURBIDITY

LRS/FSS WATER QUALITY SURVEY 1976

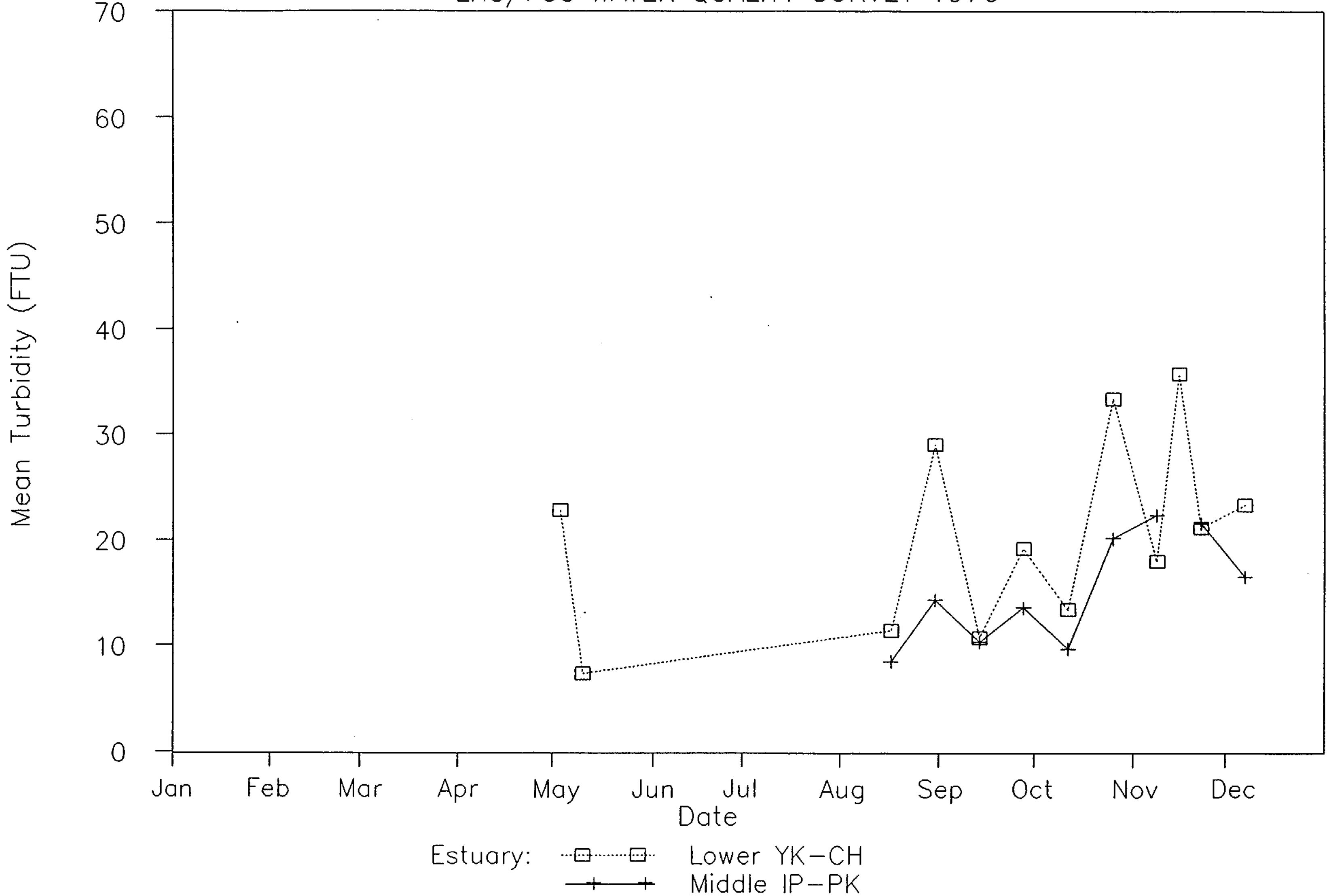


FIGURE 3-48

WEEKLY MEAN TURBIDITY

LRS/FSS WATER QUALITY SURVEY 1977

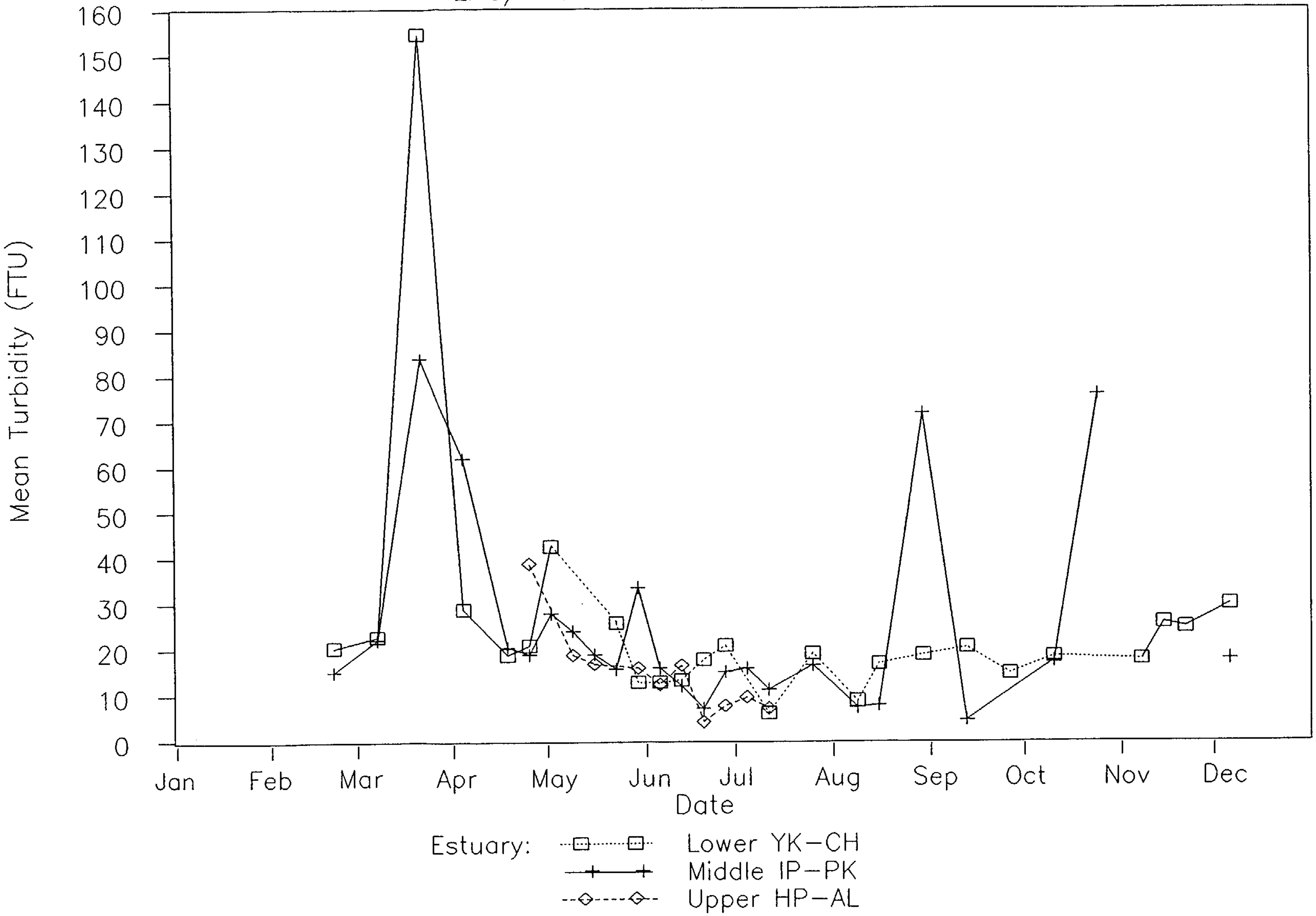
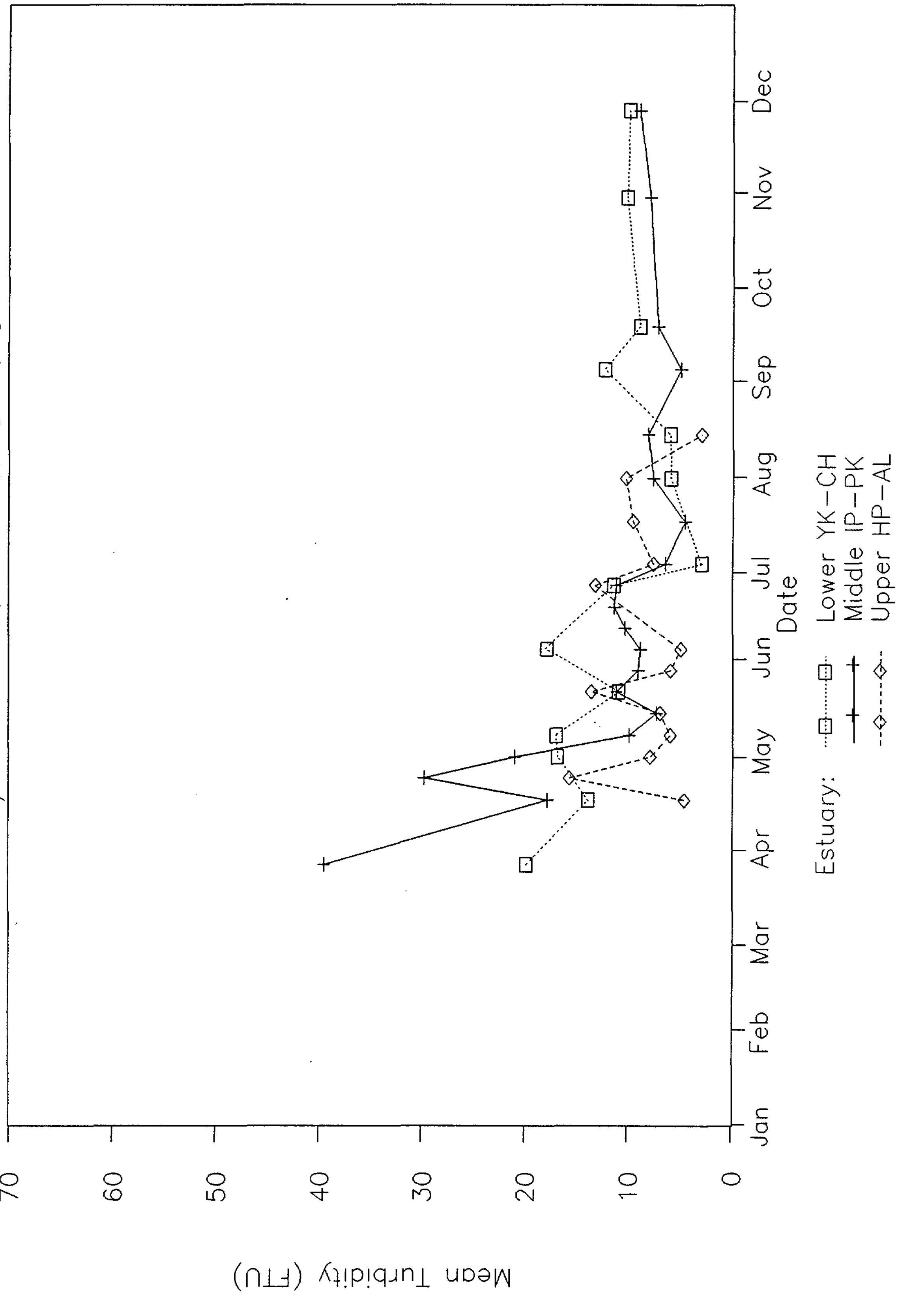


FIGURE 3-49

WEEKLY MEAN TURBIDITY

LRS/FSS WATER QUALITY SURVEY 1978



ity value, 17.62 FTUs; 1975 yielded the lowest, 10.12 FTUs. The upper estuarine regions of Saugerties, Catskill, and Albany had the lowest average turbidity values, 8.87, 9.44, and 6.23 FTUs, respectively; the lower estuarine regions of Yonkers and Tappan Zee had the highest and third highest, 20.70 and 15.38 FTUs, respectively (Table 3-21).

Turbidity values at a given location in the river may be quite variable over time because of tidal and weather conditions. Readings conducted at 3-hr intervals near the Roseton Generating Station during 1986 and 1987 (EPRI 1988) demonstrate fluctuations as great as 100 NTUs (Figures 3-50 and 3-51). The greatest fluctuation occurred during 21-25 August 1986. These values were preceded by a storm that deposited 5.0 cm (1.97 in.) of precipitation (recorded at West Point) between 17 and 24 August.

In 1986, near the Roseton Generating Station, EPRI (1988) made 56 turbidity observations during the spring and 710 during the summer/fall period at both surface and bottom locations. In general, the turbidity values were similar, 17.7, 17.7, 20.2, and 20.2 NTUs for spring surface, spring bottom, summer/fall surface, and summer/fall bottom, respectively. No significant differences were noted between surface and bottom readings. In 1987, 696 observations were made during the summer/fall period. These values tended to be somewhat lower than those recorded during 1986, and surface and bottom readings were significantly different (paired t-test, $t_{0.05,\ 2695} = 14.7$, $P < 0.001$), 11.8 and 13.6 NTUs, respectively.

3.4 ALLOCHTHONOUS DETRITAL INPUTS

3.4.1 Background

Allochthonous organic detritus or biodetritus is defined as nonliving organic material imported from a neighboring area or system (Odum and de la Cruz 1963). Major sources to estuaries, such as the Hudson River, are discharges from municipal treatment plants, urban runoff, and leaves and other terres-

TABLE 3-21

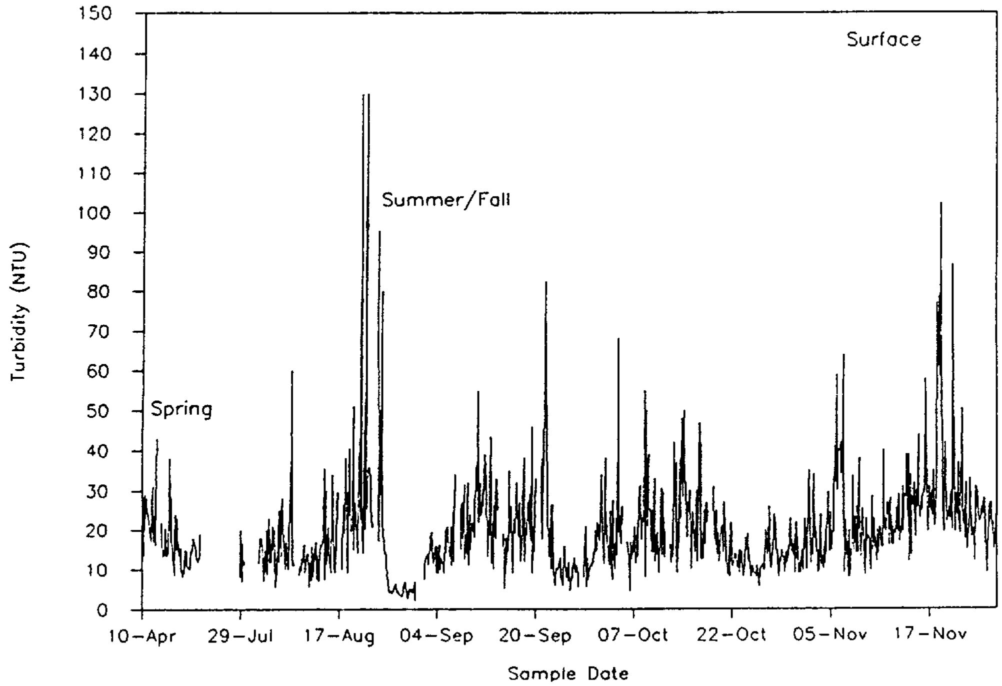
AVERAGE REGIONAL TURBIDITY (FTU) FOR HUDSON RIVER, 1974-1978

	1974	1975	1976	1977	1978	MEAN	SD	n
YK	24.8	15.3	23.7	24.2	16.0	20.7	14.2	98
TZ	13.0	11.3	17.0	21.0	13.4	15.4	14.2	148
CH	11.0	8.2	15.9	14.1	8.6	11.8	7.8	140
IP	11.0	11.3	16.1	15.9	10.7	13.2	8.2	162
WP	13.6	12.1	15.4	26.8	13.0	16.4	14.1	136
CW	11.1	11.4	14.5	12.8	11.4	12.3	9.1	116
PK	10.1	9.4	15.1	17.8	8.3	12.3	11.8	109
HP	18.2	7.3	14.0	12.5	9.9	12.4	9.0	48
KG	21.4	4.0	12.6	9.3	9.9	13.0	14.8	39
SG	8.5	4.2	9.4	17.8	11.6	8.9	7.7	41
CS	14.8	6.4	10.5	7.2	6.9	9.4	7.3	40
AL	6.5	3.5	6.4	5.6	7.3	6.2	3.2	35
Mean	14.2	10.1	15.3	17.6	11.1	13.6	11.1	1112
SD	11.7	7.3	9.0	17.3	8.5			
n	186	226	264	207	229			

Note: See Figure 2-1 for explanation of region abbreviations.
SD - Standard deviation; n - sample size.

FIGURE 3-50

DAILY MEAN TURBIDITY RECORDED DURING 1986 INTAKE BEHAVIORAL BARRIER EVALUATION PROGRAM AT ROSETON GENERATING STATION



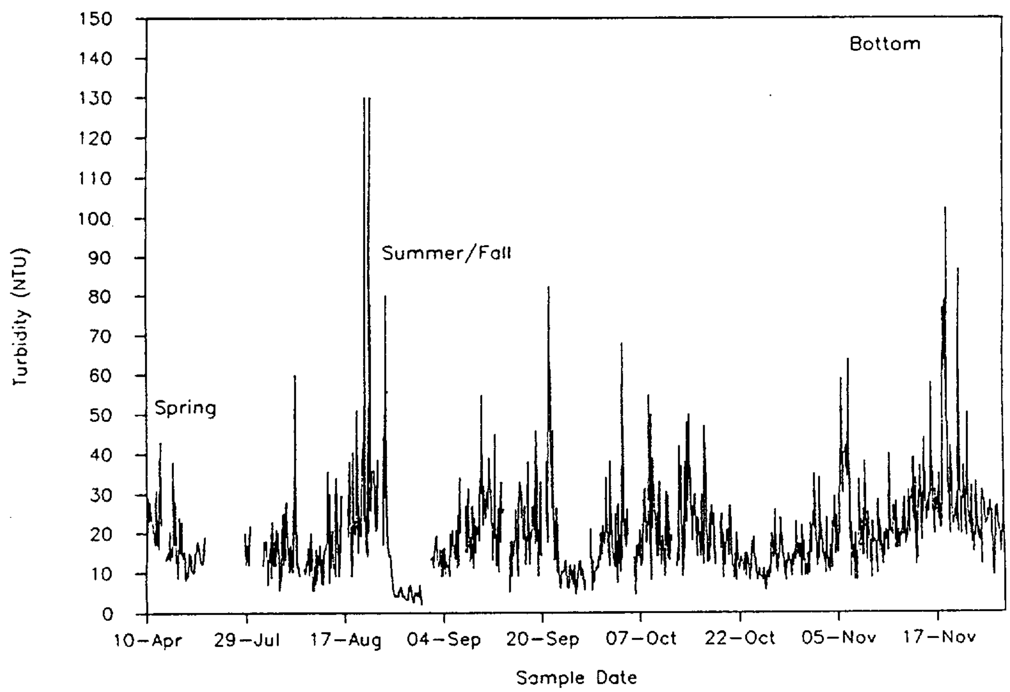
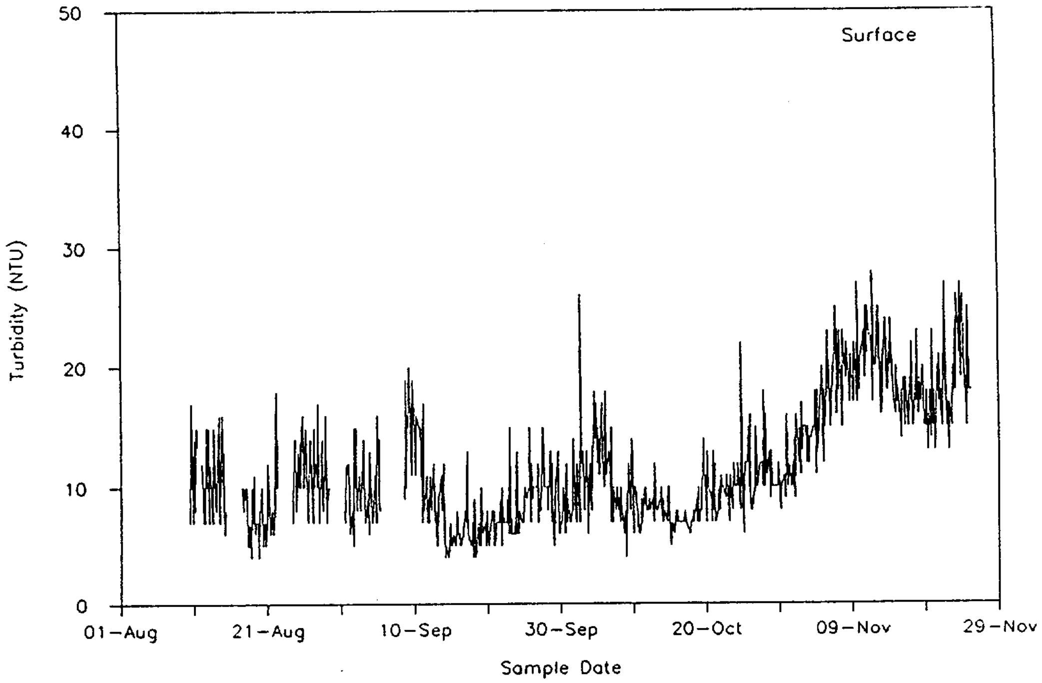
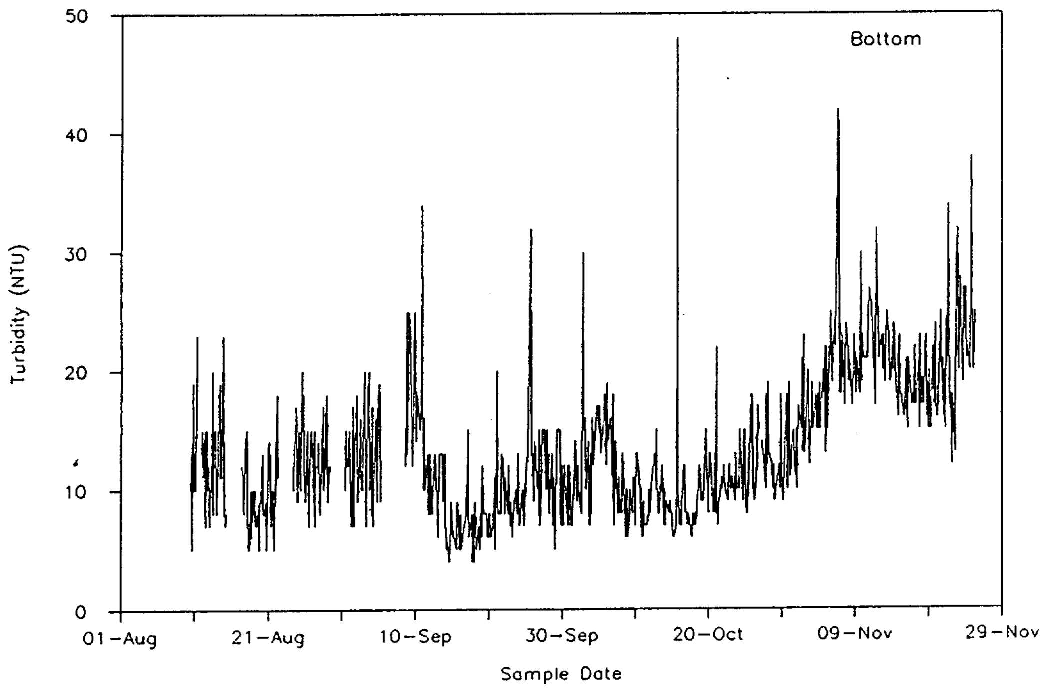


FIGURE 3-51

DAILY MEAN TURBIDITY RECORDED DURING 1987 INTAKE BEHAVIORAL BARRIER EVALUATION PROGRAM AT ROSETON GENERATING STATION





trial vegetation. Some material of marine origin also enters the system with tidal circulation and migratory fish populations (Durbin et al. 1979). Depending on the boundaries chosen, detritus originating in tributaries and marshes can be categorized as either allochthonous or autochthonous (originating within the system). Because many Hudson River fish species utilize the tributaries and marshes during at least part of their life cycle, these areas are considered part of the system for purposes of this report.

The role of organic detritus in aquatic ecosystems has been debated over the years. Although in estuaries detrital biomass often exceeds algal standing crop (Odum and de la Cruz 1967; Saunders 1972a; McFadden et al. 1978), its importance in bioenergetics is not completely understood because detrital pathways are complex (Mann 1972; Saunders 1972b; Wetzel et al. 1972). In general, detrital plant material is refractory (difficult to degrade) and not easily utilized by higher organisms; it must first be broken down by microorganisms to a more usable form. The results of a growing number of studies suggest that detrital aggregates, composed of nonliving organic material and live microorganisms, constitute an important food source for grazers (see, e.g., Rodina 1963; Odum 1968; Chervin 1976). The detritus per se is generally not utilized by the grazers; rather, the microorganisms are digested and the detrital particles egested only to be recolonized again (Mann 1972; Heinle et al. 1977).

Much of the work on detritus in estuaries has been conducted in the mid-Atlantic and southeastern United States (e.g., Heinle and Flemer 1975; Reimold et al. 1975; Haines 1977; Heinle et al. 1977). Unlike these estuaries, which have vast expanses of salt marshes containing Spartina spp. and other grasses bordering them, the Hudson has relatively few, comparatively small marsh areas. Those on the eastern shore have at best only restricted exchange with the main stem of the Hudson River because of existing railroad banks along the river's edge. As a result, these marshes may tend to accumulate more detritus than they release (Goldhammer 1987). A major source of natural allochthonous detritus is leaves and other terrestrial plant material (both dissolved and particulate) washing in from the tributaries. Even though the estuarine portion of the river, from the Battery to the Federal Dam at Troy, has only six major tributaries, natural allochthonous detrital inputs may be substantial (McFadden et al. 1978).

There are two major reasons to examine allocthonous detrital inputs to the Hudson River estuary in conjunction with the fisheries data: (1) to determine whether any trends between detrital inputs and recruitment of fish can be identified, and (2) to determine the relative importance of detritus as a carbon source for Hudson River fish. Regarding the latter, since most Hudson River fish species would not be expected to consume detritus directly, its role in the Hudson River food web is most likely via zooplankton and benthic invertebrates.

Recent studies (Summers and Rose 1987; Summers et al. 1987) have found relationships between measures of anthropogenic inputs and relative stock abundance in five major northeast estuaries, including the Hudson River. Data bases used ranged from about 40 to over 100 years in length, a period of sufficient duration for obvious trends to have occurred. Earlier studies (Heinle et al. 1977; Ulanowicz et al. 1982) suggested a relationship between detritus and striped bass year-class strength in the Maryland portion of the Chesapeake Bay. Their hypothesis was that colder than average winters, and resultant ice production in the tidal marshes, subsequently released larger than average quantities of detrital plant material. This in turn resulted in greater production of zooplankton, which serves as food for the early life stages of striped bass and other fish.

3.4.2 Data Sources

This section examines existing data sources and discusses the feasibility of developing an index of allochthonous detritus for the Hudson River estuary. The years considered were 1974 through 1987. A review of the existing data sources indicates that there is no suitable data base for all years; however, general seasonal and year-to-year trends are discussed. Recommendations for further research are provided.

3.4.2.1 Anthropogenic Inputs. Anthropogenic inputs to the estuary are primarily from municipal sewage treatment plants; useful measures of detrital inputs from these sources are biochemical oxygen demand (BOD) and total organic carbon (TOC). Data on wastewater treatment plant flows alone are not considered satisfactory in evaluating organic inputs because many such plants were upgraded to secondary treatment during the period, resulting in lower concentrations of organics in the effluent. Unfortunately, there is no readily available summary of data for plants discharging to the study area. Data would have to be extracted from discharge permit files maintained by the New York State Department of Environmental Conservation (NYSDEC). The Interstate Sanitation Commission (ISC) provides average and design flows for each permitted STP within their jurisdictional area but, as mentioned above, flow data alone are not a good measure of allochthonous detrital inputs.

Mueller et al. (1982) summarized wastewater loads discharged to the Hudson-Raritan estuary for the periods 1970-1974 and 1979-1980 to estimate pollutant loads to the New York Bight. Their data included conventional pollutants and nutrients from industrial and municipal plants in the New York City area, northern New Jersey, and New York State as far north as Poughkeepsie. Pertinent data are shown below:

PARAMETER	TOTAL DISCHARGE TO THE HUDSON-RARITAN ESTUARY 1970-1974	TOTAL DISCHARGE TO THE HUDSON-RARITAN ESTUARY 1979-1980	DISCHARGE TO THE HUDSON RIVER 1970-1974	DISCHARGE TO THE HUDSON RIVER 1979-1980
Flow (m^3/sec)	118	127	17	18
BOD (metric tons/day)	1000	731	150	110
TOC (metric tons/day)	700	698	105	105

Comparison of the two periods indicated that wastewater flows increased by about 7%, BOD decreased by about 27%, and TOC remained relatively constant. As shown above, the contribution of plants discharging to the Hudson River was calculated as only 14-15% of the total load to the Bight; of that, a significant portion was from plants located in Manhattan, downriver of the study area for this report.

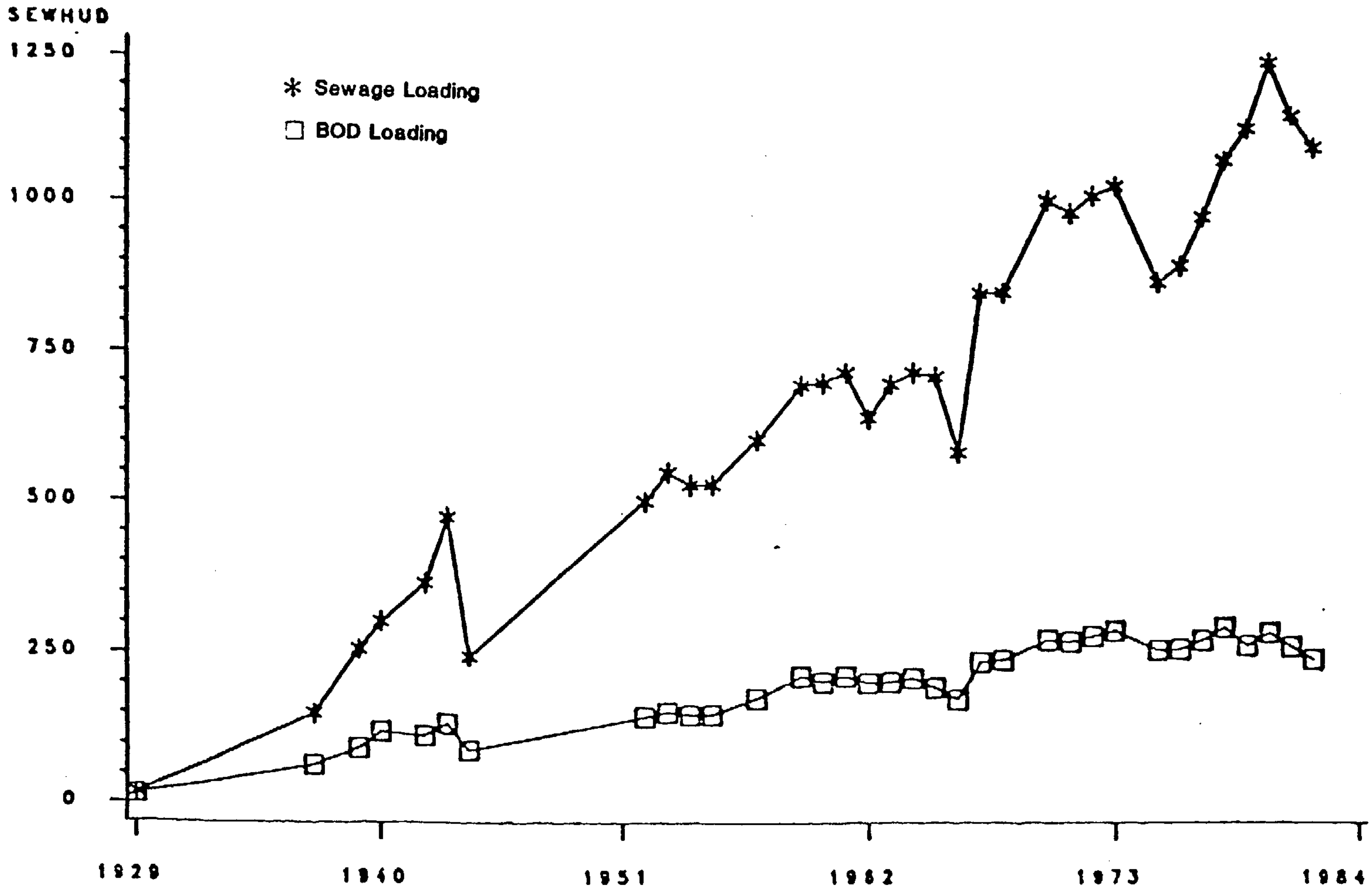
Using data from two New York City plants, Mueller et al. (1982) found seasonal variability to range from about 0.5 to 1.6 times the average annual BOD load at the Port Richmond plant and from about 0.75 to 1.20 times at the 26th Ward Plant. At the Port Richmond plant BOD load was lowest in summer and fall; the opposite occurred at the 26th Ward Plant, making prediction of seasonal cycles of sewage-derived detrital inputs difficult without data on the performance of all plants discharging to the river.

Summers et al. (1987) used sewage loading as a measure of anthropogenic influences on year-class strength of selected fish species in five northeast estuaries. Two measures of sewage loading were computed: flow in millions of gallons per day (MGD) and BOD expressed as MGD equivalents. For the Hudson River estuary values were plotted as yearly averages for all plants discharging to the Hudson River downstream of the Bear Mountain Bridge, the East River, and Upper New York Bay from 1929 to 1982 (Figure 3-52). As this figure illustrates, there has been a linear increase in both sewage flow and BOD since 1929, but BOD has increased at a much slower rate. Between 1974 and 1982, there was little difference among years in BOD loading even though sewage flow increased substantially. The most probable reason is the increase in wastewater treatment and the concurrent reduction in discharge of raw or primary treated waste.

3.4.2.2 <u>Watershed Inputs</u>. Runoff from both developed and undeveloped areas contributes to the organic detrital load to the Hudson River estuary. It is likely that urban runoff has increased over time as a result of continuing development within the watershed; however, no data are available to quantify

FIGURE 3-52

SEWAGE LOADING AND BOD LOADING FROM TREATMENT PLANTS DISCHARGING INTO THE HUDSON RIVER DOWNRIVER OF THE BEAR MOUNTAIN BRIDGE, EAST RIVER, AND UPPER NEW YORK BAY



FROM: Summers et al. (1987)

long-term trends. The Water Quality Management Studies conducted during the 1970s under Section 208 of the Clean Water Act provided some estimates of inputs from urban runoff, but data were collected for only a short time. Using data from these studies, Mueller et al. (1982) estimated an average BOD load of 190 metric tons/day to the Hudson-Raritan estuary from urban runoff; of this quantity, 11 metric tons/day originated in the mid-Hudson area (Poughkeepsie to the Bear Mountain Bridge) and the remainder from Bear Mountain south to the Narrows.

Seasonal trends in allochthonous detrital inputs from the Hudson River watershed follow rainfall patterns, and therefore are generally correlated to freshwater flow at Green Island (Cooper et al. 1988). On a shorter time scale, inputs vary with the intensity and duration of each storm and with the interval since the last storm. In urban areas materials tend to accumulate on streets, parking areas, roofs, etc., during dry periods, and their mobilization generally follows a "first flush" characteristic. This means that the highest concentrations are discharged early during a storm, decreasing to background (concentration in rainwater) if the precipitation period is of sufficient duration (Stenstrom et al. 1984).

Using USGS data from two Hudson River and four tributary gauging stations, Gladden et al. (1988) found a direct relationship between daily volume discharged and daily total organic carbon export when both parameters were standardized for watershed area. This means that in a typical year largest inputs are expected during late winter and spring and the lowest input during summer, except in the event of major storms such as hurricanes.

McFadden et al. (1978) estimated allochthonous detrital inputs as part of an energy budget for the Hudson River. For the segment of the Hudson River above the Federal Dam at Troy, limited USGS data on TOC from the Green Island gauging station were used as an estimate of terrestrial inputs. For the tidal portion of the river, estimates from a hardwood forest in New Hampshire were scaled to estimate detrital input to the lower Hudson River watershed.

Anthropogenic inputs to the tidal portion of the river were developed from BOD loads discharged by municipal and industrial point sources; nonpoint source discharges were not considered. Marine inputs were calculated from estimated losses of striped bass eggs that were then multiplied by six to approximate detrital inputs for six anadromous species. No contributions from marine plankton or mortality of adult anadromous fish were included. All values were converted to caloric equivalents. The results indicated that 97.6% of the energy inputs to the Hudson River were from terrestial inputs to the lower watershed, 1.34% from human sources, 0.76% from the upper watershed, and less than 0.01% from marine inputs. Even though the values presented may be biased because of conversion factors and the limited data on which some estimates were made (e.g., marine inputs), results clearly show a major contribution from allocthonous detrital inputs. Unfortunately, there is no readily available way to accurately predict year-to-year variations or long-term trends from these data.

Gladden et al. (1988) also found watershed inputs to be the principal source of allochthonous detrital inputs to the estuary. Using their data, approximately 84% (112,561 metric tons/year) of the total allochthonous carbon inputs originate from the watershed and 16% (21,026 metric tons/year) are from sewage. No marine inputs were considered. No attempt to make a direct comparison of the percent contribution from various sources between McFadden et al. (1978) and Gladden et al. (1988) is warranted because (1) the units used in the two studies differed (calories vs total organic carbon, respectively), (2) the estimation methods used were different, and (3) potential sources of allochthonous detritus were not consistent.

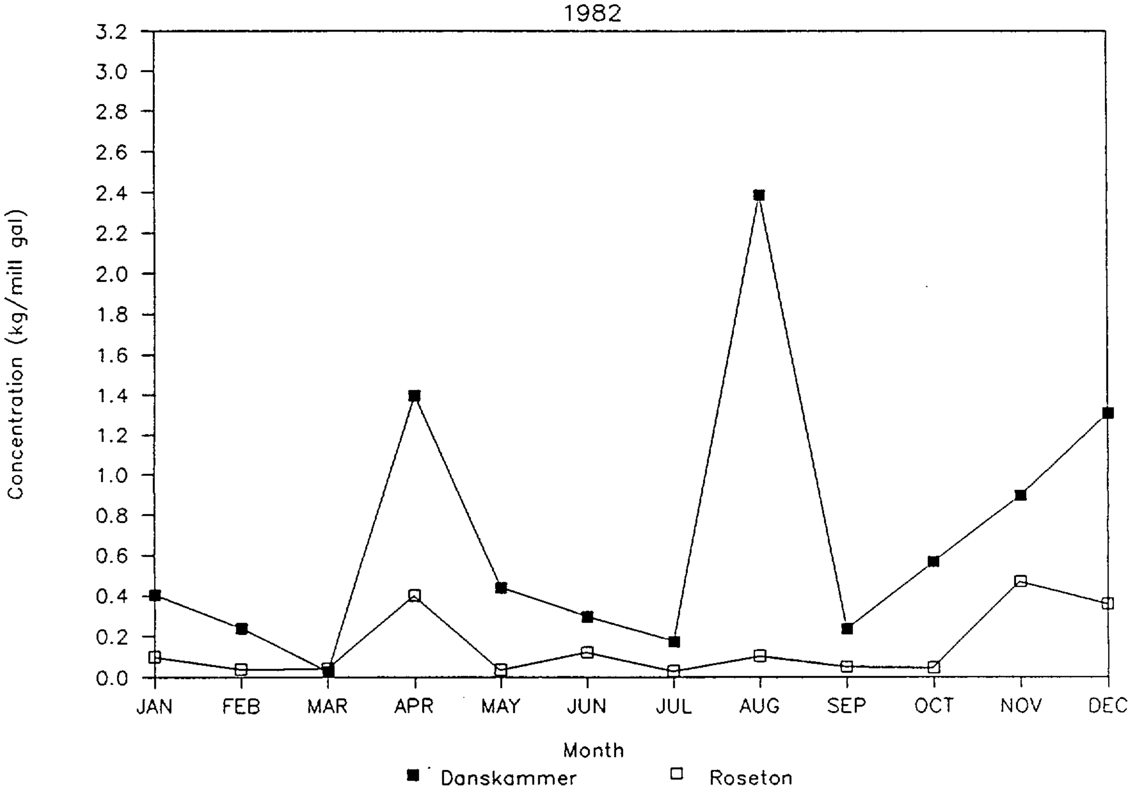
3.4.2.3 Impingement Debris Characterization. Impingement collections at Central Hudson Gas & Electric Corporation's Roseton and Danskammer Point Generating Stations have included records of debris from 1982 through the present. Only data from 1982 and 1983 are available in a readily usable format. The usefulness of the Roseton and Danskammer Point debris information as an index of allochthonous input is limited because the debris collected is a mixture of macrophytes produced in the Hudson (autochthonous), leaves and other terrestrial plant matter (allochthonous), and filamentous algae. It is not clear whether the algae (primarily a blue-green) originates in the river, the tributaries, or the marshes. Microscopic observations suggest that the algae is alive (LMS, unpub. data); therefore, it is questionable whether it should be considered as detritus at all.

In spite of its shortcomings as a measure of allochthonous detritus, the impingement debris data do provide useful information on seasonal and spatial variations in macroscopic detrital inputs. As shown in Figures 3-53 and 3-54, there are several distinct peaks in concentrations over a yearly cycle and distinct differences between the two plants. Peaks occur at both plants during the spring high-flow period. At Danskammer Point peaks also occur during late summer and winter. At Roseton a peak occurred during November-December 1982, but not during 1983. The late summer influx evident at Danskammer Point did not occur at Roseton, and overall concentrations were lower. Differences between the two plants are attributed to intake location. Danskammer Point's intake is located on the southern edge of Danskammer Cove, and the circulation patterns are such that during ebb tide debris flowing downriver is caught in the intake. Roseton's intake, on the other hand, is located on a relatively straight stretch of the river and is oriented parallel to the flow.

The debris collected was grossly categorized as aquatic vegetation, algae, leaves, sticks, twigs, and nonbiological materials such as paper and plastic. Quantities of the latter always represented a small fraction (less than 10%) of the total. Leaves, twigs, and sticks are the only materials collected that are definitely of allochthonous origin, and they appeared mostly during the spring high-flow period and from fall into early winter. The summer peak noted at Danskammer Point consisted primarily of aquatic macrophytes such as Vallsenaria sp. and Trappa natans that had broken off or had been uprooted. Except for the summer peak at Danskammer Point there was a rough correspondence between impingement debris concentrations and freshwater flow measured at Green Island (Figures 3-53 and 3-54).

FIGURE 3-53

DEBRIS CONCENTRATION AND FRESHWATER FLOW



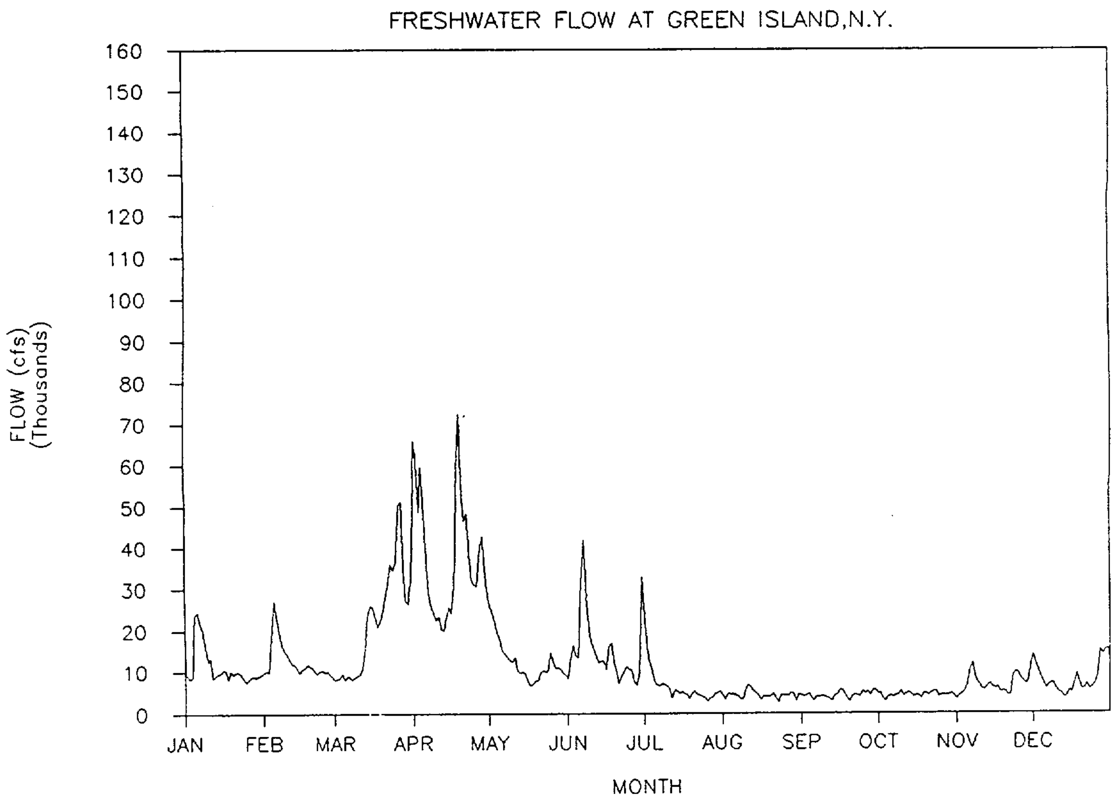
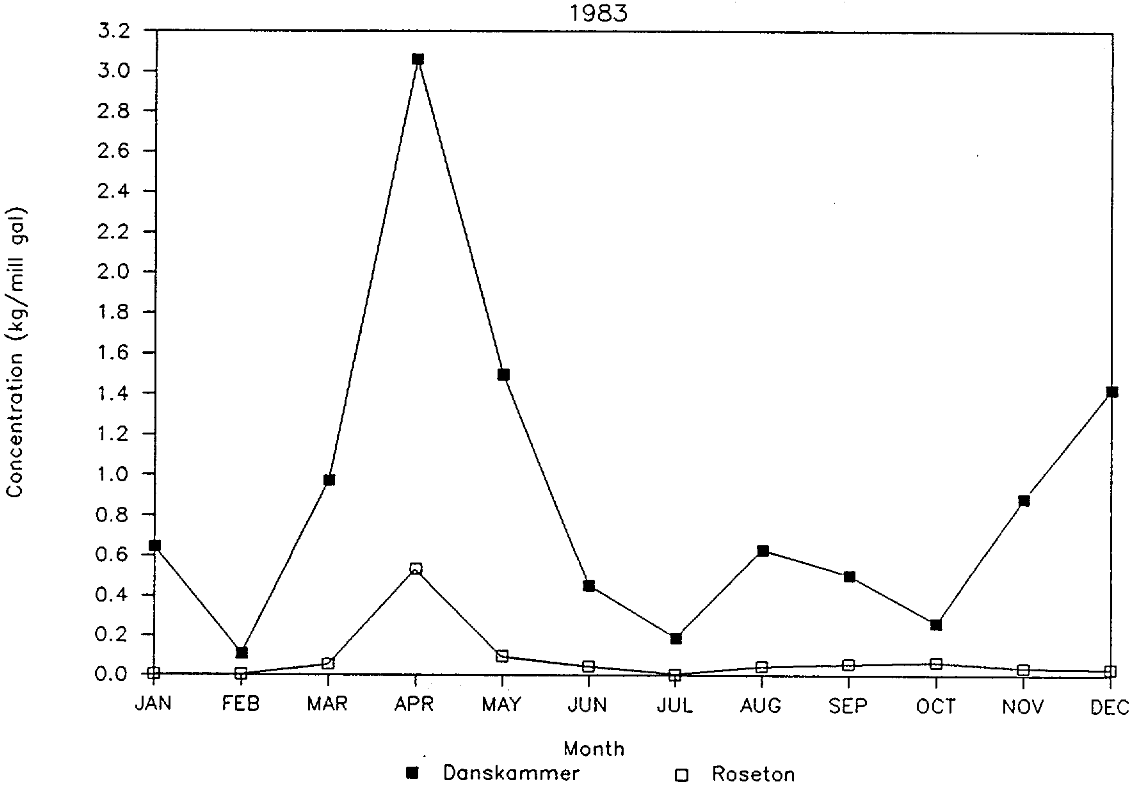
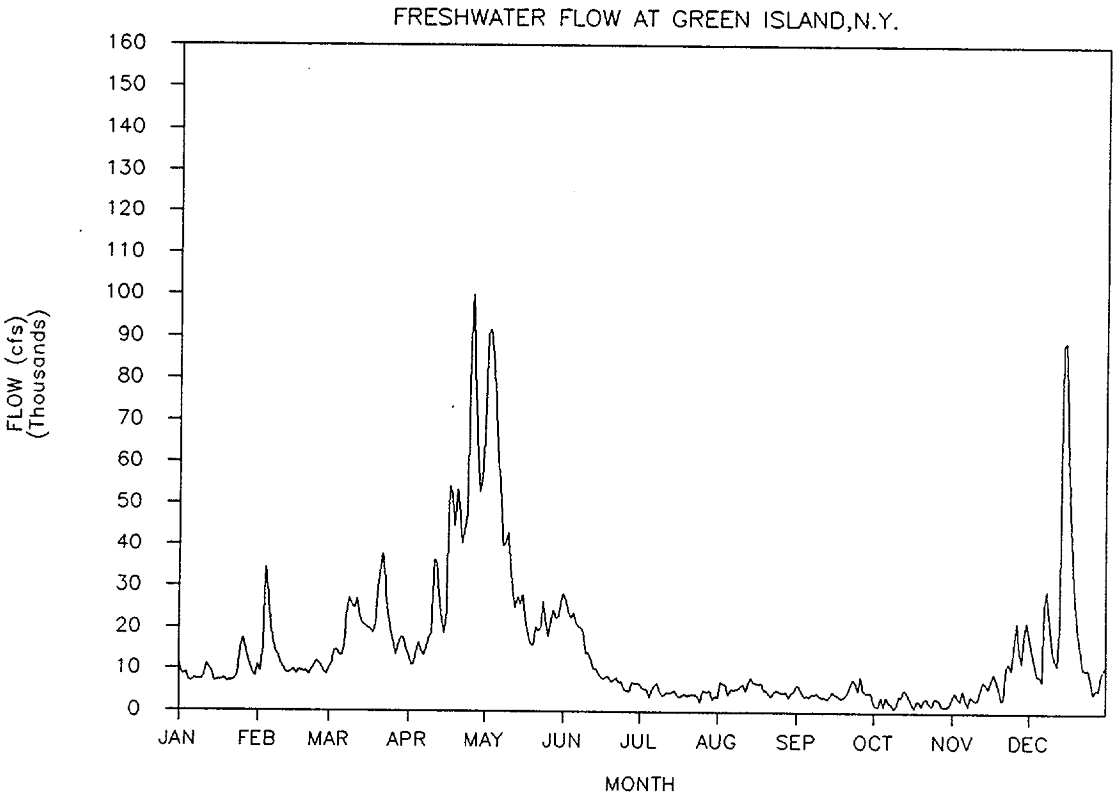


FIGURE 3-54

DEBRIS CONCENTRATION AND FRESHWATER FLOW

1983





3.4.2.4 Marine Inputs. Detrital material of marine origin enters the estuary through both active and passive means. Migratory fish actively swim up the Hudson, deposit metabolic wastes and reproductive products, and suffer mortality. Depending on the estuary, the latter can have major impacts on energy pathways. Durbin et al. (1979), for example, found that the annual mortality of spawning alewives, and to a lesser extent excretion by these fish, increased phytoplankton and invertebrate productivity in Pauacaco Pond, Rhode Island. In the reach of the Hudson River under consideration in this report detrital inputs from anadromous fish entering the estuary occur primarily in late winter and spring.

Passive inputs entering the estuary from the New York Bight apex with the two-layered circulation include fine particulate matter, zooplankton, and phytoplankton. The plankton contribute to the detrital pool via excretory products and death. Since up to 90% of the nutrients that the phytoplankton in the apex utilize for growth originate in the estuary (Malone 1977), it was again unclear whether to categorize this source as autochthonous or allochthonous. This source of detrital inputs was probably greatest during the summer months when plankton turnover rates and saltwater intrusion were greatest. However, it was also possible that most zooplankton were consumed prior to becoming detritus.

3.4.3 Recommendations

As illustrated by the discussion above, the existing data base was limited in terms of developing an index of allochthonous detrital inputs for the Hudson River that would be meaningful with respect to the Utility fishery data base. Anthropogenic inputs were dominated by sewage inputs, especially when New York City plants were included, and, based on data from 1975-1982 (Figure 3-52), no substantial changes in BOD or TOC loading appear to have occurred over the time span of the Hudson River fishery data base considered in this report. Year-to-year variability in anthropogenic inputs was not expected to be as great as the variability of terrestial inputs, which were influenced by precipitation patterns. Therefore, LMS does not recommend pursuing development of an index of anthropogenic inputs at this time.

No long-term direct measures of natural allochthonous detrital inputs are available. An index of watershed inputs could be developed based on discharge volumes using a relationship similar to the one presented by Gladden et al. (1988). This index would not include any marine inputs. The utility of a detrital index based on flow is questionable because various aspects of Hudson River fish population dynamics are influenced either directly or indirectly by flow. The difficulty is in trying to separate the influence of a flow-based detrital index from flow's direct influence on distribution and indirect effect on estimates of abundance and growth.

Although an index of allochthonous detrital inputs might prove useful for comparison to the fishery data, initial efforts should be directed toward quantifying detrital pathways in the Hudson River food web. Some subjects that should be addressed before any research to develop an index of allochthonus detrital inputs is funded include (1) the role of Hudson River marshes in the energy cycle; (2) the extent of marine inputs that will be most important in the lower reaches of the estuary; and (3) most important, the extent to which detrital carbon inputs from various sources are utilized either directly or indirectly by Hudson River fish populations. Some research directed at the marshes has been sponsored by NYSDEC, the Hudson River Foundation, and the National Oceanic and Atmospheric Administration. To date the effort has focused on carbon exchange in Tivioli Bay, one of the four National Estuarine Sanctuaries on the Hudson River (Goldhammer 1987). Utilization of detrital carbon is best studied using stable carbon isotope measurements (see, for example, Haines and Montague [1979] and Hackney and Haines [1980]), which, to our knowledge, have not been taken for the Hudson River. Once the role of biodetritus in the food web has been determined, the need for an index, its form, and the utility of the existing data base can be better established.

CHAPTER 4

SPATIOTEMPORAL DISTRIBUTION OF SELECTED SPECIES OF HUDSON RIVER ESTUARY FISHES

4.1 SPECIES COMPOSITION

During the 12 years of the Year Class study 133 fish species have been recorded (Table 4-1). The yearly mean of 79 species collected reflects resident cold, cool, and warm freshwater species; resident estuarine species; and migratory marine fishes captured in the various regions of the estuary. The species composition represents a variety of life history groups, although most of the fish species are present only as adults.

4.1.1 1986 Study

During the 1986 Hudson River study 82 fish species were recorded, including five new species - grubby, American sand lance, fat sleeper, striped burrfish, and orangespotted filefish (Table 4-1). Some species caught in 1986, such as fallfish, silver hake, northern pike, and Atlantic herring, had not been reported for several years. Fish species reported in most recent years of the study but absent from the 1986 list include chain and redfin pickerel, walleye, creek chub, and northern stargazer.

The 1986 species composition represents a variety of taxa from 63 genera and 38 families. Twenty-seven of the 82 species were taken in all three sampling programs, 35 species in only one (Table 4-2).

4.1.2 1987 Study

During the 1987 Hudson River study 75 fish species were recorded, including one new species - margined madtom (Table 4-1). Some species caught in 1987, such as northern hog sucker, central mudminnow, and Atlantic cod, had not been reported for several years. Fish species typically reported in recent years

TABLE 4-1 (Page 1 of 3)

SPECIES COMPOSITION AND ASSEMBLAGE DESIGNATION (AD) OF FISH COLLECTED AS PART OF YEAR CLASS STUDIES FROM 1974 TO 1987

TAXON	AD	74	75	76	77	78	79	80	81	82	83	84	85	86	87
Alewife	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
American eel	C	X	X	X	X	X	X	X	X	X	X	X	X	X	X
American sand lance	M													X	X
American shad	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ammodytes sp.	M		X	X	X	X	X	X	X				X		
Atlantic cod	M							X							X
Atlantic croaker	M			X	X		X						X	X	X
Atlantic herring	M		X	X		X	X			X				X	X
Atlantic menhaden	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Atlantic needlefish	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Atlantic silverside	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Atlantic sturgeon	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Atlantic tomcod	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Banded killifish	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bay anchovy	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Black bullhead	F				X				X			X	X		
Black crappie	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Black sea bass	M					X							X		
Blacknose dace	F	X	X	X	X	X	X	X					X		X
Blueback herring	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bluefish	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bluegill	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bluntnose minnow	F	X	X	X	X	X	X	X							
Bridle shiner	F	X		X						X					
Brook stickleback	F	X	X	X	X				X						
Brook trout	F				X	X									
Brown bullhead	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Brown trout	F			X	X	X	X	X	X				X		
Butterfish	M	X	X	X			X	X	X	X	X	X	X	X	X
Carp	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Central mudminnow	F			X				X							X
Chain pickerel	F	X	X	X	X	X	X	X	X	X		X			
Channel catfish	F	X							X					X	X
Comely shiner	F	X						X							
Common shiner	F	X	X	X	X	X	X	X	X		X				
Conger eel	M						X		X	X	X	X	X	X	X
Creek chub	F		X	X	X	X	X	X			X		X		
Crevalle jack	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cunner	M									X	X	X	X	X	
Cutlips minnow	F	X	X	X	X	X	X								
Eastern mudminnow	F		X					X							
Emerald shiner	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Fall fish	F	X	X	X	X	X	X	X	X	X				X	
Fathead minnow	F	X	X	X	X	X	X	X					X	X	
Fat sleeper	E													X	
Fourbeard rockling	M						X	X							

A - anadromus C - catadromous E - estuarine M - marine F - freshwater

TABLE 4-1 (Page 2 of 3)

SPECIES COMPOSITION AND ASSEMBLAGE DESIGNATION (AD) OF FISH COLLECTED AS PART OF YEAR CLASS STUDIES FROM 1974 TO 1987

TAXON	AD	74	75	76	77	78	79	80	81	82	83	84	85	86	87
Fourspine stickleback	E	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Fourspot flounder	M	X						X	X			X	X	X	
Gizzard shad	F	X	X	X	X	X	X	X	X		X	X	X	X	X
Golden shiner	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Goldfish	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Grass pickerel	F	X				X									
Gray snapper	M							X					X	X	X
Green sunfish	F		X		X			X							
Grubby	M													X	
Hickory shad	M		X			X	X				X			X	
Hogchoker	E	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Inshore lizardfish	M	X					X	X	X			X	X		
Largemouth bass	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Logperch	F	X		X	X		X	X			X				
Longhorn sculpin	M	X	X								X				
Longnose dace	F		X	X	X	X				X			X		
Lookdown	M	X	X	X	X		X	X	X				X	X	X
Margined madtom	F														X
Mimic shiner	F	X													
Moonfish	M			X										X	X
Mummichog	E	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Naked goby	M	X		X								X	X	X	X
Northern hog sucker	F	X		X	X	X		X	X			X			X
Northern kingfish	M	X	X	X	X	X	X	X	X	X	X	X	X	X	
Northern pike	F	X	X	X	X	X	X	X		X				X	X
Northern pipefish	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Northern puffer	M		X		X		X	X	X	X	X	X	X	X	X
Northern searobin	M			X		X		X	X	X		X		X	X
Northern stargazer	M	X						X		X	X	X	X		
Orangespotted filefish	M													X	
Pollack	M		X												
Pumpkinseed	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rainbow smelt	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rainbow trout	F						X								
Red hake	M	X		X			X	X	X			X	X		
Redbreast sunfish	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Redfin pickerel	F	X	X	X	X	X	X	X	X	X		X			
Rock bass	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rock gunnel	M			X	X										
Rosyface shiner	F	X													
Rough silverside	M		X	X	X	X	X	X	X	X		X	X	X	X
Satinfin shiner	F	X	X	X	X	X	X	X				X	X	X	
Scup	M	X													
Sea lamprey	A	X	X				X	X	X			X			

A - anadromus C - catadromous E - estuarine M - marine F - freshwater

TABLE 4-1 (Page 3 of 3)

SPECIES COMPOSITION AND ASSEMBLAGE DESIGNATION (AD) OF FISH COLLECTED AS PART OF YEAR CLASS STUDIES FROM 1974 TO 1987

TAXON	AD	74	75	76	77	78	79	80	81	82	83	84	85	86	87
Sea raven	M							X							
Searobin	M		X	X		X		X	X						
Seaboard goby	M		X	X				X							
Sheepshead	M								X						
Shield darter	F							X							
Shortnose sturgeon	E	X		X	X		X	X	X	X	X	X	X	X	X
Silver hake	M	X	X		X									X	
Silver perch	M	X					X					X	X	X	
Silvery minnow	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Smallmouth bass	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Smallmouth flounder	M						X	X		X		X	X		
Speckled worm eel	M					X		X				X			X
Spot	M	X	X	X	X			X		X	X		X	X	X
Spotfin butterflyfish	M									X			X		
Spotfin mojarra	M									X					
Spotfin shiner	F	X	X	X	X	X	X	X	X			X	X	X	X
Spottail shiner	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Spotted hake	M							X			X	X	X	X	X
Striped anchovy	M		X				X			X			X		
Striped bass	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Striped cuskeel	M							X					X	X	X
Striped killifish	M			X											
Striped mullet	M	X		X	X		X	X	X	X	X	X	X	X	X
Striped burrfish	M													X	
Striped searobin	M		X			X	X	X	X	X	X	X	X	X	X
Summer flounder	M	X	X	X	X	X	X	X	X	X		X	X	X	X
Tautog	M		X				X	X	X	X	X	X	X	X	X
Tessellated darter	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Threespine stickleback	E	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tidewater silverside	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trout perch	F	X	X	X	X	X	X					X			
Walleye	F			X	X	X	X				X	X			X
Weakfish	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
White bass	F				X										
White catfish	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
White crappie	F	X	X	X	X	X	X	X	X			X		X	X
White mullet	M	X	X	X	X	X	X	X		X	X	X	X	X	
White perch	E	X	X	X	X	X	X	X	X	X	X	X	X	X	X
White sucker	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Windowpane	M	X	X		X		X	X	X		X	X	X	X	X
Winter flounder	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Yellow bullhead	F		X						X						
Yellow perch	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Yellowtail flounder	M	X													

A - anadromus   C - catadromous   E - estuarine   M - marine   F - freshwater

TABLE 4-2 (Page 1 of 2)

SPECIES COMPOSITION OF FISH COLLECTED IN EACH OF THE HUDSON RIVER YEAR CLASS SURVEYS DURING 1986

TAXON	BEACH SEINE	FALL SHOALS	LONG RIVER
Alewife	X	X	X
Bay anchovy	X	X	X
American shad	X	X	X
Bluefish	X	X	X
Bluegill	X		
Brown bullhead	X	X	X
Pumpkinseed	X	X	X
Black crappie	X		
Carp	X	X	
American eel	X	X	X
Goldfish	X		
Golden shiner	X	X	X
Hogchoker	X	X	X
Tessellated darter	X	X	X
Banded killifish	X	X	X
Emerald shiner	X		
Largemouth bass	X		
Mummichog	X		
Atlantic menhaden	X	X	X
Minnow unidentified			X
Blueback herring	X	X	X
White sucker	X	X	X
Atlantic silverside	X	X	
Rainbow smelt	X	X	X
Smallmouth bass	X		
Shortnose sturgeon		X	X
Spottail shiner	X	X	X
Atlantic sturgeon		X	X
Striped bass	X	X	X
Fourspine stickleback	X	X	X
Atlantic tomcod	X	X	X
To be identified			X
White catfish	X	X	X
White perch	X	X	X
Yellow perch	X		X
Satinfin shiner	X		
Rock bass	X	X	
Northern pipefish	X	X	X
Redbreast sunfish	X		
Atlantic needlefish	X		
Crevalle jack	X	X	
Silvery minnow	X	X	
Fall fish	X		
Weakfish	X	X	X
Lookdown	X		
Alosa sp.	X	X	X
Fathead minnow	X		
Cyprinidae unidentified	X		X
Morone sp.			X

TABLE 4-2 (Page 2 of 2)

SPECIES COMPOSITION OF FISH COLLECTED IN EACH OF THE HUDSON RIVER YEAR CLASS SURVEYS DURING 1986

TAXON	BEACH SEINE	FALL SHOALS	LONG RIVER
Tautog	X		X
Striped cusk-eel			X
Northern kingfish	X	X	
Spot	X	X	X
Moonfish		X	
Acipenser sp.			X
Winter flounder	X	X	X
Tidewater silverside	X		
Gizzard shad	X	X	X
Silver hake		X	
Striped mullet	X		
Threespine stickleback	X		X
Butterfish		X	X
White crappie	X		
Northern pike	X		
Silver perch	X		
Northern puffer	X	X	
Centrarchidae unidentified	X	X	X
Spotfin shiner	X		
Grubby			X
Rough silverside	X		
Summer flounder	X	X	X
Striped searobin	X	X	
Northern searobin	X	X	
Atlantic croaker	X	X	
Hickory shad		X	
Atlantic herring			X
Conger eel			X
White mullet	X		
Channel catfish		X	
Naked goby	X	X	
Windowpane		X	X
Spotted hake		X	X
American sand lance			X
Fat sleeper	X		
Fourspot flounder		X	
Gobiidae-gobies			X
Fundulus sp.			X
Myoxocephalus sp.			X
Cottid unidentified			X
Atherinidae sp.			X
Bothidae unidentified			X
Cunner			X
Sciaenidae			X
Gadidae			X
Gray snapper	X		
Striped burrfish		X	
Gasterosteidae unidentified			X
Orangespotted filefish	X		

but absent in 1987 include satinfin shiner and fourspot flounder. Chain pickerel, redfin pickerel, northern stargazer, and creek chub were absent from the collections.

The 1987 species composition represents a variety of taxa from 61 genera and 36 families. Twenty-five of the 75 species were collected in all three sampling programs, 35 species in only one (Table 4-3).

4.2 MICRODISTRIBUTION PATTERNS

In a seasonally unstable environment the survival of any species is dependent on mechanisms that allow it to adapt physiological functions to changes in that environment. An essential factor for species survival is successful reproduction. In temperate teleosts reproduction is timed to ensure that the young hatch and commence feeding at the season most conducive to their survival. Light and temperature variations, primarily, cue seasonal gonad development in teleosts, although the relative importance of these and other environmental triggers differs among various fish species (de Vlaming 1975; Billard and Breton 1979). Although the timing of final egg maturation and ovulation is synchronized with photoperiod, some species also have strict substrate requirements for spawning. For example, goldfish and northern pike require the presence of aquatic vegetation for spawning (Fabricius 1950; Stacey et al. 1979). No experimental information was found regarding the role of vegetation in timing of ovulation in other teleosts that utilize vegetation as a spawning substrate. The selection of the microhabitat where reproductive activities are to occur is important in maximizing offspring survival.

Changing physical and chemical parameters of the environment can affect the microdistribution patterns of certain taxa and life stages, and optimal growth and survival are affected by these habitat variables. Microdistribution patterns may be related to river morphometry or other physical features, such as tributaries, meanders, or unusual meteorological events. McFadden et al. (1978) were the first to examine microdistribution patterns for Hudson River

TABLE 4-3 (Page 1 of 2)

SPECIES COMPOSITION OF FISH COLLECTED IN EACH OF THE HUDSON RIVER YEAR CLASS SURVEYS DURING 1987

TAXON	BEACH SEINE	FALL SHOALS	LONG RIVER
Alewife	X	X	X
Bay anchovy	X	X	X
American shad	X	X	X
Bluefish	X	X	X
Bluegill	X	X	
Brown bullhead	X	X	X
Pumpkinseed	X	X	X
Black crappie	X		
Carp	X	X	X
American eel	X	X	X
Goldfish	X		
Golden shiner	X		
Hogchoker	X	X	X
Tessellated darter	X	X	X
Banded killifish	X	X	X
Emerald shiner	X		X
Largemouth bass	X		
Mummichog	X		
Atlantic menhaden	X	X	X
Blueback herring	X	X	X
White sucker	X	X	X
Atlantic silverside	X		X
Rainbow smelt		X	X
Smallmouth bass	X		
Shortnose sturgeon		X	
Spottail shiner	X	X	X
Atlantic sturgeon		X	X
Striped bass	X	X	X
Fourspine stickleback	X		X
Atlantic tomcod	X	X	X
To be identified			X
White catfish	X	X	X
White perch	X	X	X
Yellow perch	X	X	X
Rock bass	X		
Northern pipefish	X	X	X
Redbreast sunfish	X		
Atlantic needlefish	X		
Crevalle jack	X	X	
Silvery minnow	X		
Weakfish		X	X
Lookdown		X	
Alosa sp.	X	X	X
Northern hog sucker	X		
Cyprinidae unidentified	X		X
Morone sp.	X		X

TABLE 4-3 (Page 2 of 2)

SPECIES COMPOSITION OF FISH COLLECTED IN EACH OF THE HUDSON RIVER YEAR CLASS SURVEYS DURING 1987

TAXON	BEACH SEINE	FALL SHOALS	LONG RIVER
Tautog	X		X
Striped cusk-eel			X
Spot	X	X	
Moonfish		X	
Acipenser sp.			X
Winter flounder	X	X	X
Tidewater silverside	X		X
Gizzard shad	X	X	X
Striped mullet	X		
Threespine stickleback	X		
Butterfish		X	
White crappie	X		
Northern pike	X		
Northern puffer		X	X
Blacknose dace	X		
Centrachidae unidentified	X	X	X
Spotfin shiner	X		
Unidentifiable			X
Central mudminnow		X	
Rough silverside	X	X	
Summer flounder	X	X	X
Striped searobin		X	
Northern searobin		X	
Atlantic croaker		X	X
Atlantic herring			X
Conger eel			X
Walleye			X
Channel catfish		X	
Naked goby	X	X	
Windowpane	X	X	X
Spotted hake			X
Triglidae unidentified			X
American sand lance			X
Gobiidae-gobies			X
Fundulus sp.			X
Myoxocephalus sp.			X
Cottid unidentified			X
Pleuronectid unidentified			X
Atherinidae sp.			X
Bothidae unidentified			X
Speckled worm eel			X
Sciaenidae			X
Gadidae			X
Gray snapper		X	
Atlantic cod			X
Percidae unidentified			X
Gasterosteidae unidentified			X
Tetraodonidae (puffer family)		X	
Margined madtom		X	

striped bass. They reported life-stage-specific distribution patterns related to currents and depth.

Changes in temperature, salinity, and dissolved oxygen may also be important in determining the microdistribution of certain teleosts. Hudson River white perch distributions are hypothesized to be influenced by temperature and salinity gradients (LMS 1988). Physiologically, white perch temperature and salinity preferences are dependent on whether the fish has been exposed to rising (spring) or declining (fall) ambient temperatures (Meldrim and Gift 1971). Higher temperatures are preferred when ambient temperatures are declining. In summer, preferred temperatures are widely available in the river and have little influence on distribution. In the fall, however, with decreasing temperatures, white perch tend to seek the warmer water available in the lower estuary. The extent of their downriver movement appears blocked at some point by high salinities. Major white perch concentrations seem to occur near the salt front.

The Hudson River conditions that affect the microdistribution patterns for the different life history stages of striped bass, white perch, and American shad are discussed in the following sections. Morphometric and physical features of the river that may affect fish microdistribution, including the locations of shallow areas, major tributaries, and vegetated areas (NAI 1987), are illustrated in Figures 4-1a through 4-1g. Many other components of the microhabitat not addressed here may influence fish distribution patterns. For example, although the cover provided by vegetation is important to fish survival, an index of values in the Hudson River is not available. Other habitat characteristics associated with areas of increased vegetation, including temperatures, current velocity, and food availability, were not measured. Substrate types as well as areas of cover other than vegetation (rock piles, old pilings, log debris) may also affect microdistribution. While Carlson (1986) stated that offshore fish aggregations were most diverse around rock piles associated with navigation markers and least diverse in the main channel,

FIGURE 4-1a

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)

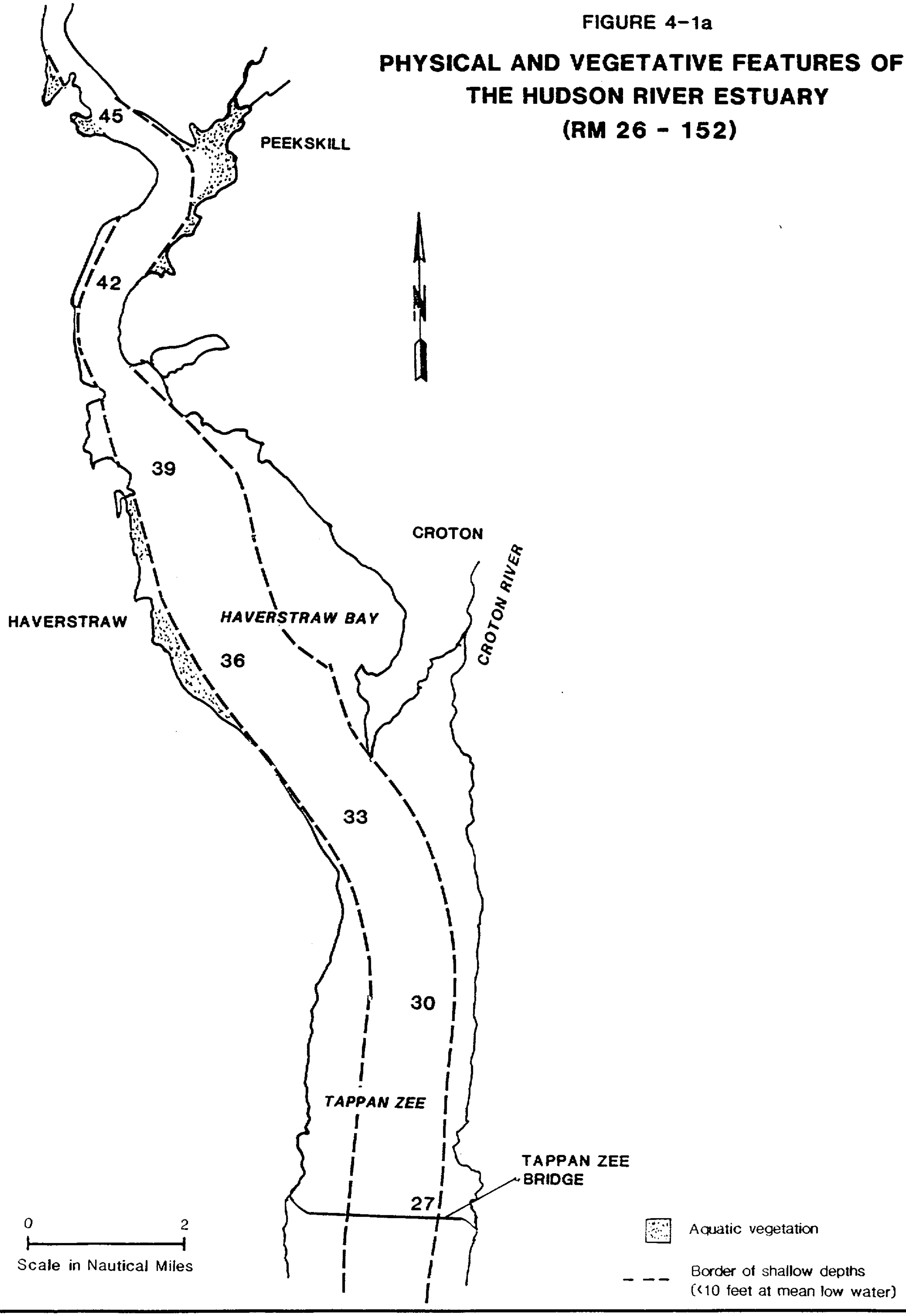
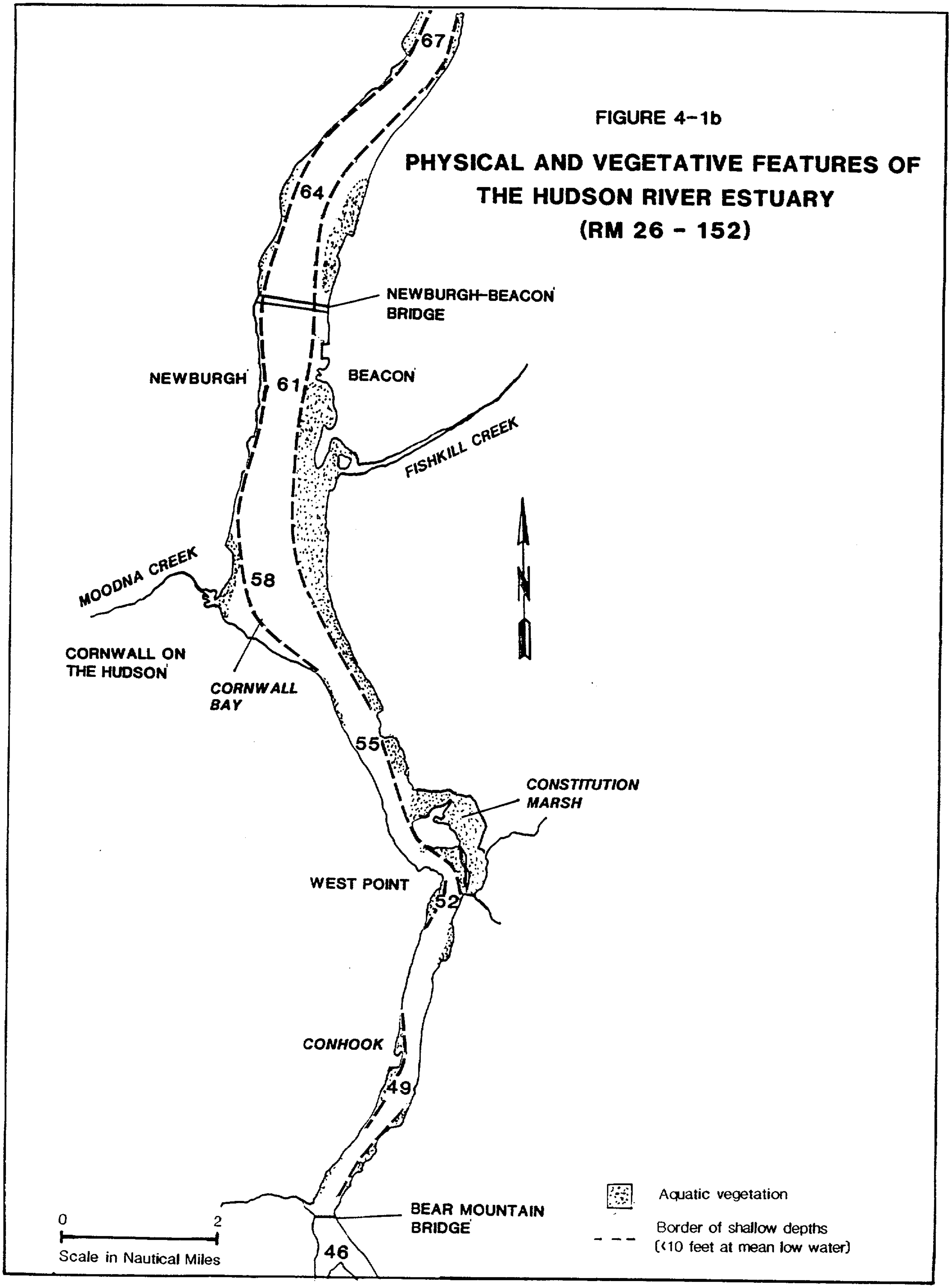


FIGURE 4-1b

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)



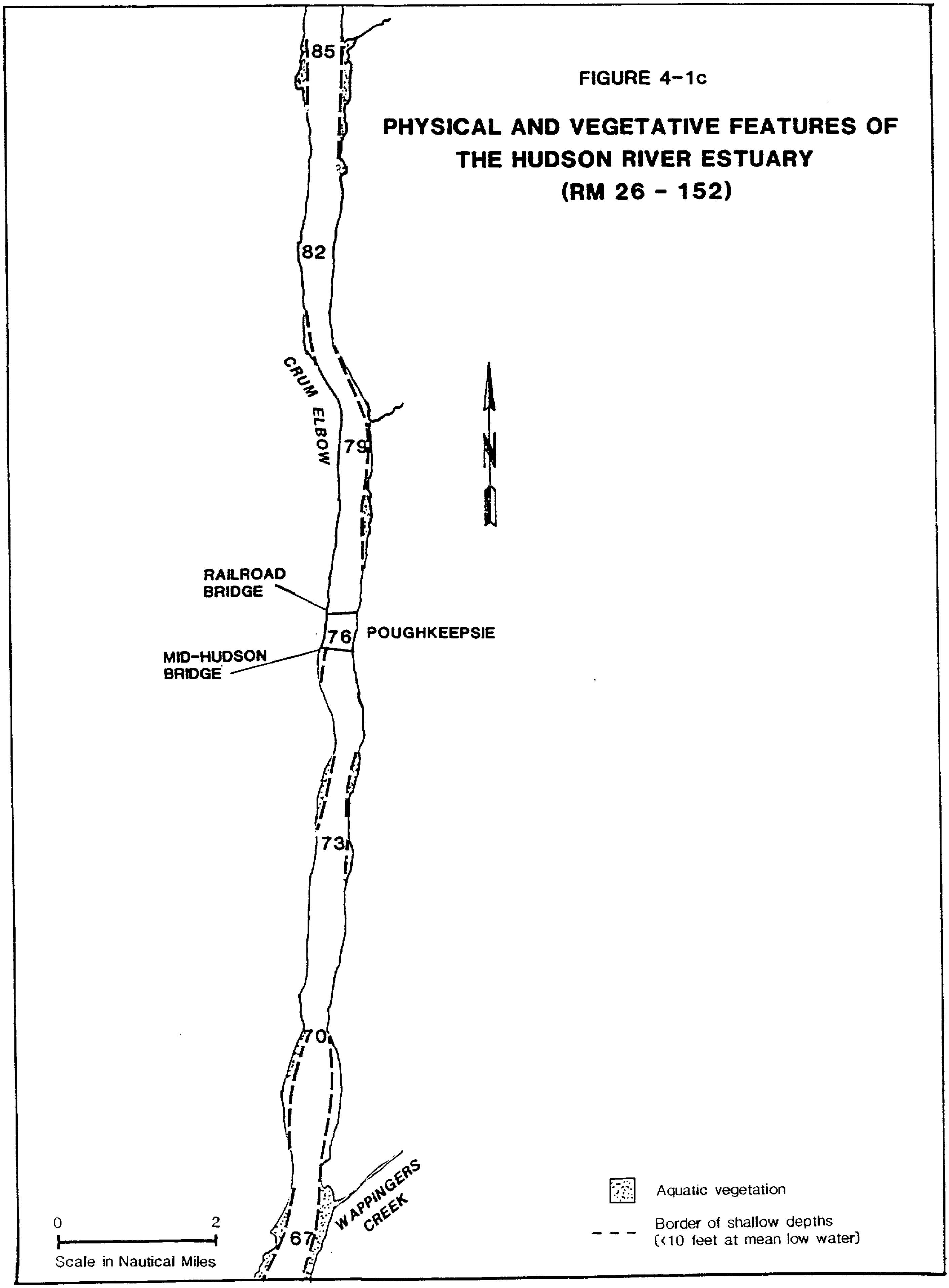


FIGURE 4-1c

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)

FIGURE 4-1d

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)

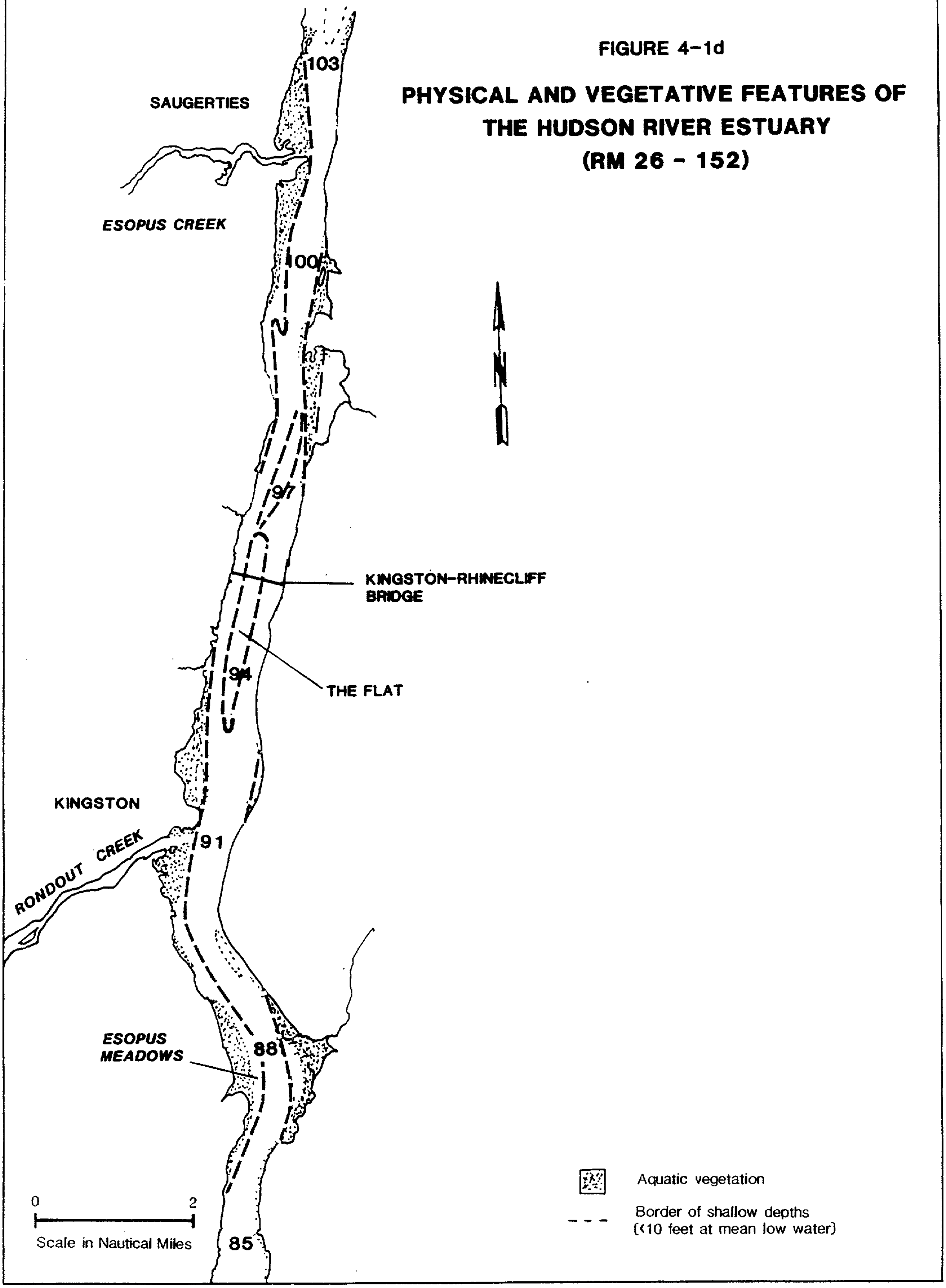


FIGURE 4-1e

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)

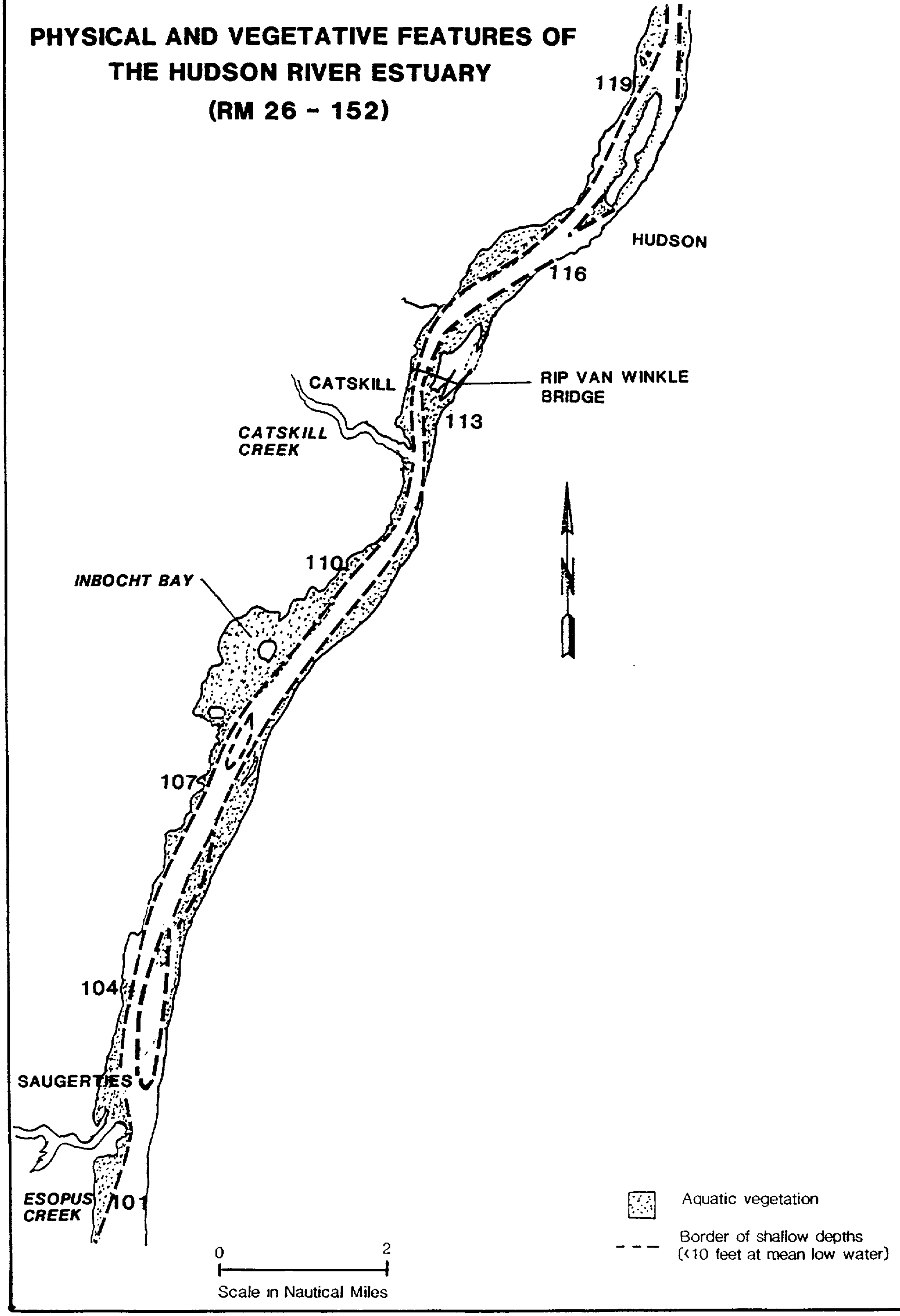
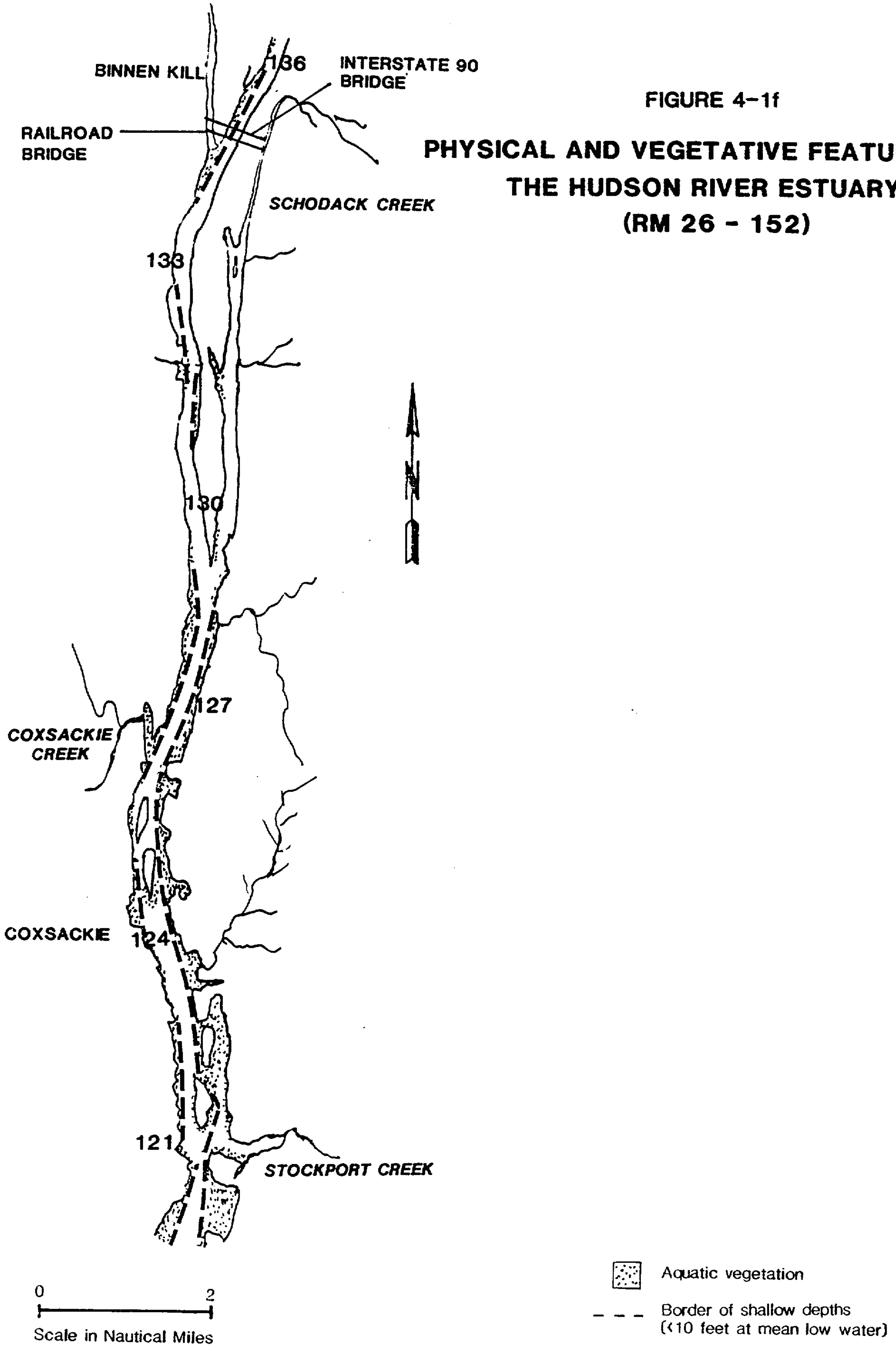


FIGURE 4-1f

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)



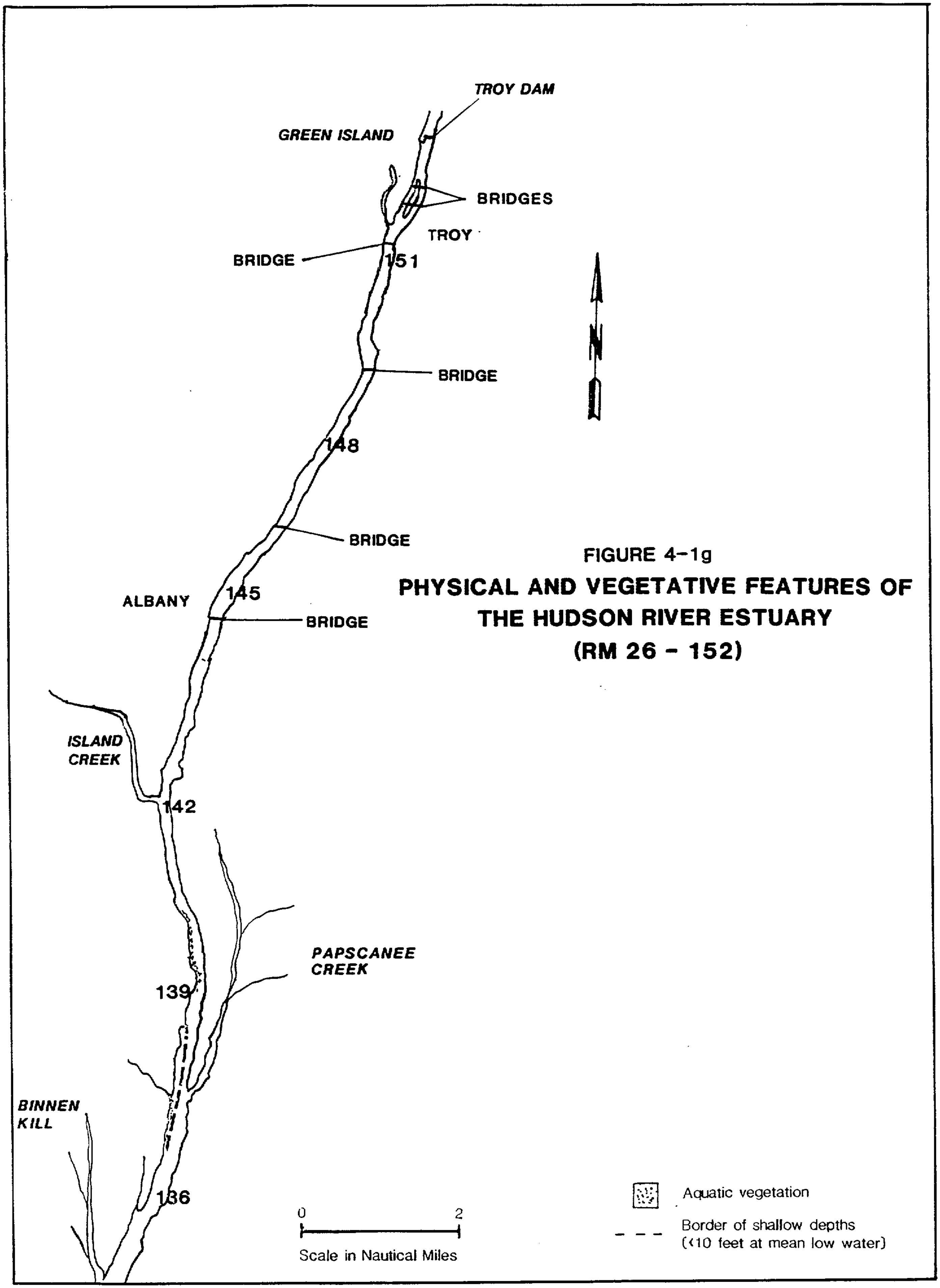


FIGURE 4-1g

PHYSICAL AND VEGETATIVE FEATURES OF THE HUDSON RIVER ESTUARY (RM 26 - 152)

microdistributional abundances cannot be determined for the rock pile cover sites due to their limited occurrence in the areas sampled during this study.

4.3 STRIPED BASS

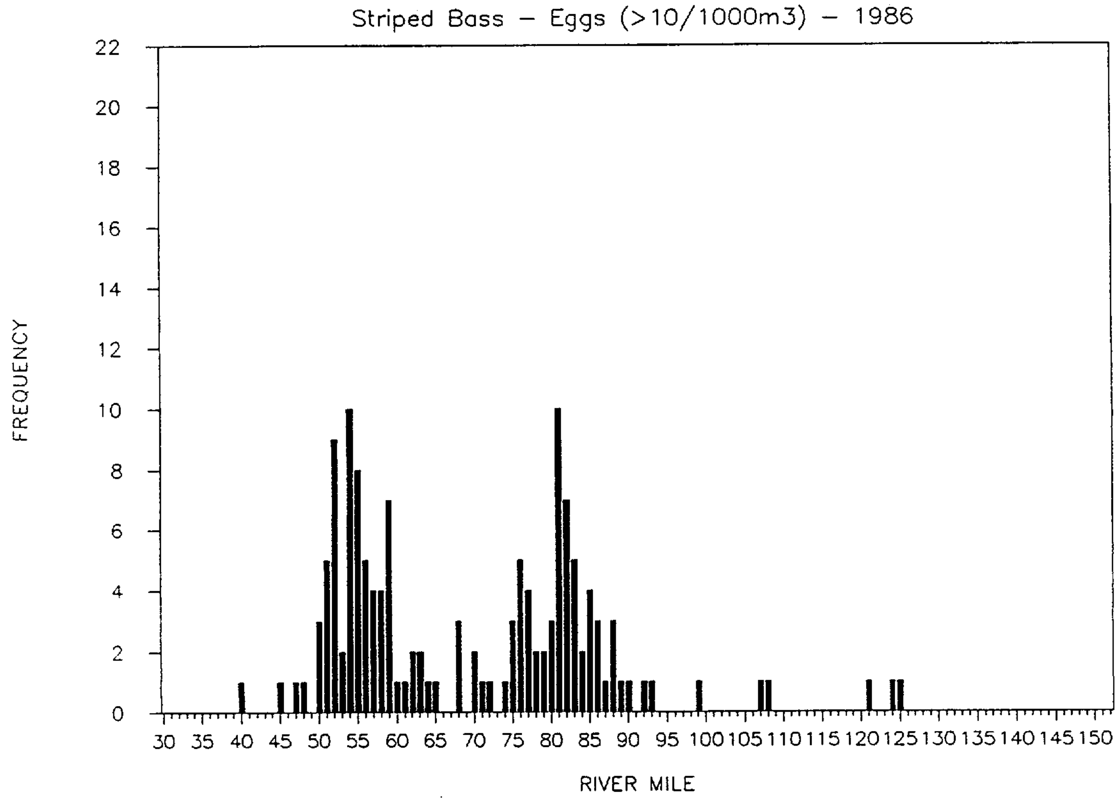
The striped bass, Morone saxatilis (Walbaum), is an anadromous species with an Atlantic coast distribution from the St. Lawrence River south to northern Florida and into the northern Gulf of Mexico. Striped bass were introduced to the Pacific coast and are now prevalent from Canada to Mexico in the Pacific Ocean as well as in many freshwater reservoirs (Bailey 1975).

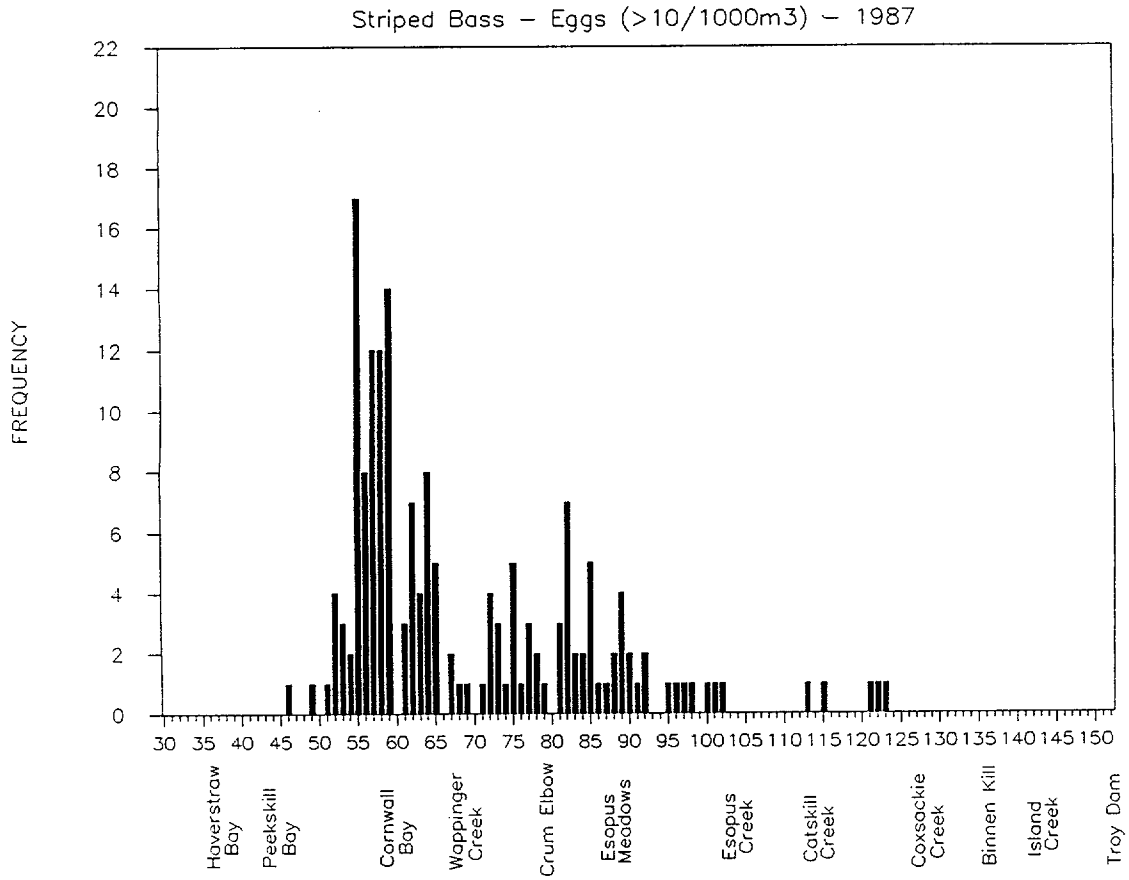
Adult striped bass enter the Hudson River estuary in late winter through early spring and spawn in May and June. Spawning generally occurs upstream of the salt front between the Croton-Haverstraw and West Point regions (RM 34-55), but may extend throughout the estuary. Spawning usually occurs within 25 miles of the salt front in tidal river systems (Tresselt 1952). In 1986 and 1987 striped bass spawned in two main locations within the Hudson River estuary. The downriver region is centered at Cornwall Bay (RM 52-65). The largest concentrations of viable eggs were collected in the immediate vicinity of the bay (RM 57-59) during both the 1986 and the 1987 ichthyoplankton sampling programs (Figure 4-2). This area of the river has large shallow flats (Figure 4-1b) with seasonally abundant vegetative mats. Another area of dense egg collections, between the Poughkeepsie and Kingston regions (RM 76-90) (Figure 4-2), has more deep areas with limited shoals (Figures 4-1c and 4-1d). Most adults return to the ocean after spawning, although some remain in the estuary for a time. The distance that striped bass travel from the mouth of the Hudson River is related to size, with smaller fish moving shorter distances (Waldman 1988). A majority of the striped bass that move out of the Hudson River generally remain within an area ranging from Sandy Hook, New Jersey, to both shores of Long Island and the Connecticut and Rhode Island coastlines (Waldman 1988).

Striped bass YOY move downriver during the summer to feed in nursery areas located in the higher salinity waters (McFadden et al. 1978). With decreasing

FIGURE 4-2

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





fall water temperatures the juveniles move either to the lower estuary or into adjacent bays and sounds to overwinter before migrating out to sea. Hudson River striped bass constitute roughly 10 to 50% of Atlantic coastal stocks, depending on the year (Van Winkle and Kumar 1982).

Female striped bass, which mature between ages 4 and 9, spawn their eggs near the surface in generally turbid areas of moderately high current or tidal flow (Rogers et al. 1982). Spawning grounds in the Hudson River are typically characterized by sand or mud substrates (Wang and Kernehan 1979); incubation time is usually two to three days, depending on water temperature (Rogers et al. 1977). Currents move the yolk-sac larvae (YSL) downstream since they are unable to swim (Mansueti 1958). After approximately one week they have absorbed available yolk supplies and feed actively on small zooplankton. At the juvenile life stage, reached after somewhat less than 30 days in the river (McFadden et al. 1978), they are described by Boynton et al. (1981) as being nonselective feeders, traveling in schools along the river shores where stronger currents are located.

Historically, striped bass made up an important commercial fishery in the Hudson River, but high polychlorinated biphenyl (PCB) levels resulted in its closing. Adult striped bass weighing 10 kg or more still attract an active recreational fishery.

4.3.1 1986 Study

4.3.1.1 Eggs. Striped bass eggs were already present when the Longitudinal River Survey (LRS) began during the last week of April 1986 (Figure 4-3). The mean water temperature for the four middle regions of the estuary had reached 12.8°C, the minimum associated with previous peak striped bass spawning activity (TI 1981), and this may have initiated the early spawning (DiNardo et al. 1985). The 1.1 to 2.2°C mean rise observed in spawning areas between the first and second weeks of the LRS may have induced spawning, as reflected in

1986 LONG RIVER SURVEY

DENSITY OF EGGS FOR STRIPED BASS

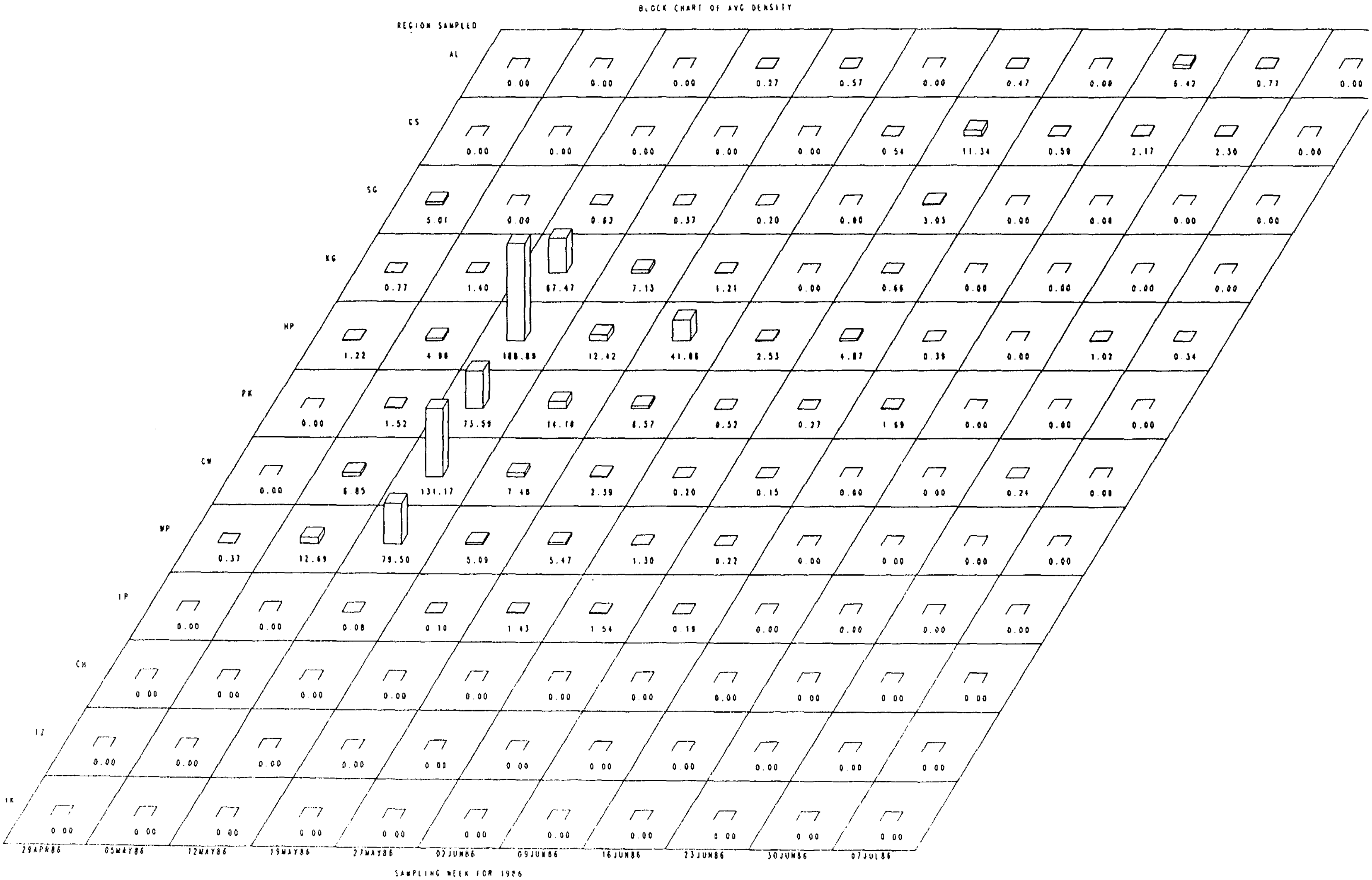


FIGURE 4-3

the peak egg abundance during the third sampling week. During the LRS eggs were collected between the Indian Point and Albany regions (RM 34-152).

The single temporal peak in egg abundance occurred in mid-May (Figure 4-4) when weekly regional mean water temperatures in the middle estuary ranged from 14.7 to 16.0°C. This unimodal peak is consistent with that observed in most other years (1976 and 1984 were bimodal). As in 1985 (Versar 1987), peak 1986 egg abundance took place farther upstream than historical records indicate (Figure 4-5), possibly due to sharply decreasing freshwater inflows prior to peak spawning activity. From the West Point through Kingston regions (RM 47-93) egg densities were greater than 50/1000 m^3 during the sampling week initiated on 12 May (Figure 4-3). No eggs were found south of the Indian Point region. Eggs were collected through the end of the 1986 survey in early July when river temperatures had just exceeded 22°C, considered the maximum temperature for striped bass spawning activity in the estuary (TI 1981).

4.3.1.2 Yolk-Sac Larvae. Striped bass YSL, initially collected during the first week of May in 1986, continued to be caught throughout the survey (Figure 4-6). Collections revealed YSL in all regions north of the Yonkers region (RM 24-152). Densities exceeded 100/1000 m^3 from the Indian Point through Kingston regions (RM 34-93) from 12 May through 2 June (Figure 4-5); these densities occurred earlier than historical accounts (Figure 4-4). Peak egg densities in the Hyde Park region resulted in similar peaks in the YSL density during the same week and the following week. Geographical distribution was similar to the long-term mean (Figure 4-5). A YSL density peak in the West Point region is likely because of the displacement of larvae from lower areas of the Cornwall region where egg densities were high during the week of 12 May. The temporal shift between life stage peaks reflects an incubation time of two to three days for striped bass in the Hudson River (Rogers et al. 1977).

Weekly mean temperature and salinity in the middle estuary ranged from 15.1 to 19.9°C and from 0.03 to 0.69 ppt, respectively, during peak YSL abundance from the 12 May through the 26 May sampling period. These values closely match the 15-18°C temperatures (Rogers et al. 1977) and the 0-1 ppt salinity at 18°C (Turner and Farley 1971) ranges reported as optimal conditions for growth and survival of striped bass early life stages. Hatching success of over 80% and survival following hatching in excess of 65% have been shown by Morgan et al. (1981) at these temperatures in laboratory tests. Above-normal freshwater flow (Figure 4-7) may have caused the observed downriver shift of YSL during the last week of May.

4.3.1.3 Post Yolk-Sac Larvae. Striped bass PYSL, first collected during the week of 12 May 1986, were collected through the end of the LRS (Figure 4-8). Peak mean regional densities in excess of 500/1000 m^3 occurred during the weeks of 27 May and 2 June from the Indian Point through Cornwall regions (RM 39-61). A one-week difference between peak YSL and peak PYSL densities corresponds to the approximate developmental time from YSL to PYSL (Setzler et al. 1980).

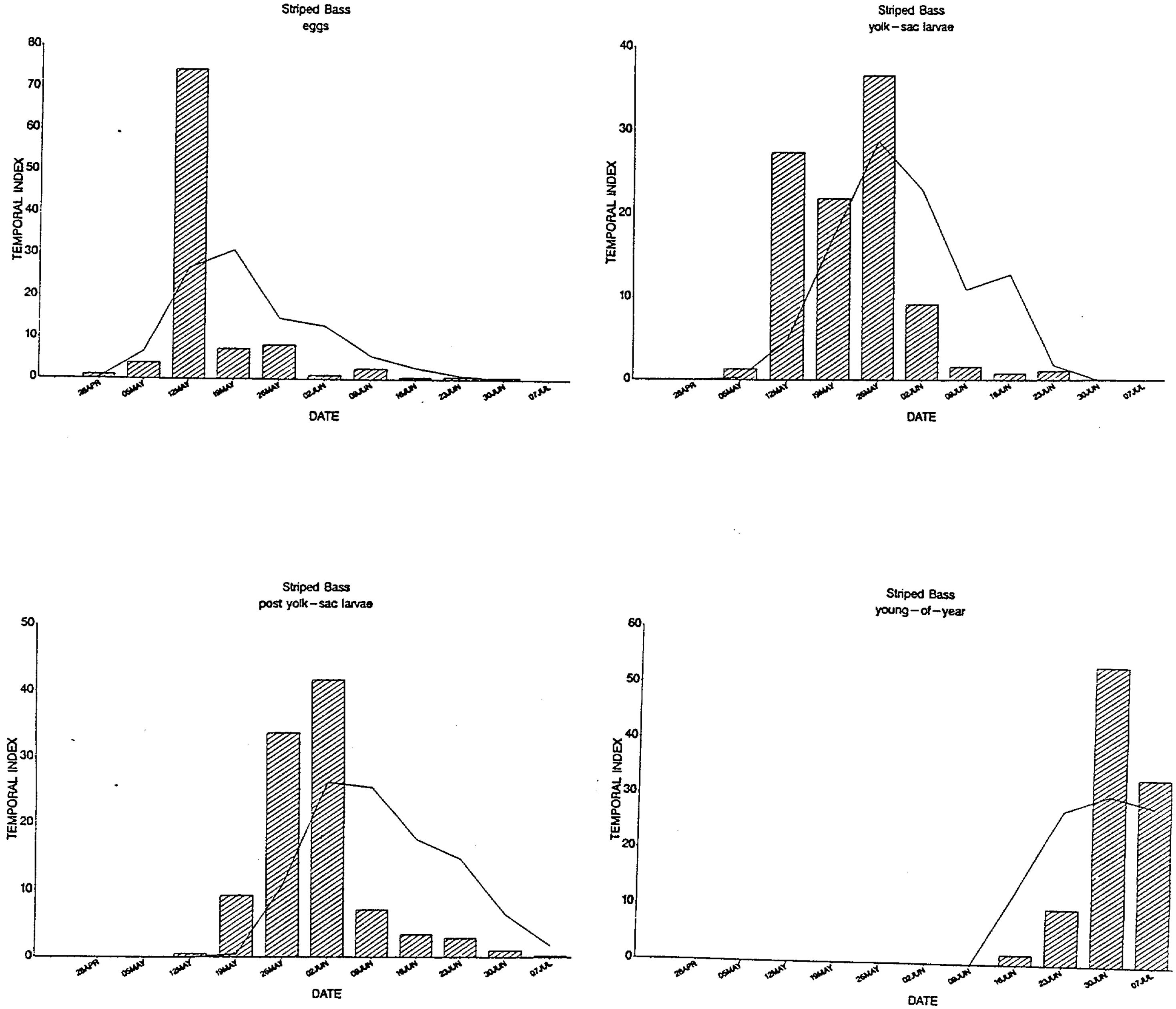
Density estimates were greatest from late May to early June (Figure 4-4), similar to patterns reported in 1975 and between 1977 and 1982. Peak PYSL densities were roughly one week later than those reported in 1985 (Versar 1987), but earlier than the long-term average. Striped bass PYSL density estimates were greatest in mid- to late June in 1974, 1976, 1983, and 1984.

Geographically, PYSL densities were greatest from the Indian Point region north through Cornwall Bay. This follows historical records in that more than 60% of striped bass PYSL were collected south of the Poughkeepsie region (Figure 4-5). High PYSL densities in the middle estuary reflect high YSL densities earlier in the season (previous one to two weeks). Higher-than-average freshwater flow rates during this period likely moved the YSL downstream through areas of typically high currents. Mean densities never exceeded 50/1000 m^3 north of the Kingston region or in the Yonkers region.

4.3.1.4 Young-of-Year. Juvenile striped bass were first collected during the LRS in mid-June (Figure 4-9), with a temporal peak in the last sampling week in June (Figure 4-4). This collection time, similar to that of 1985, is

FIGURE 4-4

TEMPORAL INDEX FOR STRIPED BASS EGGS, YOLK-SAC LARVAE, POST YOLK-SAC LARVAE, AND YOUNG-OF-YEAR COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1986

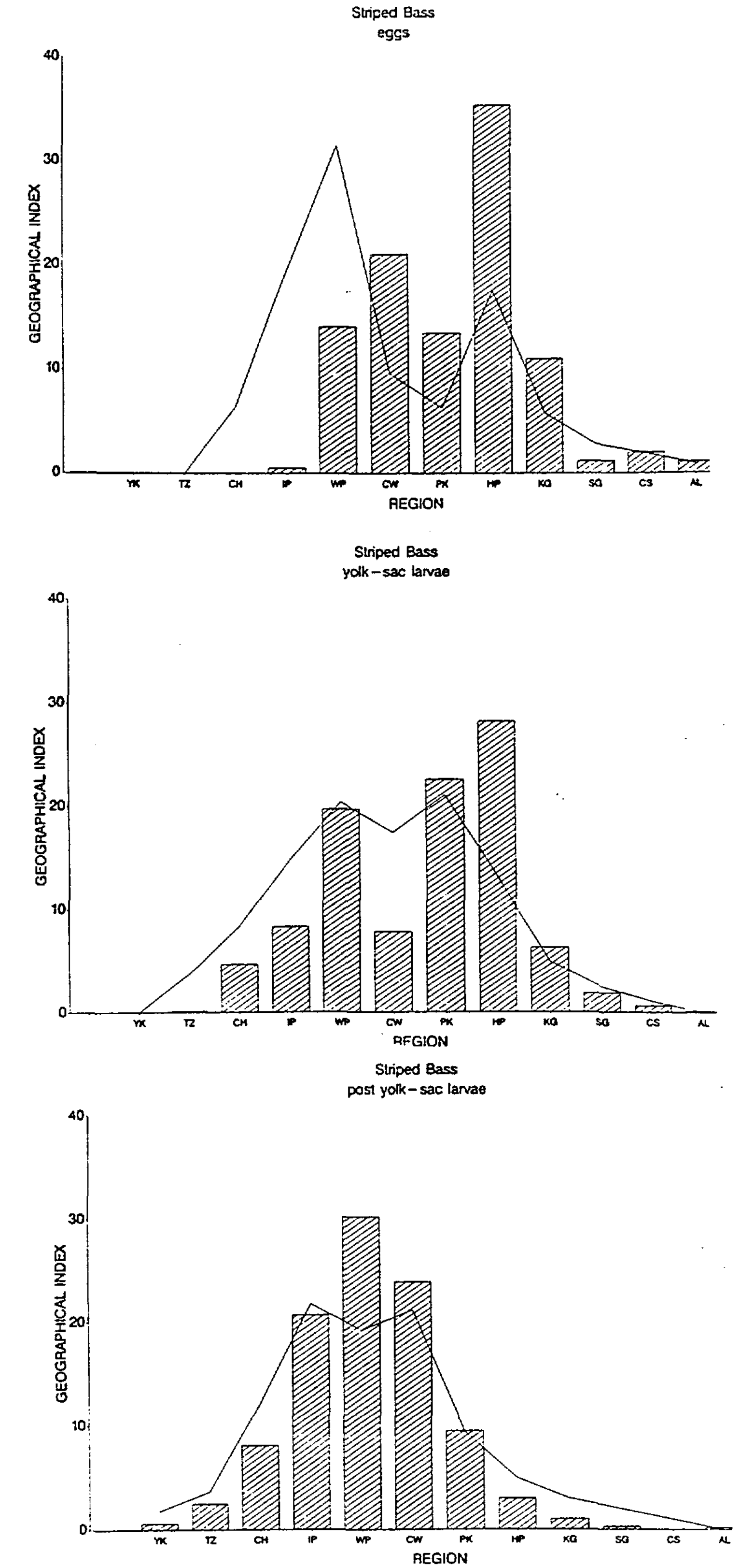


LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

FIGURE 4-5

GEOGRAPHICAL DISTRIBUTION OF STRIPED BASS EGGS, YOLK-SAC LARVAE, AND POST YOLK-SAC LARVAE COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

1986 LONG RIVER SURVEY

DENSITY OF YSL FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

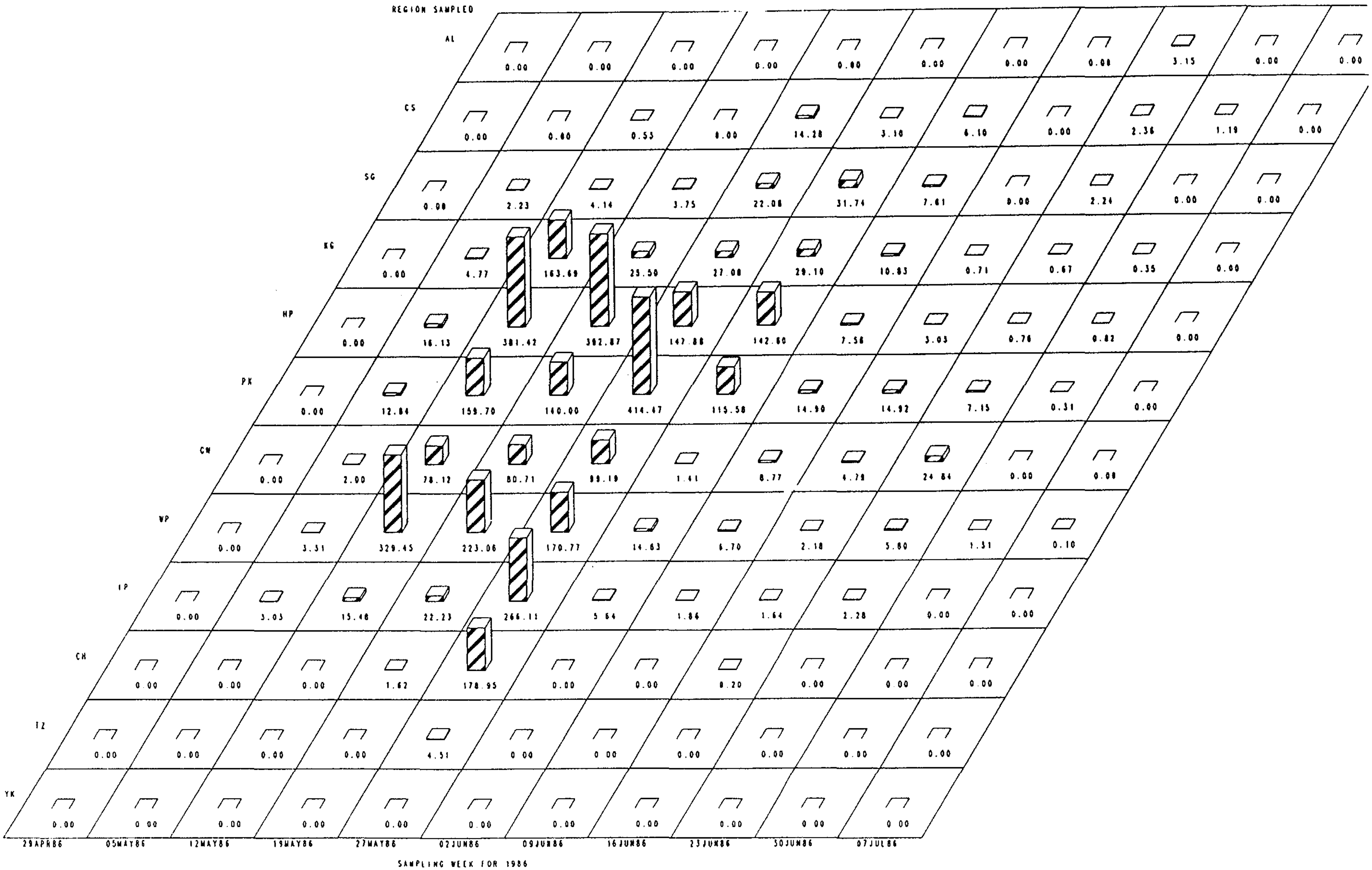
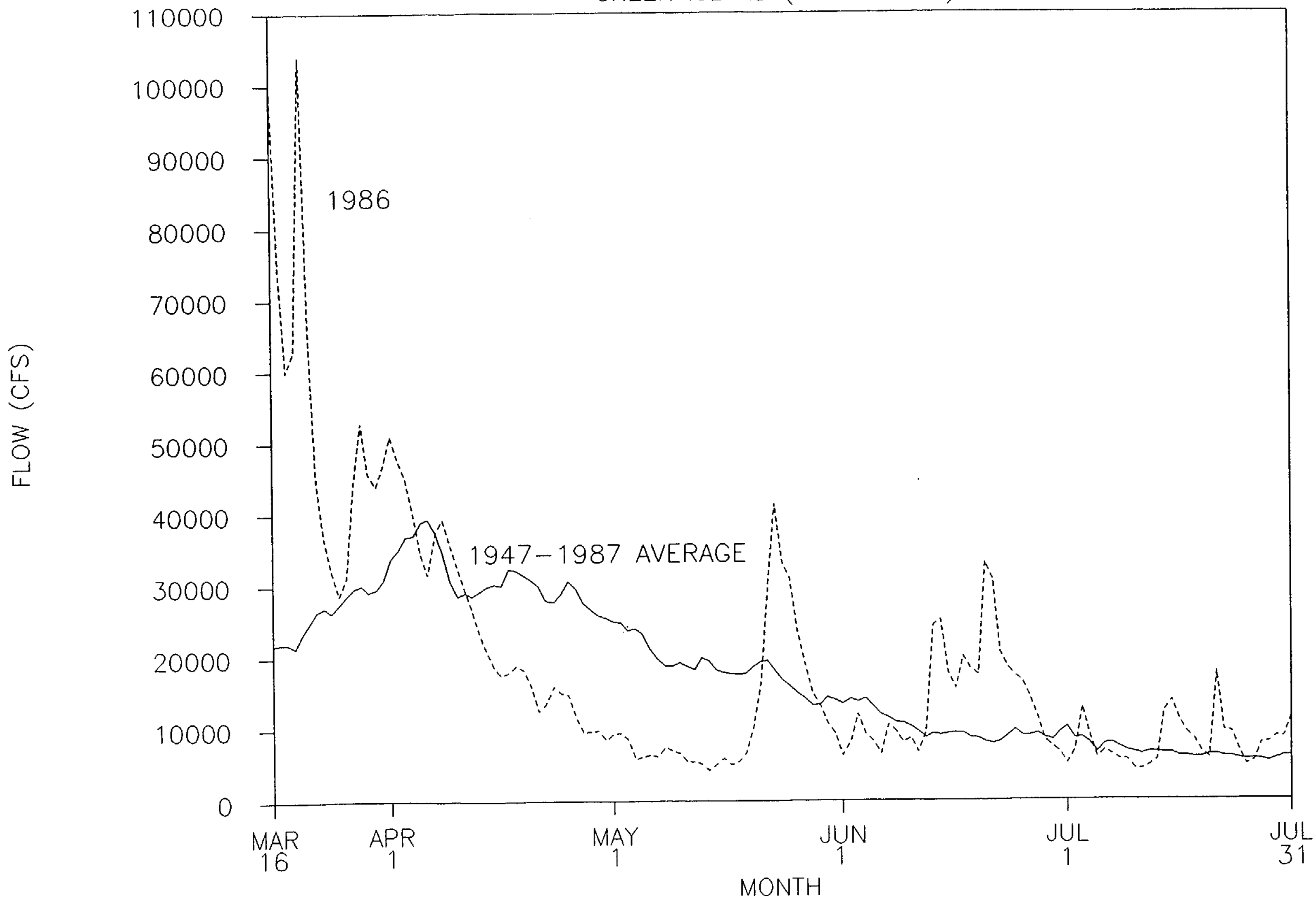


FIGURE 4-6

FIGURE 4-7

AVERAGE DAILY FLOW VS. TIME

GREEN ISLAND (1947–1987)



1986 LONG RIVER SURVEY
DENSITY OF PYSL FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

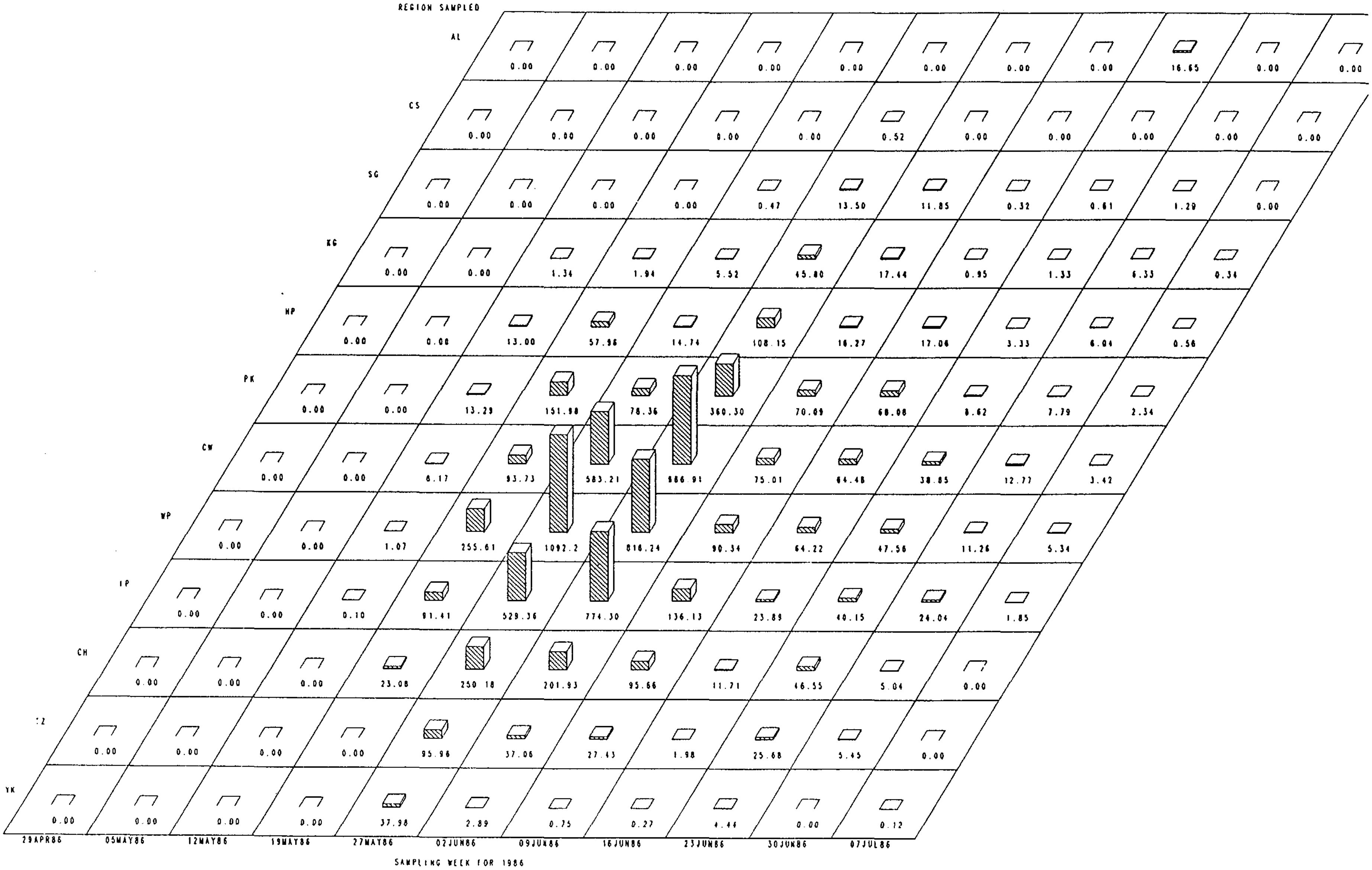


FIGURE 4-8

1986 LONG RIVER SURVEY

DENSITY OF YOY FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

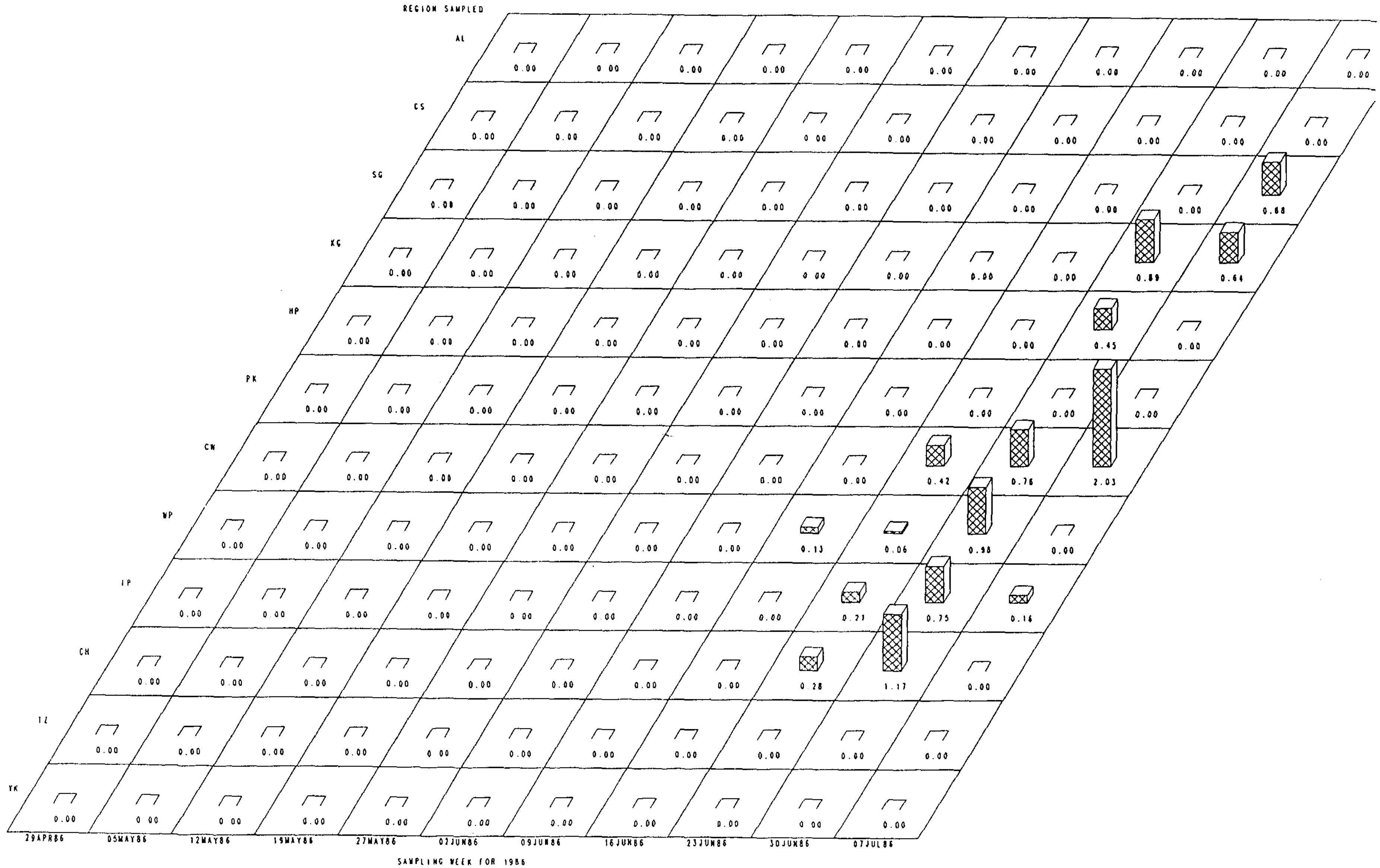


FIGURE 4-9

one of the earliest dates on which juveniles have historically been taken. YOY striped bass were collected in every sampling period of both the Fall Shoals Survey (FSS) (Figure 4-10) and the Beach Seine Survey (BSS) (Figure 4-11).

Striped bass YOY concentrations from the Croton-Haverstraw through Cornwall regions (RM 34-61) in late June and early July reflect peak PYSL abundance in the same regions during late May and early June. Declining YOY catches in upriver sections from September through the end of both the FSS and the BSS suggest the movement of juvenile striped bass to deeper channel water or down-river overwintering grounds. This seasonal migration has been reported in previous Year Class Reports as well, e.g., TI (1981) and NAI (1985a). The 1986 FSS further substantiates this migration, with peak monthly density estimates in the Croton-Haverstraw region from mid-September through late October. The geographical distribution index for the BSS is similar to that of historical records, with peak shore area catches in the Croton-Haverstraw region (Figure 4-12).

4.3.1.5 Yearling and Older Fish. Yearling and older striped bass were collected throughout the LRS (Figure 4-13), FSS (Figure 4-14), and BSS (Figure 4-15) in 1986 except for the weeks beginning on 29 April and 12 May during the LRS. There are no apparent temporal distribution trends, and regional weekly densities are never in excess of 1/1000 m^3.

Yearling or older striped bass were collected throughout the estuary, but no distribution gradient was apparent from data collected during either the LRS or the BSS. The FSS samples suggested peak regional densities from the Tappan Zee through Croton-Haverstraw regions (RM 24-38), probably the result of the migration of yearling and older fish into areas of increased salinity.

4.3.2 1987 Study

4.3.2.1 Eggs. Striped bass eggs were first collected in late April during the LRS (Figure 4-16) and were no longer found after the 22 June sampling

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

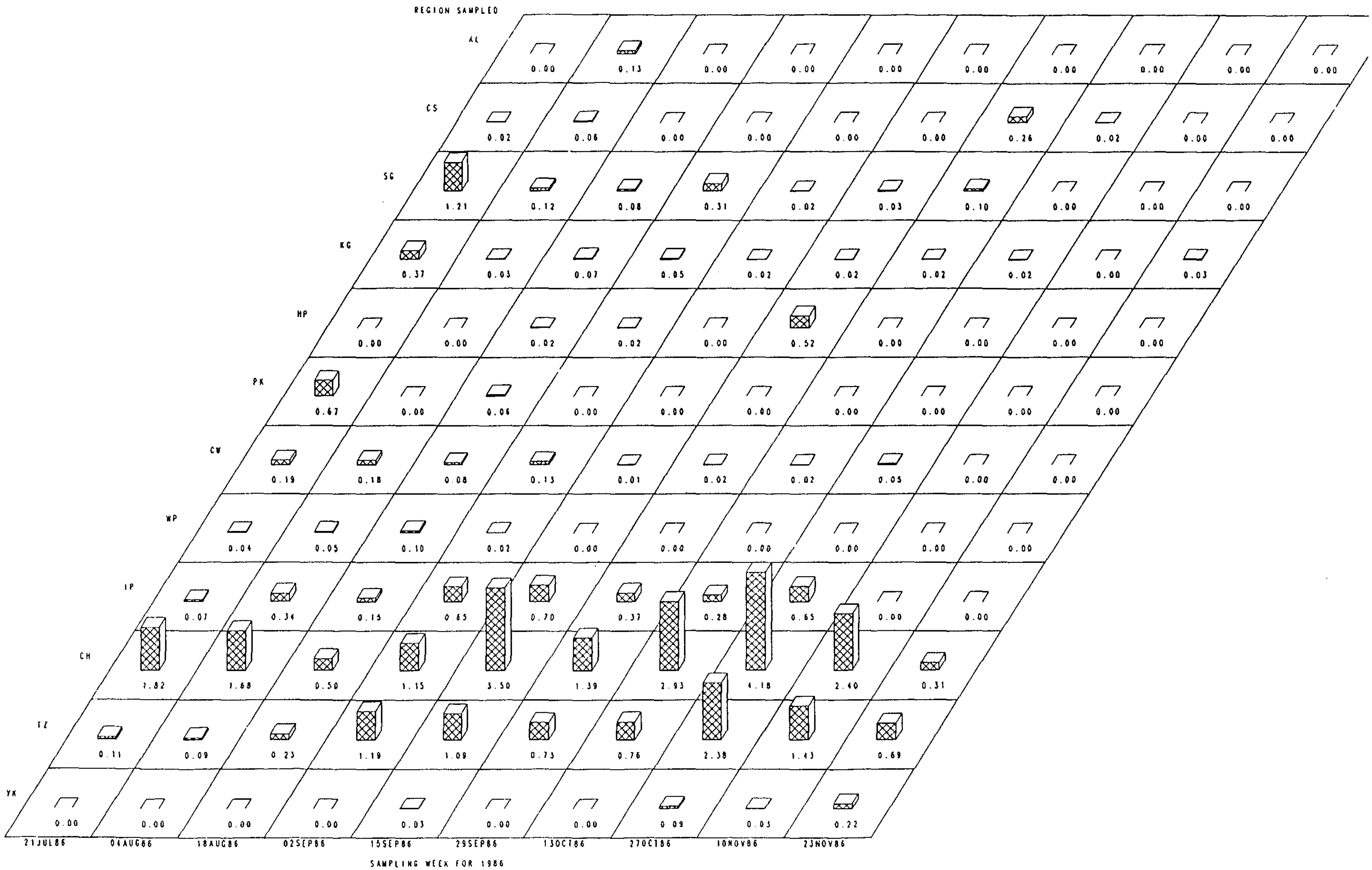


FIGURE 4-10

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR SB

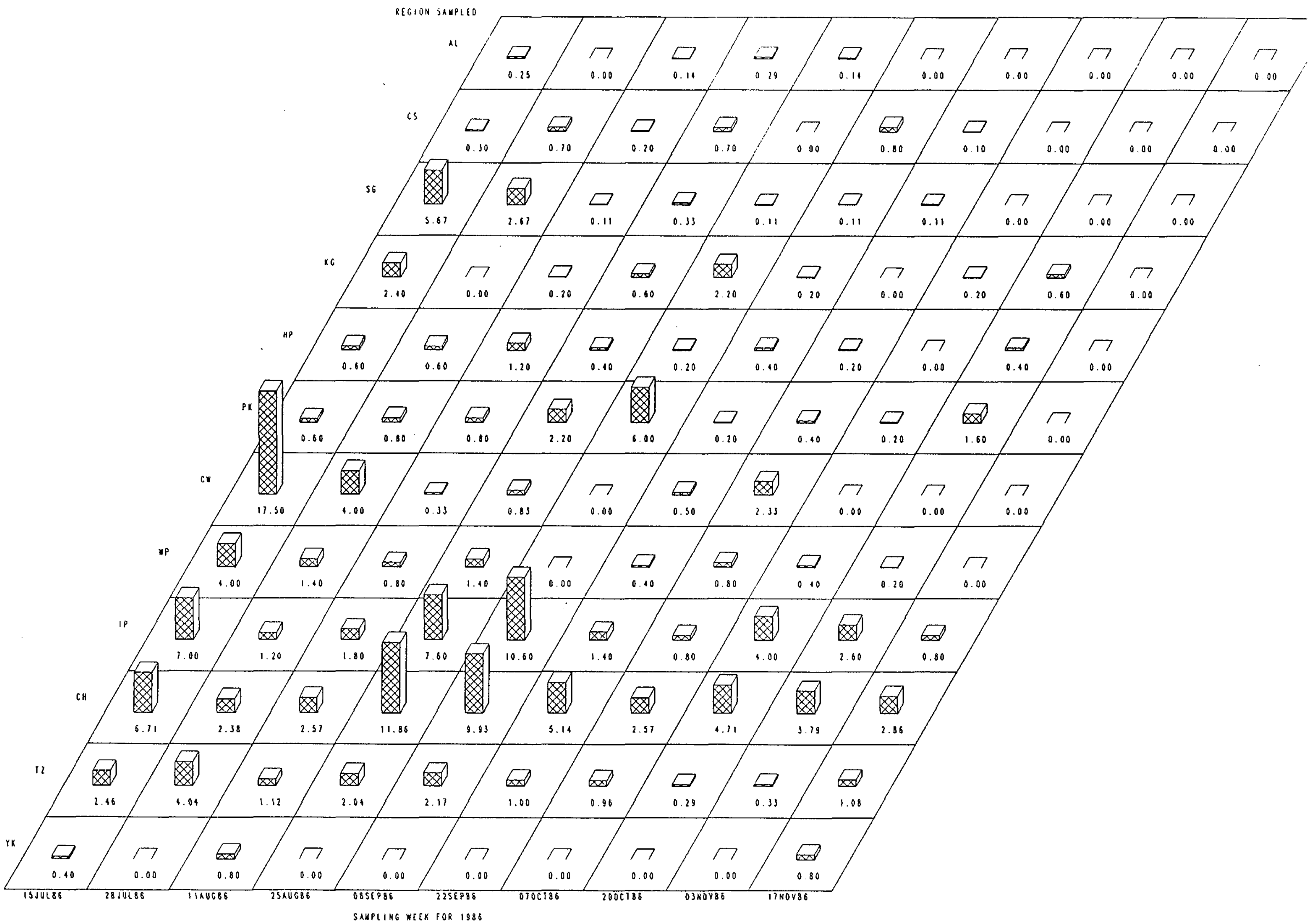
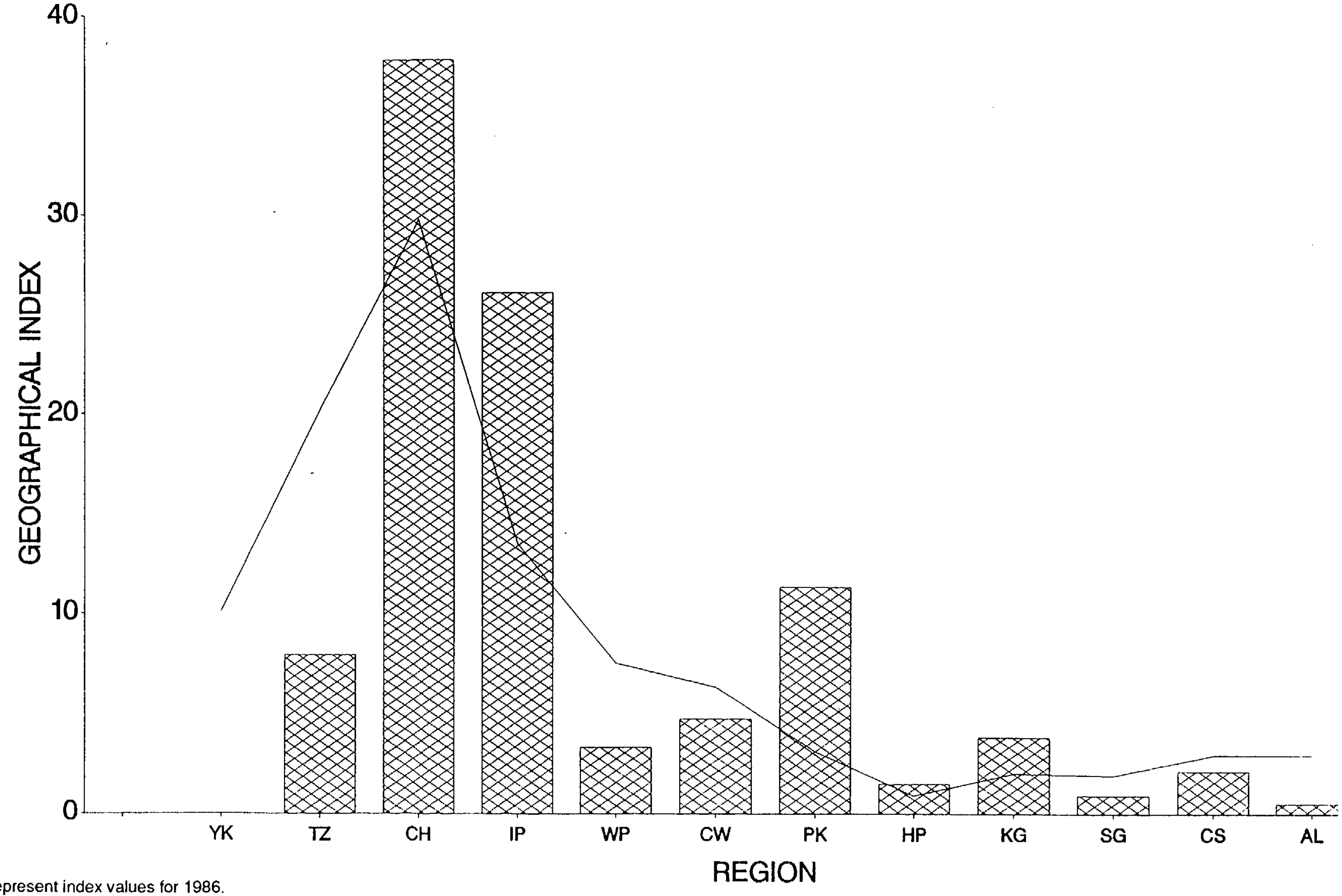


FIGURE 4-11

FIGURE 4-12

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR STRIPED BASS COLLECTED IN THE BEACH SEINE SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

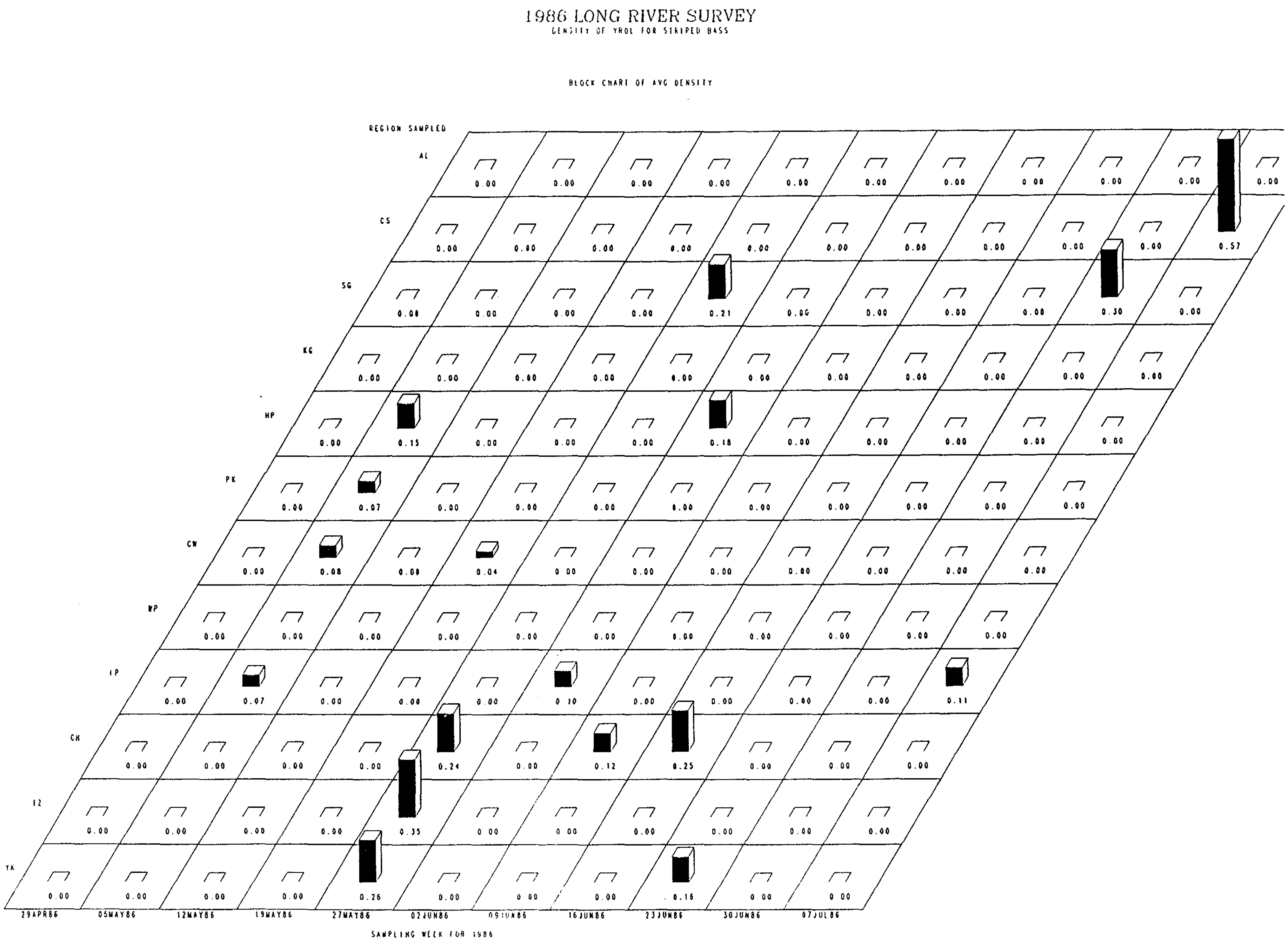

1986 LONG RIVER SURVEY
DENSITY OF YROL FOR STRIPED BASS
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CN
WP
IP
CH
12
YK
29APR86
05MAY86
12MAY86
19MAY86
27MAY86
02JUN86
09JUN86
16JUN86
23JUN86
30JUN86
07JUL86
SAMPLING WEEK FOR 1986

FIGURE 4-13

1986 FALL SHOALS SURVEY
DENSITY OF YRUL FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

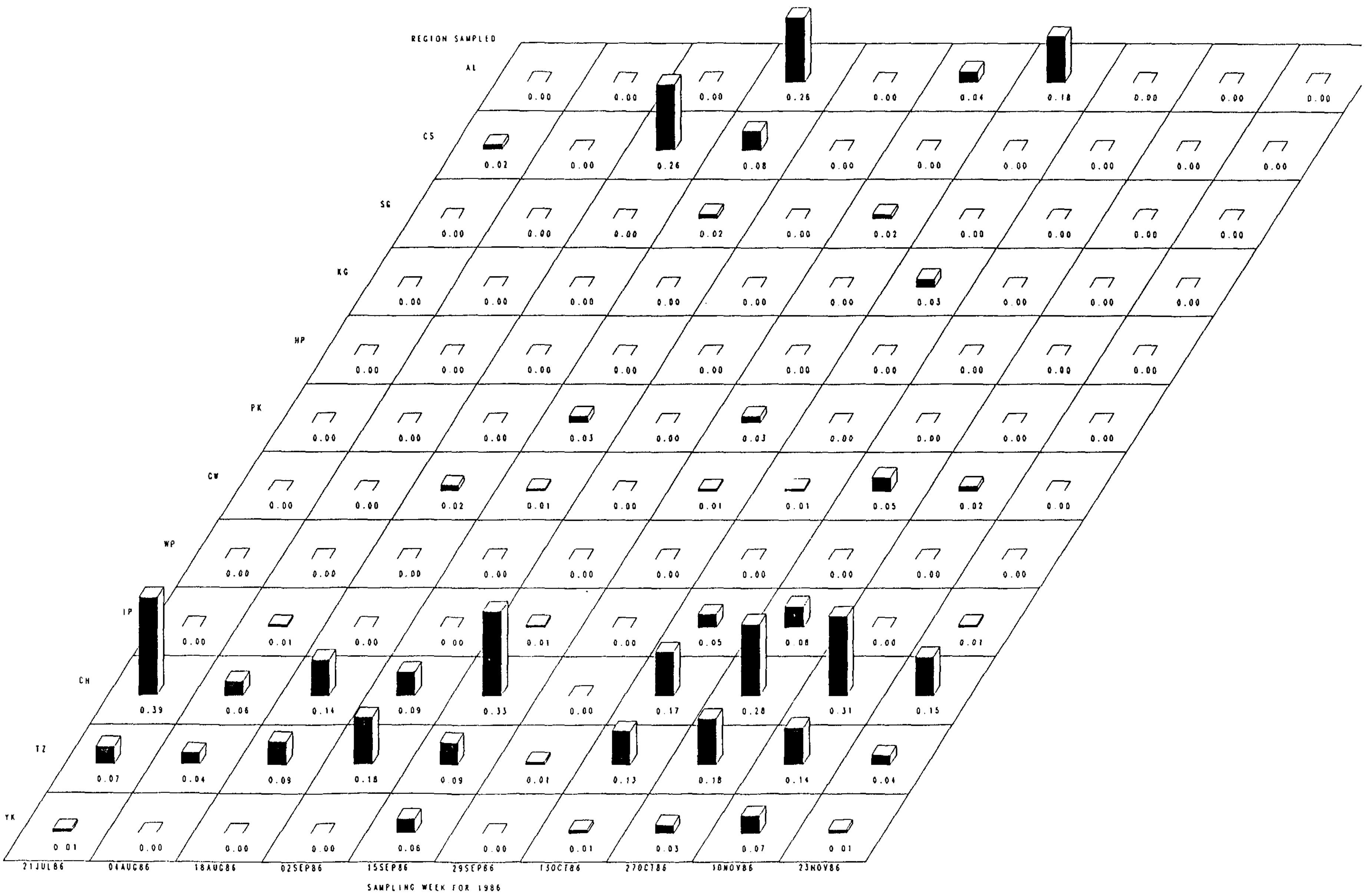


FIGURE 4-14

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR SB

BLOCK CHART OF CATCH/UNIT EFFORT

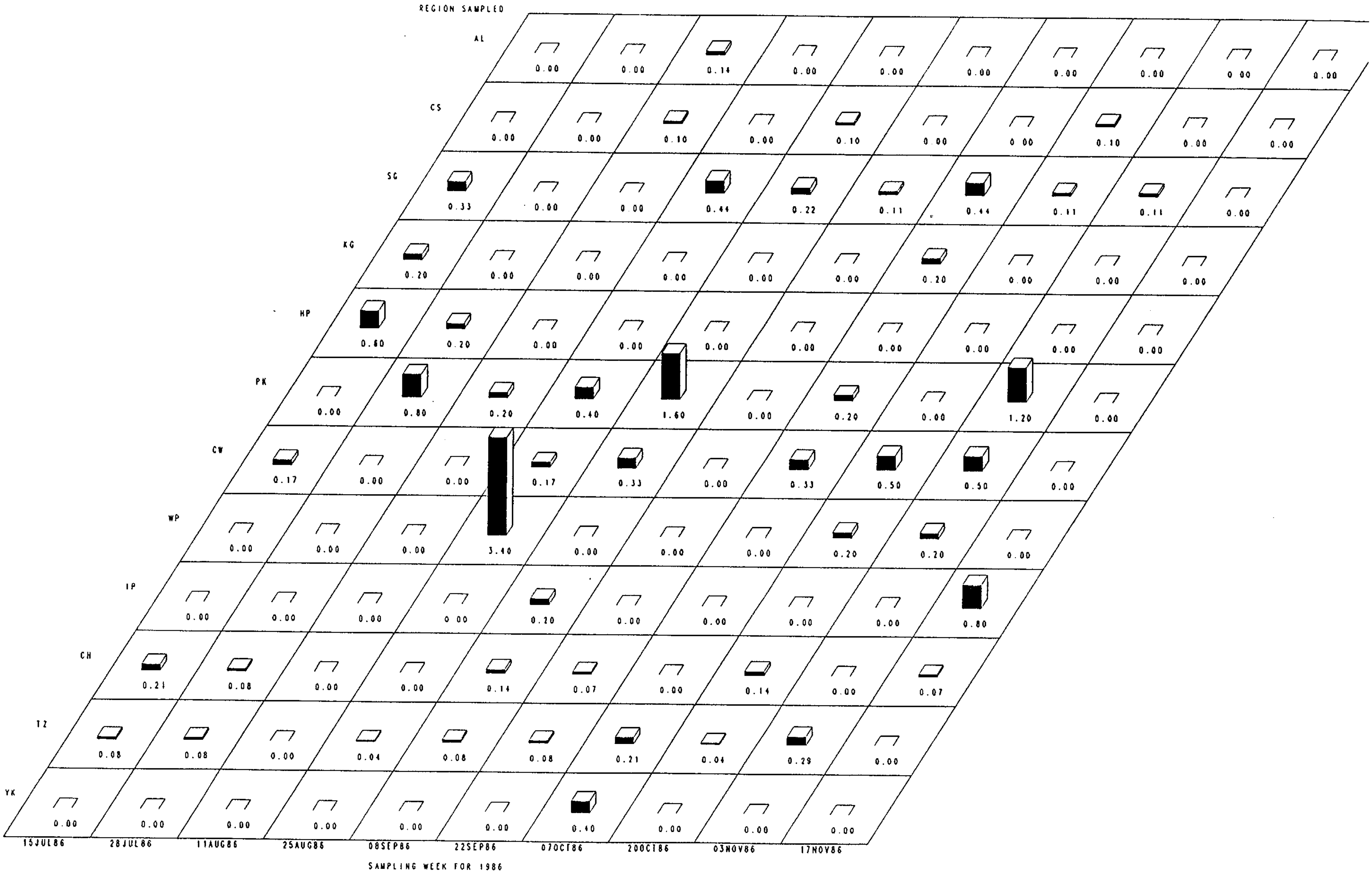


FIGURE 4-15

1987 LONG RIVER SURVEY
DENSITY OF EGGS FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

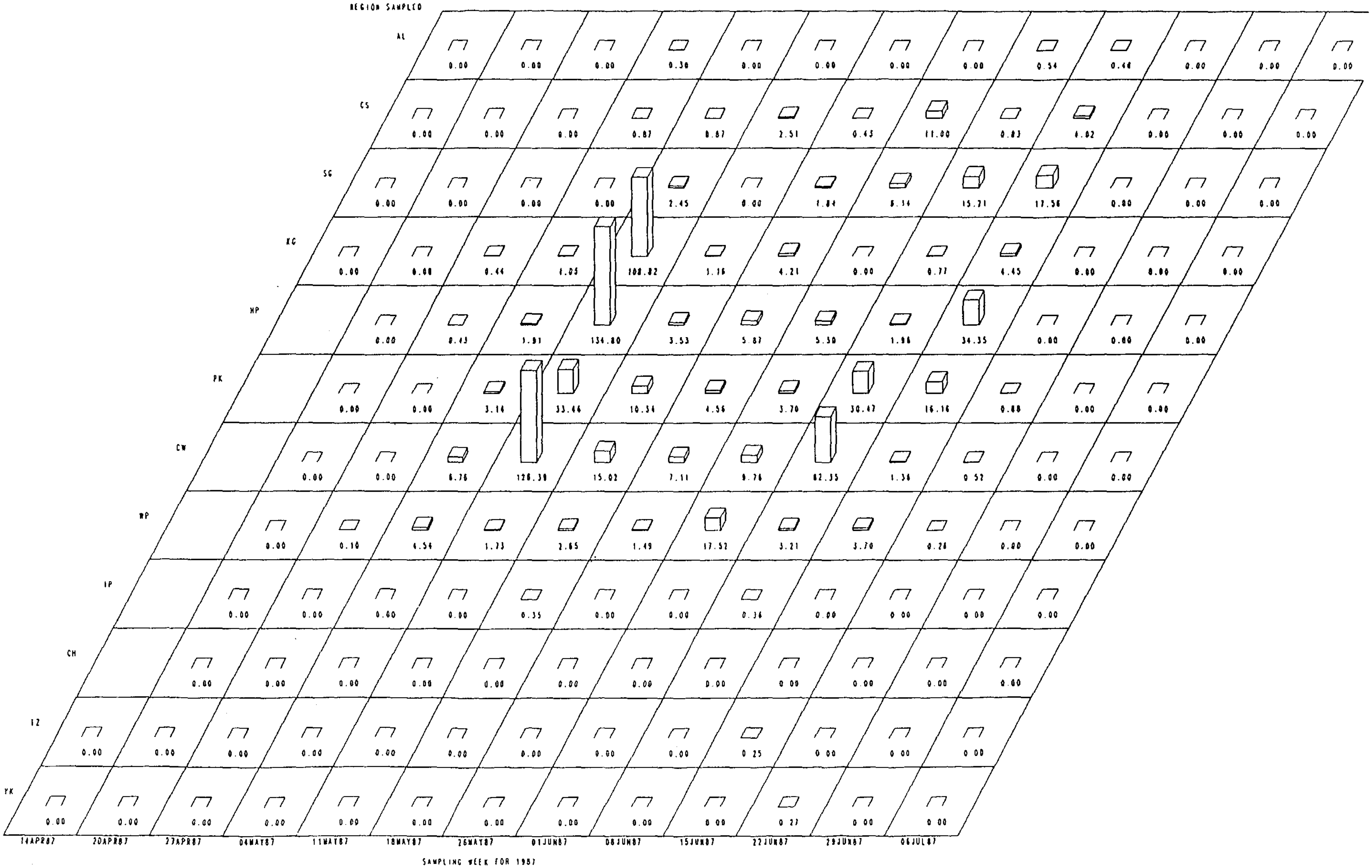


FIGURE 4-16

week. As in 1984, bimodal temporal distribution was observed; the largest peak, in mid-May, was followed by a peak of lesser abundance in mid-June (Figure 4-17). Egg densities higher than 1/1000 m^3 were observed during the first week in May when water temperatures reached the minimum 12°C required for spawning activity. Average temperatures were 14.4 and 19.7°C during the first and second peak densities, respectively. No eggs were collected after temperatures rose above 22.8°C.

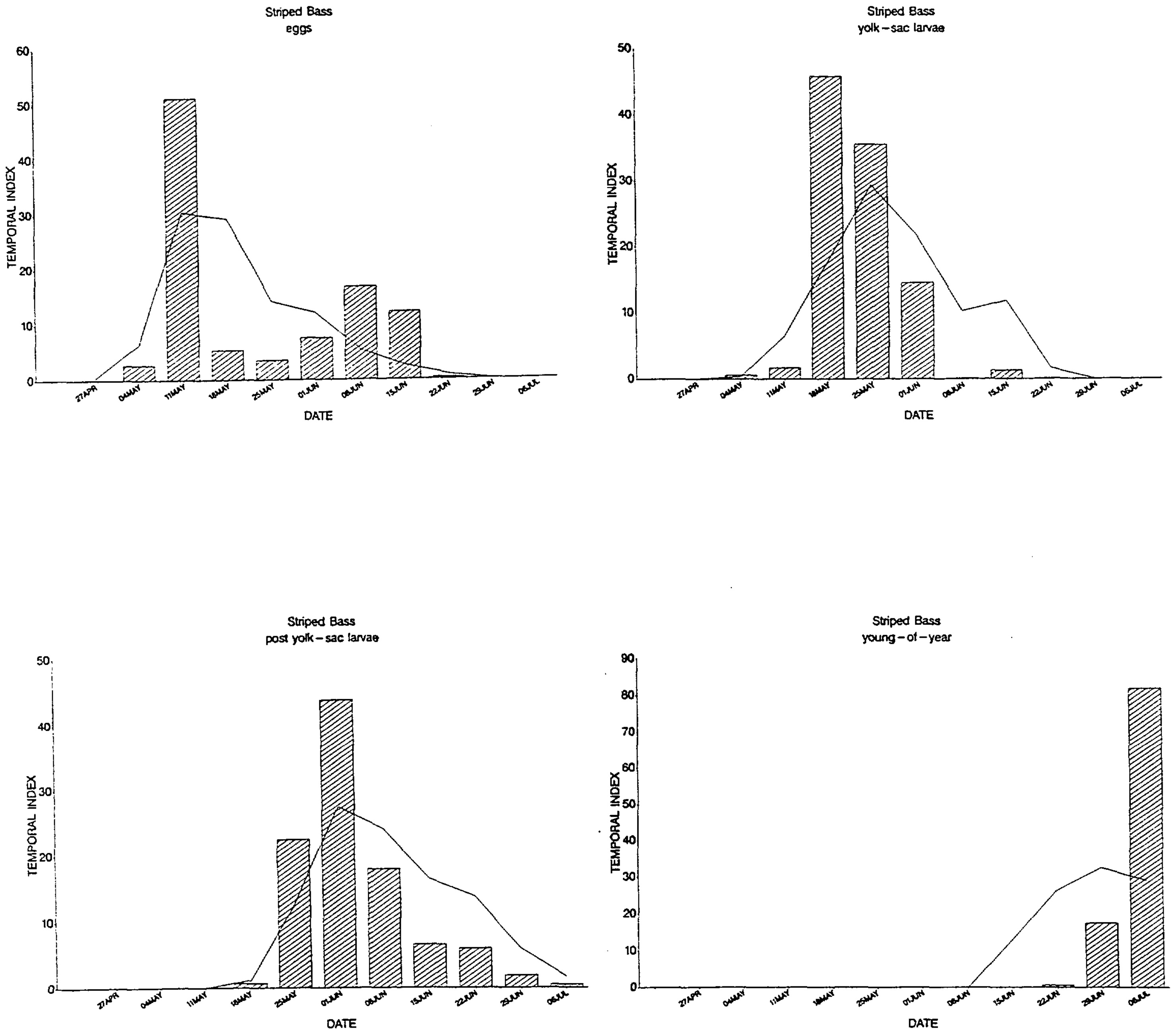
Striped bass eggs were collected in every region except Croton-Haverstraw during the 1987 LRS. Greatest densities were estimated to occur in the Cornwall and Hyde Park regions. Long-term average geographical indices indicate peak occurrence in the West Point region, downstream from the 1987 peak in the Cornwall region (Figure 4-18). Only trace densities were observed in the lower estuary. The numbers of eggs sampled here were low, probably because of minimal spawning in these regions. Given that egg duration is two days at 16.7-17.2°C (Mansueti 1958), river currents could not carry viable eggs to the Tappan Zee and Yonkers regions from the middle regions of the estuary before hatching would occur.

4.3.2.2 <u>Yolk-Sac Larvae</u>. First collected in late April 1987, YSL were collected through the end of June (Figure 4-19), peaking in mid- and late May (Figure 4-17), roughly one to two weeks after peak egg abundance (one week later than in 1986). Although the 1987 egg collections indicated a second spawning peak in June, no corresponding peak was observed in YSL densities. Peak YSL densities shifted slightly downriver from regions having peak egg abundance (Figure 4-18). This apparent difference between spatial distribution of eggs and larvae has been suggested in previous years (TI 1981). YSL catches from the Cornwall through Hyde Park regions were in general approximately five times higher in 1987 than in 1986.

