ABUNDANCE AND SEASONALITY OF KEY FORAGE SPECIES IN LONG ISLAND SOUND

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Approved for Distribution

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Special Report No. 100

Reference No. 92-08

PREFACE

This special report is Task 1 of a report submitted to the U. S. Environmental Protection Agency for the Long Island Sound Study entitled "Characterization and Assessment of Potential Impacts of Hypoxia on Forage Species in Long Island Sound." Task 1 is an overview of information from literature published on the phytoplankton, zooplankton, ichthyoplankton, forage fish and benthos in Long Island Sound for the last 40 years.

The balance of the EPA report can be obtained through EPA Region I or Region II and is as follows:

Task 2: Review of Physiological Effects of Hypoxia on Forage Base Organisms by M. McEnroe and P. M. J. Woodhead

Task 3: Effects of Hypoxia on Estuarine Communities by P. M. J. Woodhead and M. McEnroe

Task 4: Estimation of Benefits to Attaining State Water Quality Standards for Dissolved Oxygen by P. M. J. Woodhead and M. McEnroe

Task 5: Relate Changes in Fishery Abundance to Prey Abundance by P. M. J. Woodhead, D. M. Monteleone and W. T. Peterson

Task 6: Data Gaps and Research Needs by P. M. J. Woodhead, R. M. Cerrato, D. M. Monteleone and M. McEnroe

Task 7: Ecological Measures of Lower Trophic Levels for Monitoring by P. M. J. Woodhead, R. M. Cerrato, D. M. Monteleone and M. McEnroe

CHARACTERIZATION AND ASSESSMENT OF POTENTIAL IMPACTS OF HYPOXIA ON FORAGE SPECIES IN LONG ISLAND SOUND

TASK 1

Abundance and Seasonality of Key Forage Species

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1.1. INTRODUCTION

1.1.1. Background

Key fisheries in Long Island Sound have been identified by Smith *et al.* (1989). We intensively investigated the abundance and distribution of the forage species of five representative finfish and invertebrates which are exploited in the Sound: American lobster (*Homarus americanus*), hard clam (*Mercenaria mercenaria*), tautog (*Tautoga onitis*), bluefish (*Pomatomus saltatrix*), and winter flounder (*Pseudopleuronectes americanus*). These species were chosen because they represent vastly different feeding types and because of their economic importance.

The AMERICAN LOBSTER is a benthic feeding omnivore which will consume a broad range of plants and animals, but prefer molluscan, crustacean, echinoderm and polychaete remains (Weiss, 1970; Elner and Campbell, 1987). The lobster's diet changes with size. Larger lobsters having more powerful claws, have a wider range of prey available to them. Zooplankton are the preferred prey for lobster larvae (Gunn, 1987).

The HARD CLAM is used to represent the bivalve community. They are filter feeders that consume particulate matter ranging from 3-50 um (V. M. Bricelj, Marine Sciences Research Center, pers. comm.). A detailed study of the nutritive value to *M. mercenaria* of the dominant algal species in Long Island Sound has not been carried out. Additionally, most nutritional studies are based on artificial diets of algal monocultures, and very little is known of the efficiency that natural diets are utilized in any bivalve species

(Griffiths and Griffiths, 1987). M. mercenaria controls ingestion primarily by regulating filtration rate (Bricelj and Malouf, 1984) rather than by selecting between particle types as in some bivalves (Kiorboe and Mohlenberg, 1981). This suggests that they are probably feeding on a diverse assemblage of the available phytoplankton in Long Island Sound.

The TAUTOG (blackfish) feed on invertebrates (Bigelow and Schroeder, 1953; LILCO, 1983). Primary components in the tautog diet are mollusks (both gastroposd and bivalves), especially mussels and barnacles. Tautog also eat crabs, sand dollars, amphipods, shrimps, isopods and lobsters. In shallow areas blackfish readily eat polychaetes. LILCO (1983) reported that the stomach contents of blackfish off Shoreham, NY consisted of algae and fragments of crabs (Ovalipes sp. and Cancer sp.). Blackfish feed by either cracking their prey with their crushing teeth or swallowing the prey whole.

The BLUEFISH has been called "the most ferocious and bloodthirsty fish in the sea" (Bigelow and Schroeder, 1953). They will consume just about any fish. Among the documented prey of bluefish are sand lance (Ammodytes americanus), mummichog (Fundulus heteroclitus), striped killifish (Fundulus majalis), bay anchovy (Anchoa mitchilli), Atantic mackerel (Scomber scombrus), menhaden (Brevoortia tyrannus), herring (Clupea harengus), alewife (Alosa pseudoharengus), scup (Stenotomus chrysops), hake (Urophysis sp.), butterfish (Peprilus triacanthus), cunner (Tautogolabrus adspersus), squid (Logio pealei) and smaller bluefish (Bigelow and Schroeder, 1953; Richards, 1976; LILCO, 1983; Friedland et al., 1988). Juveniles have been known to eat bay anchovies, Atlantic silversides (Menidia menidia) and various crustacea and polychaetes, including opposum shrimp (Neomysis americana), sand shrimp (Crangon septemspinosa), grass shrimp (Palaemonetes vulgaris), and gammarid amphipods (Friedland et al., 1988; F. Juanes, Marine Sciences Research Center, SUNY, pers. comm.).

WINTER FLOUNDER are benthic feeders with a diet of primarily small invertebrates. Their small mouths limit winter flounders to forage on isopods, amphipods, crabs, shrimp, small bivalves, polychaetes, mollusks, small squid, fish larvae, hydroids, holothurians and clam siphons (Bigelow and Schroeder, 1953). LILCO (1983) found polychaetes to be the most important component in the diet of both adult and juvenile stages of winter flounder collected off Shoreham, NY. The diet of juveniles also was supplemented with mysids and gammarid amphipods in the winter and spring, grass shrimp and bivalves in summer and nemertean worms in the fall. In addition to polychaetes, adult winter flounder collected in the Shoreham study consumed algae and bivalves throughout the year. The adult winter flounder is limited by its small mouth to a diet of small invertebrates.

Though this study focuses on forage species of the American lobster, hard clam, tautog, bluefish and winter3flounder, there are many other invertebrates and finfish found in Long Island Sound with similar diets (Table 1.1.1). We did not report on the prey of these organisms because diets vary depending upon prey availability and are usually reported in the literature to phylum.

Our review focused on the lower trophic levels which influence some of these key fishery species throughout their life history stages. We chose the following candidates as forage species to inv~~estigate~~:

Phytoplankton because they are primary components in the diet of bivalves (Widdows et al., 1979; Steneck and Watling, 1982; V. M. Bricelj, Marine Sciences Research Center, SUNY, pers. comm.) and postlarval winter flounder (Hunter, 1981; G. Klein-MacPhee, University of Rhode Island, pers. comm.)

Microplankton because they can be important in the diet of larval fish (Last, 1978a, 1978b; Houde and Lovdal, 1984).

Zooplankton because they are extremely important prey for small forage fish and early life stages of larger fishes. Atlantic mackerel (Scomber scombrus) and most small fishes such as bay anchovy, silversides and American sand lance feed primarily on small crustaceans including copepods (Bigelow and Schroeder,

Table 1.1.1. Diets of finfish and invertebrates in Long Island Sound. Sources of information include Bigelow and Schroeder (1953); Weiss (1970); LILCO (1983); Elner and Campbell (1987); Freidland *et al*. (1988); EA (1989); F. Juanes and V. M. Bricelj, Marine Sciences Research Center, SUNY.

SPECIES		DIET CODE
American eel	*Anguilla rostrata*	FM
American lobster	*Homarus americanus*	MCL
American oyster	*Crassostrea virginica*	P
American sand lance	*Ammodytes americanus*	Z
Atlantic mackerel	*Scomber scombrus*	ZF
Atlantic menhaden	*Brevoortia tyrannus*	Z
Atlantic silversides	*Menidia menidia*	A
Bay anchovy	*Anchoa mitchilli*	Z
Bay scallop	*Argpecten irradians*	P
Black sea bass	*Centropristes striatus*	CFM
Blue crab	*Callinectes sapidus*	FMC
Blue mussel	*Mytilus edulis*	P
Bluefish	*Pomotomus saltatrix*	F
Butterfish	*Peprilus triacanthus*	ZC
Cunner	*Tautogolabrus adspersus*	CM
Hard clam	*Mercenaria mercenaria*	P
Long-finned squid	*Loligo peali*	F
Puffer	*Sphaeroides maculatus*	CM
Red hake	*Urophysis chuss*	CF
Sculpin	*Myoxocephalus* sp.	CLMF
Scup	*Stenotomus chrysops*	FM
Sea Robin	*Prionotus* sp.	FCM
Silver hake	*Merluccius bilinearis*	C
Soft clam	*Mya arenaria*	P
Striped bass	*Morone saxatilis*	F
Summer flounder	*Paralichthys dentatus*	L
Surf clam	*Spisula solidissima*	P
Tautog	*Tautoga onitis*	CM
Weakfish	*Cynoscion regalis*	FC
Whelk	*Busycon* sp.	M
Winter Flounder	*Pleuronectes americanus*	LM

P=phytoplankton, F=fish, M=mollusks, L=polychaetes, Z=zooplankton C=crustaceans (larger than zooplankton).

1953; McKown, 1984; LILCO, 1983; Johnson et al., 1990). It is well known that during the larval stages, fish primarily prey on copepods and other small zooplankters (Kjelson et al., 1974; Last, 1978a, 1978b; Houde, 1978; Hunter, 1981; Carter and Steele, 1982; Monteleone and Peterson, 1986; Peterson and Ausubel, 1984).

Forage Fish such as silversides (Menidia menidia), bay anchovy (Anchoa mitchilli), American sand lance (Ammodytes americanus) and squid (Logio peali) because they are important components in the diet of piscivores such as bluefish, weakfish and striped bass (Bigelow and Schroeder, 1953; F. Juanes, Marine Sciences Research Center, pers. comm.).

Benthos such as polychaetes, crustaceans and small bivalves because of their importance in the diet of winter flounder and tautog (Bigelow and Schroeder, 1953; P. M. J. Woodhead, Marine Sciences Research Center, SUNY, pers. comm.).

1.1.2. Methods

The abundance and biomass data used in this report were derived from previous surveys of the Long Island Sound ecosystem (Table 1.1.2). Many of these surveys were contracted by utility companies as part of the requirements necessary for power plant sitings (e. g. the Millstone Power Plant, Jamesport and Shoreham Nuclear Power Plants). Some were monitoring studies of disposal sites (e. g. Eaton's Neck Disposal Site). Others were scientific based surveys as part of the last comprehensive Long Island Sound study (e. g. Bingham Oceanographic Collection of the 1950s) or academic research (e.g., W. T. Peterson and his graduate students at the Marine Sciences Research Center, SUNY).

We were not able to make definite statements about the trends in the species composition and abundance as they relate to hypoxic and normoxic areas of Long Island Sound for several reasons. Not all studies sampled all organisms of interest. Studies were conducted at different sites (Fig. 1.1.1) during different years (Table 1.1.2) and using different sampling methods and data analyses. More detailed information could be obtained from the raw data,

Table 1.1.2. Sources of lower trophic level organism data by region for Long Island Sound with approximate distance from the Battery of the sampling stations. P=Phytoplankton, M = Microplankton, Z=Zooplankton, I=Ichthyoplankton, B=Benthos, F=Fisheries.

Source	Region	km	Year	Data
WESTERN				
Environ. Analyst (1975)	Hart Island, NY	34	1974	PZIBF
Fallon (pers. comm.)	Hart Island, NY	34	1975	B
NMFS (1972)	David's Island, NY	35	1971	PZIBF
Alexander and D'Agostino (1972)	Western Sound	35-40	1971	B
LILCO (1977b)	Hempstead, NY	41	1976	IBF
Pastalove (1973)	Western Sound		1971	Z
Olson (1976)	Western Sound		1975	P
EBASCO (1986)	Western Sound		1986	B
Aller *et al.* (1991)	Western Sound		1990	B
CENTRAL				
Monteleone *et al.* (1987)	Central Sound		1951-83	PZI
Sanders (1956)	Central Sound		1953	B
Richards and Riley (1967)	Central Sound		1960-61	B
McCall (1975)	Central Sound		1972-73	B
Serafy *et al.* (1977)	Eaton's Neck, NY	66	1974	B
Cobb *et al.* (1978)	Eaton's Neck, NY	66	1974	B
Caplan (1977)	Eaton's Neck, NY	66	1974-75	PZIBF
Williams *et al.* (1971)	Northport, NY	68	1969	PZBF
D'Agostino and Colgate (1973)	Northport, NY	68	1971-72	B
LILCO (1973)	Northport, NY	68	1972	PZIBF
Rhoads (1973a,b)	Central Sound		1972	B
Johnson (1987)	Central Sound	92	1982	Z
Peterson (1985)	Central Sound	92	1982-83	PZ
Peterson (1986)	Central Sound	92	1982-83	PZ
Boampong (1984)	Central Sound	92	1982-83	I
Monteleone (1984)	Central Sound	92	1982-83	PZI
Ausubel (1983)	Central Sound	92	1982-83	ZI
Bellantoni and Peterson (1987)	Central Sound	92	1985	PZ
Peterson and Bellantoni (1987)	Central Sound	92	1985	PZ
McManus (1986)	Central Sound	92	1982-83	PM
Dam Gurerro (1989)	Central Sound	92	1986	Z
LILCO (1977a)	Port Jefferson, NY	92	1976	IBF
Rhoads (1973c,d)	New Haven, CT	108	1972	B
Rhoads (1974)	New Haven, CT	108	1974	B
Rhoads and Michael (1974)	New Haven, CT	108	1972-73	B
Normandeau (1979)	New Haven, CT	108	1970-77	PZIBF
Normandeau (1981)	New Haven, CT	108	1977-80	PZIBF
Normandeau (1985)	New Haven, CT	108	1981-84	PZIBF
Michael (1975)	New Haven, CT	108	1972	B
McCall (1977)	New Haven, CT	108	1974	B
LILCO (1974)	Shoreham, NY	120	1973-74	PZIBF
LILCO (1979)	Shoreham, NY	120	1977-78	PZIBF

Table 1.1.2. Continued

Source	Region	km from Battery	Year	Data
CENTRAL (continued)				
LILCO (1980)	Shoreham, NY	120	1979	PZIBF
LILCO (1981)	Shoreham, NY	120	1980	PZIBF
LILCO (1982)	Shoreham, NY	120	1981	PZIBF
LILCO (1983)	Shoreham, NY	120	1982	PZIBF
EA (1987)	Shoreham, NY	120	1983-86	PZIBF
EA (1989a)	Shoreham, NY	120	1987	IBF
EA (1989b)	Shoreham, NY	120	1988	IBF
EA (1990)	Shoreham, NY	120	1989	IBF
EASTERN				
LILCO (1975)	Jamesport, NY	130	1973-74	PZIBF
NUSCO (1983)	Waterford, CT	179	1968-81	PZIBF
NUSCO (1984)	Waterford, CT	179	1983	ZBF
NUSCO (1987)	Waterford, CT	179	1975-85	BF
NUSCO (1988)	Waterford, CT	179	1986-87	BF
NUSCO (1990)	Waterford, CT	179	1989	BF
SOUNDWIDE				
Perlmutter (1939)	Soundwide		1938	IF
Conover, S. A. M. (1956)	Soundwide		1952-54	P
Deevey (1956)	Soundwide		1952-54	Z
Conover, R. J. (1956)	Soundwide		1952-54	Z
Wheatland (1956)	Soundwide		1952-54	I
Riley and Conover (1967)	Soundwide		1954-55	P
Richards (1959)	Soundwide		1954-56	I
Hardy (1970)	Soundwide		1967-69	P
Hardy and Weyl (1970)	Soundwide		1970	P
Hardy and Weyl (1971)	Soundwide		1970	P
NMFS (1974)	Soundwide		1972-73	B
Reid (1979)	Soundwide		1972-73	B
Reid _et_ _al._ (1979)	Soundwide		1972-73	B
Schnitzer (1979)	Soundwide		1978	P
Bowman _et_ _al._ (1981)	Soundwide		1978	P
Cosper _et_ _al._ (unpubl.)	Soundwide		1989	PM

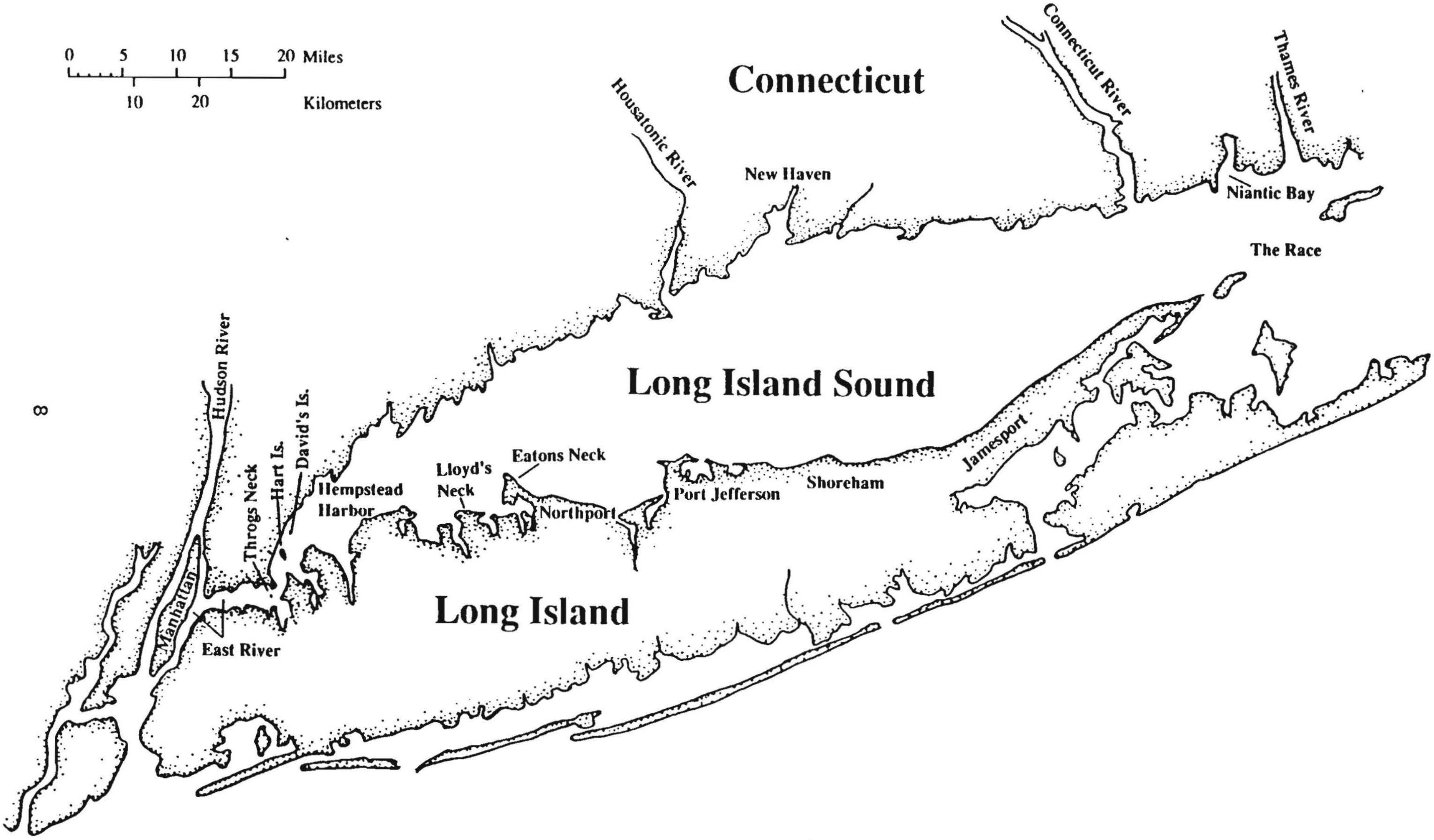


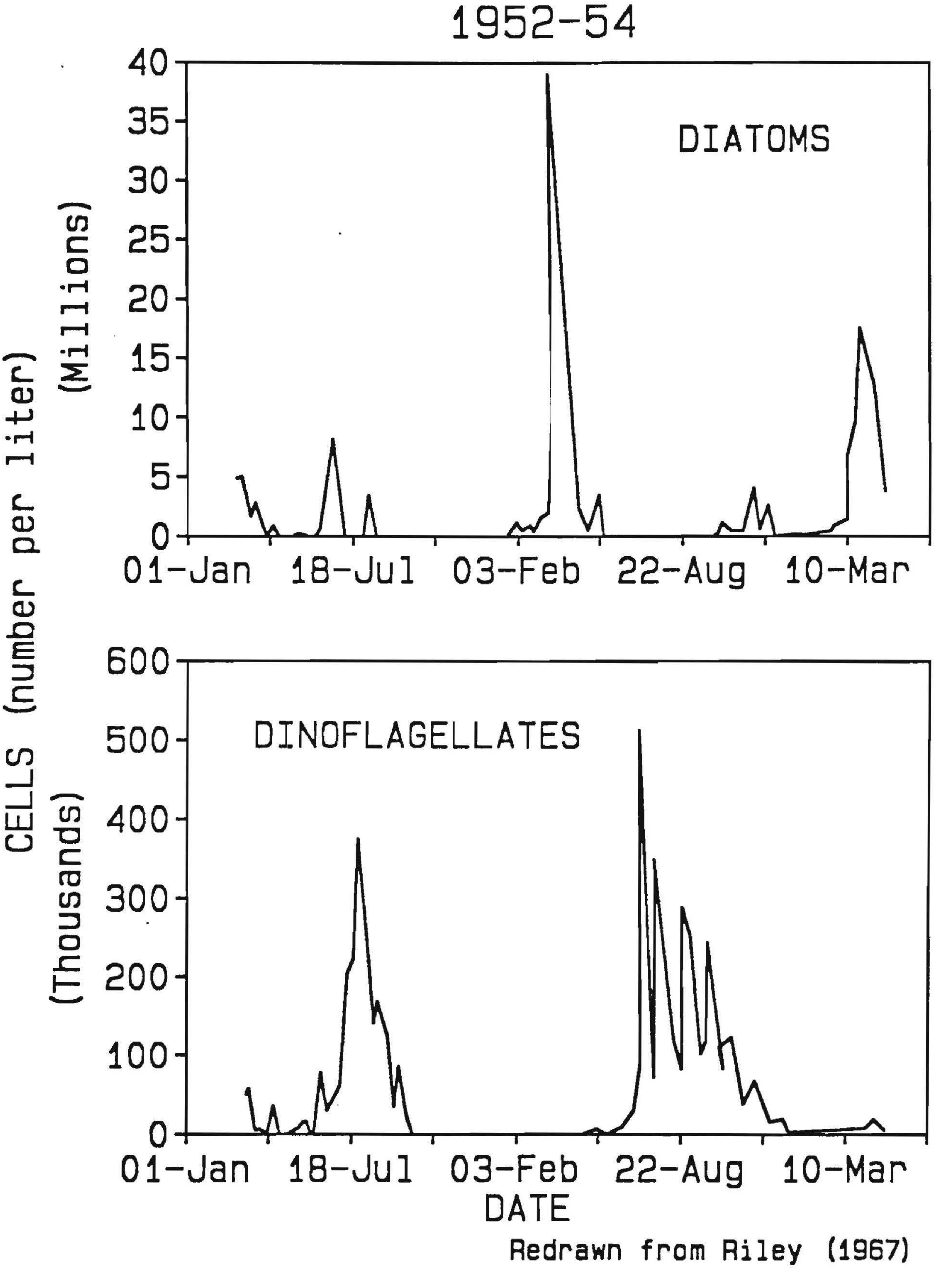
Fig. 1.1.1. Map of Long Island Sound. See Table 1.1.1 for locations of collections sites for historical surveys.

however much of the data were presented as means for regions or time periods. For some studies, especially the Shoreham surveys, these data exist in the form of computer tape and perhaps more information could be extracted in the future. In addition, there is severe lack of data from the western Sound, making analyses of effects of hypoxia on historic distribution and abundances of lower trophic levels impossible.

1.2. PHYTOPLANKTON

1.2.1. Composition, abundance and distribution in Long Island Sound

The concentration of phytoplankton changes temporally in Long Island Sound (Fig. 1.2.1; Conover, S. A. M., 1956; Riley, 1967; Riley and Conover, 1967; Capriulo and Carpenter, 1983; Peterson, 1986; EA, 1989a). A late winter-early spring phytoplankton bloom is triggered by the vernal increase in light intensity. The timing of this bloom can vary among years with the peak most often occurring during February and early March (Table 1.2.1). In the central and eastern Sound, chlorophyll concentrations during the winter-spring bloom can exceed 15 ug L^{-1} and 35,000 cells mL^{-1} (more often 10-20,000 cells mL^{-1}; Conover, S. A. M., 1956; NUSCO, 1983, 1988; Normandeau, 1985; Peterson, 1986; Bellantoni, 1987; EA, 1988). Termination of this bloom is thought to be due to nutrient reduction. A late summer-fall bloom in Long Island Sound occurs when the thermocline breaks down allowing nutrient-rich bottom water to be mixed upward. This bloom usually occurs in the upper 5-10 m, suggesting light limitation is operating at depth (Riley, 1967). Concentrations during this time can reach 10-15 ug L^{-1} chlorophyll and 5,000 cells mL^{-1} (Conover, S.



Redrawn from Riley (1967)

Fig. 1.2.1. Densities of phytoplankton cells collected by Riley (1967) in central Long Island Sound during 1952-54. Numbers are means of many stations.

Table 1.2.1. Timing of winter-spring phytoplankton bloom in Long Island Sound.

YEAR	DATE OF PEAK PHYTOPLANKTON BLOOM	REFERENCE
1953	early March	Conover, S. A. M. (1956)
1954	mid February	Conover, S. A. M. (1956)
1955	late January	Riley and Conover (1967)
1956	late February	Riley (1967)
1957	late February	Riley (1967)
1958	mid March	Riley (1967)
1959	mid January	Vishniac and Riley (1961)
1963	late February	Monteleone *et al.* (1987)
1967	mid March	Hardy (1970)
1968	mid March	Hardy (1970)
1969	mid February	Hardy (1970)
1972	mid March	LILCO (1973)
1973	early March	LILCO (1973)
1975	late March	Caplan (1977)
1979	mid March	Monteleone *et al.* (1987)
1981	early February	Monteleone *et al.* (1987)
1982	mid February	Monteleone *et al.* (1987)
1983	mid March	Monteleone *et al.* (1987)
1985	early March	Peterson and Bellantoni (1986)
1986	late March	Peterson (unpubl.)
1987	no peak event	Peterson (unpubl.)
1989	early March	EA (1990a)

A. M., 1956; NUSCO, 1983, 1988; Normandeau, 1985; Peterson, 1986; Bellantoni, 1987; EA, 1988).

Unlike deeper water bodies in the northeast, concentrations of phytoplankton in the relatively shallow and turbulent Long Island Sound can be vertically homogeneous (Conover, S. A. M., 1956). Chlorophyll concentrations are evenly distributed throughout the water column from about September through April or early May (Fig. 1.2.2; Olson, 1976; Peterson, 1986; Bellantoni, 1987, Peterson, unpubl.). The onset of stratification in April affects the vertical distribution of chlorophyll (Peterson, 1986) and chlorophyll concentrations are greatest in the upper 10 m (S. A. M. Conover, 1956; Peterson, 1986). This change in vertical distribution of chlorophyll occurs when stratification exceeds 0.05 sigma-t units m^{-1}. Thus for Long Island Sound, this physical stratification threshold defines the onset of stratification of phytoplankton (Peterson, 1986).

At times, there is a pronounced difference in the concentration of surface phytoplankton between inshore and offshore stations (Conover, S. A. M., 1956; Schnitzer, 1979; Normandeau, 1985). Both cell counts and chlorophyll concentrations tend to be higher inshore, probably due to a shallower, mixed water column, and possibly fluxes of ammonia from the sediments. However, when the whole water column is considered, the amount of phytoplankton under a unit area of surface is greater offshore Conover, S.A.M., 1956).

There are 40 major and 150 minor species constituents of the phytoplankton community present in Long Island Sound (Conover, S. A. M., 1956). Separate diatom and dinoflagellate blooms occur at different times of the year (Fig. 1.2.1; Table 1.2.2). It should be noted, however that the naked dinoflagellate communities were underestimated in many studies because

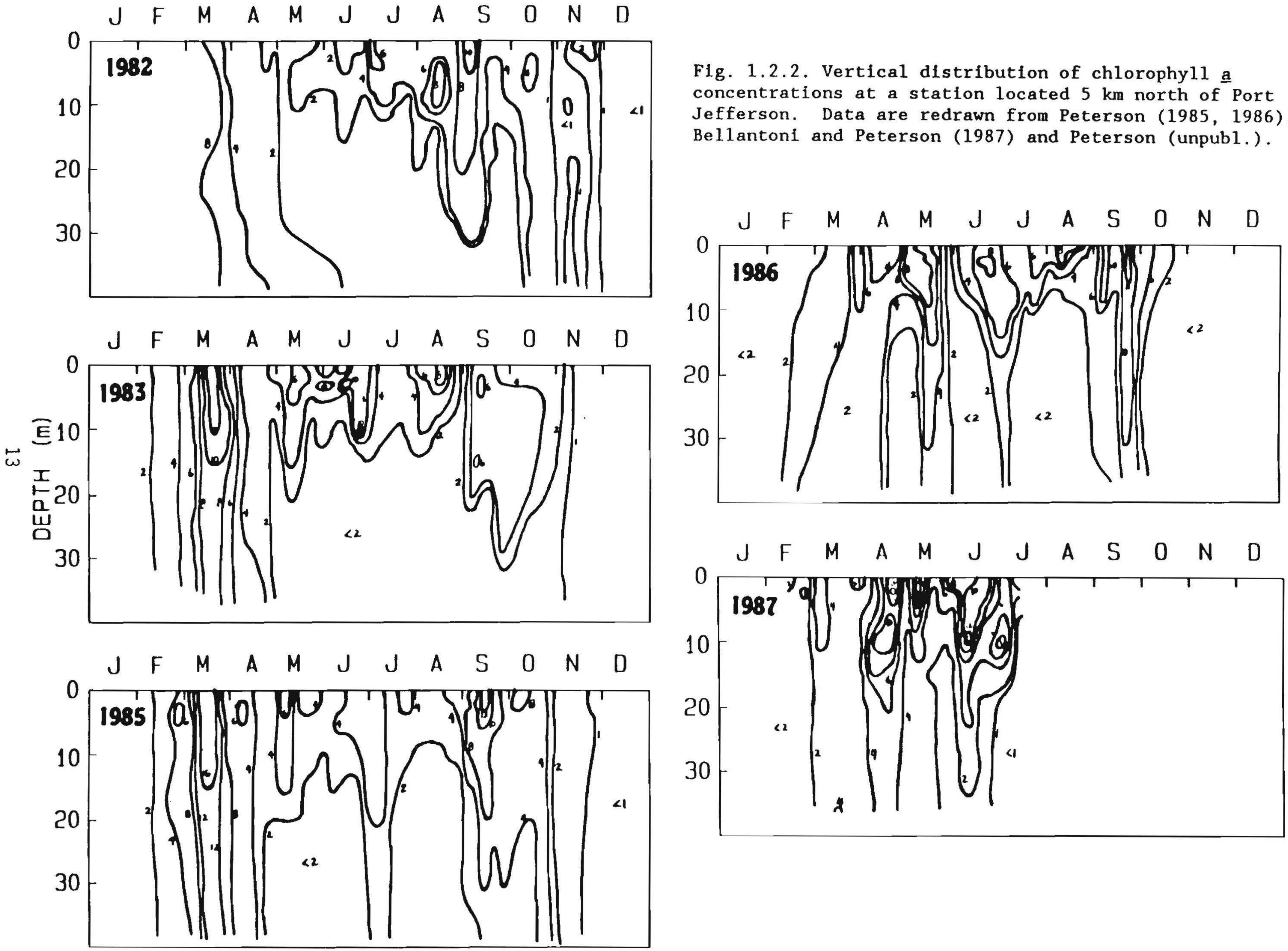


Fig. 1.2.2. Vertical distribution of chlorophyll <u>a</u> concentrations at a station located 5 km north of Port Jefferson. Data are redrawn from Peterson (1985, 1986), Bellantoni and Peterson (1987) and Peterson (unpubl.).