YSL were collected in greatest numbers in the same areas or approximately 3 miles downriver from where large egg numbers were collected during 1986 and 1987 ichthyoplankton sampling efforts (Figure 4-20). YSL are dispersed

FIGURE 4-17

TEMPORAL INDEX FOR STRIPED BASS EGGS, YOLK-SAC LARVAE, POST YOLK-SAC LARVAE, AND YOUNG-OF-YEAR COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1987

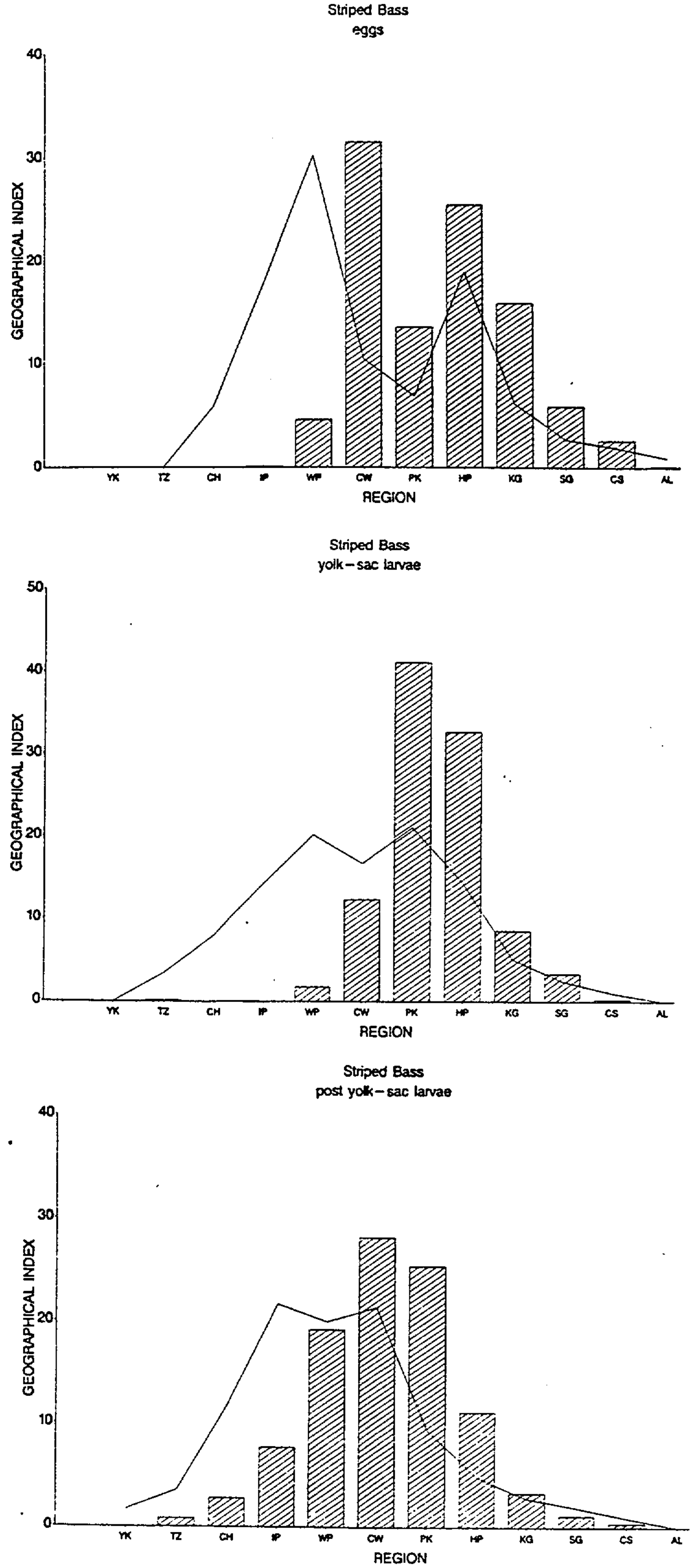


LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

FIGURE 4-18

GEOGRAPHICAL DISTRIBUTION OF STRIPED BASS EGGS, YOLK-SAC LARVAE, AND POST YOLK-SAC LARVAE COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1987



LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

1987 LONG RIVER SURVEY

DENSITY OF YSL FOR STRIPED BASS

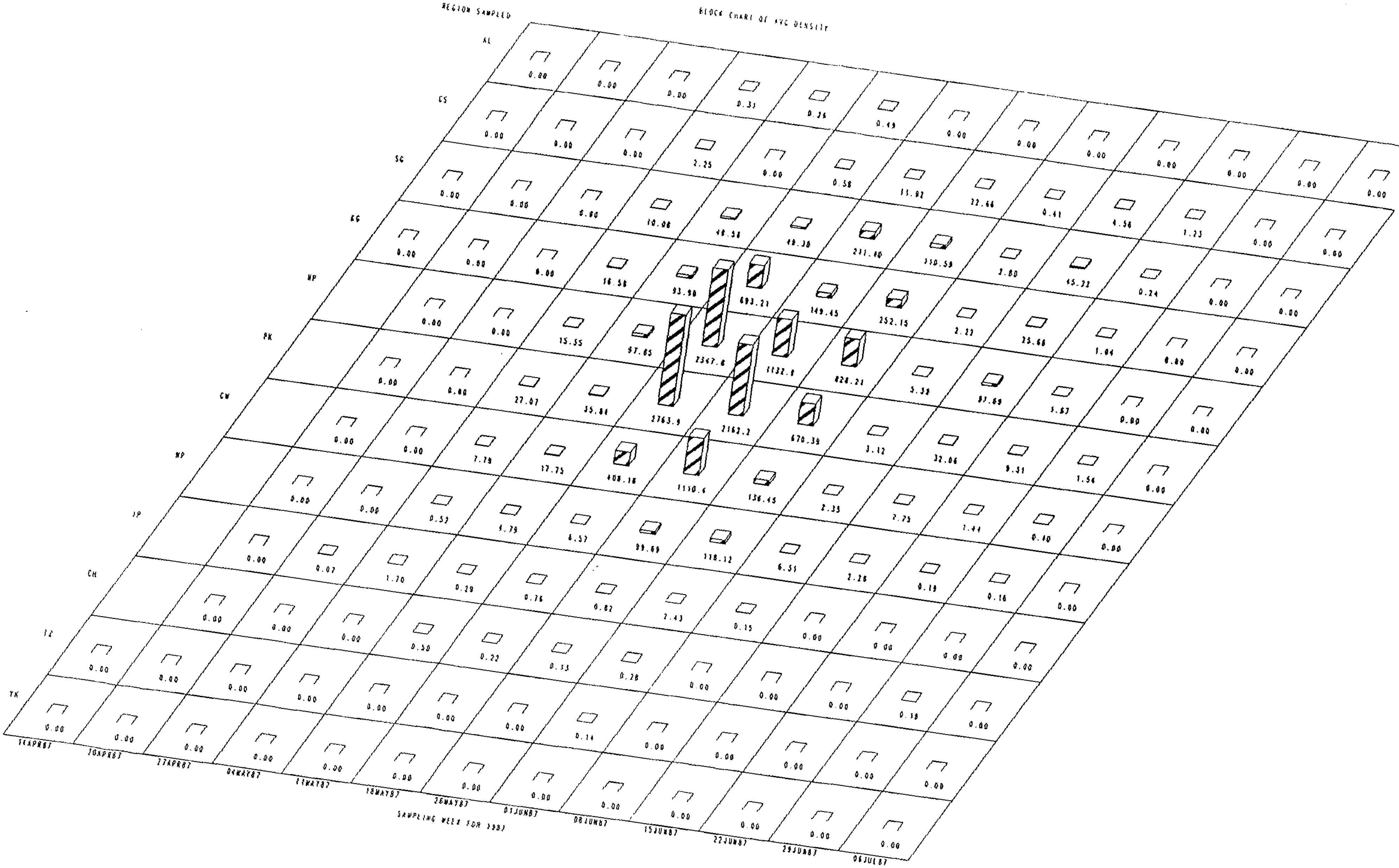
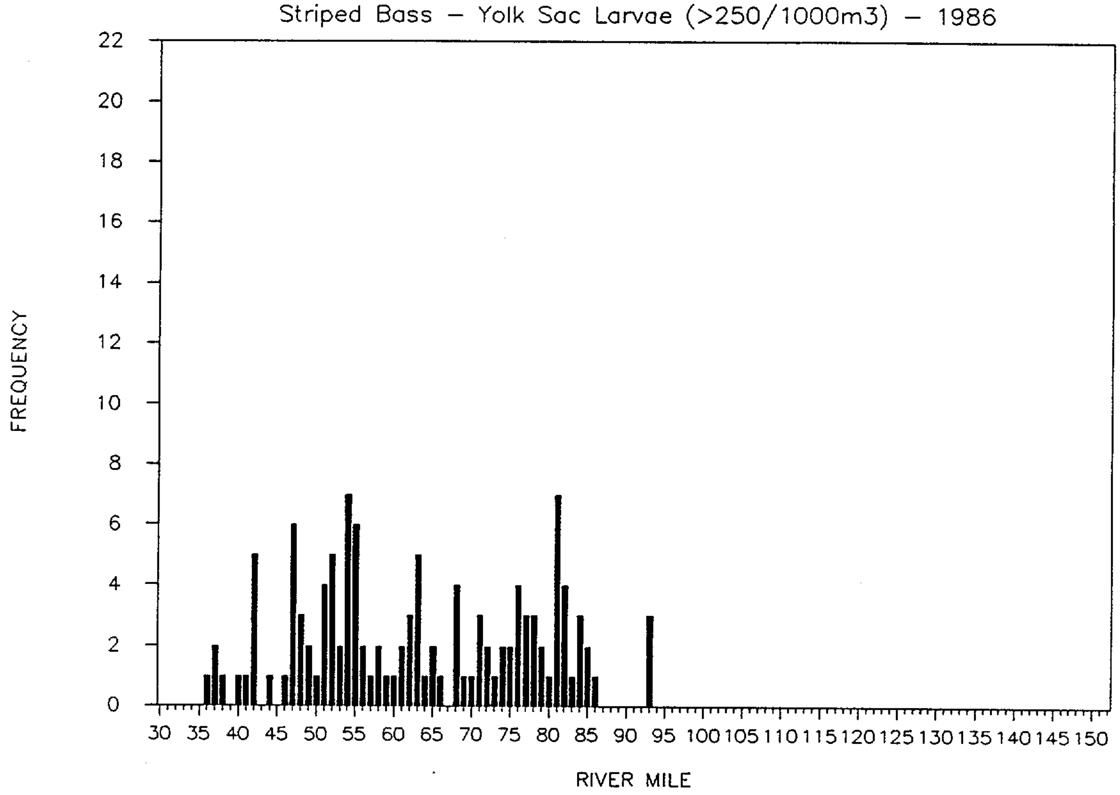
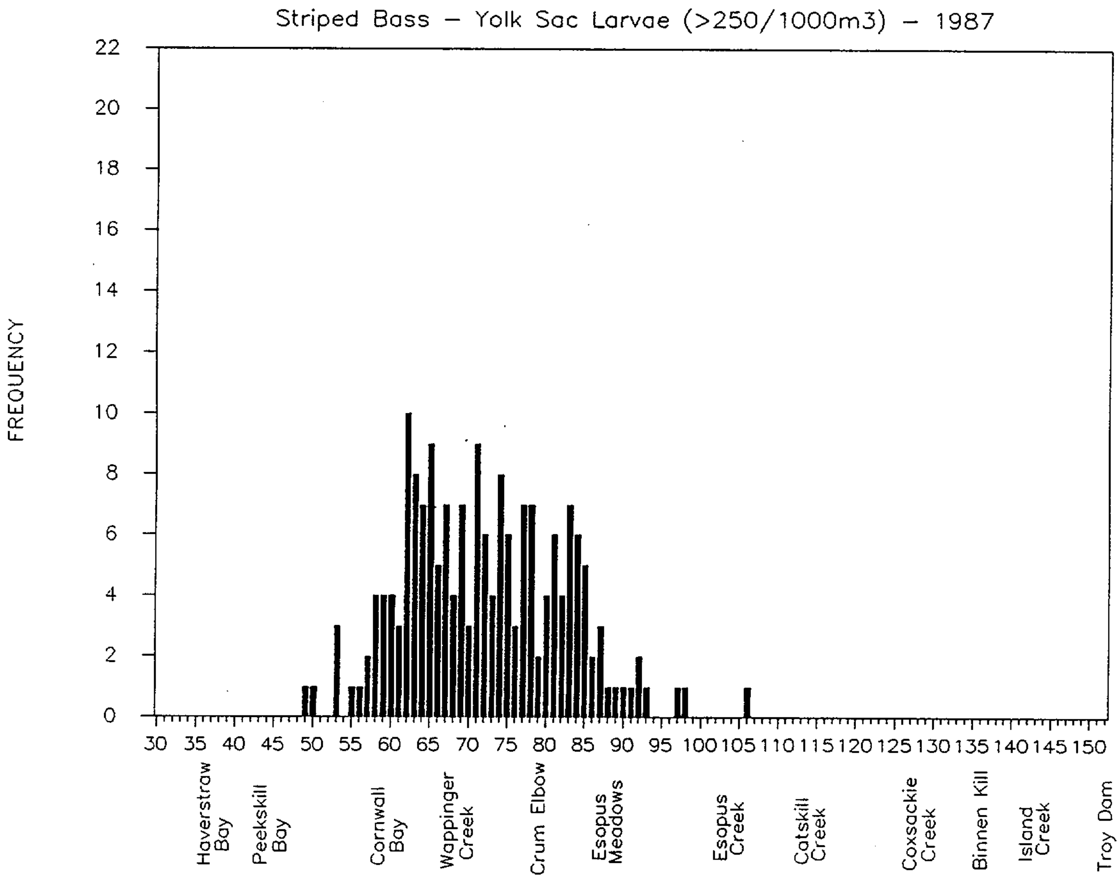


FIGURE 4–19

FIGURE 4-20

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





throughout the water column at night, but are concentrated at the bottom during daylight, according to McFadden et al. (1978), who reported no consistent lateral or longitudinal distribution owing to differential tidal stage, bottom configuration, or shoreline irregularities. Most 1986 and 1987 YSL collections were made with the Tucker trawl during sampling efforts in the upper half of the water column.

4.3.2.3 Post Yolk-Sac Larvae. The greatest PYSL abundance during 1987 took place from late May through mid-June in the LRS, with peak density estimated for the first week of June (Figure 4-21). This peak occurred roughly two weeks after the YSL peak (Figure 4-17), corresponding to yolk-sac absorption time. PYSL were collected in trace numbers as early as the 11 May sampling week and were present through the end of the sampling program.

PYSL were collected throughout the estuary in 1987, with greatest occurrence in the middle estuarine regions; peak weekly density was estimated in the Poughkeepsie region. The geographical distribution was upriver from the long-term mean location (Figure 4-18). Collection abundances were approximately twice as high in 1987 than in 1986. PYSL were collected in abundance from the Poughkeepsie region south to Peekskill Bay, with the greatest individual sample density recorded in the West Point area (Figure 4-22).

4.3.2.4 Young-of-Year. In 1987, YOY striped bass were first collected in the LRS sampling week of 22 June (Figure 4-23). The greatest densities were collected during the last sampling week, 6 July, of the LRS (Figure 4-17). FSS and BSS temporal distribution patterns indicate that the greatest abundance of YOY occurred in late August and early September, with most YOY collected from the shore zone. YOY striped bass were collected biweekly in the FSS (Figure 4-24) and BSS (Figure 4-25) in most regions of the estuary during every collection period.

Striped bass generally move shoreward and downstream of the spawning area to shallow-water nursery areas in the lower portion of the river in summer

1987 LONG RIVER SURVEY

DENSITY OF PYSL FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

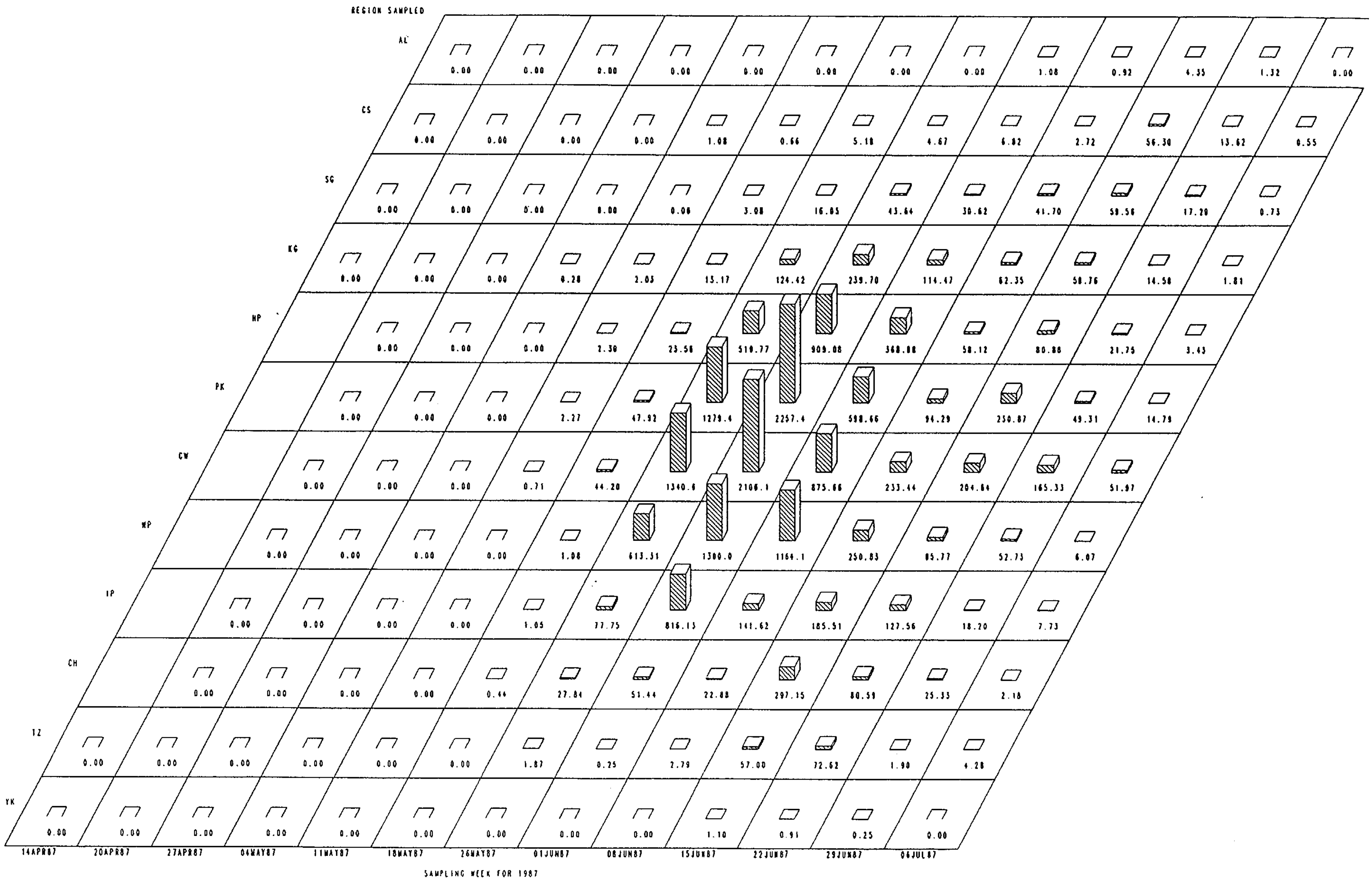
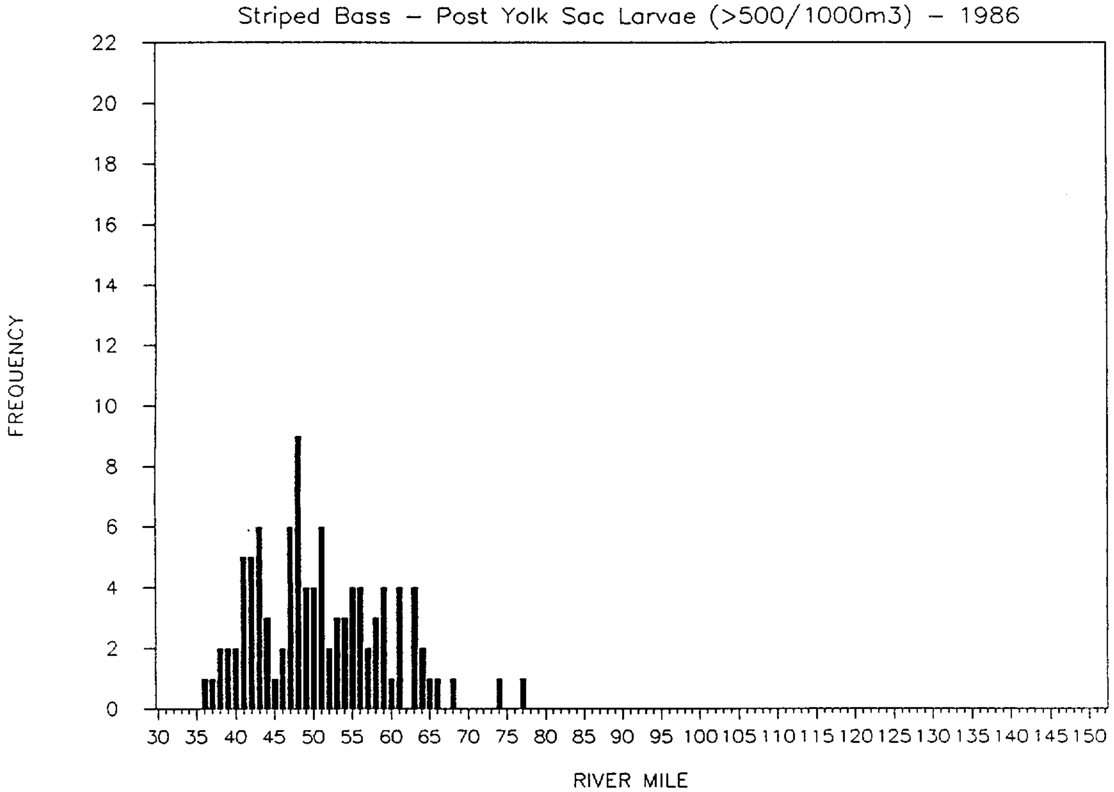
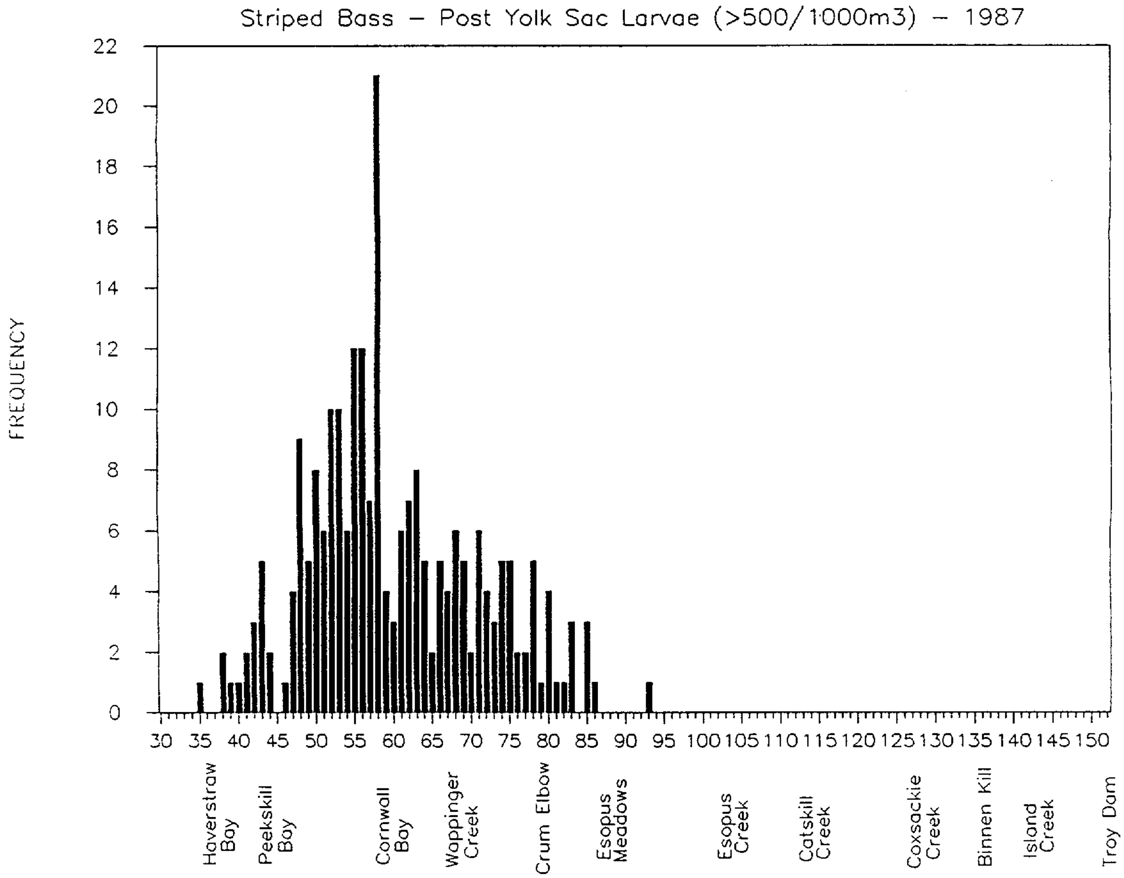


FIGURE 4-21

FIGURE 4-22

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





1987 LONG RIVER SURVEY

DENSITY OF YOY FOR STRIPED BASS

BLOCK CHART OF AVG DENSITY

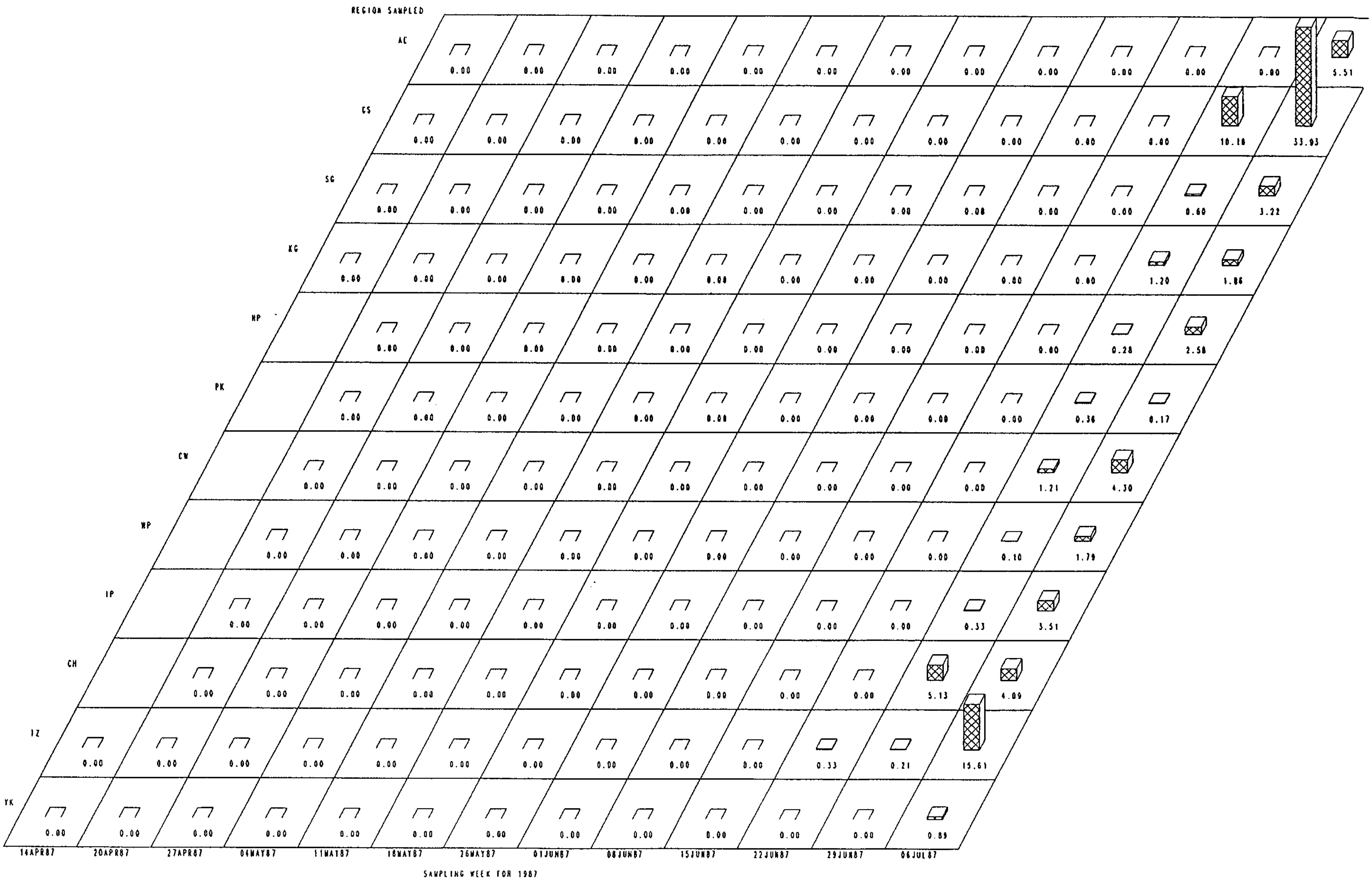


FIGURE 4-23

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR STRIPED BASS

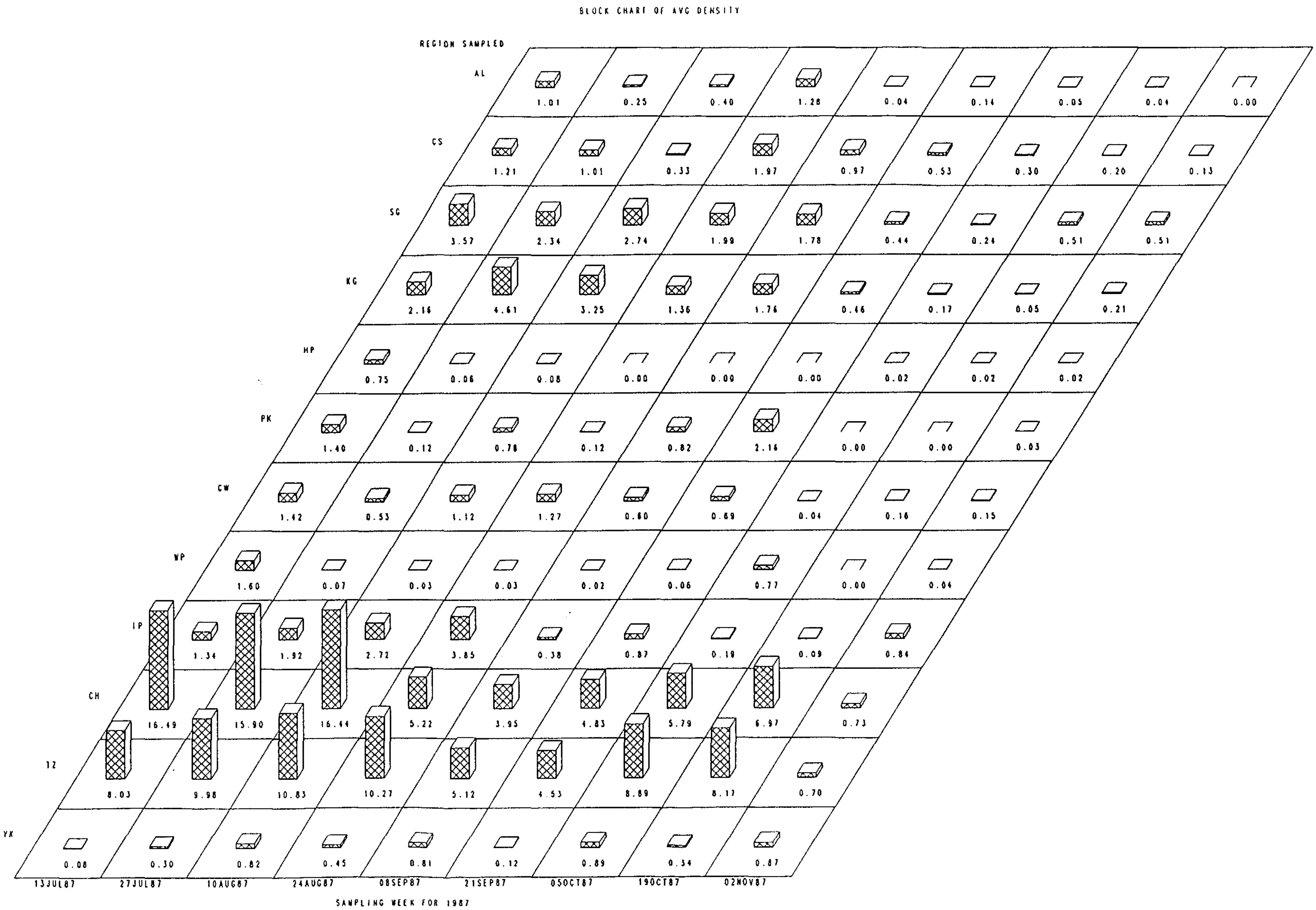


FIGURE 4-24

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR STRIPED BASS

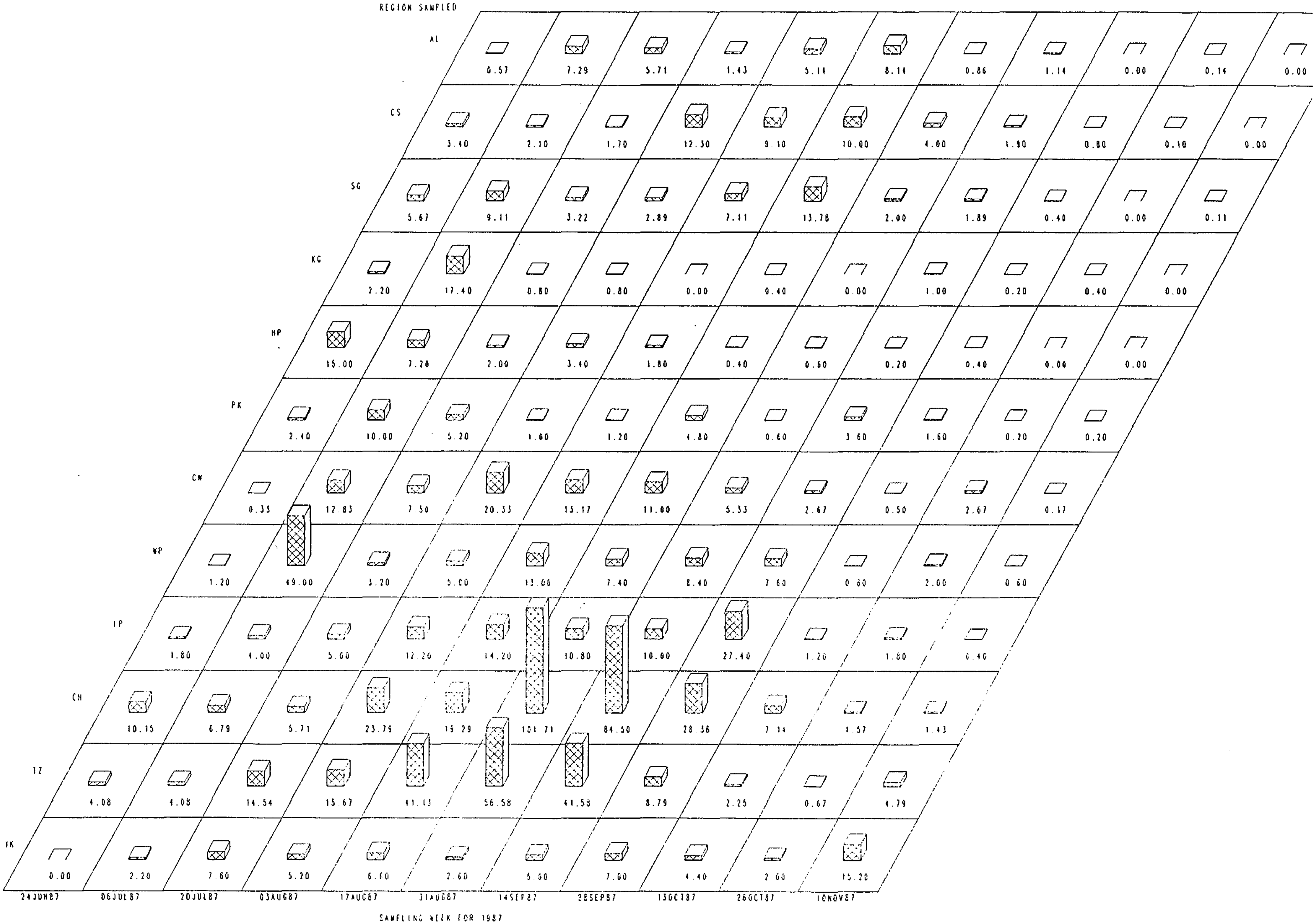


FIGURE 4-25

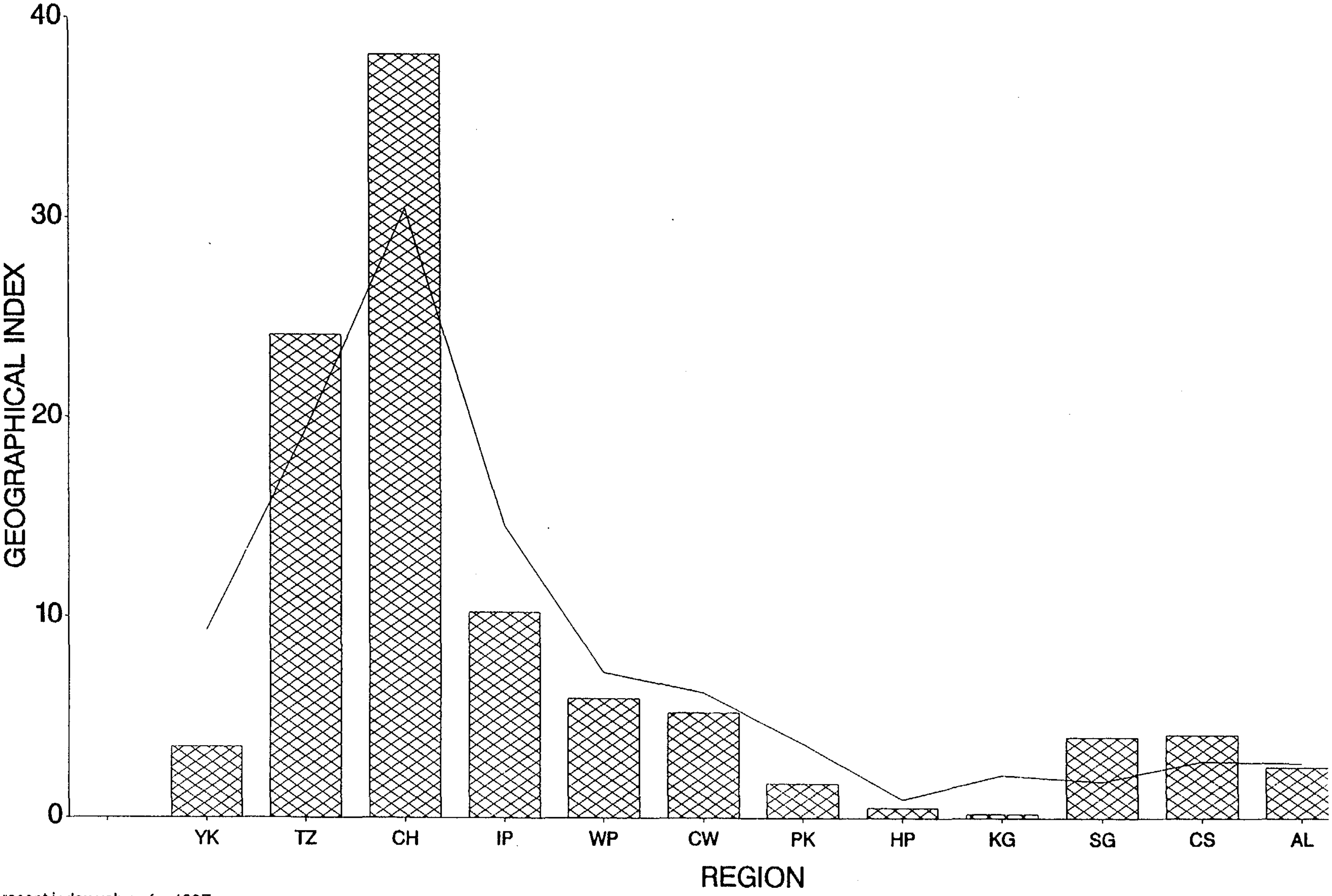
(McFadden et al. 1978). Previous Year Class Reports have reported movement of juvenile striped bass from the offshore strata into the shore zone (NAI 1985b) or to downriver shoal areas (TI 1981). The BSS spatial distribution pattern indicates that the greatest densities occurred in the lower estuarine regions of the Croton-Haverstraw and Tappan Zee regions (Figure 4-26). Decreasing shoal densities in the lower estuary during late August coincided with increasing densities in the same regions in the shore-zone sampling. These results suggest that YOY striped bass move from deeper shoal areas to the shore-zone locations. This movement was followed by an offshore shift in 1986 and 1987 when regional water temperatures dropped to approximately 21°C. Nearly all juveniles sampled during the FSS were caught in the shoal strata with the beam trawl, suggesting that YOY striped bass stay close to the shallow areas. Similar differences between shoal and shore zones can be observed if sampling bias is present, i.e., if smaller juvenile fish early in the growing season are not retained by the mesh used in the beach seine (1.9-cm wing mesh stretch; 0.9-cm bag mesh stretch) (Section 8.1). Increasing swim speed late in the season may increase juvenile avoidance of the FSS sampling gears, reducing catch efficiency and leading to an underestimation of sample abundance.

Based on tagging studies, McFadden et al. (1978) reported that declining juvenile abundance in riverwide collections in late October and early November reflected the movement of these fish to lower river locations, adjacent bays, or Long Island Sound. Marked declines in juvenile catches from the estuary in late summer 1987 are consistent with these findings. This spatial distribution shift coincides with declining estuary temperatures.

4.3.2.5 Yearling and Older Fish. Striped bass yearling (members of the 1986 year class) and older fish were collected throughout the 1987 LRS (Figure 4-27), FSS (Figure 4-28), and BSS (Figure 4-29). In general, the temporal distribution did not change throughout the sampling period. The greatest densities were observed in the middle and lower regions of the estuary, primarily in the Croton-Haverstraw and Tappan Zee regions. All upriver stations recorded sporadic catches of low density. Migration out of the Hudson River

FIGURE 4-26

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR STRIPED BASS COLLECTED IN THE BEACH SEINE SURVEY, 1987



LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

1987 LONG RIVER SURVEY

DENSITY OF TROL FOR STRIPED BASS

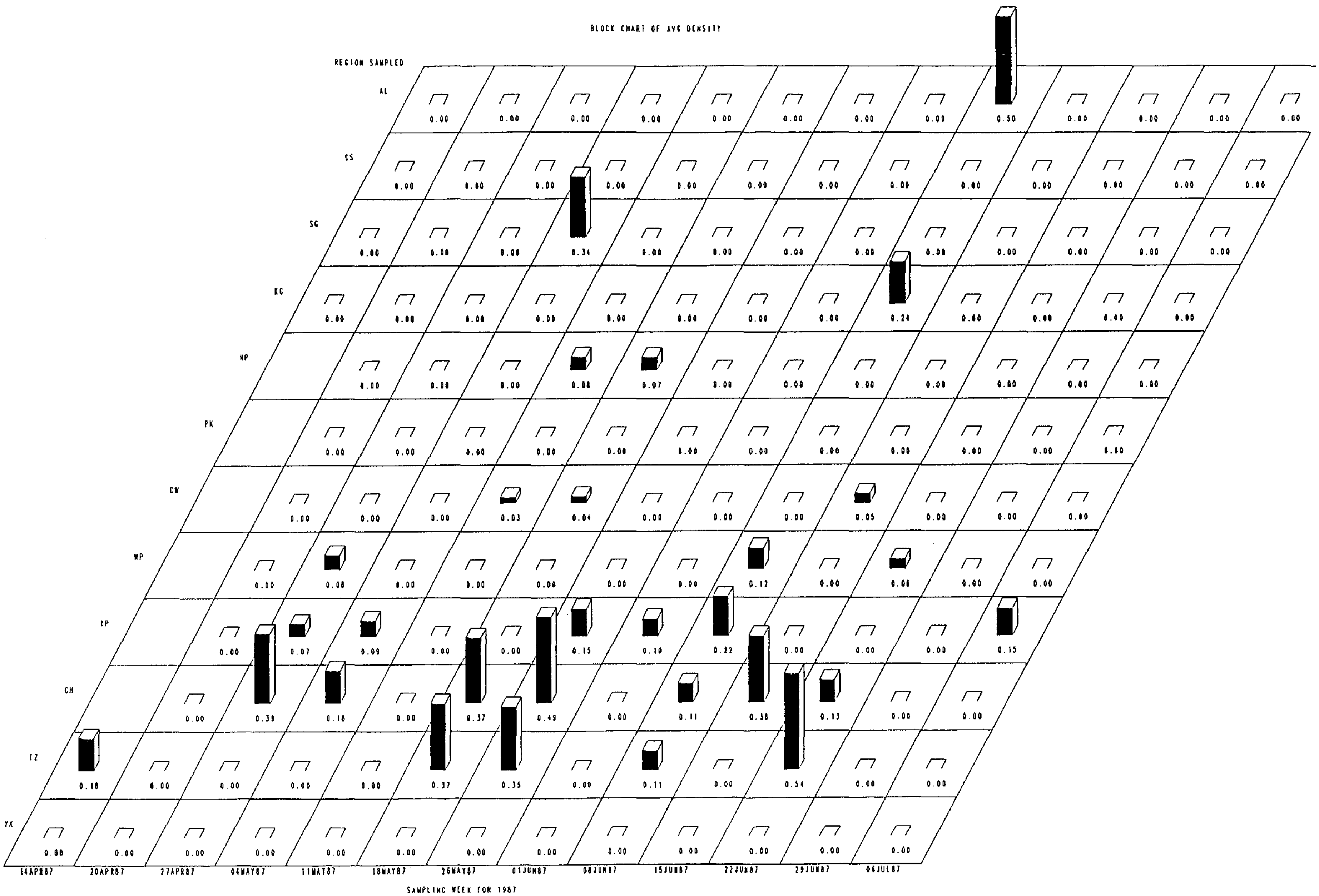


FIGURE 4-27

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR STRIPED BASS

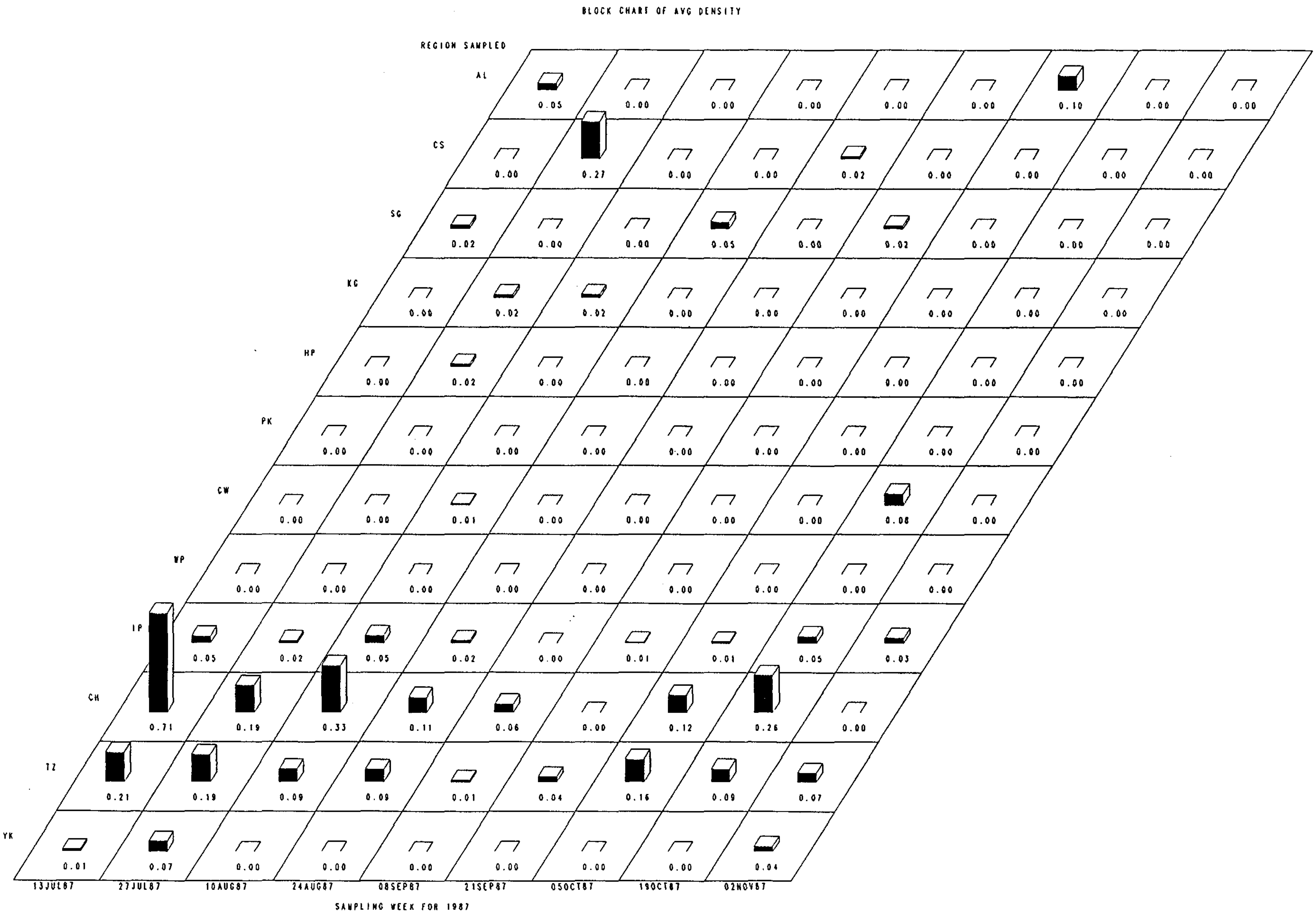


FIGURE 4-28

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR STRIPED BASS

BLOCK CHART OF CATCH/UNIT EFFORT

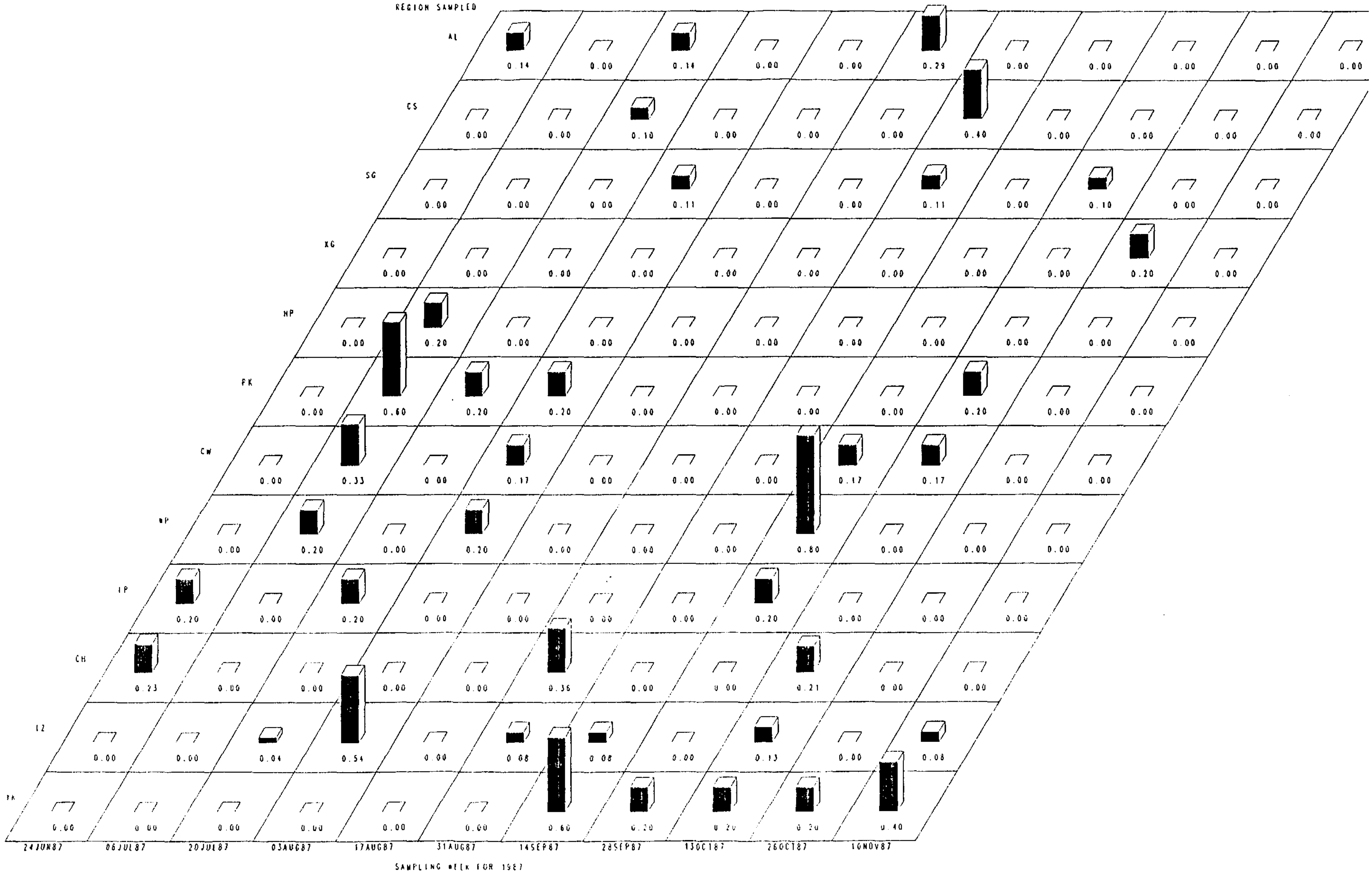


FIGURE 4-29

is suggested by the near absence of yearling and older striped bass from regions north of the Tappan Zee region in the BSS and FSS in late fall and increasing appearance in the Yonkers region.

4.4 WHITE PERCH

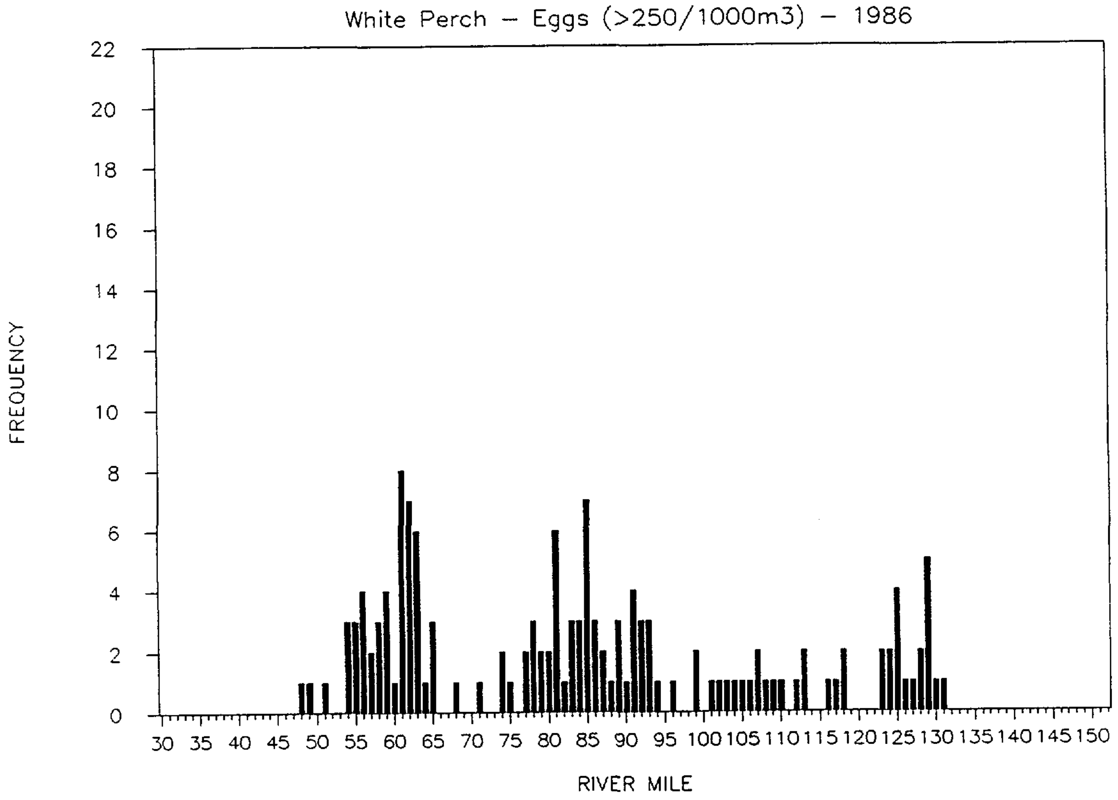
White perch, Morone americana (Gmelin), are endemic to the coastal rivers and estuaries of North America, occurring from Nova Scotia to South Carolina (Scott and Crossman 1973). They have invaded the lower Great Lakes and have been introduced into many inland reservoirs (Woolcott 1962; Scott and Christie 1963). Except for landlocked freshwater populations, this euryhaline species is considered semi-anadromous since it exhibits seasonal spawning migrations, but it is limited to estuary regions in its overall distribution. White perch are found in the Hudson River from the Battery at Manhattan to the Troy Dam at Albany (RM 0-152) (TI 1981). They are most common in brackish waters, but may be found in areas with salinity concentrations ranging from 0 to 30 ppt (NAI 1985b).

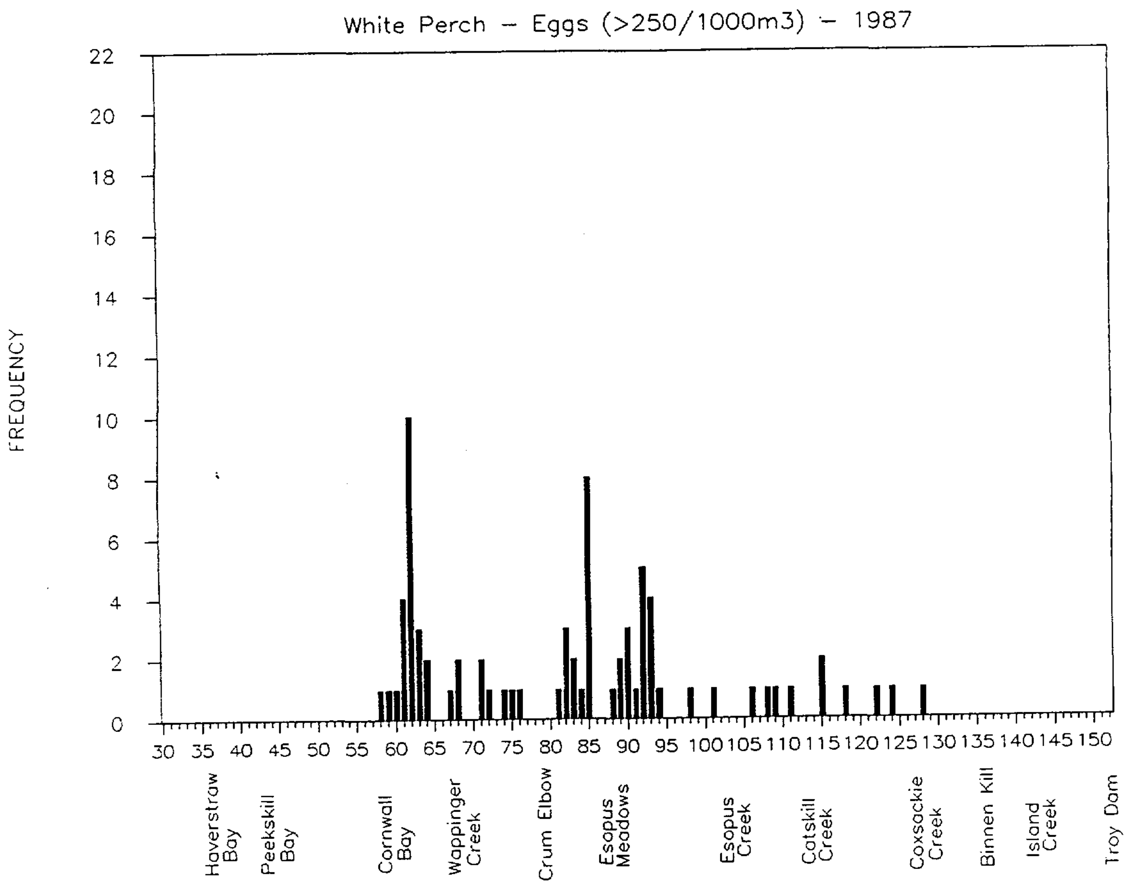
White perch are prolific spawners that deposit demersal adhesive eggs over shoals and in estuary tributaries (Bath and O'Connor 1982). Holsapple and Foster (1975) reported that the relationship of Hudson River white perch length to egg production was curvilinear; the number of ova produced ranged from 33,000 to 185,000 for 3- to 8-year-old females. Spawning usually occurs upriver in areas of fresh water, but may occur in saline areas up to 5 ppt (Hardy 1978). During the fall the adults move downriver to overwintering grounds (LMS 1987). Offshore movement to deepwater overwintering areas from Yonkers to Indian Point (RM 12-46) is reported by Texas Instruments (1981).

During 1986 and 1987 egg densities over 1000/1000 m^3 were usually associated with areas of aquatic vegetation (Figures 4-1a - 4-1g). Egg densities greater than 250/1000 m^3 were found in vegetated shallows as far downriver as ConHook (RM 49) and Constitution Marsh (RM 54) during 1986 (Figure 4-30). Consistently large egg catches were made between Cold Spring and Danskammer Point (RM

FIGURE 4-30

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





55-66), an area with extensive vegetative floating mats, primarily of water chestnut (Figure 4-1b). Similarly large catches (over 1000/1000 m^3) were made throughout the Hyde Park and Kingston regions (RM 77-93) in 1986; large catches were scattered in the regions in 1987.

Another river area of large spawning activity is between Esopus Creek (RM 103) and Catskill Creek (RM 113), two large tributaries of the Hudson River (Figure 4-1e). This area of the river has extensive vegetated shallows, with water depths less than 3 ft at mean low tide. Five ichthyoplankton collections in this area produced large egg densities, including three over 10,000/1000 m^3, during a period of sudden high freshwater flow. These high collection densities may in part reflect dislodgement from adjacent tributaries. Large egg numbers were also observed between RM 123 and 130, an area of large vegetated shallows with numerous bays and tributaries. All white perch spawning areas were located upriver from the salt front.

Larval and juvenile white perch feed on cladocerans, copepods, and amphipods (Marcy 1976; Elrod et al. 1981). Adults are predatory, relying on invertebrates such as Gammarus, annelids, bryozoans, and various crustaceans (de Sylva et al. 1962; Moore et al. 1975) and increasing amounts of fish and fish eggs (Elrod et al. 1981). No major fishery exists for white perch in the Hudson River even though it is the most abundant predatory fish within the estuary. The Chesapeake and Delaware bays, however, support an important commercial fishery of white perch (IA 1984).

4.4.1 1986 Study

4.4.1.1 Eggs. White perch eggs were caught during every week of the 1986 LRS program (Figure 4-31), with the greatest densities appearing in the first sampling period in the Catskill region when the weekly mean water temperature was 14.3°C. Hardy (1978) reported that white perch spawning generally begins as water temperatures reach 14.0°C; however, peak white perch spawning has oc-

1986 LONG RIVER SURVEY

DENSITY OF EGGS FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

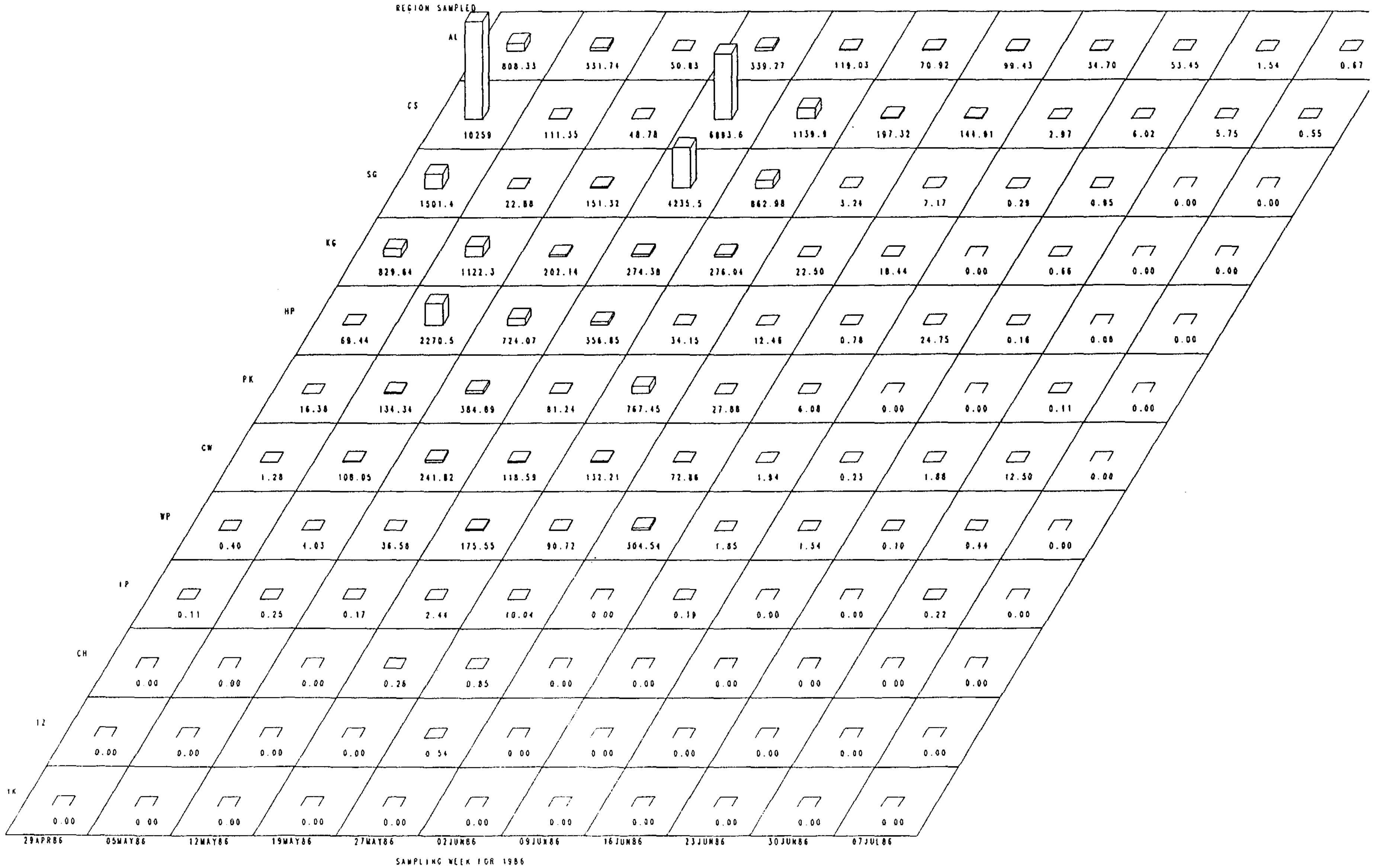


FIGURE 4-31

curred in the Hudson River estuary at a temperature of 13°C (NAI 1985a). It is possible that spawning activity began prior to the first LRS sampling date on 29 April.

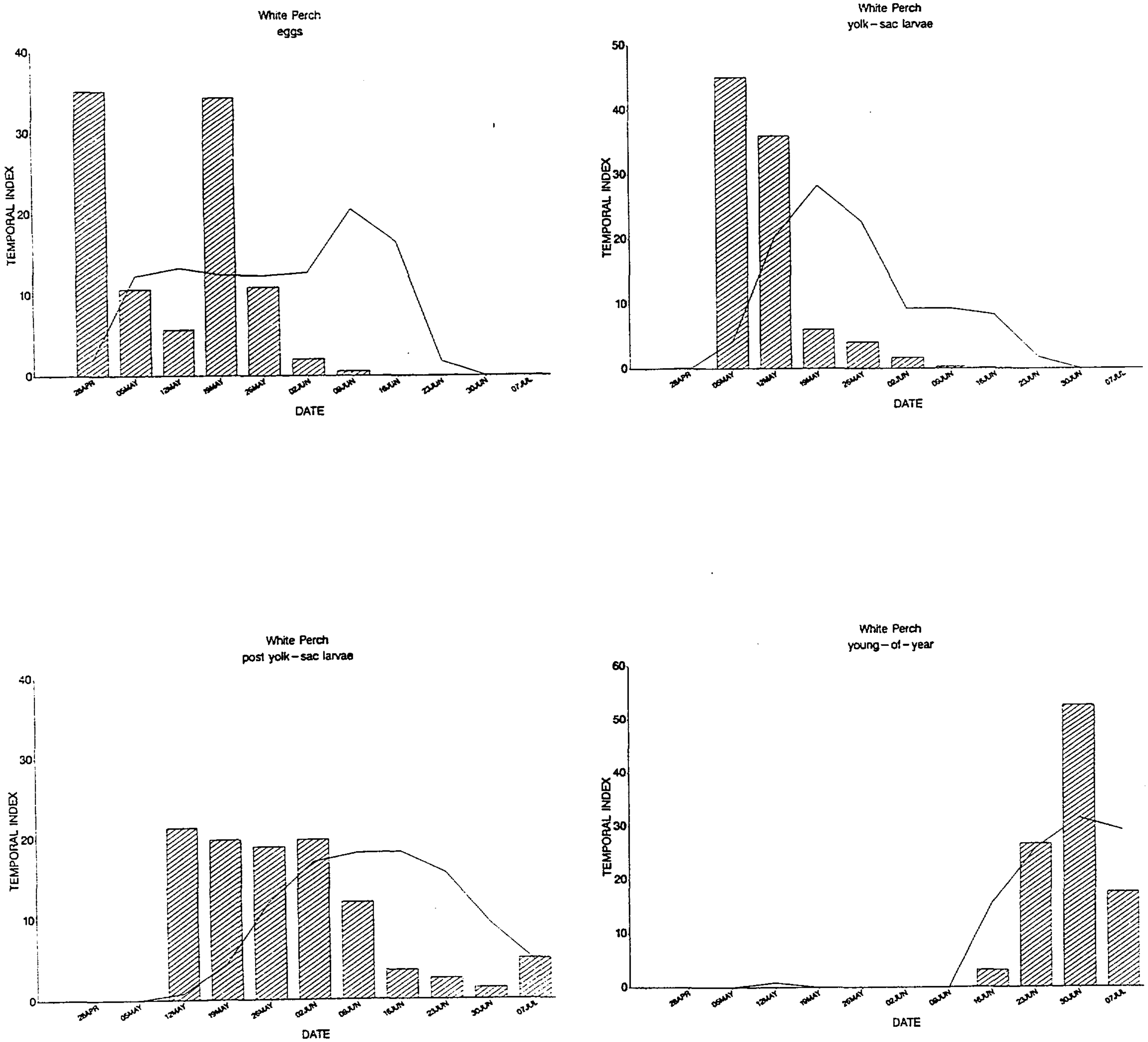
Temporally, a bimodel density pattern was observed (Figure 4-32). Examination of individual samples revealed that adults were caught in ichthyoplankton gear during April sampling efforts. Ripe females caught in the sampling gear could have released eggs into the collection nets, resulting in biased density estimates for April. However, it is possible that peak egg estimates at this time reflect actual spawning activity since the most abundant sample (29,163/1000 m^3) did not contain any adult white perch.

The second abundance peak that occurred three weeks later in the Catskill and Saugerties regions could be explained in two ways. White perch eggs are demersal and highly adhesive, with low vulnerability to LRS sampling techniques. As stated previously, above-average freshwater flows (Figure 4-7) during this period may have dislodged the eggs, which increased collection densities. White perch egg standing crop has been found to be correlated to freshwater flows (NAI 1985a); therefore, densities reported may be related in part to the magnitude of freshwater flow. Along with increased dislodgement, there may have been an increase in spawning activity. Spawning and egg development are influenced by increases in water temperature combined with low salinity (Morgan and Rasin 1982). During the week before the May egg abundance peak, mean water temperatures rose from 16.9 to 19.4°C in the Catskill region. Klauda et al. (1988) reported peak egg deposition to occur at 16 to 20°C in the Hudson River. Peak YSL abundance in early May reflects the April peak egg densities; a lower YSL peak in late May-early June may reflect the mid-May egg density peak.

White perch eggs were found in every region north of Yonkers during the 1986 LRS, with mean weekly densities in late April to early June exceeding 100/1000 m^3 throughout the estuary north of the Indian Point region (Figure 4-31). Catches in the lower estuary took place during high freshwater flow in late May when recorded salinities dropped to 1.7 ppt. These salinities are within the 2 ppt reported to be the limit of preferential spawning conditions

FIGURE 4-32

TEMPORAL INDEX FOR WHITE PERCH EGGS, YOLK-SAC LARVAE, POST YOLK-SAC LARVAE, AND YOUNG-OF-YEAR COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

(Mansueti 1961; TI 1981). Peak egg abundance was located in the Catskill region (RM 77-124) (Figure 4-33); geographical distribution patterns were consistent with long-term trends.

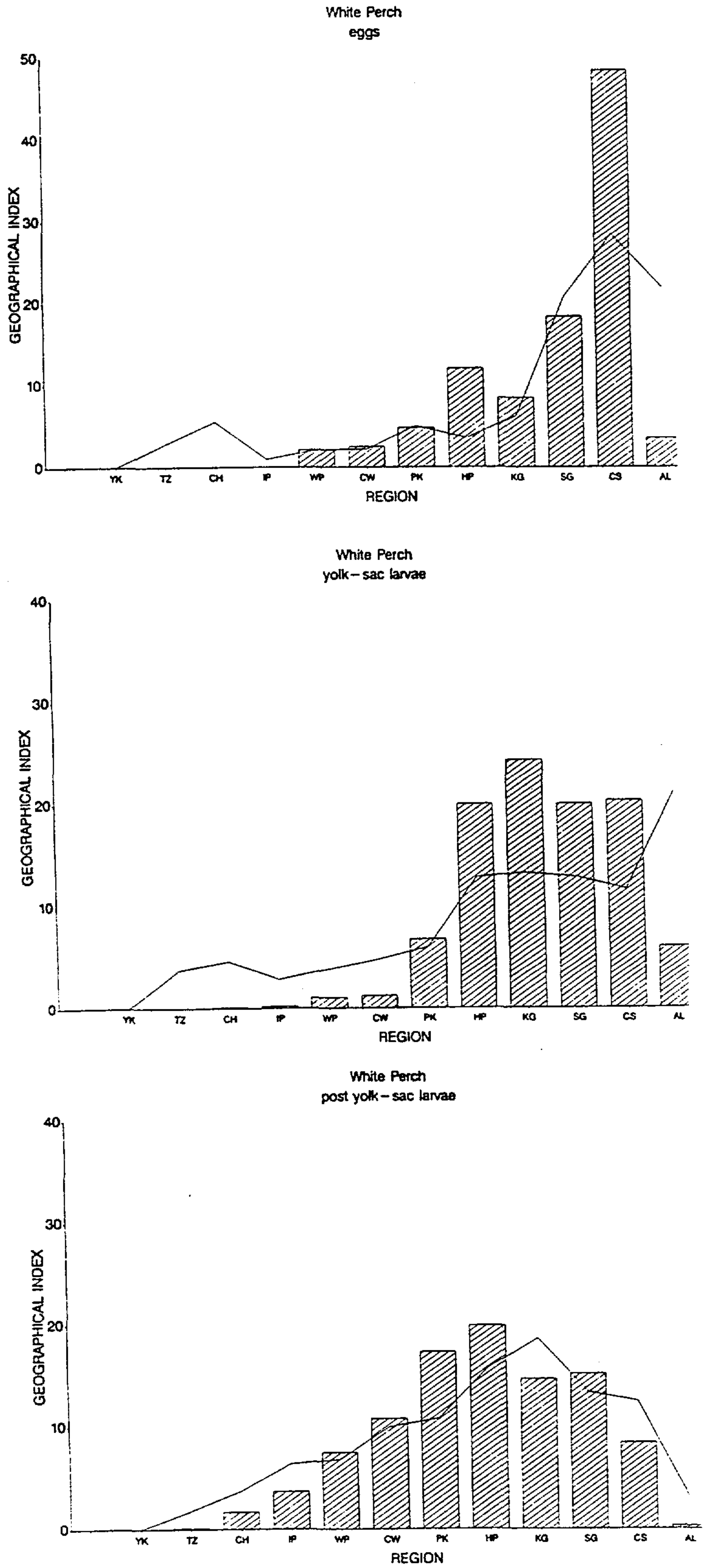
4.4.1.2 Yolk-Sac Larvae. White perch YSL were already present in most of the upper and middle estuary when the 1986 LRS program began (week of 29 April) (Figure 4-34). The greatest larval abundance was observed during the first week of May (Figure 4-32), one week after the first egg abundance peak, when the weekly mean temperature was 14.7°C. Morgan and Rasin (1982) reported temperatures of 14.1°C as being optimal for egg hatching. The temporal peak reported is two weeks earlier than the historic mean peak date (Figure 4-32). YSL continued to be collected in decreasing densities through the last sampling period in June. No YSL were collected after the 30 June sampling period. This pattern of YSL density suggests that the peak egg density in April reflects peak egg deposition.

White perch YSL were collected in every region of the estuary during the 1986 LRS program (Figure 4-34). Sample densities of larvae exceeding 750/1000 m^3 were collected between the Poughkeepsie and Catskill regions (RM 62-124), with peak weekly abundance occurring in the Saugerties region (RM 94-106). YSL were collected primarily from the Hyde Park through Catskill regions during the LRS sampling program (Figure 4-33). A small proportion of the larvae were found downriver as far as the Yonkers region, possibly as a result of being carried downstream with the late May increase in freshwater river flow.

4.4.1.3 Post Yolk-Sac Larvae. White perch PYSL were first collected in the week of 5 May during the 1986 LRS program (Figure 4-35). Peak regional PYSL density in excess of 5000/1000 m^3 was measured during the 12 May sampling week; samples in excess of 100/1000 m^3 were collected during the final sampling week. Peak PYSL abundance followed the YSL peak by one week (Figure 4-32); the time period required for yolk absorption is four to 13 days (Hardy 1978). The 1986 peak in post yolk-sac abundance was two weeks earlier than in past surveys.

FIGURE 4-33

GEOGRAPHICAL DISTRIBUTION OF WHITE PERCH EGGS, YOLK-SAC LARVAE, AND POST YOLK-SAC LARVAE COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

1986 LONG RIVER SURVEY

DENSITY OF YSL FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

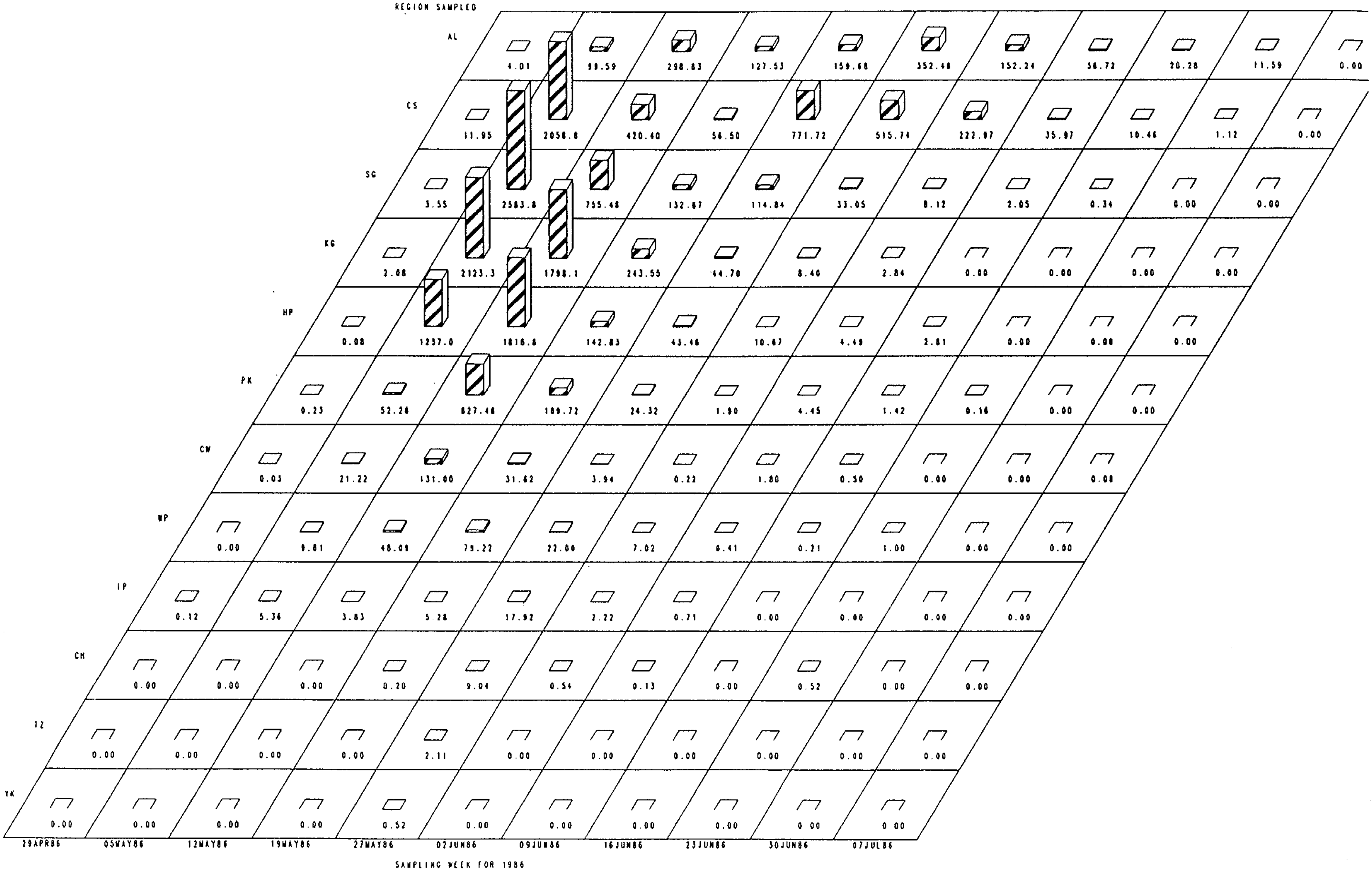


FIGURE 4-34

1986 LONG RIVER SURVEY

DENSITY OF PYSL FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

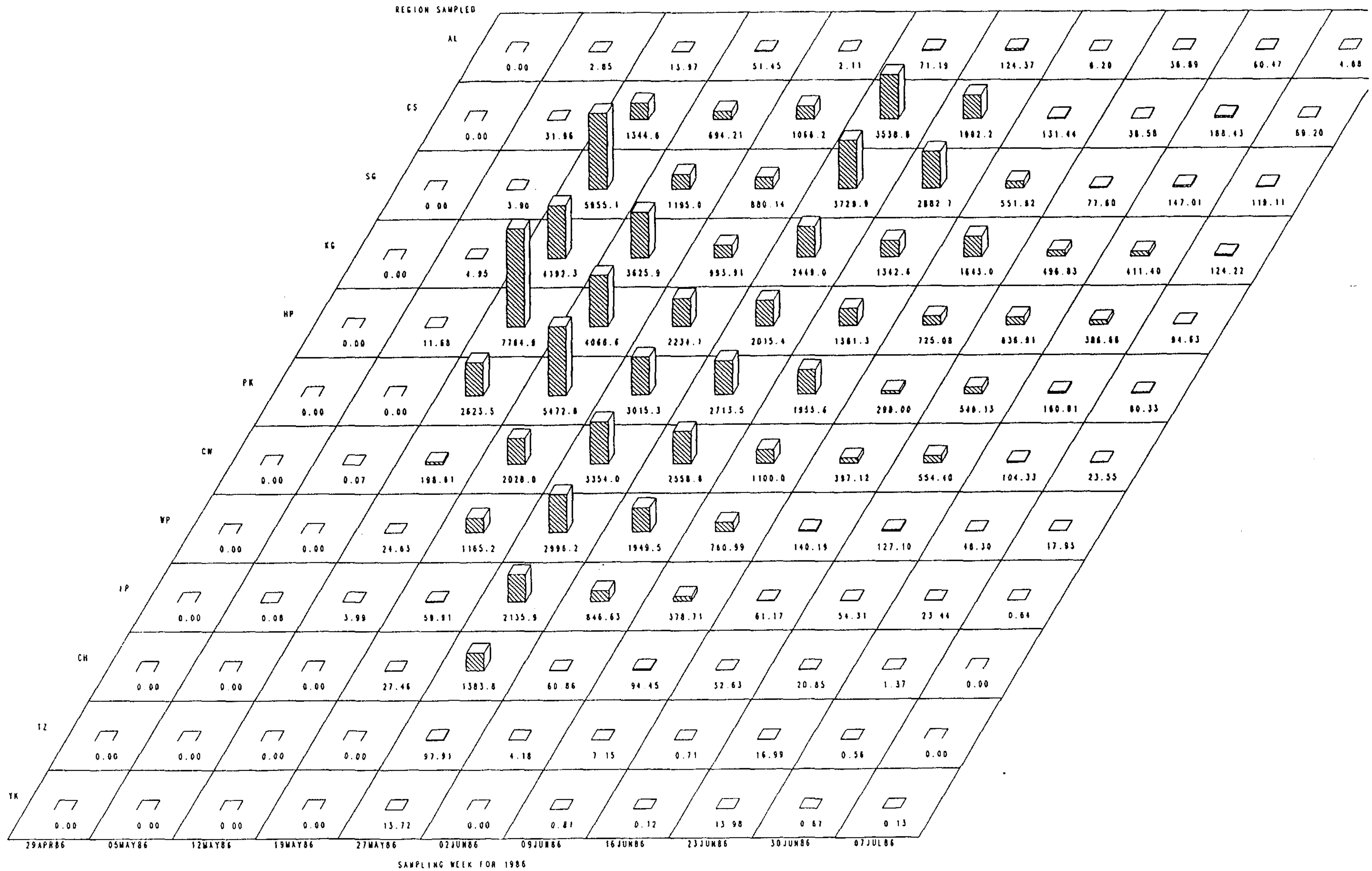


FIGURE 4-35

Post yolk-sac larvae were collected in every region of the estuary, with greatest abundance between the Poughkeepsie and Saugerties regions (RM 62-106). The distribution pattern is similar to that for the YSL except that PYSL appear to be shifted downriver by one region (Figure 4-33). This shift is likely due to the planktonic nature of the larvae, which allows transport with river flows. This is further exemplified by the downriver shift in PYSL density in late May following the increased freshwater river flow that peaked on 23 May (Figure 3-35).

4.4.1.4 <u>Young-of-Year</u>. White perch YOY were first collected during the 16 June 1986 sampling week from the West Point through Kingston regions (RM 47-93) (Figure 4-36). This first encounter followed the peak density of PYSL by approximately five weeks (Figure 4-32). The time lapse between peak PYSL abundance and the appearance of YOY corresponds to life stage developmental requirements of about five weeks (Mansueti 1961).

White perch YOY were collected in every sampling period of both the FSS (Figure 4-37) and BSS (Figure 4-38) programs in 1986; greater average densities were collected by the FSS. In late July and early August white perch YOY were most abundant in the middle and upper estuary BSS samples, the FSS samples having greatest densities in the middle estuary. As river temperatures dropped in late September and early October, YOY fish were collected in decreasing numbers from the shore zone, especially in the upper and middle estuary. In late October and throughout November greater YOY densities were caught by FSS sampling gear in the lower half of the estuary; peak densities were from the Indian Point through Cornwall regions (RM 39-61). Downriver movement is suggested because of the declining upriver fall shore-zone densities without corresponding increases in adjacent shoal densities; also, fall shoal densities in the lower half of the estuary increase during this time. This downriver movement is likely linked to the downriver shift in the salt front during this time period (Figure 3-39) (LMS 1987). Similar results were observed in the white perch stock assessment program conducted from September to December (LMS 1987, 1988). YOY densities were higher in the middle and

1986 LONG RIVER SURVEY

DENSITY OF YOY FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

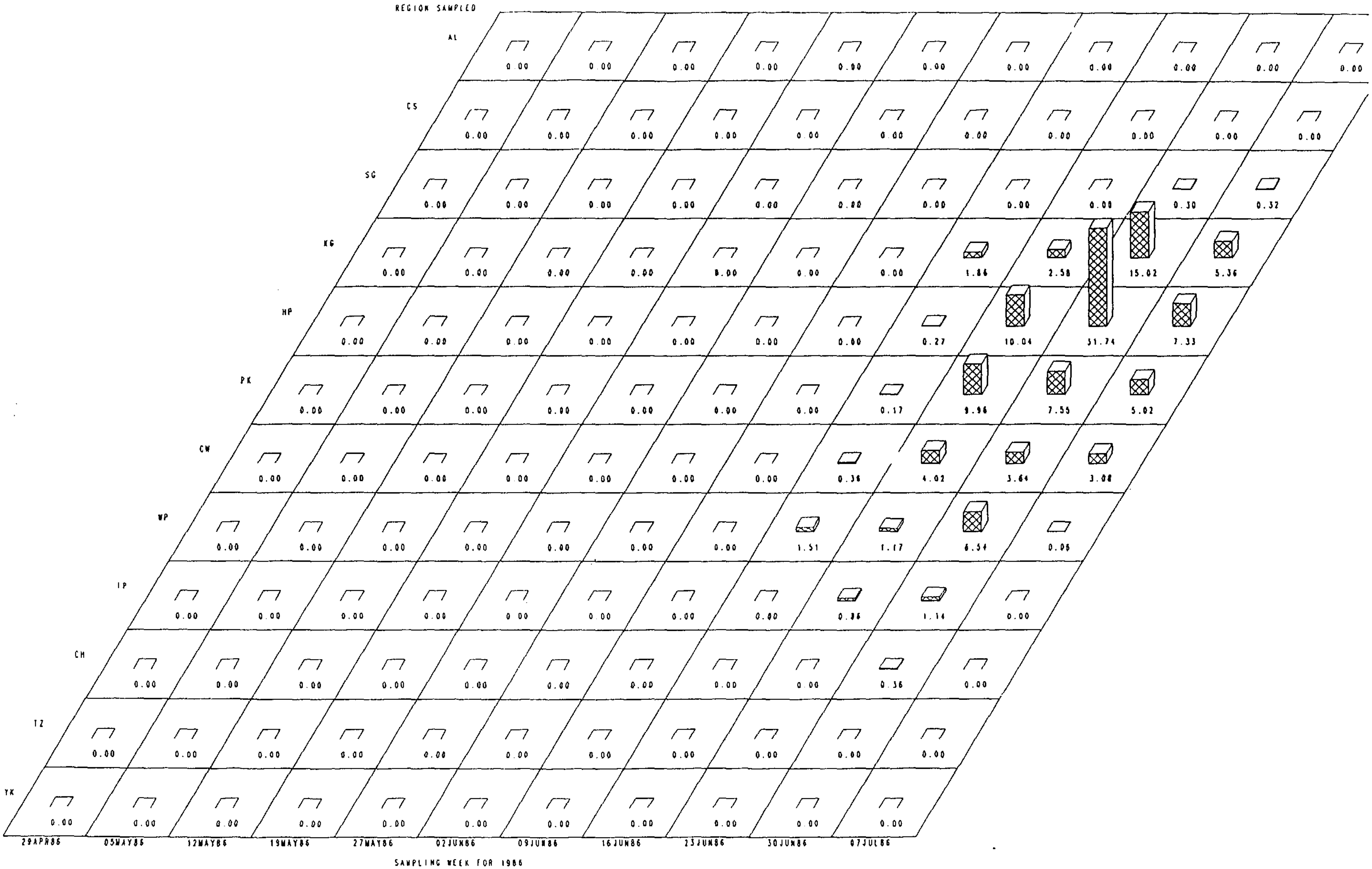


FIGURE 4-36

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

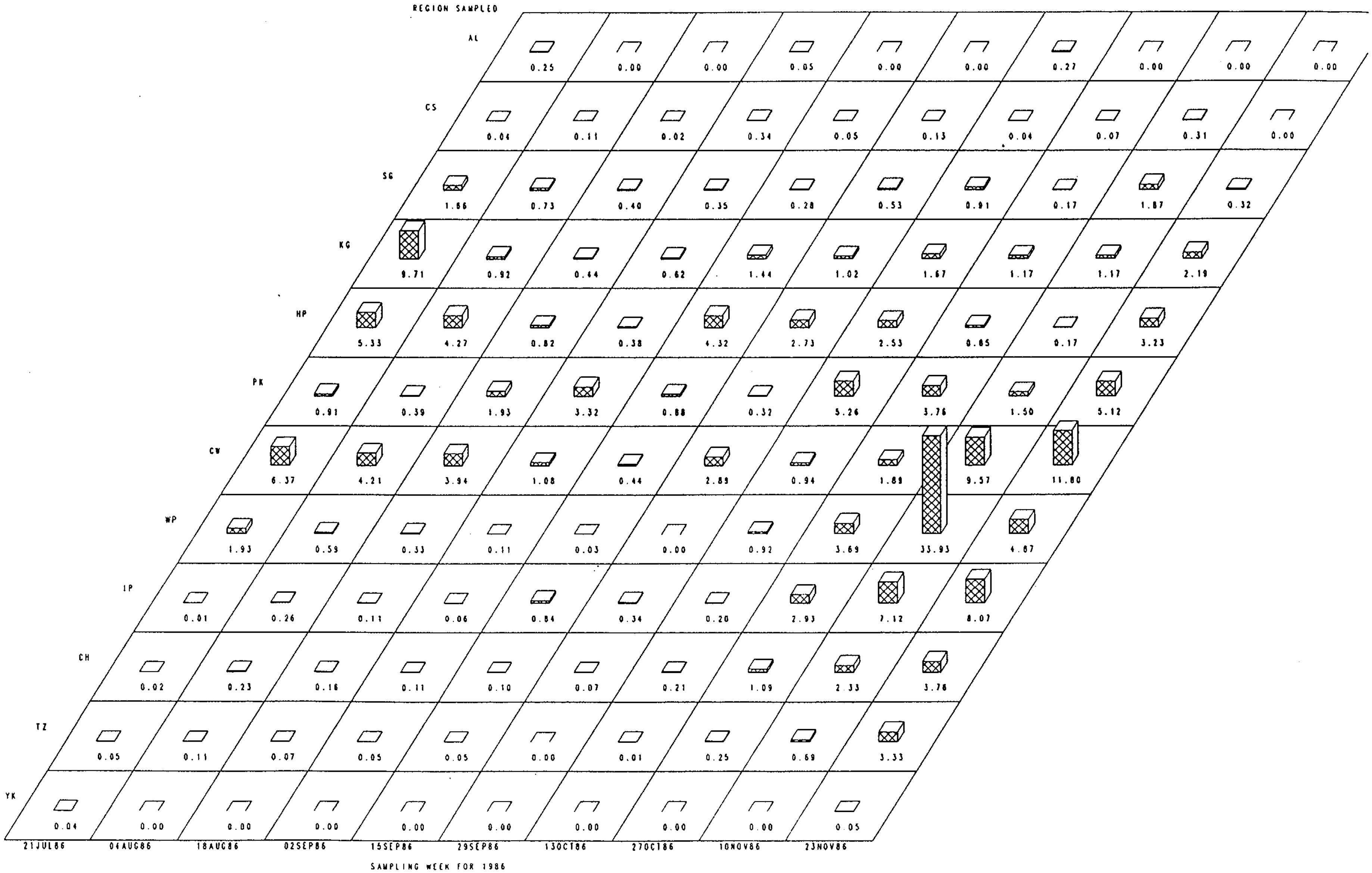


FIGURE 4-37

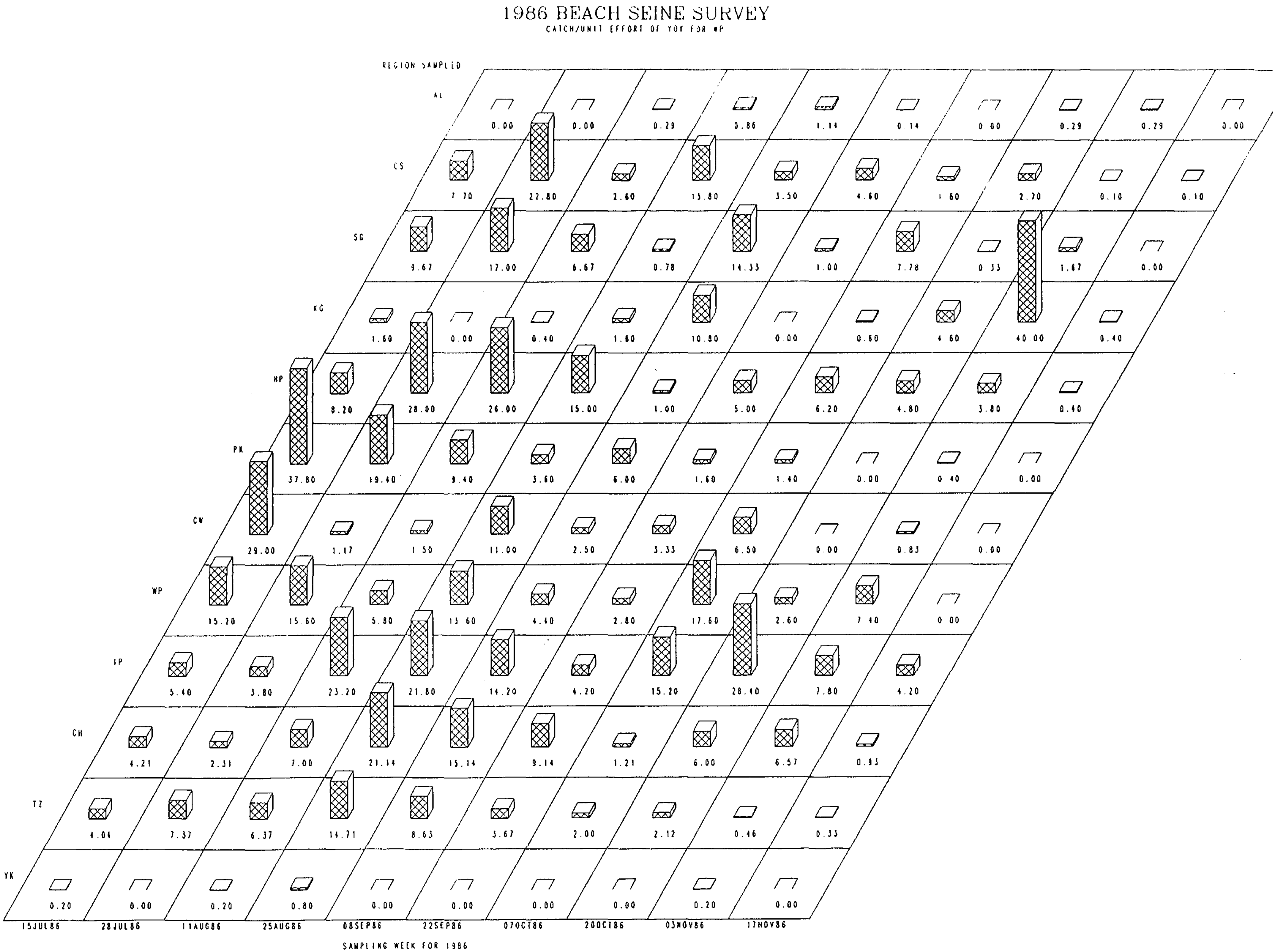
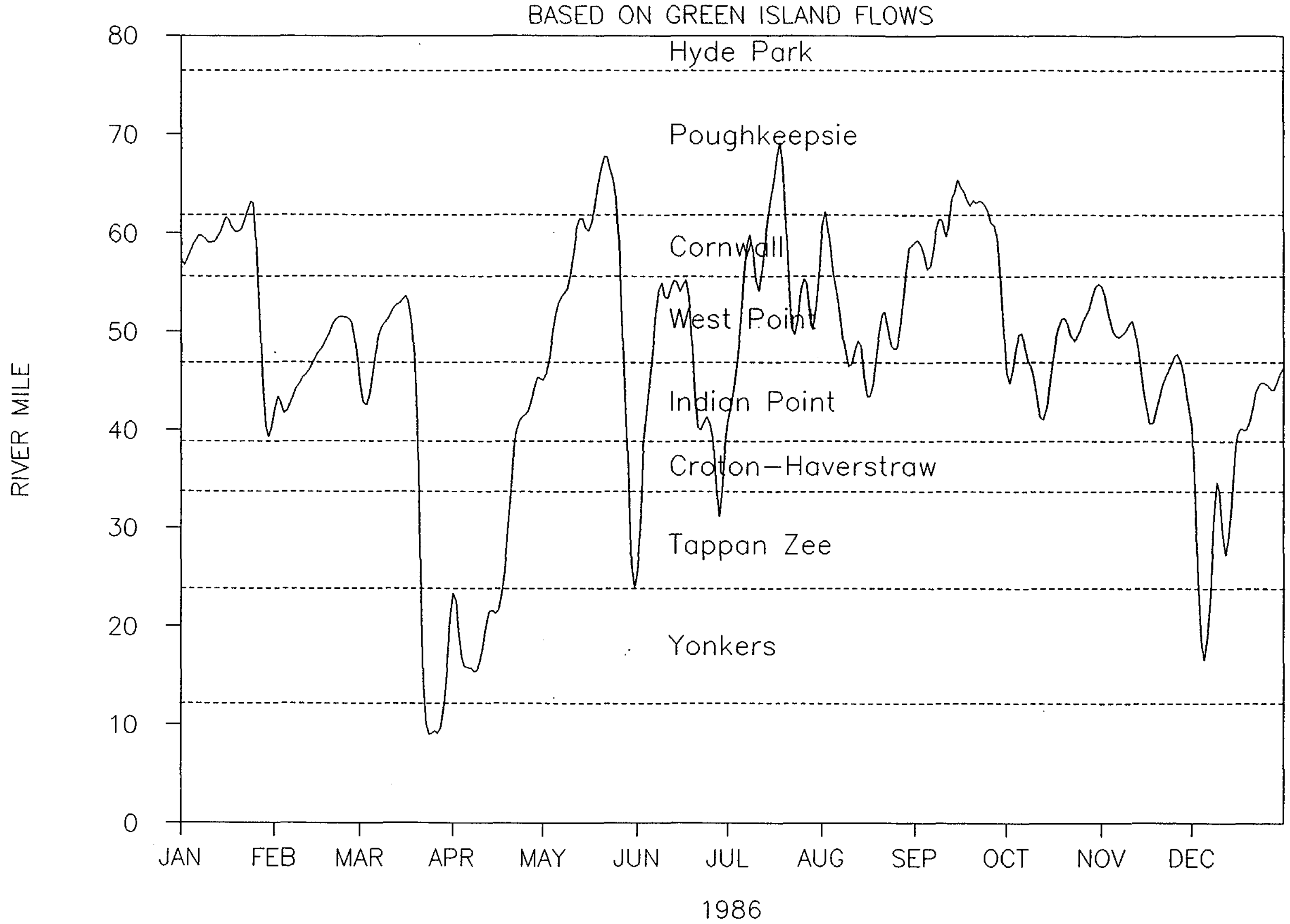

1986 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF YOY FOR WP
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
TZ
YK
15JUL86
28JUL86
11AUG86
25AUG86
08SEP86
22SEP86
07OCT86
20OCT86
03NOV86
17NOV86
SAMPLING WEEK FOR 1986

FIGURE 4-38

FIGURE 4-39

SALT FRONT LOCATION VS. TIME



upper estuary (West Point-Saugerties regions, RM 54-107) than in the lower estuary (Piermont-Bowline Point regions, RM 26-37). Catches decreased markedly from the upper and middle estuary regions starting in early to mid-November.

The historic BSS geographical distribution peaks from the Croton-Haverstraw to the West Point region (Figure 4-40); a similar pattern was observed in 1986. This is a downriver shift from the PYSL distribution (Figure 4-33), again indicating a downriver movement.

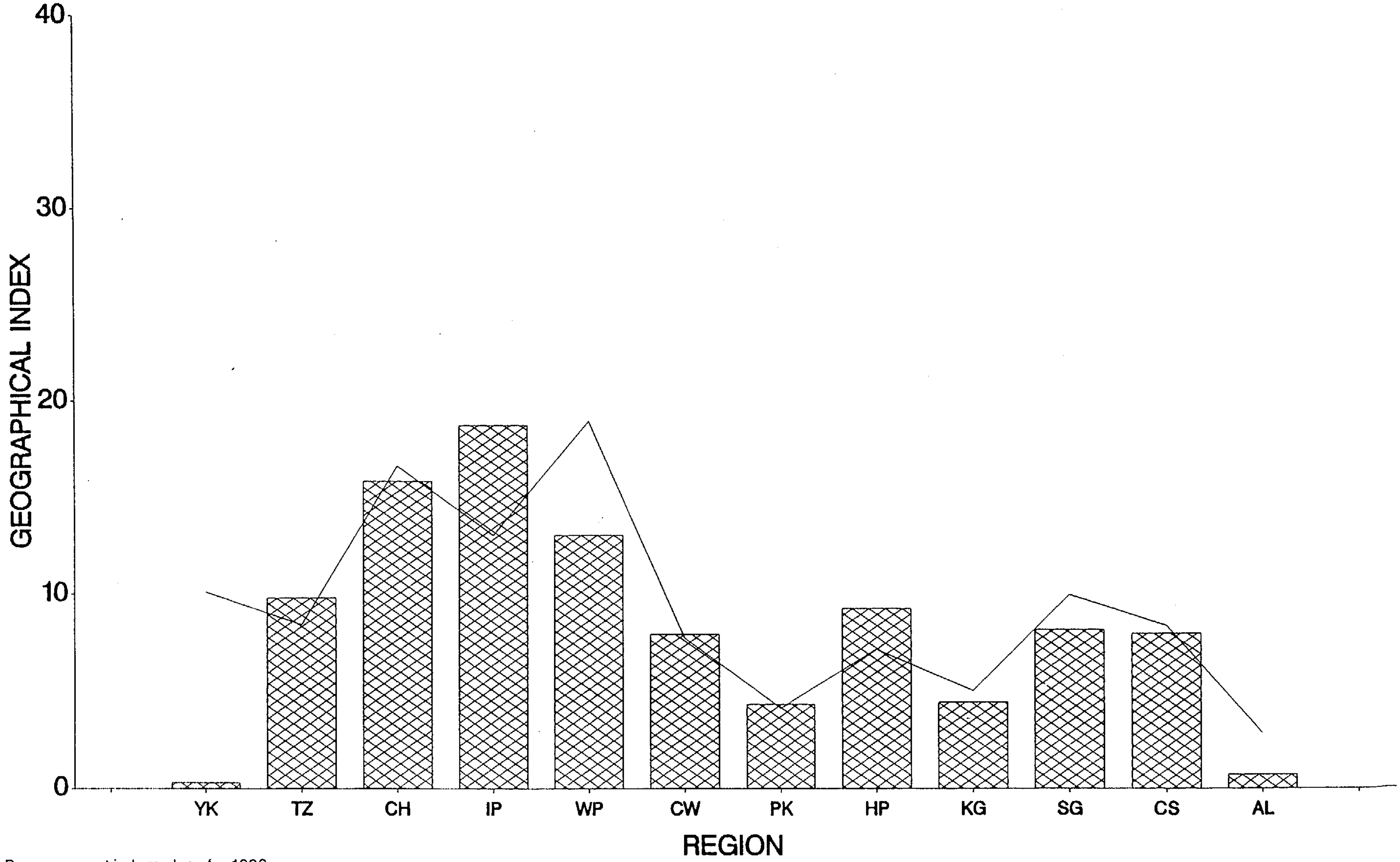
4.4.1.5 Yearling and Older Fish. Yearling and older white perch were collected during every sampling period of the 1986 LRS (Figure 4-41), FSS (Figure 4-42), and BSS (Figure 4-43) programs in almost all regions of the estuary. The 1986 LRS suggests a shift in yearling and older fish abundance from the Croton-Haverstraw through West Point areas north to the middle and upper estuary in mid-May. This movement likely corresponds to the upriver shift in the salt front (Figure 4-39) during this time (see Section 3.4.3).

No temporal distribution peak was apparent in 1986, and there was a slight increase in abundance in the FSS samples collected in October. Shore-zone catches were generally greatest in July and August; the peak beach seine catch, however, was during early November in the Indian Point region.

Both the FSS and BSS results indicate that yearling and older white perch were most abundant in the lower and upper estuary regions in 1986, with peak abundances in the Tappan Zee, Croton-Haverstraw, Kingston, and Saugerties regions; most catches were from the bottom strata. In the FSS in late September to early November highest densities were observed in the upper estuary; similar results were observed in the white perch stock assessment program (LMS 1987). Decreasing BSS sample densities in October and November coincided with increasing FSS sample densities, which suggests offshore movement. The lack of decreasing densities in the FSS is likely the result of the temporal extent of the program; a decline in yearling and adult white perch densities starting in November was observed from other trawl samples in the white perch stock as-

FIGURE 4-40

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR WHITE PERCH COLLECTED IN THE BEACH SEINE SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

1986 LONG RIVER SURVEY

DENSITY OF YROL FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

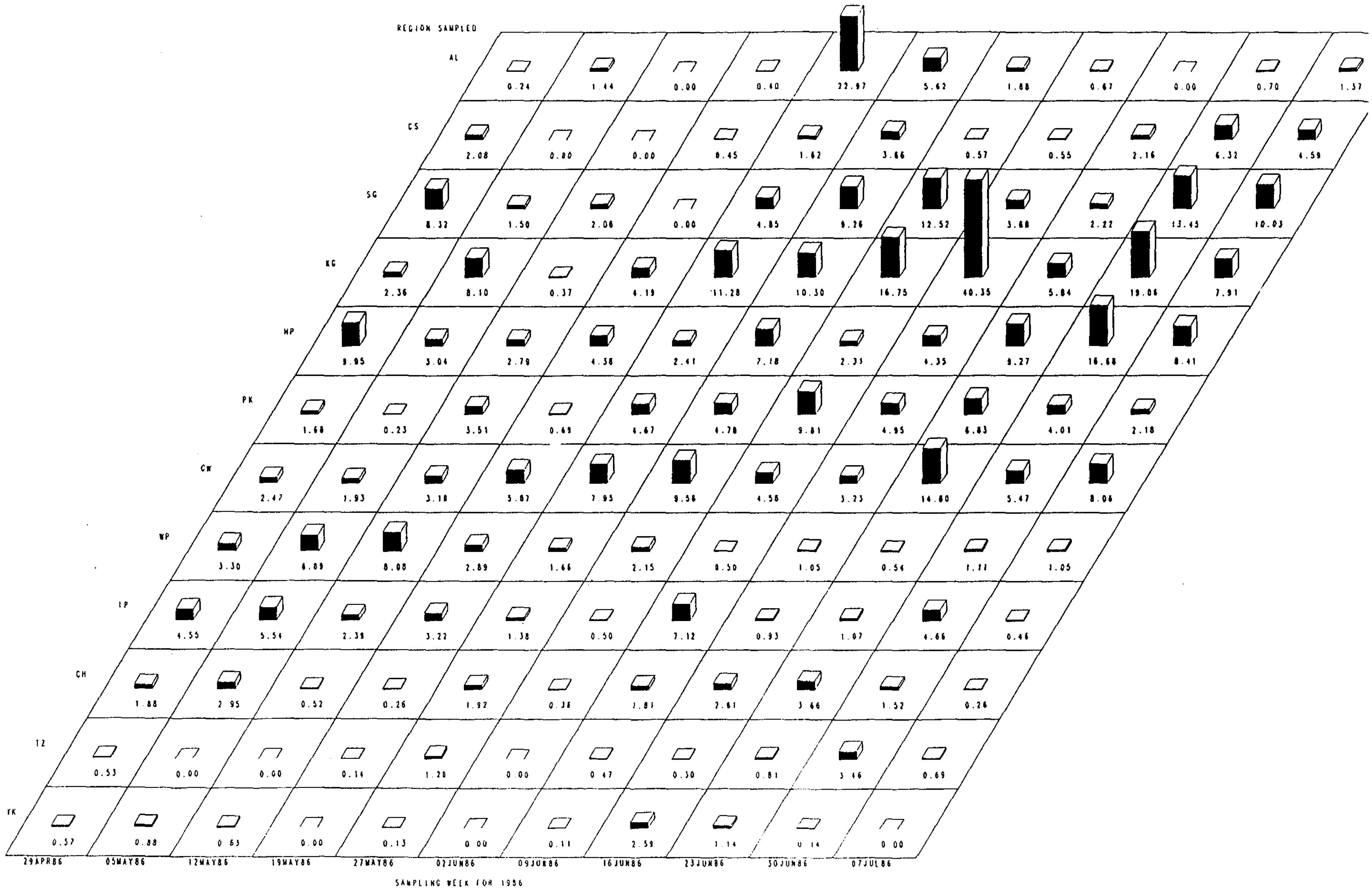


FIGURE 4-41

1986 FALL SHOALS SURVEY

DENSITY OF YROL FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

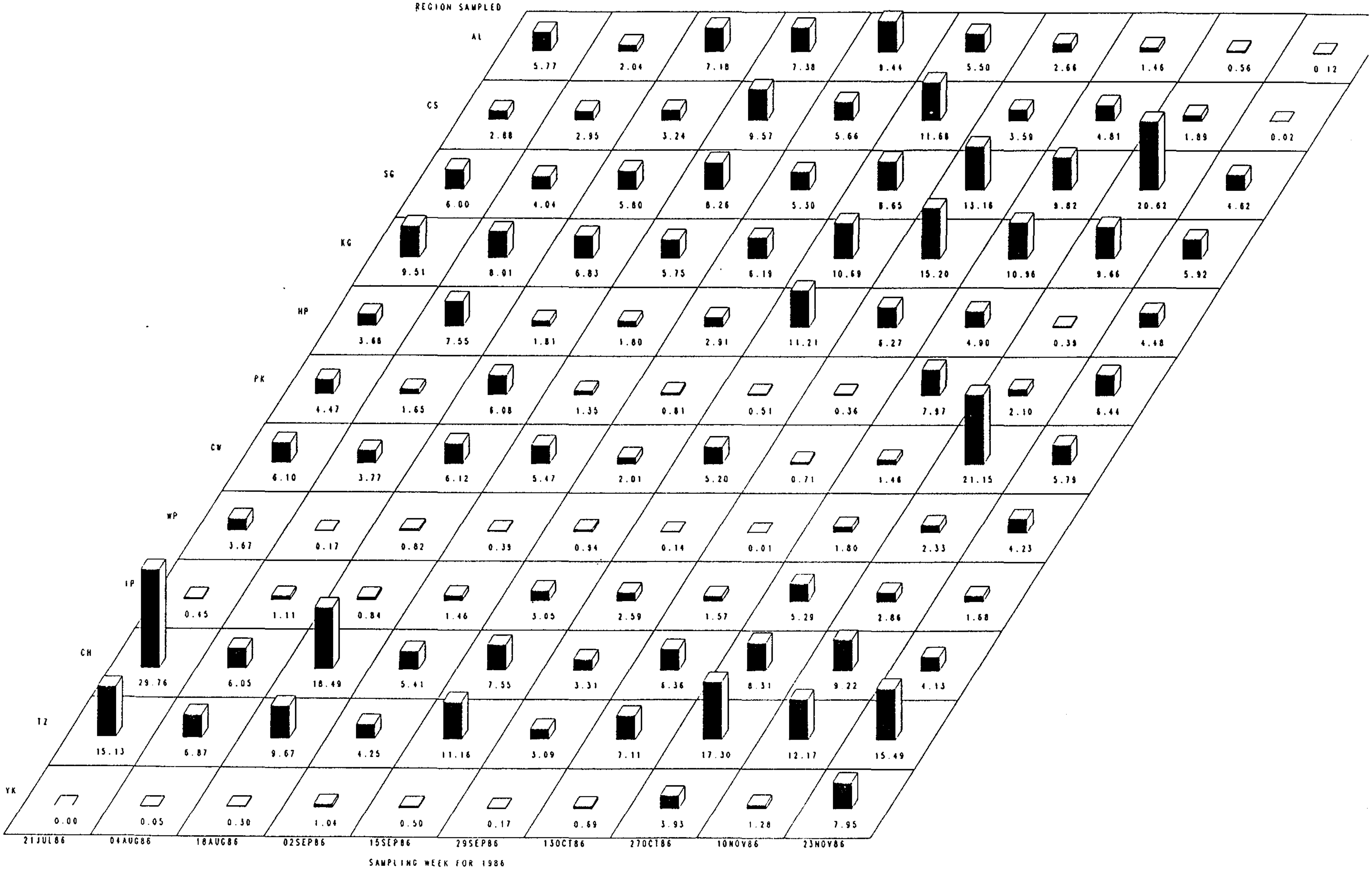


FIGURE 4-42

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR WP

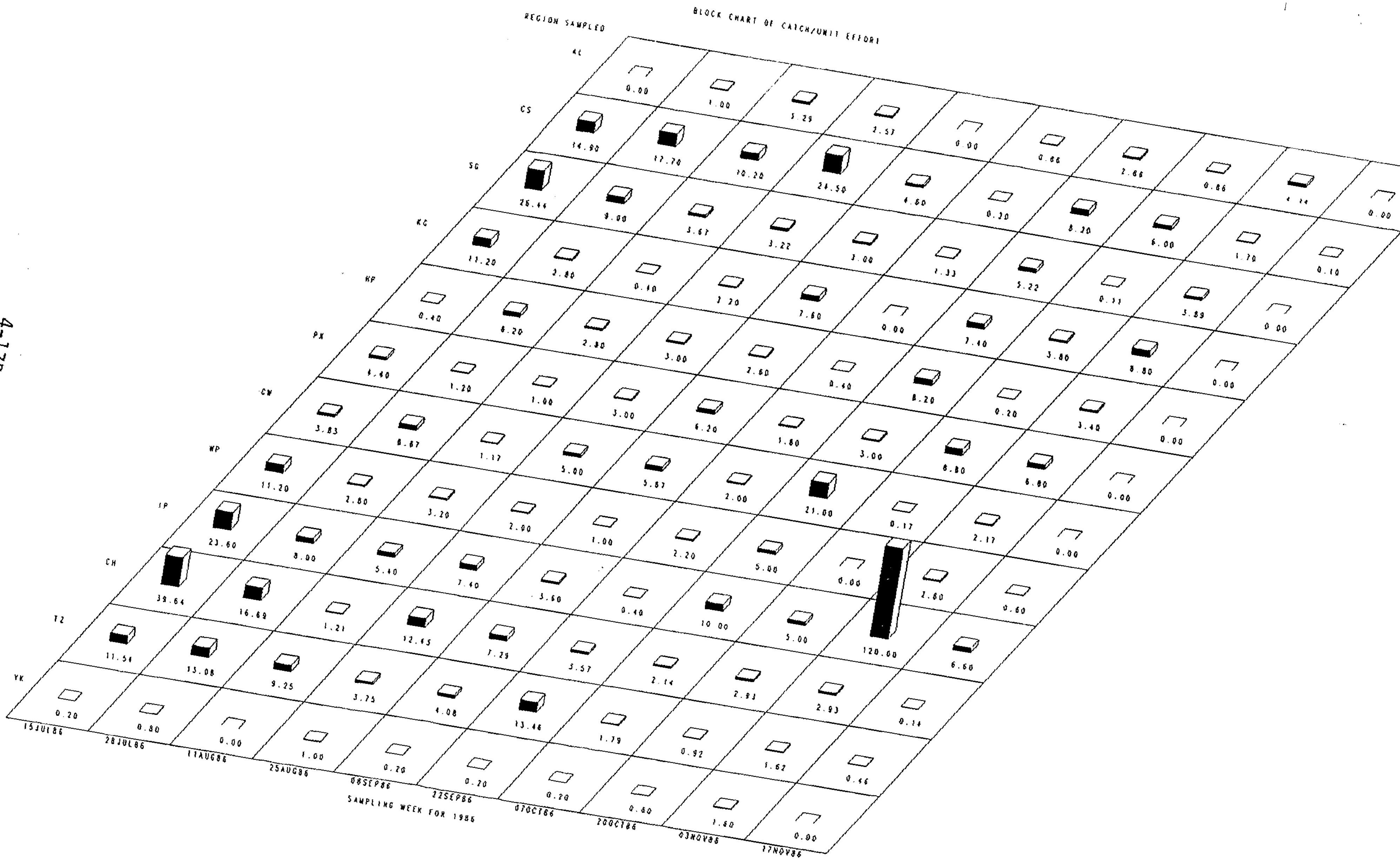


FIGURE 4-43

sessment program (LMS 1987). As with the YOY, a slight increase in lower estuary abundance as upper estuary catches decrease probably indicates that yearling and older white perch are moving downriver with the salt front.

4.4.2 1987 Study

4.4.2.1 Eggs. Eggs were collected for the first time during the 20 April sampling week of the 1987 LRS and continued to be collected throughout the sampling program (Figure 4-44). White perch eggs may have been present during the previous week, but none of the stations in the middle estuary were sampled. Greatest egg densities occurred in May and peaked during the sampling weeks of 11 and 18 May (Figure 4-45). The large estimated density for the Kingston region during the 18 May sampling period suggests that other than normal sampling conditions prevailed. Low egg densities located both temporally and spatially adjacent to this sample and no corresponding YSL abundance suggest the likelihood of an overestimation. The possibility of capturing large adhesive egg masses could result in an unrealistic representation of spatial and temporal distributions. Examination of the 18 May field data revealed that there were coincidental catches of ripe females during 75% of the Kingston region samples that were greater than 1000/1000 m^3, which may have resulted in the exudation of eggs. Eggs collected by this method would bias the sample, resulting in an overestimation of regional density. All potentially affected samples were taken in the shoal stratum from RM 92 and 93 where white perch spawning is known to occur.

Eggs were collected in 1987 from all regions in the estuary. The highest densities were noted from the Cornwall region north (RM 56-152). Discounting the Kingston region estimate, density peaks were sampled in the Poughkeepsie and Catskill regions (Figure 4-46), which are downriver of the historic pattern of peak occurrence in the upper estuary. Throughout the LRS program, egg densities of less than 10/1000 m^3 were estimated for regions south of Indian Point.

1987 LONG RIVER SURVEY

DENSITY OF EGGS FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

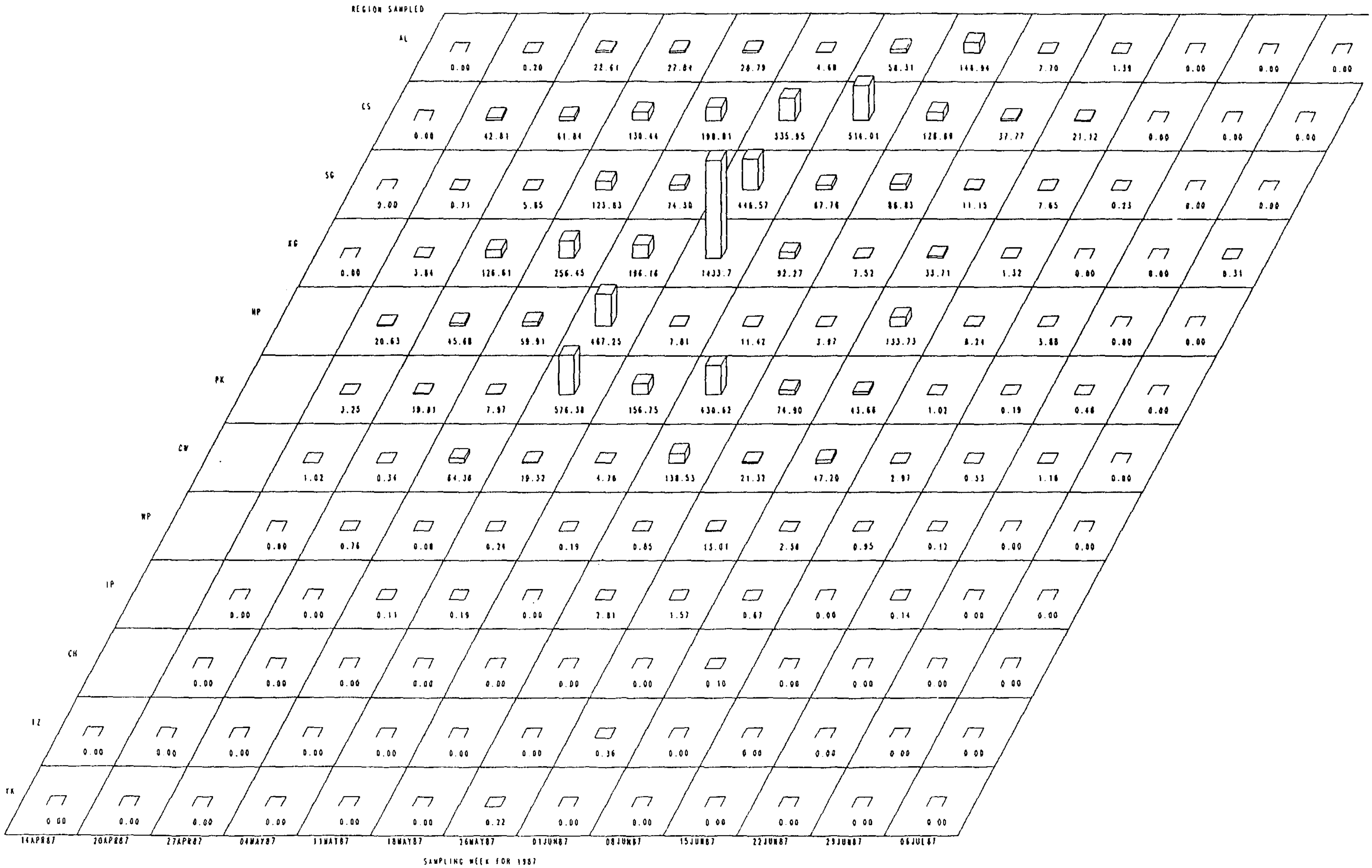
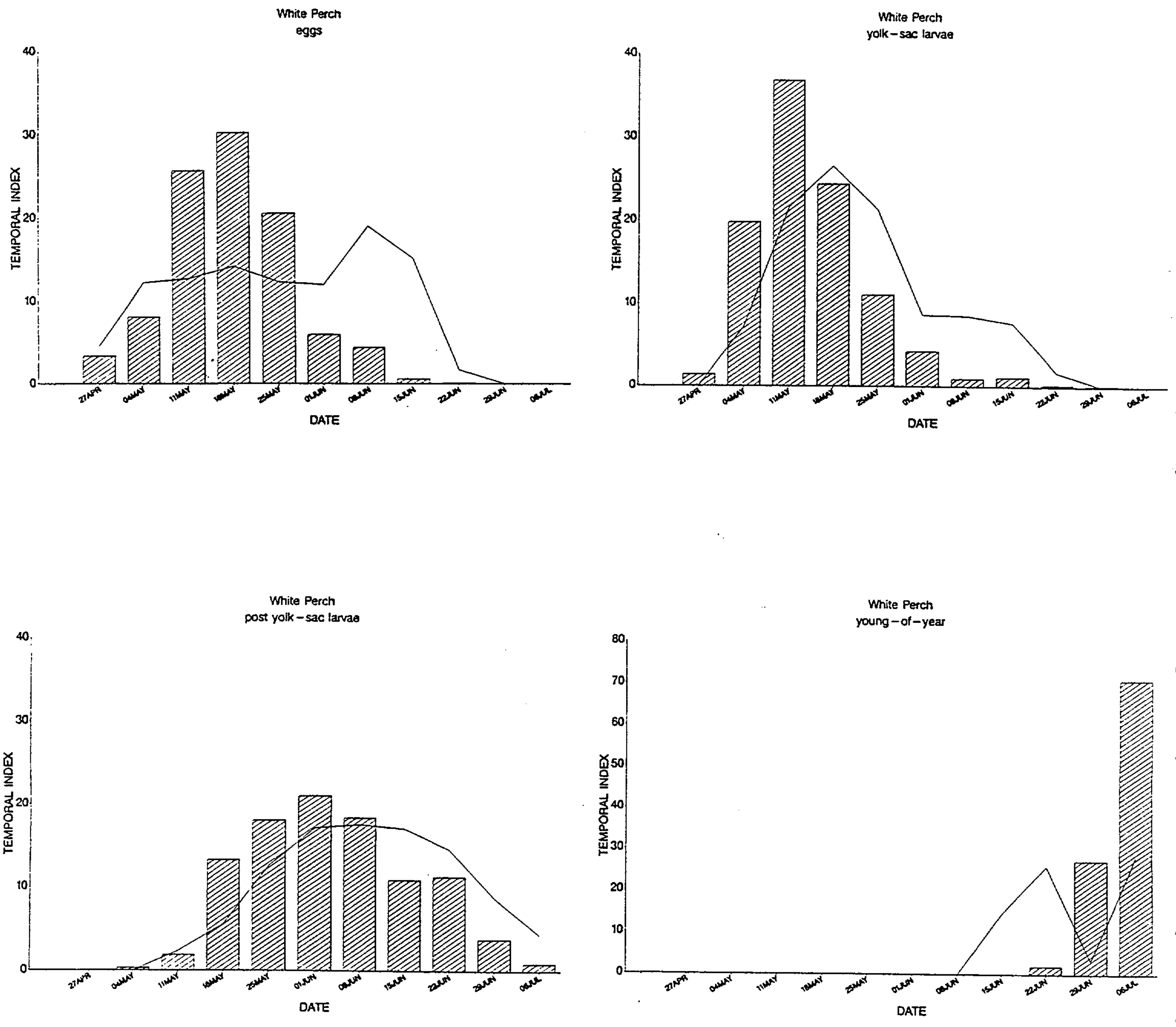


FIGURE 4-44

FIGURE 4-45

TEMPORAL INDEX FOR WHITE PERCH EGGS, YOLK-SAC LARVAE, POST YOLK-SAC LARVAE, AND YOUNG-OF-YEAR COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1987

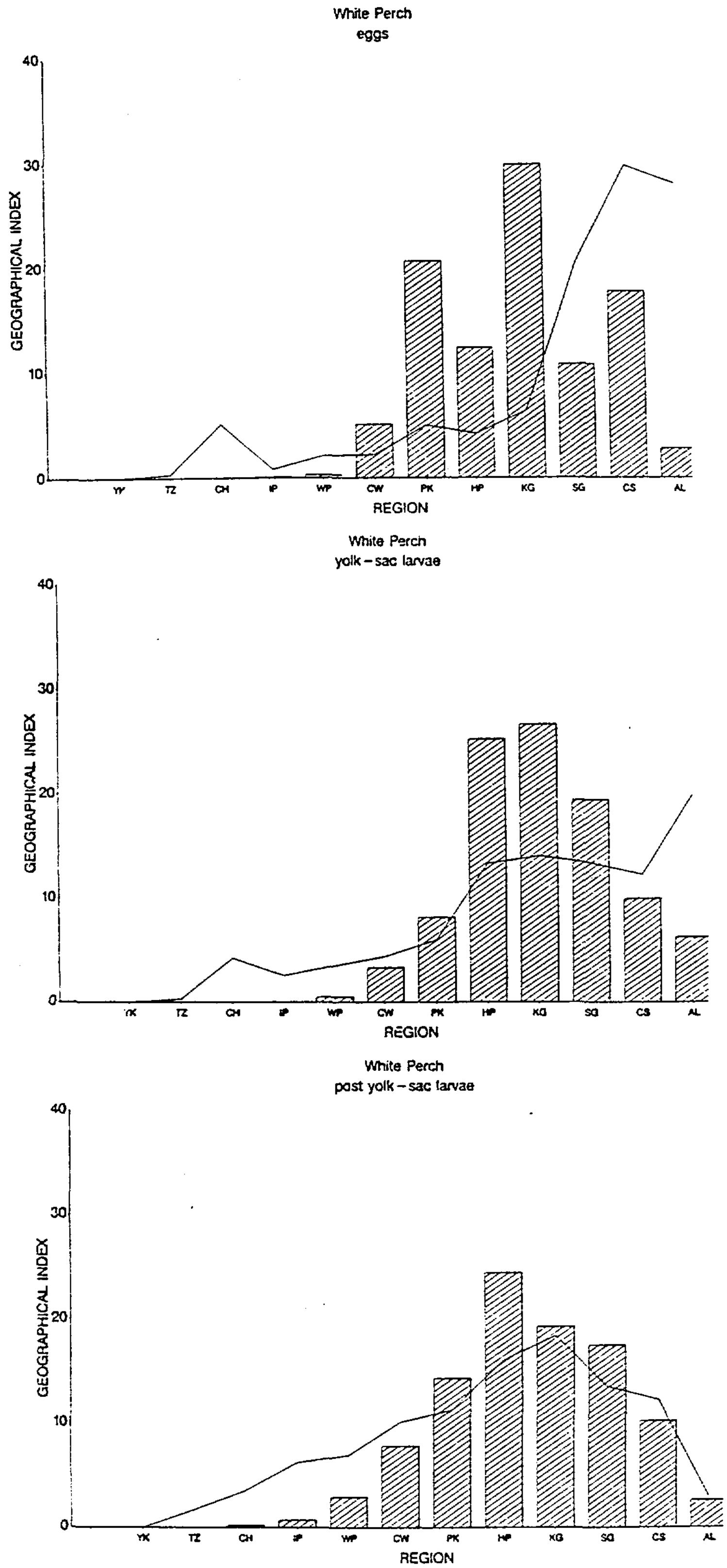


LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

FIGURE 4-46

GEOGRAPHICAL DISTRIBUTION OF WHITE PERCH EGGS, YOLK-SAC LARVAE, AND POST YOLK-SAC LARVAE COLLECTED IN THE LONGITUDINAL RIVER SURVEY, 1987



LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

4.4.2.2 Yolk-Sac Larvae. YSL were first sampled during the 20 April 1987 sampling week and were present in LRS samples through the end of June (Figure 4-47). Greatest occurrence was during May, with peak density estimated for the 11 May sampling week, one week earlier than the historic average period (Figure 4-45).

YSL were found only at trace levels (<10/1000 m^3) below the West Point region (RM 12-46). Greatest abundance was distributed between the Poughkeepsie and Catskill regions (RM 62-124), with peak density estimated in the Kingston region (Figure 4-46). This peak is downriver from the historic peak. YSL densities were downstream from the areas of dense egg collections. Based on comparisons between peak egg location and large larval densities, net movement of YSL appeared to be roughly 4-5 miles downstream in 1986 and 1987 (Figures 4-30 and 4-48).

4.4.2.3 Post Yolk-Sac Larvae. PYSL first appeared in late April 1987 and were still present at the end of the LRS in early July (Figure 4-49). Peak densities were collected from mid-May through early June, in densities greater than 500/1000 m^3 until late June. Peak temporal distribution was during the 1 June sampling week, one week earlier than the recorded long-term mean (Figure 4-45).

White perch PYSL were most abundant in the middle and upper estuary. Only trace numbers (<10/1000 m^3) were generally collected below the West Point region (RM 12-55). Greatest density estimates were from the Poughkeepsie through Saugerties regions (RM 62-106). Peak regional density was in the Hyde Park region (Figure 4-46). This spatial distribution is slightly downriver from that of the YSL (Figure 4-50). Throughout June 1987 there was an increase in upper estuary PYSL abundance, suggesting movement of larvae out of larger tributaries in the northern regions. Low tidal effects in this area would limit possible upriver movements.

1987 LONG RIVER SURVEY

DENSITY OF YSL FOR WHITE PERCH

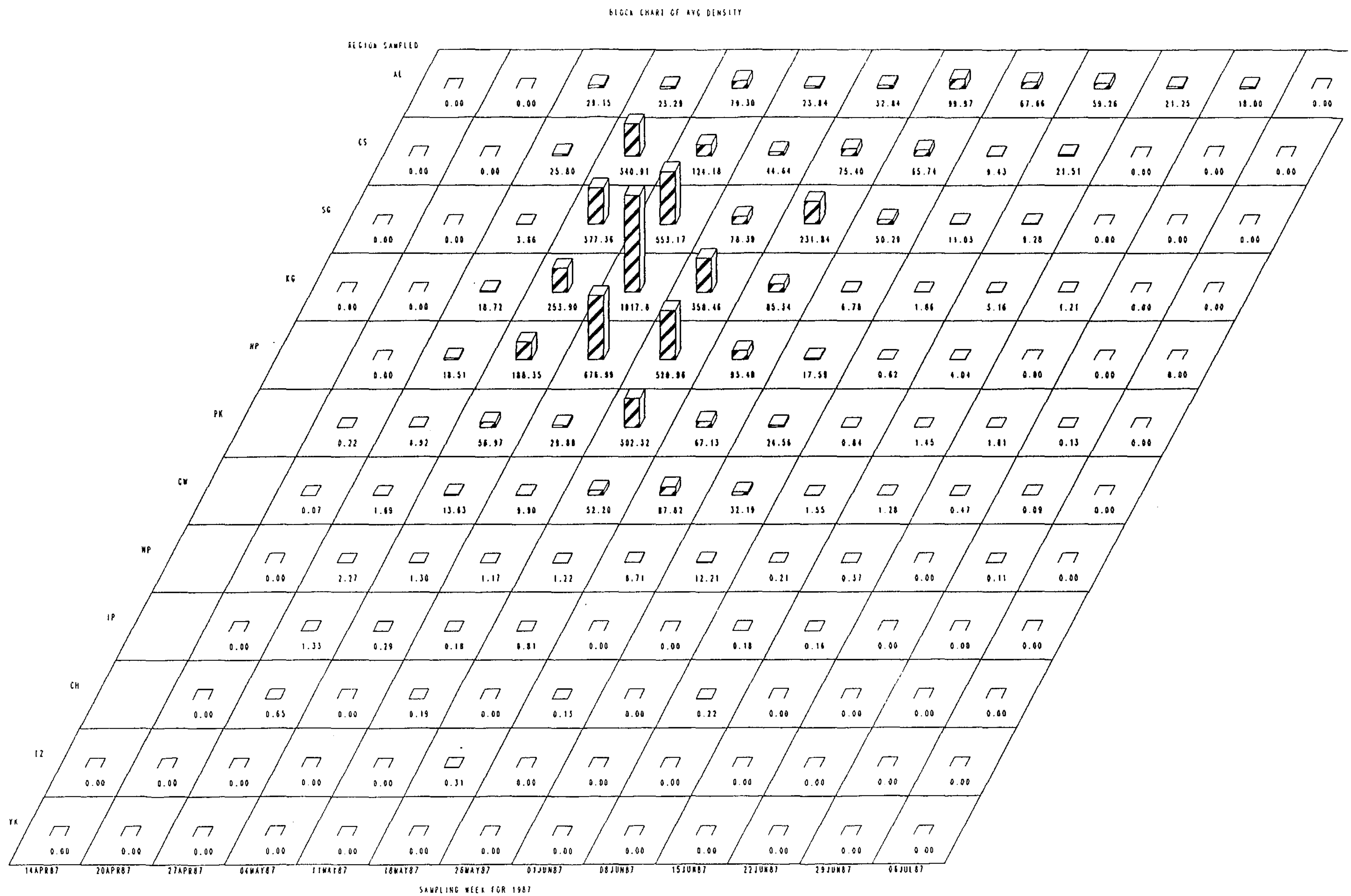
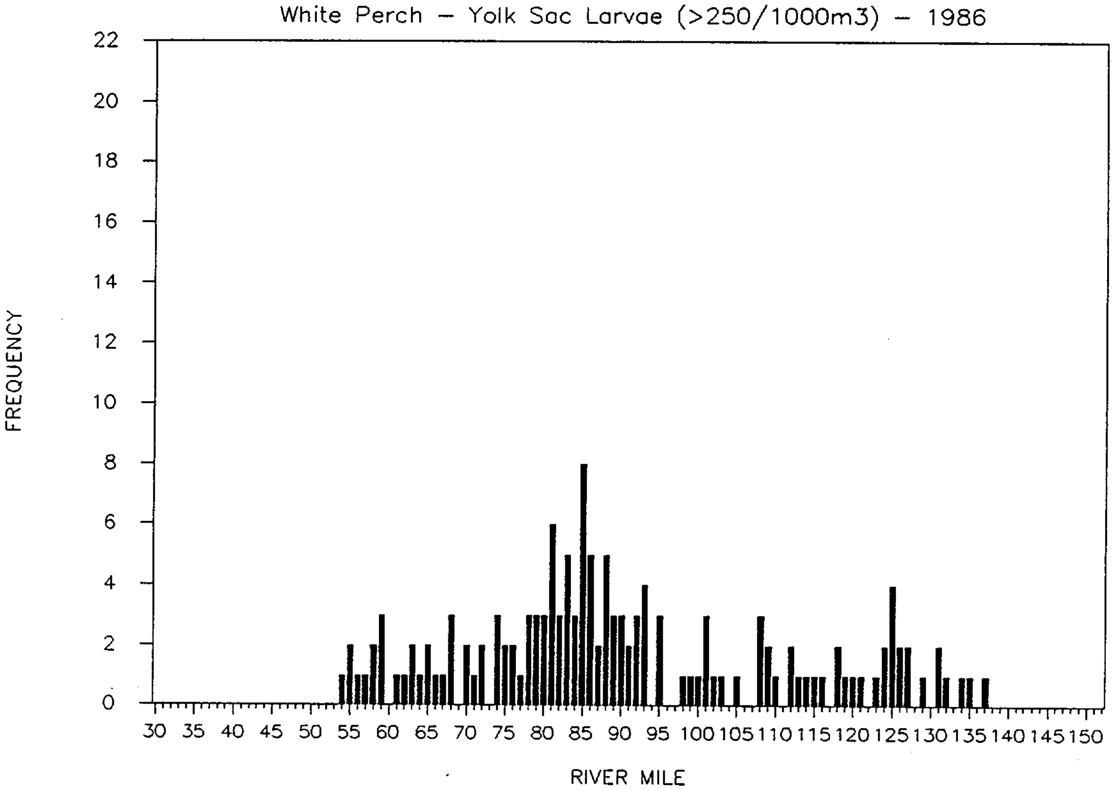
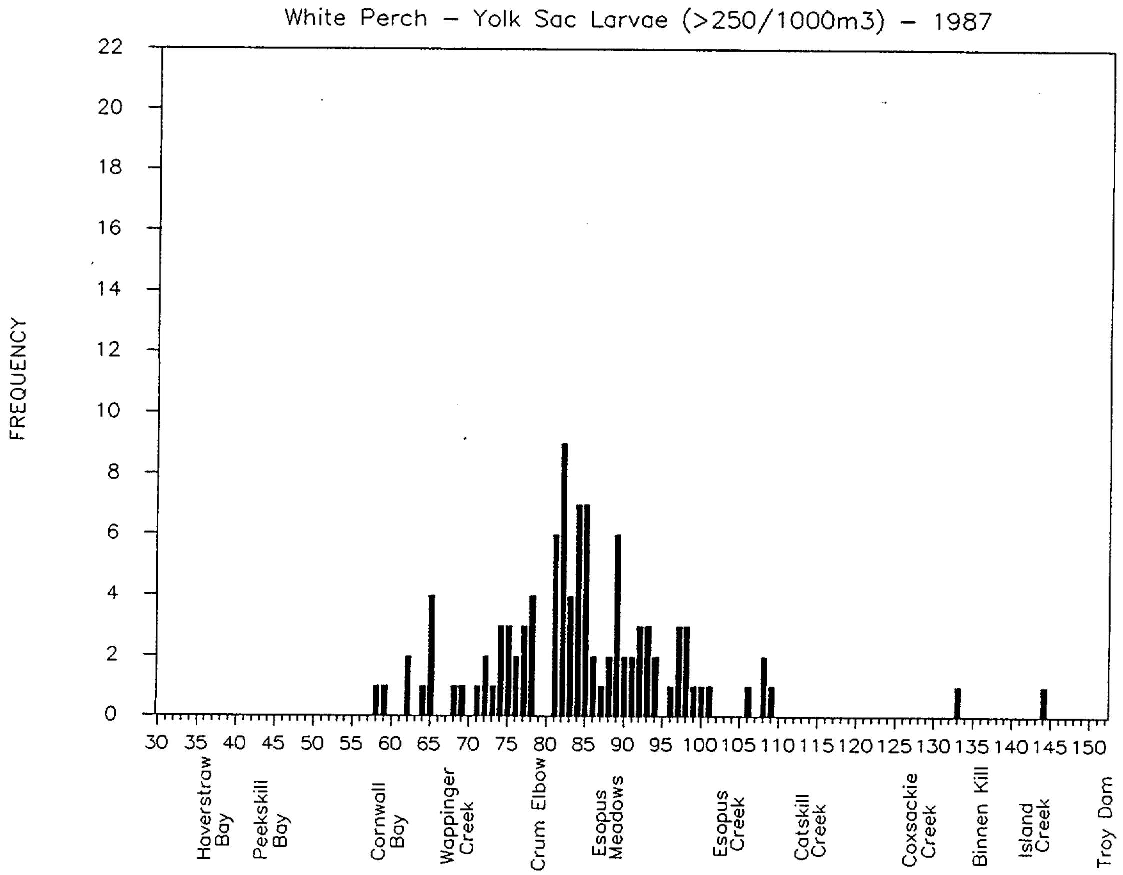


FIGURE 4-47

FIGURE 4-48

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





1987 LONG RIVER SURVEY

DENSITY OF PYSL FOR WHITE PERCH

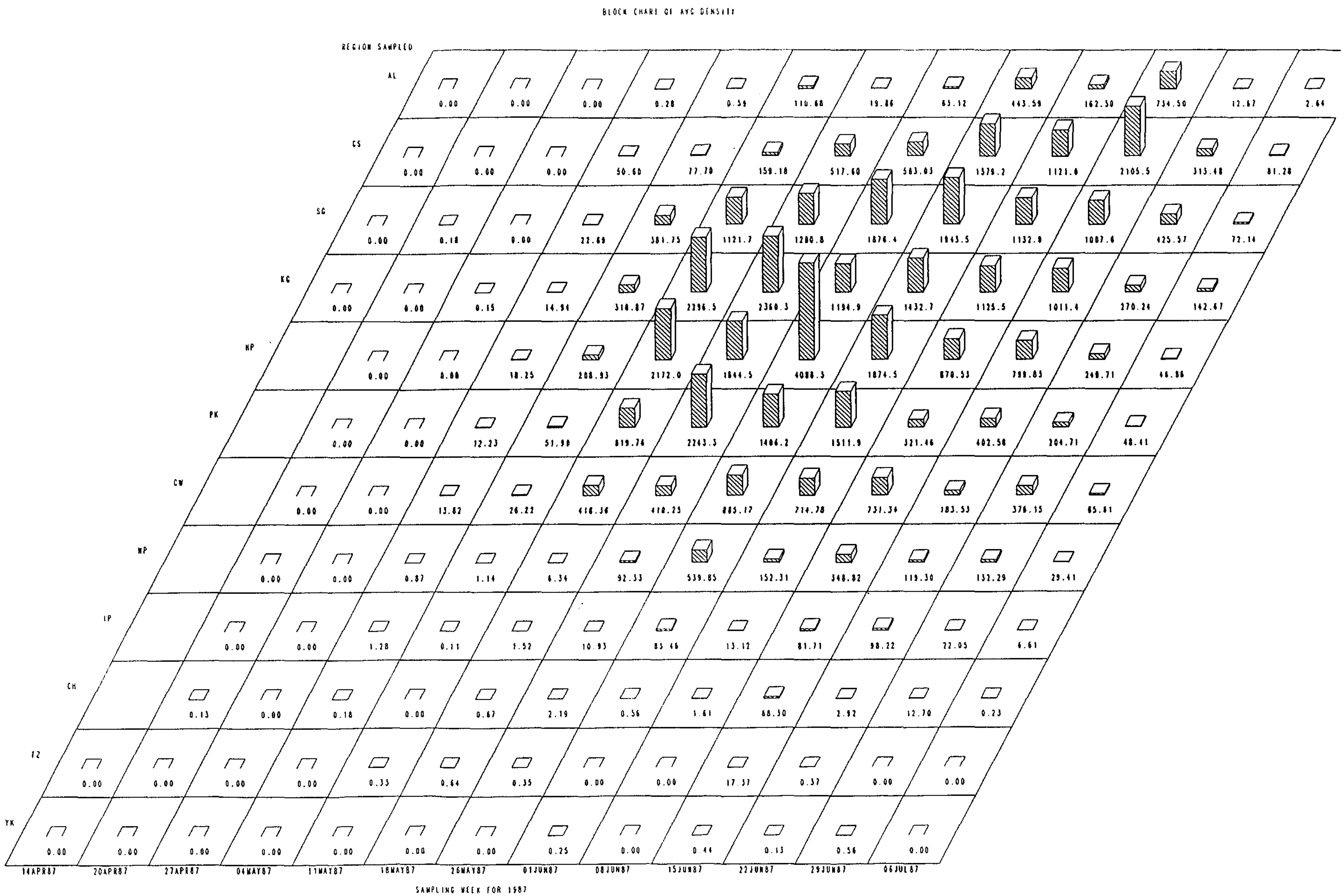
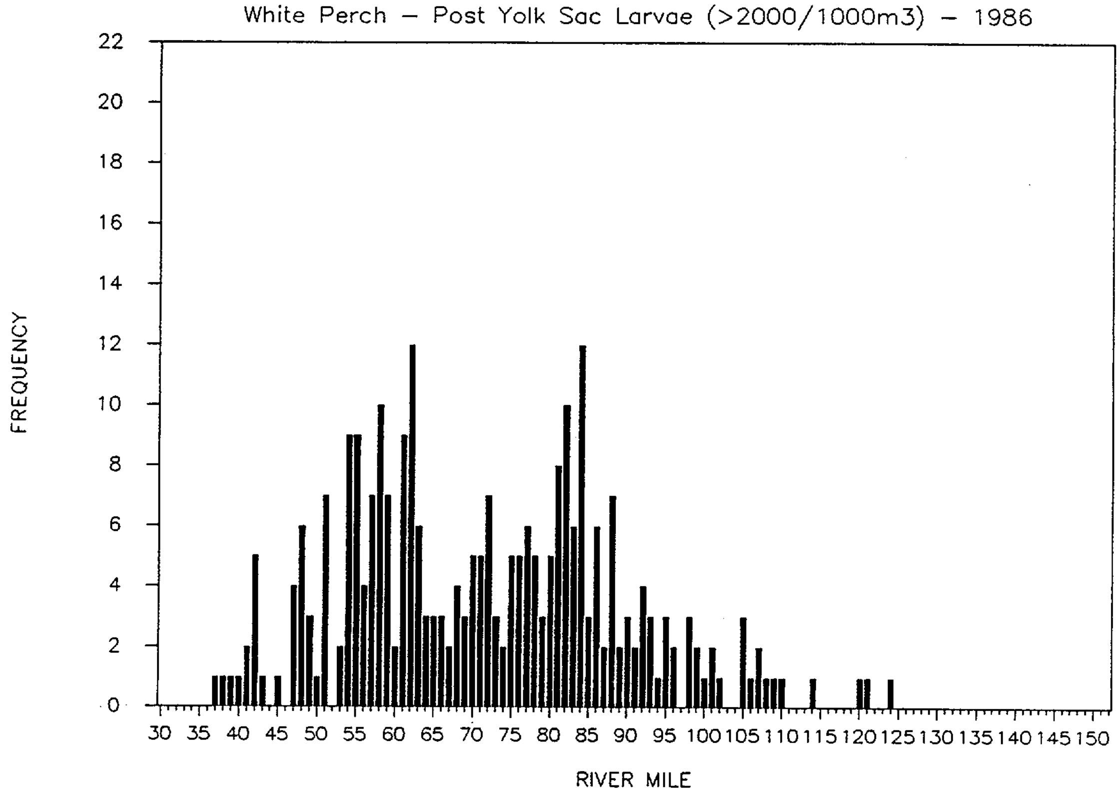
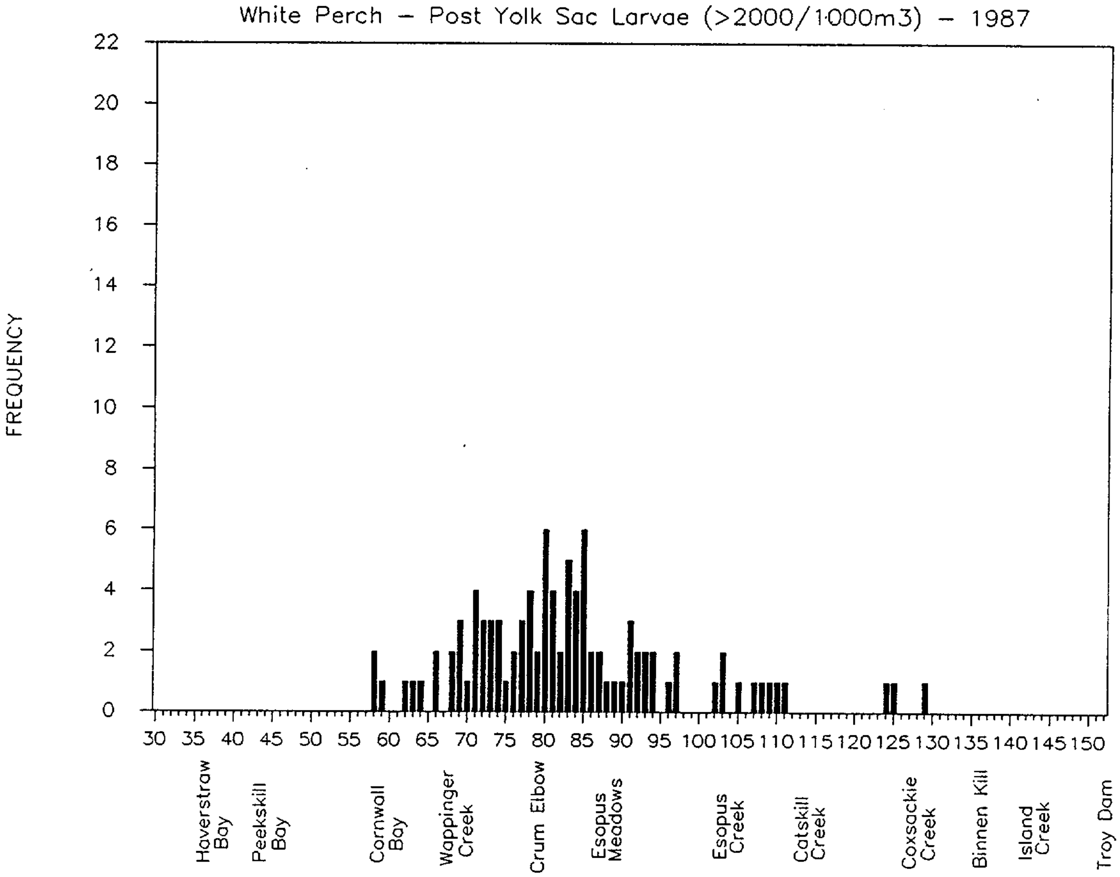


FIGURE 4-49

FIGURE 4-50

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





4.4.2.4 Young-of-Year. White perch YOY were first collected during the 1987 LRS sampling week of 22 June (Figure 4-51). This was approximately five to six weeks after PYSL were starting to be observed. The highest YOY densities were observed in the 6 July sampling week, the last week of the survey (Figure 4-45). YOY were collected in all biweekly samples during the FSS (Figure 4-52) and BSS (Figure 4-53). Greatest densities were recorded in early November in the FSS and in mid-August in the BSS.

The BSS catches were relatively constant from the start of the program in mid-June through early August, increased slightly, and then essentially disappeared from the samples in October; catches were evenly distributed from the Croton-Haverstraw through Catskill regions (RM 34-124), with slight peaks in the West Point and Catskill regions (Figure 4-54). FSS collections in 1987 suggest that white perch YOY were abundant in regions north of West Point throughout the sampling program; a similar density distribution was observed in the white perch stock assessment program (LMS 1988). Greatest densities were observed in these regions during October and November. Lower estuary FSS sampling did not have white perch YOY densities above 1/1000 m^3 in any region downstream of Indian Point until early October. At this time fewer YOY were caught in beach seine samples, whereas the concurrent shoal sampling efforts caught larger numbers of white perch YOY. This suggests that offshore movement occurs at this time; regional shore-zone temperatures throughout the study area dropped below 20°C (Appendix B) at this time. Increasing density in the lower estuary in October and November, accompanied by decreases in shore-zone density and increases in bottom density, has been noted in previous years as well (TI 1981; Battelle 1983; NAI 1985a). Peak density occurred in the Hyde Park region during the 19 October sampling period of the FSS. Decreases in YOY white perch densities were observed in the white perch stock assessment program starting in November (LMS 1988); because of the temporal extent of the FSS this decline was not observed. The 1987 distributional shifts further substantiate the hypothesis that juveniles move offshore as temperatures decline.

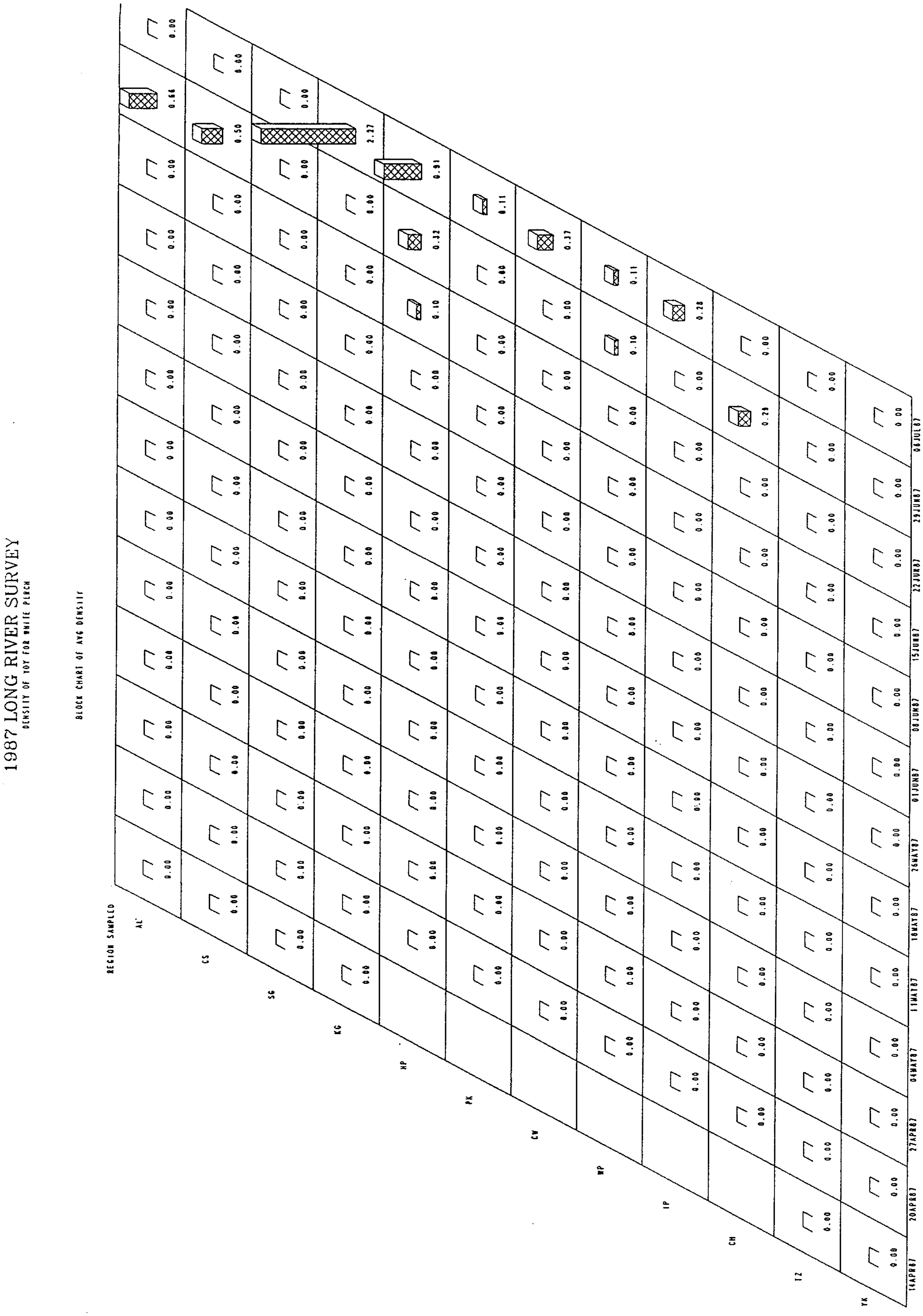

1987 LONG RIVER SURVEY
DENSITY OF YOY FOR WHITE PERCH
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AC
CS
SG
KG
HP
PK
CW
WP
IP
CH
TZ
YK
14APR87
20APR87
27APR87
04MAY87
11MAY87
18MAY87
26MAY87
01JUN87
08JUN87
15JUN87
22JUN87
29JUN87
06JUL87
SAMPLING WEEK FOR 1987

FIGURE 4-51

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

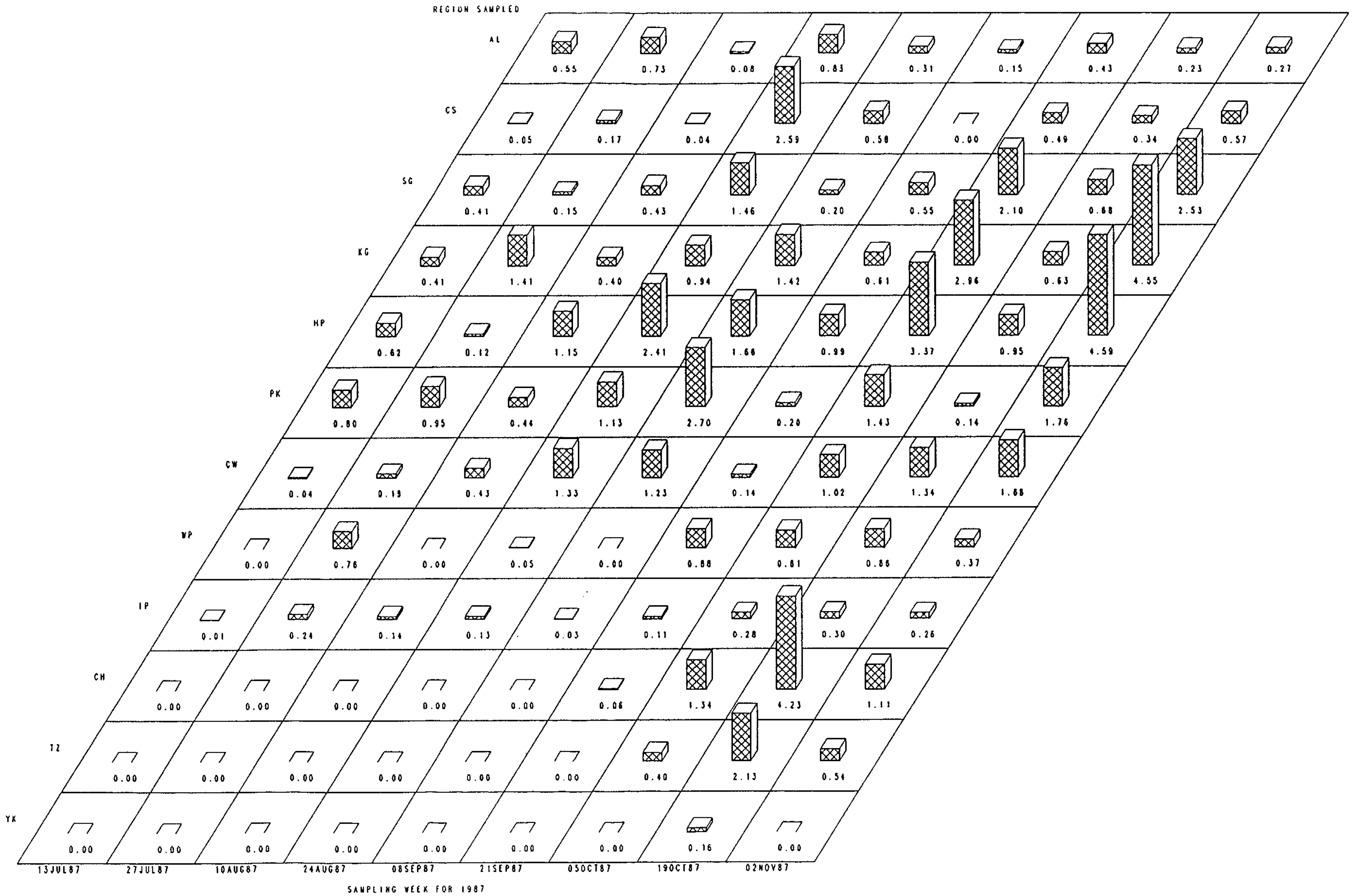


FIGURE 4-52

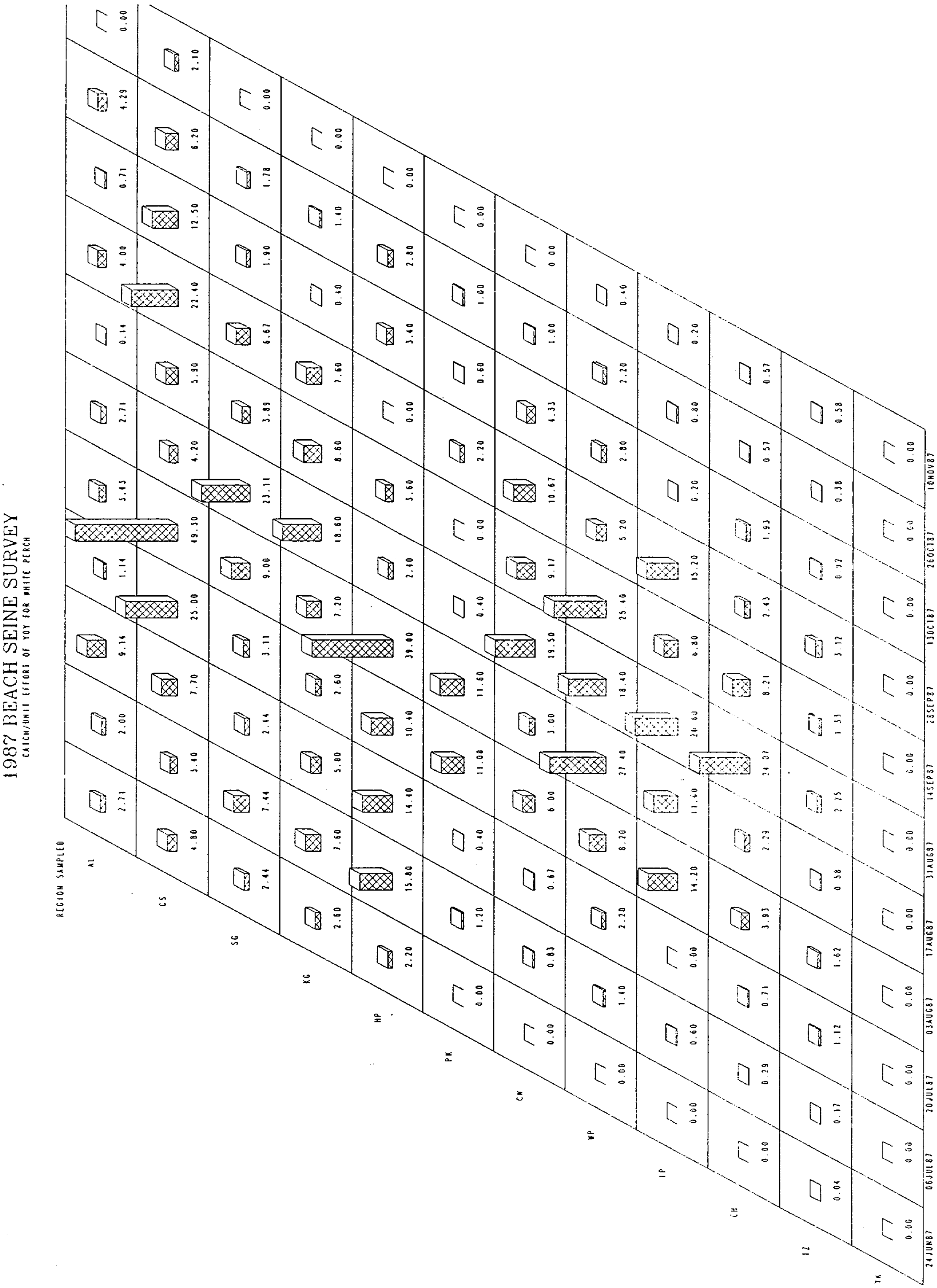
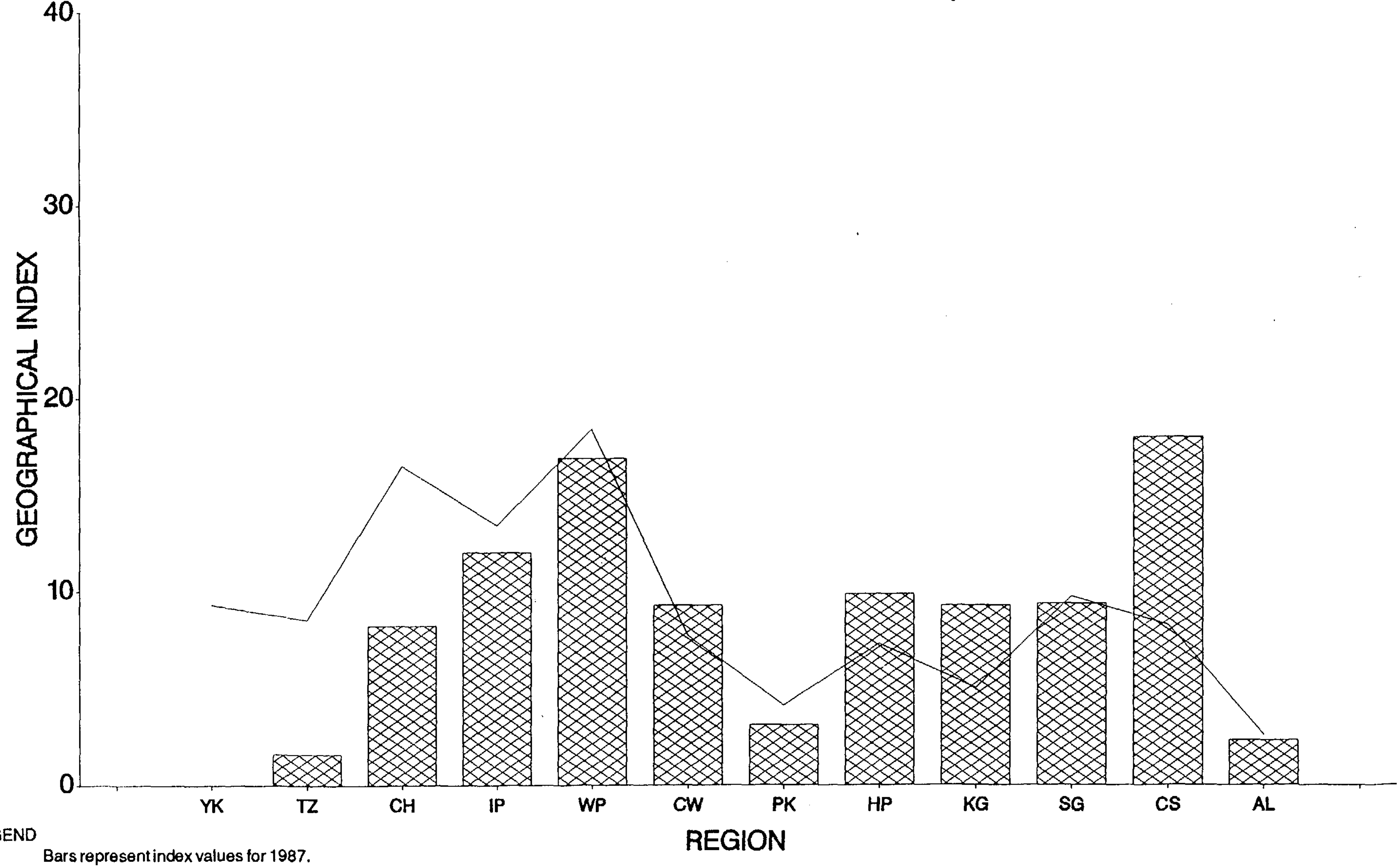

1987 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF YOY FOR WHITE PERCH
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
IZ
TK
SAMPLING WEEK FOR 1987
24JUN87
06JUL87
20JUL87
03AUG87
17AUG87
31AUG87
14SEP87
28SEP87
13OCT87
26OCT87
10NOV87

FIGURE 4-53

FIGURE 4-54

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR WHITE PERCH COLLECTED IN THE BEACH SEINE SURVEY, 1987



LEGEND
Bars represent index values for 1987.
Lines represent average for 1974-1986.

4.4.2.5 Yearling and Older Fish. In 1987 yearling and older white perch were collected in every sampling period of the LRS (Figure 4-55), FSS (Figure 4-56), and BSS (Figure 4-57) programs in almost all regions of the estuary. The 1987 LRS distribution pattern suggests that there was an upriver shift similar to that reported for 1986 in late April and early May, which also corresponds to the salt front advancing upriver. LRS and FSS density estimates for regions north of West Point indicate that abundance peaks occurred in mid-May to early June and in late August to early September. After September, abundances in the middle and upper regions tended to decrease; a similar decrease in yearling and older fish was observed at this time in the white perch stock assessment program (LMS 1988).

In the BSS the highest densities of yearling and older fish occurred between the Tappan Zee and Indian Point regions (RM 24-46). Yearling and older white perch were concentrated in the shore zone of the lower estuary until mid-September when water temperatures in the shore zone declined (Appendix B). As lower estuary BSS catches declined, deeper water FSS samples increased in abundance. In the FSS increasing yearling-and-older density in the lower estuary also coincides with decreasing upper estuary density, suggesting that both downriver and offshore movements occur, as reported in past years (TI 1981).

Abundances of yearling and older white perch in the bottom strata north of the Poughkeepsie region increased throughout July and August during the 1986 and 1987 FSS. Peak bottom strata catches for both years occurred in early October and early September, respectively. Coincident with a decrease in bottom catches following these peaks is an increase in channel strata catches in late October and early November. This shift suggests that yearling and older white perch not only move from the upriver bottom strata to lower estuarine overwintering areas, but that they also shift from the bottom strata to channel strata in the upper and middle estuary. Similar abundance shifts between strata in the upper and middle estuaries occur with juvenile white perch populations.

1987 LONG RIVER SURVEY

DENSITY OF YSOL FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

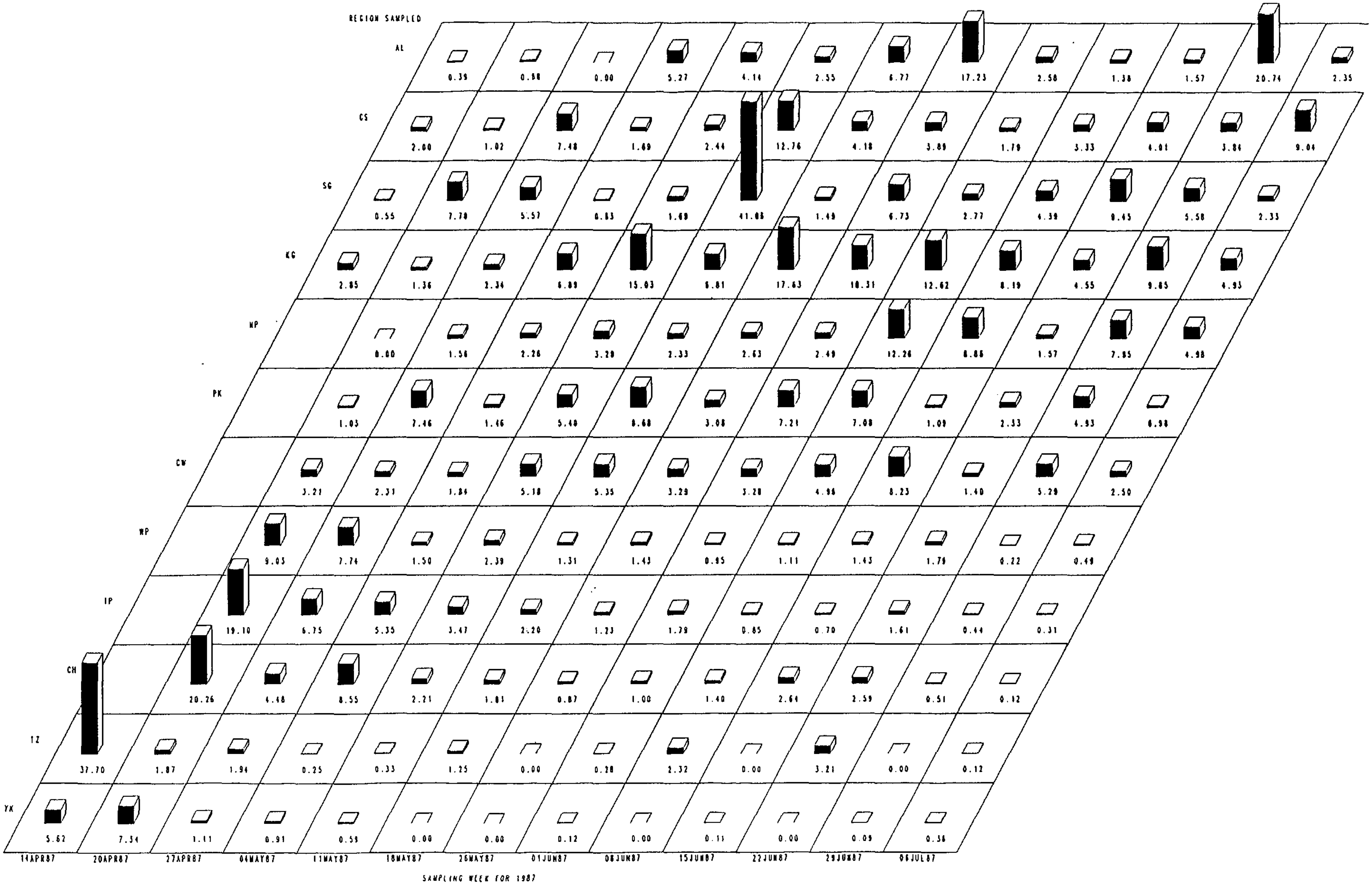


FIGURE 4-55

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR WHITE PERCH

BLOCK CHART OF AVG DENSITY

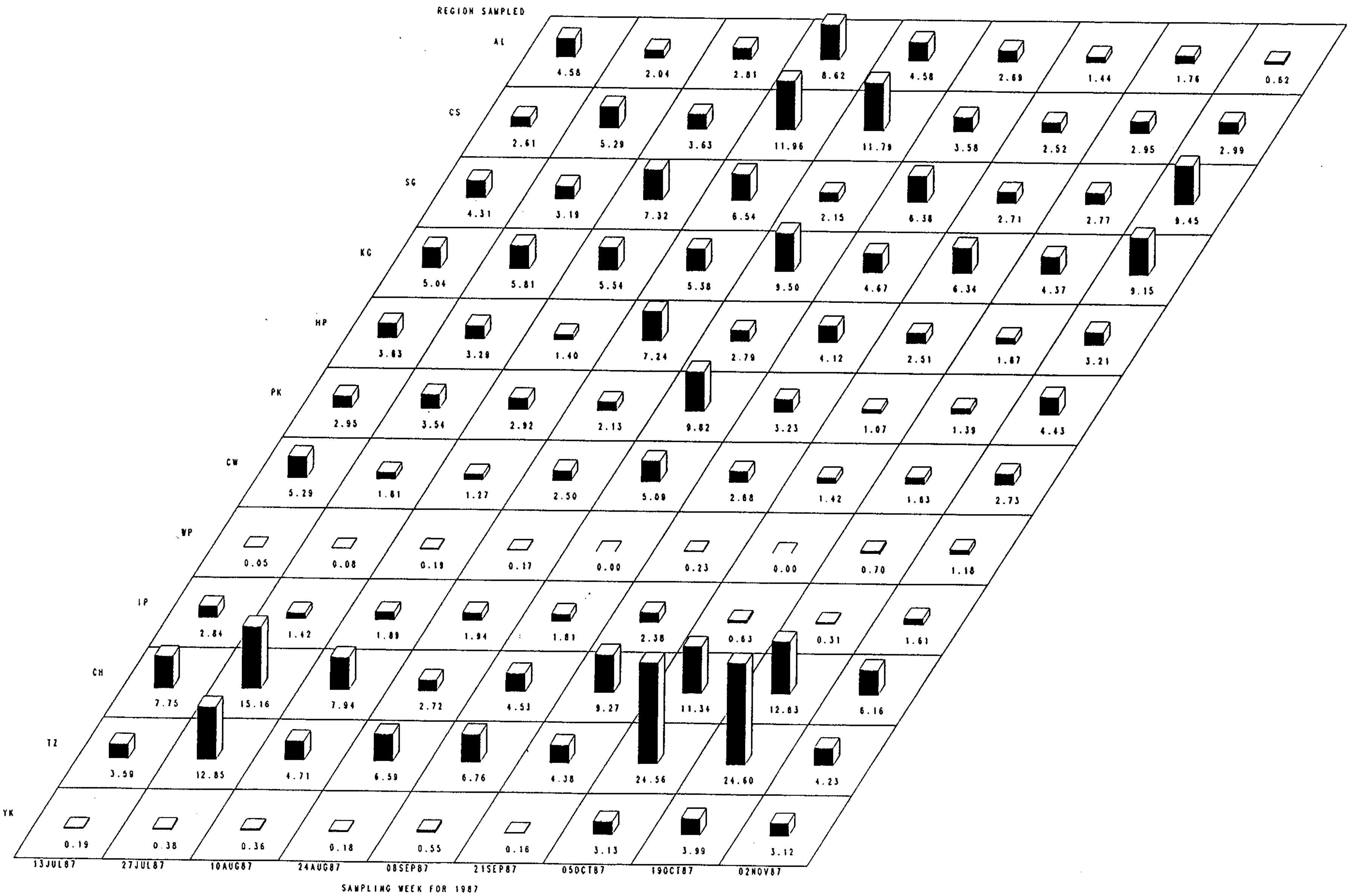


FIGURE 4-56

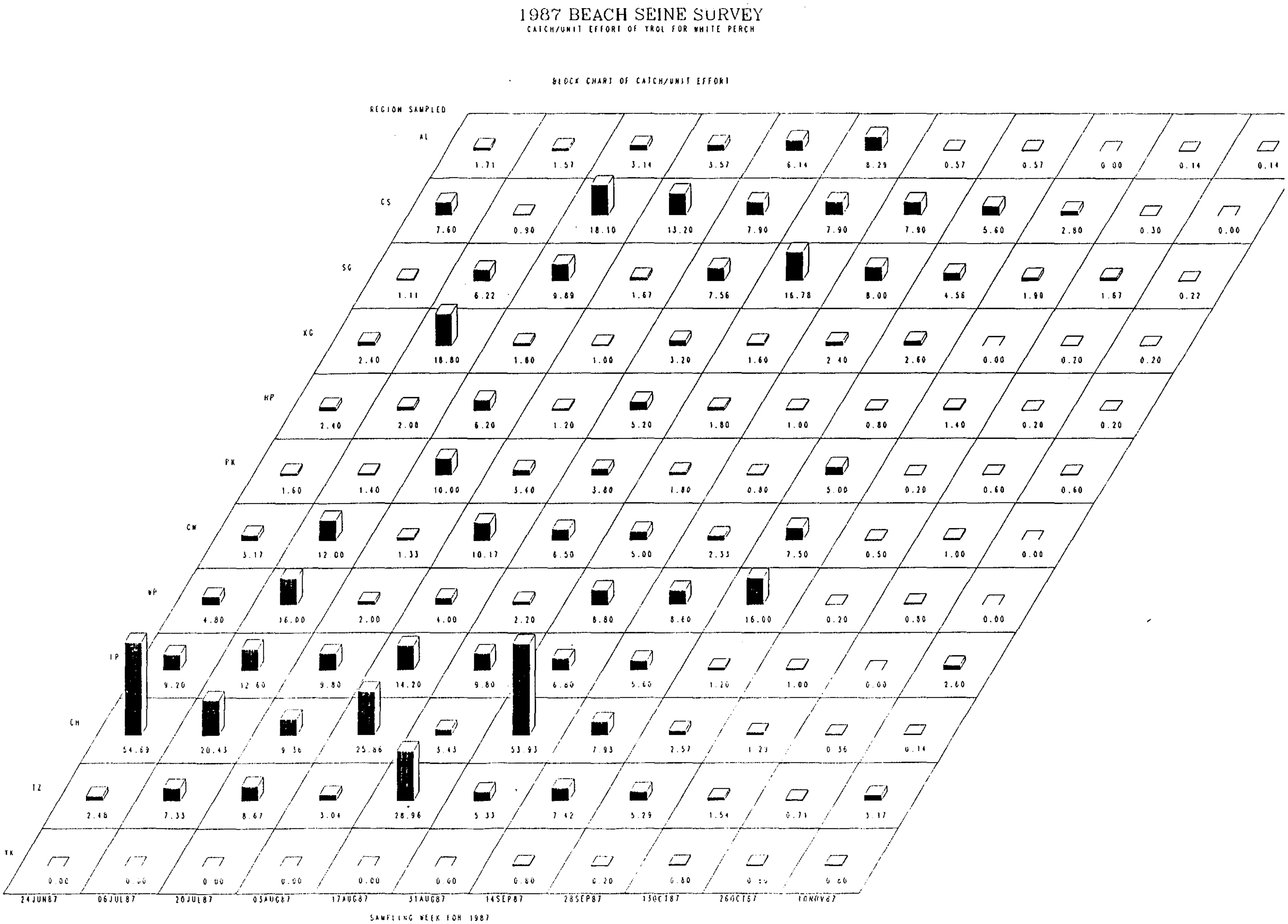

1987 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF YROL FOR WHITE PERCH
BLOCK CHART OF CATCH/UNIT EFFORT
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
TZ
YK
24JUN87
06JUL87
20JUL87
03AUG87
17AUG87
31AUG87
14SEP87
28SEP87
13OCT87
26OCT87
10NOV87
SAMPLING WEEK FOR 1987

FIGURE 4-57

4.5 ATLANTIC TOMCOD

The Atlantic tomcod, Microgadus tomcod (Walbaum), an anadromous euryhaline species of the family Gadidae, inhabits the Atlantic coast from Canada to Virginia (Peterson et al. 1980). In the Hudson they occur as far upriver as the Saugerties region, but are uncommon above the Kingston region. Adult tomcod enter the estuary in November to spawn over sand or gravel bottoms in fresh water; fertilization is limited to salinities of less than 2 ppt (Booth 1967). Demersal adhesive eggs, deposited between December and February, have an incubation time of about 24 days at 6°C. Upon hatching, the buoyant larvae drift downstream to waters with higher salinity where larval development occurs (Peterson et al. 1980). Yolk-sac absorption occurs in four to five days. As salinity decreases in the middle estuary toward fall, juvenile tomcod move downriver to the lower estuary and adjacent coastal areas.

4.5.1 1986 Study

4.5.1.1 Eggs. Atlantic tomcod eggs were not present during the 1986 LRS programs. This is not surprising as tomcod spawn in the winter and the temporal extent of the LRS does not cover this time period. Limited seasonal sampling dates also did not facilitate egg collection.

4.5.1.2 Yolk-Sac Larvae. No Atlantic tomcod YSL were present in the 1986 sampling program; in previous years, however, when the LRS started in March, YSL were collected through early April (Battelle 1983).

4.5.1.3 Post Yolk-Sac Larvae. In 1986 Atlantic tomcod PYSL were collected from the first sampling week (29 April) of the LRS through mid-May (Figure 4-58). In previous years maximum abundance has occurred in early to mid-April. The initial LRS sampling week in 1986 may have been preceded by peak larval densities. Larval abundance diminished by mid-May of the sampling schedule. PYSL were found mainly from the Yonkers region to the West Point

1986 LONG RIVER SURVEY

DENSITY OF PYSL FOR ATLANTIC TOMCOD

BLOCK CHART OF AVG DENSITY

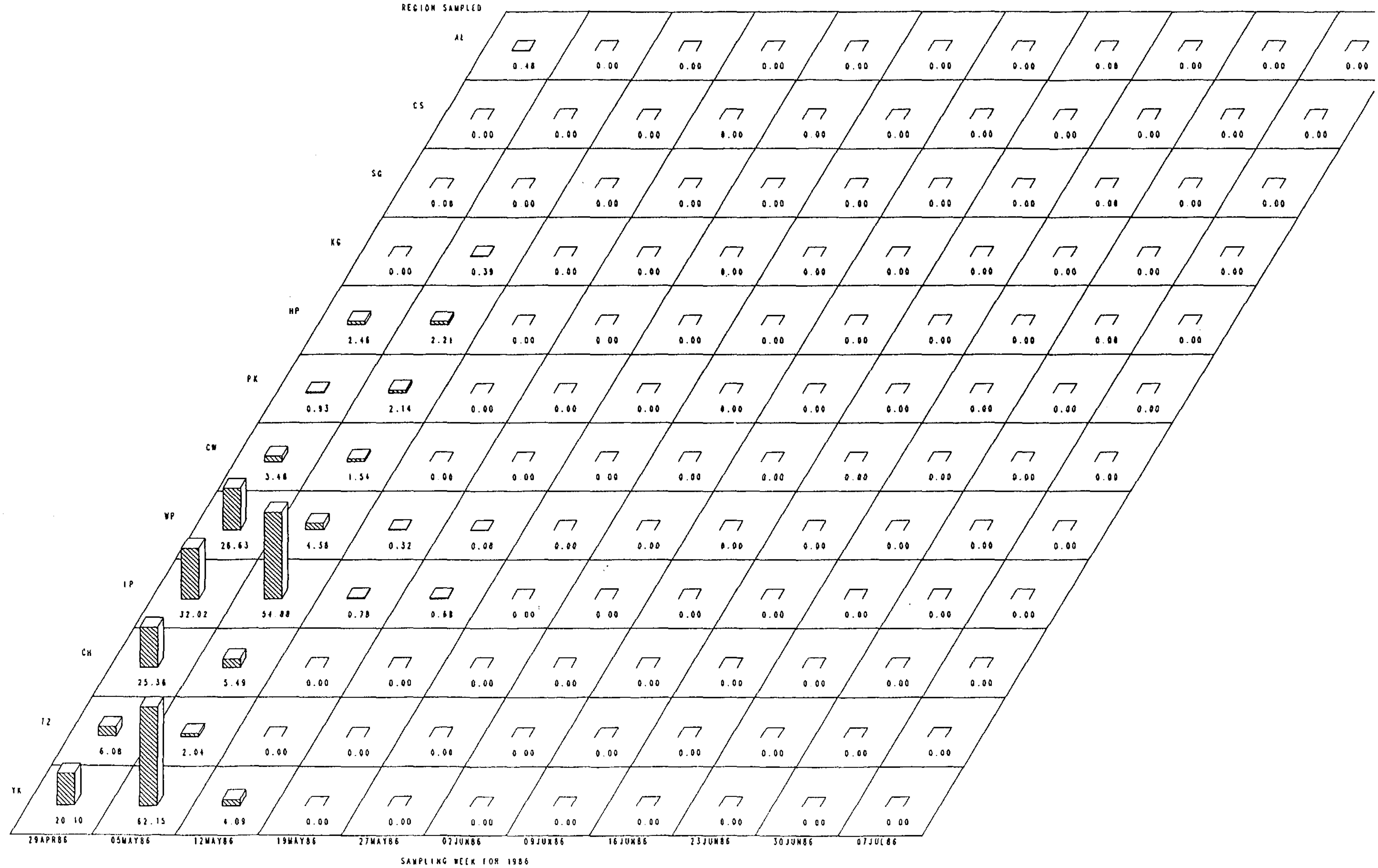


FIGURE 4-58

region (RM 12-55), with trace numbers (<4/1000 m^3) found as far upriver as the Albany region.

4.5.1.4 Young-of-Year. Juvenile tomcod were present in the Hudson River at the initiation of the 1986 LRS (Figure 4-59), FSS (Figure 4-60), and BSS (Figure 4-61), and continued to be collected throughout the sampling period of each program. In all three programs YOY were caught mainly in the lower estuary, in greatest numbers in the West Point, Indian Point, and Yonkers regions. Peak abundance occurred in May in the Indian Point and West Point regions. In the LRS and FSS catches were highest in the early part of the programs and declined with time. As FSS Atlantic tomcod YOY densities declined, shore-zone catches increased. Peak geographical distribution occurred in the Tappan Zee region (Figure 4-62).

4.5.1.5 Yearling and Older Fish. Combining the 1986 LRS (Figure 4-63), FSS (Figure 4-64), and BSS (Figure 4-65), yearling and older Atlantic tomcod were caught from May through the end of November. In the BSS Atlantic tomcod were collected only in trace numbers (<0.1/haul), and solely from the Tappan Zee region between late August and the end of the program in November (Figure 4-65). The FSS program collected yearling and older tomcod with increasing abundance during October and November, mainly in the Tappan Zee and Yonkers regions, probably because of adults moving into the estuary to spawn. Regional abundances were greatest in the lower estuary; however, trace numbers (<0.1/1000 m^3) were sampled in the FSS program as far upriver as the Catskill region.

4.5.2 1987 Study

4.5.2.1 Eggs. As in the 1986 LRS study, no Atlantic tomcod eggs were collected during the 1987 LRS because of the temporal extent of the program. Also, limited seasonal sampling dates did not facilitate egg collection.

1986 LONG RIVER SURVEY

DENSITY OF YOY FOR ATLANTIC TOMCOD

BLOCK CHART OF AVG DENSITY

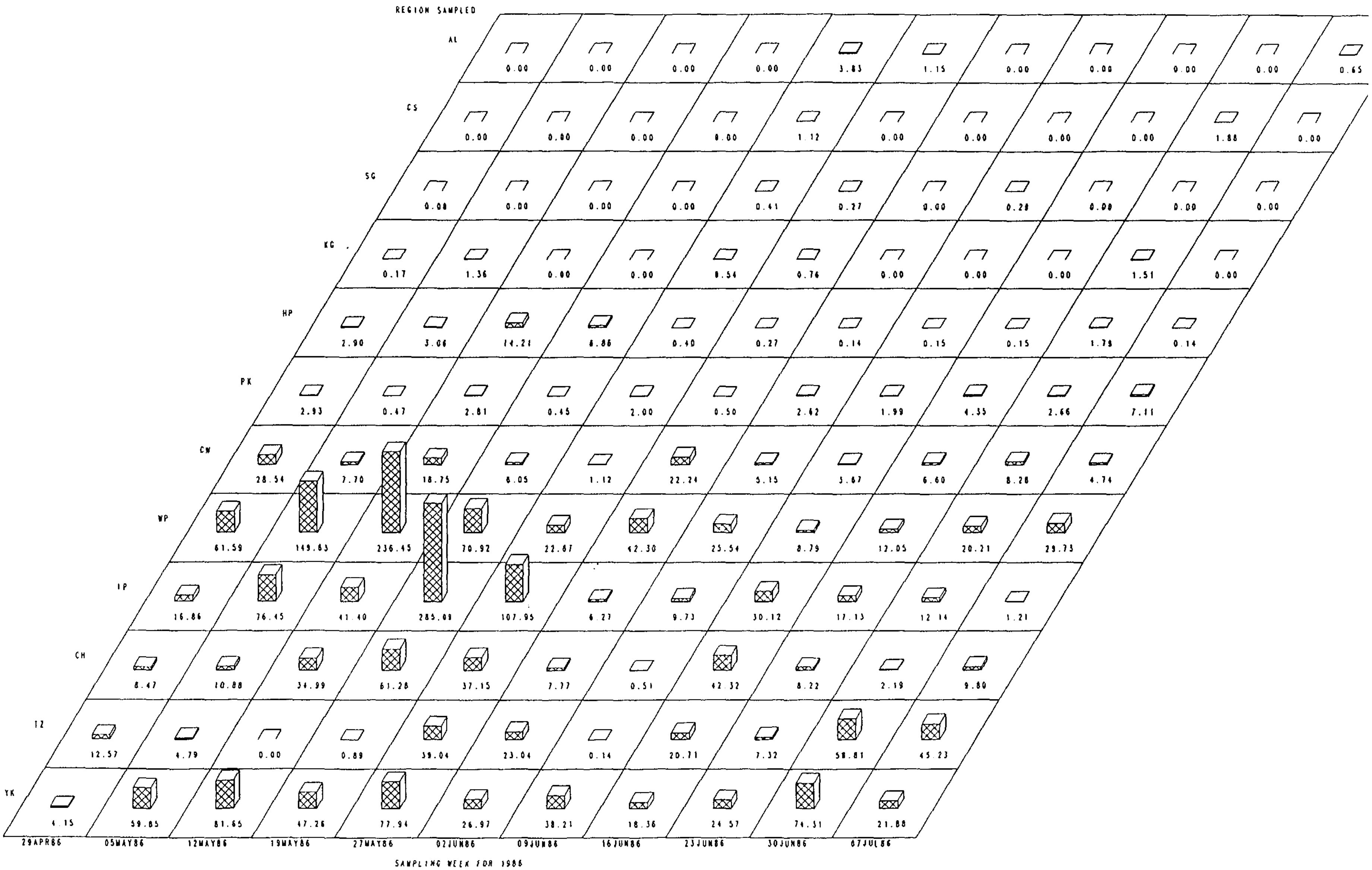


FIGURE 4-59

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR ATLANTIC TOMCOD

BLOCK CHART OF AVG DENSITY

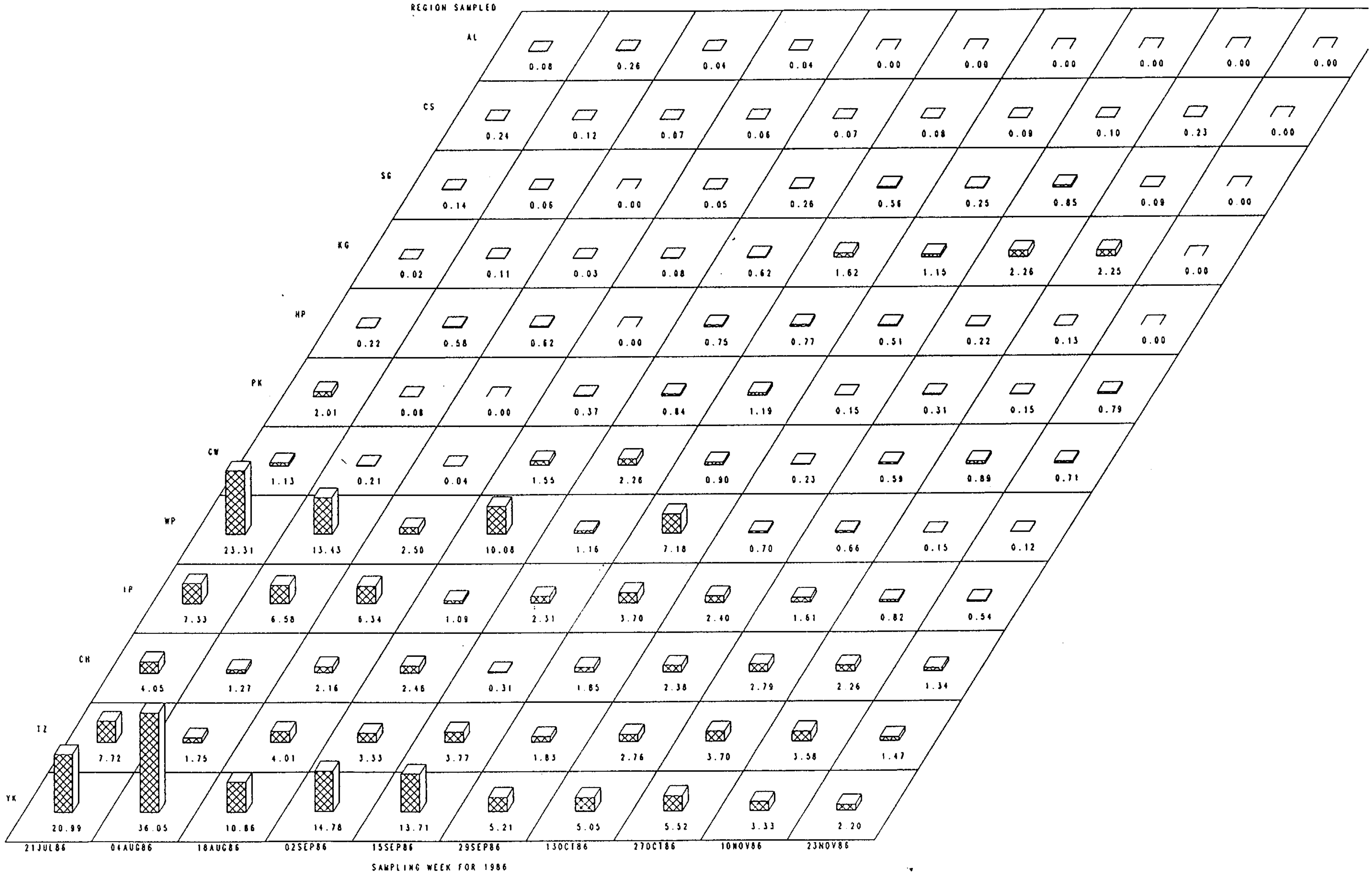


FIGURE 4-60

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR AT

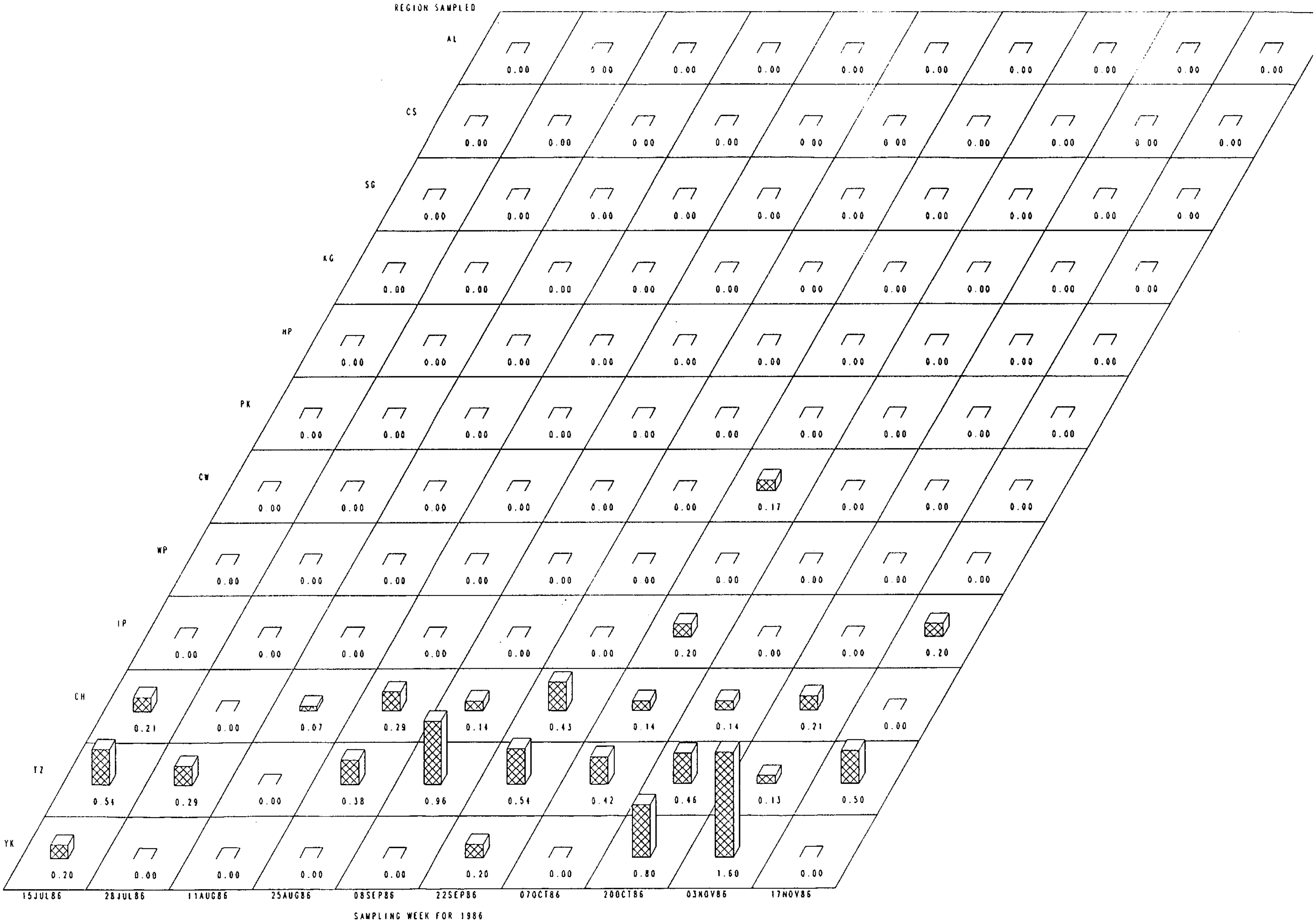
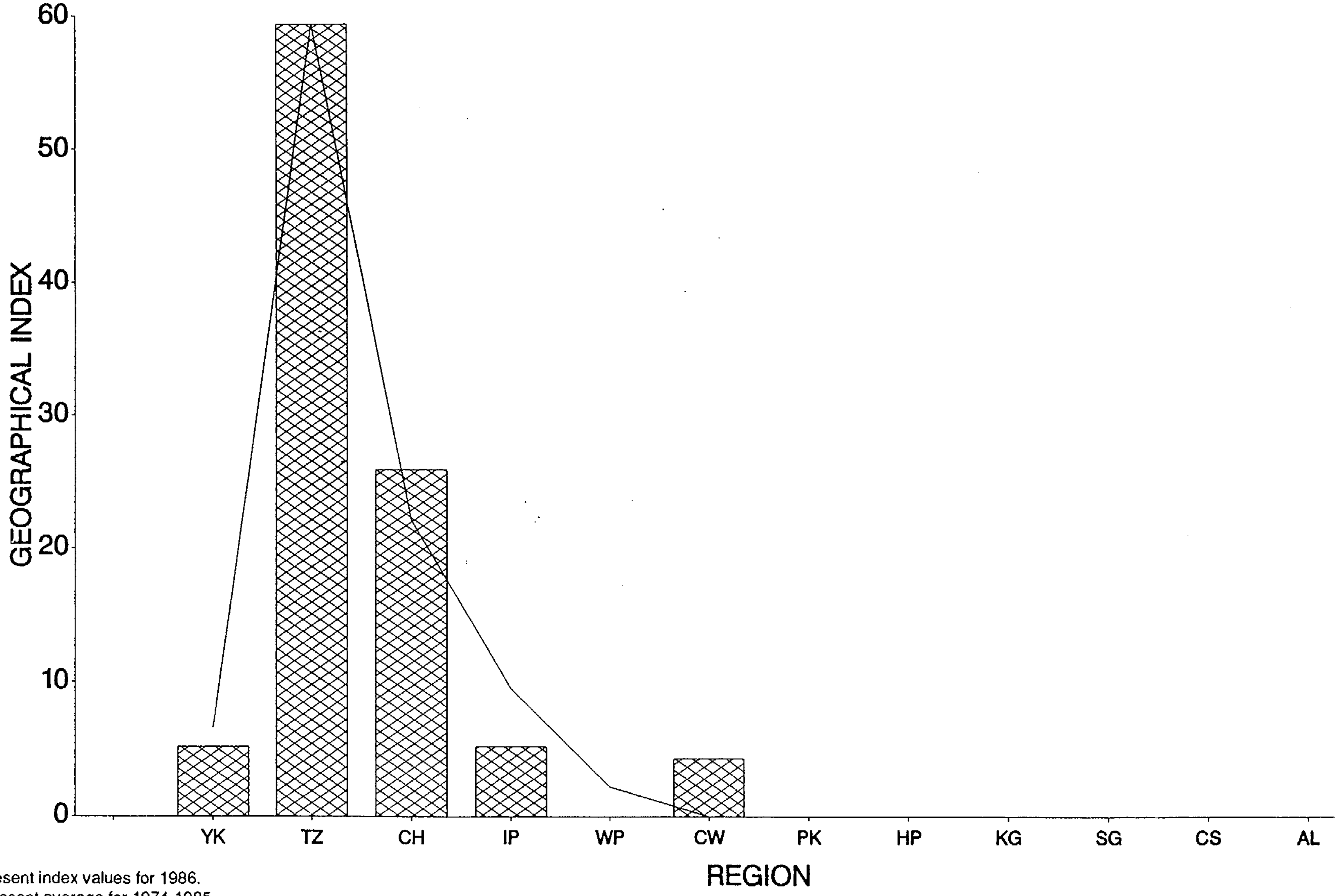


FIGURE 4-61

FIGURE 4-62

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR ATLANTIC TOMCOD COLLECTED IN THE BEACH SEINE SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

1986 LONG RIVER SURVEY

DENSITY OF YROL FOR ATLANTIC TOMCOD

BLOCK CHART OF AVG DENSITY

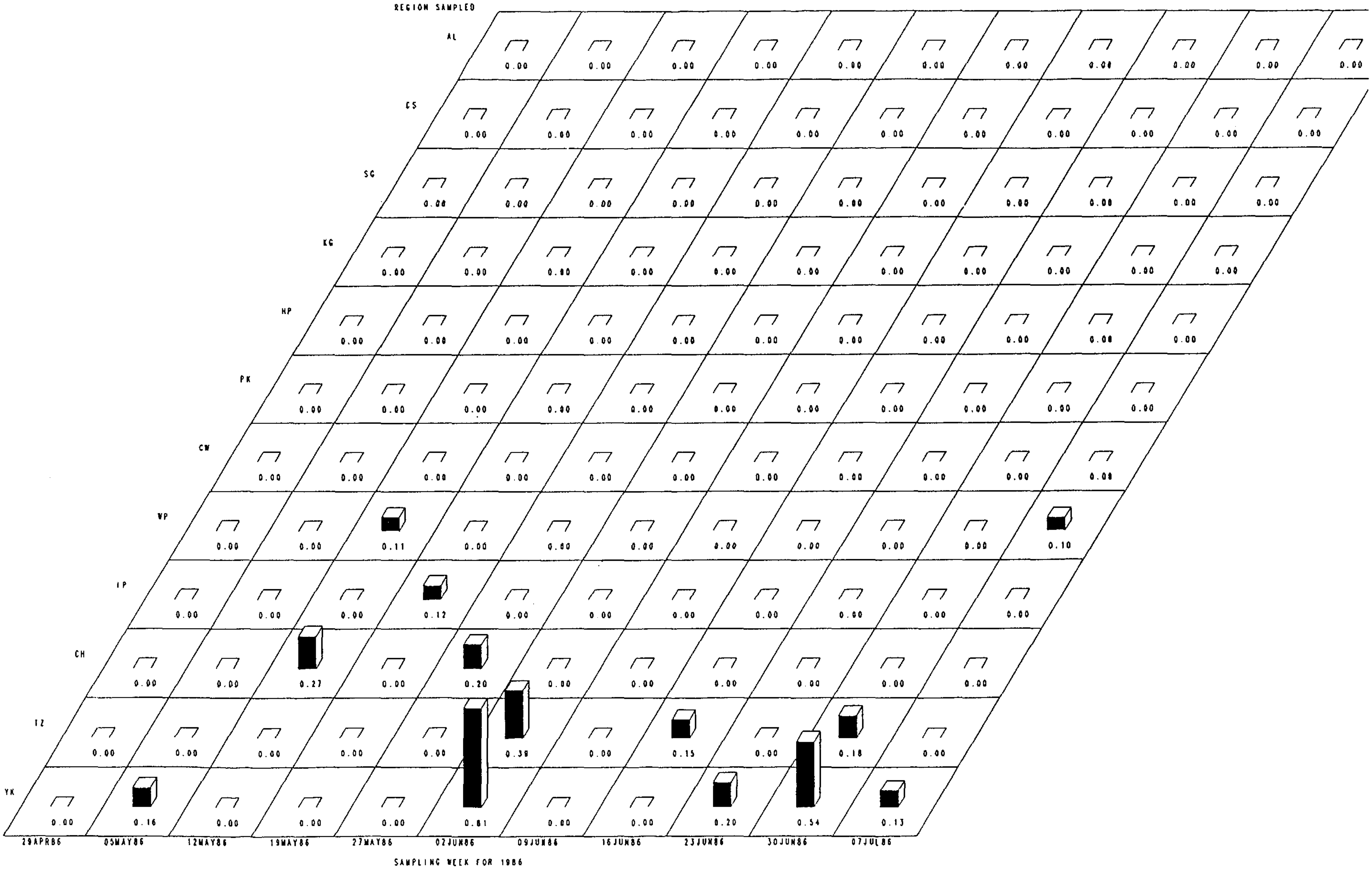


FIGURE 4-63

1986 FALL SHOALS SURVEY

DENSITY OF YRGL FOR ATLANTIC TOMCOD

BLOCK CHART OF AVG DENSITY

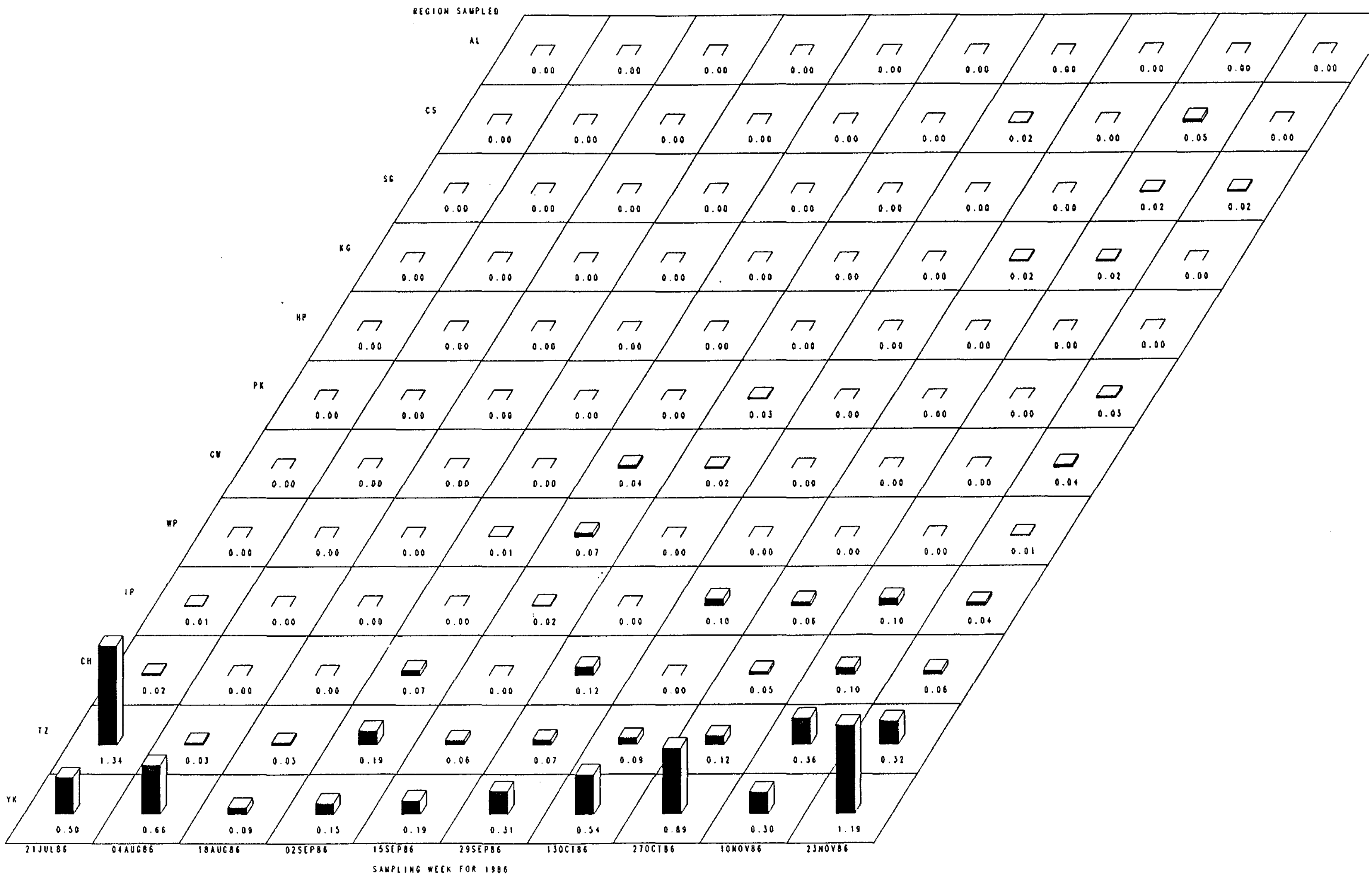


FIGURE 4-64

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR AT

BLOCK CHART OF CATCH/UNIT EFFORT

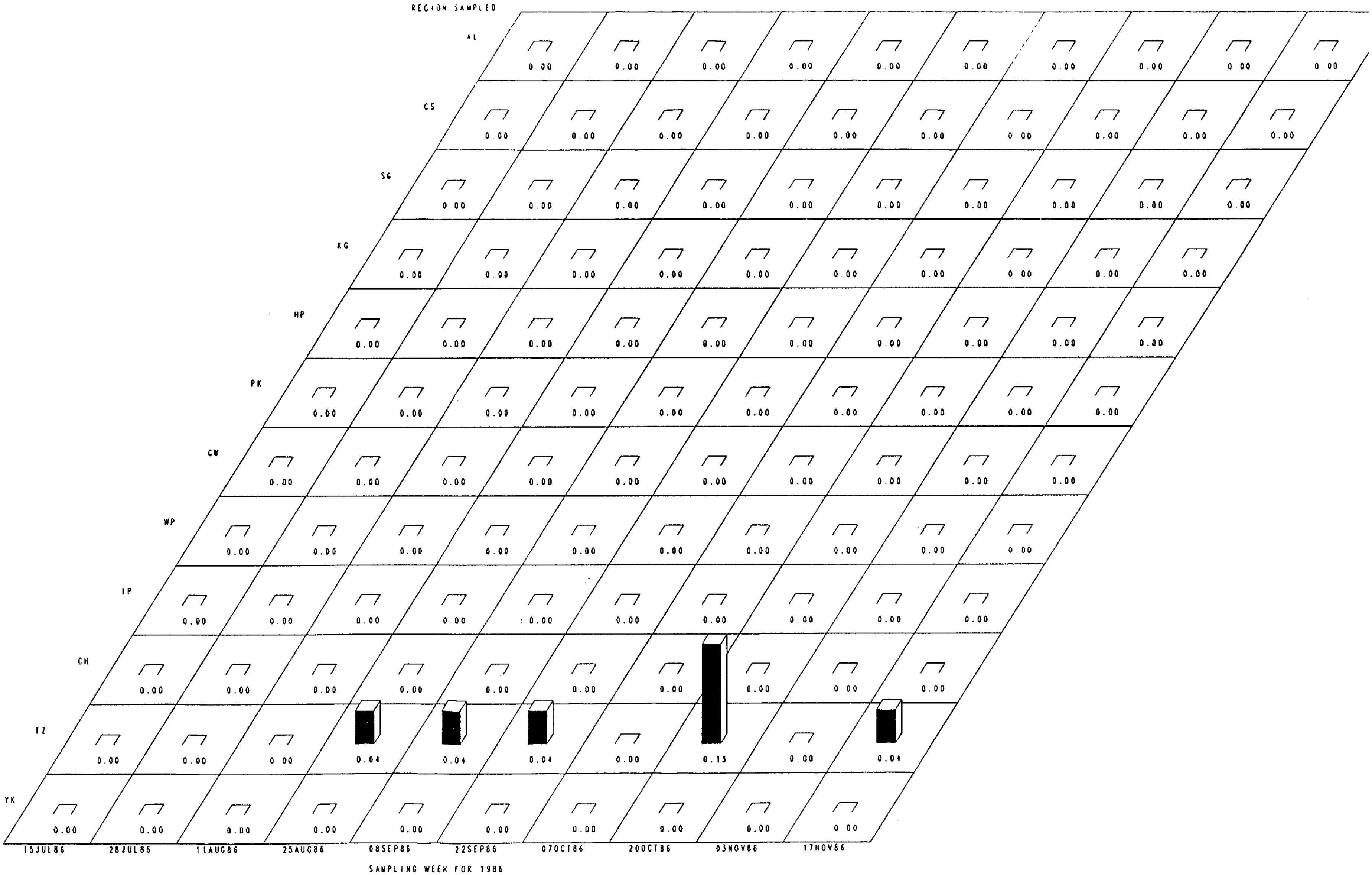


FIGURE 4–65

4.5.2.2 Yolk-Sac Larvae. No Atlantic tomcod YSL were present during the 1987 sampling program; in previous years, however, when the LRS started in March, YSL were collected through early April (Battelle 1983).

4.5.2.3 Post Yolk-Sac Larvae. PYSL were present in large numbers (>250/1000 m^3) in mid-April 1987, when the LRS program began (Figure 4-66); the densities remained high until May. Tomcod PYSL catches were limited mainly to the Yonkers and Tappan Zee regions. They were collected, however, as far upriver as the Poughkeepsie region. Peak densities occurred in the Yonkers region during mid- and late April, probably at or later than their peak abundance as reported in previous years.

4.5.2.4 Young-of-Year. Atlantic tomcod YOY were first collected during the 1987 LRS sampling week of 20 April (Figure 4-67) and were present in catches through the end of the FSS (Figure 4-68) and BSS (Figure 4-69) in November. Greatest densities occurred in the LRS from late April through early June; peak densities were estimated to have occurred during mid-May. In the FSS Atlantic tomcod YOY densities declined steadily throughout the sampling period. After August, mean regional densities were always less than 10/1000 m^3. Beach seine collections were sporadic and of low density, reflecting a deeper water preference by juveniles.

In the LRS Atlantic tomcod were found mainly from the Yonkers through Cornwall regions, but some YOY were collected in all regions. Densities of 1/1000 m^3 or more were typically limited to regions where mean salinity was greater than 1 ppt. Peak YOY density occurred in the Yonkers region. Juveniles were collected north of the West Point region on only one occasion during the BSS. The BSS geographical distribution pattern observed was similar to that of previous Year Class Reports (Figure 4-70).

4.5.2.5 Yearling and Older Fish. Yearling and older Atlantic tomcod were collected in every sampling period of the 1987 LRS (Figure 4-71) and FSS (Figure 4-72) programs. Temporal distribution was nearly evenly distributed

1987 LONG RIVER SURVEY

DENSITY OF PYSL FOR ATLANTIC TOMCOD

BLOCK CHART OF AVG DENSITY

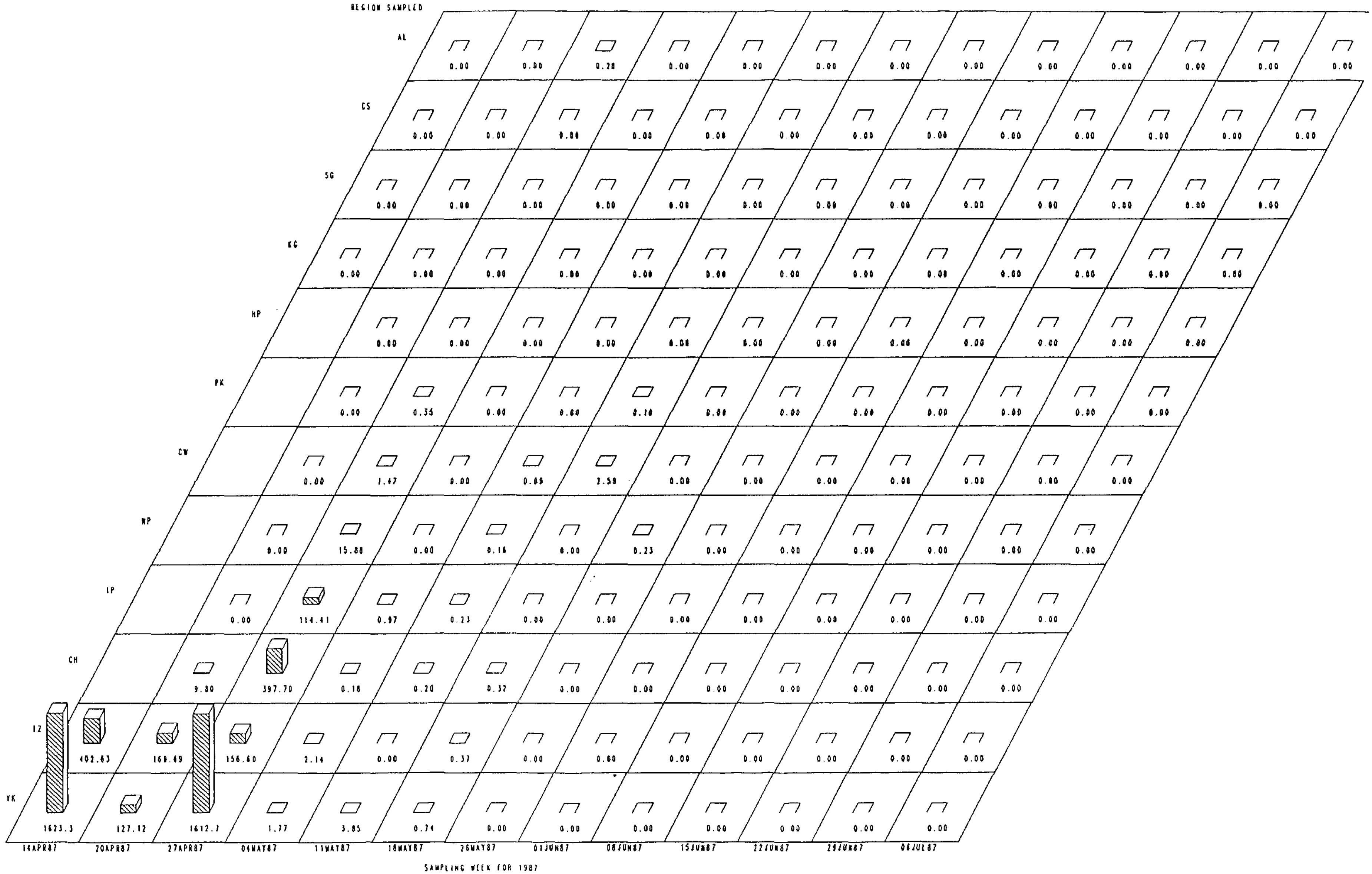


FIGURE 4-66

1987 LONG RIVER SURVEY

DENSITY OF YOY FOR ATLANTIC TOMCOD

BLOCK CHART OF AVG DENSITY

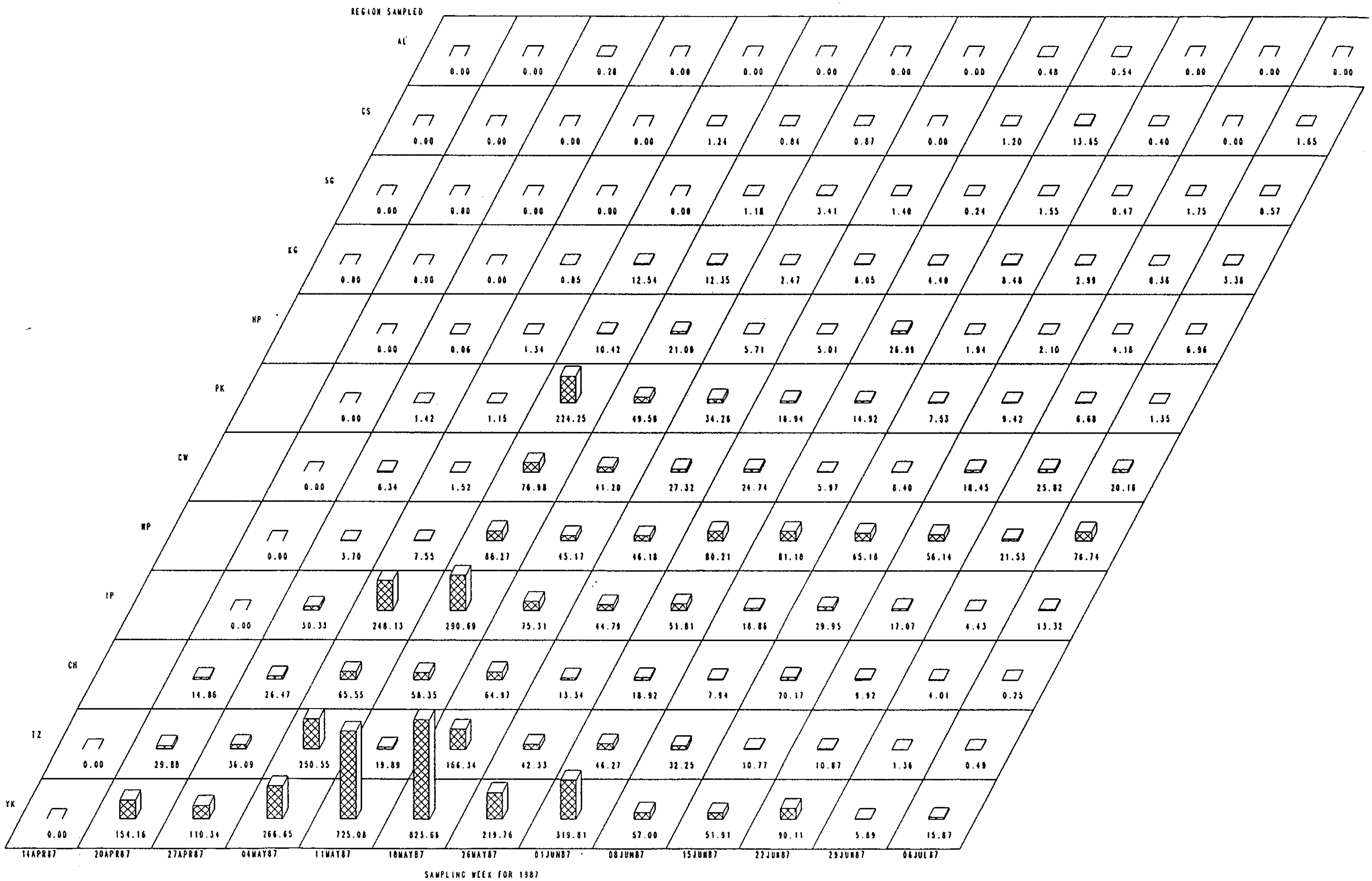


FIGURE 4-67

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR ATLANTIC TOMCOD

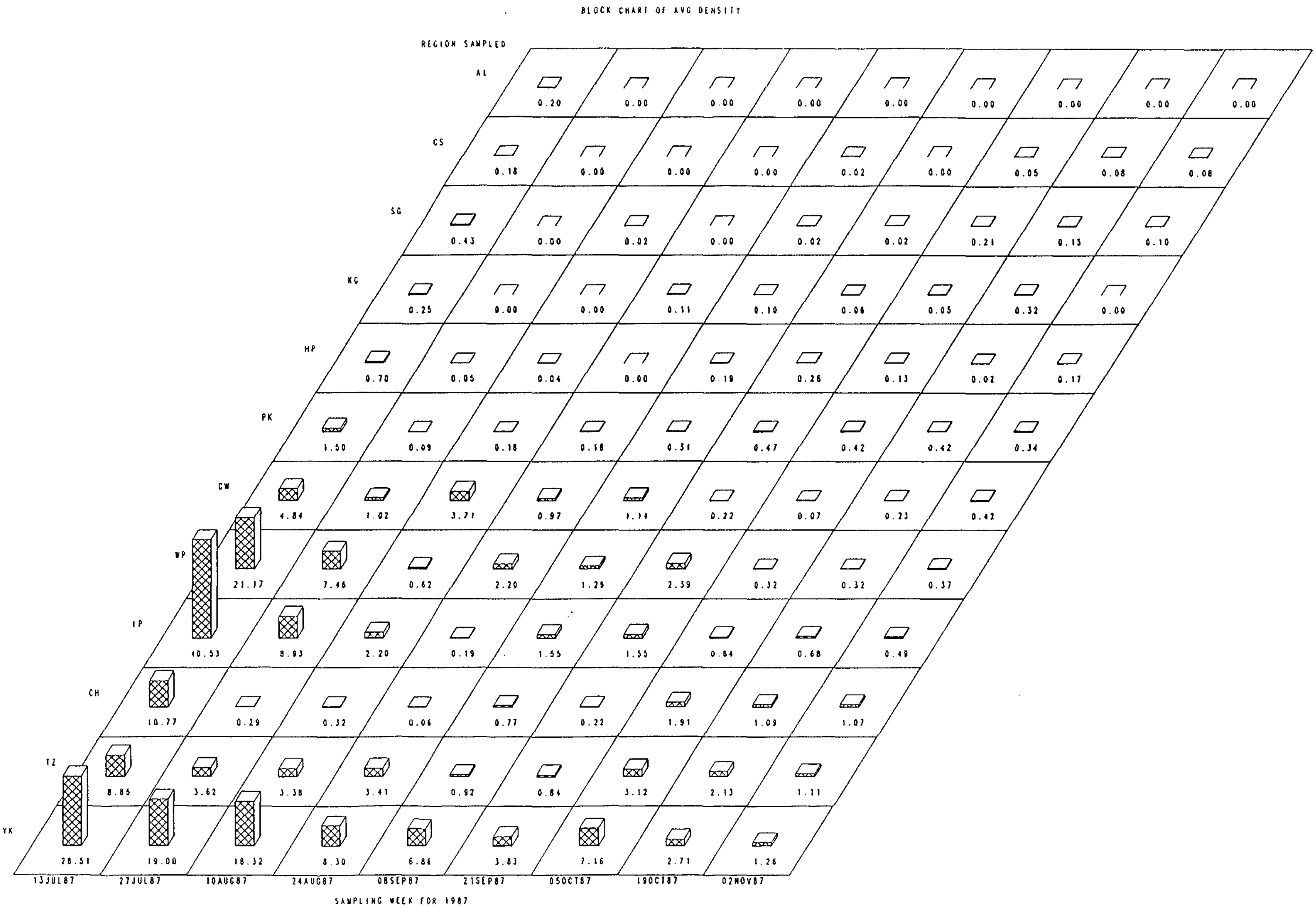


FIGURE 4-68

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR ATLANTIC TOMCOD

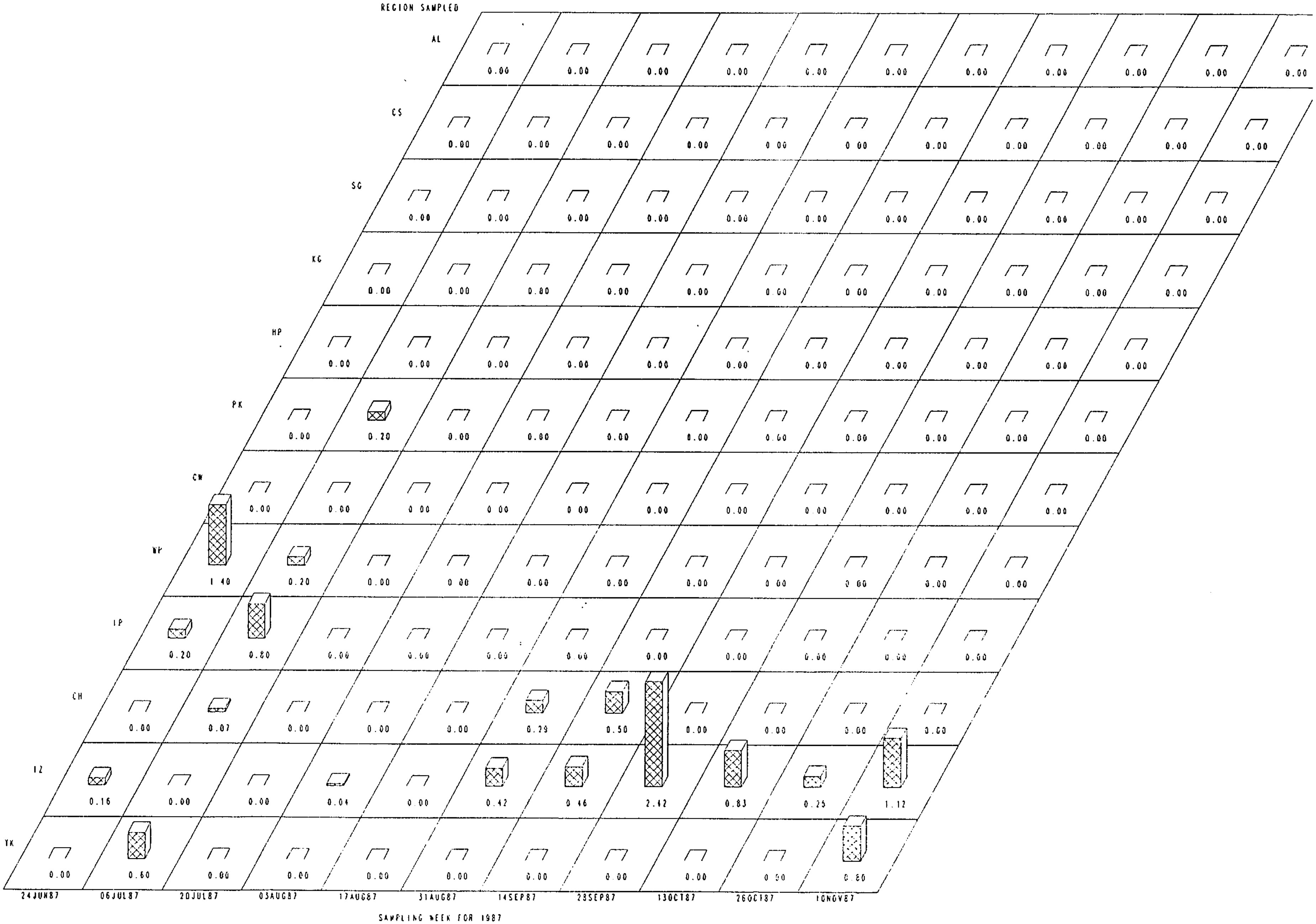
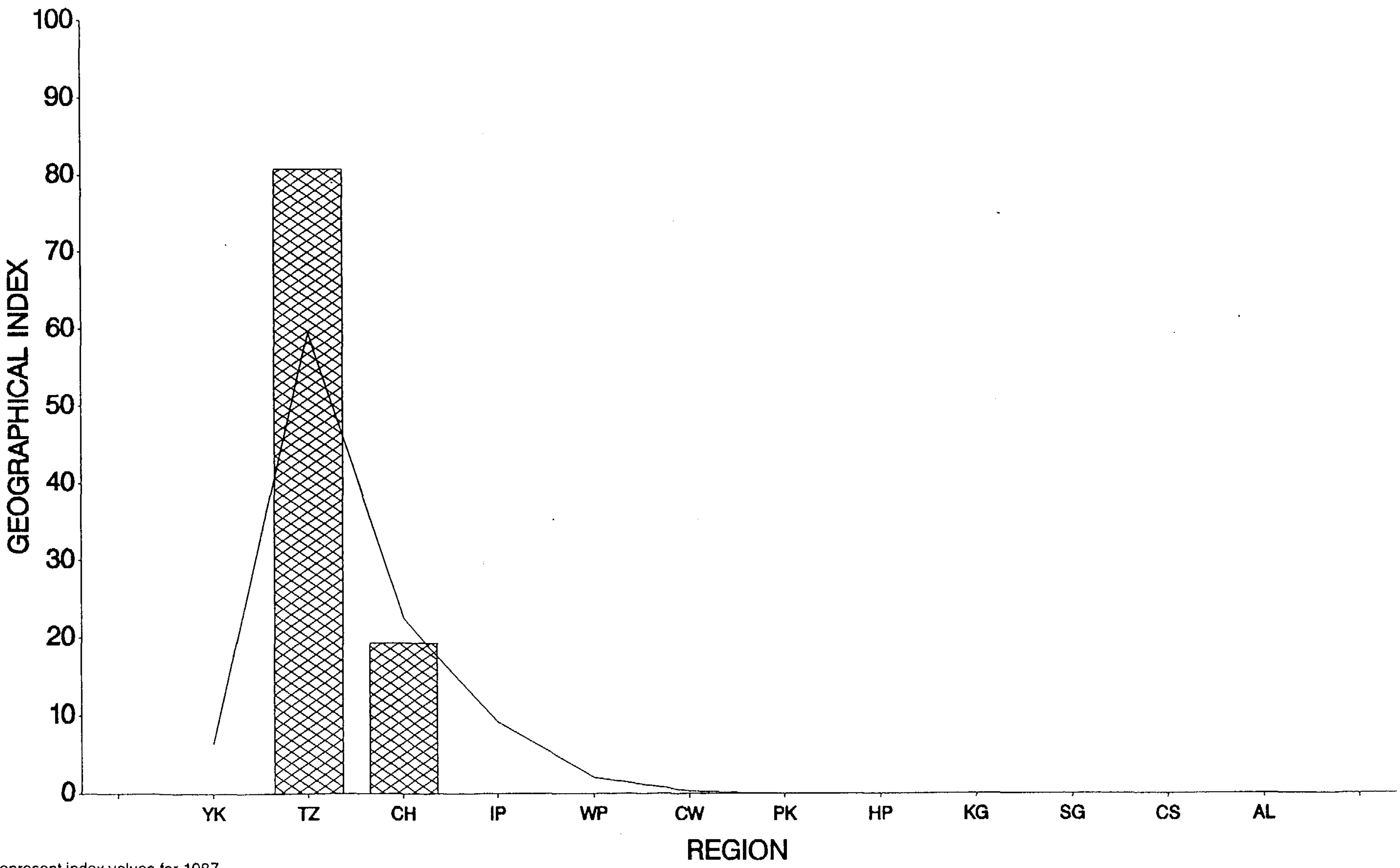


FIGURE 4-69

FIGURE 4-70

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR ATLANTIC TOMCOD COLLECTED IN THE BEACH SEINE SURVEY, 1987



LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

1987 LONG RIVER SURVEY
DENSITY OF YROL FOR ATLANTIC TOMCOD

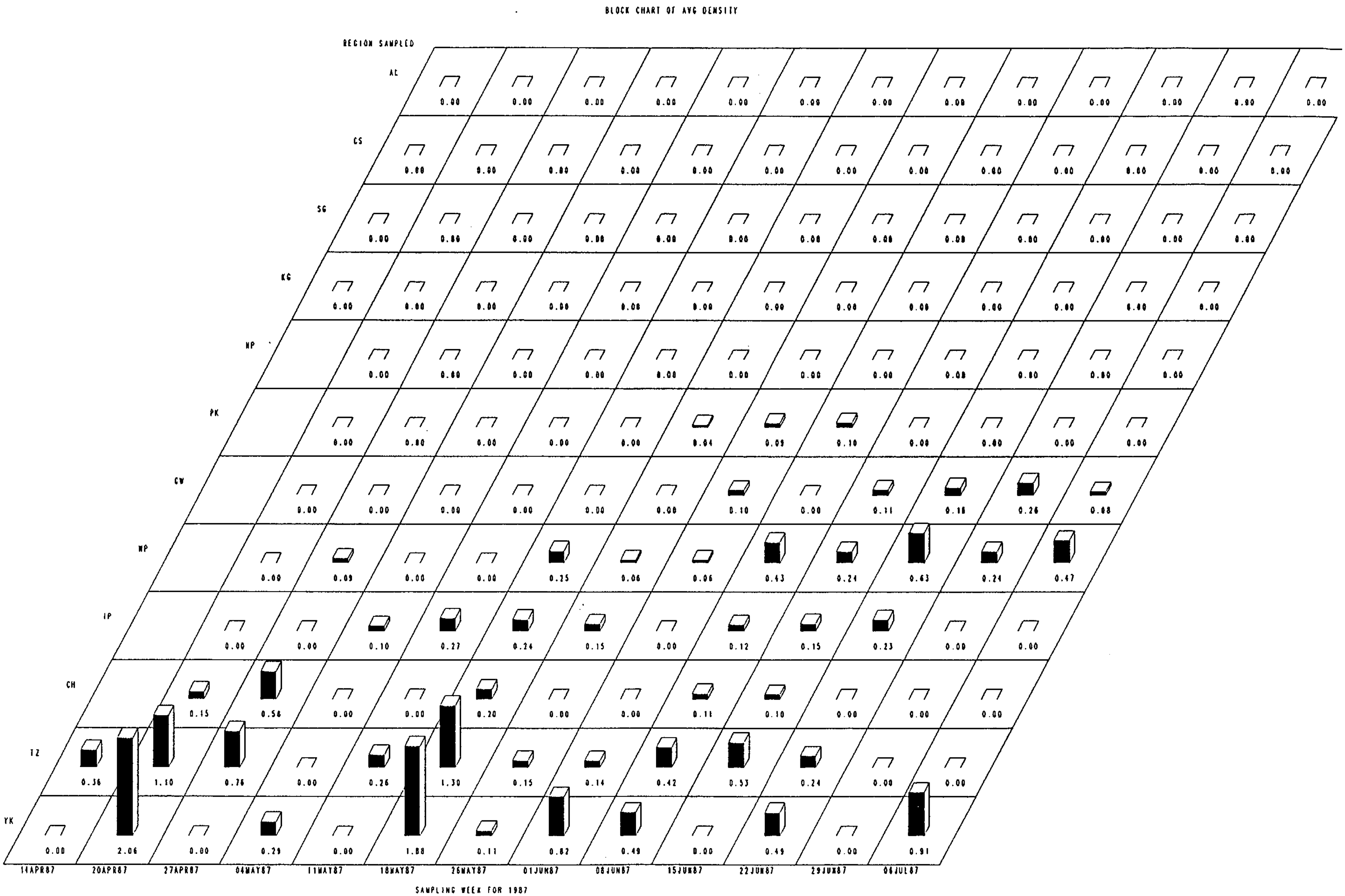


FIGURE 4-71

1987 FALL SHOALS SURVEY
DENSITY OF YROL FOR ATLANTIC TOMCOD

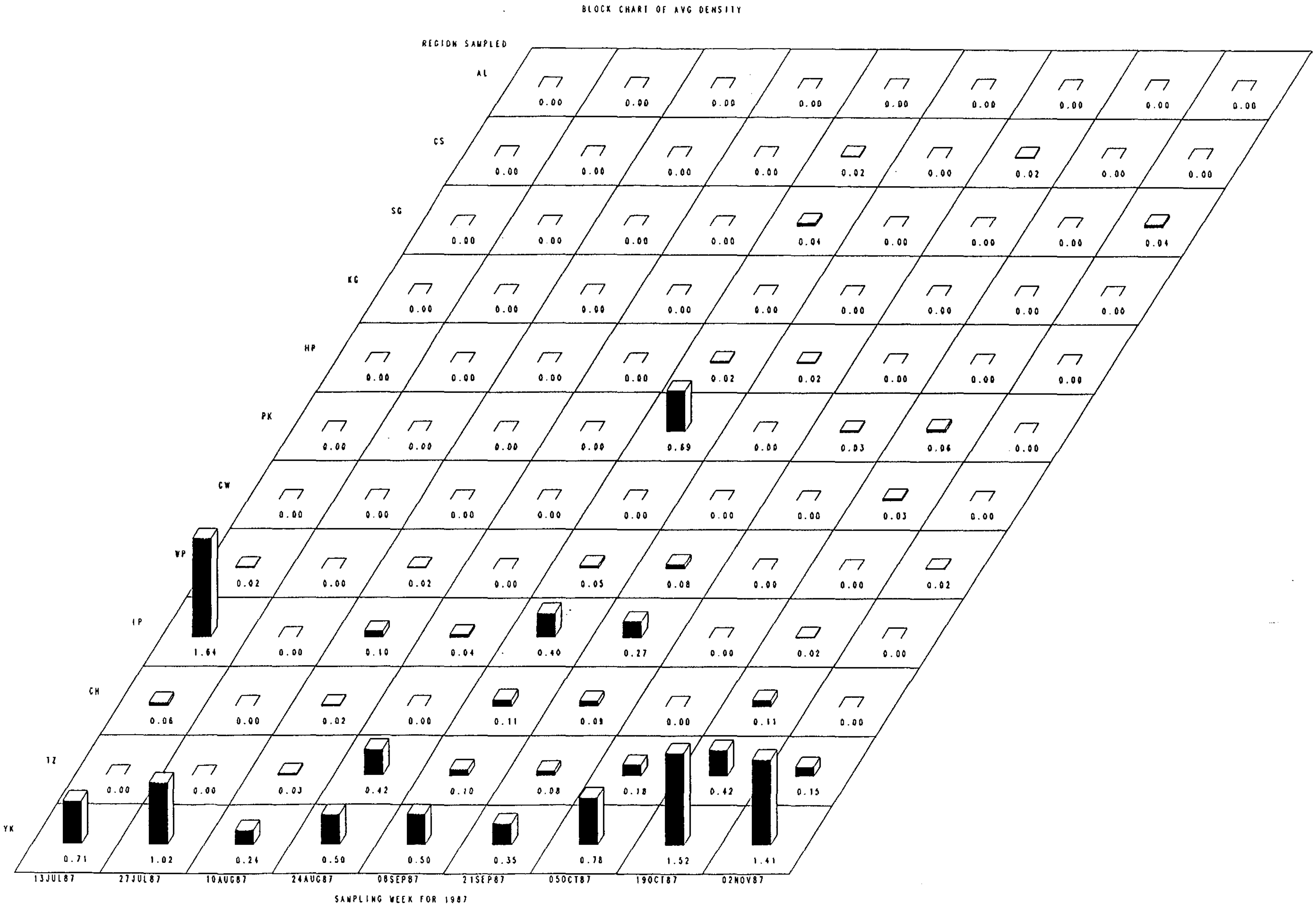


FIGURE 4-72

throughout the LRS, with only a slight peak in late April. Beach seine catches were recorded from late August through the final sampling week of the BSS (Figure 4-73); all but one catch was made at the Tappan Zee region. As in the 1986 FSS and BSS, yearling and older Atlantic tomcod densities increased in late fall, probably as a result of fish moving upriver to spawn.

Spatial distribution was limited primarily to the Yonkers and Tappan Zee regions, with greatest densities estimated in the bottom strata. Yearling and older tomcod abundance increased upriver through the Poughkeepsie region during June and July and appeared to be limited to waters with salinities greater than 1 ppt. The increasing occurrence of tomcod in freshwater portions of the estuary throughout September and October likely reflects upriver movement related to spawning.

4.6 AMERICAN SHAD

The range of the American shad, Alosa sapidissima (Wilson), an anadromous fish belonging to the herring family Clupeidae, extends from Newfoundland to Florida. Spawning occurs in the spring in freshwater tributaries of coastal rivers. American shad are found throughout the Hudson River estuary. Their migration is impeded by the Federal Dam at Troy, New York (Sheppard 1976).

American shad generally spawn in flat, shallow areas or in river channels where sand and/or gravel substrates are present. Water depths are usually 3 to 30 ft, with currents from <1 to >3 fps (Walburg and Nichols 1967). Spawning was observed by Chittenden (1969) in waters as shallow as 6 to 12 in. Smith (1907) concluded that although flats are the typical spawning location, egg deposition could also occur elsewhere. Spawning in the Hudson River occurs in tributaries as well as in river flats, primarily from the Hyde Park to Catskill regions (RM 77-124) when water temperatures are from 7 to 14°C (TI 1981). American shad spawning locations in 1986 and 1987, as inferred from coincidental large egg densities (>10/1000 m^3), were scattered upriver from Kingston (RM 92), with greatest abundance between Coxsackie and the Binnen

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF TROL FOR ATLANTIC TOMCOD

BLOCK CHART OF CATCH/UNIT EFFORT

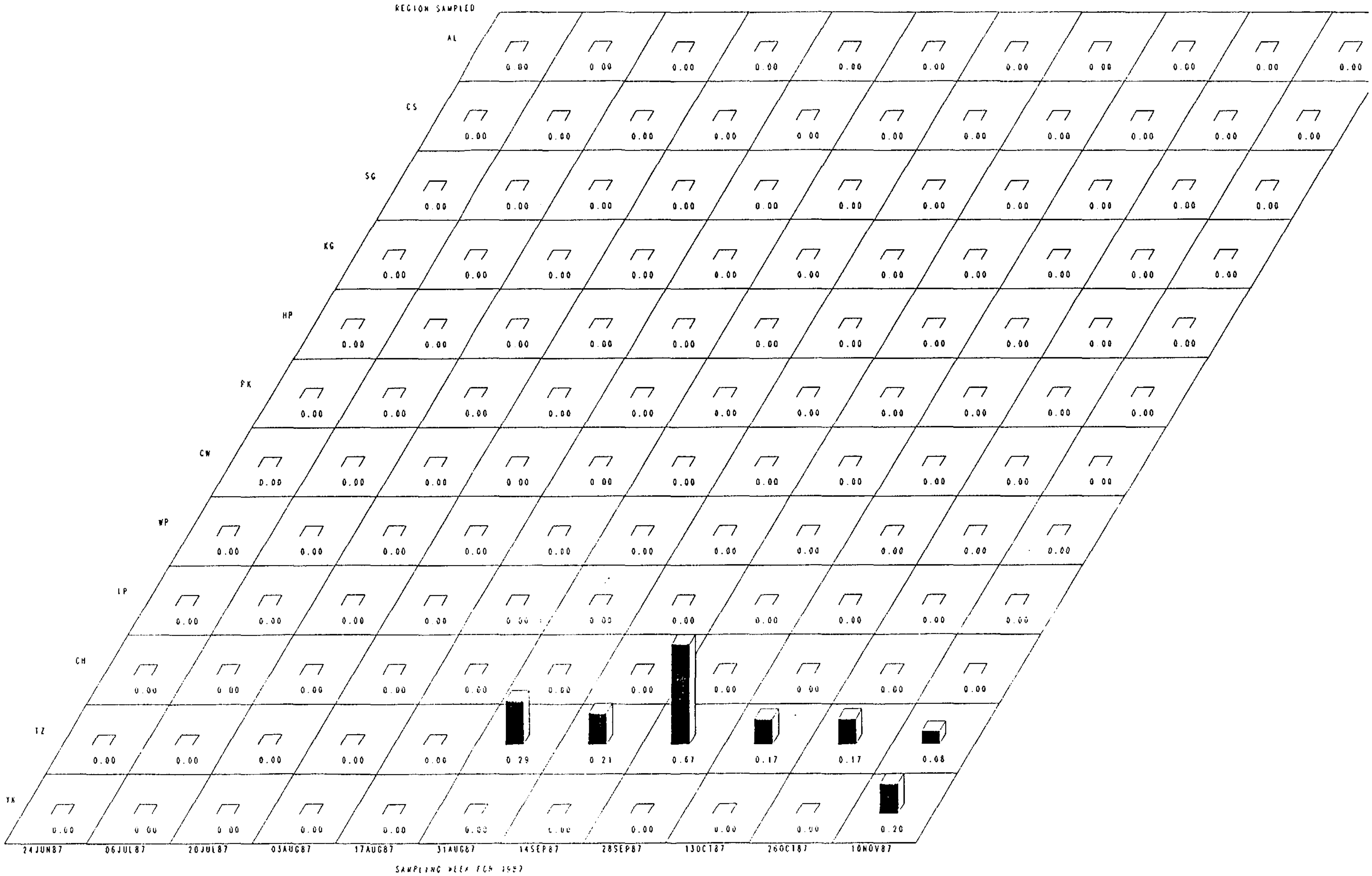


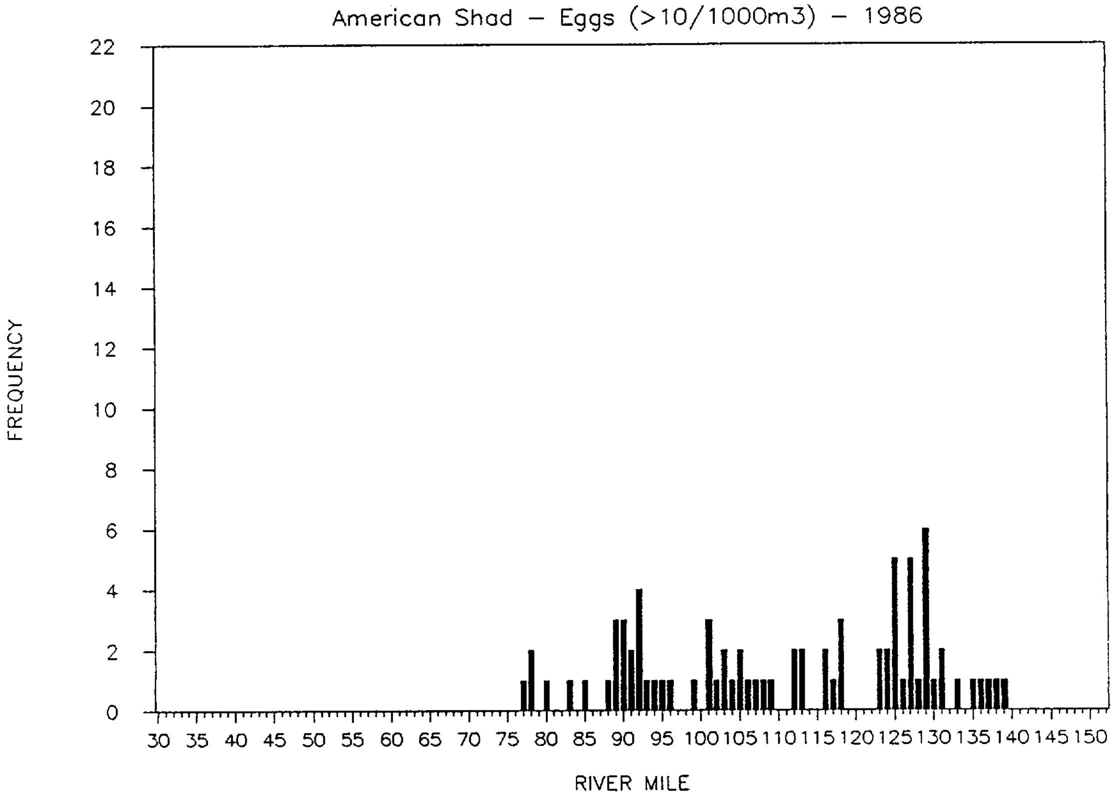
FIGURE 4-73

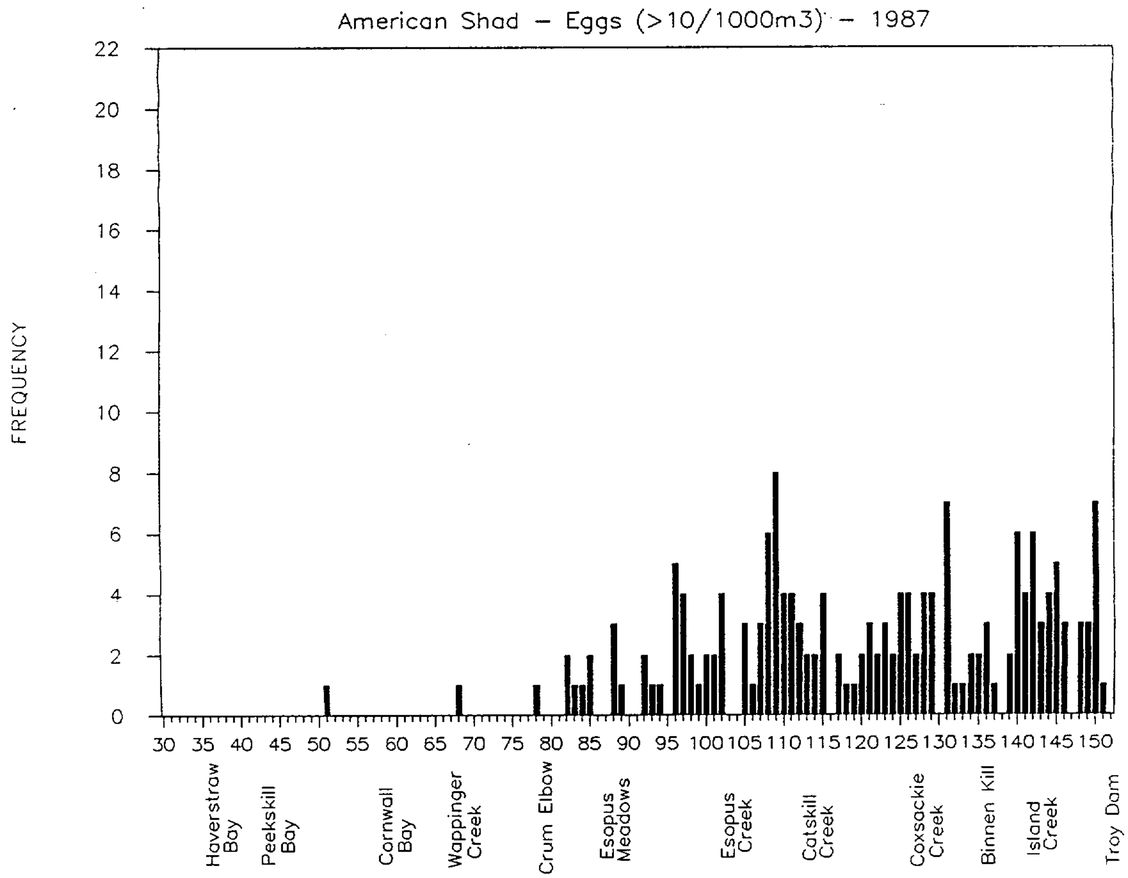
Kill (RM 125-136) (Figure 4-74). During 1987 large egg densities were also found from RM 139 to 142, with densities from 100 to 1000/1000 m^3 collected upriver to Albany (RM 151). No spawning areas were indicated in these upper reaches of the estuary in 1986, probably because the sampling effort began after spawning events had occurred. Egg collections in 1987 first occurred in the Catskill and Albany regions (RM 107-151), when mean regional weekly water temperatures were 13.0 and 12.5°C, respectively. During the initial 1986 sampling week the temperatures were already above 14°C in these same regions. Walburg and Nichols (1967) reported that American shad can spawn at water temperatures from 8 to 26°C, but that most spawning occurs from 12 to 21°C. Most of the river areas where eggs were collected in large density (>10/1000 m^3) were adjacent to shallow flats and bays or were near large river tributaries (Figures 4-1b to 4-1g). Mansueti and Kolb (1953) noted that at suitable water temperatures American shad will spawn wherever they are in the river.

The eggs of American shad are demersal and nonadhesive, with each female typically laying over 50,000 (Leggett 1969). After spawning, those adult shad that survive return to the ocean to spend summers in the Gulf of Maine (Scott and Crossman 1973). In many rivers north of Chesapeake Bay, adults may return to spawn as many as five times, with spawning first occurring at age 3 or 4 (Leggett and Carscadden 1978). Mansueti and Hardy (1967) reported incubation time from two days at 27°C to 17 days at 12°C. Larvae are no longer dependent on their yolk-sac after five days at 17°C (Mansueti and Hardy 1967) and feed throughout the summer on copepods, terrestrial insects, and certain cladocerans (Domermuth and Reed 1980). As fall river temperatures decline, the juvenile shad migrate out of the estuary and remain in the ocean until mature (approximately three to five years). Adult shad are commercially harvested each spring, primarily from the lower river through RM 144 (Kahnle and Brandt 1984). Sport harvest has not been assessed in the Hudson, but is relatively popular and occurs in the same reach.

FIGURE 4-74

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





4.6.1 1986 Study

4.6.1.1 Eggs. In 1986 American shad eggs were most abundant in the Hudson River estuary during the first week of sampling (29 April through 4 May). Extensive concentrations were located in the Catskill and Albany regions (Figure 4-75). Previous Year Class Reports have reported peak egg density for shad in early to mid-May. The late April peak abundance in 1986 was also reported in the 1978 Year Class Report when a bimodal peak was observed (TI 1980). Shad eggs were caught in all regions north of the Indian Point region, with mean regional density estimates exceeding 10/1000 m^3 from the Kingston to the Albany region (RM 86-151). Similar spatial distribution and peak density were reported in previous Year Class Reports from 1979 through 1984 with the exception of 1982.

Peak spawning temperatures have been reported from several shad spawning rivers: 16 and 17°C for Virginia streams (Massman 1952), approximately 18°C for Canadian waters (Scott and Crossman 1973), and peaks of 22°C in 1967 and 14.8°C in 1968 in the lower Connecticut River (Marcy 1976). The recorded water temperature of 14 to 15°C during the initial sampling run, when program egg densities were highest in the upper estuary, approximates those recorded by Marcy (1976) for the Connecticut River. Spawning likely started prior to the initial sampling run since American shad can spawn at temperatures as cold as 8°C (Walburg and Nichols 1967).

In 1986 American shad eggs were collected in the upper estuary until the end of June when water temperatures were 23°C. Egg densities above 10/1000 m^3, however, were not collected from any sample region after water temperatures rose above 21°C. All of the high egg densities in both 1986 and 1987 were sampled during shoal sampling efforts; most were collected with the epibenthic sled. In plankton sampling by Massman (1952) American shad eggs were six times more abundant in bottom than surface collections. A slight bimodal temporal distribution of egg densities was noticeable in the upper estuary. The first peak, which occurred during the initial sampling run, was followed by a

1986 LONG RIVER SURVEY

DENSITY OF EGGS FOR AMERICAN SHAD

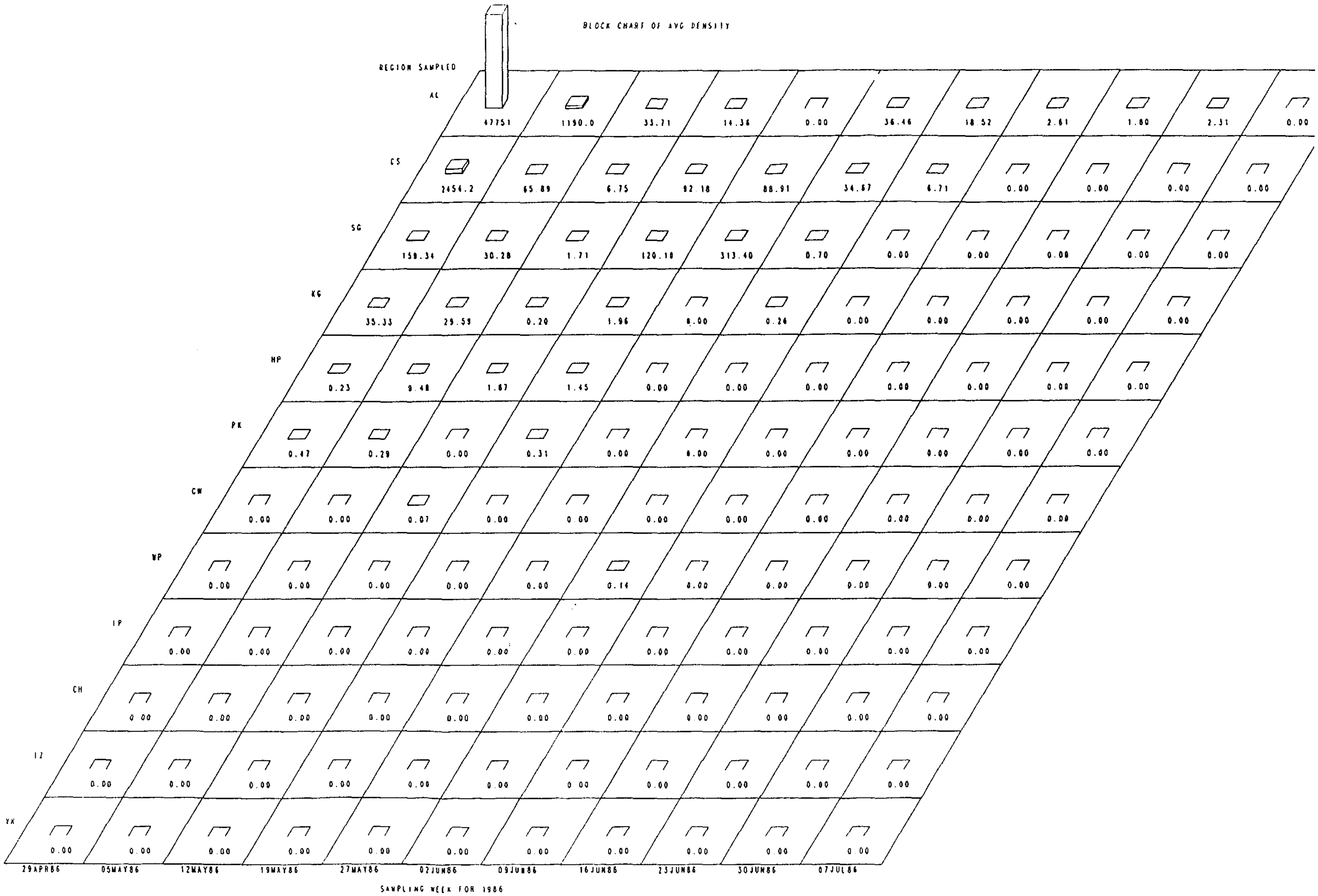


FIGURE 4-75

lower peak toward the end of May. The second peak corresponds to a period of above-normal water flow (Figure 4-7); therefore, the high densities observed may represent increased egg vulnerability to the sampling gear rather than a second spawning peak.

4.6.1.2 Yolk-Sac Larvae. In 1986 YSL were already present in the estuary when the LRS was initiated and were collected throughout the sampling program (Figure 4-76). Greatest abundances occurred from early May through early June. Peak YSL abundance followed the first peak in egg density by about one week. YSL were concentrated in the Albany and Catskill regions, with trace numbers sampled as far downriver as the Poughkeepsie region. This is the typical spatial distribution pattern reported in most previous years (TI 1981; Battelle 1983; NAI 1985a; Versar 1987). In 1984 shad YSL were sampled at densities exceeding 100/1000 m^3 as far south as the Indian Point region. This occurred during periods of above-average freshwater flow.

4.6.1.3 Post Yolk-Sac Larvae. American shad PYSL were present in the 1986 LRS beginning in mid-May and were collected throughout the sampling program (Figure 4-77). Peak abundance was estimated during early June, with densities tapering off throughout the month.

Greatest densities were estimated for the Catskill region during the 2 June sampling week. As in most previous years, PYSL abundance was spread throughout the upper estuary, with catches occurring as far south as the Croton-Haverstraw region. The presence of larvae in the lower estuary in early June was likely the result of downstream dispersion caused by the above-average flow in late May.

4.6.1.4 Young-of-Year. YOY were first collected during the seventh sampling week (9 June) of the LRS 1986 (Figure 4-78) and were present in every sample run of the FSS (Figure 4-79) and BSS (Figure 4-80) programs. Peak density occurred during the last week of June and the first week of July from the

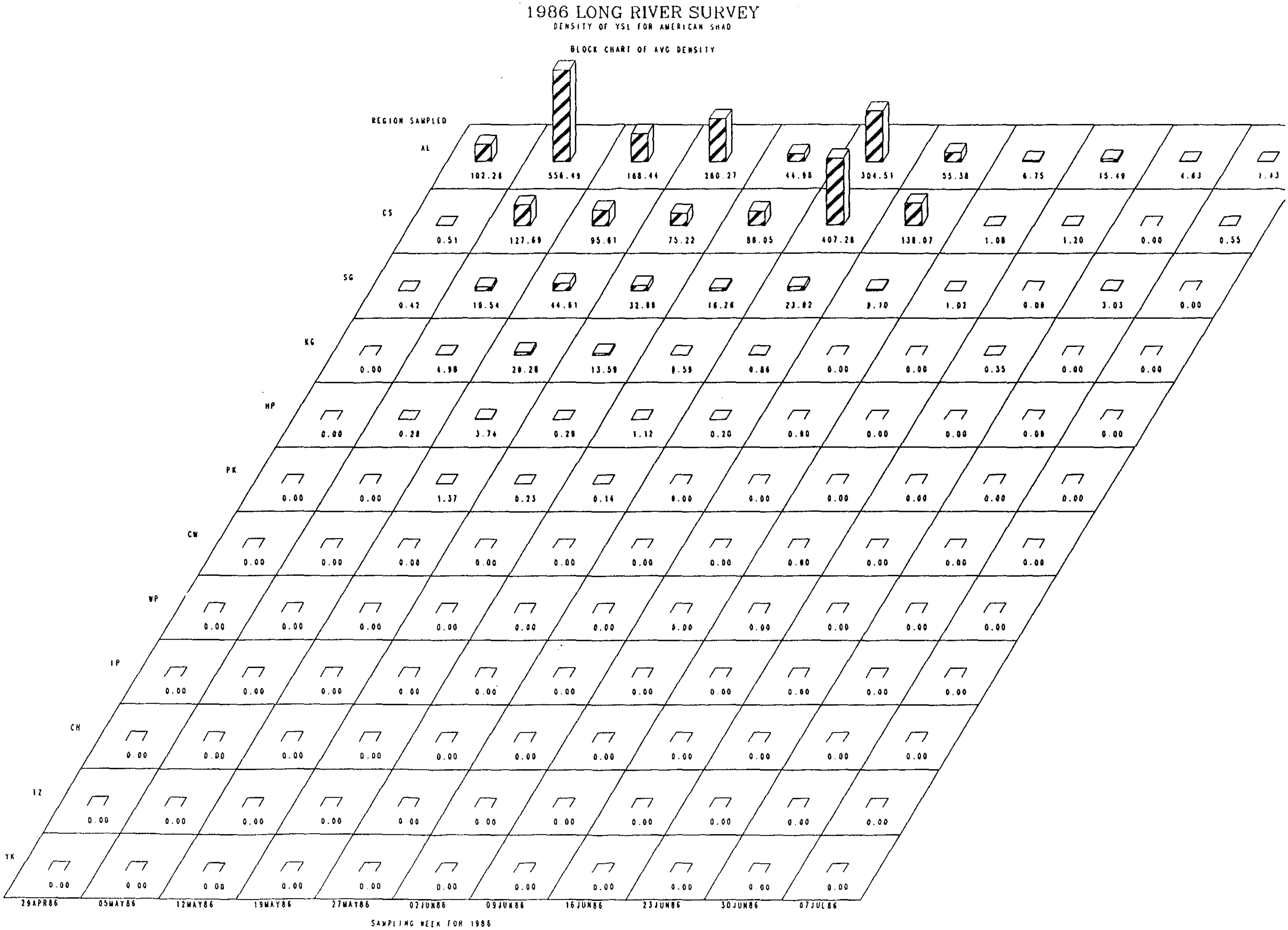

1986 LONG RIVER SURVEY
DENSITY OF YSL FOR AMERICAN SHAD
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
IZ
YK
29APR86
05MAY86
12MAY86
19MAY86
27MAY86
02JUN86
09JUN86
16JUN86
23JUN86
30JUN86
07JUL86
SAMPLING WEEK FOR 1986

FIGURE 4-76

1986 LONG RIVER SURVEY

DENSITY OF PYSL FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

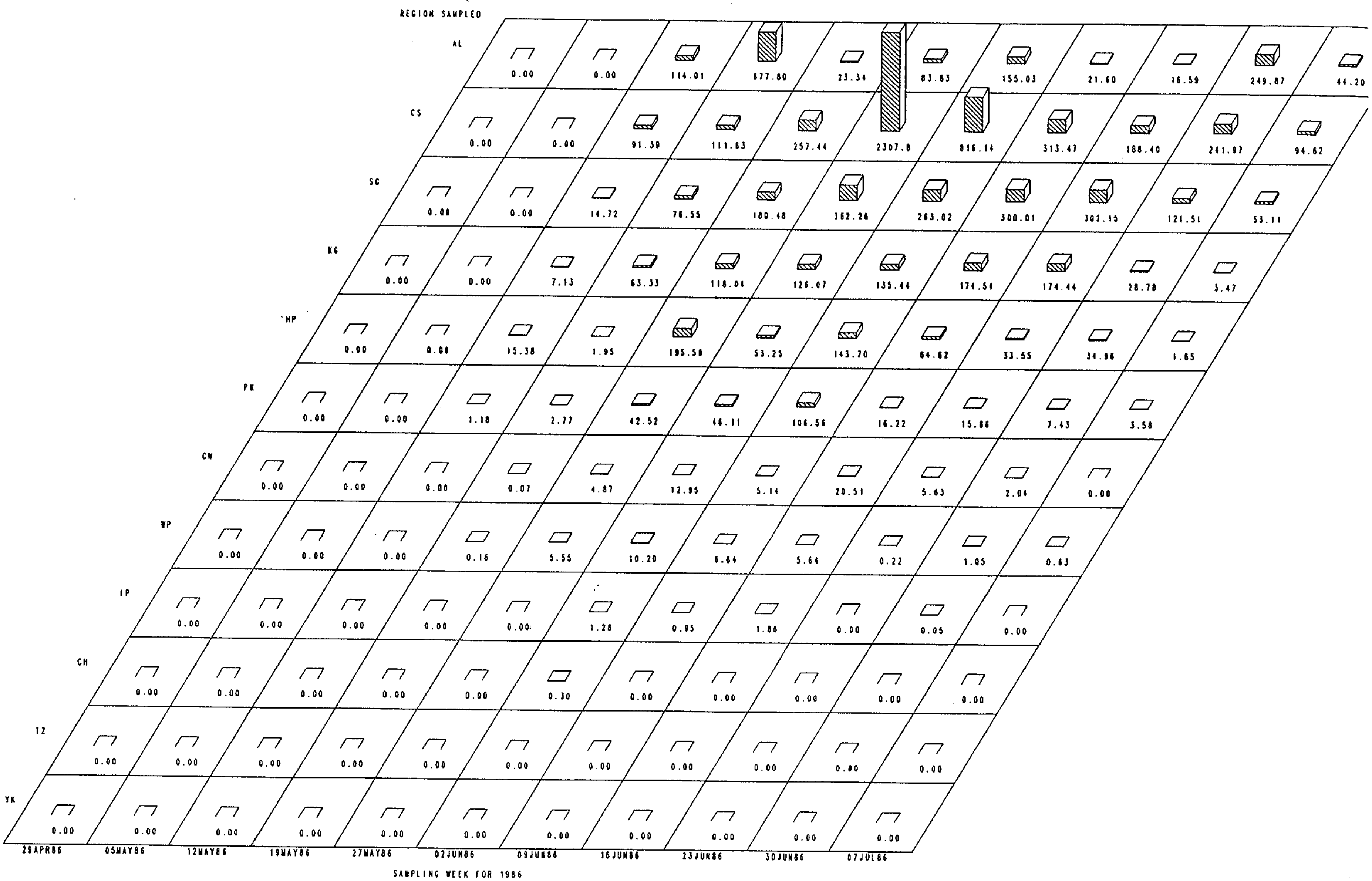


FIGURE 4-77

1986 LONG RIVER SURVEY

DENSITY OF YOY FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

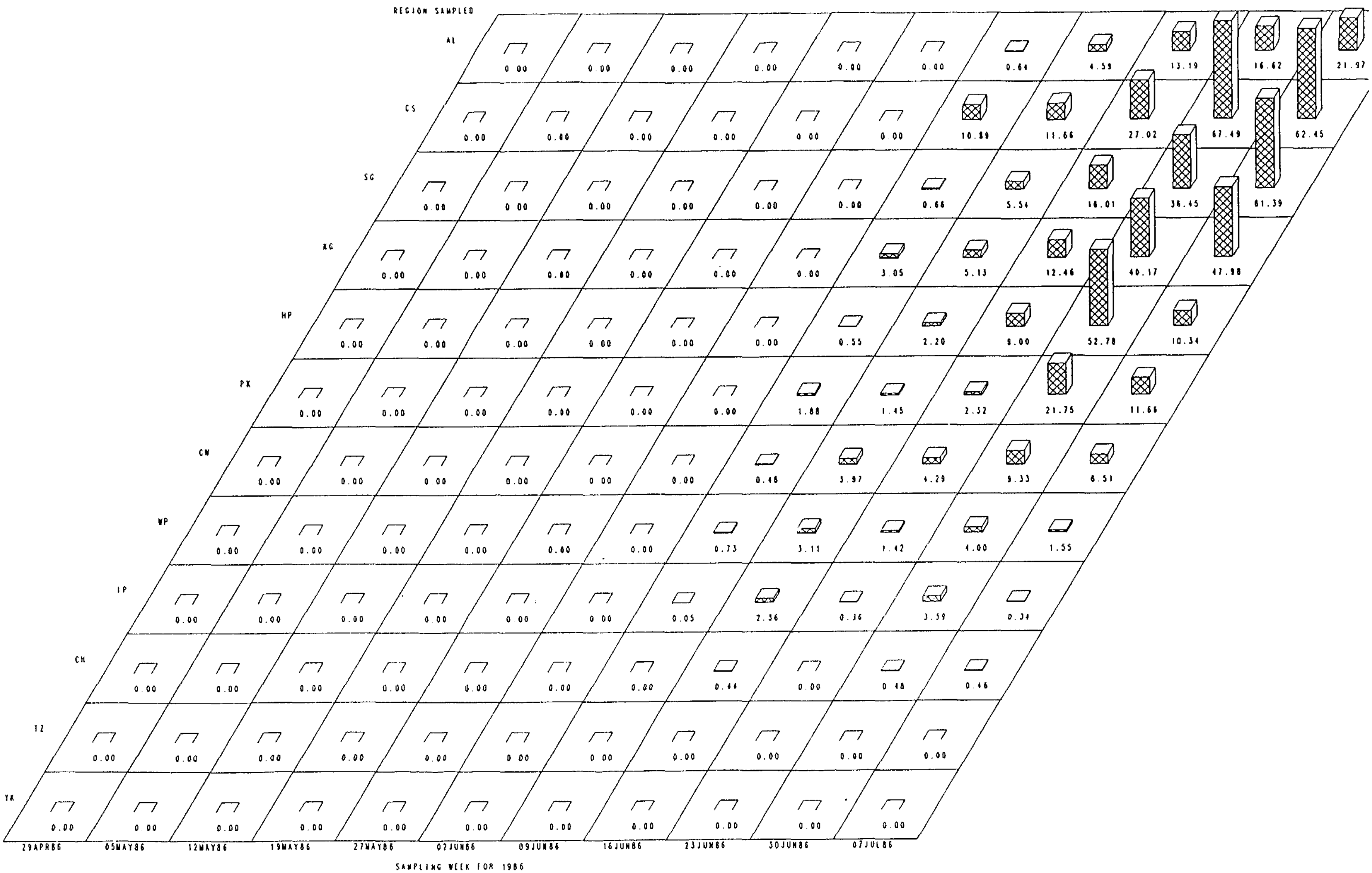


FIGURE 4-78

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

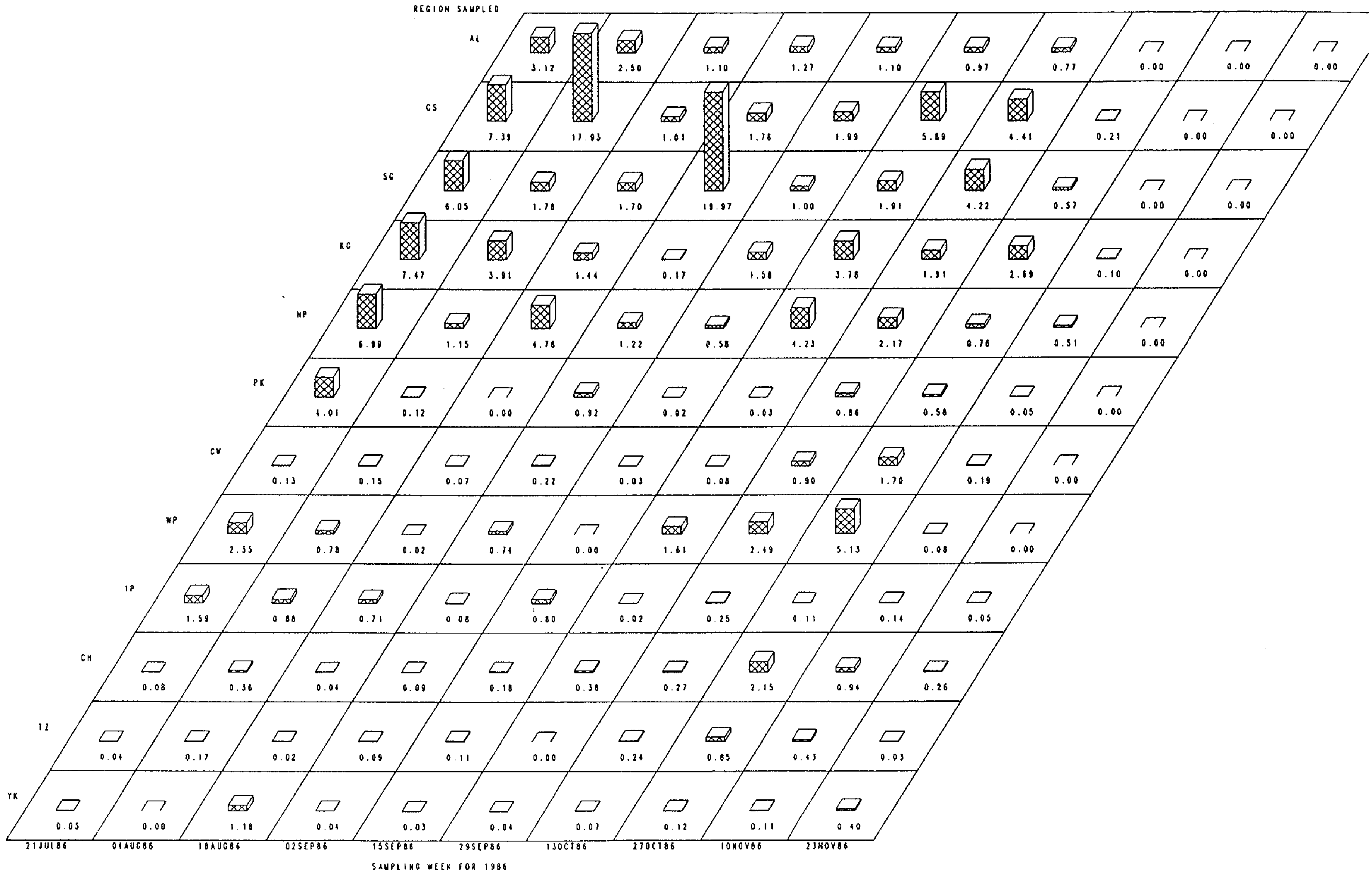


FIGURE 4-79

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR AS

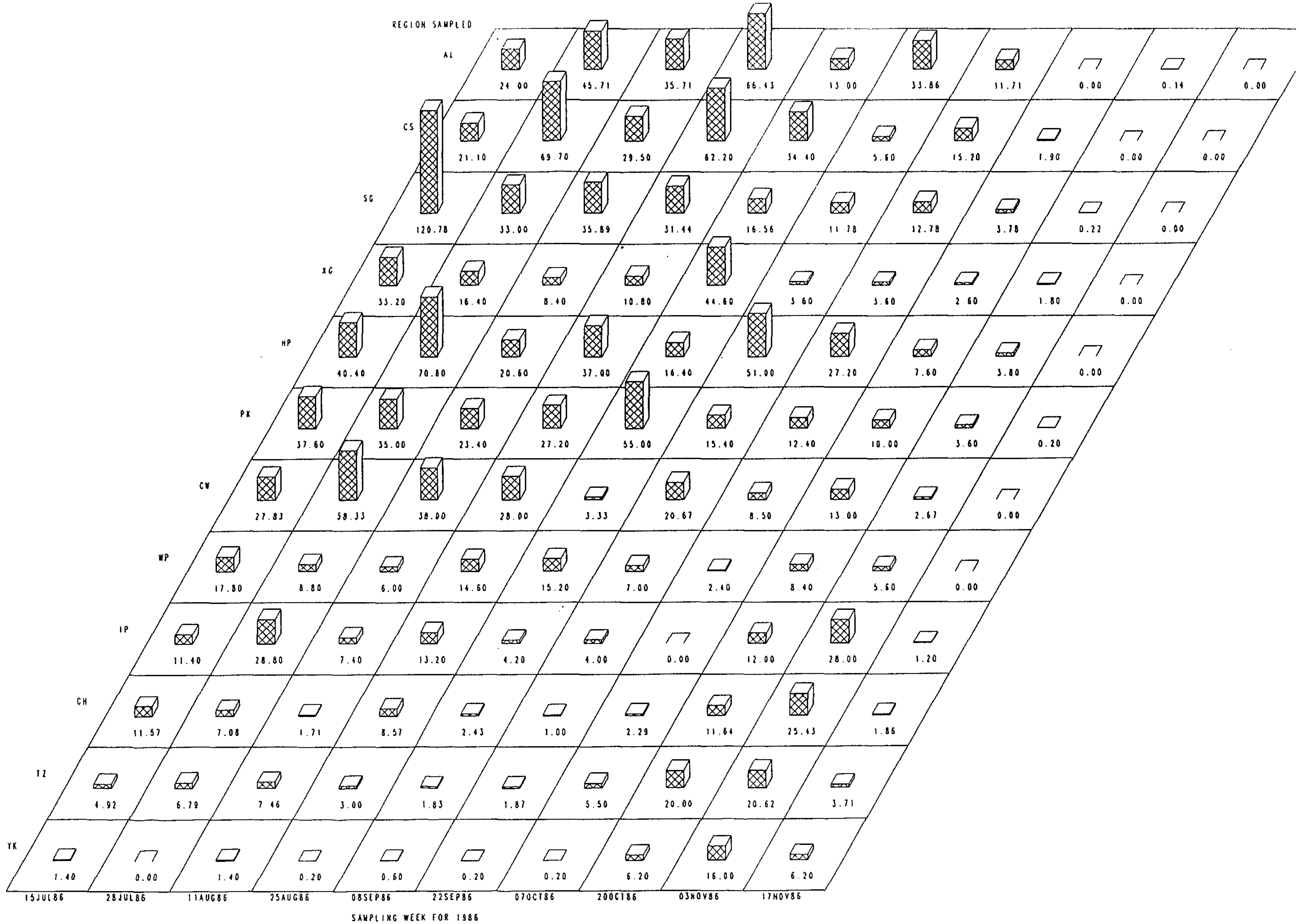


FIGURE 4-80

LRS. Beach seine collections had greatest densities from the beginning of the program in mid-July through early September.

Throughout most of the sampling program YOY American shad were in greatest densities from the Poughkeepsie region through the Catskill region (RM 62-124). During beach seine collections most YOY catches were made from the Saugerties region through the Albany region (Figure 4-81). Downriver movements became apparent in October and November. During this period upper estuary densities declined as abundance increased in the lower estuary. American shad YOY move downriver in the Hudson River (TI 1980, 1981), as evidenced by the 1986 Croton-Haverstraw region collections in mid-June and increasing lower estuary abundance beginning in mid-July. Only trace numbers were collected in the middle and upper estuary in November.

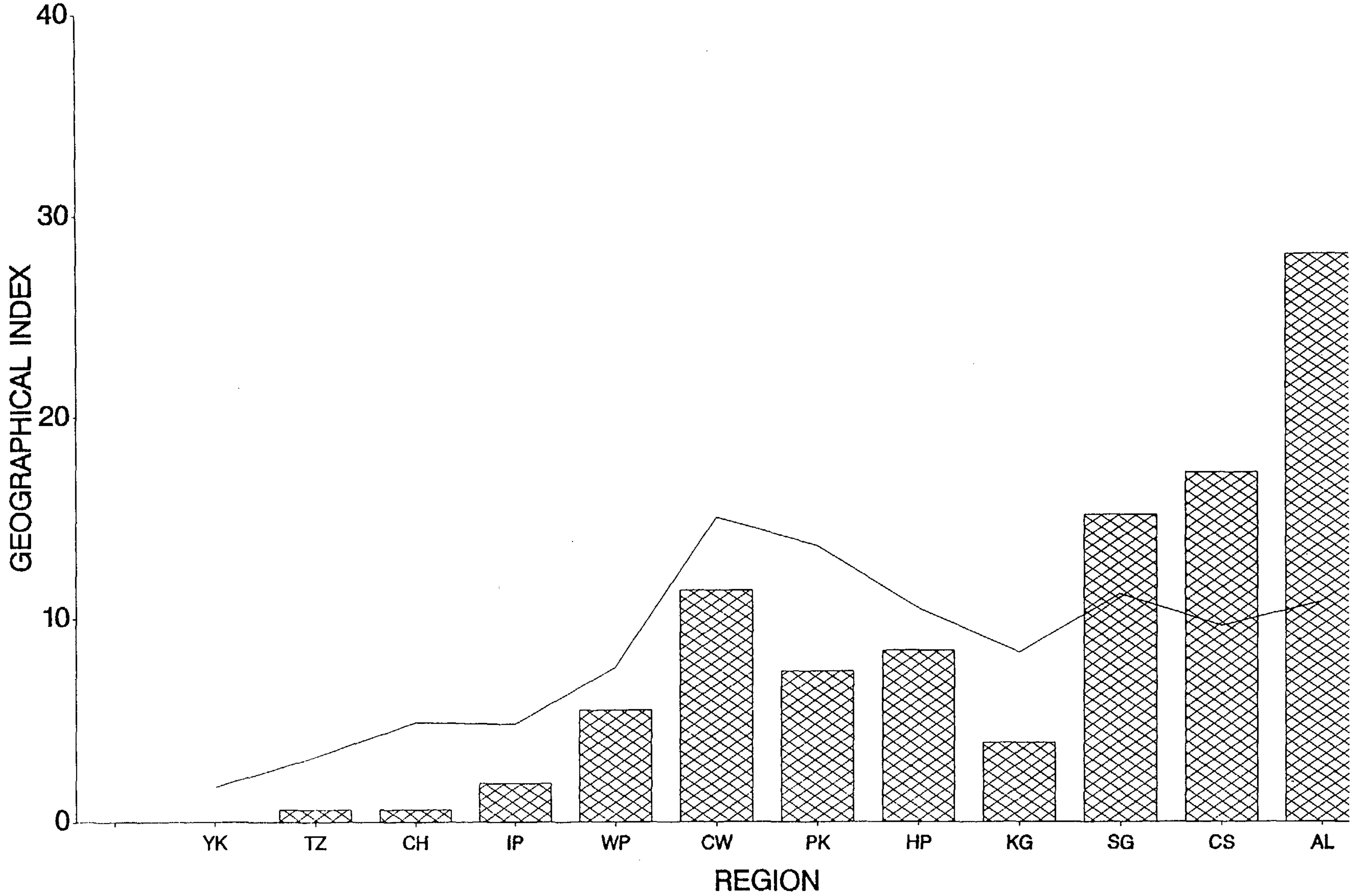
4.6.1.5 Yearling and Older Fish. Yearling and older American shad were collected during the initial sample week (29 April) of the 1986 LRS (Figure 4-82) and were caught sporadically in low numbers throughout the program. The FSS (Figure 4-83) and BSS (Figure 4-84) sampling programs had trace yearling and older shad catches in September and October, with the greatest occurrence in late September. No spatial distribution pattern was apparent from FSS and BSS program samples. LRS data revealed that most yearling and older shad were caught from the Yonkers through Cornwall regions (RM 12-61). Abundance estimates likely reflect yearling abundance, as the sampling programs were not designed to sample adult fish.

4.6.2 1987 Study

4.6.2.1 Eggs. American shad eggs were already present during the initial LRS sampling week of 14 April 1987 (Figure 4-85) when the upper estuary temperature was 10.0°C. As in the previous year, egg deposition may have begun before the program began. Ichthyoplankton samples continued to contain shad eggs through mid-June.

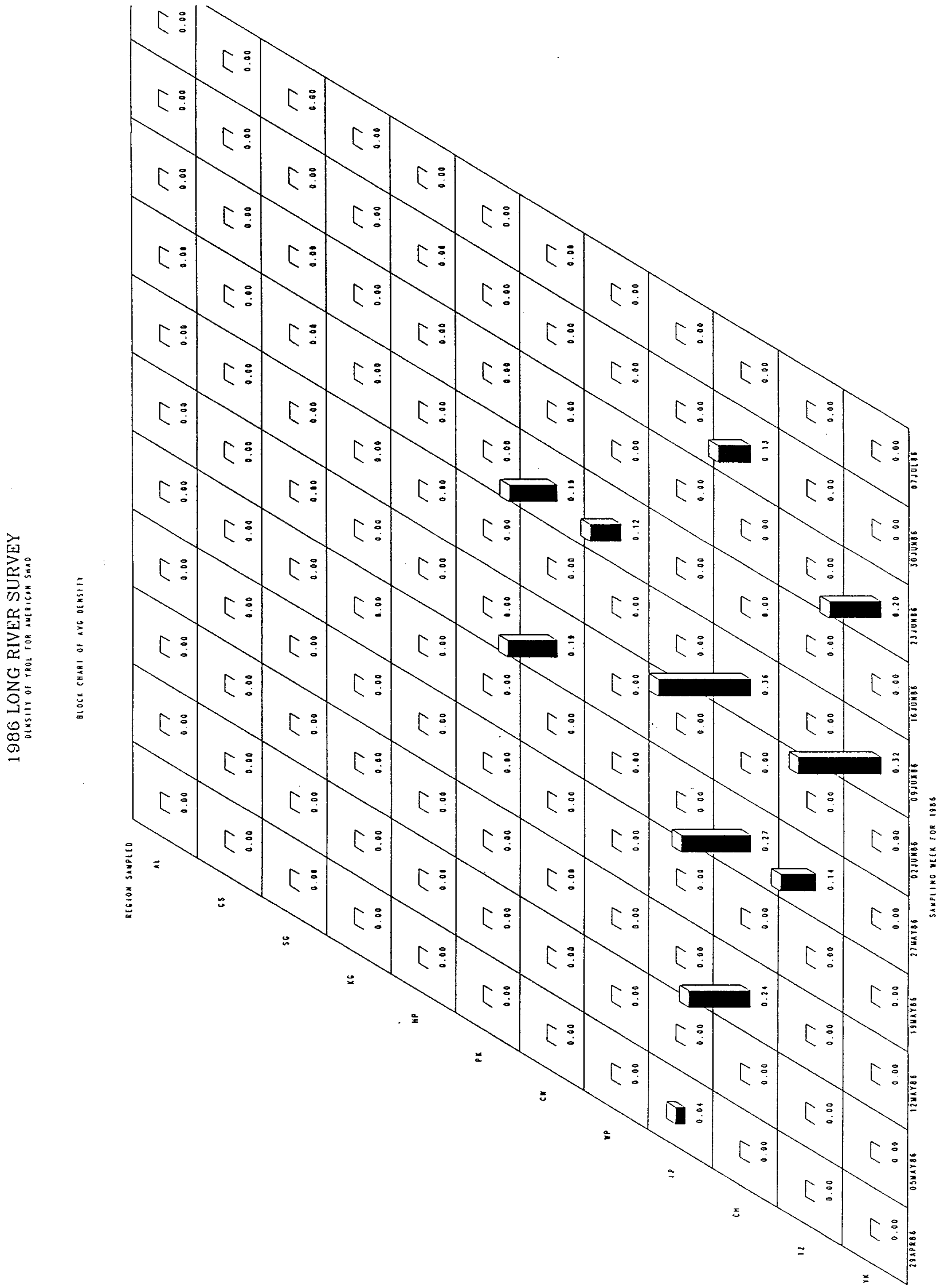
FIGURE 4-81

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR AMERICAN SHAD COLLECTED IN THE BEACH SEINE SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.



1986 LONG RIVER SURVEY
DENSITY OF YROL FOR AMERICAN SHAD
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
IZ
YK
28APR86
05MAY86
12MAY86
19MAY86
27MAY86
02JUN86
09JUN86
16JUN86
23JUN86
30JUN86
07JUL86
SAMPLING WEEK FOR 1986

FIGURE 4-82

1986 FALL SHOALS SURVEY
DENSITY OF YROL FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

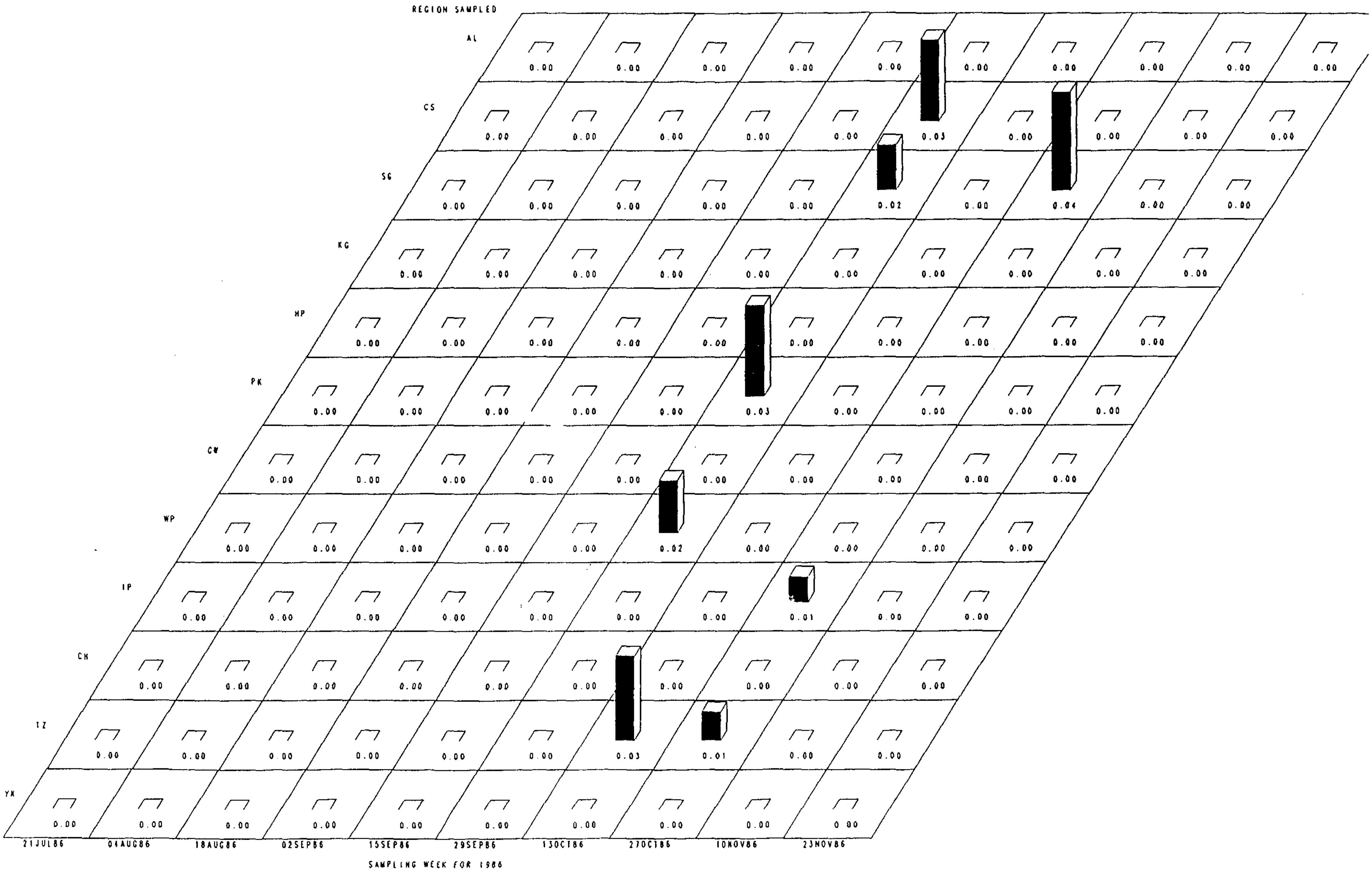


FIGURE 4-83

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR AS

BLOCK CHART OF CATCH/UNIT EFFORT

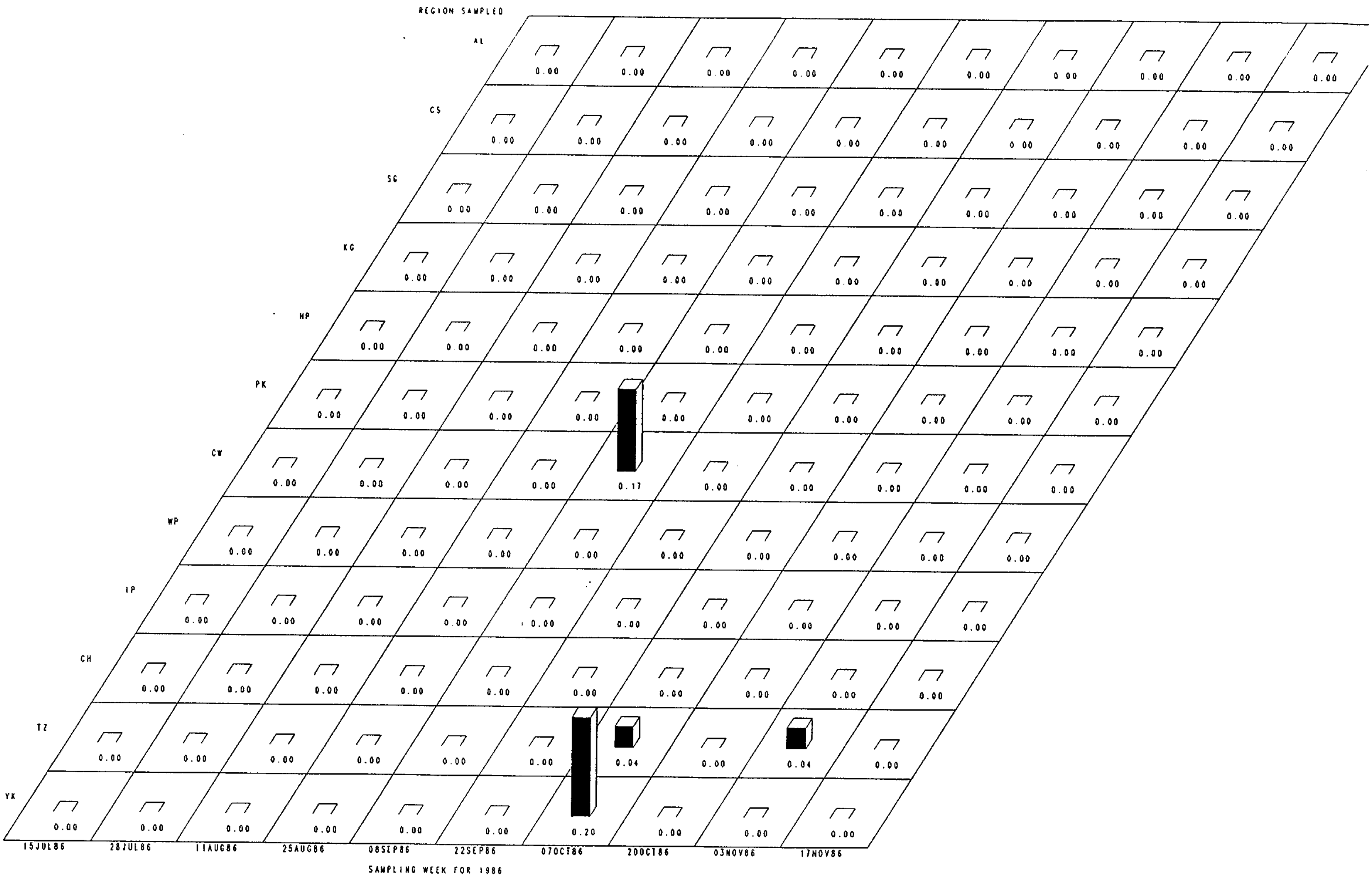


FIGURE 4-84

1987 LONG RIVER SURVEY

DENSITY OF EGGS FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

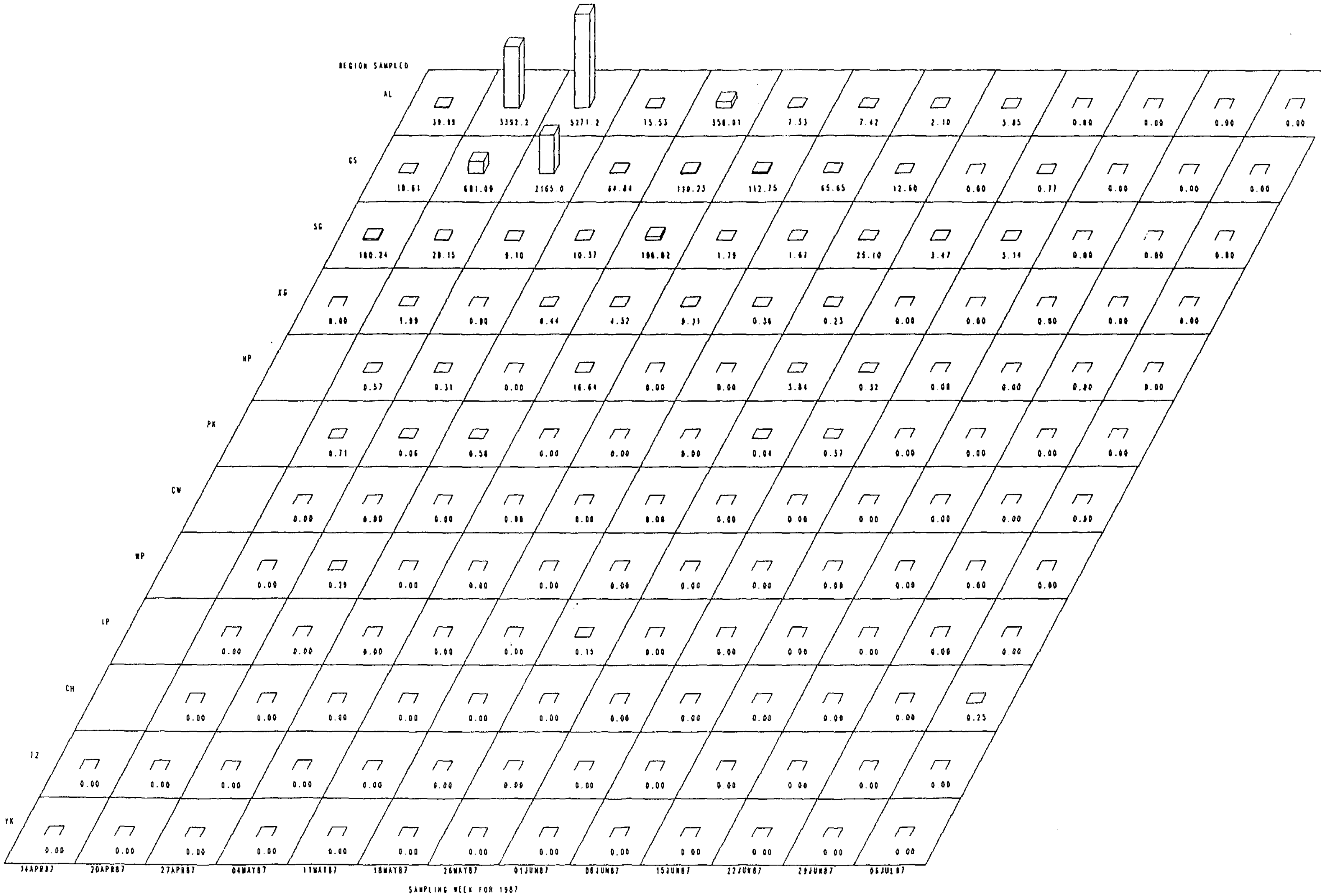


FIGURE 4-85

Almost all egg deposition was limited to fresh water, with only trace numbers (<10/1000 m^3) collected downriver from Hyde Park (RM 77) (Figure 4-74). Greatest concentrations were estimated for regions north of Kingston, with peak densities collected in the Albany region. Shad eggs were collected as far downriver as the Indian Point region. Spatial distribution of eggs in 1987 was similar to that of most previous years. The period of peak egg abundance in late April was earlier than that reported in previous Year Class Reports.

4.6.2.2 Yolk-Sac Larvae. Shad YSL were collected from late April through mid-June in 1987 (Figure 4-86), with greatest abundance during the 11 May sampling week, two weeks after peak egg density. The spatial distribution for YSL was similar to the 1987 shad egg distribution; peak densities were estimated from the Albany region. YSL collection was limited to regions north of Cornwall, unlike previously reported spatial patterns that included catches from all estuary regions. Large downriver concentrations in 1984 were attributed to particularly large freshwater inflows to the Hudson River (MMES 1986). The absence of YSL in the lower half of the estuary in 1987 could be a reflection of the lower-than-normal freshwater inflows to the Hudson River during the spring (Figure 4-87).

American shad YSL do not appear to move far from spawning locations (Figure 4-88). Almost all samples with densities greater than 10/1000 m^3 were taken in the shoal strata. Vertical distribution varied substantially between sampling years.

4.6.2.3 Post Yolk-Sac Larvae. PYSL were first present in LRS samples during the first week of May 1987 (Figure 4-89). Greatest abundance was from the 18 May sampling week through the 22 June sampling week. Peak temporal distribution was during the week of 8 June, one week later than the 1986 PYSL peak.

Little passive movement appears to have occurred during early life stages. PYSL spatial distribution thus reflects egg distribution. Greatest larval

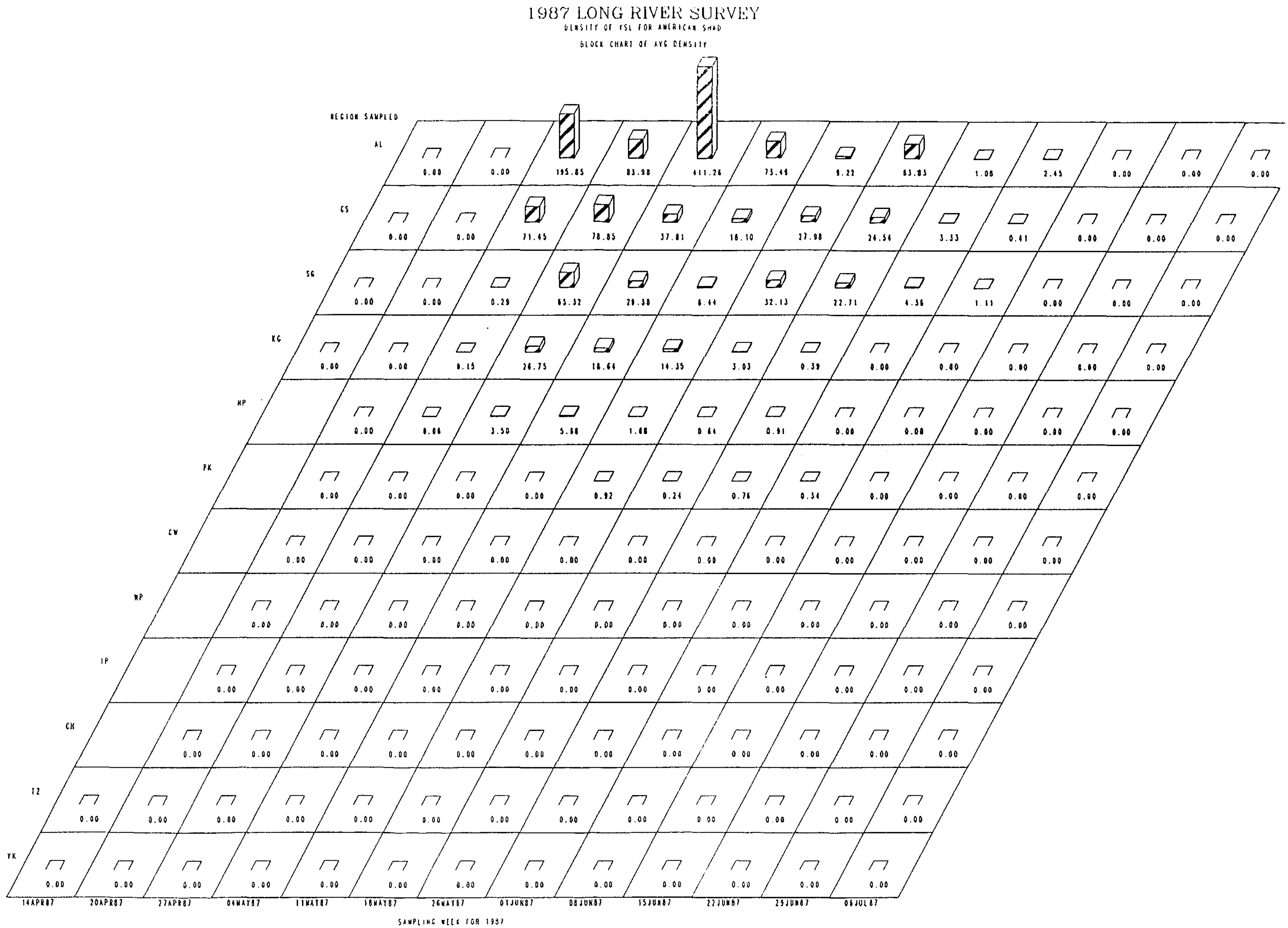

1987 LONG RIVER SURVEY
DENSITY OF YSL FOR AMERICAN SHAD
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL 0.00 0.00 195.85 83.98 411.26 75.49 9.22 83.83 1.08 2.45 0.00 0.00 0.00
CS 0.00 0.00 71.45 78.85 37.81 16.10 27.98 24.54 3.33 0.41 0.00 0.00 0.00
SG 0.00 0.00 0.29 65.32 29.38 6.44 32.13 22.71 4.36 1.11 0.00 0.00 0.00
KG 0.00 0.00 0.15 26.75 18.64 14.35 3.03 0.39 0.00 0.00 0.00 0.00 0.00
HP 0.00 0.06 3.50 5.68 1.48 0.64 0.91 0.00 0.00 0.00 0.00 0.00
FK 0.00 0.00 0.00 0.00 0.92 0.24 0.76 0.34 0.00 0.00 0.00 0.00
CW 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
WP 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
IP 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
CH 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
TZ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
YK 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
14APR87 20APR87 27APR87 04MAY87 11MAY87 18MAY87 26MAY87 01JUN87 08JUN87 15JUN87 22JUN87 29JUN87 06JUL87
SAMPLING WEEK FOR 1987

FIGURE 4-86

FIGURE 4-87

AVERAGE DAILY FLOW VS. TIME

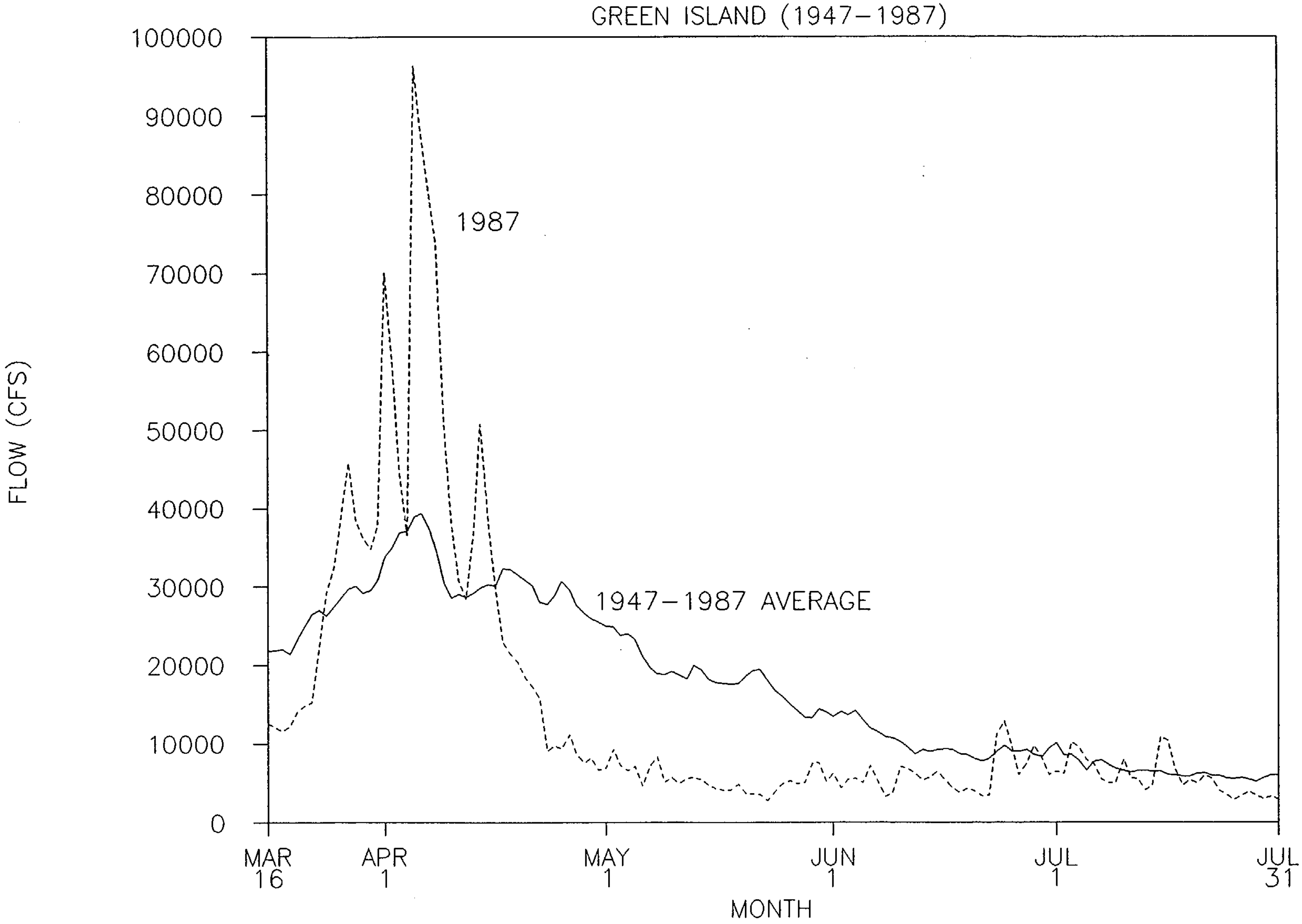
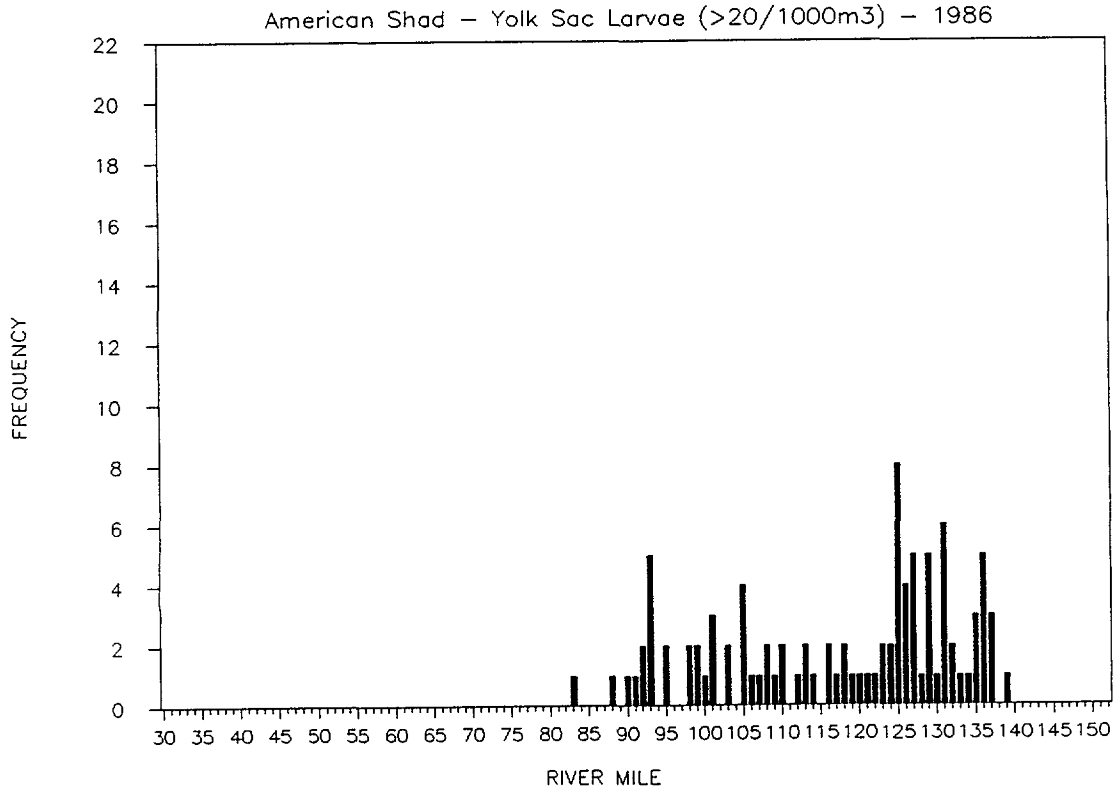
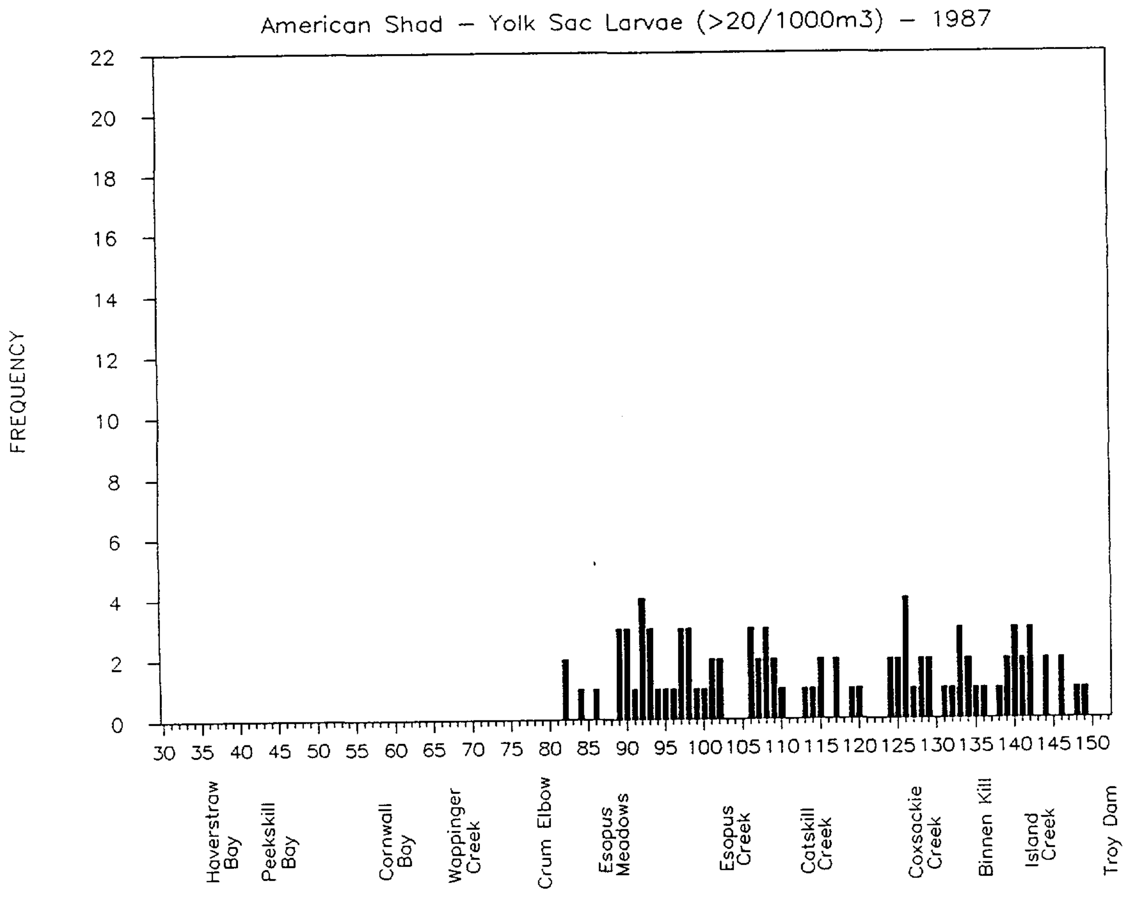


FIGURE 4-88

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





1987 LONG RIVER SURVEY

DENSITY OF PYSL FOR AMERICAN SHAD

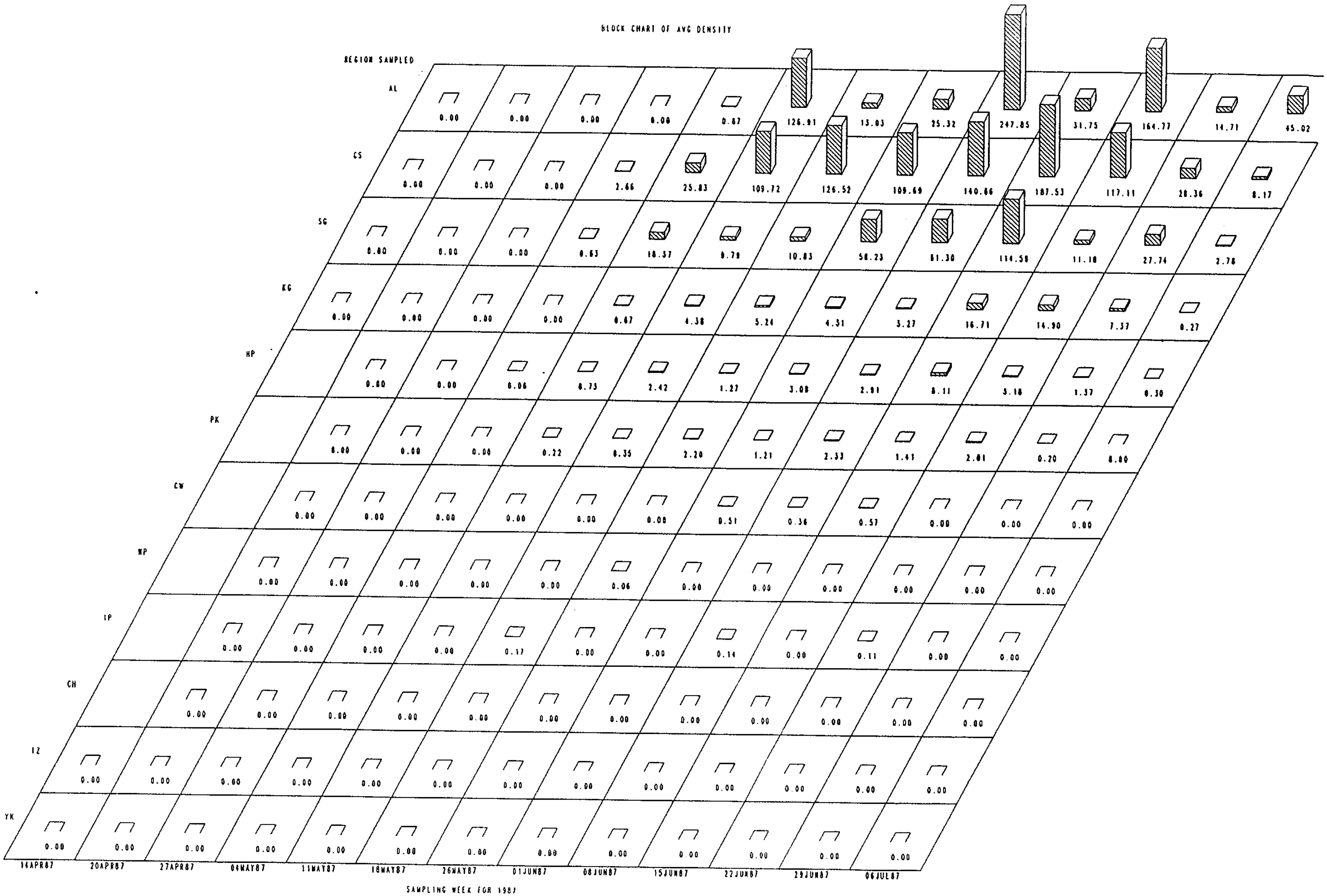


FIGURE 4-89

densities (>500/1000 m^3) were restricted to the Saugerties, Catskill, and Albany regions, with peak weekly density estimated in the Albany region. Shad PYSL larvae were collected downriver to the Indian Point region. No weekly density over 10/1000 m^3 was estimated for regions south of the Poughkeepsie region. Downstream movement from the upper to middle estuary regions became apparent in mid-June. Greater numbers of PYSL were caught during 1986 than 1987, and individual collection densities greater than 50/1000 m^3 extended downstream to Peekskill Bay (Figure 4-90).

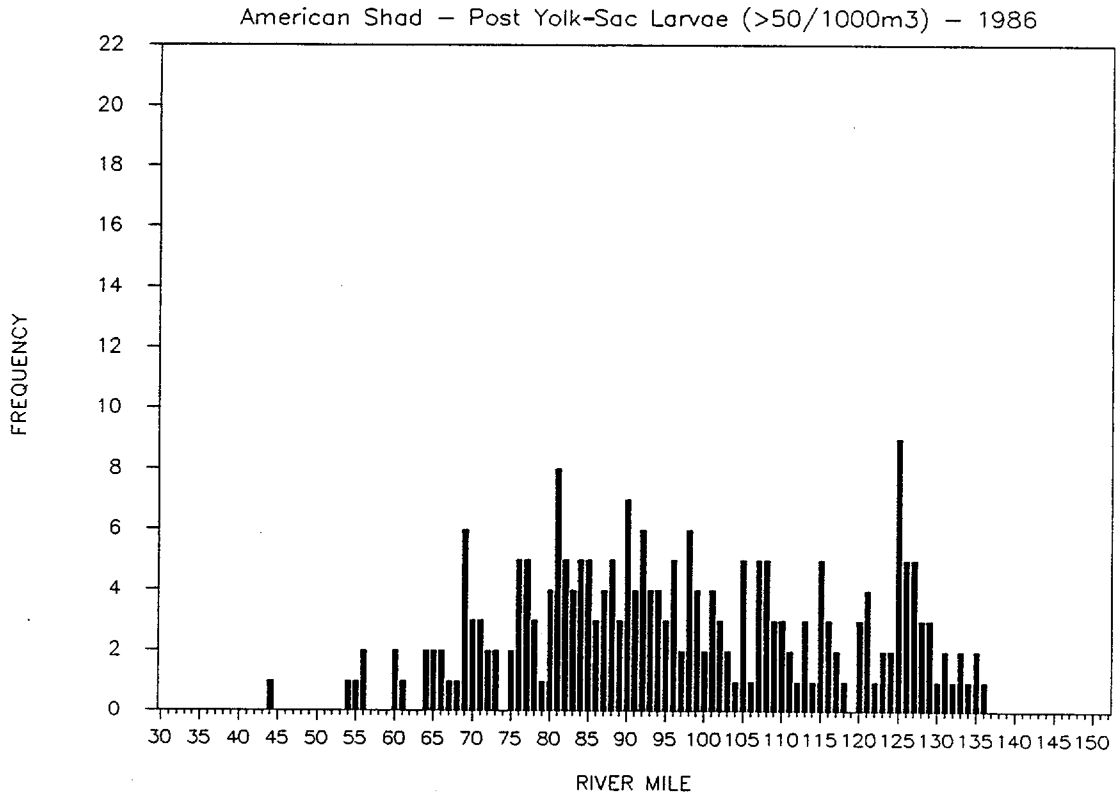
American shad PYSL were found in greater densities in the shoal strata than in the deeper channel and bottom areas during both the 1986 and 1987 sampling programs. Large numbers were collected near Coxsackie (RM 125), Catskill (RM 113), Inhocht Bay (RM 109-110), and "The Flat" (RM 95) (Figure 4-89). These areas all have adjacent shallow flats that are usually vegetated (Figures 4-1d to 4-1f). Sample densities greater than 100/1000 m^3 were more common with the Tucker trawl than the epibenthic sled; however, no vertical distribution pattern was apparent.

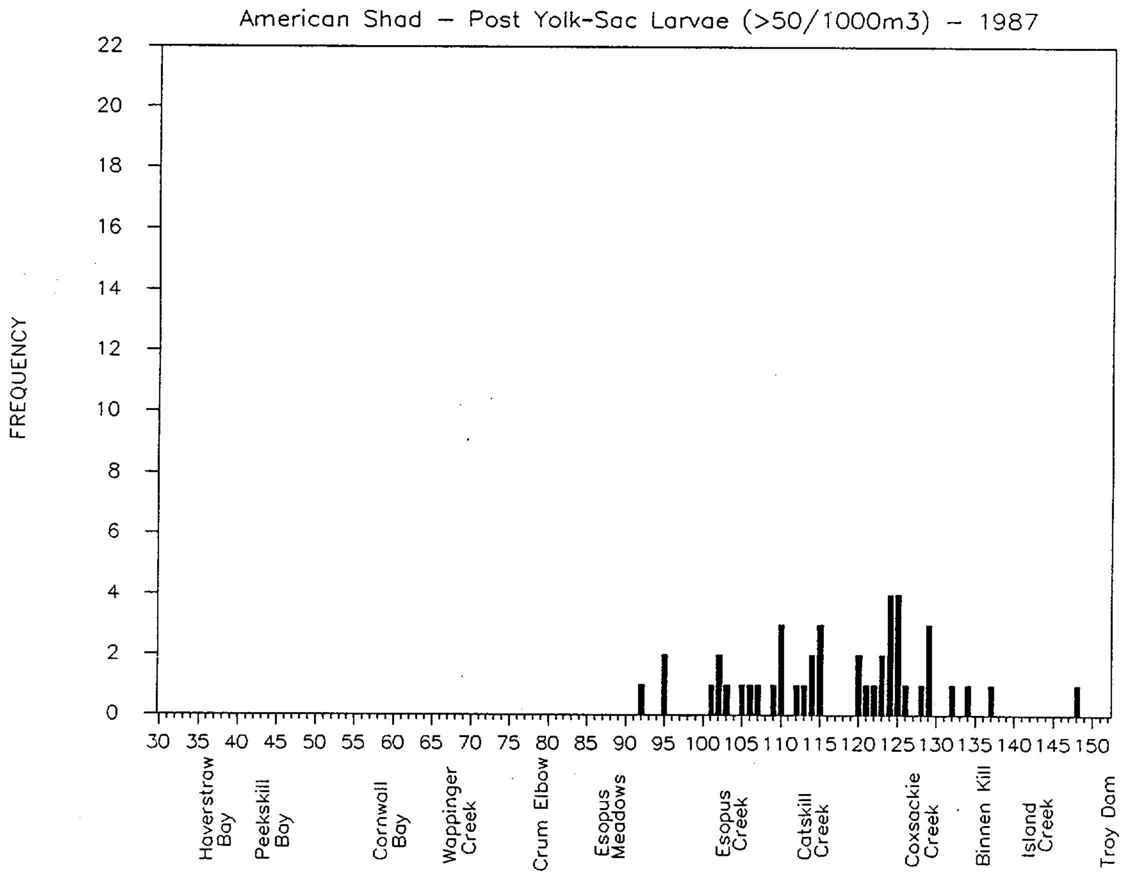
4.6.2.4 Young-of-Year. American shad YOY were first collected during the 8 June 1987 LRS sampling week (Figure 4-91) and were present in every subsequent sample of the LRS and every biweekly sample of the FSS (Figure 4-92) and BSS (Figure 4-93) programs. Temporal distribution patterns based on estimated regional densities suggest peak occurrence from early July through September.

Spatial distribution patterns in 1987 suggest the greatest occurrence of American shad YOY in the Catskill and Albany regions. The geographical distribution during the BSS was greatest in the Hyde Park, Catskill, and Albany regions (Figure 4-94). BSS catches indicate that YOY shad are in greater concentrations in the shore zone than in the FSS sample stratum. Upper estuary shore-zone samples showed peak shad YOY abundance in late August, with no density estimates exceeding 10/1000 m^3 sampled after the 28 September sampling week. Mean temperatures associated with the upper estuary BSS dropped from 17.4 to 11.0°C between the 28 September and 13 October sampling weeks. Watson

FIGURE 4-90

LONGITUDINAL RIVER FREQUENCY DISTRIBUTION BY RIVER MILE





1987 LONG RIVER SURVEY

DENSITY OF YOY FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

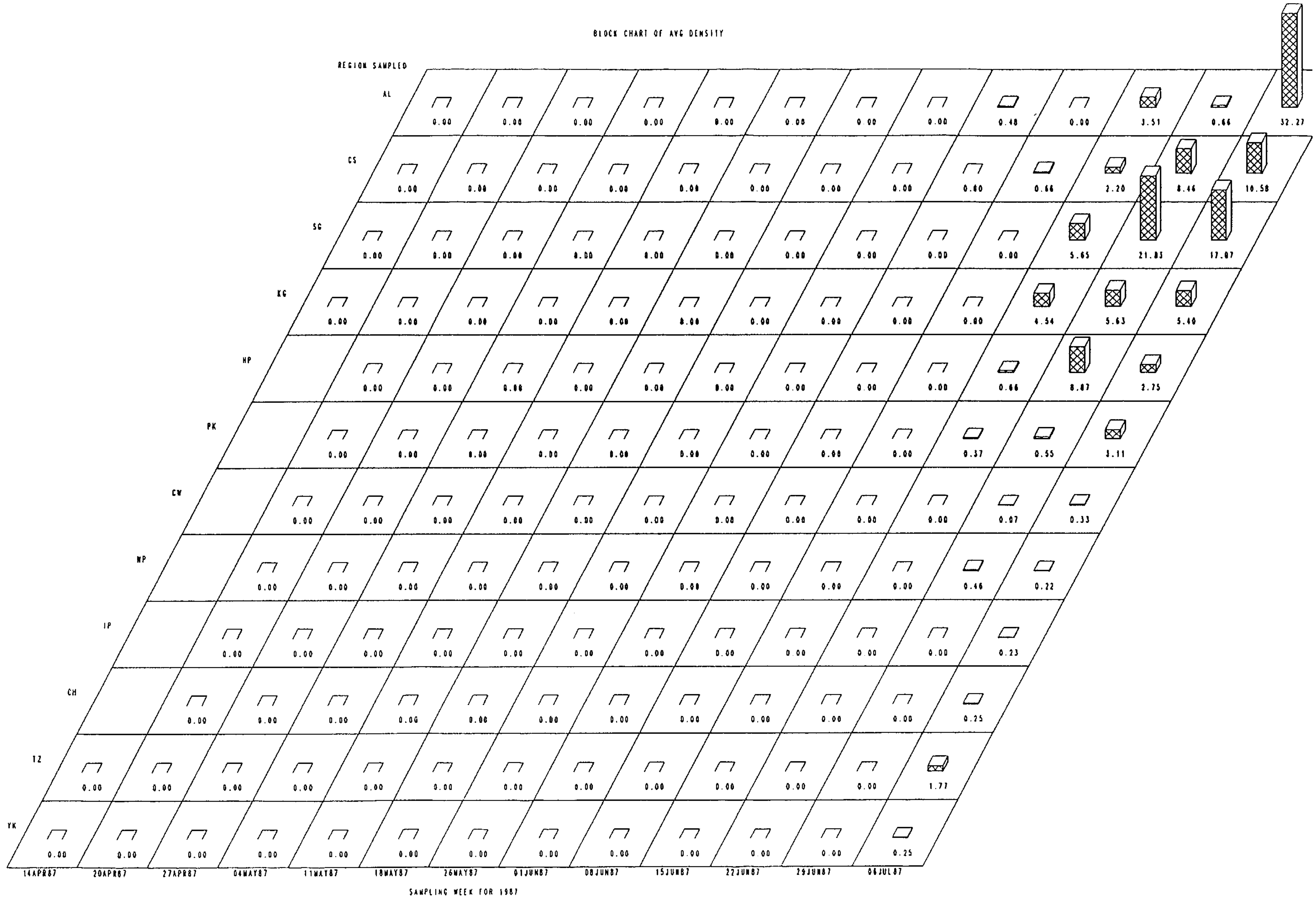


FIGURE 4-91

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

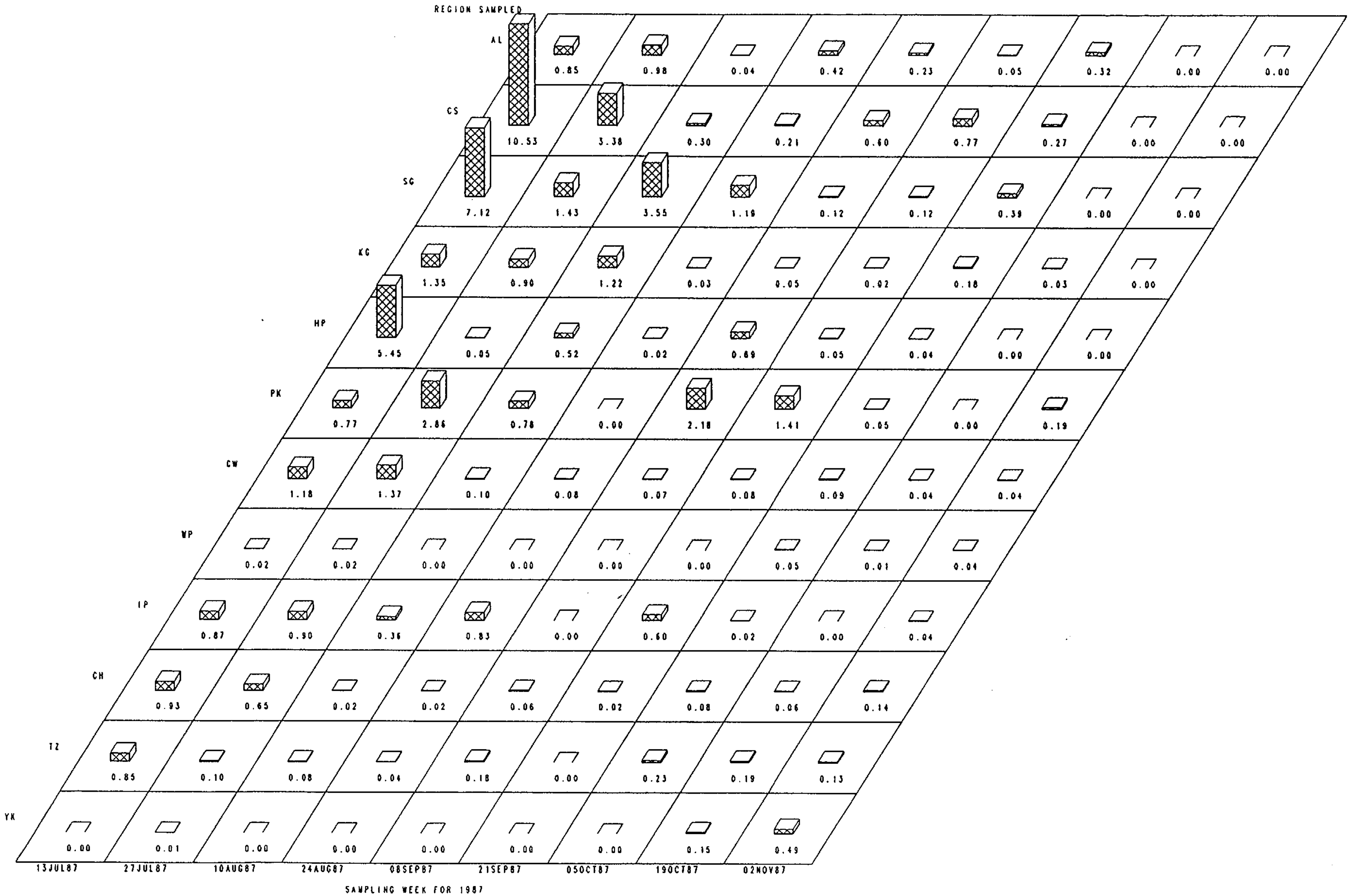


FIGURE 4-92

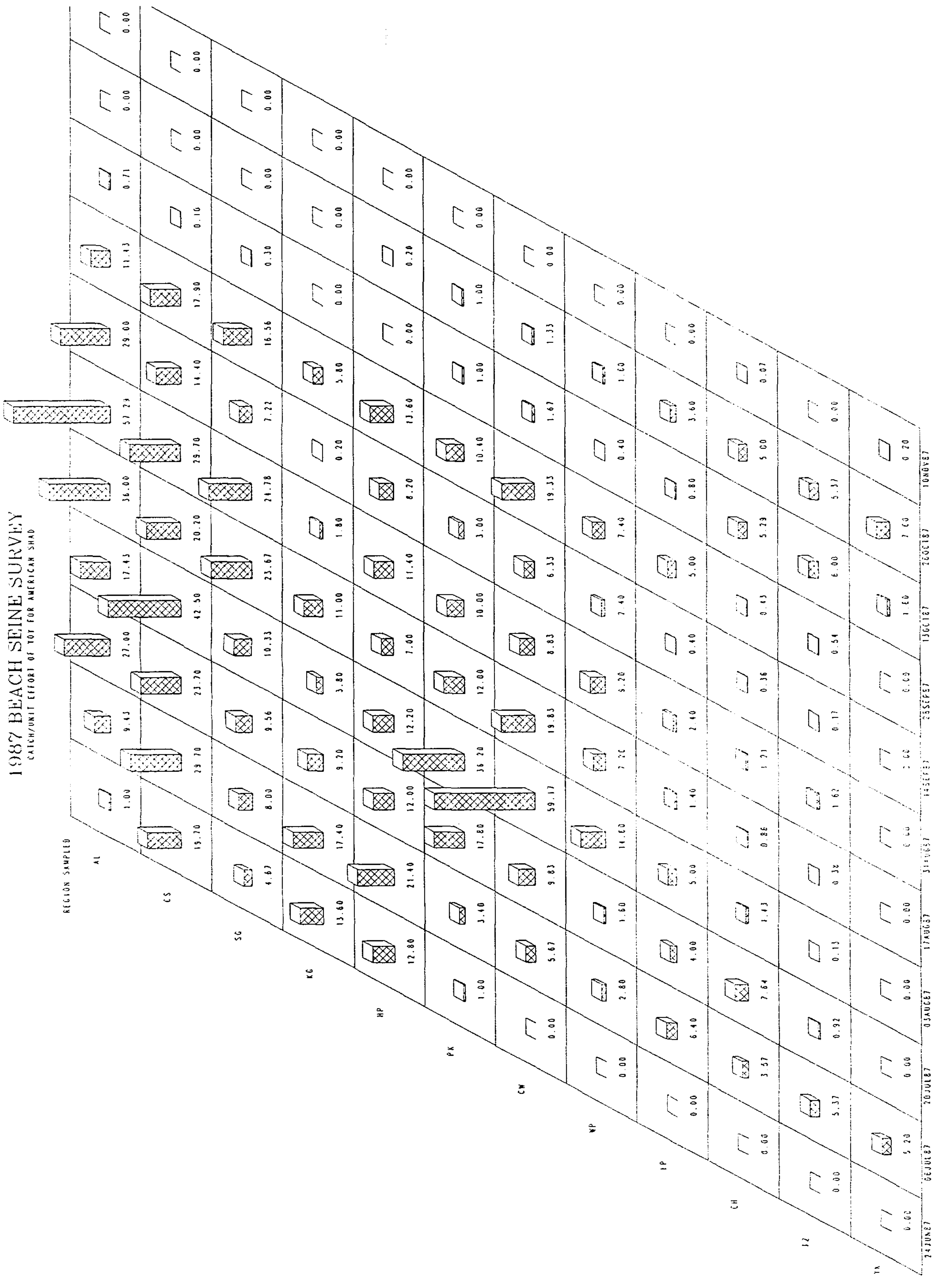
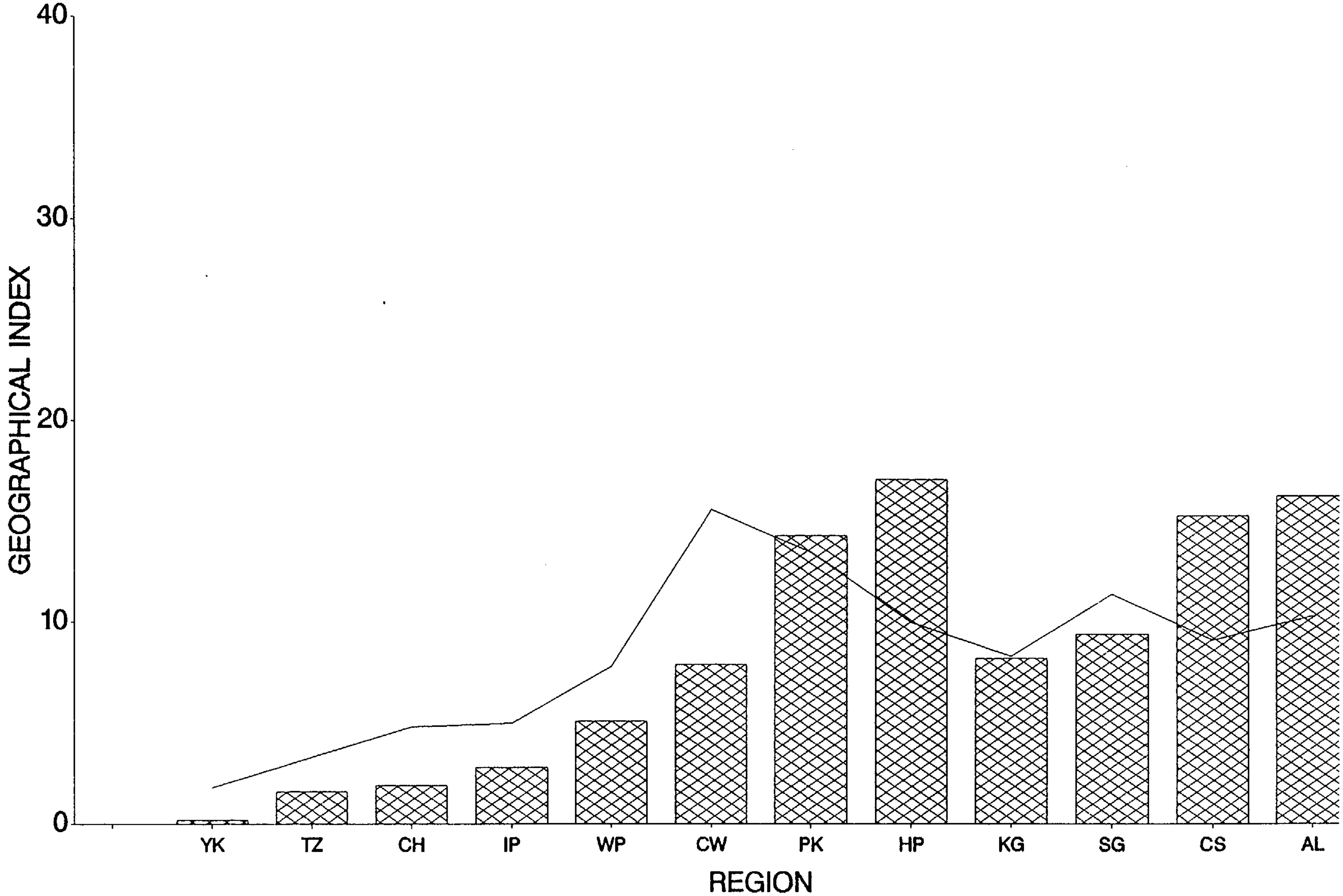

1987 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF YOY FOR AMERICAN SHAD
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
TZ
YK
SAMPLING WEEK FOR 1987
24JUN87
06JUL87
20JUL87
03AUG87
17AUG87
31AUG87
14SEP87
28SEP87
13OCT87
26OCT87
10NOV87

FIGURE 4-93

FIGURE 4-94

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR AMERICAN SHAD COLLECTED IN THE BEACH SEINE SURVEY, 1987



LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

(1968) reported that shad YOY migration started when temperatures dropped below 18.3°C and was essentially complete as temperatures dropped below 10.0°C. Juvenile American shad densities in the upper half of the estuary began to decline in September in response to apparent downriver migration. The mean regional shore-zone temperature during the week when most shad appeared to leave the upper half of the estuary was 18.9 and 17.6°C during 1986 and 1987, respectively. No upper estuary catches were recorded following the 13 October sampling week, suggesting that the shad YOY had migrated downriver. The lack of FSS density increases in the middle and lower estuary in early October suggests that shad disperse downriver but remain in the shallower areas, evidenced from increased shore-zone densities in these areas. Decreasing catches in the lower regions of the estuary as the temperature dropped below 10°C in mid-November reflect juvenile emigration from the estuary.

4.6.2.5 Yearling and Older Fish. Yearling and older American shad were first collected during the 1987 LRS sampling week of 4 May, with peak river abundance estimated during mid-May (Figure 4-95). Sporadic occurrences were reported for June and July in all sampling programs. The final collection occurred during the late July FSS sampling (Figures 4-96 and 4-97). Spatial distribution indicates that individuals were scattered throughout the estuary, and no conclusion could be drawn regarding either spatial or temporal distribution trends.

4.7 UNIDENTIFIED CLUPEIDS, *Alosa* spp.

River herrings, blueback herring (*Alosa aestivalis*) and alewife (*A. pseudoharengus*), are anadromous clupeids that are difficult to distinguish before they reach a juvenile total length of 35 to 40 mm (TI 1981). For this reason early life stages of these two species are considered together. A third anadromous clupeid, American shad, is presented separately in Section 4.6. American shad are easily distinguished from other river herring early life stages because of their size.