Table 1.2.2. Dominant phytoplankton species (% by number) off New Haven, CT (Normandeau, 1979) and Shoreham, NY (LILCO, 1983; EA, 1988).

NEW HAVEN (% Not Available)

	1974	1975	1976	1977
March		Thalassiosira sp.	S. costatum	S. costatum
		Unspecified flagellates	T. nitzschioides	Unspecified flagellates
		Unspecified Pennales	T. rotula	Chaetocerous sp.
		Cyclotella sp.	L. minimus	T. nordenskoldii
		Chroomas sp.	S. delicatula	Thalassiosira sp.
June	T. pseudonana	S. costatum	Cyclotella sp.	S. costatum
	Peridinium sp.	T. pseudonana	Thalassiosira sp.	Unspecified flagellates
	Rhodomonas sp.	Thalassiosira sp.	H. triquetrum	T. nitzschioides
	Cryptomonas sp.	Rhodomonas sp.	Unspecified flagellates	R. fragelissima
		Chroomas sp.	T. nitzschioides	Thalassiosira sp.
September	C. gracilis	S. costatum	Thalassiosira sp.	Chaetocerous sp.
	C. curvisetus	Chroomas sp.	Unspecified flagellates	Unspecified flagellates
	S. costatum	C. curvisetus	S. costatum	T. pseudonana
	T. pseudonana	Unspecified flagellates	Chaetocerous sp.	S. costatum
	Cryptomonas sp.	A. formosa	L. minimus	Thalassiosira sp.
December	Thalassiosira sp.	Thalassiosira sp.	Unspecified flagellates	
	L. minutus	Calycomonas sp.	Thalassiosira sp.	
	S. costatum	Unspecified flagellates	S. costatum	
	T. nitzschioides	Cyclotella sp.	Chaetocerous sp.	
	Cyclotella sp.	T. nitzschioides	T. nitzschioides	

Table 1.2.2. Continued

SHOREHAM

	1977		1978		1979		1980	
March								
	S. costatum	81	S. costatum	87	S. costatum	37	S. costatum	53
	T. nordenskioldii	10	T. nordenskioldii	3	Thalassiosira sp.	22	T. nitzschioides	16
	T. nitzschioides	4	Chaetoceros sp.	2	D. confervacea	15	T. nordenskioldii	10
	Chaetoceros sp.	1	T. condensata	1	Nitzschia sp.	7	Thalassiosira sp.	8
					T. nitzschioides	7		
June								
	S. costatum	75	C. pelagica	70	R. fragilissima	42	Navicula sp.	43
	C. pelagica	10	R. delicatula	16	Thalassiosira sp.	26	T. nitzschioides	20
	T. nitzschioides	2	T. nitzschioides	8	C. pelagica	11	Gymnodinium sp.	9
	Chlorella sp.	1	S. costatum	1	S. costatum	5	E. marina	8
September								
	S. costatum	75	S. costatum	60	S. costatum	84	S. costatum	95
	Chaetoceros sp.	14	Thalassiosira sp.	17	T. rotula	3	Chaetoceros sp.	1
	T. gravida	4	T. rotula	5	Chaetoceros sp.	2	N. closterium	1
	N. closterium	1	S. seriata	2	T. nitzschioides	2	L. minimus	1
Dececember								
	P. sulcata	25	S. costatum	38	T. nitzschioides	33	S. costatum	35
	T. nitzschioides	24	Thalassiosira sp.	17	R. delicatula	27	Thalassiosira sp.	28
	Cyclotella sp.	18	A. japonica	17	P. sulcata	9	T. nitzschioides	14
	S. costatum	9	Chaetoceros sp.	7	Thalassiosira sp.	9	P. sulcata	8

	1981		1982		1983		1984	
March								
	Thalassiosira sp.	46	Thalassiosira sp.	62	Nannochloris sp.	93	Phaeocystis sp.	78
	E. marina	11	T. nitzschioides	10	S. costatum	1	S. costatum	16
	R. fragilissima	11	S. costatum	8	R. delicatula	1	T. nitzschioides	1
			R. fragilissima	5	T. nordenskioldii	1	T. nordenskioldii	1
June								
	C. pegalica	85	Diatoma sp.	67	R. delicatula	52	Nannochloris sp.	91
	Gymnodinium sp.	3	Thalassiosira sp.	17	C. bergonii	46	R. delicatula	4
			P. sulcata	4	T. nitzschioides	1	C. bergonii	3
							T. nitzschioides	1
September								
	L. borealis	23	S. costatum	77	S. costatum	78	pennate diatoms	61
	Chaetoceros sp.	22	Thalassiosira sp.	11	C. curvisetus	8	microflagellates	22
	N. seriata	17			L. minimus	3	T. pseudonana	3
					S. turris	2	L. danicus	3
December								
	Thalassiosira sp.	48	Thalassiosira sp.	37	"small forms"	98	"small forms"	90
	T. nitzschioides	11	S. costatum	19			T. condensata	3
	P. sulcata	9	Diatoma sp.	16			Thalassiosira sp.	2

Table 1.2.2. Continued. List of genus and species of phytoplankton.

A. formosa = Asterionella formosa
A. japonica = Asterionella japonica
C. bergonii = Ceratulina bergonii
C. curvisetus = Chaetoceros curvisetus
C. gracilis = Calycomonas gracilis
C. pelagica = Cerataulina pelagica
D. confervacea = Detonula confervacea
E. marina = Eutreptiella marina
H. triquetrum = Heterocapsa triquetrum
L. borealis = Lauderia borealis
L. minimus = Leptocylindrus minimus
M. sulcata = Melosira sulcata
N. closterium = Nitzschia closterium
N. seriata = Nitzschia seriata
P. sulcata = Paralia sulcata
R. delicatula = Rhizosolenia delicata
R. fragilissima = Rhizosolenia fragilissima
S. costatum = Skeletonema costatum
S. turris = Stephanopyxis turris
T. condensata = Thalassiosira condensata
T. gravida = Thalassiosira gravida
T. nitzschioides = Thalassionema nitzschioides
T. nordenskioldii = Thalassiosira nordenskioldii
T. pseudonana = Thalassiosira pseudonana
T. rotula = Thalassiosira rotula

samples were preserved in formalin which is not appropriate for protists. In general, the diatoms *Skeletonema costatum*, and *Thalassiosira nordenskioldii* are abundant during the winter-spring bloom. *Thalassionema nitzschoides*, several *Thalassiosira* species and *Rhizosolenia delicatulum* occur later in the spring and *S. costatum*, *T. nitzschoides*, *Ditylum brightwellii*, *Coscinodiscus*, *Leptocylindricus danicus* and *Thalassiosira pseudonana* dominate in late summer (Olson, 1976; Peterson, 1986). *S. costatum* has been shown to be the overwhelmingly dominant species present in at least trace quantities throughout the year in the Sound (Conover, S. A. M., 1956; Riley, 1967; LILCO, 1983; EA, 1988). The dinoflagellate genera *Prorocentrum*, *Peridinium*, *Gyrodinium* and *Exuviella* are abundant when the water column is stratified from May through August (Peterson, 1986).

Many of the same phytoplankton species continue to dominate numerically, however, there can be fluctuations of dominant species among years and seasons (Conover, S. A. M., 1956; LILCO, 1983; EA, 1988). Though *Skeletonema costatum* dominated the winter-spring bloom of 1952, *Thalassiosira nordenskioldii* was equally abundant as *S. costatum* in 1953 (Conover, S. A. M., 1956). The species composition and abundance off Shoreham from 1983-84 resembled the trends seen in 1977-80 (Table 1.2.2). It appeared that a decline of *Skeletonema costatum* in 1981-82 precipitated a rise of other species as the most abundant forms (EA, 1988). *Thalassiosira* sp. was ranked number one in March and December 1981 and 1982, and number two in June and September 1982. In 1983 and 1984, different species were ranked number one each month except in December when "small forms" was number one. It is not clear if these "small forms" were present prior to 1983 or if they were overlooked. This discrepancy also could be explained by the fact that identifications were conducted by a different taxonomist in 1983-84. If small forms were not included in Table 1.2.2, species ranking would be more consistent.

As part of an EPA Long Island Sound Study funded project, chlorophyll a concentrations were measured in the surface waters (at a depth of 2 m) of Long Island Sound during 1989 (E.M. Cosper, Marine Sciences Research Center, SUNY, unpubl.). These measurements provided information on west-east spatial distribution of phytoplankton. In general, concentrations were relatively low in the East River and increased toward the western Sound (Fig. 1.2.3). This trend has been demonstrated in data collected by New York City Department of Environmental Protection (Harbor Monitoring Program). Surface chlorophyll concentrations tend to be greater in western Long Island Sound and decrease toward the east (Fig. 1.2.3). The highest concentrations were consistently located between the Throgs Neck Bridge and Lloyd's Neck (on the NY side) when at times the surface chlorophyll concentrations exceeded 30 ug L^{-1}. These concentrations are consistent with Olson (1976) and Schnitzer (1979) who collected samples in the Sound 14 and 11 years earlier, respectively. Olson (1976) found concentrations exceeding 70 ug L^{-1} in the same region in March 1975. There was more than a 50 ug L^{-1} increase in the surface chlorophyll values over an east-west transect about 25 km long (from about north of Smithtown Bay to north of Oyster Bay).

When compared on a seasonal basis to other regions in Long Island Sound, chlorophyll concentrations are always substantially higher in the Throgs Neck to Lloyd's Neck region. This area is represented as the Throgs Neck station in Fig. 1.2.4. Though chlorophyll concentrations declined after the spring bloom, values always exceeded concentrations at other stations. In fact for most of the year, values at Throgs Neck exceeded bloom conditions in the rest of the Sound. This suggests that phytoplankton in the vicinity of Throgs Neck may not become nutrient limited. These high chlorophyll concentrations may be

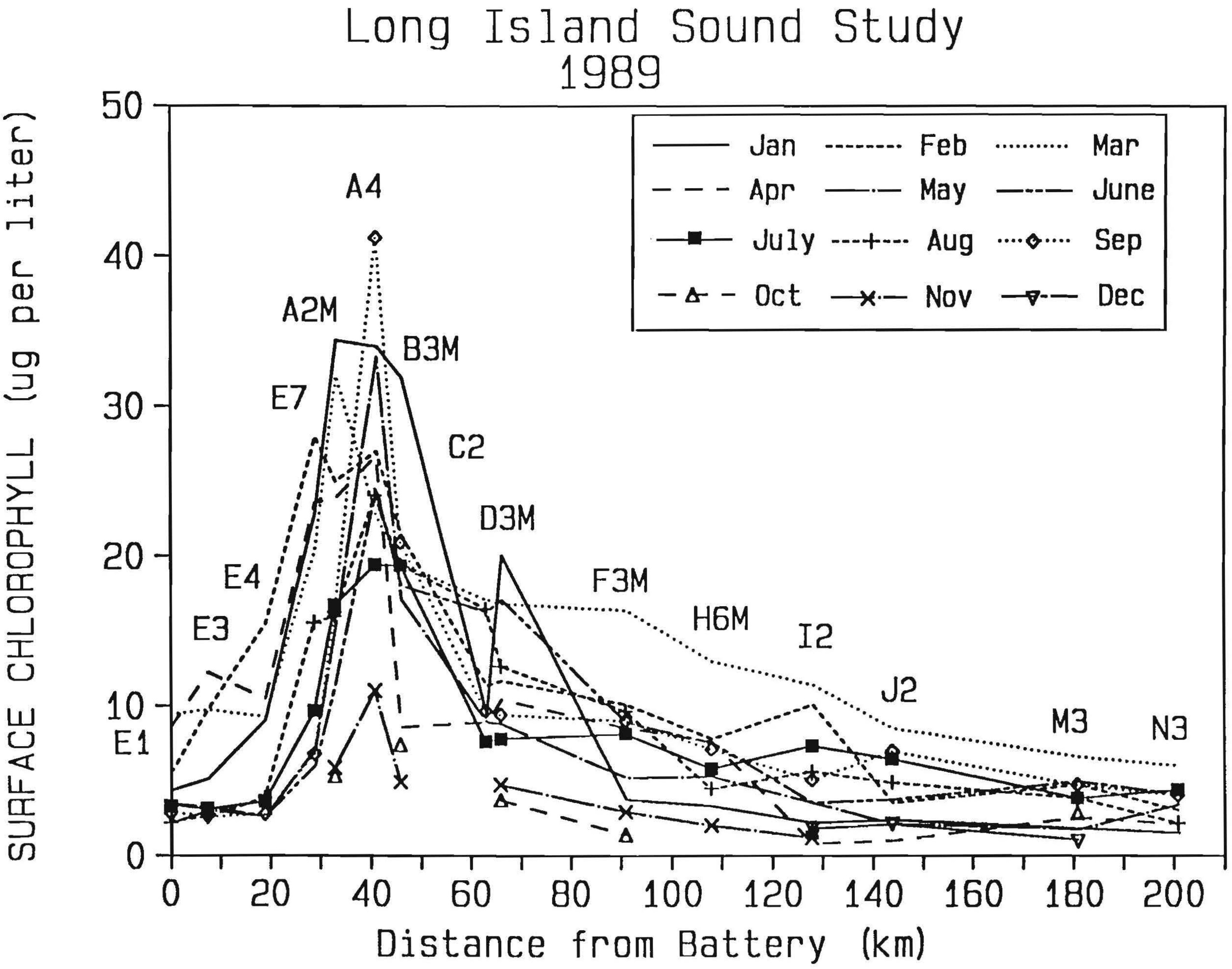


Fig. 1.2.3. Surface chlorophyll a concentrations from a 1989 study of Long Island Sound from Cosper et al. (unpubl.).

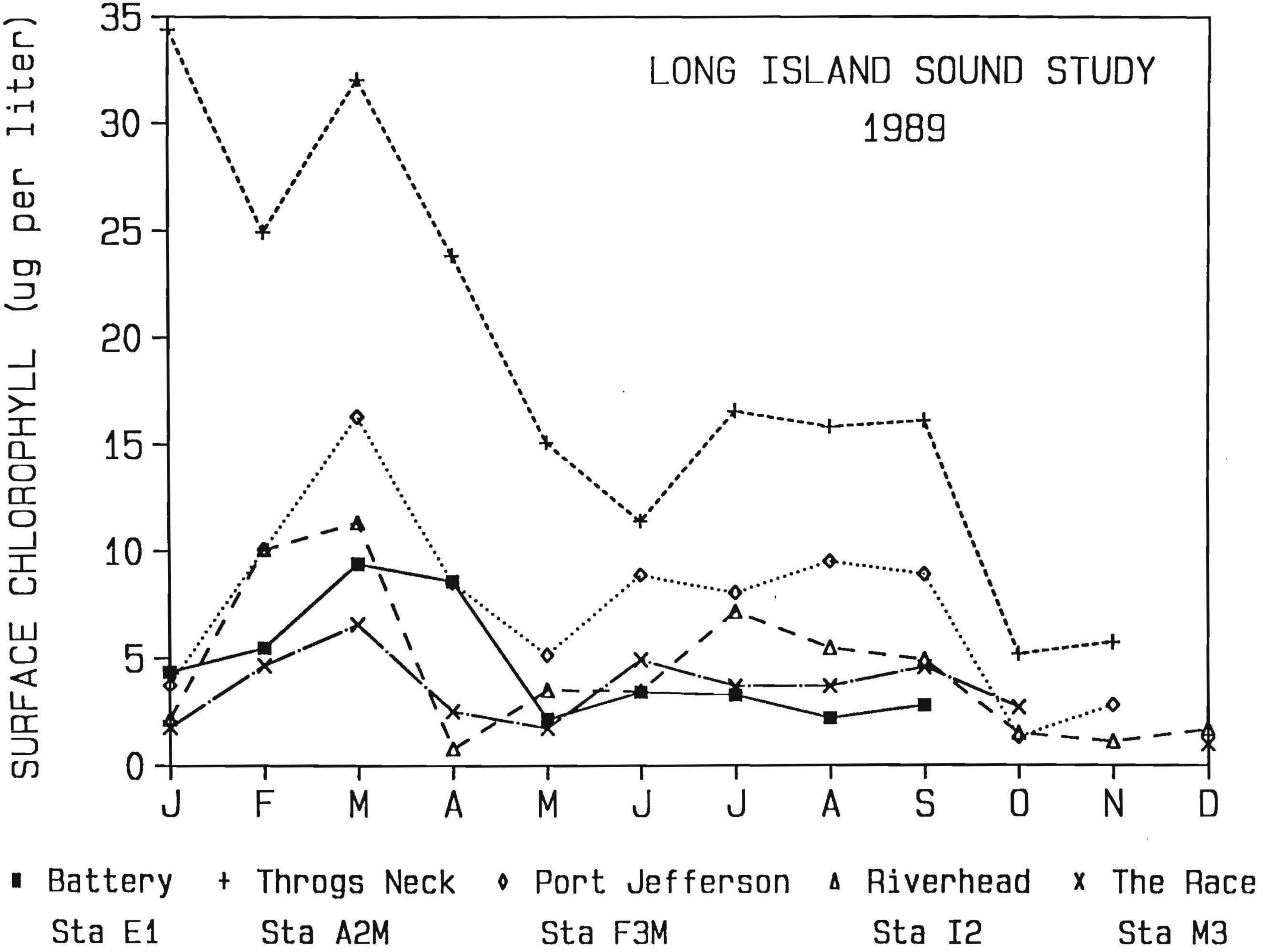


Fig. 1.2.4. Mean monthly chlorophyll a concentrations from 1989 at selected stations in Long Island Sound. Data are from Cosper et al. (unpubl.).

direct evidence of the effects of greater nutrient input to the western Sound. Another proposed alternative to this hypothesis is that phytoplankton biomass could be accumulating in some areas due to circulation patterns (E. M. Cosper, Marine Sciences Research Center, SUNY, pers. comm.). However, similar trends of high concentrations of chlorophyll a in 1969 and 1970 (Hardy, 1970; Hardy and Weyl, 1970, 1971) had associated oxygen supersaturation (> 200%), implying high primary productivity.

Besides the difference in chlorophyll concentrations, Riley and Conover (1967) reported differences in species composition along the axis of the Sound. As part of their 1954-55 study, they were able to differentiate among species which were common throughout the Sound, and those prevalent only in eastern or western waters (Table 1.2.3). They concluded that regional composition of phytoplankton species was influenced by environmental conditions such as salinity. The western end is enclosed and nutrient enriched, while the eastern end is more representative of the open coastal conditions. Those species found throughout the Sound are well adapted to the full range of environmental conditions. Perhaps, species more common in the eastern end are derived from the ocean. Some of the dinoflagellates in the western end are littoral and brackish-water species that thrive in shallow basins and narrows.

Cosper et al. (unpubl.) counted nanoplankton (<10 um diameter) and netplankton (>10 um diameter) diameters at several Long Island Sound Study master stations in 1989. These data show that based on cell counts, an intense bloom occurred in the western end of Long Island Sound with a high biomass of netplankton (diatom dominated) (Fig. 1.2.5; Fig. 1.2.6). Another intense netplankton bloom occurred in the fall. Diatom abundance has been shown to be significantly and positively related to dissolved inorganic

Table 1.2.3. Comparison of phytoplankton communities in Long Island Sound during the 1950s, from Riley and Conover (1967).

UNIFORMLY DISTRIBUTED THROUGHOUT THE SOUND

Chaetocerous ccompressum
C. didymum
C. radians-C. tertissimum
Corethron criophilium
Cocscinodiscus perforatus celluliosa
Leptocylindricus danicus
Paralia sulcata
Skeletonema costatum
Thalassiosira decipiens
T. gravida
Asterionella formosa
A. japonica
Thalassionema nitzschioides
Dinophysis acuminata
Peridinium trichoideum

HIGHER FREQUENCY IN WESTERN SOUND

Chaetocerous debile
C. constrictum
Lithodesmium undulatum
Exuviella apora
E. baltica
Glenodinium pilula
Peridinium globulus
P. triquetum

HIGHER FREQUENCY IN EASTERN SOUND

Chaetoceros affine
C. curvisetun
C. danicum
Coscinodiscus centralis pacifica
C. radiatus
Ditylium brightwellii
Navicula disteus
Nitzschia seriata
N. delicatussima
Pleurosigma normani
Thalassiothrix frauenfeldii

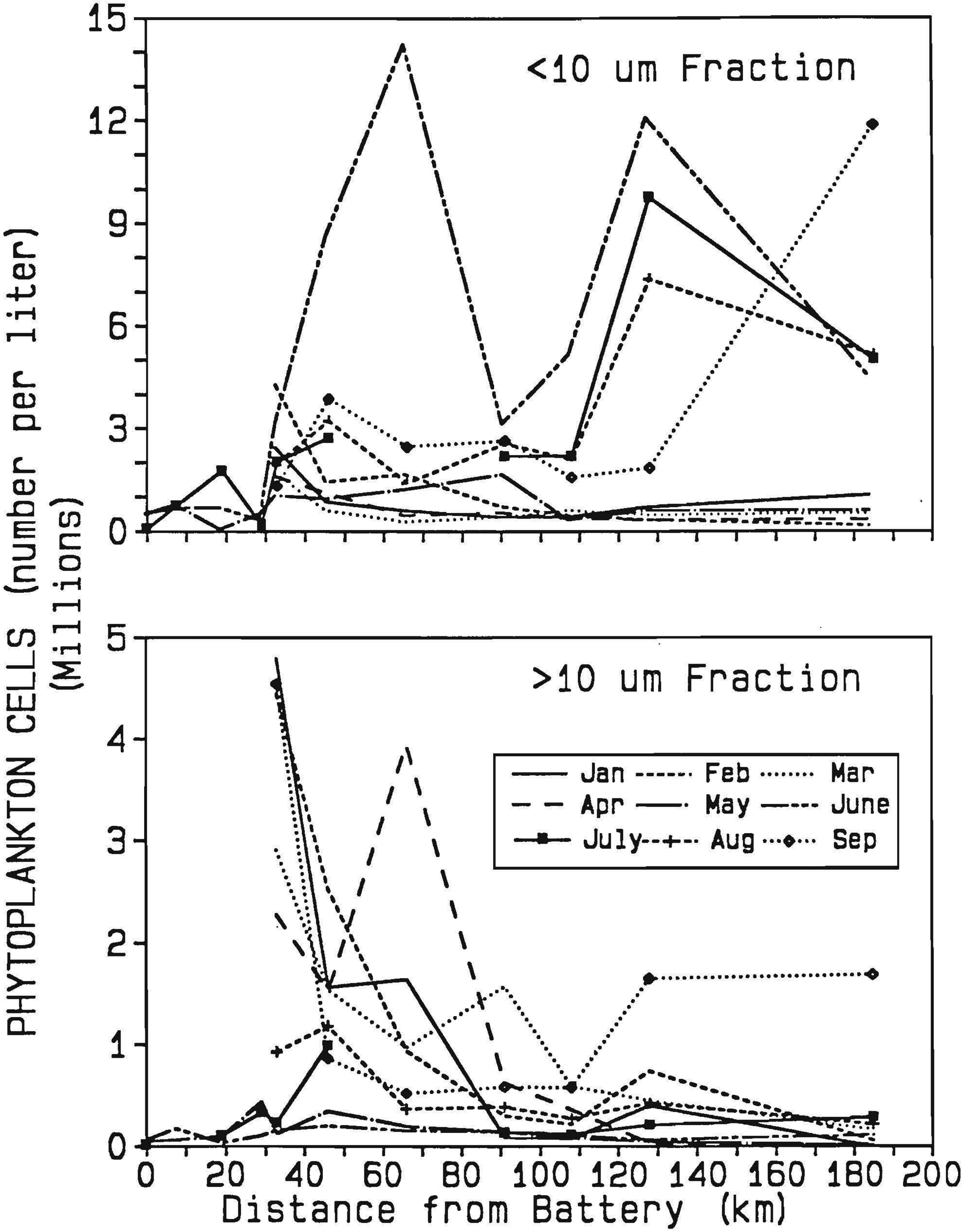
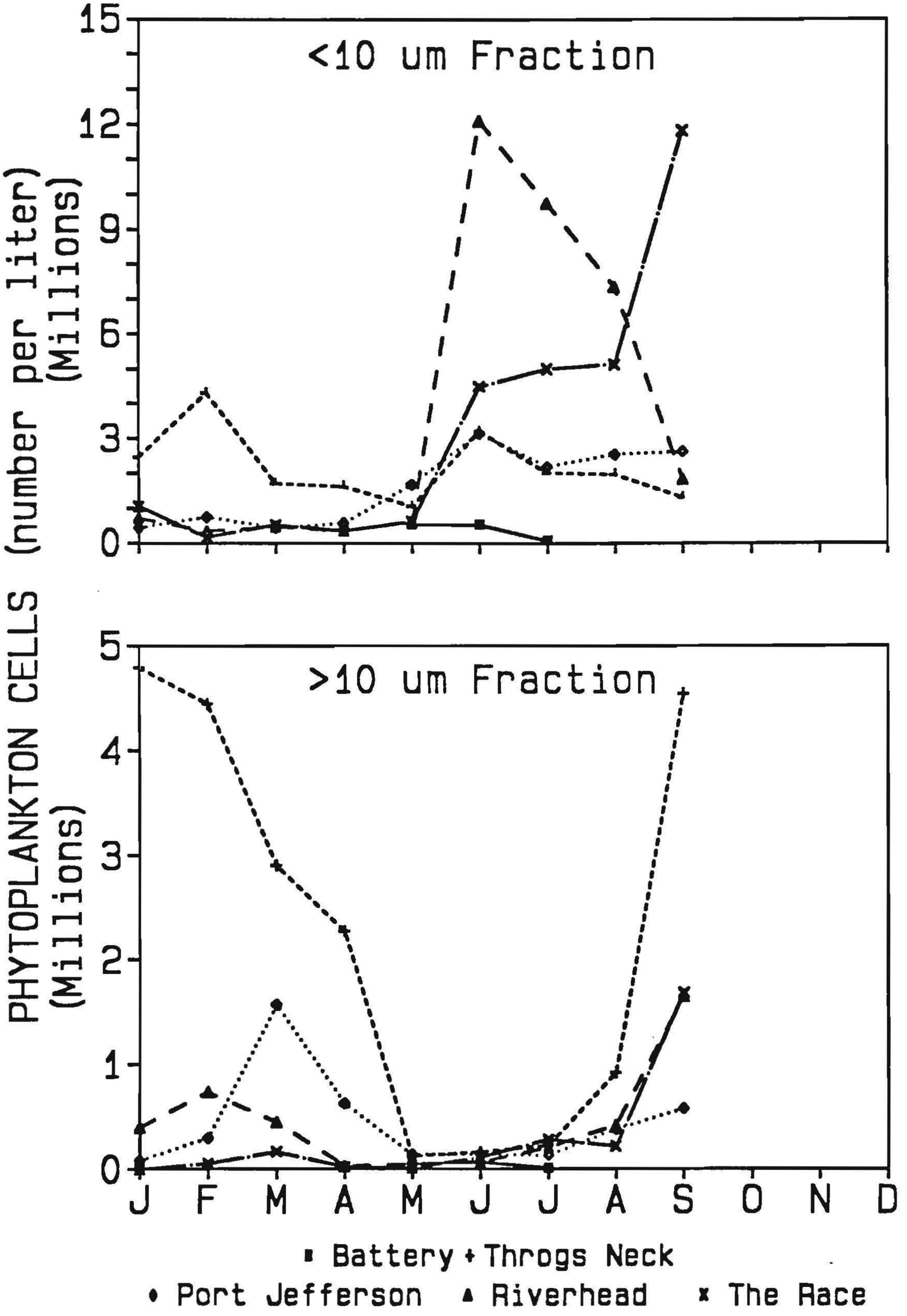


Fig. 1.2.5. Mean monthly phytoplankton cell densities from Long Island Sound in 1989. Values for surface samples are plotted against distance from the Battery. Upper panel is the <10 um size fraction and lower panel is the >10 um size fraction. Data are from Cosper *et al*. (unpubl.).

Fig. 1.2.6. Mean monthly densities of size fractioned phytoplankton cells collected at selected sites in Long Island Sound during 1989. Upper panel is the <10 um size fraction and lower panel is the >10 um size fraction. Data are from Cosper *et al.* (unpubl.).



nitrogen concentrations, while small species such as the brown tide alga *Aureococcus anophagefferens* can be suppressed under similar conditions (Keller and Rice, 1989). The data from the Sound indicate that nanoplankton tend to be more abundant at the eastern stations, however the samples collected in the western region were not refrigerated and perhaps the smaller, more fragile forms disintegrated (E.M. Cosper, Marine Sciences Research Center, SUNY, pers. comm.). Schnitzer (1979) determined that in September 1978 the percent nanoplankton (nanoplankton chlorophyll *a*/total chlorophyll *a*) in the surface waters of Long Island Sound were lowest in the west and along the Connecticut shore where nutrient levels were high, and increased toward the east and Long Island shore.

Because phytoplankton is at the base of the food web and there are apparent spatial differences in this component, the implications of effects on the trophic dynamics of the Sound may be substantial. It is apparent from the chlorophyll concentrations measured in 1989 that there are considerable phytoplankton available for consumers. However, whether the phytoplankton is the proper type or quality is unknown. Bellantoni and Peterson (1987) showed that cell size can affect egg production of the copepod *Acartia tonsa*. Though variations in rates of egg production of the copepod *Temora longicornis* were not well related to total chlorophyll, they were correlated with concentrations of chlorophyll in the >20 um size fractions (Peterson and Bellantoni, 1987). On the other hand, Kleppel *et al.* (1991) determined that dinoflagellates and microzooplankton may provide a major portion of these copepod's diets. For bivalves, cell size and quality also is critical (Durbin and Durbin, 1989). There may be very high chlorophyll concentrations in the Sound but as a food source, it could be of little value to the traditional consumers (it may support a bacterial community). Further research is needed to address this topic.

1.2.2. Comparison with Nearby Waters

The mean standing stock of phytoplankton numerical abundance in mid-Atlantic coastal and shelf waters varies spatially over 6 orders of magnitude, from about 10^3 to 10^8 cells L^{-1} (Fig. 1.2.7; Smayda, 1975). Phytoplankton is generally much higher in coastal bays such as Great South Bay, NY followed by semi-enclosed water bodies such Long Island Sound and average abundances decreases with increasing distance offshore.

1.3. MICROPLANKTON

1.3.1. Heterotrophic nanoplankton

Bacterivorous heterotrophic nanoplankton composed mainly of small, colorless flagellates are ubiquitous and abundant in the coastal ocean. These organisms consume bacteria which can account for 5-25 % of the heterotrophic production in Long Island Sound (McManus, 1986).

In Long Island Sound, the abundance of heterotrophic nanoplankton peaks in May (Fig. 1.3.1; McManus, 1986). At that time, densities can reach 3500 cell mL^{-1}. Even though the bacterial population remains high in the fall, the heterotrophic nanoplankton population declines rapidly from August through October. Heterotrophic nanoplankton mortality in the fall may be due to grazing by microzooplankton such as tintinnids, copepod nauplii, copepodites and other ciliates. The population of heterotrophic nanoplankton remains low

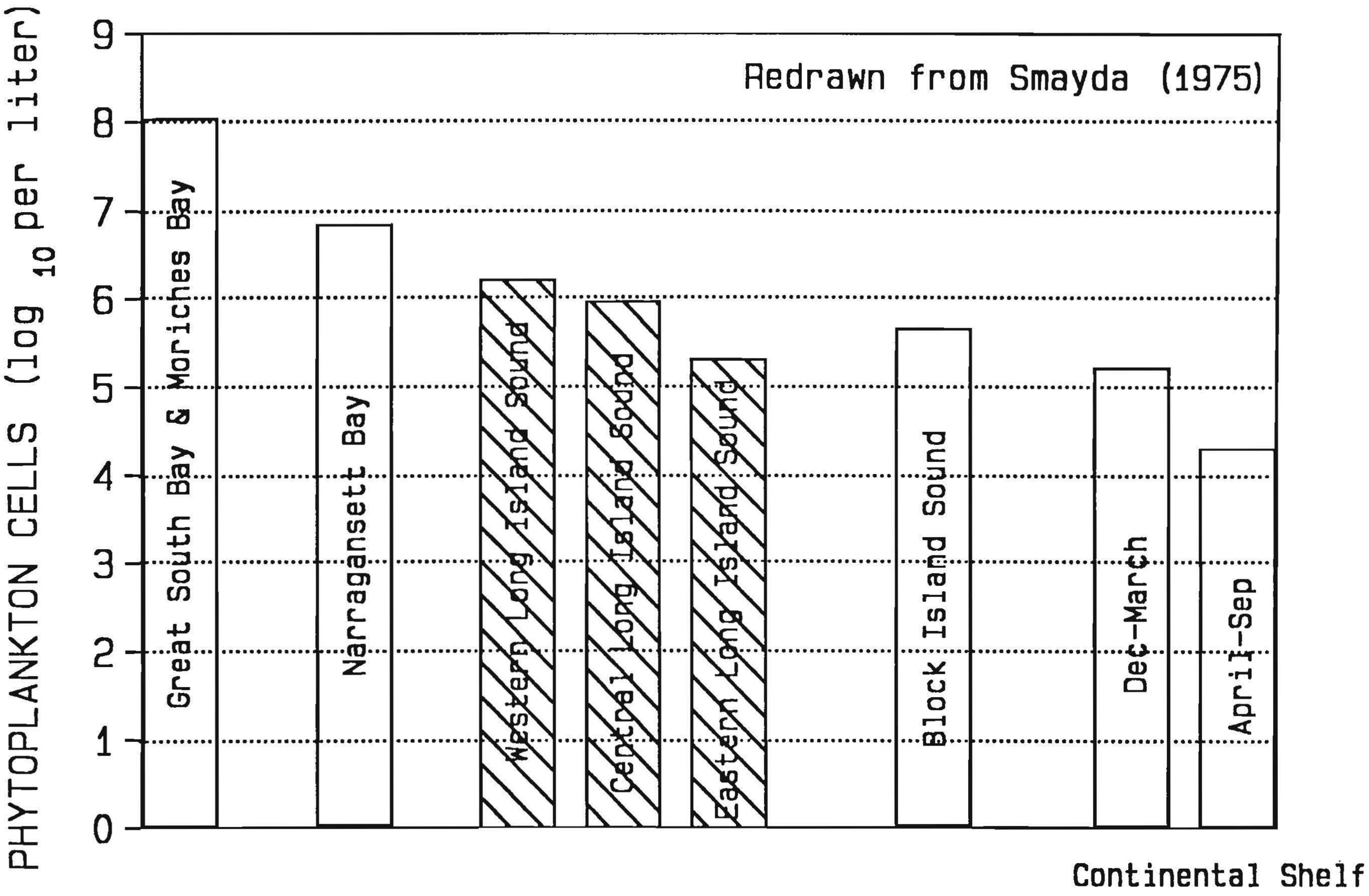
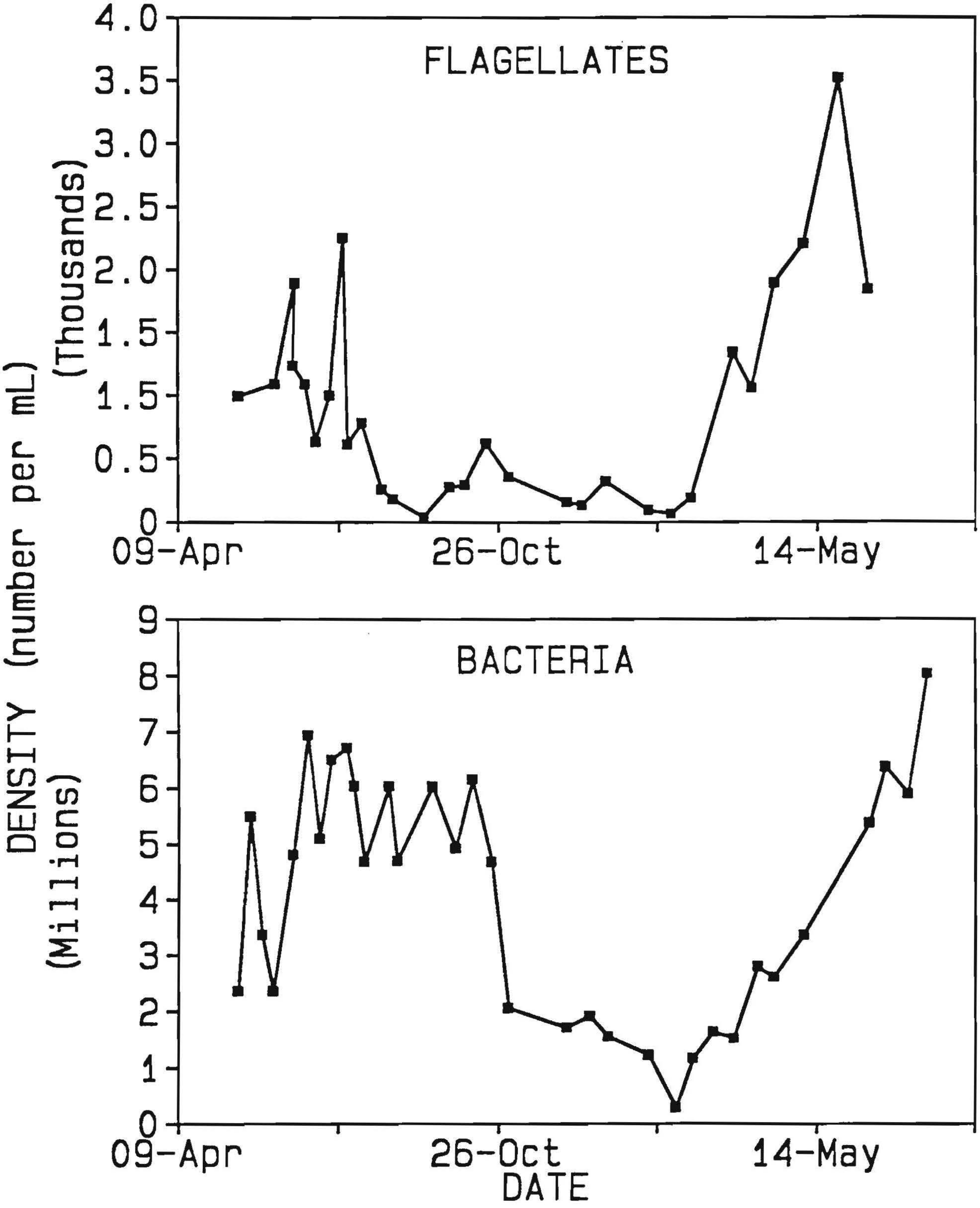


Fig. 1.2.7. Comparison of mean annual phytoplankton cell abundance from Long Island Sound with several nearby regions. Long Island Sound measurements were broken up into three regions (hatched bars).



Redrawn from McManus (1986)

Fig. 1.3.1. Density of microplankton in central Long Island Sound 1982-83.

until the spring bloom.

McManus (1986) determined that the heterotrophic nanoplankton population is dominated by chrysomonads and other small unidentified flagellates. Choanoflagellates and colorless cryptomonads are also present. These forms constituted < 10% of the total abundance on most occasions, but at times could exceed 50%. Calyconomas ovalis was often a dominant form during the early spring. Cosper et al. (unpubl.) found Calyconomas in excess of 50,000 l^{-1} at stations in the East River during May-July and in eastern Long Island Sound during February and May (Fig. 1.3.2).

1.3.2. Microzooplankton

Microzooplankton (defined as zooplankton < 202 um) have been shown to be abundant in central Long Island Sound. The dominant microzooplankters are tintinnids, of which Capriulo and Carpenter (1983) identified 24 species. They found tintinnid abundances ranging from 268-12,600 L^{-1} in the upper 1 m of the water column. Cosper et al. (unpubl.) found similar densities in the 1989 Long Island Sound Study survey (Fig. 1.3.3). Highest concentrations occurred during the temperature maximum (Capriulo and Carpenter, 1983; Cosper et al., unpubl.). At that time, Tintinnopsis minuta dominated and other ciliates occurred only occasionally. Rotifers do not preserve well and were not enumerated.

Microzooplankton play a significant role as primary consumers in Long Island Sound. Riley (1956) estimated that perhaps as much as 43% of the net carbon fixed annually by photosynthesis is consumed by microzooplankton and bacteria in the water column. Capriulo and Carpenter (1980) indicated that microzooplankton, consisting primarily of tintinnids, removed 41% of the

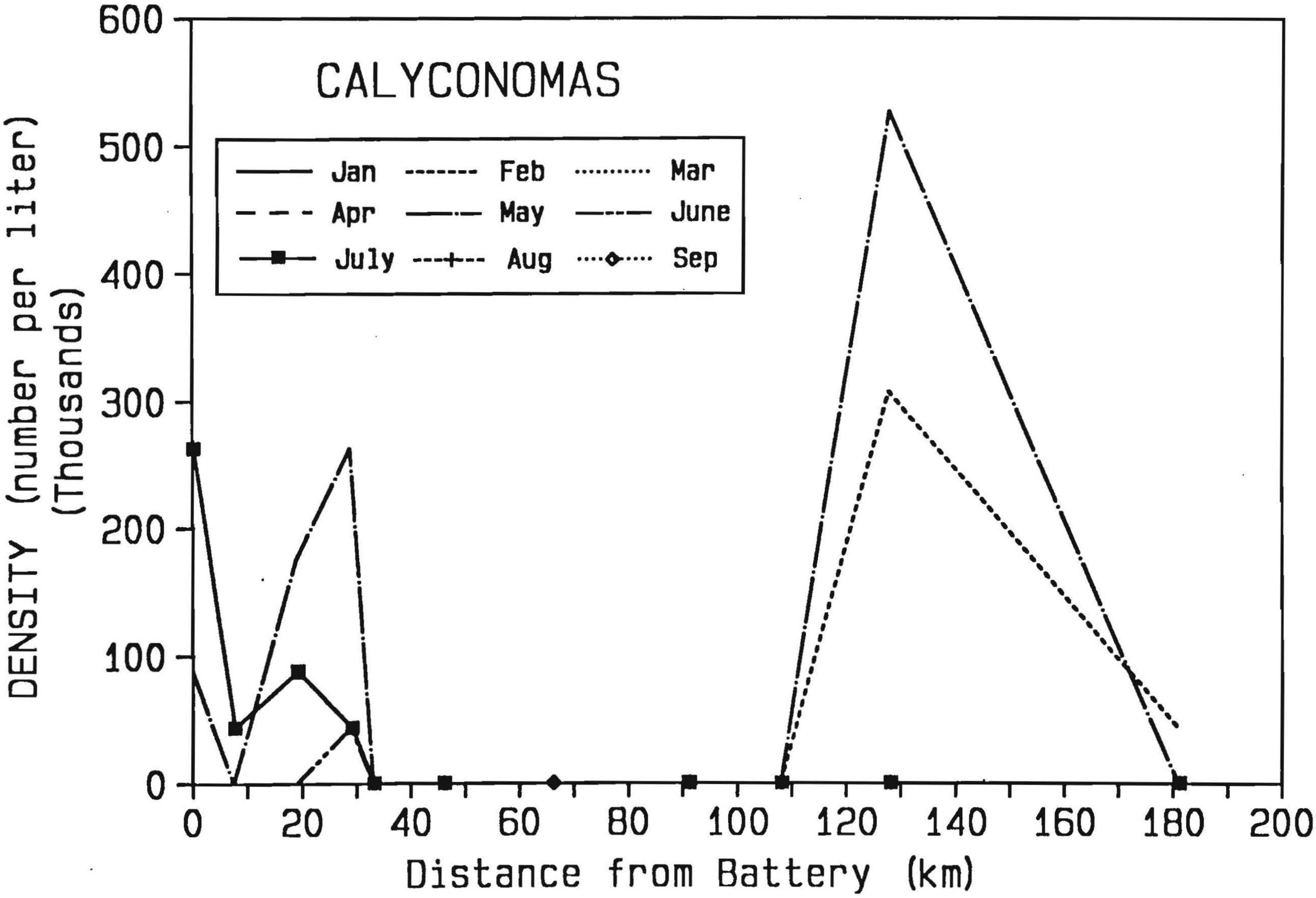


Fig. 1.3.2. Mean monthly density of Calycomonas sp. in surface samples collected in Long Island Sound during 1989 (Cosper *et al.*, unpubl.).

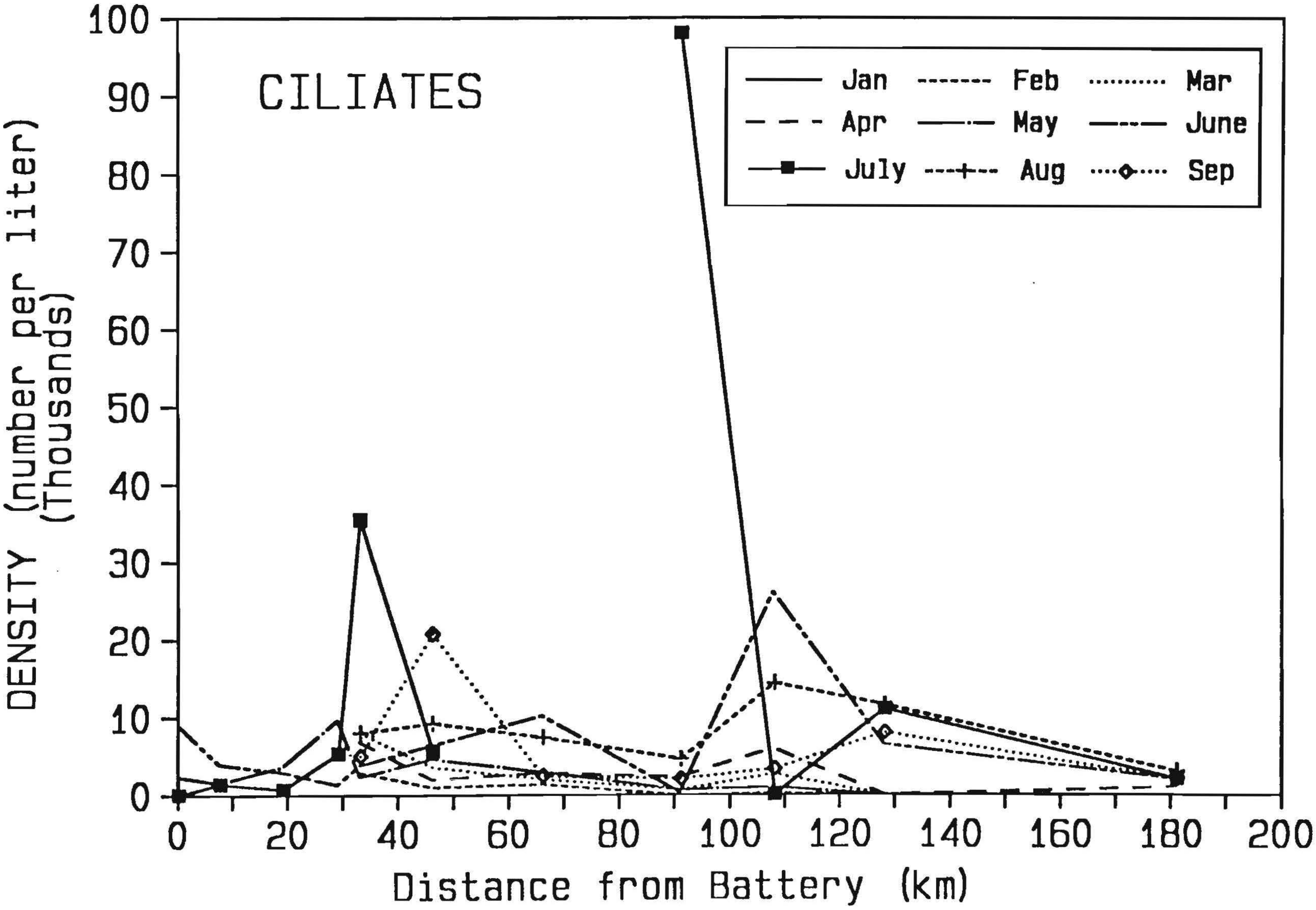


Fig. 1.3.3. Mean monthly density of ciliates collected in surface samples from in Long Island Sound during 1989 (Cosper *et al.*, unpubl.).

chlorophyll standing crop per day and exhibited community ingestion rates equal to those of the copepod community. With the exception of size constraints, tintinnids feed on the most abundant phytoplankton (Capriulo and Carpenter, 1980).

1.4. ZOOPLANKTON

1.4.1. Overview

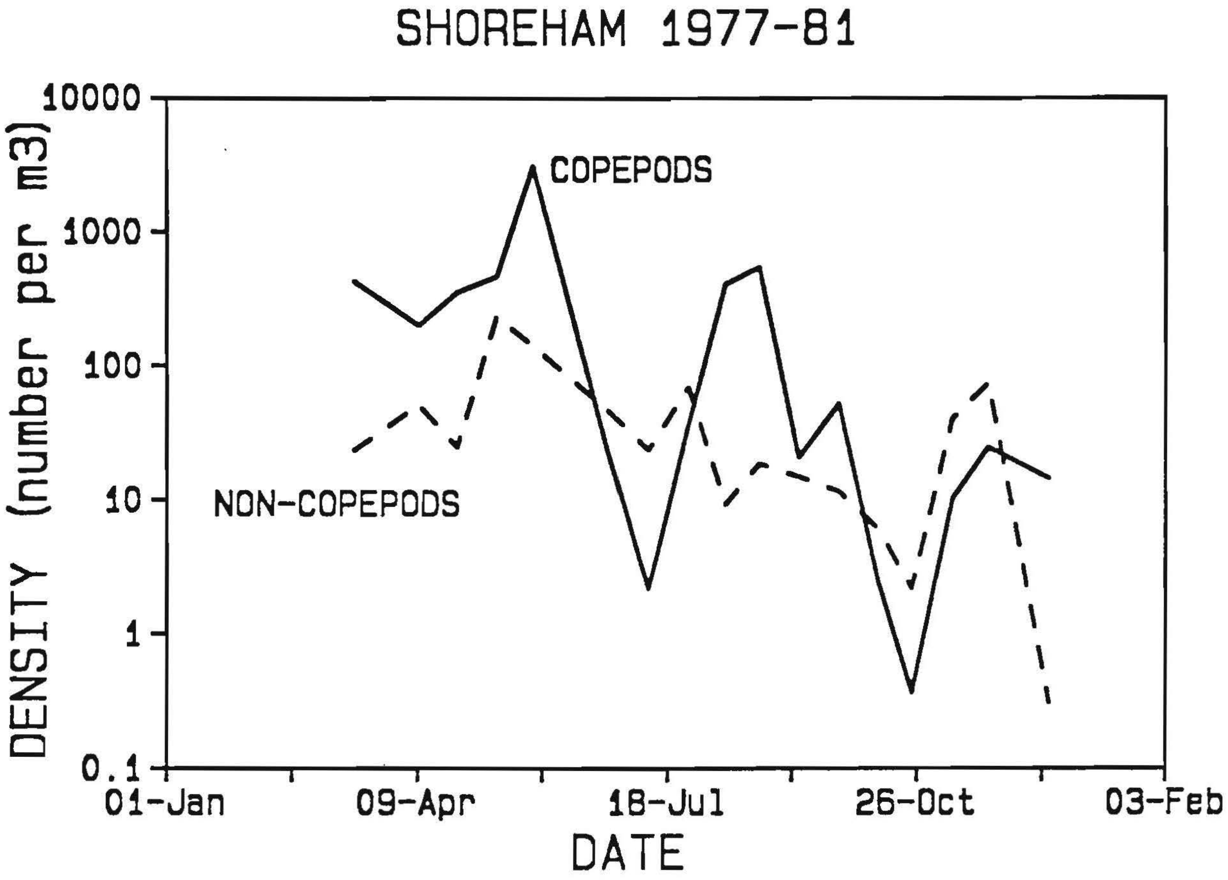
Several investigators have sampled zooplankton in Long Island Sound using disparate methods. Deevey (1956) used 158 um (number 10) and 366 um (number 2) mesh plankton nets. It was apparent that only a small portion of the zooplankton population was sampled by the larger mesh net. Some copepod nauplii and other early stages of zooplankton, which can be more than 10 times as abundant as adult stages (Deevey, 1956; Monteleone, 1988; Duguay et al., 1989), pass through the larger mesh nets. Likewise, this complicated direct comparisons of densities of zooplankton collected by LILCO (1979-83), where a 363 um mesh net was used, with Pastalove (1973) who used a 239 um net, and with collections by Peterson (1986) and Johnson (1987) who counted samples filtered through a 64 um mesh. However, Deevey's (1956) 366 um data can be compared to LILCO's (1979-83). Also, for some of the larger copepod species Deevey's (1956) 158 um data can be compared to Peterson (1986) and Johnson (1987). The depths at which the samples were collected also varied and this, as will later be discussed, made some comparisons impossible but provides more detailed information on the distribution of the organisms.

Six major taxonomic groups contribute to more than 96% of the zooplankton collected in Long Island Sound. At the Millstone Power Station (northeastern Sound) in 1983, copepods accounted for 88.7%; cirripedians, 5.4%; gastropods, 3.2%; decapods, 1.2%; cladocerans, 0.7% and amphipods, 0.5%. In general, copepods are the principal mesozooplankters (by number and biomass) collected in the coastal waters of New York (Fig. 1.4.1; Turner, 1982; LILCO, 1979-83; Gunn, 1987; Monteleone, 1988).

1.4.2. Copepods

In Long Island Sound, two copepod assemblages occur during the course of the year (Fig. 1.4.2, LILCO, 1979-83; NUSCO, 1983; Peterson, 1986; Johnson, 1987). The winter-spring population is dominated by *Temora longicornis*, *Acartia hudsonica* (formerly *A. clausii*) and *Pseudocalanus* sp. During the summer and fall *Acartia tonsa*, *Paracalanus crassirostris* (formerly *Parvocalanus crassirostris*) and *Oithona similis* prevail. The temporal distribution of dominance of these species noted by Peterson (1986) and Johnson (1987) from their 1982 survey at a station in the central Sound was consistent with the 1952-1953 survey by Deevey (1956) 30 years earlier. These patterns were noted in all Sound surveys of several months duration including those mentioned above and by Pastalove (1973) in western Long Island Sound; Normandeau (1979, 1981, 1985) at New Haven Harbor, CT; NUSCO (1983) at Niantic Bay, CT; Caplan (1977) off Eaton's Neck, NY and LILCO (1979-83) off Shoreham, NY. There are approximately 18 species of copepods common to most of these studies (Table 1.4.1) and they are probably a good representation of the copepod community in Long Island Sound.

The occurrence of various species of copepods depends on several factors. The abundance of cold-water species decreases when temperatures



Redrawn from LILCO (1983)

Fig. 1.4.1 Mean densities of copepod and non-copepod fractions of zooplankton collected with a 363 um mesh plankton net (surface and bottom tows) off Shoreham, NY.

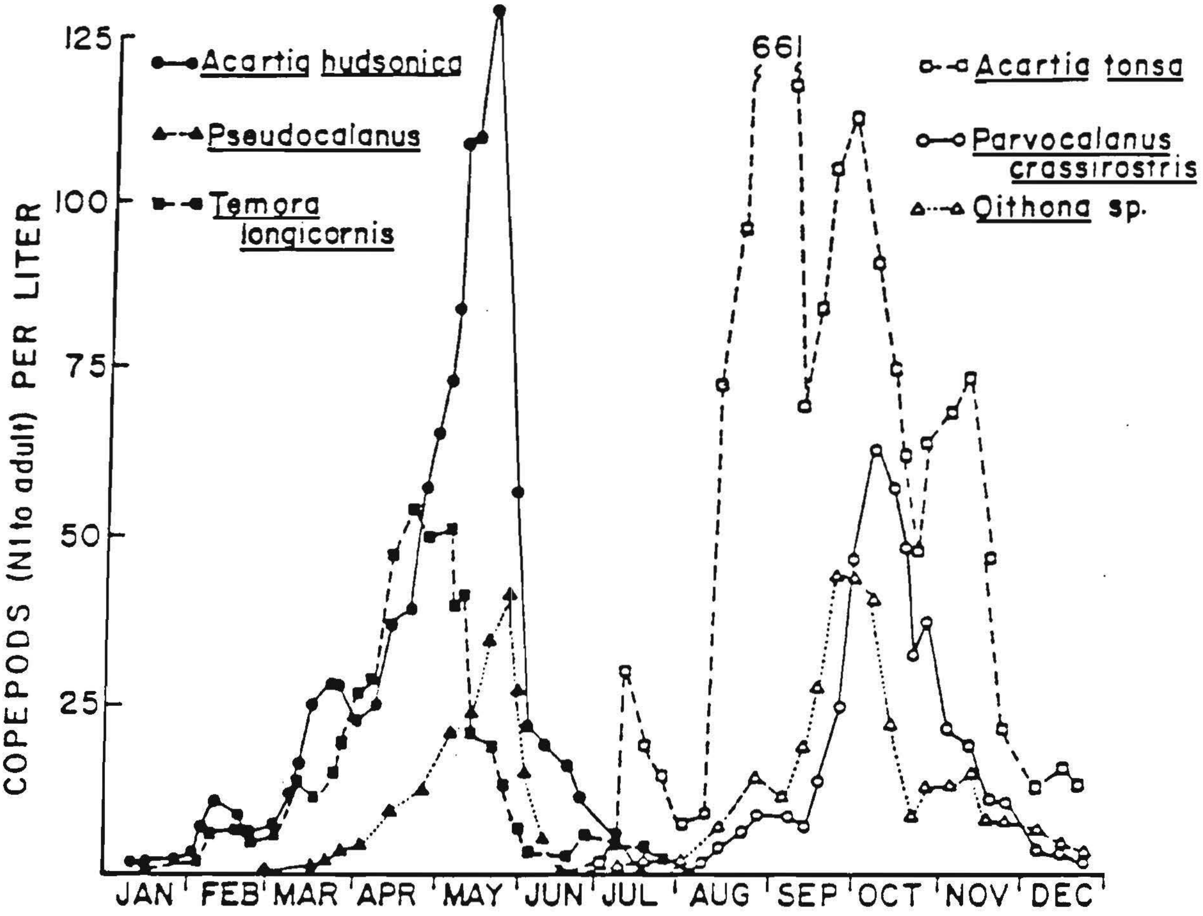


Fig. 1.4.2. Densities of copepod populations in central Long Island Sound during 1982. Data are integrated over the whole water column. From Peterson (1985).

Table 1.4.1. Copepod species present in Long Island Sound (Deevey, 1956; LILCO, 1979-83; NU, 1984; Peterson, 1985; Monteleone, 1984; Johnson, 1987).