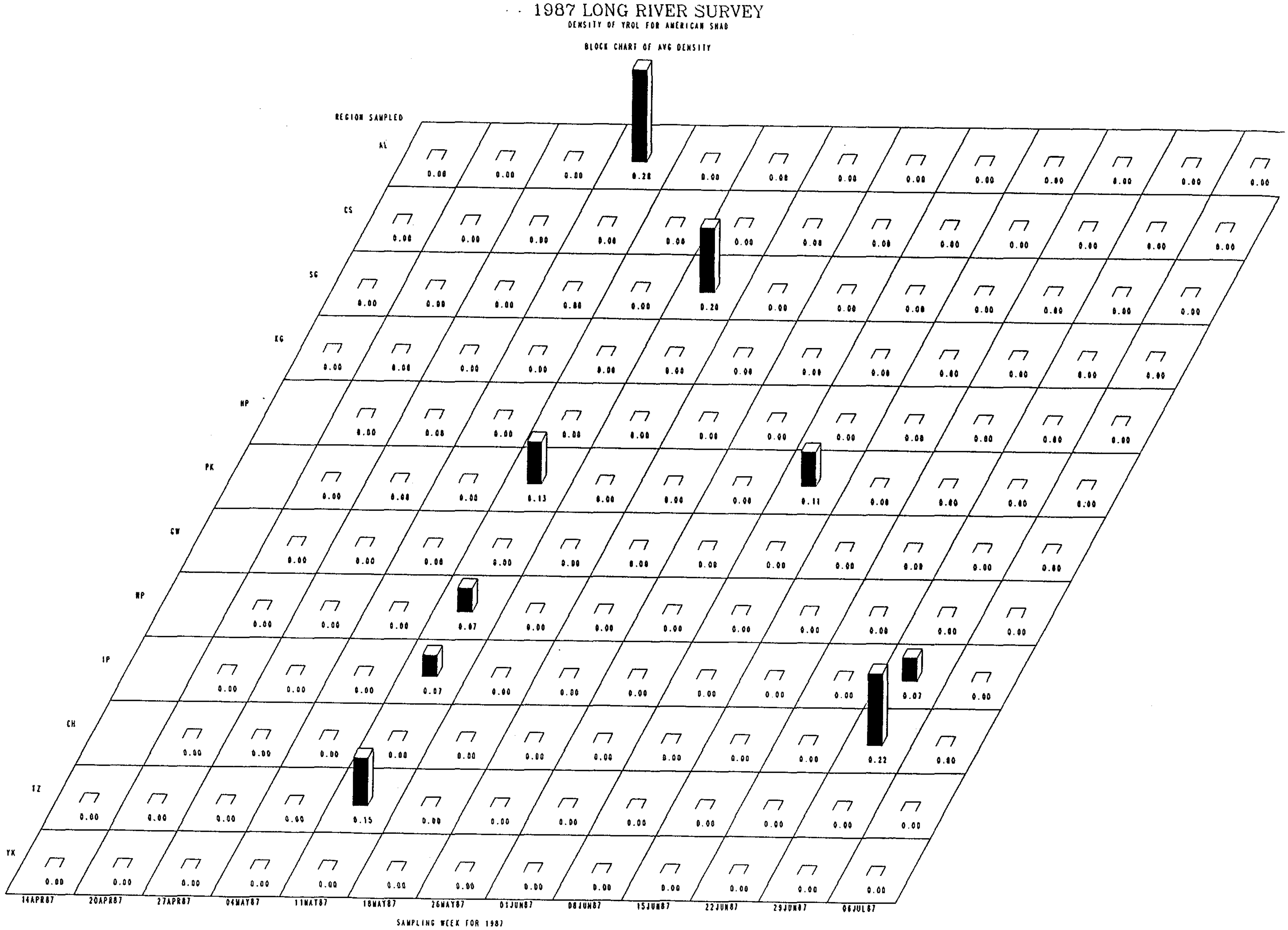

1987 LONG RIVER SURVEY
DENSITY OF YROL FOR AMERICAN SHAD
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
SG
EG
HP
PK
CW
MP
IP
CH
TZ
YK
14APR87
20APR87
27APR87
04MAY87
11MAY87
18MAY87
26MAY87
01JUN87
08JUN87
15JUN87
22JUN87
29JUN87
06JUL87
SAMPLING WEEK FOR 1987

FIGURE 4-95

1987 FALL SHOALS SURVEY
DENSITY OF YROL FOR AMERICAN SHAD

BLOCK CHART OF AVG DENSITY

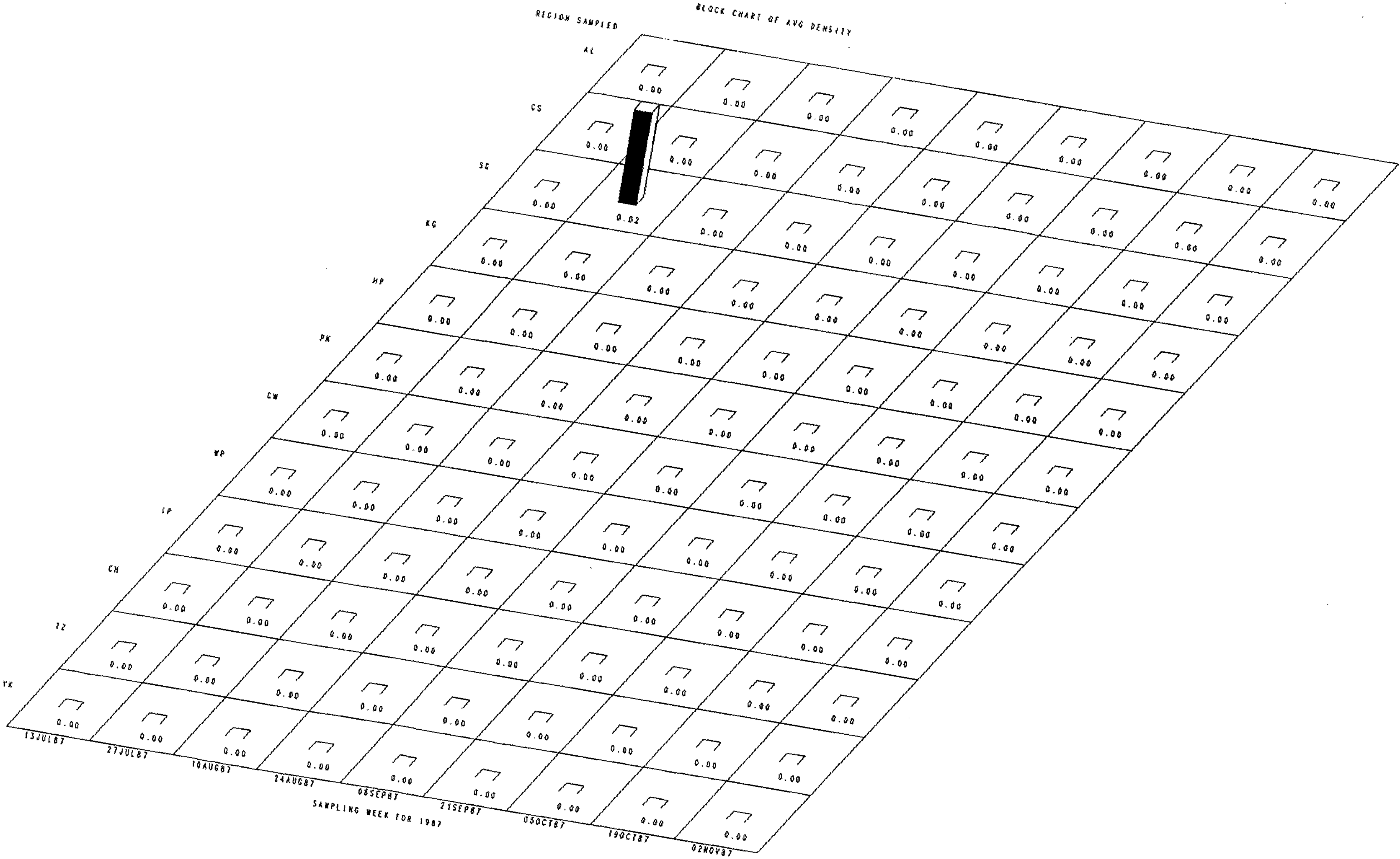


FIGURE 4-96

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR AMERICAN SHAD

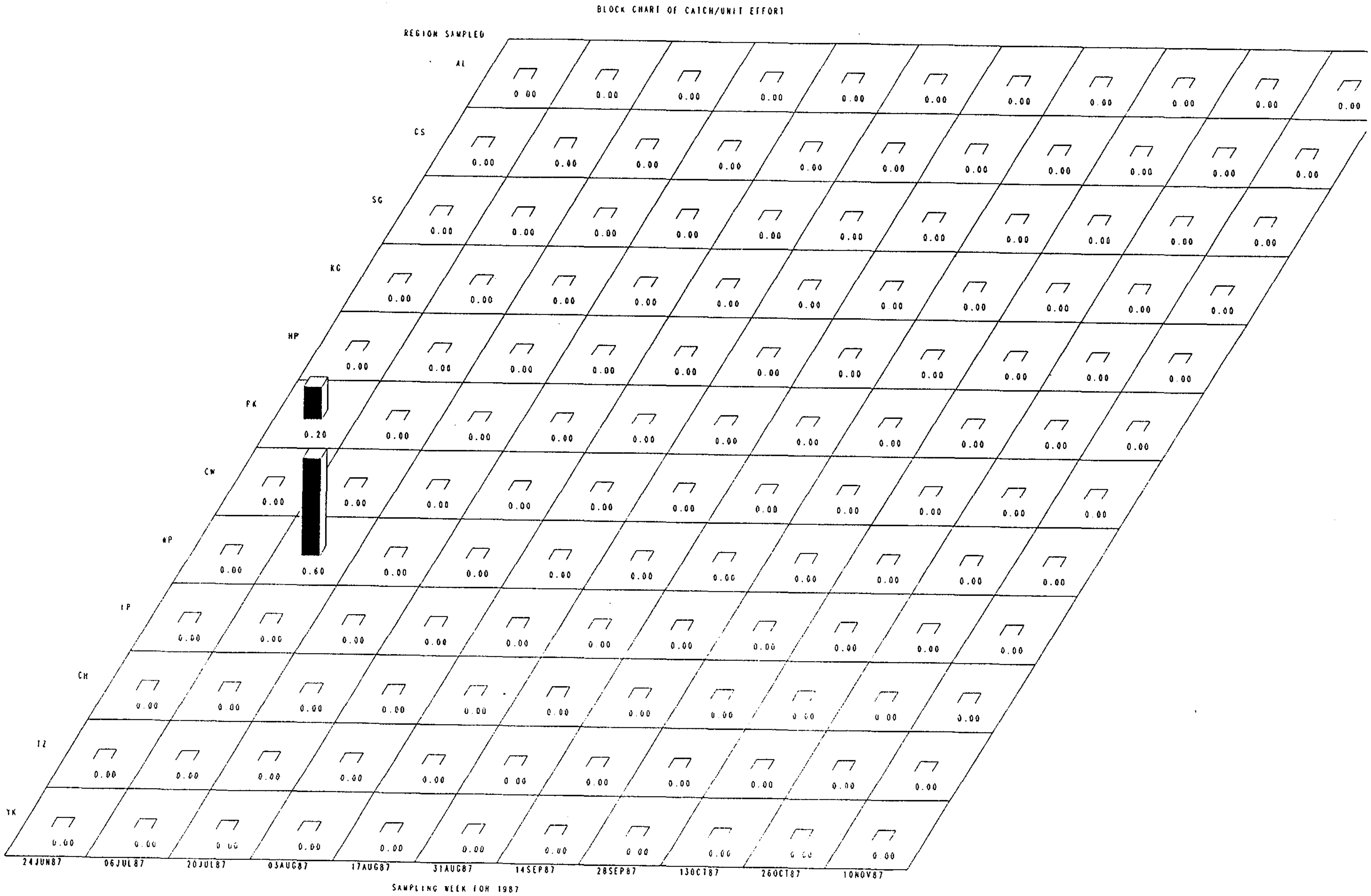


FIGURE 4-97

Both blueback herring and alewife enter rivers and estuaries along the Atlantic Coast in spring to spawn in brackish or freshwater areas. Both species spawn in the tributaries of the Hudson River estuary. Alewife prefer ponds and slow-moving streams; blueback herring spawn in deeper, faster waters. Alewife and blueback herring spawning runs overlap to some extent, allowing peak egg abundance for each species to be identified based on spawning substrate, water depth, and temperature at time of spawning. Alewife spawning occurs first at temperatures near 13°C (Tyus 1974), followed by blueback herring which may not spawn until temperatures exceed 20°C (Loesch and Lund 1977). Both species are repeat spawners; adults return to the sea following spawning and juveniles usually migrate out of the estuary as water temperatures decrease in the fall. Alewife and blueback herring eggs, YSL, and PYSL are presented and discussed together in Section 4.7.1. YOY and yearling and older stages are presented separately by river herring species in subsequent sections.

4.7.1 1986 Study

4.7.1.1 Eggs. *Alosa* spp. peak egg abundance occurred in 1986 during the initial sampling week of 29 April when water temperatures were about 12°C. A minor second peak occurred in mid-May at water temperatures of 17 to 19°C (Figure 4-98). This bimodal peak may be the result of separate spawning periods for the two species. Water temperatures of 12°C and 17 to 19°C correspond to spawning temperatures favored by the alewife (Tyus 1974) and blueback herring (Loesch and Lund 1977), respectively, suggesting sequential spawning peaks. This bimodal abundance pattern could also be explained by an increase in gear selectivity during mid-May due to above-normal freshwater flows that increase larval vulnerability to the sampling techniques. Eggs were collected in the upper estuary through the final sampling week (7 July) of the LRS program.

1986 LONG RIVER SURVEY

DENSITY OF EGGS FOR ALOSA

BLOCK CHART OF AVG DENSITY

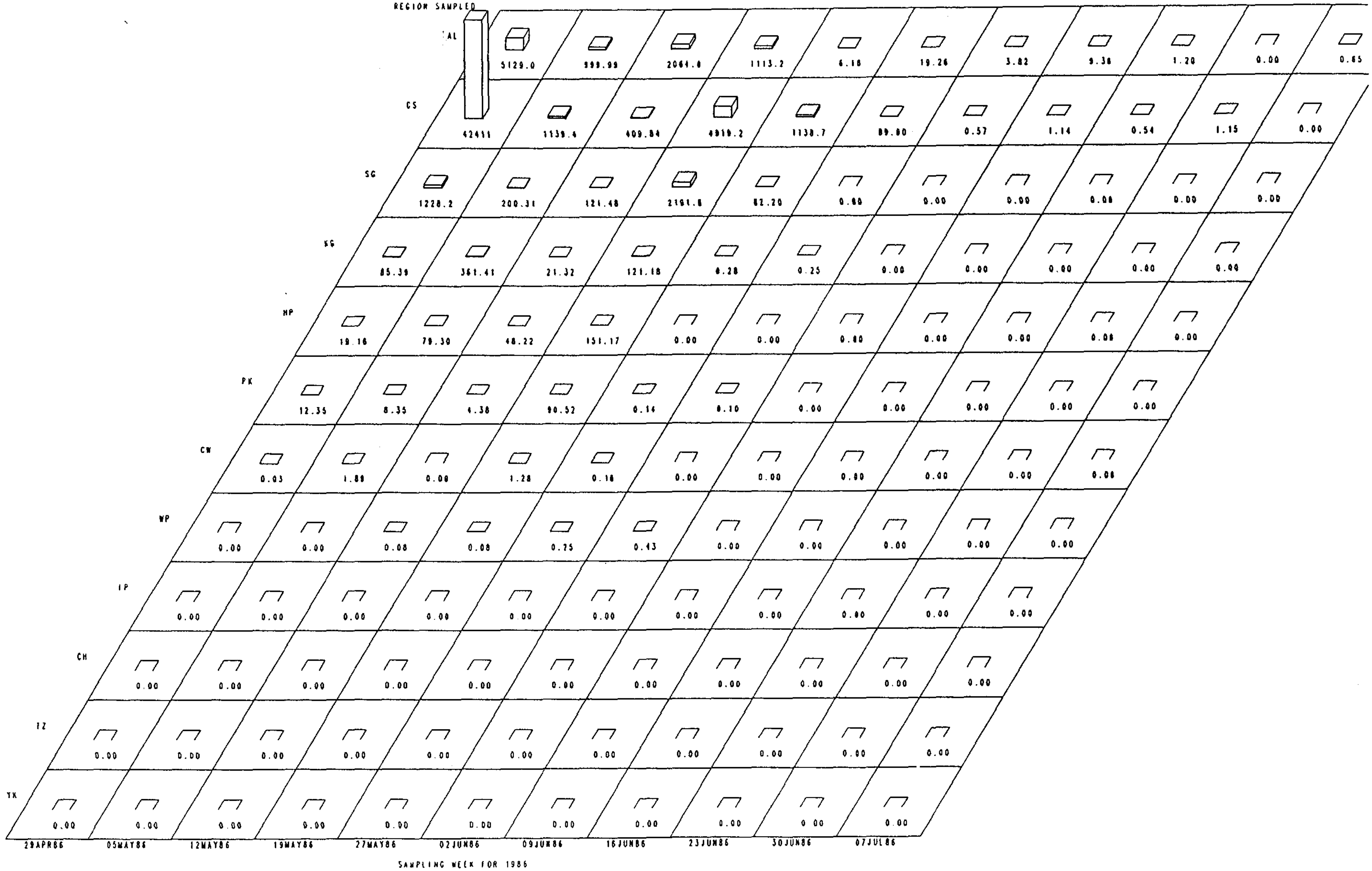


FIGURE 4-98

River herring eggs were determined to be at densities in excess of 100/1000 m^3 from the Hyde Park region through the Albany region during 1986, with peak density in the Catskill region.

4.7.1.2 Yolk-Sac Larvae. River herring YSL were collected from late April through mid-June in 1986, with peak abundance in early May and again in early June (Figure 4-99). The first YSL peak occurred about one week after the first egg abundance peak. The second YSL peak occurred two weeks after the second peak in egg density, and was located in the Albany region, one region upstream of the peak egg location. This peak further suggests that increased vulnerability due to high freshwater flow may have caused the minor egg abundance peak since no directly corresponding larval peak was apparent. Increased flow in the Hudson River tributaries of the Mohawk River drainage may have shifted larvae downstream into the estuary, resulting in a density increase in the Albany region.

4.7.1.3 Post Yolk-Sac Larvae. River herring PYSL were identified in 1986 estuary collections from the onset of the LRS through the final sampling week of 7 July (Figure 4-100). Peak abundance occurred during the third week of May, with the majority of larvae collected between mid-May and mid-June. PYSL estimated densities exceeded 200/1000 m^3 during all LRS collections following the initial sampling week.

PYSL were collected in every region of the estuary, with greatest abundance between the Hyde Park and Catskill regions (RM 77-124). Peak density was estimated to be in the Saugerties region, one region downriver from peak YSL abundance. No bimodality was evident, although a spatial shift in peak regional density from the Saugerties to the Hyde Park region was apparent in late May. The downriver shift is likely a reflection of increased river flow. Increases in PYSL density in the Catskill and Saugerties regions following the period of high flow is likely the result of larval movement upriver or from tributaries of the upper estuary. River herring PYSL were collected in trace numbers as far south as the Tappan Zee and Yonkers regions.

1986 LONG RIVER SURVEY

DENSITY OF YSL FOR ALOSA

BLOCK CHART OF AVG DENSITY

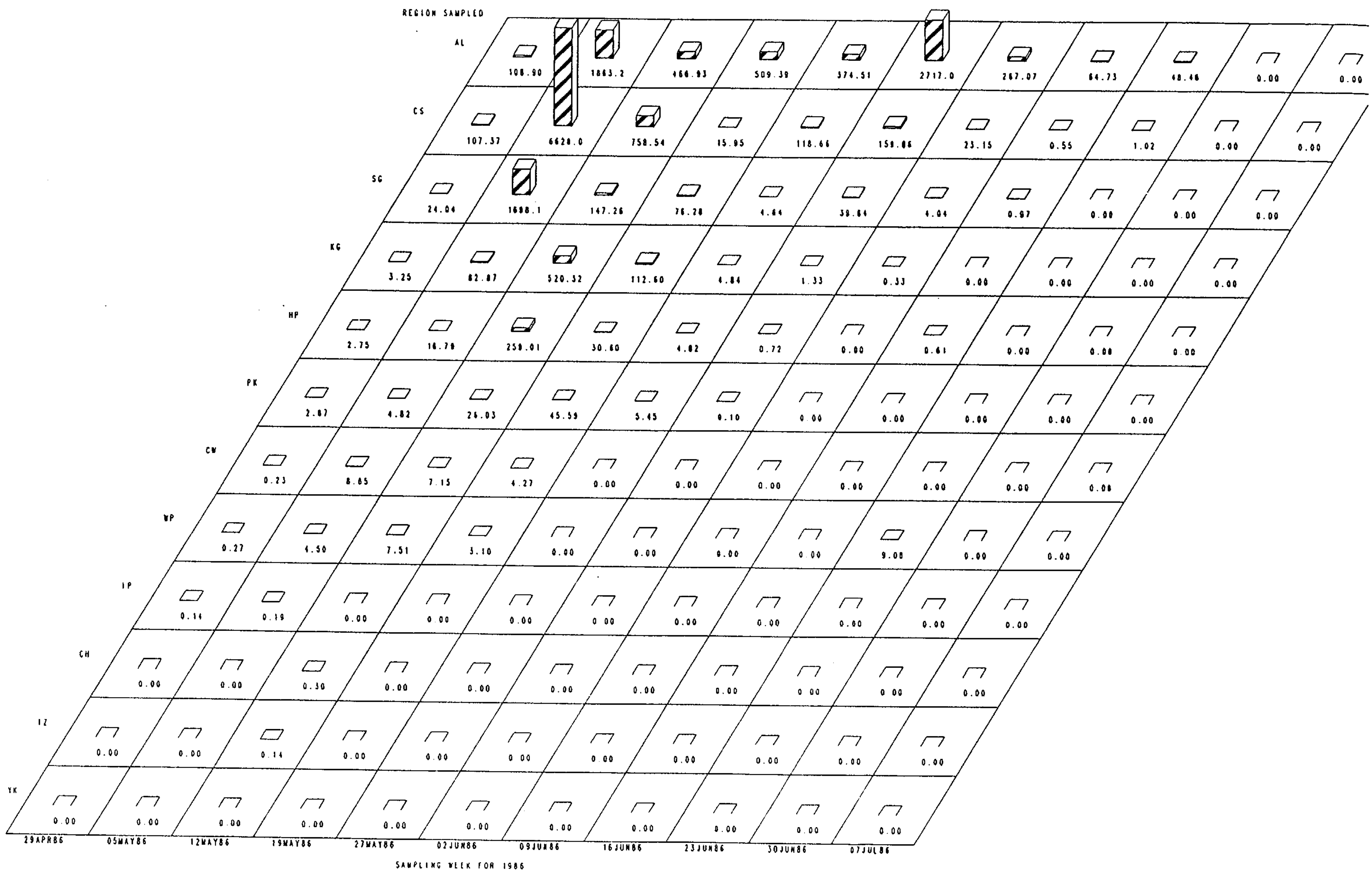


FIGURE 4-99

1986 LONG RIVER SURVEY

DENSITY OF PYSL FOR ALOSA

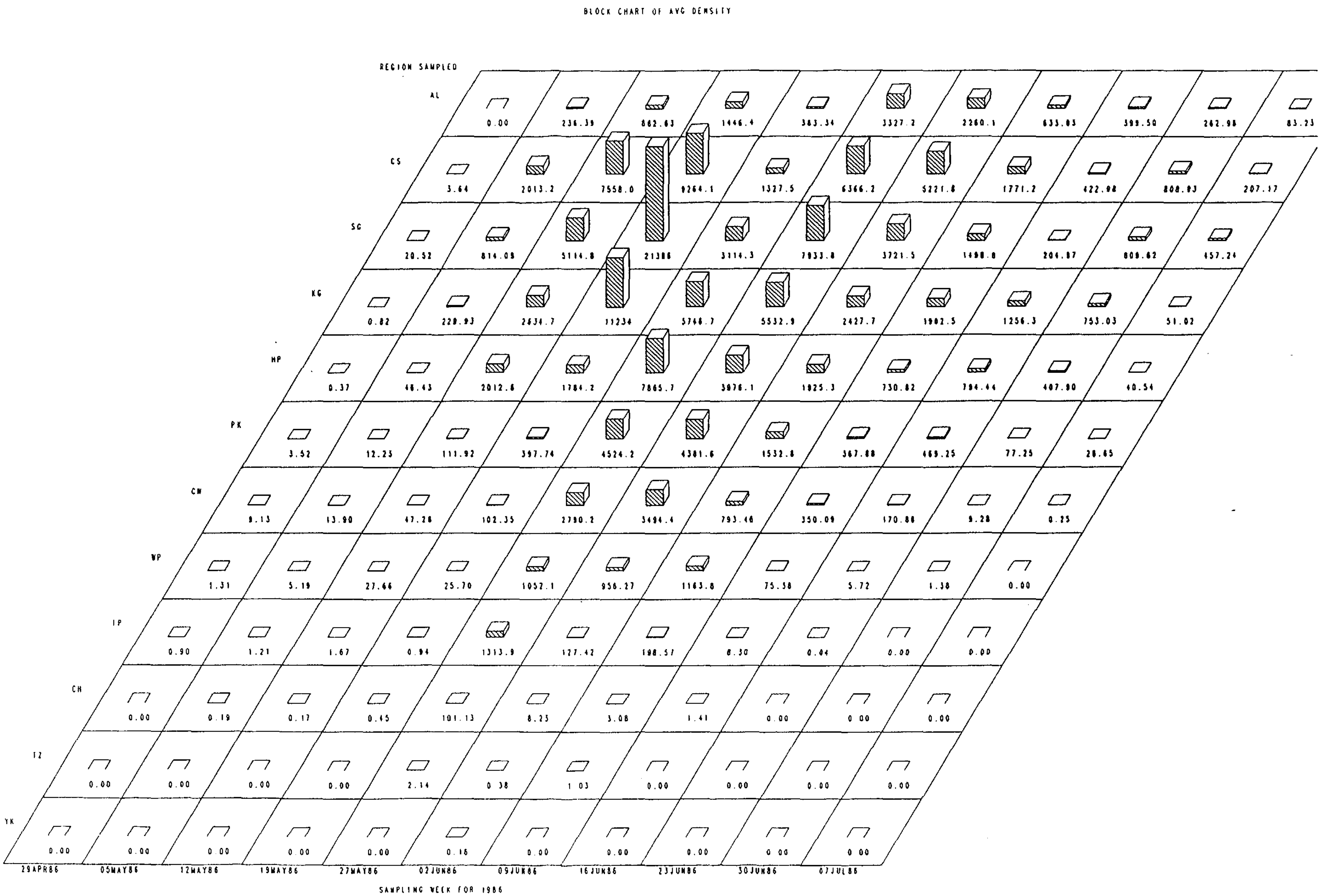


FIGURE 4-100

4.7.1.4 Early Young-of-Year. Early river herring YOY were collected during the last week of May in the 1986 LRS and were most abundant during the final sampling week in June (Figure 4-101). Greatest abundance of unidentified river herring YOY occurred from the Poughkeepsie through Catskill regions (RM 62-124) in late June, with peak density estimated at Hyde Park. Downriver movement was apparent, with trace numbers caught as far south as the Indian Point region. The FSS caught unidentified river herring YOY from late July through early September, with spatial distribution limited to estuary regions north of the Poughkeepsie region (Figure 4-102).

4.7.2 1987 Study

4.7.2.1 Eggs. River herring eggs were present in the upper estuary when the 1987 LRS sampling began (Figure 4-103) and continued to be collected through mid-June. A single temporal density peak from early to mid-May suggests that only one spawning event occurred; sequential spawning by alewife and blueback herring was not apparent. Eggs were concentrated in the upper estuary regions, with peak density estimated in the Kingston region. Average water temperature in the upper estuary during this period was approximately 14.5°C. River herring eggs were sampled as far downriver as the Tappan Zee region; mean density never exceeded 15/1000 m^3 anywhere south of the Poughkeepsie region.

Temporal distribution of eggs in the upper estuary varied with geographical region during 1987. The Albany and Catskill regions had egg density estimates in excess of 500/1000 m^3 from the 20 April through 1 June sampling weeks. Estimated egg densities over 500/1000 m^3 were sampled from the first week in May through the 18 May sampling week in the Saugerties and Kingston regions.

4.7.2.2 Yolk-Sac Larvae. River herring YSL were collected during all but the last sampling week of the 1987 LRS (Figure 4-104), with peak regional densities during the week of 11 May. The YSL density peak occurred one week after the peak in egg abundance in the upper estuary. Previous Year Class Reports

1986 LONG RIVER SURVEY
DENSITY OF YOY FOR ALOSA

BLOCK CHART OF AVG DENSITY

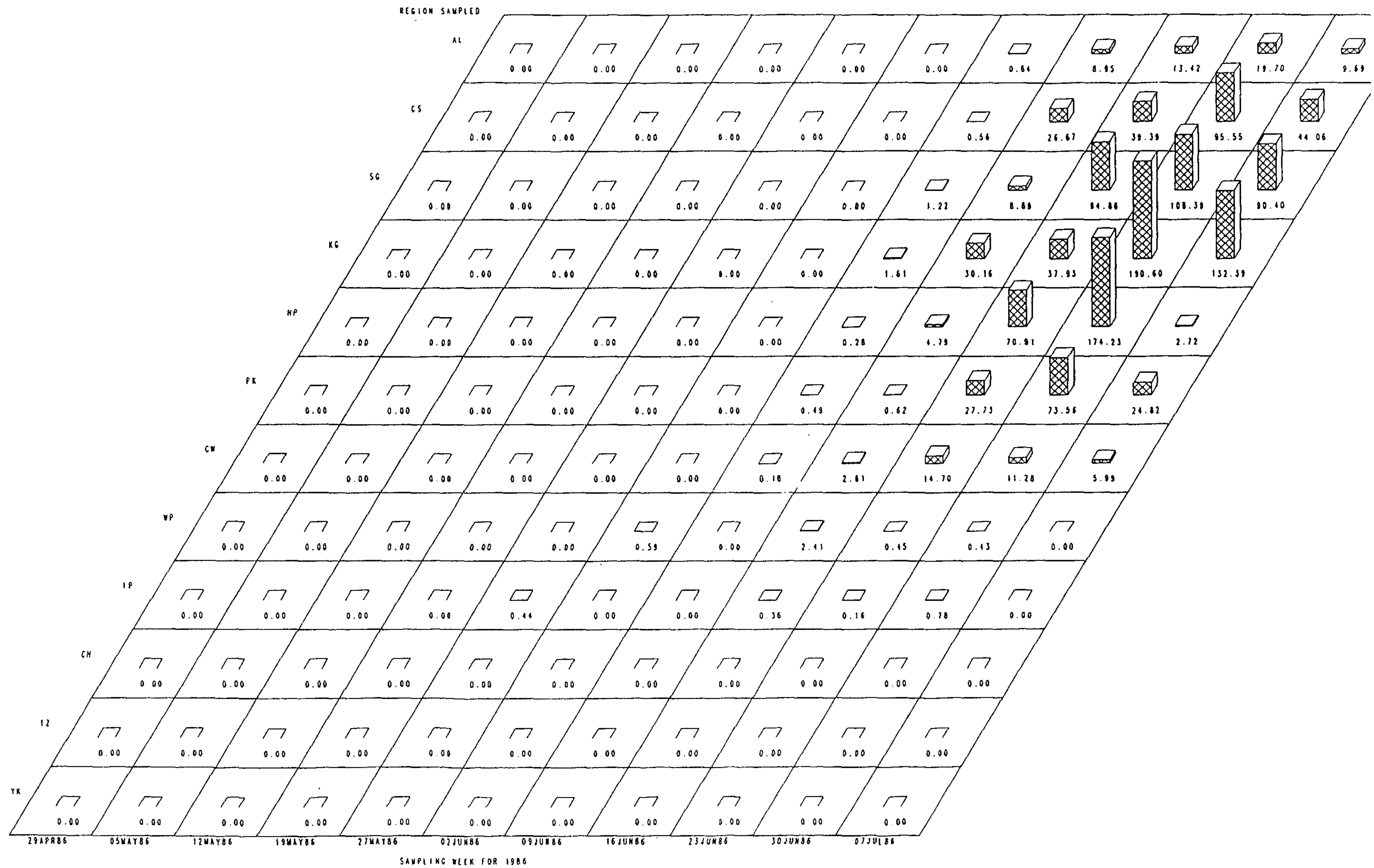


FIGURE 4-101

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR ALOSA

BLOCK CHART OF AVG DENSITY

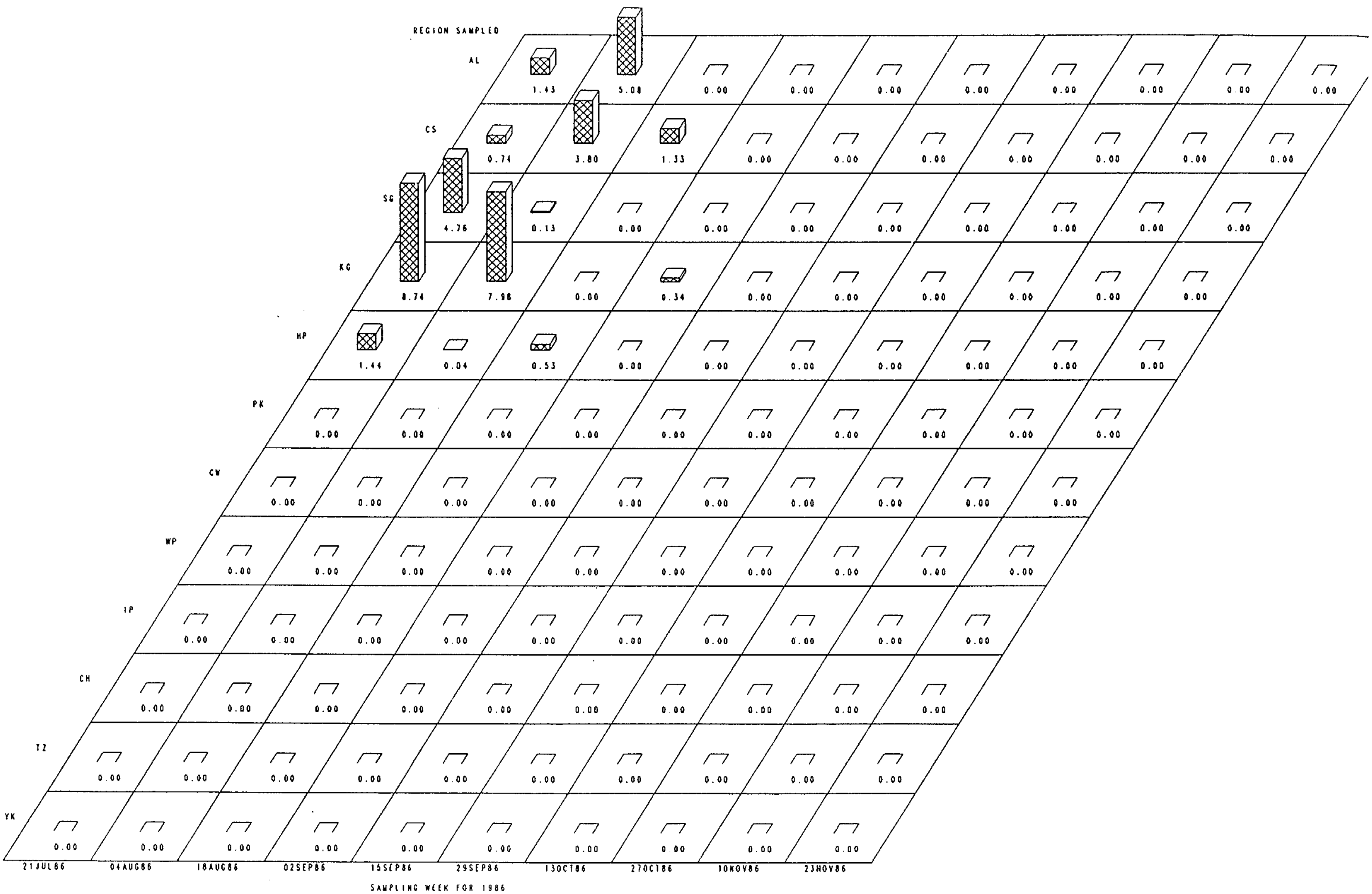
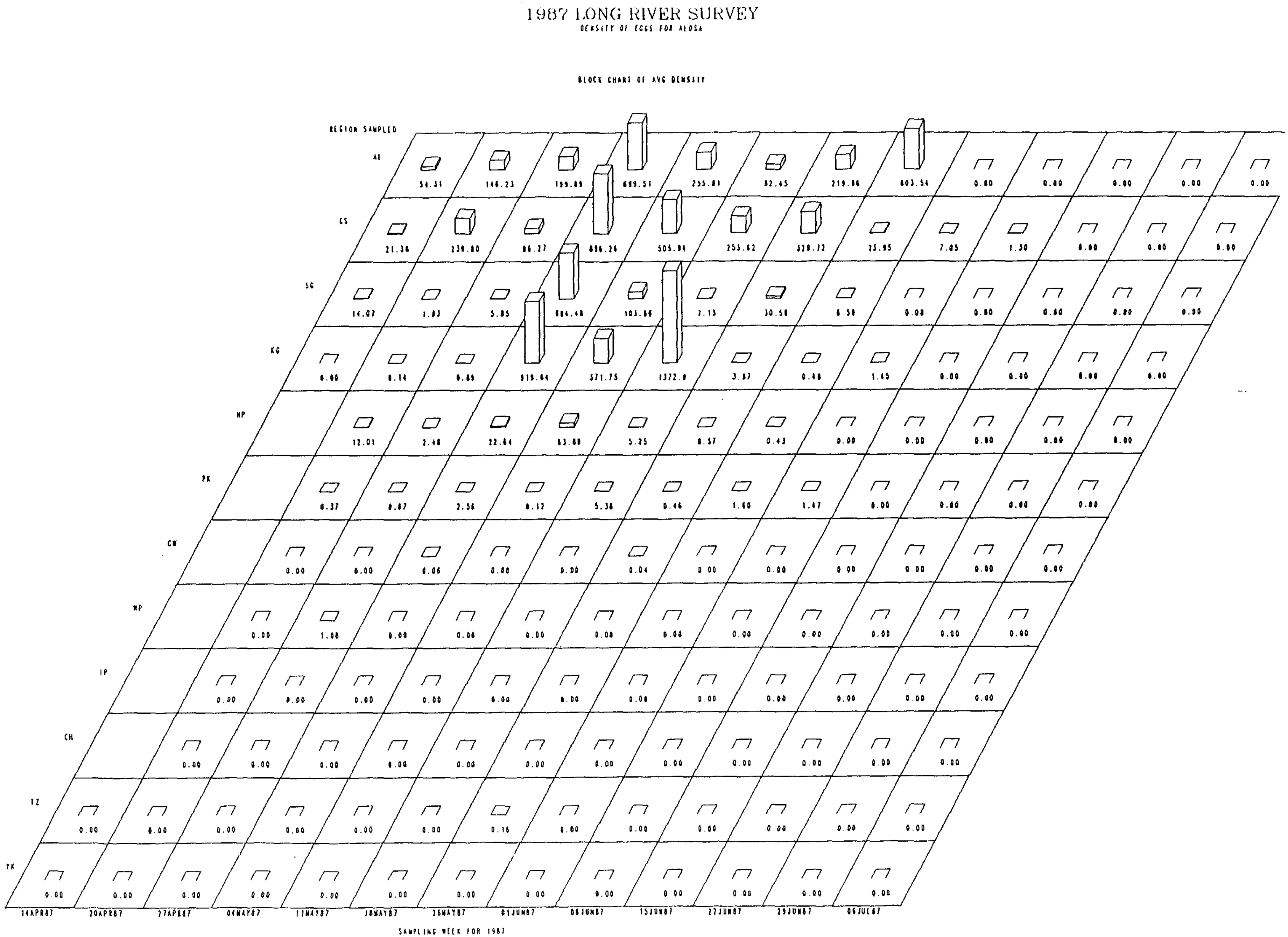


FIGURE 4-102


1987 LONG RIVER SURVEY
DENSITY OF EGGS FOR ALOSA
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
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PK
CW
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CH
TZ
YK
14APR87
20APR87
27APR87
04MAY87
11MAY87
18MAY87
26MAY87
01JUN87
08JUN87
15JUN87
22JUN87
29JUN87
06JUL87
SAMPLING WEEK FOR 1987

FIGURE 4-103

1987 LONG RIVER SURVEY

DENSITY OF YSL FOR ALOSA

BLOCK CHART OF AVG DENSITY

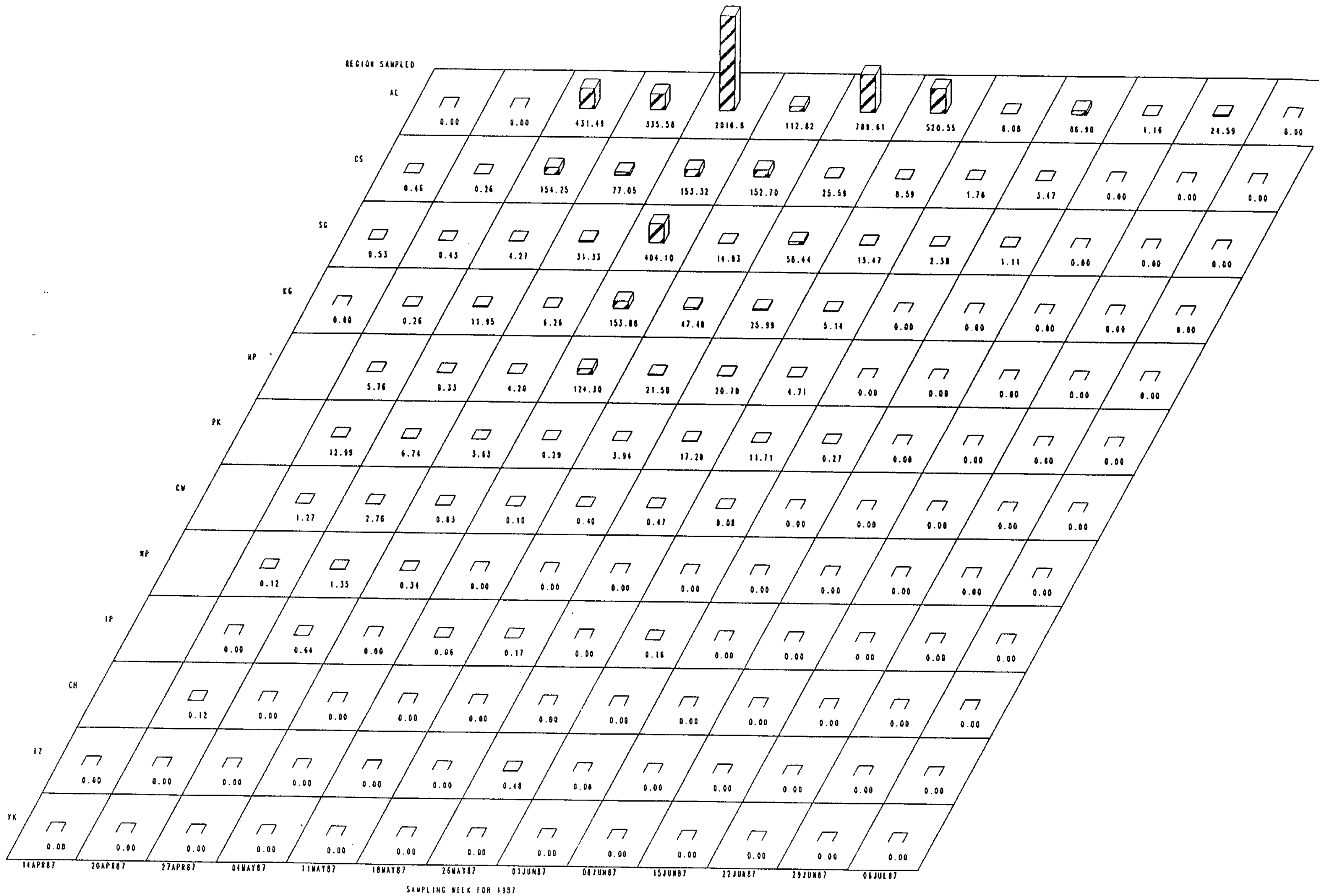


FIGURE 4-104

have also recorded YSL peaks one week after the egg abundance peak (NAI 1985a,b; MMES 1986; Versar 1987). Most river herring YSL were collected from the Albany region, with estimated larval density over 100/1000 m^3 in all regions downriver to the Poughkeepsie region (RM 62-152). Eggs were collected in every region except Yonkers during different sampling weeks through the end of June. No eggs were collected in samples south of the Poughkeepsie region after the 1 June sampling week.

Temporal distributions in the upper estuary during 1987 varied with geographical region in a manner similar to the pattern described for river herring eggs. Larval densities over 1000/1000 m^3 were estimated for the Albany region from late April through early June. Similar densities in the Saugerties, Kingston, and Hyde Park regions were limited to the sampling week of 11 May, the period of peak estuary abundance.

4.7.2.3 Post Yolk-Sac Larvae. River herring PYSL were captured during every sampling week of the 1987 LRS, with peak density estimated in late May and early June (Figure 4-105). This temporal peak tends to follow peak abundances of river herring egg and YSL in the upper estuary. Between late April and late June river herring PYSL were collected during every sampling week in regions north of Croton-Haverstraw. PYSL were present during at least two sampling weeks in all regions sampled during 1987. Greatest density estimates (>1000/1000 m^3) were determined for regions north of Poughkeepsie from mid-May through the end of the LRS sampling program. PYSL densities in excess of 10,000/1000 m^3 were found in the regions of the upper estuary from the last week in May through the second week of June.

4.7.2.4 Early Young-of-Year. Early river herring YOY were first collected during mid-May of the 1987 LRS (Figure 4-106). Greatest abundance of unidentified river herring YOY occurred from the Kingston region through the Albany region (RM 86-152) during the 6 July sampling period; peak density occurred in the Albany region. Trace levels were evident in all regions downriver of Hyde Park with the exception of Yonkers. The FSS caught unidentified river herring

1987 LONG RIVER SURVEY

DENSITY OF PYSL FOR ALOSA

BLOCK CHART OF AVG DENSITY

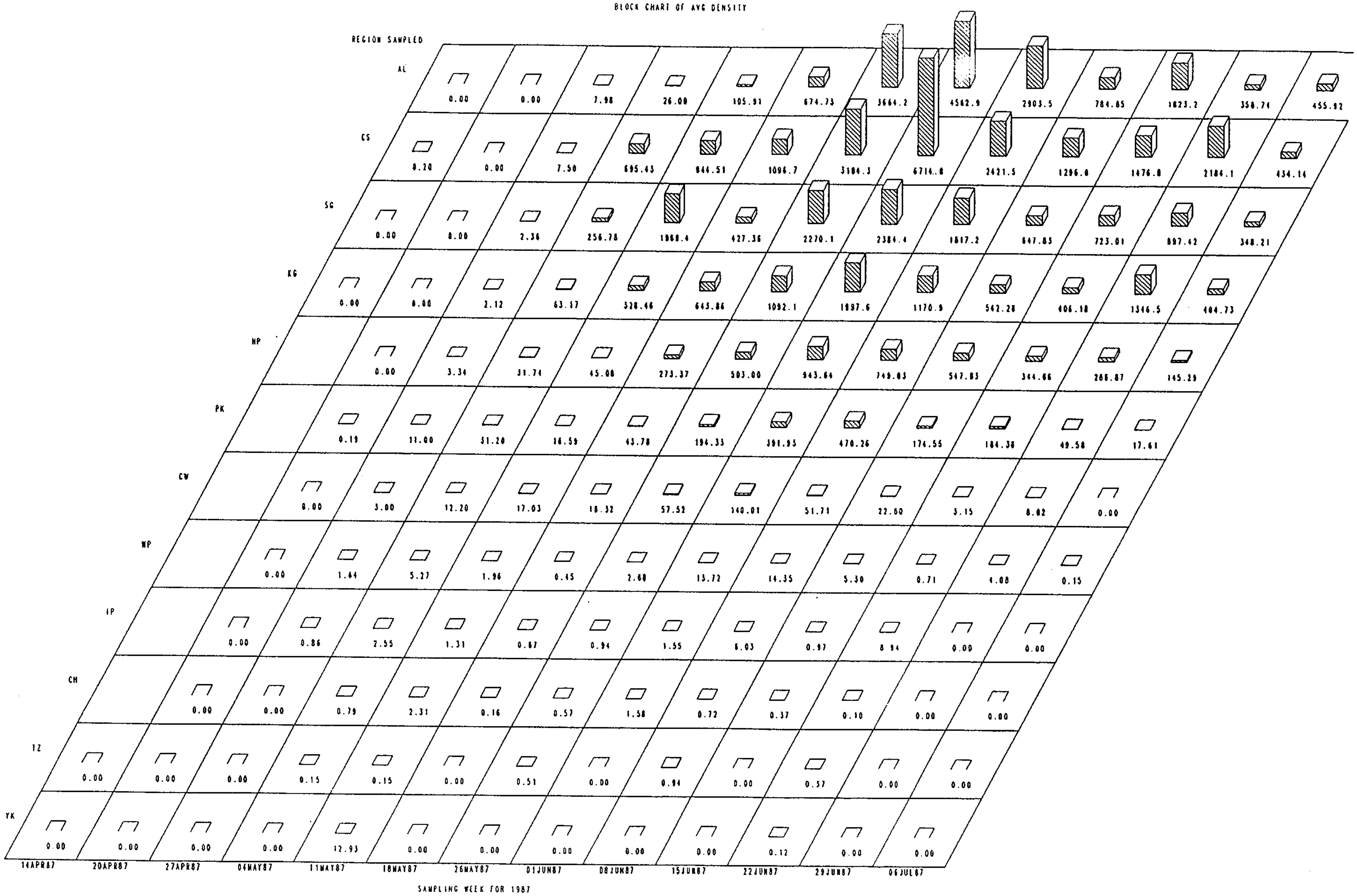


FIGURE 4-105

1987 LONG RIVER SURVEY

DENSITY OF YOY FOR ALOSA

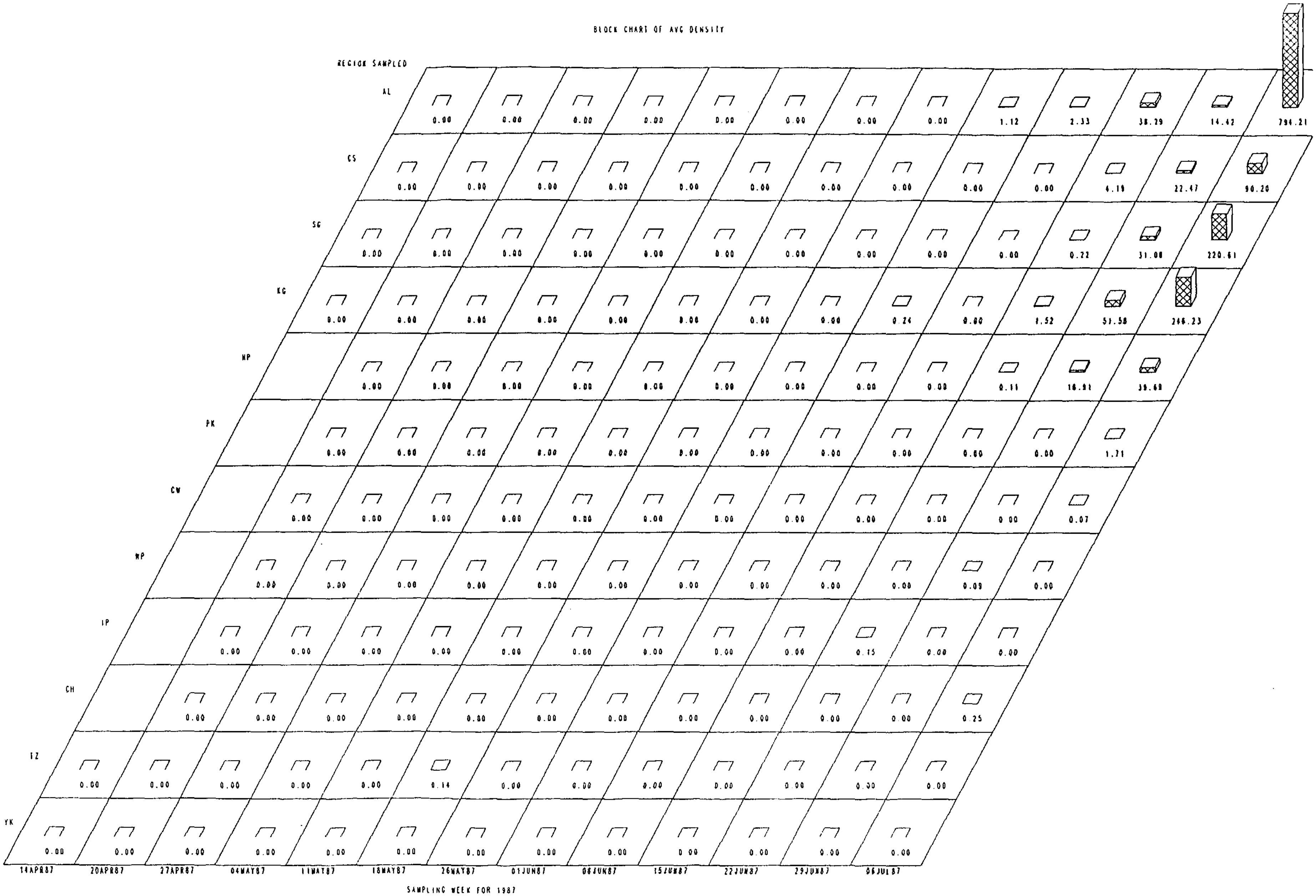


FIGURE 4-106

YOY from mid-July through early September (Figure 4-107). Densities estimated at greater than 10/1000 m^3 were observed in the Poughkeepsie through Catskill regions (RM 62-124) during the first FSS sampling period. No early YOY were collected after the 24 August sampling period.

4.8 BLUEBACK HERRING

Blueback herring (Alosa aestivalis) are anadromous clupeidae, occurring from Nova Scotia to Florida (Bigelow and Schroeder 1953). As noted previously, blueback herring spawning takes place in the spring, following that of the alewife. In the Hudson River estuary most spent adults return to sea from mid-June to mid-August (TI 1981). Blueback herring eggs are demersal and somewhat adhesive, hatching in three to four days at 20 to 21°C (Jones et al. 1978). Juveniles begin to leave the estuary in mid-October as water temperatures rapidly decrease (TI 1981).

4.8.1 1986 Study

4.8.1.1 Young-of-Year (>35 to 40 mm). Identifiable blueback herring YOY (>35 to 40 mm) were first collected during the 23 June 1986 LRS sampling week (Figure 4-108) and were caught in every sampling week of the FSS (Figure 4-109) and BSS (Figure 4-110) programs. Shore-zone collections diminished in September as water temperatures decreased. The estimated density of blueback herring YOY was highest from the July LRS through the mid-September FSS samples in the Poughkeepsie through Catskill regions (RM 62-124). Peak density was estimated to be in the Kingston and Poughkeepsie regions for the LRS and FSS programs, respectively. YOY began to emigrate from the Hudson River nursery grounds in mid-October, apparently triggered when upper and middle estuary temperatures dropped 4 to 5°C to about 14 to 16°C. Large estimated YOY densities were found in the middle estuary during the FSS sampling weeks of 13 and 27 October. No YOY were captured north of the Croton-Haverstraw area during the 23 November sampling week of the FSS program.

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR ALOSA

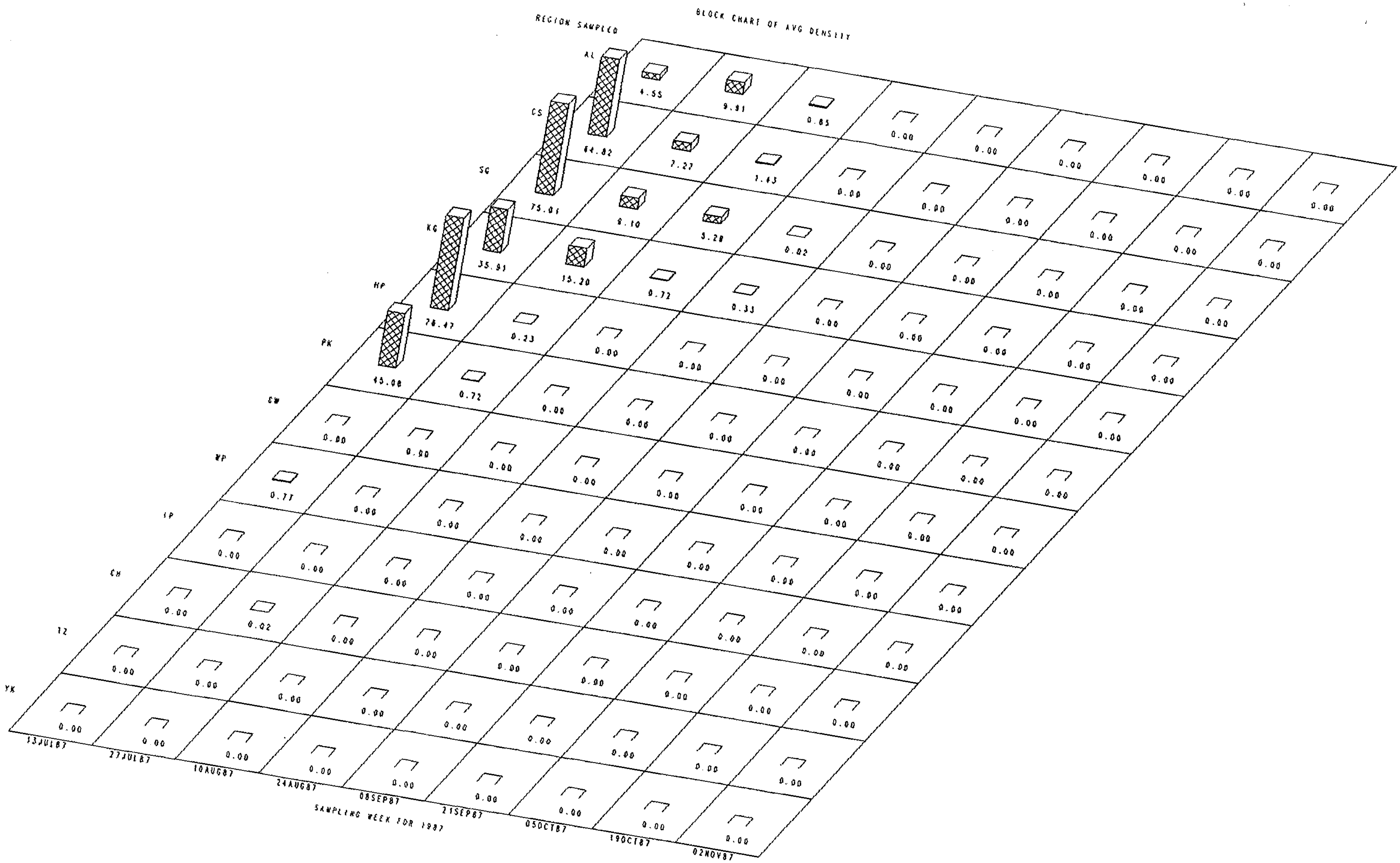


FIGURE 4–107

1986 LONG RIVER SURVEY

DENSITY OF YOY FOR BLUEBACK HERRING

BLOCK CHART OF AVG DENSITY

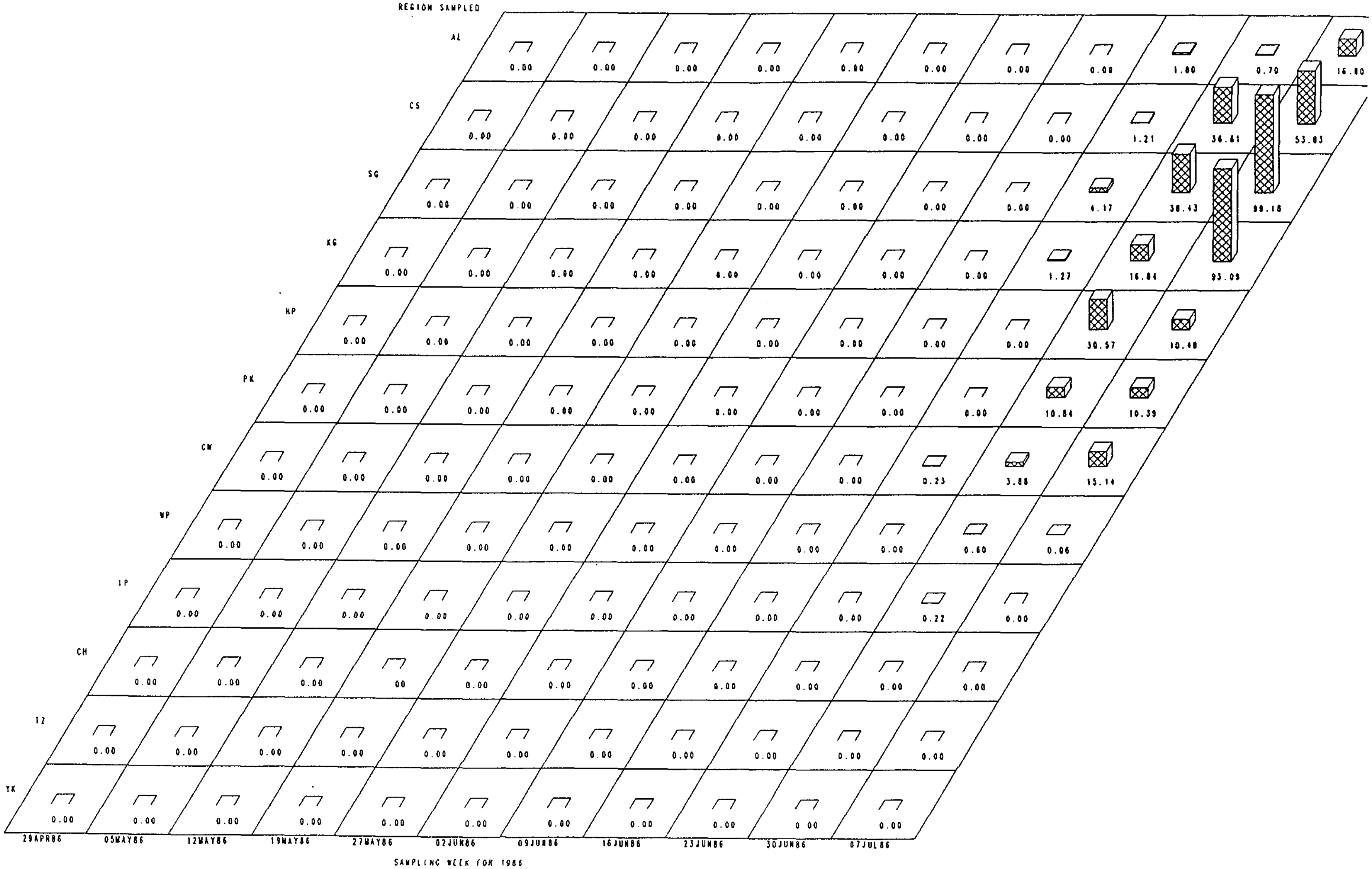


FIGURE 4-108

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR BLUEBACK HERRING

BLOCK CHART OF AVG DENSITY

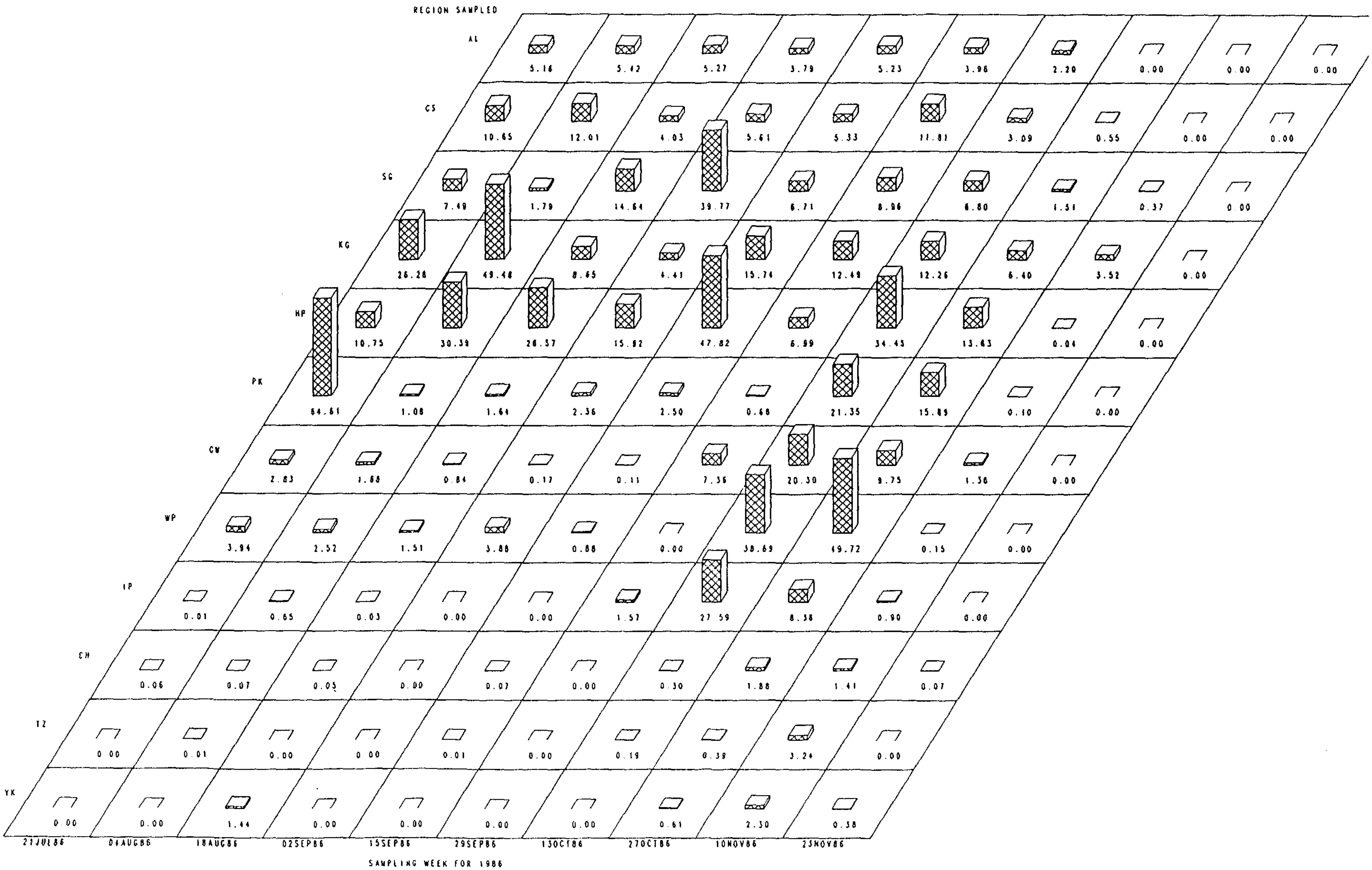


FIGURE 4-109

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR BH

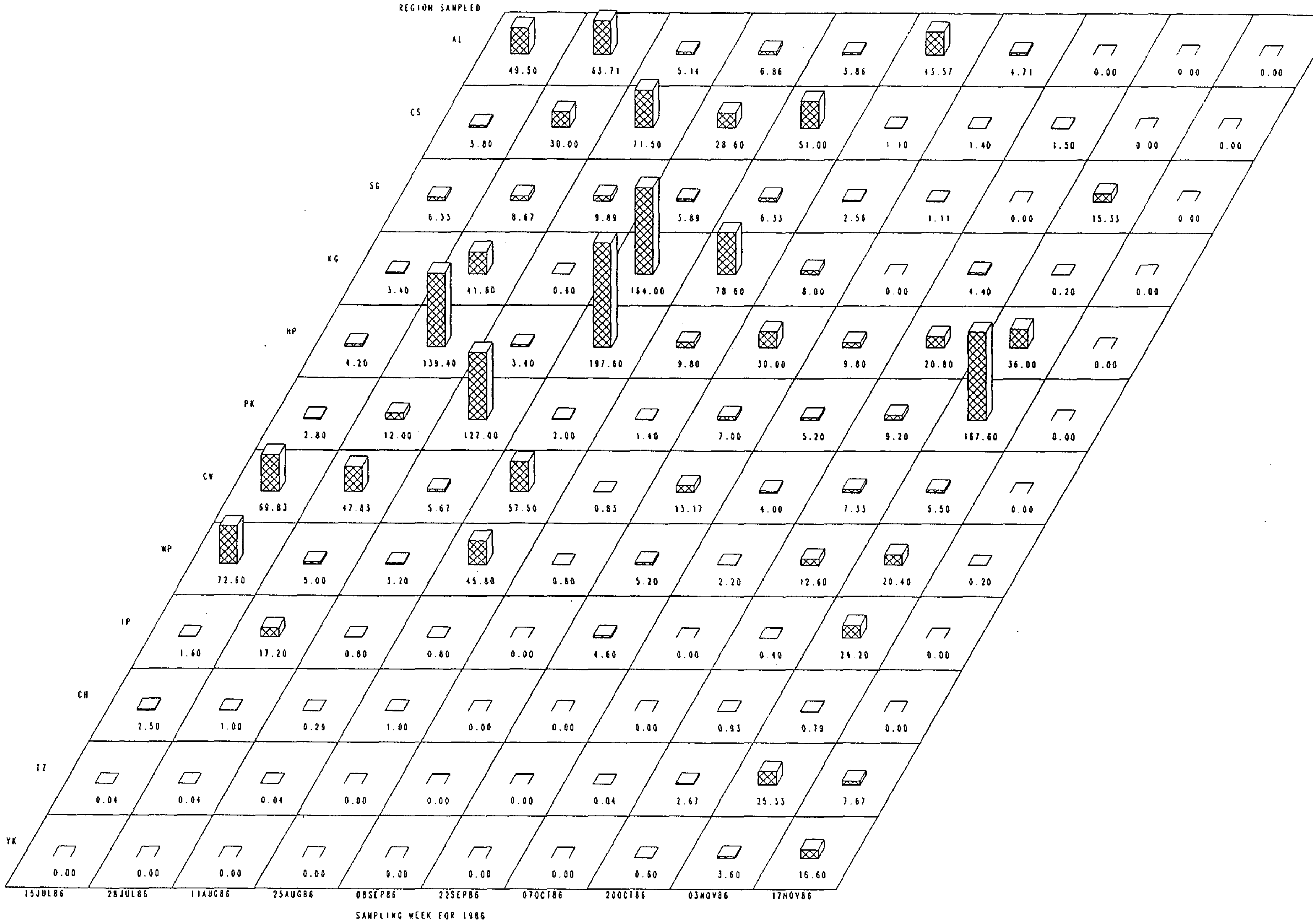


FIGURE 4-110

4.8.1.2 Yearling and Older Fish. Yearling and older blueback herring were caught sporadically in very low numbers in all 1986 sampling programs from late April through late October in sampling regions south of the Catskill area (Figures 4-111, 4-112, and 4-113). No suggestions of temporal or spatial distribution could be made from available catch data.

4.8.2 1987 Study

4.8.2.1 Young-of-Year. The 1987 LRS first identified blueback herring YOY during the 22 June sampling week (Figure 4-114). The FSS collected blueback herring YOY during every sampling week, with temporal distribution patterns suggesting that greatest abundance occurred in late September (Figure 4-115). BSS temporal distribution patterns were similar to FSS patterns, with collections occurring in all but the initial sampling week (Figure 4-116).

Spatial distribution patterns for both the FSS and BSS suggest greatest abundance between the Poughkeepsie region and the Albany region, with peak densities estimated for the Poughkeepsie and Hyde Park regions. An increase in lower estuary abundance coinciding with an upriver decline in both the FSS and BSS is associated with fall emigration from the estuary beginning in late September.

4.8.2.2 Yearling and Older Fish. Yearling and older blueback herring were caught from the initial 1987 LRS sampling week (Figure 4-117) through the last October sample of the FSS (Figure 4-118). Greatest occurrence was in early and mid-May, presumably a reflection of spawning activity and the associated movement of yearling with the older fish. Most of the yearling and older blueback herring were collected in the upper estuary, with peak occurrence in the Albany region. No apparent downstream movement followed the upper estuary peak. Only sporadic collections of very low numbers occurred in subsequent samples. There were only sporadic collections of low numbers in the BSS (Figure 4-119), which indicated no apparent spatial or temporal distribution trends.

1986 LONG RIVER SURVEY

DENSITY OF YROL FOR BLUEBACK HERRING

BLOCK CHART OF AVG DENSITY

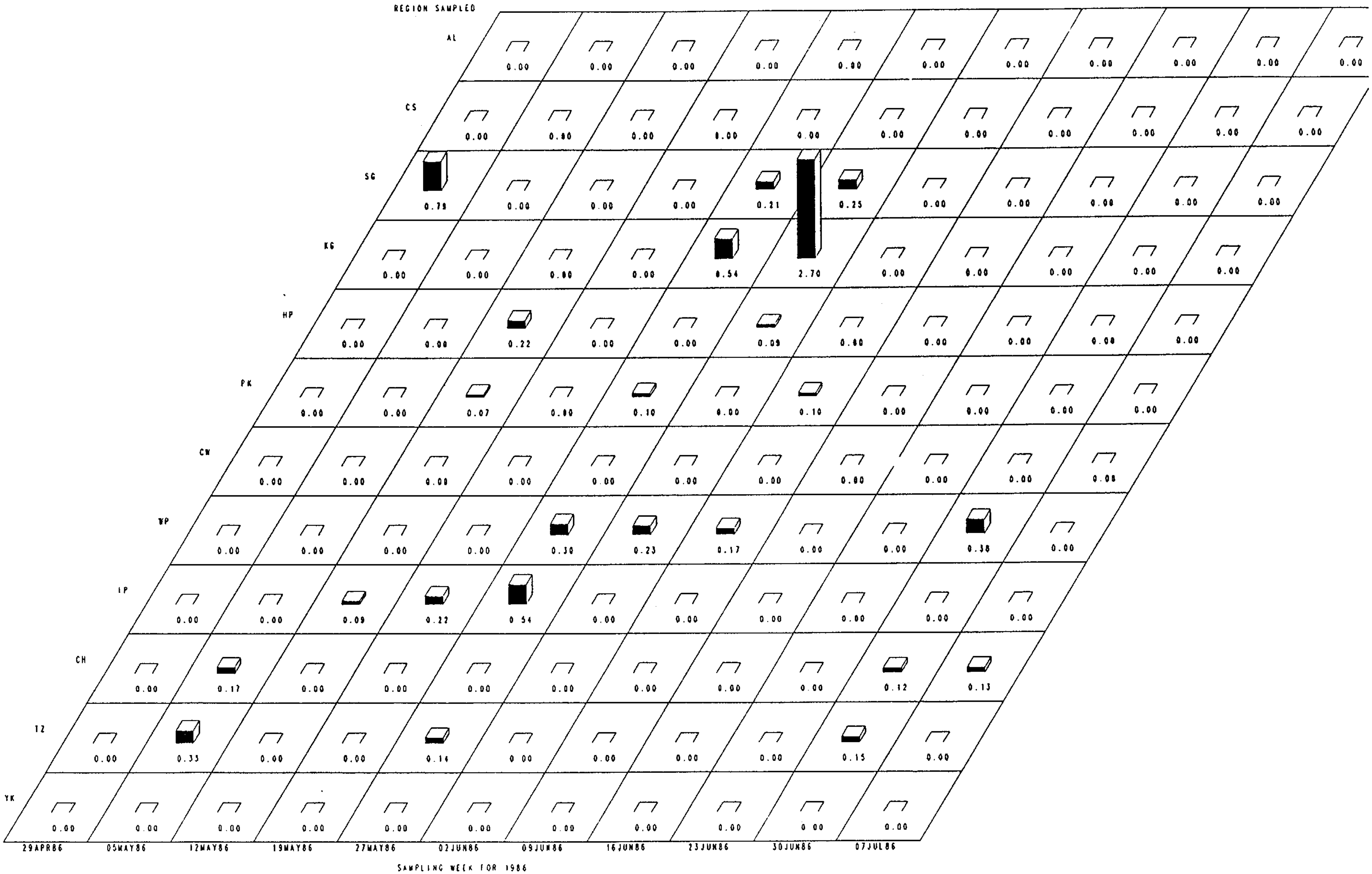


FIGURE 4-111

1986 FALL SHOALS SURVEY

DENSITY OF YROL FOR BLUEBACK HERRING

BLOCK CHART OF AVG DENSITY

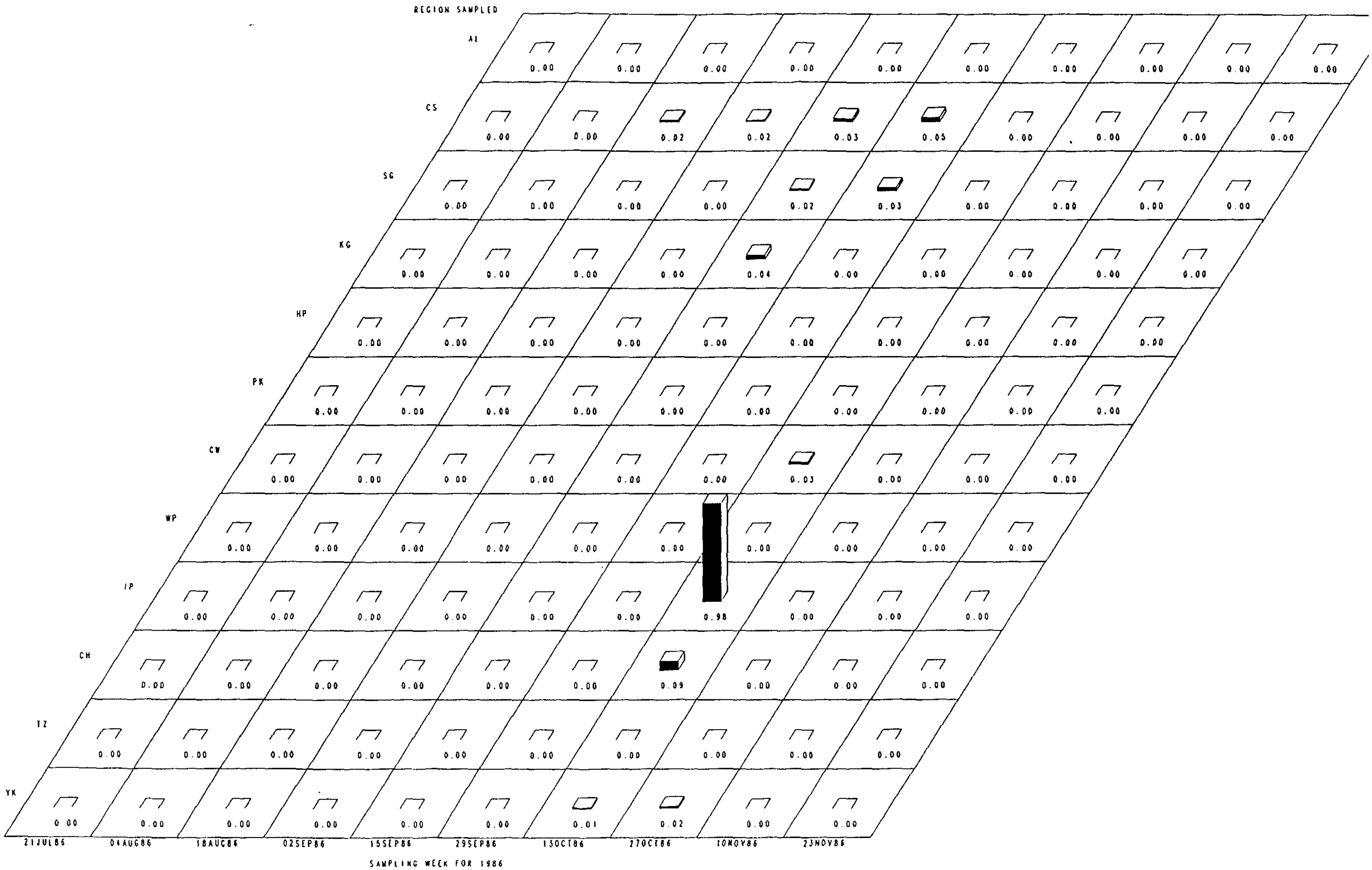


FIGURE 4-112

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR BH

BLOCK CHART OF CATCH/UNIT EFFORT

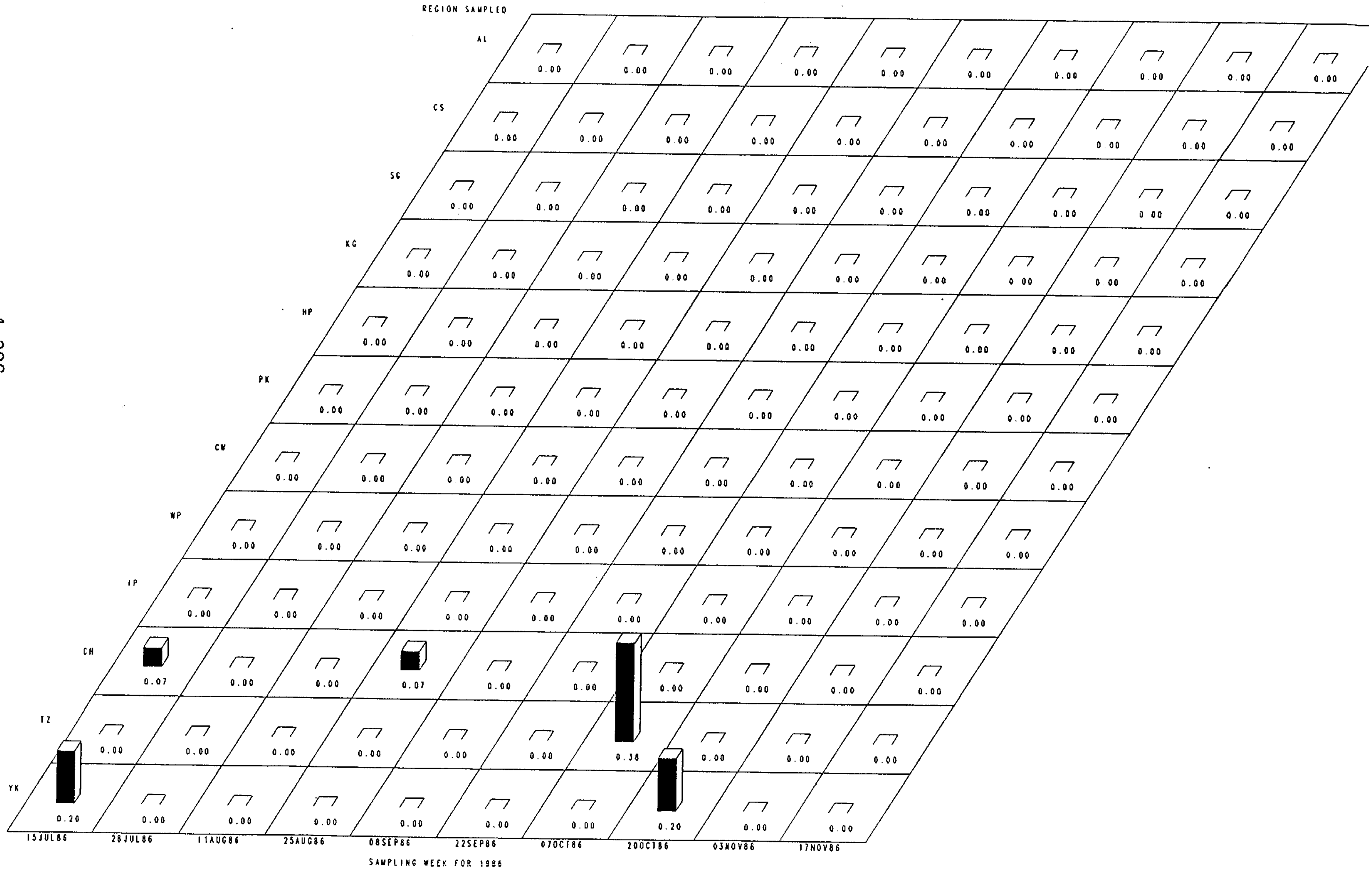


FIGURE 4-113

1987 LONG RIVER SURVEY

DENSITY OF YOY FOR BLUEBACK HERRING

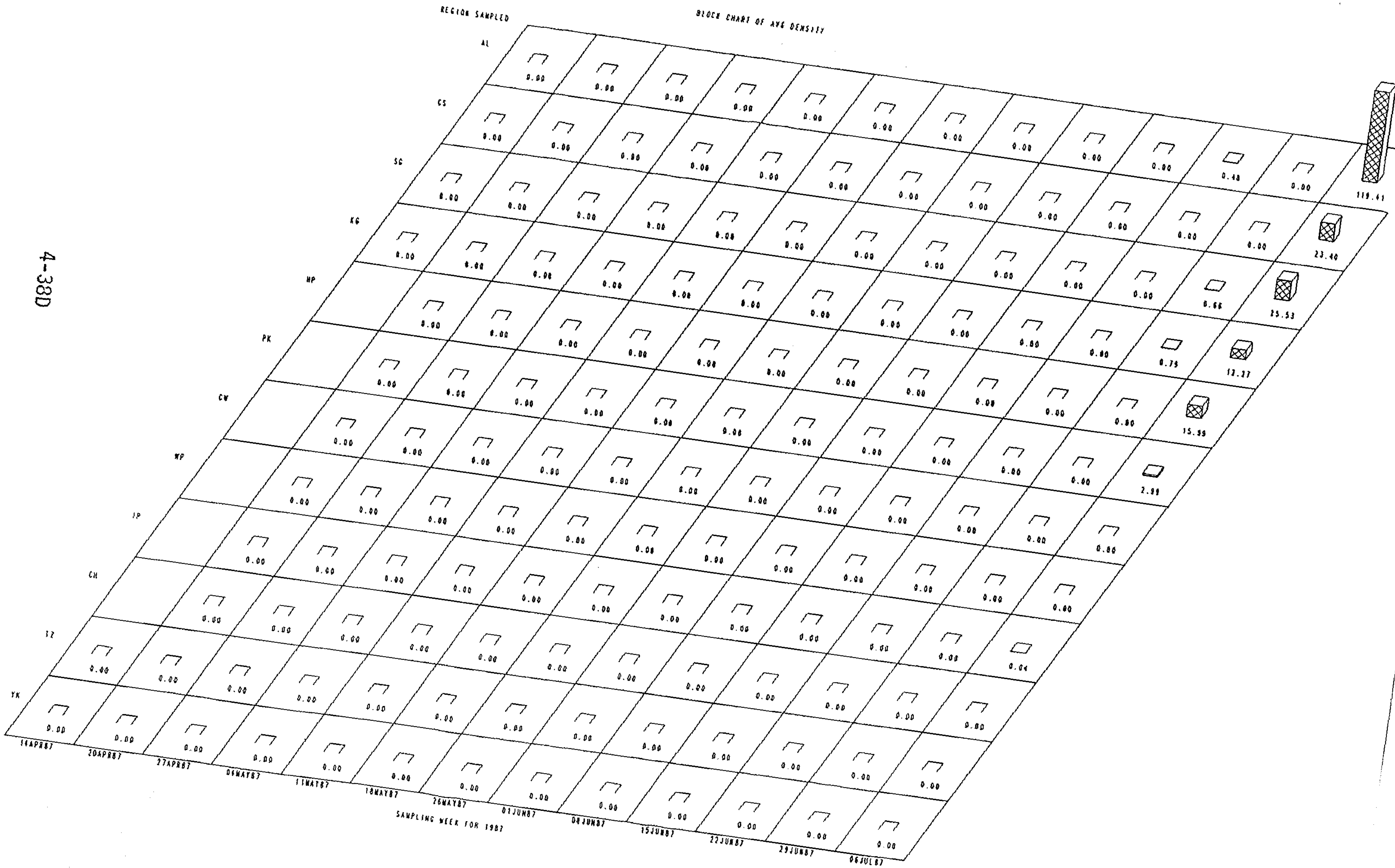


FIGURE 4-114

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR BLUEBACK HERRING

BLOCK CHART OF AVG DENSITY

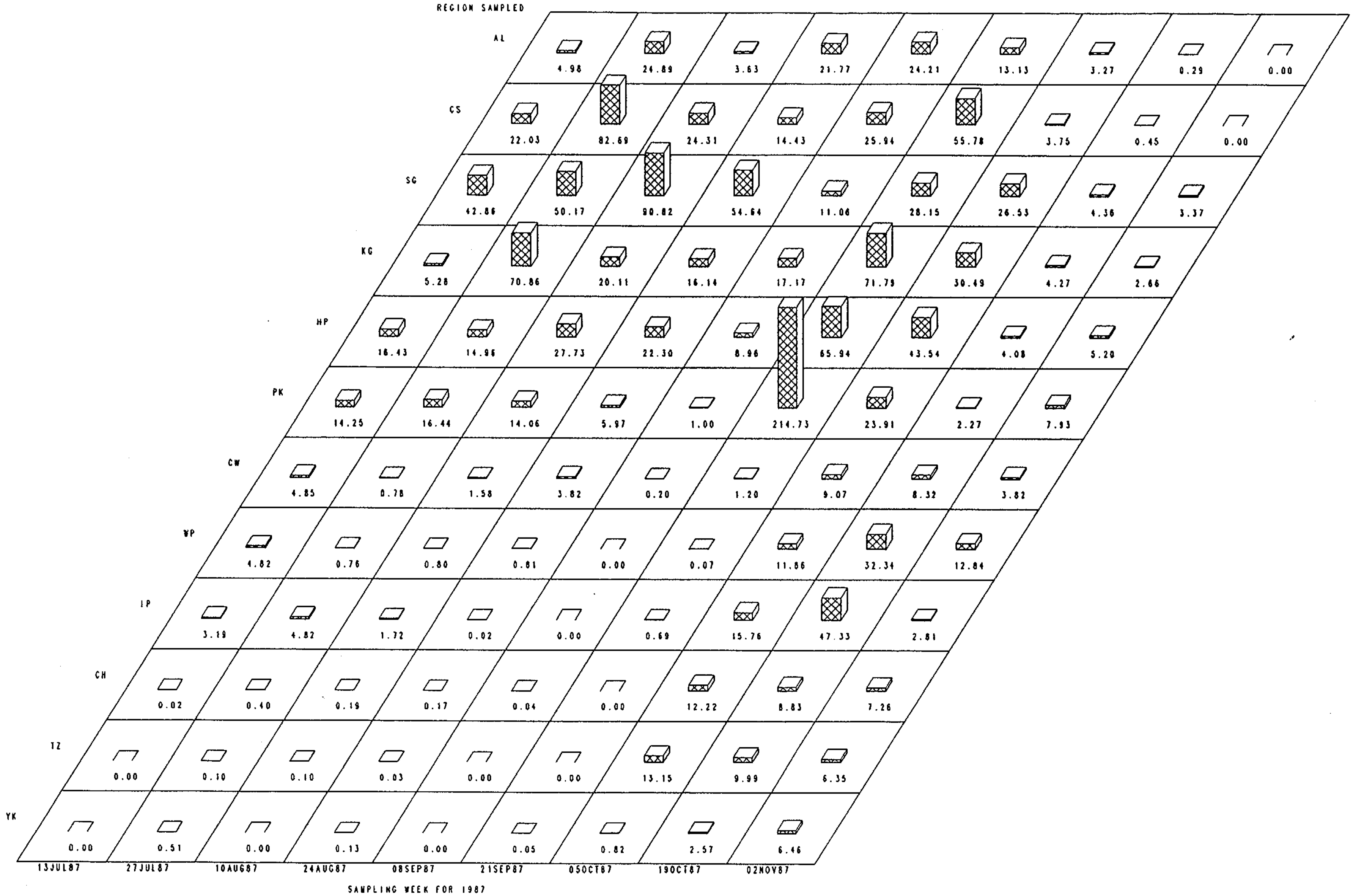


FIGURE 4-115

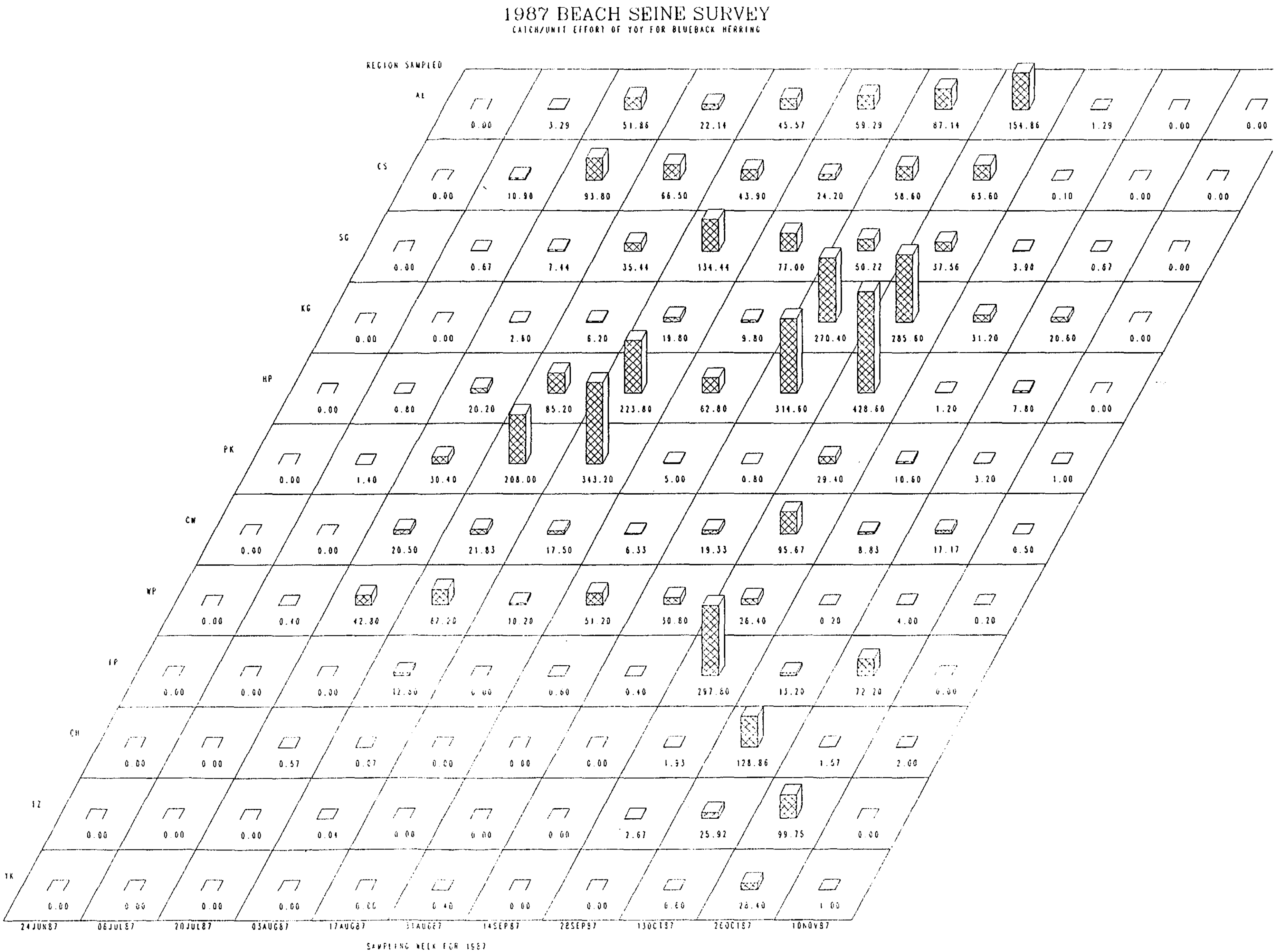

1987 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF YOY FOR BLUEBACK HERRING
REGION SAMPLED
AL
0.00 3.29 51.86 22.14 45.57 59.29 87.14 154.86 1.29 0.00 0.00
CS
0.00 10.90 93.80 66.50 43.90 24.20 58.60 63.60 0.10 0.00 0.00
SG
0.00 0.67 7.44 35.44 134.44 77.00 50.22 37.56 3.90 0.67 0.00
KG
0.00 0.00 2.60 6.20 19.80 9.80 270.40 285.60 31.20 20.60 0.00
HP
0.00 0.80 20.20 85.20 223.80 62.80 314.60 428.60 1.20 7.80 0.00
PK
0.00 1.40 30.40 208.00 343.20 5.00 0.80 29.40 10.60 3.20 1.00
CW
0.00 0.00 20.50 21.83 17.50 6.33 19.33 95.67 8.83 17.17 0.50
WP
0.00 0.40 42.80 67.20 10.20 51.20 30.80 26.40 0.20 4.00 0.20
IP
0.00 0.00 0.00 0.60 0.40 297.60 13.20 72.20
CH
0.00 0.00 0.57 0.07 0.00 0.00 0.00 1.33 128.86 1.57 2.00
IZ
0.00 0.00 0.00 0.04 0.00 0.00 0.00 2.67 25.92 99.75 0.00
TK
0.00 0.00 0.00 0.00 0.40 0.00 0.00 0.60 26.40 1.00
24JUN87 06JUL87 20JUL87 03AUG87 17AUG87 31AUG87 14SEP87 28SEP87 13OCT87 26OCT87 10NOV87
SAMPLING WEEK FOR 1987

FIGURE 4-116

1987 LONG RIVER SURVEY

DENSITY OF YROL FOR BLUEBACK HERRING

BLOCK CHART OF AVG DENSITY

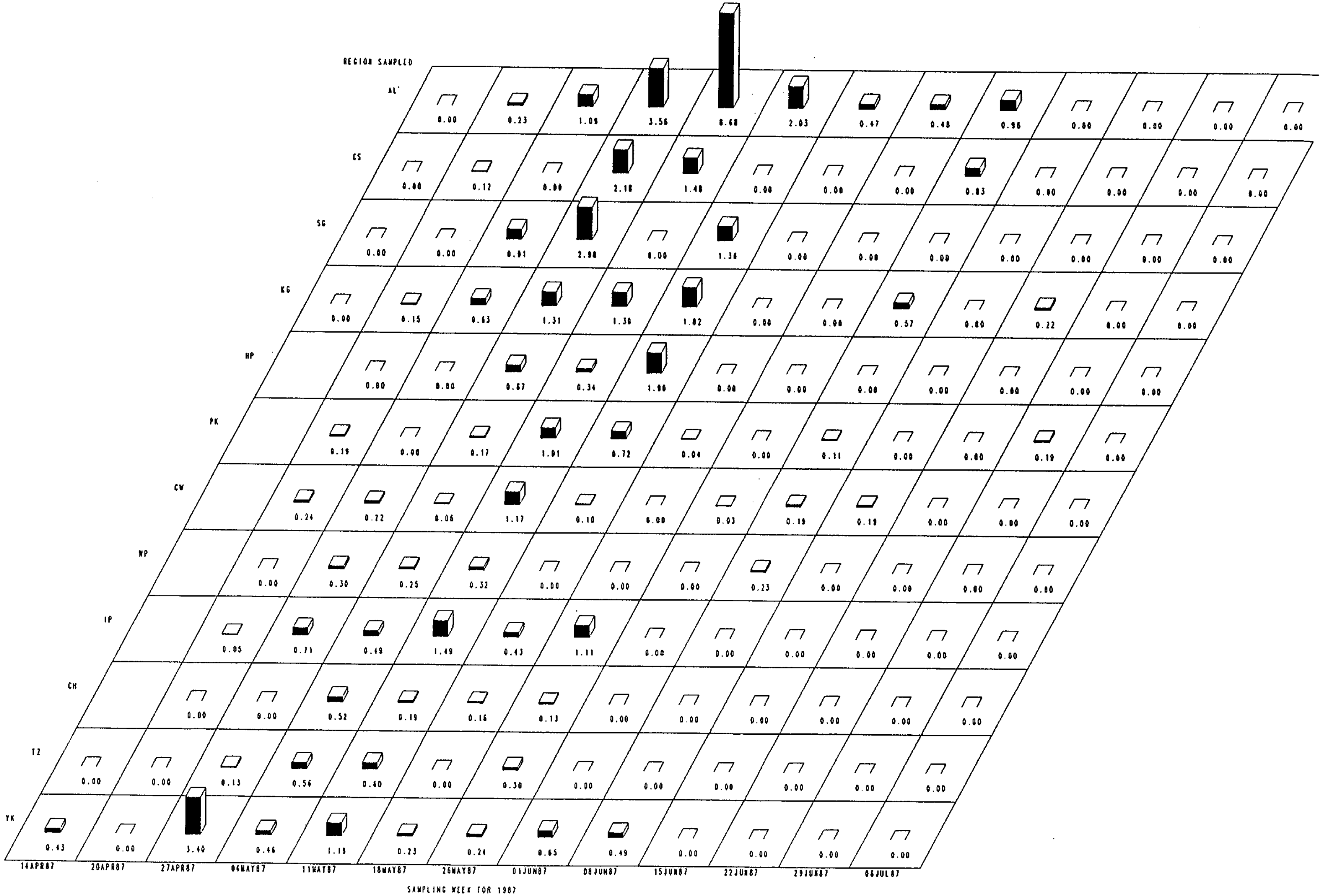


FIGURE 4-117

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR BLUEBACK HERRING

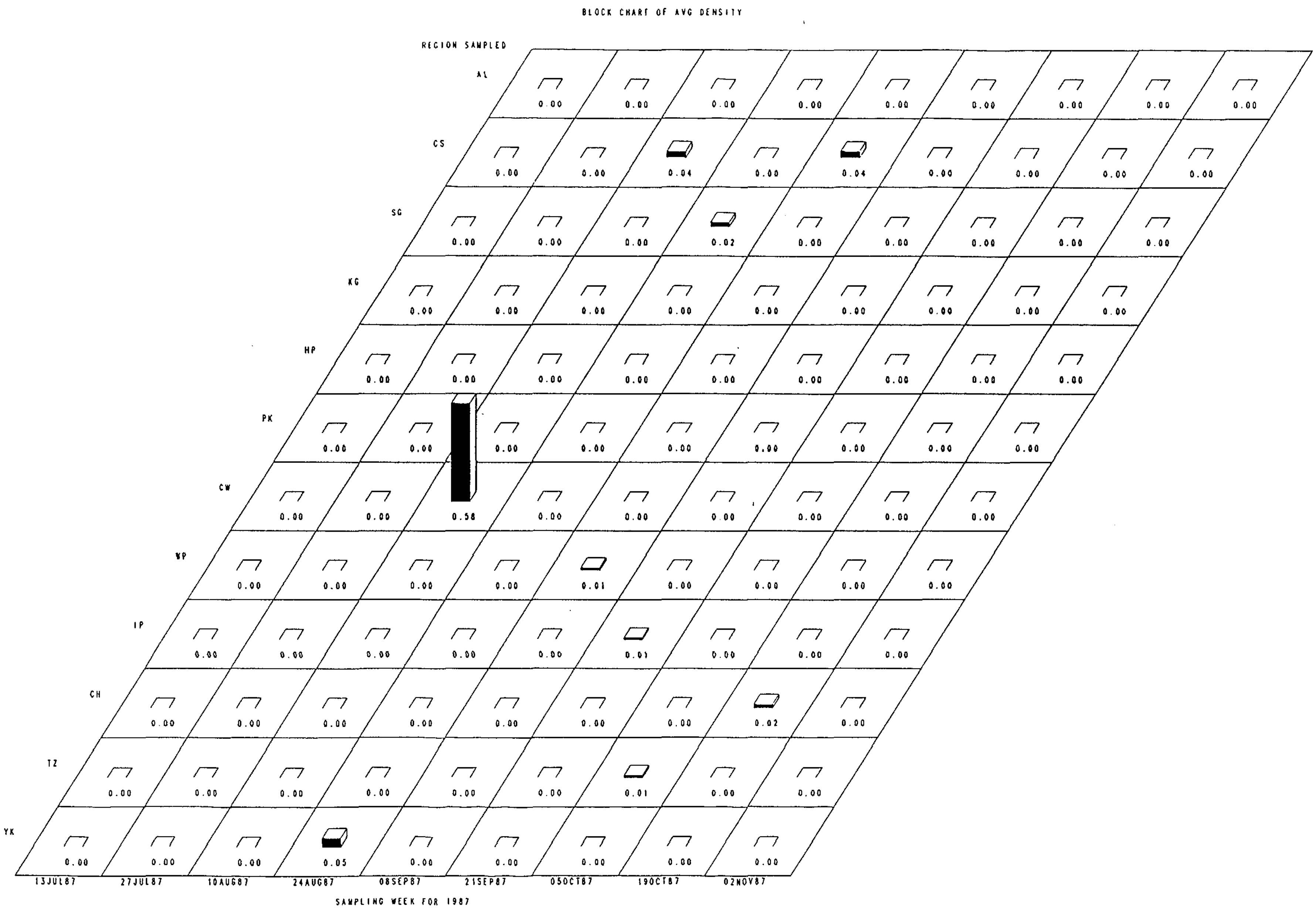


FIGURE 4-118

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR BLUEBACK HERRING

BLOCK CHART OF CATCH/UNIT EFFORT

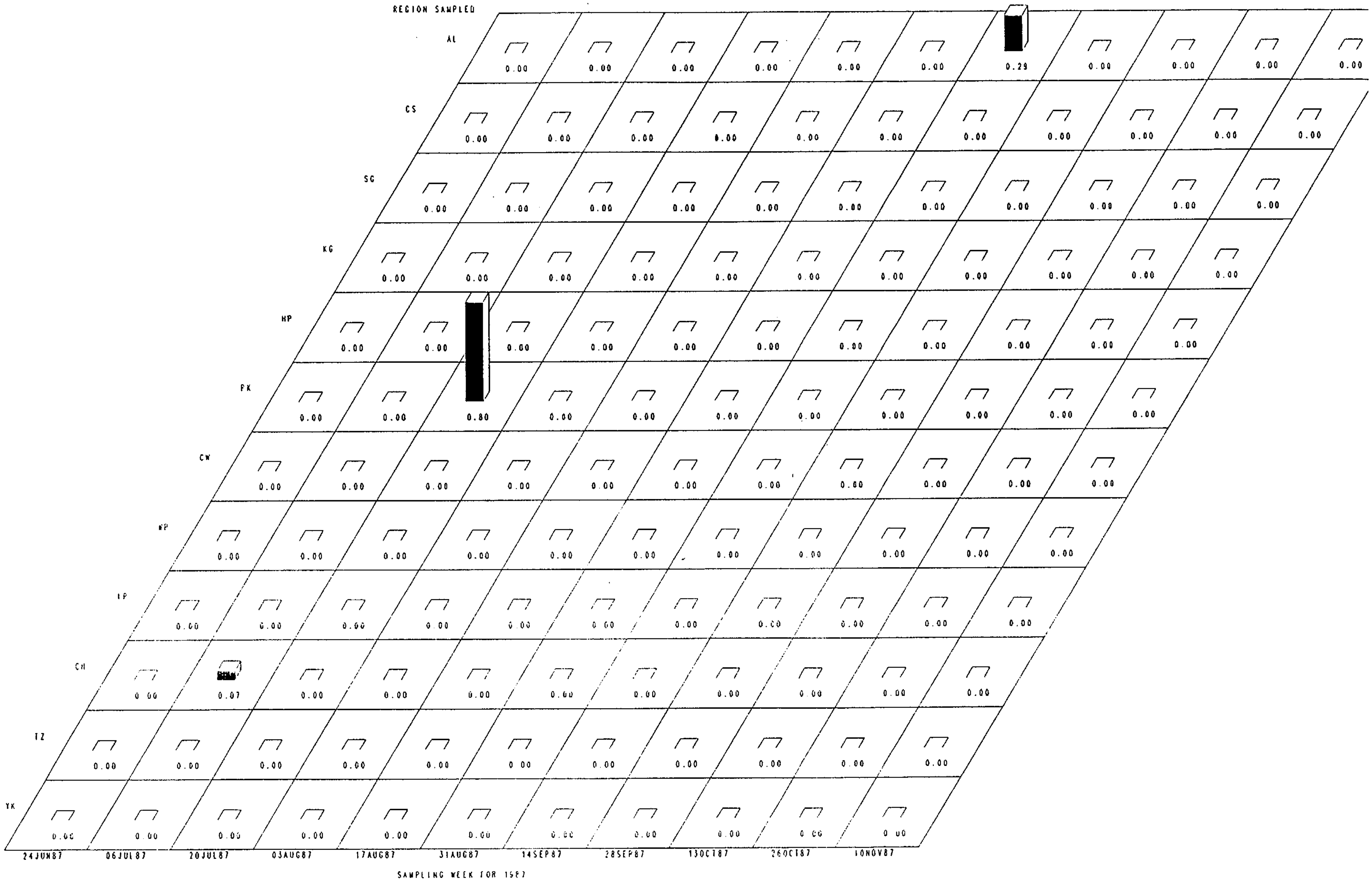


FIGURE 4-119

4.9 ALEWIFE

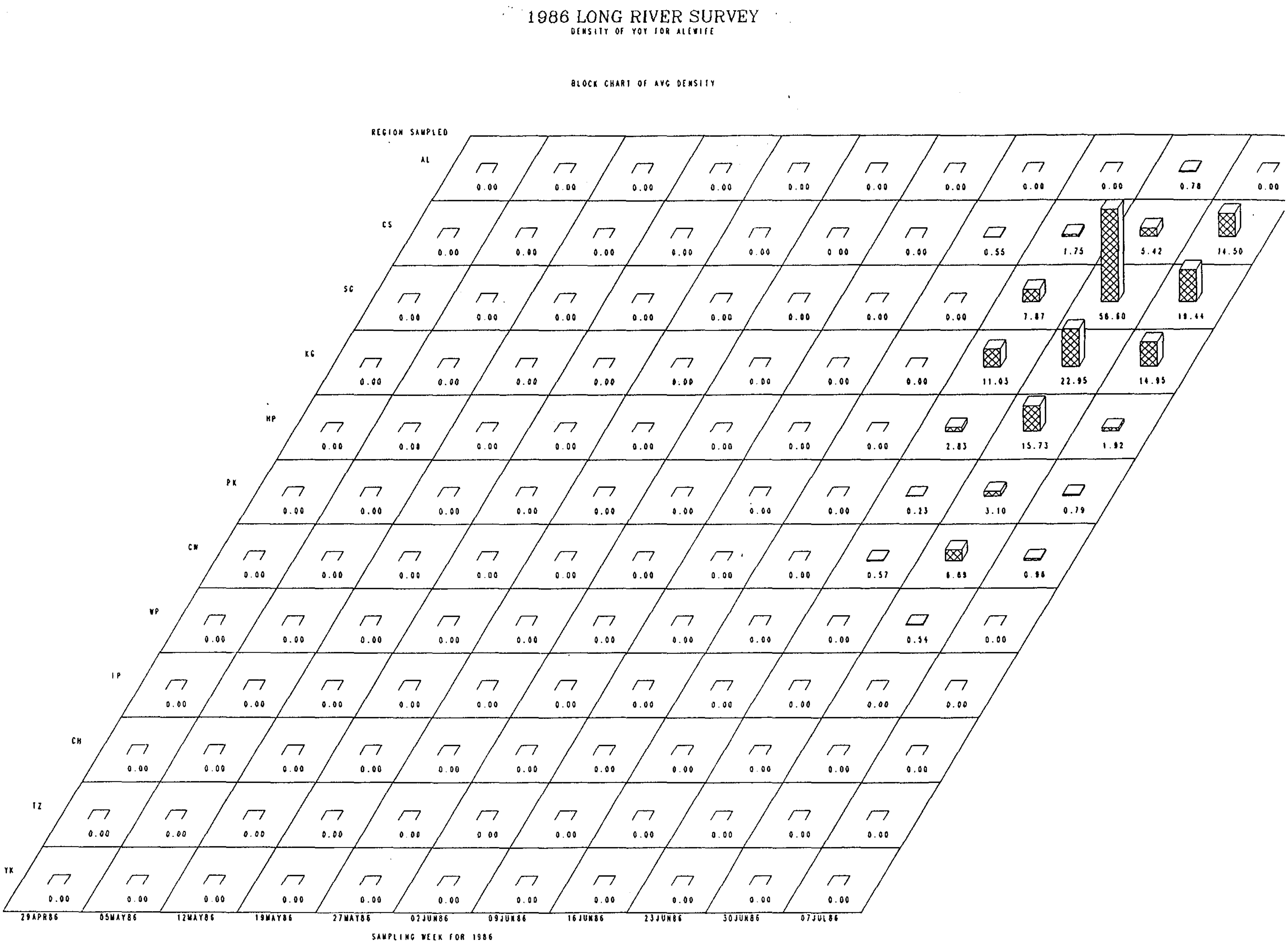
The alewife (Alosa pseudoharengus) is an anadromous fish inhabiting coastal waters from Newfoundland to South Carolina (Winters et al. 1973). Spawning occurs during the spring, with adults apparently emigrating from the estuary by mid-June (TI 1981). The demersal and semi-adhesive alewife eggs have a six-day incubation period at 15°C (Mansueti and Hardy 1967). Juveniles begin moving out of the estuary in the summer and are nearly absent by fall (Bigelow and Schroeder 1953).

4.9.1 1986 Study

4.9.1.1 Young-of-Year (>35 to 40 mm). Identifiable alewife YOY, first collected in the 16 June sampling week of the 1986 LRS (Figure 4-120), were caught in every sampling week of the FSS (Figure 4-121) and the BSS (Figure 4-122) programs. Shore-zone catches from the BSS were greatest during July, with lower estuary catches occurring throughout the program. Greatest abundance in the estuary occurred during late June and early July in the LRS and during late October in the FSS.

High estimated densities were determined for the Hyde Park through Saugerties regions from late June through mid-October when rapidly decreasing water temperatures caused alewife YOY to move out of the estuary. Peak middle estuary densities occurred in late October, with no YOY caught above the regions of the lower estuary during the 23 November FSS sampling week.

4.9.1.2. Yearling and Older Fish. Yearling and older alewife were collected during every sampling week of the 1986 LRS (Figure 4-123) and FSS (Figure 4-124) from 29 April through the week of 23 November. Shore-zone catches made during the BSS (Figure 4-125) were limited to trace abundances in late July and late August in the lower estuary. Catches were evenly distributed throughout the LRS and FSS programs, with a peak riverwide abundance in late



1986 LONG RIVER SURVEY
DENSITY OF YOY FOR ALEWIFE
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
TZ
YK
29APR86
05MAY86
12MAY86
19MAY86
27MAY86
02JUN86
09JUN86
16JUN86
23JUN86
30JUN86
07JUL86
SAMPLING WEEK FOR 1986
0.78
0.55
1.75
5.42
14.50
7.87
58.60
18.44
11.03
22.95
14.95
2.83
15.73
1.92
0.23
3.10
0.79
0.57
6.63
0.96
0.54

FIGURE 4-120

1986 FALL SHOALS SURVEY
DENSITY OF YOY FOR ALEWIFE

BLOCK CHART OF AVG DENSITY

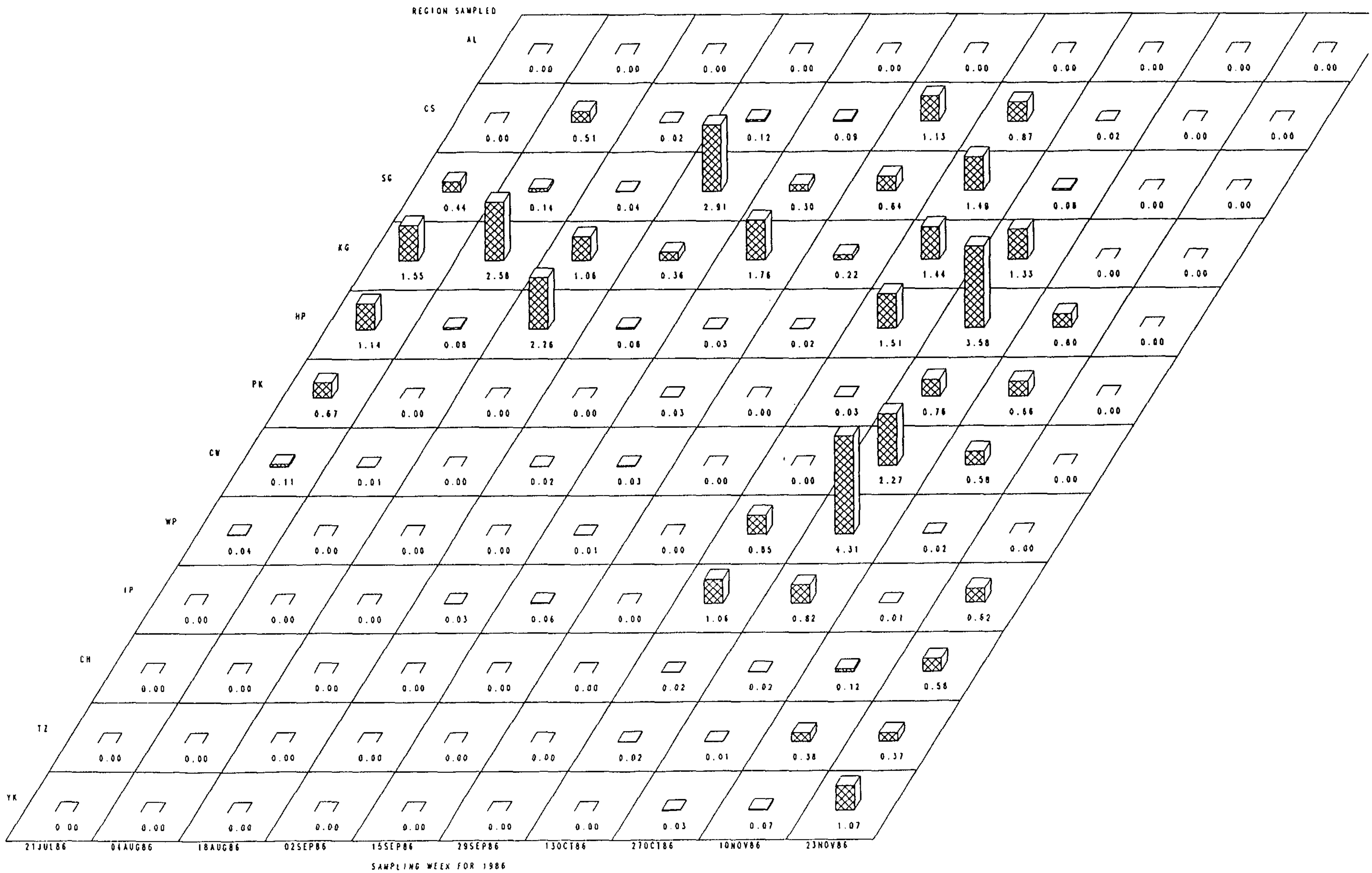


FIGURE 4-121

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR AL

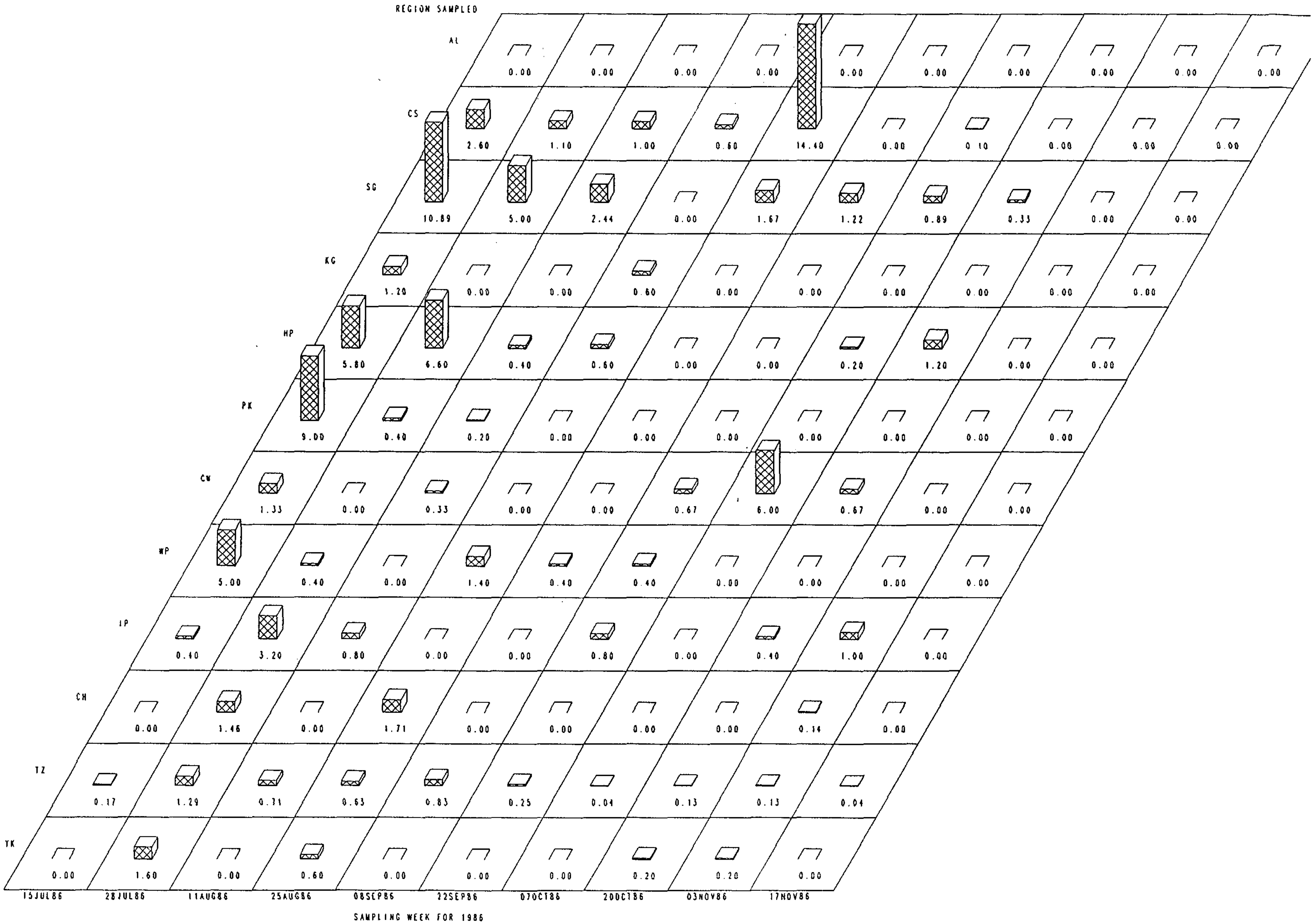


FIGURE 4-122

1986 LONG RIVER SURVEY
DENSITY OF TROL FOR ALEWIFE

BLOCK CHART OF AVG DENSITY

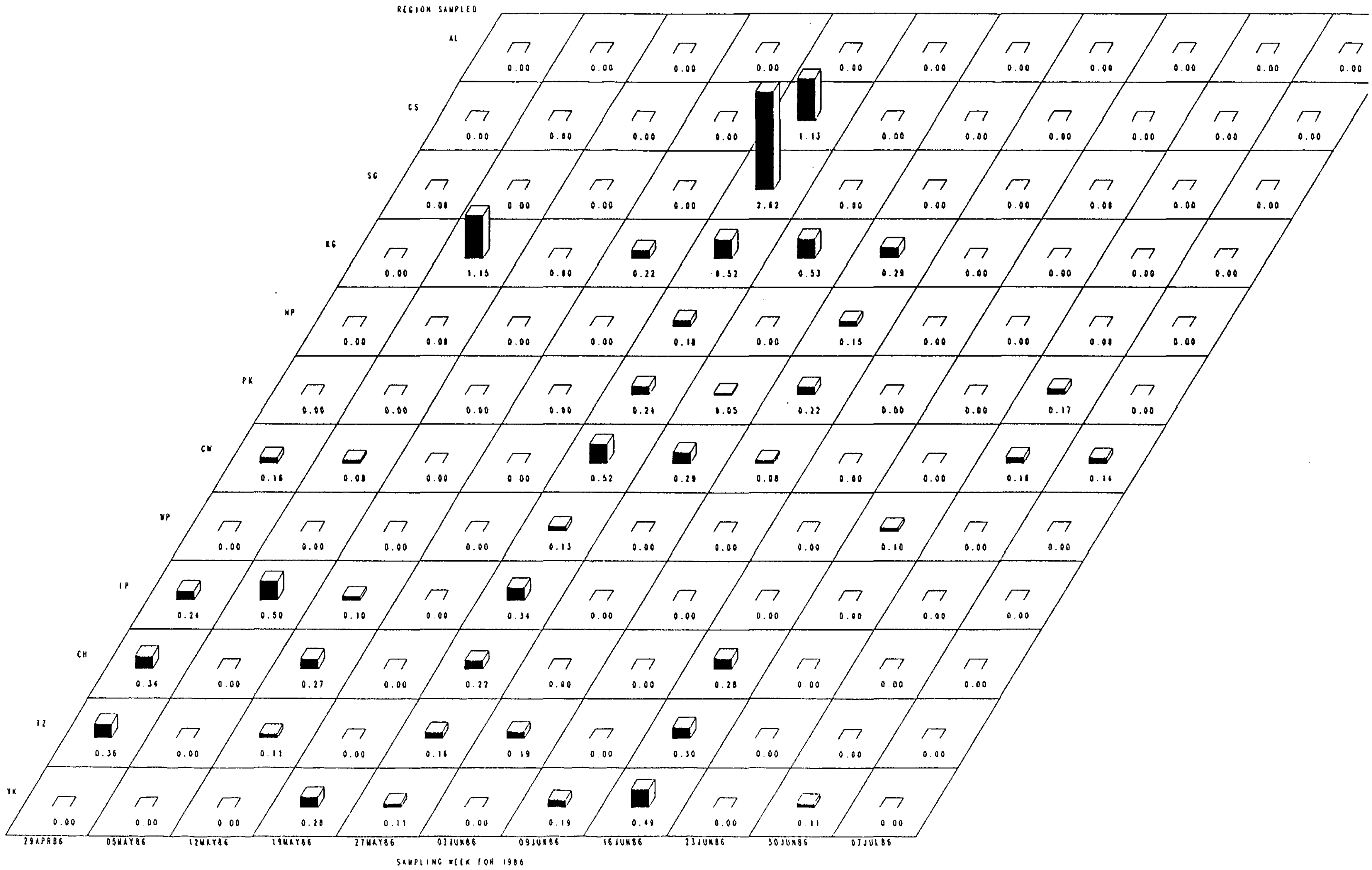


FIGURE 4-123

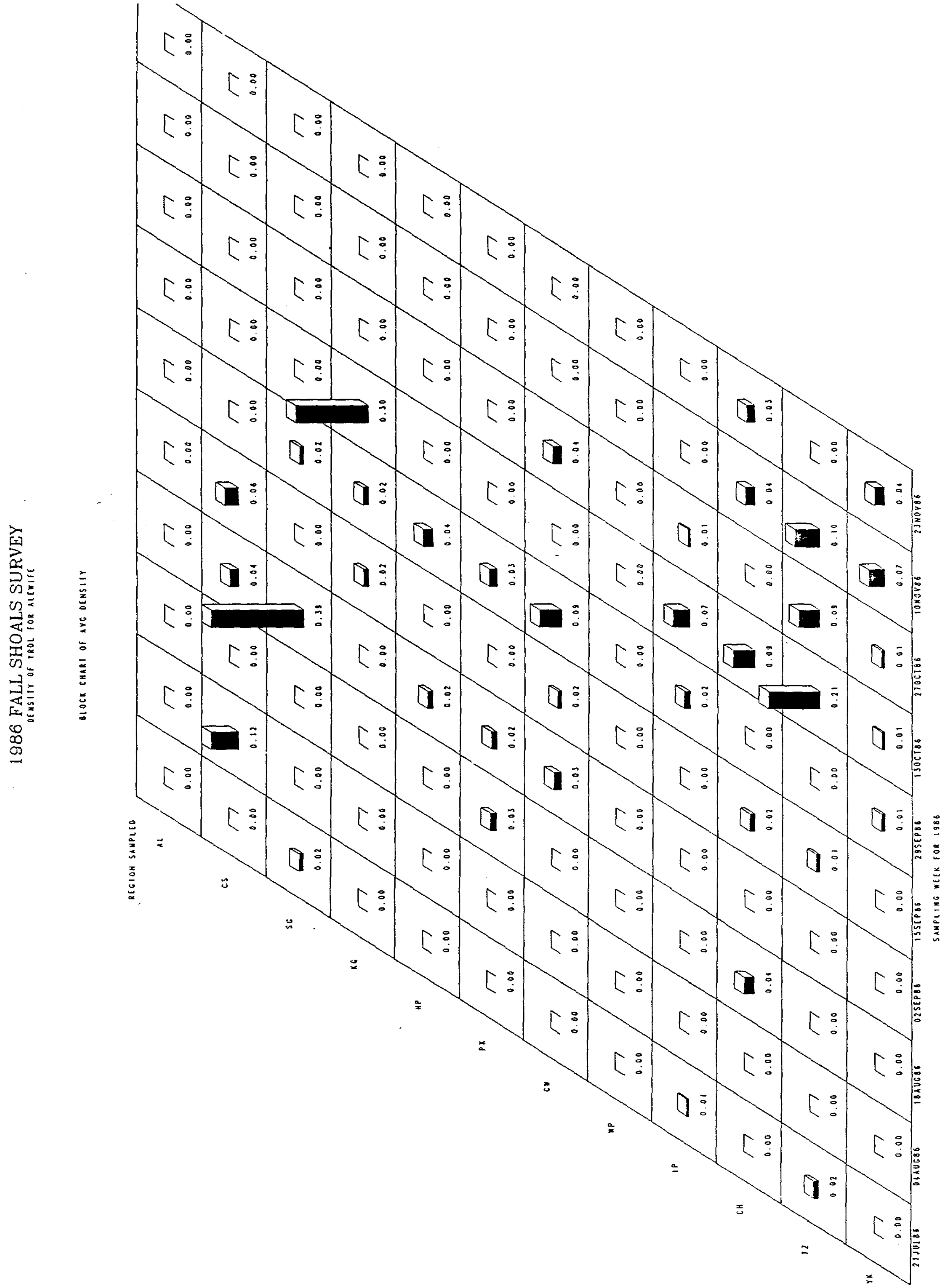

1986 FALL SHOALS SURVEY
DENSITY OF TROL FOR ALEWIFE
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
SG
KG
HP
PK
CW
WP
IP
CH
TZ
YK
21JUL86
04AUG86
18AUG86
02SEP86
15SEP86
29SEP86
13OCT86
27OCT86
10NOV86
23NOV86
SAMPLING WEEK FOR 1986

FIGURE 4-124

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR AL

BLOCK CHART OF CATCH/UNIT EFFORT

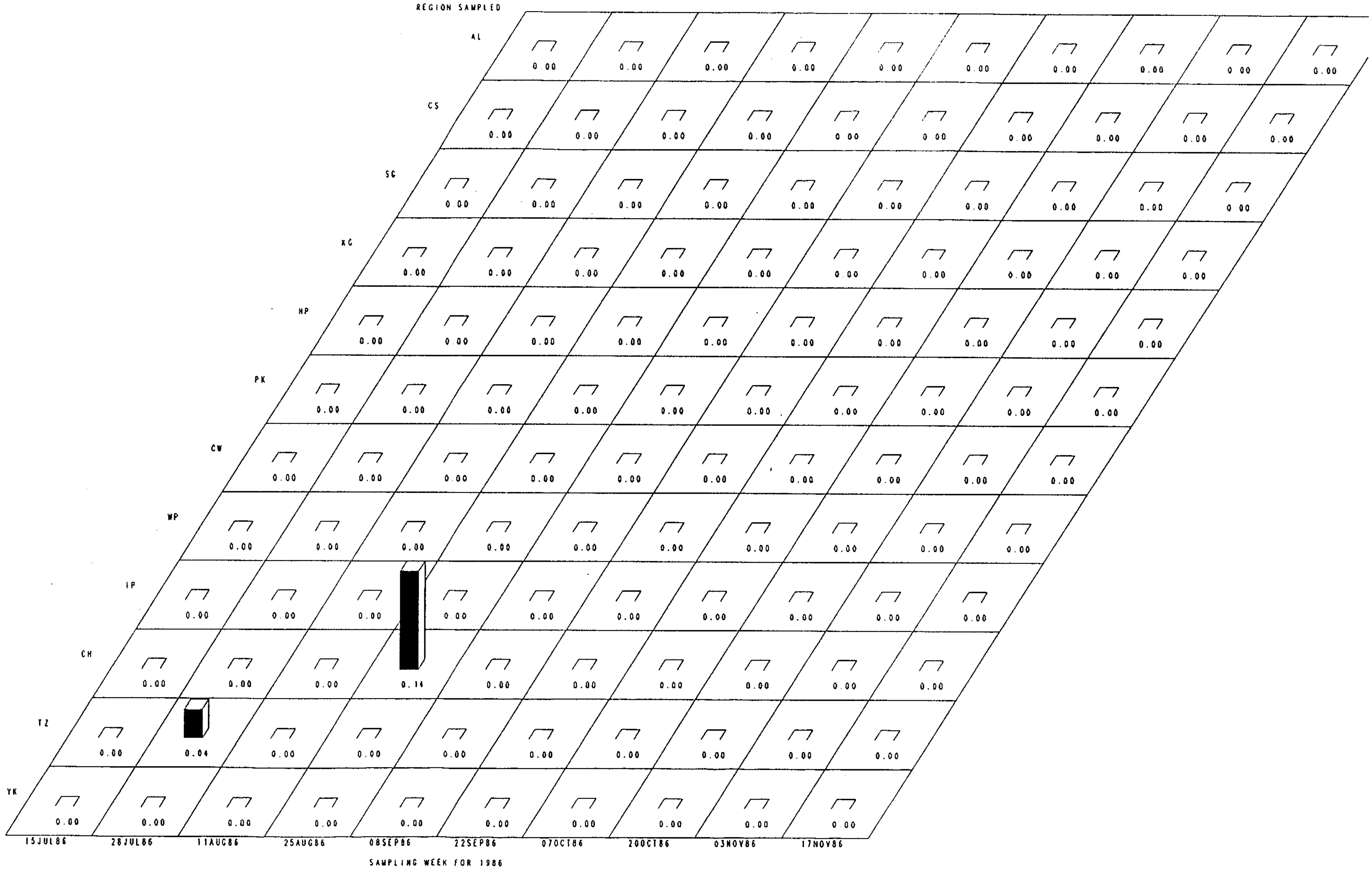


FIGURE 4-125

May. At this time catches were recorded from the Yonkers region through the Catskill region, with highest estimated densities in the upper estuary.

Yearling and older alewife were collected in every region of the estuary in 1986. Upper and middle estuary regional densities were greatest during late May through early June and again in September. Lower estuary regional densities were consistent through May and June, but dropped off through August and September. A downriver distribution shift through October is apparent from FSS samples; catches were restricted to the lower estuary during November sampling.

4.9.2 1987 Study

4.9.2.1 Young-of-Year. Alewife YOY were first identified in 1987 LRS samples during the week of 15 June (Figure 4-126) and continued to be present throughout the program. All biweekly samples of the FSS (Figure 4-127) and BSS (Figure 4-128) yielded alewife YOY in various regions of the estuary. Temporal density patterns revealed peak density estimates from late June through late July, limited mainly to the region between Hyde Park and Catskill (RM 77-124).

The general pattern of YOY distribution suggested by the 1987 FSS and BSS indicates a shift in YOY abundance from deeper waters into the shore zone for alewife between the Hyde Park and Catskill regions. Peak FSS densities in these regions in July fell to only trace collections in early September. During this same period a coincidental increase in shore-zone catches appeared from the Hyde Park region through the Saugerties region. BSS catches remained relatively constant in all regions from early August through late September, with dispersion to offshore or downriver areas suggested by declining catches beginning in late September. After mid-October no juvenile alewife were caught in the BSS north of the Croton-Haverstraw region. Lower estuary regional density estimates were greatest in October and November FSS sampling as juveniles emigrated from the estuary.

1987 LONG RIVER SURVEY
DENSITY OF YOY FOR ALEWIFE

BLOCK CHART OF AVG DENSITY

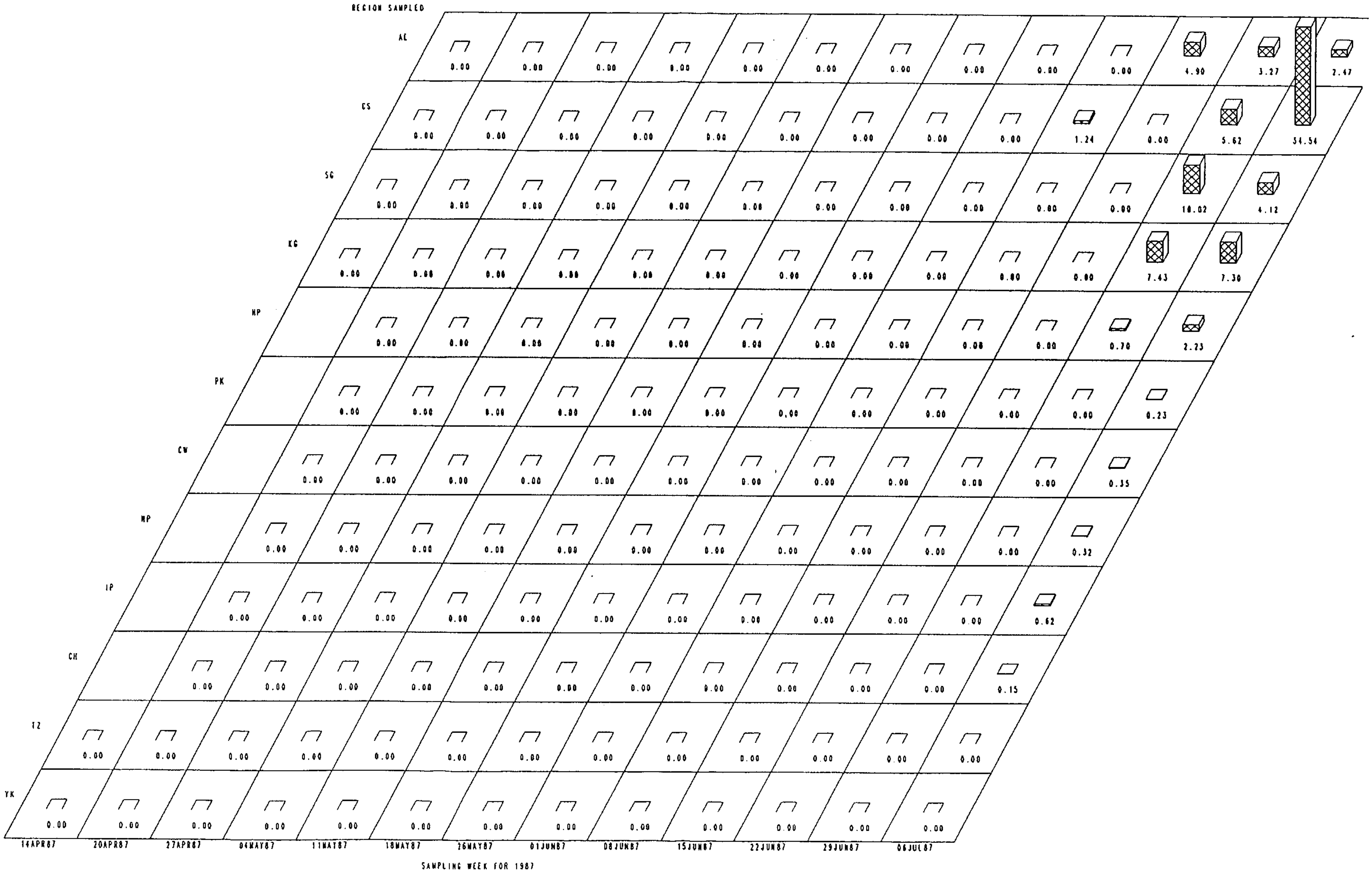


FIGURE 4-126

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR ALEWIFE

BLOCK CHART OF AVG DENSITY

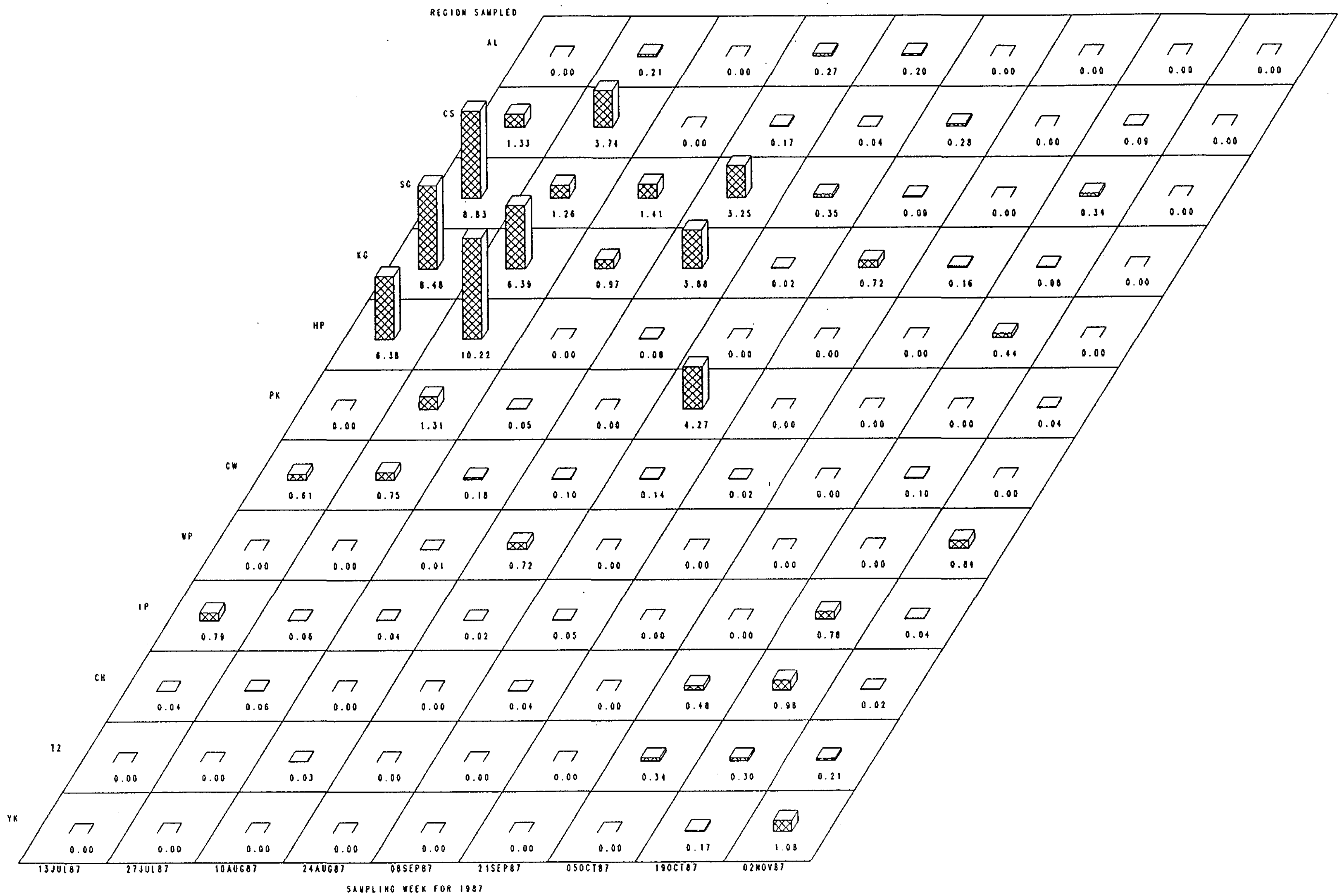


FIGURE 4-127

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR ALEWIFE

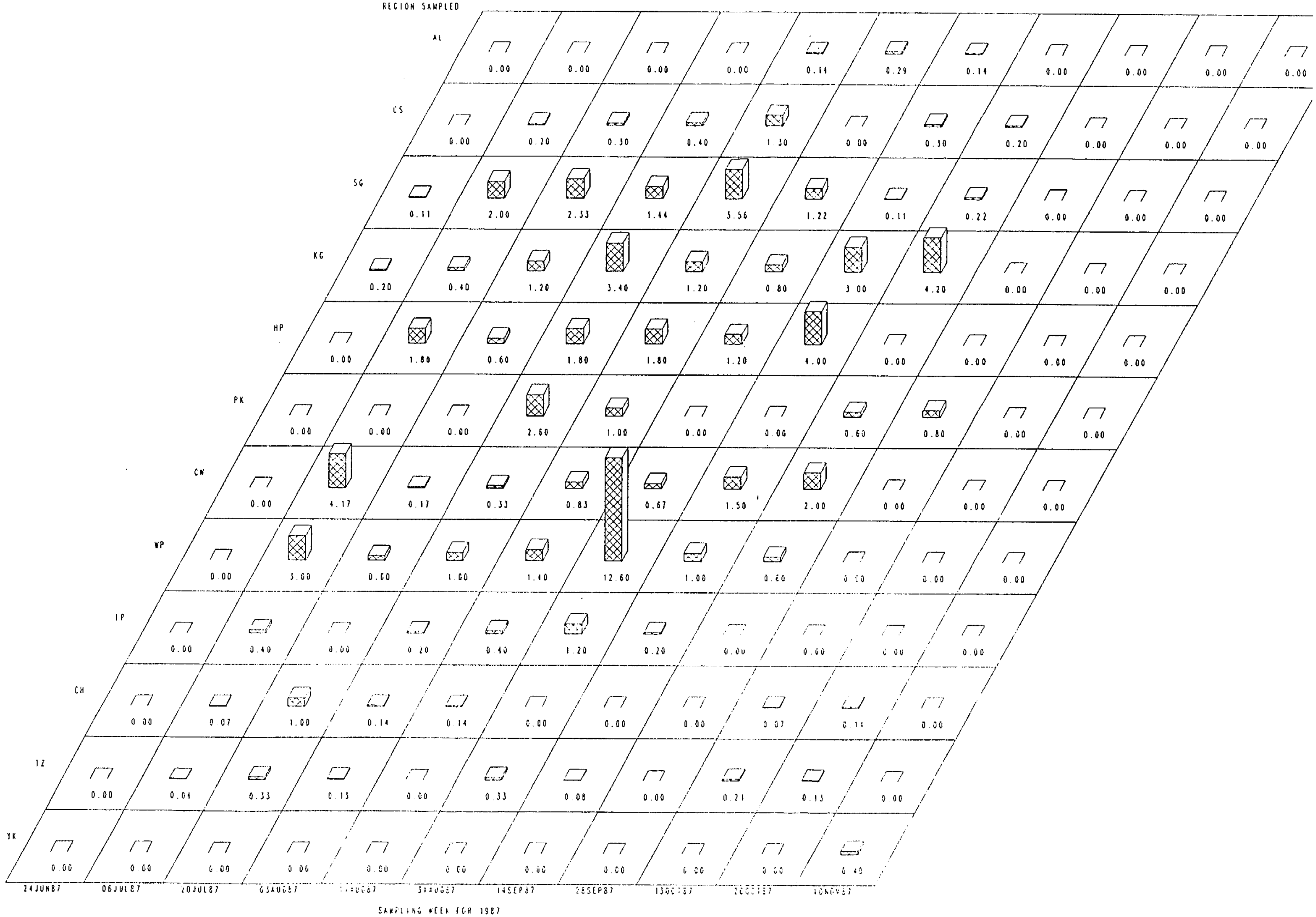


FIGURE 4-128

4.9.2.2 Yearling and Older Fish. Yearling and older alewife were first collected during the 27 April sampling week of the 1987 LRS program (Figure 4-129). Peak density estimates from late April through mid-May suggest that yearling alewife followed mature fish up into the estuary during the spawning run. Upper estuary densities associated with spawning were suggested from mid-May through June, with peak occurrence during the 11 May sampling week. This peak corresponds to a period of high *Alosa spp.* egg abundance in the same regions. Yearling and older alewife were caught during every sampling week from late April through late October in the LRS and FSS (Figure 4-130) programs; only sporadic trace numbers were collected after May.

High density in the lower estuary in late April, followed by a shift to the upper estuary, reflects upriver movements of alewife. Spatial distribution patterns suggest declining upper estuary abundance beginning in late August; alewife were collected only in areas south of the Poughkeepsie region during October. Abundance in the shore zone was minimal, with trace catches occurring in the Tappan Zee, Croton-Haverstraw, and Kingston regions during the BSS (Figure 4-131).

4.10 BAY ANCHOVY

The bay anchovy, *Anchoa mitchilli* (Valenciennes), is found primarily in Atlantic Coast estuaries from Maine south to the Yucatan peninsula of Mexico. This species moves from brackish water to salt water, apparently related to spawning and maturation. Many important estuarine fish such as striped bass, bluefish, and white perch rely heavily on bay anchovies as forage (NAI 1985a).

Spawning typically occurs over an extended period from May to September when water temperatures are from 15 to 30°C (Wang and Kernehan 1979). In the Hudson River, spawning is generally believed to be greatest from the Tappan Zee region south to the Narrows, particularly in the Yonkers region (Dovel 1981; TI 1981). Peak spawning occurs in July at salinities greater than 10 ppt. The larval fish sink to the denser saline waters and are moved upstream by

1987 LONG RIVER SURVEY

DENSITY OF TROL FOR ALEWIFE

BLOCK CHART OF AVG DENSITY

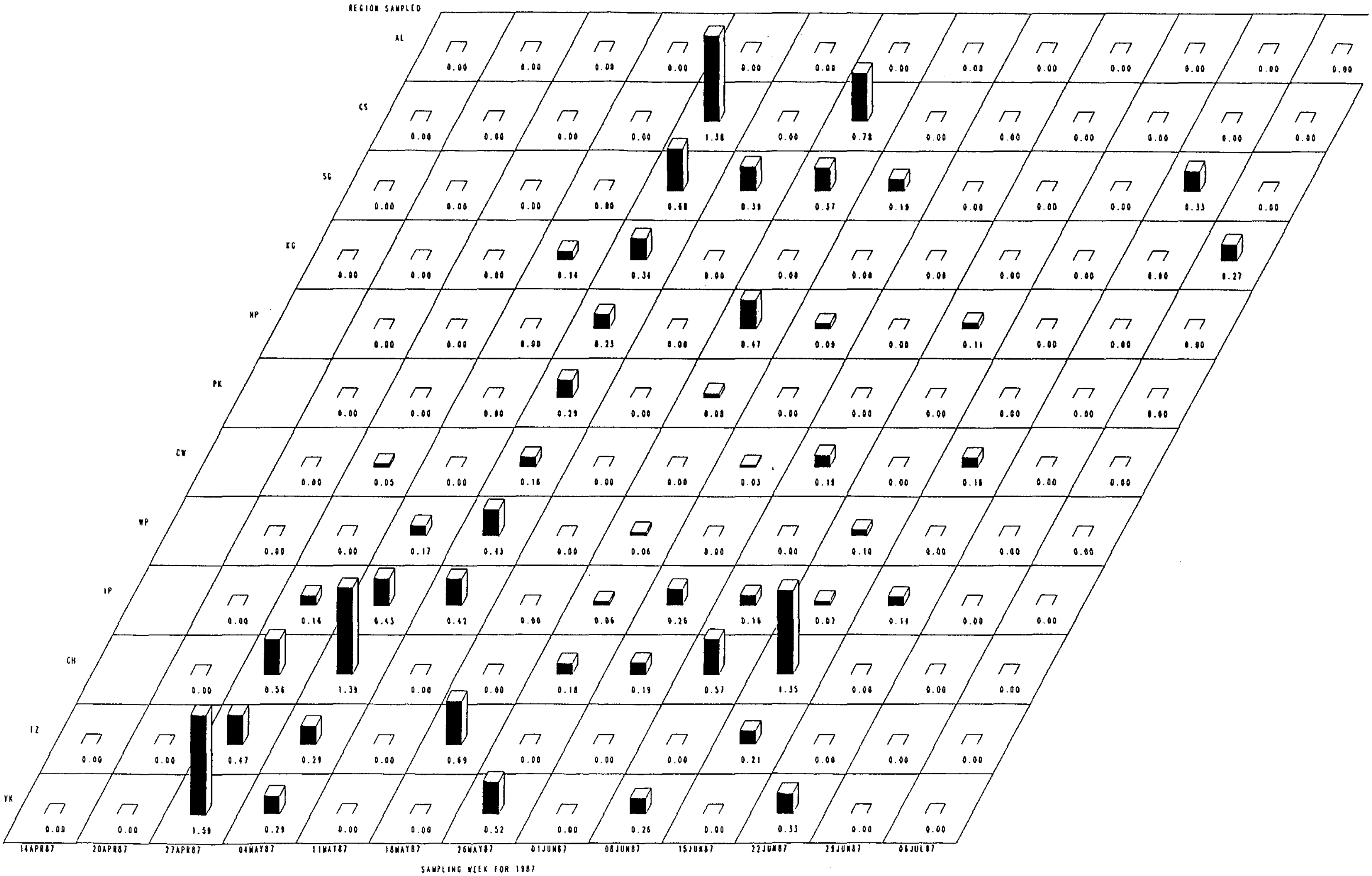


FIGURE 4-129

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR ALEWIFE

BLOCK CHART OF AVG DENSITY

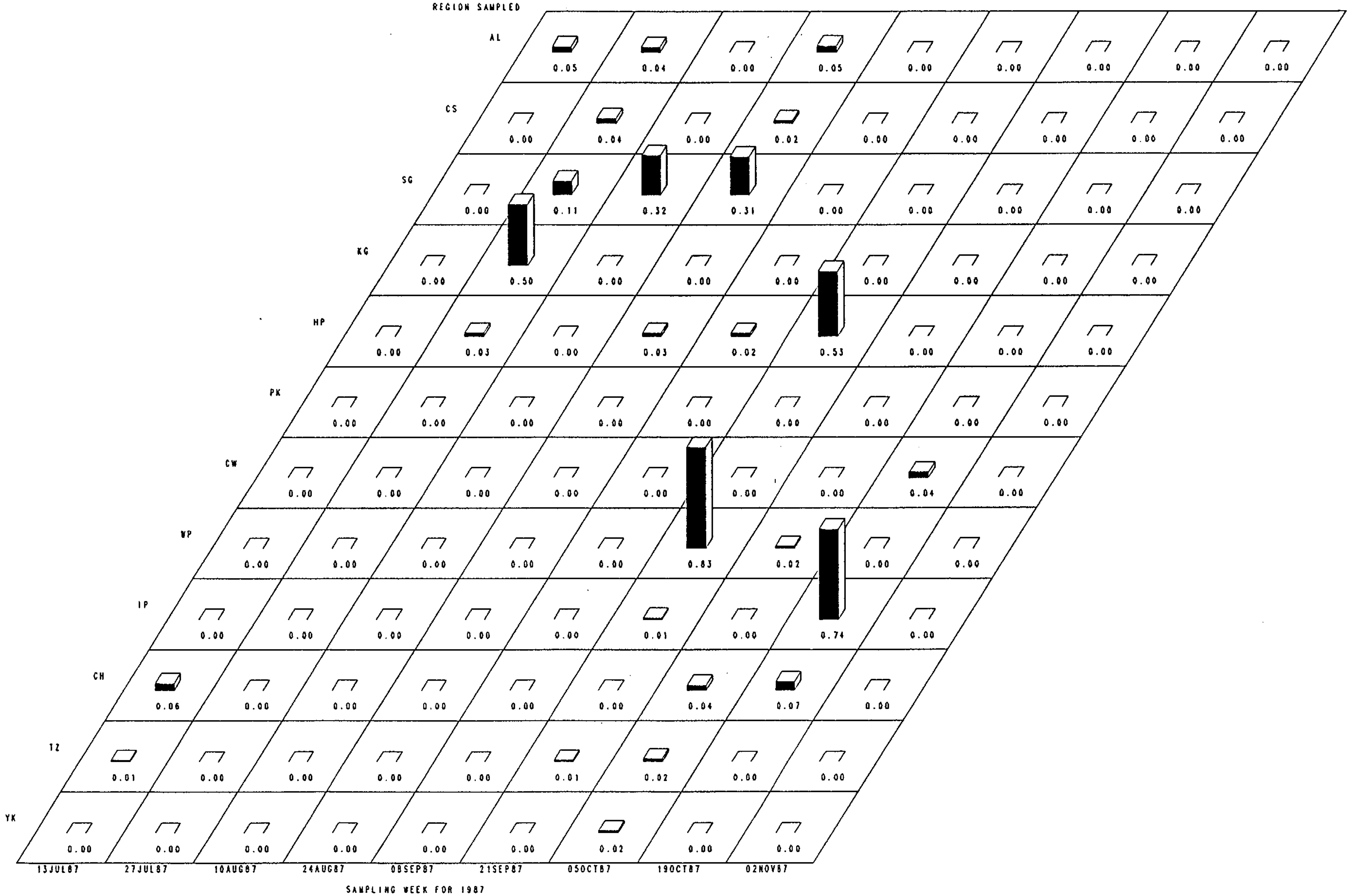


FIGURE 4-130

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YRDL FOR ALEWIFE

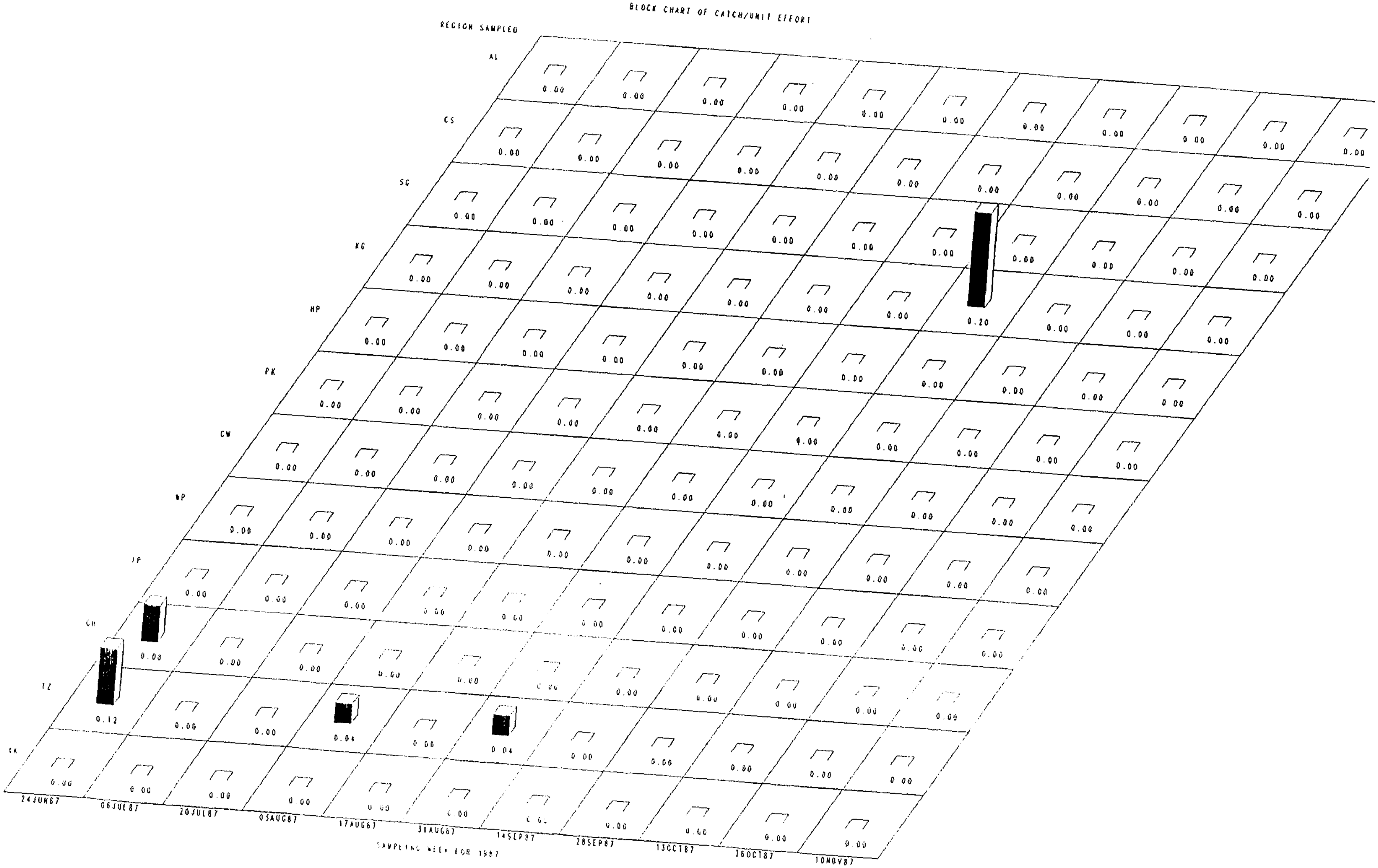


FIGURE 4-131

flood tides to areas of lower salinity. The larvae remain between the Tappan Zee and Indian Point regions to feed (Dovel 1981). YOY move downstream out of the nursery area in early fall to overwinter at higher salinities. Mature fish return to low salinity waters as far north as Poughkeepsie (RM 62) to feed before moving to the higher salinity spawning areas.

4.10.1 1986 Study

4.10.1.1 Eggs. Bay anchovy eggs were collected during the 1986 LRS from the 12 May sampling week through the end of the program (Figure 4-132). Regional egg densities in excess of 2500/1000 m^3 were sampled during every collection period beginning with the week of 2 June when peak egg abundance occurred. Spawning activities were almost entirely limited to the lower estuary, which had mean weekly salinities greater than 1 ppt. High egg density was sampled from the Tappan Zee and Yonkers regions, with peak abundance in the Yonkers region and probably farther south. Egg abundance in excess of 10/1000 m^3 was sampled in all regions of the lower estuary where salinities were over 3 ppt during the last LRS sampling period. Bay anchovy eggs were sampled as far north as the Hyde Park region during 1986, upriver of the salt front.

4.10.1.2 Yolk-Sac Larvae. Bay anchovy YSL were first collected during the 1986 LRS sampling week of 9 June (Figure 4-133) and were not captured again until the final week of the program. Peak density occurred during the last sampling run in the Yonkers region, with YSL collected as far north as the Indian Point region (RM 46).

4.10.1.3 Post Yolk-Sac Larvae. Bay anchovy PYSL first appeared in June 1986 and greatest densities were sampled during the final two weekly collections of the LRS program (Figure 4-134). PYSL were located between the Yonkers and Indian Point regions (RM 12-46) at densities in excess of 500/1000 m^3, with peak abundance sampled in the Indian Point region. Trace numbers were collected as far north as the Kingston region.

1986 LONG RIVER SURVEY

DENSITY OF EGGS FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

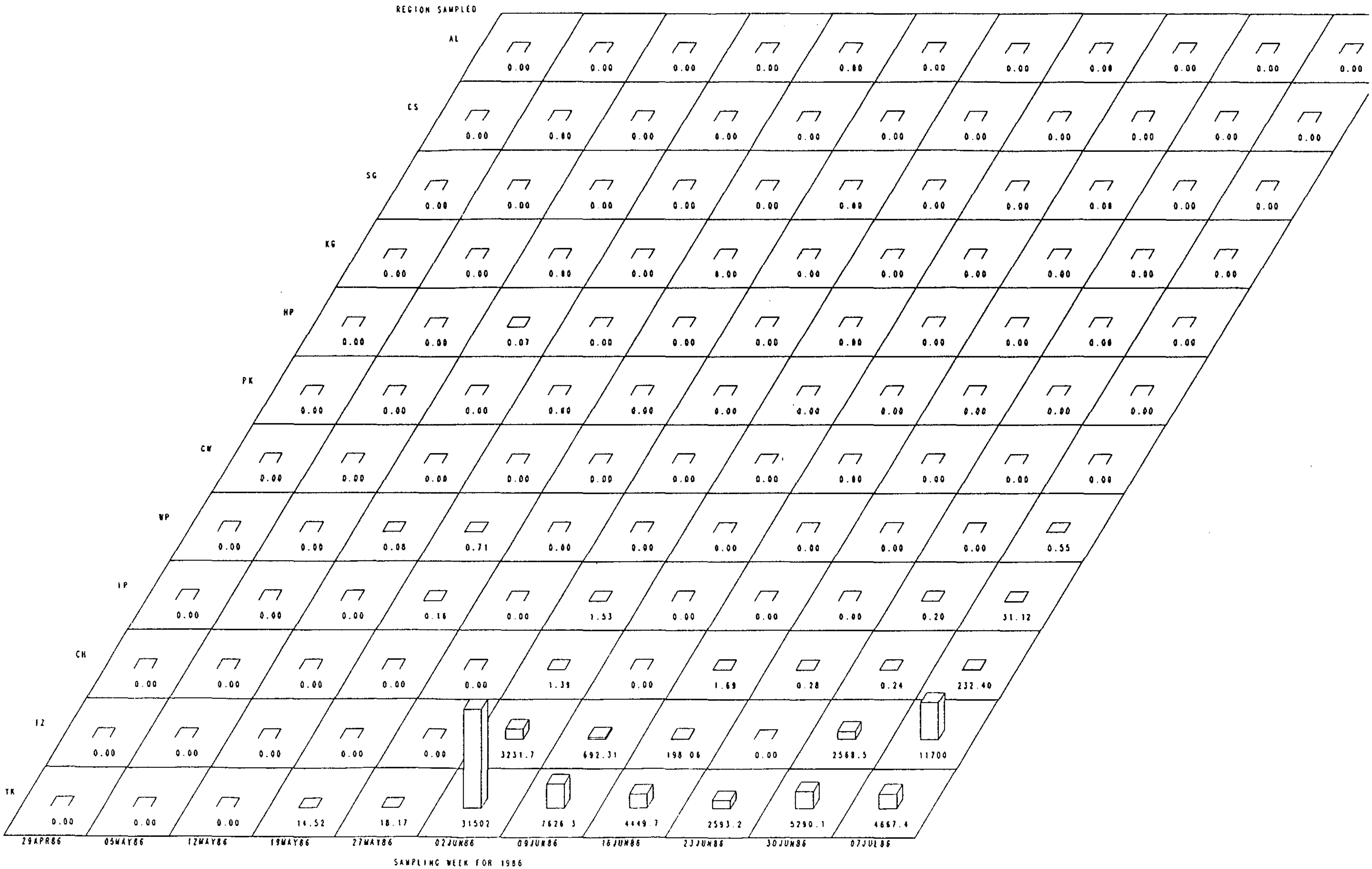


FIGURE 4-132

1986 LONG RIVER SURVEY

DENSITY OF YSL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

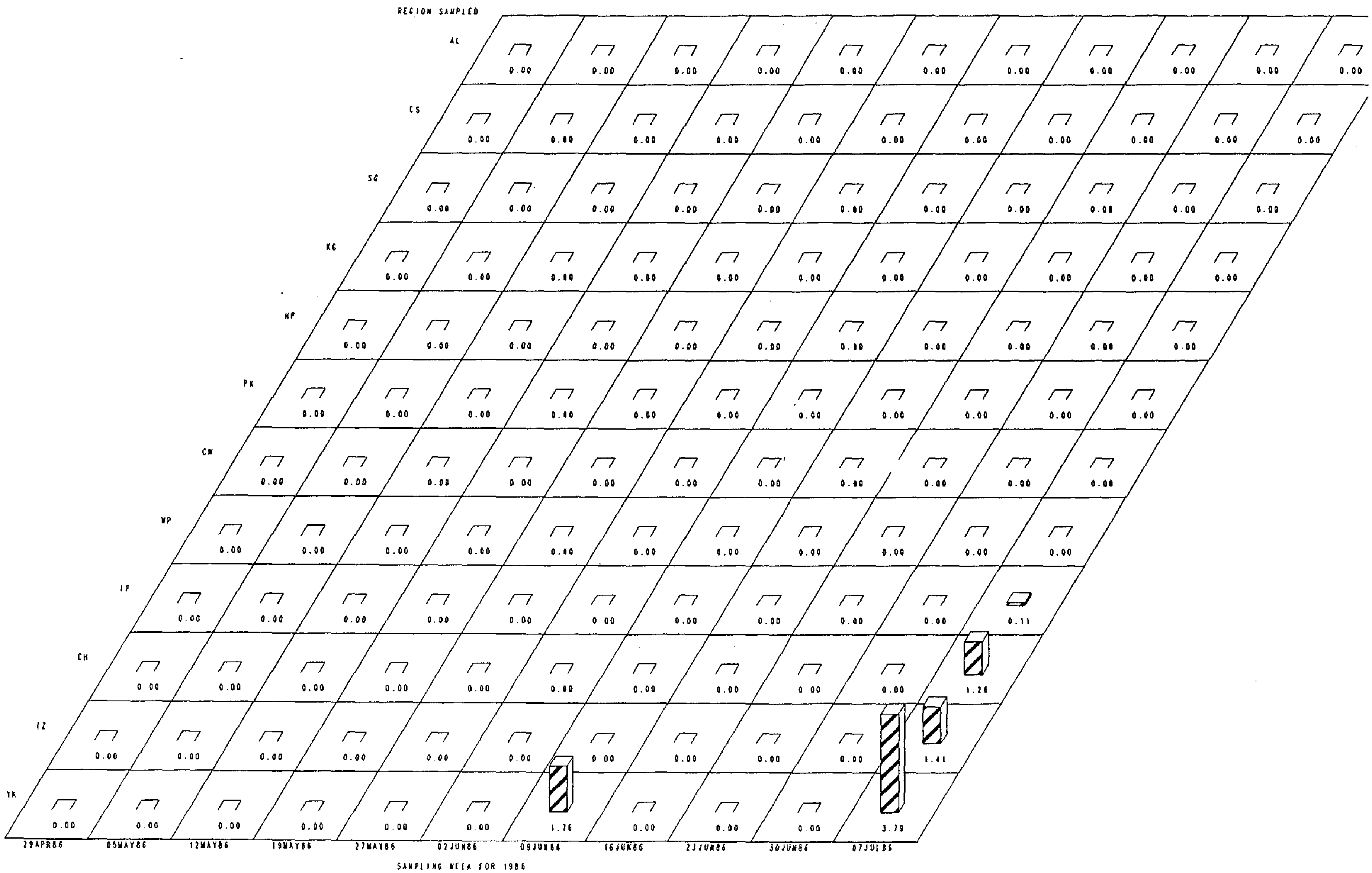


FIGURE 4-133

1986 LONG RIVER SURVEY

DENSITY OF PYSL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

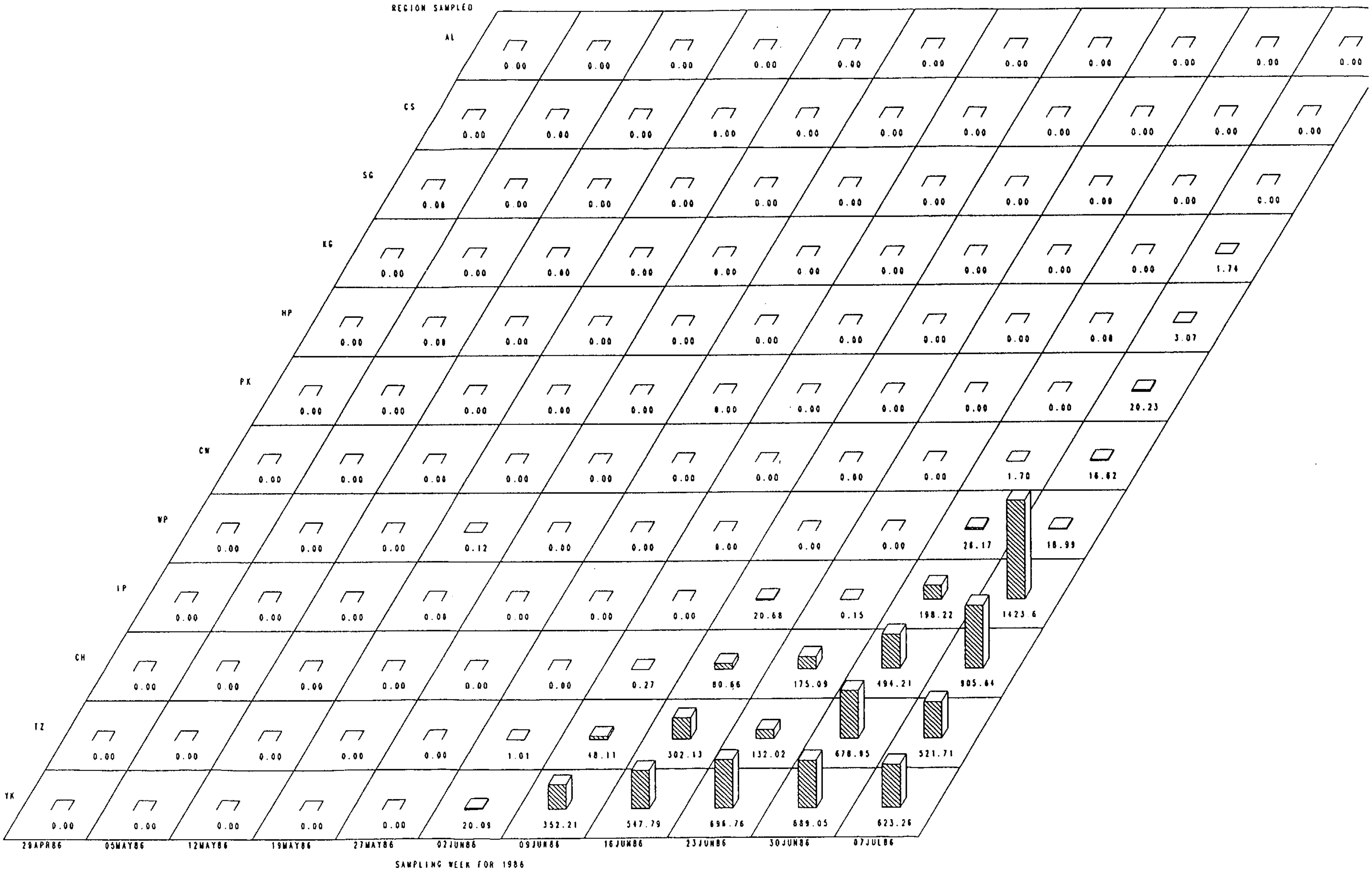


FIGURE 4-134

4.10.1.4 Young-of-Year. Juvenile bay anchovy were taken initially in the last two sampling weeks of the 1986 LRS program (Figure 4-135). YOY were present during every sampling week of the FSS (Figure 4-136) and the BSS (Figure 4-137) programs. Trace numbers were collected from the Yonkers through West Point regions (RM 12-55) in the shore zone, with the greatest geographical distribution in the Yonkers region (Figure 4-138). The FSS revealed juvenile densities in excess of 10/1000 m^3 in regions south of Kingston, with the greatest abundance in the lower estuary. Juvenile abundance in the middle estuary peaked in early September and decreased as water temperatures fell below 20°C. Peak densities in the lower estuary occurred in late September and early October, with collections dropping off to just a trace by the final FSS sampling period; none were caught during the final two BSS sampling periods. Emigration of juvenile anchovy from the estuary began in October; only trace densities were determined in the lower estuary by mid-November.

4.10.1.5 Yearling and Older Fish. Yearling and older bay anchovy were first collected in 1986 during the initial sampling week of the LRS program in late April (Figure 4-139). Highest densities were caught from late May through the end of the LRS in early July and remained high until early August in the FSS (Figure 4-140) program. Yearling and older bay anchovy were present in the lower estuary until early November. By this time most had returned to higher salinity waters located south of the Yonkers region. Peak density occurred during the first week of June in the LRS. The shore zone sampled in the BSS revealed only trace levels of yearling or older bay anchovy, with no evidence of fish after October (Figure 4-141). Yearling and older fish were collected as far upriver as the Saugerties region; most were limited to the high saline waters of the lower estuary. Peak abundance occurred in the Yonkers region.

4.10.2 1987 Study

4.10.2.1 Eggs. Bay anchovy eggs were first collected in 1987 LRS samples in early May; peak densities occurred during the third and fourth sampling weeks of June (Figure 4-142). Egg densities over 1000/1000 m^3 were observed from

1986 LONG RIVER SURVEY

DENSITY OF PYSL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

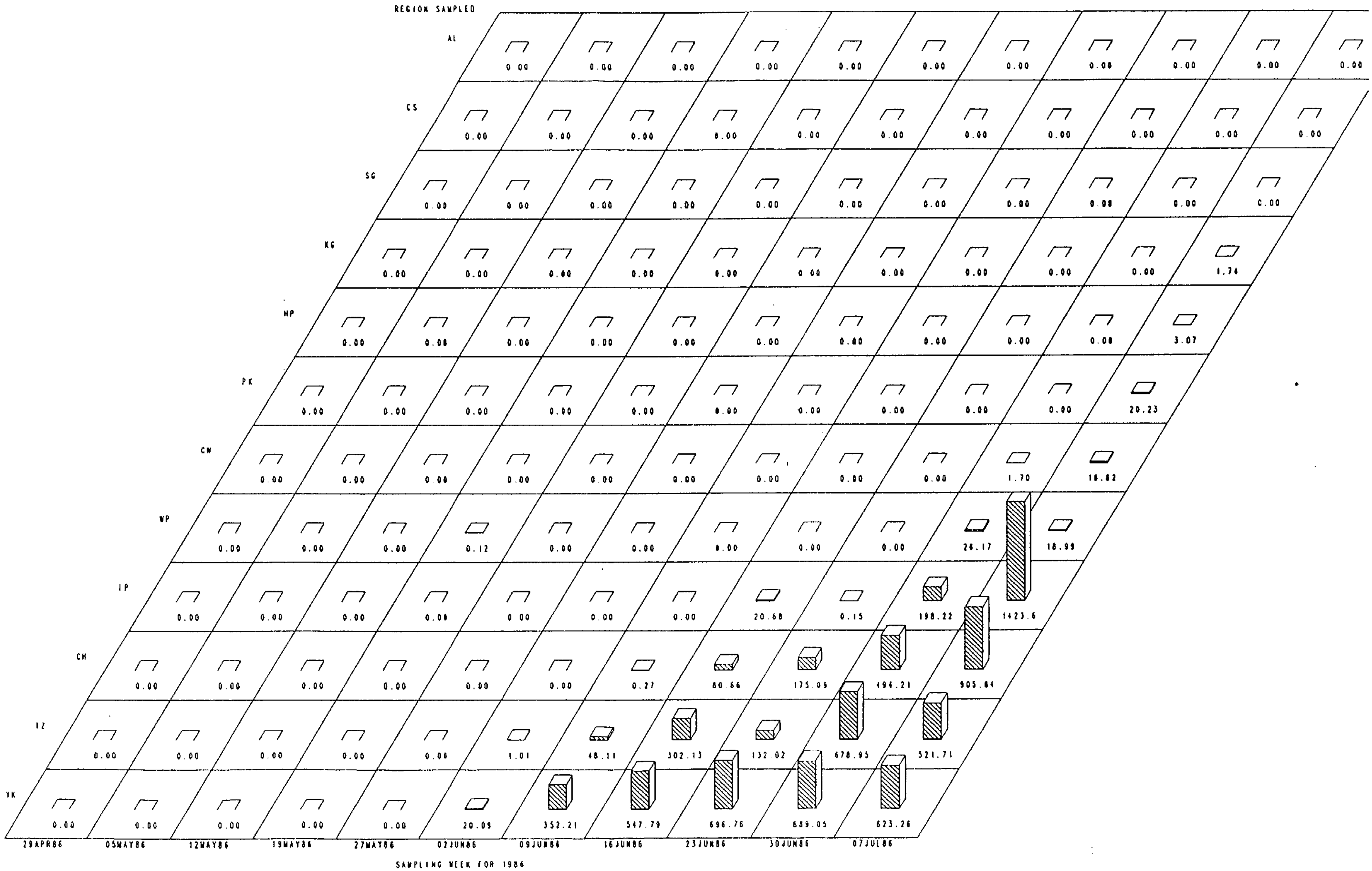


FIGURE 4-134

4.10.1.4 Young-of-Year. Juvenile bay anchovy were taken initially in the last two sampling weeks of the 1986 LRS program (Figure 4-135). YOY were present during every sampling week of the FSS (Figure 4-136) and the BSS (Figure 4-137) programs. Trace numbers were collected from the Yonkers through West Point regions (RM 12-55) in the shore zone, with the greatest geographical distribution in the Yonkers region (Figure 4-138). The FSS revealed juvenile densities in excess of 10/1000 m^3 in regions south of Kingston, with the greatest abundance in the lower estuary. Juvenile abundance in the middle estuary peaked in early September and decreased as water temperatures fell below 20°C. Peak densities in the lower estuary occurred in late September and early October, with collections dropping off to just a trace by the final FSS sampling period; none were caught during the final two BSS sampling periods. Emigration of juvenile anchovy from the estuary began in October; only trace densities were determined in the lower estuary by mid-November.

4.10.1.5 Yearling and Older Fish. Yearling and older bay anchovy were first collected in 1986 during the initial sampling week of the LRS program in late April (Figure 4-139). Highest densities were caught from late May through the end of the LRS in early July and remained high until early August in the FSS (Figure 4-140) program. Yearling and older bay anchovy were present in the lower estuary until early November. By this time most had returned to higher salinity waters located south of the Yonkers region. Peak density occurred during the first week of June in the LRS. The shore zone sampled in the BSS revealed only trace levels of yearling or older bay anchovy, with no evidence of fish after October (Figure 4-141). Yearling and older fish were collected as far upriver as the Saugerties region; most were limited to the high saline waters of the lower estuary. Peak abundance occurred in the Yonkers region.