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Acartia hudsonica			****	****	****	****	****				****	****
Acartia tonsa			****	****	****	****	****	****	****	****	****	****
Alteutha depressa	****			****								
Centropages hamatus			****	****	****	****	****			****	****	****
Centropages typicus				****		****				****		****
Cyclopoida											****	
Eurytemora americana						****						
Harpacticoida					****				****			****
Labidocera aestiva						****	****	****	****	****	****	****
Oithona sp.									****	****	****	****
Parasitic copepods						****						
Paracalanus crassirostris							****	****	****	****	****	****
Pontella sp.									****	****		
Pseudocalanus minutus			****	****	****	****	****					
Pseudodiaptomus coronatus			****			****	****				****	****
Temora longicornis			****	****	****	****	****		****		****	****
Tortanus discaudatus						****						

within the upper mixed layer exceed 19°C, at which time they are replaced by the warm water species which dominate until the water temperature falls to 15°C (Peterson, 1986). The population increases usually are dependent on temperature and food concentrations. Populations can be "restarted" by a few adults which may have persisted throughout the year (Smith and Lane, 1987), by hatching of resting eggs (Marcus, 1982; Sullivan and McManus, 1986) and by an influx of adults from Block Island Sound (W. T. Peterson, hypothesis). The early spring "restart" of the Temora longicornis population results from (1) a gradual increase in the abundance of adult females during the winter as the bottom water of Long Island Sound is replaced with Block Island Sound water, and (2) a burst in egg production in response to the annual spring phytoplankton bloom, in February. The restart of the Acartia hudsonica and Pseudocalanus populations are not as well understood, but in the case of A. hudsonica, the hatching of resting eggs may be important (Sullivan and McManus, 1986).

The biomass of the boreal (cool water) assemblage reaches a peak in mid-May, then begins to decline. The period of decline is driven almost entirely by a decrease in the abundance of the relatively large species, Temora longicornis. Its decline results from a lack of egg production following termination of the spring bloom; about two months prior to the observed decline in biomass. The demise of all three species making up the winter-spring population occurs by mid-July, and is believed to result because water temperatures become warmer than 18-19°C, the upper limit of tolerance for these cool-water species.

The summer-fall assemblage of copepods is dominated by Acartia tonsa, Paracalanus crassirostris and Oithona similis, species with subtropical affinities. They begin to increase in abundance when the Sound has warmed to

> $15^{o}C$, in late spring/early summer. Though conditions are suitable for rapid growth at that time (high phytoplankton concentration and elevated water temperatures), the populations of the dominant species do not achieve maximum potential levels because of intense predation by the ctenophore, Mnemiopsis leidyi (Deason and Smayda 1982; Monteleone 1988). Substantial increases in copepod abundance are not initiated until mid August for A. Tonsa and September for P. crassirostris and Oithona sp. At that time there is a burst in copepod egg production in response to the fall phytoplankton bloom, and lowered mortality rates resulting from declines in ctenophore abundances (Beckman and Peterson, 1986). The copepod population begins to decline again in early November because egg production rates become severely limited by cool temperatures and food availability.

Although there are seasonal consistencies of peaks of occurrence of certain species of copepods, there can be considerable interannual variability within seasons. Deevey (1956) and Conover, R. J. (1956) recognized that the quantity of zooplankton was considerably greater in 1952 than 1953. They attributed that to a change in the species composition of phytoplankton, where diatoms and other larger phytoplankton were more abundant in 1952. The LILCO (1979-83) time series reported copepod densities from 1977-1982 (Fig. 1.4.3). Although they used a relatively large mesh net (363 um) to sample zooplankton, resulting in losses of smaller stages of organisms and whole species (like Paracalanus crassirostris), however, the within-study data are comparable because sampling methods were consistent from year-to-year. The LILCO data clearly show the two seasonal copepod assemblages (Temora longicornis and Acartia hudsonica in the winter-spring and A. tonsa in the summer), however timing and peak densities of these species varied. Moreover, Johnson (1987) found considerable differences in magnitude and timing of the population

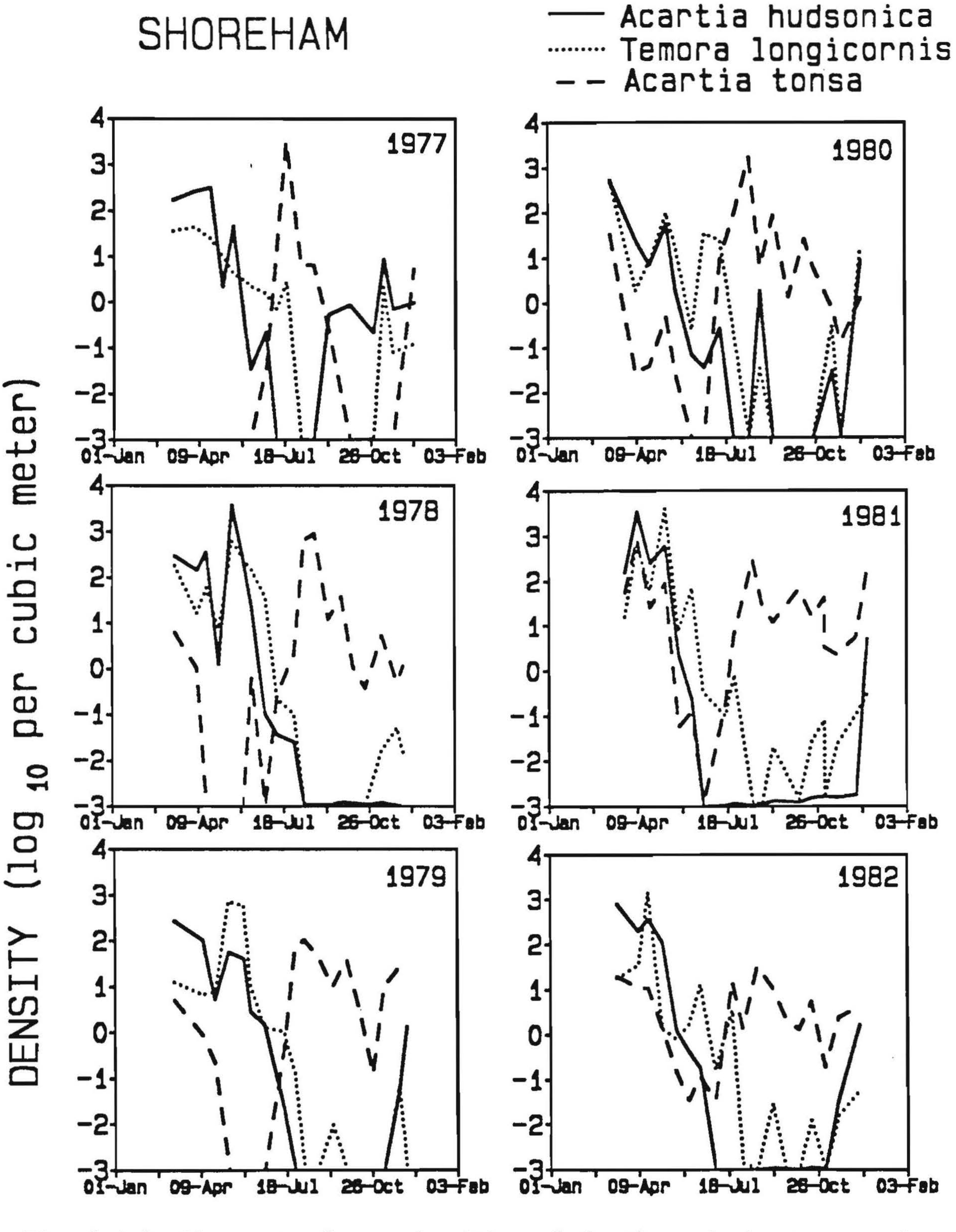


Fig. 1.4.3. Six years of mean densities of the three dominant copepod species off Shoreham, NY. Samples were collected by surface and bottom tows of 363 um mesh plankton nets. Data are from LILCO (1979, 1980, 1981, 1982, 1983).

increase from year-to-year of the small copepod, P. crassirostris, in Long Island Sound.

Densities of zooplankton populations in Long Island Sound also vary somewhat from year-to-year. Deevey (1956) found a four-fold difference in the abundance of Temora longicornis copepodites between 1952 and 1953 and Peterson (unpublished) found about the same degree of variation for the 1982-1987 time series. For Acartia hudsonica there is little evidence from Peterson's six year time series to suggest any degree of interannual variations in abundance.

No data set was collected during the same years to be able to make direct spatial distribution comparisons in Long Island Sound, however, there were no outstanding differences in the densities of copepods reported by various investigators. For western Long Island Sound, Pastalove (1973) reported densities of copepods collected in April as Acartia hudsonica 12.4 L^{-1}, A. tonsa 0.3 L^{-1}, Temora longicornis 9.8 L^{-1}. In August, the densities were A. hudsonica 0.05, A. tonsa 17.0, and T. longicornis 0.03 L^{-1}.

Other studies, conducted further east reported similar densities of the three dominant copepods. The Eaton's Neck disposal site study (Caplan, 1977) was conducted by sampling with relatively large mesh nets (202 and 363 um) at fixed locations and following a drogue. Sampling protocol was not consistent within this study. Different mesh sizes were used and depths sampled varied. Densities of several species of copepods were reported for the 26 m deep sampling site, and again, they focused on the three dominant species; Temora longicornis, Acartia hudsonica and A. tonsa. Sampling was more frequent than in Pastalove (1973) so seasonal increases in the populations of species were reported. These peaks were similar in timing to those reported by LILCO (1979-83) for samples collected off Shoreham with similar size mesh plankton nets (363 um). However, the magnitude of the peaks appear greater in the samples taken off Eaton's Neck. This could be due to (1) the use of a smaller mesh net which would collect copepodites, in addition to the adult stages; (2) that the Eaton's Neck figures represent collections taken at depths at which these species would be more abundant (Peterson, 1986); and/or (3) actual differences in the densities of these organisms.

The relationship between the vertical distribution of copepods to the vertical structure of the water column is an important factor to consider because of the possible importance of gradients of temperature, salinity and in particular, dissolved oxygen. Turner and Dagg (1983) found that in the nearby New York Bight and Georges Bank, the vertical distribution of the dominant species (Centropages typicus, Paracalanus parvus, Oithona similis spp.) were stratified in thermally-stratified waters but uniform with depth in mixed water columns. Peterson (1986) demonstrated a similar distribution pattern for Long Island Sound during a study conducted in May 1981, for Temora longicornis and Acartia hudsonica (Fig. 1.4.4). A. hudsonica were found primarily within the upper 15 m of the water column and T. longicornis below 15 m. In the summer, A. tonsa were found primarily in the upper 10 m. Dam Gurrero (1989) found that T. longicornis was found deeper in the water column as the water temperature increased.

Dam Gurerro (1989) showed that in Long Island Sound Temora longicornis and Acartia tonsa vertically migrate. Huntingford and Metcalfe (1986) found that some freshwater zooplankters will avoid predators by migrating deeper in the water column during the day. If hypoxia restricts movement of copepods into the bottom layer, copepods may become more vulnerable to predators.

The selection of specific depths is dependent upon both the stage of development of each copepod species, and upon seasonal variations in the physical stratification of the water column. During February-April, before

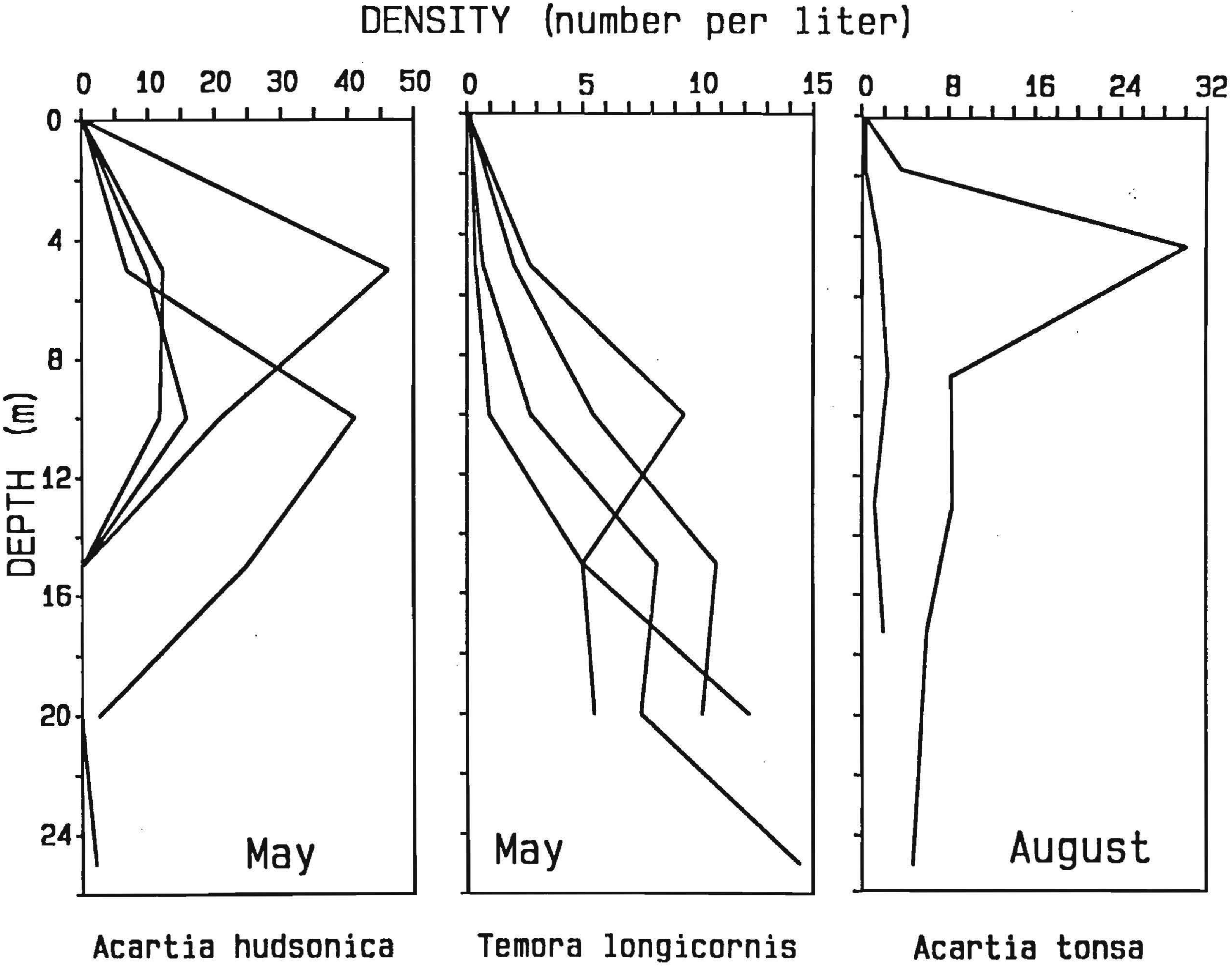


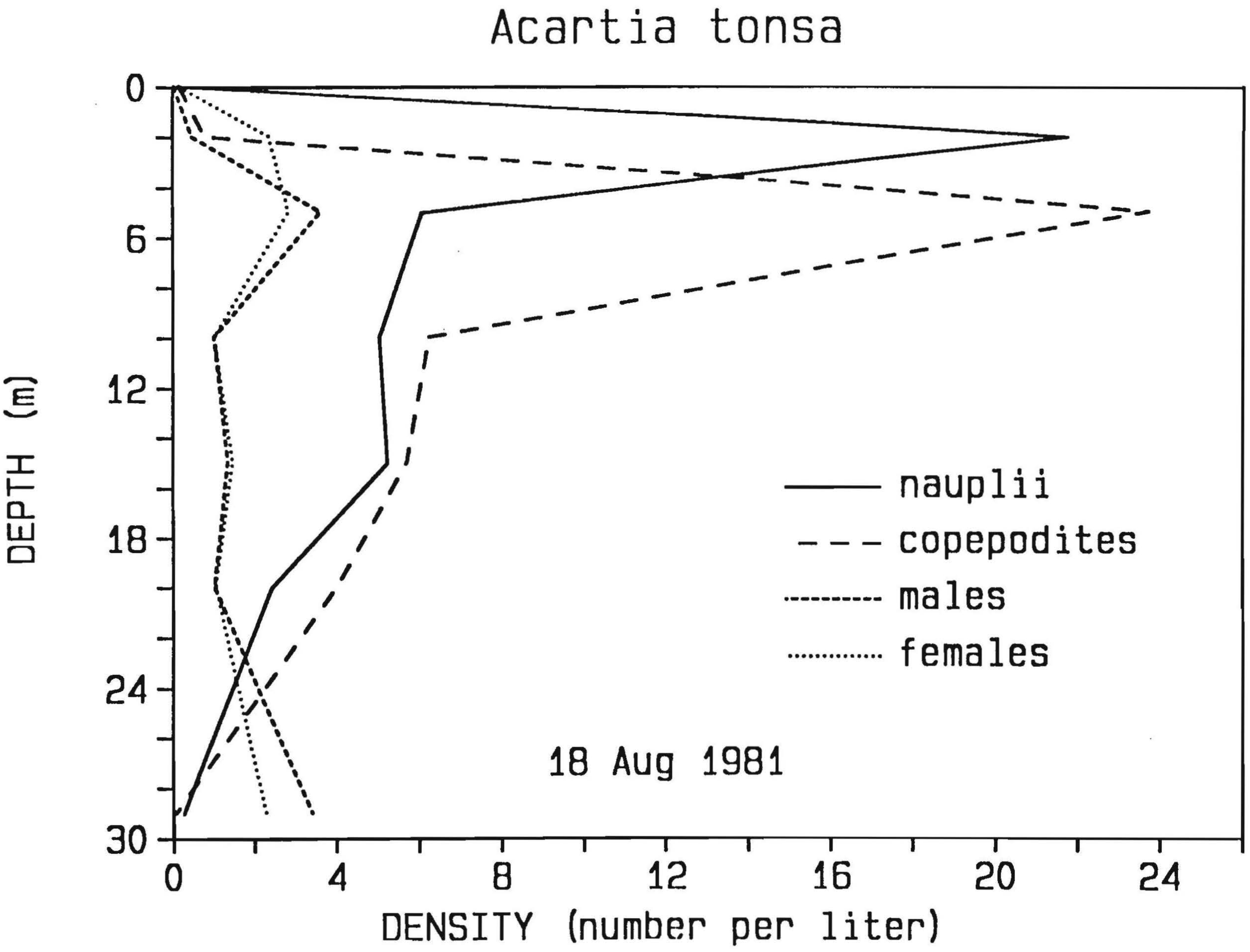
Fig. 1.4.4. Vertical distribution of three dominant copepod species at several stations in central Long Island Sound. W.T. Peterson (unpubl.).

the waters of the deep basins of the Sound have become stratified, juvenile and adult copepods occur in an equal abundance throughout the water column (Peterson, unpubl.). Following the onset of seasonal stratification (in April), nauplii and younger copepodite stages of all species are observed in their greatest abundance within the upper 5-10 m of the water column, and older stages are found throughout the water column (Fig. 1.4.5). Johnson (1987) found older stages of *Parvocalanus crassirostris* progressively deeper in the water column.

There are no adequate data available on the distribution and abundance of Long Island Sound copepods to determine if they avoid deeper waters containing low dissolved oxygen concentrations. Verheye (1989) showed that the copepod *Calanoides carinatus* avoided water with oxygen concentrations of ≤ 1 mg L^{-1} in the southern Benguela upwelling system. Tinson and Laybourn-Parry (1985, 1986) demonstrated that freshwater benthic copepods will become planktonic under hypoxic conditions or move laterally to shallower, more oxygenated water. If the vertical structure of the copepod populations is altered, they would become more concentrated in the upper layers of the water column, making them more vulnerable to predation. This will be further discussed in Task 2 of this report.

1.4.3. Other Zooplankters

Zooplankters, other than copepods, represent a diverse species assemblage in Long Island Sound. Some are holoplankton spending their whole life as free drifters (e.g., cladocerans, ctenophores and tintinnids). Others are meroplankton, spending only a portion of their life cycle as plankton (e.g., early life stages of bivalves, gastropods, barnacles, polychaetes,



18 Aug 1981

Fig. 1.4.5. Vertical distribution of various life stages of the summer dominant copepod *Acartia tonsa*. Collections were from the central Long Island Sound (Peterson, unpubl.).

shrimp, and crabs (Table 1.4.2)). In Long Island Sound, total numbers of zooplankton (excluding copepods) can reach densities of greater than 0.1 L^{-1} (10^2 m^{-3}) (LILCO, 1979-83; EA, 1987-90).

1.4.4. Comparison with Nearby Waters

Deevey (1956) compared abundances of zooplankton in Long Island Sound to the then reported values for Block Island Sound and Georges Bank (Fig. 1.4.6). The population abundances of zooplankton in Long Island Sound were at least two fold greater than those reported for the other two regions. Abundance values are reported in numbers beneath a square meter of water surface and therefore take into consideration the depth of the water column. Even though Long Island Sound is shallower, abundances were still greater, demonstrating its relatively greater productivity.

1.5. EARLY LIFE HISTORY STAGES OF FORAGE FISH and KEY FISH SPECIES

1.5.1. Overview

Long Island Sound is an area of considerable spawning activity by fishes. As part of the David's Island study (NMFS, 1972), conducted in western Long Island Sound, at least 18 species of fish larvae were identified from plankton tows (eggs were not identified). The LILCO/EA (1979-90) studies found representatives of approximately 30 taxa in their plankton samples taken off Shoreham, NY. Northeast Utilities (NUSCO) (1983), collected 30 species from waters near the Millstone Nuclear Power Plant, CT. Earlier surveys have

Table 1.4.2. Zooplankton other than copepods present in Long Island Sound (Deevey, 1956; EA, 1988).

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cladocera												
Bosmina sp.						****			****	****		
Daphnia sp.						****						
Evadne nordmanni				****	****	****	****	****				
Penilia avirostris							****	****	****	****		
Podon intermedius						****	****			****		
Podon polyphemoides					****	****	****					
Crab Zoea												
Callinectes sapidus						****	****	****	****	****		
Cancer irroratus					****	****	****	****		****		
Libinia sp.							****	****	****	****		
Neopanope sayi							****	****	****	****		
Pelia mulica									****	****		
Pinnixa sp.							****	****	****	****		
Pinnotheres maculatus										****		
Megalope								****	****	****		
Coelenterates												
Hydromedusae	****	****	****	****	****	****	****	****	****	****	****	****
Siphonophores											****	
Ctenophores												
Mnemiopsis leidyi								****	****	****	****	
Pleurobrachia pileus	****	****	****	****	****							

Table 1.4.2. Continued

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Other Zooplankters												
Acarina						****						
Balanus balanoides cyprids	****	****	****	****	****							
Balanus balanoides nauplii	****	****	****	****								
Bivalve larvae					****	****	****	****	****	****	****	****
Caprellid amphipods									****			
Crangon larvae	****	****	****	****	****	****	****	****	****	****	****	****
Cumacea sp.									****	****	****	****
Cyphonautes larvae			****	****		****		****	****	****		
Echinoderm larvae						****	****	****	****			
Foraminifera				****	****	****	****	****	****	****	****	****
Gammerid amphipods						****			****		****	****
Gastropod veligers	****			****	****	****	****	****	****	****	****	****
Isopoda									****			
Lamellibranch veligers	****	****	****	****	****	****	****	****	****	****	****	
Mysid larvae	****	****	****	****	****	****	****		****	****	****	****
Mysidacea						****	****	****	****	****	****	****
Nematodes				****	****				****	****		
Oikopleura sp.								****	****	****	****	
Ostracoda						****						
Polychaete larvae	****	****	****	****	****	****	****	****	****	****	****	****
Porcellanid larvae				****								
Sagitta elegans	****	****	****	****	****	****	****			****	****	****
Squid larvae								****	****	****		
Squilla larvae								****				
Tintinnids	****	****	****	****	****	****	****	****	****	****	****	
Trochophore larvae					****	****	****	****				

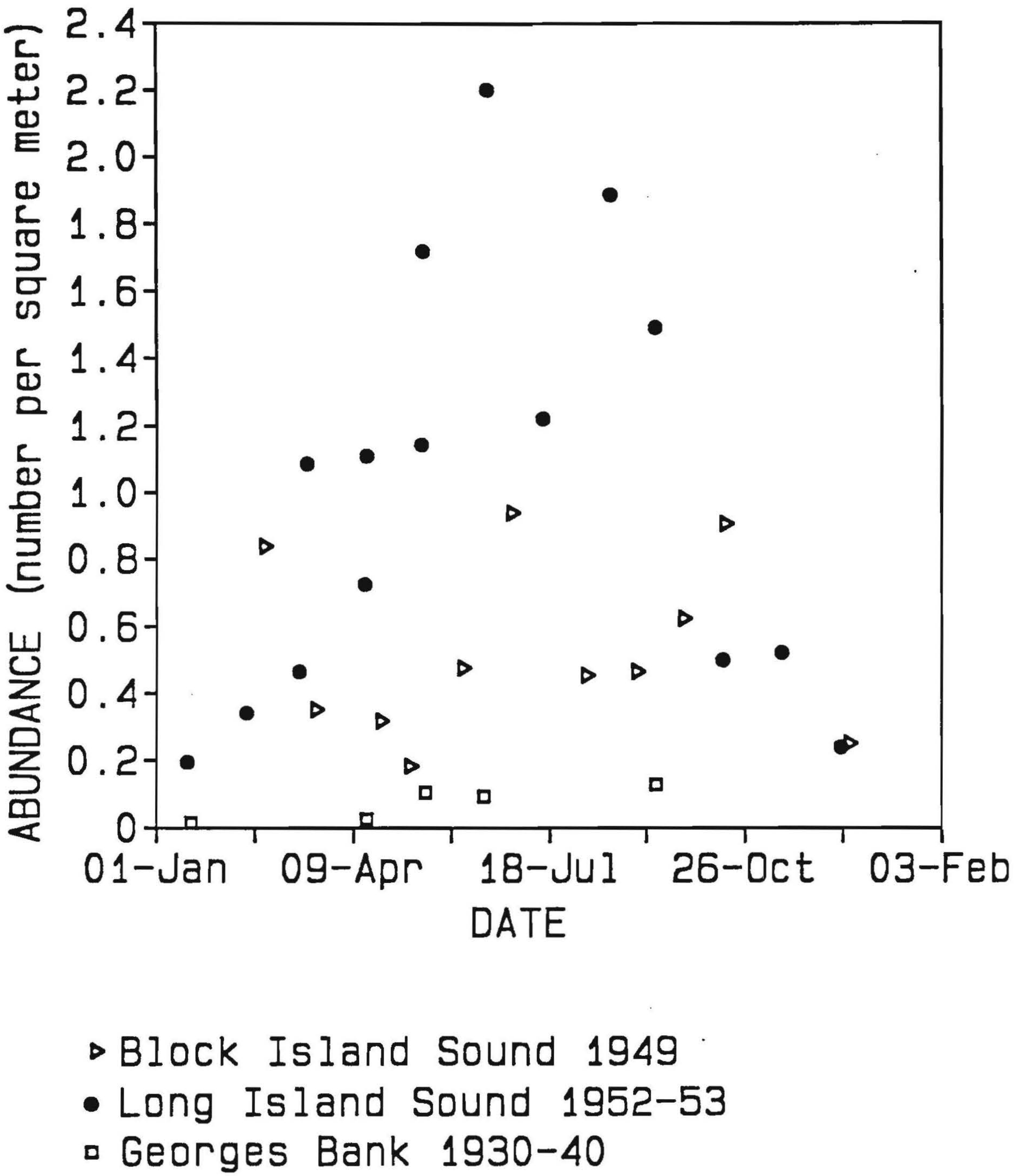


Fig. 1.4.6. Comparison of abundance of copepods from different areas. Figure is redrawn from Deevey (1956).

reported similar diversities including Wheatland (1956), 23 species; Merriman and Sclar (1952), 20 species; and Richards (1959), 22 species.

Most fish spawn on a seasonal basis in temperate waters (Herman, 1959; Ferraro, 1980; Monteleone, 1988) with some spawning seasons more protracted than others. Spawning seasons, the time period when eggs and larvae were collected, are illustrated in Table 1.5.1.

The dominant species identified in the studies mentioned above suggest most of the major spawners are ubiquitous throughout these studies. Tables 1.5.2 and 1.5.3 were constructed using all available information on the ranking of eggs and larvae collected by the various studies. Because some studies did not encompass a full year, species were under-represented in their calculations, such as American sand lance (Ammodytes americanus) larvae being missed by not sampling during December-January.

In general, the dominant fish eggs present in Long Island Sound are the bay anchovy (Anchoa mitchilli) (Table 1.5.2). Other representatives in the top 5 most abundant fish eggs by species (not in order) were Atlantic mackerel (Scomber scombrus); two labrids, tautog (Tautoga onitis) and cunner (Tautogolabrus adspersus); fourbeard rockling (Enchelyopus cimbrius); windowpane flounder (Scopthalmus aquosus); summer flounder or fluke (Paralychthys dentatus); and yellowtail flounder (Limanda ferruginea). These plankton samples did not adequately collect eggs of species which have demersal eggs (such as winter flounder, Pleuoronectes americanus and American sand lance). It is interesting to note that very few Atlantic mackerel eggs collected in the 1950s and they were relatively abundant in the more recent surveys.

American sand lance and bay anchovy were the two most abundant species of fish larvae collected in the Sound (Table 1.5.3). The American sand lance

Table 1.5.1. Occurrence (* = range; X = peak) of fish eggs and larvae in Long Island Sound (Wheatland, 1956; Richards, 1959; LILCO, 1979-83; Ausubel, 1983; Boampong, 1984; Monteleone, 1984)

EGGS

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Ammodytes americanus	****										XXXX	XXXX
Anchoa mitchilli					****	XXXX	XXXX	XXXX	****			
Brevoortia tyrannus					XXXX	XXXX	****	****	****	****		
Cynoscion regalis						****	****					
Enchelyopus cimbrius	****	****	****	XXXX	****	****						
Limanda ferruginea				****								
Menticirrhus saxatilis						****	****					
Peprilus triacanthus						XXXX	****	****	****			
Prionotus carolinus						****	XXXX	****				
Pleuronectes americanus				XXXX	****	****						
Scomber scombrus				****	XXXX	****						
Scopthalmus aquosus			****	****	XXXX	****	****	****	****	****		
Stenotomus chrysops					****	****	****					
Tautoga onitis					****	XXXX	XXXX	****	****	****		
Tautogolabrus adspersus					****	XXXX	XXXX	****	****			
Trinectes maculatus						****	XXXX	****				

LARVAE

SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Ammodytes americanus	****	****	****	****	****	****						XXXX
Anchoa mitchilli						****	XXXX	****	****	****		
Anchoa sp.					****	****	XXXX	****	****	****		
Anguilla rostrata	****											
Brevoortia tyrannus					****	****	XXXX	****	****	XXXX		
Clupea harengus			****									
Cynoscion regalis						****	XXXX					
Enchelyopus cimbrius					XXXX	****						
Limanda ferruginea				****	****	****						
Menidia menidia						****						
Mentricirrhus saxatilis								****				
Myoxocephalus octodemispinosus			XXXX	XXXX	****							
Paralychthys oblongus									****			
Peprilus triacanthus						****	****	****	****	**		
Prionotus carolinus								XXXX	****			
Pleuronectes americanus				*****	XXXX	****	***					
Scomber scombrus						****	****	****				
Scopthalmus aquosus						XXXX	****	****	*			
Sphaeroides maculatus							****					
Stenotomus chrysops						****	****					
Sygnanthus fuscus							****					
Tautoga onitis						XXXX	****					
Tautogolabrus adspersus						XXXX	****	****	****			

Table 1.5.2. List of top 5 ranked fish eggs in Long Island Sound, by area, year and month. Note: Differences in ranking may result from the months sampled.

Months	Year	Location	1	2	3	4	5	Reference
<u>WESTERN</u>								
Feb-Dec	1976	Hempstead	Tautogolabrus	Scomber	Tautoga	Anchoa	Scopthalmus	LILCO (1977b)
<u>CENTRAL</u>								
Jan-Jun	1975	Eaton's Neck	Scomber	Anchoa	Brevoortia	Enchelyopus	Tautoga	Caplan (1977)
Feb-Dec	1976	Pt Jefferson	Anchoa	Tautogolabrus	Tautoga	Scomber	Scopthalmus	LILCO (1977a)
Jul-Dec	1974	New Haven	Labrid/Limanda	Anchoa spp.				Normandeau (1979)
Jan-Dec	1975	New Haven	Anchoa	Scomber	Labrid/Limanda			Normandeau (1979)
Jan-Dec	1976	New Haven	Anchoa	Labrid/Limanda	Uro/Ench/Pep	Scomber		Normandeau (1979)
Feb-Oct	1977	New Haven	Anchoa	Labrid/Limanda	Scop/Paral			Normandeau (1979)
Jan-Nov	1978	New Haven	Anchoa	Labrid/Limanda	Scop/Paral	Enchelyopus		Normandeau (1981)
Feb-Nov	1979	New Haven	Anchoa	Labrid/Limanda	Scomber	Enchelyopus	Labrid/Limanda	Normandeau (1981)
Feb-Oct	1980	New Haven	Labrid/Limanda	Anchoa	Scop/Paral	Enchelyopus		Normandeau (1981)
Feb-Nov	1981	New Haven	Anchoa	Labrid/Limanda	Scop/Paral	Enchelyopus		Normandeau (1985)
Feb-Nov	1982	New Haven	Labrid/Limanda	Anchoa	Scop/Paral	Enchelyopus		Normandeau (1985)
Feb-Nov	1983	New Haven	Anchoa	Labrid/Limanda	Scop/Paral	Enchelyopus		Normandeau (1985)
Feb-Nov	1984	New Haven	Anchoa	Labrid/Limanda	Scop/Paral	Enchelyopus		Normandeau (1985)
Feb-Dec	1977	Shoreham	Scomber	Anchoa	Tautoga	Enchelyopus	Tautogolabrus	LILCO (1979)
Mar-Dec	1978	Shoreham	Scomber	Anchoa	Enchelyopus	Scopthalmus	Tautoga	LILCO (1979)
Jan-Dec	1979	Shoreham	Anchoa	Scomber	Enchelyopus	Tautogolabrus	Tautoga	LILCO (1980)
Jan-Dec	1980	Shoreham	Scomber	Anchoa	Enchelyopus	Tautogolabrus	Scopthalmus	LILCO (1981)
Jan-Dec	1981	Shoreham	Anchoa	Scomber	Enchelyopus	Tautoga	Scopthalmus	LILCO (1982)
Feb-Dec	1982	Shoreham	Scomber	Enchelyopus	Anchoa	Scopthalmus	Tautoga	LILCO (1983)
Mar-Dec	1983	Shoreham	Anchoa	Enchelyopus	Tautogolabrus	Scomber	Tautoga	EA (1987)
Jan-Dec	1984	Shoreham	Anchoa	Enchelyopus	Scomber	Tautogolabrus	Scopthalmus	EA (1987)
Feb-Dec	1985	Shoreham	Anchoa	Scomber	Enchelyopus	Scopthalmus	Trinectes	EA (1987)
Jan-Dec	1986	Shoreham	Anchoa	Enchelyopus	Tautoga	Scopthalmus	Scomber	EA (1987)
Jan-Dec	1987	Shoreham	Enchelyopus	Anchoa	Tautoga	Scopthalmus	Prionotis	EA (1989a)
Jan-Dec	1988	Shoreham	Enchelyopus	Scopthalmus	Anchoa	Tautogolabrus	Tautoga	EA (1989b)
<u>EASTERN</u>								
Jan-Sep	71-75	Waterford	Labrid/Limanda	Scomber	Anchoa	Brevoortia	Prionotus	NUSCO (1976)
<u>SOUNDWIDE</u>								
Jan-Dec	52-54	Sound	Anchoa	Tautogolabrus	Brevoortia	Enchelyopus	Scopthalmus	Wheatland (1956)
	1954	Sound	Anchoa	Tautogolabrus	Tautoga	Enchelyopus	Scopthalmus	Wheatland (1956)
	1955	Sound	Anchoa	Enchelyopus	Tautogolabrus	Tautoga	Stenotomus	Richards (1959)

Table 1.5.3. List of top 5 ranked fish larvae in Long Island Sound, by area, year and month. Note: Differences in ranking may result from the months sampled.

Months	Year	Location	1	2	3	4	5	Reference
WESTERN								
Apr-Sep	1971	David's Is	Clupeids	Tautoga	Ammodytes	Pleuronectes	Menidia	NMFS (1972)
Feb-Dec	1976	Hempstead	Ammodytes	Anchoa	Brevoortia	Pleuronectes	Sygnanthus	LILCO (1977b)
CENTRAL								
Jan-Jun	1975	Eaton's Neck	Scomber	Brevoortia	Prionotus	Tautoga	Anchoa	Caplan (1977)
Feb-Dec	1976	Port Jefferson	Anchoa	Tautoga	Tautogolabrus	Sygnanthus	Brevoortia	LILCO (1977a)
Jul-Dec	1974	New Haven	Anchoa					Normandeau (1979)
Jan-Dec	1975	New Haven	Anchoa	Ammodytes				Normandeau (1979)
Jan-Dec	1976	New Haven	Anchoa	Myoxo	Pleuronectes	Cynoscion	Ammodytes	Normandeau (1979)
Feb-Oct	1977	New Haven	Anchoa	Ammodytes	Pleuronectes			Normandeau (1979)
Jan-Nov	1978	New Haven	Anchoa	Ammodytes	Cynoscion	Brevoortia	Pleuronectes	Normandeau (1981)
Feb-Nov	1979	New Haven	Anchoa	Ammodytes	Sygnanthus	Pleuronectes	Myoxocephalus	Normandeau (1981)
Feb-Oct	1980	New Haven	Anchoa	Ammodytes	Sygnanthus			Normandeau (1981)
Feb-Nov	1981	New Haven	Anchoa	Ammodytes	Sygnanthus	Cynoscion		Normandeau (1985)
Feb-Nov	1982	New Haven	Anchoa	Ammodytes	Sygnanthus	Cynoscion	Pleuronectes	Normandeau (1985)
Feb-Nov	1983	New Haven	Anchoa	Cynoscion	Pleuronectes	Sygnanthus	Myoxocephalus	Normandeau (1985)
Feb-Nov	1984	New Haven	Anchoa	Sygnanthus	Pleuronectes	Cynoscion	Ammodytes	Normandeau (1985)
Feb-Dec	1977	Shoreham	Anchoa	Scomber	Ammodytes	Tautogolabrus	Peprilus	LILCO (1979)
Mar-Dec	1978	Shoreham	Ammodytes	Anchoa	Scomber	Pleuronectes	Scopthalmus	LILCO (1979)
Jan-Dec	1979	Shoreham	Ammodytes	Anchoa	Scomber	Pleuronectes	Scopthalmus	LILCO (1980)
Jan-Dec	1980	Shoreham	Ammodytes	Anchoa	Scomber	Enchelyopus	Myoxocephalus	LILCO (1981)
Jan-Dec	1981	Shoreham	Ammodytes	Anchoa	Pleuronectes	Scomber	Myoxocephalus	LILCO (1982)
Feb-Dec	1982	Shoreham	Ammodytes	Anchoa	Pleuronectes	Enchelyopus	Scomber	LILCO (1983)
Mar-Dec	1983	Shoreham	Anchoa	Ammodytes	Enchelyopus	Brevoortia	Pleuronectes	EA (1987)
Jan-Dec	1984	Shoreham	Ammodytes	Anchoa	Brevoortia	Enchelyopus	Pleuronectes	EA (1987)
Feb-Dec	1985	Shoreham	Anchoa	Ammodytes	Pleuronectes	Brevoortia	Scopthalmus	EA (1987)
Jan-Dec	1986	Shoreham	Ammodytes	Anchoa	Pleuronectes	Enchelyopus	Scomber	EA (1987)
Jan-Dec	1987	Shoreham	Ammodytes	Enchelyopus	Pleuronectes	Anchoa	Myoxocephalus	EA (1989a)
Jan-Dec	1988	Shoreham	Anchoa	Ammodytes	Enchelyopus	Pleuronectes	Tautogolabrus	EA (1989b)
EASTERN								
Jan-Sep	71-75	Waterford	Engraulidae	Scomber	Tautogolabrus	Tautoga	Pleuronectes	NUSCO (1976)
SOUNDWIDE								
Jan-Dec	52-54	Sound	Anchoa	Ammodytes	Brevoortia	Pleuronectes		Wheatland (1956)
	1954	Sound	Anchoa	Brevoortia	Pleuronectes	Cynoscion	Ammodytes	Richards (1959)
	1955	Sound	Ammodytes	Anchoa	Brevoortia	Pleuronectes	Tautogolabrus	Richards (1959)

would have undoubtedly outrank bay anchovy in the New Haven Harbor studies (Normandeau, 1979, 1981, 1985) if sampling was conducted in December and January. Other dominant larval fish species were tautog, winter flounder, Northern pipefish (*Sygnanthus fuscus*), Atlantic mackerel, Atlantic menhaden, fourbeard rockling, weakfish (*Cynoscion regalis*), sculpin (*Myoxocephalus* sp.), butterfish (*Peprilus triacanthus*) and Atlantic silverside (*Menidia menidia*).

Richards (1959) was the only study which attempted to address horizontal distributions of ichthyoplankton in Long Island Sound. During her 1954-55 surveys, eggs and larvae appeared to be more abundant in the western part of the central Sound, though the existence of a marked east-west gradient could not be determined with certainty because of the irregular sampling schedule. Sand lance larvae were found almost exclusively in the central and western section. During spring, though salinity gradients strengthened, sculpin and winter flounder larvae were widely distributed while the pelagic eggs of fourbeard rockling and windowpane were almost exclusively in the central and western sections. In the summer, the salinity gradients were strongest and though she noted high densities of zooplankton throughout the Sound, fish eggs and larvae were most abundant in the western end than elsewhere. These eggs and larvae were presumably bay anchovy.

1.5.2. American sand lance (*Ammodytes americanus*)

American sand lance spawn in the winter beginning in November and continue into early January (Monteleone *et al.*, 1987). Sand lance eggs are demersal and adhere to sand grains making them unavailable to conventional plankton tows. Hence, there is no available description of sand lance egg distribution for Long Island Sound. Because they spawn early in winter, the eggs and larvae are not likely to be exposed to hypoxic conditions.

Sand lance larvae, present in plankton samples from December through May, have gone through extreme fluctuations in abundance in Long Island Sound. Monteleone et al. (1987) summarized information on the abundance of sand lance larvae in Long Island Sound from 1951-1983. They found that over a 23 year period there were at least two boom and bust periods. The two peaks occurred in 1965-66 and 1978-79, while low densities were evident in the mid 1950s and early 1980s. The authors could not attribute these fluctuations to available food resources, but they were able to show a relationship to temperature. In years when water temperature in December was warm, the total density of larvae was low. Eggs that might hatch sooner at the warmer temperatures may be ready to feed before the spring bloom and therefore experience starvation mortality. Monteleone et al. (1987) also suggested that fluctuations in adult spawning biomass and predation pressure by Atlantic mackerel (Scomber scombrus) and common and least terns (Sterna sp.) may contribute to sand lance fluctuations. Since the early 1980s, the densities of sand lance larvae in Long Island Sound have continued to decline (Fig. 1.5.1). Whether in a boom or bust period, however, sand lance are one of the relatively dominant larval fish species found in the Sound. They have been the most dominant larval taxa in 8 of 11 years (1977-87) at Shoreham (LILCO, 1988). Wheatland (1956) found sand lance larvae were more abundant in the central portion of the Sound than either the western or eastern end during her 1952-54 survey.

1.5.3. Bay anchovy (Anchoa mitchilli)

The LILCO (1979-83)/EA(1987-1990) studies showed densities of bay anchovy (Anchoa mitchilli) eggs near Shoreham, NY have undergone large

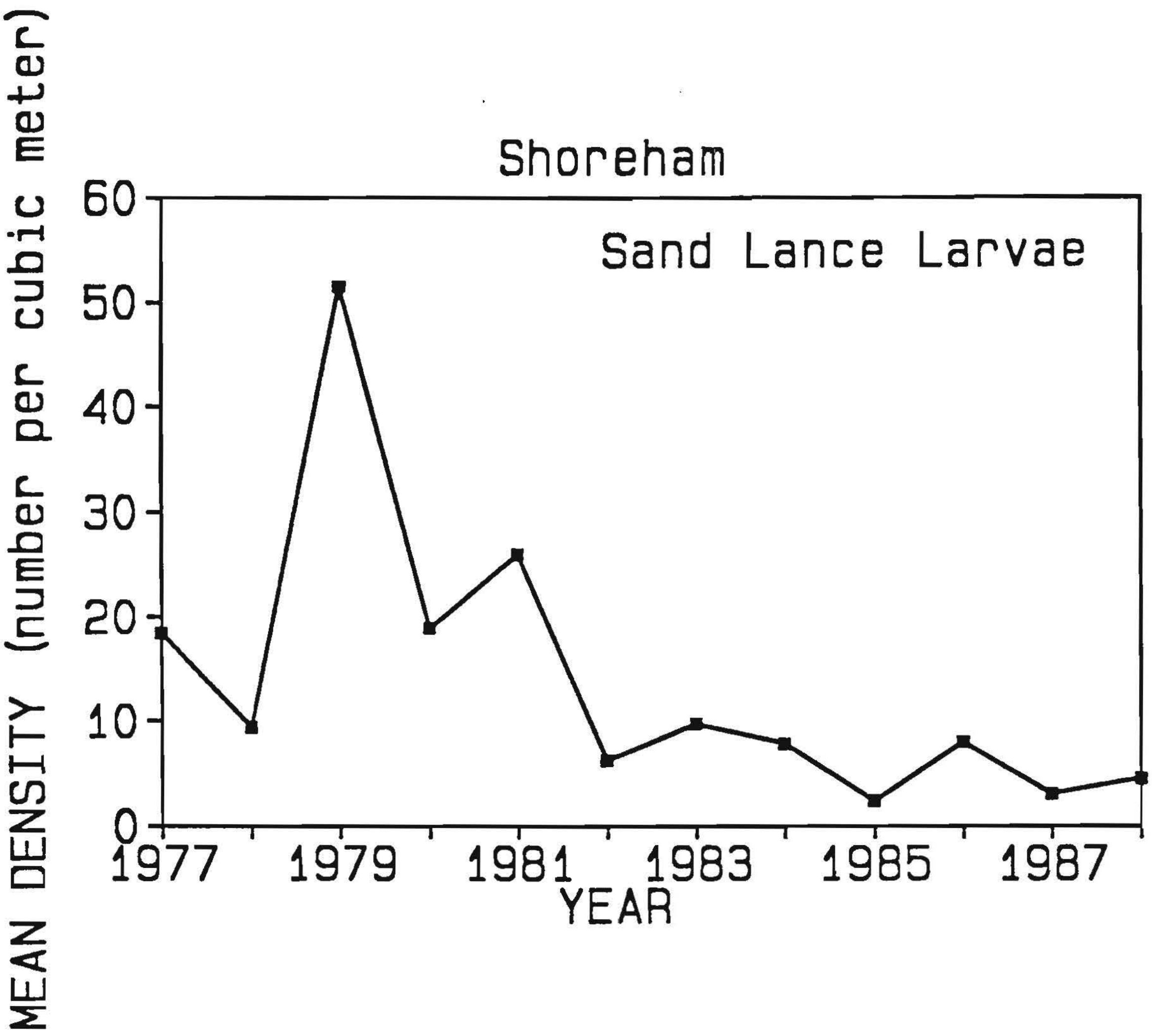


Fig. 1.5.1. Mean annual density of American sand lance (Ammodytes americanus) larvae collected with 363 um plankton nets off Shoreham, NY (LILCO, 1979, 1980, 1981, 1982, 1983; EA, 1987, 1988, 1989a).

fluctuations over an 11-year sampling period (Fig. 1.5.2; Horvath, 1985; EA, 1988). Annual mean egg density levels varied from a high of 126.4 m^{-3} in 1977 to a low of 6.1 m^{-3} in 1988. Wheatland (1956) also noted similar fluctuations, finding that the number of eggs taken in 1952 was five times greater than in 1953.

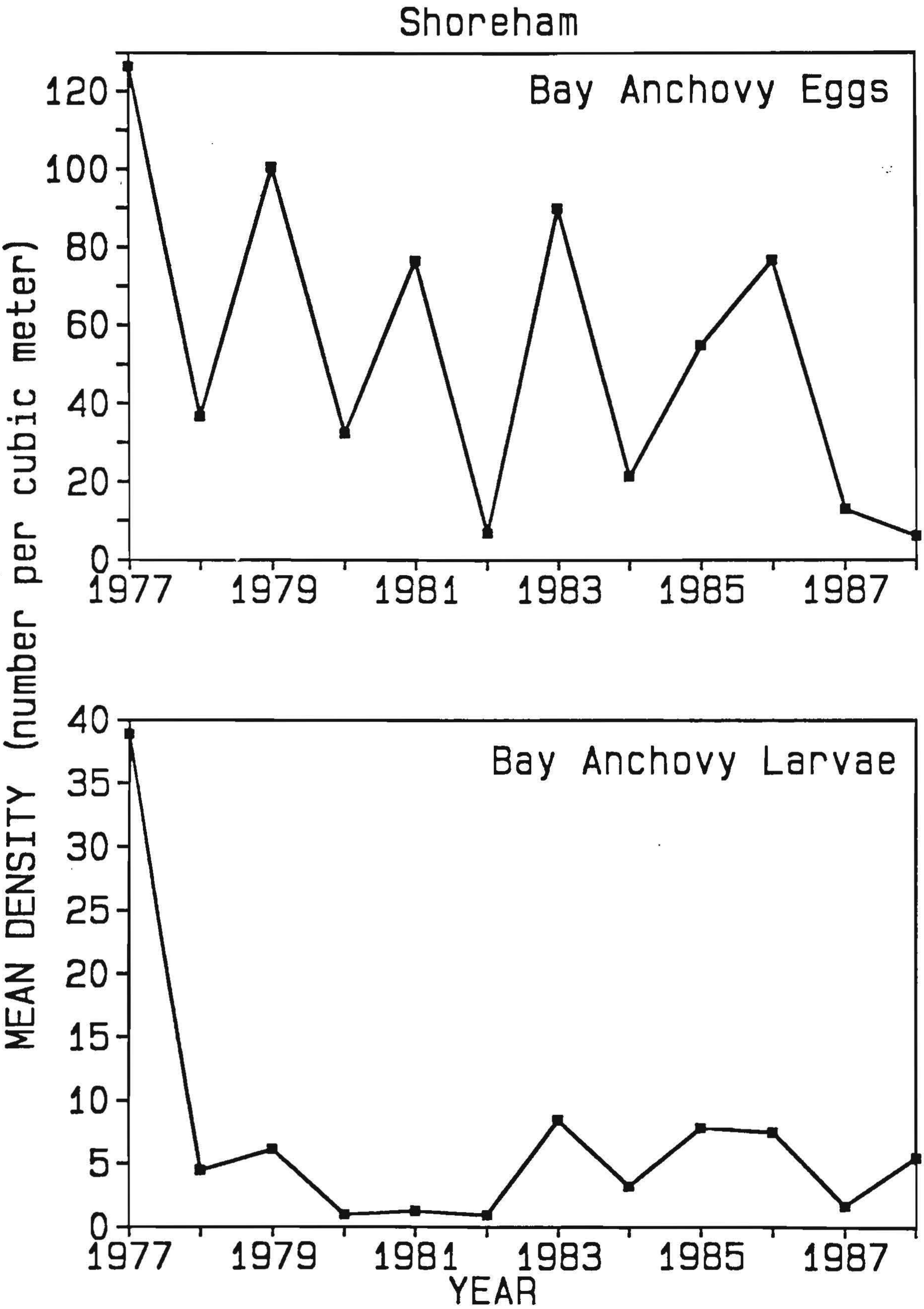
Bay anchovy eggs have characteristically been collected from May through August or September in Long Island Sound (Boampong, 1984; Monteleone, 1988; EA, 1988). The peak spawning period for bay anchovy is June-July. The eggs tend to be found in the surface waters (Williams, 1968) and, therefore, are probably not directly affected by hypoxia under calm conditions. The larvae, however, are thought to penetrate deeper in the water column and may reach depths of lowered oxygen concentrations (Boampong, 1984). It is possible that larvae may be confined to the upper layers of the water column because they are avoiding the lower oxygen levels. In that case, that the larvae would not be able to undergo a vertical migration and may be more exposed to predators. This phenomenon has not been studied.

Near Shoreham, bay anchovy have consistently ranked among the top two larval taxa collected from 1977-86 (LILCO, 1987). Annual densities throughout the years have varied from a high of 38.8 m^{-3} in 1977 to a low of 0.8 m^{-3} in 1982 (Fig. 1.5.2; LILCO, 1987). LILCO (1988) attributed this variability to several factors including changes in adult biomass, changes in environmental parameters, mortality, predation and sampling bias.

1.5.4. Atlantic silversides (<u>Menidia menidia</u>)

The Atlantic silverside, a permanent resident of Long Island Sound, spawns in May, June and July in shallow, coastal areas of Long Island Sound

Fig. 1.5.2. Mean annual density of early life stages of bay anchovy (<u>Anchoa mitchilli</u>) collected with 363 um plankton nets off Shoreham, NY (LILCO, 1979, 1980, 1981, 1982, 1983; EA, 1987, 1988, 1989a).



(Bigelow and Schroeder, 1953; Wheatland, 1956). The eggs have sticky filaments which mat together or attach to plant material or sand and can not be quantified by plankton tows. There has been no quantification of abundance of silverside eggs in the Sound.

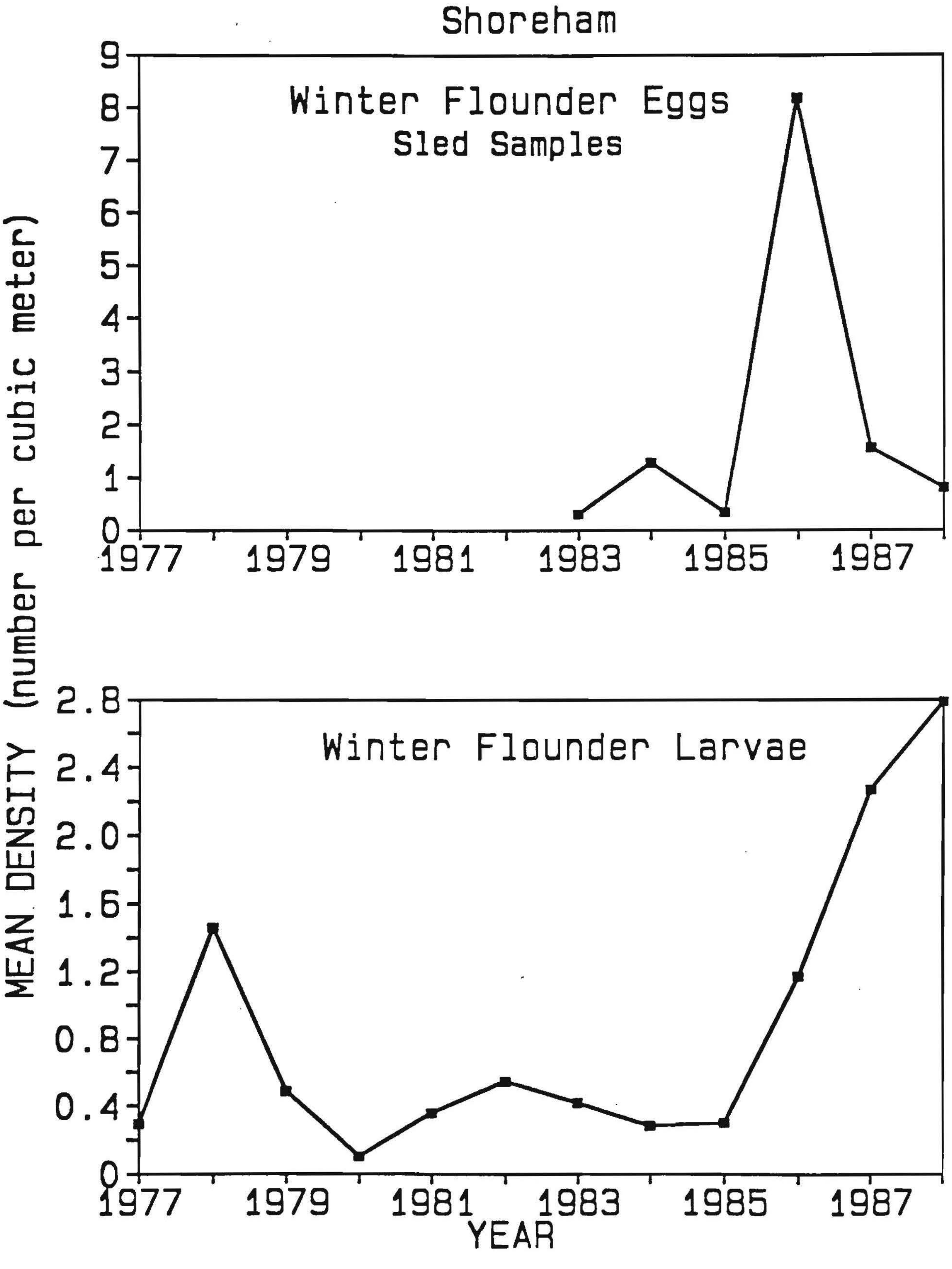
Silverside larvae tend to remain in brackish, shallow areas containing vegetation (Wheatland, 1956). Because they remain close to shore, in the vicinity salt marshes, silversides are not well represented in the plankton collections despite their high abundance as later stages in beach seines (see forage fish section). Because they have an affinity for shallow water, they are less likely to be exposed to the hypoxic conditions of deep sections of the Sound, but they may be exposed to localized hypoxic events sometimes experienced along the shores.

1.5.5. Winter flounder (*Pleuronectes americanus*)

Winter flounder spawn in February to May (Wheatland, 1956; LILCO, 1979-83). Their eggs are negatively buoyant and are only rarely collected in plankton nets. EA (1987-90) was able to sample winter flounder eggs using an epibenthic sled fitted with a 363 um mesh plankton net. They found that from their 1983 through 1988 surveys, there was a peak of over 8 eggs m^{-3} in 1987 (Fig. 1.5.3). Annual densities were typically 0.5-2 eggs m^{-3}. The time series of abundance of winter flounder larvae off Shoreham shows a period of lower abundance from 1978-1985 with a steady increase from 1985 through 1988 (Fig. 1.5.3; LILCO, 1979-83; EA, 1987-90). The 1952-54 soundwide survey reported no spatial center of abundance of winter flounder spawning (Wheatland, 1956).

In Long Island Sound, peak abundances of winter flounder larvae tend to

Fig. 1.5.3. Mean annual density of early life stages of winter flounder (Pleuronectes americanus) collected off Shoreham, NY. Demersal eggs were sampled with an epi-benthic sled (363 um mesh) while the larvae were sampled with a 363 um plankton net (LILCO, 1979, 1980, 1981, 1982, 1983; EA, 1987, 1988, 1989a).



occur in April when the water temperature is 5.6 to 13.3°C (Wheatland, 1956; LILCO 1979-83; EA, 1987-90). Because they spawn early in the year, the eggs and larvae are not exposed to hypoxic conditions. However, later in the year, when the juveniles metamorphose and aggregate on the bottom ,they may encounter hypoxic waters.

1.5.6. Tautog (<u>Tautoga onitis</u>)

In Long Island Sound, the tautog (blackfish) spawning season extends from May until mid-August (Wheatland, 1956; LILCO, 1979-83) at temperatures between 10 and 26°C. Though tautog spawn throughout the Sound, Wheatland (1956) found spatial differences in 1952-54. Spawning at the western end was almost as great as the eastern end, but the central area was considerably less than at either end.