4.10.2 1987 Study

4.10.2.1 Eggs. Bay anchovy eggs were first collected in 1987 LRS samples in early May; peak densities occurred during the third and fourth sampling weeks of June (Figure 4-142). Egg densities over 1000/1000 m^3 were observed from

1986 LONG RIVER SURVEY

DENSITY OF YOY FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

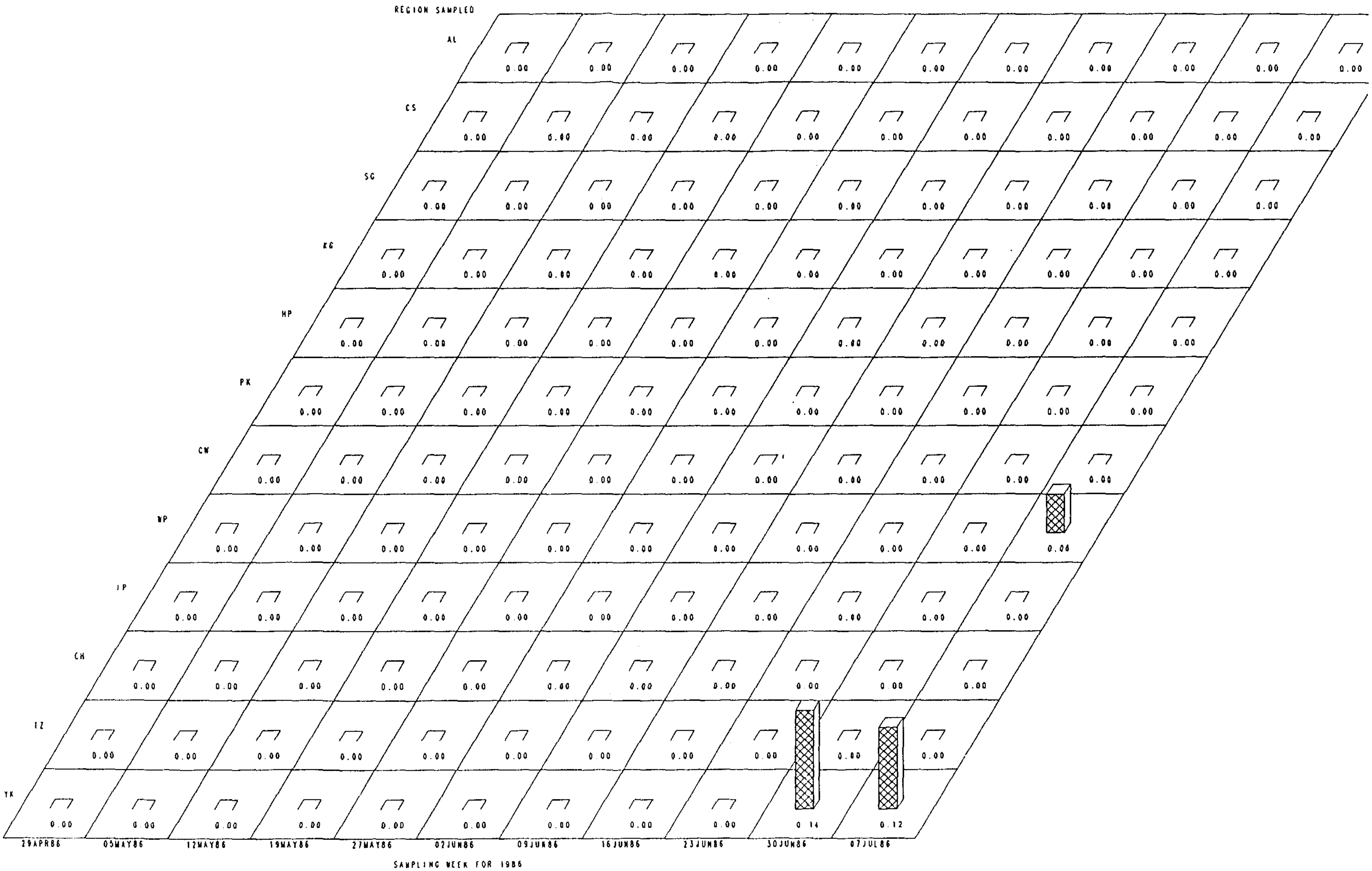


FIGURE 4-135

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

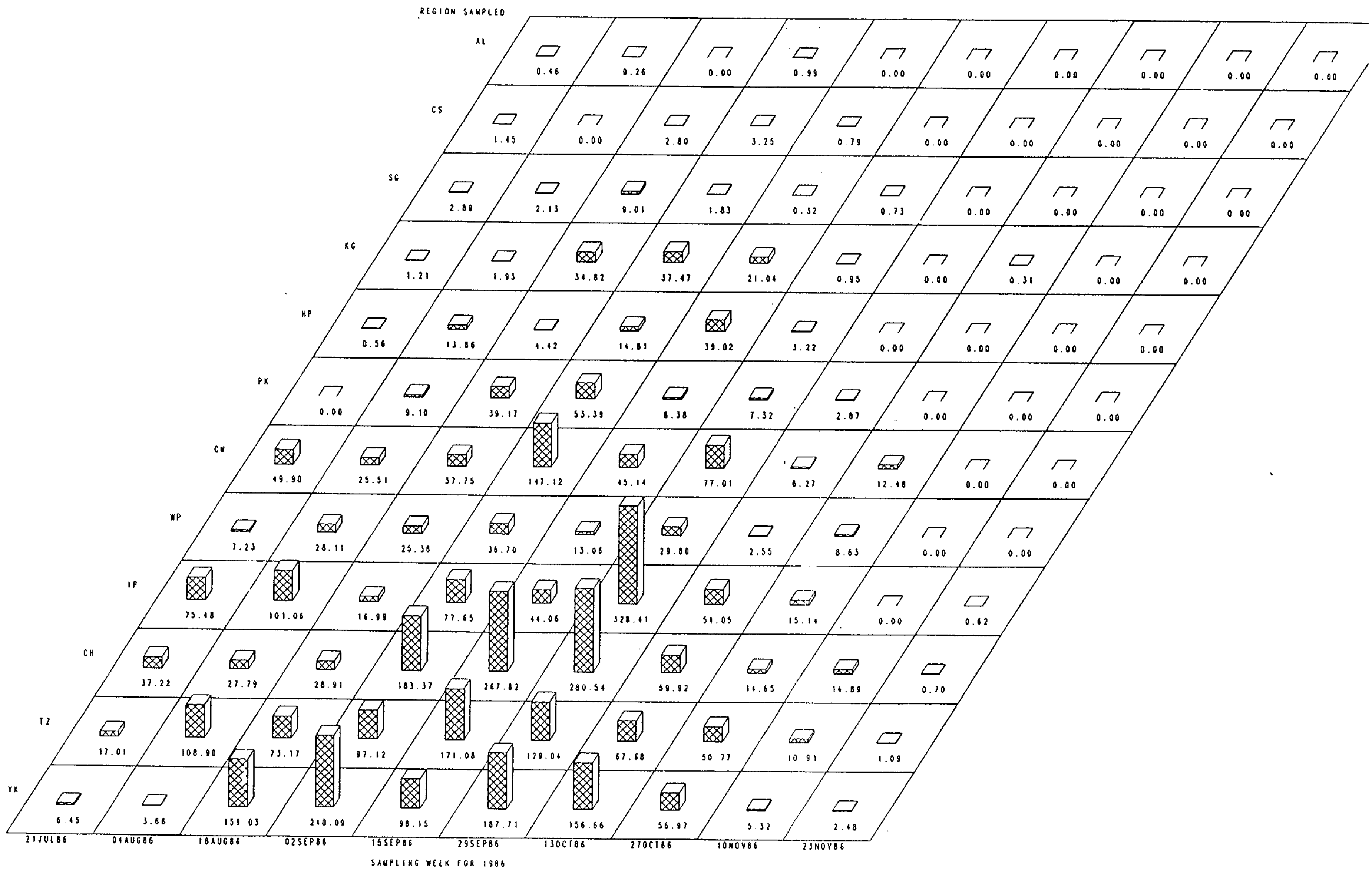


FIGURE 4-136

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR BA

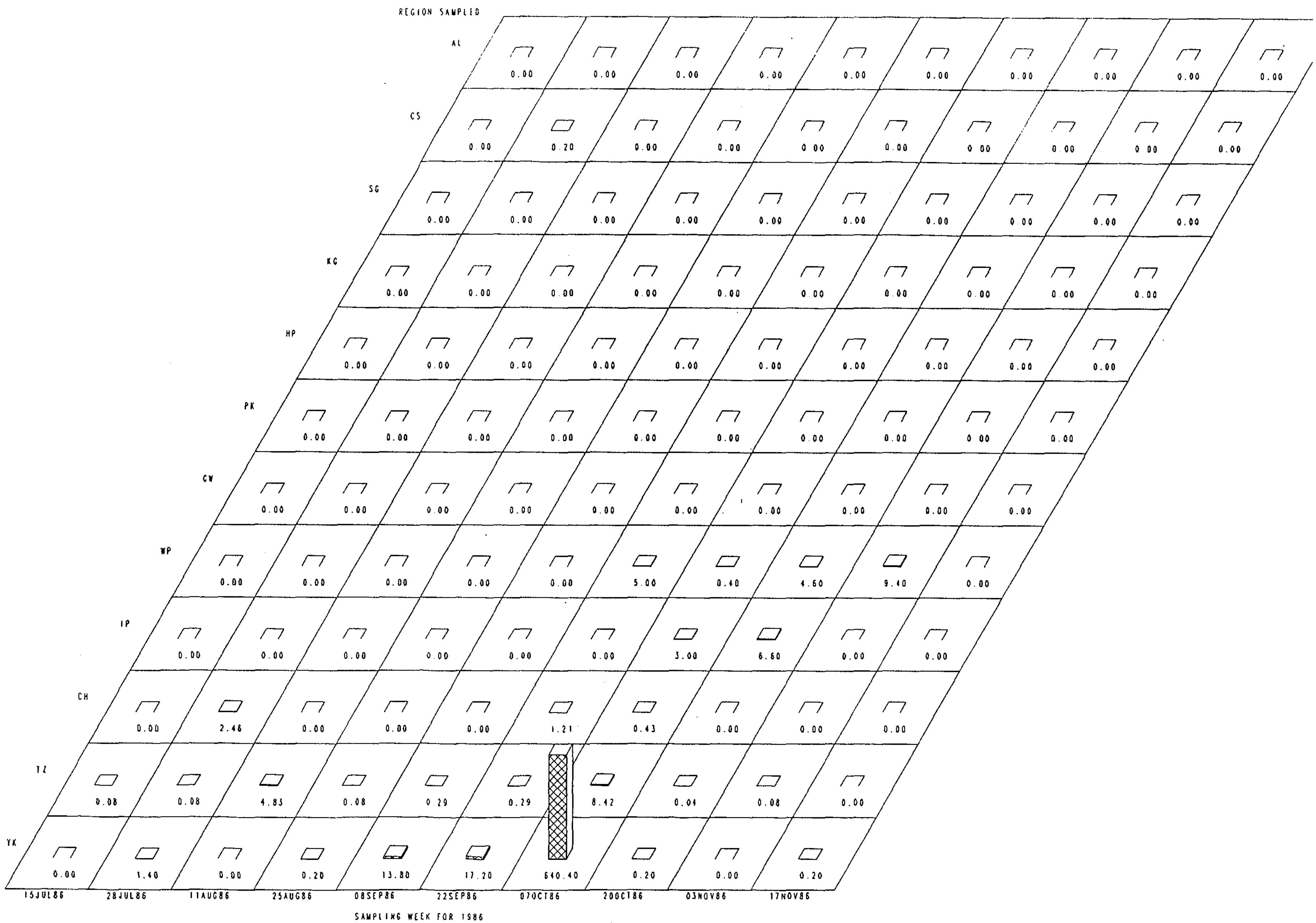
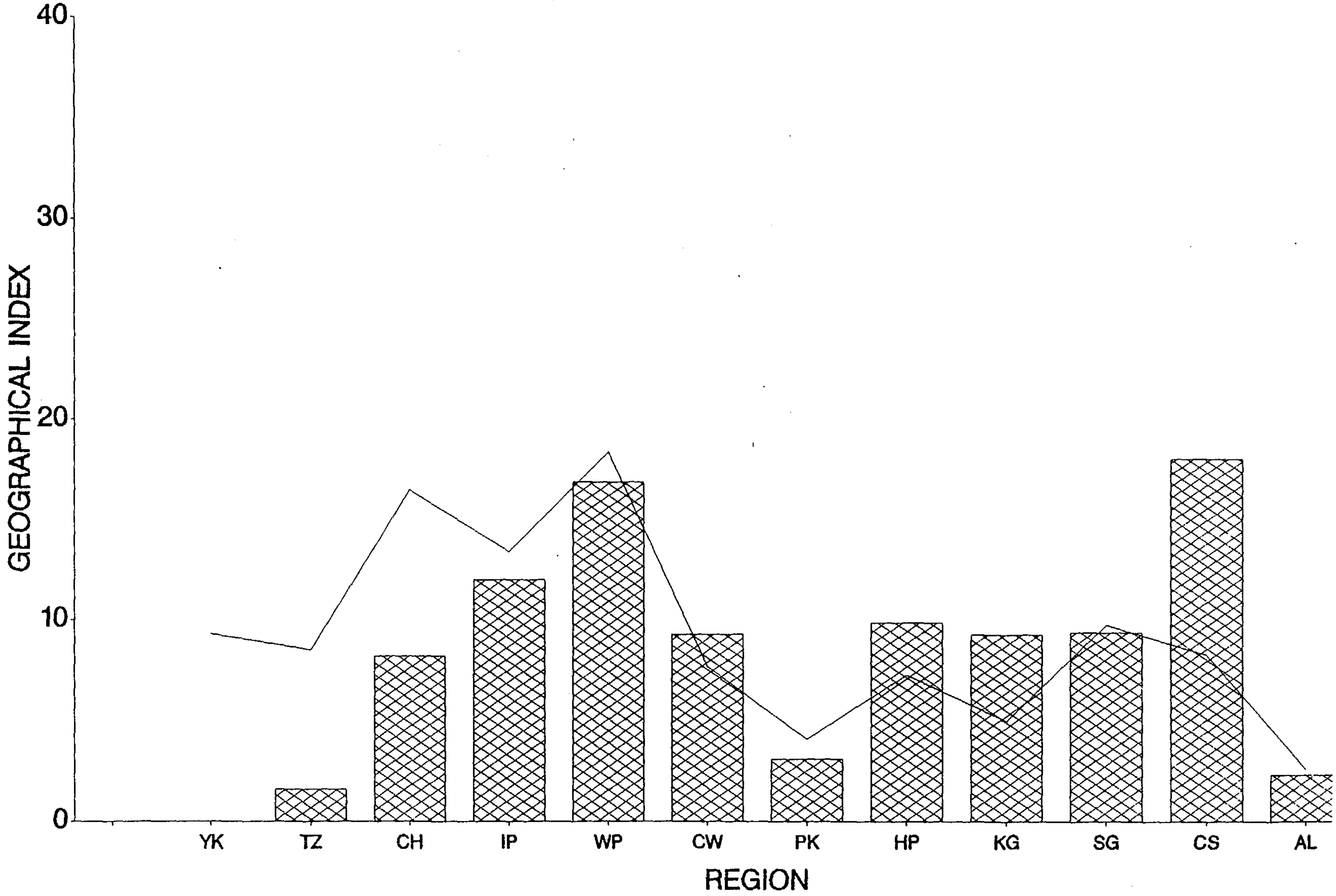


FIGURE 4-137

FIGURE 4-138

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR BAY ANCHOVY COLLECTED IN THE BEACH SEINE SURVEY, 1986



LEGEND

Bars represent index values for 1986.
Lines represent average for 1974-1985.

1986 LONG RIVER SURVEY

DENSITY OF TROL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

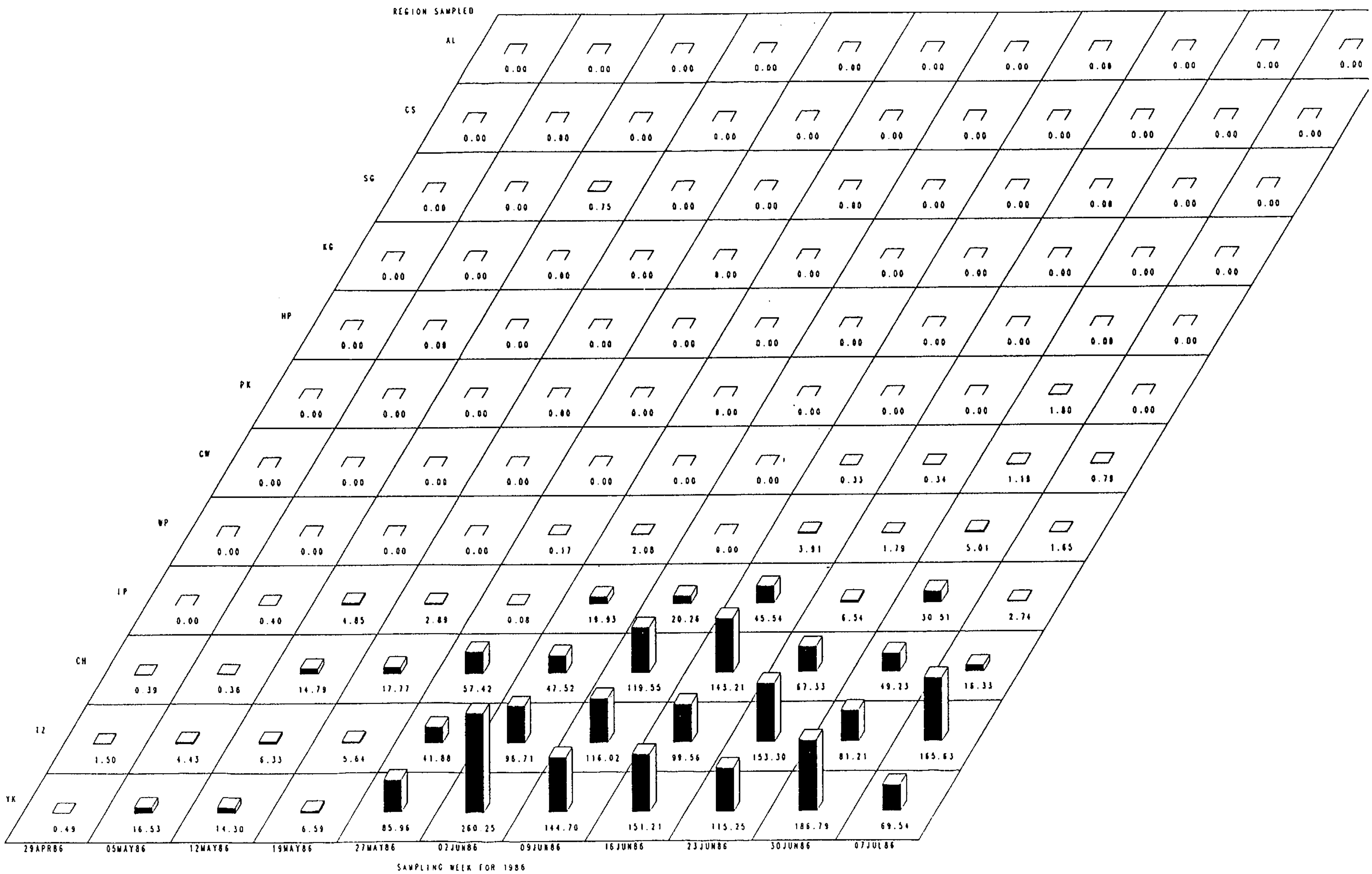


FIGURE 4-139

1986 FALL SHOALS SURVEY
DENSITY OF YROL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

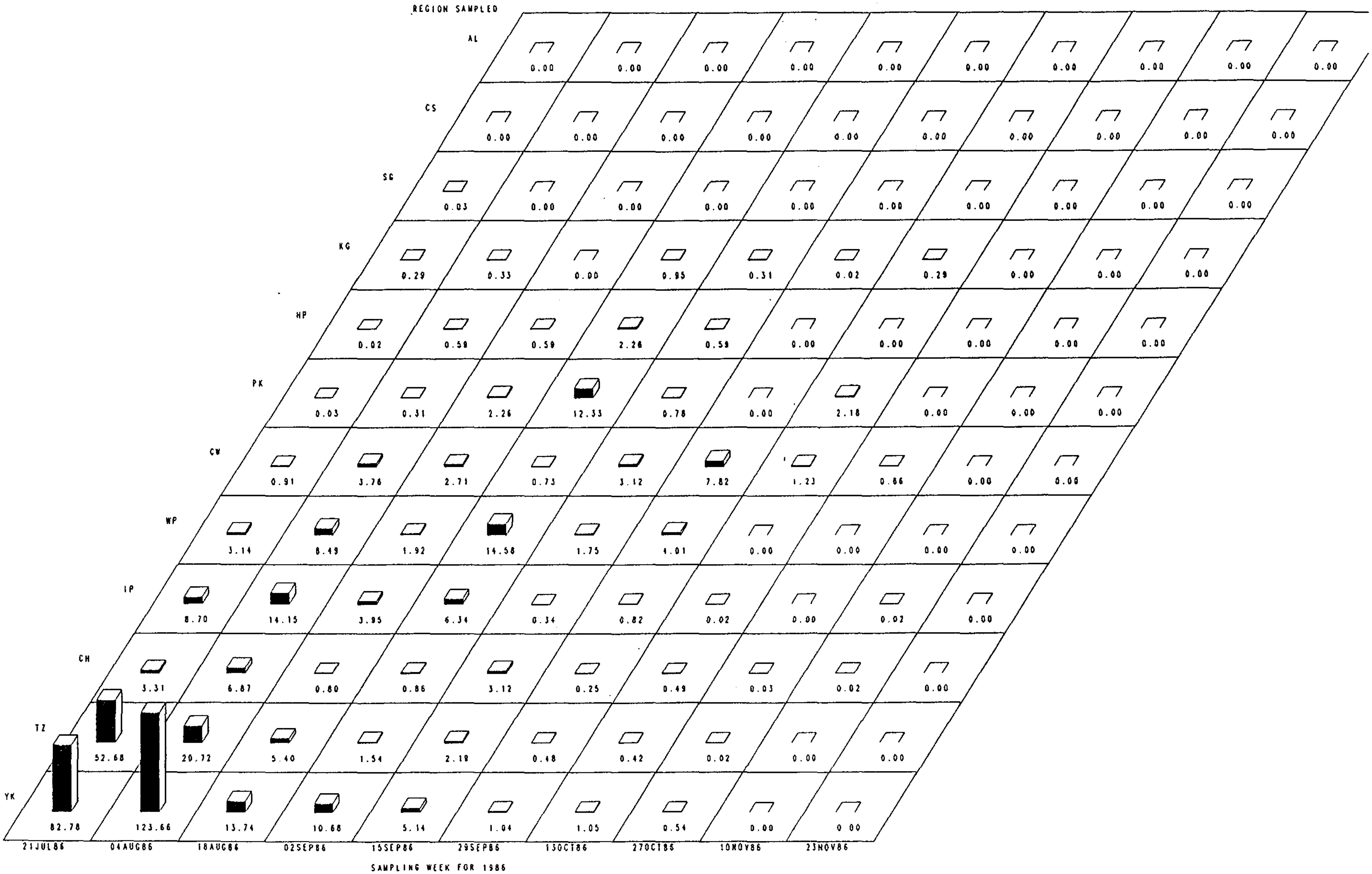


FIGURE 4-140

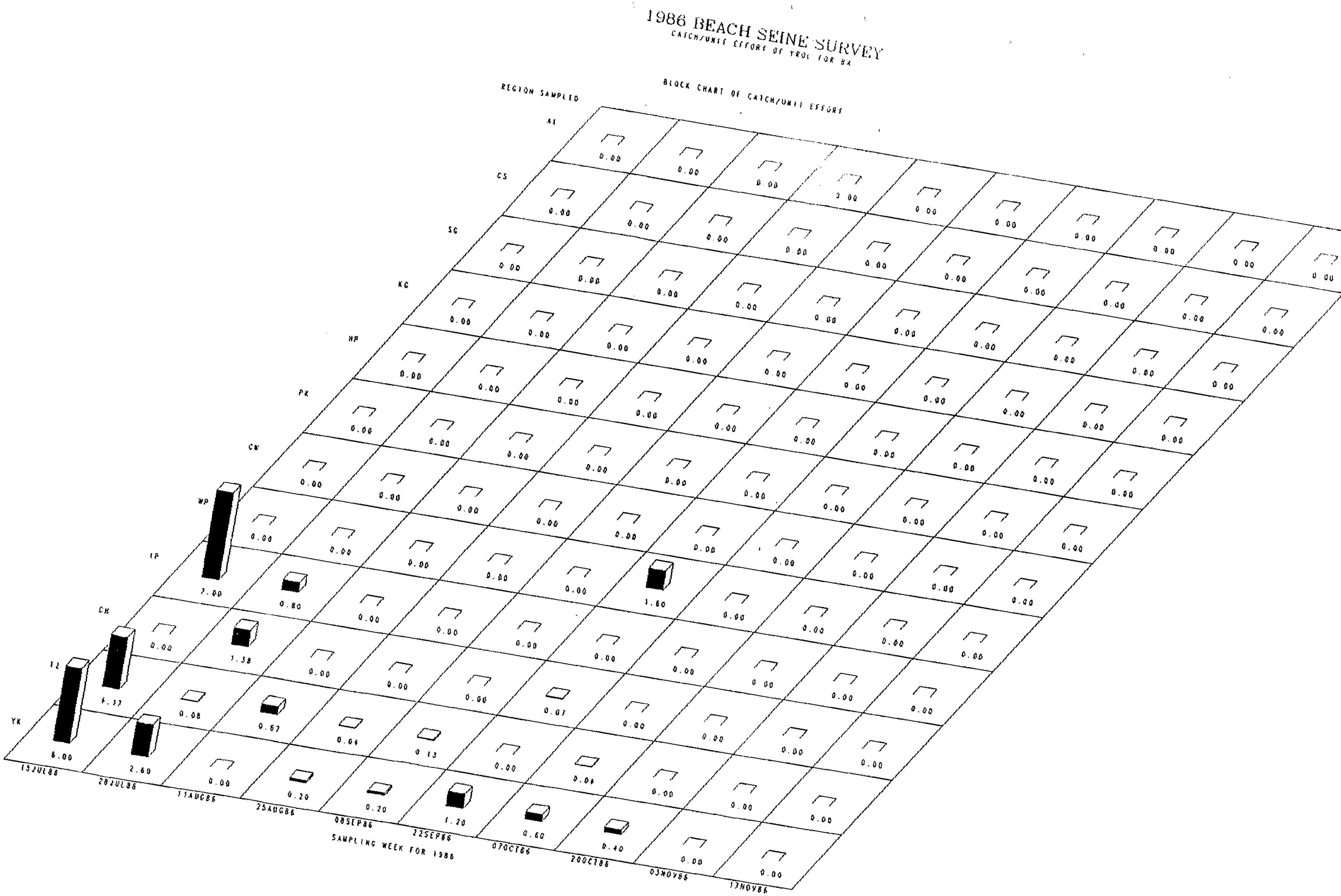

1986 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF YROL FOR BA
BLOCK CHART OF CATCH/UNIT EFFORT
REGION SAMPLED
AI
CS
SG
KG
NP
PK
CW
WP
IP
CH
TZ
YK
15JUL86
28JUL86
11AUG86
25AUG86
08SEP86
22SEP86
07OCT86
20OCT86
03NOV86
17NOV86
SAMPLING WEEK FOR 1986

FIGURE 4-141

1987 LONG RIVER SURVEY

DENSITY OF EGGS FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

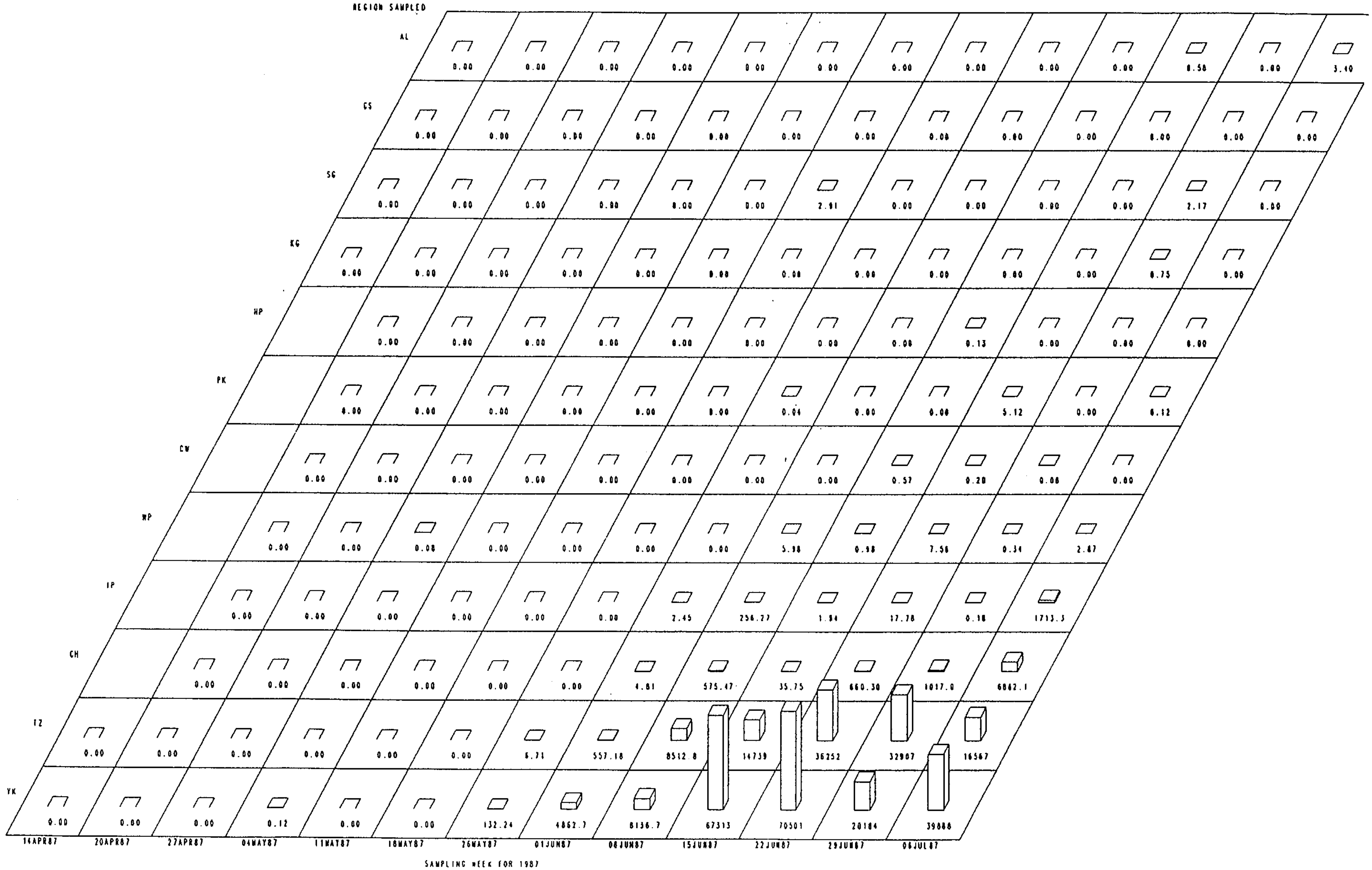


FIGURE 4-142

the second sampling week of June through the first sampling week of July in the Yonkers and Tappan Zee regions. Elevated salinity levels in the lower regions of the estuary were associated with densities in excess of 1000/1000 m^3 as far upriver as Indian Point. Peak occurrence was in the Yonkers region. Bay anchovy eggs were collected in every region of the estuary except Catskill during the June and July sampling weeks.

4.10.2.2 Yolk-Sac Larvae. Bay anchovy YSL were first collected during the second sampling week of June and were present until the end of the LRS program (Figure 4-143). Greatest abundance occurred from the second week of June through the 22 June sampling week, mainly in the lower estuary. Peak YSL density was estimated in the Yonkers region during the 22 June sampling week; however, actual peak occurrence may have been downstream in unsampled areas of the estuary. No YSL were sampled upriver from the West Point region.

4.10.2.3 Post Yolk-Sac Larvae. Bay anchovy PYSL were first collected during the 1987 LRS in late May; larval density estimates exceeding 1000/1000 m^3 were collected from mid-June through the end of the sampling program (Figure 4-144). A peak in temporal abundance occurred during the final LRS sampling week, two weeks after the YSL abundance peak. Collections included bay anchovy larvae from every region of the estuary except Saugerties and Catskill. Greatest occurrence was in the lower estuary, with peak estimated densities in the Indian Point region. Spatial distribution comparisons between YSL and PYSL suggest an upriver movement of larvae to lower salinity nursery areas.

4.10.2.4 Young-of-Year. Juvenile bay anchovy were not collected during the 1987 LRS but were present in all collection periods of the FSS (Figure 4-145) and BSS (Figure 4-146) programs. FSS weekly juvenile density estimates exceeded 100/1000 m^3 from 13 July through the 5 October sampling week, with peak temporal abundance occurring in early September. Although beach zone collections were sporadic, an abundance peak corresponding with that of the FSS was

1987 LONG RIVER SURVEY

DENSITY OF YSL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

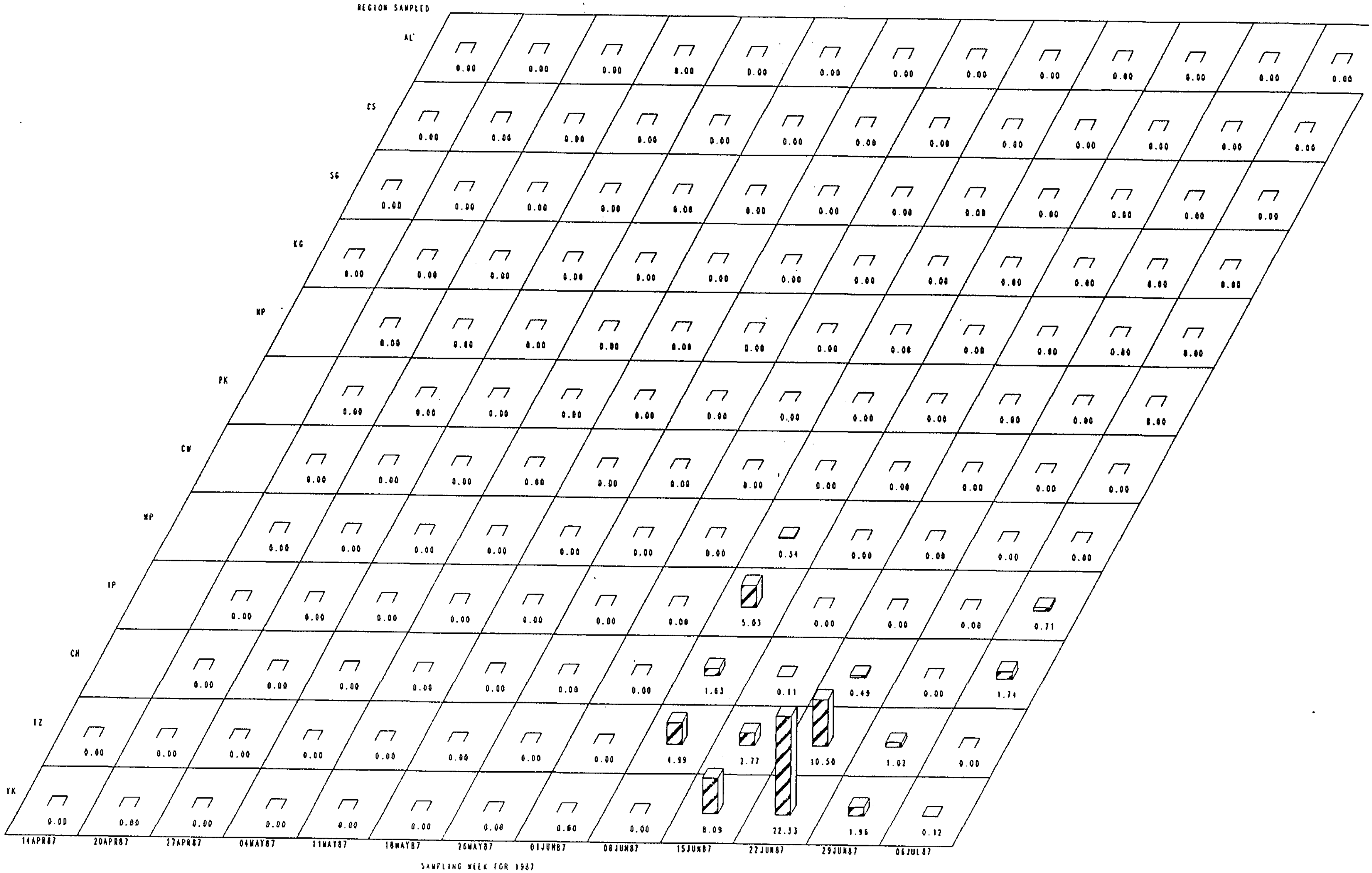


FIGURE 4-143

1987 LONG RIVER SURVEY

DENSITY OF PYSL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

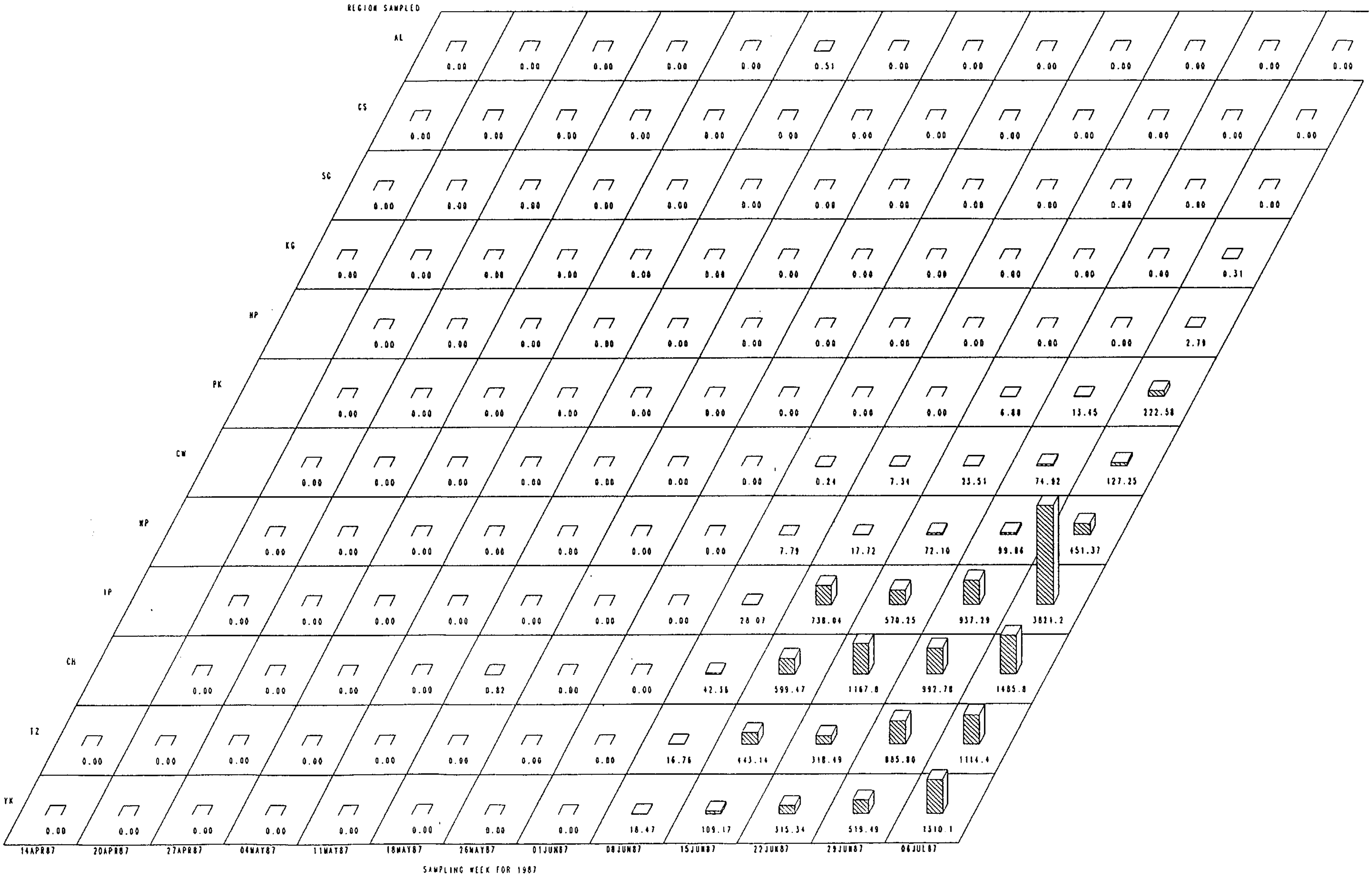


FIGURE 4-144

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

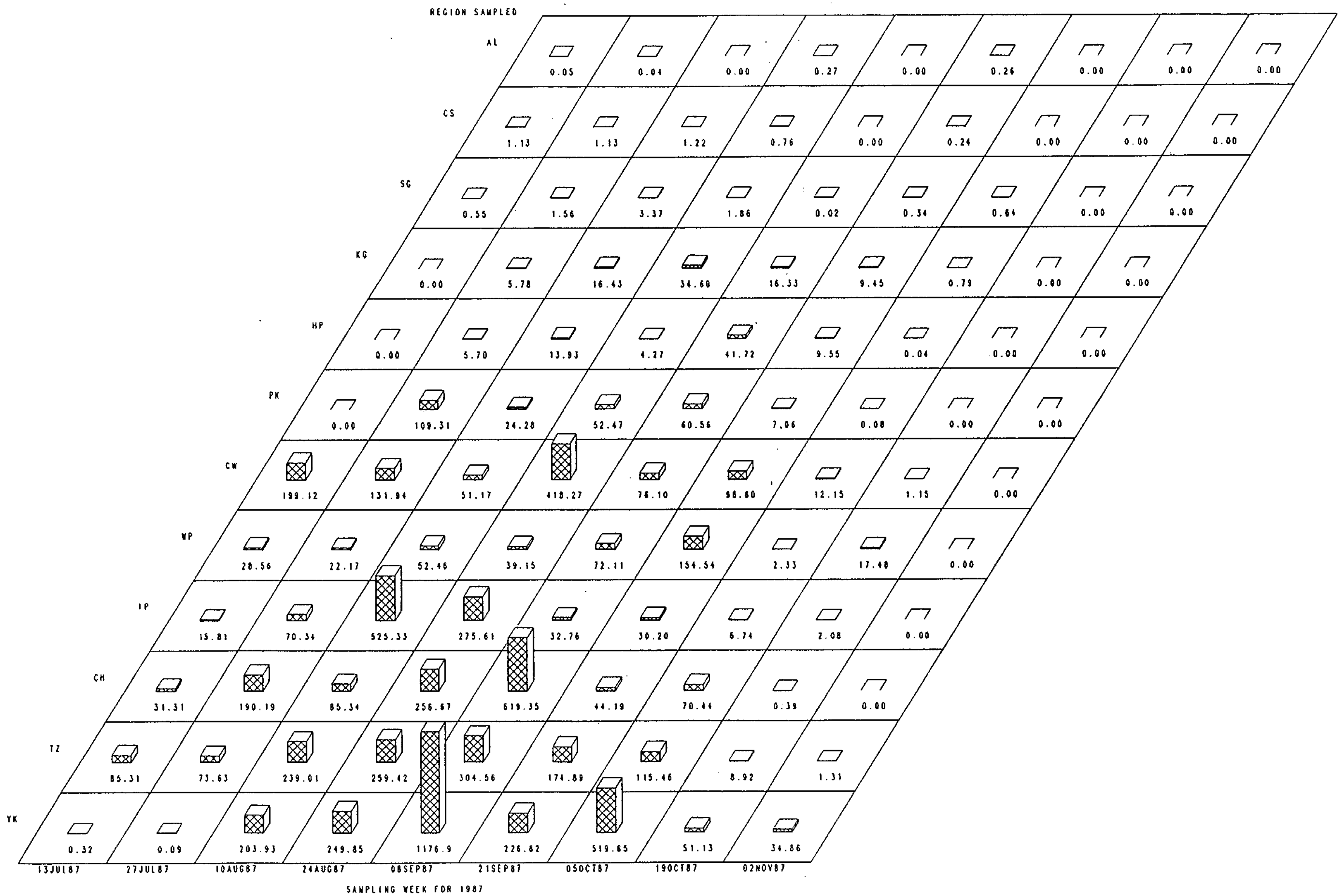


FIGURE 4-145

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR BAY ANCHOVY

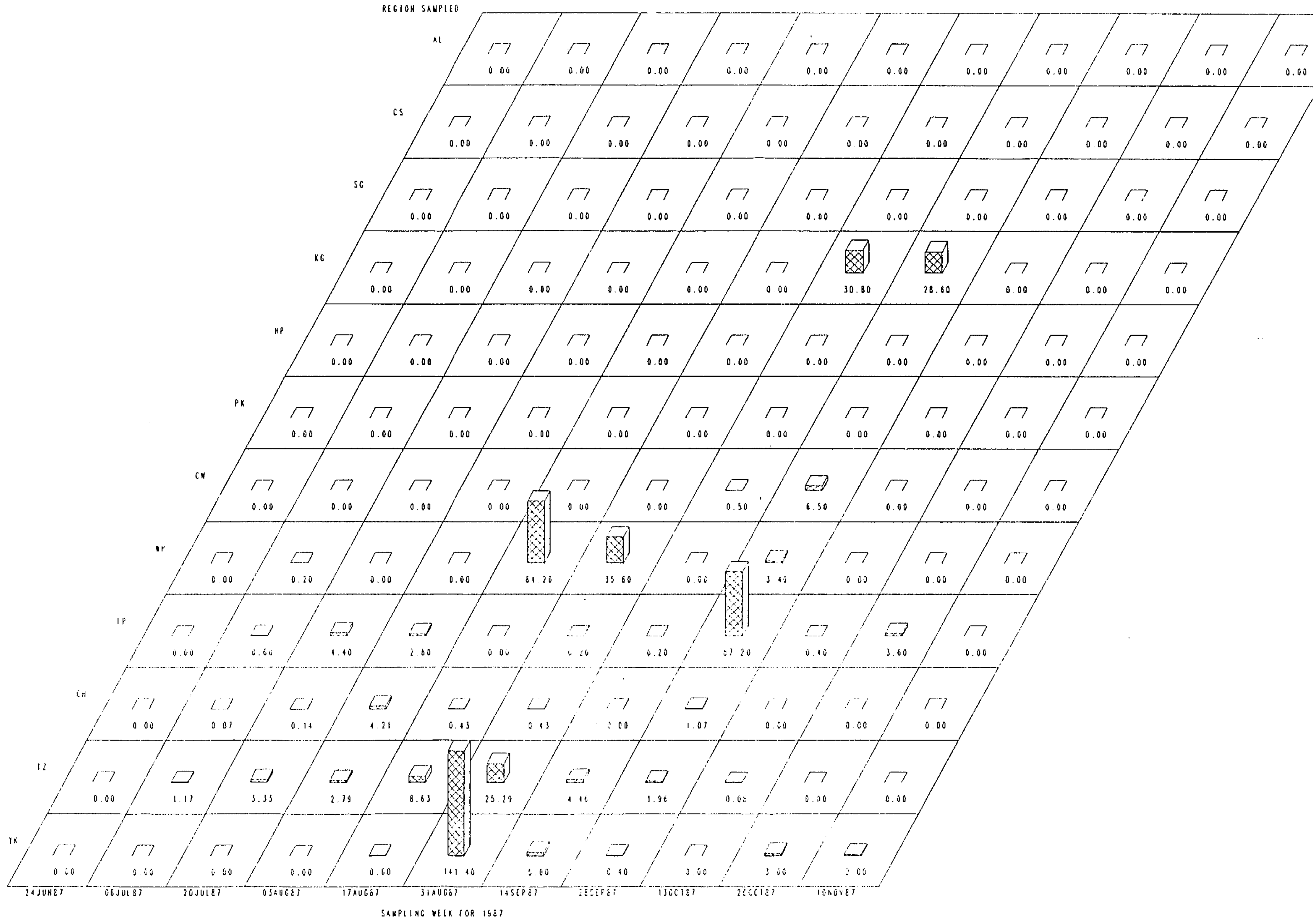


FIGURE 4-146

observed. Yearling and older bay anchovy were present only in the Yonkers region in November samples, probably a result of their fall seaward migration.

YOY catches in 1987 were made in all sampling regions, with greatest densities (>100/1000 m^3) occurring from the Yonkers region north through the Poughkeepsie region (RM 12-76). Peak occurrence was in the Yonkers region for both the FSS and BSS programs (Figure 4-147).

4.10.2.5 Yearling and Older Fish. Yearling and older bay anchovy were first collected during the first 1987 LRS sampling week of May (Figure 4-148) and remained present in catches throughout the LRS, FSS, and BSS (Figures 4-149 and 4-150) programs. Sample densities greater than 10/1000 m^3 were estimated from 26 May through the 24 August sampling period of the FSS, with greatest occurrence during the 22 June sampling week.

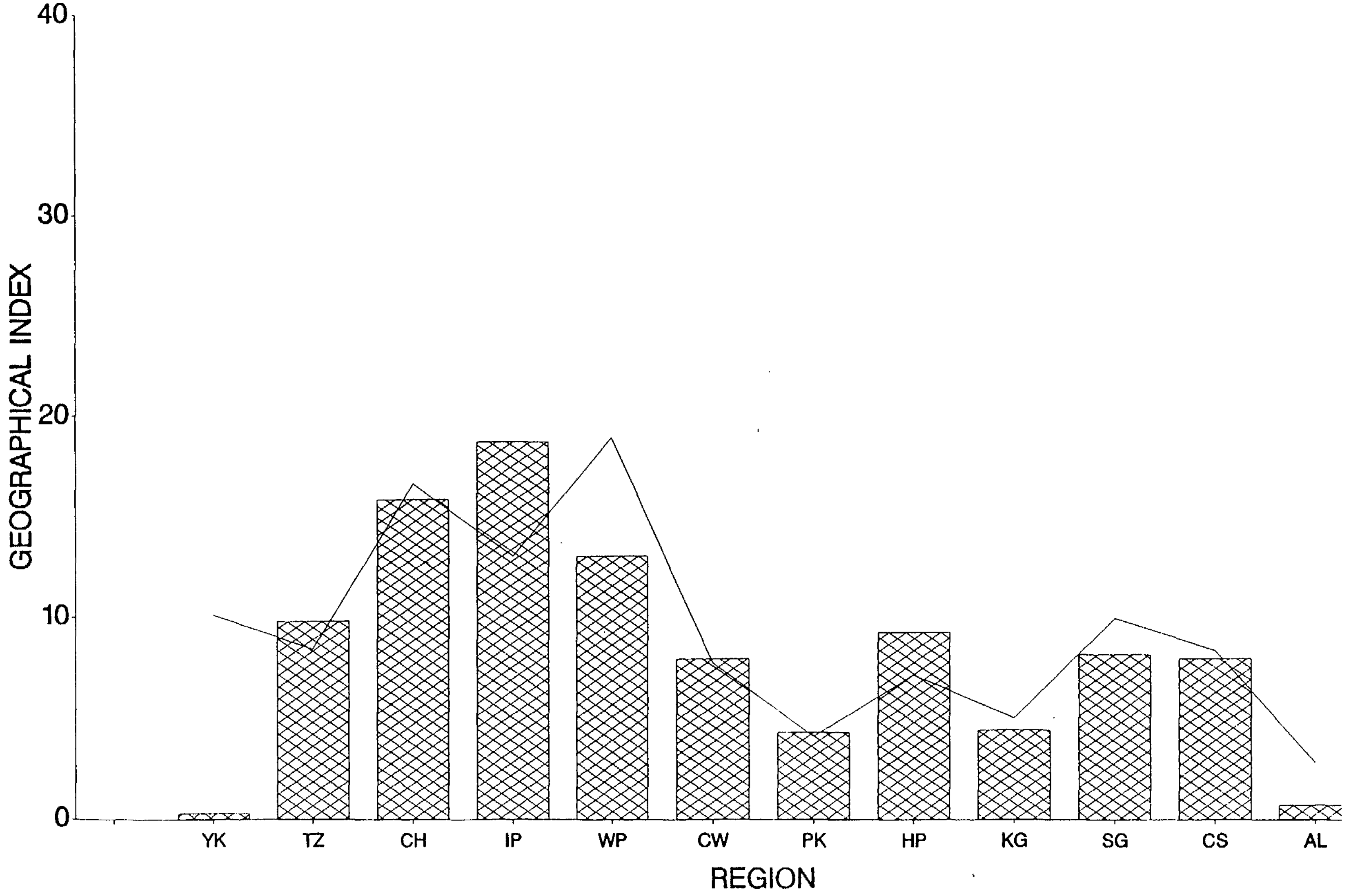
Yearling and older fish were collected almost entirely in the lower estuary, with trace numbers sampled as far upriver as the Catskill region. Peak occurrence was in the Yonkers and Tappan Zee regions. Trace numbers were caught in the middle estuary when the salt front moved upriver in July and August. Decreasing salinities and temperatures through September and October may have caused yearling and older bay anchovy to migrate to the sea; November catches were limited to the Yonkers region.

4.11 WEAKFISH

The weakfish, Cynoscion regalis (Bloch and Schneider), is a euryhaline species important both commercially and recreationally. Its coastal range is from Nova Scotia to Florida, with greatest concentrations from Long Island Sound to Chesapeake Bay (Colton et al. 1979). In the Hudson River weakfish are found upriver to Hyde Park (RM 86), with greatest abundances in the lower reaches of the estuary (RM 0-55).

FIGURE 4-147

GEOGRAPHICAL DISTRIBUTION OF YOUNG-OF-YEAR BAY ANCHOVY COLLECTED IN THE BEACH SEINE SURVEY, 1987



LEGEND

Bars represent index values for 1987.
Lines represent average for 1974-1986.

1987 LONG RIVER SURVEY
DENSITY OF YBOL FOR BAY ANCHOVY

BLOCK CHART OF AVG DENSITY

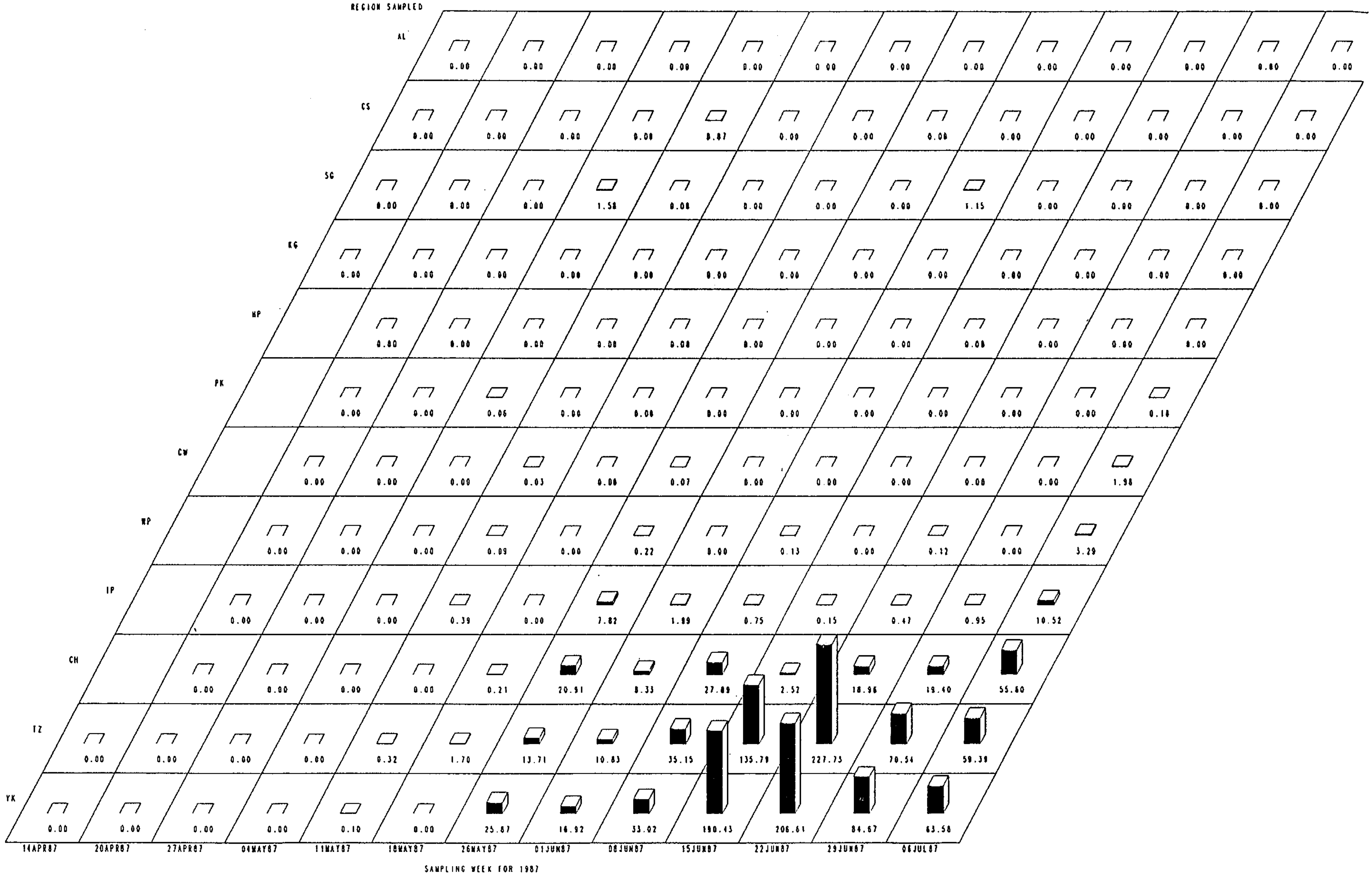


FIGURE 4-148

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR BAY ANCHOVY

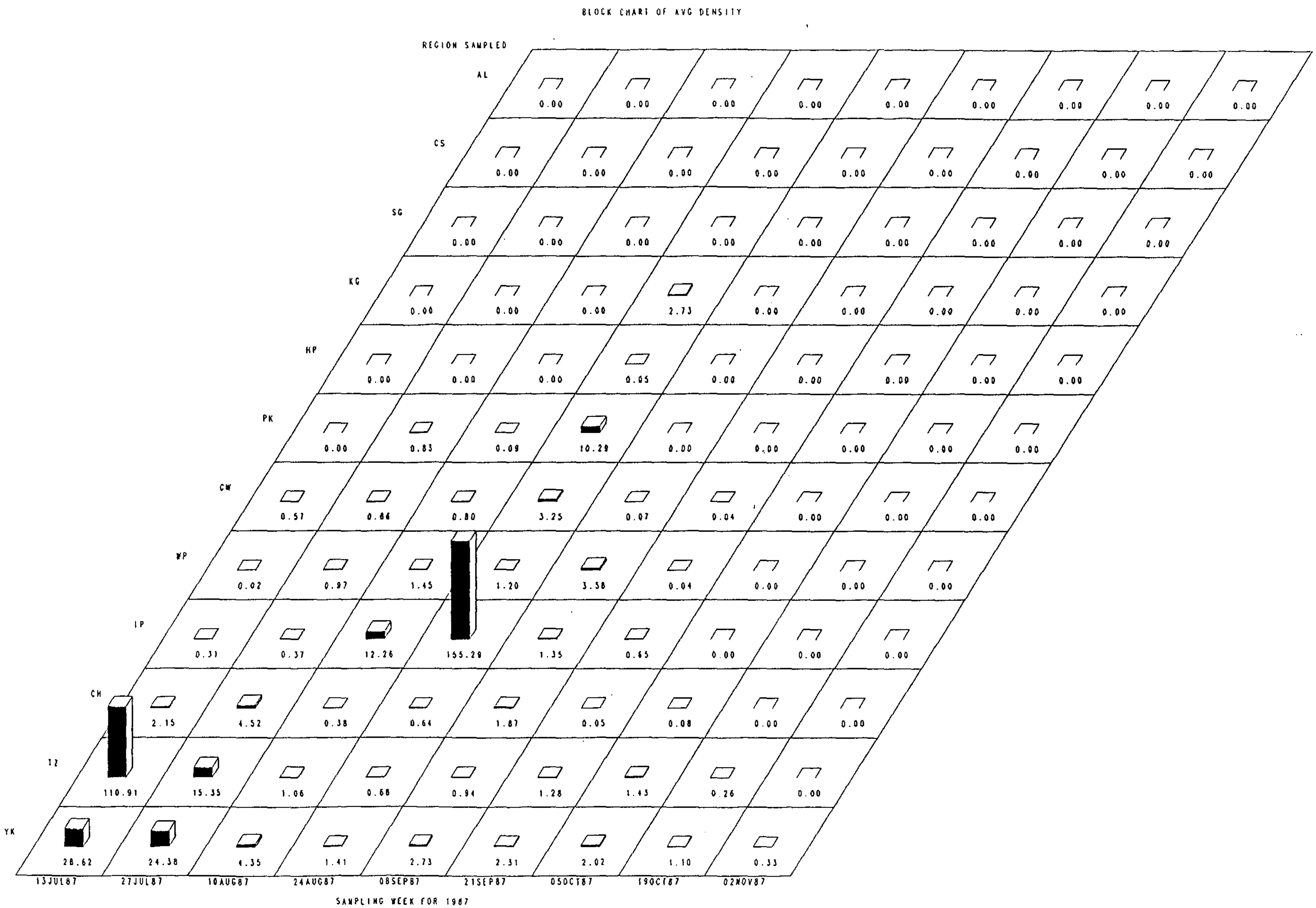


FIGURE 4-149

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR BAY ANCHOVY

BLOCK CHART OF CATCH/UNIT EFFORT

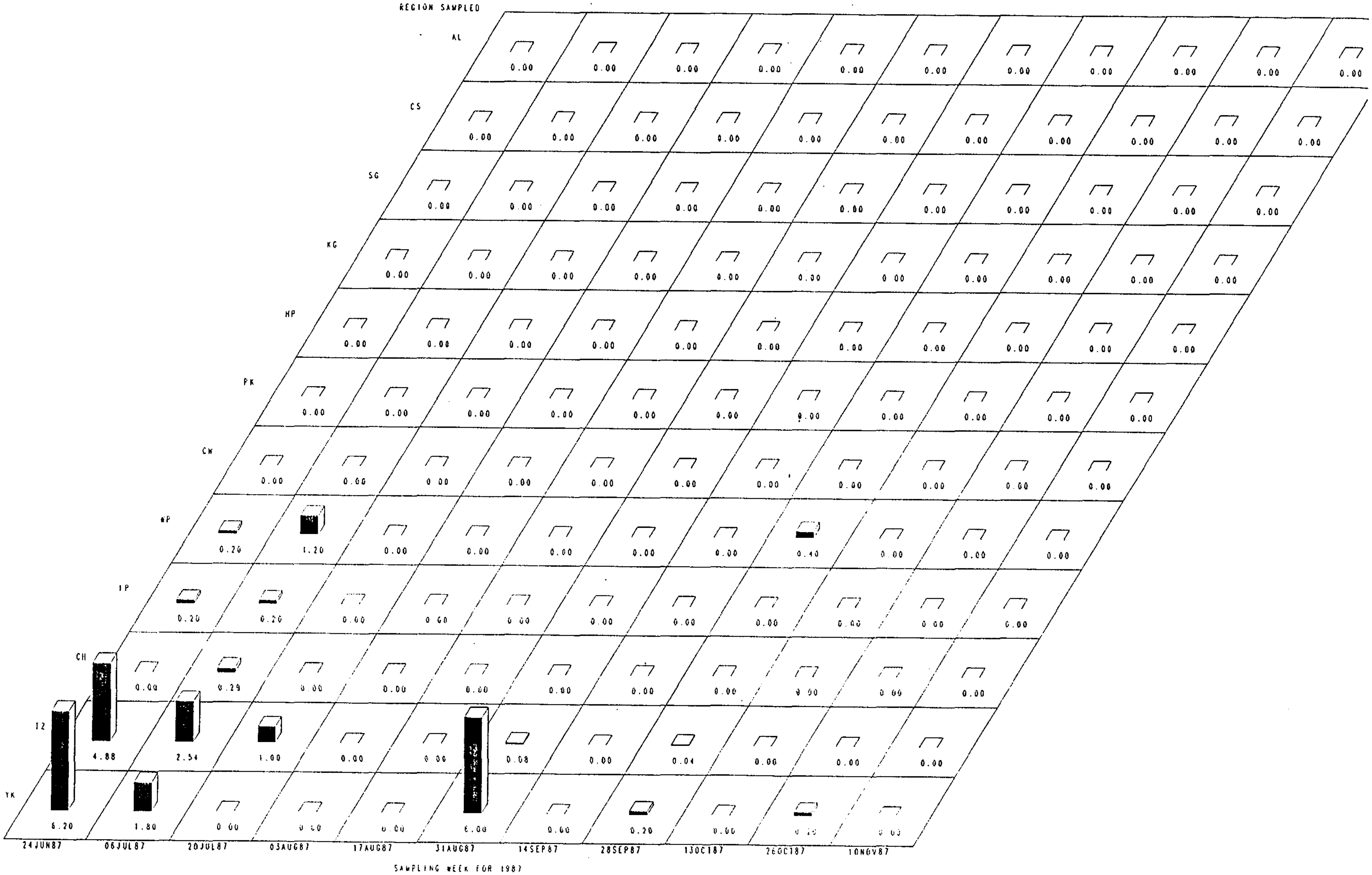


FIGURE 4-150

Spawning occurs in coastal waters and estuaries from April to August when water temperatures are from 15 to 21°C and salinities range from 28 to 31 ppt (Lippson and Moran 1974). The Hudson River appears to be near the northern limit of their spawning range (Colton et al. 1979). After spawning, adult weakfish move off the Virginia-Carolina coast to overwinter (Yetman et al. 1985).

Weakfish eggs are pelagic and buoyant (Lippson and Moran 1974), but when hatched the larvae sink to the bottom and are carried upstream by denser bottom currents (Thomas 1971). YOY fish remain in the brackish environment of the deeper shoals and channel waters until cooler fall temperatures cause them to leave the estuaries. The YOY weakfish then move south to join the adults in the overwintering areas. No eggs or YSL have ever been collected during LRS sampling efforts.

4.11.1 1986 Study

4.11.1.1 Post Yolk-Sac Larvae. Weakfish PYSL were first sampled during early June 1986 in the Yonkers region. Peak abundances occurred during the last week of the LRS (Figure 4-151). At this time densities in excess of 10/1000 m^3 were present in the lower estuary, with peak occurrence in the Indian Point region.

4.11.1.2 Young-of-Year. Weakfish YOY were caught only in the FSS (Figure 4-152) and BSS (Figure 4-153) programs in 1986. Earliest collections occurred during the initial sampling period of the FSS, with peak abundance during the 2 September sampling week. Shore-zone sampling in the BSS caught only trace densities of juvenile weakfish from late July through late September, almost exclusively in the Yonkers region.

FSS samples revealed a sharp increase in densities between late July and early August in the lower estuary, peaking in the Yonkers region in early September, followed by steady declines throughout the lower estuary. This pattern of

1986 LONG RIVER SURVEY

DENSITY OF PYSL FOR WEAKFISH

BLOCK CHART OF AVG DENSITY

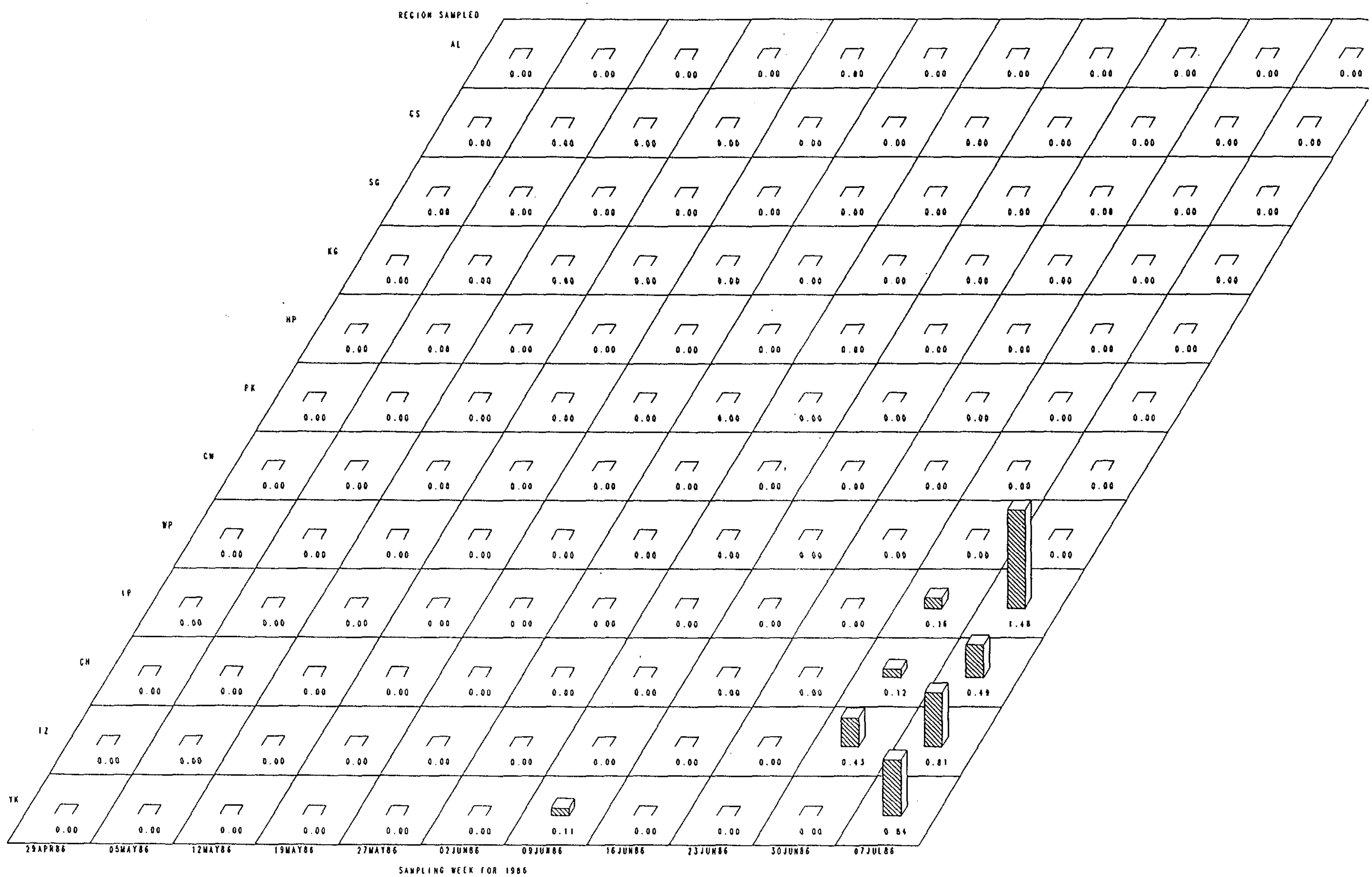


FIGURE 4-151

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR WEAKFISH

BLOCK CHART OF AVG DENSITY

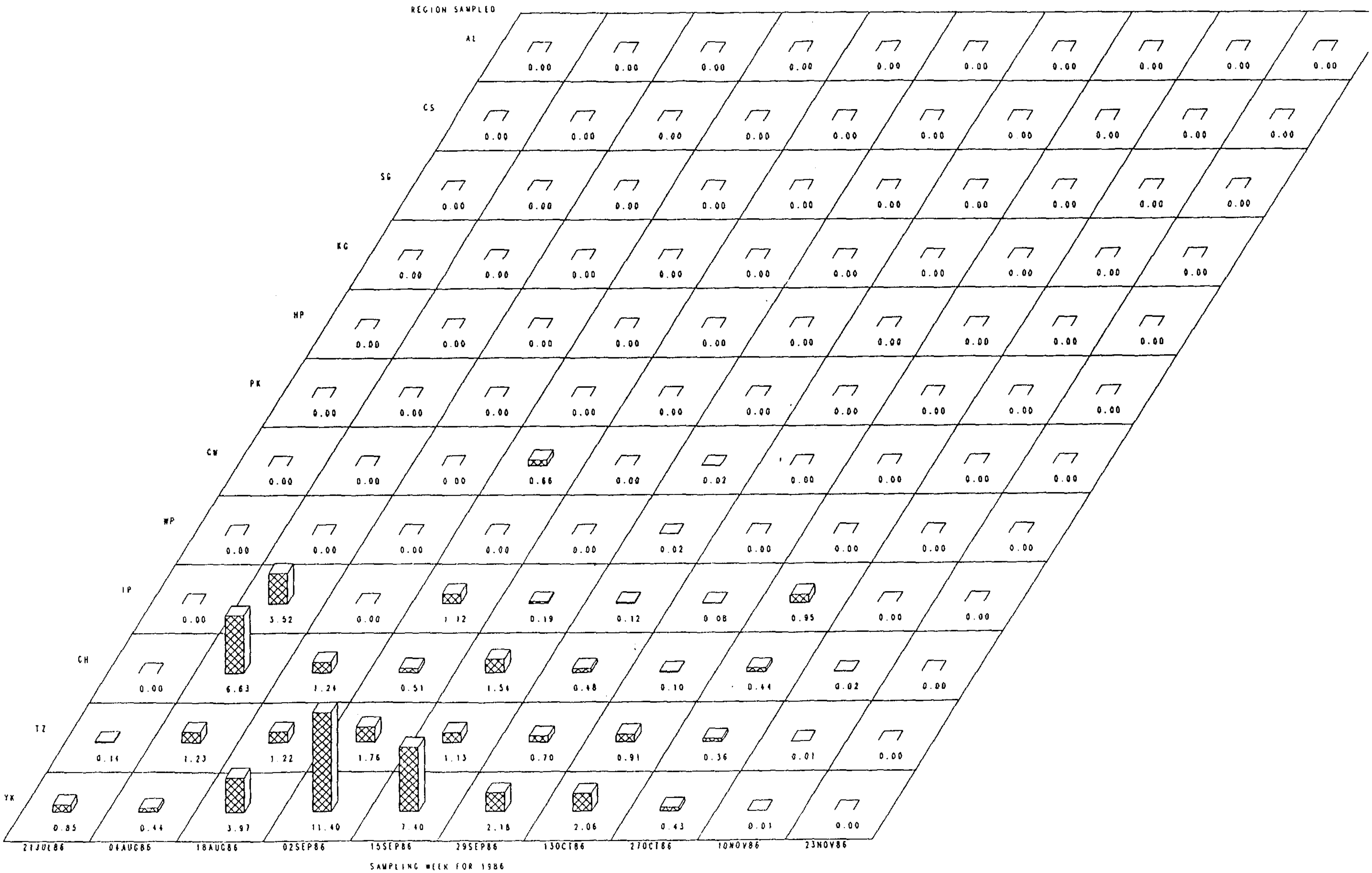


FIGURE 4-152

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR WK

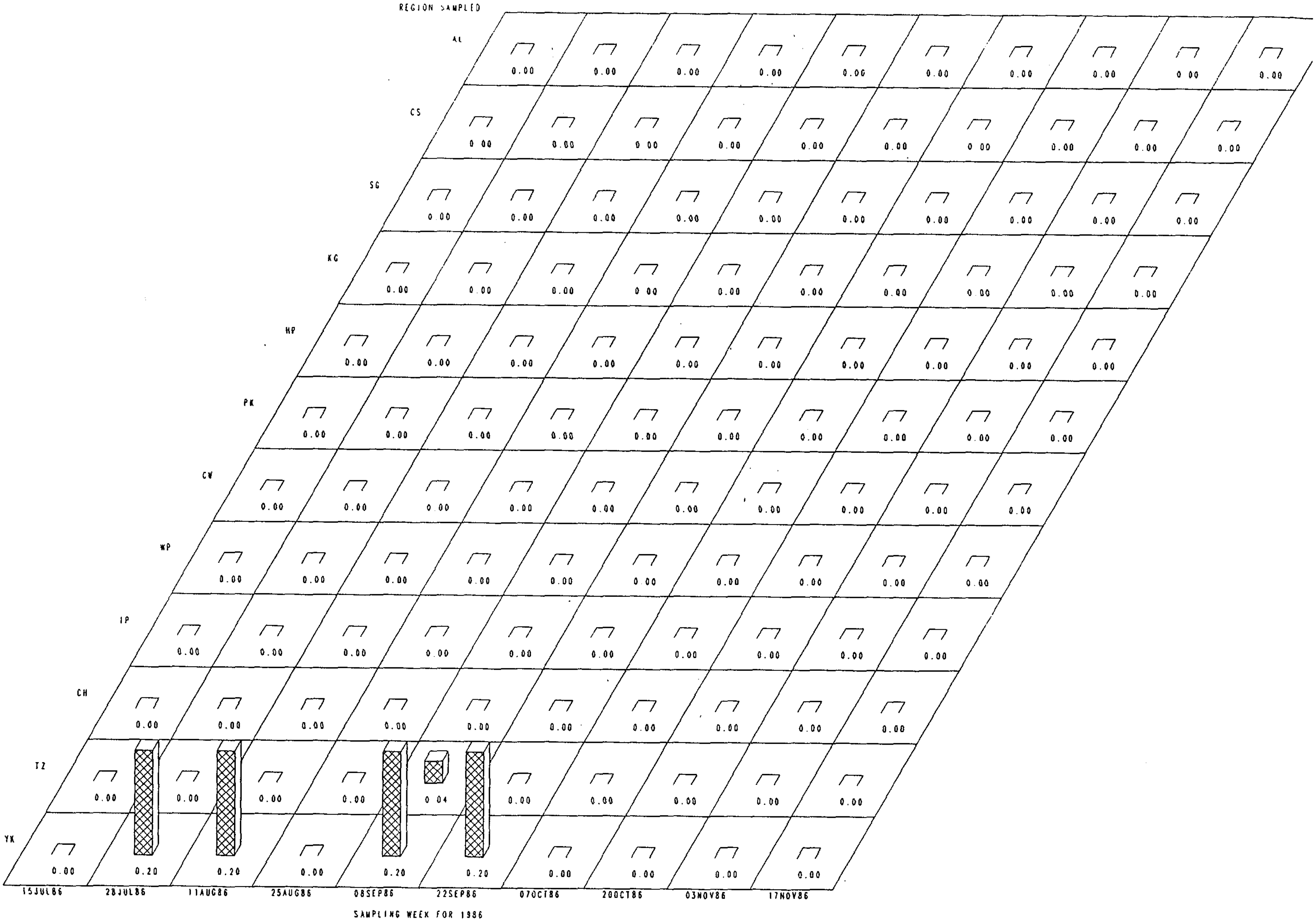


FIGURE 4-153

weakfish abundance has been reported in previous years (Battelle 1983; NAI 1985a,b; MMES 1986). Juveniles were caught as far upriver as the Cornwall region during periods when the salt front was far upstream. No juvenile weakfish were captured in the estuary during the final FSS sampling.

4.11.1.3 Yearling and Older Fish. No yearling or older weakfish were collected during the 1986 LRS and BSS programs. FSS sampling caught yearling or older weakfish during the sampling weeks of 15 September and 13 October (Figure 4-154). Collections occurred in the Yonkers and Tappan Zee regions, with peak density in the Yonkers region during the 15 September sampling week. Most yearling and older weakfish presumably were located farther south, reflecting their high salinity requirements. Gear avoidance is likely as yearling and older weakfish are powerful swimmers. This could be one reason for the low catch records in the sampling programs.

4.11.2 1987 Study

4.11.2.1 Post Yolk-Sac Larve. Weakfish PYSL were first sampled during mid-June 1987 when the lower estuary temperature was 21.8°C, and remained present in all subsequent LRS sampling weeks (Figure 4-155). In the lower estuary peak temporal occurrence was during the 15 June sampling week. Spatial distribution was limited to the lower estuary, with a slight upriver shift occurring in late June-early July.

4.11.2.2 Young-of-Year. Juvenile weakfish were initially collected in 1987 during the LRS sampling week of 29 June (Figure 4-156); fish remained present in all sampling periods of the FSS program (Figure 4-157). No weakfish were collected in the shore-zone samples of the BSS. Sharp density increases reported during 1986 and in previous years were not apparent; however, peak abundance occurred in early September in the Yonkers region, as noted in the past. During the August period of higher salinity in the middle estuary juvenile weakfish were collected as far north as the Cornwall region. Lower estu-

1986 FALL SHOALS SURVEY

DENSITY OF YROL FOR WEAKFISH

BLOCK CHART OF AVG DENSITY

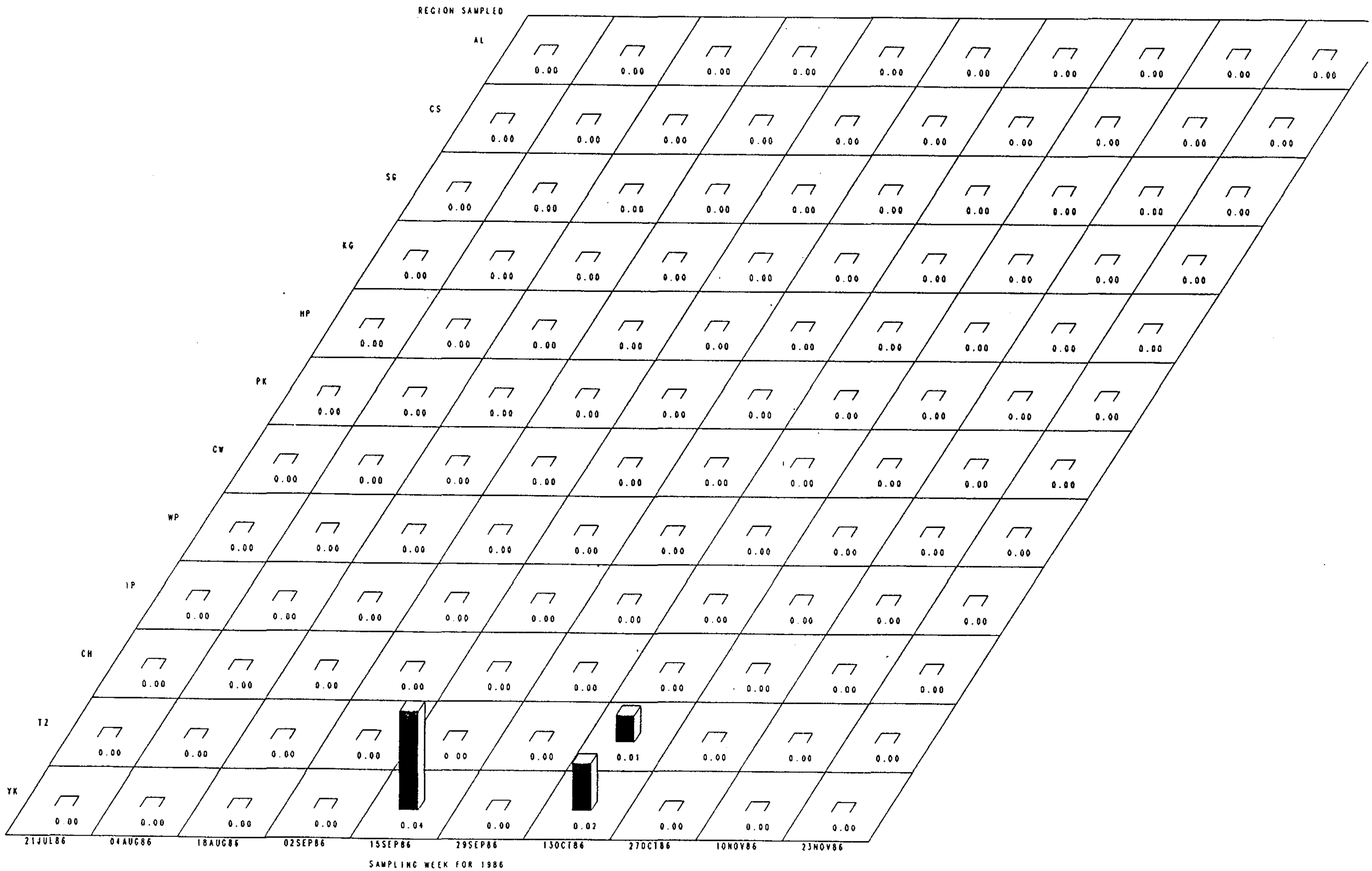


FIGURE 4-154

1987 LONG RIVER SURVEY

DENSITY OF PYSL FOR WEAKFISH

BLOCK CHART OF AVG DENSITY

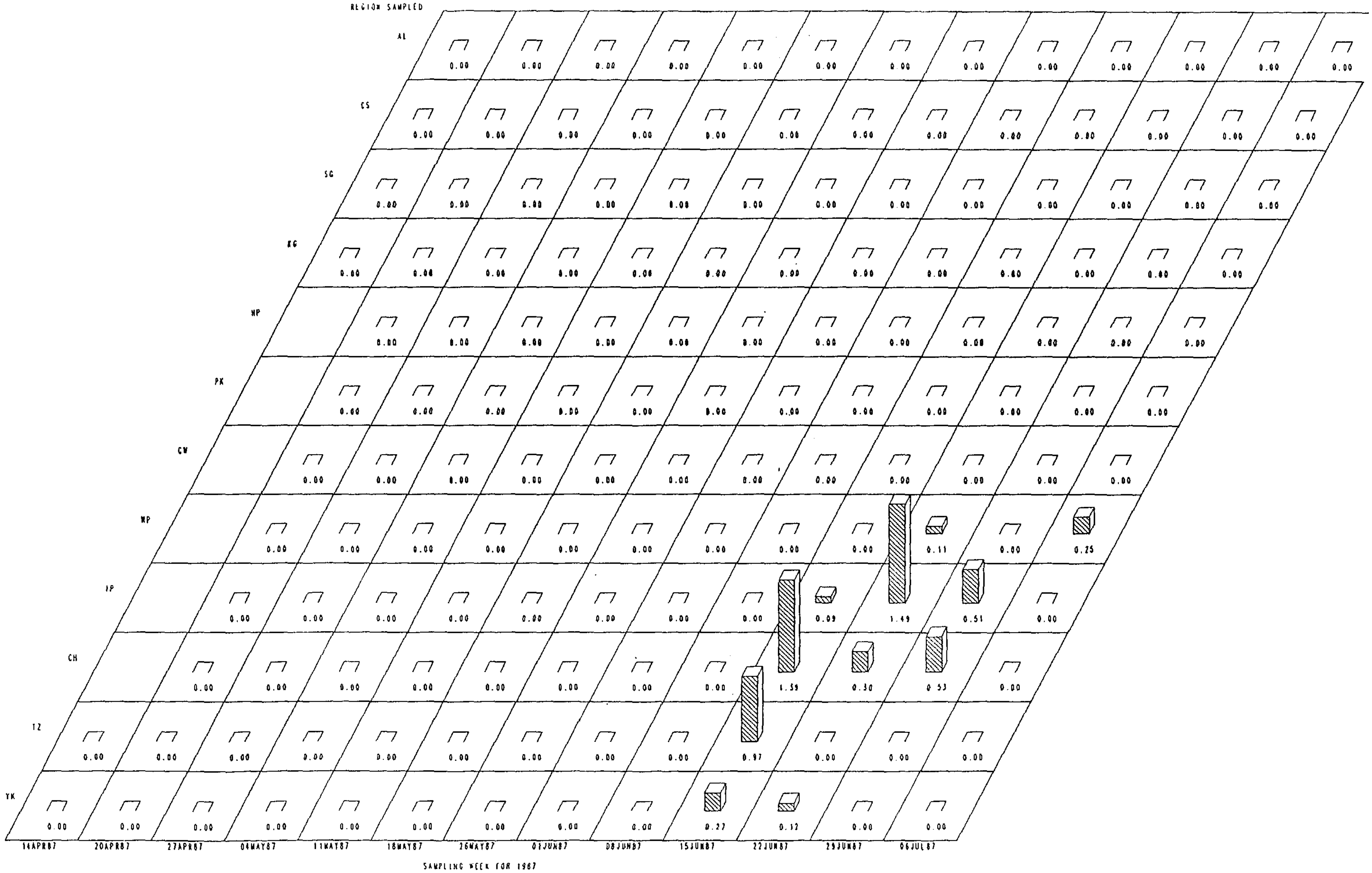


FIGURE 4-155

1987 LONG RIVER SURVEY

DENSITY OF YOY FOR WEAKFISH

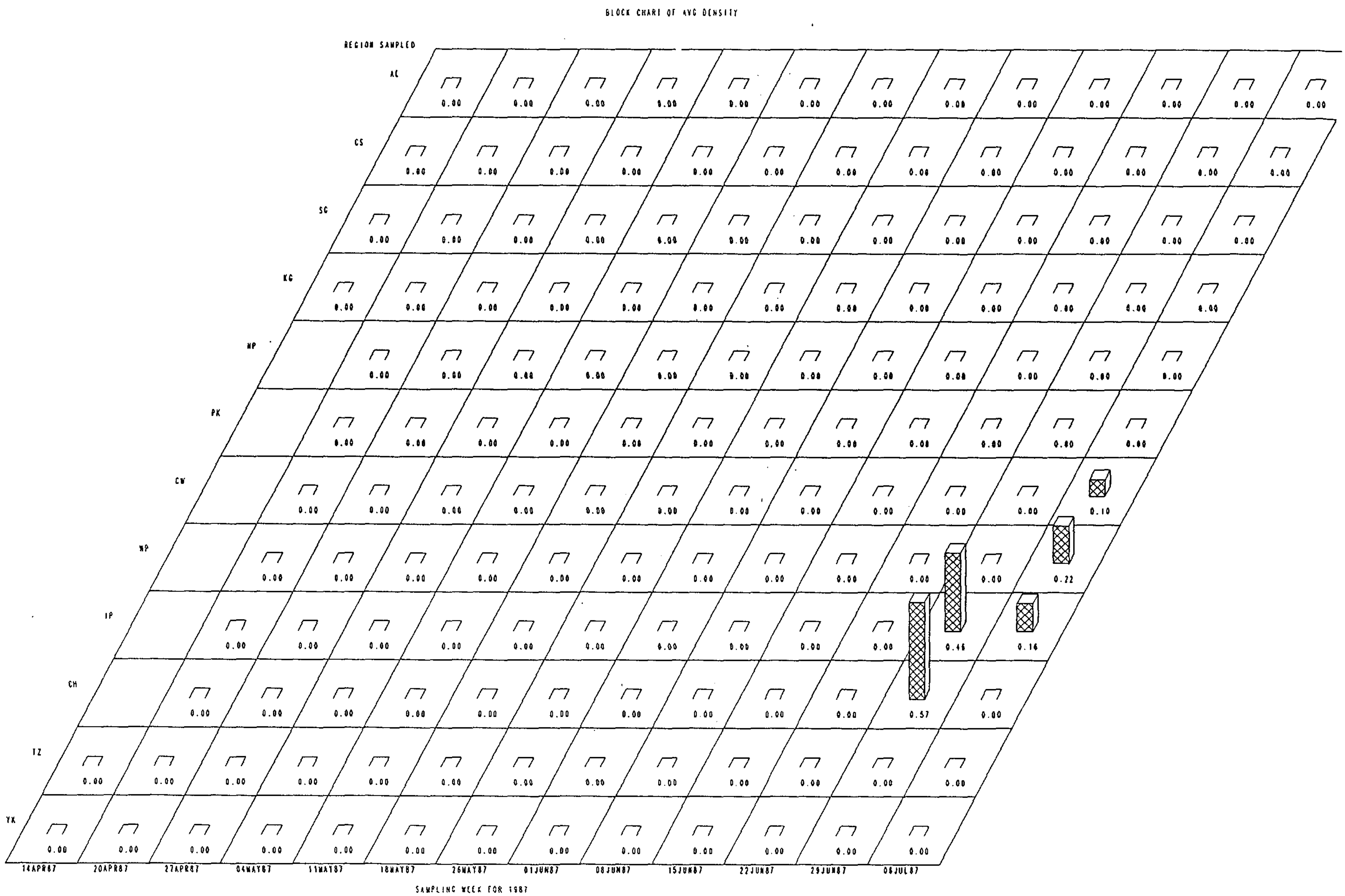


FIGURE 4-156

1987 FALL SHOALS SURVEY
DENSITY OF YOY FOR WEAKFISH

BLOCK CHART OF AVG DENSITY

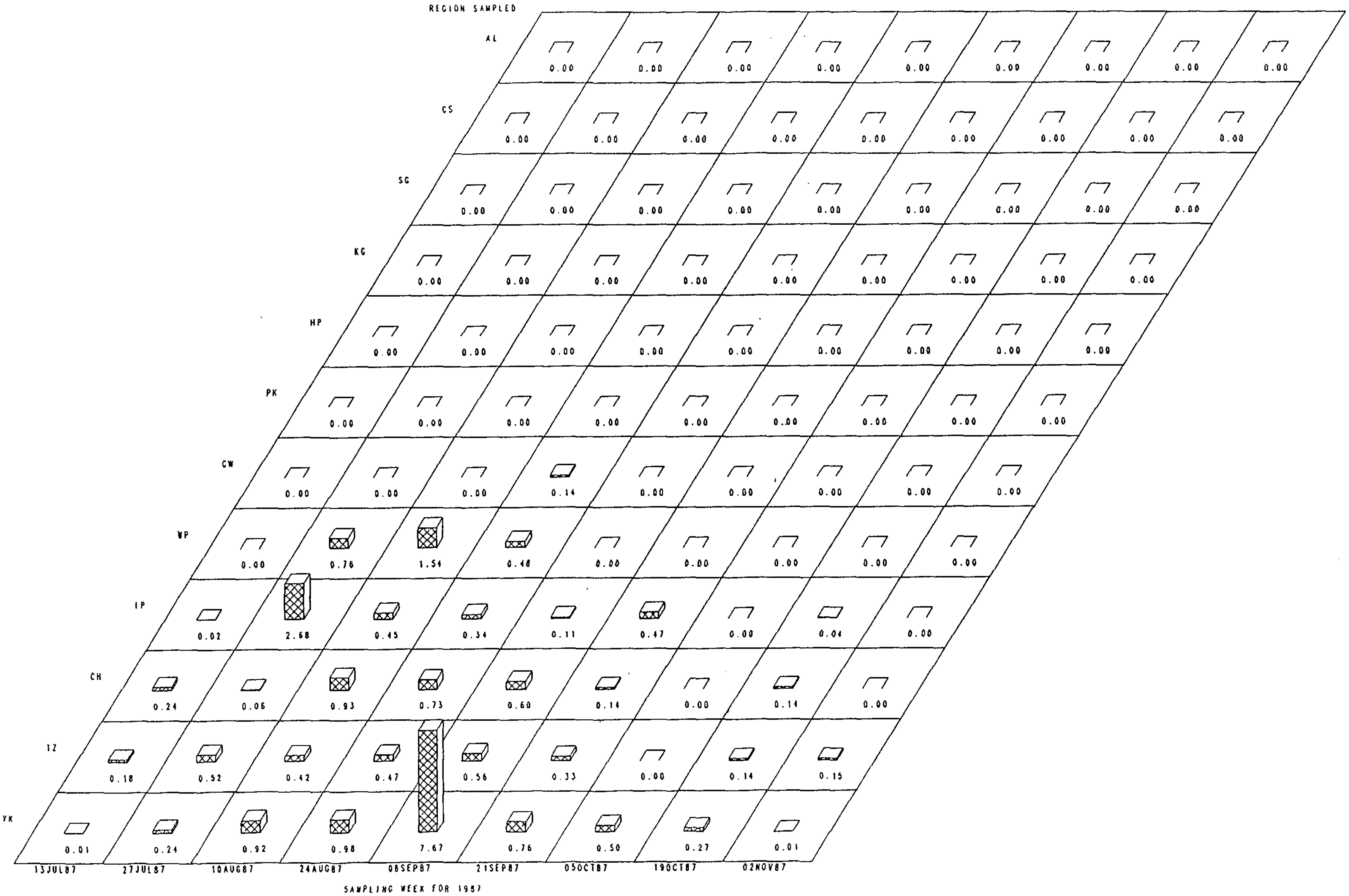


FIGURE 4-157

ary catches declined during October and November as fish emigrated from the estuary.

4.11.2.3 Yearling and Older Fish. Yearling and older weakfish were caught during two sampling periods of the 1987 FSS (Figure 4-158); 1986 records were similar. Catches occurred during the sampling periods of 10 August and 8 September and were reported from the Croton-Haverstraw, Tappan Zee, and Yonkers regions. Most weakfish were likely located farther south in areas of higher salinity.

4.12 WHITE CATFISH

The white catfish, *Ictalurus catus*, is a resident freshwater species found in coastal rivers along most of the east coast of the United States (Trautman 1957). Although adult white catfish will tolerate brackish waters with salinity up to 14 ppt (Kendall and Schwartz 1968), spawning is restricted to water with salinity less than 2 ppt (Perry and Avault 1968).

Spawning occurs in late spring or early summer, with large shore and shoal catches of adults in June and July, possibly related to spawning activities (TI 1981). Generally found in deep-water areas, the adult white catfish lays adhesive eggs in prepared nests found in the shallower shoal and shore zones, remaining there to provide parental care. No spatiotemporal distribution information is available for prejuvenile stages of white catfish because of the invulnerability of eggs and larvae to LRS sampling gear. Because of high downriver salinities it is probable that spawning occurs only in the middle and upper regions of the estuary or in the tributaries. No eggs or larvae were collected during the 1986 or 1987 sampling programs.

Juvenile white catfish are found from the Poughkeepsie region north to the upper limit of the estuary at the Troy Dam from late July through early August. After moving into the deeper river strata during September and October, the yearling and older catfish migrate downstream to overwintering grounds

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR WEAKFISH

BLOCK CHART OF AVG DENSITY

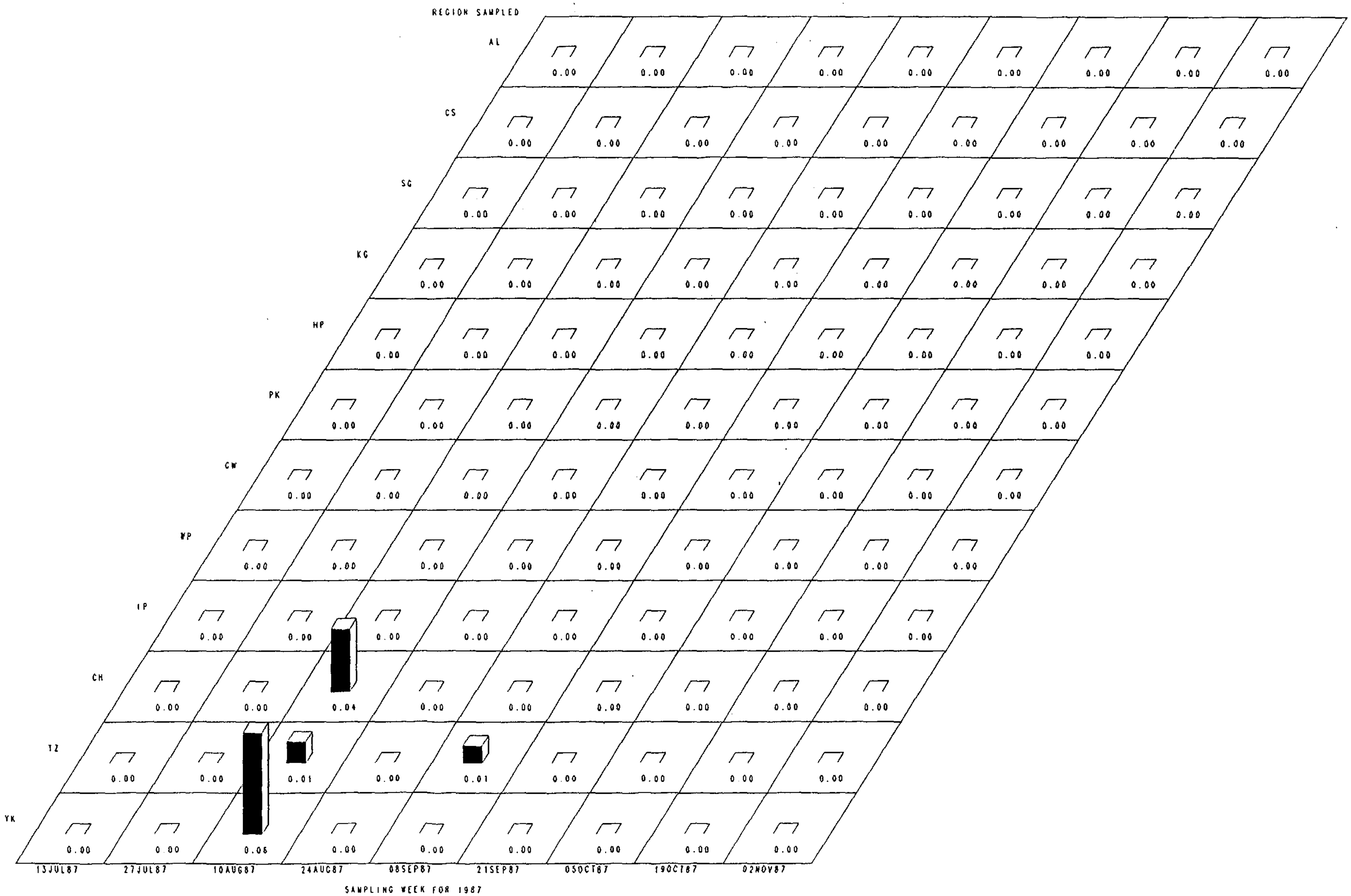


FIGURE 4-158

when upper estuary temperatures drop to 14 to 15°C (NAI 1985b). Mansueti (1950) and Schmidt (1971) reported similar fall movements to deeper waters with changing water temperatures. White catfish are bottom dwellers, feeding on vegetation and benthic invertebrates as well as small vertebrates.

4.12.1 1986 Study

4.12.1.1 Young-of-Year. White catfish YOY were collected in 1986 from the initial FSS sampling period on 21 July through the 10 November collection period (Figure 4-159). Temporal distribution data for white catfish YOY were not sufficient to establish population trends; however, peak regional density was recorded in the West Point region during the 10 November sampling week. YOY were collected primarily north of the Cornwall region, with greatest densities found from the Saugerties region to the Federal Dam at Troy, New York (RM 94-152). The deep-water habitat of white catfish was apparent since only two shore-zone samples revealed juveniles during the BSS program (Figure 4-160). Beach seine catches were made only in the Tappan Zee region.

4.12.1.2 Yearling and Older Fish. Yearling and older white catfish were caught from the first sampling week (29 April) of the 1986 LRS (Figure 4-161) through the final collection period (23 November) of the FSS (Figure 4-162). Highest regional densities were collected during the May and June LRS sampling periods from regions upriver of West Point. Yearling or older white catfish were caught in all Hudson River estuary regions during both the LRS and the FSS.

The BSS program collected limited numbers of yearling or older white catfish; spatial distribution patterns were evident, however, with captures made consistently in the Tappan Zee region during all but the final sampling week (Figure 4-163). A similar spatial distribution pattern was apparent from the FSS, with consistent catches made throughout the survey in the Tappan Zee and Croton-Haverstraw regions. Another area of abundance appears to be Catskill from mid-May through mid-October.

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR WHITE CATFISH

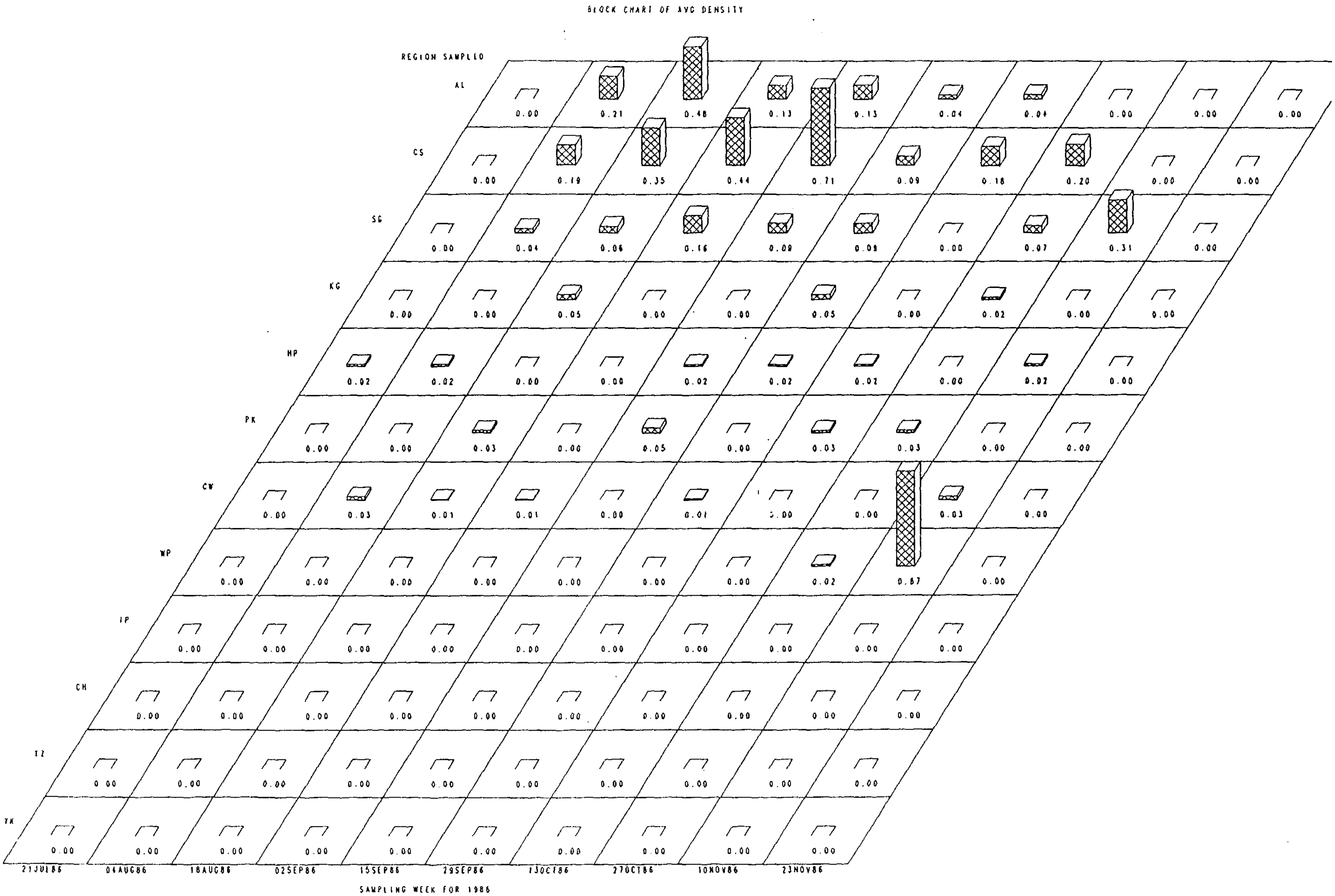


FIGURE 4-159

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR WC

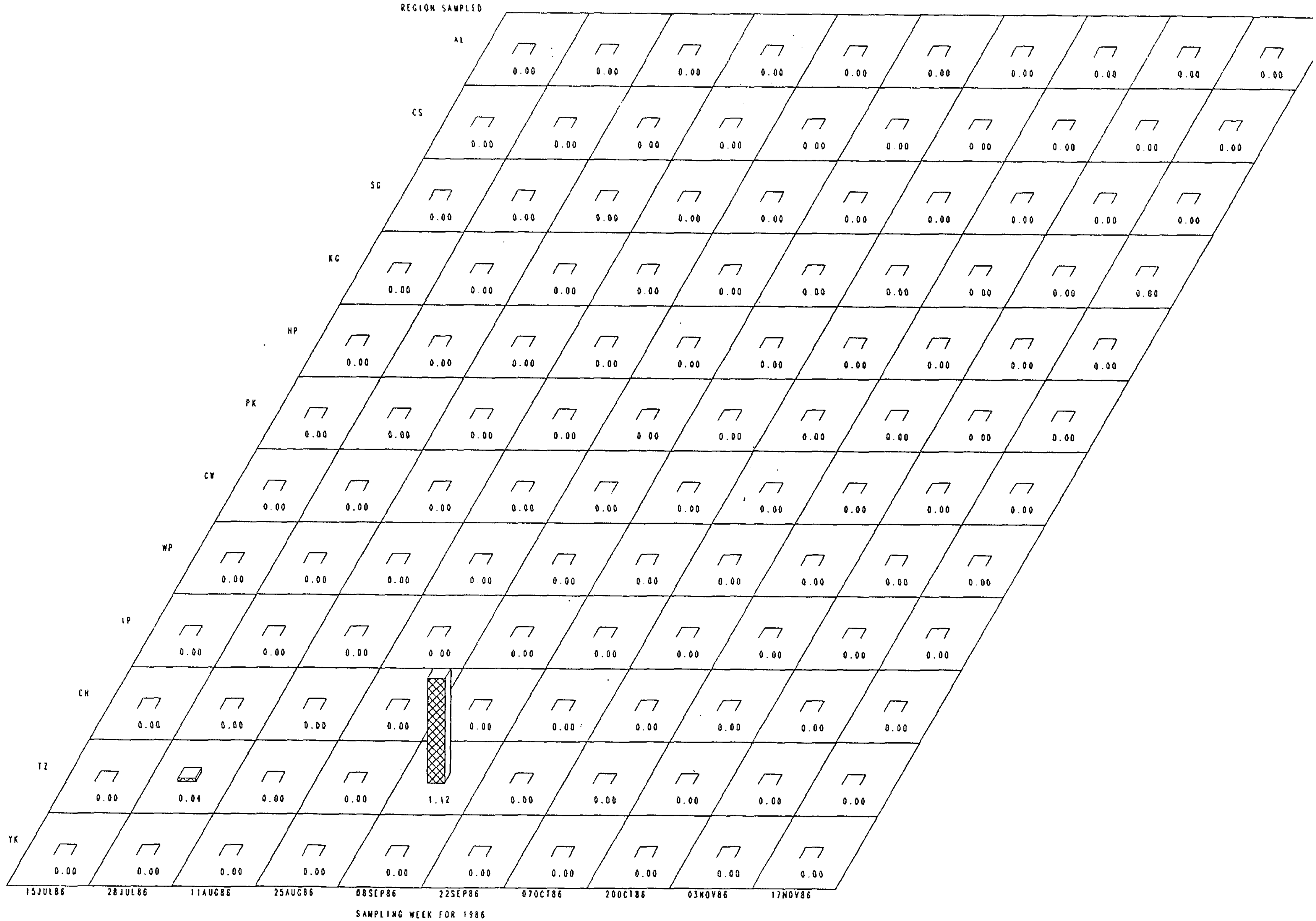


FIGURE 4-160

1986 LONG RIVER SURVEY

DENSITY OF YROL FOR WHITE CATFISH

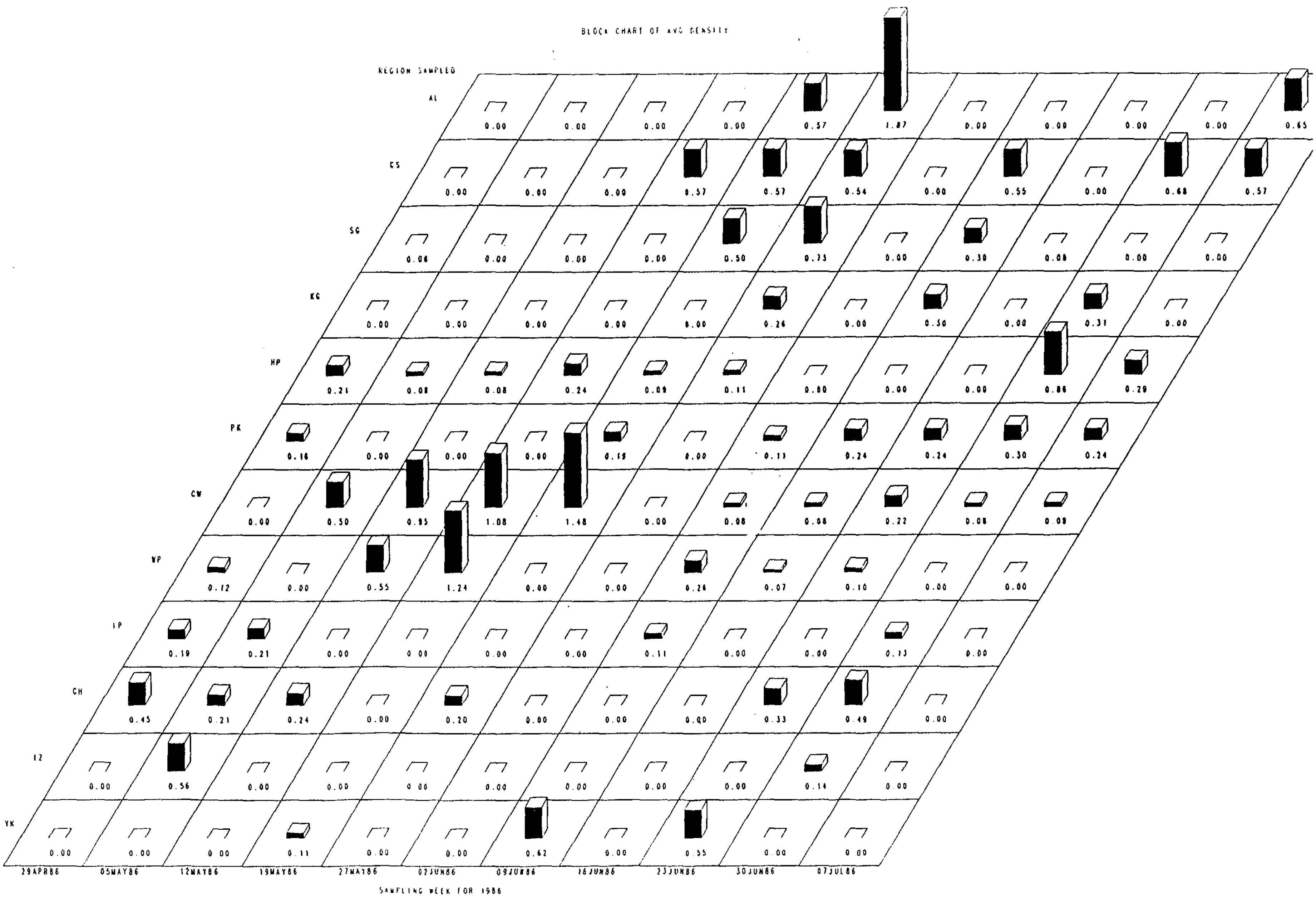


FIGURE 4-161

1986 FALL SHOALS SURVEY

DENSITY OF YROL FOR WHITE CATFISH

BLOCK CHART OF AVG DENSITY

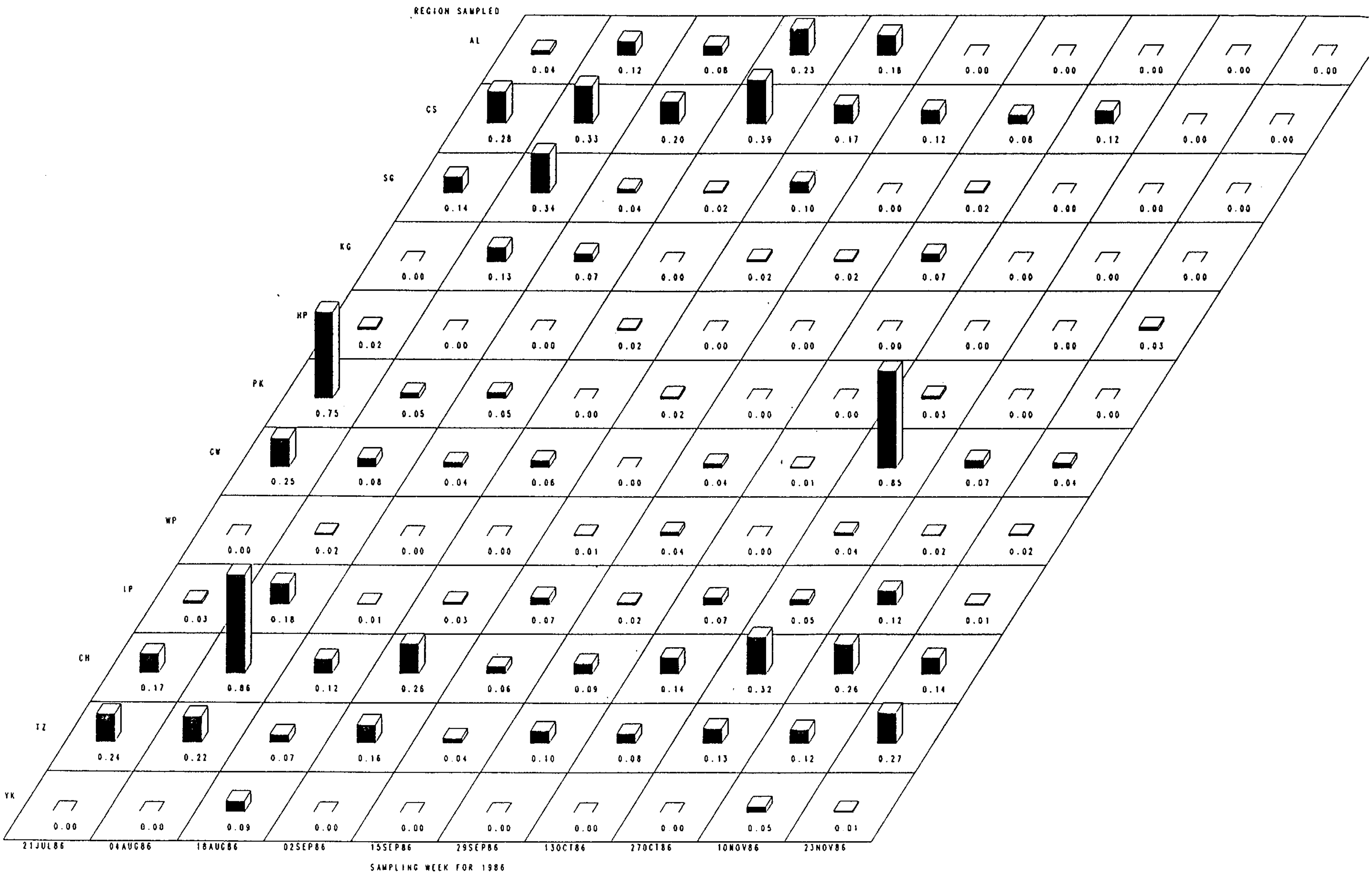


FIGURE 4-162

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR WC

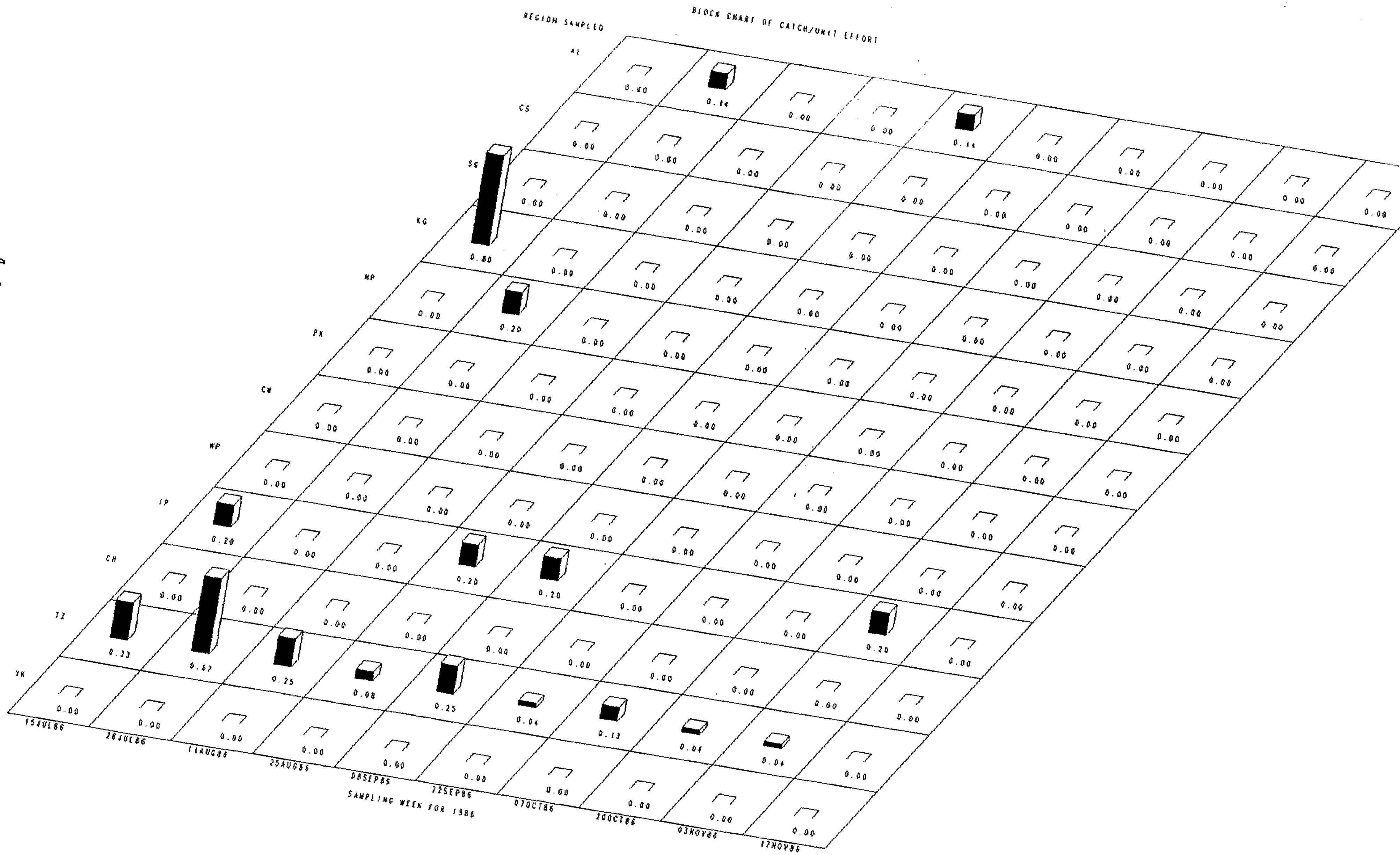


FIGURE 4–163

4.12.2 1987 Study

4.12.2.1 Young-of-Year. Juvenile white catfish were collected during the 29 June and 6 July 1987 LRS sampling weeks (Figure 4-164) and during every collection period of the FSS program (Figure 4-165). In the FSS peak occurrence took place during the initial collection week; density estimates were greater than 1/1000 m^3 from late June through September. YOY were collected primarily in the upper estuary, with greatest densities in the Catskill and Albany regions (RM 107-152). Catches were made in all regions except Yonkers and were limited to shoal and bottom strata.

4.12.2.2 Yearling and Older Fish. Yearling and older white catfish, first collected during the 1987 LRS sampling week of 20 April (Figure 4-166), remained in samples through the final FSS collection period beginning on 10 November (Figure 4-167). A temporal distribution peak occurred in early June. No spatial distribution pattern was apparent from the LRS and FSS programs; collections occurred at every region. The 1987 BSS had peak catches from the Tappan Zee through the Indian Point region; trace numbers were caught in all other regions except Yonkers, Poughkeepsie, and Kingston where no catches were made (Figure 4-168). As in 1986, consistent catches were made in the Tappan Zee region from May through November.

4.13 SPOTTAIL SHINER

Spottail shiner, Notropis hudsonius (Clinton), occurs in freshwater rivers and lakes from Canada south to Georgia on the east coast of the United States, and extends west to Iowa and Missouri (Scott and Crossman 1973). A small midwater schooling fish, the spottail shiner is omnivorous, feeding on algae, insects, small crustaceans, water mites, eggs, and small fish larvae. They are an important forage source for the many piscivorous fish found throughout their range.

1987 LONG RIVER SURVEY

DENSITY OF YOY FOR WHITE CATFISH

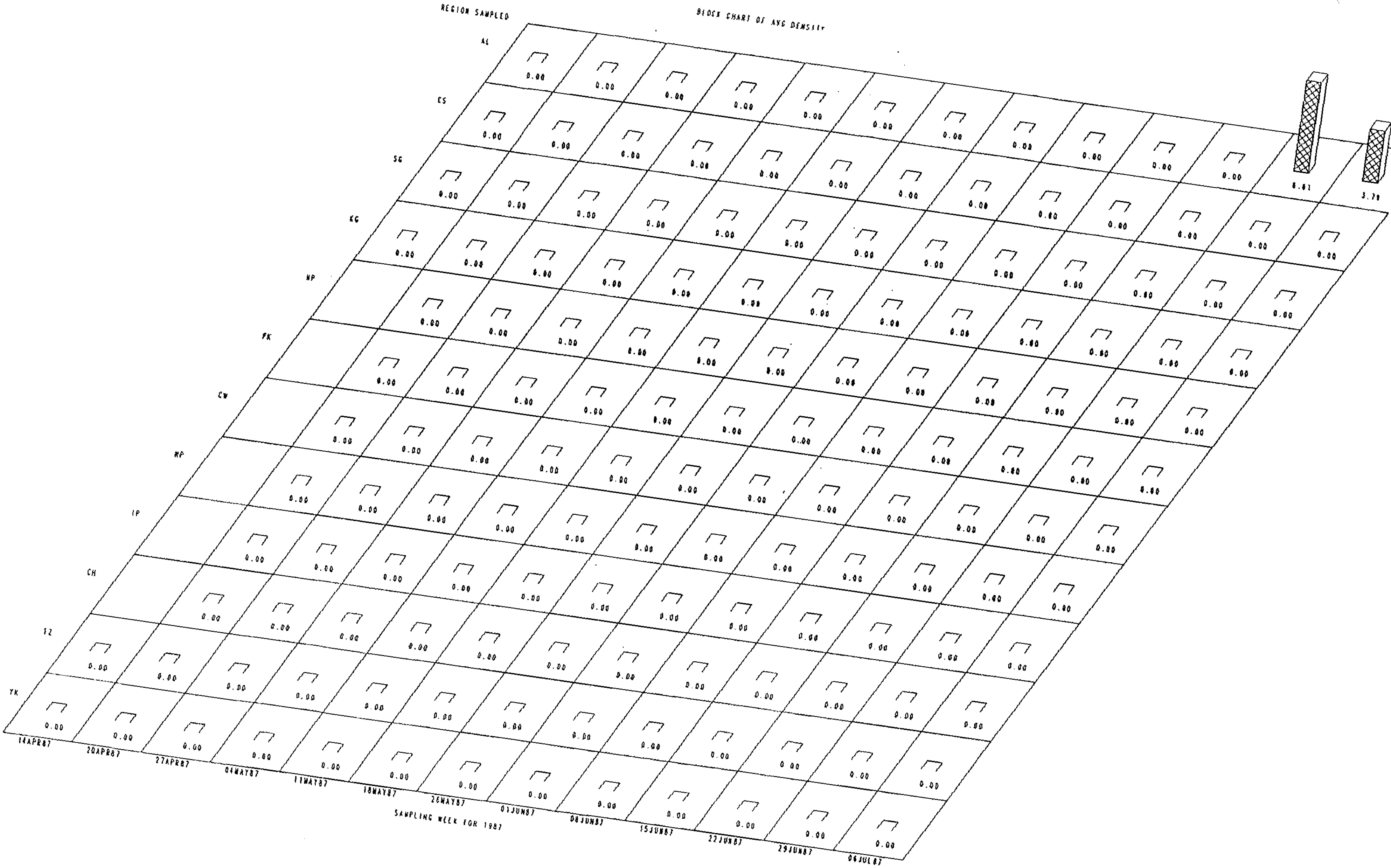


FIGURE 4–164

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR WHITE CATFISH

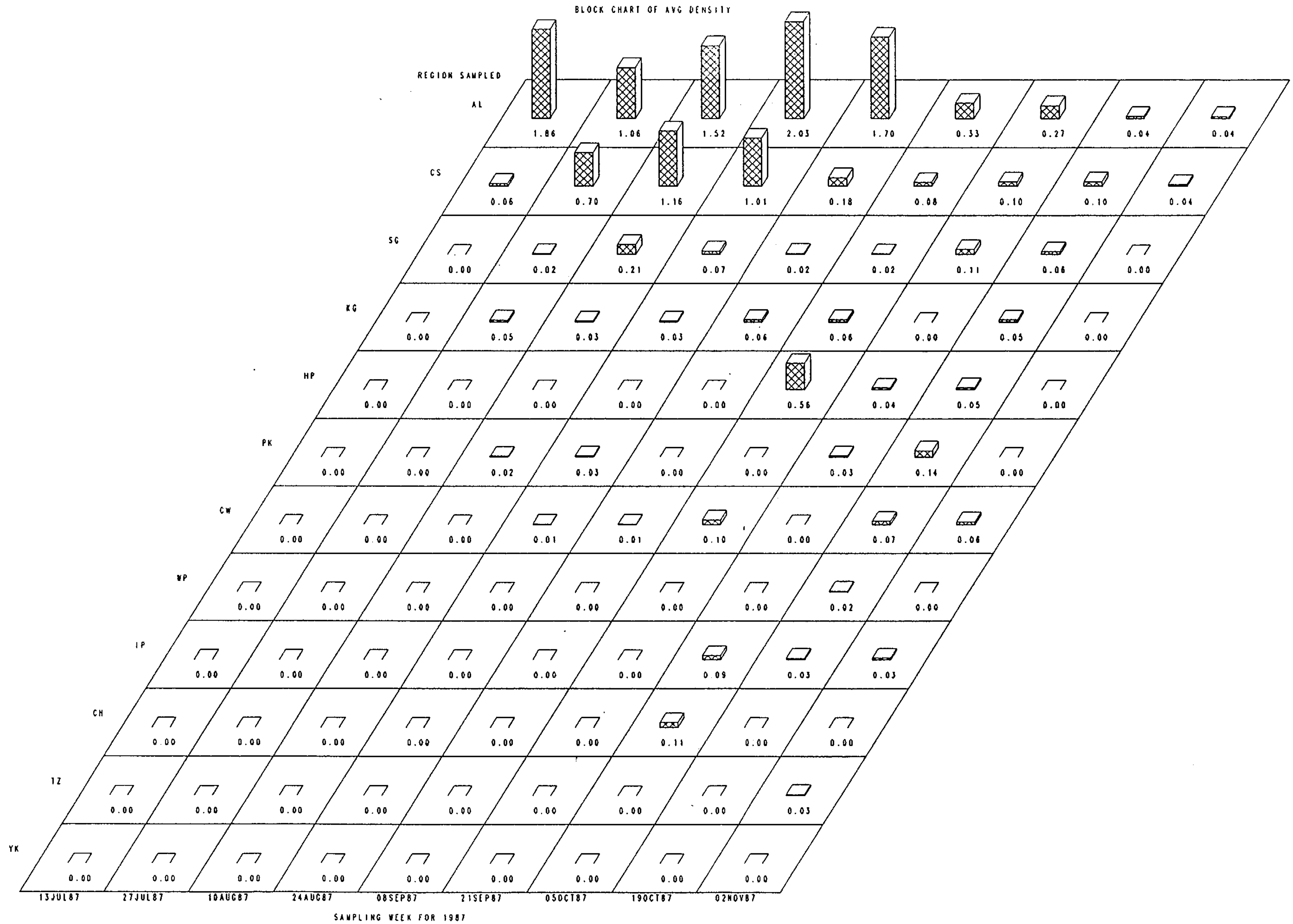


FIGURE 4-165

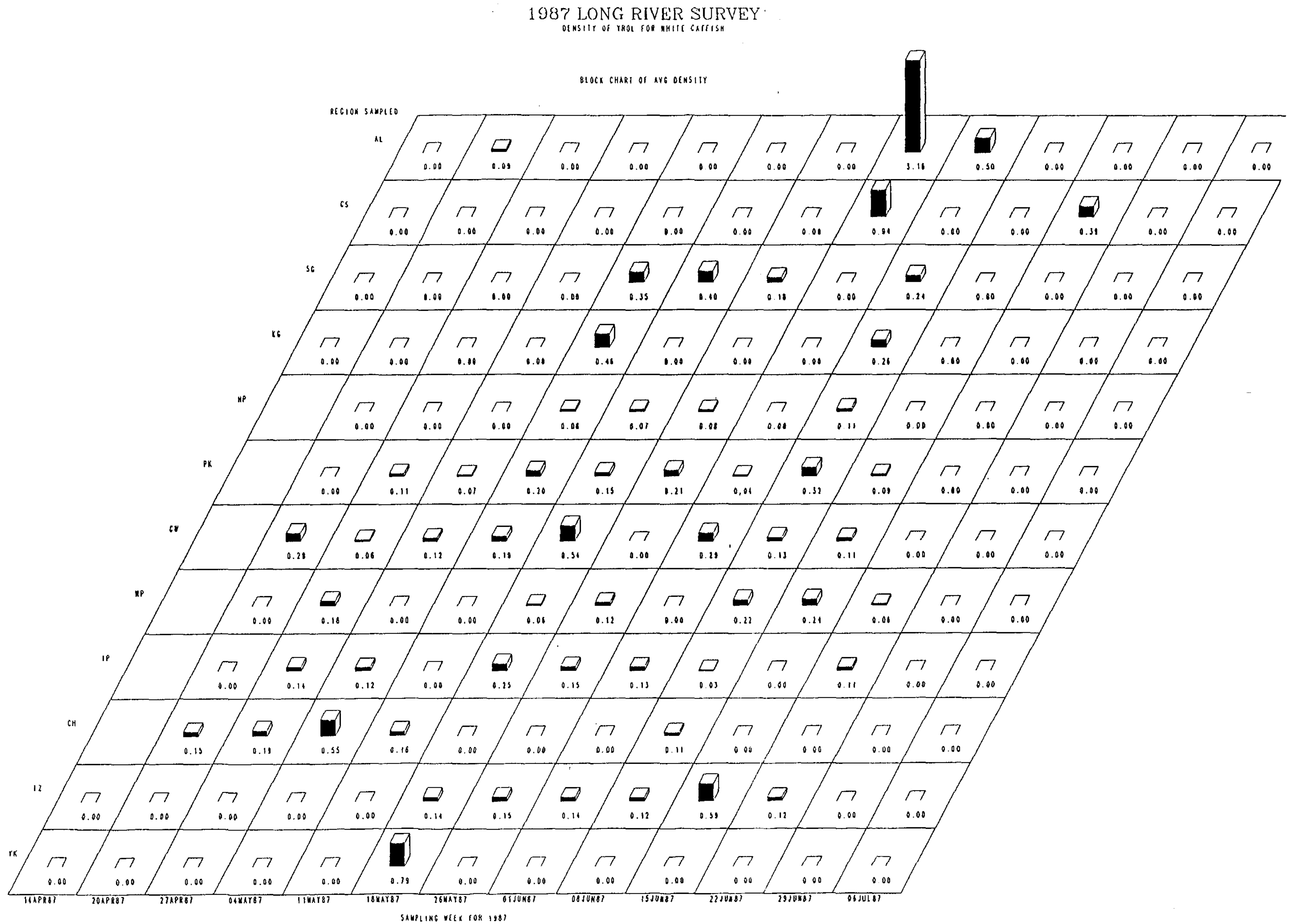

1987 LONG RIVER SURVEY
DENSITY OF YROL FOR WHITE CATFISH
BLOCK CHART OF AVG DENSITY
REGION SAMPLED
AL
CS
SG
KG
NP
PK
CW
WP
IP
CH
IZ
YK
14APR87
20APR87
27APR87
04MAY87
11MAY87
18MAY87
26MAY87
01JUN87
08JUN87
15JUN87
22JUN87
29JUN87
06JUL87
SAMPLING WEEK FOR 1987

FIGURE 4-166

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR WHITE CATFISH

BLOCK CHART OF AVG DENSITY

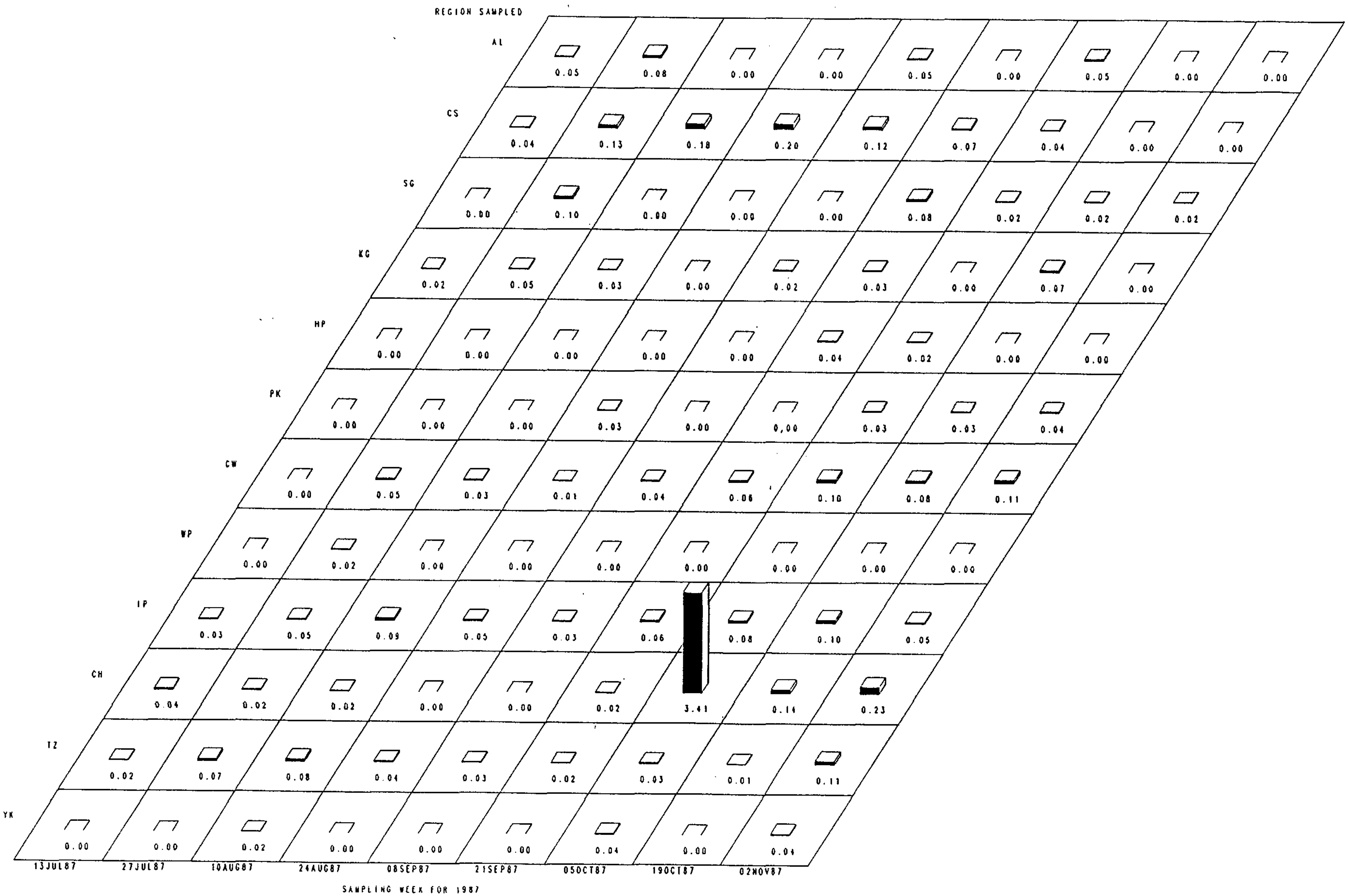


FIGURE 4-167

1987 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YBOL FOR WHITE CATFISH

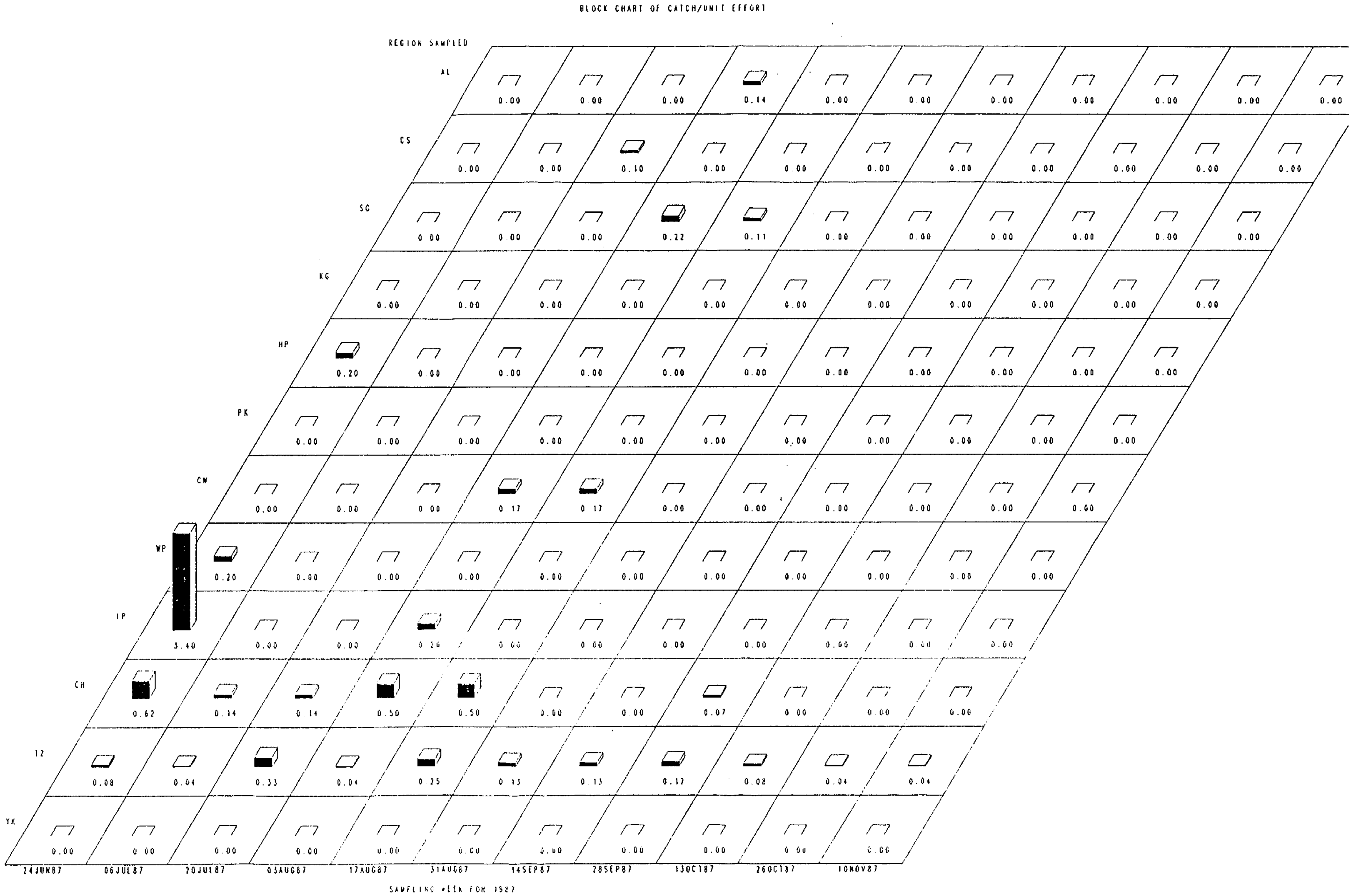


FIGURE 4-168

In the Hudson River estuary the spottail shiner is restricted to the upriver regions, preferring areas of low turbidity away from strong currents (Pflieger 1975). Adults move from the overwintering shoal and bottom strata of the middle and upper estuary to shore-zone areas of the upper estuary to spawn during June and July (Werner 1980), typically preferring habitats with sand or gravel substrates. Spawning takes place over sandy bottoms and at the mouth of tributaries where the fish assemble in large aggregations (Smith 1985a). After spawning, the adults return to offshore areas, with juveniles following in September to overwinter.

4.13.1 1986 Study

4.13.1.1 Young-of-Year. Juvenile spottail shiner were first collected in the 1986 LRS during the second week of June and then remained absent from catches until the week of 7 July (Figure 4-169). Spottail shiner YOY were found in every sampling period of the FSS and BSS programs (Figures 4-170 and 4-171), with peak abundance from mid-July through early August. Catches were recorded from the Croton-Haverstraw region to the Federal Dam at Troy, New York (RM 34-152), with greatest abundance in the middle estuary. Previous Year Class Reports have reported geographic distribution peaks to occur commonly in the upper estuary. The more southern 1986 peaks appear to coincide with above-normal freshwater flow rates in June and July (Figure 4-7).

4.13.1.2 Yearling and Older Fish. Yearling and older spottail shiner were first collected during the last week of May in the 1986 LRS program (Figure 4-172) and were present in every succeeding sample period, including all bi-weekly samples collected during the FSS and BSS (Figures 4-173 and 4-174) programs. Peak abundance occurred in early September, with monthly mean regional densities in excess of 5/1000 m^3 every month from June through November. The abundance pattern was sporadic, with no apparent density trends.

Spottail shiner were collected in every region except Yonkers. Highest regional densities were concentrated in freshwater areas north of Poughkeepsie.

1986 LONG RIVER SURVEY

DENSITY OF YOY FOR SPOTTAIL SHINER

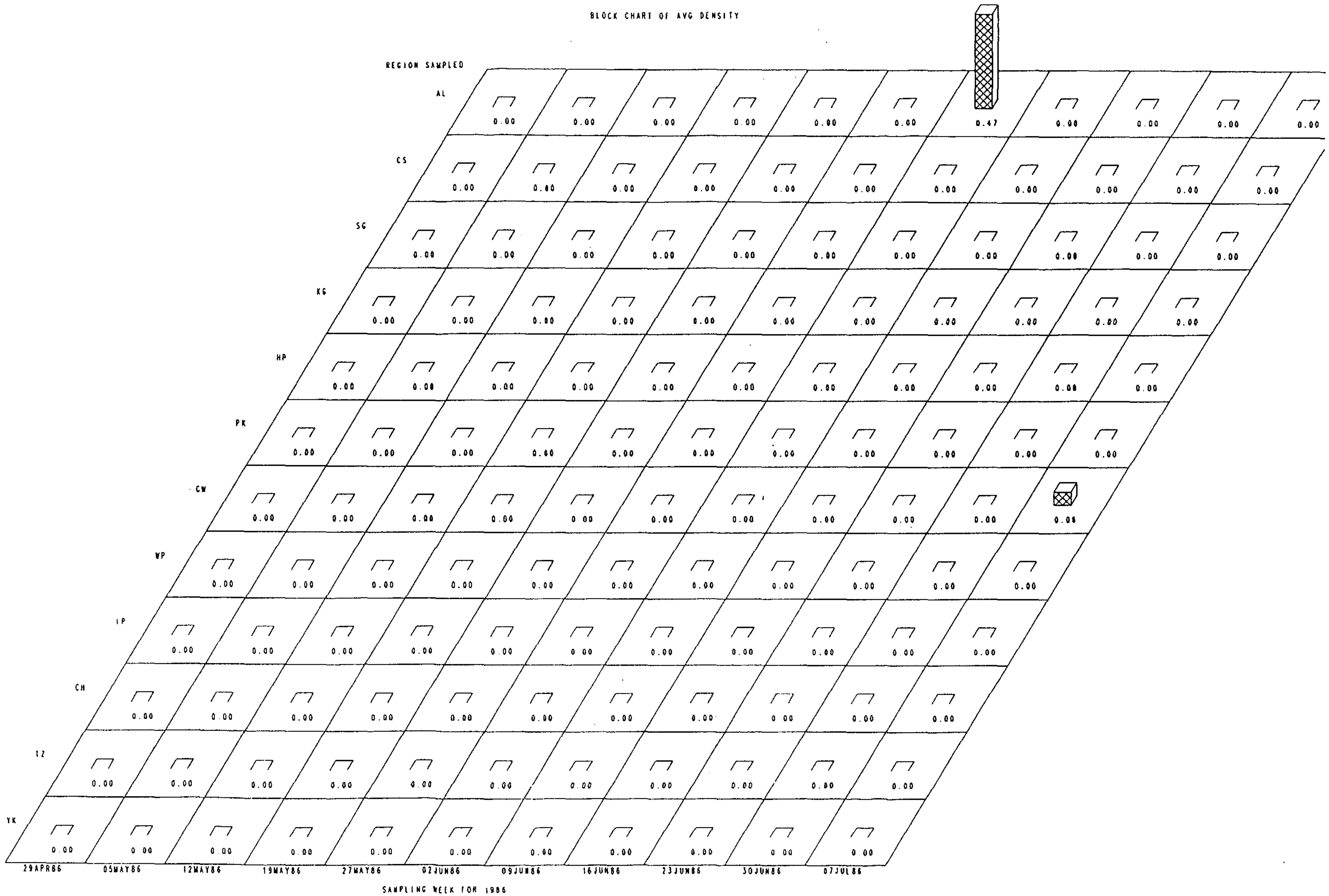


FIGURE 4-169

1986 FALL SHOALS SURVEY

DENSITY OF YOY FOR SPOTTAIL SHINER

BLOCK CHART OF AVG DENSITY

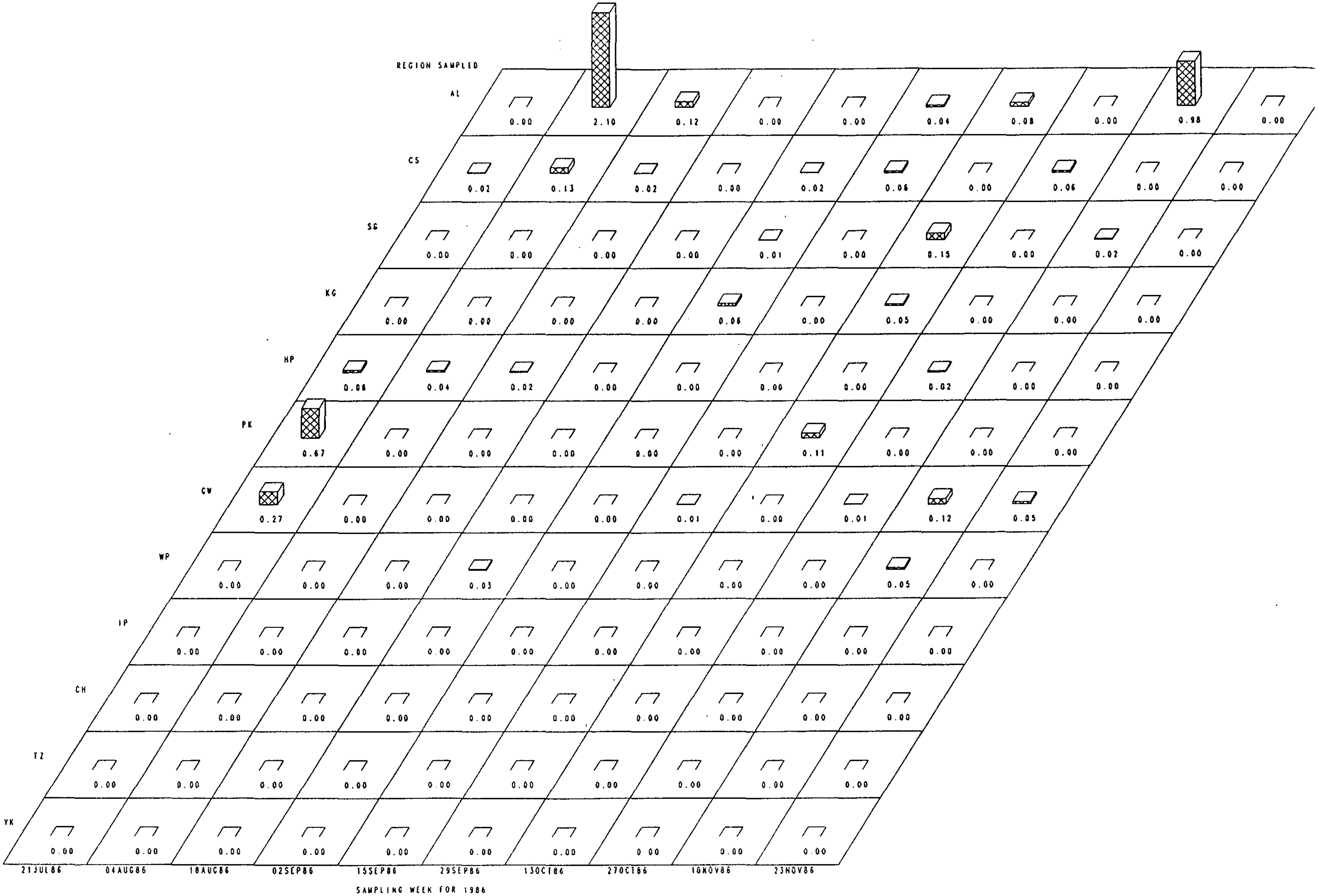


FIGURE 4-170

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YOY FOR SS

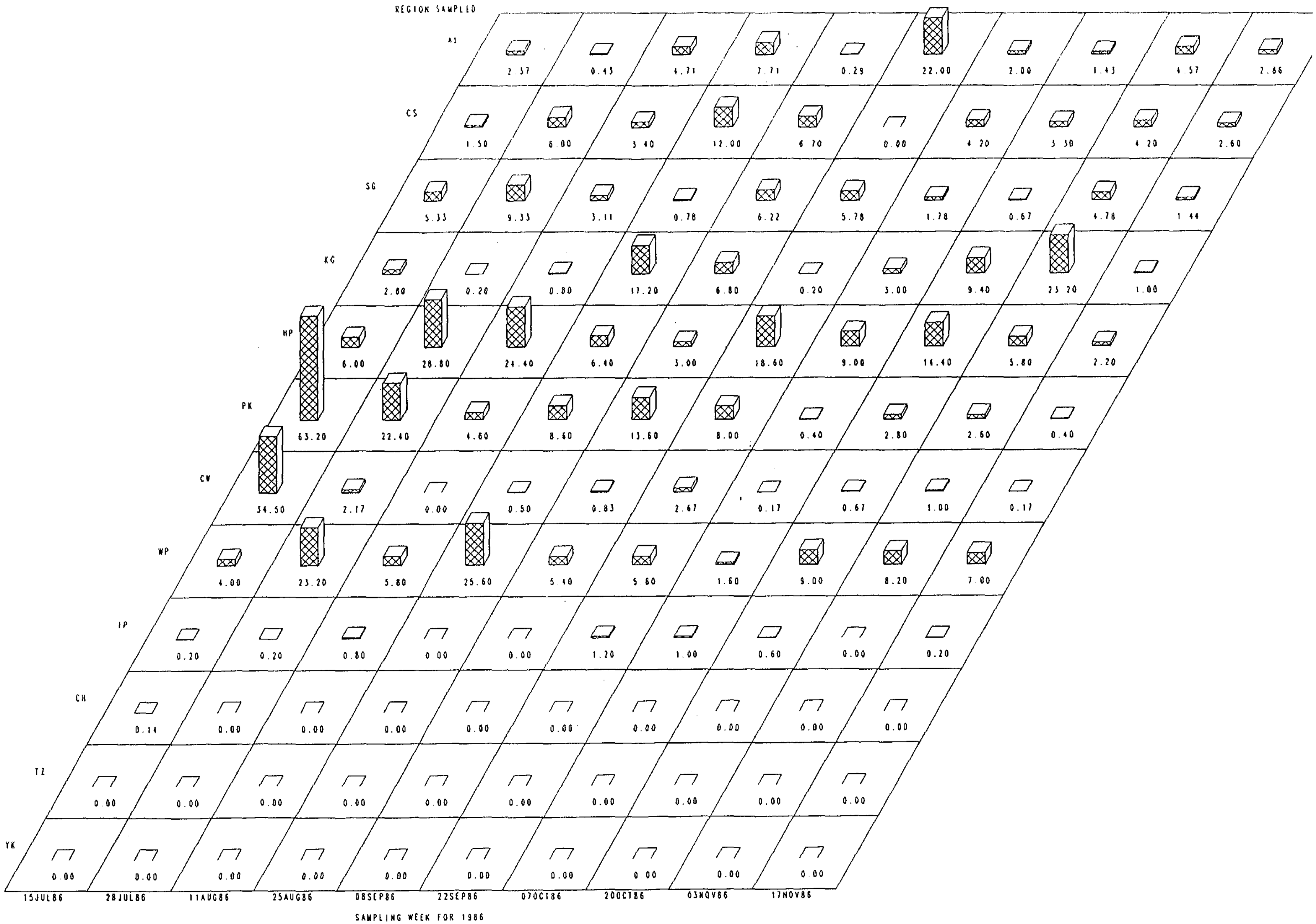


FIGURE 4-171

1986 LONG RIVER SURVEY

DENSITY OF YAOL FOR SPOTTAIL SHINER

BLOCK CHART OF AVG DENSITY

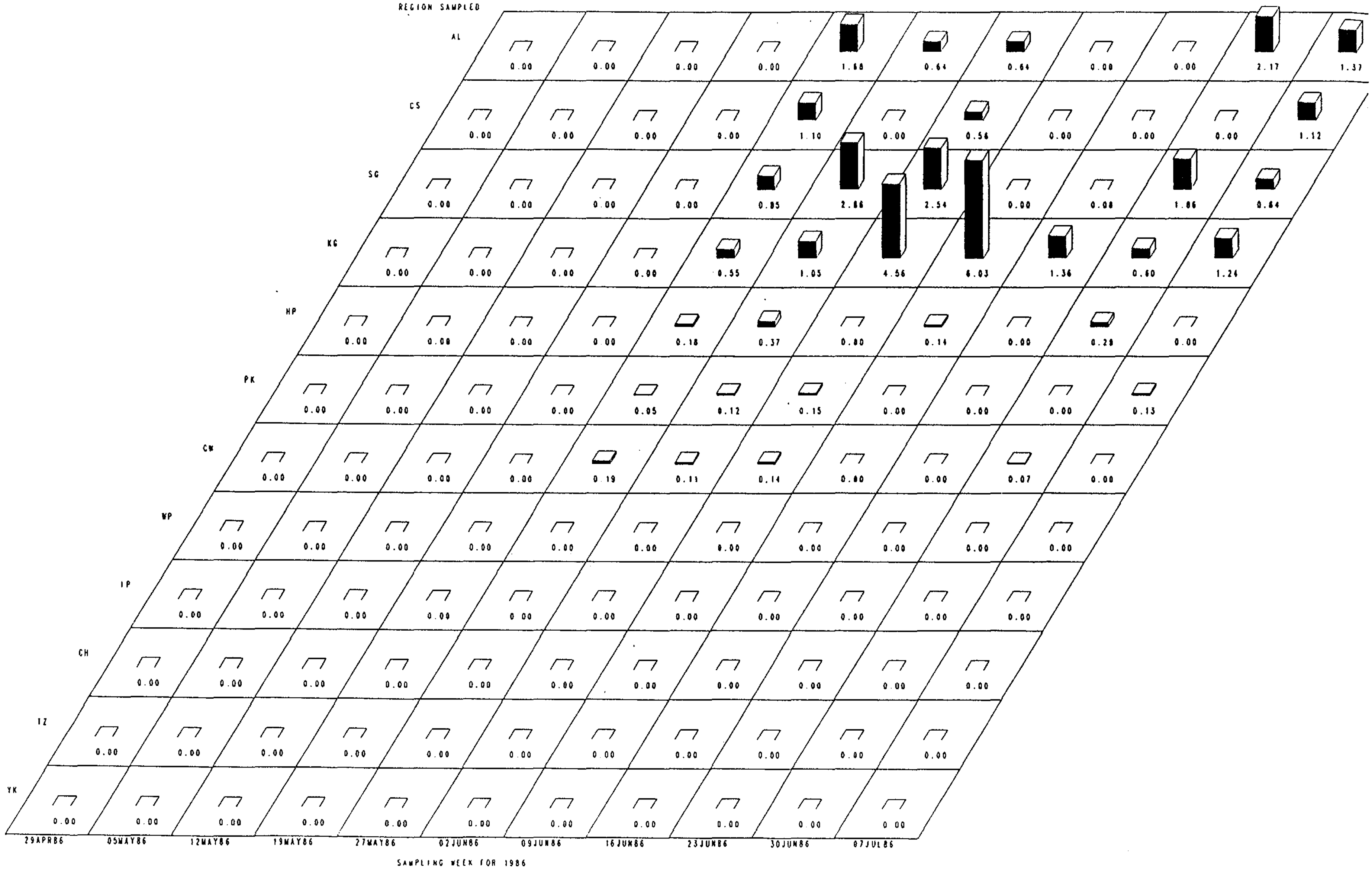


FIGURE 4-172

1986 FALL SHOALS SURVEY

DENSITY OF YRGL FOR SPOTTAIL SHINER

BLOCK CHART OF AVG DENSITY

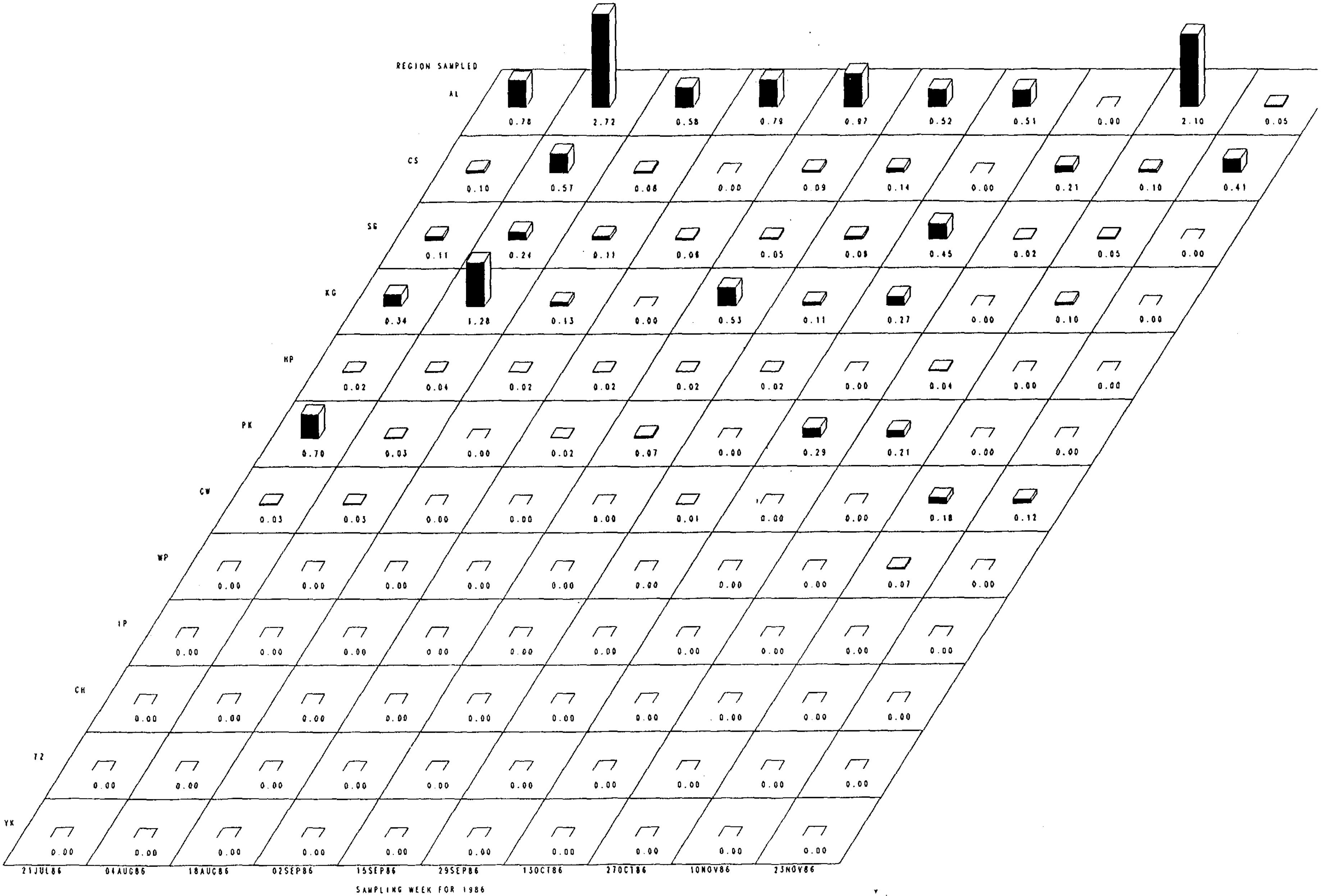


FIGURE 4-173

1986 BEACH SEINE SURVEY

CATCH/UNIT EFFORT OF YROL FOR SS

BLOCK CHART OF CATCH/UNIT EFFORT

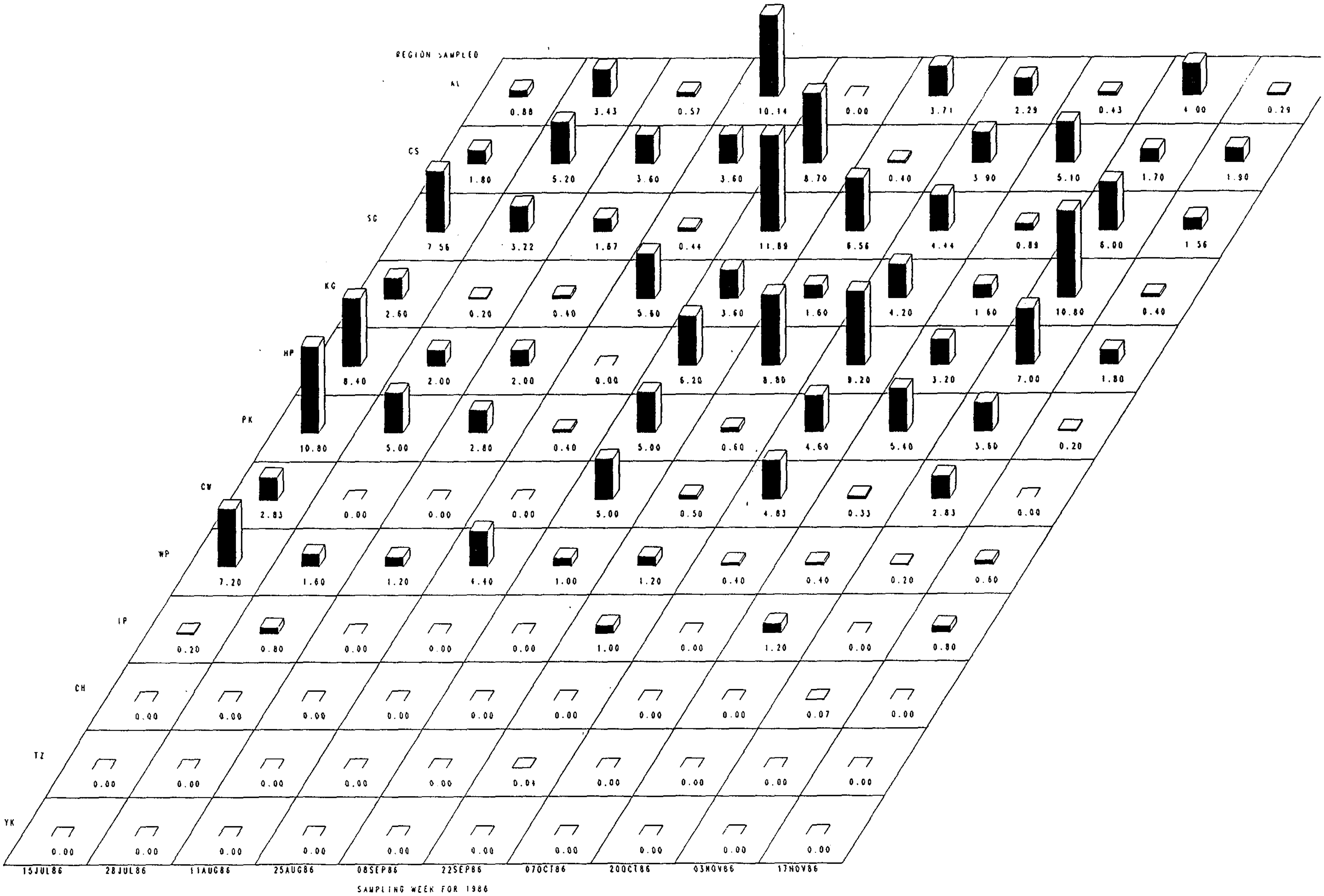


FIGURE 4-174

Peak abundance in the upper estuary during June presumably corresponds with adult spawning activity. As observed in past Year Class Reports, the upriver concentration of spottail shiners was more pronounced in the FSS than in the BSS. This is likely because of vulnerability differences between gears or a preference for the inshore areas sampled by the BSS.

4.13.2 <u>1987 Study</u>

4.13.2.1 Young-of-Year. Spottail shiner YOY were first sampled during the 1987 LRS sampling week of 29 June (Figure 4-175) and were present in every collection period throughout the FSS (Figure 4-176) and BSS (Figure 4-177) programs. Greatest BSS abundance occurred during the two-week sampling period following 17 August. Captures in the FSS catches from the Albany region were restricted to the bottom strata because channel and shoal stratum are too limited to be sampled. Shore-zone catches were extensive in all regions from Poughkeepsie to Albany (RM 62-152), with greatest densities in the Hyde Park and Albany regions. Juvenile densities over 10/1000 m^3 were present from the Poughkeepsie through Albany regions except at Saugerties. No regions south of Cornwall had density estimates of 1/1000 m^3 or greater; no spottail juveniles were captured south of Indian Point.