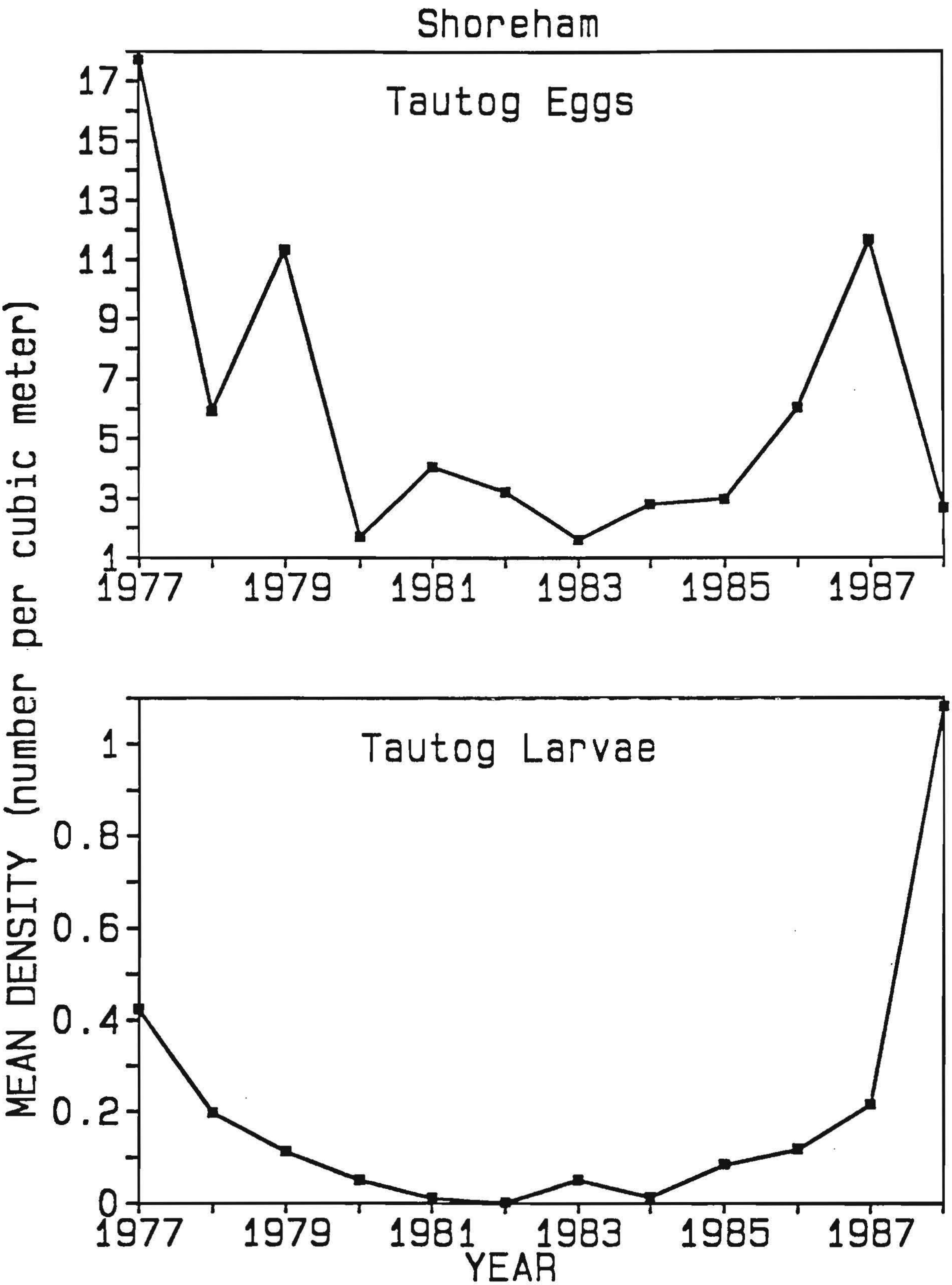
The Shoreham time series (1977-1988) shows variability in the abundance of both tautog eggs and larvae (Fig. 1.5.4). From 1980 through 1984 densities of both eggs and larvae tended to be lower.

Early life stages of tautog may be exposed to hypoxic waters. Tautog eggs tend to be most abundant in the surface waters down to 5 m (Williams, 1968) and may not be exposed to hypoxic deep waters. However, they may encounter localized hypoxic conditions in nearshore areas. Nothing is known about the vertical distribution of the larvae. If they undergo vertical migration, they may be impacted by water of low dissolved oxygen.

1.5.7. Bluefish (<u>Pomatomus saltatrix</u>)

Bluefish do not spawn in Long Island Sound but on the continental shelf

Fig. 1.5.4. Mean annual density of early life stages of tautog (Tautoga onitis) collected 363 um plankton nets off Shoreham, NY (LILCO, 1979, 1980, 1981, 1982, 1983; EA, 1987, 1988, 1989a).



(Kendall and Walford, 1979). Juveniles begin to appear in the Sound in early July (Nyman and Conover, 1988). Little information has been collected on the distribution and abundance of juveniles in the Sound because of their avoidance capability of most sampling gear. However, these juveniles, commonly known as snappers, are quite abundant and are a prized sportfish.

1.6. ADULT AND JUVENILE FORAGE FISHES

1.6.1. American sand lance (_Ammodytes_ _americanus_)

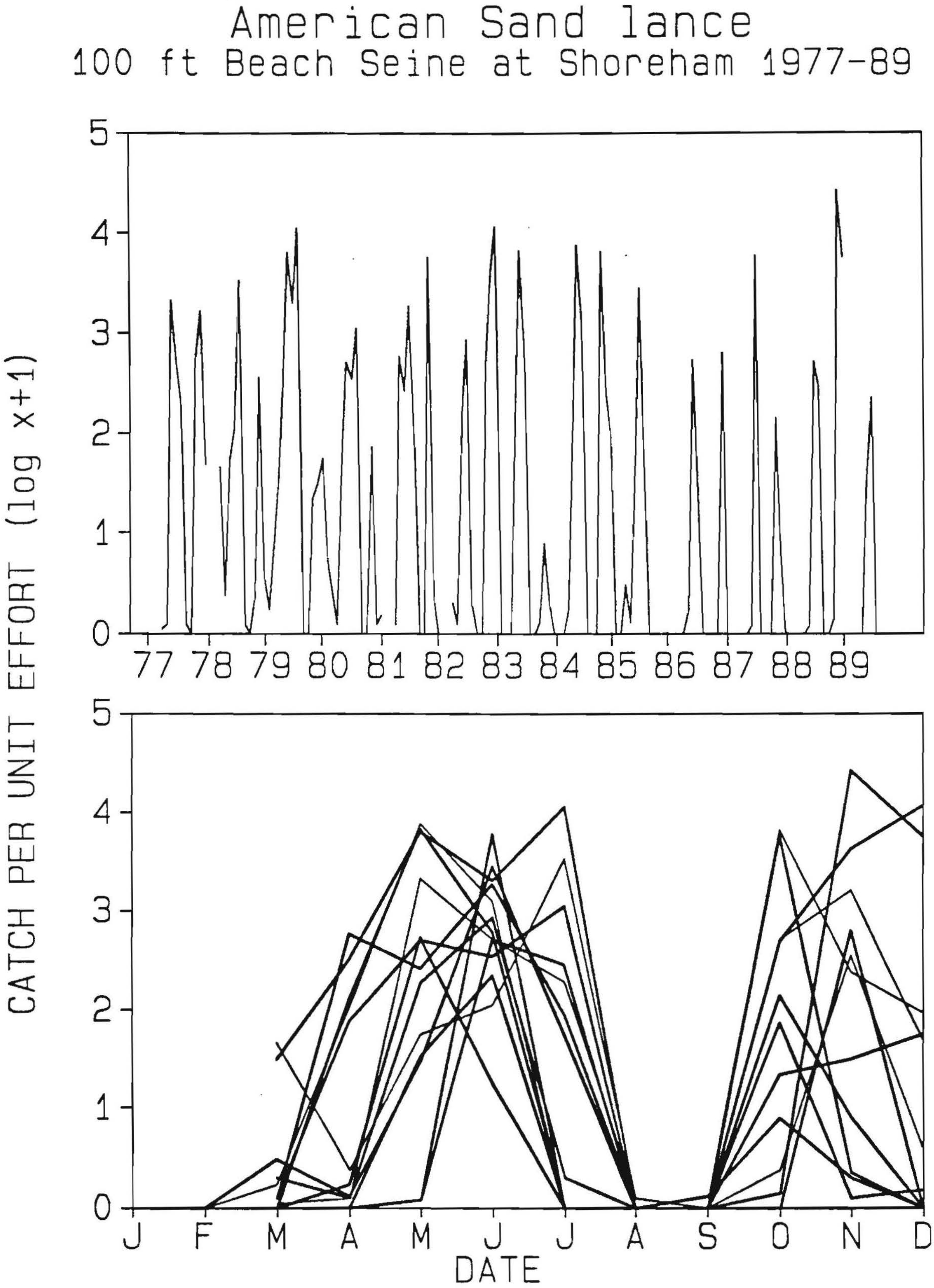
American sand lance, also known as sand eels, are small schooling fish common in New York estuaries (Williams _et_ _al._ 1964; McKown, 1984; Monteleone _et_ _al._, 1987; Monteleone, in press). Sand lance are slender fish that reach a maximum of 22 cm and 2 to 3 years of age (Reay, 1970). When sand lance metamorphose from larvae to juvenile stages they leave the water column and aggregate on sandy substrates. They derive their name from their curious habit of digging themselves into the sand. As planktivorous fish (Reay, 1970; Sekiguchi, 1978), they feed primarily on copepods, especially _Temora longicornis_ (Covill, 1959; Richards, 1963; McKown, 1984).

Sand lance have consistently ranked as a dominant fish species in Long Island Sound. Bireley (1984) sampled with a beach seine in February, May, July, September and December (1969-1974) off the Millstone Nuclear Power Station in Niantic Bay, CT and found that sand lance ranked second (10.46%) in abundance in the nearshore finfish assemblage. The LILCO (1979-83) studies used several types of gear to sample finfish off Shoreham, NY, including baited pots, beach seine and otter trawl and found that in 1982 sand lance ranked number one representing 69.8% of the total number of fish collected. Not surprisingly, sand lance were found primarily in beach seines. In these samples, they ranked second in biomass to bay anchovy and accounted for 41.3% of the total number. These fish may have been undersampled at certain times of the year because of their habit of digging themselves into the sand (Bigelow and Schroeder, 1953; McKown, 1984; NUSCO, 1989).

Although always relatively abundant, sand lance populations have exhibited wide fluctuations in abundance. Beach seine data are available to examine interannual fluctuations of the sand lance population off Shoreham (LILCO 1977-90; Fig. 1.6.1). The catch per unit effort (CPUE) represents the mean of 4 hauls of a 100 ft beach seine. These data, from 1977-1989, show that the peak abundance of sand lance has fluctuated by more than an order of magnitude with no apparent trend in the time series. It is interesting to note that the abundance of sand lance was much less in the beach seine collections from 1976-89 on the Connecticut shore (NUSCO, 1989). The maximum annual catch using similar collection methods was 520 fish in 72 samples (1977-78).

On a seasonal basis, sand lance begin to be collected in beach seines in early spring. At this time the young-of-the-year (YOY) juveniles begin to recruit into schools. Abundance peaks in late-spring and mid-summer followed by a sharp decline in August. It is believed that this late summer decline is observed as the sand lance migrate to deeper water to avoid the elevated water temperatures of the shallows. In the deeper waters they are thought to "hibernate" by burying in the sand (S.W. Richards, Little Harbor Laboratory, pers. comm.). By hibernating, sand lance may be able to withstand hypoxic conditions that frequently occur in the bottom waters during the late summer-early autumn. However, this phenomenon has not been studied. When

Fig. 1.6.1. Catch-per-unit-effort of American sand lance (*Ammodytes americanus*) juveniles and adults off Shoreham, NY. Upper panel is catches from 1977 through 1989. Lower panel is shows annual trends by month.



surface water temperature drops and the water column mixes in September, the adults return to shallow water. These adults represent the population which spawns in November and December. It is uncertain if sand lance adults are present in shallow water in January and February because sampling for adults has been limited during the winter months.

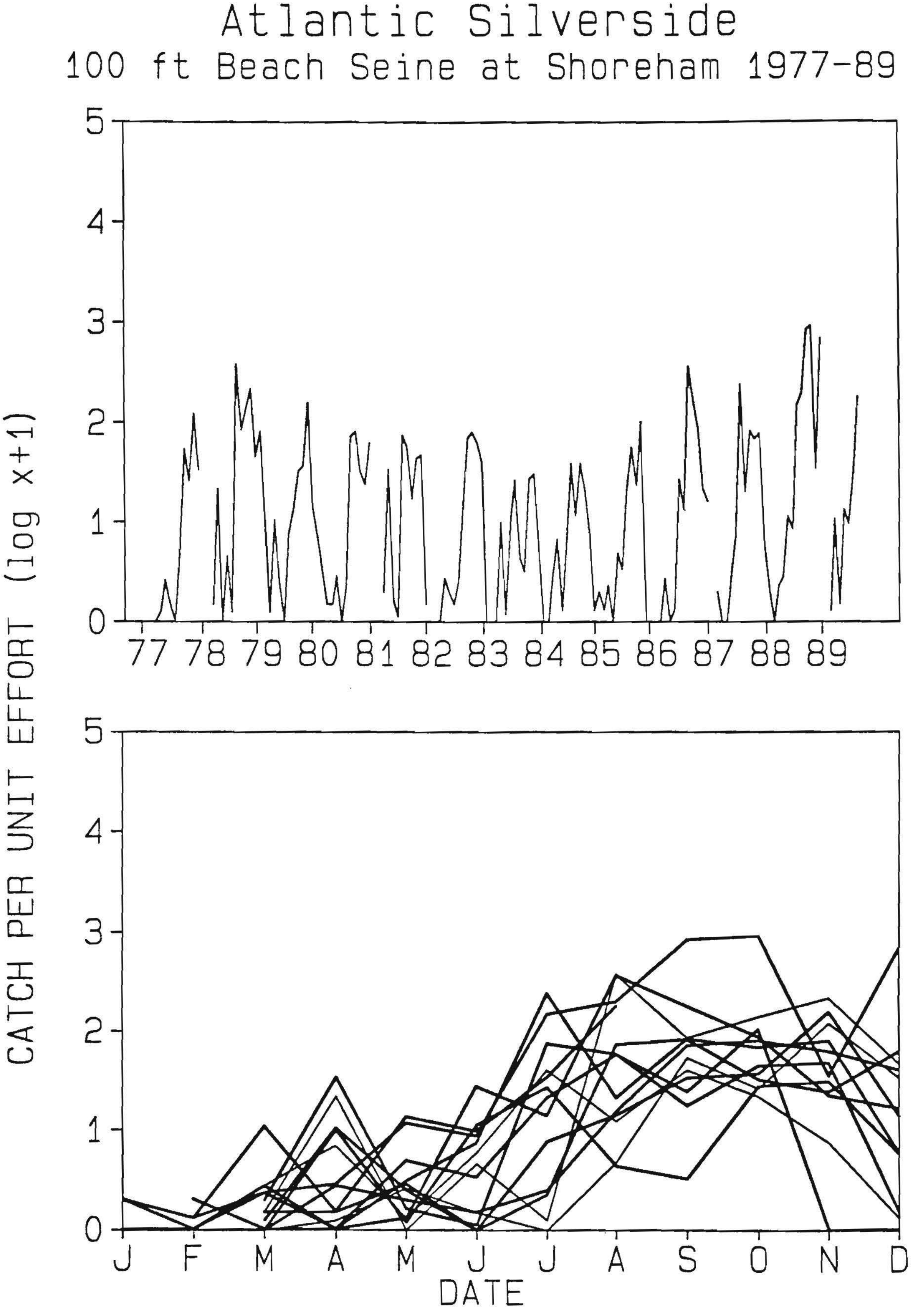
1.6.2. Atlantic silverside (*Menidia menidia*)

Atlantic silversides are also small (maximum 14 cm total length) schooling fish and live from 1 to 2 years (Bigelow and Schroeder, 1953). LILCO (1974) found the Atlantic silverside to be a year-round resident of Long Island Sound. Their diet varies little throughout the year, feeding primarily on copepods, cirripedia (planktonic stage of barnacle), amphipods and insects (LILCO, 1982).

In a summary of finfish collected in 1982 by LILCO (1983), Atlantic silverside ranked fifth, representing 1.6% of the total number. In the beach seine collections, they ranked fourth in number representing 2.5% of the total. The trends in abundance of silversides could be constructed from available data collected near Shoreham. During the 1977-89 LILCO surveys, the peak abundance of silversides has fluctuated by an order of magnitude (Fig. 1.6.2). The data reveal a possible cyclic tendency with higher abundances in the late 1970s, a low period in the early 1980s, followed by an increase through the late 1980s.

The seasonal trends in CPUE of silversides off Shoreham (LILCO 1977-90) show a consistent increase in beach seine catches of silversides from the beginning of the year through September-October followed by a relatively rapid decrease (Fig. 1.6.2). NUSCO (1983) found silversides in the shore zone near

Fig. 1.6.2. Catch-per-unit-effort of Atlantic silverside (<u>Menidia menidia</u>) juveniles and adults off Shoreham, NY. Upper panel is catches from 1977 through 1989. Lower panel is shows annual trends by month.



the Millstone Power Plant, Niantic CT primarily from November through May. Young-of-the-year silversides (20-50 mm) dominated the summer seine catches while adult fish (60-120 mm) were abundant in the trawl and impingement collections. Silversides tend to remain inshore during the warmer months and only swim into deeper water to avoid low temperatures (Bigelow and Schroeder, 1953). Because this species is in relatively shallow and better mixed water during the summer months, they are perhaps not usually exposed to hypoxic conditions.

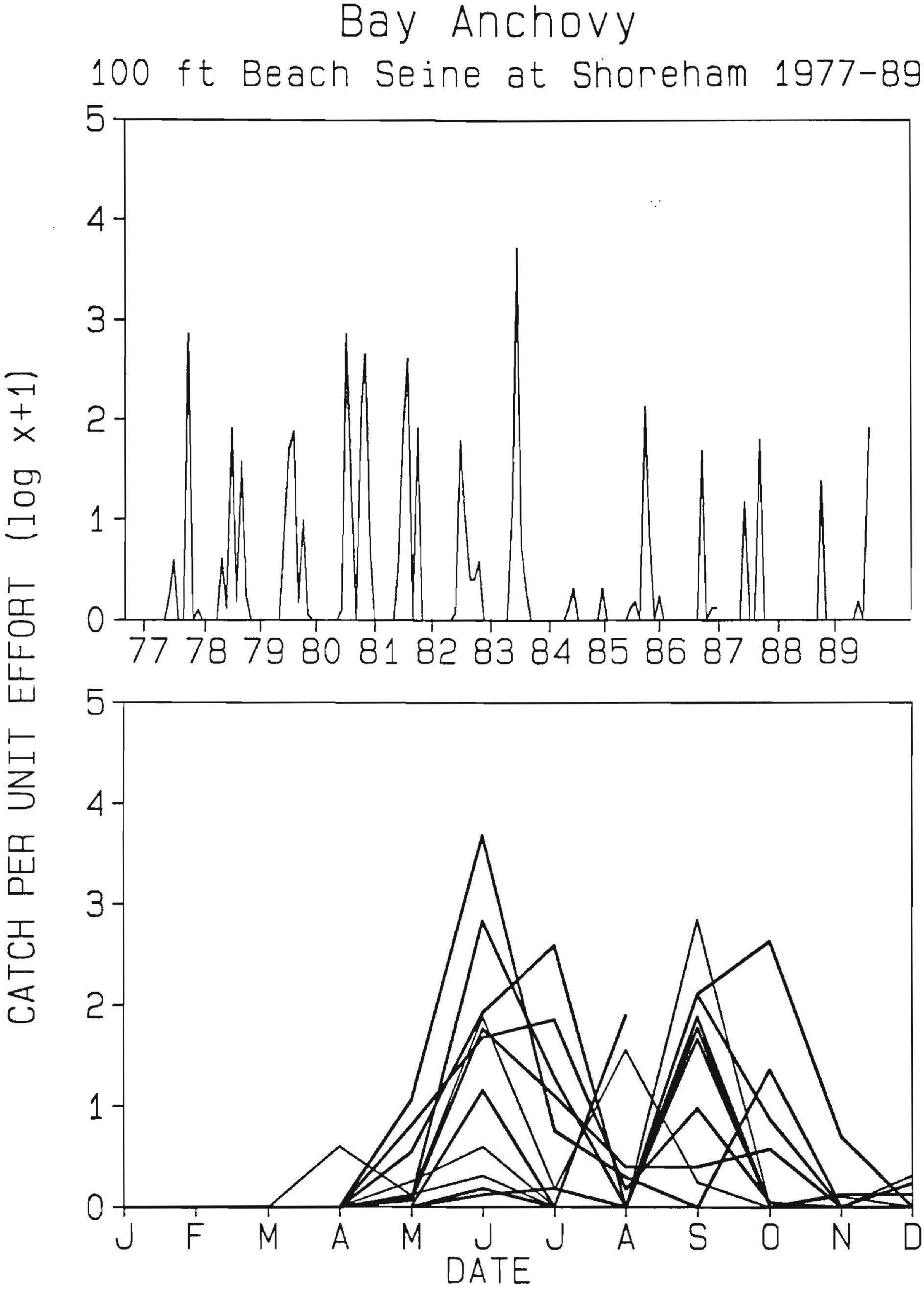
1.6.3. Bay anchovy (Anchoa mitchilli)

Like sand lance and silversides, bay anchovy also are schooling fish. They reach a maximum length of 7.5 cm and are selective particle feeders consuming copepods, decapod shrimp, crab zoea, amphipods and barnacle cyprids (Johnson et al., 1990). They can often be seen feeding at the water surface (Monteleone, pers. obs.).

The data collected on the abundance of bay anchovy in the beach seine samples taken off Shoreham, NY (Fig. 1.6.3) illustrate that the bay anchovy population has gone through dramatic fluctuations in abundance over the 14 year sampling period. The CPUE has varied by over 3 orders of magnitude.

Abundance of bay anchovy in the Shoreham collections varies seasonally (LILCO, 1977-90; Fig. 1.6.3). During the colder months (January-March), Bay anchovy tend to be in deeper waters and are not collected in beach seines. Adults move into shallow water by April-May to spawn during May-July. During August, bay anchovy may be exposed to hypoxic conditions as this is when they are completing spawning and moving into deeper waters. The fall peak in bay anchovy abundance is due to numeric contribution by YOY juveniles (NUSCO,

Fig. 1.6.3. Catch-per-unit-effort of bay anchovy (<u>Anchoa</u> <u>mitchilli</u>) juveniles and adults off Shoreham, NY. Upper panel is catches from 1977 through 1989. Lower panel is shows annual trends by month.



1983). The numbers decrease in late fall as the population returns to offshore waters. This migration pattern has been reported for New York and New Jersey populations of bay anchovy (Grosslein and Azarovitz, 1982; Vouglitois et al., 1987).

1.6.4. Long-finned Squid (Loligo pealei)

Long-finned squid (Loligo pealei) are common from Cape Hatteras to Cape Cod (Gosner, 1978). Squid are one of the few invertebrates that are sufficiently strong swimmers to be qualified as nekton. Their mantle can reach a length of 425 mm.

Long-finned squid occur seasonally in Long Island Sound. They appear in the inshore warmer water in the early summer and leave to return offshore in late fall (Fig. 1.6.4). This trend is obvious in the catch-per-unit-effort by otter trawl in the Shoreham area. It is likely that during the summer, long-finned squid may encounter hypoxic conditions which might limit their migration into or use of the water column in the Sound.

Long-finned squid prey on small fishes such as anchovies and young of other fishes (McHugh and Ginter, 1978).

1.7. BENTHOS

1.7.1. Western Long Island Sound

The most extensive benthic survey of Long Island Sound was conducted by the National Marine Fisheries Service during the early 1970's. Faunal results

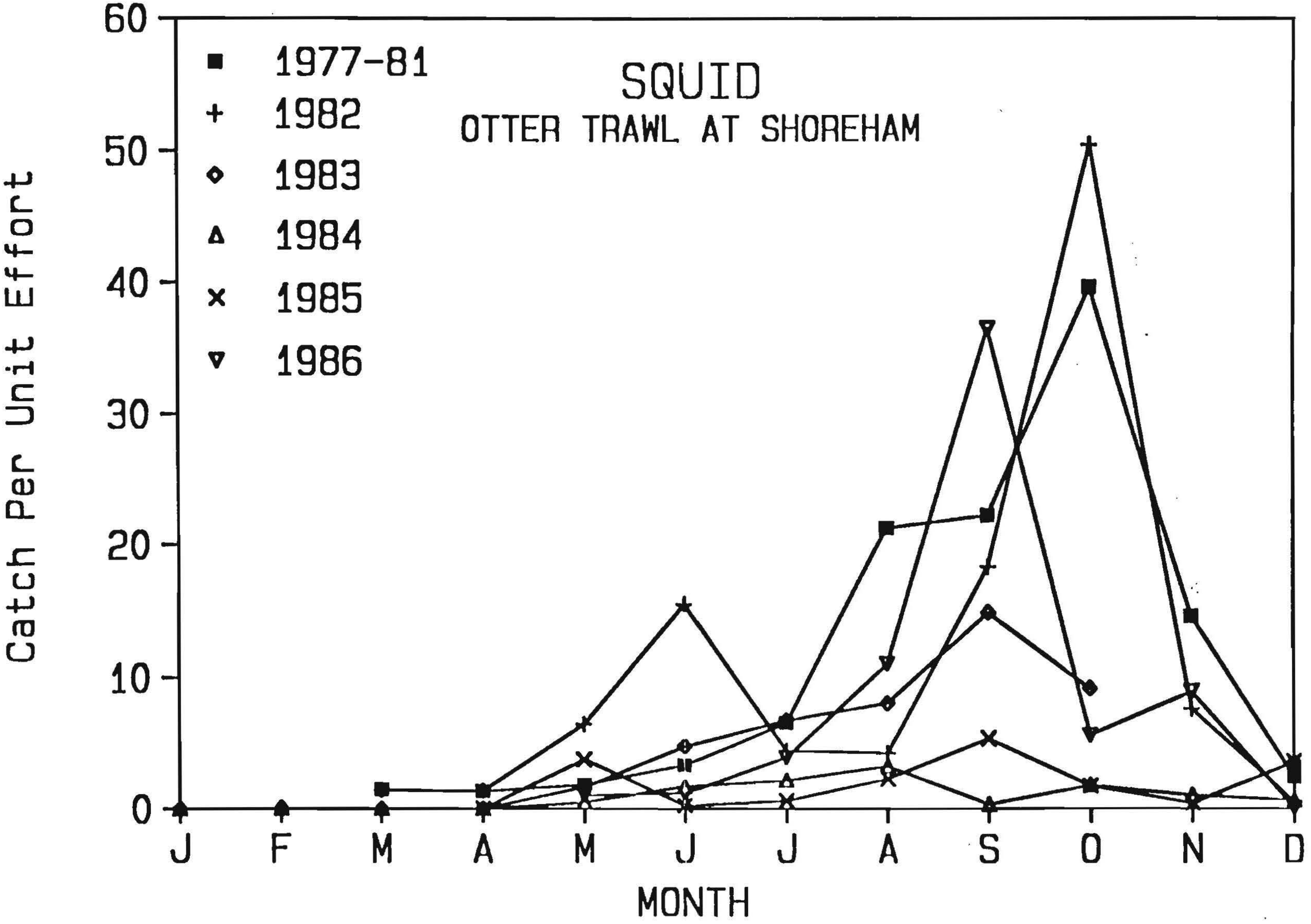


Fig. 1.6.4. Monthly catch-per-unit-effort of long-finned squid (<u>Loligo pealei</u>) off Shoreham, NY.

from this study have been reported in several places (NMFS, 1974; Reid 1979; Reid *et al.*, 1979). The principal collecting period was in the summer of 1972 when Smith-McIntyre grabs were taken at 142 stations distributed throughout Long Island Sound. Samples were sieved through a 1 mm mesh screen. Subsequent surveys resampled a fraction of the original stations in April and September 1973, September 1975 and 1976, and July 1977 and 1978.

Water and sediment samples collected during this survey indicated that the western end of Long Island Sound, from Hempstead Harbor to Throgs Neck, contained the highest concentrations of contaminants and was apparently the most heavily stressed area (NMFS, 1974). Clear evidence of sewage input was present as seen in elevated levels of sediment organics, fecal coliform bacteria, and heavy metals. Water column nutrients (i.e., nitrate, ammonium, urea, and orthophosphorus) were also highest in the western end. Some of the sediment contaminants such as chromium, copper, nickel, lead, and zinc were found to be higher in western Long Island Sound than at the dredge spoil and sewage sludge disposal sites in the New York Bight (NMFS, 1974).

Dissolved oxygen levels in summer 1972 followed an inverse relationship with nutrient concentrations (NMFS, 1974; Reid *et al.*, 1979). Hypoxic conditions were recorded in western Long Island Sound, and DO levels fell below 2 mg/l at two stations. NMFS (1974) cites a U.S. Fish and Wildlife Service report (Anon. 1973), which we have not been able to find, which describes the occurrence of periodic fish kills in western Long Island Sound. They provide as an example, a die-off of 35,000 menhaden during August 1970.

The National Marine Fisheries Service analysis of the Summer 1972 faunal data indicated that the benthos could be subdivided into three faunal assemblages based on depth, sediment type, and geographic location (NMFS, 1974; Reid *et al.*, 1979). These faunal assemblages were: 1) a muddy ($\geq$69%

silt-clay), deep-water (>15 m) group located in the central and western Sound, 2) a shallow-water (≤6.1 m), sand (≤3.7% silt-clay) group distributed along the Long Island coast, and 3) a transitional assemblage associated with stations intermediate between the shallow-sand and deep-muddy habitats.

The dominant fauna from each of these benthic assemblages are listed in Table 1.7.1. Based on our analysis of the sources listed in Table 1.1.2, this characterization of the benthos appears to be fairly consistent with most of the other benthic studies conducted in Long Island Sound. The only modifications to this list which we would suggest would be to include the polychaete Capitella capitata in each assemblage, to include the bivalve Tellina agilis in the muddy, deep-water group, and to possibly exclude the gastropod Cylichna oryza from the list. Capitella capitata is a pioneering or early colonizing species which is often an important dominant in recently disturbed habitats in Long Island Sound (McCall, 1977; Rhoads et al., 1978). Results from Aller et al. (1991) suggest that Tellina agilis has become a dominant species in muddy areas. The gastropod Cylichna orza is not reported as a dominant in other Long Island Sound studies. It is not clear whether this is due to a change in the distribution and abundance of this species, or whether it is the result of differences in taxonomic classification.

The National Marine Fisheries Service analysis of the Summer 1972 data set also indicated that faunal composition in western Long Island Sound at all depth and sediment strata differed from comparable stations further to the east (NMFS, 1974). A greater dominance of polychaetes was found at the western stations at the expense of molluscs and amphipods. The dominant polychaetes included those that are often found to be prominent in organically enriched areas (e.g., Polydora, Streblospio, Mediomastus, and Capitella) (Pearson and Rosenberg, 1978). Species richness and diversity were found to

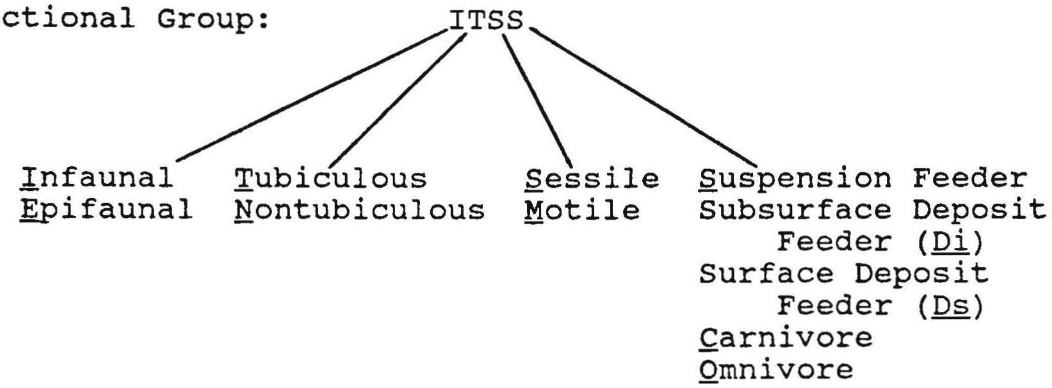
Table 1.7.1. Dominant taxa in various sediment regimes in Long Island Sound as listed by Reid et al. (1979). Also listed are the functional group characteristics for each species.

	Sediment Group	Functional Group
Cnidaria		
Anthozoa		
Ceriantheopsis americanus	M	ITSS
Annelida		
Polychaeta		
Ampharete arctica	S,T	ITSDs
Mediomastus ambiseta	T	ITMDi
Tharyx acutus	T	INMDs
Pherusa affinis	M,T	INMDs
Glycera americana	T	INMC
Nephtys incisa	M	INMC
Nephtys picta	S	INMC
Nereis succinea	T	ITMDs
Aricidea catherinae	S	INMDi
Owenia fusiformis	S	ITMS&Ds
Asychis elongata	M	INMDi
Pectinaria gouldii	T	ITMDi
Eumida sanguinea	T	ENMC
Polydora ligni	M,T	ITMDs
Spiophanes bombyx	S,T	ITMDs
Streblospio benedicti	T	ITMDs
Mollusca		
Gastropoda		
Acteocina canaliculata	M	ENMC
Cylichna oryza	M	ENMC
Crepidula fornicata	S	ENSS
Nassarius trivittata	M,S,T	ENMO
Bivalvia		
Lyonsia hyalina	M	INSS
Mulinia lateralis	M	INSS
Spisula solidissima	S	INMS
Yoldia limatula	M	INSDi
Nucula proxima	M	INMDi
Pandora gouldiana	M	INSS
Ensis directus	S,T	INMS
Tellina agilis	S,T	INSDs
Pitar morrhuana	M	INSS
Arthropoda		
Amphipoda		
Ampelisca abdita	M,T	ITSDs
Ampelisca vadorum	S,T	ITSDs
Unciola irrorata	S,T	ETMDs
Paraphoxus epistomus	S	INMDi
Cumacea		
Oxyurostylis smithi	M,S,T	
Decapoda		
Cancer irroratus	M	ENMO
Crangon septemspinosa	M,S,T	ENMO
Pagurus longicarpus	S,T	ENMO
Echinodermata		
Asterias forbesii	T	ENMC

Table 1.7.1. Continued

KEY
Sediment Group:
M = Mud
S = Sand
T = Transitional

Functional Group:


ITSS

Infaunal
Epifaunal

Tubiculous
Nontubiculous

Sessile
Motile

Suspension Feeder
Subsurface Deposit Feeder (Di)
Surface Deposit Feeder (Ds)
Carnivore
Omnivore

be lower (but not significantly so) than less perturbed areas further east. However, macrofaunal abundances were high and species that are sensitive stress indicators (e.g., amphipods) still occurred at the western stations. The NMFS (1974) report concludes that high levels of stress were present in western Long Island Sound but the benthos seemed to be "much less impoverished or altered than that of local systems which appear to be under similar stresses - Raritan Bay (McGrath 1974) and portions of the New York Bight (Pearce 1972)."

Results of other studies in western Long Island Sound during the 1970's agree fairly well with the National Marine Fisheries Service's characterization of the benthos. Alexander and D'Agostino (1972) and NMFS (1972) collected benthic samples in the Execution Rocks - Davids Island area during 1971-72. The macrofauna were dominated by the polychaetes _Streblospio benedicti_, _Mediomastus ambiseta_, and _Scoloplos_ sp., while bivalve and amphipods were less numerous than in more eastern areas. EA (1975) and Fallon (Kemron Environmental Services, Inc., pers. comm.) report the results of a benthic survey during 1974-75 near Hart Island. Annelids comprised about 80% of the total fauna. Dominant macrofauna in sandy sediments included the polychaetes _Mediomastus ambiseta_ and _Polydora_ spp. In sandy-mud and mud sediments, the dominants were _Mediomastus ambiseta_, _Streblospio benedicti_, _Nepthys_ spp., and _Polydora_ spp. The other less common taxa were represented by the gastropod _Nassarius trivittatus_ (all sediment types), the bivalves _Tellina agilis_ (sand and sandy-mud), _Nucula proxima_ (sandy-mud and mud), and _Yoldia limatula_ (mud), and the crustaceans _Ampelisca_ spp. (all sediments), _Corophium_ spp. (sand and sandy-mud), and _Crangon septemspinosa_ (sand and sandy-mud).

Only two studies, EBASCO (1986) and Aller _et al._ (1991), provide recent data on the benthic fauna in western Long Island Sound. Both show notable differences from earlier studies. EBASCO (1986) collected benthic samples along several potential power cable routes across Long Island Sound in a triangular area bounded by Hewlett Point and Hempstead Harbor in Nassau County and Echo Bay in Westchester County. Samples were collected from April to June 1986. Polychaetes represented over 83% of the total fauna. *Aricidea* sp. and other members of the polychaete family Paraonidae were the dominant taxon present. This is in contrast to the dominance by Spionids (e.g., *Polydora* and *Streblospio*) found by NMFS (1974). The bivalve *Mulinia lateralis* and the amphipod *Ampelisca vadorum* were both common and ranked 4th and 5th, respectively, in overall abundance.

Aller *et al.* (1991) sampled the benthos seasonally from May 1988 to April 1989 at 7 reference stations distributed throughout Long Island Sound. Two of these stations (A and C) were located in the western Sound. Results indicate that the benthic fauna at both of these stations appears to be fairly impoverished, with unusually low abundance (7 - 506 ind/m^2 for A and 73 - 1259 ind/m^2 for C) and species richness (1 - 5 species for A and 4 - 9 for C) values occurring throughout the year. Bivalves (*Mulinia lateralis* and *Tellina agilis*) dominated the fauna at these western stations, and polychaetes were considerably reduced when compared to prior studies. *Nepthys incisa* was the only polychaete found at station A and the only polychaete collected throughout the year at station C. At stations further to the east (G and K), both abundance and species richness increased considerably. Results of this study will be examined in more detail in a later section of this report (Section 3.3.1).

1.7.2. Evidence for Severe Sound-Wide Hypoxia

The NMFS (1974) study and a concurrent study by Rhoads (1973d) in central Long Island Sound documented the occurrence of a widespread, dramatic "crash" in the benthos between Summer 1972 and Spring 1973. The earliest and most extensive declines were observed at the deep-water, muddy stations (Rhoads, 1973d; NMFS, 1974). By April 1973, species richness in the muddy, deep-water assemblage was halved, and abundances were reduced to 14% of their Summer 1972 values (Reid, 1979). Almost all taxa and all of the dominant fauna (Mulinia lateralis, Polydora ligni, Acteocina canaliculata, Yoldia limatula, and Pitar morrhuana) were affected (Reid, 1979; Reid et al., 1979). The only exceptions to this were the anthozoan Ceriantheopsis americanus, the polychaetes Nepthys incisa and Pherusa affinis, and the bivalve Nucula proxima (Reid et al., 1979). The fauna in the shallower, transitional assemblage underwent a somewhat less severe decline during this period, while the shallow-water, sand assemblage appeared to be unaffected (Reid et al., 1979).

Explanations for this abrupt, severe crash have included the possible occurrence of a major erosion event, trophic group amensalism, competition, predation, and increased pollutant loadings (Rhoads and Michael, 1974; Reid, 1979). In light of the results of the Long Island Sound Study, it is reasonable to propose that this crash may have been the result of widespread hypoxia in late Summer 1972. Mulinia lateralis, which was by far the most abundant species present in the muddy, deep-water assemblage during 1972 (Reid et al., 1979), is especially sensitive to low dissolved oxygen (Shumway et al., 1983). Alternatively, it is also possible that the hypoxia event occurred in 1970-71, and the disturbance resulted in recruitment and dominance by Mulinia and other pioneering species. The 1972-73 decline would then be the result of faunal succession as short-lived opportunists reached the end of their lifespan or were outcompeted. In support of this alternative, Reid (1979) found little further change in the deep-water benthos between 1973 and 1978. A disturbance event, if it occurred in 1972 or 1973, should have been followed by substantial benthic recolonization (e.g., Rhoads et al., 1978).

1.7.3. Long Term Trends in the Benthos

We felt it appropriate to end this section by briefly noting the results of an extensive (12 year) series of benthic samples collected as part of the preoperational study for the Shoreham Nuclear Power Plant (LILCO 1974, 1979-1983; EA 1987, 1989a, 1989b, 1990). Benthic samples were collected at five stations: three in a sandy, shallow (5-6 m) habitat and two at muddy-sand, deep-water (20 m) locations. Five replicate Smith-McIntyre grabs were taken at each station. Samples were washed through a 1 mm sieve.

The Shoreham data may not at first be considered important to an evaluation of potential hypoxia effects since the sampling stations are in the eastern half of the Sound and are nearshore. However, hypoxic conditions do occur at the muddy-sand, deep-water stations (e.g., Figure 1.7.1). Given the length of this time series, analysis of these data could potentially indicate whether long term trends have occurred in the benthos. Since it is in a relatively pristine location compared to the western Sound, these data also provide an opportunity to examine the potential effects of hypoxia without the confounding influence of toxic contaminants being present.

The Shoreham reports (LILCO, 1974, 1979-1983; EA, 1987, 1989a, 1989b, 1990) are basically summaries and for the most part do not contain raw data. Thus, for example, while biweekly dissolved oxygen measurements were taken at

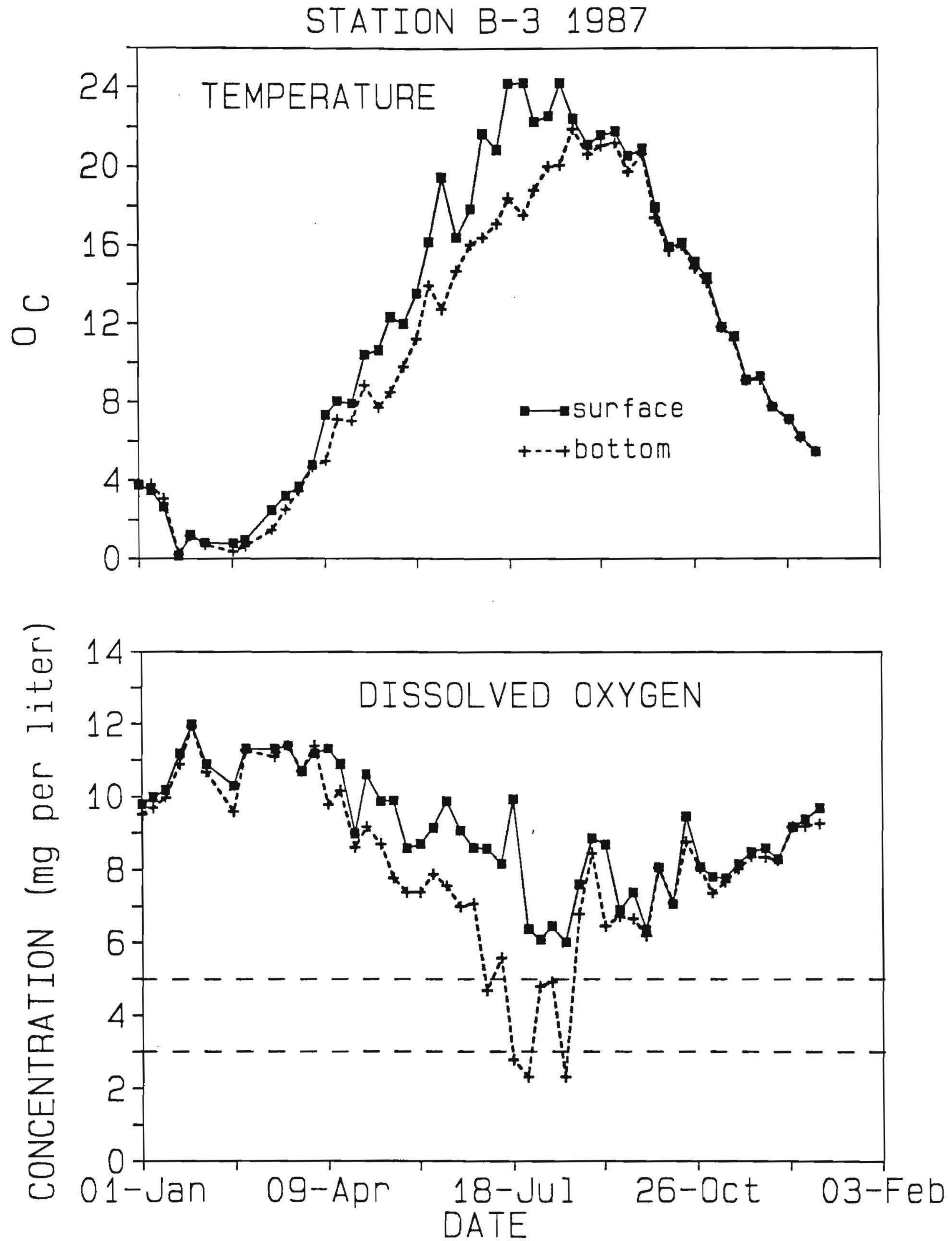


Fig. 1.7.1. Measurements of temperature and dissolved oxygen concentration at the deep water station off Shoreham, NY during 1987.

surface and bottom at each benthic sampling station, the data are usually presented as monthly means or in other forms which did not allow us to piece together the DO conditions over the time series. Presumably, LILCO and the firms contracted to perform these studies have retained all of the raw data. Both time and resources were inadequate in the present study to attempt to obtain these data.

Using all of the reports, the most we were able to accomplish was to assemble the complete time series for the 12 most abundant benthic species (Figures 1.7.2-1.7.13). Three of these species were dominants only at the muddy-sand stations (the bivalves Nucula proxima and Yoldia limatula and the polychaete Nepthys incisa), five were dominants only at the sand stations (the bivalve Spisula solidissima, the polychaetes Nepthys picta and Spiophanes bombyx, and the amphipods Paraphoxus epistomus and Acanthohaustorius millsi), and four species were commonly found in both habitat types (the bivalves Mulinia lateralis and Tellina agilis, the gastropod Nassarius trivittatus, and the polychaete Owenia fusiformis). Most species show evidence for fairly high seasonal variability. The time series for some of the species indicate the presence of long-term cycles in abundance (e.g., Nepthys incisa, Nepthys picta, Acanthohaustorius millsi), while others suggest episodic recruitment (Spisula solidissima and Owenia fusiformis). Without accompanying dissolved oxygen data, no further analysis of these results is warranted at the present time. However, these data do offer a unique opportunity for future study.

1.8. ACKNOWLEDGMENTS

We would like to thank the following for providing data used to compile this report: Thomas Brosnan, New York City Department of Environmental Protection;

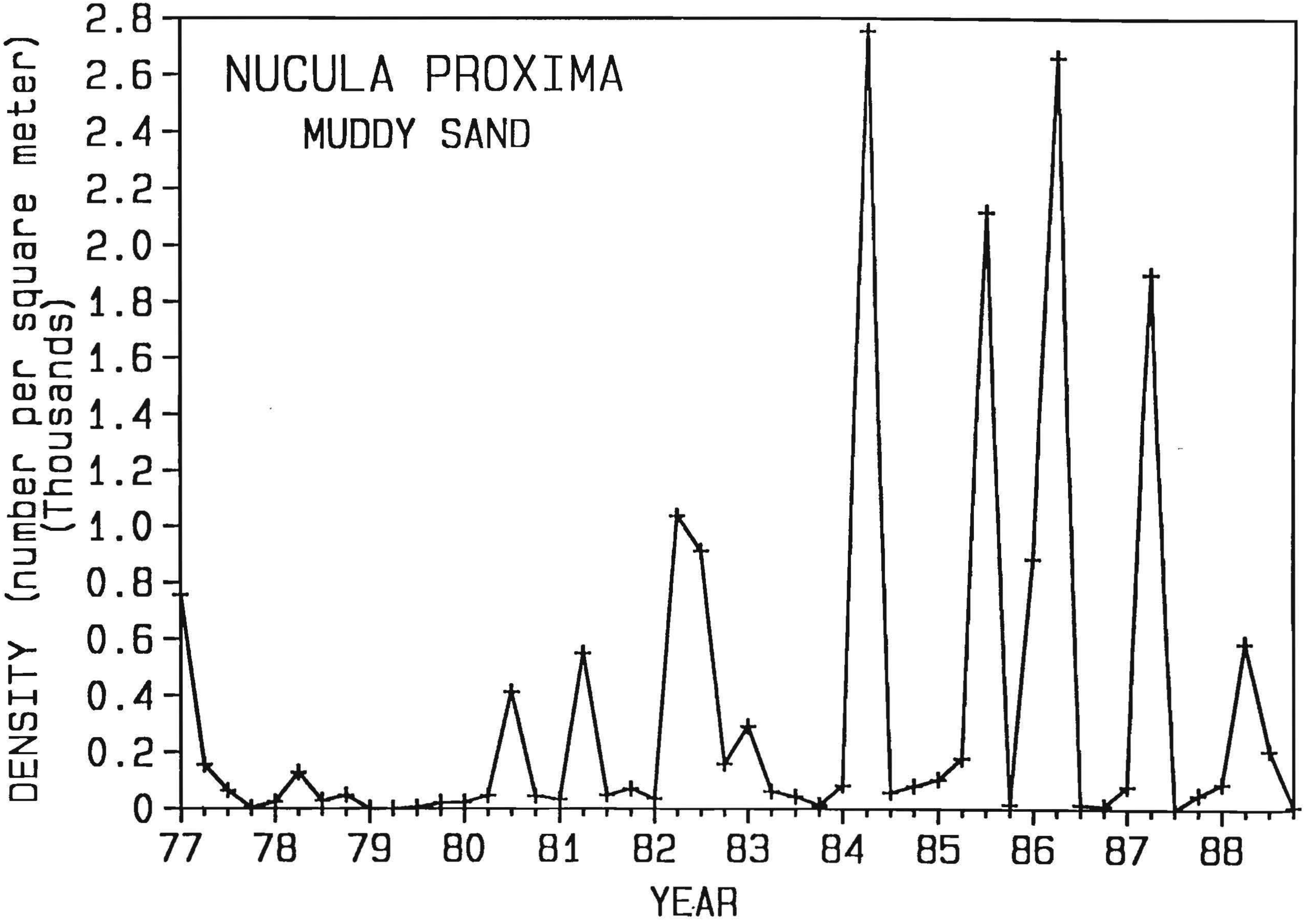


Fig. 1.7.2. Mean seasonal densities of Nucula proxima (near nut shell) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

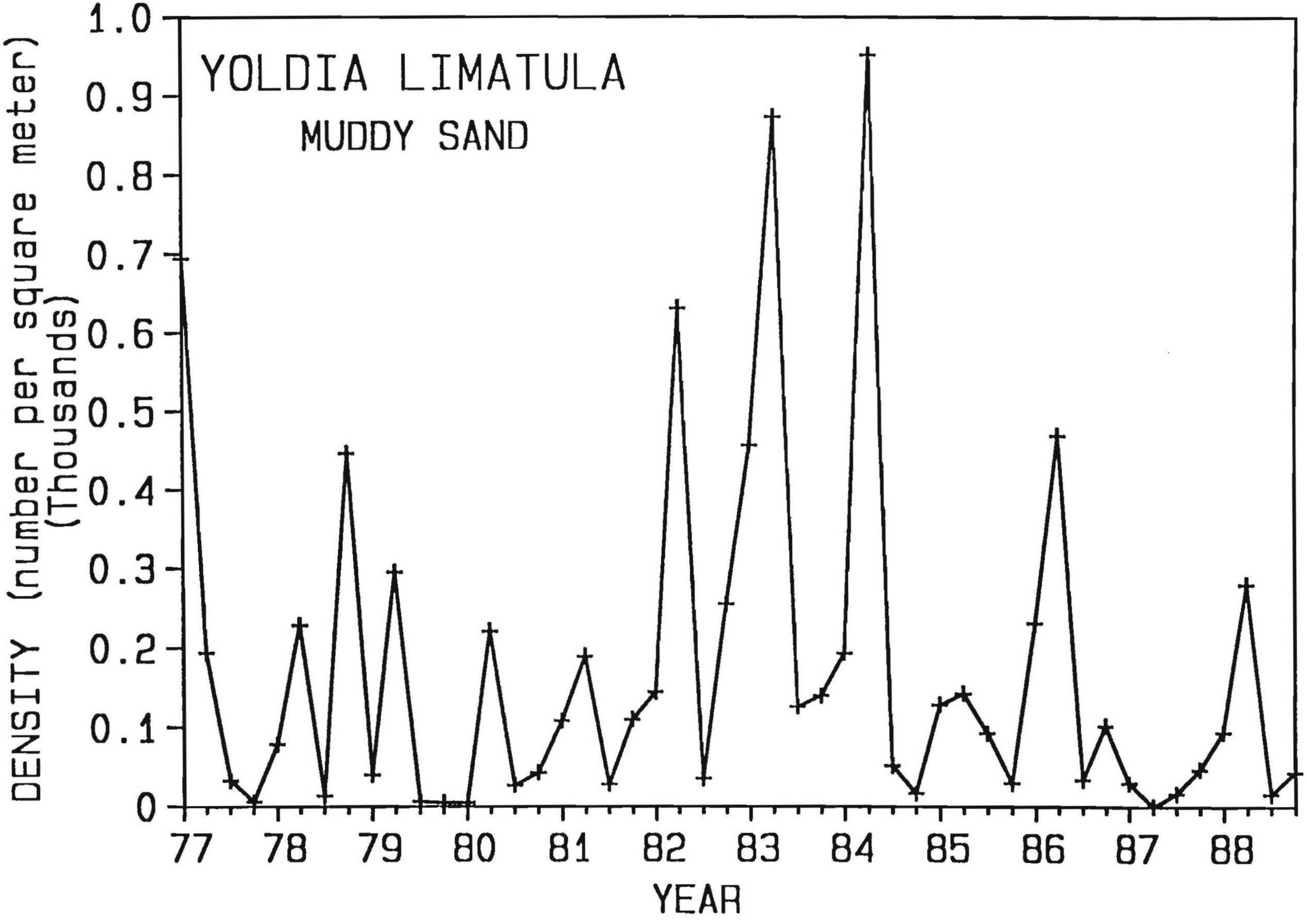


Fig. 1.7.3. Mean seasonal densities of _Yoldia limatula_ (file yoldia) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

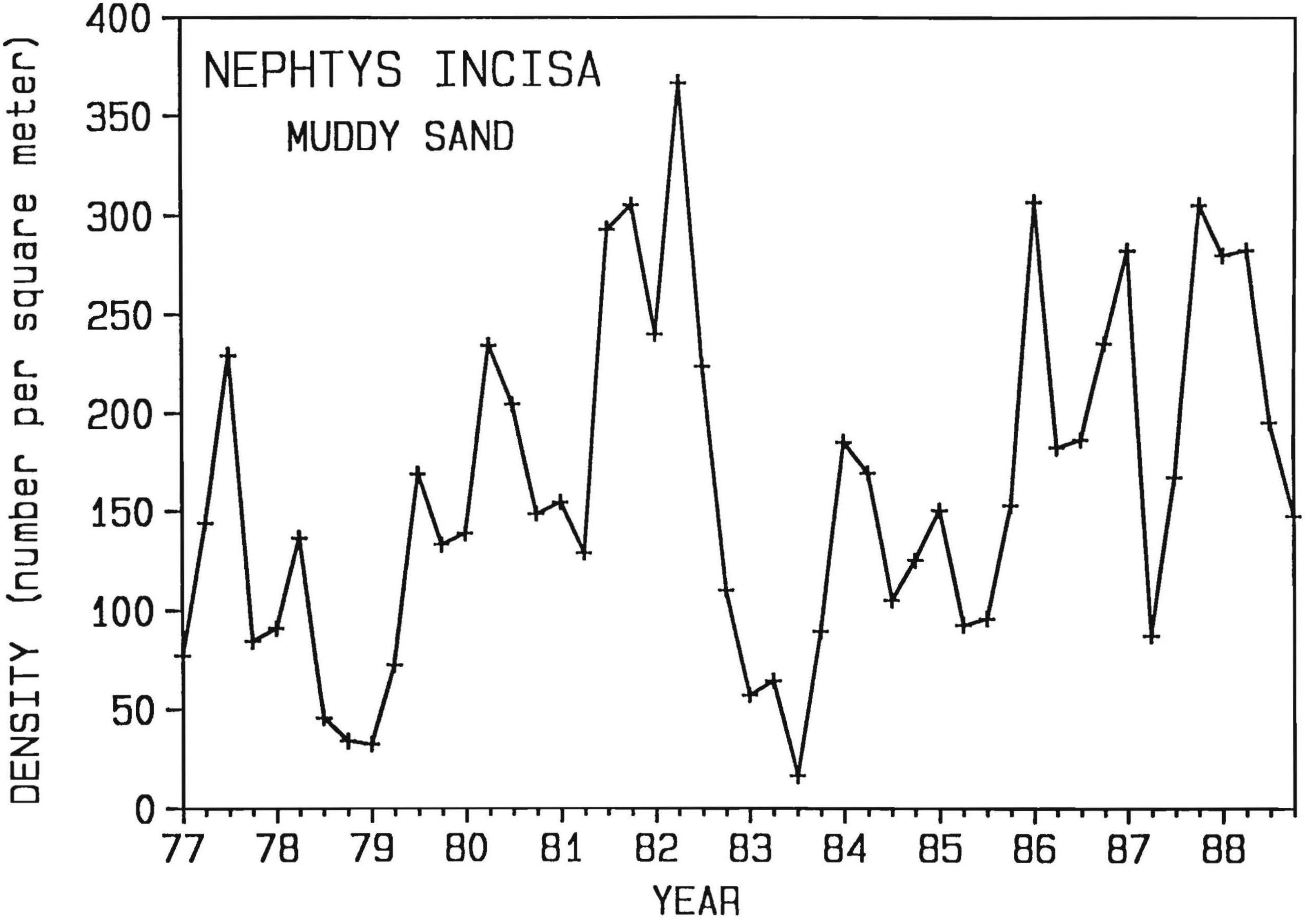


Fig. 1.7.4. Mean seasonal densities of <u>Nephtys</u> <u>incisa</u> (red-lined worm) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

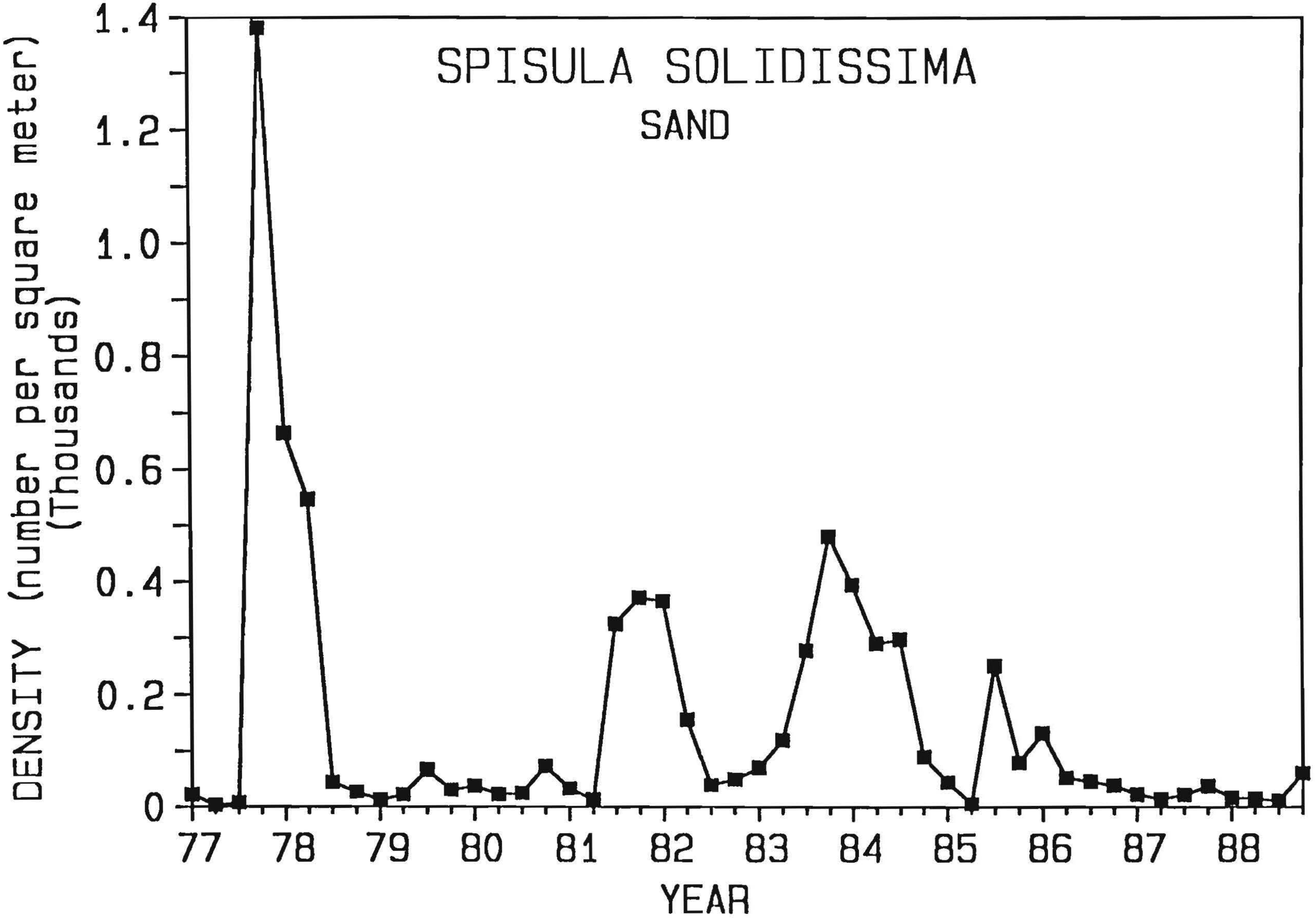


Fig. 1.7.5. Mean seasonal densities of <u>Spisula</u> <u>solidissima</u> (surf clam) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