4.13.2.2 Yearling and Older Fish. Yearling and older spottail shiner were caught during every sampling period of the 1987 LRS (Figure 4-178), FSS (Figure 4-179) and BSS (Figure 4-180) programs except the week of 27 April. Most spottail shiners sampled during the LRS and FSS programs were captured in the bottom strata. Greatest regional densities were noted in the shore zone, with peak abundance in late September and early October. A smaller abundance peak was suggested in late June and early July from the Indian Point region through the Hyde Park region (RM 39-85). Yearling and older spottail shiners were collected in 1987 as far south as the Indian Point region in bottom strata and the Croton-Haverstraw region in the shore zone. Greatest bottom strata density (>1/1000 m^3) was in the Kingston and Albany regions. Densities in excess

1987 LONG RIVER SURVEY

DENSITY OF YOY FOR SPOTTAIL SHINER

BLOCK CHART OF AVG DENSITY

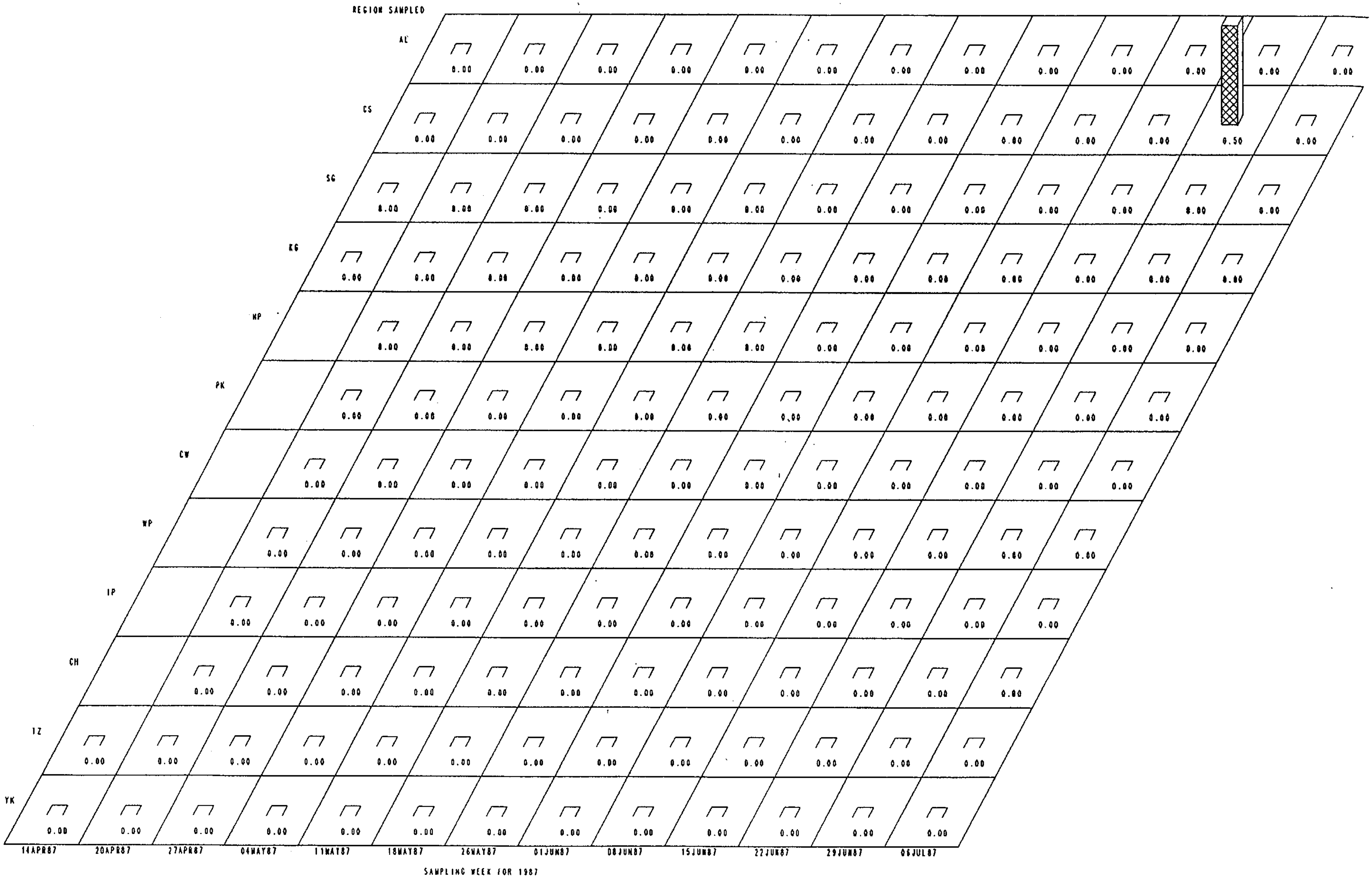


FIGURE 4-175

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR SPOTTAIL SHINER

BLOCK CHART OF AVG DENSITY

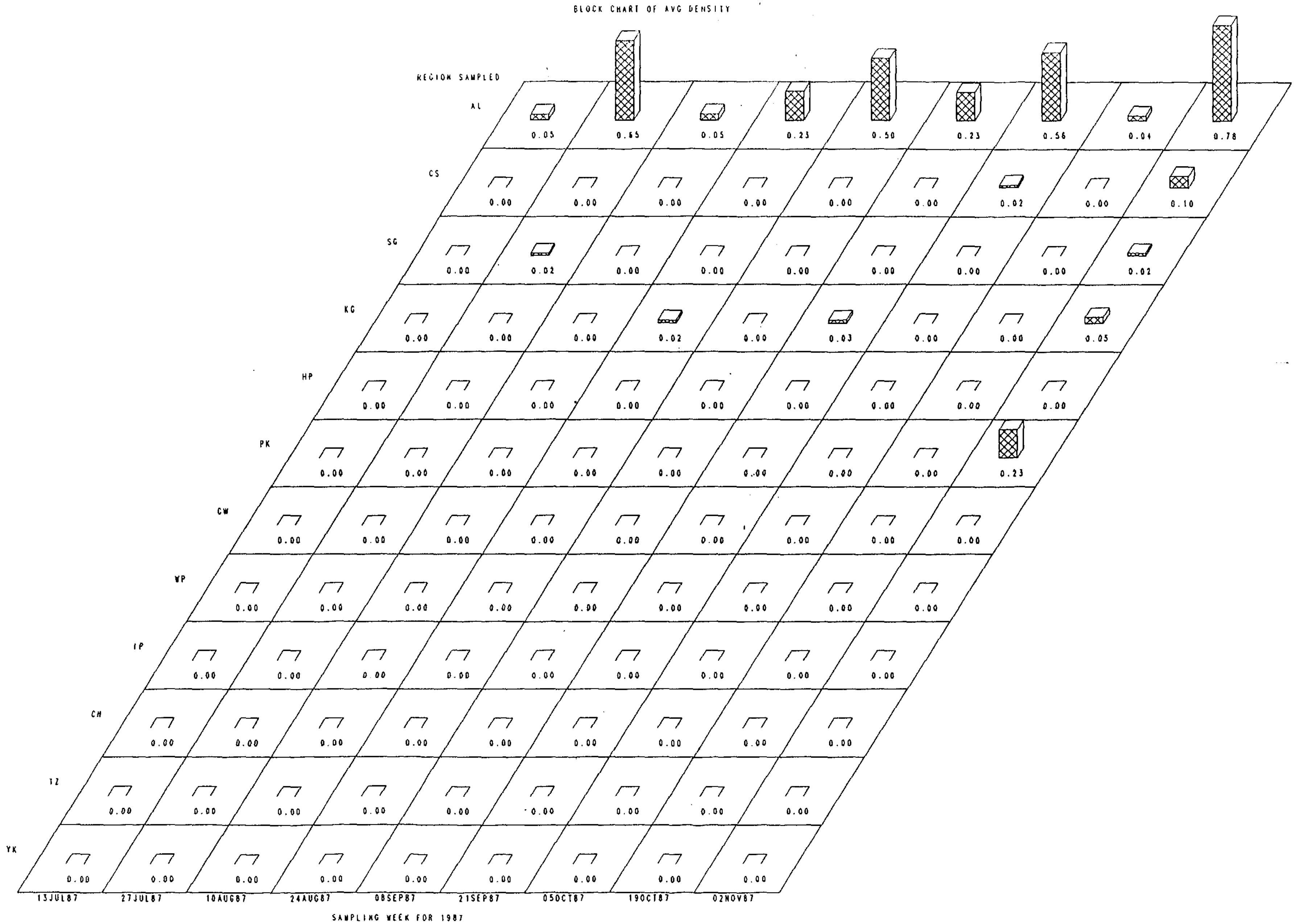


FIGURE 4-176

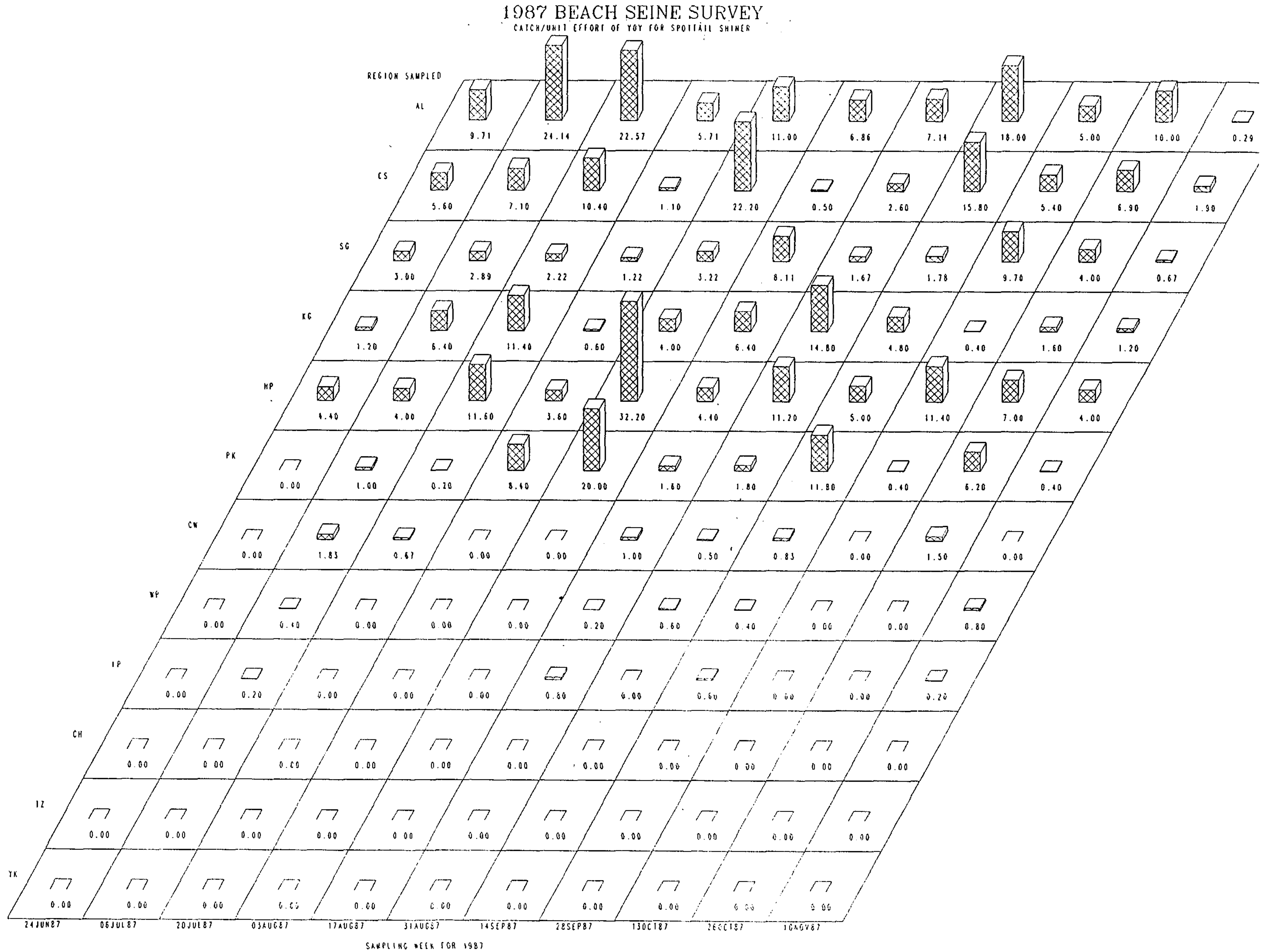

1987 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF YOY FOR SPOTTAIL SHINER
REGION SAMPLED
AL
9.71 24.14 22.57 5.71 11.00 6.86 7.14 18.00 5.00 10.00 0.29
CS
5.60 7.10 10.40 1.10 22.20 0.50 2.60 15.80 5.40 6.90 1.90
SG
3.00 2.89 2.22 1.22 3.22 8.11 1.67 1.78 9.70 4.00 0.67
KG
1.20 6.40 11.40 0.60 4.00 6.40 14.80 4.80 0.40 1.60 1.20
HP
4.40 4.00 11.60 3.60 32.20 4.40 11.20 5.00 11.40 7.00 4.00
PK
0.00 1.00 0.20 8.40 20.00 1.60 1.80 11.80 0.40 6.20 0.40
CW
0.00 1.83 0.67 0.00 0.00 1.00 0.50 0.83 0.00 1.50 0.00
WP
0.00 0.40 0.00 0.00 0.00 0.20 0.60 0.40 0.00 0.00 0.80
IP
0.00 0.20 0.00 0.00 0.00 0.80 0.00 0.60 0.00 0.00 0.20
CH
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
IZ
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
YK
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
24JUN87
06JUL87
20JUL87
03AUG87
17AUG87
31AUG87
14SEP87
28SEP87
13OCT87
26OCT87
10NOV87
SAMPLING WEEK FOR 1987

FIGURE 4-177

1987 LONG RIVER SURVEY

DENSITY OF YROL FOR SPOTTAIL SHINER

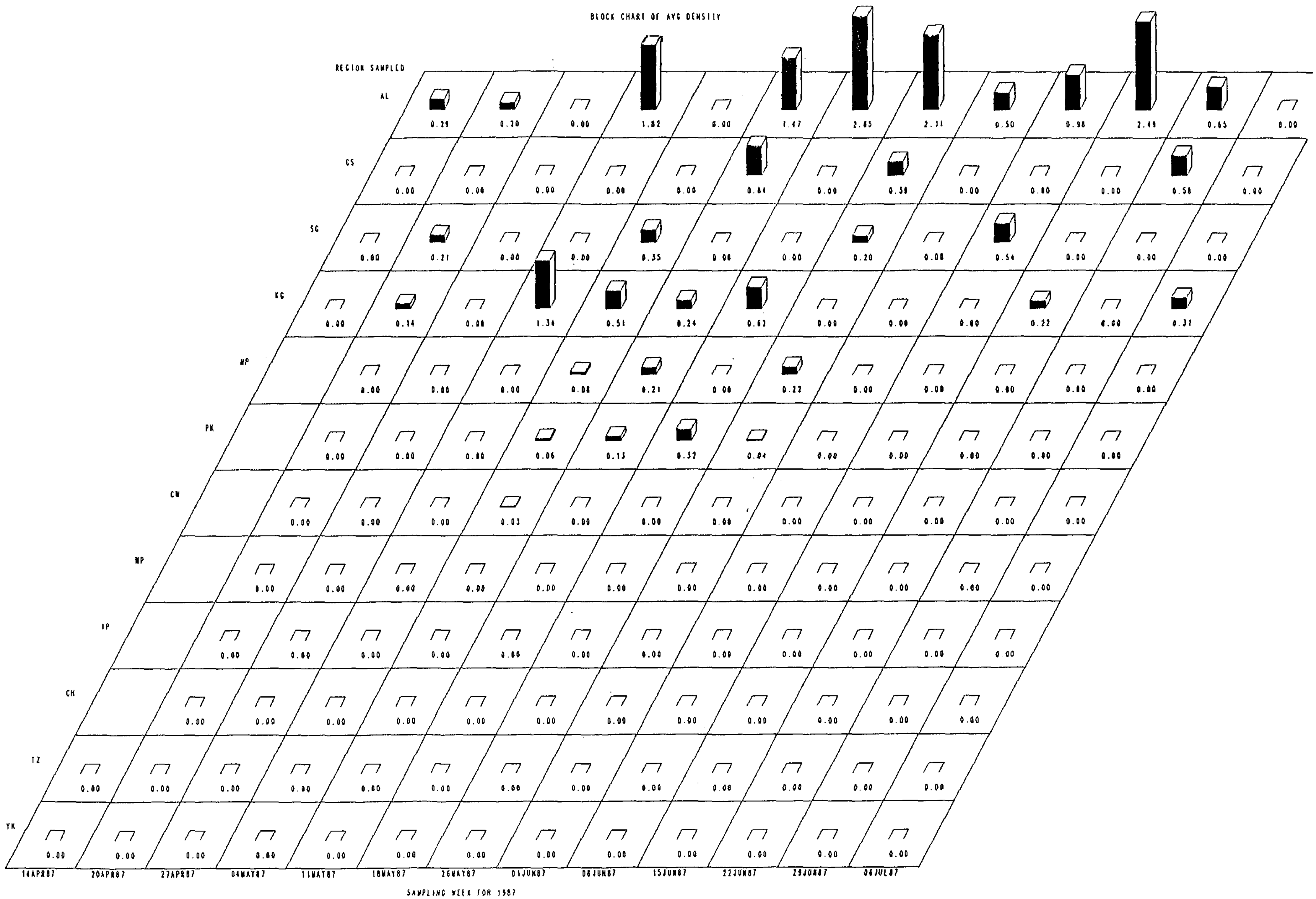


FIGURE 4-178

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR SPOTTAIL SHINER

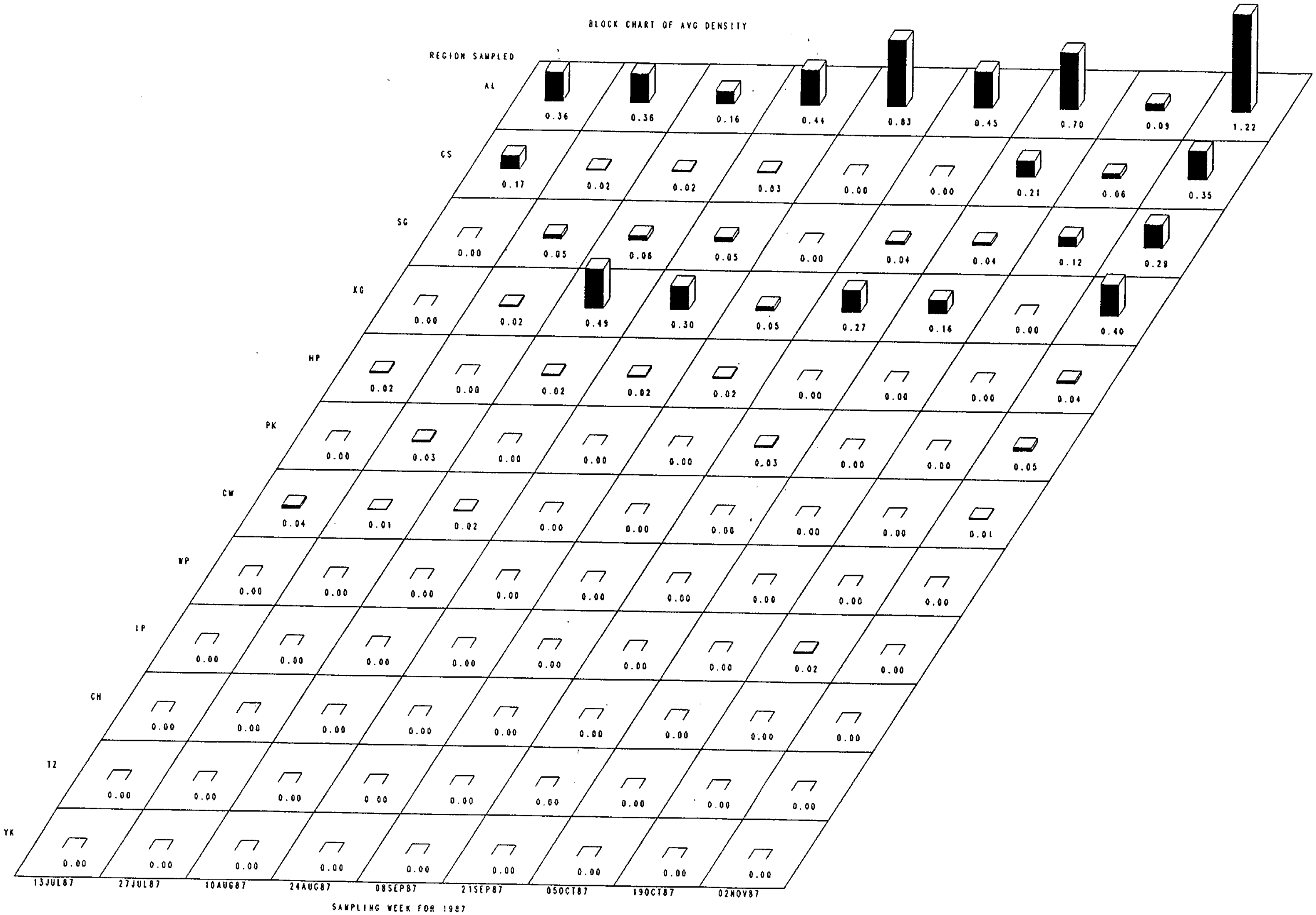


FIGURE 4-179

1987 BEACH SEINE SURVEY
CATCH/UNIT EFFORT OF TROL FOR SPOTTAIL SHINER

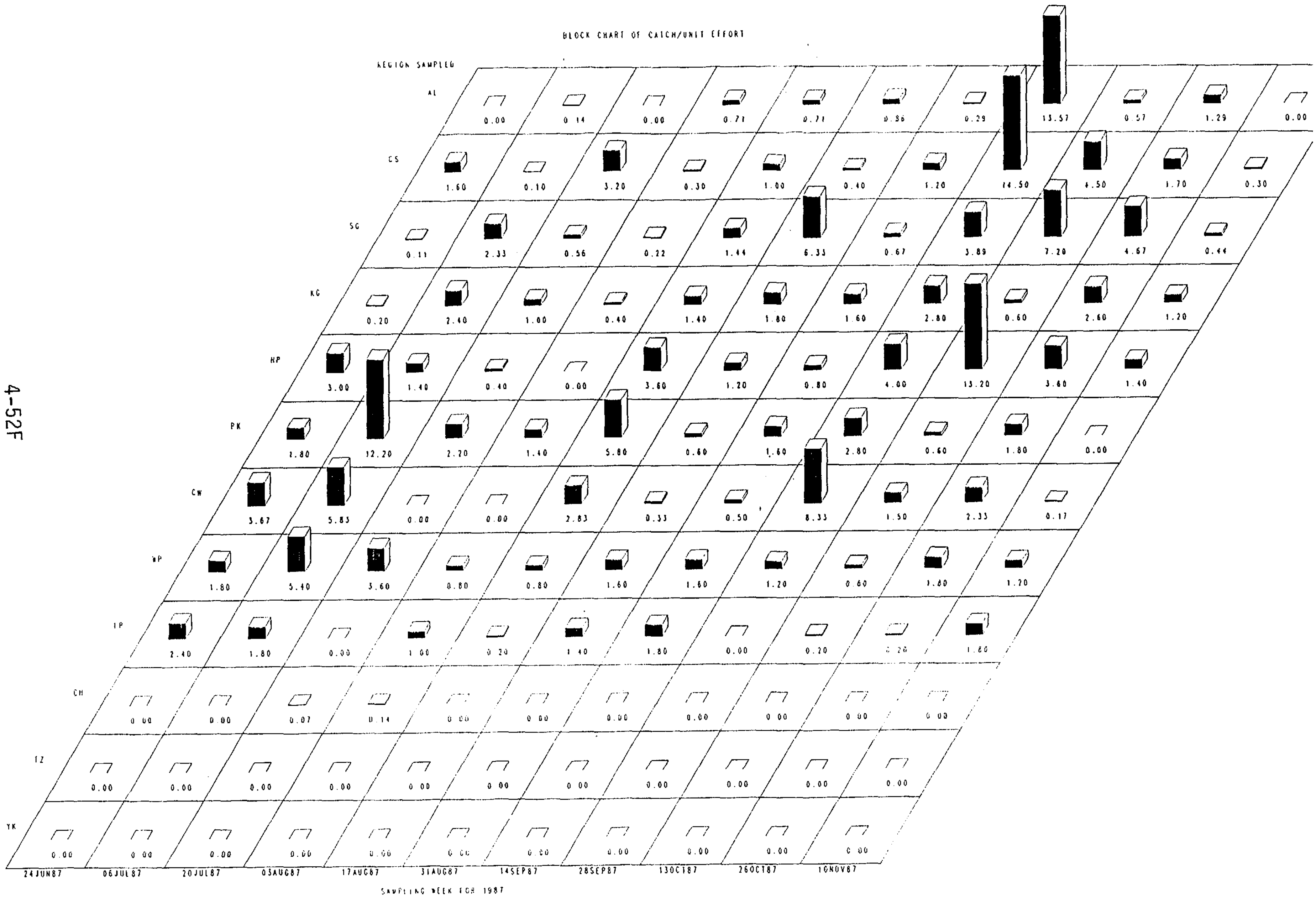


FIGURE 4-180

of 1/1000 m^3 were observed in the shore zone of all regions north of Croton-Haverstraw, with sporadic abundance peaks over 10/1000 m^3.

4.14 ATLANTIC STURGEON

The Atlantic sturgeon, Acipenser oxyrhynchus (Mitchell), is an anadromous species inhabiting estuarine and offshore waters from Labrador to eastern Florida. In the Hudson River estuary Atlantic sturgeon have been found from the Croton-Haverstraw region through the Catskill region (RM 34-1234). Adults generally reside in or near their natal estuaries, although they are occasionally collected offshore (Murawski and Pacheco 1977).

Spawning occurs in the spring in fresh water, near the salt front, when temperatures reach 13 to 18°C (Borodin 1925). Adult Atlantic sturgeon move out of the estuary following spawning; the young remain in fresh water for three to five years before migrating out of the estuary (Huff 1975). While in the estuary, juveniles are demersal, feeding on insect larvae, zooplankton, and plant material (TI 1981). In the Hudson River maturity is reached beginning at about age 20, with spawning occurring at three- to five-year intervals (Smith 1985b).

4.14.1 1986 Study

4.14.1.1 Young-of-Year. No Atlantic sturgeon YOY were collected in any of the year class studies during 1986.

4.14.1.2 Yearling and Older Fish. A total of 189 yearling and older Atlantic sturgeon were collected in 1986. Their first appearance in the 1986 sampling programs was during the last week of May in the LRS (Figure 4-181). Each run of the FSS captured from six to 30 yearling or older Atlantic sturgeon in all regions except Yonkers. Greatest abundances appeared to be from the Poughkeepsie through Saugerties regions (RM 62-106) (Figure 4-182). No consistent temporal distribution is apparent. Distribution among strata was mainly lim-

1986 LONG RIVER SURVEY

DENSITY OF YROL FOR ATLANTIC STURGEON

BLOCK CHART OF AVG DENSITY

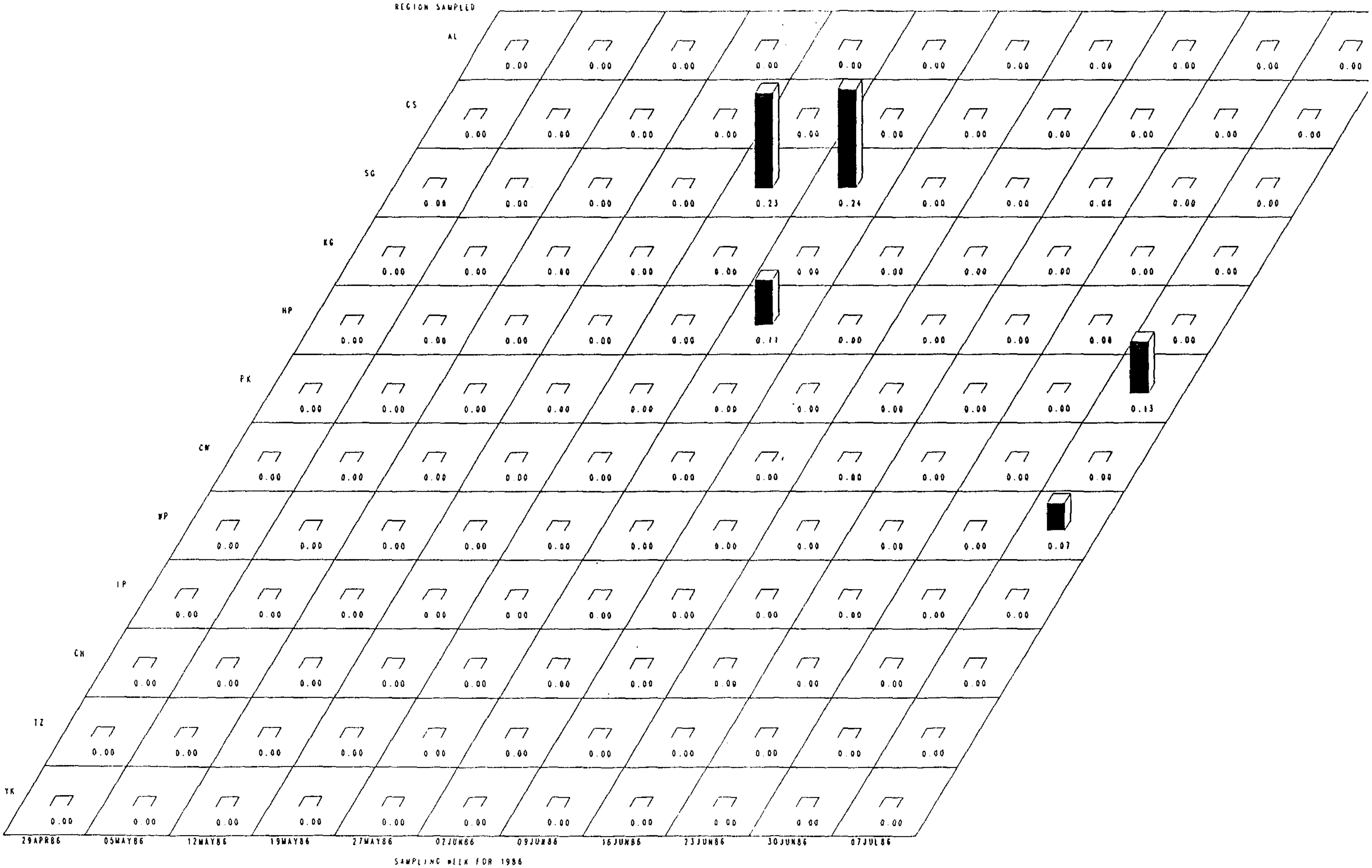


FIGURE 4-181

1986 FALL SHOALS SURVEY

DENSITY OF YROL FOR ATLANTIC STURGEON

BLOCK CHART OF AVG DENSITY

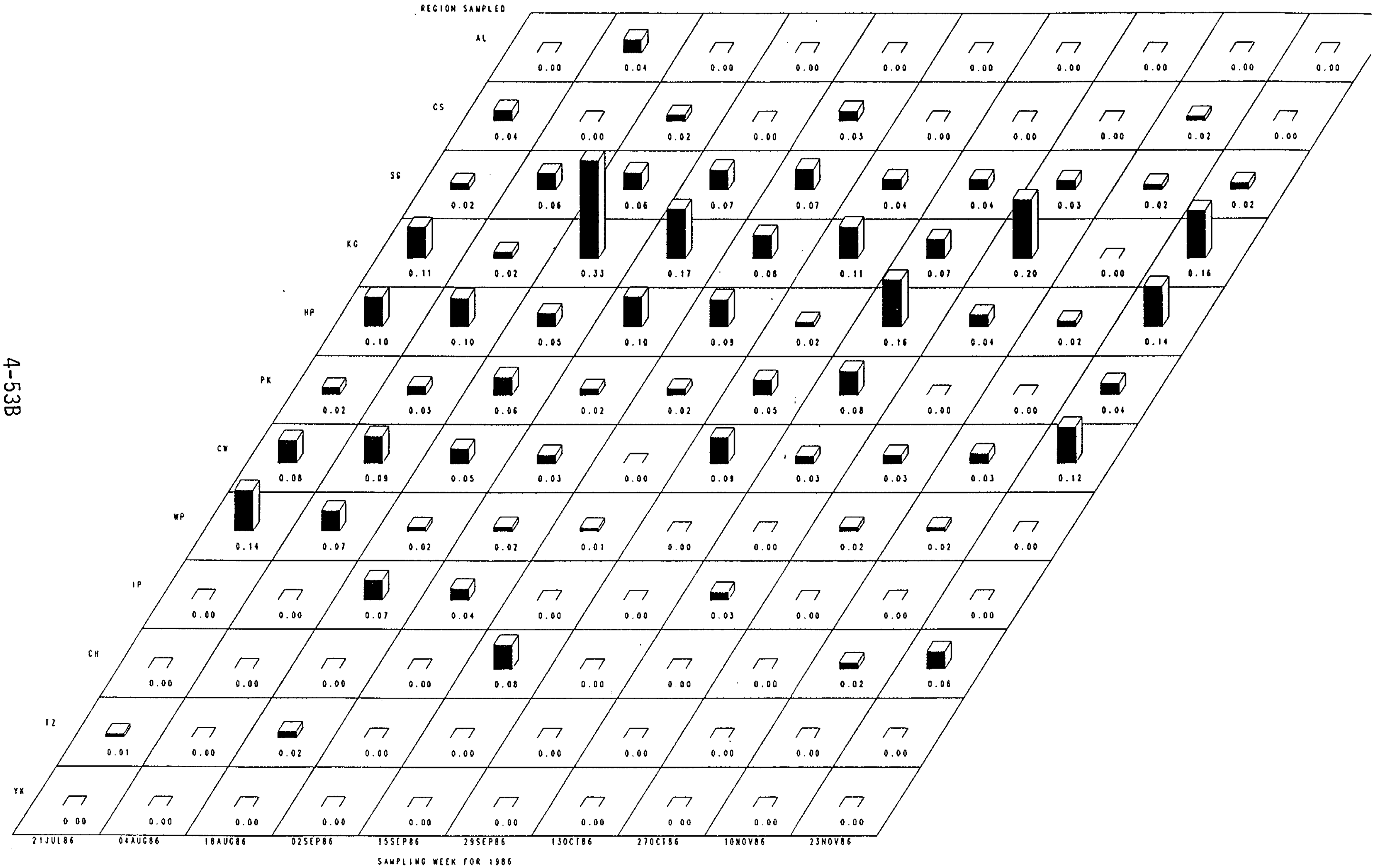


FIGURE 4-182

ited to bottom strata: three Atlantic sturgeon were captured in the shoals and none in the channel strata. No Atlantic sturgeon were collected in any of the BSS samples.

4.14.2 1987 Study

4.14.2.1 Young-of-Year. One YOY was collected during the 1987 FSS from the Saugerties region on 3 November (Figure 4-183). Prior to this no juveniles had been collected from any sampling programs since 1980, when 37 were collected.

4.14.2.2 Yearling and Older Fish. A total of 148 yearling and older Atlantic sturgeon were collected in 1987. The initial capture was during the LRS sampling week of 18 May (Figure 4-184), with catches made consistently throughout the FSS program (Figure 4-185). Greatest temporal abundance was evident from mid-August through early September. Between seven and 39 yearling and older Atlantic sturgeon were caught during each run of the FSS, with greatest estimated densities occurring from the Hyde Park through Kingston regions (RM 77-93). Yearling and older fish were sampled from every region except Yonkers and Albany. Distribution was concentrated in the bottom strata, with one Atlantic sturgeon captured in the shoals and none in the channel strata. The 1987 BSS did not collect any Atlantic sturgeon.

4.15 SHORTNOSE STURGEON

The shortnose sturgeon, *Acipenser brevirostrum*, is an anadromous species listed as endangered by the Endangered Species Act of 1973. These fish inhabit estuaries and nearshore waters from Canada to Florida, and tend to remain within estuaries for most of their lives. They have been reported to move up to 20 km/day within an estuary (McCleave et al. 1977; Buckley and Kynard 1985). In the Hudson River estuary shortnose sturgeon are thought to overwinter in the middle estuary, moving upriver to spawn.

1987 FALL SHOALS SURVEY

DENSITY OF YOY FOR ATLANTIC STURGEON

BLOCK CHART OF AVG DENSITY

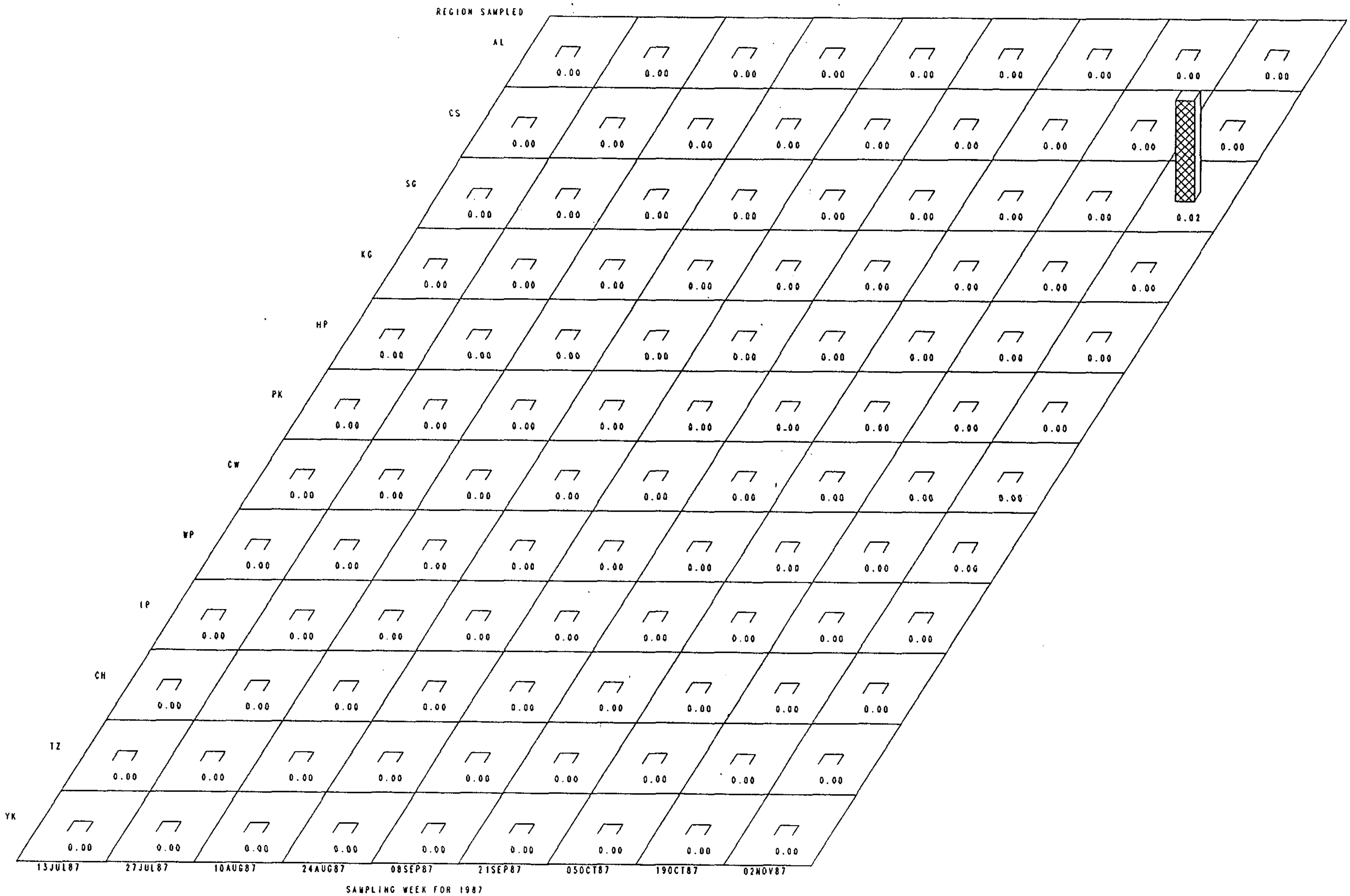


FIGURE 4-183

1987 LONG RIVER SURVEY

DENSITY OF TROL FOR ATLANTIC STURGEON

BLOCK CHART OF AVG DENSITY

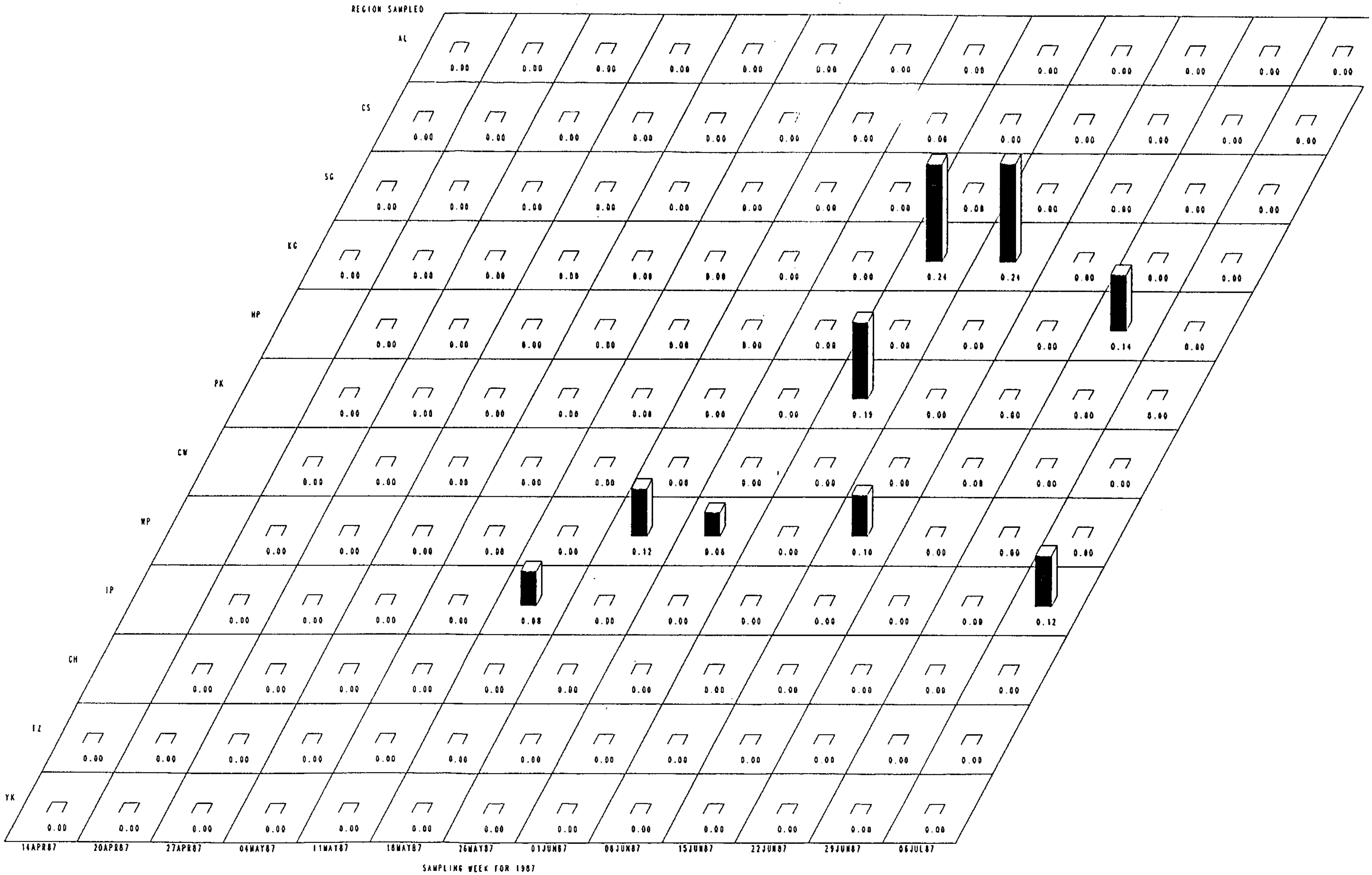


FIGURE 4-184

1987 FALL SHOALS SURVEY

DENSITY OF YROL FOR ATLANTIC STURGEON

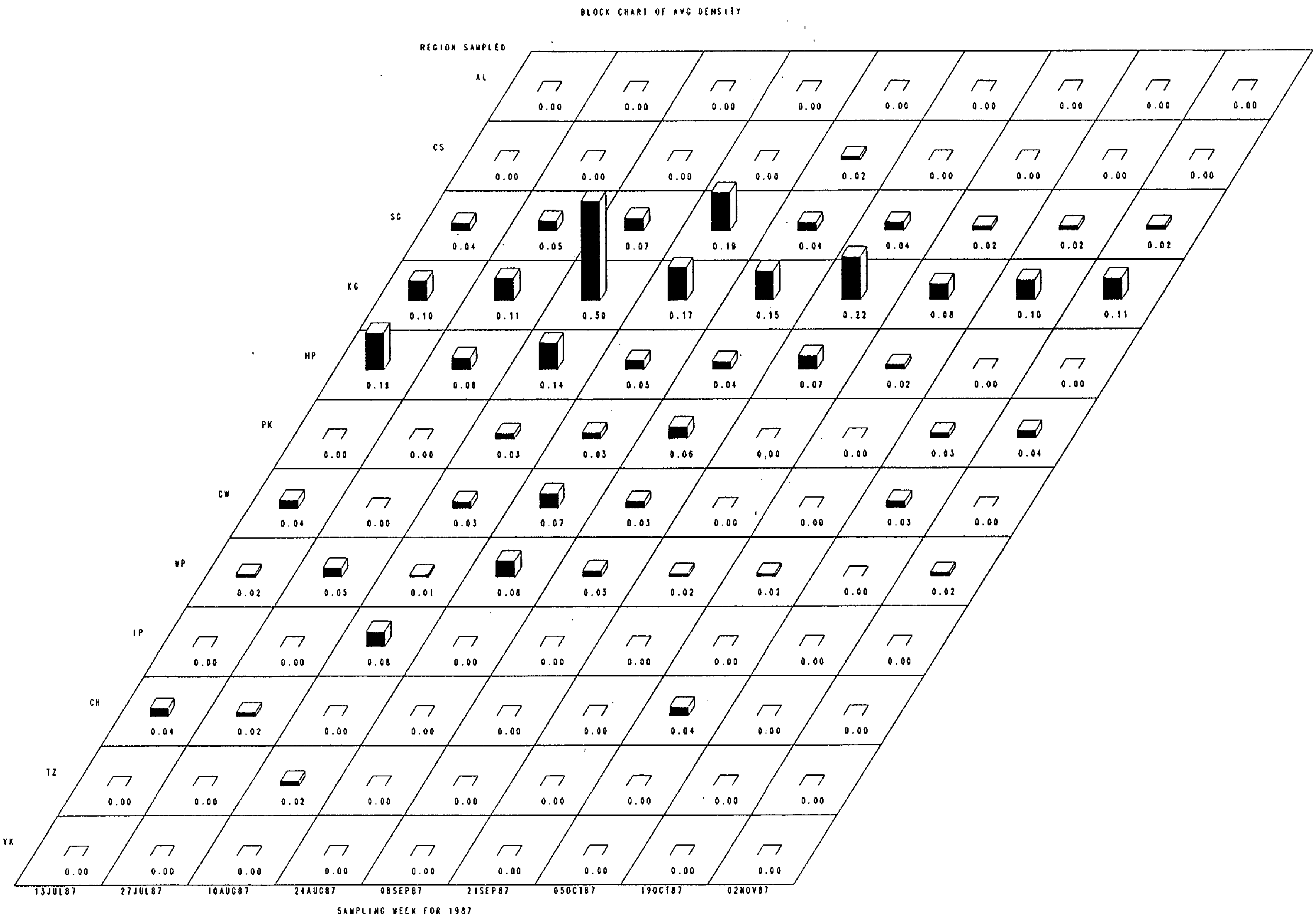


FIGURE 4-185

Spawning occurs in the uppermost areas of the estuary in late April and early May when water temperatures range from 6 to 17°C (TI 1981). Adult shortnose sturgeon spawn periodically, with the first spawn occurring at age 8 to 17 years and as many as 20 years between spawns (Taubert 1980).

4.15.1 1986 Study

4.15.1.1 Young-of-Year. No YOY or earlier life stages of shortnose sturgeon were collected in any of the 1986 sampling programs. Since larval stages have only recently been described (Taubert and Dadswell 1980; Bath et al. 1981), abundance and distribution figures in the Hudson River are not clearly known. No larvae have been captured since early June 1984 when only two PYSL were collected.

4.15.1.2 Yearling and Older Fish. Only 10 shortnose sturgeon were captured during 1986 (Table 4-4); all were yearling or older, with two collected during the LRS (Figure 4-186) and the remaining eight caught during the FSS (Figure 4-187). Six were caught in bottom strata where salinities were less than 1 ppt (RM 55-123) and four were caught in shoal strata where salinities were greater than 5 ppt (RM 29 and 32). The low number of yearling or older fish caught does not warrant discussion of geographic or temporal distribution trends.

4.15.2 1987 Study

4.15.2.1 Young-of-Year. No YOY or earlier life stages of shortnose sturgeon were collected in any of the 1987 sampling programs.

4.15.2.2 Yearling and Older Fish. Eleven shortnose sturgeon were captured during the 1987 FSS program; all were yearling and older (Table 4-5). One was caught in the shoals strata, with the remainder sampled from the bottom strata. Spatial distribution was sporadic: six were captured in the Kingston through Saugerties regions, two in the Poughkeepsie region, two in the Tappan

TABLE 4-4

COLLECTIONS OF SHORTNOSE STURGEON DURING THE 1986 YEAR CLASS STUDIES

DATE	SURVEY	REGION	STRATA	NUMBER COLLECTED
30 Apr	LRS	Catskill	Bottom	1
4 Jun	LRS	Saugerties	Bottom	1
23 Jul	FSS	Tappan Zee	Shoal	1
25 Jul	FSS	West Point	Bottom	1
7 Aug	FSS	Cornwall	Bottom	1
20 Aug	FSS	Kingston	Bottom	1
21 Aug	FSS	Hyde Park	Bottom	1
4 Sep	FSS	Kingston	Bottom	1
30 Sep	FSS	Catskill	Bottom	1
15 Oct	FSS	Tappan Zee	Shoal	1

1986 LONG RIVER SURVEY
DENSITY OF YROL FOR SHORTNOSE STURGEON

BLOCK CHART OF AVG DENSITY

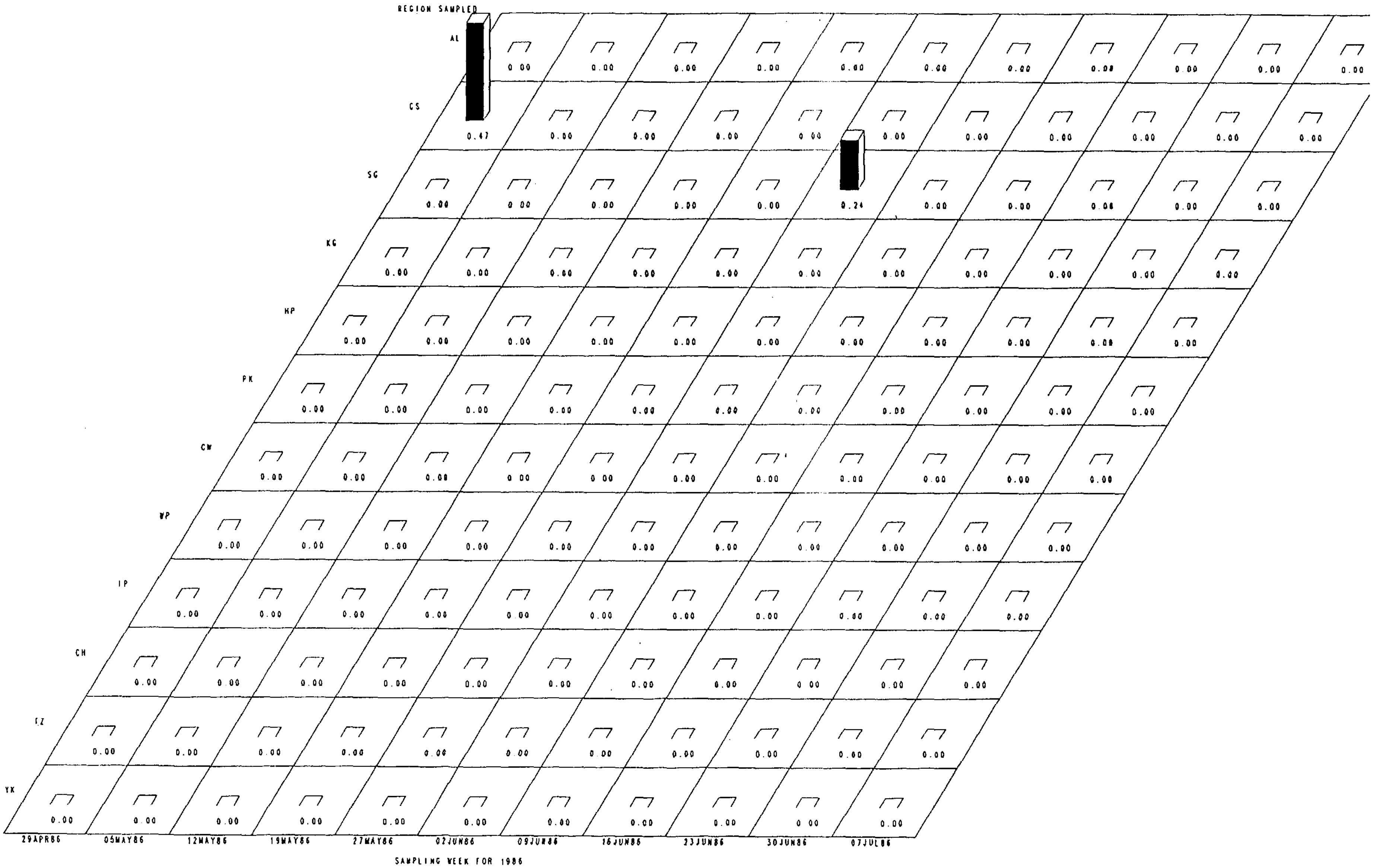


FIGURE 4-186

1986 FALL SHOALS SURVEY

DENSITY OF YROL FOR SHORTNOSE STURGEON

BLOCK CHART OF AVG DENSITY

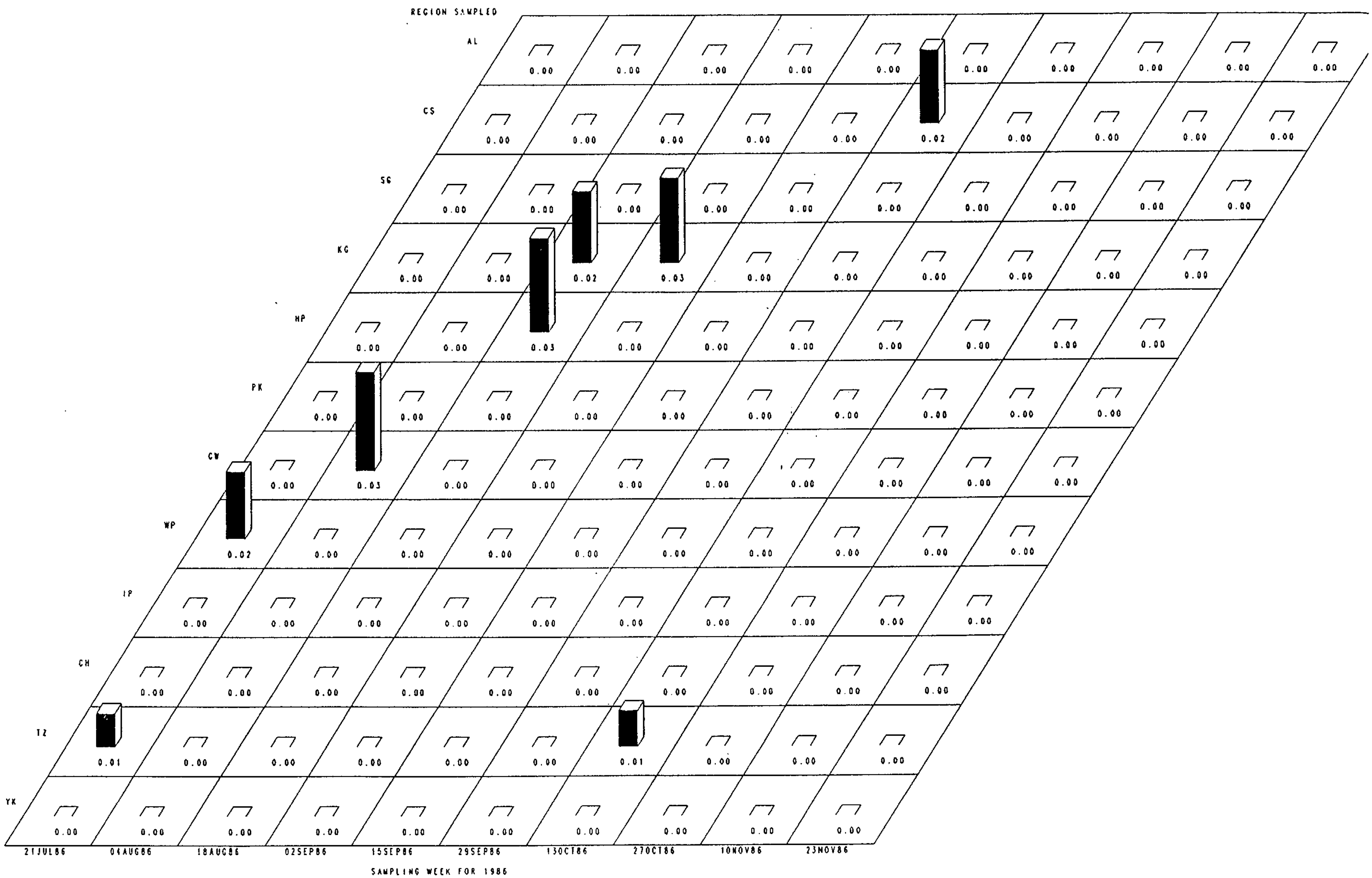


FIGURE 4-187

TABLE 4-5

COLLECTIONS OF SHORTNOSE STURGEON DURING THE 1987 YEAR CLASS STUDIES

DATE	SURVEY	REGION	STRATA	NUMBER COLLECTED
29 Jul	FSS	Tappan Zee	Shoal	2
30 Jul	FSS	Poughkeepsie	Bottom	2
10 Sep	FSS	Kingston	Bottom	2
11 Sep	FSS	West Point	Bottom	1
23 Sep	FSS	Kingston	Bottom	2
23 Sep	FSS	Saugerties	Bottom	1
3 Nov	FSS	Saugerties	Bottom	1

Zee region, and one in the West Point region (Figure 4-188). Temporal distribution trends cannot be determined because of the low numbers sampled. No shortnose sturgeon were sampled during the LRS and BSS programs.

1987 FALL SHOALS SURVEY

DENSITY OF TROL FOR SHORTNOSE STURGEON

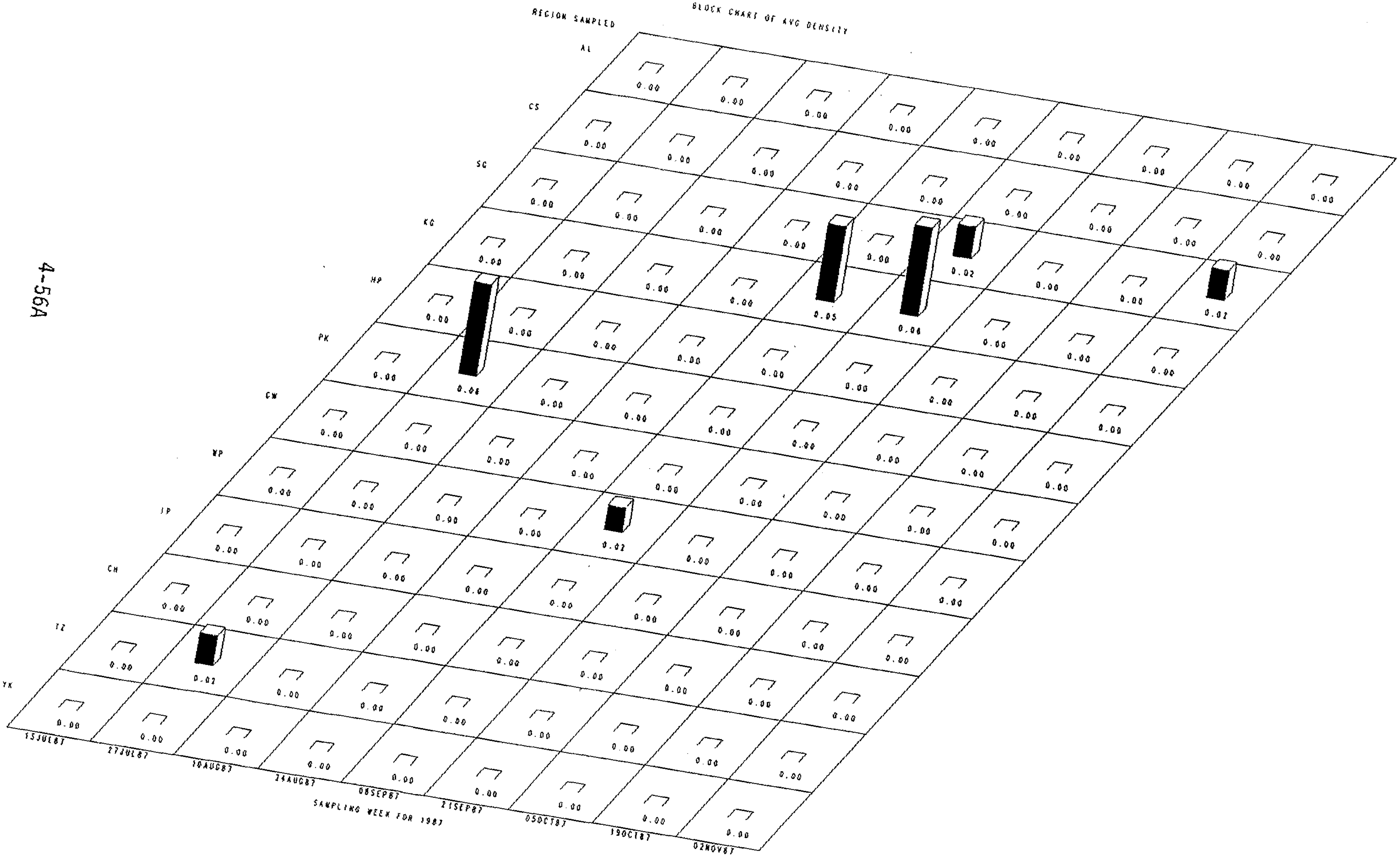


FIGURE 4-188

CHAPTER 5

SPECIAL STUDIES TO EVALUATE PREVIOUSLY UNSAMPLED AREAS OF THE HUDSON RIVER

5.1 INTRODUCTION

Since 1973, Year Class Reports describing the abundance and distribution of Hudson River fish and ichthyoplankton have been prepared for New York utilities. The data in these reports are used to estimate the year-class strength and standing crop of selected species. In 1980 a Settlement Agreement that addressed the relationship between water use for power generation on the Hudson River and protection of Hudson River fish communities was reached. The agreement stipulated plant outages and reduced flows for selected plants. An assessment program was developed to determine whether outages and reduced flows may result in beneficial effects to fish populations (MMES 1986). Several of the approaches used to evaluate the efficacy of outages require accurate estimates of riverwide abundance for selected species by life stage.

A key assumption underlying each of the estimators for abundance and standing crop is that the full geographic distribution of the target organism is sampled. Historically, this assumption has not been met because obstructions or limitations in gear have restricted sampling in some locations and prevented a few areas from being sampled at all. For the purpose of estimating fish and ichthyoplankton abundance in Year Class Reports, the density in unsampled areas has been assumed to be equivalent to that of adjacent areas.

In 1986 and 1987 a series of special studies examined fish abundance in previously unsampled areas and compared these estimates to those from adjacent areas. The overall purpose of these studies was to evaluate the adequacy of the assumption that densities in adjacent areas reasonably represent densities in historically unsampled areas.

As described in Chapter 2 (Materials and Methods), regular sampling takes place from river mile (RM) 12 to RM 152. This portion of the Hudson River is divided into 12 longitudinal regions; each is then further divided into four strata: shore zones (water depth less than 10 ft), shoals (water depth 10-20 ft), bottom (the lower 10 ft of the water column in areas with a depth of 20 ft or more), and channel (all other areas). Samples are collected from all areas where it is practical to deploy standard gear. The unsampled areas fall into three general categories:

- Type 1 - Unsampled Upriver Shoals. These are the shoal areas at the West Point, Poughkeepsie, Hyde Park, Kingston, Saugerties, Catskill, and Albany regions, which are not sampled for either juvenile fish or ichthyoplankton. Taken together, these unsampled areas account for 34.4% of the total shoal volume and about 5% of the entire river volume (Table 5-1). For each of the unsampled shoal regions the density of juveniles, eggs, and larvae is assumed to be equal to that of the bottom stratum.

- Type 2 - Unsampled Shore Zones. The shoreline along most of the Hudson River estuary is not accessible with the 100-ft beach seine for the collection of juveniles. Only limited areas of the shoreline have the proper bottom contour, freedom from submerged obstructions, and open beach area to retrieve a seine. The density of juveniles in these unsampled areas is assumed to be equal to that of adjacent sampled beaches. In all regions at least some beaches can be sampled; thus, all estimates of shore strata populations are based on calculations that include some actual samples. Historically, shore zones have also not been sampled for ichthyoplankton because of the difficulty in operating large boats and deploying the standard gear (epibenthic sleds and Tucker trawls) in shallow water. The density of ichthyoplankton in the shore zone is assumed to be equal to that of the shoal of the corresponding region. Thus, for ichthyoplankton, the bottom densities for unsampled upriver shoal regions have been used to calculate standing crops in both shore and shoal strata.

- Type 3 - Unsampled, Obstructed Bottom, Shoal, and/or Shore Zones. These areas, obstructed by wrecks, cable crossings, or piers, represent a small portion of the regions in which they occur. Fish density in these areas is assumed to be equal to that of unobstructed areas within the same strata of these regions. The

TABLE 5-1

STRATUM AND REGION VOLUMES (m^3) AND SURFACE AREAS (m^2) USED IN ANALYSIS OF THE 1986 AND 1987 HUDSON RIVER 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[a]	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[a]	298,133,444	3,193,000
Hyde Park	131,165,041	32,012,000	2,307,625[a]	165,484,666	558,000
Kingston	93,657,021	35,479,990	12,332,868[a]	141,469,879	3,874,000
Saugerties	113,143,296	42,845,077	20,307,338[a]	176,295,711	7,900,000
Catskill	83,924,081	42,281,206	34,526,456[a]	160,731,743	8,854,000
Albany	32,025,080	13,517,183	25,606,842[a]	71,149,105	6,114,000
Total	1,461,633,658	479,425,027	326,757,424	2,267,816,109	76,555,000

[a]Historically unsampled shoals. Volume added to bottom stratum for analytical purposes.

potential error in abundance estimates attributable to these areas is small.

In 1986 Normandeau Associates, Inc. (NAI), performed a hydrographic survey to evaluate the possibility of sampling previously unsampled areas with modified sampling gear and to identify areas so choked with aquatic vegetation or other obstructions as to make sampling impossible with any gear. Although a considerable portion of the shore areas above MP 50 cannot be sampled because of thick aquatic vegetation, sampleable shoals in previously unsampled regions were identified (NAI 1987) and in 1986 and 1987 efforts were made to collect fish from previously unsampled areas. To assure sample collection, some gear was modified for deployment in the previously unsampled areas and some new gear was used. Simultaneously, previously sampled regions were resampled with new, modified, or standard gear, thus allowing a comparison of collections for sampled and previously unsampled areas.

5.2 ABUNDANCE OF JUVENILE FISH

Special studies were conducted during 1986 and 1987 to identify the relationship between abundance of juvenile fish in sampled and previously unsampled regions. Efforts during the first year of the special studies were directed toward developing gear that was similar in design and method of deployment to that historically used in the fall shoals surveys. Appropriate sampling locations within selected regions and strata were also identified. The 1987 special study for juvenile fish relied on the information gathered during 1986 with respect to effective sampling gears and locations. Because the 1987 program was focused on gear demonstrated to be successful in sampling previously unsampled regions and strata known to support target species in abundance, the value of data collected in 1987 was maximized. The quality of the data collected in 1987 allowed careful statistical analyses to identify significant differences in abundance among strata.

The juvenile fish program focused on five target species: Atlantic tomcod, bay anchovy, and striped bass from the lower river regions of Croton-Haverstraw and West Point; white perch from Kingston; and American shad from

Catskill. When sufficient numbers of a species were collected, data were analyzed by year class: young of the year, yearling, and older (length divisions 1, 2, and 3; see Section 2.5).

For both sampling years, analysis of variance (ANOVA) was used to investigate the sources of variation and differences among gears and life stages and between previously sampled and unsampled strata. The dependent variable was ln (CPUE + 1). For preliminary statistical evaluation of 1986 data, factorial ANOVA using SAS GLM (SAS 1985) procedure with Type III sum of squares was used to compare results. This procedure is unaffected by the order in which independent variables are entered into the analysis. Results indicated significant effects associated with gear and life stage. To clearly identify significant differences between previously sampled and unsampled strata, data were classified by gear, regions, and life stages, then subjected to individual ANOVA (SAS GLM, Type I sum of squares). Where statistical differences were identified, the relationship among means was explored using Student-Newman-Keuls (SNK) groupings (SAS 1985).

5.2.1 1986 Juvenile Fish Abundance in Previously Unsampled Areas

The objective of the 1986 special study on juvenile fish abundance was to test the hypothesis that fish density in unsampled areas is the same as in adjacent sampled areas. Samples were collected from previously sampled and previously unsampled areas in three different strata. Beach strata (1 to 5 ft depth) were sampled with a 0.9-m^2 pushnet. Shore zones (5 to 10 ft) were sampled with pushnets and 2.0-m beam trawls. Previously unsampled upriver shoal areas (10 to 20 ft) were sampled with 2.0-m beam trawls. The latter samples were paired with beam trawl collections made in previously sampled bottom strata adjacent to the unsampled shoals. (Sampling gear and strata categories are described in detail in Chapter 2, Volume 1.) Samples from the Catskill region were used for gear comparisons between the pushnet and the beam trawl.

5.2.1.1 Beach and Shore Strata Collections. Estimates of juvenile abundance and standing crop in shore zones have been based on beach seine collections;

however, the sampling regions of the Hudson are composed primarily of shores that cannot accommodate seines. The species composition and abundance of juveniles are assumed to be the same in unsampled shore zone habitat as on sampleable beaches. The adequacy of this assumption was tested by comparing the abundance of juveniles estimated from data collected with pushnets and beam trawls from historically sampled beaches with that from previously unsampled shores.

Pushnets deployed in previously sampled beaches and previously unsampled shore zone strata collected a diversity of species, but numbers were low (Table 5-2). The species collected in the beach strata were typical of shallow, shore-zone fish communities. Of the target species, only American shad and white perch were collected. Considering the small numbers collected, frequency of catch and abundance were similar in both previously sampled and previously unsampled strata. The limited numbers collected precluded credible statistical analysis.

When deployed in the Catskill region shore stratum (5 to 10 ft deep), pushnets collected only a few species in low numbers (Table 5-3). Pushnets caught a few midwater and surface-oriented species and only two white perch. The beam trawl collected more species in larger numbers; however, they were almost entirely bottom-oriented species. Because of the low (and frequently zero) catches, statistical analyses could not be credibly performed on data from pushnet collections in the shore stratum. The results indicate that the pushnet deployed in the shore zone did not provide data representative of actual species diversity and abundance.

When regional data are combined, average CPUE for beam trawl collections in previously sampled and previously unsampled shore zones indicates that bay anchovy, striped bass, and white perch were higher in unsampled areas (Table 5-4). The variation in abundance among samples and regions was high, however (Table 5-5).

TABLE 5-2

TOTAL NUMBER COLLECTED IN PUSHNET COMPARISON STUDY

1986, Catskill Region

SPECIES	PREVIOUSLY SAMPLED BEACHES 57 SAMPLES			PREVIOUSLY UNSAMPLED BEACHES 52 SAMPLES		
	LENGTH 1	LENGTH 2	LENGTH 3+	LENGTH 1	LENGTH 2	LENGTH 3+
Alewife[b]	27(11)[a]	0	0	40(8)	2	0
Bay anchovy	1(2)	1	0	9(4)	0	0
American shad[b]	29(11)	0	0	38(11)	1	0
Bluegill	0(1)	1	0			
Black crappie	0(1)	1	0	0(1)	1	0
American eel	0(2)	0	2	0(1)	0	2
Golden shiner	0(3)	0	5	0(3)	0	5
Tessellated darter	6(1)	0	0	42(4)	2	0
Banded killifish	3(2)	0	0			
Atlantic menhaden	1(1)	0	0	3(2)	0	0
Blueback herring[b]	26(11)	0	0	20(7)	0	0
Spottail shiner	25(7)	6	0	26(8)	8	0
White catfish	0(4)	0	4	0(3)	0	3
White perch[b]	17(8)	3	1	11(3)	1	0
Centrarchidae UID	5(2)	0	0	25(4)	0	0
Pumpkinseed				0(6)	4	3
Emerald shiner				0(1)	1	0
Fourspine stickleback				0(1)	1	0
Atlantic needlefish				0(1)	0	1

[a]Number in ( ) denotes number of collections containing each species.
[b]Length catagories represent YOY, yearling, and older.

TABLE 5-3

TOTAL NUMBER COLLECTED IN PUSHNET COMPARISON STUDY

1986 Shore Stratum, Catskill Region
(5 to 10 ft deep)

SPECIES	PUSHNET						BEAM TRAWL		
	PREVIOUSLY SAMPLED STRATUM 10 SAMPLES			PREVIOUSLY UNSAMPLED STRATUM 10 SAMPLES			PREVIOUSLY UNSAMPLED STRATUM 7 SAMPLES		
	LENGTH 1	LENGTH 2	LENGTH 3+	LENGTH 1	LENGTH 2	LENGTH 3+	LENGTH 1	LENGTH 2	LENGTH 3+
American shad[b]	8(3)[a]			4(3)			7		
American eel			1(1)						19
Blueback herring	17(4)			10(3)					
White perch[b]	2(1)						8	371	393
Hogchoker								7	
Tessellated darter							5	3	
Spottail shiner								1	
Striped bass[b]							1		1
White catfish									1

[a]Number in ( ) denotes frequency of collection.
[b]Length catagories represent YOY, yearling, and older.

TABLE 5-4

CPUE (No./1000 m^3) IN PREVIOUSLY SAMPLED AND PREVIOUSLY UNSAMPLED SHORE ZONES

1986 Beam Trawl Data, All Regions Combined

SPECIES	PREVIOUSLY SAMPLED BEACHES 18 SAMPLES			PREVIOUSLY UNSAMPLED BEACHES 28 SAMPLES		
	LENGTH 1	LENGTH 2	LENGTH 3+	LENGTH 1	LENGTH 2	LENGTH 3+
Alewife[b]	0.28			0.05	0.09	0.04
Bay anchovy[a]	0.85	0.06		3.79	0.72	
American shad[ab]	0.68	0.00		0.57		
Brown bullhead		0.12				0.04
Pumpkinseed			0.11			
Carp			0.00			0.04
American eel		0.12	0.35			1.06
Hogchoker	0.19	0.57		0.35	6.17	
Tessellated darter	0.80			0.36	0.75	
Blueback herring[ab]	0.63			0.14		
Rainbow smelt				0.18		
Spottail shiner		0.18		0.16	0.04	
Striped bass[ab]	0.07			0.66	0.04	0.06
White catfish						0.06
White perch[ab]	23.12	7.05	3.52	9.40	22.57	6.13
Weakfish				0.04		

[a]Target species.
[b]Length catagories represent YOY, yearling, and older.

TABLE 5-5

CPUE (No./1000 m^3) IN PREVIOUSLY SAMPLED AND PREVIOUSLY UNSAMPLED SHORE ZONES

1986 Beam Trawl Data by Region

	PREVIOUSLY SAMPLED 6 SAMPLES						PREVIOUSLY UNSAMPLED 9 SAMPLES					
	YOY		YEARLING		OLDER		YOY		YEARLING		OLDER	
CROTON-HAVERSTRAW	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Bay anchovy[a]	2.55	2.43	0.19[a]	0.46[a]	0.00	0.00	5.61	8.52	0.14[a]	0.43[a]	0.00	0.00
Striped bass	0.22	0.53	0.00	0.00	0.00	0.00	0.81	0.86	0.00	0.00	0.00	0.00
White perch	0.20	0.50	0.00	0.00	0.40	0.61	0.27	0.54	0.14	0.41	0.14	0.41

	PREVIOUSLY SAMPLED 0 SAMPLES						PREVIOUSLY UNSAMPLED 8 SAMPLES					
	YOY		YEARLING		OLDER		YOY		YEARLING		OLDER	
WEST POINT	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Bay anchovy							6.47	9.28	2.37[a]	4.45[a]	0.00	0.00
Striped bass							0.57	0.84	0.00	0.00	0.00	0.00
White perch							14.75	19.00	5.87	8.72	11.35	16.50

	PREVIOUSLY SAMPLED 4 SAMPLES						PREVIOUSLY UNSAMPLED 4 SAMPLES					
	YOY		YEARLING		OLDER		YOY		YEARLING		OLDER	
KINGSTON	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
White perch	102.22	182.34	26.85	39.24	9.29	10.79	20.20	23.28	10.82	15.39	6.44	6.68

	PREVIOUSLY SAMPLED 8 SAMPLES						PREVIOUSLY UNSAMPLED 7 SAMPLES					
	YOY		YEARLING		OLDER		YOY		YEARLING		OLDER	
CATSKILL	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
American shad	0.89	1.24	0.00	0.00	0.00	0.00	1.39	2.31	0.00	0.00	0.00	0.00
White perch	0.76	1.13	2.45	4.00	2.98	4.75	8.85	14.78	77.23	90.99	7.68	6.12

[a]Yearling represents yearling and older.

With the exception of white perch, analyses of regional data showed no statistically significant differences between previously sampled and unsampled shore zones for any age class of target species (Table 5-6). Analysis of white perch data showed no significant differences when data from all regions were combined. In the Catskill region white perch yearlings and older fish were significantly more abundant in the previously unsampled shore stratum.

At Kingston, more white perch were collected in previously sampled areas, although the difference was not significant.

For American shad, bay anchovy, and striped bass, historic estimates of abundance in shore zones adequately represent abundance in both previously sampled and previously unsampled areas. For white perch, overall historic standing crop values are adequate, but may result in low estimates for some life stages in some regions.

5.2.1.2 Shoal Strata Collections. The abundance of species by year class in CPUE, as estimated by beam trawl collections in the previously sampled bottom strata, was compared to estimates for the previously unsampled shoal strata (Table 5-7). In the river regions of West Point, Kingston, and Catskill these areas have been historically unsampled, i.e., Type 1 Unsampled Upriver Shoals. The density for these regions has been assumed to be equal to that of the bottom strata. Seventy-six beam trawl samples were collected: 36 from previously unsampled shoal areas and 40 from previously sampled bottom areas.

Statistical analysis of the catches from unsampled shoals and adjacent bottom strata indicate that white perch are statistically more abundant in previously unsampled shoals in the Kingston and West Point regions (Table 5-8; see also Appendix G). Catches of white perch were also higher in the Catskill shoals, but the differences were not statistically significant.

Bay anchovy young-of-the-year and yearlings were also more abundant in the West Point shoals; however, only the differences for yearlings were statistically significant.

TABLE 5-6

RESULTS OF ANOVA (GLM) ON THE EFFECT OF PREVIOUSLY SAMPLED VS PREVIOUSLY (S) VS UNSAMPLED (U) SHORES[a]

1986 Beam Trawl Collections

REGION	SPECIES	ERROR PROBABILITY YOY	YEARLING	OLDER
Croton-Haverstraw	Bay anchovy[b]	0.50	0.82	-
	Striped bass	0.15	-	-
	White perch	0.81	0.43	0.34
Kingston	White perch	0.45	0.63	0.88
Catskill	American shad	0.82	-	-
	White perch	0.06	0.01 U > S	0.05 U > S

[a]Error probabilities of 0.05 or less indicate a statistically significant effect. Where significant effects are identified, the relationship between unsampled (U) and previously sampled (S) means, as determined by SNK, appears below the probability.
[b]Yearling represents yearling and older.

TABLE 5-7 (Page 1 of 2)

CPUE (No./1000 m^3) IN PREVIOUSLY UNSAMPLED SHOALS AND ADJACENT BOTTOM STRATA: MEAN AND STANDARD DEVIATION BY LIFE STAGE FOR TOTAL RIVER AND BY REGION

1986 Beam Trawl Data

ALL REGIONS

	PREVIOUSLY SAMPLED BOTTOM 40 SAMPLES						PREVIOUSLY UNSAMPLED SHOALS 36 SAMPLES					
	LENGTH 1		LENGTH 2		LENGTH 3+		LENGTH 1		LENGTH 2		LENGTH 3+	
SPECIES	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Alewife[a]	1.35	5.17	0.02	0.15	0.19	0.79	0.28	0.74	0.00	0.00	0.00	0.00
Bay anchovy	0.16	0.39	0.04	0.19	0.00	0.00	1.03	2.85	1.20	2.53	0.00	0.00
American shad[a]	1.09	1.82	0.00	0.00	0.00	0.00	0.56	1.26	0.00	0.00	0.00	0.00
Bluefish	0.02	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brown bullhead	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.25	0.04	0.23	0.27	0.68
American eel	0.00	0.00	0.00	0.00	1.46	2.77	0.00	0.00	0.00	0.00	1.05	1.96
Hogchoker	0.68	1.47	74.34	211.74	0.48	3.04	1.12	2.02	31.43	55.92	0.00	0.00
Tessellated darter	0.12	0.62	0.03	0.17	0.00	0.00	1.15	1.63	0.18	0.46	0.12	0.74
Banded killifish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.21	0.00	0.00
Atlantic menhaden	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00	0.00	0.00	0.12	0.57
Minnow unidentified	0.00	0.00	0.00	0.00	0.13	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Blueback herring[a]	11.34	13.85	0.06	0.26	0.00	0.00	1.99	5.14	0.00	0.00	0.00	0.00
Rainbow smelt	0.05	0.22	0.00	0.00	0.00	0.00	0.16	0.68	0.00	0.00	0.00	0.00
Shortnose sturgeon	0.00	0.00	0.00	0.00	0.03	0.20	0.00	0.00	0.00	0.00	0.04	0.23
Spottail shiner	0.00	0.00	0.08	0.29	0.00	0.00	0.00	0.00	0.17	0.52	0.00	0.00
Atlantic sturgeon	0.00	0.00	0.00	0.00	0.06	0.38	0.00	0.00	0.00	0.00	0.06	0.27
Striped bass[a]	0.02	0.14	0.00	0.00	0.02	0.16	0.42	1.23	0.00	0.00	0.00	0.00
Atlantic tomcod[a]	5.56	16.29	0.00	0.00	0.00	0.00	3.16	8.62	0.00	0.00	0.00	0.00
White catfish	0.36	0.80	0.00	0.00	0.16	0.45	0.06	0.26	0.06	0.27	0.29	0.87
White perch[a]	2.21	4.55	3.57	4.88	10.75	13.93	10.92	26.39	17.73	28.27	39.17	49.42
Atlantic needlefish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crevalle jack	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00	0.00	0.00
Weakfish	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.17	0.00	0.00	0.00	0.00
Gizzard shad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.24	0.00	0.00

[a]Length categories represent YOY, yearling, and older.

TABLE 5-7 (Page 2 of 2)

CPUE (No./1000 m^3) IN PREVIOUSLY UNSAMPLED SHOALS AND ADJACENT BOTTOM STRATA: MEAN AND STANDARD DEVIATION BY LIFE STAGE FOR TOTAL RIVER AND BY REGION

1986 Beam Trawl Collections

	PREVIOUSLY SAMPLED BOTTOM 10 SAMPLES						PREVIOUSLY UNSAMPLED SHOALS 10 SAMPLES					
	YOY		YEARLING		OLDER		YOY		YEARLING		OLDER	
WEST POINT	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Bay anchovy[a]	0.63	0.56	0.18	0.37	0.00	0.00	3.73	4.53	4.32	3.15	0.00	0.00
Striped bass	0.09	0.29	0.00	0.00	0.10	0.31	1.40	2.05	0.00	0.00	0.00	0.00
Atlantic tomcod	16.69	29.08	0.00	0.00	0.00	0.00	10.63	14.20	0.00	0.00	0.00	0.00
White perch	1.11	1.91	0.59	1.30	0.93	3.06	31.80	44.08	21.61	34.60	44.03	74.10

	PREVIOUSLY SAMPLED BOTTOM 20 SAMPLES						PREVIOUSLY UNSAMPLED SHOALS 16 SAMPLES					
	YOY		YEARLING		OLDER		YOY		YEARLING		OLDER	
CATSKILL	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
American shad	1.97	2.18	0.00	0.00	0.00	0.00	0.71	1.42	0.00	0.00	0.00	0.00
White perch	1.31	3.39	3.94	5.33	7.72	7.43	0.15	0.58	13.03	29.62	16.86	21.38

	PREVIOUSLY SAMPLED BOTTOM 10 SAMPLES						PREVIOUSLY UNSAMPLED SHOALS 10 SAMPLES					
	YOY		YEARLING		OLDER		YOY		YEARLING		OLDER	
KINGSTON	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
White perch	5.08	7.05	5.81	5.09	25.62	19.06	7.29	7.72	21.37	19.43	70.01	35.72

[a]Yearling represents yearling and older.

TABLE 5-8

RESULTS OF ANOVA (GLM) ON THE EFFECT OF PREVIOUSLY UNSAMPLED (U) SHOALS VS PREVIOUSLY SAMPLED BOTTOM (B) STRATA[a]

1986

REGION	SPECIES	ERROR PROBABILITY YOY	YEARLING	OLDER
West Point	Bay anchovy[b]	0.06	0.0001 U > B	-
	Striped bass	0.06	-	0.33
	Atlantic tomcod	0.64	-	-
	White perch	0.002 U > B	0.05 U > B	0.16 U > B
Kingston	White perch	0.45	0.009 U > B	0.003 U > B
Catskill	American shad	0.05 B > U	-	-
	White perch	0.18	0.33	0.14

[a]Error probabilities of 0.05 or less indicate a statistically significant effect. Where significant effects are identified, the relationship between unsampled (U) and previously sampled (S) means, as determined by SNK, appears below the probability.
[b]Yearling represents yearling and older.

Statistically larger catches of young-of-the-year American shad were collected from the bottom stratum in Catskill as compared to the shoal stratum. The numbers of shad collected were low in both strata, however.

For those species and life stages showing no statistically significant differences in catch, the assumption that abundance of adjacent bottom samples adequately estimates the abundance in the unsampled shoals is adequate. For white perch and bay anchovy, species with statistically significantly higher catches in unsampled areas during 1986, estimates based on abundance in the adjacent bottom strata underestimate the actual population. Thus, for these species, the assumption of equivalent abundance between bottom strata and unsampled shoals is conservative and results in lower estimates of standing crop than actually exist in the river.

Standing crop estimates of American shad in the Catskill region, based upon bottom abundance, would overestimate actual abundance; however, catches during 1986 were small and the pattern was not consistent in the lower river regions.

5.2.2 1987 Juvenile Fish Abundance in Previously Unsampled Areas

During 1987 the juvenile fish program focused on providing a statistical comparison of samples collected from previously sampled bottom areas with samples collected from previously unsampled shoal areas in the Kingston region and the adjacent, lower portion of Saugerties. Data were not evaluated on a regional basis because of the proximity of sampling locations within regions. The purpose of the 1987 juvenile special study was to confirm the results of the shoal-to-bottom abundance comparison conducted in 1986 and, thus, verify the accuracy of the assumption that abundance of fish in bottom areas adequately estimated abundance in unsampled shoal regions.

Sixty-seven beam trawl samples were collected, 33 from the previously sampled bottom stratum in the Kingston region. Thirty-four samples were collected from previously unsampled shoals in the Kingston Region and the lower portion of the Saugerties region. Seven samples were collected in the lower portion of the Saugerties region. Samples were collected beginning at milepoint 87 and extending to milepoint 96. All samples were collected within a four-day period. The species collected in each stratum were similar (Table 5-9), except that Atlantic tomcod and naked goby were present in the bottom and channel catfish were present in the shoals. The numbers of each of these species were low.

Statistically significant differences between strata were identified for striped bass and white perch (Table 5-10). For both of the Morone species, abundance in the previously unsampled shoals was greater than that in the sampled bottom stratum. For these species the assumption that bottom strata abundances adequately represented shoal strata abundance resulted in underestimates of true abundance and standing crop. Blueback herring were more abundant in the bottom than in the previously unsampled shore.

5.2.3 Abundance of Target Species in Shoals

Only white perch abundance showed a consistent statistical pattern between 1986 and 1987 (Table 5-11). Abundance of all age classes in shoals exceeded that in the bottom strata for both years in all regions sampled. These differences were statistically significant for the Kingston and West Point regions, which suggests that estimates of white perch standing crops have been consistently underestimated. The degree of underestimation is variable depending on region and life stage (Section 5.2.4).

Abundance of young-of-the-year striped bass in the Kingston shoals was significantly greater than that in the bottom stratum during 1987. No statistical difference was noted in 1986 when few bass were collected. Juveniles of both Morone spp. make use of shoals for feeding and protection. Greater abundance in these shallow areas as compared to deeper bottom waters is consistent with life history patterns.

In 1986 abundances of bay anchovy young of the year and yearlings in the West Point shoal region were greater than abundances in bottom samples; the differ-

TABLE 5-9

CPUE (No./1000 m^3) IN PREVIOUSLY UNSAMPLED SHOALS AND ADJACENT BOTTOM STRATA: MEAN AND STANDARD DEVIATION FOR KINGSTON AND SAUGERTIES COMBINED[a]

1987 Beam Trawl Collections

	PREVIOUSLY SAMPLED BOTTOM STRATUM						PREVIOUSLY UNSAMPLED SHOALS STRATUM					
	LENGTH 1		LENGTH 2		LENGTH 3+		LENGTH 1		LENGTH 2		LENGTH 3+	
SPECIES	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Alewife[b]	1.32	2.09	0.05	0.28	0.00	0.00	2.67	4.60	0.06	0.37	0.00	0.00
Bay anchovy	2.24	3.29	0.00	0.00	0.00	0.00	2.78	4.23	0.00	0.00	0.00	0.00
American shad[b]	0.79	1.27	0.00	0.00	0.00	0.00	0.38	1.00	0.00	0.00	0.00	0.00
Pumpkinseed	0.04	0.25	0.00	0.00	0.00	0.00	0.12	0.50	0.00	0.00	0.00	0.00
Hogchoker	3.40	4.30	1.16	2.47	0.00	0.00	4.20	4.00	0.81	1.85	0.00	0.00
Tessellated darter	0.47	1.83	0.16	0.66	0.00	0.00	0.65	0.97	0.32	0.79	0.00	0.00
Blueback herring[b]	40.11	47.98	0.05	0.30	0.00	0.00	19.14	38.58	0.00	0.00	0.00	0.00
Striped bass[b]	2.25	5.41	0.00	0.00	0.00	0.00	5.03	7.16	0.00	0.30	0.05	0.30
Atlantic tomcod[b]	0.43	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
White catfish	0.74	1.42	0.12	0.47	0.00	0.00	0.62	0.96	0.06	0.36	0.00	0.00
White perch[b]	5.21	5.18	7.01	7.19	26.15	33.70	14.04	17.89	41.66	41.30	68.52	76.22
Channel catfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.42	0.00	0.00
Naked goby	0.06	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]Regions are adjacent.
[b]Length categories represent YOY, yearling, and older.

TABLE 5-10

RESULTS OF ANOVA (GLM) ON THE EFFECT OF PREVIOUSLY SAMPLED BOTTOM (B) STRATA VS UNSAMPLED (U) SHOALS[a]

1987 Beam Trawl Collections

SPECIES	YOY	YEARLING	OLDER
White perch	0.005 U > B	0.01 U > B	0.18
Striped bass	0.03 U > B	-	-
Bay anchovy	0.62	-	-
American shad	0.11	-	-

[a]Error probabilities of 0.05 or less indicate a statistically significant effect. Where significant effects are identified, the relationship between unsampled (U) and previously sampled (S) means, as determined by SNK, appears below the probability.

TABLE 5-11

SUMMARY OF DIFFERENCES IN ABUNDANCE OF JUVENILES IN PREVIOUSLY UNSAMPLED SHOALS VS ABUNDANCE IN ADJACENT BOTTOM STRATA[a]

	1986	1987
White perch	Shoals > bottom	Shoals > bottom
Striped bass	NSD	Shoals > bottom
Bay anchovy	Shoals > bottom	NSD
American shad	Bottom > shoals[b]	NSD
Atlantic tomcod	NSD	Insufficient data

NSD - Not significantly different for total fish.
[a]ANOVA at = 0.001 using SAS GLM (SAS 1985).
[b]For Catskill region only. Riverlong comparison shows nonsignificant difference.

ence in yearlings was statistically significant. During 1987 only the Kingston region was sampled. Although sufficient anchovy were collected to allow statistical analysis, abundance was not different between strata.

Although average yearling abundance of both Atlantic tomcod and American shad was higher in bottom samples than in samples collected from shoals, these differences were not statistically significant. In the absence of consistent, statistically significant data on differences in abundance, historic estimates should be used.

5.2.4 Impact of Unsampled Regions on Standing Crop Estimates

The data presented above indicate that, for most species, abundance in the bottom strata adequately represents abundance in previously unsampled shoals; therefore, historic values for abundance and standing crop are a reasonable estimate of real values. Abundance of some target species in the shoals statistically exceeds that in the bottom strata; thus, historic estimates, although reasonable approximations, tend to negatively bias standing crops.

Only white perch showed consistent statistical differences through years, regions, and year classes. Data for this species have been used to explore the impact of consistent underestimation of abundance in unsampled upriver shoals (Table 5-12). A differential factor representing the ratio of abundance in shoals to that in bottom strata represents the degree to which abundance has been adequately estimated. Factors near 1 indicate that abundance in the two strata are similar and thus adequately represent each other. Factors range from 0.1 for YOY in the Catskill region during 1986 to 30 for older fish in the West Point region during 1986. The range is large due to variations in strata abundance over the length of the river; CPUE varies among strata and from region to region. Because the distribution of fish between shoals and other strata is variable by region, data from those specific shoals sampled during the special study cannot readily be applied to all unsampled upriver shoals. However, most differential factors fall between 2 and 4, i.e., the CPUE in shoal samples is two to four times higher than that of the bottom.

TABLE 5-12

RELATIONSHIP BETWEEN SHOALS AND BOTTOM ABUNDANCE (CPUE) OF WHITE PERCH

ABUNDANCE	ALL REGIONS	WEST POINT	KINGSTON	CATSKILL
1986				
YOY				
Shoals	10.9	31.8	7.3	0.15
Bottom	2.2	1.1	5.1	1.3
Factor	5	29	1.5	0.1
Older				
Shoals	56.9	65.4	91.4	29.9
Bottom	14.3	1.5	34.4	11.7
Factor	4	44	2.5	2.5
Total				
Shoals	67.8	97.2	138.2	42.9
Bottom	16.5	2.6	39.5	13.0
Factor	4	37	3.5	3
1987				
YOY				
Shoals			14.0	
Bottom			5.2	
Factor			2.7	
Older				
Shoals			110.2	
Bottom			33.2	
Factor			3.3	
Total				
Shoals			124.2	
Bottom			38.4	
Factor			3.2	

The relationship between the volume of water in previously unsampled shoals, the volume of water in sampled shoals, and the total river volume provides a framework in which to evaluate the impact of abundant fish in unsampled shoals on total abundance and standing crop estimates (Table 5-1). The total river volume is 2267 x 10^6 m^3; of this, 323 x 10^6 m^3 is shoals (14.4%). Unsampled upriver shoals (including West Point) account for 103 x 10^6 m^3, which is 31.7% of the total shoals and 4.6% of the total volume. The total volume of bottom strata is 479 x 10^6, of which 255 x 10^6 m^3 is adjacent to unsampled shoals. Thus, unsampled shoals are less than half the volume of adjacent bottom strata (40.6%). If it may be assumed that estimates of total abundance of white perch are related to volume, the portion of the estimate that is likely to be low is about 5% of the total estimated standing crop and about 32% of the shoal standing crop.

Specific standing crop data for white perch estimated from fall shoals and beach seine collections during the week of the special study provide additional insight into the impact of the negative bias on abundance estimates (Table 5-13). An estimate of 234,000 YOY white perch was made for upriver bottom regions. Using these upriver data to represent shoals abundance, 49,000 YOY white perch are attributed to unsampled shoals. Given that this shoal's abundance estimate is underestimated by a factor of 2, the actual abundance in unsampled shoals is 98,000 YOY white perch. The resulting difference between the two estimates is 7.5% of the total weekly standing crop attributed to bottom, channel, and shoal strata and 3% of the weekly total including shore strata. If abundance in unsampled shoals is underestimated by a factor of 4, actual unsampled shoal abundance is 196,000 YOY white perch, 23% of the total bottom standing crop, and 10% of total standing crop. If abundance in unsampled shoals is underestimated by a factor of 4, the number of additional fish is less than the standard error attributable to weekly channel estimates.

The standing crop described above for YOY white perch is compared with similar estimates for juvenile and older fish in Table 5-14. The effect of underestimating actual abundance in shoals is greater for older fish than for YOY.

TABLE 5-13

1987 FALL SHOALS AND BEACH SEINE SURVEYS STANDING CROP DATA (IN THOUSANDS) FOR YOUNG-OF-YEAR AND YEARLING AND OLDER WHITE PERCH FROM 14SEP87 TO 24SEP87 . STANDARD ERRORS (IN THOUSANDS) ARE PRINTED BELOW EACH STANDING CROP. "NS" INDICATES THAT THE STRATUM WAS NOT SAMPLED

REGION	YOUNG-OF-YEAR				YEARLING AND OLDER			
	FALL SHOALS			BEACH SEINE	FALL SHOALS			BEACH SEINE
	CHANNEL	BOTTOM	SHOAL	SHORE	CHANNEL	BOTTOM	SHOAL	SHORE
YONKERS	0	0	0	0	0	0	36	6
	0	0	0	0	0	0	21	4
TAPPAN ZEE	0	0	0	61	0	187	1221	337
	0	0	0	30	0	77	273	178
CROTON-HAVERSTRAW	0	0	8	221	0	142	1228	213
	0	0	4	66	0	30	216	136
INDIAN POINT	0	24	0	63	0	206	290	52
	0	24	0	39	0	50	89	36
WEST POINT	141	37	NS	67	0	43	NS	23
	141	9		38	0	23		18
CORNWALL	0	5	15	98	0	188	186	25
	0	5	8	33	0	109	19	19
POUGHKEEPSIE	0	53	NS	0	0	880	NS	6
	0	27		0	0	702		4
HYDE PARK	93	66	NS	4	282	373	NS	1
	93	21		4	181	102		<0.5
KINGSTON	0	64	NS	74	0	490	NS	21
	0	32		33	0	72		17
SAUGERTIES	82	10	NS	68	327	542	NS	140
	82	6		31	327	121		99
CATSKILL	0	0	NS	116	168	224	NS	155
	0	0		66	87	44		62
ALBANY	0	4	NS	2	0	66	NS	8
	0	4		2	0	19		8
TOTAL STANDING CROP	316	261	24	774	776	3342	2961	987
	188	54	9	125	383	739	360	257

TABLE 5-14

COMPARISON OF STANDING CROP ESTIMATES (IN THOUSANDS)

	WHITE PERCH		STRIPED BASS
	YOUNG OF YEAR	YEARLING AND OLDER	YOUNG OF YEAR
Bottom abundance adjacent to unsampled shoals	234	2618	103
Shoals based on bottom abundance (historic method, i.e., factor 1)	49	840	42
Shoals based on underestimation factor 2	98	1680	84
Shoals based on underestimation factor 4	196	3360	168
Total standing crop	650	7919	3370
Total standing crop with beaches	1424	8906	7871

If shoal abundance estimates from bottom strata are underestimates of actual shoal abundance by a factor of 4, the weekly total standing crop of white perch may be low by 9 to 28%.

Underestimating weekly standing crops in unsampled shoals is likely to have a greater impact on white perch standing crops than on those of other target species. White perch is a resident species found primarily in shoal strata. Those species that migrate downriver as juveniles (striped bass, American shad, Atlantic tomcod, and bay anchovy) would progressively vacate regions with unsampled upriver shoals.

Disregarding unsampled shoals, more than half the total standing crop of striped bass during the week of the special study was located in the shore zone (Table 5-15). Underestimates of abundance in upriver shoals has little effect on total standing crop (Table 5-14). The impact of underestimating abundance in upriver shoals by a factor of 4 is 126,000 fish, which is 3.7% of the total weekly standing crop for bottom channel and shoal strata and 1.6% of the total weekly standing crop including beaches.

5.3 ABUNDANCE OF FISH EGGS AND LARVAE

Special studies conducted during 1987 identified the relationship between abundance of fish eggs and larvae in sampled vs previously unsampled strata. Two major unsampled strata were evaluated: (1) the previously unsampled upriver shoals that were also evaluated for abundance of juvenile fish, and (2) the shore zone. Abundance of eggs and larvae in upriver shoals has traditionally been estimated on the basis of abundance in bottom samples (as was abundance of juvenile fish). The technical difficulties of operating large boats and deploying standard gear in the shore zone has precluded sampling for ichthyoplankton in this stratum throughout the length of the Hudson River. The volume of the shore zone is very small due to its limited depth, about a quarter of the shoal volume or 81,689,000 m^3. Estimates of standing crop have been made by assuming that the densities in the shore zone are equal to those in the shoal of the corresponding region. When the shoal is too limited

TABLE 5-15

1987 FALL SHOALS AND BEACH SEINE SURVEYS STANDING CROP DATA (IN THOUSANDS) FOR YOUNG-OF-YEAR AND YEARLING AND OLDER STRIPED BASS FROM 14SEP87 TO 24SEP87 . STANDARD ERRORS (IN THOUSANDS) ARE PRINTED BELOW EACH STANDING CROP. "NS" INDICATES THAT THE STRATUM WAS NOT SAMPLED

	YOUNG-OF-YEAR				YEARLING AND OLDER			
	FALL SHOALS			BEACH SEINE	FALL SHOALS			BEACH SEINE
REGION	CHANNEL	BOTTOM	SHOAL	SHORE	CHANNEL	BOTTOM	SHOAL	SHORE
YONKERS	0 0	0 0	28 28	38 23	0 0	0 0	0 0	5 5
TAPPAN ZEE	0 0	381 136	1077 152	1889 520	0 0	0 0	12 7	4 3
CROTON-HAVERSTRAW	0 0	190 59	523 95	2272 808	0 0	0 0	0 0	0 0
INDIAN POINT	0 0	110 44	71 17	92 24	0 0	0 0	2 2	0 0
WEST POINT	0 0	12 5	NS	22 12	0 0	0 0	NS	0 0
CORNWALL	80 80	5 5	12 5	57 21	0 0	0 0	0 0	0 0
POUGHKEEPSIE	626 357	15 9	NS	4 3	0 0	0 0	NS	0 0
HYDE PARK	0 0	0 0	NS	1 <0.5	0 0	0 0	NS	0 0
KINGSTON	44 44	16 10	NS	0 0	0 0	0 0	NS	0 0
SAUGERTIES	0 0	53 24	NS	35 16	0 0	3 3	NS	2 2
CATSKILL	78 78	4 4	NS	79 39	0 0	0 0	NS	8 8
ALBANY	0 0	3 2	NS	12 10	0 0	0 0	NS	0 0
TOTAL STANDING CROP	828 377	789 158	1711 182	4501 963	0 0	3 3	13 7	18 10

for sampling (upriver areas), densities in the bottom strata have been used for estimates in both the shoal and shore areas.

Ichthyoplankton special studies were conducted in the Catskill, Poughkeepsie, and Tappan Zee regions, each selected to yield maximum numbers of target species. The sample design identified specific target species and life stages for each region (Table 5-16). In order to evaluate very shallow shore regions, the shore zone was subdivided into (1) beaches 1-5 ft deep that could be sampled with pushnets, and (2) shores 5-10 ft deep that could be sampled with both epibenthic sleds and pushnets (Figure 5-1). Samples from the Catskill and Poughkeepsie regions were used to evaluate abundance in both upriver unsampled shoals and beach areas. Samples from the Tappan Zee region were used only to evaluate the effect of unsampled shore zones. Most samples were collected in the Catskill region (Table 5-17).

Tables showing CPUE for all species and life stages collected by gear type and stratum are presented in Appendix H. Data presented here are restricted to the target species. Analysis of variance (ANOVA), using the SAS GLM (SAS 1985) procedure, was used to investigate the sources of variation and differences among gears and life stages and between previously sampled and unsampled strata. The dependent variable was ln (CPUE+1). Where statistical differences were identified, the relationship among means was explored using Student-Newman-Keuls (SNK) groupings (SAS 1985). Results of statistical analyses, including ANOVA tables, are presented in Appendix I.

Samples from the beach and shore zone strata were collected with a previously unused gear type, the 1-m^2 pushnet. To properly interpret data collected with this gear, abundance of species collected with pushnets was compared with abundance collected by traditional gear, the epibenthic sled. As discussed in detail for each species, the comparability of the gear differed by species, region, and life stage. The comparability of traditionally deployed gear, Tucker trawls and epibenthic sleds, was also evaluated. A comparison of catches by gear from the shoal regions suggested that the various types of gear collected similar catches for target species.

TABLE 5-16

SAMPLE DESIGN FOR 1987 ICHTHYOPLANKTON SPECIAL STUDY

REGION	SAMPLE DATES 1987	GEAR	DEPTH (ft)	TARGET SPECIES AND LIFE STAGE
Catskill	Jun 18 - 22	Pushnet	1-5	American shad eggs and yolk-sac larvae
		Epibenthic sled	5-10	
		Pushnet	5-10	
		Epibenthic sled	10-20	
		Tucker trawl	10-20	
		Epibenthic sled	>20	
Poughkeepsie	Jun 8 - 11	Pushnet	1-5	Striped bass and white perch post-yolk-sac larvae
		Epibenthic sled	5-10	
		Pushnet	5-10	
		Epibenthic sled	10-20	
		Tucker trawl	10-20	
		Epibenthic sled	>20	
Tappan Zee	Jun 23 - 26	Pushnet	1-5	Bay anchovy post-yolk-sac larvae
		Epibenthic sled	5-10	
		Pushnet	5-10	
		Epibenthic sled	10-20	
		Tucker trawl	10-20	

FIGURE 5-1

SCHEMATIC OF RIVER STRATA AND SAMPLING GEAR USED IN THE SPECIAL ICHTHYOPLANKTON STUDY TO EVALUATE ABUNDANCE IN PREVIOUSLY UNSAMPLED REGIONS

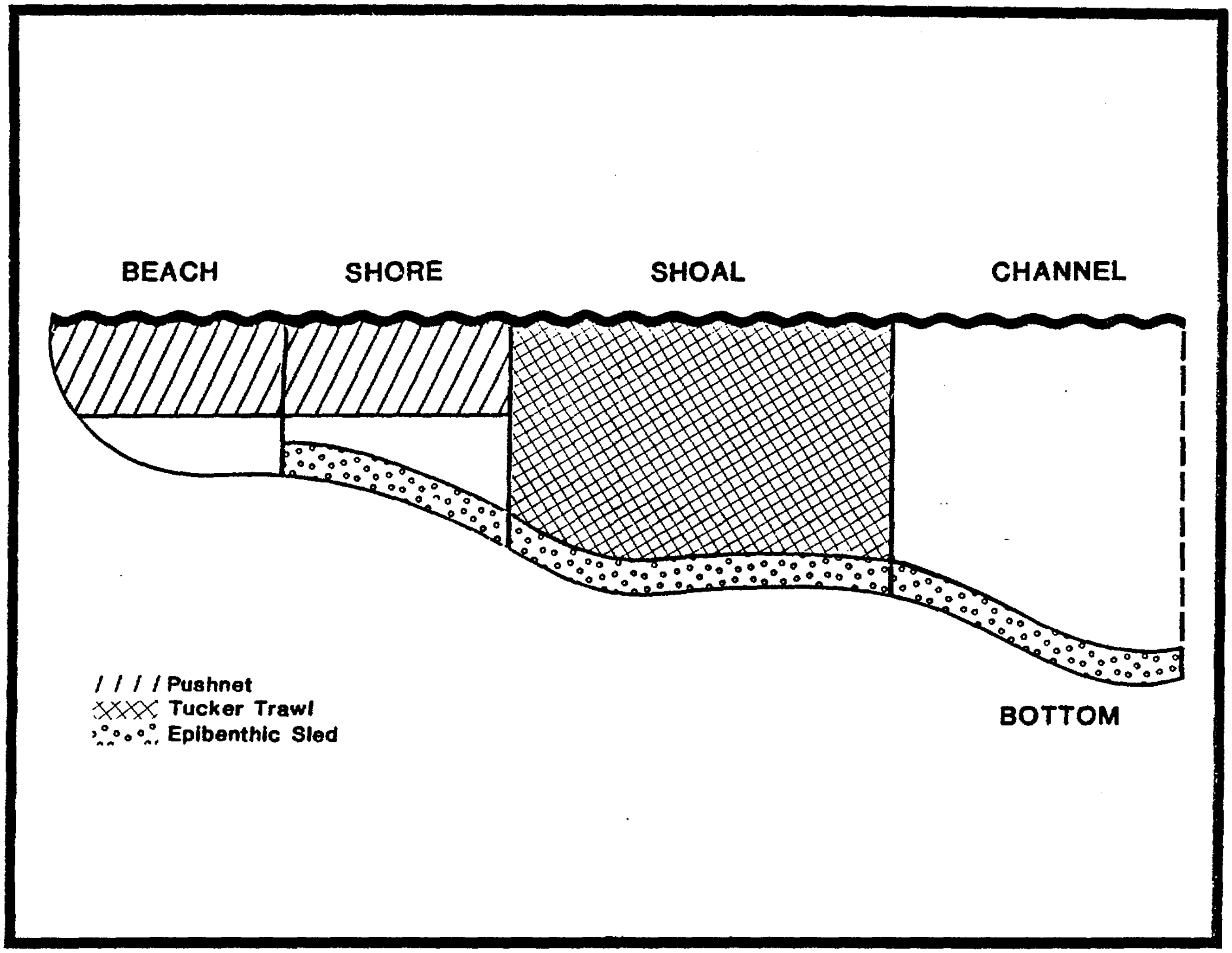


TABLE 5-17

ALLOCATION OF SAMPLES ANALYZED BY RIVER REGION AND GEAR FOR THE 1987 ICHTHYOPLANKTON SPECIAL STUDY

REGION (TARGET SPECIES)	BEACH (1-5 ft)	SHORE ZONE (5-10 ft)		SHOAL (10-20 ft)		BOTTOM (>20 ft)	
	(1.0-m^2 PUSHNET)	EPIBENTHIC SLED-MOUNTED 1.0-m^2 NET	1.0-m^2 PUSHNET	EPIBENTHIC SLED-MOUNTED 1.0-m^2 TUCKER TRAWL	1.0-m^2 TUCKER TRAWL	EPIBENTHIC SLED-MOUNTED 1.0-m^2 TUCKER TRAWL	TOTAL
Tappan Zee (Bay anchovy)	15	8	9	16	16		64
Poughkeepsie (*Morone*)	18	9	9	19	18	10	83
Catskill (American shad)	50	25	25	33	67	40	240
TOTAL	83	42	43	68	101	50	387

5.3.1 American Shad

American shad ichthyoplankton in the Catskill region were distributed so that eggs were most abundant in shoals, yolk-sac larvae were generally dispersed through the strata, and post-yolk-sac larvae were most abundant in shallow areas (Table 5-18; Figure 5-2). Statistical analysis of catch data for American shad eggs in the shoal region indicated that the epibenthic sled and Tucker trawl collected similar numbers. Similarly, catches from epibenthic sled collections in the shore zone were no different from those collected by pushnet.

Comparison of egg catches by stratum demonstrated that abundance in the bottom stratum is significantly greater than abundance in shoals, shore, or beach strata ($P = 0.0001$). Therefore, estimates of total egg standing crop based on the assumption that bottom abundance adequately represents abundance in shoals, shore, and beach zones would overestimate the real standing crop of shad eggs. This overestimate effects only the uppermost river regions, Albany, Catskill, and Saugerties. Eggs are collected primarily from these upper regions. American shad spawn in flat, shallow areas or in river channels. Water depths range from 3 to 30 ft, with currents from <1 to >3 fps (Walburg and Nichols 1967). The preponderance of eggs in the bottom stratum may reflect a preference in the location of deposition or a redistribution brought about by current patterns. Eggs are demersal and nonadhesive, thus subject to movement with currents. At the time of the special study (June 18-22, 1987) water temperatures in the Catskill region were less than 21°C. Thus, hatching required several days, during which time eggs could be redistributed through strata. In 1987 the period of peak egg abundance occurred in late April, earlier than reported for previous years; thus, the collections taken for this special study reflect conditions at the end of the period of peak abundance.

Abundances of yolk-sac larvae (YSL) were not significantly different by gear or stratum. Peak YSL abundance occcurred during mid-May in 1987, with peak abundance in the Albany region.

TABLE 5-18

EGGS AND LARVAE OF AMERICAN SHAD AVERAGE CPUE (No./1000 m^3) IN THE CATSKILL REGION

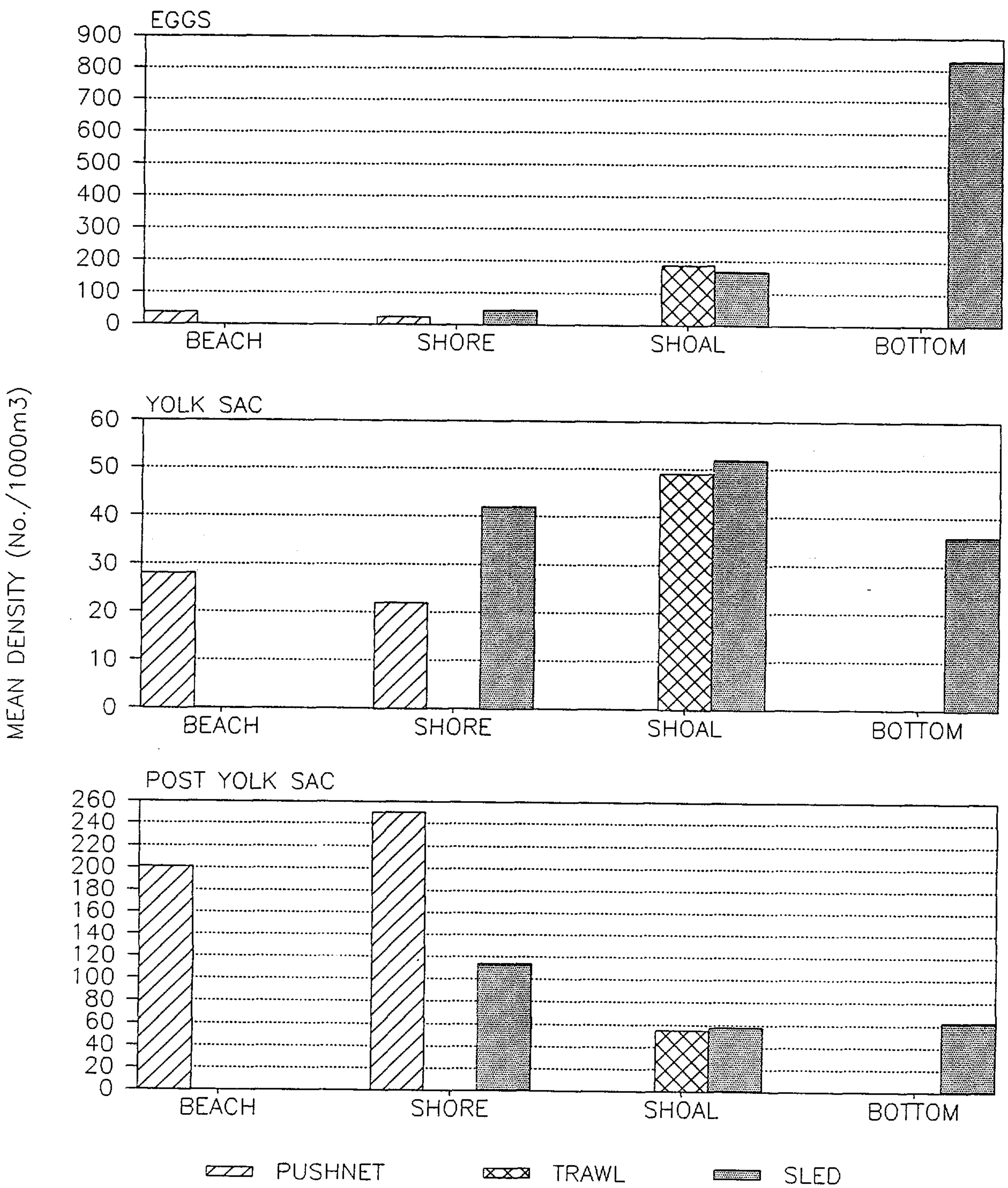
STRATA GEAR	LIFE STAGE: EGGS			YOLK-SAC			POST-YOLK-SAC		
	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]
Beach									
Pushnet	37	4	C	28	22	A	201	156	A
Shore									
Pushnet	24	6	B C	22	15	A	250	185	A
Epibenthic sled	46	8	B C	42	30	A	114	95	B
Shoals									
Epibenthic sled	168	21	B C	52	28	A	58	40	C
Tucker trawl	187	17	B C	49	24	A	55	35	C
Bottom									
Epibenthic sled	828	110	A	36	21	A	63	31	C
F Value		11.13			1.28			27.82	
Probability		0.0001			0.27			0.0001	

[a]Means with the same letter are not significantly different.

FIGURE 5-2

AMERICAN SHAD ICHTHYOPLANKTON FROM THE CATSKILL REGION, 1987:

COMPARISON OF MEAN DENSITY (No./1000m3) BY STRATA



The special study was conducted shortly after peak post-yolk-sac (PYSL) abundance. Catches of PYSL American shad were greater in shallow beach and shore strata than in shoals and bottom strata. Pushnets collected more PYSL in beach and shore strata than did epibenthic sleds in the shore strata. Results of the LRS in 1987 indicate that little longitudinal movement of early life stages took place (see Chapter 4, Volume 1). Downstream movement of PYSL was apparent in mid-June. Downriver shoal strata in the LRS consistently show higher densities than do channel-area bottom strata. The special study results indicate that shallow, upriver shore strata contain even greater densities than observed in downriver shoals.

5.3.2 Bay Anchovy

The abundance of bay anchovy PYSL in beach and shore zones was compared with the abundance in historically sampled shoals in the Tappan Zee region (Table 5-19; Figure 5-3). Spawning of bay anchovy typically occurs from May to September from the Tappan Zee south. Hatching occurs approximately 24 hrs after spawning (Kuntz 1914). No statistically significant differences in CPUE of bay anchovy PYSL were identified among gear types or strata using ANOVA ($P = 0.66$).

5.3.3 White Perch

The special study on white perch ichthyoplankton was conducted in the Poughkeepsie region. The study was designed to determine whether PYSL white perch make use of shallow beach and shore zones, and whether abundance estimates from bottom upriver strata can be used to estimate abundance in unsampled upriver shoals, including shore zones.

The distribution of white perch ichthyoplankton in the Poughkeepsie region can be compared with the distribution among strata in the Catskill region during the shad special study. These data were collected three weeks earlier (18 May 1988) than the white perch data (8 June 1988). Although the study was not designed to evaluate the distribution of eggs among strata, analysis of egg

TABLE 5-19

EGGS AND LARVAE OF BAY ANCHOVY AVERAGE CPUE (No./1000 m^3) IN THE TAPPAN ZEE REGION

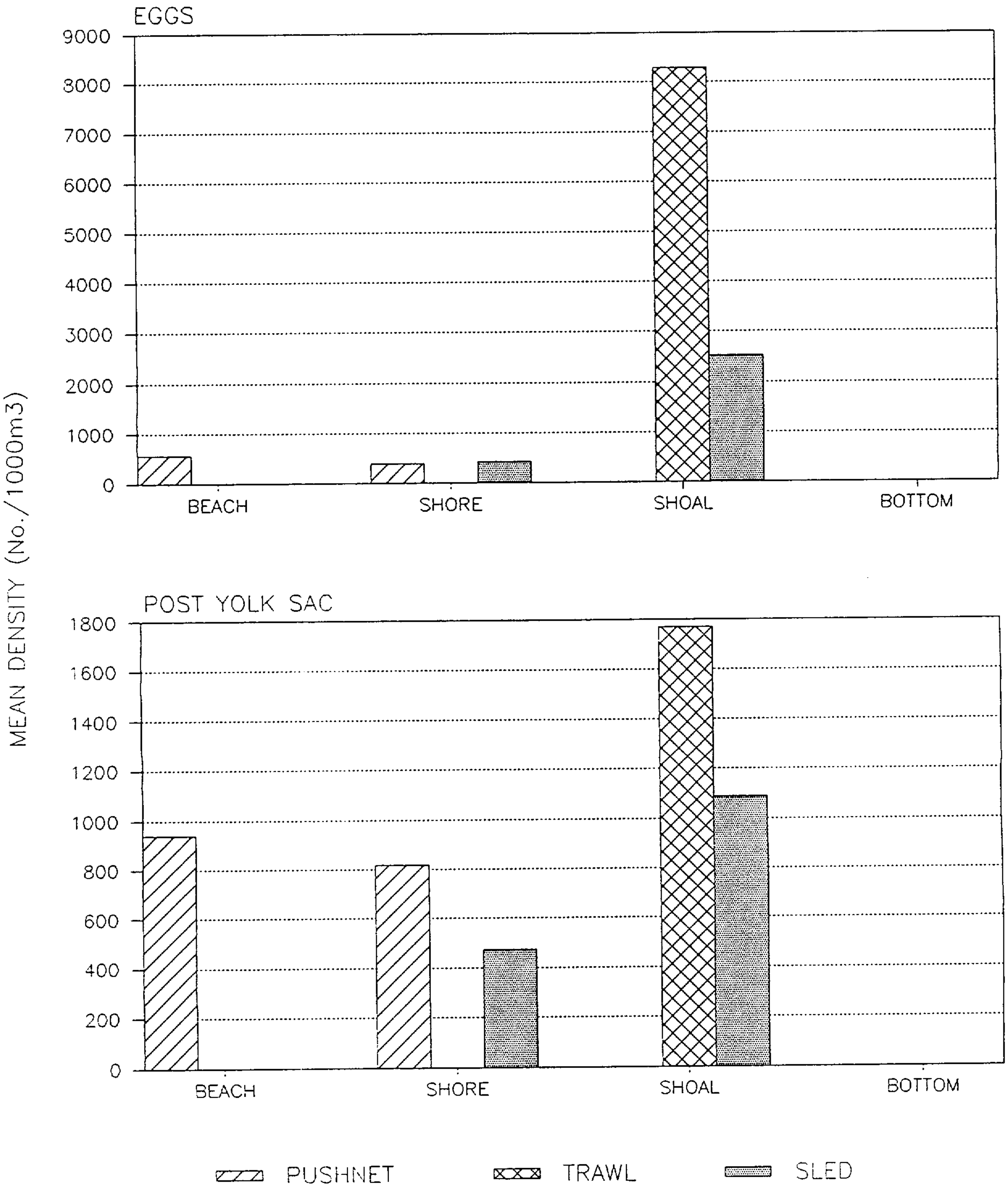
STRATA GEAR	LIFE STAGE								
	EGGS			YOLK-SAC			POST-YOLK-SAC		
	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]
Beach									
Pushnet	561	15	B	0.2			940	456	A
Shore									
Pushnet	391	32	B				819	689	A
Epibenthic sled	420	112	A B				474	401	A
Shoals									
Epibenthic sled	2534	538	A	5			1088	728	A
Tucker trawl	8290	978	A				1771	620	A
F Value		7.59			-			0.61	
Probability		0.0001			-			0.66	

[a]Means with the same letter are not significantly different.

FIGURE 5-3

BAY ANCHOVY ICHTHYOPLANKTON FROM THE TAPPAN ZEE REGION, 1987:

COMPARISON OF MEAN DENSITY (No./1000m3) BY STRATA



data indicated that significantly more eggs were collected from bottom and shoal strata for both the Poughkeepsie (Table 5-20; Figure 5-4) and Catskill (Table 5-21; Figure 5-5) regions. Collections in shallow strata produced fewer eggs.

White perch deposit demersal adhesive eggs in upriver embayments and tributaries. The eggs are easily dislodged and collected with ichthyoplankton sampling gear (Lippson et al. 1980). Thus, egg distribution may not adequately reflect deposition locations or dominant strata. The distribution of eggs observed during the special study, especially those collected by Tucker trawl, may reflect locations of eggs dislodged by strong currents and freshwater runoff patterns.

Few YSL were collected in the Poughkeepsie region. In the Catskill region YSL were collected from all strata by all gear types. Although CPUEs were statistically different, there was no apparent pattern to the differences with reference to distribution among strata. In general, however, epibenthic sleds in the Catskill region collected fewer white perch YSL than either pushnets or the Tucker trawl.

White perch PYSL are more dispersed through sampling regions than eggs or YSL (Klauda et al. 1988). Both the Poughkeepsie and Catskill regions showed statistically significant differences in CPUE by strata, although the pattern was not consistent between regions. The upriver Catskill region sampled between 18 and 22 June produced catches that were relatively similar among strata; catches by epibenthic sled, however, were lower than those from other gear deployed in the same stratum. In Poughkeepsie, catches of PYSL from shore, shoal, and bottom strata were similar. In contrast to the Catskill region, catches from epibenthic sleds were similar or higher than those of other gear.

To summarize, pushnets rather than sleds collected more white perch PYSL in the Catskill region, but the opposite was true in the Poughkeepsie region. Assuming that these statistically significant differences are real, they must

TABLE 5-20

EGGS AND LARVAE OF WHITE PERCH CPUE (No./1000 m^3) IN THE POUGHKEEPSIE REGION

STRATA GEAR	LIFE STAGE								
	EGGS			YOLK-SAC			POST-YOLK-SAC		
	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]
Beach									
Pushnet	23	5	B	2	0.7	A B	105	80	C
Shore									
Pushnet	1	0.2	B	1	0.3	B	353	309	B
Epibenthic sled	1	0.5	B	3	2.1	A	1382	969	A
Shoals									
Epibenthic sled	11	3	B	>1	0.1	A B	662	600	A B
Tucker trawl	164	14	A	1	0.4	B	719	569	A B
Bottom									
Epibenthic sled	254	5	A B	2	0.8	A B	912	713	A
F Value		2.91			2.62			25.04	
Probability		0.02			0.03			0.0001	

[a]Means with the same letter are not significantly different.

FIGURE 5-4

WHITE PERCH ICHTHYOPLANKTON FROM THE CATSKILL REGION, 1987:

COMPARISON OF MEAN DENSITY (No./1000m3) BY STRATA

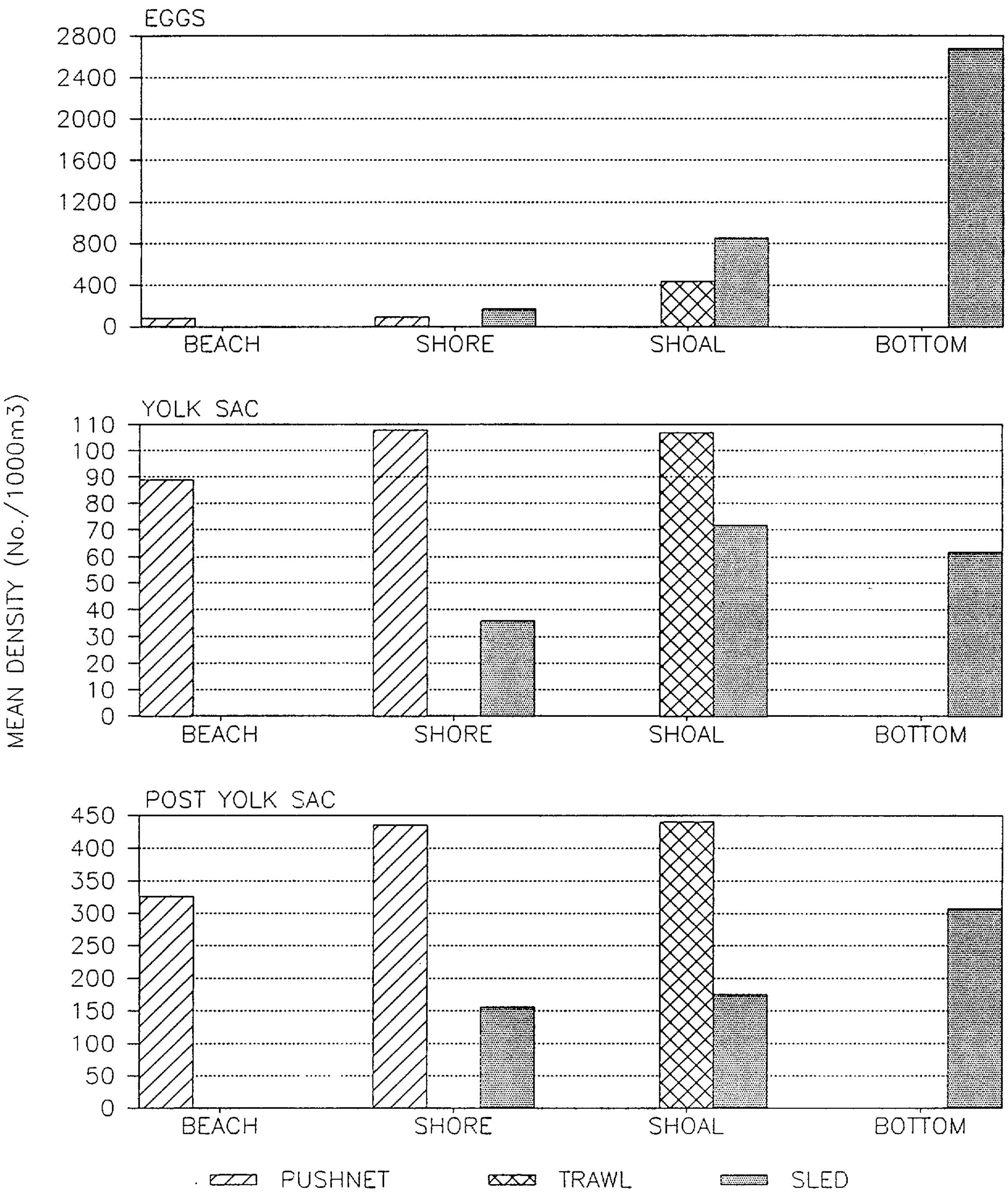


TABLE 5-21

EGGS AND LARVAE OF WHITE PERCH CPUE (No./1000 m^3) IN THE CATSKILL REGION

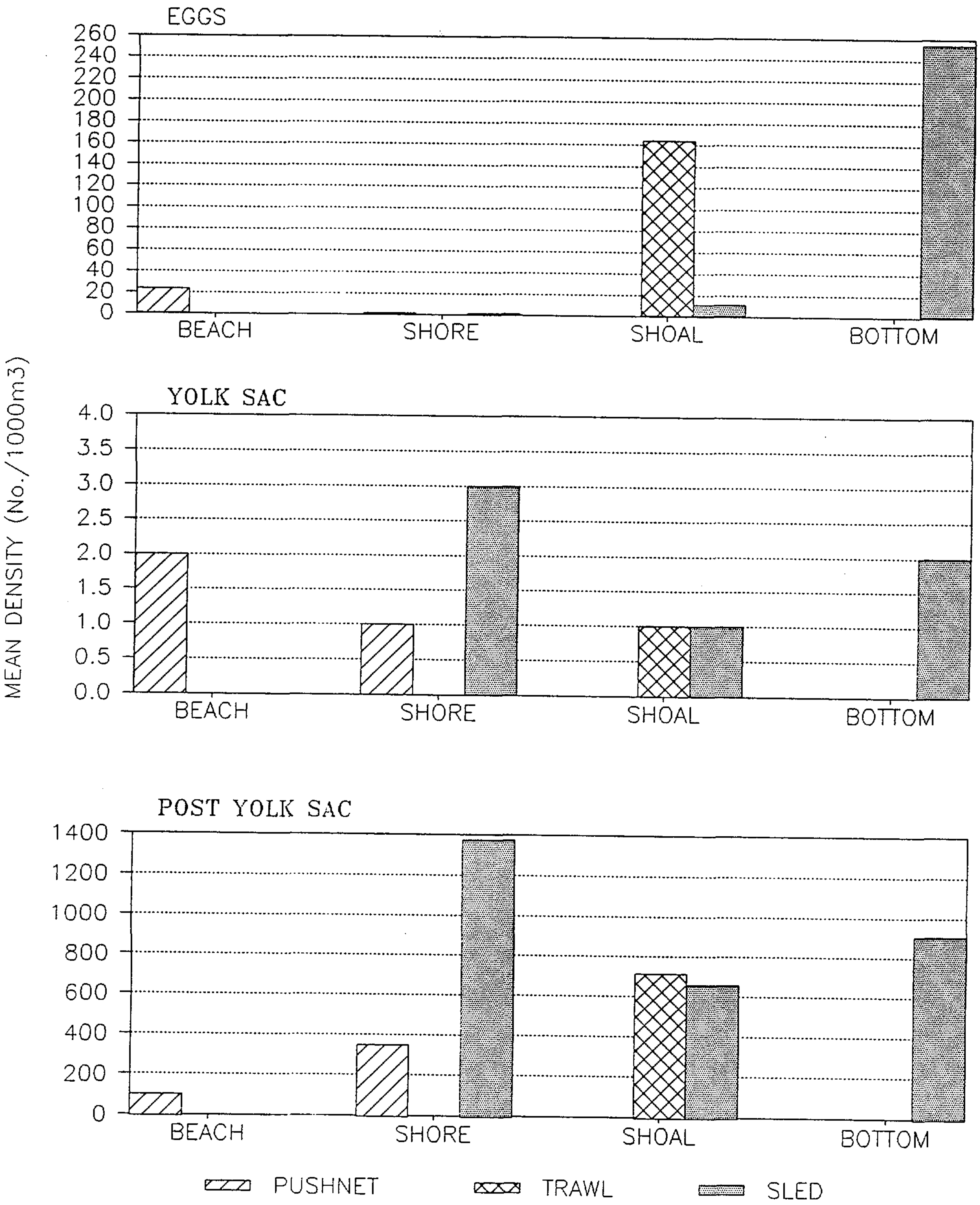
STRATA GEAR	LIFE STAGE								
	EGGS			YOLK-SAC			POST-YOLK-SAC		
	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]	MEAN	MEDIAN	SNK[a]
Beach									
Pushnet	81	8	D	89	72	A	326	166	B C
Shore									
Pushnet	89	16	D	108	81	A	435	342	A
Epibenthic sled	168	29	C D	36	27	B	156	110	C
Shoals									
Epibenthic sled	852	163	B	72	56	A	175	135	C
Tucker trawl	435	72	B C	107	84	A	440	340	A
Bottom									
Epibenthic sled	2671	863	A	62	35	B	308	243	A B
F Value		21.84			9.70			8.68	
Probability		0.0001			0.0001			0.0001	

[a]Mean with the same letter are not significantly different.

FIGURE 5-5

WHITE PERCH ICHTHYOPLANKTON FROM THE POUGHKEEPSIE REGION, 1987:

COMPARISON OF MEAN DENSITY (No./1000m3) BY STRATA



be attributable to some regional difference that affects gear deployment. The most obvious difference is the presence of aquatic vegetation, primarily water chestnut, in the upriver Catskill region. The presence or absence of vegetation does not appear to alter distribution among strata.

5.3.4 Striped Bass

The distribution of striped bass PYSL among strata was evaluated from samples collected in the white perch study. Previously unsampled shores and shoals produced significantly more larvae than the previously sampled bottom stratum from the Poughkeepsie region (Table 5-22, Figure 5-6). Of the unsampled regions, shore strata produced significantly larger catches than shoals. No differences were detected between the catches of pushnets and the catches of epibenthic sleds deployed in the shore strata. Collections made by Tucker trawls and epibenthic sleds in the shoals produced similar catches, suggesting that PYSL were relatively evenly distributed through the water column during the special study.

5.3.5 Impact of Unsampled Shoals on Standing Crop Estimates

Results of analyses to identify statistically significant differences in abundance of target species and life stages among strata differed by species and life stage (Table 5-23). No statistically significant differences were identified for white perch or bay anchovy PYSL, but statistically significant differences were identified in the distribution of shad and striped bass ichthyoplankton. PYSL of both species were more abundant in shallow water than in deeper water. American shad PYSL were more abundant in beach and shore strata than in shoal and bottom areas. The impact of this distribution is relatively small because the beach and shore strata constitute approximately one-quarter of the total shoal. Striped bass PYSL are more abundant in both shoals and shore zones than in the bottom stratum. Abundance in the beach strata was similar to that in the bottom. The beach is the shallow-water portion of the shore, which in turn is only one-quarter of the total

TABLE 5-22

EGGS AND LARVAE OF STRIPED BASS CPUE (No./1000 m^3)
IN THE POUGHKEEPSIE REGION

STRATA GEAR	EGGS MEAN	EGGS MEDIAN	EGGS SNK[a]	YOLK-SAC MEAN	YOLK-SAC MEDIAN	YOLK-SAC SNK[a]	POST-YOLK-SAC MEAN	POST-YOLK-SAC MEDIAN	POST-YOLK-SAC SNK[a]	RATIO TO BOTTOM
Beach										
Pushnet	>1			12			321	275	C	
Shore										
Pushnet	0			3			2684	2484	A	6.5
Epibenthic sled	4			5			3093	2079	A	7.5
Shoals										
Epibenthic sled	9			1			910	828	B	2.2
Tucker trawl	0			3			1103	930	B	2.7
Bottom										
Epibenthic sled	9			3			410	302	C	
F Value								23.83		
Probability								0.0001		

[a]Means with the same letter are not significantly different.

FIGURE 5-6

STRIPED BASS ICHTHYOPLANKTON FROM THE POUGHKEEPSIE REGION, 1987:

COMPARISON OF MEAN DENSITY (No./1000m3) BY STRATA

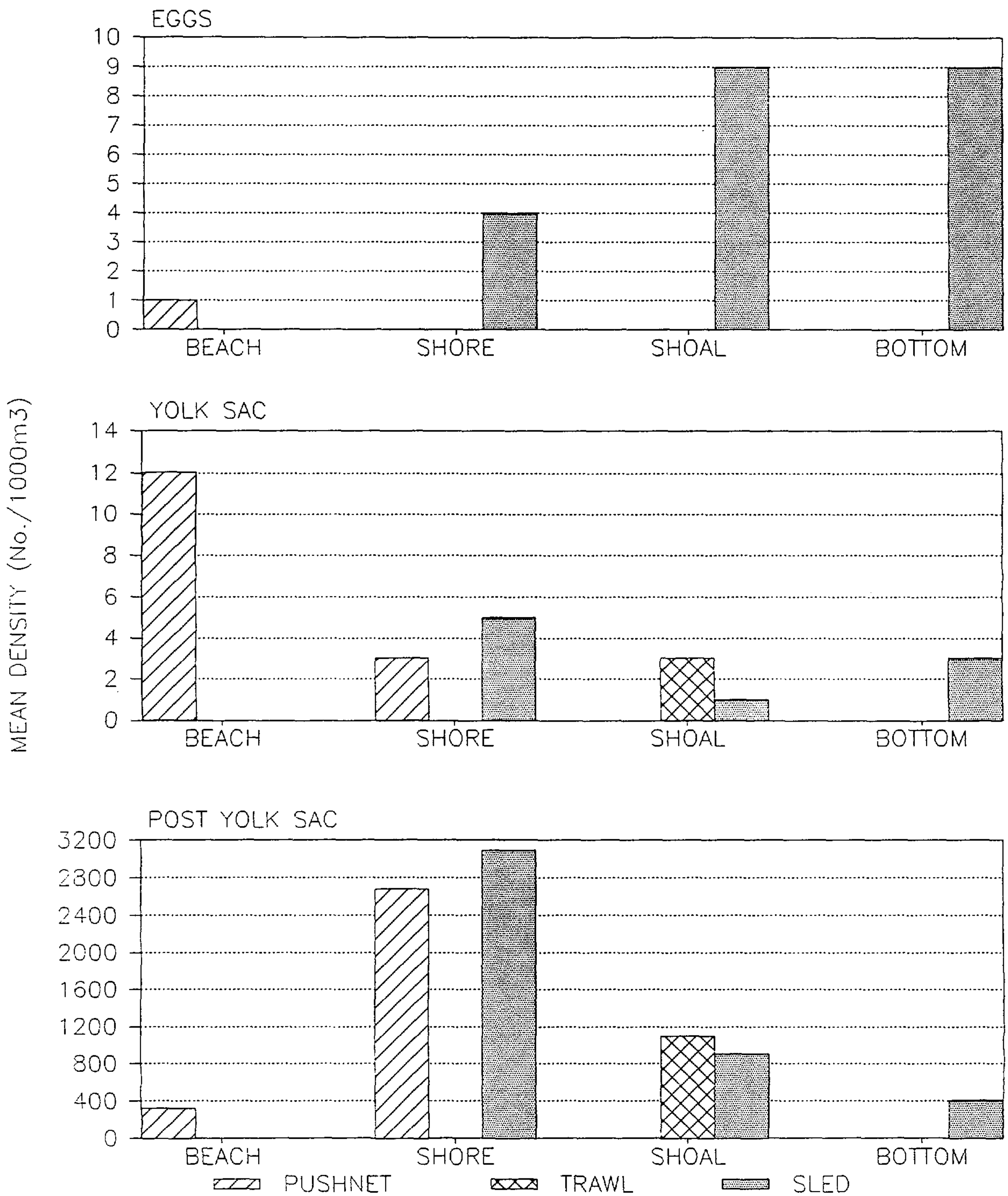


TABLE 5-23

SUMMARY OF STATISTICAL ANALYSES COMPARING ABUNDANCE IN PREVIOUSLY SAMPLED BEACHES AND SHOALS WITH ABUNDANCE IN ADJACENT BOTTOM STRATA

TARGET	STATISTICAL RESULT	Pr > F
American shad		
Eggs	Bottom > shoals > shores	0.0001
Yolk-sac	NSD	0.2749
Post-yolk-sac	Beach and shores > shoals and bottom	0.0001
Striped bass (PYS)	Shores > shoals > bottom and beach	0.0001
White perch (PYS)	NSD	0.1010
Bay anchovy (PYS)	NSD	0.6577

NSD - Not statistically different at 0.05 level.

shoals volume. For both species bottom abundance data underestimate the abundance of PSYL in the shoals; thus, historic standing crop data may be low.

Of each of the target species and life stages, only American shad eggs were present in significantly greater abundances in bottom samples as compared to adjacent shoals and shores. This distribution suggests that historic standing crop estimates, based on the assumption that bottom abundance adequately represents the adjacent shore, and shoal abundance would overestimate the actual standing crop for eggs of American shad.

5.3.5.1 Standing Crop Estimates for Striped Bass Post-Yolk-Sac Larvae. Weekly standing crops for selected species and life stage are estimated from CPUE data collected during the LRS. Riverwide, total standing crop estimates are based on weekly estimates. Where CPUE data are unavailable, i.e., shore and beach strata plus upriver shoals, the abundances in adjacent strata are used to estimate standing crop in unsampled strata. Results of the special study on PYSL striped bass indicate that the abundance in the Poughkeepsie shore strata is 7 times that in the adjacent bottom stratum (Table 5-22). Abundance in unsampled shoals is approximately 2.5 times that in the adjacent bottom. Using these distributional ratios, standing crop estimates for the week of the special study were compared with historic estimates based on equivalent abundance in previously sampled and unsampled strata (Table 5-24). Estimates are calculated on a region-by-region basis to reflect the actual distribution of striped bass PYSL throughout the river. The Albany region, which is the largest unsampled shoals area, did not include any striped bass larvae (Table 5-25). The peak of striped bass PYSL fell in the Poughkeepsie vicinity, i.e., the area sampled during the special study.

Abundance in shoals was approximately 2.5 times the abundance in the bottom. In order to calculate standing crops based on abundance distribution ratios, the shore and beach strata were estimated to represent one-quarter of the total shoal volume. The beach and shore volumes were not separated, even though data suggest that their abundances may differ. The standing crop of bottom strata adjacent to unsampled shoals was 81 million PYSL. Using the

TABLE 5-24

COMPARISON OF STANDING CROP ESTIMATES (IN THOUSANDS)

	STRIPED BASS POST-YOLK-SAC
Bottom abundance adjacent to unsampled shoals	81,385
Shoals based on bottom abundance (historic method)	7,529
Shoals based on underestimation factors of 7 for shores and 2.5 for shoals	19,680
Total standing crop	657,160

TABLE 5-25

1987 LONGITUDINAL RIVER SURVEY STANDING CROP DATA (IN THOUSANDS) FOR STRIPED BASS POST YOLK-SAC LARVAE AND YOUNG OF YEAR FROM 08JUN87 TO 12JUN87 . STANDARD ERRORS (IN THOUSANDS) ARE PRINTED BELOW EACH STANDING CROP. "NS" INDICATES THAT THE STRATUM WAS NOT SAMPLED.

REGION	POST YOLK-SAC LARVAE			YOUNG-OF-YEAR		
	CHANNEL	BOTTOM	SHOAL	CHANNEL	BOTTOM	SHOAL
YONKERS	0 0	0 0	0	0 0	0 0	0
TAPPAN ZEE	365 134	129 129	405 269	0 0	0 0	0 0
CROTON-HAVERSTRAW	654 249	1236 516	1491 275	0 0	0 0	0 0
INDIAN POINT	23483 7599	3742 2271	2280 790	0 0	0 0	0 0
WEST POINT	209919 30763	28655 7042	NS	0 0	0 0	NS
CORNWALL	91787 15251	28214 7087	2408 771	0 0	0 0	0 0
POUGHKEEPSIE'	138869 20058	36181 9590	NS	0 0	0 0	NS
HYDE PARK	52667 6783	7813 2135	NS	0 0	0 0	NS
KINGSTON	7211 2839	6666 3784	NS	0 0	0 0	NS
SAUGERTIES	2926 2114	1678 632	NS	0 0	0 0	NS
CATSKILL	385 249	392 192	NS	0 0	0 0	NS
ALBANY	77 77	0 0	NS	0 0	0 0	NS
TOTAL STANDING CROP	528343 41204	114704 14715	6584 1169	0 0	0 0	0 0

assumption that bottom abundance represents shoal abundance, the standing crop in adjacent shoals was estimated at 7.5 million striped bass PYSL. Revised estimates based on distributional ratios attribute 19.7 million larvae to unsampled shoals, which is higher than historic estimates by 12 million larvae.

In comparison to the total standing crop estimate of 60,057 million larvae, the underestimate is only 1.8%, less than the standard error associated with abundance in bottom samples (14.7 million larvae). Since the underestimate is small in comparison to both the total weekly standing crop and the standard errors associated with standing crops data, historic standing crops do not appear to be substantially biased as a result of substituting bottom density values for the shoals.

5.4 SUMMARY OF FINDINGS

5.4.1 Juveniles

1. Pushnets deployed in shore strata collected few juvenile fish.

2. Abundance of juvenile fish is similar for previously sampled beaches and beaches that have not been sampled.

3. Beam trawl collections in previously sampled and previously unsampled shore zones (5-10 ft) demonstrate that abundance is similar in these areas.

4. Abundance of American shad and Atlantic tomcod was not statistically different between previously unsampled shoals and adjacent bottom strata.

5. In 1987 striped bass were more abundant in shoals than in bottom strata.

6. Bay anchovy were more abundant in shoals than in bottom strata in 1986.

7. White perch juveniles were more abundant in shoals than in adjacent bottom strata for both sampling years.

8. In general, the assumption that abundance in bottom strata is equivalent to abundance in adjacent unsampled shoals results in reasonable or conservatively low standing crop data.

5.4.2 Ichthyoplankton

1. For most species, pushnets deployed in shore zones adequately sample available life stages.

2. No differences in abundance among strata were identified for American shad yolk-sac larvae or for striped bass, white perch, and bay anchovy post-yolk-sac larvae.

3. Shallow, previously unsampled strata produced greater abundance of striped bass post-yolk-sac larvae. Historic standing crop data for this species are likely to be conservatively low.

4. Shad eggs were more abundant in bottom samples than in previously unsampled shoals. Historic standing crop data for this life stage are likely to be high.

CHAPTER 6

ABUNDANCE INDICES

6.1 INTRODUCTION

An essential element of many fishery evaluation programs is the accurate determination of fish population abundance. The variability in abundance indices from year to year is, in part, determined by the recruitment that occurs annually to each new year class. The number of individuals from a single age group that will be recruited to the adult stock exhibits extensive annual variability in response to biotic and abiotic influences. The biotic factors that regulate fish abundance result from inter- and intra-specific interactions such as predator-prey relationships, competition, and habitat availability. Abiotic influences associated with estuarine communities include physical and chemical factors such as temperature, freshwater discharge, tides, salinity, and dissolved oxygen. Anthropogenic factors that regulate fish populations include fishing exploitation and pollution. Variability in abundance indices is also due to size-specific gear avoidance, spatial and temporal variability in sampling efficiency, and differential selectivity between sampling gears. To reduce this variability in estimating population strength, catch data for one size class (YOY), from the same spatiotemporal window and from surveys with the same or similar sampling methods, are used. Annual abundance indices, based on standardized survey collection techniques, can be utilized to evaluate fish stocks and year-class strength over multiyear periods.

Historically, Hudson River FSS and BSS data have been used to calculate indices of annual year-class strength of selected Hudson River fish populations. Striped bass are of interest because of their recreational and commercial importance. White perch were selected as a target species because they are widespread residents commonly found in entrainment and impingement samples at Hudson River power plants. Indices have also been examined for American shad, Atlantic tomcod, bluefish, and bay anchovy.

Historically, population abundance indices used in year-class reports were based on YOY catch data (Table 6-1); the beach seine index, first used in 1973, uses BSS catch-per-unit-effort (CPUE) data. Weekly combined standing crop (CSC) estimates, first used in the 1974 Year-Class Report, incorporate data from both the FSS and BSS (Young et al. 1988). In order to compare among year changes in abundance, the weekly CSC estimates have been used to generate three separate indices: (1) the peak method index for striped bass (TI 1981), (2) the geometric mean index for white perch (TI 1981), and (3) summer and fall regression indices for both species (NAI 1985a). The coordinate pair index was developed from BSS and FSS data in the 1985 Year-Class Report (Versar 1987). As several of the scalar indices have been shown to have characteristics that can cause serious bias or low precision in abundance estimates (Versar 1987), they will not be presented here. Methods for calculating abundance indices used in this Year-Class Report are described in Section 2.6.3. Standing crop estimates for 1986 and 1987 LRS, FSS, and BSS are in Appendix J.

The purpose of this chapter is to present the results of the 1986 and 1987 year-class abundance indices and to evaluate long-term abundance trends. The results presented were determined by using the standardized methods developed by TI (Young et al. 1988) and Versar (1987) in an attempt to eliminate minor differences that previously existed in calculation of the indices among years. Year-to-year comparisons of riverwide abundance are presented as well as apparent long-term trends in year-class strength.

6.2 HUDSON RIVER RECRUITMENT INDICES

6.2.1 Univariate Indices

CPUE, the simplest index of fish stock abundance, is the basis for evaluating many fisheries (Gulland 1966). CPUE is calculated by dividing the number of individuals of a particular species captured by the effort expended in obtaining the individuals. Effort can be based on sample time, number of samples, area, or volume. For the BSS the effort is the number of seine hauls conducted and for the FSS the effort is volume of water filtered.

TABLE 6-1

INDICES OF RELATIVE YEAR-CLASS STRENGTH PRESENTED IN HUDSON RIVER YEAR-CLASS REPORTS (1973-1985)

INDEX	FIRST APPLIED IN:	FIRST APPLIED TO:	CITATION
Beach seine catch per unit area	1973	Striped bass White perch Bluefish	TI (1975)
Combined standing crop - peak and no extrapolation	1974	Striped bass White perch Atlantic tomcod	TI (1977)
Combined standing crop - peak and extrapolation	1979	Striped bass	TI (1981)
Combined standing crop - geometric mean and extrapolation	1979	White perch	TI (1981)
Combined standing crop - summer and fall regression	1982	Striped bass White perch	NAI (1985a)
Coordinate pair	1985	Striped bass White perch American shad Bay anchovy	Versar (1987)

Source: Versar (1987).

The BSS and FSS CPUE were calculated for YOY striped bass, white perch, American shad, and bay anchovy. Beach seine data collected using the same gear and methodology were available from all segments of the lower Hudson River estuary for the years 1974 through 1987. The sampling period in common among the 14 years is the nine-week period extending from the second week in August (week 33) through the middle of October (week 41) (Figure 6-1). The FSS information included epibenthic sled samples (1974-1984), beam trawl samples (1985-1987), and Tucker trawl samples (1974-1987). The FSS also included information from three depth components (shoal, channel, and bottom) (Figures 6-2 through 6-4). The sampling period in common among the 14 years is the nine-week period extending from the first week in August (week 32) through the middle of October (week 40) (Figure 6-5). The temporal and spatial extent used to calculate BSS and FSS seasonal average CPUEs for YOY striped bass, white perch, American shad, and bay anchovy is the same as that utilized in the unweighted bivariate index (see Section 6.2.3). The sampling regions and dates used to calculate the 1986 and 1987 BSS and FSS CPUE are the same as used in previous years (Versar 1987), permitting long-term trend analysis.

No overall trend in striped bass juvenile abundance with time was apparent from the 1974-1987 BSS or FSS CPUE index values (Figure 6-6). The striped bass BSS CPUE index peaked in 1978 (9.0/haul) and in 1987 (13.0/haul); the lowest value observed occurred in 1985 (1.0/haul). The striped bass FSS stock index peaked in 1977 (8.8/1000 m^3) and then declined to 0.1/1000 m^3 in 1985, the lowest value observed in the 14-year program.

Both the BSS and FSS stock indices for white perch exhibited peak values in 1979 followed by a decline in the FSS index through 1987 (Figure 6-7). There was also a decrease in the BSS index from 1979 to 1984, but in contrast to the FSS index this period is followed by an increase from the low of 4.0/haul recorded in 1984 to 9.0/haul in 1987. During the 1970s the FSS CPUE index for white perch varied considerably; the highest index value was recorded in 1975 at 5.8/1000 m^3.

FIGURE 6-1

HUDSON RIVER UTILITIES SAMPLING PROGRAM
Beach Seine Survey

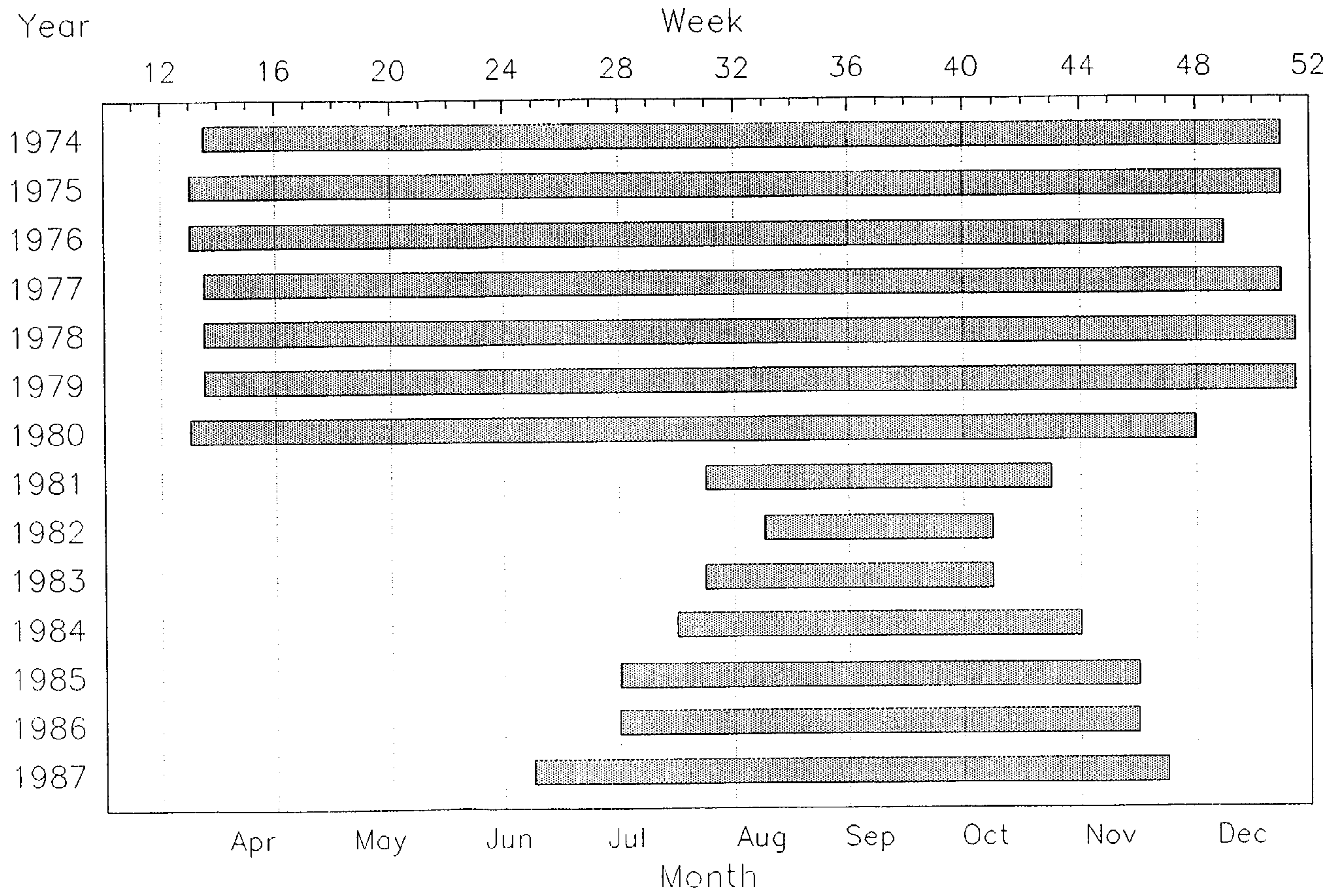


FIGURE 6-2

HUDSON RIVER UTILITIES SAMPLING PROGRAM
Shoal Stratum

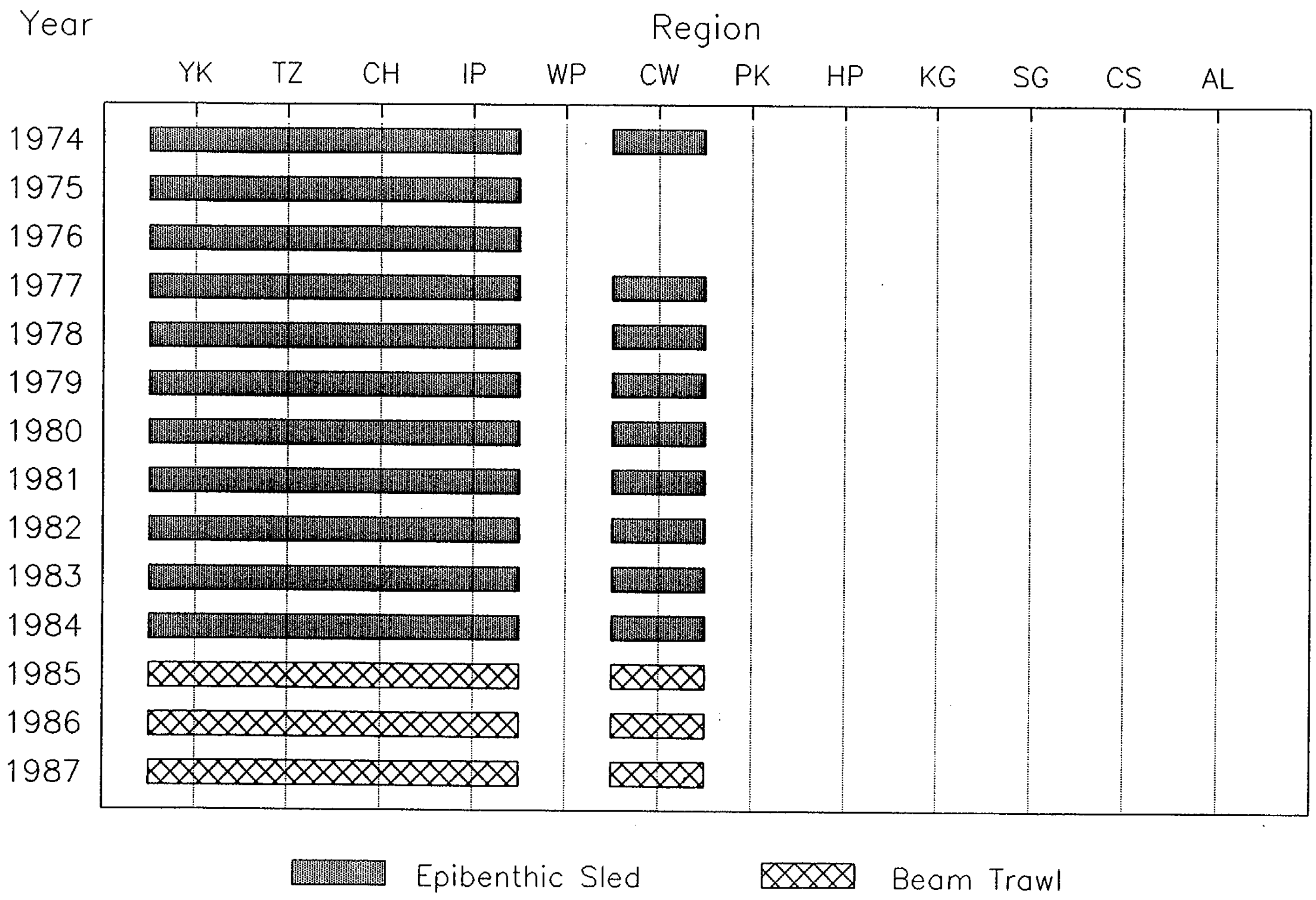


FIGURE 6-3

HUDSON RIVER UTILITIES SAMPLING PROGRAM
Channel Stratum

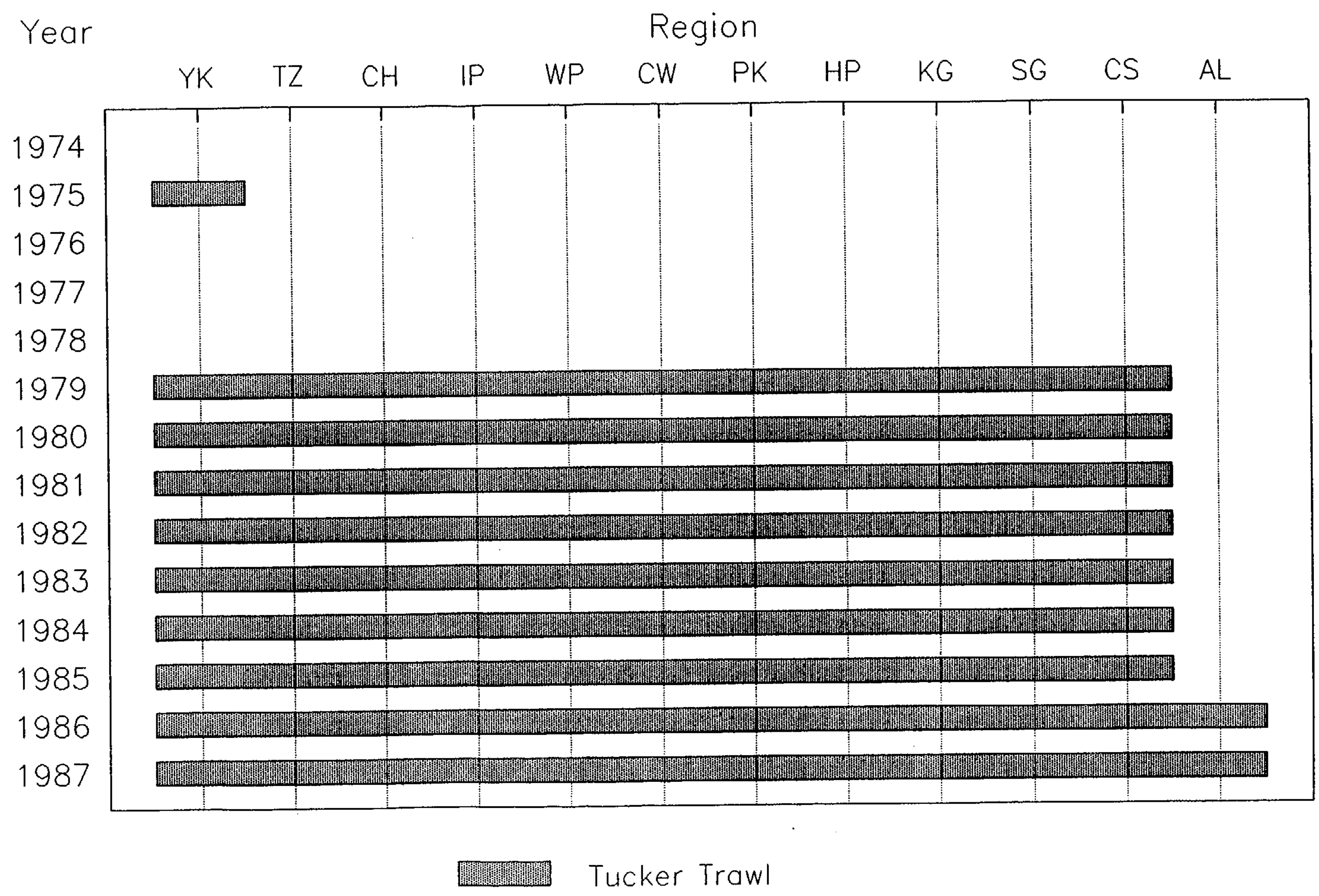


FIGURE 6-4

HUDSON RIVER UTILITIES SAMPLING PROGRAM
Bottom Stratum

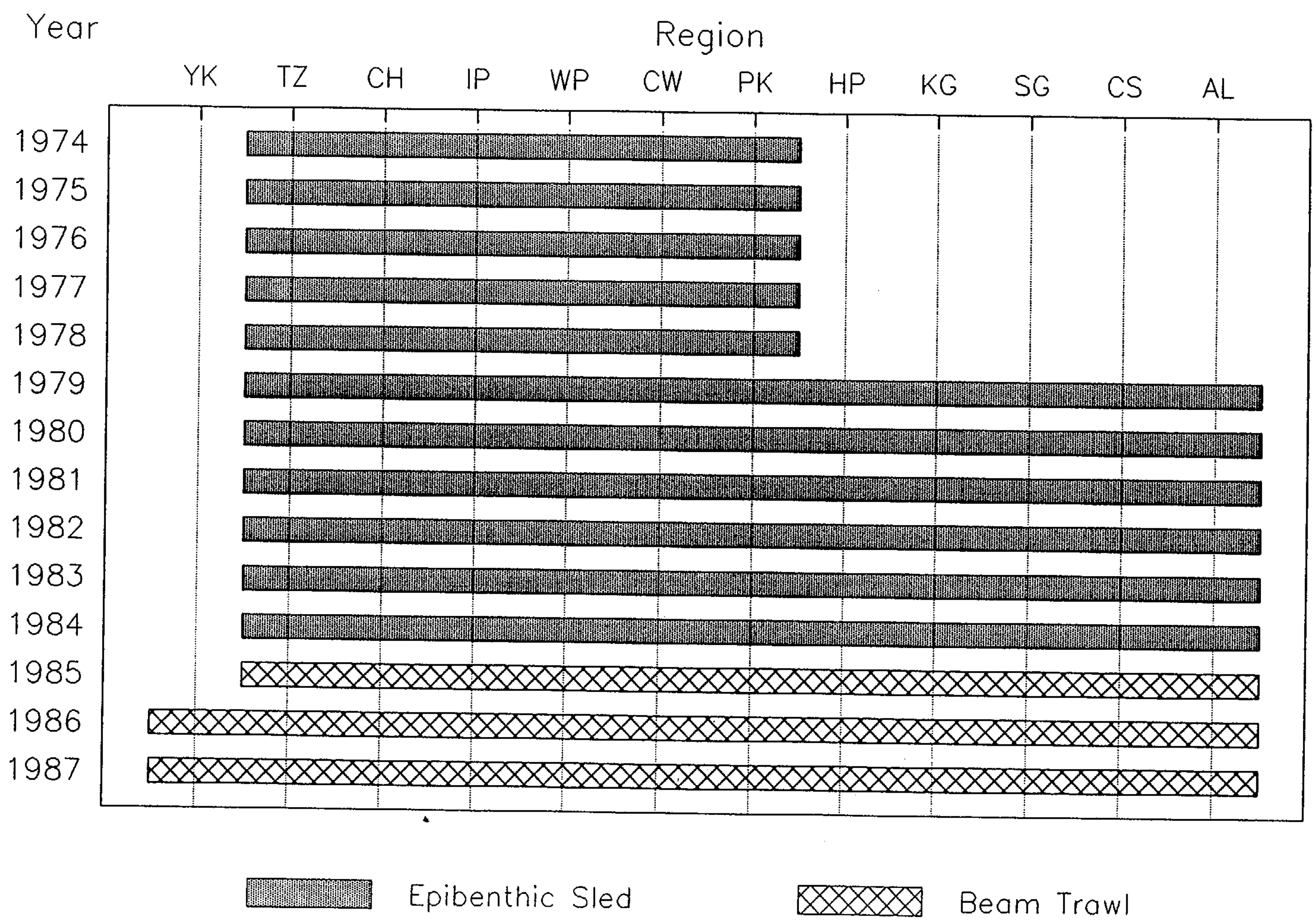


FIGURE 6-5

HUDSON RIVER UTILITIES SAMPLING PROGRAM
Fall Shoals

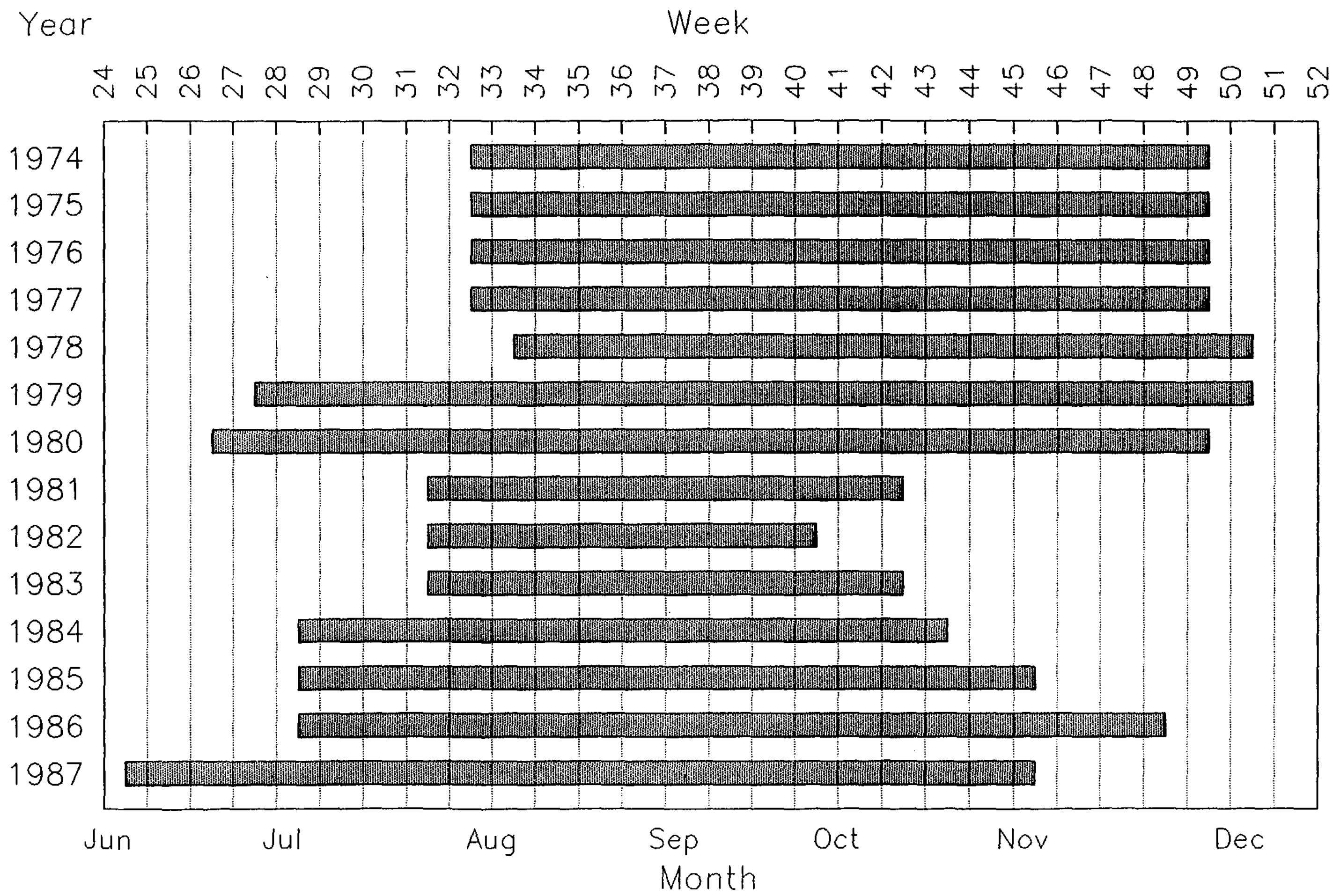
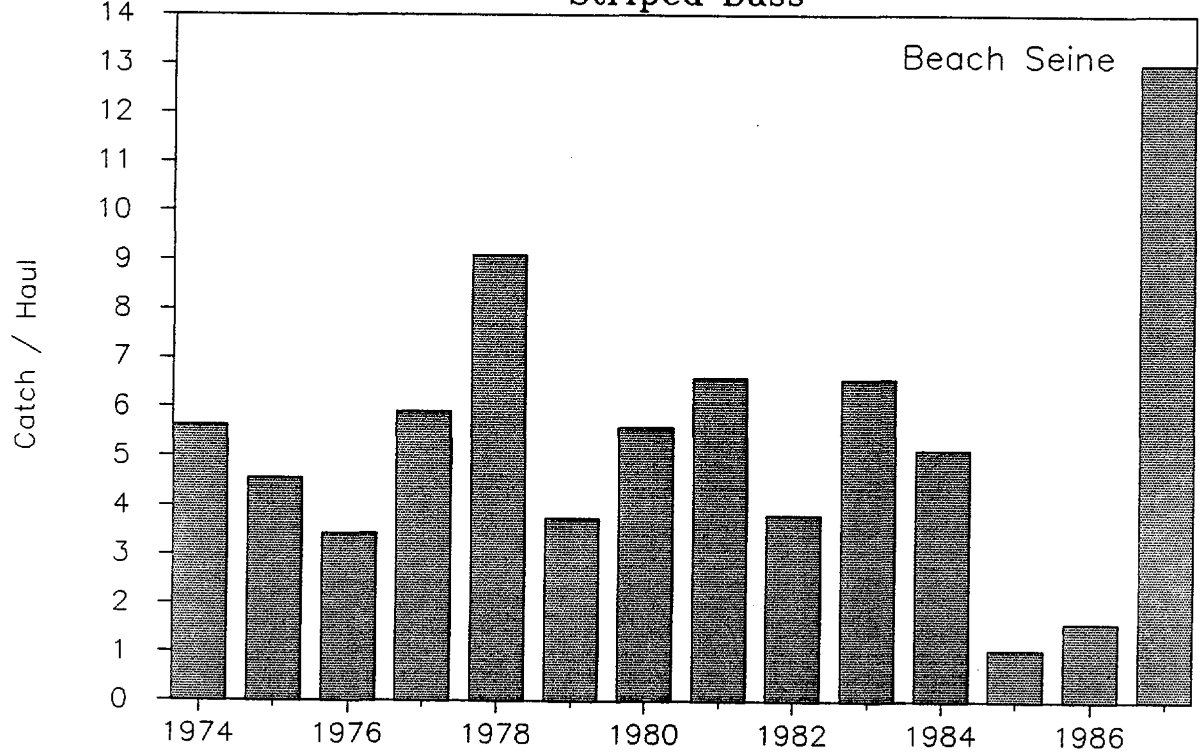


FIGURE 6-6

HUDSON RIVER JUVENILE INDEX

Striped Bass



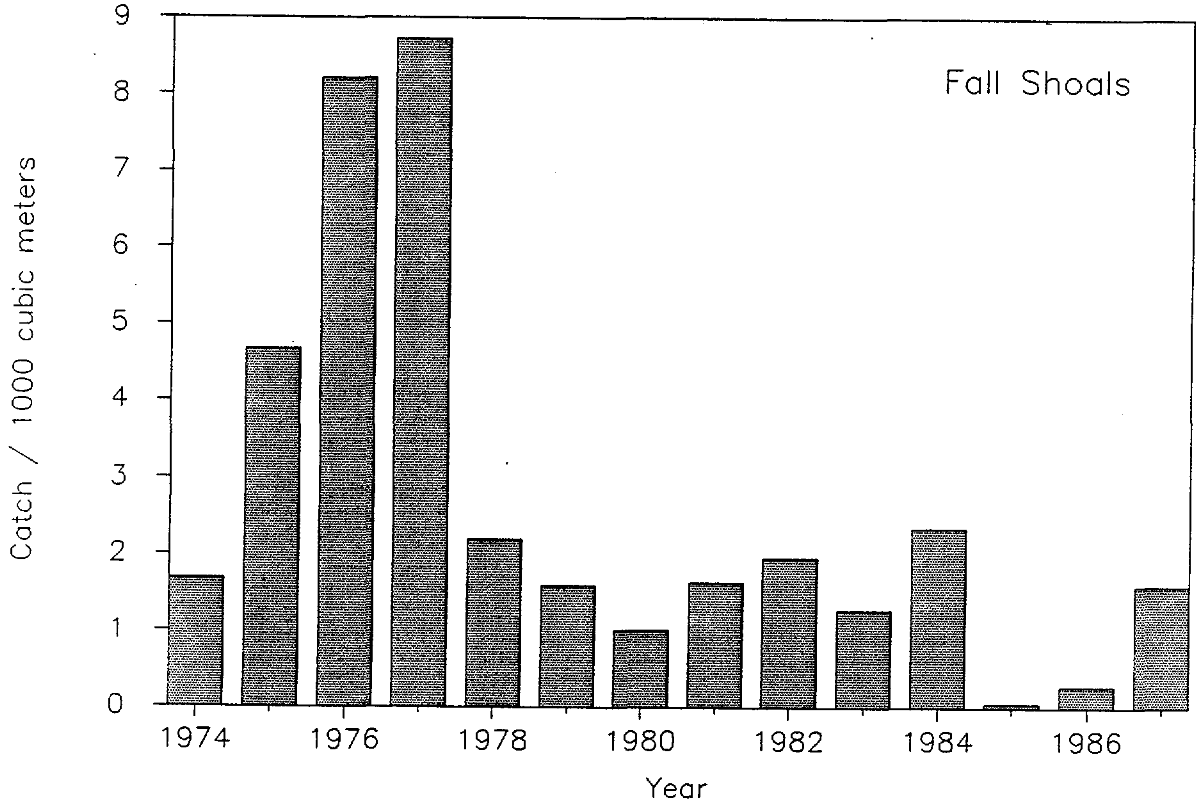
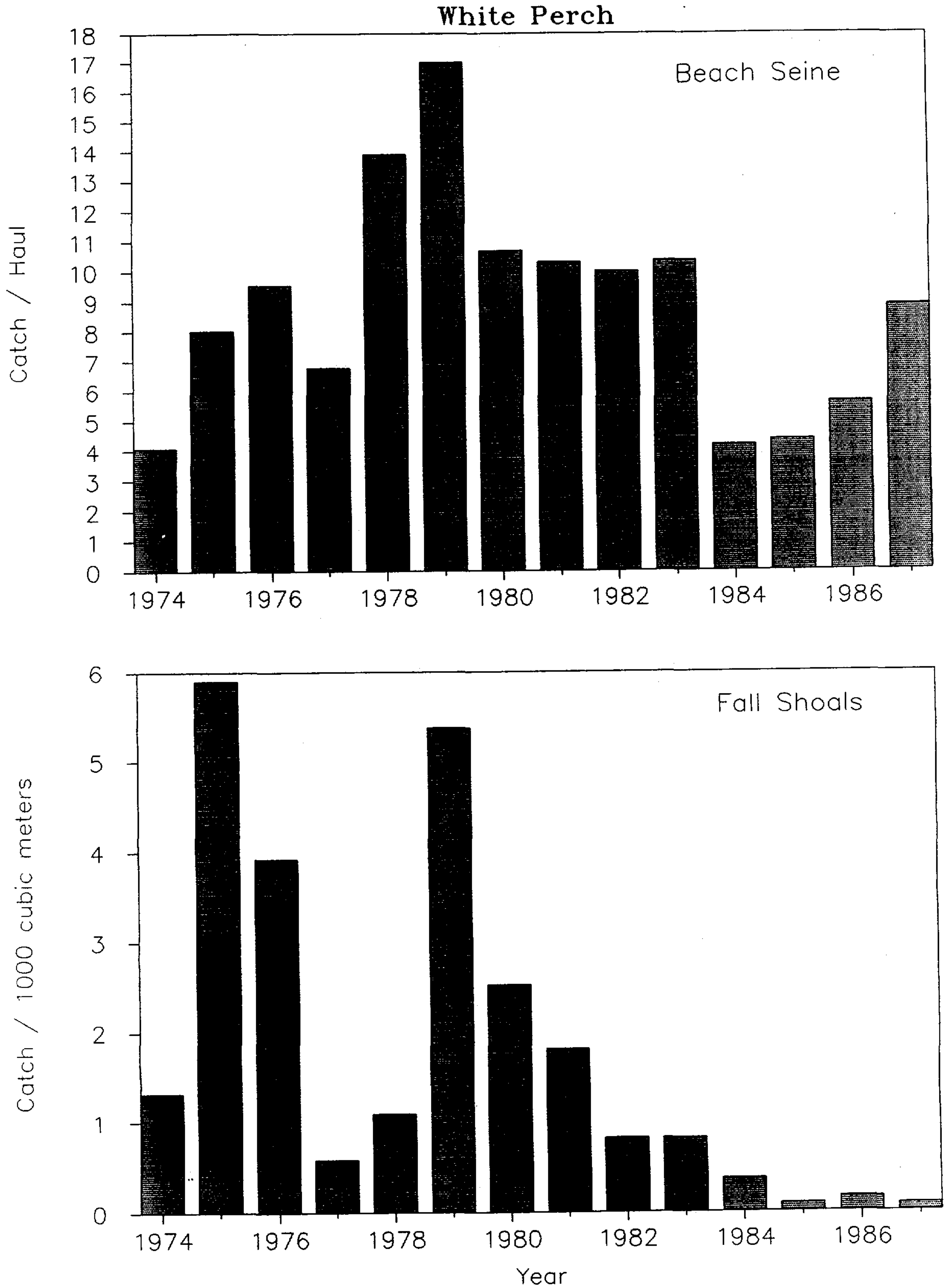


FIGURE 6-7

HUDSON RIVER JUVENILE INDEX



Because of the among year variability no trend in American shad juvenile abundance with time is apparent from either the BSS or FSS juvenile indices (Figure 6-8). The BSS index was high during 1981-1983 and 1986; the nine-year low of 8.0/haul occurred in 1985. The FSS juvenile index also had relatively high values in 1983 and 1986.

The BSS bay anchovy index is highly variable, with substantial shifts between years (Figure 6-9). The 1986 and 1987 BSS indices were intermediate values and close to the long-term average. The FSS juvenile index is also highly variable; the mid-1980's contained relatively lower values.

In 1985 the striped bass and white perch FSS juvenile index values were the lowest observed and for striped bass were large declines from the 1984 index values. BSS juvenile indices, for both these species, also exhibited similar low values during this time. By 1987, the striped bass BSS and FSS juvenile indices had increased. However, the white perch FSS values remained low. American shad exhibited similar declines in the 1984 and 1985 BSS and FSS index values. In the 1985 FSS the epibenthic sled that had been used since 1974 was replaced with a 3-m beam trawl. The drop in the FSS indices since 1984 may, at least in part, be a result of the change in sampling methodology and biased gear adjustment factors derived from a limited comparison study in 1984 (NAI 1986). However, the BSS juvenile indices reflect similar declines. Also, similar declines in YOY striped bass and white perch abundance were observed in 1985-1987 beach seine data from the NYSDEC striped bass study (NYSDEC 1988).

Versar (1987) examined distributional changes between the shore zone and offshore area by comparing the ratio of nearshore to offshore catches. A 12-fold variability in the ratio was found among years, suggesting that the proportion of the population in each sampling stratum is variable between years. Based on the sampling only a single startum, Versar (1987) hypothesized that neither the BSS nor the FSS index may be consistent indices of the river fish populations.

FIGURE 6-8

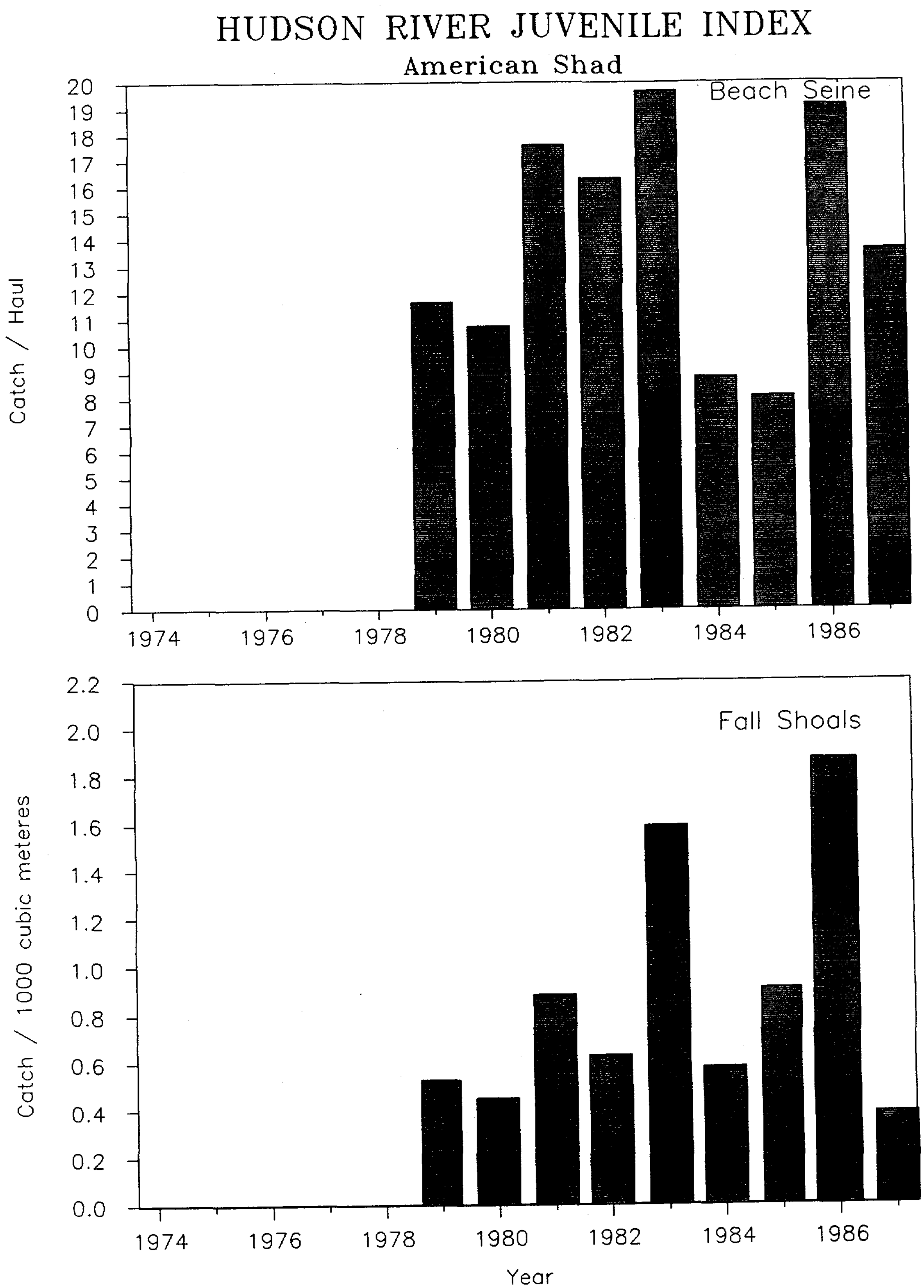
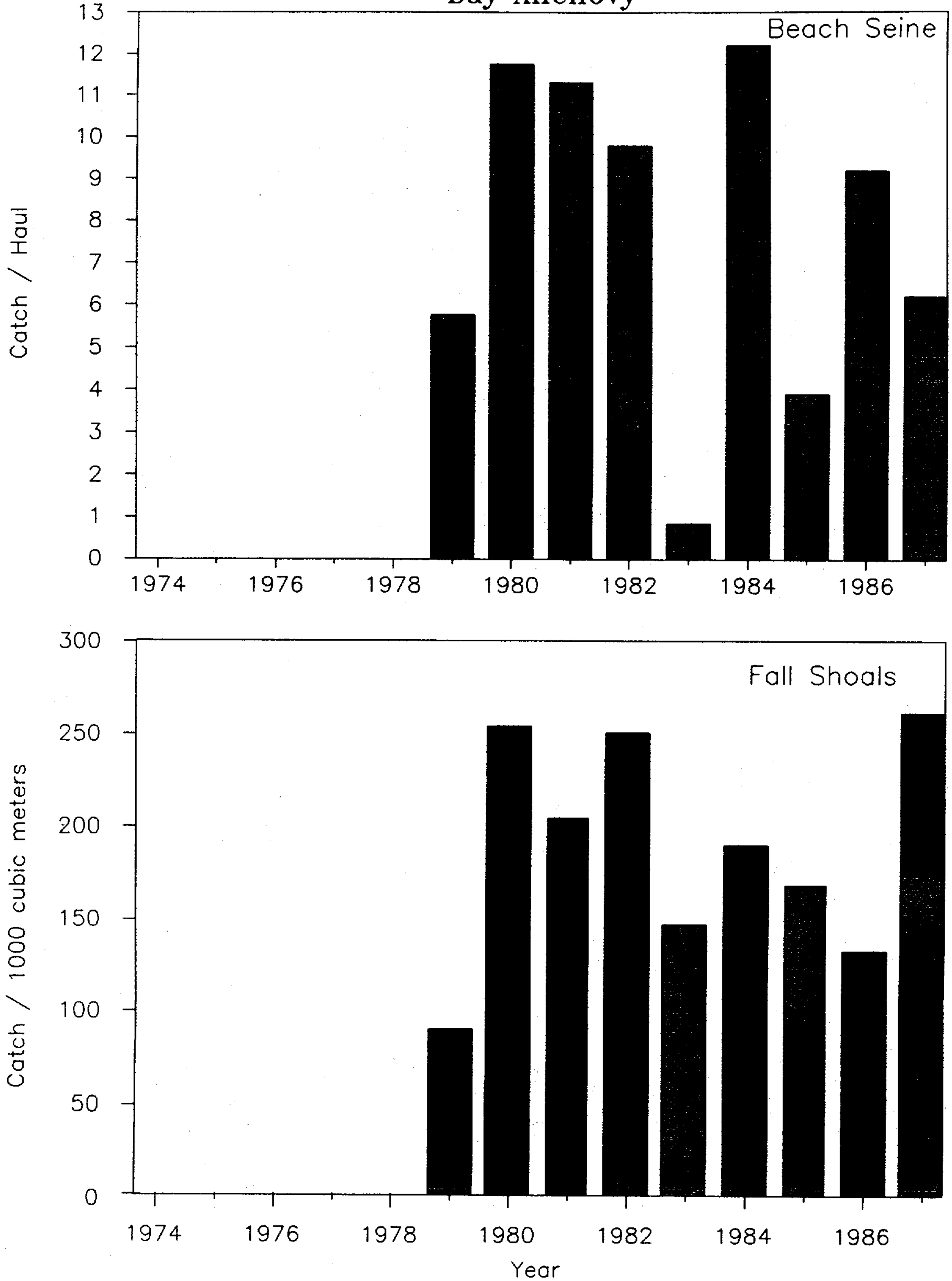

HUDSON RIVER JUVENILE INDEX
American Shad
Beach Seine
Catch / Haul
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1974
1976
1978
1980
1982
1984
1986
Fall Shoals
Catch / 1000 cubic meteres
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1974
1976
1978
1980
1982
1984
1986
Year

FIGURE 6-9

HUDSON RIVER JUVENILE INDEX

Bay Anchovy



6.2.2 Weighted Bivariate Indices

The combined standing crop (CSC) index, an estimate of the number of fish in the river at a given point in time, is based on combined catch data from the BSS and FSS (Young et al. 1988). The CSC is calculated as the sum of the standing crop estimates in the offshore areas (volumetrically expanded FSS density estimates) and the shore zone region (areally expanded BSS density estimates). CSC index values were determined for striped bass and white perch collected during 1986 and 1987.

The CSC index approach improves upon the univariate indices because data from sampling efforts distributed in both nearshore and offshore areas are included, thus minimizing bias associated with habitat preference and diel distribution patterns. The FSS and BSS collection data are weighted based on shore zone surface area for the BSS and strata volumes for the trawls. One concern about the relative weighting factors used is that they do not correspond to the areas and volumes actually subject to random sampling, especially for the BSS where the actual area sampled represents only 2% of the total shore zone (Versar 1987). The portion of the total river covered by the FSS is much higher than that covered by the BSS, and is therefore weighted disproportionally higher. If the proportion of the population subject to sampling in each survey changes from year to year, and the weighting factors for the two surveys are incorrect, year-to-year differences in the CSC may simply reflect changes in distribution patterns rather than abundance.

The weekly CSC index for YOY striped bass in 1986 was at its peak during the sampling weeks of 14 and 21 July, with a second period of increased abundance from the end of August through the middle of September (Figure 6-10). The 1987 riverwide abundance of striped bass YOY was calculated to be at its peak during the sampling weeks of 31 August and 7 September (Figure 6-11). The 1987 peak CSC index value, which was more than seven times greater than the 1986 CSC peak, corresponded in time to the second protracted, but smaller, 1986 period of higher abundance. Typically, striped bass abundance in previ-

FIGURE 6-10

HUDSON RIVER WEEKLY COMBINED STANDING CROP

Striped Bass – 1986

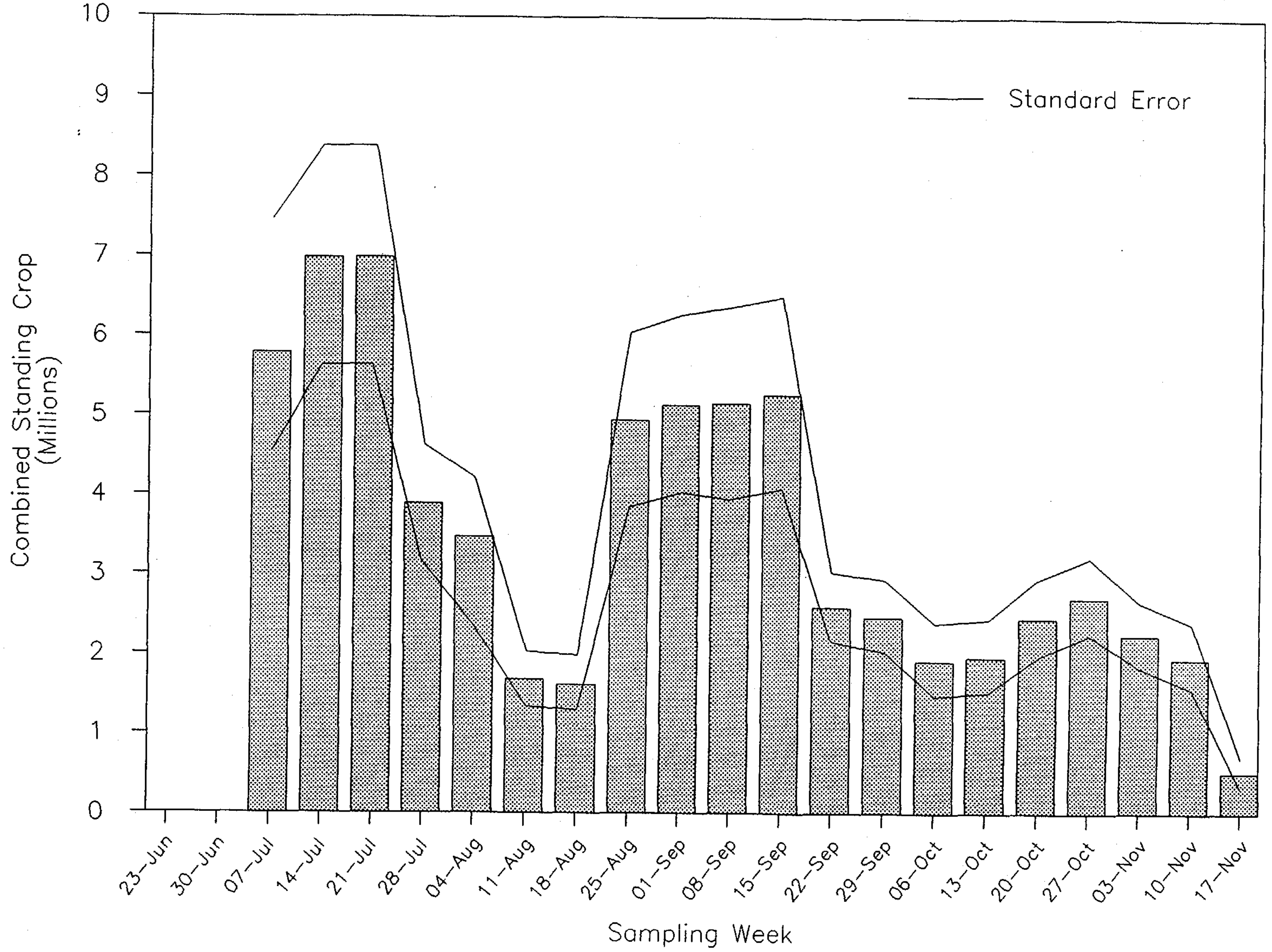
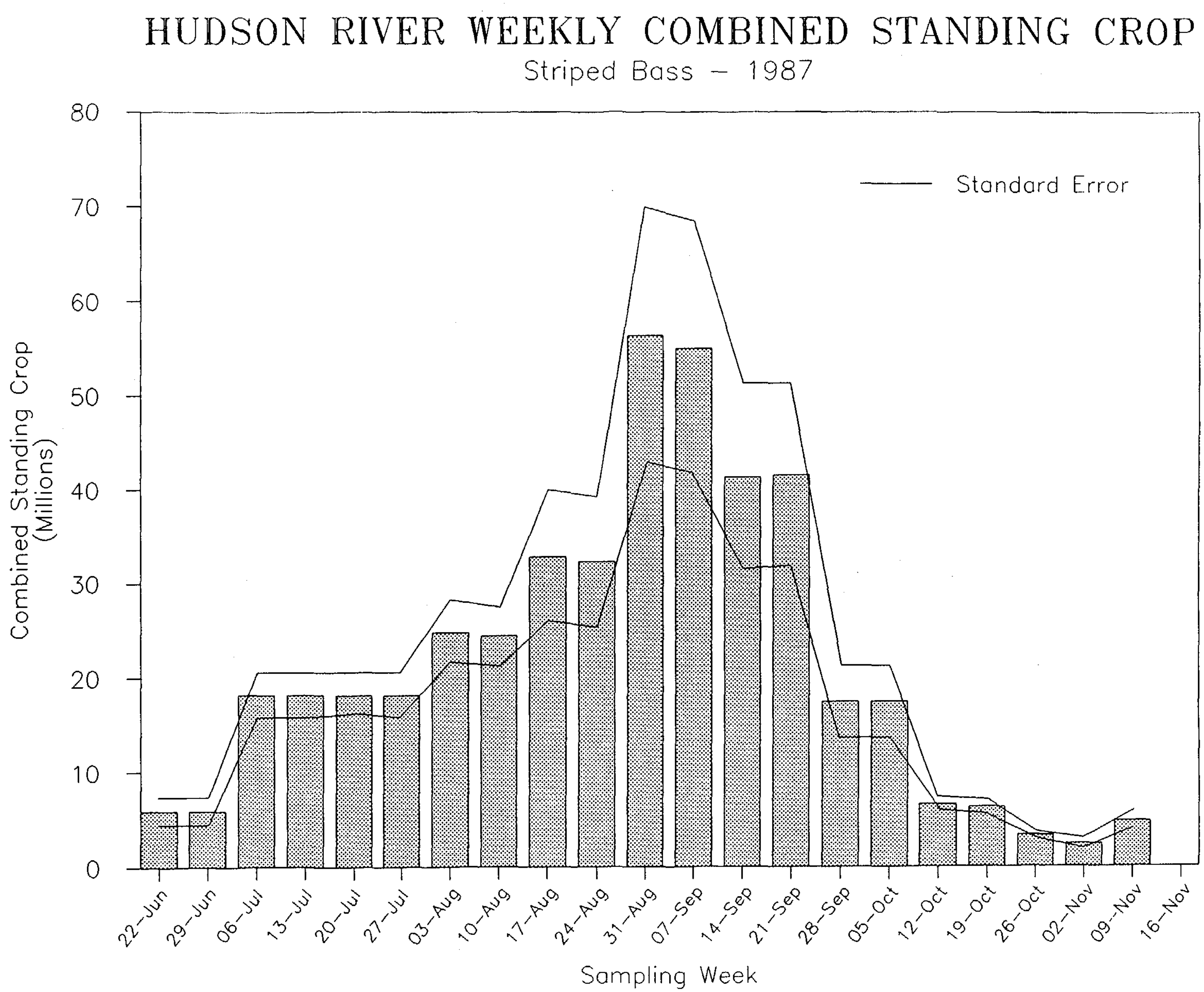


FIGURE 6-11



HUDSON RIVER WEEKLY COMBINED STANDING CROP
Striped Bass - 1987
Standard Error
Combined Standing Crop (Millions)
0
10
20
30
40
50
60
70
80
22-Jun
29-Jun
06-Jul
13-Jul
20-Jul
27-Jul
03-Aug
10-Aug
17-Aug
24-Aug
31-Aug
07-Sep
14-Sep
21-Sep
28-Sep
05-Oct
12-Oct
19-Oct
26-Oct
02-Nov
09-Nov
16-Nov
Sampling Week

ous years has peaked in August, but the peaks have occurred later in recent years (1982, 1983, and 1984).

Based on the CSC index, white perch were most abundant in the Hudson River during the 10 November sampling week in 1986 (Figure 6-12) and during the 31 August and 7 September sampling weeks in 1987 (Figure 6-13). The relatively high CSC index values estimated during early September for both 1986 and 1987 reflected relatively large BSS collections in the lower regions of the estuary. Early September has historically been the peak CSC period reported in previous year-class reports. The 1986 peak CSC value is the result of large numbers in FSS collections during 10 November sampling in the West Point region (see Section 4.4.1.4, Figure 4-37). This late peak is likely the result of increased vulnerability to the FSS as white perch move offshore and downriver in response to declining temperatures.

6.2.3 Unweighted Bivariate Index

A bivariate index of year-class strength for striped bass, white perch, American shad, and bay anchovy was developed in the 1985 Year Class Report (Versar 1987). The rationale for the new index was presented in the 1985 report; the method of calculating the index is presented in Section 2.6.3.7 (Materials and Methods). The data used in calculating the index for 1986 and 1987 follow Versar (1987).

The coordinate pair index is a bivariate index with one axis based on a weighted average CPUE from the BSS and the other based on a weighted average CPUE from the FSS. Unlike the scalar indices, the coordinate pair approach treats the two data sets independently and does not use a relative weighting on the two axes. Conclusions concerning relative year-class strength are drawn when one year is superior to another on both the BSS and FSS axes. This approach is conservative in that a more limited set of among-year differences in year-class strength is identified than with the CSC index, which allow for a superior value on one axis to mask an inferior value on the other. Hence, the coordinate pair approach is less likely to produce erroneous among-year

FIGURE 6-12

HUDSON RIVER WEEKLY COMBINED STANDING CROP

White Perch – 1986

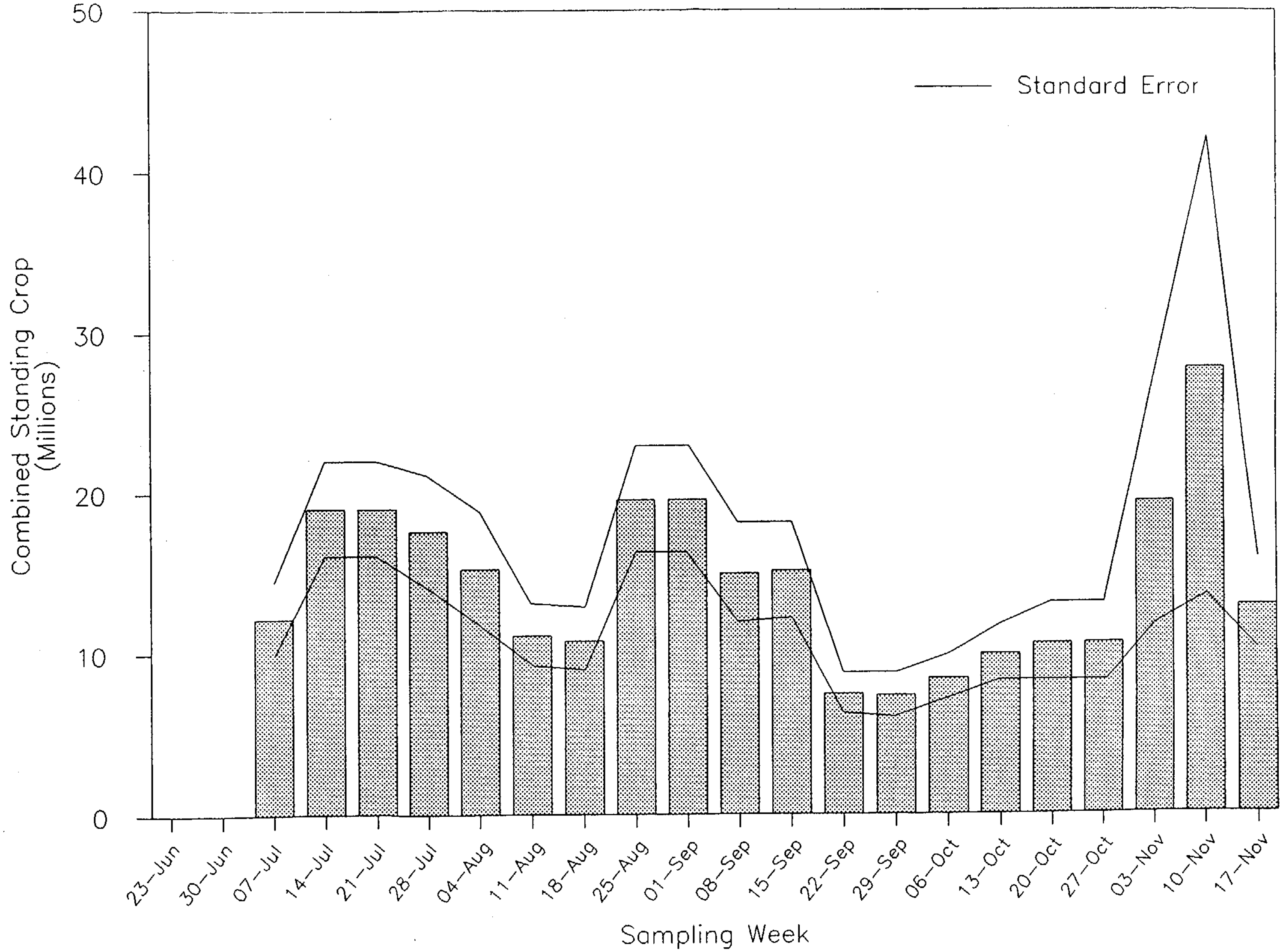
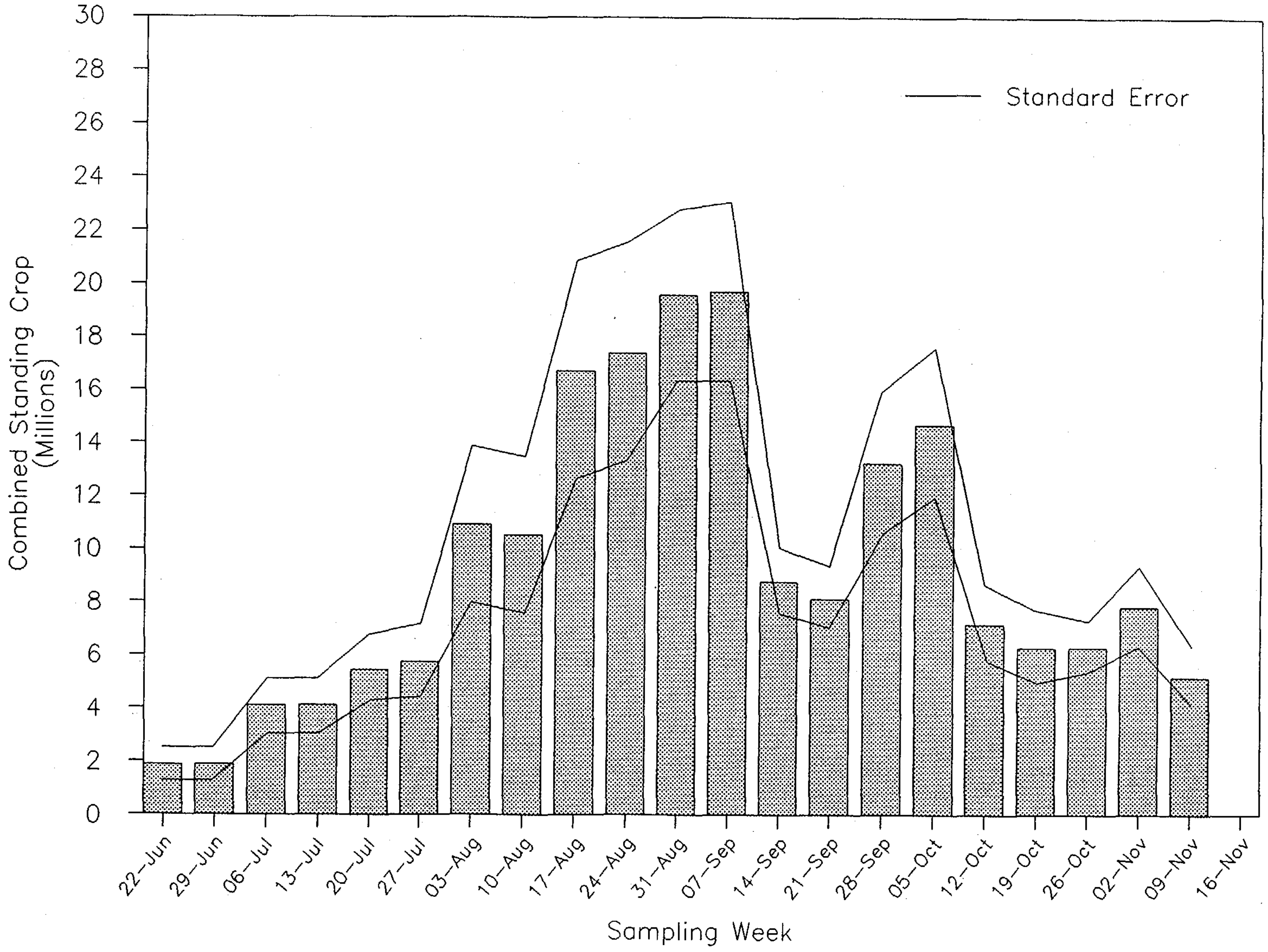


FIGURE 6-13

HUDSON RIVER WEEKLY COMBINED STANDING CROP

White Perch - 1987



differences since it uses information from both sets of available data without basing conclusions on assumed weightings for the two axes.

The coordinate pair approach uses a ranking procedure to assign CPUE values to each axis for each year. Weekly CPUE values are first calculated for the BSS and FSS programs for each year. Then, for a given axis, all weeks in all years are ranked and a mean rank is calculated for each year. The mean ranking procedure is preferable to using an annual mean CPUE procedure because of the decided non-normality of the data, i.e., over 90% of the offshore samples in most years contain no striped bass or white perch.

The index is based on data collected from all 12 river regions during weeks 33-40. Geographic extent used in the offshore component varied among species. (See Versar [1987] for further details on the sensitivity analysis used to determine which regions and strata were sampled consistently). For those species affected by addition of the more recent (post-1979) data, American shad and bay anchovy, the index was calculated only for 1979-1987 using the larger geographic extent sampled in those years. Results of the coordinate pair index for striped bass, white perch, American shad, and bay anchovy are discussed below.

Striped Bass

Rank-transformed CPUE data for striped bass taken from 1974 through 1987 were analyzed for year-class strength. A Kruskal-Wallis test on weekly ranks of densities showed statistically significant differences among years for both the beach seine and offshore components of the index, χ^2_{13}= 38.4 ($P \leq 0.001$) and χ^2_{13}= 38.6 ($P \leq 0.001$), respectively.

Results from Dunn's nonparametric multiple comparison procedure, applied to determine specific among-year differences (Table 6-2), indicate relatively few differences among years. (Note: Most years are not significantly different from one another even when the experiment-wise alpha rate is raised to 0.25.) For most of the comparisons the index values in 1985 and 1986 were more than

TABLE 6-2

MULTIPLE COMPARISON TEST RESULTS FOR STRIPED BASS YEAR CLASS STRENGTH, 1974-1987

BEACH SEINE

LOW							YEAR						HIGH
85	86	76	82	79	75	84	74	80	83	77	81	78	87
			———	———	———	———	———	———	———	———	———	———	———
		———	———	———	———	———	———	———	———	———	———	———	
	———	———	———	———	———	———	———	———	———	———	———		
———	———	———	———	———	———	———	———	———	———				

$\alpha = 0.25$

FALL SHOALS

LOW							YEAR						HIGH
85	86	80	83	79	82	87	81	74	78	84	75	76	77
		———	———	———	———	———	———	———	———	———	———	———	———
———	———	———	———	———	———	———	———	———	———	———			

$\alpha = 0.25$

NOTE: Underline indicates homogeneous subset.

an order of magnitude smaller on both axes (Figure 6-14), indicating these were relatively poor years. However, there was little overall correspondence between the two indices (Spearman's rank correlation coefficient = 0.169, n=14, P>0.05).

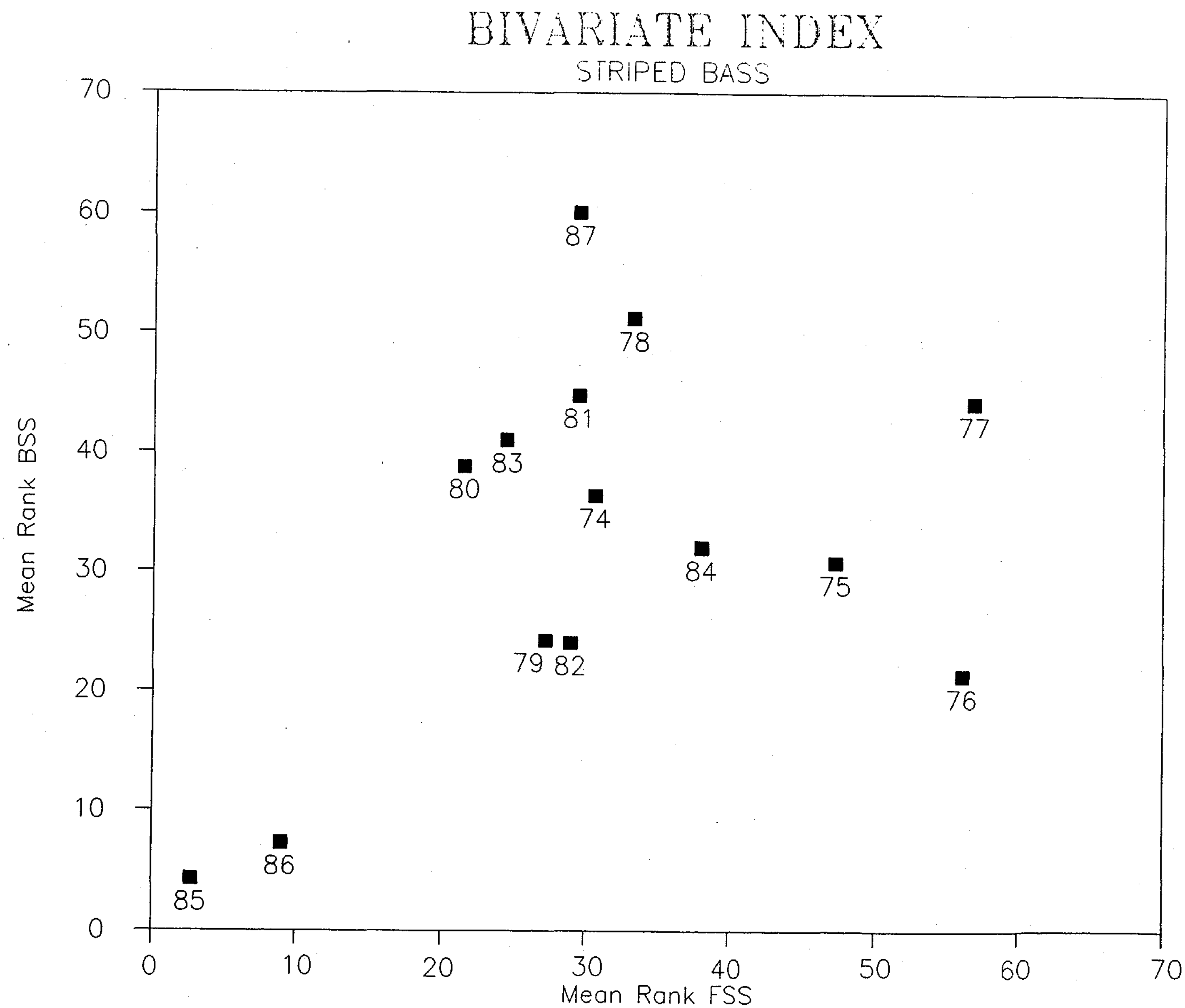
White Perch

CPUE data from 1974 through 1987 were analyzed for white perch year-class strength. A Kruskal-Wallis test on weekly ranks of densities showed statistically significant differences among years for both the beach seine and offshore components of the index, χ^2_{13} = 32.1 ($P \leq 0.001$) and χ^2_{13} = 50.8 ($P \leq 0.001$), respectively. Results from Dunn's nonparametric multiple comparison procedure, applied to determine specific differences among years (Table 6-3), indicate relatively few differences among years. The coordinate pair index indicates that 1984 through 1986 are relatively poor years in both components (Figure 6-15). The offshore component for 1987 was the lowest recorded; the BSS component was intermediate, however. Overall, there was only a moderate, and not statistically significant, correlation between the two sources of data (Spearman's rank correlation coefficient = 0.477, n=14, P>0.05).

American Shad

Unlike striped bass and white perch, the coordinate pair index for American shad was calculated only for the years 1979 through 1985 in order to use data from the greater geographical extent (upriver and channel areas) sampled in those years. A Kruskal-Wallis test suggests no significant difference among years for the FSS or BSS axes, χ^2_8 = 11.9 (P>0.05) and χ^2_8 = 10.7 (P>0.05), respectively (Table 6-4). Also, there was no significant correlation between the FSS and BSS indices (Spearman's rank correlation coefficient = 0.300, n=9, P>0.05) (Figure 6-16).

FIGURE 6-14



BIVARIATE INDEX
STRIPED BASS
Mean Rank BSS
Mean Rank FSS
0
10
20
30
40
50
60
70
87
78
81
77
83
80
74
84
75
79
82
76
86
85

TABLE 6-3

MULTIPLE COMPARISON TEST RESULTS FOR WHITE PERCH YEAR-CLASS STRENGTH, 1974-1987

BEACH SEINE

LOW YEAR HIGH

74	84	85	86	77	75	87	76	80	83	82	81	78	79
		—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—		

$\alpha = 0.25$

FALL SHOALS

LOW YEAR HIGH

87	85	86	84	77	83	82	78	74	81	80	76	79	75
				—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	—	—	
		—	—	—	—	—	—	—	—	—			
—	—	—	—	—	—	—	—	—					

$\alpha = 0.25$

NOTE: Underline indicates homogeneous subset.

FIGURE 6-15

BIVARIATE INDEX
WHITE PERCH

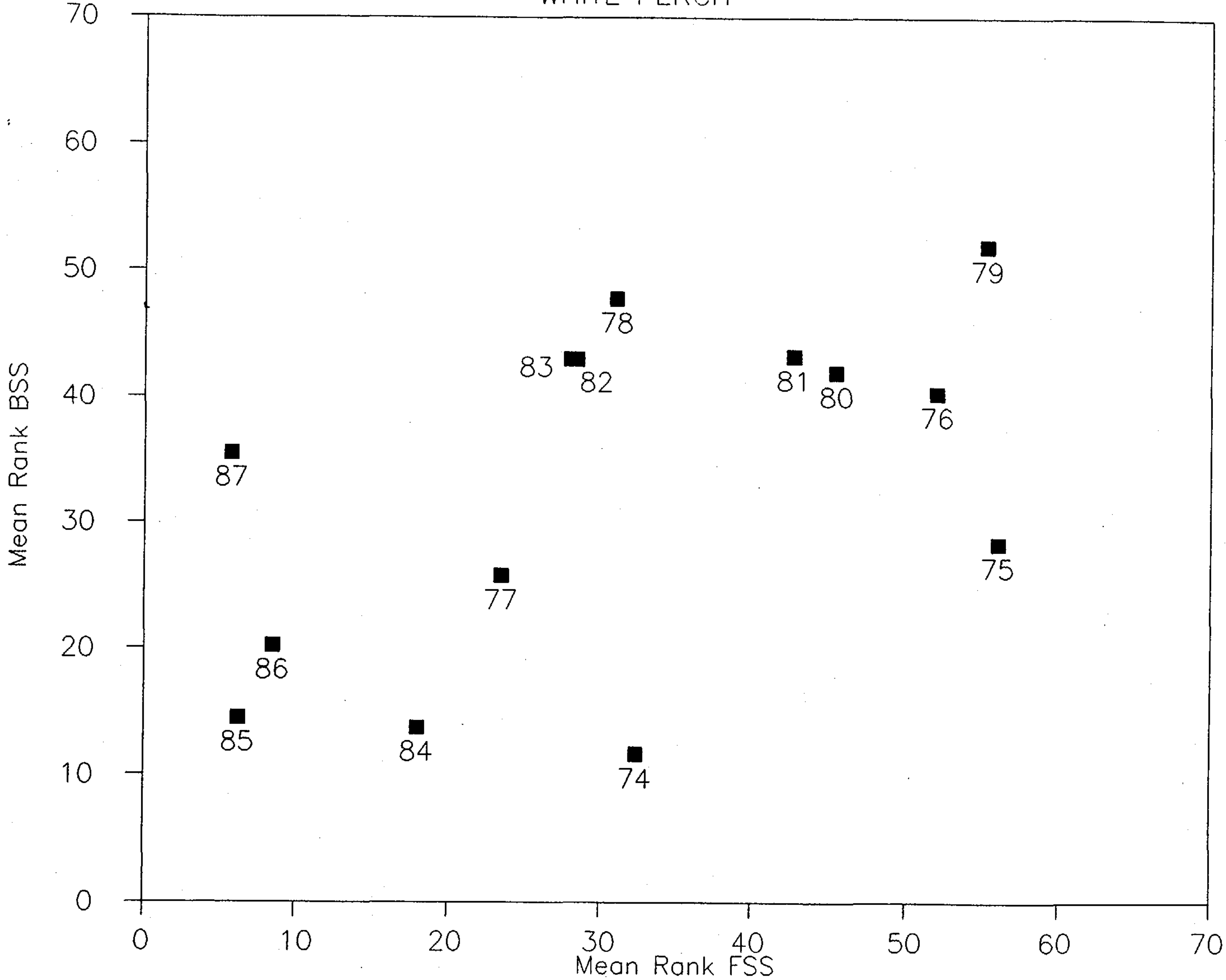


TABLE 6-4

MULTIPLE COMPARISON TEST RESULTS FOR AMERICAN SHAD YEAR CLASS STRENGTH, 1974-1987

BEACH SEINE

LOW YEAR HIGH

85	84	80	79	87	82	83	86	81

Kruskal-Wallis test at α = 0.05 indicates no significant difference among years

FALL SHOALS

LOW YEAR HIGH

80	79	87	83	84	82	81	85	86

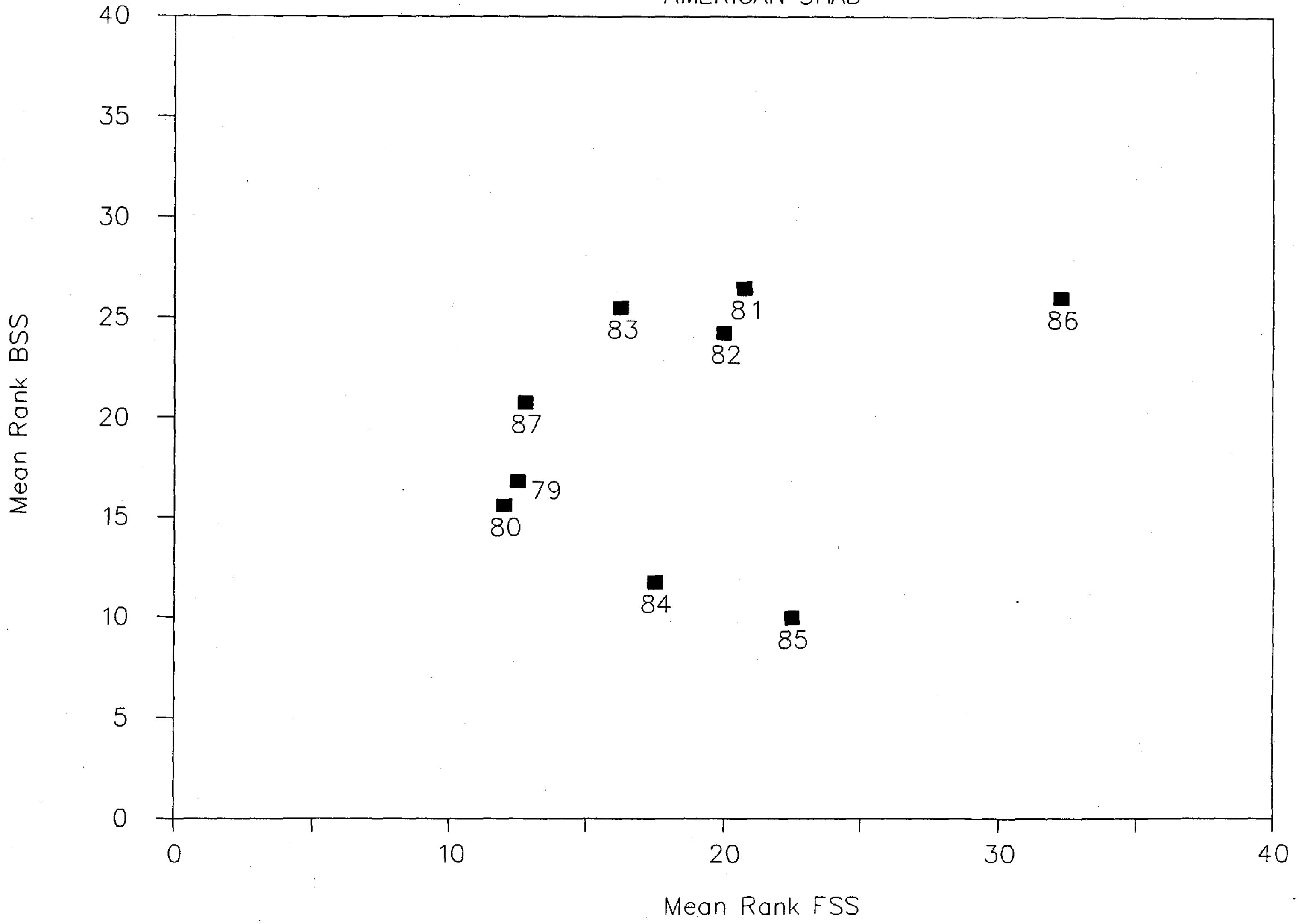
Kruskal-wallis test at α = 0.05 indicates no significant differences among years

NOTE: Underline indicates homogeneous subset.

FIGURE 6-16

BIVARIATE INDEX

AMERICAN SHAD



Bay Anchovy

As with American shad, the bay anchovy data set was restricted to the years 1979 through 1987. A Kruskal-Wallis test suggests no significant difference in yearly indices for the FSS and BSS axes, χ^2_8 = 13.2 (P>0.005) and χ^2_8= 12.7 (P>0.05), respectively (Table 6-5). The early 1980s tended to yield the highest indices (except 1983 BSS) (Figure 6-17). There was no statistically significant correlation between the two data sources (Spearman's rank correlation coefficient = 0.750, n=9, P>0.05).

6.3 ABUNDANCE TRENDS

6.3.1 Seasonal Patterns

The weekly CSC index for striped bass indicates two distinctly different abundance patterns during 1986 and 1987. Two periods of higher abundance were observed in 1986, one during July and the second from the end of August through the middle of September. Since the CSC is an estimate of actual population size, sampling efficiency is obviously changing through the July-September period. The September peak period was followed by a sharp decline (approximately half the September peak value) to a stable population through early November. During 1987 the abundance pattern was characterized by a gradual increase through July and mid-August that peaked in late August to early September, then a steady and fairly rapid decline to a November low.

The 1986 and 1987 weekly CSC index values for white perch exhibited the same general pattern as that noted for the 1986 striped bass. However, the white perch pattern differed in that during both years November was marked by an increased index value; the 1986 November index was the seasonal peak.

Multiple peaks in abundance were also observed in the 1970s. Young et al. (1988) attributed them to biased efficiency estimates and shifts in distribution among strata. During 1986 the July and September striped bass abundance peaks correspond to the months with the lowest monthly averaged freshwater

TABLE 6-5

MULTIPLE COMPARISON TEST RESULTS FOR BAY ANCHOVY YEAR CLASS STRENGTH, 1979-1987

BEACH SEINE

LOW — YEAR — HIGH

83	86	85	79	87	84	81	82	80

Kruskal-Wallis test at $\alpha = 0.05$ indicates no significant differences among years

FALL SHOALS

LOW — YEAR — HIGH

85	86	87	79	83	80	84	81	82

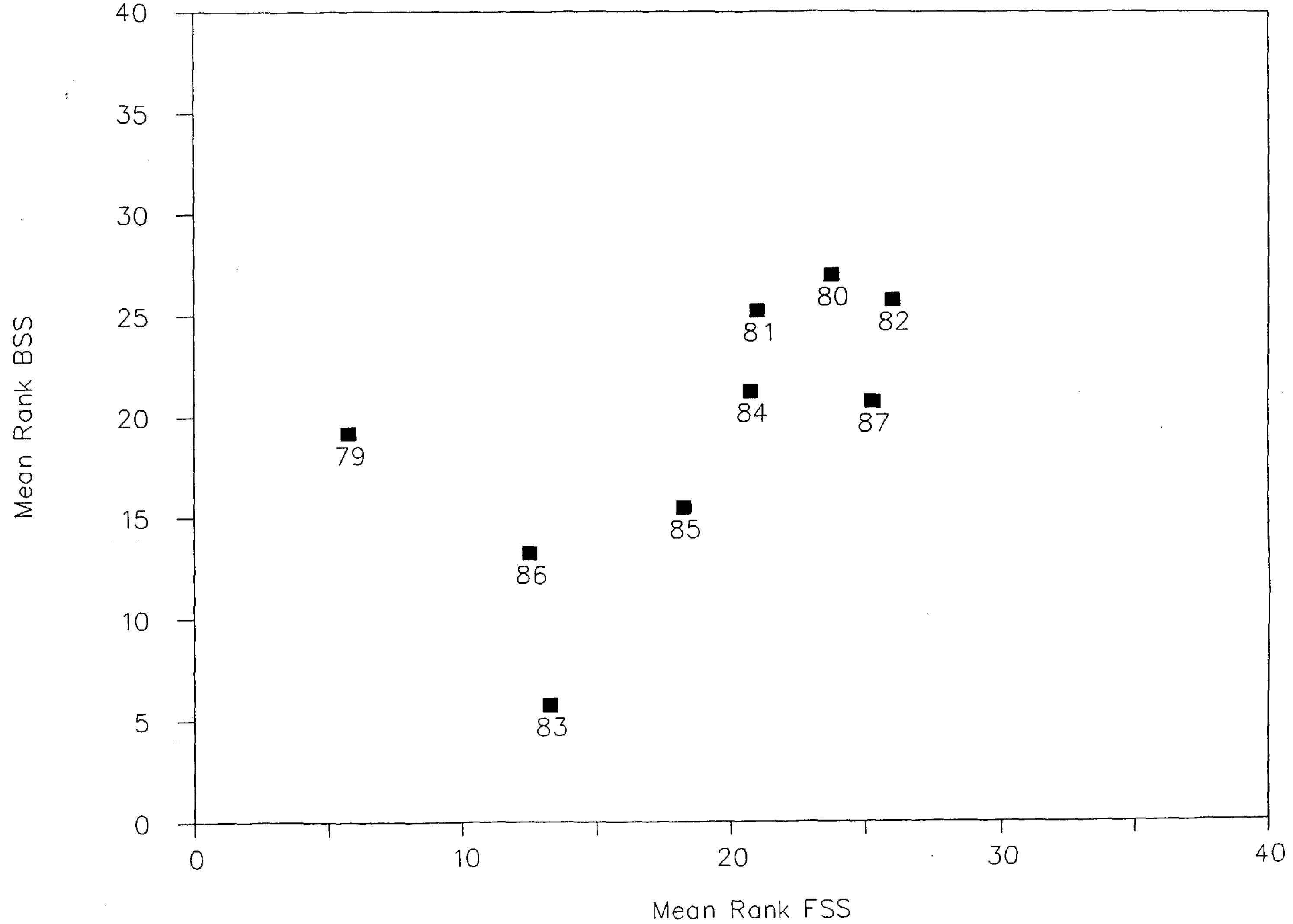
Kruskal-Wallis test at $\alpha = 0.05$ indicates no significant differences among years

NOTE: Underline indicates homogeneous subset.

FIGURE 6-17

BIVARIATE INDEX

BAY ANCHOVY



flow and the weeks with lower abundance correspond to months with relatively higher flows. A protracted period of lower-than-average monthly flows in August 1986 was followed by above-average flows in September. The gradual increase in abundance corresponds to the low-flow period, with the sharp decline corresponding to the increased flow period.

6.3.2 Multiyear Abundance Trends

The standardized survey collection techniques and abundance indices provide a basis for multiyear comparison of fish population strength that can be used to determine trends in abundance.

Both the univariate and bivariate indices indicate a decrease from peaks recorded in 1977-1978 to relatively low values in 1985 for striped bass, white perch, and American shad. The decline was most pronounced for the FSS data. The BSS and FSS CPUE indices and coordinate pair index for striped bass indicate that year-class strength was relatively poor in 1986 and very strong in 1987. Overall, striped bass abundance based on the juvenile indices has been variable since 1974 and no long-term trend is evident.

Both the BSS and FSS white perch juvenile indices indicate a decline from peak abundance in 1979 to poor year-class strength in 1984-1985. The most dramatic and consistent decrease was noted for the offshore collections while the beach seine catches, although declining to lows in 1984 and 1985, have again increased. However, the coordinate pair index indicates that except for 1984-1986, which were poor years, there is very little difference in among-year YOY year-class strength.

Both the BSS and FSS American shad stock indices were highly variable. The BSS index indicated low abundance in the shore zone during 1984 and 1985; YOY abundance in 1986 and 1987, however, corresponded to the long-term average (1979-1987). The coordinate pair index for American shad indicates no consistent change in year-class strength from 1979 to 1987.

In comparison to the FSS program, the number of bay anchovy collected in the beach seine program is considerably lower for the entire nine years (1979-1987), reflecting their preference for open-water areas. The FSS index, indicates no trend in abundance. The coordinate pair index, also, indicates no from 1979 to 1987.

For striped bass and white perch the BSS and FSS abundance indices point to a generally consistent trend among years, with strong year-classes at the end of the 1970s and poor year-classes in 1984 and 1985. Index values for both populations generally increased after 1985. No change in year-class strength was detected for either American shad or bay anchovy. Abundance trends in other Hudson River estuary programs support reduced recruitment in striped bass, white perch, and American shad populations in 1985 and for striped bass and white perch in 1986.

CHAPTER 7

COMMUNITY ANALYSIS

7.1 INTRODUCTION

Since the late 1960s applied ecologists have advocated the idea that biological communities can be used to monitor the degree of "stress" on an ecosystem (Wilhm and Dorris 1968; Cairns and Dickson 1971; Kushlan 1976; Skud 1982). The basic argument contends that communities of low diversity fall into three general categories: (1) "new" environments, (2) "severe" environments, or (3) "unpredictable" environments (Sanders 1969; Slobodkin and Sanders 1969), and that low-diversity communities are inherently less stable than more diverse communities (Elton 1958). Any increase in environmental severity, such as pollutants or excessive cropping by power plants, will tend to lower diversity and weaken community stability. In recent years the link between diversity and stability has been questioned and has found little support (Margalef 1969; Krebs 1978; Green 1979); however, ecologists have shown reduced diversity with increased environmental stress (Washington 1984).

This chapter describes in general the structure and dynamics of the fish communities in the Hudson River estuary and selectively examines the long-term data for evidence of community change. Of special concern is evidence for reductions in diversity and stability (persistence). Fisheries data from the years 1975, 1979, 1983, 1986, and 1987 were used in the community analysis evaluation.

7.2 HUDSON RIVER FISH COMMUNITIES DESCRIPTION

Hudson River fish communities can be described on the basis of two attributes: structure and dynamics. Structure, the most easily observed attribute, refers to the spatial and temporal organization of populations; dynamics refers to the interactional processes, energetic relationships, and patterns of change within communities (Southwick 1972).

Various authors offer different definitions of biological communities; however, three main concepts are generally mentioned in each evaluation of community analysis (Krebs 1978): First, a community represents the presence of several species in an area; second, a community is a group of species that recur in space and in time; and third, a community has a tendency toward dynamic stability, that is, the assemblage of populations will be restored following a perturbation. A pervasive view is that the community is a "fundamental unit" of nature, analogous to the "species," that can be described and classified. This view has been challenged by a number of workers, including Curtis and McIntosh (1951), Curtis (1955), and Whittaker (1962), who believe that populations are distributed along environmental gradients according to the species' physiological requirements. In this situation associations are continuous with one another and discrete communities cannot be unambiguously described.

Fish assemblages in estuaries seem to fit more closely the continuum concept than the discrete community concept. Weinstein et al. (1980), in studying the Cape Fear River estuary in North Carolina, noted that salinity gradients, and to a lesser degree substrate characteristics, determined the community structure. Classification attempts using binary discriminant analysis resulted in a complex multidimensional classification along several salinity gradients. McFadden (1977), using cluster analysis on presence-absence data, attempted to uncover communities among 29 common species from the Hudson River. The procedure was unable to clearly distinguish aggregations of species that could be interpreted as communities. Such a result is, again, consistent with a continuum established along a gradient.

7.2.1 Community Structure

Fishes of the Hudson River estuary can be divided into five more-or-less natural species assemblages based primarily on salinity preference or tolerance and secondarily on reproductive strategies. In some cases the boundaries of these groups are indistinct due to the continuous distribution of the species over the salinity gradient. Those species generally exhibiting limited tolerance for varying salinity gradients are grouped as either freshwater or marine species. Those species with broad tolerance to varying salinity can be categorized on their reproductive migratory habits - anadromous species live in salt water but migrate into fresh water to spawn while catadromous species live in fresh water and migrate into salt water to spawn. Those that display a wide salinity tolerance but with no clear-cut reproductive migrations into fresh or salt water are referred to as estuarine species. A complete species list is presented in Section 4.1 of this report, and a list for 1975, 1979, 1983, 1986, and 1987 with numbers collected is given in Tables 7-1 through 7-3. The abundance categorization described below closely follows McFadden (1977) and is also based on the relative frequency with which a species is observed in the sampling programs. Although the BSS and FSS have a wide temporal and spatial extent of sampling and use a wide variety of gears, the relative abundances still reflect the selectivity inherent in the sampling program. Thus, large bottom-dwelling species, e.g., sturgeon, or surface-oriented pelagic fish, e.g., needle fish, could be more common than they appear.

7.2.1.1 Freshwater Assemblage. The freshwater species are concentrated in the upstream limnetic zone, usually upriver from the salt front. This region varies seasonally, but is generally upstream of Rkm 40 (RM 25) during high freshwater flow conditions and ranges to Rkm 113 (RM 70) at low freshwater flow conditions. Approximately 56 species (Table 4-1) can be considered members of this assemblage; the greatest in abundance are goldfish, golden shiner, spottail shiner, white catfish, banded killifish, redbreast sunfish,

TABLE 7-1 (Page 1 of 2)

FISH SPECIES COLLECTED DURING THE FALL SHOALS AND BEACH SEINE SURVEYS

Lower Regions (Yonkers through Indian Point) of the Hudson River Estuary, August - October

		FALL SHOALS SURVEY					BEACH SEINE SURVEY				
ASSEMBLAGE	COMMON NAME	1975	1979	1983	1986	1987	1975	1979	1983	1986	1987
Anadromous	Atlantic sturgeon	6	4	0	10	7	0	2	0	0	0
	Blueback herring	12587	2573	2290	250	2682	8713	3474	607	144	7067
	Alewife	958	1000	225	65	85	896	224	73	102	40
	American shad	374	901	383	365	104	1886	1340	598	1589	684
	Rainbow smelt	96	61	0	102	17	0	0	0	0	0
	Atlantic tomcod	943	767	165	5453	2775	42	226	40	95	153
	Striped bass	948	692	549	1715	6506	2697	2100	4157	851	8316
Catadromous	American eel	1382	1079	305	790	661	76	74	41	49	48
Estuarine	Shortnose sturgeon	0	0	0	1	0	0	0	0	0	0
	Mummichog	0	0	0	0	0	46	106	23	13	51
	Fourspine stickleback	0	2	0	0	0	52	308	26	173	180
	Threespine stickleback	0	0	0	0	0	0	1	3	10	8
	White perch	3167	1936	633	9684	9999	3719	12341	6932	3657	3996
	Fat sleeper	0	0	0	0	0	0	0	0	1	0
	Hogchoker	7802	4724	2847	54558	52432	38	88	239	106	165
Freshwater	Gizzard shad	2	0	1	0	1	9	0	12	0	21
	Chain pickerel	0	0	0	0	0	1	0	0	0	0
	Northern pike	0	0	0	0	0	0	0	0	0	1
	Goldfish	1	0	0	0	0	9	11	1	0	1
	Carp	0	0	0	2	0	7	15	4	21	20
	Cutlips minnow	1	0	0	0	0	0	0	0	0	0
	Golden shiner	1	35	0	0	0	49	44	41	10	12
	Emerald shiner	0	0	0	0	0	0	2	0	0	0
	Spottail shiner	1	2	0	0	1	488	399	191	30	33
	Bluntnose minnow	0	0	0	0	0	0	0	1	0	0
	White sucker	0	0	0	0	0	6	8	4	3	4
	White catfish	128	21	6	174	234	38	19	14	48	36
	Brown bullhead	8	21	0	7	7	12	16	10	15	1
	Banded killifish	4	10	0	3	0	2554	2096	446	886	1570
	Rock bass	0	0	0	0	0	6	1	0	0	0
	Bluegill	0	0	0	0	0	47	149	87	12	32
	Pumpkinseed	0	2	6	0	5	826	503	203	66	62
	Redbreast sunfish	0	0	0	0	0	163	62	8	5	16
	Smallmouth bass	0	0	0	0	0	0	0	0	1	0
	Largemouth bass	0	0	0	0	0	52	20	2	7	5
	Black crappie	0	0	0	0	0	1	0	1	0	48
	Tessellated darter	67	4	0	2	1	308	156	63	10	25
	Yellow perch	0	0	0	0	0	22	6	7	7	9
Marine	Hickory shad	0	0	0	3	0	8	1	0	0	0
	Atlantic menhaden	12	16	317	100	43	443	57	16	220	0

TABLE 7-1 (Page 2 of 2)

FISH SPECIES COLLECTED DURING THE FALL SHOALS AND BEACH SEINE SURVEYS

Lower Regions (Yonkers through Indian Point) of the Hudson River Estuary, August - October

ASSEMBLAGE	COMMON NAME	FALL SHOALS SURVEY 1975	1979	1983	1986	1987	BEACH SEINE SURVEY 1975	1979	1983	1986	1987
	Striped anchovy	0	0	0	0	0	1	0	0	0	0
	Bay anchovy	79201	97399	121116	16928	29401	12614	7065	1363	3800	2382
	Silver hake	0	0	0	3	0	0	0	0	0	0
	Spotted hake	0	0	0	1	0	0	0	0	0	0
	Atlantic needlefish	0	1	0	0	0	26	68	32	28	37
	Rough silverside	7	3	0	0	3	220	7	0	0	23
	Tidewater silverside	0	0	0	0	0	169	318	43	285	133
	Atlantic silverside	2	0	17	1	0	92	116	439	4058	1108
	Northern pipefish	9	40	16	12	16	21	288	200	102	267
	Northern searobin	0	0	0	2	7	0	0	0	2	0
	Striped searobin	0	4	24	129	10	0	0	8	0	0
	Longhorn sculpin	0	0	0	0	0	0	0	1	0	0
	Bluefish	14	19	83	45	63	208	137	313	124	221
	Crevalle jack	0	2	2	1	0	24	0	5	6	3
	Lookdown	0	0	0	0	1	2	0	1	0	0
	Moonfish	0	0	0	1	2	0	0	0	0	0
	Grey snapper	0	0	0	0	0	0	0	0	1	3
	Silver perch	0	0	0	0	0	0	0	0	1	0
	Weakfish	457	707	831	1470	483	2	3	33	4	0
	Spot	0	0	0	13	1	0	0	1	7	2
	Northern kingfish	0	0	0	6	0	1	3	4	6	0
	Atlantic croaker	0	2	0	1	5	0	0	0	0	0
	White mullet	0	0	0	0	0	0	2	2	2	0
	Striped mullet	0	0	0	0	0	0	1	3	4	1
	Tautog	0	0	0	0	0	0	1	0	5	2
	Naked goby	0	0	0	5	40	0	0	0	8	11
	Butterfish	2	1	62	103	38	0	0	2	0	0
	Smallmouth flounder	0	1	0	0	0	0	0	0	0	0
	Summer flounder	0	12	0	314	38	2	12	0	32	3
	Fourspot flounder	0	0	0	2	0	0	0	0	0	0
	Windowpane	0	0	0	0	5	0	0	1	0	0
	Winter flounder	0	99	1	108	47	3	10	7	32	23
	Northern puffer	0	1	1	1	6	0	0	2	1	0
	Striped burrfish	0	0	0	1	0	0	0	0	0	0
Number of samples		449	504	593	728	625	258	322	290	288	336

TABLE 7-2 (Page 1 of 2)

FISH SPECIES COLLECTED DURING THE FALL SHOALS AND BEACH SEINE SURVEYS

Middle Regions (West Point through Hyde Park) of the Hudson River Estuary, August - October

		FALL SHOALS SURVEY					BEACH SEINE SURVEY				
ASSEMBLAGE	COMMON NAME	1975	1979	1983	1986	1987	1975	1979	1983	1986	1987
Anadromous	Atlantic sturgeon	2	0	9	59	35	0	0	2	0	0
	Blueback herring	5509	10642	9013	1777	2377	11065	21757	50317	2996	10795
	Alewife	145	202	204	90	63	641	299	471	70	184
	American shad	41	156	375	206	49	1268	2891	3279	2454	1544
	Rainbow smelt	83	327	12	146	254	0	0	0	1	0
	Atlantic tomcod	687	139	180	1000	567	1	0	0	1	0
	Striped bass	15	12	53	71	233	516	247	827	142	664
Catadromous	American eel	114	71	207	232	190	149	128	35	25	24
Estuarine	Shortnose sturgeon	0	0	0	2	1	0	0	0	0	0
	Mummichog	0	0	0	0	0	10	17	0	0	2
	Fourspine stickleback	0	0	0	2	0	57	342	9	62	7
	Threespine stickleback	0	0	0	0	0	0	0	0	3	0
	White perch	486	1027	590	4866	2996	1314	3660	2025	1265	1749
	Hogchoker	218	85	1043	19583	9721	7	33	16	23	37
Freshwater	Gizzard shad	0	0	0	0	3	38	0	0	0	16
	Chain pickerel	0	1	0	0	0	0	0	0	0	0
	Goldfish	0	0	0	0	0	121	160	2	2	3
	Carp	0	0	8	7	0	111	19	13	18	22
	Cutlips minnow	0	0	0	0	0	1	0	0	0	0
	Golden shiner	0	0	0	0	0	274	251	217	197	233
	Fallfish	0	0	0	0	0	0	4	0	0	0
	Satinfin shiner	0	0	0	0	0	1	0	0	0	0
	Emerald shiner	0	0	0	0	0	3	0	1	0	0
	Spottail shiner	9	12	4	45	6	2989	3604	2144	1211	1000
	Spotfin shiner	0	0	0	0	0	4	2	0	0	0
	Blacknose dace	0	0	0	0	0	1	3	0	0	1
	White sucker	0	0	0	0	0	11	2	3	2	9
	Northern hog sucker	0	0	0	0	0	0	0	0	0	1
	White catfish	40	3	64	55	55	0	2	2	0	2
	Yellow bullhead	0	0	0	0	0	1	0	0	0	0
	Brown bullhead	3	5	34	40	54	13	14	40	11	3
	Channel catfish	0	0	0	0	2	0	0	0	0	0
	Banded killifish	0	21	0	2	1	5423	5463	595	867	870
	Rock bass	0	0	0	0	0	1	0	0	4	0
	Bluegill	0	3	0	0	0	359	49	20	12	14
	Pumpkinseed	0	2	0	4	0	1662	1043	493	195	373
	Redbreast sunfish	0	0	0	0	0	155	116	91	24	39
	Smallmouth bass	0	0	0	0	0	1	2	3	6	4
	Largemouth bass	0	0	0	0	0	69	63	11	29	13

TABLE 7-2 (Page 2 of 2)

FISH SPECIES COLLECTED DURING THE FALL SHOALS AND BEACH SEINE SURVEYS

Middle Regions (West Point through Hyde Park) of the Hudson River Estuary, August - October

		FALL SHOALS SURVEY					BEACH SEINE SURVEY				
ASSEMBLAGE	COMMON NAME	1975	1979	1983	1986	1987	1975	1979	1983	1986	1987
	Black crappie	0	0	0	0	0	6	1	1	2	1
	Tessellated darter	7	7	1	74	8	1809	1283	266	255	169
	Yellow perch	0	0	0	0	0	19	13	14	11	8
Marine	Atlantic menhaden	1	1	8	14	1	0	1	8	6	2
	Bay anchovy	3668	5662	13949	1452	2608	1966	4	14	58	660
	Fourbeard rockling	0	2	0	0	0	0	0	0	0	0
	Atlantic needlefish	0	0	0	0	0	0	0	1	1	6
	Rough silverside	0	0	0	0	0	9	0	0	0	0
	Tidewater silverside	0	0	0	0	0	0	2	0	49	5
	Northern pipefish	0	0	0	0	0	0	0	1	0	0
	Bluefish	0	2	7	1	7	15	4	60	3	3
	Crevalle jack	0	0	0	0	0	2	0	0	0	0
	Weakfish	11	5	138	5	131	0	0	0	0	0
	Atlantic croaker	0	2	0	0	0	0	0	0	0	0
	Naked goby	0	0	0	0	1	0	0	0	0	0
	Summer flounder	0	0	0	2	0	0	0	0	0	0
	Winter flounder	0	0	0	0	0	0	0	2	0	0
Number of samples		87	235	234	273	234	166	159	126	126	147

TABLE 7-3 (Page 1 of 2)

FISH SPECIES COLLECTED DURING THE FALL SHOALS AND BEACH SEINE SURVEYS

Upper Regions (Kingston through Albany) of the Hudson River Estuary, August - October

		FALL SHOALS SURVEY					BEACH SEINE SURVEY				
ASSEMBLAGE	COMMON NAME	1975	1979	1983	1986	1987	1975	1979	1983	1986	1987
Anadromous	Atlantic sturgeon	-	1	19	67	65	0	0	0	0	0
	Blueback herring	-	28158	38484	3584	7302	12194	26535	34187	3604	11753
	Alewife	-	620	773	237	131	85	564	464	223	149
	American shad	-	443	2352	1099	113	1273	1607	5468	3991	3170
	Rainbow smelt	-	1	0	3	1	0	0	0	0	0
	Atlantic tomcod	-	7	4	398	57	0	0	0	0	0
	Striped bass	-	41	128	68	749	169	157	659	63	777
Catadromous	American eel	-	228	147	1339	575	189	91	57	28	34
Estuarine	Shortnose sturgeon	-	0	3	3	5	0	0	0	0	0
	Mummichog	-	0	0	0	0	26	64	37	11	407
	Fourspine stickleback	-	0	0	1	0	5	211	2	81	5
	Threespine stickleback	-	0	0	0	0	0	0	0	3	0
	White perch	-	1462	2086	7055	4631	1762	2752	3058	1541	3076
	Hogchoker	-	94	308	11551	7144	1	2	8	0	6
Freshwater	Gizzard shad	-	0	0	4	4	71	0	0	8	54
	Redfin pickerel	-	0	0	0	0	6	0	0	0	0
	Northern pike	-	0	0	0	0	1	1	0	1	3
	Goldfish	-	0	0	0	0	63	265	1	0	8
	Carp	-	0	0	2	1	11	19	24	17	11
	Silvery minnow	-	0	0	0	0	207	11	1	12	22
	Golden shiner	-	10	3	0	0	374	124	125	137	209
	Creek chub	-	0	0	0	0	0	0	1	0	0
	Fallfish	-	0	0	0	0	0	2	0	1	0
	Satinfin shiner	-	0	0	0	0	0	5	0	1	0
	Emerald shiner	-	1	0	0	0	73	274	2	1	2
	Common shiner	-	0	0	0	0	15	6	4	0	0
	Spottail shiner	-	16	46	427	168	5804	2765	3038	1612	2078
	Spotfin shiner	-	0	0	0	0	2	72	0	7	10
	Bluntnose minnow	-	0	0	0	0	6	0	0	0	0
	White sucker	-	3	0	3	1	11	2	1	1	1
	White catfish	-	37	179	288	310	1	2	9	1	4
	Brown bullhead	-	6	96	10	8	6	11	3	8	3
	Channel catfish	-	0	0	4	7	0	0	0	0	0
	Margined madtom	-	0	0	0	1	0	0	0	0	0
	Trout perch	-	0	0	0	0	1	0	0	0	0
	Banded killifish	-	11	0	1	1	1644	3502	3165	915	1171
	Rock bass	-	0	0	1	0	5	0	3	2	0
	Bluegill	-	0	0	0	1	44	18	8	14	21
	Pumpkinseed	-	1	3	2	5	1183	584	685	290	326
	Redbreast sunfish	-	0	0	0	0	48	101	92	51	59

FISH SPECIES COLLECTED DURING THE FALL SHOALS AND BEACH SEINE SURVEYS

Upper Regions (Kingston through Albany) of the Hudson River Estuary, August - October

		FALL SHOALS SURVEY					BEACH SEINE SURVEY				
ASSEMBLAGE	COMMON NAME	1975	1979	1983	1986	1987	1975	1979	1983	1986	1987
	Green sunfish	-	0	0	0	0	1	0	0	0	0
	Smallmouth bass	-	0	0	0	0	5	2	17	12	4
	White crappie	-	0	0	0	0	0	3	0	1	0
	Black crappie	-	0	0	0	0	14	3	8	39	3
	Tessellated darter	-	22	2	250	103	748	823	530	394	275
	Yellow perch	-	0	0	0	1	9	13	17	16	10
Marine	Hickory shad	-	0	1	0	0	0	0	0	0	0
	Atlantic menhaden	-	0	3	3	0	0	0	0	0	2
	Bay anchovy	-	358	1901	399	386	1	3	0	0	297
	Red hake	-	7	0	0	0	0	0	0	0	0
	Atlantic needlefish	-	0	0	0	0	0	0	0	1	3
	Tidewater silverside	-	0	0	0	0	0	1	0	7	2
	Atlantic silverside	-	0	1	0	0	0	0	142	1	0
	Weakfish	-	6	1	0	0	0	0	0	0	0
Number of samples		0	323	372	469	402	118	139	187	186	218

pumpkinseed, bluegill, largemouth bass, and tessellated darter (Tables 7-1 through 7-3). The largemouth bass is the most abundant piscivorous predator in the freshwater group. Common, but less frequently encountered, are such species as carp, silvery minnow, white sucker, brown bullhead, and yellow perch. Freshwater species that are uncommon or rarely encountered in the utility sampling programs include pickerel, northern pike, brown trout, brook trout, rock bass, smallmouth bass, and crappie. Other uncommon or rare species include mudminnows, various species of shiner (Notropis), trout perch, log perch, and shield darter. The emerald shiner, apparently abundant during the early to mid-1970s (McFadden 1977), has been uncommon since 1979.

Carlson (1986) further identified assemblages within the freshwater region by habitat type (Table 7-4). Species such as brown bullhead, yellow perch, and goldfish predominate vegetated backwaters while white catfish, smallmouth bass, and largemouth bass predominate near or over rock piles.

7.2.1.2 Marine Assemblage. The marine species are concentrated in the lower reaches of the estuary downstream of the salt front, which reaches to Rkm 113 (RM 70) during low freshwater flow conditions. Approximately 61 species (Table 4-1) can be considered as belonging to this assemblage. Of these, however, only five can be considered abundant or common: bluefish, Atlantic menhaden, tidewater silverside, Atlantic silverside, and weakfish (Tables 7-1 through 7-3). The remaining 55 species are uncommon or rare. Judging from distribution patterns given by Ursin (1977) and Robins et al. (1986), such rare species as barndoor skate, Atlantic herring, pollock, red hake, American sandlance, grubby, and windowpane are cold-temperate species and would be expected to occur more frequently when offshore water temperatures are cooler than normal. Rare species such as striped anchovy, inshore lizardfish, spotted hake, striped killifish, lookdown, Atlantic moonfish, silver perch, spot, northern kingfish, Atlantic croaker, striped mullet, white mullet, and northern puffer are warm-temperate species and would be expected to occur more frequently when offshore water temperatures are warmer than normal.

TABLE 7-4

FISH AGGREGATIONS[a] BY SPECIFIC HABITATS IN THE UPPER HUDSON ESTUARY[b]

VEGETATED BACKWATERS	TRIBUTARIES	ROCK PILE	SHORE
Brown bullhead	White sucker	White catfish	Banded killifish
Yellow perch	Smallmouth bass	Smallmouth bass	Golden shiner
Goldfish	Redbreast sunfish	Largemouth bass	Emerald shiner
Golden shiner	Yellow perch	Rock bass	Gizzard shad
Banded killifish	Largemouth bass	Redbreast sunfish	Bay anchovy
Largemouth bass	Goldfish		Bluegill
White catfish	Golden shiner		Smallmouth bass
White sucker	Rock bass		Yellow perch
Gizzard shad	Bluegill		
Northern pike	Black crappie		
Emerald shiner			
Rock bass			
Redbreast sunfish			
Bluegill			
Smallmouth bass			
Offshore Shoals and Channel			**Tailwater**
Adults and juveniles	Larvae and fry		
Tessellated darter	Tessellated darter		White sucker
Brown bullhead	Rainbow smelt		Golden shiner
Hogchoker	Centrarchids		White catfish
Shortnose sturgeon	Yellow perch		Largemouth bass
White sucker	Shortnose sturgeon		Walleye

[a]Species are listed in order of abundance, excluding ubiquitous species (American eel, blueback herring, alewife, American shad, common carp, spottail shiner, white perch, striped bass, and pumpkinseed).

[b]Based on Carlson 1986.

7.2.1.3 Estuarine Assemblage. The estuarine assemblage is represented by seven euryhaline resident species. White perch, hogchoker, and mummichog are abundant, while fourspine stickleback is common (Tables 7-1 through 7-3). The shortnose sturgeon and threespine stickleback are uncommon and the fat sleeper is rare. As they are tolerant of a wide range of salinities, they are found throughout the estuary. However, these species may demonstrate movement patterns associated with reproduction and may have salinity tolerances narrower than a casual inspection of the data may suggest. For example, although at least some white perch overwinter in the lower estuary, comparison of catch data with simultaneously collected salinity data indicates that much of the population resides upriver of the 0.5 ppt isohaline at least into December (the end of the survey) (LMS 1986, 1987, 1988). In spring the adults migrate well upriver, especially into shallow, vegetated regions and tributaries.

7.2.1.4 Anadromous Assemblage. Although only eight species belong to this assemblage (Table 4-1), they are among the most abundant species collected in the estuary (Tables 7-1 through 7-3). They enter the mouth of the estuary and proceed upriver into fresh water to spawn, then return to salt water. Blueback herring, alewife, American shad, rainbow smelt, striped bass, and Atlantic tomcod are abundant; Atlantic sturgeon are uncommon; and hickory shad are rare. All but the tomcod, which spawns during the winter, ascend the river during the spring.

7.2.1.5 Catadromous Assemblage. Only a single species, the American eel, belongs to this category. Young eels migrate upriver in the spring and remain in fresh and brackish water until they reach sexual maturity in 5-18 years. When sexually mature, adults move seaward in the fall and migrate to the vicinity of the Sargasso Sea where they spawn and, presumably, die (Scott and Crossman 1973; Hain 1975).

7.2.2 Community Dynamics

The structure of Hudson River fish assemblages changes on a seasonal basis (Figures 7-1 through 7-10). Overall species richness and diversity is highest during the summer and lowest from December through early spring. This seasonality is readily apparent in the 1975 and 1979 BSS data; most other surveys have insufficient temporal coverage to demonstrate this change. The decrease in richness and diversity in the winter is not spread evenly among all five assemblages. Little if any change occurs in the estuarine and catadromous species. Even the number of anadromous species, despite extensive migrations, remains relatively constant since many young striped bass, blueback herring, and alewife overwinter in the lower estuary. The freshwater component decreases in numbers, going from a peak of 20-23 species in summer to 6-8 species in winter and early spring; this may reflect movement of resident freshwater species into deepwater areas from the shore zone (McFadden et al. 1978). The marine component also undergoes a considerable seasonal change. Typically there are 8-14 species in the summer and none during the winter and early spring (Figures 7-1 and 7-2).

Not only is there a shift in species composition over an annual cycle, but there is also a pronounced shift in distribution as a result of changes in freshwater discharge and salinity patterns. Freshwater discharge, as measured at Green Island, New York, averages approximately 15,000 cfs from January through March, peaks at about 30,000 cfs in May, gradually decreases to about 5000 cfs in the summer, then gradually increases throughout the fall (Figure 7-11).

Changes in flow influence the salinity gradient in the lower and middle estuary. High freshwater flows push the salt front farther downriver; low freshwater flows allow the salt front to penetrate upriver. The effects of several different discharge levels are demonstrated in Figures 7-12 through 7-14. The lowest flow of the three examples is 4979 cfs, averaged for the week preceding

FIGURE 7-1

HUDSON RIVER FISH FAUNA - 1975

Species Richness - Beach Seines

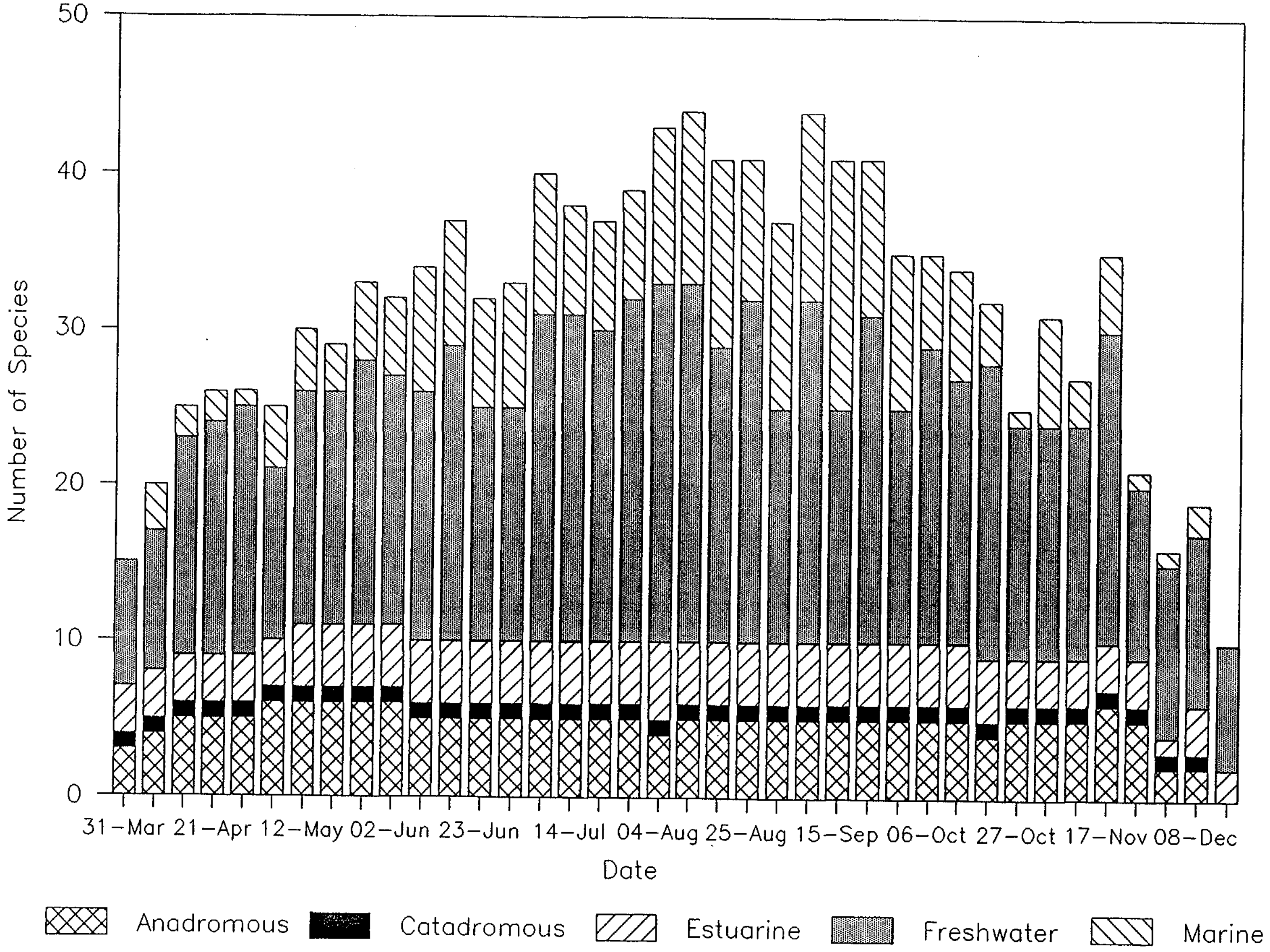


FIGURE 7-2

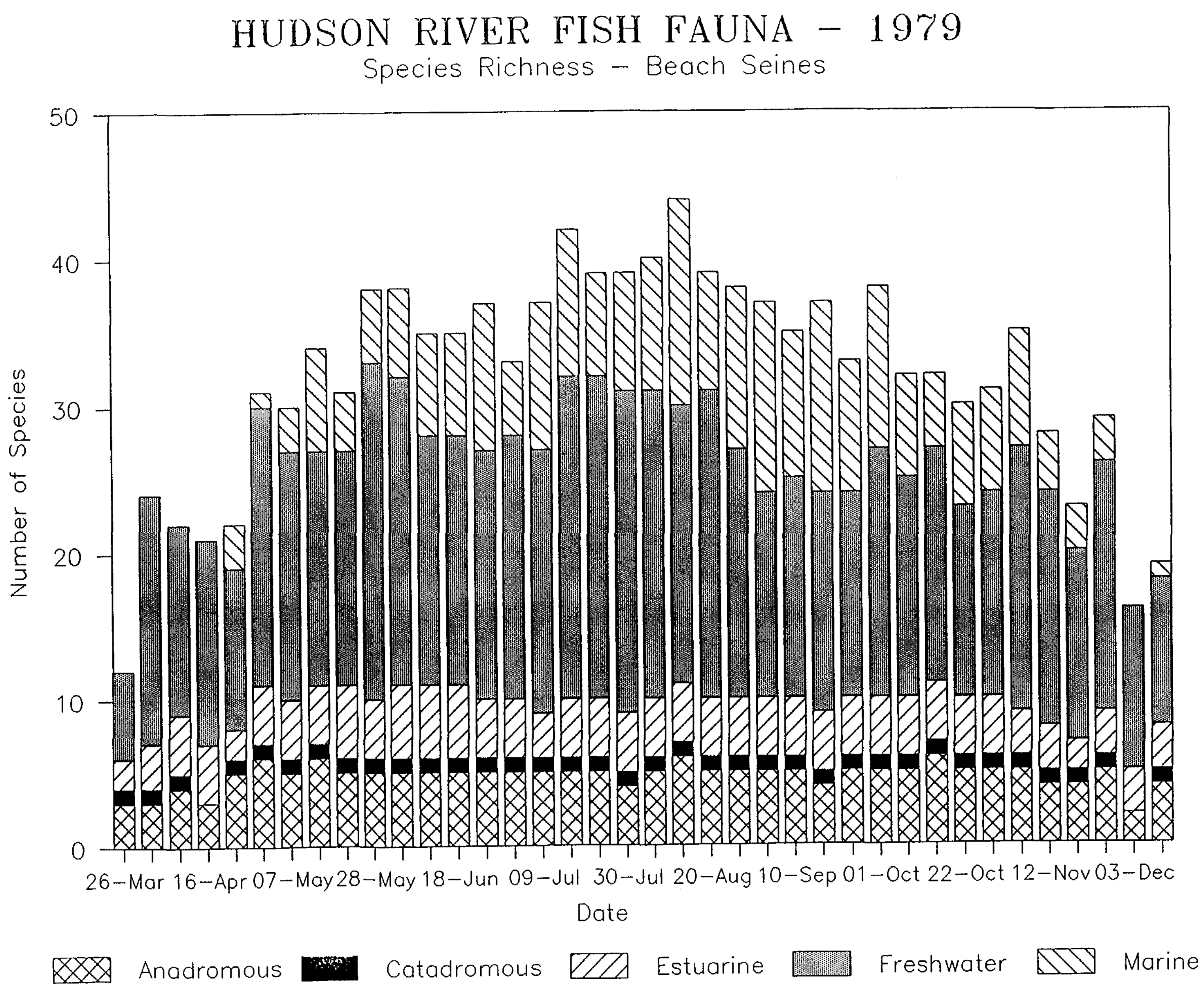
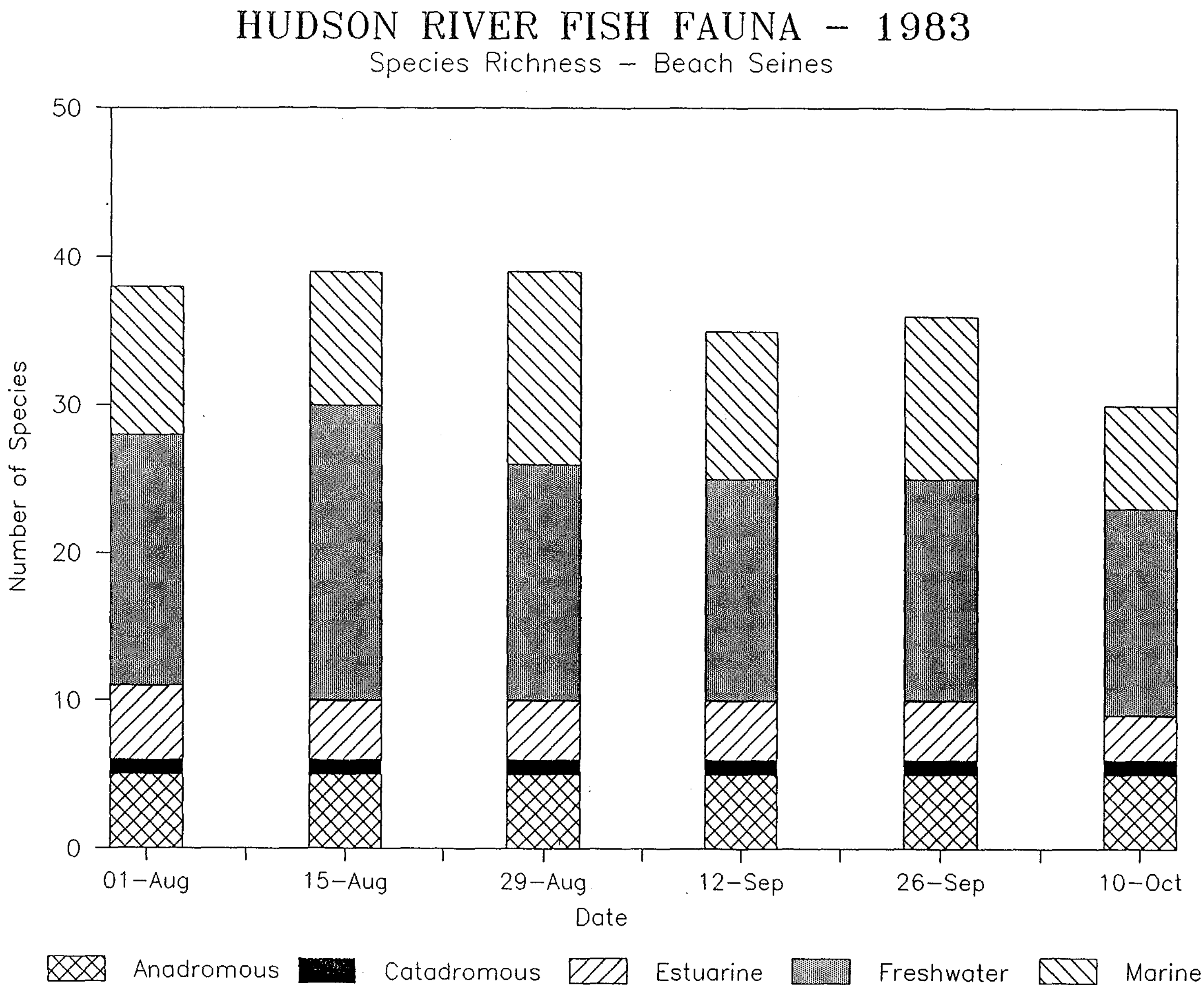

HUDSON RIVER FISH FAUNA - 1979
Species Richness - Beach Seines
Number of Species
0
10
20
30
40
50
26-Mar
16-Apr
07-May
28-May
18-Jun
09-Jul
30-Jul
20-Aug
10-Sep
01-Oct
22-Oct
12-Nov
03-Dec
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-3



HUDSON RIVER FISH FAUNA - 1983
Species Richness - Beach Seines
Number of Species
50
40
30
20
10
0
01-Aug
15-Aug
29-Aug
12-Sep
26-Sep
10-Oct
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-4

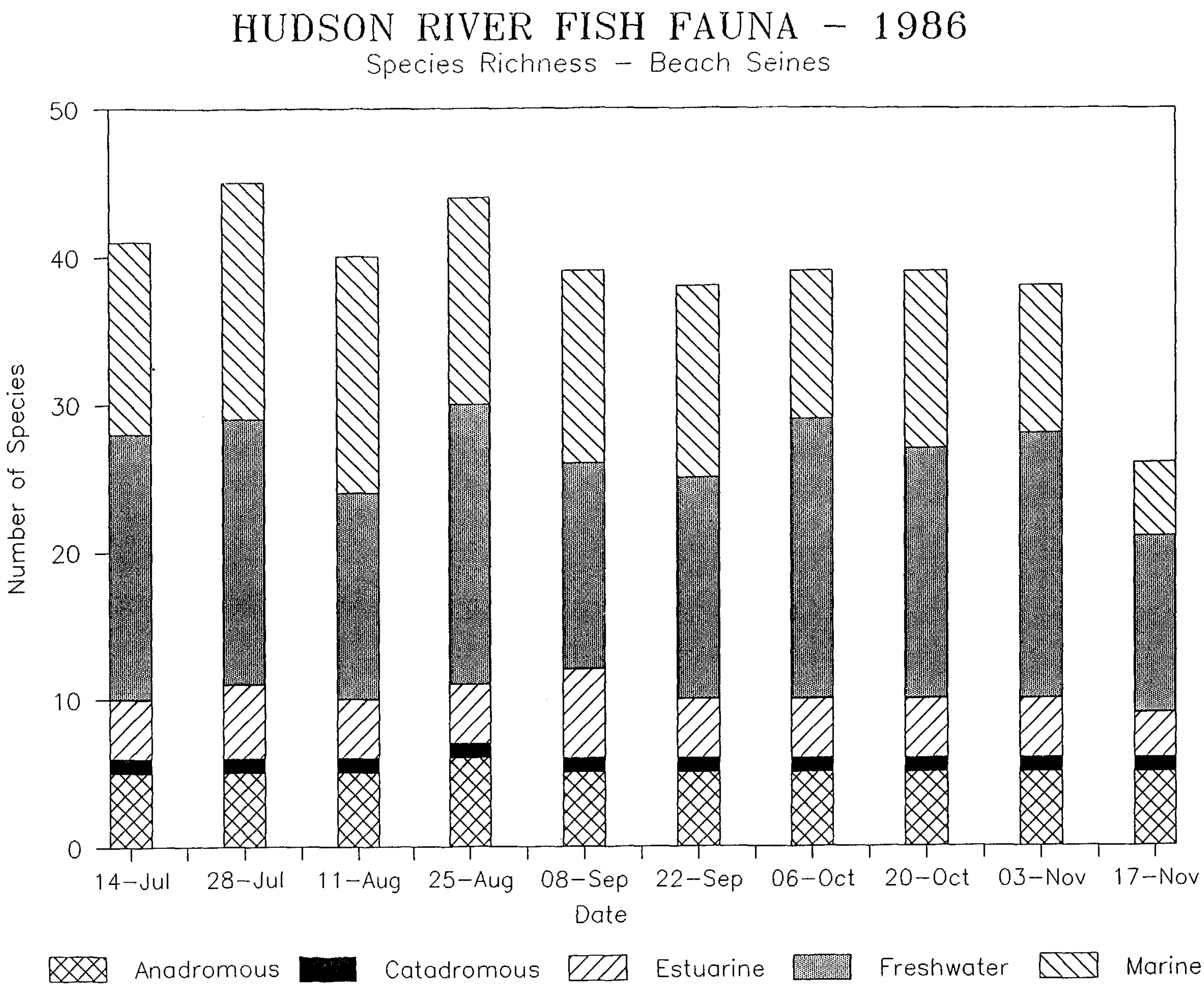
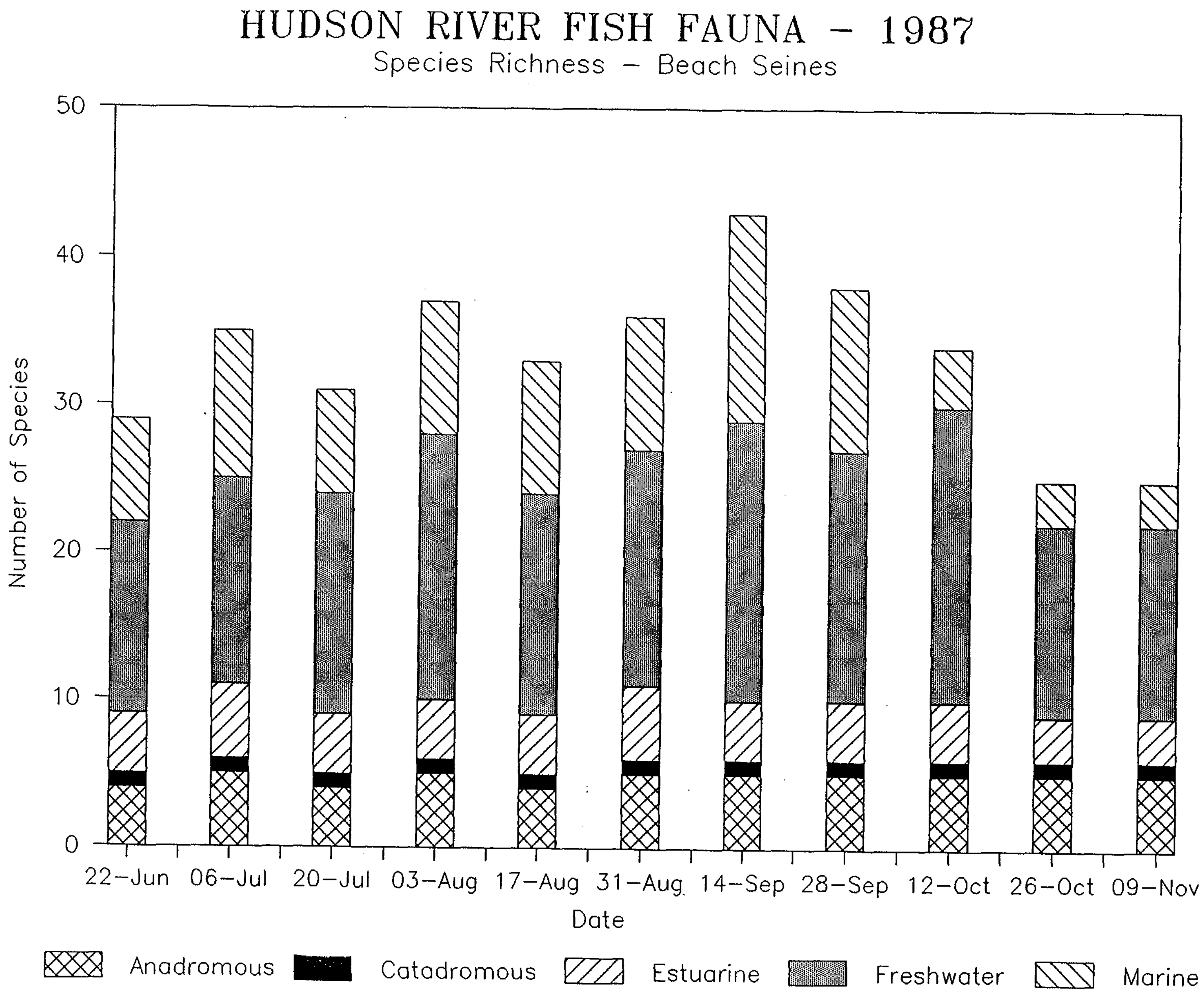
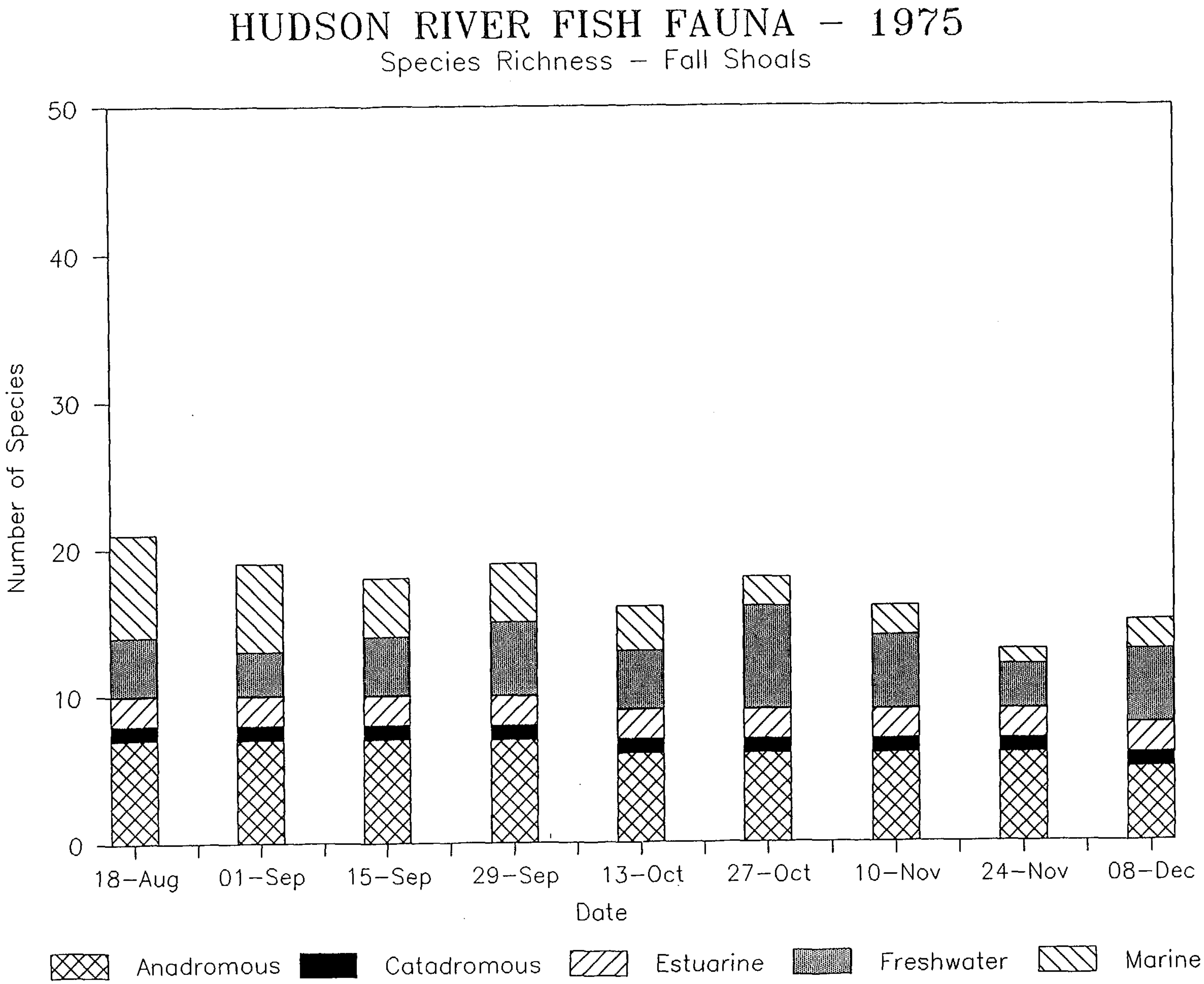

HUDSON RIVER FISH FAUNA - 1986
Species Richness - Beach Seines
Number of Species
0
10
20
30
40
50
14-Jul
28-Jul
11-Aug
25-Aug
08-Sep
22-Sep
06-Oct
20-Oct
03-Nov
17-Nov
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-5



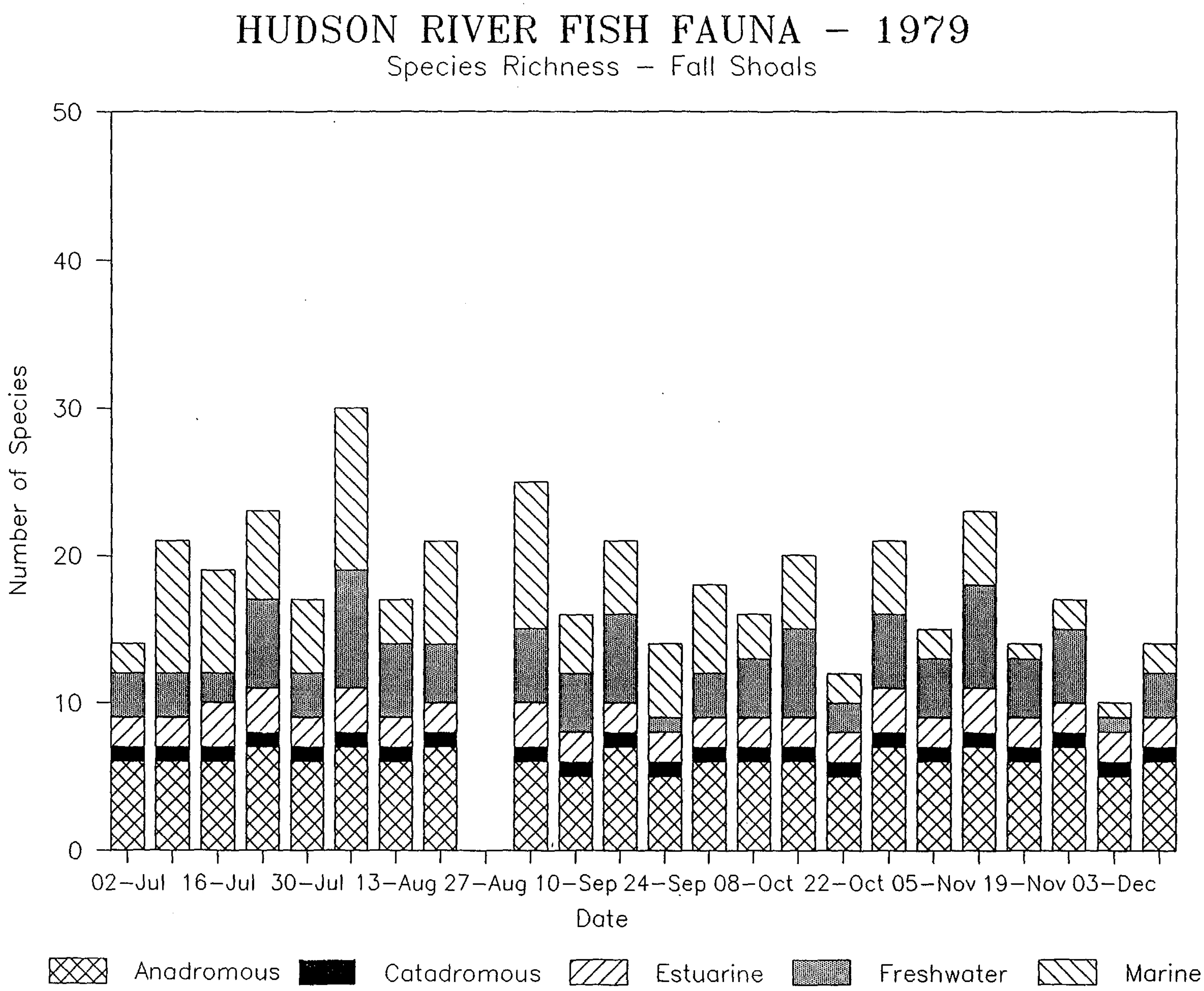
HUDSON RIVER FISH FAUNA – 1987
Species Richness – Beach Seines
Number of Species
50
40
30
20
10
0
22–Jun
06–Jul
20–Jul
03–Aug
17–Aug
31–Aug
14–Sep
28–Sep
12–Oct
26–Oct
09–Nov
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-6



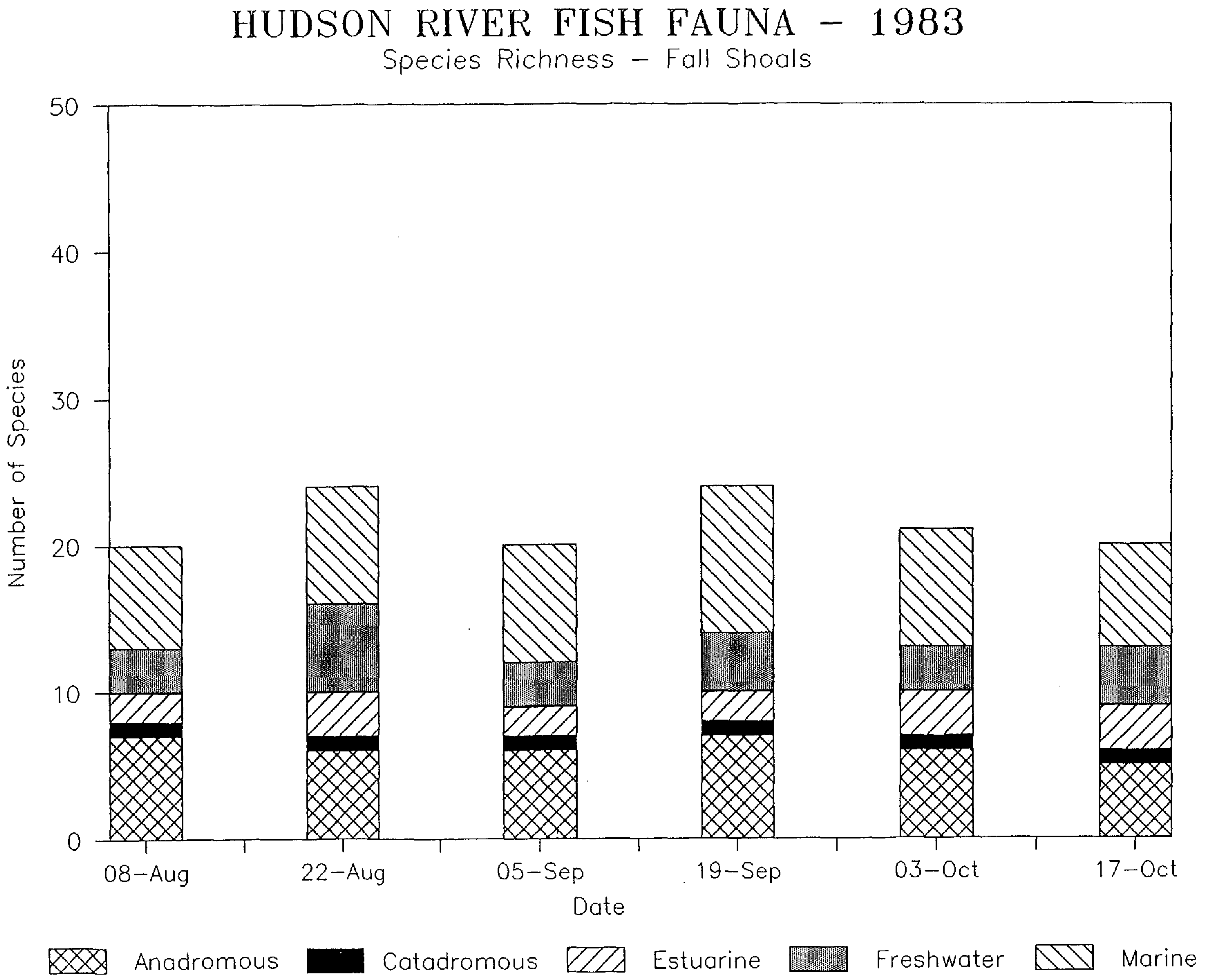
HUDSON RIVER FISH FAUNA – 1975
Species Richness – Fall Shoals
Number of Species
50
40
30
20
10
0
18-Aug
01-Sep
15-Sep
29-Sep
13-Oct
27-Oct
10-Nov
24-Nov
08-Dec
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-7



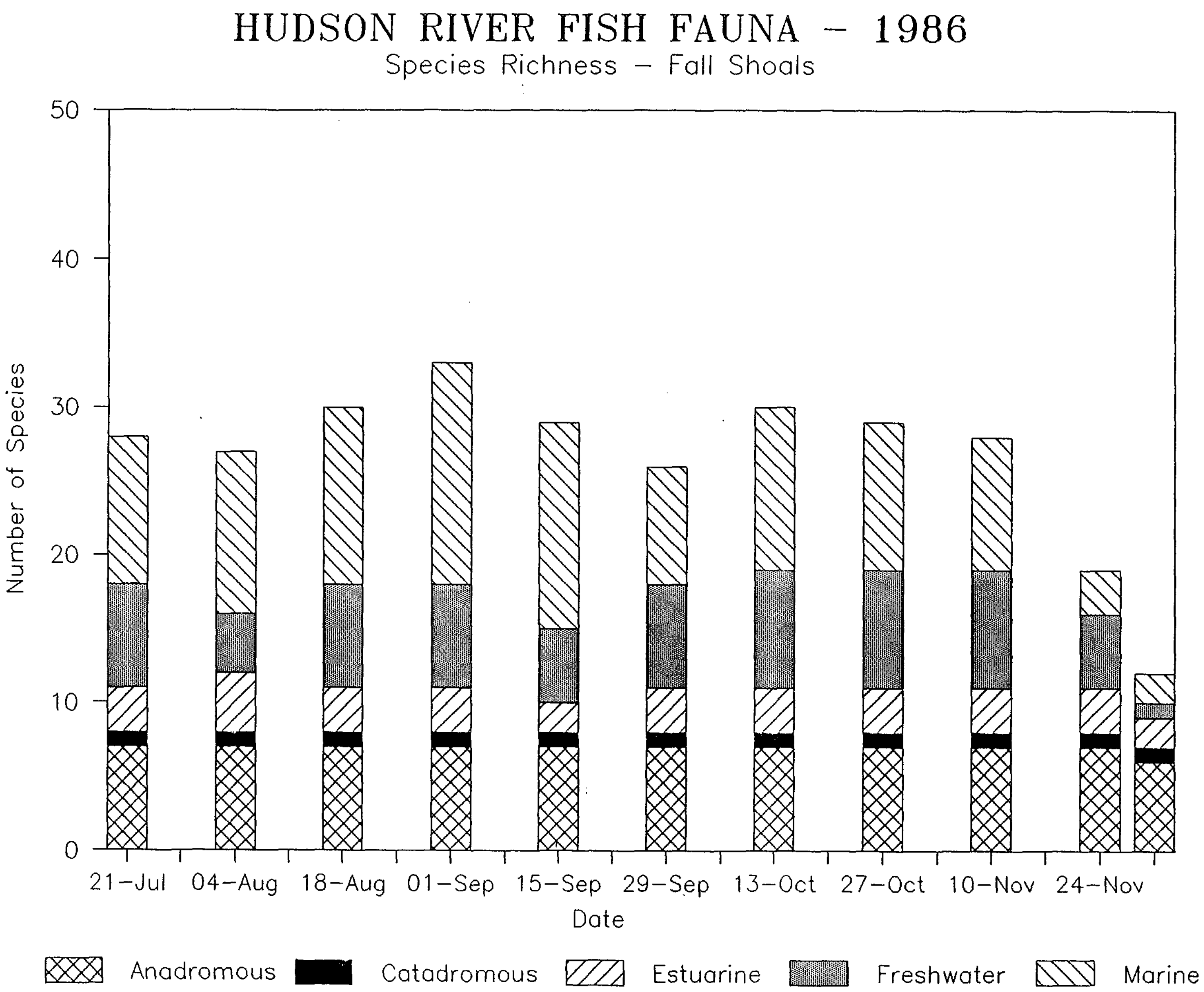
HUDSON RIVER FISH FAUNA – 1979
Species Richness – Fall Shoals
Number of Species
0
10
20
30
40
50
02–Jul 16–Jul 30–Jul 13–Aug 27–Aug 10–Sep 24–Sep 08–Oct 22–Oct 05–Nov 19–Nov 03–Dec
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-8



HUDSON RIVER FISH FAUNA - 1983
Species Richness - Fall Shoals
Number of Species
0
10
20
30
40
50
08-Aug
22-Aug
05-Sep
19-Sep
03-Oct
17-Oct
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-9



HUDSON RIVER FISH FAUNA – 1986
Species Richness – Fall Shoals
Number of Species
50
40
30
20
10
0
21-Jul
04-Aug
18-Aug
01-Sep
15-Sep
29-Sep
13-Oct
27-Oct
10-Nov
24-Nov
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-10

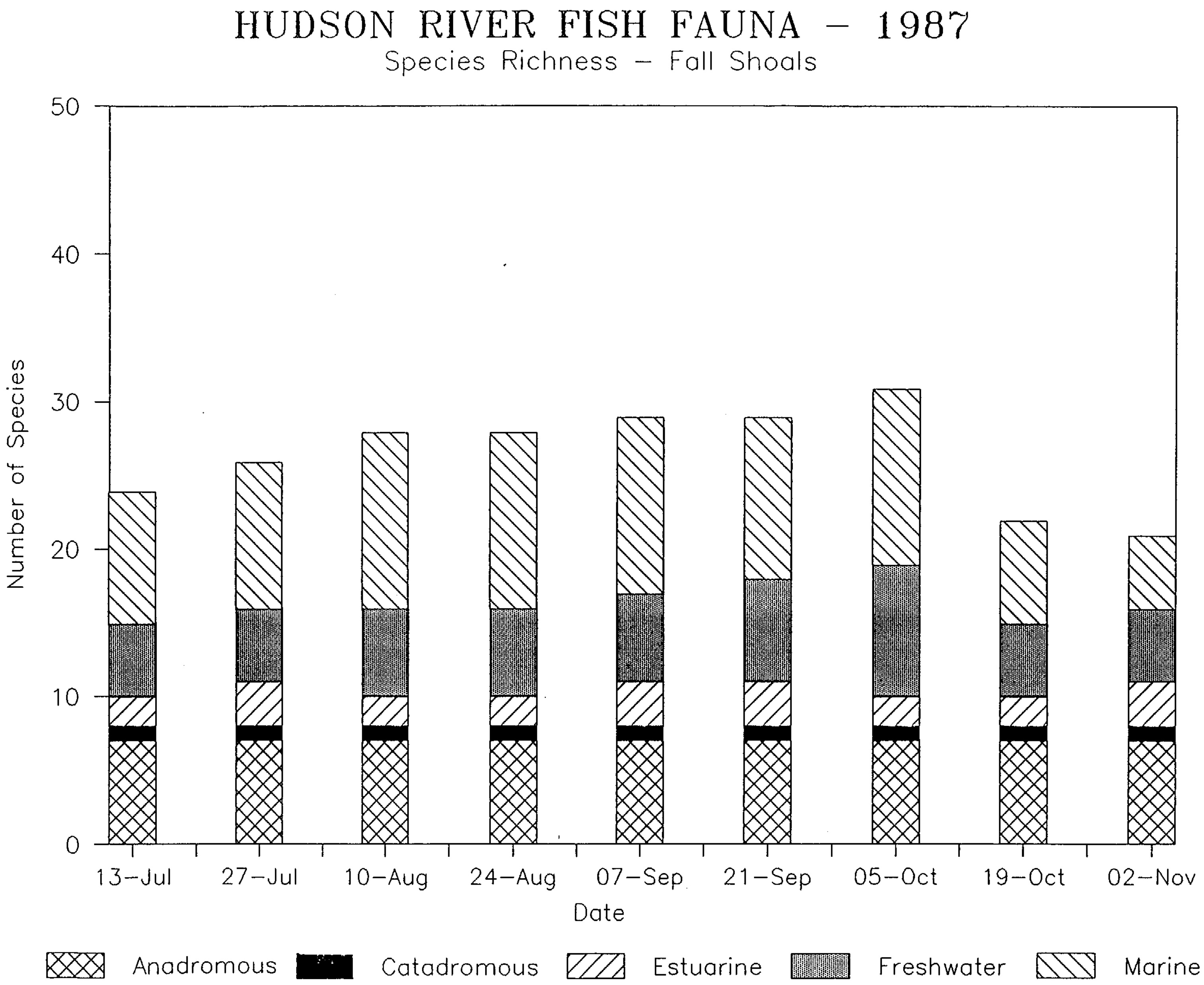

HUDSON RIVER FISH FAUNA – 1987
Species Richness – Fall Shoals
Number of Species
50
40
30
20
10
0
13–Jul
27–Jul
10–Aug
24–Aug
07–Sep
21–Sep
05–Oct
19–Oct
02–Nov
Date
Anadromous
Catadromous
Estuarine
Freshwater
Marine

FIGURE 7-11

DAILY FLOW

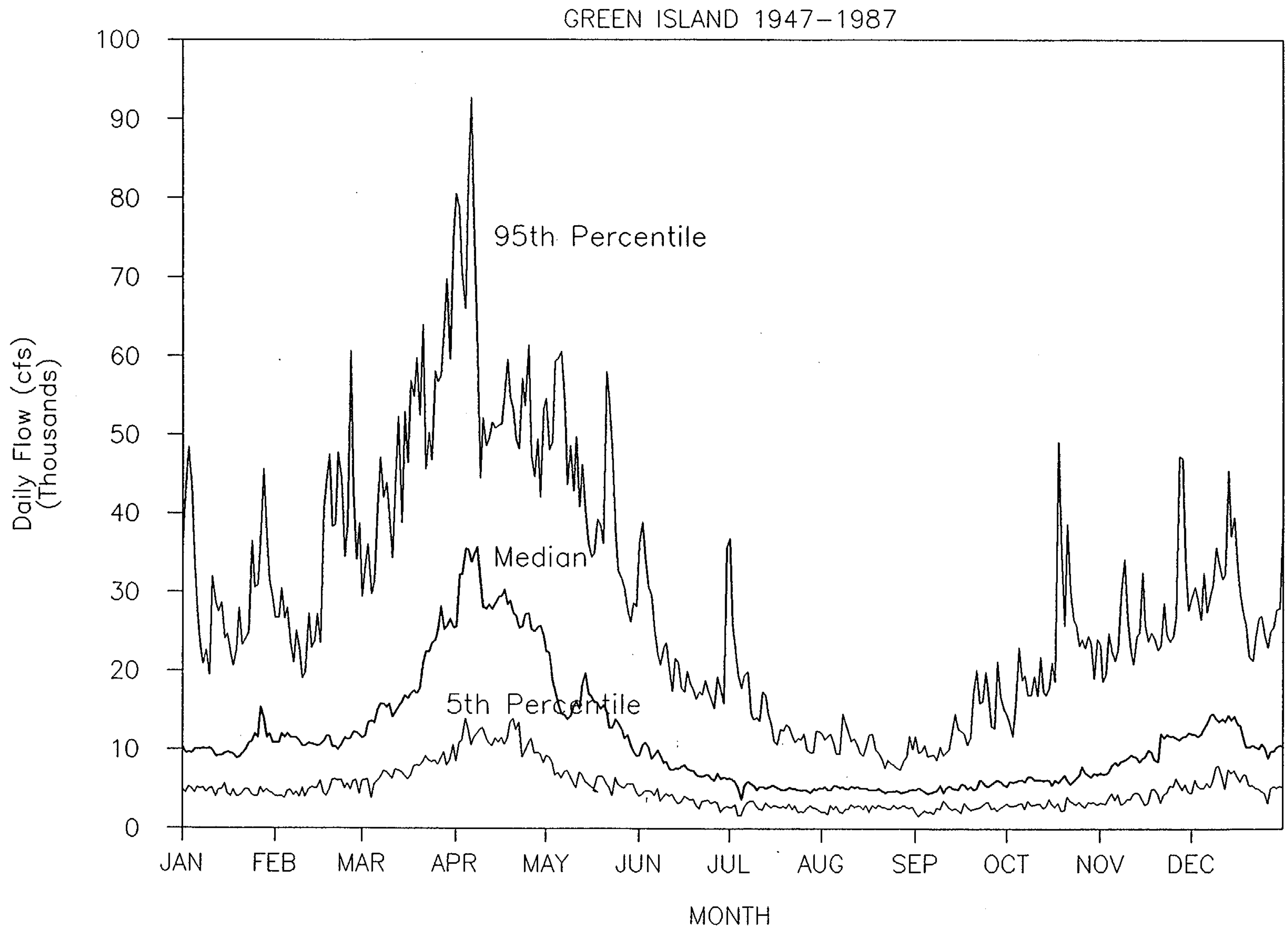


FIGURE 7-12

RELATIVE LOCATION OF SPECIES ASSEMBLAGES

Hudson River – 17 Aug 87 Beach Seine Survey

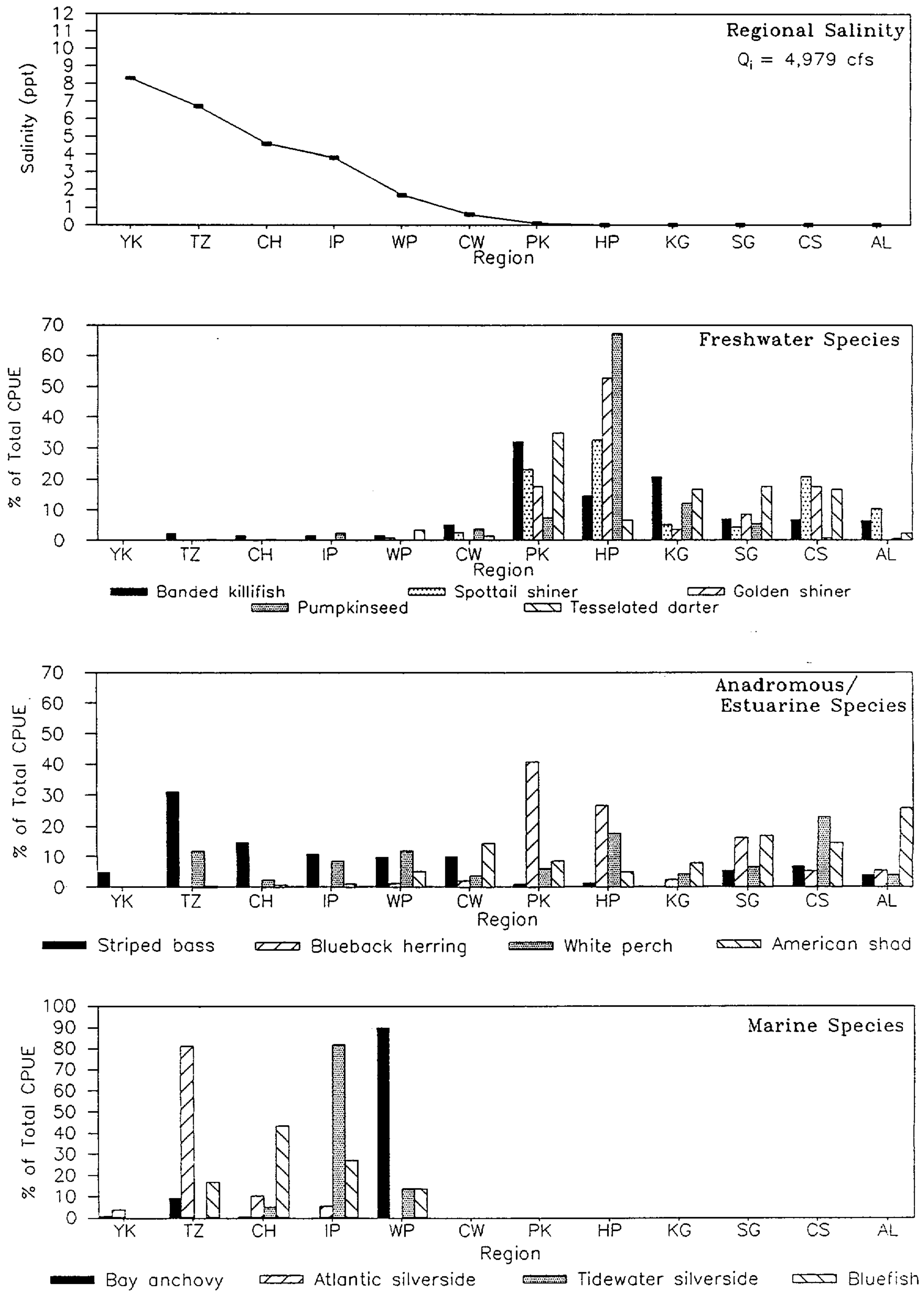


FIGURE 7-13

RELATIVE LOCATION OF SPECIES ASSEMBLAGES

Hudson River – 14 Jul 86 – Beach Seine Survey

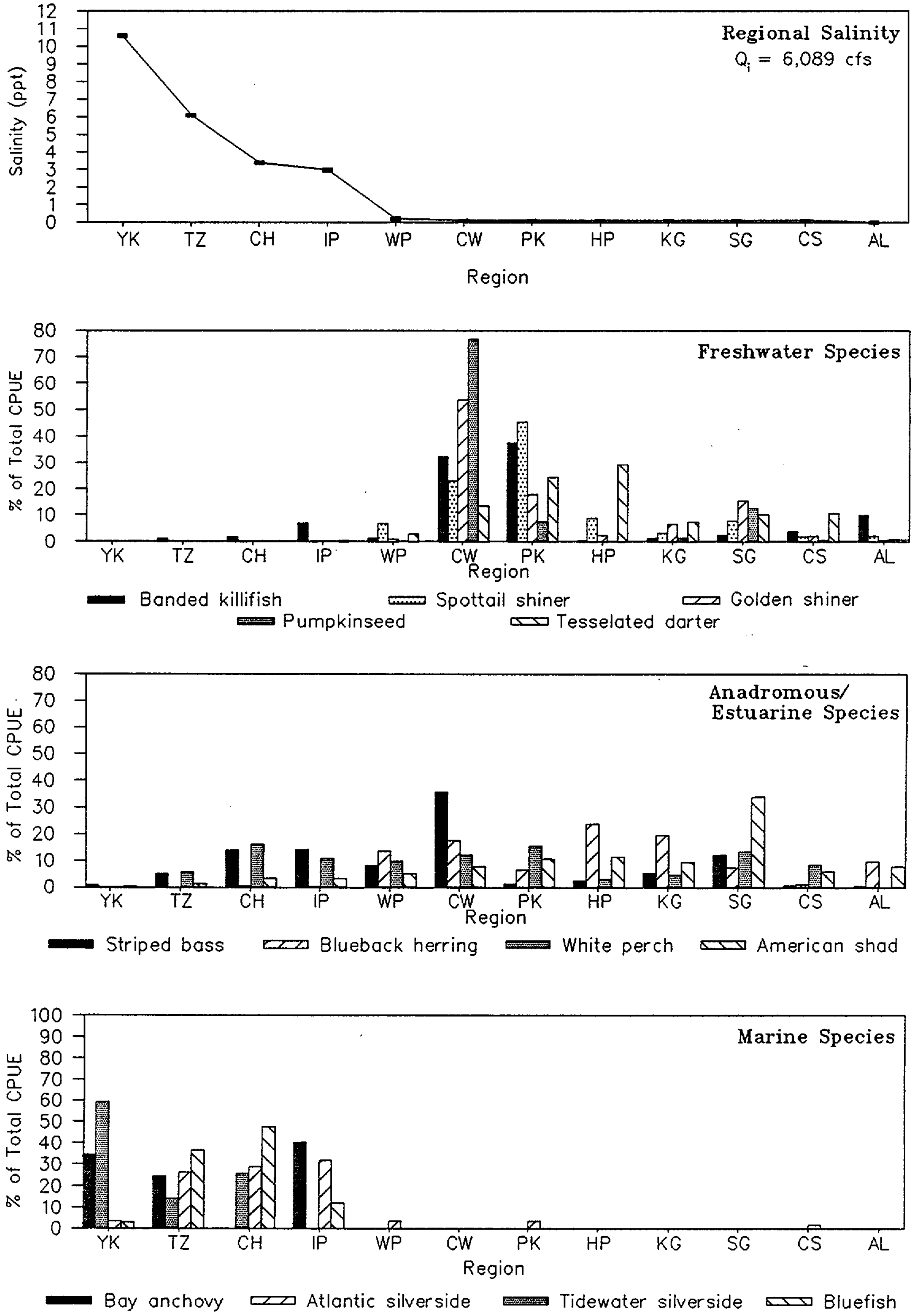
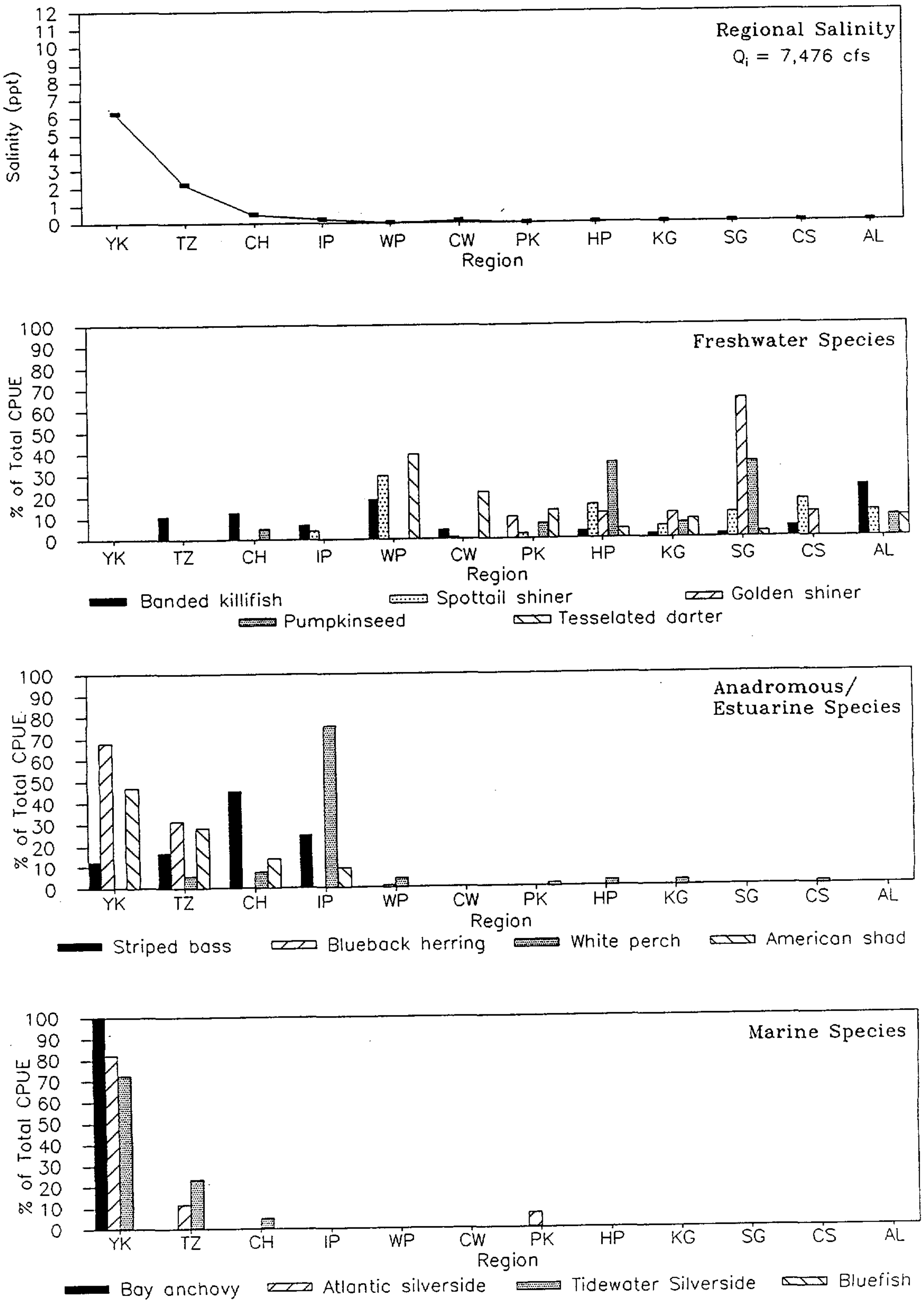


FIGURE 7-14

RELATIVE LOCATION OF SPECIES ASSEMBLAGES

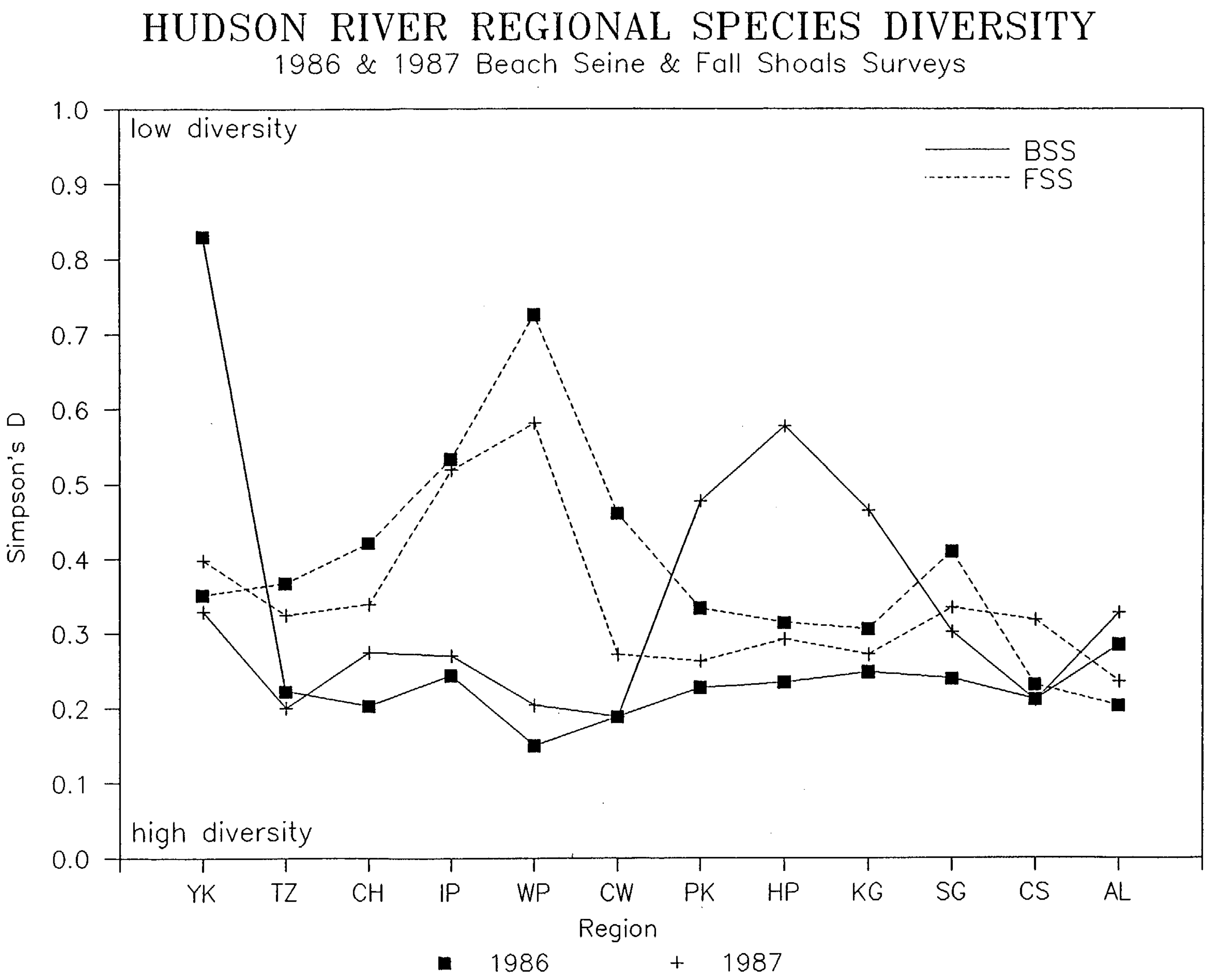
Hudson River – 17 Nov 86 – Beach Seine Survey



17 August 1987. Under this flow the salt front is located in the Poughkeepsie region; freshwater species are found in greatest abundance above the Poughkeepsie region while the marine species are found below the West Point region. As flow increased to 6089 cfs, the freshwater assemblage was found abundantly in the Cornwall region while the marine assemblage was shifted even farther downriver to the Indian Point region. At 7476 cfs the freshwater species were found as far downriver as West Point while the marine species were found primarily in the Yonkers and Tappan Zee regions. The anadromous and estuarine species are found throughout the estuary during the August flows of 4979 and 6089 cfs. These two assemblages are found primarily below the Indian Point region during the 7476 cfs flow period, but during late November these species generally migrate downriver regardless of flow (probably in response to decreasing temperature).

Species diversity, as measured by Simpson's D (see below), suggests that there are spatial differences in species assemblages. For the FSS during 1986 and 1987, Simpson's D increased from approximately 0.3 in Yonkers through Croton-Haverstraw and Poughkeepsie through Albany to approximately 0.5 in the Indian Point through Cornwall region (Figure 7-15). This indicated an increase in species dominance (a decrease in diversity). A possible explanation was the river morphometry. The river narrows through these regions (upper Indian Point through lower Cornwall) and becomes significantly deeper (Cooper et al. 1988); the deepest point in the river is located in the West Point region. Shallow areas typically display greater diversity than deeper zones, i.e., the shallow sampling BSS program generally displays greater diversity than the deeper sampling FSS program (Figure 7-15). The decrease in the 1987 BSS diversity from Poughkeepsie through Kingston in comparison to 1986 is probably due to the significantly stronger 1987 blueback herring year-class strength. In 1986, although blueback herring were abundant in the middle and upper regions of the estuary, they did not dominate the catch as in 1987 (Tables 7-2 and 7-3). Also, the 1987 blueback herring appeared to be located primarily in the Cornwall through Kingston regions (Figure 7-12).

FIGURE 7-15



HUDSON RIVER REGIONAL SPECIES DIVERSITY
1986 & 1987 Beach Seine & Fall Shoals Surveys
low diversity
high diversity
BSS
FSS
Simpson's D
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
YK
TZ
CH
IP
WP
CW
PK
HP
KG
SG
CS
AL
Region
1986
+ 1987

7.3 HUDSON RIVER FISH COMMUNITY STABILITY

Community stability can be defined in several different ways: the ability of a system to bounce back from disturbances (neighborhood stability), the ability to return to the same point after disturbances (global stability), or the absence of fluctuation (persistence) (Krebs 1978). In the absence of known disturbances, only the persistence definition is a practical measure and is the definition that will be adopted herein. A community is considered stable (persistent) if its constituent populations show little fluctuation. Usually this definition is considered over many years and excludes seasonal variations. Stability can be measured as (1) stability of numbers, (2) stability of relative abundance, (3) stability of diversity and dominance, and (4) stability of species composition. Stability of numbers can be measured by catch per unit effort (CPUE) data and is discussed for the dominant species in Chapter 6.

Stability in relative abundance was examined by comparing of the rank abundance within assemblages. In this and subsequent measures of stability, only the anadromous and the estuarine components were utilized. This was done because (1) the freshwater and marine assemblages were too dependent on prevailing river flow conditions, (2) the freshwater and marine assemblage populations were likely strongly influenced by factors outside the estuary, and (3) the estuarine and anadromous assemblages would most likely be the groups influenced most by power plant operations.

Stability of diversity and dominance were measured by two indices - Shannon's H' and Simpson's D. Despite its debated interpretation, Shannon's H' is probably the most widely used diversity index (see Washington 1984 for details). This index, based on information theory, is a measure of the average uncertainty of knowing what a discrete symbol is in a long message or, in the present sense, the degree of uncertainty attached to knowing what the specific identity (species) of any randomly selected individual will be. If only one species is present H' = 0. The greater the number of species and the greater their equality of proportions, the greater the inability to predict what species a randomly chosen individual will be (H' tends toward a large positive number) and therefore the greater the diversity (complexity or organization of the message). The formula is:

$$H' = -\sum_{i=1} (n_i/n) \log_2(n_i/n)$$

where:

n_i = number of individuals of the ith species
n = total number of individuals

Washington (1984), in reviewing diversity indices, found information-theory-based indices unsuitable for most applications, primarily due to their lack of biological relevance, and suggested that Simpson's index was a better choice. Simpson's D (Simpson 1949) is one of the oldest and simplest measures of diversity:

$$D = \sum_{i=1} (n_i(n_i-1)/n(n-1))$$

Krebs (1978) describes Simpson's D as the probability of picking two organisms of different species at random. The index tends to disproportionately assign importance to dominant species and give little weight to rarer ones, leading some authors to refer to Simpson's index as an index of dominance. This index ranges from 0 to 1.0 to quantify the range from high diversity (all individuals are different species) to low diversity (all individuals are the same species.

Stability in species composition and relative abundance can be measured in several ways. One of the most commonly used methods is the Percent Similarity Index (PSI) (EPRI 1980):

$$PSI_{k,l} = 100 \sum_{i=1}^{s} \min\left(\frac{d_{ik}}{\sum_{i=1} d_{ik}} , \frac{d_{il}}{\sum_{i=1} d_{il}} \right)$$

where:

d_{ik} = density of the ith taxon at the k site
d_{il} = density of the ith taxon at the l site
s = total species collected

Because PSI standardizes by the total, it measures similarity in the distribution of species independent of the number of individuals. PSI varies from zero (no faunal similarity) to 100 (all elements identical).

A second measure of this type is Morisita's Index (Im):

$$I_m = (2 \sum_{i=1} n_{1i}\, n_{2i}) \;/\; (\lambda_1 + \lambda_2)\, N_1\, N_2$$

where

$$\lambda_1 = \sum_{i=1} n_{1i}(n_{1i}-1)/(N_1(N_1-1))$$

$$\lambda_2 = \sum_{i=1} n_{2i}(n_{2i}-1)/(N_2(N_2-1))$$

where

n_{1i} = number of individuals from the ith taxon from location 1
n_{2i} = number of individuals from the ith taxon from location 2
N_1 = total number of individuals of all species at location 1
N_2 = total number of individuals of all species at location 2

This index was also used because Matthews et al. (1988), after an extensive literature review of its use in various fisheries applications, concluded that values greater than about 0.7 indicated stability in assemblages. Morisita's Index is also independent of sample size and species diversity (Wolda 1981).

Examination of the estuarine assemblage indicates that species composition and relative abundance have been remarkably consistent among the five years examined. In the beach seine study four to six of the seven assemblage members were taken annually (August through October), with white perch always the most abundant species (Table 7-5). Fourspine stickleback was the second most abundant species except during 1983 and 1987, when it ranked fourth. Threespine stickleback was absent from the 1975 collections and ranked fifth in all other years. A year-to-year comparison using I_m and PSI also indicates a high degree of persistence. I_m was always above 0.7, generally >0.99, while PSI values were greater than 0.94 (Table 7-6). Species diversity, as measured by Shannon's H', indicates an increasing diversity that ranged from 0.267 in 1975 to 0.572 in 1987. Simpson's D also suggests a trend toward increasing diversity, or decreasing dominance, ranging from 0.933 in 1975 to 0.832 in 1987. The high values for Simpson's D, i.e., near 1.0, and the relatively low values for H' reflect a nearshore component heavily dominated by a single species - white perch.

The FSS catches of the estuarine assemblage also reflect a high degree of persistence. Only two species are typically captured, although as many as four are sometimes taken. The most abundant species captured in all years was hogchoker, followed by white perch. Fourspine stickleback and shortnose sturgeon were taken less frequently and not in every year. As in the beach seine collections, indices of faunal resemblance indicate a high degree of persistence. All I_m values were above 0.7; the lowest value, comparing 1979 with 1986, was 0.874. PSI values ranged from a low of 0.727 for 1979 vs 1986 to a high of 0.999 for 1986 vs 1987. Shannon's H' and Simpson's D indicate a reduction in diversity or increase in dominance during 1986 and 1987. This change appears to be brought about by a large increase in hogchoker catches during 1986 and 1987. The increased hogchoker catch may be due in part to the switch in gear from the epibenthic sled to the beam trawl in 1985. However, a comparison of FSS catch data for 1983, 1986, and 1987 (3.5, 58.3, and 55.0/10-min haul) with otter trawl catches (LMS 1986, 1987, 1988) from 1983

TABLE 7-5

SPECIES DIVERSITY IN THE ESTUARINE AND ANADROMOUS ASSEMBLAGES OF THE HUDSON RIVER

ESTUARINE ASSEMBLAGE	1975	1979	1983	1986	1987
Beach Seine Survey					
Richness	4	5	5	6	5
Shannon's H'	.267	.387	.225	.457	.572
Simpson's D	.933	.888	.943	.867	.832
Ranking	WP	WP	WP	WP	WP
	FSB	FSB	HC	FSB	MG
	MG	MG	MG	HC	HC
	HC	HC	FSB	MG	FSB
		TSB	TSB	TSB	TSB
				FS	

ESTUARINE ASSEMBLAGE	1975	1979	1983	1986	1987
Fall Shoals Survey					
Richness	2	3	3	4	3
Shannon's H'	.897	1.00	.995	.726	.729
Simpson's D	.570	.501	.507	.678	.677
Ranking	HC	HC	HC	HC	HC
	WP	WP	WP	WP	WP
		FSB	SNST	SNST	SNST
				FSB	

ANADROMOUS ASSEMBLAGE	1975	1979	1983	1986	1987
Beach Seine Survey					
Richness	5	6	6	6	5
Shannon's H'	1.122	.852	.830	1.460	1.328
Simpson's D	.615	.721	.720	.418	.488
Ranking	BBH	BBH	BBH	ASD	BBH
	ASD	ASD	ASD	BBH	SB
	SB	SB	SB	SB	ASD
	AW	AW	AW	AW	AW
	ATC	ATC	ATC	ATC	ATC
		AS	AS	RSM	

ANADROMOUS ASSEMBLAGE	1975	1979	1983	1986	1987
Fall Shoals Survey					
Richness	7	7	7	7	7
Shannon's H'	1.099	.763	.626	2.013	1.670
Simpson's D	.663	.787	.817	.302	.595
Ranking	BBH	BBH	BBH	ATC	BBH
	ATC	AW	ASD	BBH	SB
	AW	ASD	AW	SB	ATC
	SB	ATC	SB	ASD	AW
	ASD	SB	ATC	AW	RSM
	RSM	RSM	AS	RSM	ASD
	AS	AS	RSM	AS	AS

AS = Atlantic sturgeon
ASD = American shad
ATC = Atlantic tomcod
AW = alewife
BBH = blueback herring
FSB = fourspine stickleback
HC = hogchoker
MG = mummichog
SB = Striped bass
SNST = shortnose sturgeon
RSM = rainbow smelt
TSB = threespine stickleback
WP = white perch

TABLE 7-6

SIMILARITY OF FISH FAUNA OF THE HUDSON RIVER BETWEEN SELECT YEARS, WITH DATA POOLED BY FISH ASSEMBLAGE[a]

ESTUARINE SPECIES	1975	1979	1983	1986
Fall Shoals Survey				
1979	.951-.838			
1983	.970-.872	.998-.966		
1986	.980-.888	.874-.727	.903-.760	
1987	.981-.890	.875-.728	.904-.762	1.00 -.999
Beach Seine Survey				
1979	.999-.973			
1983	1.00 -.980	.998-.955		
1986	.999-.956	1.00 -.983	.998-.955	
1987	.997-.945	.998-.946	.997-.940	.998-.953

ANADROMOUS ASSEMBLAGE	1975	1979	1983	1986
Falls Shoals Survey				
1979	.993-.909			
1983	.989-.868	.999-.959		
1986	.639-.501	.570-.434	.558-.433	
1987	.841-.658	.792-.578	.782-.554	.778-.624
Beach Seine Survey				
1979	.994-.926			
1983	.995-.930	1.00 -.985		
1986	.731-.610	.699-.570	.698-.572	
1987	.970-.852	.945-.801	.949-.811	.757-.609

[a]Tabled values = Morisita's Index, followed by percent similarity index.

through 1987 (65.4, 111.1, 143.1, and 55.3/10-min haul) does not indicate the presence of differential gear efficiency.

The beach seine collections of anadromous species were relatively persistent, but not to the degree exhibited by the estuarine assemblage. Five to six of the eight species in this assemblage were taken annually, with the blueback herring the top-ranked species in every year except 1986. Morisita's Index of faunal resemblance was above 0.7 except for 1979 vs 1986 and 1983 vs 1986 when it was 0.699 and 0.698, respectively. I_m ranged as high as 0.995 for 1975 vs 1983. The PSI values paralleled the I_m results. Shannon's H' and Simpson's D suggest a tendency for increasing diversity and decreasing dominance, at least since 1979.

The FSS collections for the anadromous assemblage exhibit the most year-to-year variation among the four groups examined, but overall the degree of persistence is very high. The same seven species were taken in all five years; hickory shad was absent. Blueback herring ranked first in abundance in all years except 1986, when it ranked second. The relative abundance of the remaining species changed from year to year. Morisita's Index was above 0.7 for seven of the 10 comparisons; only 1975 vs 1986, 1979 vs 1986, and 1983 vs 1986 were below 0.7. PSI values ranged from a high of 0.959 for 1979 vs 1983 to a low of 0.433 for 1983 vs 1986. Shannon's H' and Simpson's D suggest a decrease in diversity and an increase in dominance during 1979 and 1983. The highest H' and lowest D was from 1986. This increase in diversity and decrease in dominance likely results from the large decrease in blueback herring catches during 1986; with fewer blueback herring the overall species composition becomes more equitable.

7.4 CONCLUSIONS

Examination of Hudson River fish assemblages indicates that distinct fish communities do not exist. Instead, species are distributed along a salinity gradient that changes spatially with freshwater discharge. Under low-flow conditions marine species penetrate far upriver; under high-flow conditions freshwater species are found far downriver. After these discharge-sensitive distribution patterns are eliminated, the Hudson River fish assemblages appear to have remained stable among the five years examined since 1975. Typically, the same species in nearly the same rank order of abundance are caught year after year. Blueback herring and American shad dominate the anadromous component; white perch and hogchoker dominate the estuarine assemblage.

CHAPTER 8

GROWTH

Most fish species have the capacity for sustained growth over their entire life cycle (Lagler et al. 1962; Bond 1979). The greatest percentage of total growth occurs in the first year after hatching and diminishes with increased age (Crowder et al. 1987; Miller et al. 1988). Age and growth studies of fish populations are used to characterize the life span and determine the age at sexual maturity, help to evaluate the influence of environmental variables (abiotic and biotic) on life stages, and help in understanding trends in abundance and distribution (Chugunova 1959; Lenski and Service 1982).

Fish growth is affected by density-independent factors, like temperature, salinity, and diel periodicity, and by density-dependent factors, such as food availability, feeding behavior, and competition. The effects of both types of factors are interrelated. Fish populations from temperate latitudes normally assume a seasonal growth pattern, with growth occurring during the period of warm water temperatures (spring through fall) and a cessation of growth during the cold, winter months. Attainment of sexual maturity also affects growth, with both males and females exhibiting slower growth prior to spawning as a result of energy requirements for gonad development.

Fish growth studies, especially those that concentrate on fish during the first year following hatching, are important to fisheries investigations and management programs. Growth studies provide information on recruitment, mortality, abundance, and the rate of survival in successive years of life (Ricker 1947; Chugunova 1959; Bond 1979; Miller et al. 1988). Hatching size is important since larger larvae tend to have greater food reserves, faster development of motility capabilities (which are useful in successful feeding and escapement), and earlier achievement of sizes larger than predator feeding preference or capabilities (Crowder et al. 1987; Miller et al. 1988). Recruitment and reproductive capabilities are also related to size, with larger fish generally exhibiting both greater survival and earlier sexual maturation than smaller fish of the same species.

This chapter presents estimated growth rates of larval and juvenile striped bass, white perch, and American shad for 1984 through 1987. Estimates were based on population growth rather than individual growth by comparing the mean length of the fish population through time.

Before growth rates were estimated, the mean regional densities of eggs and larvae over time, in conjunction with length-frequency distributions (Appendix K), were examined in an attempt to differentiate and minimize the effect of multiple cohorts. If bimodal peaks (representing separate cohorts) are present, the mean length would be an intermediate value between the two peaks. In this case the mean misrepresents the population growth and therefore should not be used to estimate growth rates.

Bimodal egg abundance distributions were observed for striped bass in 1984 and 1987 and in white perch from 1984 through 1986. The 1984 striped bass and white perch bimodal pattern did not continue throughout the season; prior to the second cohort, cold temperatures (Figure 8-1) and high freshwater flows (Figure 8-2) in late May resulted in the apparent mortality or loss from the Hudson Bay estuary of the first cohort. Adjustments in the 1984 logistic growth estimates were made for the presence of a second cohort (Sections 8.1.1.2 and 8.2.1.2). Although bimodal egg abundance patterns were observed for striped bass in 1987 and for white perch in 1986, no bimodal length-frequency patterns were observed for larvae. In addition, an examination of length-frequency distributions for all remaining species did not exhibit any consistent bimodal length-frequency patterns, suggesting the presence of sampling artifacts rather than distinguishable cohorts. As a result, weekly mean lengths were used in all of the following growth calculations.

Two growth models, a log-linear regression model (similar to the one used in previous Year-Class Reports) and a nonlinear regression model, were used in the evaluation of growth for the 1984-1987 year classes. Zweifel and Lasker

FIGURE 8-1

WEEKLY MEAN TEMPERATURES, 1984-1987

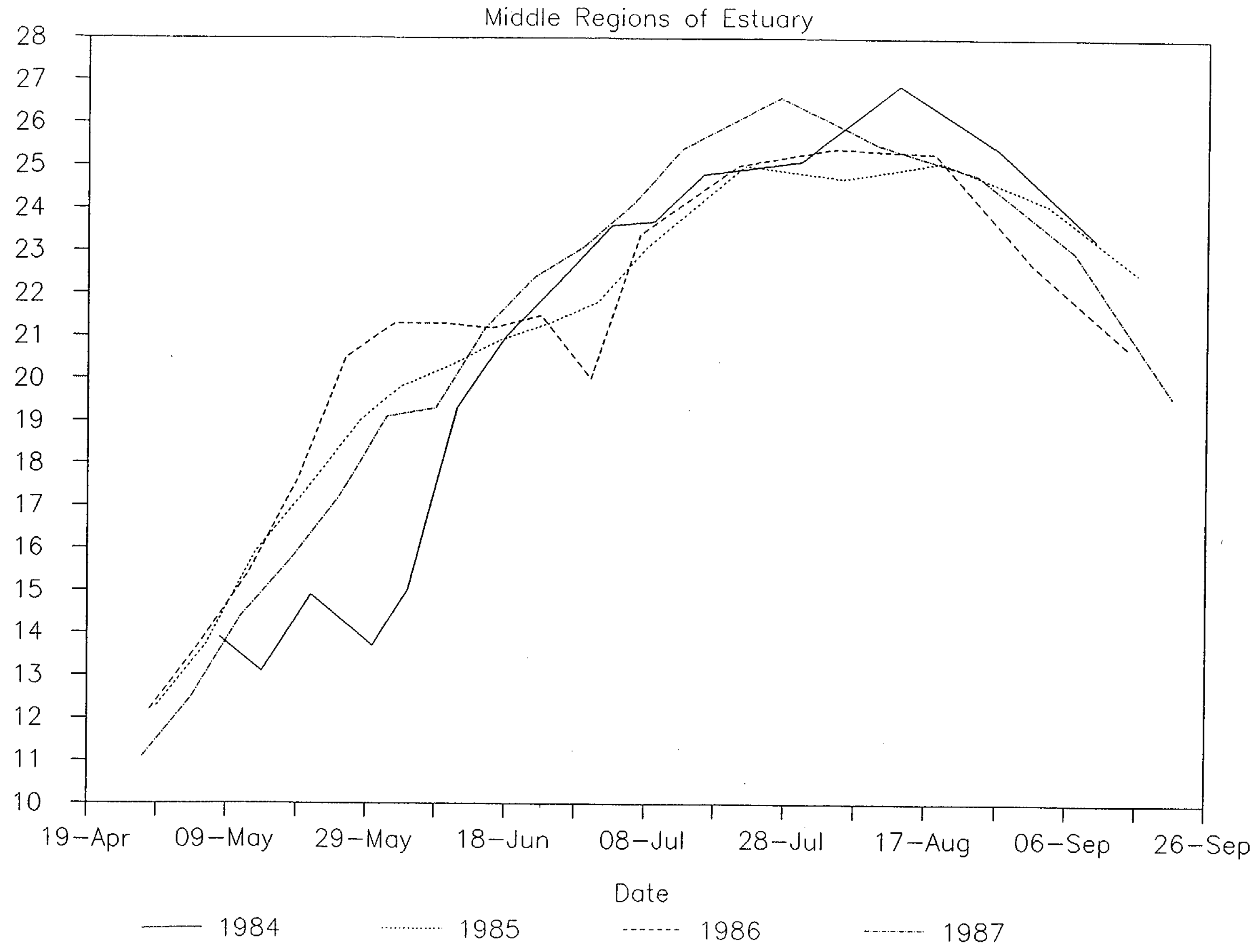
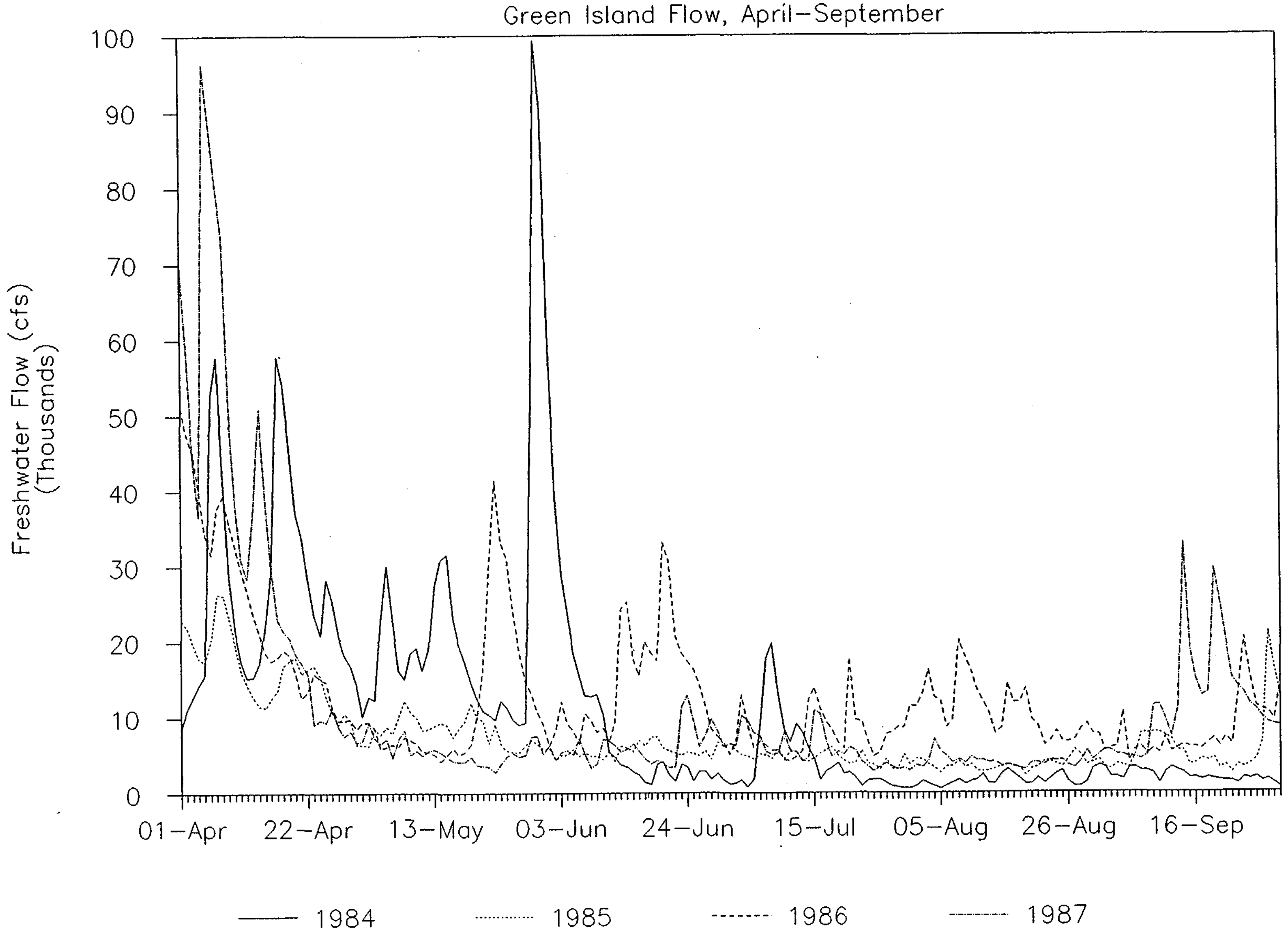


FIGURE 8-2

HUDSON RIVER FRESHWATER FLOW



(1976) reported that early stages of fish growth exhibit an exponential increase followed by an exponential decay. They also observed that the effect of temperature on growth follows a similar pattern. Because of the exponential growth pattern, the logistic function used in the nonlinear regression may provide a more appropriate model of fish growth. Methods for calculating growth rates are described in Section 2.6.5.

8.1 STRIPED BASS

8.1.1 1984 Survey

8.1.1.1 Log-Linear Estimates. The average length of the 1984 Hudson River striped bass population was estimated to have reached 30 and 60 mm (TL) on 12 July and 17 August, respectively (Table 8-1). These dates were estimated based on the log-linear regression ($\ln Y = 0.019416x + 2.003790$, $r^2 = 0.9987$) of BSS mean length data from samples taken from 23 July through 20 August (Figure 8-3). Larval growth rate was calculated as 0.7 mm/day based on peak egg abundance during the week of 4 June (MMES 1986). Juvenile growth (30 to 60 mm) was calculated at 0.8 mm/day. The 1984 striped bass population reached mean lengths of 30 and 60 mm later in the year than reported in previous year-class studies (not including 1982 and 1983). However, a different analytical procedure was used for 1982 and 1983 because of a four-week gap between ichthyoplankton and juvenile sampling that precluded use of the standard regression methods.

8.1.1.2 Logistic Estimates. From the logistic equation ($K = 85.610847$, $R = 0.052704$, $A = 6.494099$, $r^2 = 0.9933$) (Figure 8-3), the Hudson River striped bass population was estimated to have reached mean lengths of 30 and 60 mm (TL) on 21 July and 18 August, respectively (Table 8-1). Using these dates, the growth rates from hatching to recruitment size (30 mm) and from recruitment size to 60 mm were calculated to be 0.6 and 1.1 mm/day, respectively. The 1984 logistic estimated growth rates were closer in size to historic growth rate estimates than the 1984 log-linear values.

TABLE 8-1

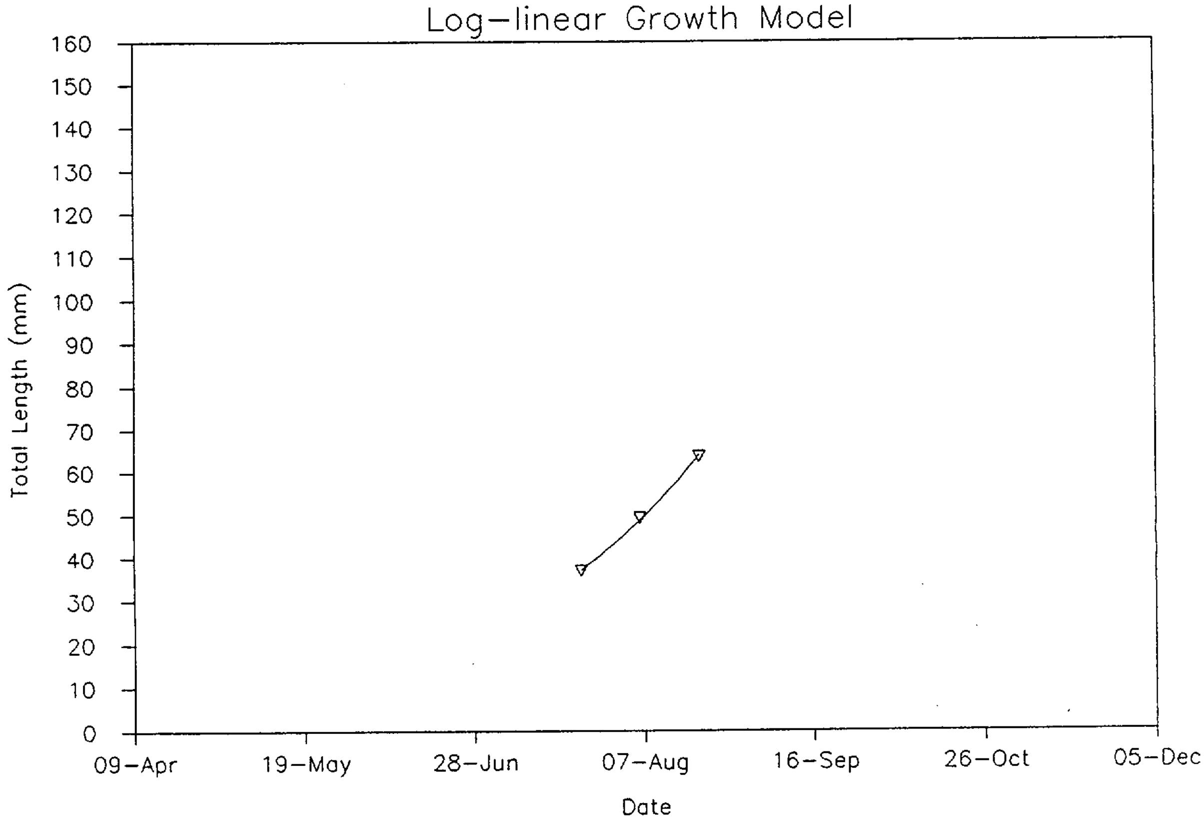
ESTIMATES OF LARVAL AND EARLY JUVENILE (4-30 mm TL) AND JUVENILE (30-60 mm TL) GROWTH RATES OF STRIPED BASS COLLECTED FROM THE HUDSON RIVER ESTUARY SINCE 1973[a]

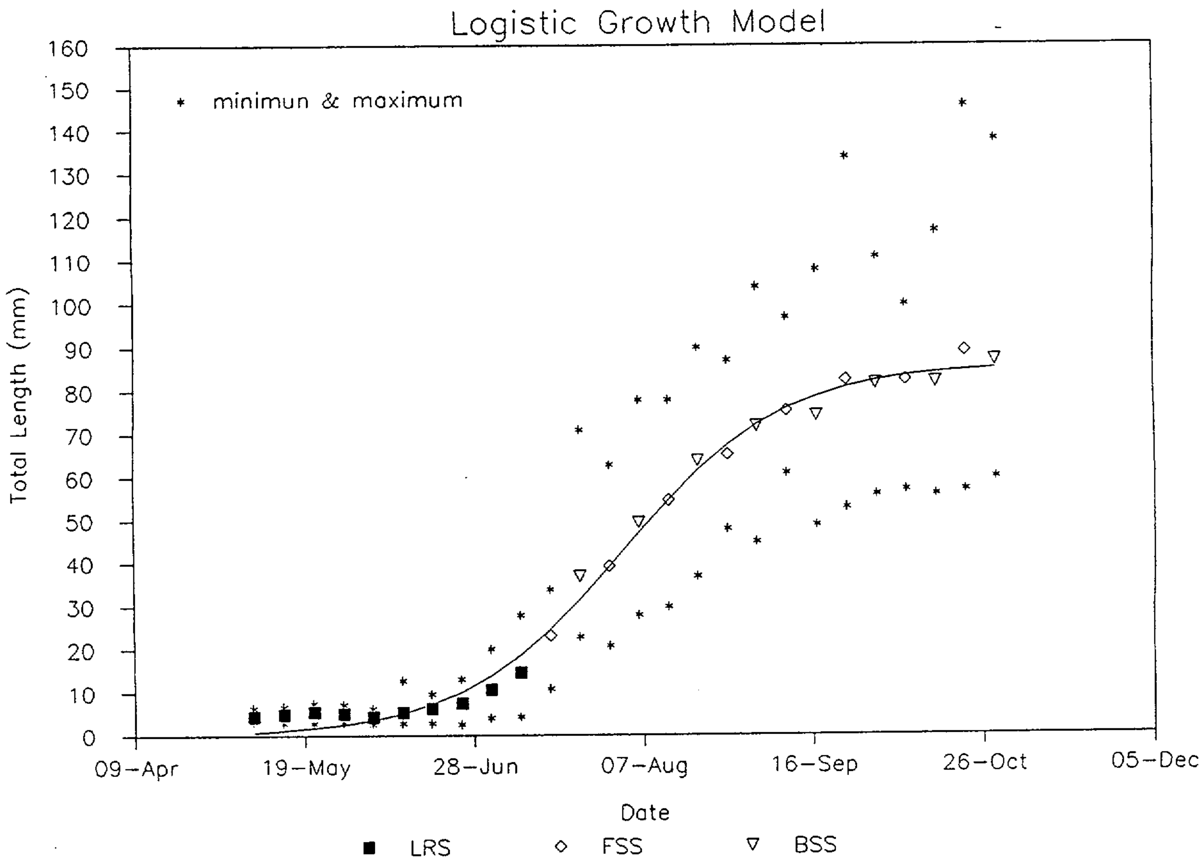
	LARVAE AND EARLY JUVENILES		JUVENILES	
YEAR	TIME PERIOD	RATE (mm/day)	TIME PERIOD	RATE (mm/day)
1973	16 May - 09 Jul	0.5	09 Jul - 05 Aug	1.1
1974	16 May - 06 Jul	0.5	16 Jul - 09 Aug	0.9
1975	21 May - 28 Jun	0.7	28 Jun - 30 Jul	0.9
1976	08 Jun - 10 Jul	0.8	10 Jul - 12 Aug	0.9
1977	18 May - 06 Jul	0.5	06 Jul - 05 Aug	1.0
1978	24 May - 03 Jul	0.7	03 Jul - 02 Aug	1.0
1979	09 May - 27 Jun	0.5	27 Jun - 01 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	07 Jun - 12 Jul	0.7	12 Jul - 17 Aug	0.8
1984[c]	07 Jun - 21 Jul	0.6	21 Jul - 18 Aug	1.1
1985	08 May - 06 Jul	0.4	06 Jul - 25 Jul	1.6
1985[c]	08 May - 08 Jul	0.4	08 Jul - 05 Aug	1.1
1986	28 May - 05 Jul	0.5	05 Jul - 21 Jul	1.8
1986[c]	28 May - 08 Jul	0.5	08 Jul - 31 Jul	1.3
1987	13 May - 30 Jun	0.5	30 Jun - 08 Aug	0.8
1987[c]	13 May - 09 Jul	0.5	09 Jul - 09 Aug	1.0

[a]Growth rates were not available from 1980 or 1981 data.
[b]Methods used were different from those described in Section 2.6.5 (NAI 1985a,b).
[c]Growth rates using the logistic growth model.

FIGURE 8-3

STRIPED BASS GROWTH - 1984





Egg abundance distribution was bimodal in 1984. The first cohort appeared to contribute little to the juvenile population; this is likely due to mortality of the early cohort. Cold water temperatures (Figure 8-1) and high freshwater flows (Figure 8-2) during late May and early June 1984 were primarily responsible for the mortality. Because the logistic model includes mean length data prior to 1 June sampling, there is a possible discrepancy in growth rates between the two models. The logistic equation was therefore recalculated using only the larval mean lengths from collections after 1 June so as not to include information on the nonrecruited cohorts. Using the new equation (K = 85.117706, R = 0.054522, A = 6.705854, r^2 = 0.9353), it was determined that the striped bass population reached a mean length of 30 and 60 mm (TL), respectively, on 21 July and 18 August, the same dates as determined previously using larval mean lengths from all sample collections (Figure 8-4); thus, growth rates also remain the same.

Mean temperatures during peak egg, YSL, and PYSL abundance were within the range observed in other years (Table 8-2). Compared to other years (1974-1987), peak egg, YSL, and PYSL abundance occurred approximately two weeks later in the season (Table 8-2). This resulted in a later growing season, evidenced by the shift toward the right in the sigmoid growth curve as compared to years 1985-1987 (Figure 8-5); growth achieved during the fall period also appears to be smaller. However, larval and juvenile growth rates are similar to striped bass 1985-1987 values (Table 8-1), which have earlier egg abundance dates.

8.1.2 1985 Survey

8.1.2.1 Log-Linear Estimates. The striped bass population in 1985 reached mean total lengths of 30 and 60 mm on 6 and 25 July, respectively (Table 8-1). These dates were estimated from the log-linear regression (ln Y = 0.035909x + 1.011067, r^2 = 0.9838) of striped bass mean lengths from the 15 and 29 July BSS and the 20 May LRS sampling periods (Figure 8-6). Because of the small sample size in the 12 and 26 August BSS samples and the small number of regression points, the 20 May LRS sample period, midpoint of peak striped

FIGURE 8-4

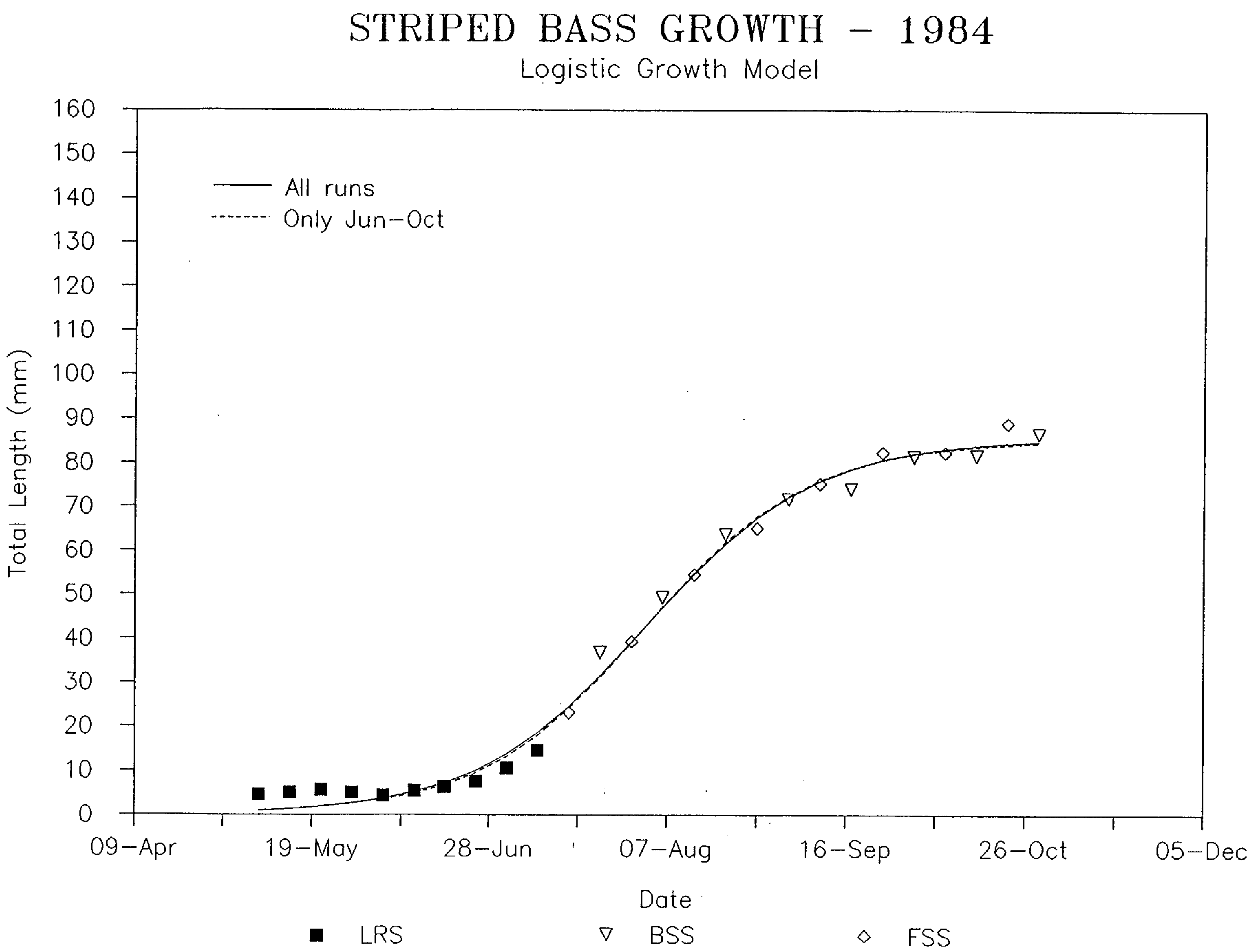

STRIPED BASS GROWTH - 1984
Logistic Growth Model
All runs
Only Jun-Oct
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
LRS
BSS
FSS

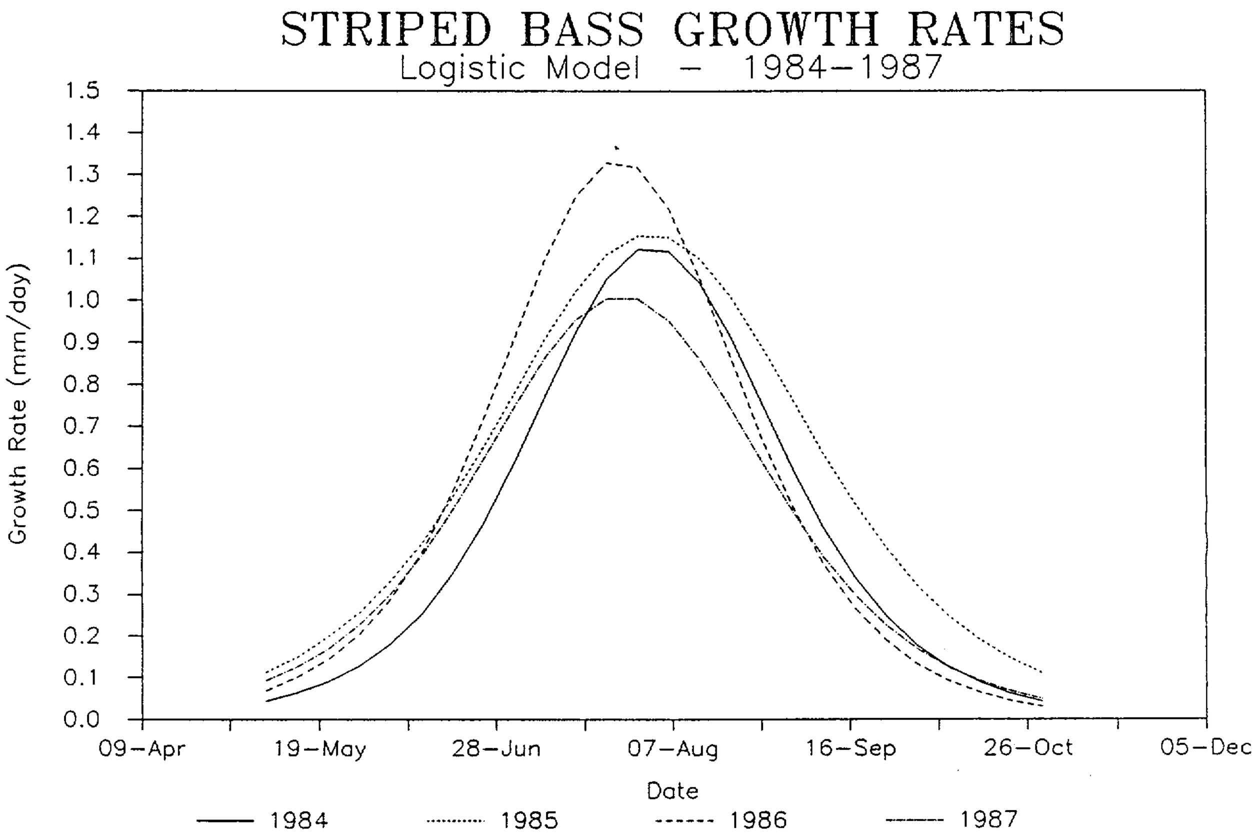
TABLE 8-2

MEAN WATER TEMPERATURE (C°) IN REGIONS AND PERIODS OF PEAK ABUNDANCE OF STRIPED BASS EGGS AND LARVAE, HUDSON RIVER ESTUARY, 1974-1987[a]

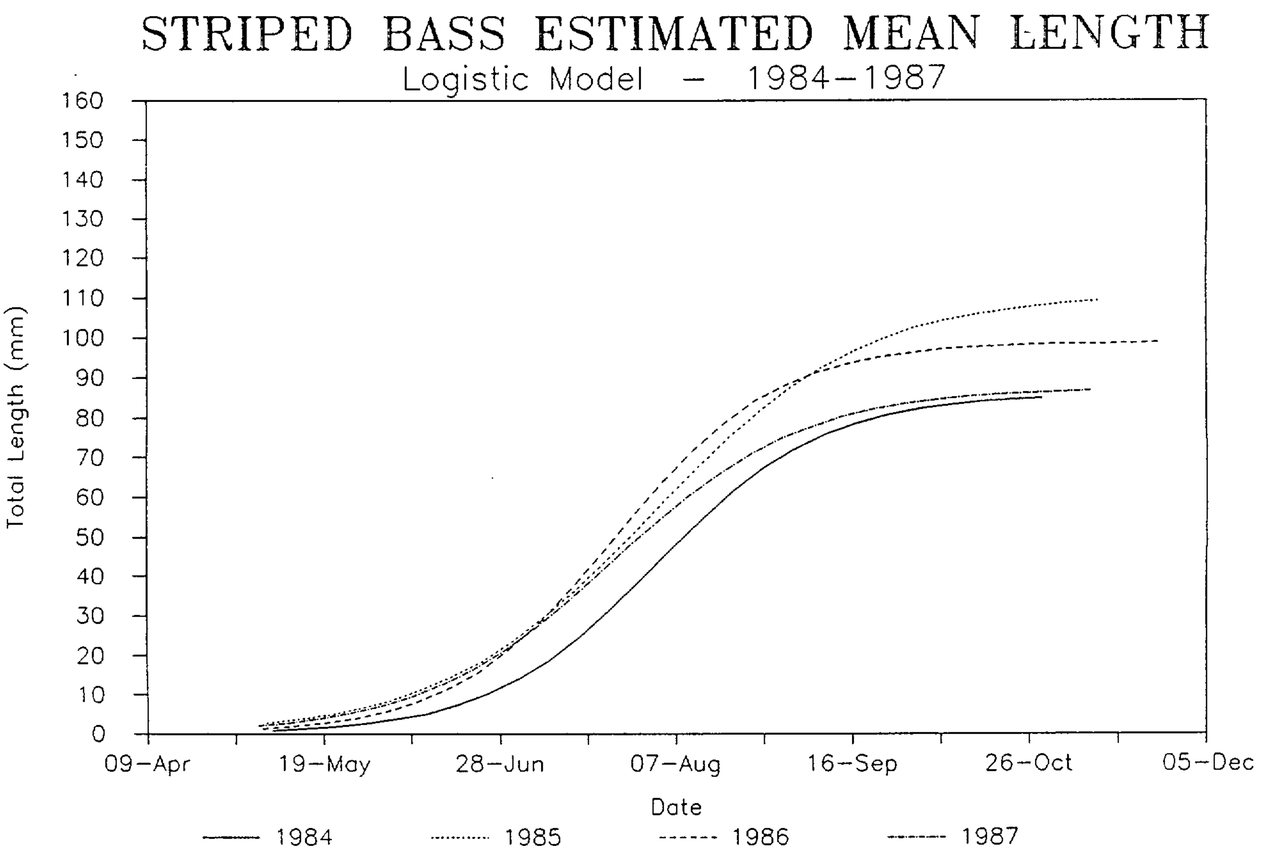
YEAR	EGGS		YOLK-SAC LARVAE		POST-YOLK-SAC LARVAE	
	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE
1974	12 May - 25 May	15.4	26 May - 08 Jun	17.5	09 Jun - 22 Jun	21.5
1975	18 May - 31 May	19.0	25 May - 07 Jun	19.9	01 Jun - 14 Jun	20.6
1976	23 May - 05 Jun	15.0	30 May - 12 Jun	16.4	06 Jun - 19 Jun	18.6
1977	15 May - 28 May	14.36	22 May - 04 Jun	17.0	29 May - 18 Jun	19.3
1978	21 May - 27 May	15.7	28 May - 10 Jun	20.2	04 Jun - 17 Jun	20.7
1979	06 May - 19 May	16.2	20 May - 02 Jun	18.2	27 May - 02 Jun	18.4
1980	19 May - 22 May	16.3	27 May - 30 May	17.2	02 Jun - 13 Jun	18.2
1981	18 May - 21 May	15.9	18 May - 21 May	15.9	01 Jun - 13 Jun	18.0
1982	24 May - 28 May	17.1	24 May - 28 Jun	17.1	31 May - 09 Jun	18.5
1983	16 May - 05 Jun	13.6	06 Jun - 19 Jun	19.2	13 Jun - 26 Jun	21.7
1984	04 Jun - 10 Jun	14.7	11 Jun - 17 Jun	19.0	18 Jun - 25 Jun	21.1
1985	06 May - 20 May	15.5	13 May - 20 May	16.9	28 May - 03 Jun	19.3
1986	12 May - 18 May	17.9	26 May - 01 Jun	20.9	02 Jun - 08 Jun	21.0
1987	11 May - 17 May	14.2	18 May - 24 May	15.5	25 May - 07 Jun	18.2

[a]Adapted from MMES (1986).