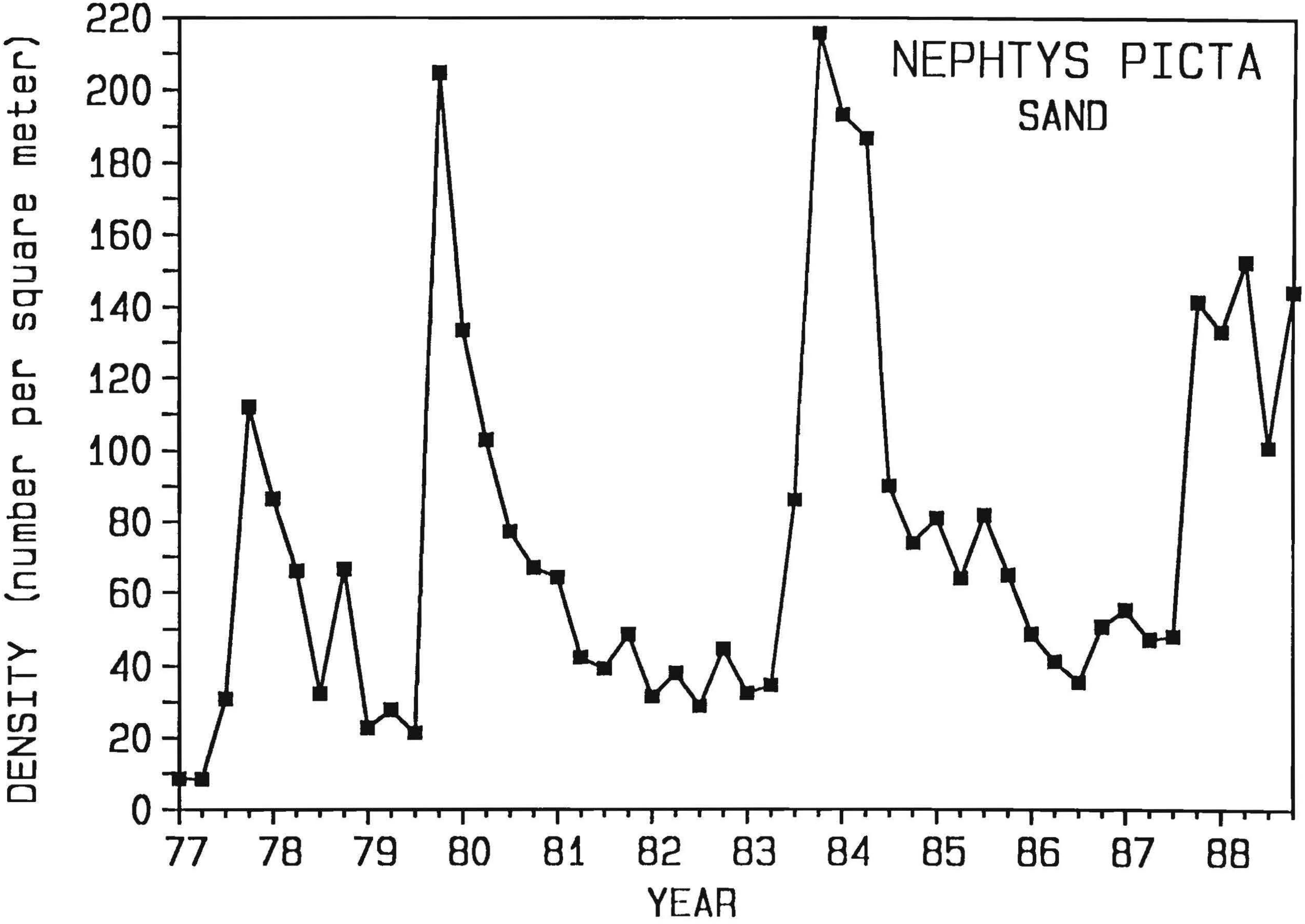


Fig. 1.7.6. Mean seasonal densities of <u>Nephtys picta</u> (red-lined worm) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

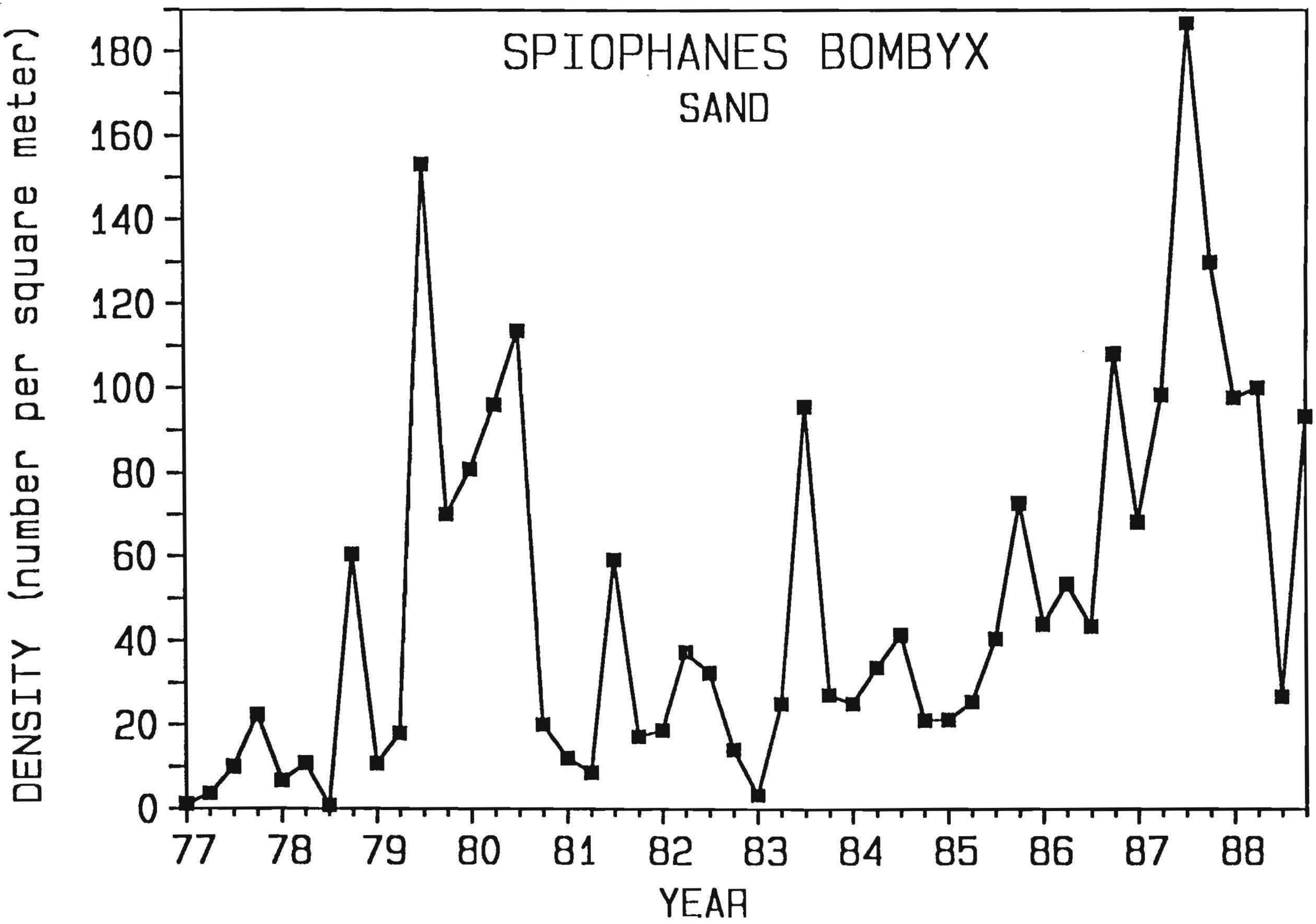


Fig. 1.7.7. Mean seasonal densities of Spiophanes bombyx off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

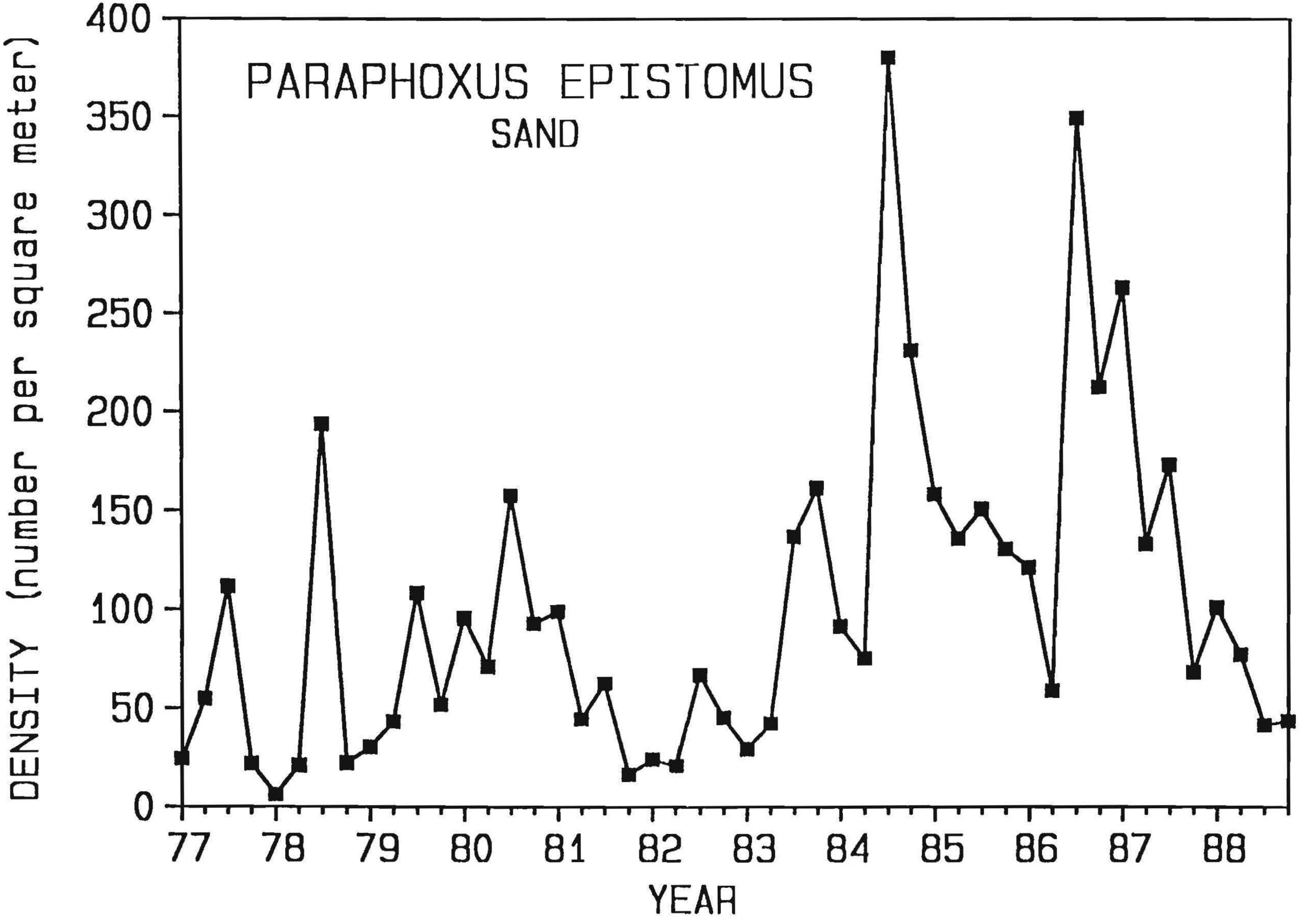


Fig. 1.7.8. Mean seasonal densities of <u>Paraphoxus</u> <u>epistomus</u> (amphipod) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

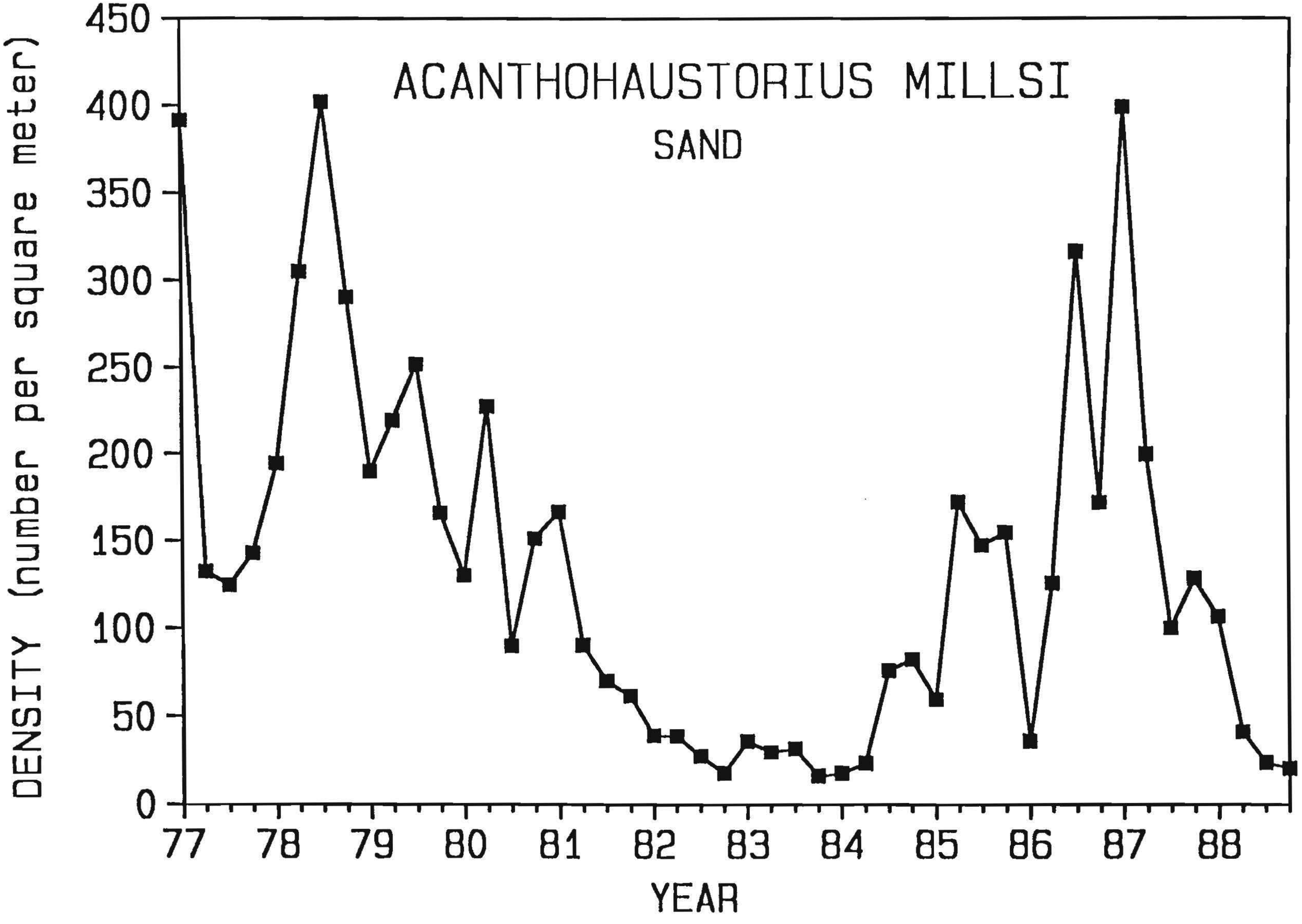


Fig. 1.7.9. Mean seasonal densities of <u>Acanthohaustorius</u> <u>millsi</u> off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

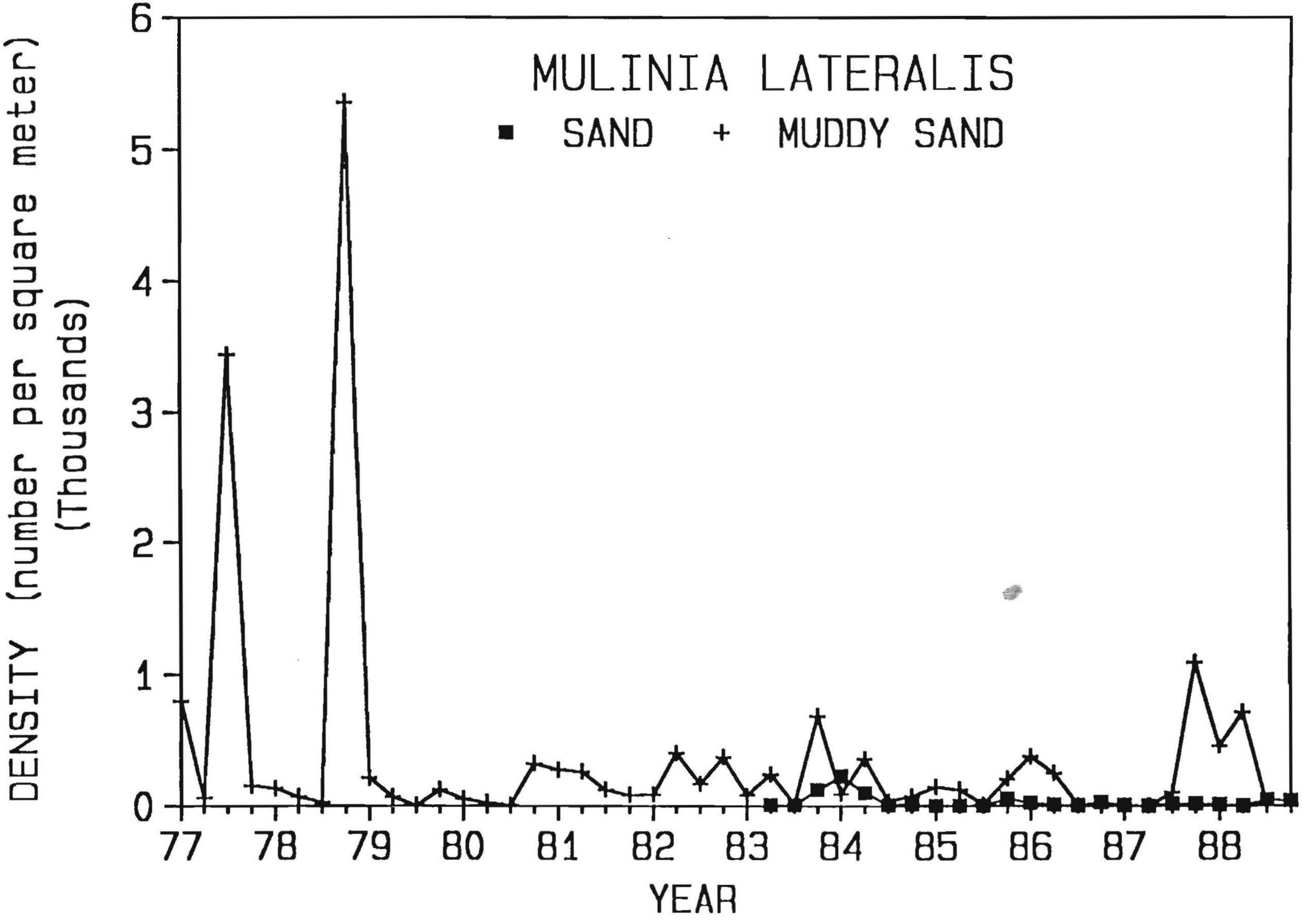


Fig. 1.7.10. Mean seasonal densities of *Mulinia lateralis* (little surf clam) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

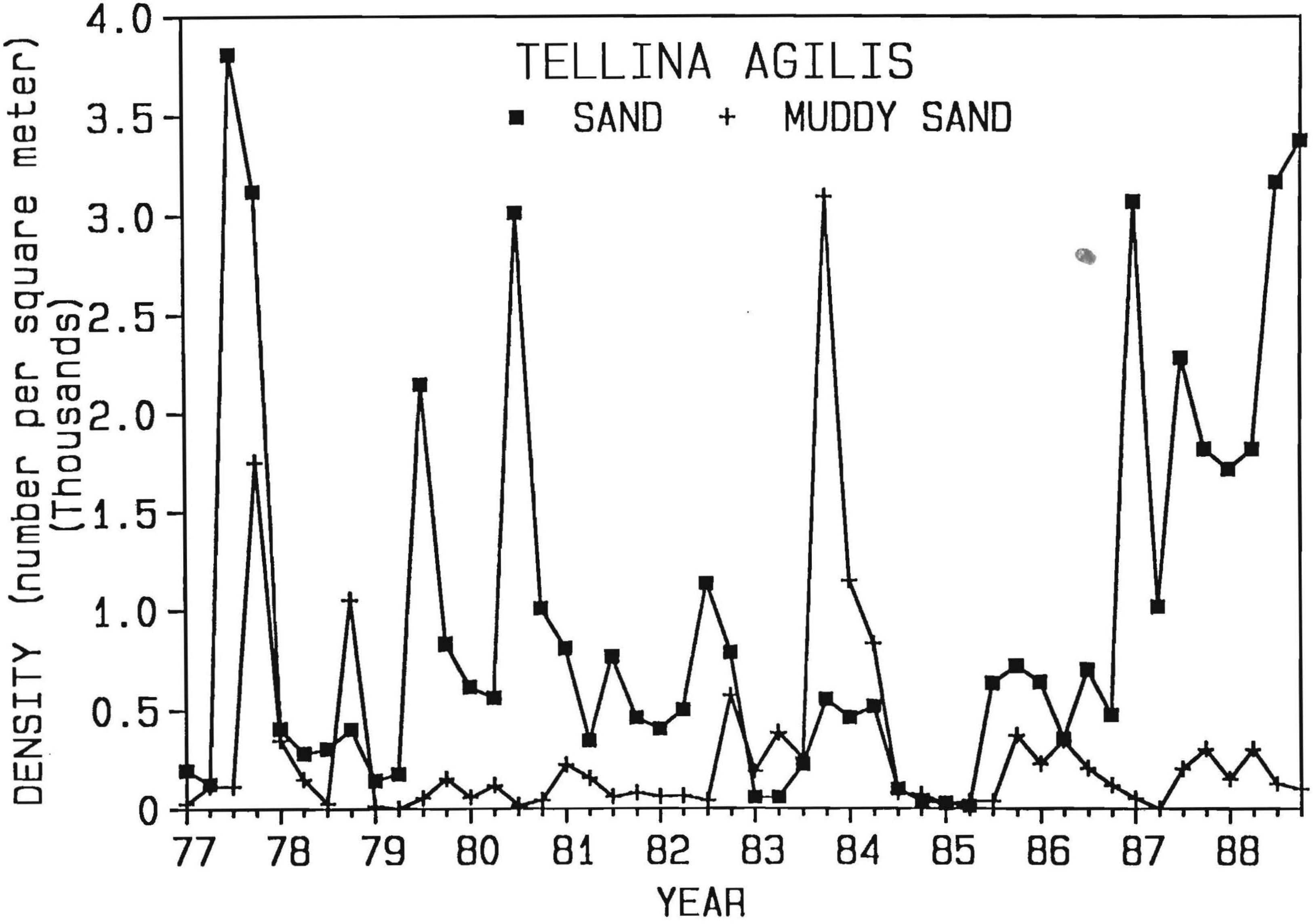


Fig. 1.7.11. Mean seasonal densities of *Tellina agilis* (tellin clam) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

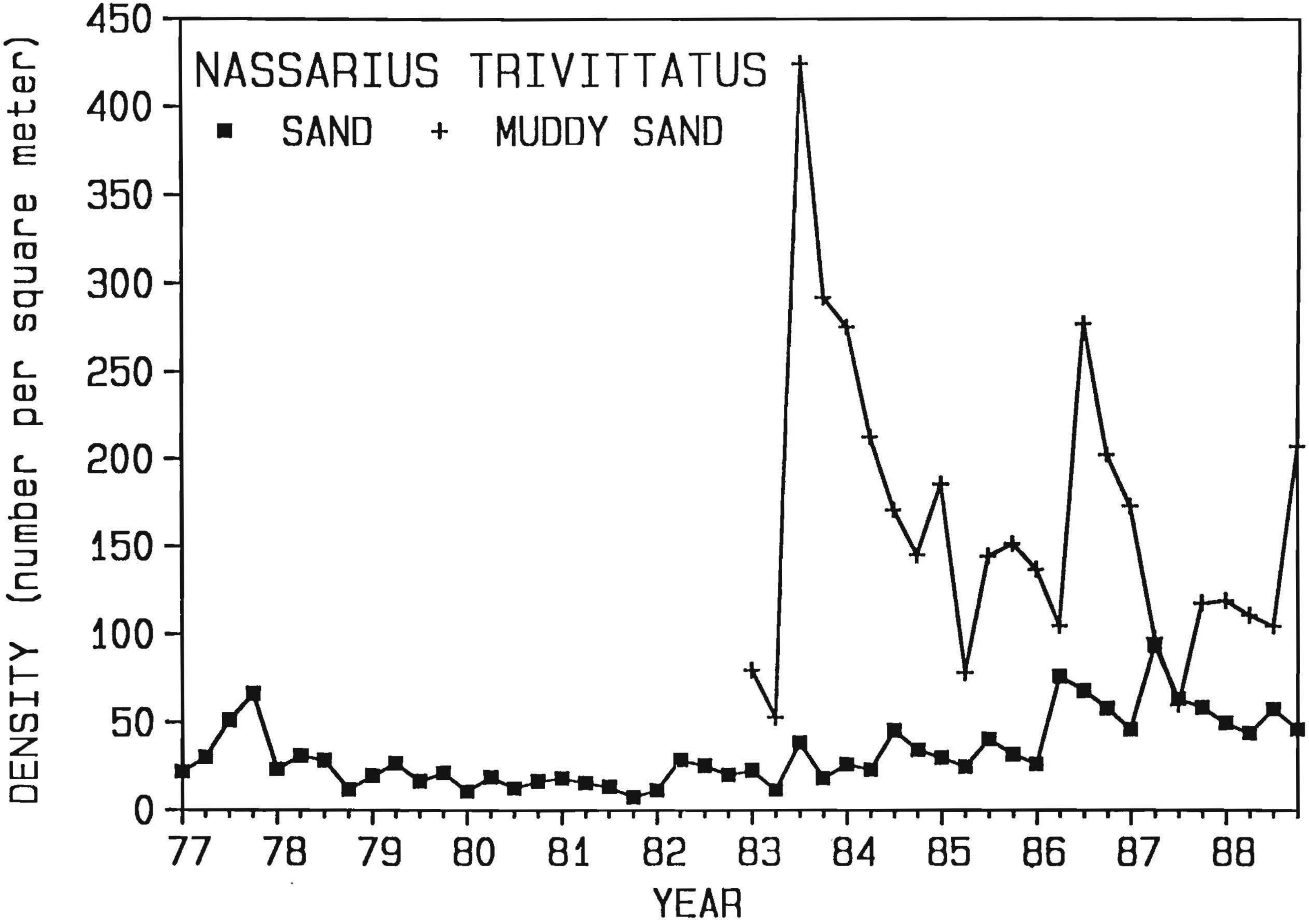


Fig. 1.7.12. Mean seasonal densities of Nassarius trivitattus (New England dog whelk) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

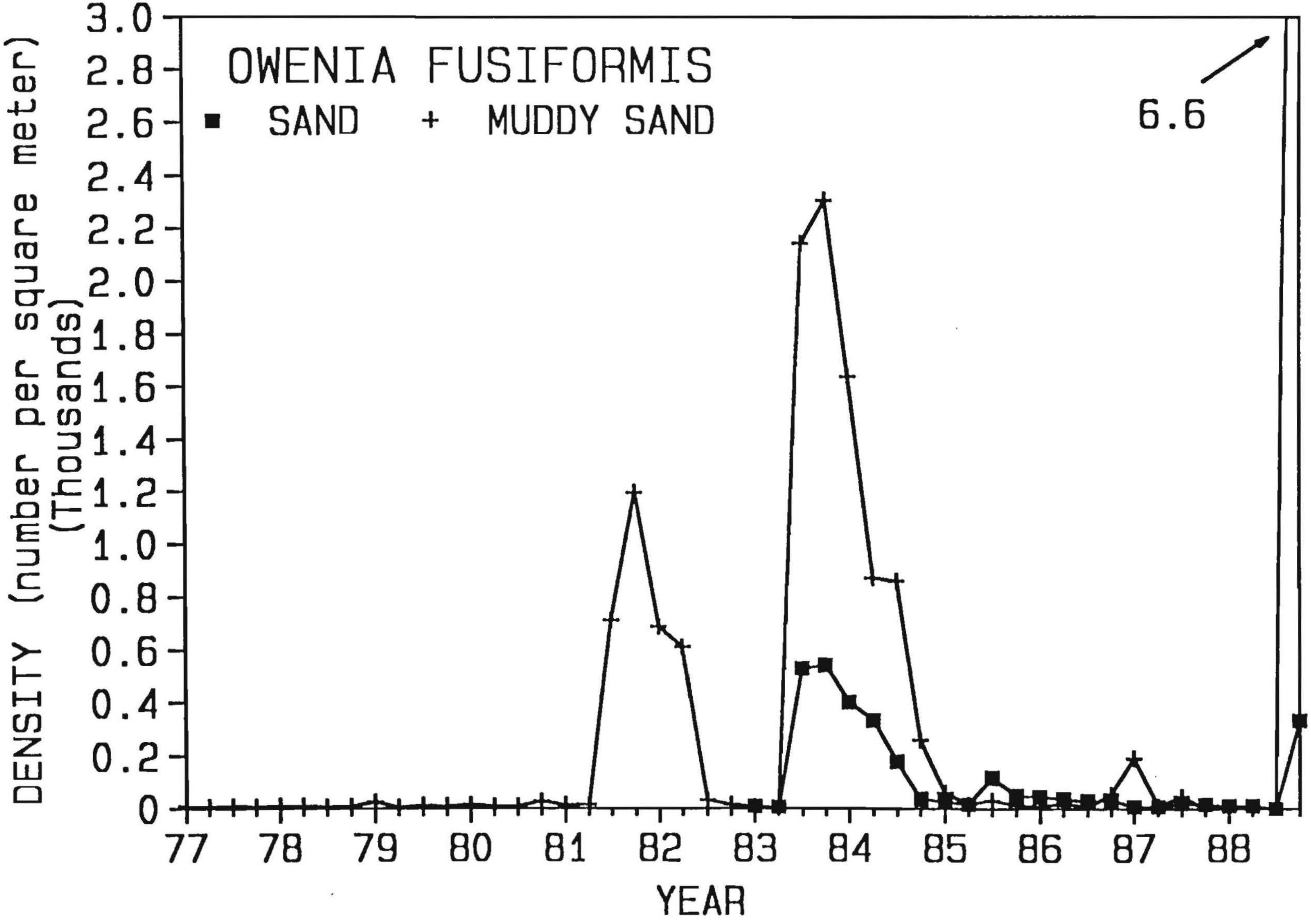


Fig. 1.7.13. Mean seasonal densities of *Owenia fusiformis* (bamboo worm) off Shoreham, NY (data are from LILCO, 1979-83 and EA, 1988-89a).

John Castleman, Northeast Utilities Service Company; Elizabeth M. Cosper, Marine Sciences Research Center, The University at Stony Brook; Phillip J. Fallon, Jr., Kemron Environmental Services; A. Christopher Gross, Long Island Lighting Company; and Robert J. Klancko, United Illuminating. Special thanks to Patrick Dooley for doing a great job collecting and sorting through data.

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