FIGURE 8-5

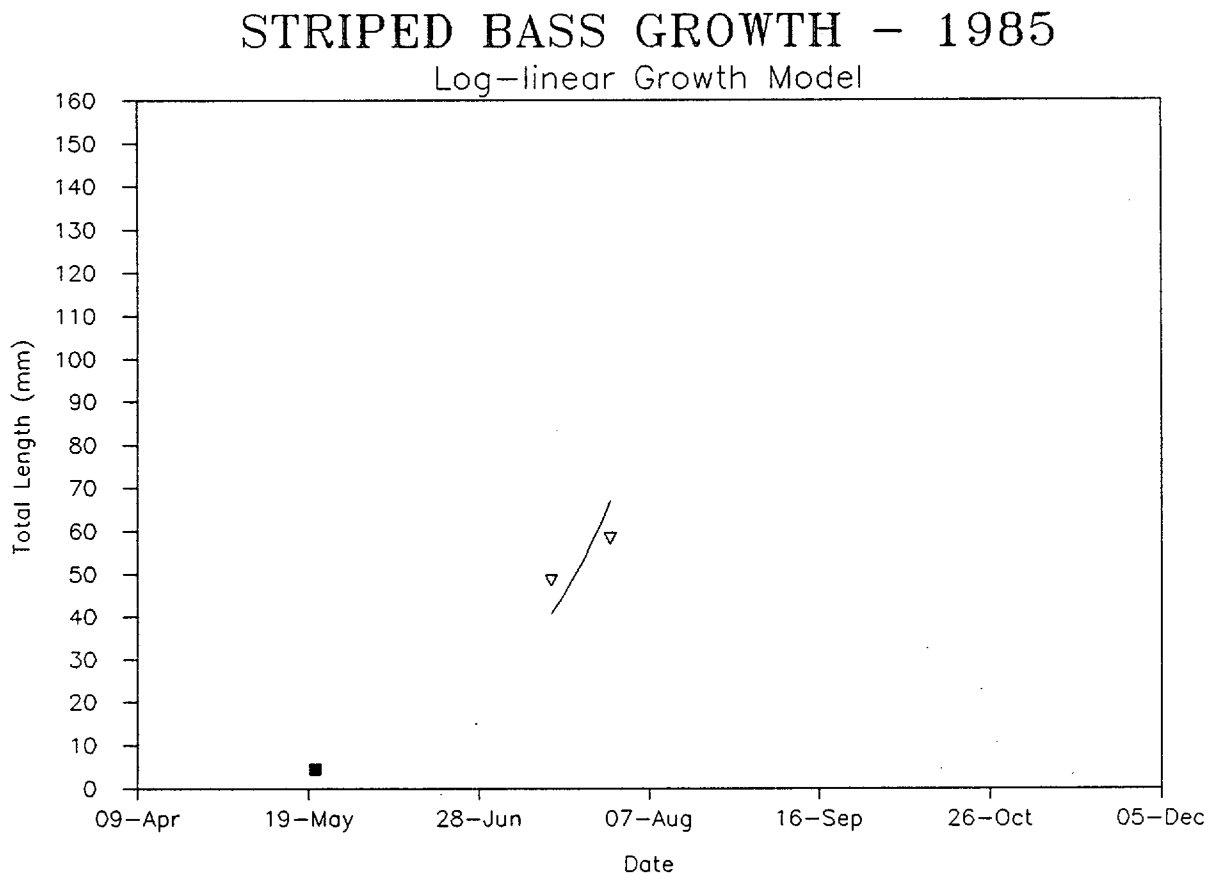


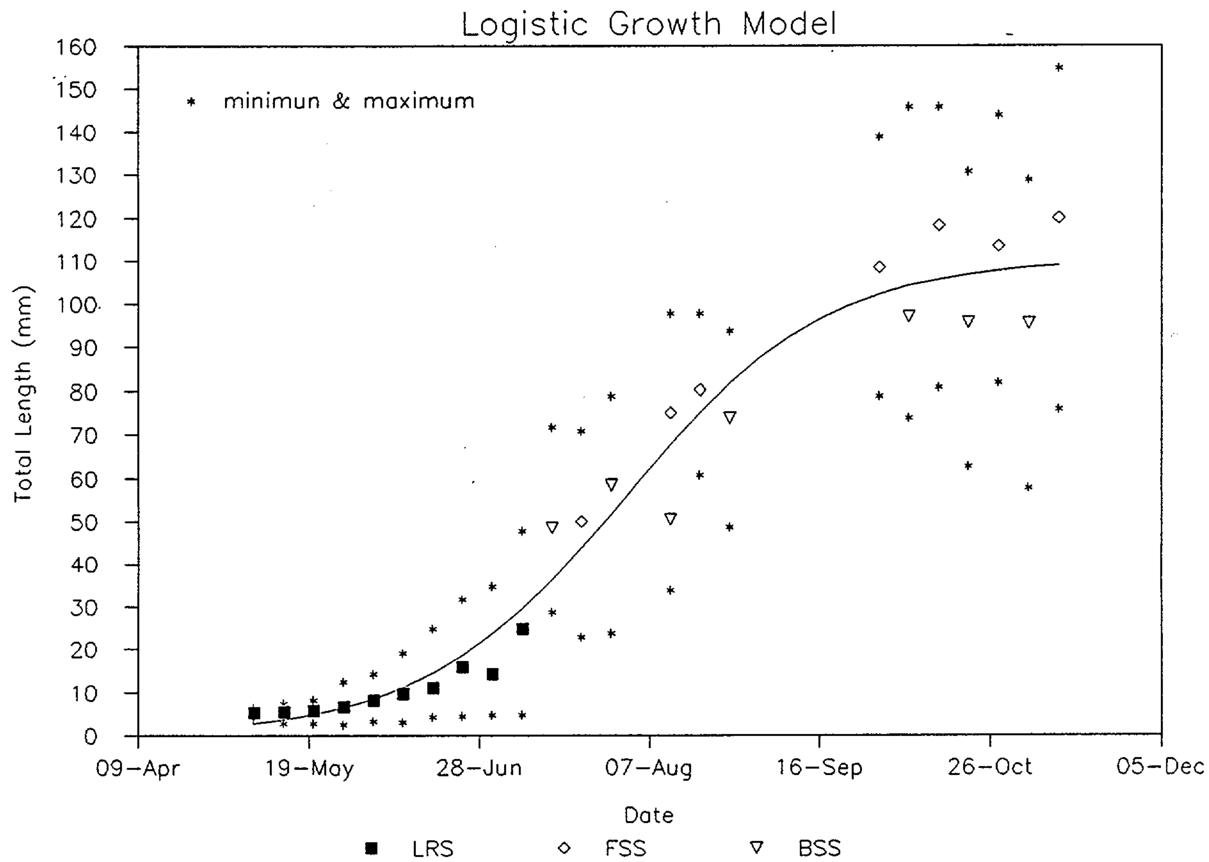
STRIPED BASS GROWTH RATES
Logistic Model - 1984-1987
Growth Rate (mm/day)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
1984
1985
1986
1987



STRIPED BASS ESTIMATED MEAN LENGTH
Logistic Model - 1984-1987
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
1984
1985
1986
1987

FIGURE 8-6


STRIPED BASS GROWTH - 1985
Log-linear Growth Model
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date


Logistic Growth Model
* minimun & maximum
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
LRS
FSS
BSS

bass YSL abundance, was included as an additional observation (see Section 2.6.5.1).

Estimated mean growth rates for larvae and juveniles were 0.4 and 1.6 mm/day, respectively. A mean length at hatching of 4.0 mm (L_0) and a T_0 = 7 days (number of days from 2 May to midweek [8 May] of peak egg abundance) were used to calculate the larval growth rate. The 1985 juvenile growth rate was one of the three highest values observed in the year-class study program (Table 8-1).

8.1.2.2 Logistic Estimates. Using the logistic function (K = 110.535919, R = 0.041912, A = 5.115495, r^2 = 0.9628), the Hudson River striped bass population was estimated to reach a mean length of 30 and 60 mm on 8 July and 5 August, respectively (Figure 8-6). Estimated mean larval and juvenile growth rates were 0.4 and 1.1 mm/day, respectively. The estimated larval growth rate was the same for both growth models and although similar to other years was the lowest rate reported in the history of the Year-Class Report program.

Mean temperatures during peak egg, YSL, and PYSL abundance were within the ranges observed in other years (Table 8-2). However, peak egg and YSL abundance occurred a week earlier in the sampling season (Table 8-2). There is a shift in the sigmoid growth curve toward the left in comparison to 1984; the main difference with reference to 1986 and 1987 appears to be a higher growth rate for the YOY in the latter part of the sampling season (Figure 8-5); growth achieved during the latter period also appears to be greater. Larval and juvenile growth rates, however, are similar to those in other years (Table 8-1).

8.1.3 1986 Survey

8.1.3.1 Log-Linear Estimates. The 1986 Hudson River striped bass population was fully recruited to the beach seine (30 mm TL) on 5 July and attained the mean total length of 60 mm on 21 July. The dates were estimated from the log-linear regression (ln Y = 0.041093x + 0.737471, r^2 = 0.9747) of mean length data from the 14 and 28 July BSS and the 28 May LRS (peak in YSL abundance) sampling periods (Figure 8-7). Because the mean length exceeded 50 mm during initial BSS collections, the 28 May LRS sample period (peak striped bass YSL abundance) was included to estimate the date at which 30 mm was reached.

Estimated mean growth rates of larvae and juveniles were 0.5 and 1.8 mm/day, respectively. A mean length at hatching of 4.0 mm (L_0) and a T_0 = 27 days (28 May - peak egg abundance) were used to calculate the larval growth rate. The 1986 estimated larval growth rate is similar to previous Year-Class Reports (Table 8-1) and to the 1973-1985 average of 0.6 mm/day. The 1986 juvenile growth rate was the second highest observed (Table 8-1) and is larger than the long-term (1973-1985) average of 1.1 mm/day.

8.1.3.2 <u>Logistic Estimates</u>. The logistic growth model (K = 98.639702, R = 0.054159, A = 6.156946, r^2 = 0.9647) was used to estimate the dates when the mean total length of the striped bass population reached 30 and 60 mm (Figure 8-7), on 8 and 31 July, respectively. Estimated growth rates for larvae and juveniles were 0.5 and 1.3 mm/day, respectively. Both larval and juvenile growth rate estimates were slightly lower than those determined using the linear regression growth model.

The 1986 juvenile growth rate is the highest logistic model rate observed from 1984 to 1987 (Table 8-1). In 1986 the daily growth rates during the period of peak growth (mid-June to early August) were the highest reported between 1984 and 1987 (Figure 8-5). Mean temperature in the middle estuary region for this period of time was similar to that in other years (Figure 8-1).

8.1.4 <u>1987 Survey</u>

8.1.4.1 <u>Log-Linear Estimates</u>. In 1987 the striped bass population was fully recruited to the beach seine (30 mm TL) and had achieved a mean population length of 60 mm (TL) on 29 July and 6 September, respectively. To determine these dates, BSS mean lengths from the 22 June through the 17 August sampling periods were used in a log-linear regression growth model (ln Y = 0.017839x + 2.336285, r^2 = 0.9733) (Figure 8-8). Estimated mean larval and juvenile

FIGURE 8-7

STRIPED BASS GROWTH - 1986

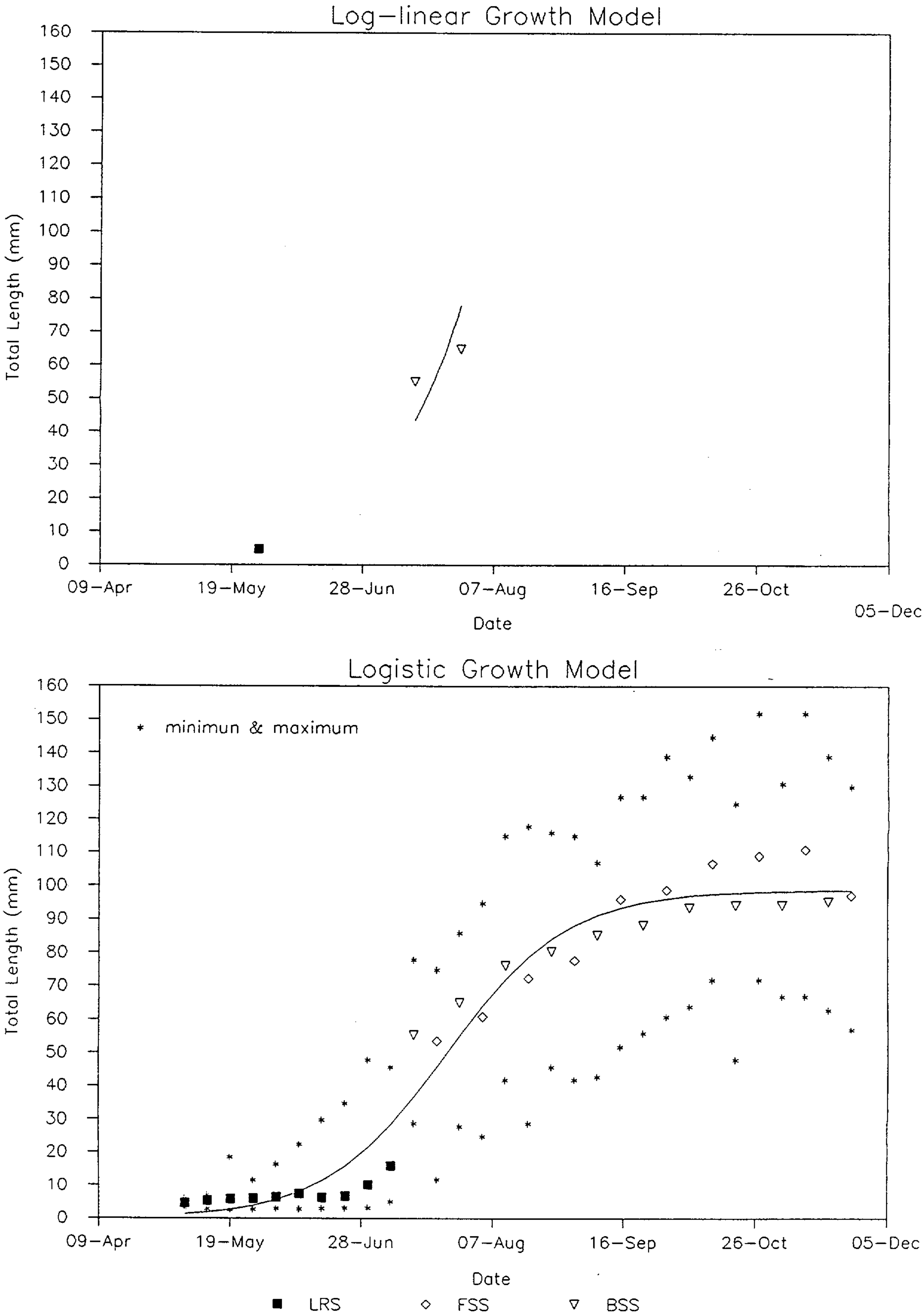
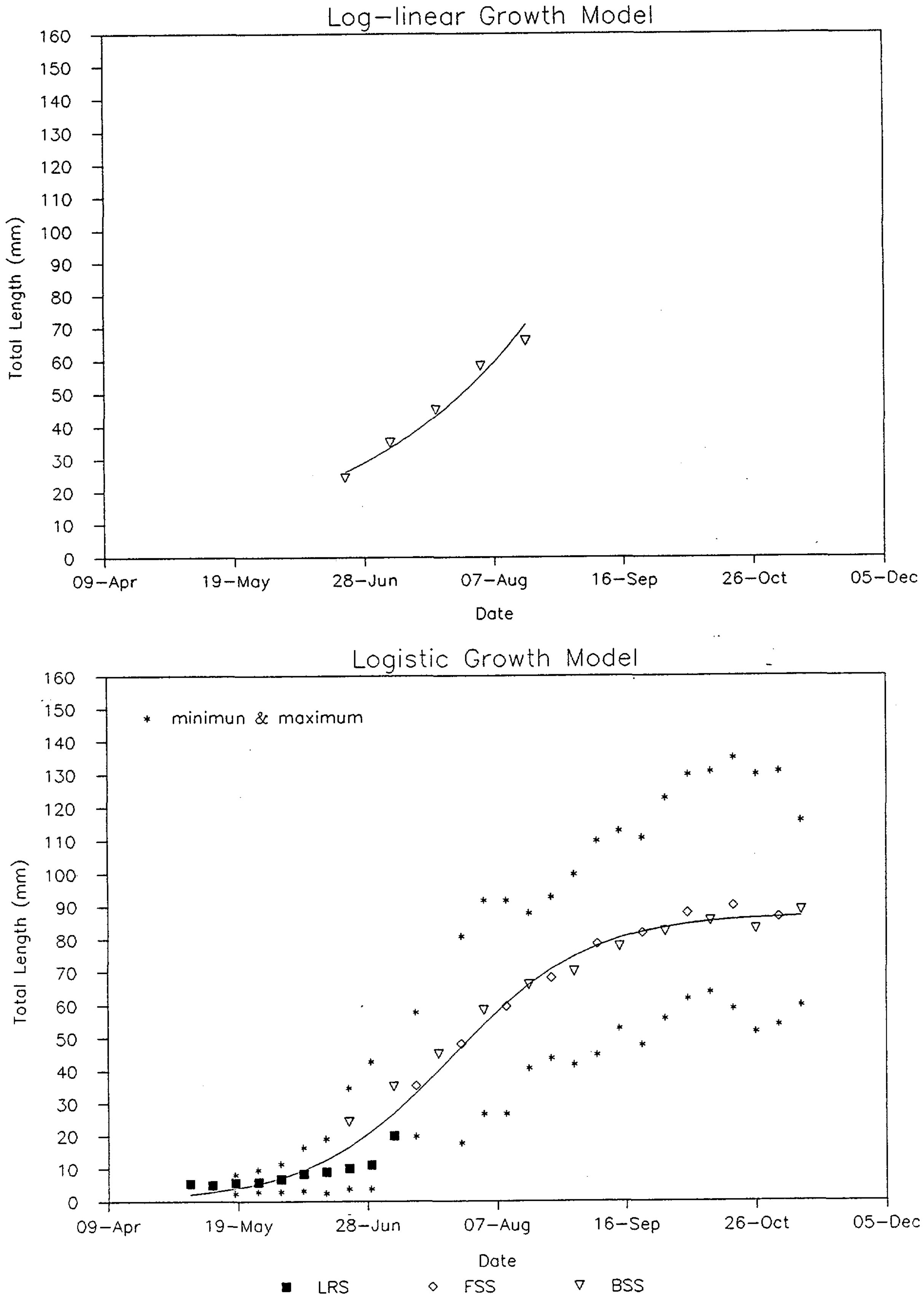


FIGURE 8-8

STRIPED BASS GROWTH - 1987



growth rates were 0.6 and 0.8 mm/day, respectively. The larval growth rate, calculated using L_0 = 4.0 mm and T_0 = 12 days (13 May - midpoint of peak egg abundance), was equal to the 1973-1986 long-term average. The 1987 juvenile growth rate was similar to the 1984 estimate, the lowest observed during the 13-year program.

8.1.4.2 Logistic Estimates. Using the logistic model for growth (K = 87.262779, R = 0.046326, A = 5.2542, r_2 = 0.9843), the dates at which the population mean total lengths were 30 and 60 mm were estimated to be 9 July and 9 August, respectively (Figure 8-8). The mean larval and juvenile growth rates were 0.5 and 1.0 mm/day, respectively. Although the 1987 larval and juvenile growth rates were similar to 1984-1986, the maximum YOY growth rate was lower (Figure 8-5). Mean temperatures during peak egg, YSL, and PYSL abundance were within ranges observed in other years (Table 8-2).

8.2 WHITE PERCH

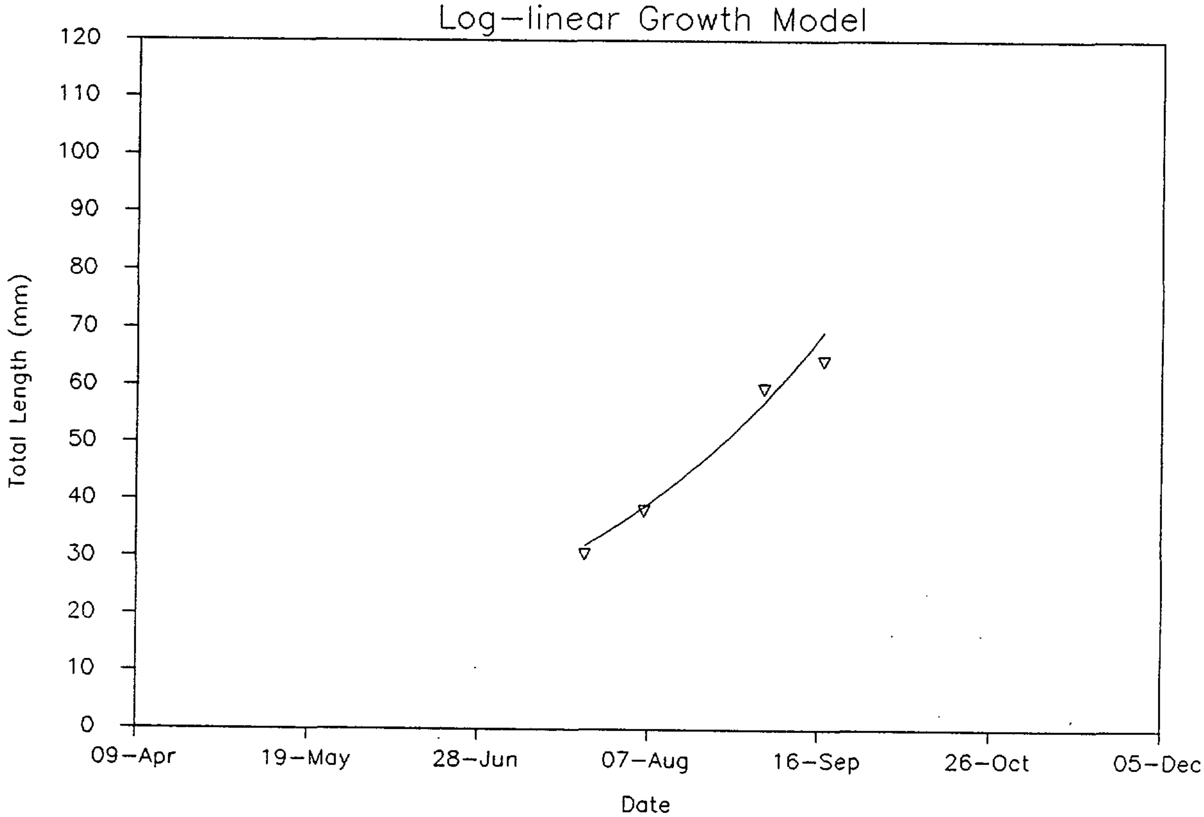
8.2.1 1984 Survey

8.2.1.1 Log-Linear Estimates. The log-linear regression (ln Y = 0.013831x + 2.317127, r^2 = 0.9470) (Figure 8-9), based on mean length data from 23 July through 17 September BSS samples, indicated that white perch reached recruitment size (25 mm TL) and 60 mm (TL) on 5 July and 6 September, respectively (Table 8-3). The mean larval growth rate was calculated as 1.0 mm/day based on the 11 June YSL abundance peak (MMES 1986). The estimated larval growth rate was the highest observed since the beginning of the year-class report program in 1973 (Table 8-3). The mean juvenile (25 to 60 mm) growth rate was estimated at 0.6 mm/day. The juvenile growth rate was similar to that in other years, but the date at which the population was estimated to have attained 60 mm (TL) was one of the latest reported (Table 8-3).

8.2.1.2 Logistic Estimates. The Hudson River white perch population was estimated (K = 70.775032, R = 0.051192, A = 6.504293, r^2 = 0.9830) (Figure 8-9) to have reached mean lengths of 25 and 60 mm (TL) on 25 July and 8

FIGURE 8-9

WHITE PERCH GROWTH – 1984



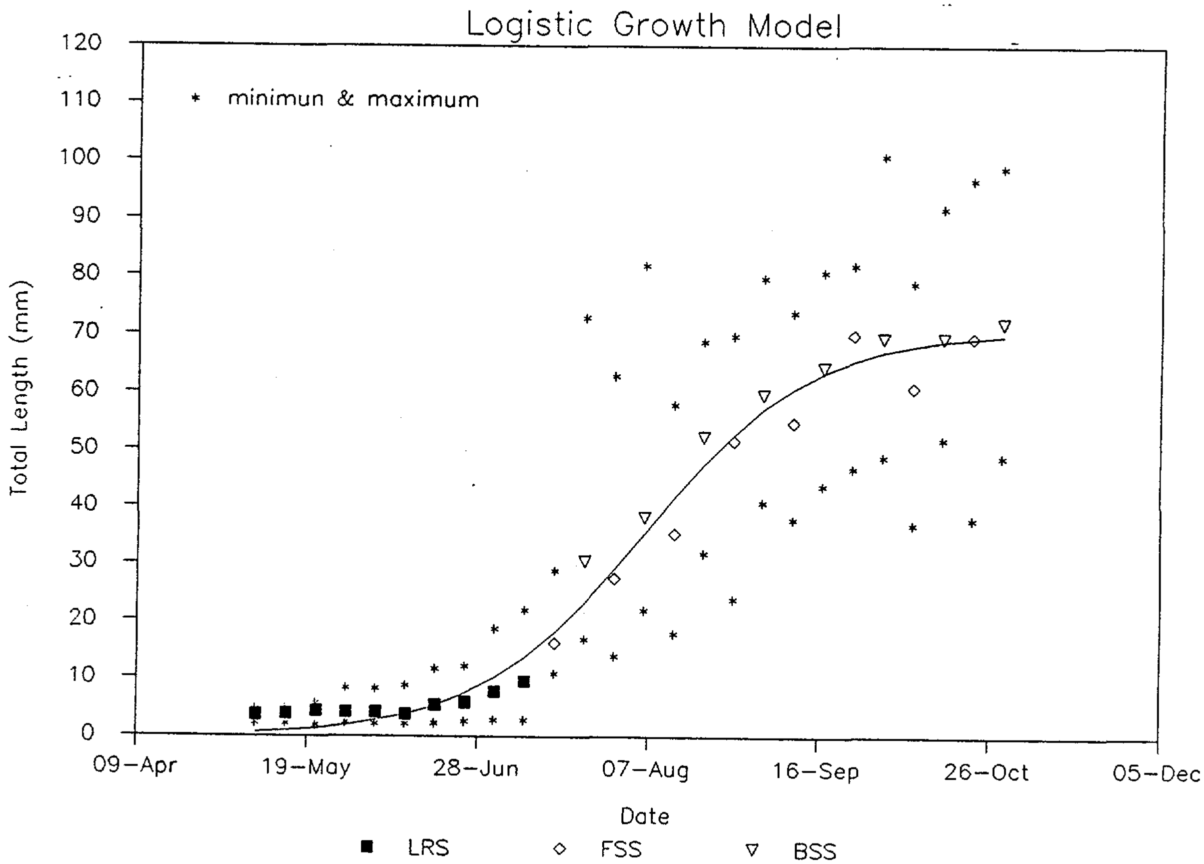


TABLE 8-3

ESTIMATES OF LARVAL AND EARLY JUVENILE (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 TIME PERIOD	LARVAE AND EARLY JUVENILES RATE (mm/day)	JUVENILES TIME PERIOD	JUVENILES 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 - 08 Jul	0.8	08 Jul - 02 Sep	0.6
1977	24 May - 01 Jul	0.6	01 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	19 May - 25 Jul	0.3[b]	25 Jul - 08 Sep	0.8[b]
1983	25 May - 27 Jul	0.4[b]	27 Jul - 01 Sep	1.0[b]
1984	14 Jun - 05 Jul	1.0	05 Jul - 06 Sep	0.6
1984	14 Jun - 25 Jul	1.0[c]	25 Jul - 08 Sep	0.8[c]
1985	08 May - 18 Jun	0.5	18 Jun - 20 Aug	0.6
1985	08 May - 14 Jul	0.4[c]	14 Jul - 19 Aug	1.0[c]
1986	08 May - 01 Jun	0.9	01 Jun - 18 Aug	0.4
1986	08 May - 10 Jul	0.4[c]	10 Jul - 18 Aug	0.9[c]
1987	14 May - 23 Jul	0.3	23 Jul - 18 Sep	0.6
1987	14 May - 09 Jul	0.3[c]	09 Jul - 13 Aug	1.0[c]

[a]Growth rates were not available from 1980 or 1981 data.
[b]Methods used were different from those described in Section 2.6.5 (NAI 1985a,b).
[c]Growth rates using the logistic growth model.

September, respectively (Table 8-3). Larval and juvenile growth rates were calculated to be 1.0 and 0.8 mm/day, respectively, (Table 8-3).

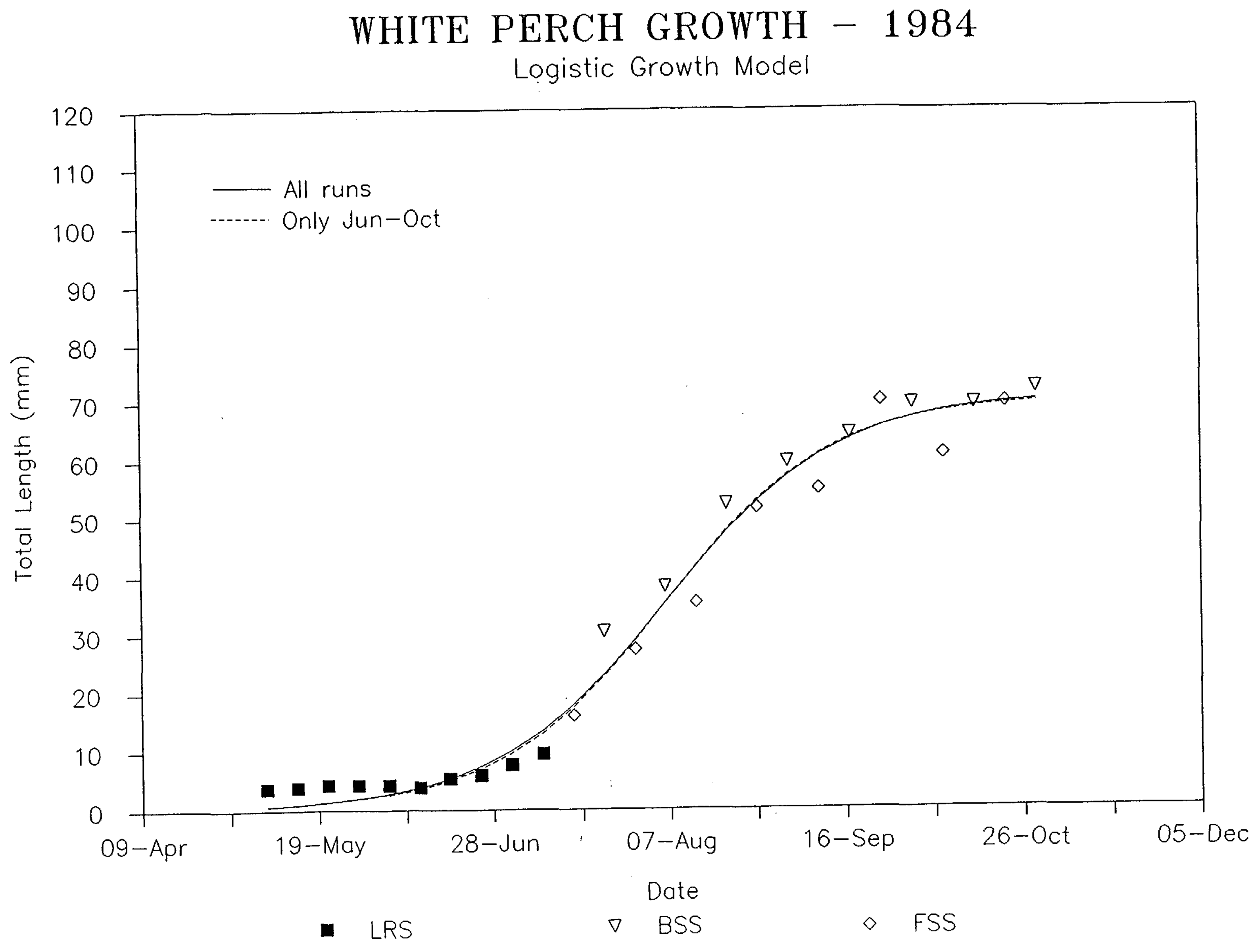
Egg and YSL abundance was bimodal in 1984. As previously discussed (Section 8.1.1), high freshwater flow and cooler temperatures in late May probably resulted in the loss of larval cohorts hatched prior to 1 June. To assure that the growth estimates are not biased by failed cohorts, the logistic regression equation was recalculated using only mean larval lengths from collections after 1 June. Using the new logistic equation (K = 70.372559, R = 0.052818, A = 6.699268, r^2 = 0.9803), it was estimated that full recruitment (25 mm TL) was reached on 26 July and a population mean of 60 mm (TL) was reached on 7 September (Figure 8-10). These dates differ by only one day from the previous estimates, which include larval mean lengths of nonrecruited cohorts; these dates occur later in the growing season than in 1985-1987 (Table 8-3). Larval and juvenile growth rates were 0.9 and 0.8 mm/day, respectively; except for the very slight decrease in the larval growth rate estimate, there was no difference between the two logistic model growth estimates.

Compared to years 1985-1987 (Figure 8-11), it appears as though the growing season was delayed and the TL achieved by the YOY at the end of the season was smaller. The delayed growing season appears to be associated with the high flows and cooler temperatures during late May, which resulted in mortality of the first cohort. The estimated 1984 larval growth for both the logistic and log-linear models was the highest observed in the program (Table 8-3). Although the logistic-estimated 1984 juvenile growth rate was the lowest observed in 1984-1987, it was similar in value. Mean temperatures during peak egg, YSL, and PYSL abundance were higher than in 1985-1987 (Table 8-4).

8.2.2 <u>1985 Survey</u>

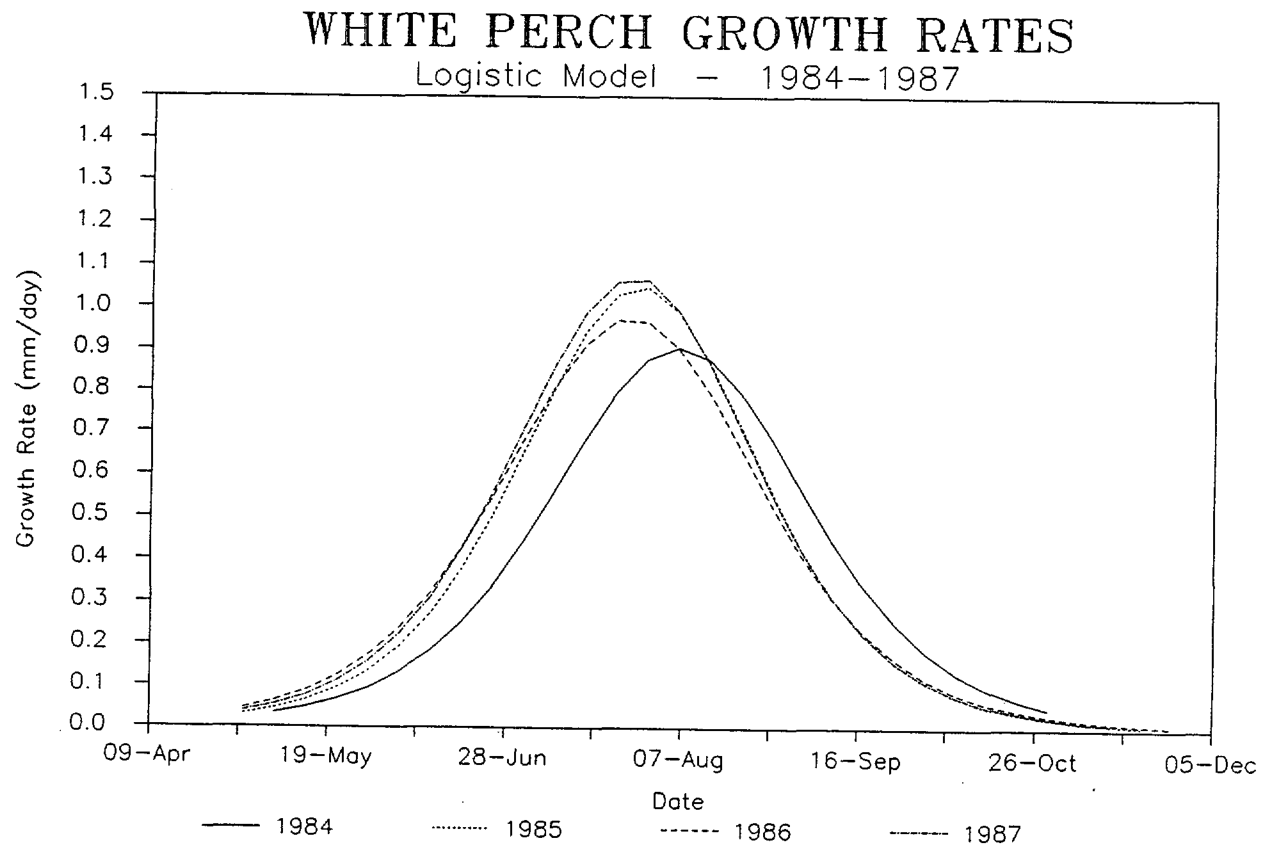
8.2.2.1 <u>Log-Linear Estimates</u>. The log-linear regression (ln Y = 0.013889x + 2.546158, r^2 = 0.9789), based on BSS mean length data from 15 July through 26 August, was used to estimate the date at which the white perch population was fully recruited to the beach seine and had grown to 60 mm total length (Figure

FIGURE 8-10



WHITE PERCH GROWTH - 1984
Logistic Growth Model
Total Length (mm)
120
110
100
90
80
70
60
50
40
30
20
10
0
All runs
Only Jun-Oct
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
LRS
BSS
FSS

FIGURE 8-11


WHITE PERCH GROWTH RATES
Logistic Model – 1984–1987
Growth Rate (mm/day)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
09–Apr
19–May
28–Jun
07–Aug
16–Sep
26–Oct
05–Dec
Date
1984
1985
1986
1987

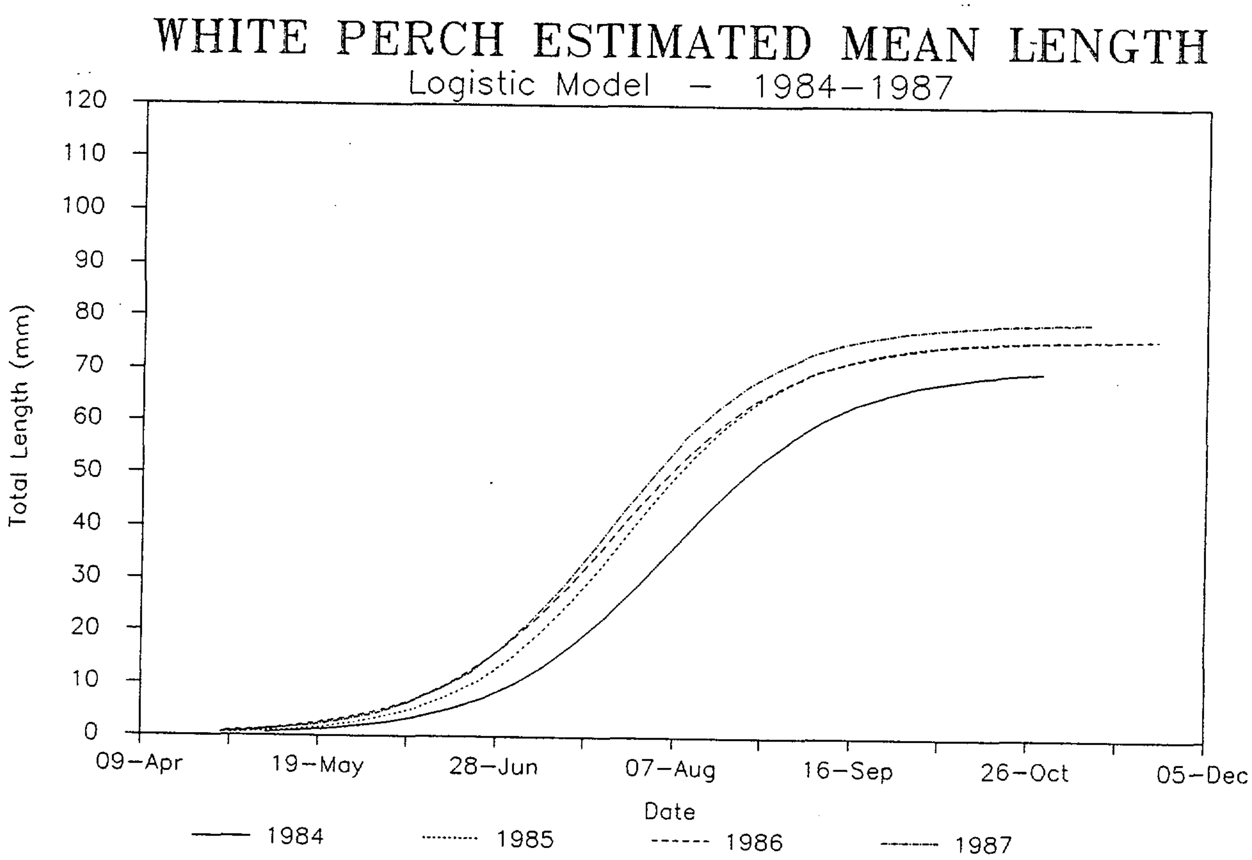

WHITE PERCH ESTIMATED MEAN LENGTH
Logistic Model – 1984–1987
Total Length (mm)
120
110
100
90
80
70
60
50
40
30
20
10
0
09–Apr
19–May
28–Jun
07–Aug
16–Sep
26–Oct
05–Dec
Date
1984
1985
1986
1987

TABLE 8-4

MEAN WATER TEMPERATURE (°C) IN REGIONS AND PERIODS OF PEAK ABUNDANCE OF WHITE PERCH EGGS AND LARVAE, HUDSON RIVER ESTUARY, 1984-1987

	EGGS		YOLK-SAC LARVAE		POST-YOLK-SAC LARVAE	
YEAR	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE
1984	11 Jun - 17 Jun	19.0	11 Jun - 17 Jun	19.0	18 Jun - 24 Jun	21.1
1985	29 Apr - 19 May	15.2	6 May - 19 May	15.5	27 May - 16 Jun	19.9
1986	28 Apr - 25 May	16.3	5 May - 18 May	15.7	12 May - 15 Jun	19.4
1987	11 May - 31 May	16.3	4 May - 31 May	15.4	18 May - 28 Jun	19.7

8-12). Full recruitment was attained on 18 June and a population mean total length of 60 mm was reached on 20 August. Using 8 May as the date of peak yolk-sac abundance, the larval and juvenile growth rates were estimated at 0.5 and 0.6 mm/day, respectively. The juvenile growth rate was within the range previously reported in the year-class report programs (Table 8-3).

8.2.2.2 Logistic Estimates. Using the logistic growth function (K = 76.252785, R = 0.055170, A = 6.455642, r^2 = 0.9803), it was determined that full recruitment to the beach seine was reached on 14 July and a mean length of 60 mm on 19 August (Figure 8-12). The larval and juvenile growth rates were calculated as 0.4 and 1.0 mm/day, respectively. These nonlinear growth rates were similar to previous estimates using a log-linear model (Table 8-3).

8.2.3 1986 Survey

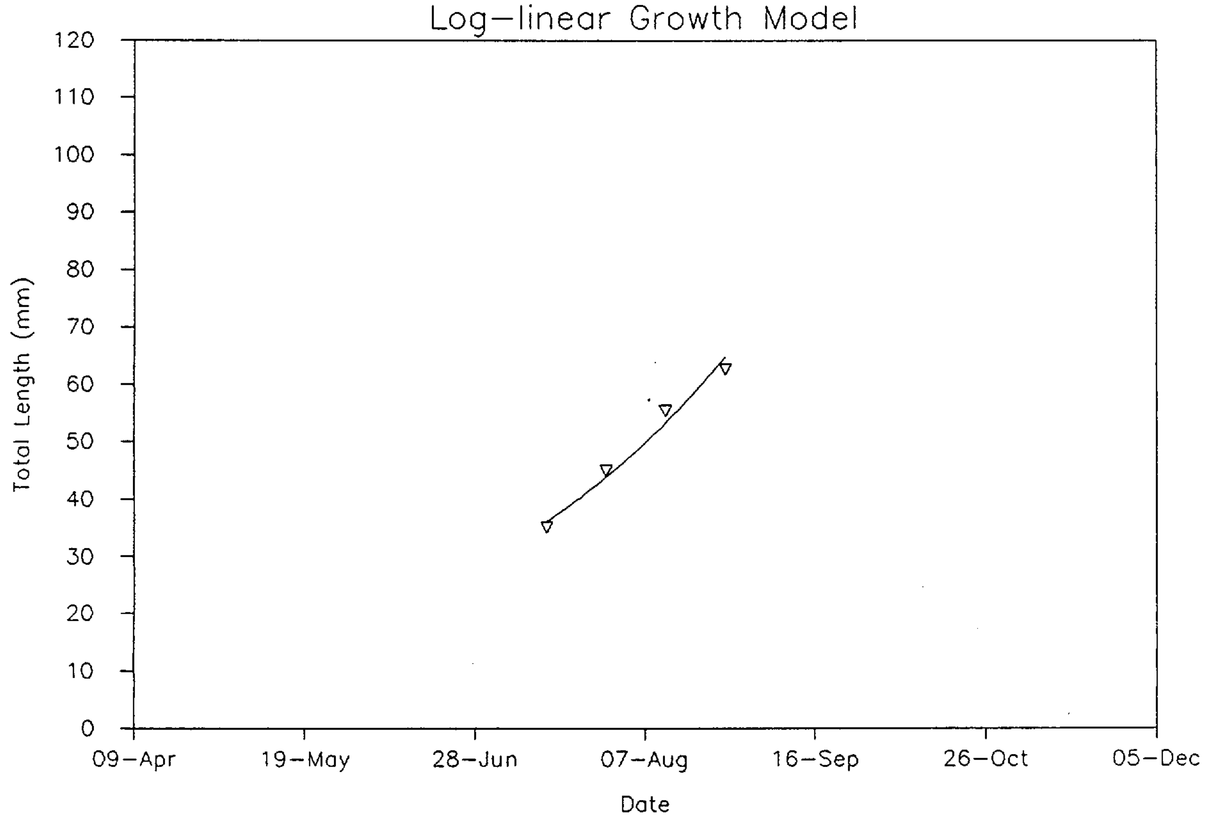
8.2.3.1 Log-Linear Estimates. In 1986 the white perch population reached a mean total length of 25 mm on 1 June and 60 mm on 18 August. These estimates are based on the log-linear regression ($\ln Y = 0.011160x + 2.869527$, r^2 = 0.9830) of mean lengths from biweekly BSS data collected between 14 July and 25 August (Figure 8-13). Larval and juvenile growth rates were calculated as 0.9 and 0.4 mm/day, respectively.

The 1986 larval growth rate is the second highest estimated since the program began in 1973 (Table 8-3). The estimate was based on the earliest peak yolk-sac abundance reported (5 May sampling week) as well as the earliest reported date (1 June) at which full recruitment was estimated to have occurred - four weeks earlier than during any previous year. The juvenile growth rate was the lowest ever reported.

8.2.3.2 Logistic Estimates. Using the logistic growth function (K = 76.345512, R = 0.051123, A = 5.834624, r^2 = 0.9843), it was estimated that in 1986 the white perch population reached mean total lengths of 25 and 60 mm on 10 July and 18 August, respectively (Figure 8-13). The estimated larval and juvenile growth rates were 0.4 and 0.9 mm/day, respectively. The disparity

FIGURE 8-12

WHITE PERCH GROWTH – 1985



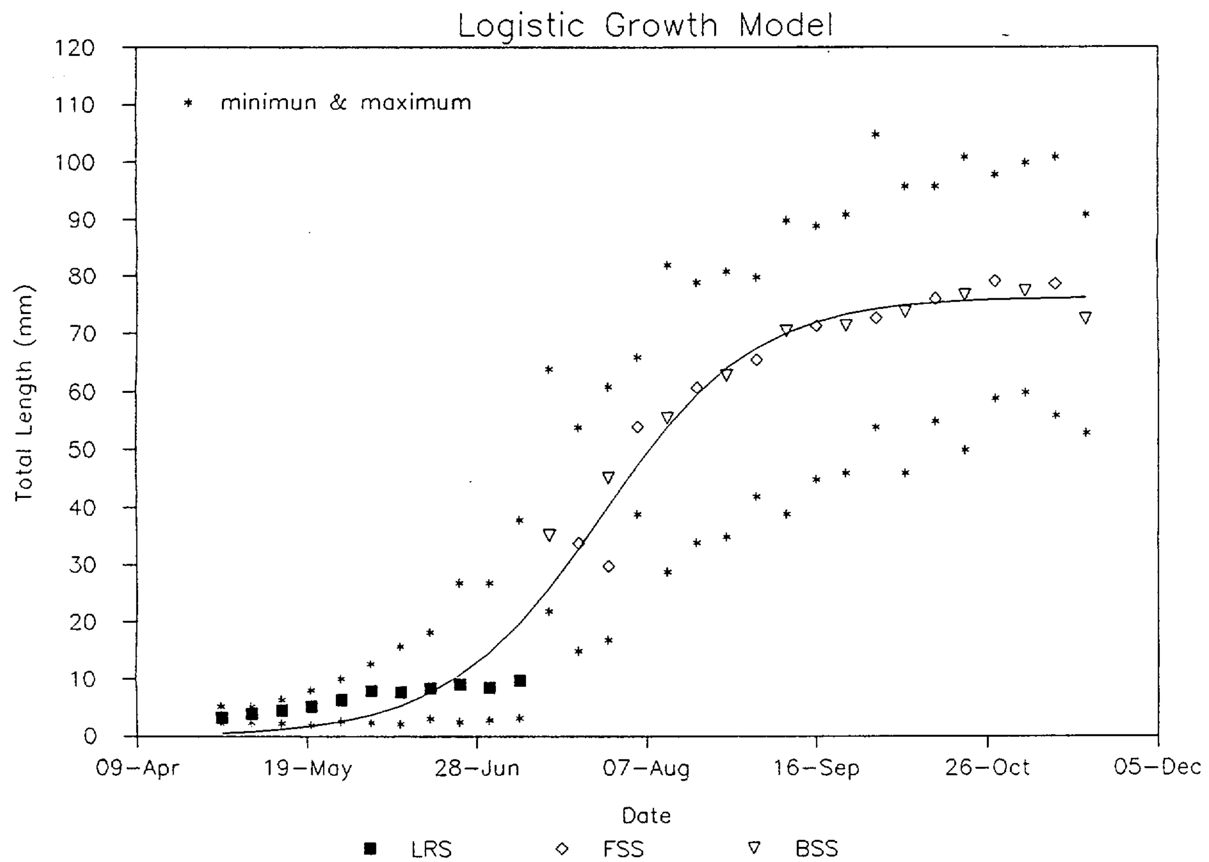
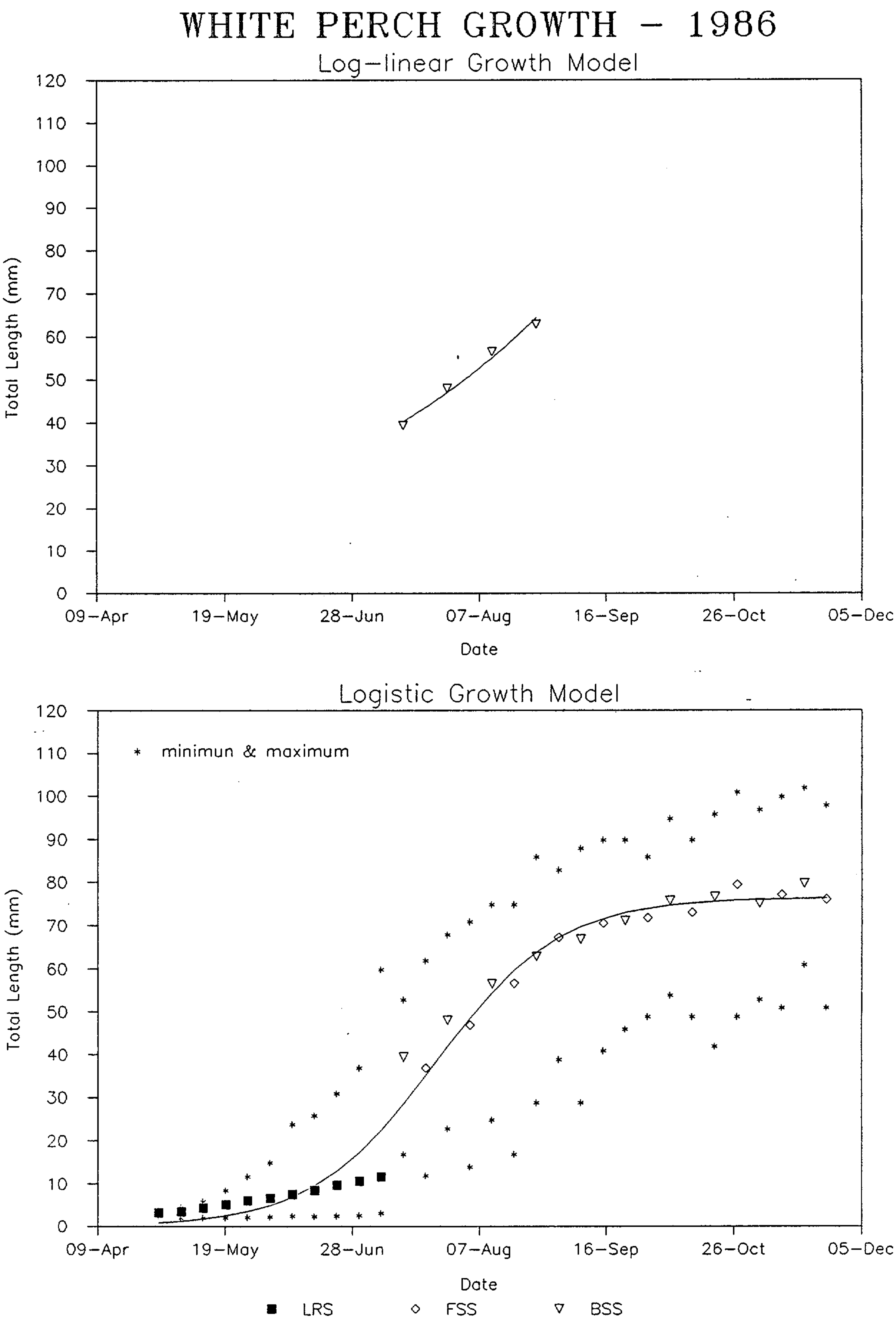


FIGURE 8-13



WHITE PERCH GROWTH - 1986
Log-linear Growth Model
Total Length (mm)
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
Logistic Growth Model
* minimun & maximum
Total Length (mm)
Date
LRS
FSS
BSS

between growth rates estimated by the two models is due to the different estimates of when the population reached full recruitment size. The logistic function prediction was more than a month later than the log-linear regression estimate (Table 8-3), but was close to the log-linear long-term mean date (1973 through 1985) of 8 July.

Hudson River temperature patterns in the middle regions of the estuary (Figure 8-1) and during peak egg, YSL, and PYSL abundance (Table 8-4) were similar during the 1985-1987 growth period. Hudson River flow patterns were higher in 1986 (from mid-May to mid-August) than in 1985 and 1987 (Figure 8-2). However, in 1986 estimated population mean lengths were similar to 1985 and 1987 data during the same sampling period (Figure 8-11).

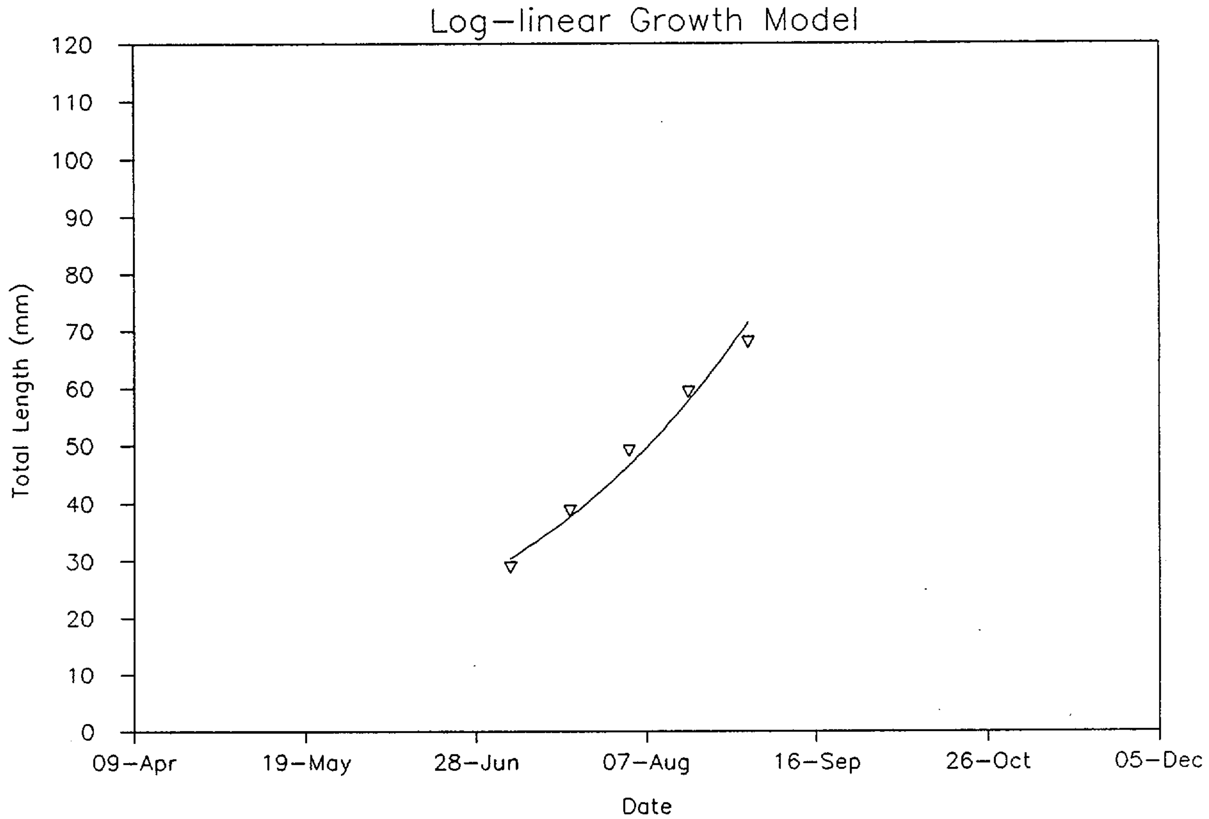
8.2.4 <u>1987 Survey</u>

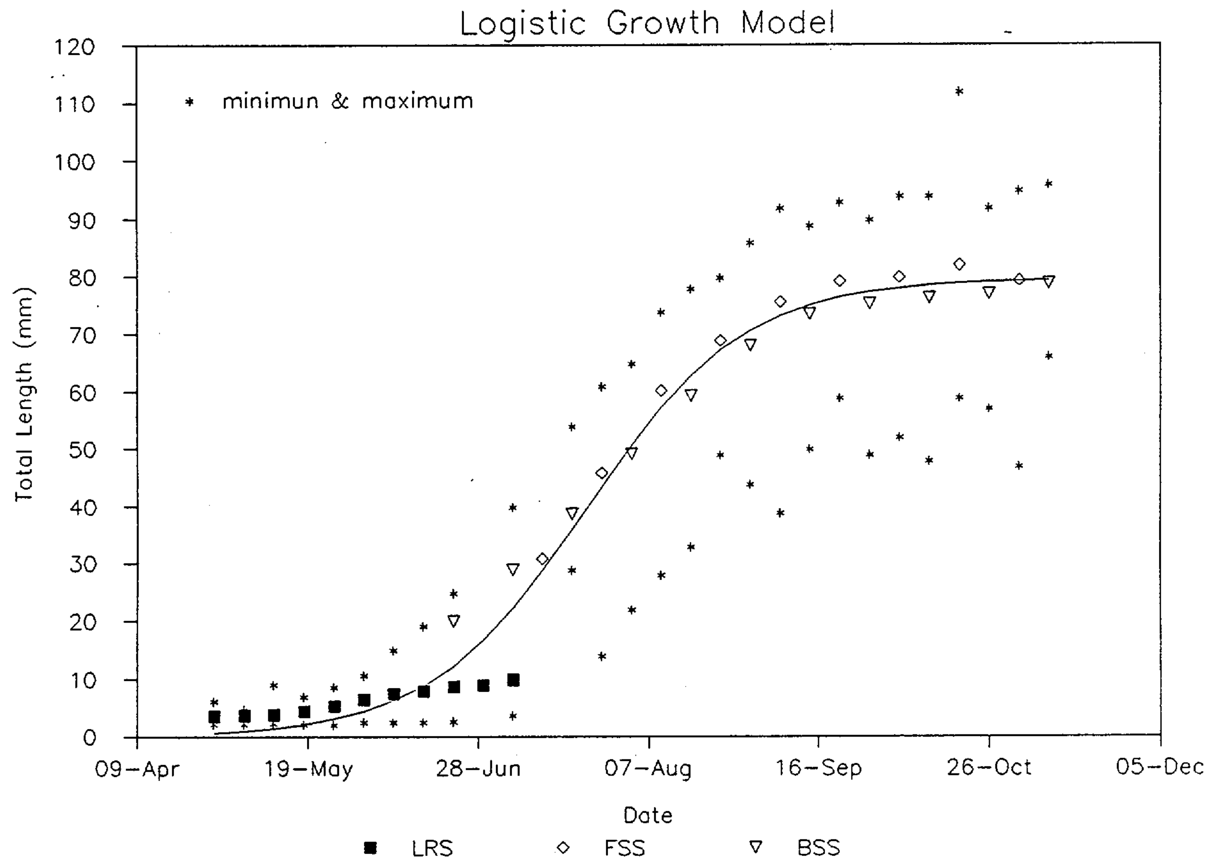
8.2.4.1 <u>Log-Linear Estimates</u>. The log-linear regression ($\ln Y = 0.015230x + 1.953987$, $r^2 = 0.9804$), based on weekly BSS mean lengths from 22 June through the 13 August sampling period (Figure 8-14), estimated that full recruitment to the beach seine occurred on 29 July. A population mean length of 60 mm was attained on 18 September. Except for 1982 and 1983 when growth rates were estimated differently, these estimated dates were the latest in the 13-year history of the year-class study (Table 8-3). The peak YSL abundance date of 13 May was used to calculate the larval growth rate of 0.3 mm/day. This estimate, similar to the 1982 larval rate, is the lowest ever reported for the Hudson River white perch population since the year-class study began. The juvenile growth rate of 0.6 mm/day for 1987 was the same as the long-term average between 1973 and 1986.

8.2.4.2 <u>Logistic Estimates</u>. Using the logistic model for white perch growth ($K = 79.492378$, $R = 0.054032$, $A = 6.137221$, $r^2 = 0.9845$), it was estimated that full recruitment to the beach seine first occurred on 9 July (Figure 8-14). The population reached a mean total length of 60 mm on 13 August. The larval growth rate, calculated using the YSL peak abundance date of 13 May, was 0.3 mm/day. The juvenile white perch population grew at the rate of

FIGURE 8-14

WHITE PERCH GROWTH – 1987





1.0 mm/day. Similar growth rates were calculated for 1984-1986 (Table 8-3). Although mean lengths during the latter part of the growth season were the highest calculated between 1984 and 1987 (Figure 8-11), they were close to 1985 and 1986 values.

8.3 AMERICAN SHAD

8.3.1 1984 Survey

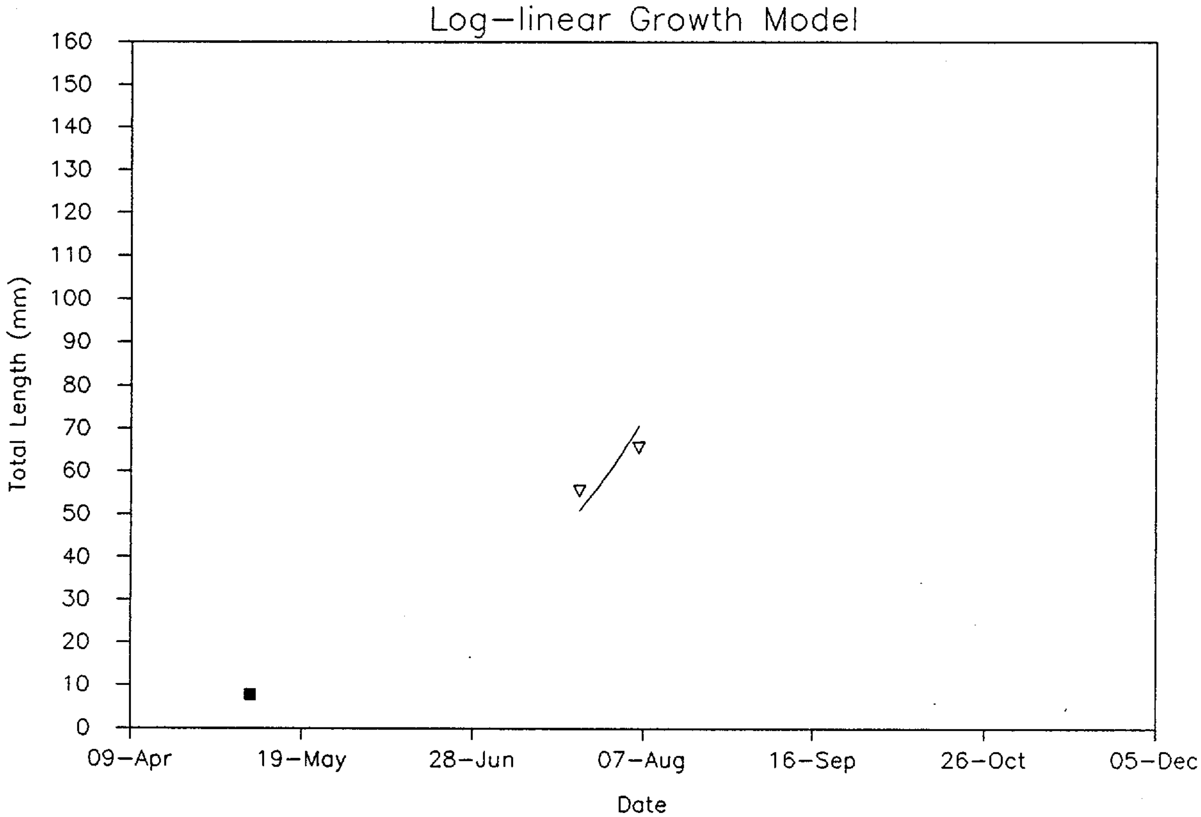
8.3.1.1 Log-Linear Estimates. In 1984 the American shad population was estimated to have reached a mean total length of 60 mm on 30 July, based on the log-linear regression ($\ln Y = 0.011909x + 3.029364$, $r^2 = 1.00$) of mean lengths collected during the 23 July and 6 August BSS collections. The date on which recruitment size (30 mm TL) was reached was not interpolated from the BSS data because mean length exceeded 50 mm when sampling began. Because of the small number of regression points and to estimate the date of recruitment, the midpoint of peak YSL abundance (9 May) and the associated YSL mean length were included as additional observations (see Section 2.6.5.1). Using the resultant log-linear model (Figure 8-15) ($\ln Y = 0.023480x + 1.981053$, $r^2 = 0.9946$), it was estimated that the population mean length was 30 mm on 1 July (Table 8-5). The larval and juvenile growth rates were 0.4 and 1.0 mm/day, respectively, based on the 9 May YSL peak abundance. As growth rates were not reported in previous Year-Class Reports, comparisons to historic records are not made.

8.3.1.2 Logistic Estimates. Using the logistic function for growth ($K = 90.271072$, $R = 0.045560$, $A = 4.853046$, $R^2 = 0.9843$), it was estimated that the Hudson River American shad population had grown to a mean TL of 30 and 60 mm on 1 July and 1 August, respectively (Figure 8-15). The larval and juvenile growth rates were 0.5 and 1.0 mm/day, respectively, similar to the estimates produced from the log-linear regression model (Table 8-5).

From the 1984 Year-Class Report larval distribution figures, it is apparent that above-average freshwater flow during late May resulted in a spatial down-

FIGURE 8-15

AMERICAN SHAD GROWTH – 1984



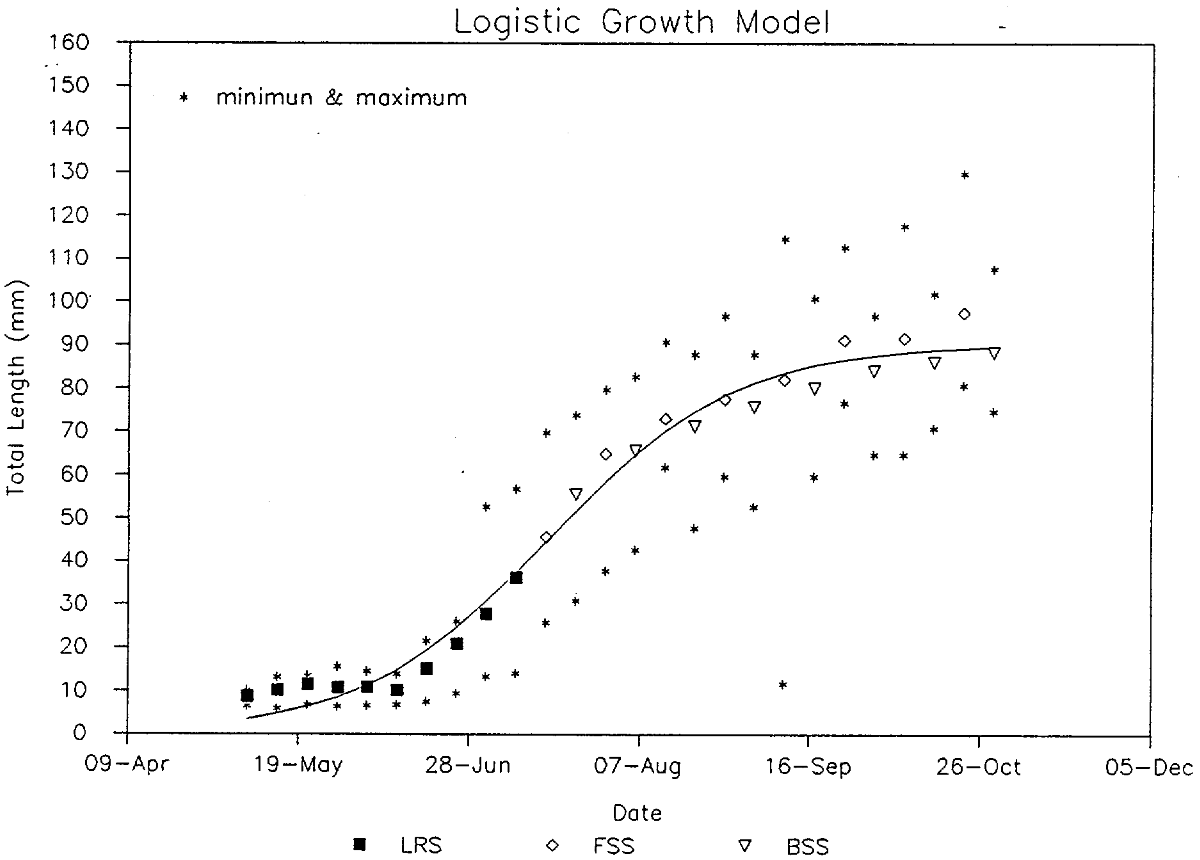


TABLE 8-5

ESTIMATES OF LARVAL AND EARLY JUVENILE (8-30 mm TL) AND JUVENILE (30-60 mm TL) GROWTH RATES OF AMERICAN SHAD COLLECTED FROM THE HUDSON RIVER ESTUARY SINCE 1984

	LARVAE AND EARLY JUVENILES		JUVENILES	
YEAR	TIME PERIOD	RATE (mm/day)	TIME PERIOD	RATE (mm/day)
1984[a]	9 May - 1 Jul	0.4	1 Jul - 30 Jul	1.0
1984[b]	9 May - 1 Jul	0.5	1 Jul - 1 Aug	1.0
1985[a]	8 May - 12 Jul	0.3	12 Jul - 27 Aug	0.7
1985[b]	8 May - 17 Jun	0.5	17 Jun - 24 Jul	0.8
1986[a]	7 May - 20 Jun	0.4	20 Jun - 20 Jul	1.0
1986[b]	7 May - 20 Jun	0.5	20 Jun - 28 Jul	0.8
1987[a]	6 May - 9 Jul	0.3	9 Jul - 24 Aug	0.7
1987[b]	6 May - 20 Jul	0.5	20 Jul - 24 Aug	0.8

[a]Log-linear growth rate estimates.
[b]Logistic growth rate estimates.

river shift in the distribution of larval American shad. It was also apparent that, unlike the striped bass and white perch populations, the cohort present prior to 1 June was recruited into the population. However, the latter cohort from the upper reaches of the estuary became the major source of recruitment to the juvenile population. Therefore, growth estimates were recalculated, but the cohort prior to 1 June was excluded. Using the logistic growth function (K = 88.900475, R = 0.050649, A = 5,373760, r^2 = 0.9831), mean total lengths of 30 and 60 mm TL were estimated to have occurred on 3 and 31 July, respectively (Figure 8-16). Growth rates of 0.9 and 1.1 mm/day were calculated for American shad larvae and juveniles, respectively. Exclusion of the earlier cohort information from the regression analysis resulted in a higher estimated larval growth rate. The exclusion of the cohorts prior to 1 June without also excluding their contribution to later estimates could produce an artificially high larval growth rate.

For both logistic equations the lower portion of the sigmoid growth curve is shifted toward the right, in comparison to 1985-1987 (Figure 8-17). The temporal distribution of yolk-sac density was bimodal, with peaks occurring in late May (one to two weeks after peak egg density) and early June (four weeks after peak egg density) (MMES 1986). Low weekly mean temperatures in the upper regions of the estuary during this time (Figure 8-18) probably resulted in a longer development time. Mansueti and Hardy (1967) reported incubation times ranging from two days at 17°C to 17 days at 12°C; mean water temperature during peak egg abundance was 9.5°C (Table 8-6).

8.3.2 1985 Survey

8.3.2.1 Log-Linear Estimates. In 1985 the American shad population reached full recruitment size on 12 July and a mean total length of 60 mm on 27 August. These estimates are based on the log-linear regression (ln Y = 0.014940x + 2.324066, r^2 = 0.9814) of mean length data from the BSS between 15 July and 12 August and from 6 May (midpoint of peak YSL abundance) (Figure 8-19). The mean length of the population was in excess of 50 mm at the onset of the beach seine sampling, similar to data collected during 1984. There-

FIGURE 8-16

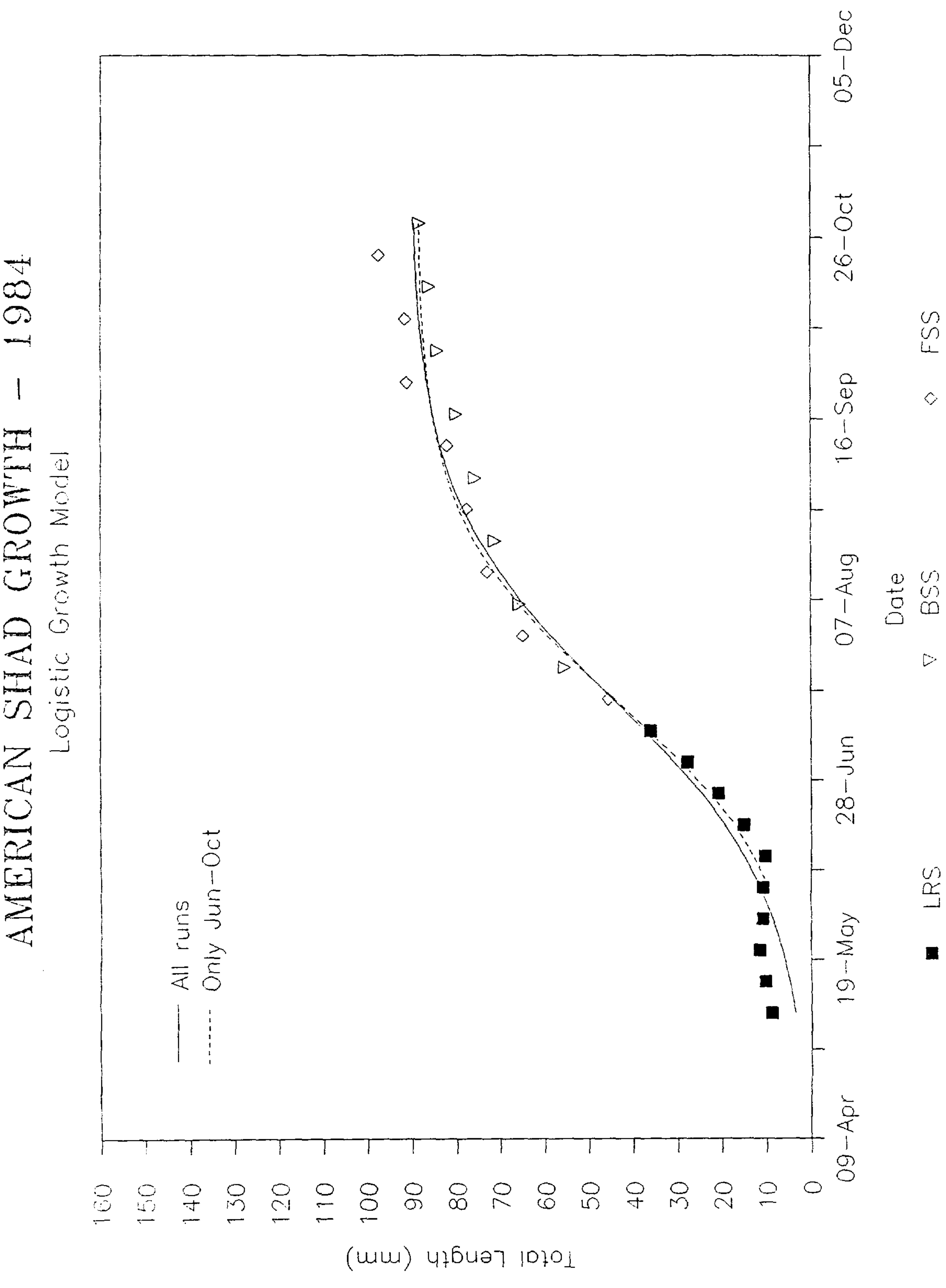
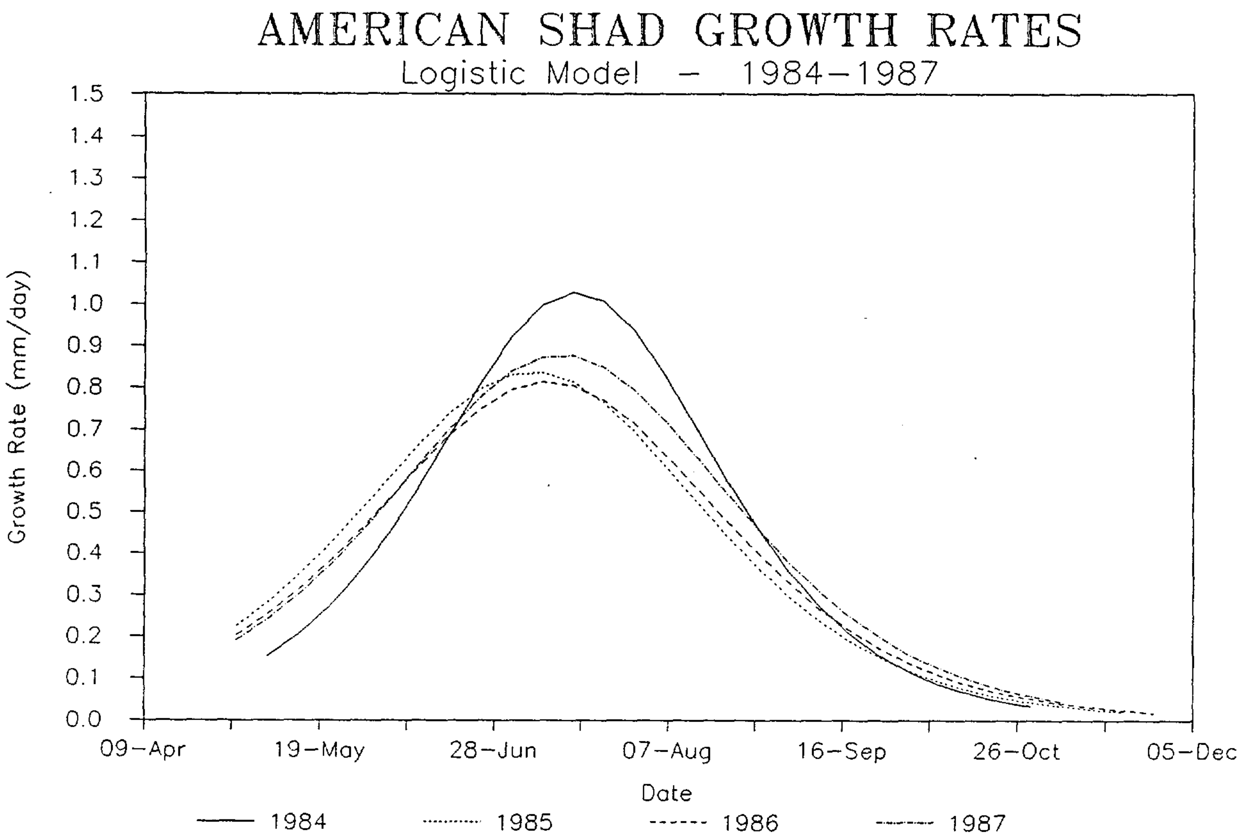
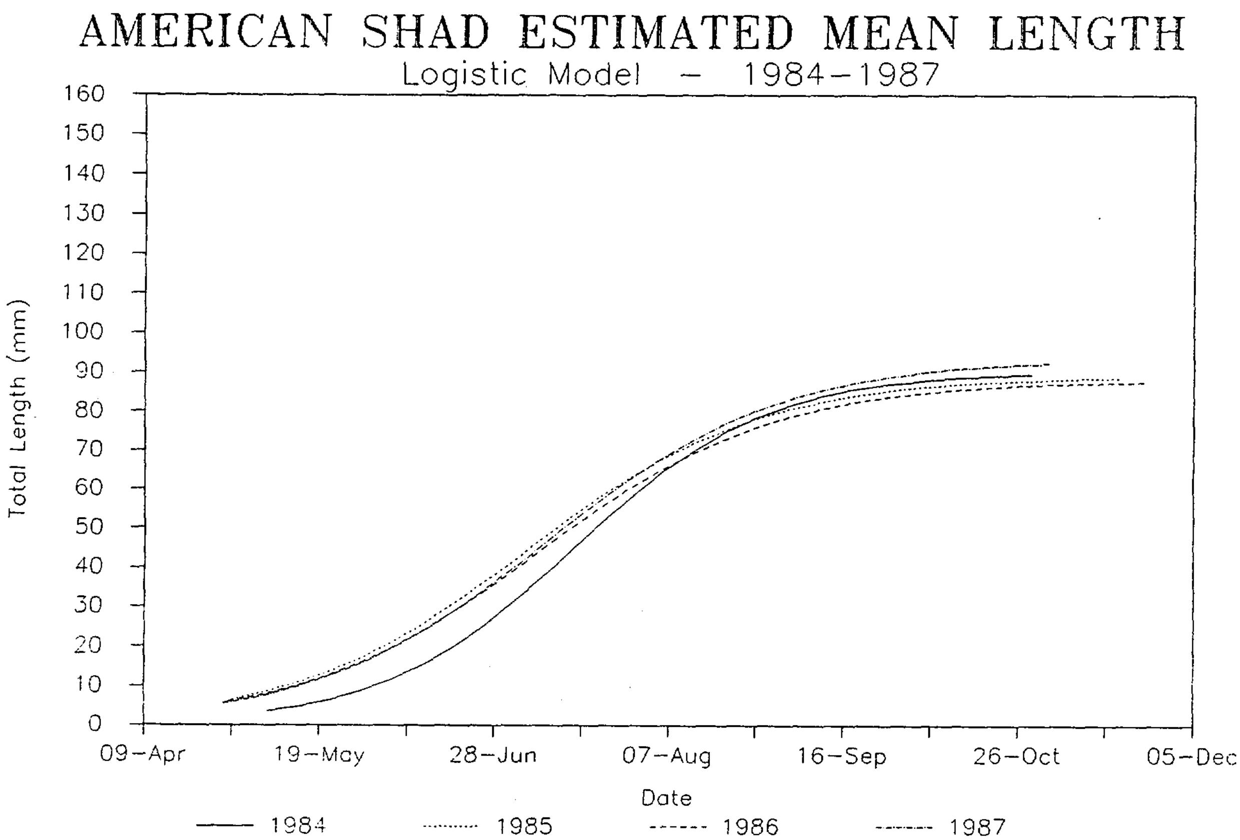

AMERICAN SHAD GROWTH - 1984
Logistic Growth Model
All runs
Only Jun-Oct
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
LRS
BSS
FSS

FIGURE 8-17



AMERICAN SHAD GROWTH RATES
Logistic Model – 1984–1987
Growth Rate (mm/day)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
09–Apr
19–May
28–Jun
07–Aug
16–Sep
26–Oct
05–Dec
Date
1984
1985
1986
1987



AMERICAN SHAD ESTIMATED MEAN LENGTH
Logistic Model – 1984–1987
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09–Apr
19–May
28–Jun
07–Aug
16–Sep
26–Oct
05–Dec
Date
1984
1985
1986
1987

FIGURE 8-18

WEEKLY MEAN TEMPERATURES, 1984-1987

TABLE 8-6

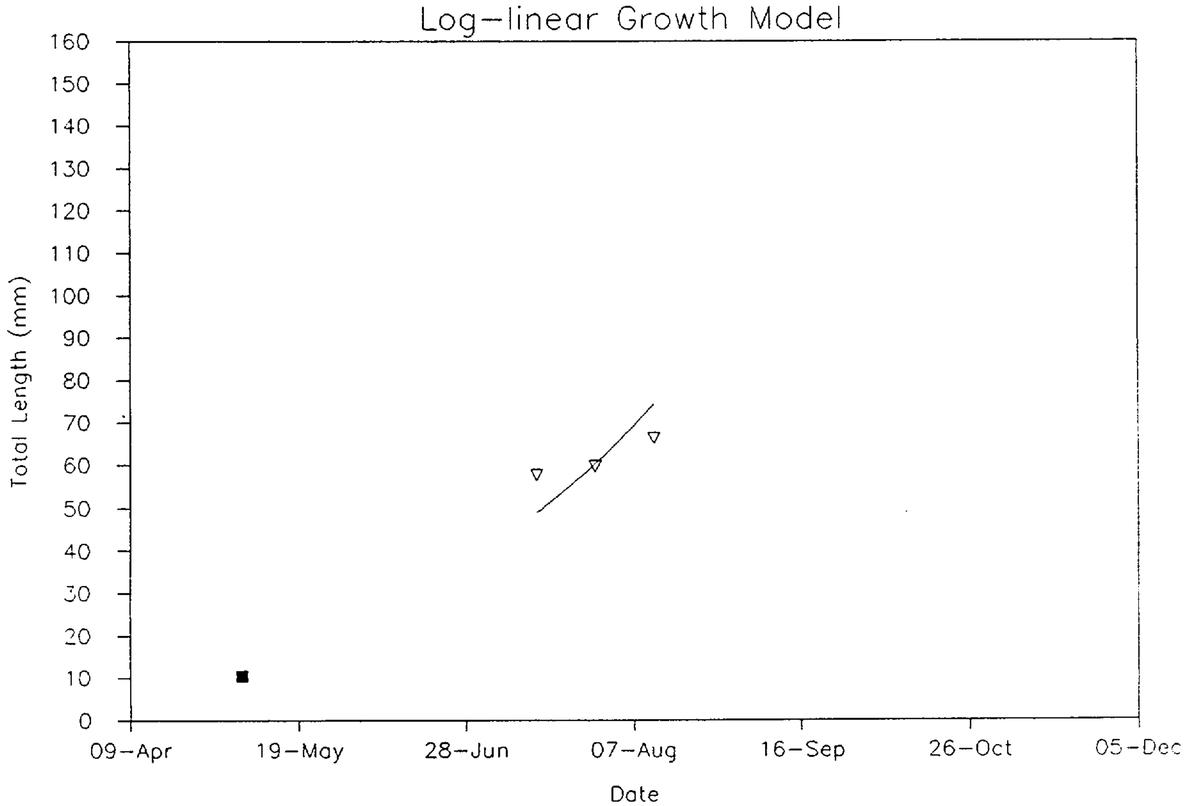
MEAN WATER TEMPERATURE (C°) IN REGIONS AND PERIODS OF PEAK ABUNDANCE OF AMERICAN SHAD EGGS AND LARVAE, HUDSON RIVER ESTUARY, 1976-1987[a]

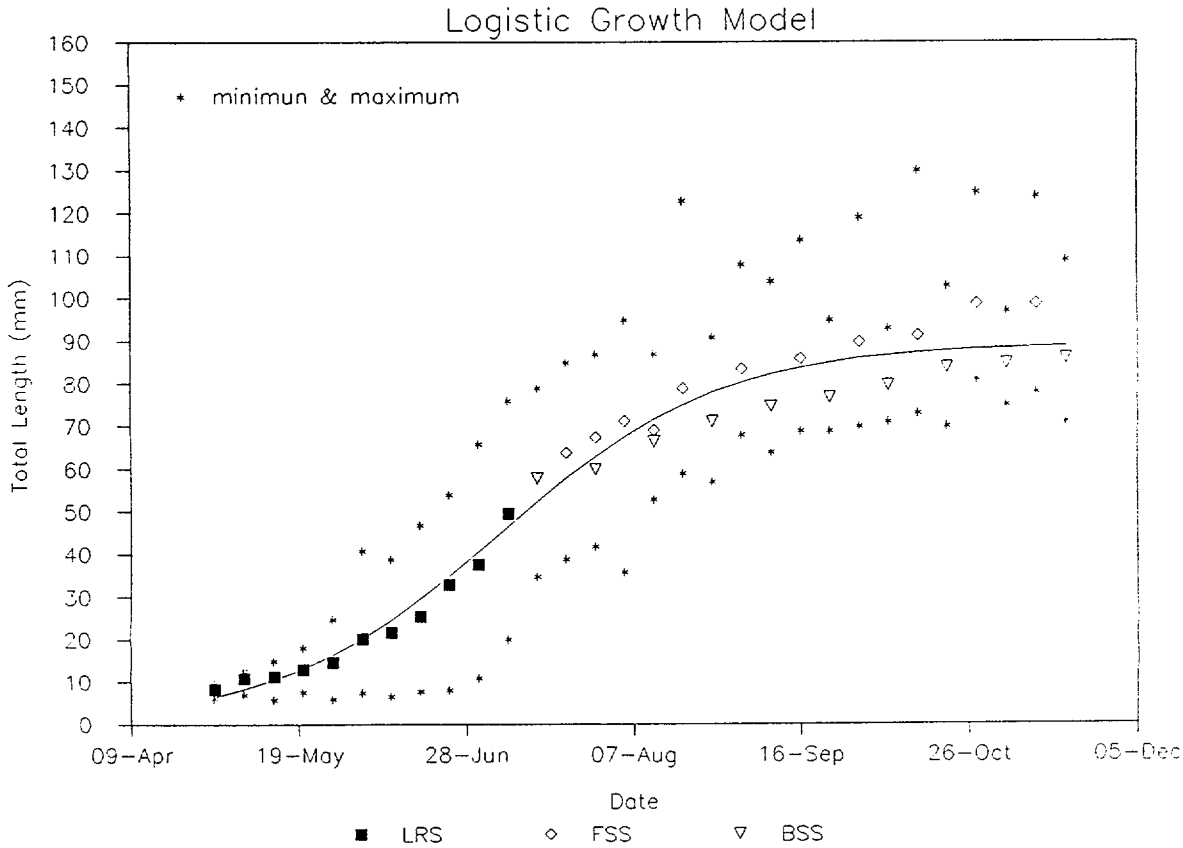
YEAR	EGGS		YOLK-SAC LARVAE		POST-YOLK-SAC LARVAE	
	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE	PEAK PERIOD	MEAN TEMPERATURE
1976	02 May - 22 May	13.3	09 May - 12 Jun	15.6	13 Jun - 26 Jun	22.9
1977	01 May - 21 May	13.5	08 May - 28 May	16.6	22 May - 04 Jun	20.5
1978	30 Apr - 27 May	13.1	21 May - 03 Jun	14.8	28 May - 03 Jun	21.4
1979	13 May - 19 May	17.3	13 May - 26 May	18.0	10 Jun - 16 Jun	19.4
1980	05 May - 08 May	15.5	12 May - 15 May	15.5	02 Jun - 13 Jun	20.0
1981	04 May - 09 May	10.0	18 May - 21 May	15.8	18 May - 21 May and	15.8
					08 Jun - 13 Jun	21.0
1982	10 May - 14 May	13.0	17 May - 20 May	16.6	24 May - 03 Jun	18.5
1983	09 May - 18 May	11.9	06 Jun - 09 Jun	16.0	13 Jun - 18 Jun	20.6
1984	07 May - 14 May	9.5	14 May - 04 Jun	9.7	11 Jun - 25 Jun	18.0
1985	29 Apr - 10 May	14.4	06 May - 24 May	16.5	20 May - 07 Jun	19.2
1986	28 Apr - 02 May	15.1	05 May - 06 Jun	18.7	02 Jun - 13 Jun	21.0
1987	20 Apr - 01 May	12.8	27 Apr - 05 Jun	16.2	18 May - 26 Jun	20.6

[a]Adapted from data presented in MMES (1986).

FIGURE 8-19

AMERICAN SHAD GROWTH – 1985





fore, as an additional observation, and to estimate the date of full recruitment, the period of peak YSL abundance was used in the regression. Estimated larval and juvenile growth rates were 0.3 and 0.7 mm/day, respectively. Both of the growth rates, although lower than those reported in 1984, were within the range of values observed in 1986 and 1987 (Table 8-5).

8.3.2.2 Logistic Estimates. Using the logistic growth function (K = 89.166618, R = 0.037425, A = 3.580425, r^2 = 0.9724), mean total lengths of 30 and 60 mm were estimated to have been reached on 17 June and 24 July, respectively (Figure 8-19). Growth rates of 0.5 and 0.8 were calculated for American shad larvae and juveniles, respectively. The estimated growth rates based on the logistic model were similar for all year classes between 1984 and 1987.

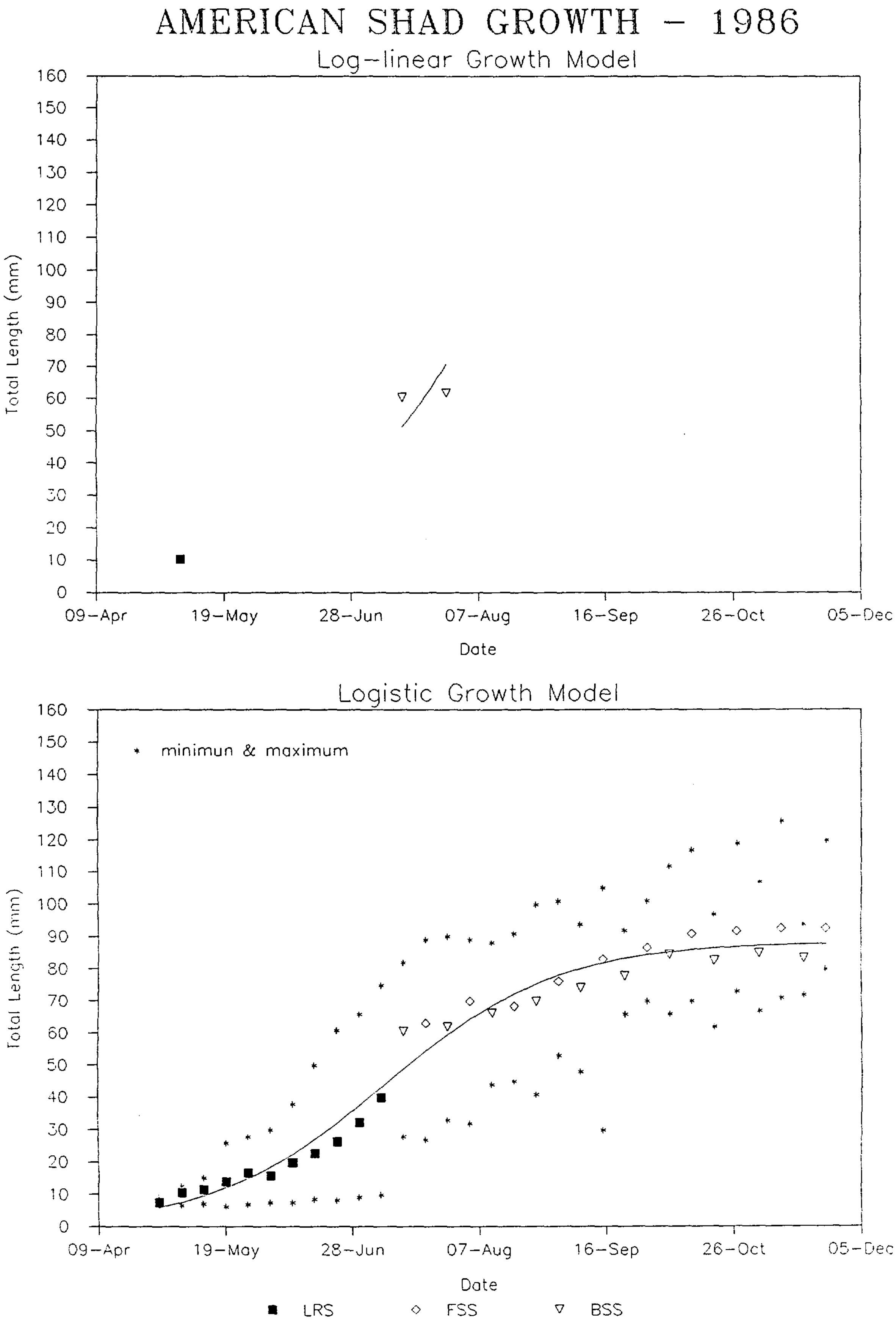
8.3.3 1986 Survey

8.3.3.1 Log-Linear Estimates. In 1986 the Hudson River American shad population reached mean lengths of 30 and 60 mm on 20 June and 20 July, respectively. These estimates are based on the log-linear regression (ln Y = 0.023187x + 2.220966, r^2 = 0.9773) of the mean length of the population during the 5 May LRS sample period, peak YSL abundance, and the 14 and 28 July BSS collections (Figure 8-20). As in 1984 and 1985, the addition of LRS data to the regression was necessary to get a reasonable estimate of the recruitment date. The dates when 30 and 60 mm were attained were earlier than the 1984, 1985, and 1987 log-linear regression estimates (Table 8-5).

Larval and juvenile growth rates were estimated at 0.4 and 1.0 mm/day, respectively. The larval growth rate was based on the 7 May YSL peak abundance during the LRS. The larval and juvenile growth rates were similar to 1984, 1985, and 1987 values (Table 8-5).

8.3.3.2 Logistic Estimates. Using the logistic function (K = 88.096191, R = 0.036974, A = 3.633024, r^2 = 0.9765), it was estimated that the 30 and 60 mm mean TLs were reached by the American shad population on 20 June and 28 July,

FIGURE 8-20


AMERICAN SHAD GROWTH - 1986
Log-linear Growth Model
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
Logistic Growth Model
minimun & maximum
Total Length (mm)
Date
LRS
FSS
BSS

respectively (Figure 8-20). The recruitment size of 30 mm (TL) was estimated to occur on the same date for both growth models; however, the log-linear model estimated that 60 mm (TL) was attained one week earlier compared to the logistic estimate.

Larval and juvenile growth rates were calculated as 0.5 and 0.8 mm/day, respectively. These estimates were the same as 1984, 1985, and 1987 values (Table 8-5).

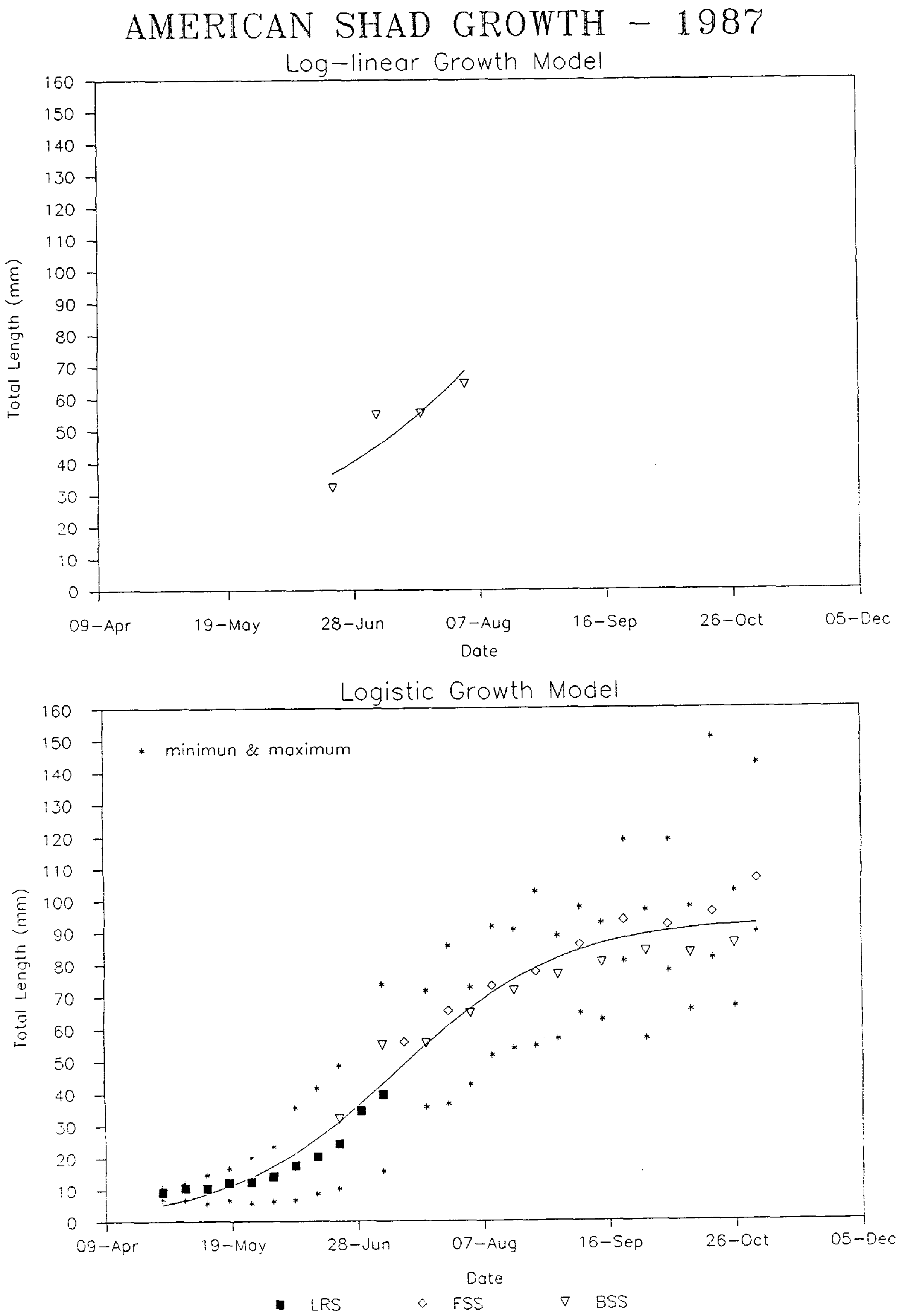
8.3.4 1987 Survey

8.3.4.1 Log-Linear Estimates. The Hudson River American shad population reached mean total lengths of 30 and 60 mm on 9 July and 24 August, respectively. These estimates are based on the log-linear regression ($\ln Y = 0.014934x + 2.378153$, $r^2 = 0.7883$) of biweekly mean length data from the 22 June through 3 August BSS sampling periods (Figure 8-21). Larval and juvenile growth rates were calculated as 0.3 and 0.7 mm/day, respectively. These growth rates are identical to the 1985 estimates for approximately the same time periods.

8.3.4.2 Logistic Estimates. Full recruitment to the beach seine first occurred on 20 July based on the nonlinear logistic growth function ($K = 93.585144$, $R = 0.037506$, $A = 3.762566$, $r^2 = 0.9712$) (Figure 8-21). The American shad population was estimated to have reached 60 mm TL on 24 August. The larval growth rate was calculated as 0.5 mm/day based on the 7 May YSL abundance peak. The juvenile growth rate was calculated as 0.8 mm/day.

The larval growth rate was the same for the 1984 through 1987 year classes; however, the dates when they attained a population mean length of 30 mm varied among years. Peak YSL abundance occurred between 7 and 10 May during all studies, but the date that recruitment size was reached ranged from 17 June in 1985 to 20 July in 1987. Juvenile growth rates were the same during 1985, 1986, and 1987, with only a slightly higher rate estimated for the 1984 year class (Table 8-5).

FIGURE 8-21


AMERICAN SHAD GROWTH - 1987
Log-linear Growth Model
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
Logistic Growth Model
* minimun & maximum
Total Length (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
09-Apr
19-May
28-Jun
07-Aug
16-Sep
26-Oct
05-Dec
Date
LRS
FSS
BSS

8.4 DISCUSSION

Despite the wide range in dates during which a given species reaches recruitment length or 60 mm TL, there was little variability in larval and juvenile growth rates. Logistic model coefficients calculated using the minimum and maximum TLs are listed in Table 8-7. The variability in growth rates within years was much greater than the among-year variability (Table 8-8). Therefore, only extreme differences in growth rates among years would be discernible as a change.

Differences in absolute TL appear to be due to differences in the duration of the growing season rather than to differences in growth rate. In 1984-1987 the primary influence on absolute TL was timing of spawning in the spring. The timing of peak egg abundance in 1984 for striped bass and white perch occurred two to three weeks later than in 1985-1987 (Tables 8-2 and 8-4), and although larval and juvenile growth rates were the same or similar, the population mean length at the end of the growing season was smaller. The delayed 1984 spawning season for both striped bass and white perch appears to have been influenced by temperature; in 1984 mean water temperatures during the normal early to mid-May spawning period were 1 to 5 degrees cooler (Figure 8-1); however, peak egg abundance in 1984 for American shad occurred only a few days to a week later, and mean population TL by the end of the season did not differ in comparison to 1985-1987. Although not observed in 1984-1987, duration of the fall growth period could also influence population mean TL, with extended warmer temperatures in the fall lengthening the growing season. Flow pattern did not appear to influence growth or growth rate.

Although TL appears to be related to duration of the growing season, other factors may be involved. For example, mean sizes observed in the white perch stock assessment program (LMS 1988) suggest contrary results. Although there are numerous differences in sampling gear, duration, and timing between the two programs, if there are temperature-related growth effects, there should be a positive correlation between their yearly YOY mean TLs. Contrary to this expectation, there was a significant negative correlation ($r = -0.909$, $df = 2$,

TABLE 8-7

LOGISTIC MODEL COEFFICIENTS CALCULATED USING MINIMUM, MAXIMUM, AND MEAN TOTAL LENGTHS

	K	R	A
STRIPED BASS			
Min			
1984	58.3924	0.0594	7.6552
1985	73.9876	0.0590	7.4339
1986	65.6830	0.0432	5.7531
1987	60.2228	0.0438	5.6072
Max			
1984	129.6156	0.0426	5.2794
1985	148.0124	0.0356	4.2256
1986	138.8263	0.0422	4.4754
1987	128.3216	0.0393	4.2575
Mean			
1984	85.6108	0.0527	6.4941
1985	110.5359	0.0419	5.1155
1986	98.6397	0.0542	6.1569
1987	87.2678	0.0463	5.2542
WHITE PERCH			
Min			
1984	47.6058	0.0532	7.1083
1985	55.7884	0.0442	5.7764
1986	55.2001	0.0400	5.6969
1987	57.6602	0.0440	5.6317
Max			
1984	89.0501	0.0558	6.1233
1985	99.2357	0.0419	4.5173
1986	96.7636	0.0404	3.9972
1987	98.0410	0.0439	4.7021
Mean			
1984	70.7750	0.0512	6.5043
1985	76.2528	0.0552	6.4556
1986	76.3453	0.0511	5.8346
1987	79.4924	0.0540	6.1372
AMERICAN SHAD			
Min			
1984	77.9492	0.0326	4.2183
1985	74.1068	0.0492	5.5744
1986	78.4653	0.0293	4.0192
1987	79.4784	0.0377	4.5666
Max			
1984	111.7634	0.0443	4.4860
1985	112.1621	0.0381	3.2493
1986	108.0054	0.0399	3.2155
1987	122.6176	0.0294	2.8488
Mean			
1984	90.2711	0.0456	4.8530
1985	89.1667	0.0374	3.5804
1986	88.0962	0.0370	3.6330
1987	93.5851	0.0375	3.7626

TABLE 8-8

LARVAL AND JUVENILE GROWTH RATES CALCULATED USING MINIMUM, MAXIMUM, AND MEAN TOTAL LENGTHS

	LARVAL HATCHING-RECRUIT			JUVENILE RECRUITMENT 60 MIN		
	MIN	MEAN	MAX	MIN	MEAN	MAX
STRIPED BASS						
1984	0.4	0.6	0.7	-	1.1	1.2
1985	0.4	0.4	0.5	0.9	1.1	1.1
1986	0.4	0.6	0.8	0.5	1.3	1.2
1987	0.3	0.5	0.6	0.2	1.0	1.1
WHITE PERCH						
1984	0.4	0.5	0.8	-	0.8	1.1
1985	0.3	0.4	0.4	-	1.0	1.0
1986	0.2	0.4	0.5	-	0.9	0.9
1987	0.3	0.4	0.5	-	1.0	1.0
AMERICAN SHAD						
1984	0.3	0.5	0.6	0.6	1.0	1.6
1985	0.4	0.6	0.7	0.8	0.6	1.0
1986	0.3	0.5	0.7	0.5	0.8	1.0
1987	0.4	0.5	0.5	0.7	0.8	0.9

$P \leq 0.05$) between the white perch stock assessment and the Hudson River monitoring program 1984-1987 YOY mean TLs.

In some years the FSS population mean length tended to be larger than the BSS mean length: striped bass, 1985 and 1986 (Figures 8-6 and 8-7); white perch, 1987 (Figure 8-14); American shad, 1984-1987 (Figures 8-15, 8-19, 8-20, and 8-21). The difference in population mean lengths between the two sampling programs is probably one of size-related gear bias: larger fish may be avoiding the beach seine net; smaller fish may not be retained by the mesh used in the FSS beam trawl; and if there is size-related movement of fish into the deeper stratum, the strata population mean lengths would differ.

CHAPTER 9

SIZE-RELATED DISTRIBUTION AND MIGRATION

Several studies have noted size (Chittenden 1969, 1972; Miller et al. 1973) and age-related (LMS 1986) differences in seasonal distribution and movement patterns. Sampling bias due to size-related migration patterns among YOY can result in biased estimates of growth, abundance, and standing crop. Therefore, the distribution and migration patterns of various size classes of YOY striped bass, white perch, and American shad over time were examined for evidence of size-related migration (i.e., do smaller individuals migrate earlier, later, or at the same time as larger individuals?).

9.1 LONGITUDINAL MIGRATION

The YOY, BSS, and FSS collection data for 1985 through 1987 were separated into various length categories and a river mile index (RMI) of size-specific distributions was constructed to evaluate size-related longitudinal (upriver or downriver) movement patterns (see Section 2.6.6 for RMI equation). Size-related longitudinal migration is indicated by lateral shifts in the relative timing of migration among size-specific RMIs (Figure 9-1a). Parallel movement alone in size-specific RMIs indicates simultaneous migration by different size classes in the same direction at the same rate (Figure 9-1b). Horizontal lines indicate no upriver or downriver movement. Differences in river mile sampling locations between the BSS and FSS preclude direct comparison among RMI BSS and FSS values; however, relative movement is comparable.

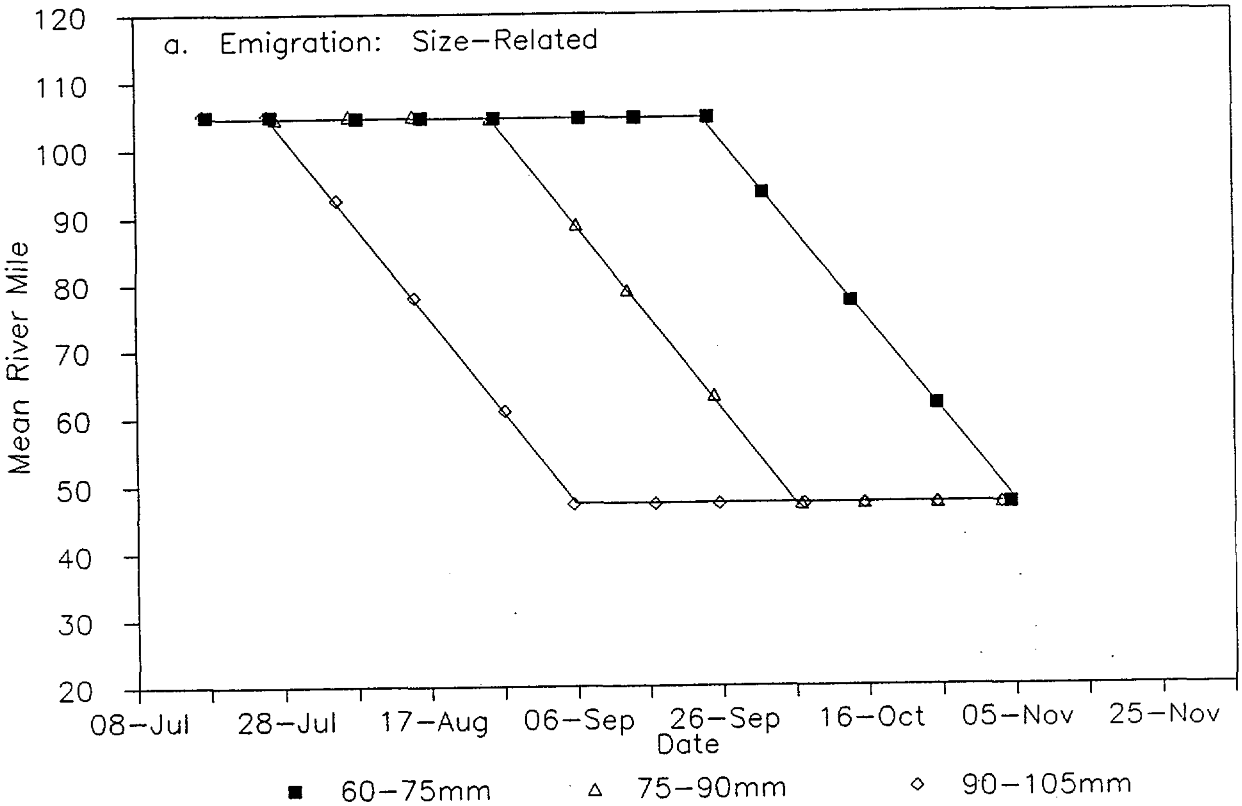
9.1.1 Striped Bass

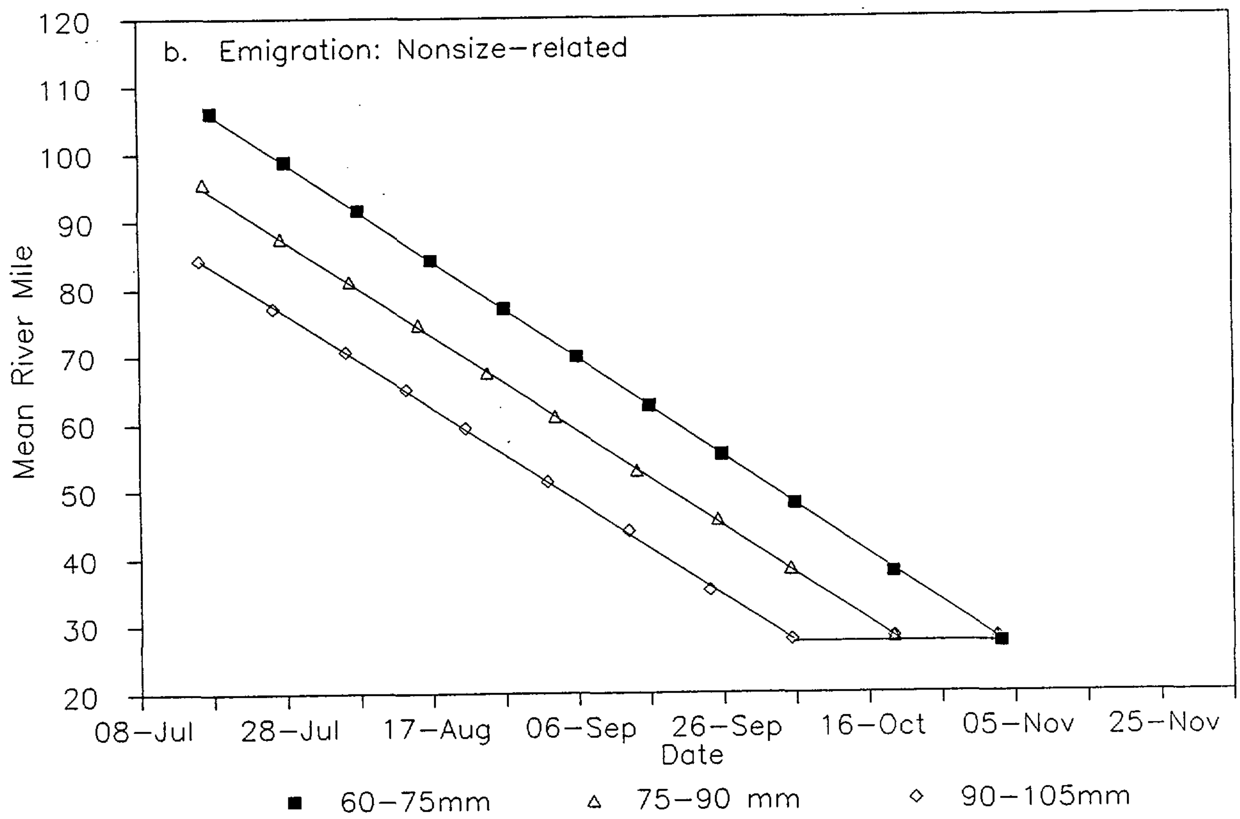
The general movement pattern of Hudson River striped bass during their first year was described by McFadden et al. (1978). During late summer the YOY fish leave the upriver nursery area, moving shoreward and downstream to shallow-water nursery areas in the lower part of the tidal river. They then move into

FIGURE 9-1

LENGTH CLASS LOCATIONS IN THE ESTUARY

Hypothetical Results





deeper waters in the fall and may overwinter in the lower estuary, bays, or adjacent sounds.

Examination of the relative movement of size-specific RMIs for 1984 through 1987 in both the BSS and FSS (Figures 9-2 and 9-3) suggests no evidence of a size-related difference in the timing of YOY fall downstream migration. However, McFadden et al. (1978) noted migration in October and November; therefore, sampling during 1984, 1985, and 1987 may have ended before fall migration took place. Data from 1986 and 1987 suggest a progressive downriver movement over time, but with no size-related migration among YOY striped bass.

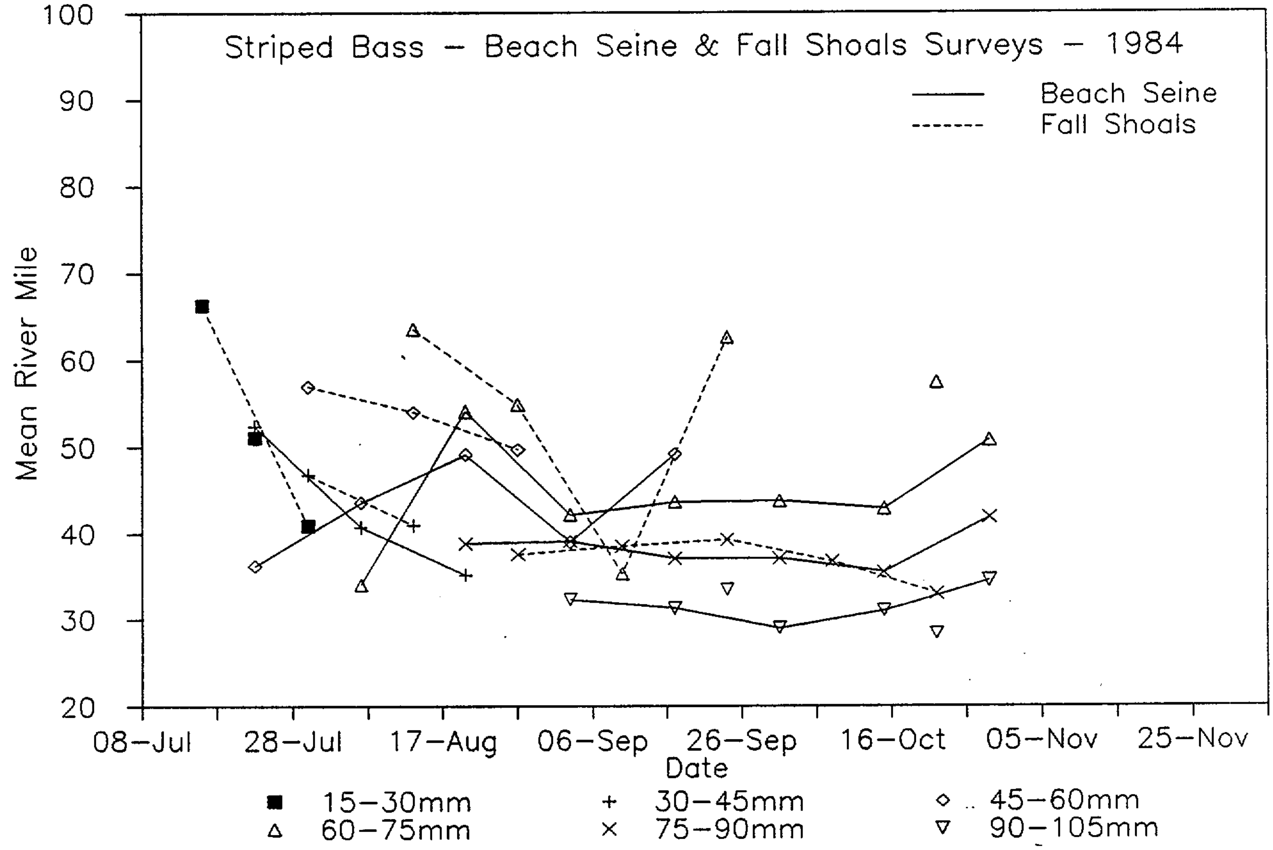
9.1.2 White Perch

Generally, the movement pattern of Hudson River white perch during their first year is similar to that of juvenile striped bass. From 1972 through 1979 Klauda et al. (1988) found larvae concentrated in the middle and upper estuary during the summer, with juveniles (20-25 mm) moving downriver and into the shallows in early August. Juvenile white perch remained in the nearshore area through September and then gradually began to move offshore through the shoals. By the end of fall major concentrations became established in deeper water (>6 m), where they overwinter.

The BSS RMI patterns for YOY white perch in 1984 (Figure 9-4) appeared to indicate the presence of size-related movement. However, this pattern was not observable in other years or in the FSS data (Figures 9-4 and 9-5). In previous studies, using similar methods, LMS (1986) has observed differential fall migration rates and distribution patterns among Hudson River white perch age classes 0+, I+, II+, and older. However, their study extended into December and fall migration was observed to occur in late November. Thus, the FSS and BSS sampling from 1984 through 1987 may have ended before fall migration took place. Although data from 1984 and 1986 suggest a progressive downriver movement over time, no size-related movement was apparent for the time period sampled.

FIGURE 9-2

LENGTH CLASS LOCATIONS IN THE ESTUARY



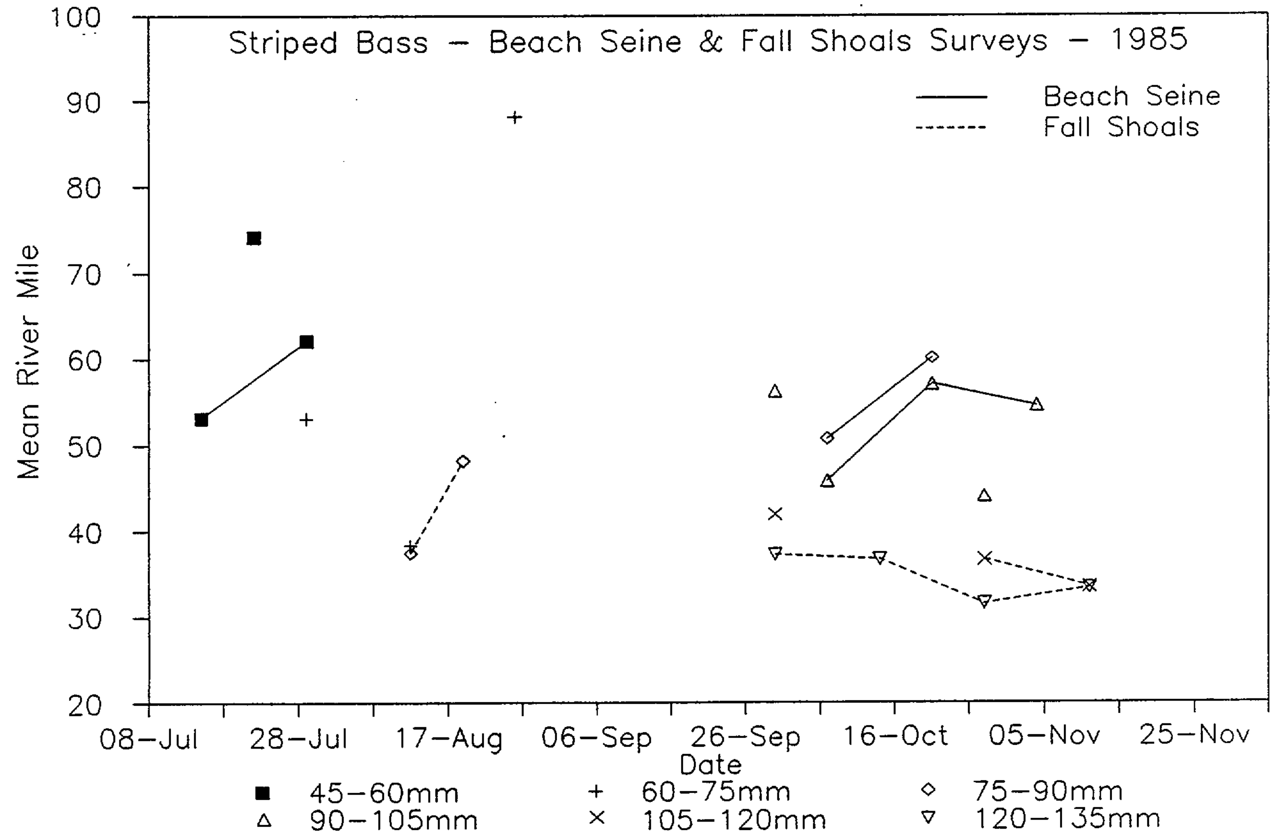
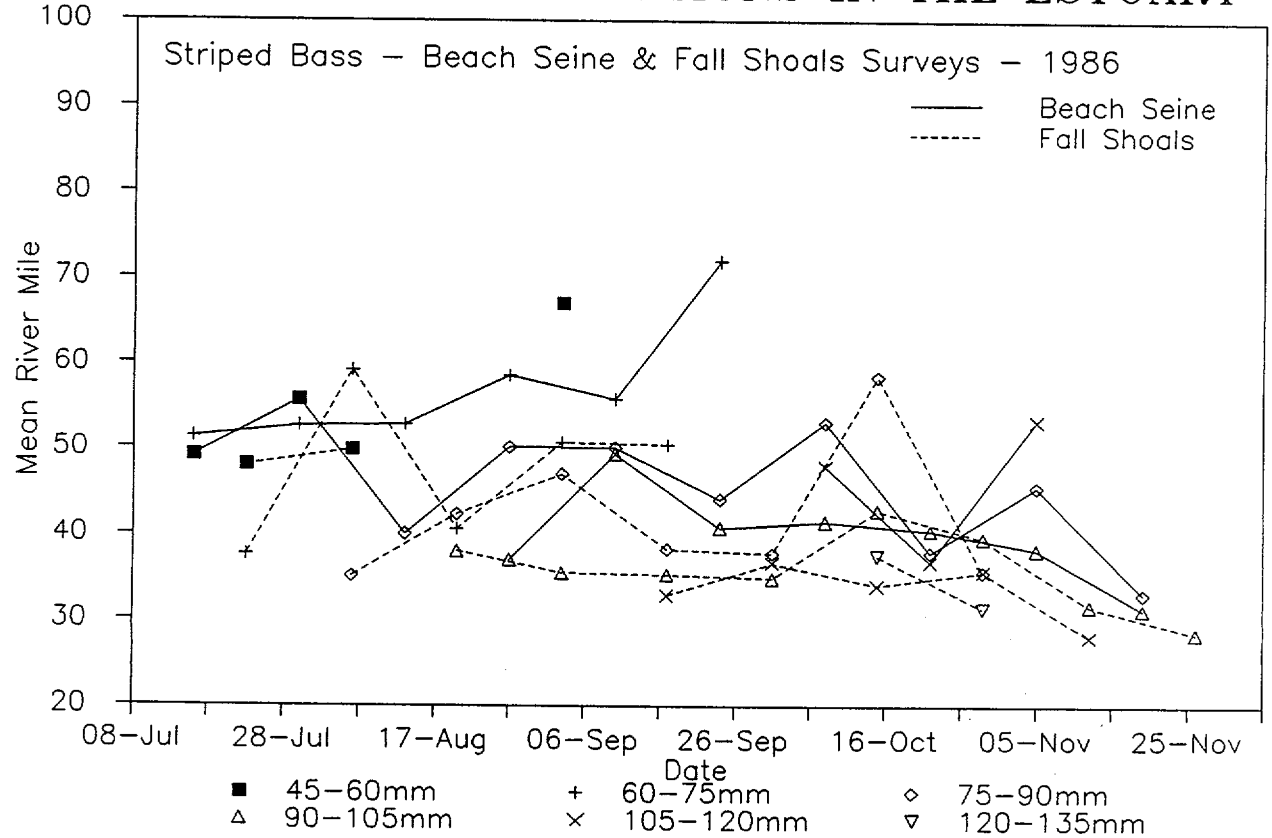


FIGURE 9-3

LENGTH CLASS LOCATIONS IN THE ESTUARY



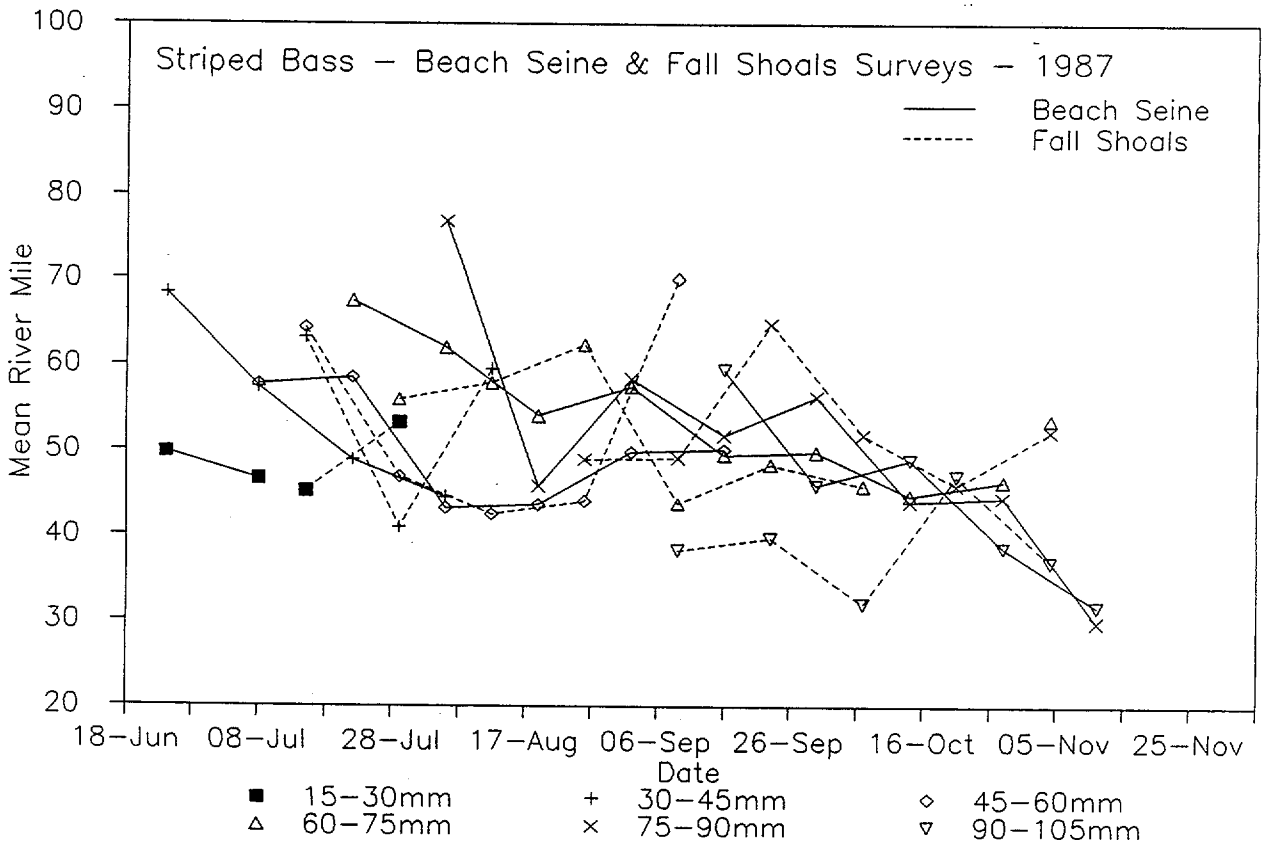
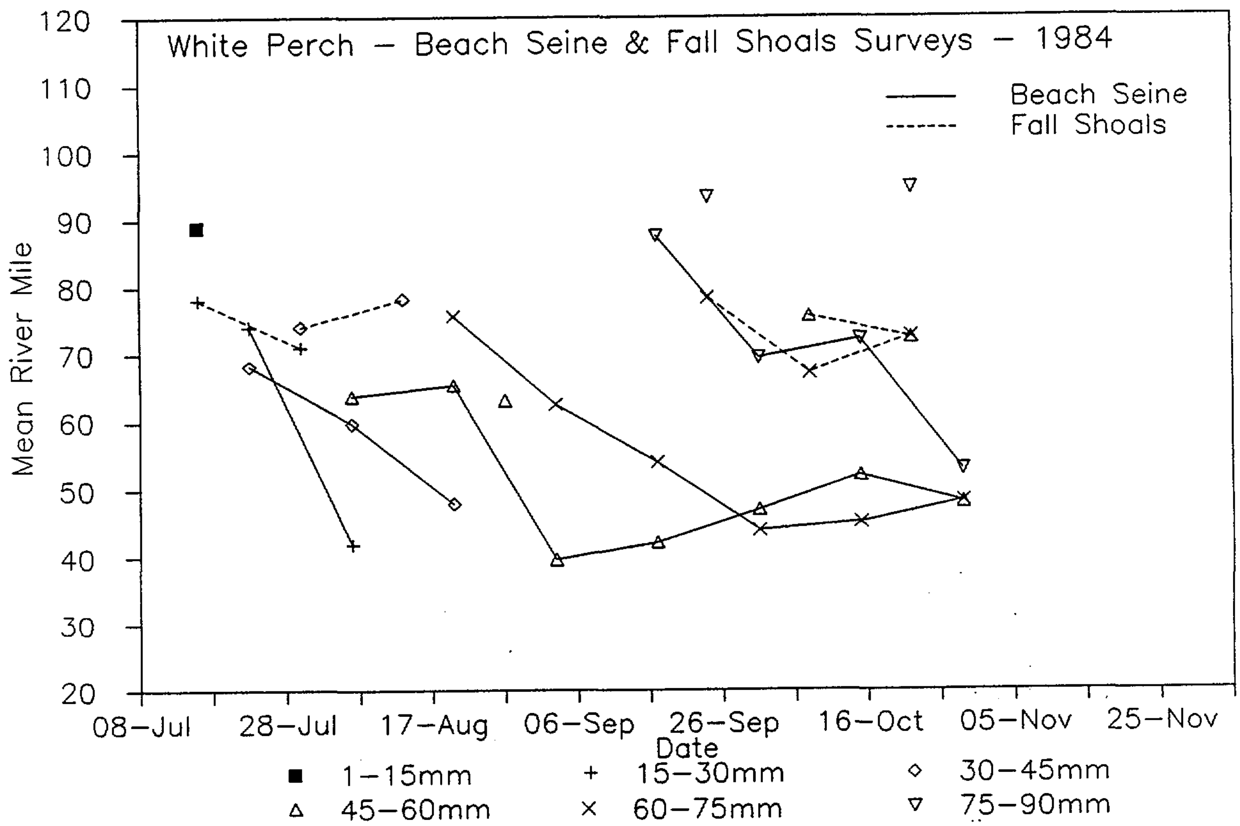


FIGURE 9-4

LENGTH CLASS LOCATIONS IN THE ESTUARY



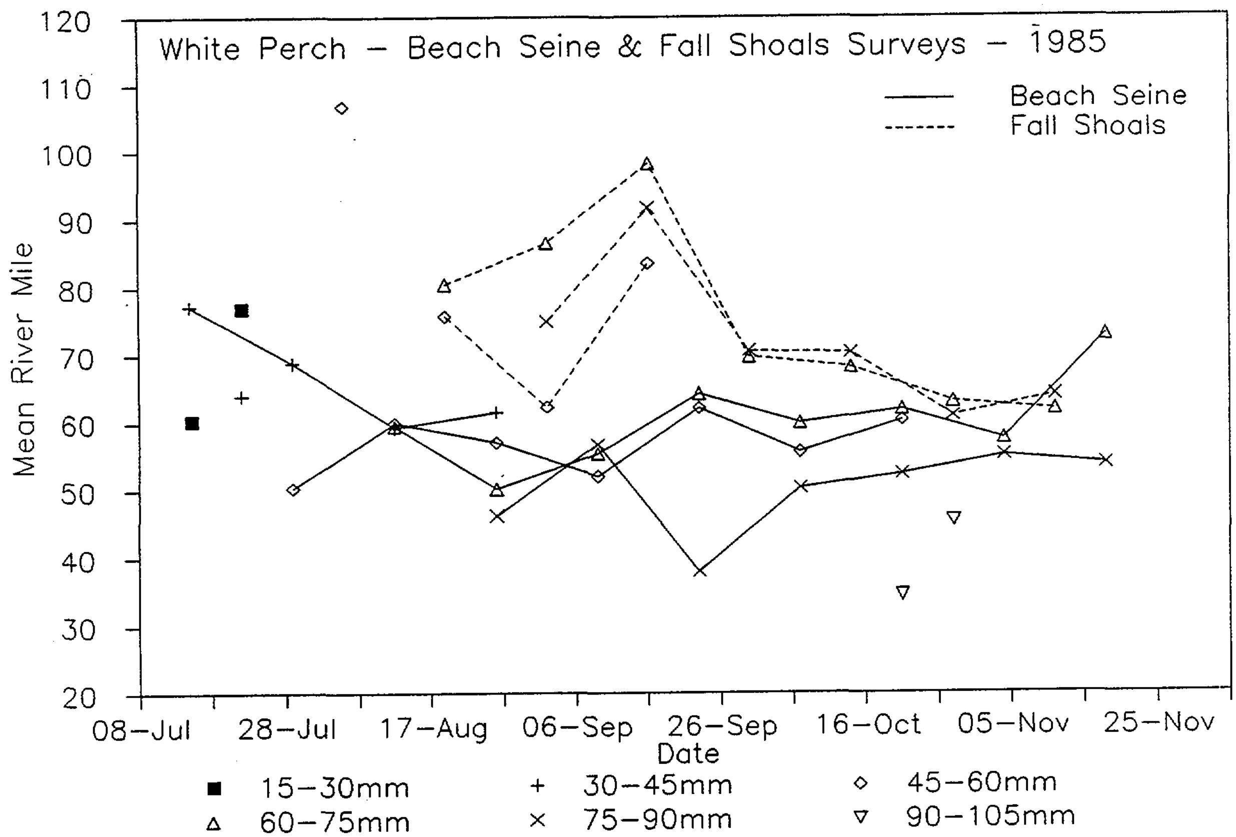
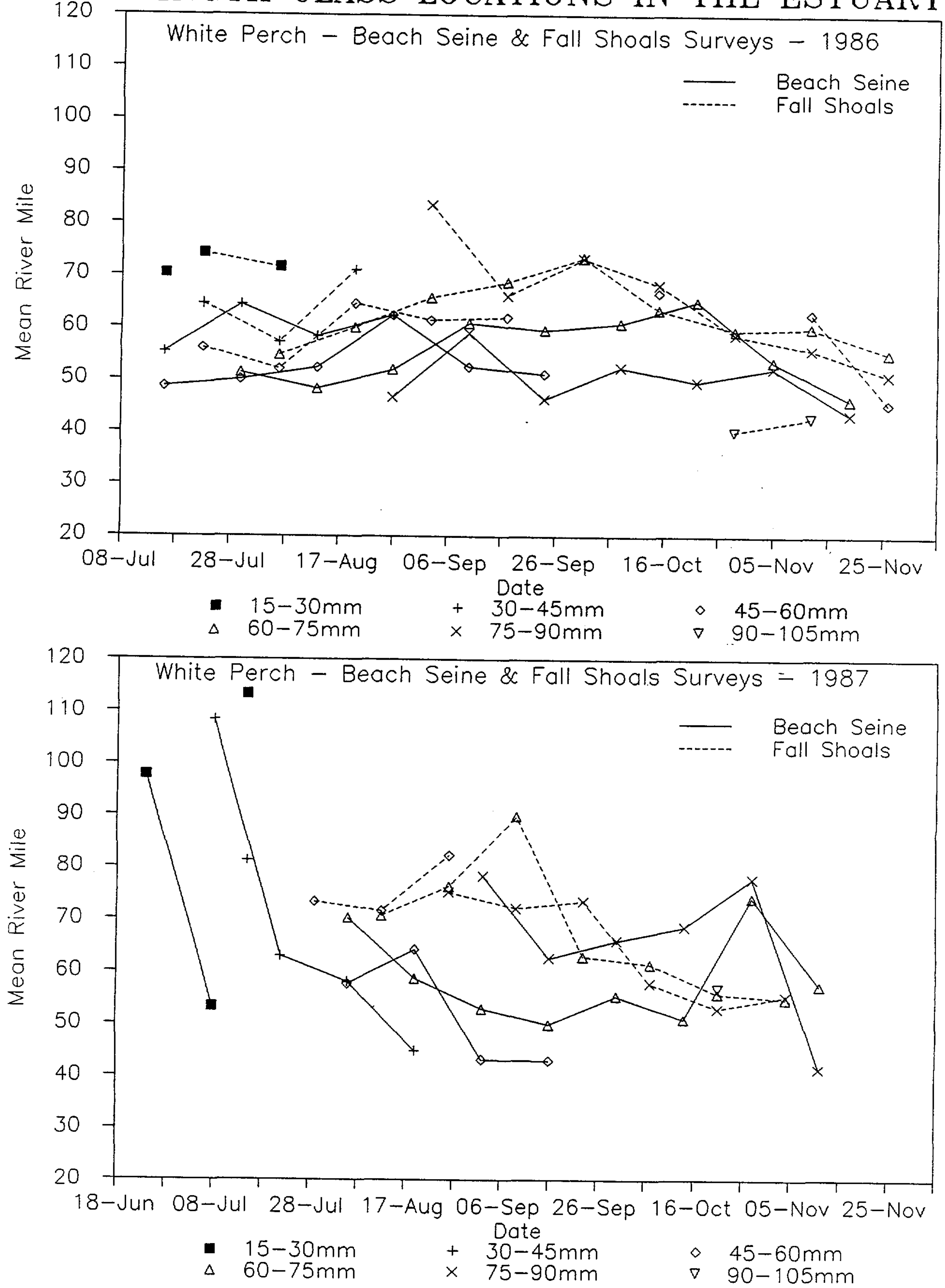


FIGURE 9-5

LENGTH CLASS LOCATIONS IN THE ESTUARY



9.1.3 American Shad

In the Connecticut River Watson (1968) reported that juvenile migration began in late September when the water temperature dropped below 18.3°C. Delaware River juvenile shad begin downriver emigration in September and October in response to declining temperature, increased river flows, and, to a lesser extent, specimen size (Sykes and Lehman 1957; Miller et al. 1973).

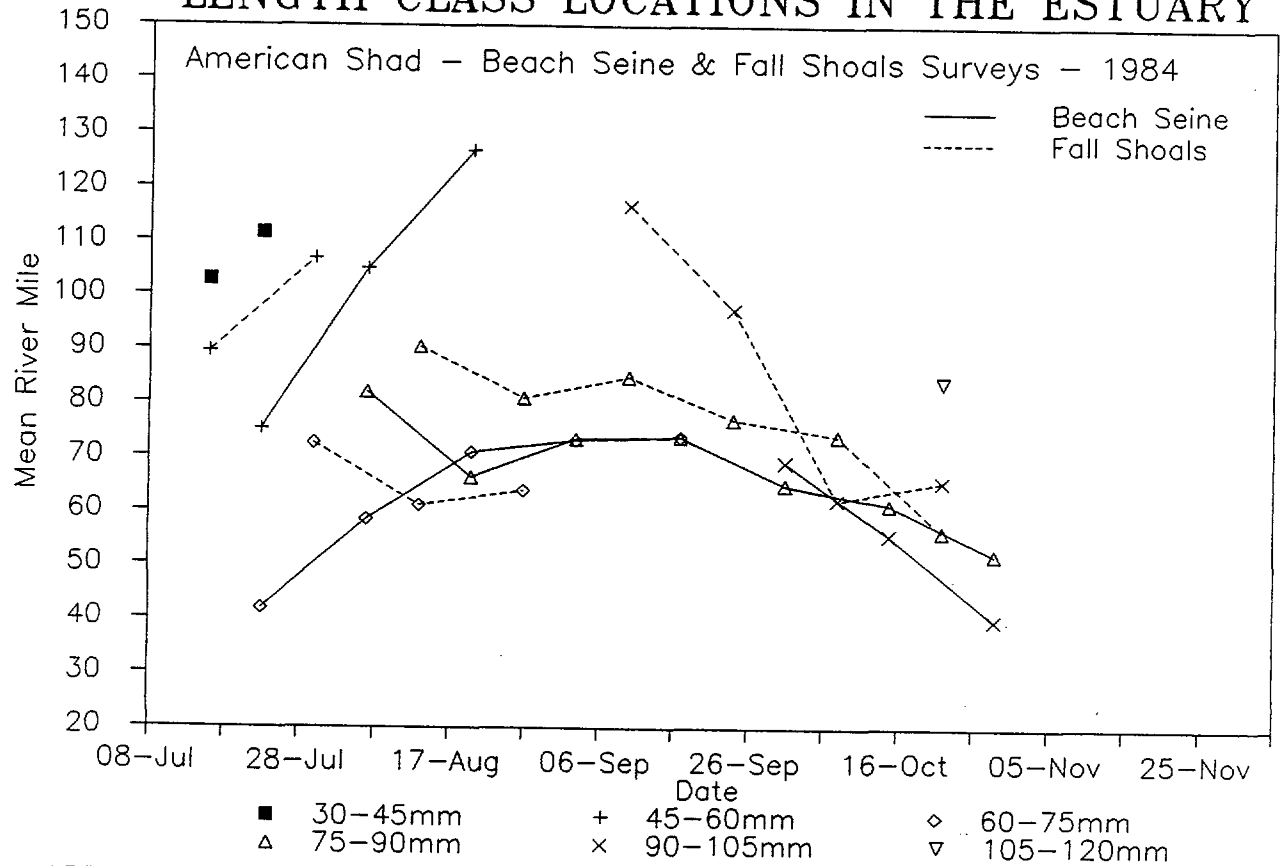
Size-related distribution and emigration has been reported in the Delaware River. Chittenden (1969, 1972) noted a generally decreasing maximum size of juveniles in nursery areas during the summer, and Miller et al. (1973) reported a differential distribution in size range between the upper and lower nursery area. Chittenden (1969, 1972) stated that migratory activity prior to temperature-related movement may be related to growth since larger fish appeared to emigrate from the nursery areas first. Although data from 1984 to 1987 suggest a progressive downriver movement over time, after mid-October no differential size-related migration pattern (Figures 9-6 and 9-7) is apparent among YOY American shad in the Hudson River.

9.2 ONSHORE/OFFSHORE DISTRIBUTION

The river mile index is best suited for displaying longitudinal, i.e., upriver vs downriver, changes in distribution. If, however, distribution and movement patterns are closely tied to the salt front position and freshwater flows, then the extent of fish movements may be largely determined by the prevailing flow. Due to salinity preference or the physiological adjustments necessary to enter more saline waters, fish may tend to congregate near the salt front. As flows increase during the fall, the salt front recedes downriver (see Chapter 3). In high freshwater flow years the downriver displacement of the salt front and fish may be extensive; in low-flow years little or no downriver displacement may be observed. In this situation the fall emigration may be largely a passive process for some species. Flow-related movement has been suggested for white perch during their fall emigration (LMS 1986, 1987, and 1988). Distribution pattern changes with freshwater flow (Chapter

FIGURE 9-6

LENGTH CLASS LOCATIONS IN THE ESTUARY



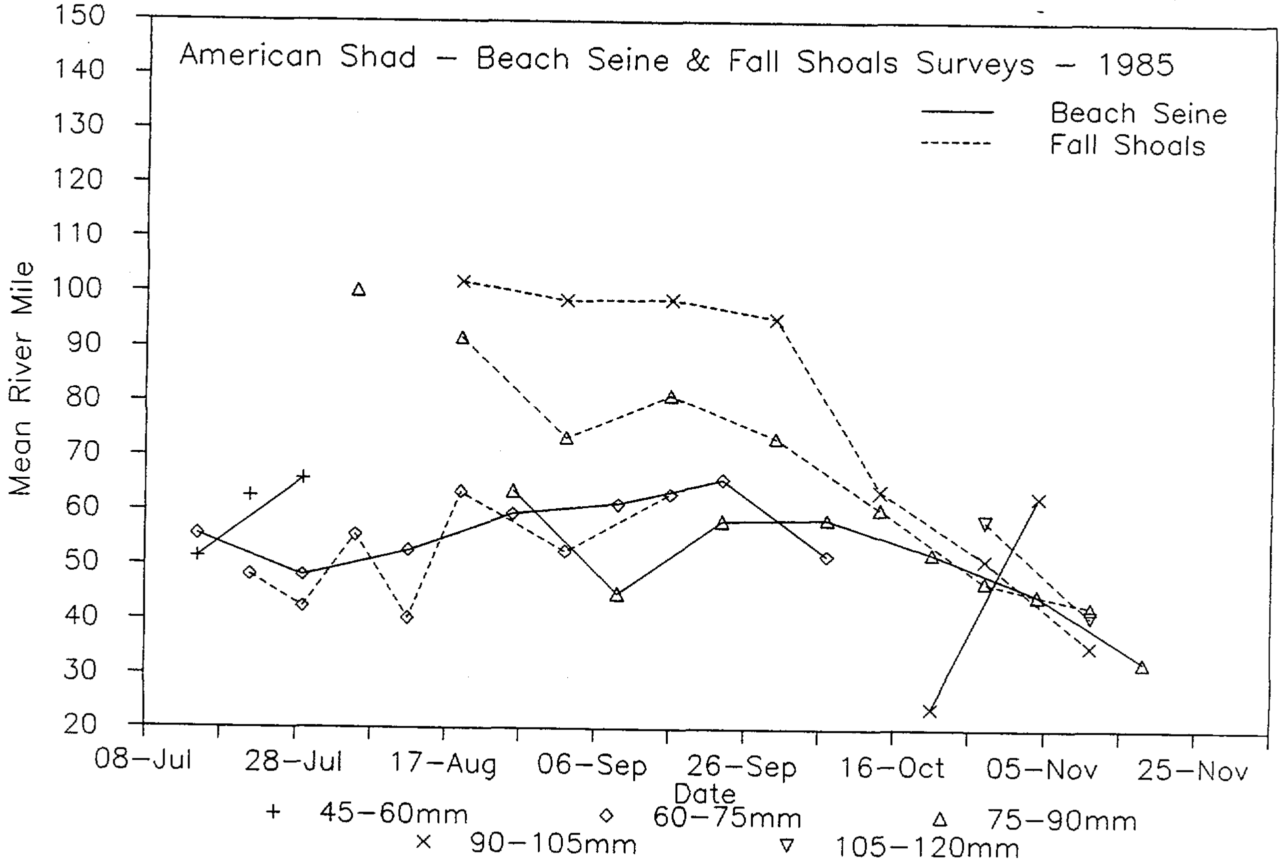
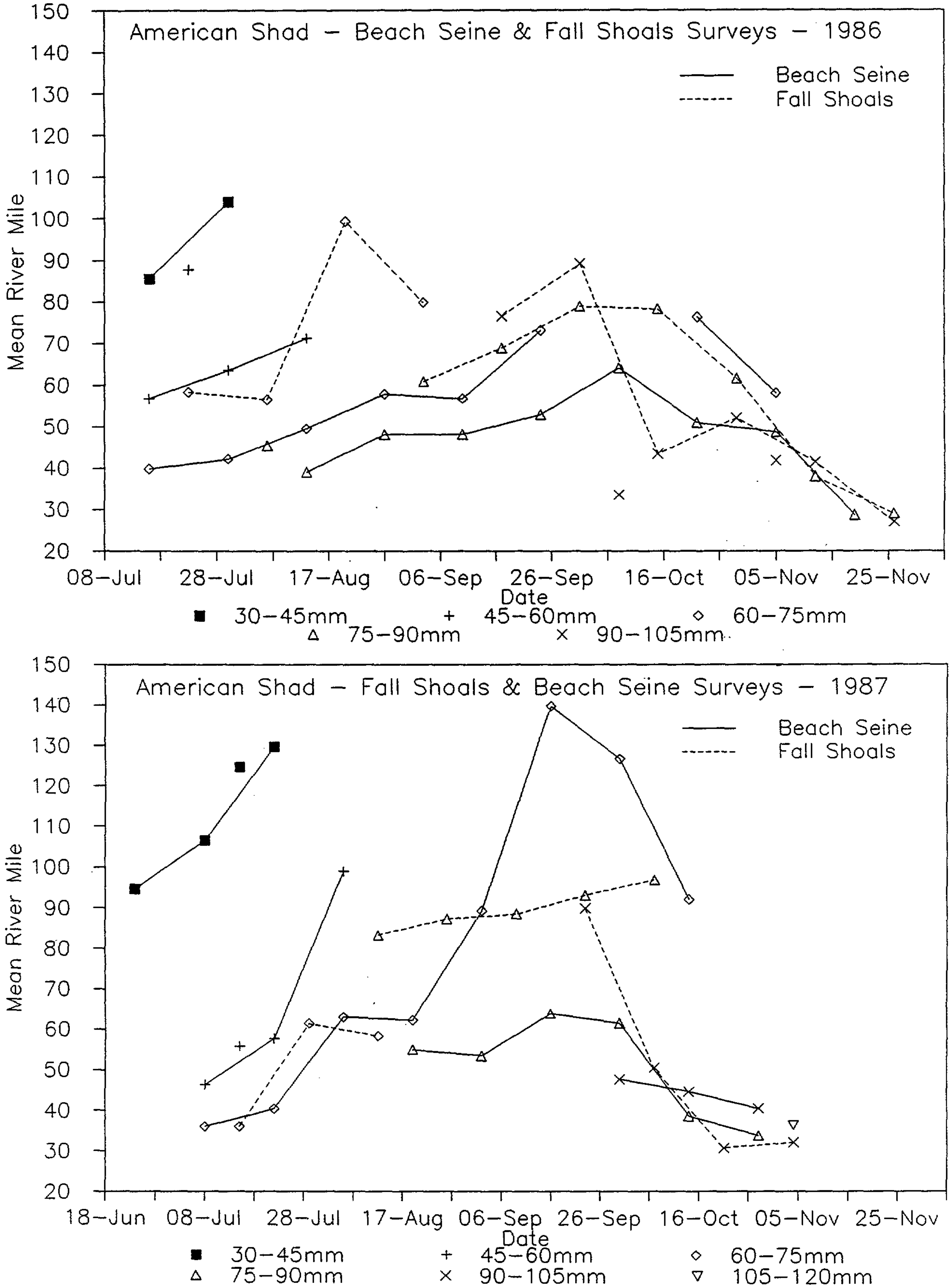


FIGURE 9-7

LENGTH CLASS LOCATIONS IN THE ESTUARY



7) also suggest that distributions are closely tied to freshwater flows and the position of the salt front.

Rather than a freshwater flow-related longitudinal movement pattern, emigration may be an onshore/offshore movement. With declining water temperatures in the fall, juveniles may leave the shore zone. A late season offshore movement of striped bass and white perch has been noted by several authors, e.g., Mansueti (1961), McFadden et al. (1978), and TI (1979). The question of concern is then, "Do larger young-of-year fish leave the shore zone earlier than their smaller cohorts?"

To examine this question, the most appropriate data sets appear to be from two programs conducted by the New York State Department of Environmental Conservation (NYSDEC). The first program, a beach seine survey, uses a 200-ft seine with 13-mm stretch mesh to sample 25 stations on a biweekly schedule from RM 23 to 41. The second program, an offshore trawl survey, uses a 26-ft bottom trawl to collect approximately 20 samples on a biweekly schedule from RM 24 to 62. The cod-end liner of the trawl is constructed of 13-mm stretch mesh. Both programs sample from August through November and focus on juvenile striped bass. These data are better suited for examining the size-related emigration problem than the Hudson River Utilities data because (1) the larger size of the sampling gear decreases sampling bias related to gear avoidance, and (2) the larger number of length measurements taken during any given sampling period gives a more precise estimate of the length distribution of the juvenile population.

If large and small fish leave the shore zone at the same time, except for minor differences resulting from the inability to sample both locations with the same gear, the length-frequency distributions of fish sampled onshore and offshore should be the same. If, on the other hand, larger fish leave the shore zone earlier than smaller fish, then there should be a difference between the relative length-frequency distributions over time. The distribution of offshore fish lengths should display a skewness toward larger sizes at some point during the season, while the distribution of onshore fish lengths will not. This shift can be evidenced by the 90th percentile (although any upper percentile could be used) of the distribution. Once emigration has begun, the upper percentile of the offshore fish will increase relative to offshore fish.

Striped bass length-frequency data over time for 1986 and 1987 NYSDEC beach seine (onshore) and trawl (offshore) are presented in Tables 9-1 and 9-2. From mid-August through early September the distributions are relatively similar; the upper percentiles of length are nearly identical. Examination of the 90th percentile of the frequency distribution reveals only a 0-5 mm difference between the two distributions. Beginning in about late September, however, both years display a pronounced shift to larger sizes in the trawl data. This appears to be brought about by an increase in fish greater than 125 mm in length. This is especially apparent in the 6 October 1986 and 29 September 1987 samples (Figures 9-8 and 9-9). These differences are highly significant (Kolomogorov-Smirnov two-sample test, $P<0.001$ for both years). The 90th percentile values for the offshore fish are 15-20 mm greater. The differences between the onshore and offshore zone distributions appear to lessen somewhat from late October through early November, with differences between 90th percentile values averaging approximately 5-10 mm.

These results suggest that larger young-of-year fish do tend to leave the shore zone before the smaller fish. Larger fish begin the offshore movement as early as mid-September (although some fish are present in offshore areas at all times). This behavior pattern would explain the fact that for striped bass, white perch, and American shad the mean length of the FSS-captured fish (see Chapter 6) was consistently greater than the BSS-captured fish.

TABLE 9-1

LENGTH FREQUENCIES FOR STRIPED BASS BY COLLECTION WEEK AND GEAR

From 1986 NYSDEC Striped Bass Trawl (T) and Beach Seine (S) Surveys

LENGTH	15 JUL		29 JUL		12 AUG		26 AUG		9 SEP		23 SEP		6 OCT		21 OCT		5 NOV	
	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S
15							1											
20																		
25				1														
30	1	2	3	2		2												
35	6	4	2		1													
40	7	7	3	3		2												
45	22	25	8	4		5	1											
50	37	69	11	12	1	3	2	2						1				
55	54	137	12	22	1	12	4	3	3	3								
60	44	149	16	32	3	16	5	5	4			3				1		2
65	18	95	23	41	8	19	3	2	11	3	1	1	1	1				2
70	1	41	24	53	17	26	11	11	6	11		2		3	2	5		1
75		4	18	45	21	45	20	17	16	9	3	10	5	2	3	4		2
80			14	22	20	43	35	35	27	17	8	10	4	2	3	2	3	4
85			4	11	21	31	45	42	41	32	13	15	11	12	11	4	6	10
90			2	2	20	29	30	30	40	33	25	24	14	12	16	10	4	4
95					13	15	29	28	47	44	32	26	26	18	30	5	11	10
100					2	3	20	29	23	37	42	27	15	14	26	6	10	5
105					2	1	17	17	31	24	39	23	43	11	45	4	30	13
110					1	1	14	11	17	14	32	22	20	5	37	2	22	8
115					1	1	4		7	9	19	15	21	7	36	1	10	6
120							1	1	10	2	28	14	17	5	27	2	12	1
125									5		25	6	20	1	28	2	8	4
130									1		20	6	11		14	2	7	1
135											12		12		14	3	7	
140											3		9		12	2	9	
145											1	1	5		7		3	1
150											3			1	1	1		
90 %ile	62	65	80	80	95	90	105	105	110	110	130	120	135	115	135	135	135	115
Mean	54	58	64	67	81	76	87	88	92	93	108	100	110	97	111	99	112	98
SD	7	7	13	11	12	13	14	13	14	12	16	15	17	14	16	21	16	17
N	190	533	140	250	132	254	242	233	289	238	306	205	234	95	342	56	142	74

TABLE 9-2

LENGTH FREQUENCIES FOR STRIPED BASS BY COLLECTION WEEK AND GEAR

From 1987 NYSDEC Striped Bass Trawl (T) and Beach Seine (S) Surveys

	22 JUL		3 AUG		18 AUG		1 SEP		15 SEP		29 SEP		13 OCT		27 OCT		9 NOV	
LENGTH	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S
15																		
20		3		2														
25		5		2														
30	3	62	1	1		2												
35	25	181	1	5		4												
40	55	301	6	32		5		1										
45	94	357	23	76	3	25	1	6										
50	102	316	55	121	3	64		20	1	2	2							
55	69	257	105	271	20	174	7	76		7		3		5		2		
60	43	152	95	267	40	264	16	148	4	28	6	5	1	6	1	6		3
65	17	82	78	216	89	338	34	241	7	100	9	30	3	30	6	15	2	15
70	10	43	50	123	56	230	74	279	36	178	18	70	2	37	4	27	6	18
75	2	6	23	70	60	198	61	270	54	206	51	92	15	51	19	45	13	26
80		1	6	28	47	128	66	171	77	234	78	112	25	59	23	52	15	14
85			1	13	15	86	58	105	88	205	115	128	39	77	39	69	23	20
90				3	7	22	28	54	81	157	92	110	57	62	48	50	32	26
95					4	9	14	32	38	72	58	80	45	40	45	35	27	21
100					2	2	6	13	34	50	39	57	38	28	34	33	21	4
105						1	2	10	13	26	17	26	31	16	35	33	16	7
110								3	6	7	13	21	28	10	13	17	5	6
115									3	3	4	7	17	7	17	8	5	1
120									1	2	4	2	6	4	7	4	5	2
125									1		1	5	4	1	3	1	1	
130											1		4	1	2			
135											2		3		3		2	1
140											2				3			
145											2						1	1
150											1				1			
90 %ile	60	60	70	70	80	80	90	85	100	95	100	100	115	100	115	105	110	105
Mean	50	48	60	60	70	67	77	72	85	80	88	86	96	85	95	87	93	84
SD	8	10	8	10	9	10	10	11	11	11	13	12	13	13	15	13	13	14
N	420	1766	444	1230	346	1552	367	1429	444	1277	515	748	318	434	303	397	174	165

FIGURE 9-8

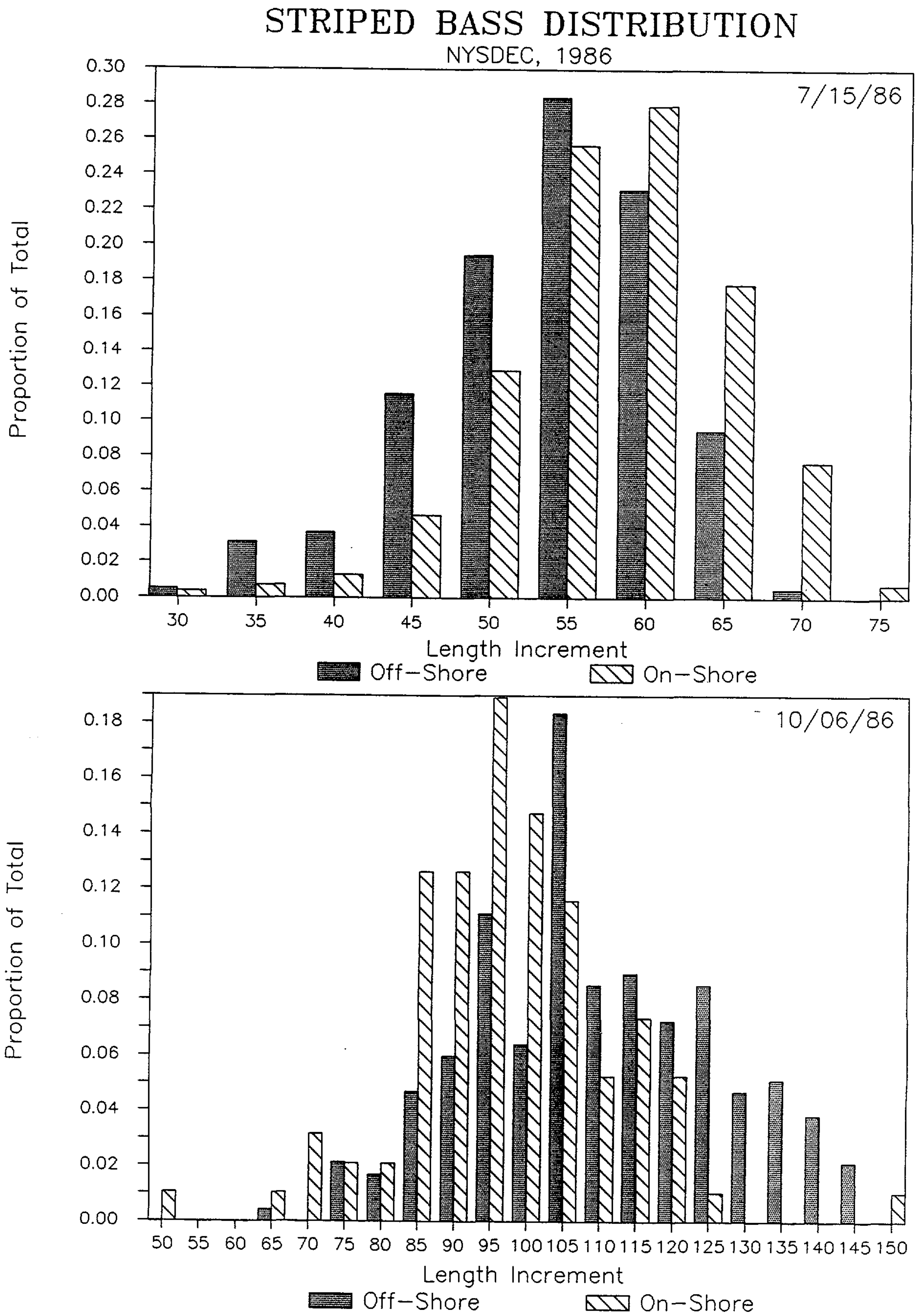
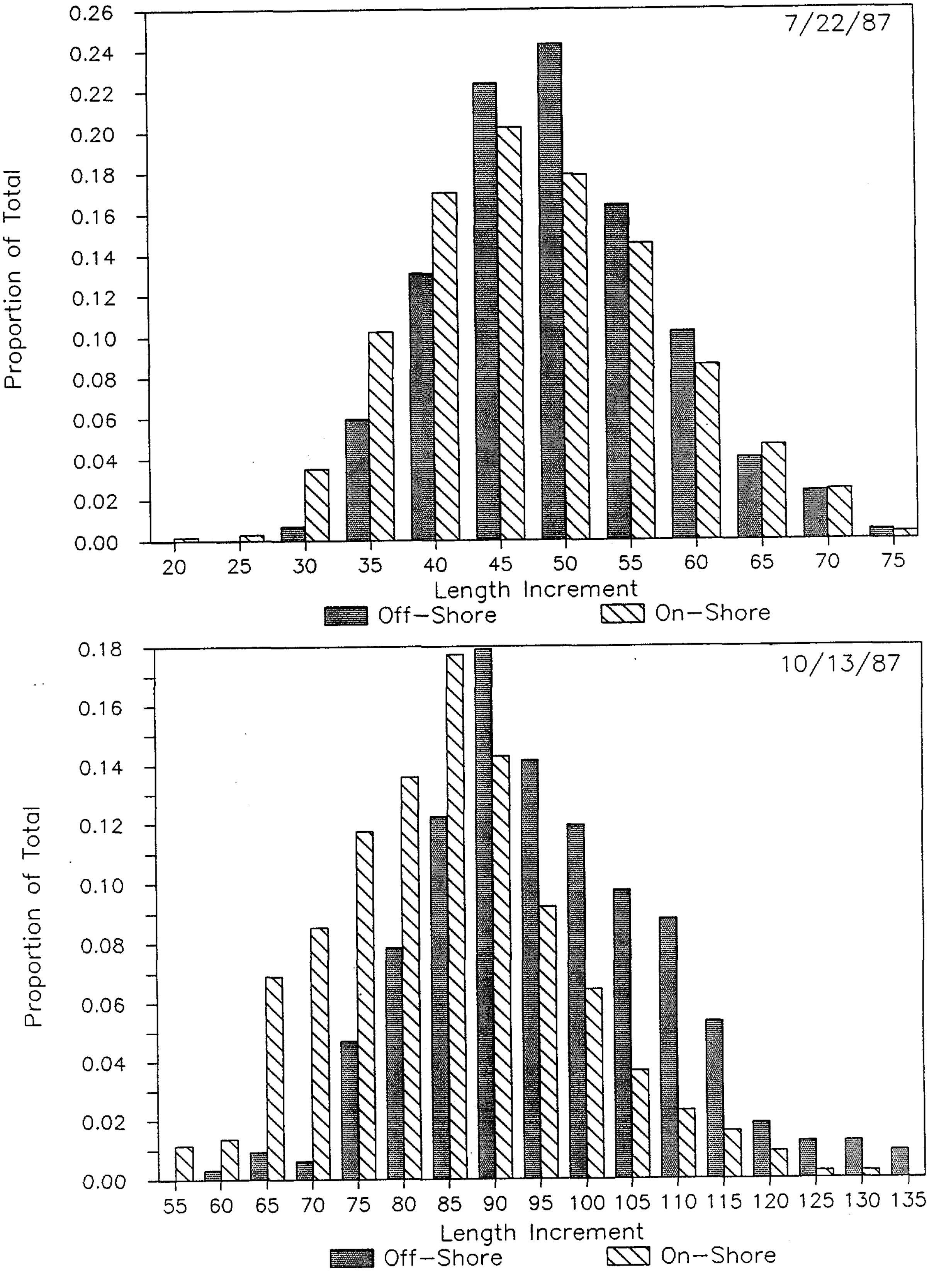

STRIPED BASS DISTRIBUTION
NYSDEC, 1986
7/15/86
Proportion of Total
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
30 35 40 45 50 55 60 65 70 75
Length Increment
Off-Shore
On-Shore
10/06/86
Proportion of Total
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150
Length Increment
Off-Shore
On-Shore

FIGURE 9-9

STRIPED BASS DISTRIBUTION

NYSDEC, 1987



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