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Distribution and Relative Abundance of American Lobster, *Homarus americanus*, Larvae: New England Investigations During 1974-79

Michael J. Fogarty (editor)

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U.S. DEPARTMENT OF COMMERCE
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William G. Gordon, Assistant Administrator for Fisheries

PREFACE

In this volume, surveys of the distribution and relative abundance of American lobster, *Homarus americanus*, larvae conducted in New England during 1974-79 are described. The results of eight individual investigations, ranging from 1 to 4 yr in duration, conducted by members of an Ad Hoc Larval Lobster Working Group are provided. In addition, the relative sampling efficiency of neuston nets and Tucker trawls with respect to lobster larvae is examined.

As an introduction to this volume, factors influencing the diurnal, vertical, and spatial distribution of lobster larvae are reviewed, providing background for interpretation of the results of our investigations and obviating the need for extensive reviews within each paper. The results of these studies are then synthesized in an overview paper which precedes the individual research reports in this volume.

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Distribution and Relative Abundance of American Lobster, *Homarus americanus*, Larvae: New England Investigations During 1974-79

MICHAEL J. FOGARTY (editor)[1]

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Distribution and Relative Abundance of American Lobster, *Homarus americanus*, Larvae: A Review

MICHAEL J. FOGARTY[1]

INTRODUCTION

The American lobster, *Homarus americanus*, is among the most valuable fishery resources of the east coast of the United States. Preliminary U.S. landings of American lobster in 1980 were 16,800 metric tons (t) with an estimated ex-vessel value of $75 million (National Marine Fisheries Service 1980). Intensive exploitation of this valuable resource has resulted in concern over possible impacts of increasing fishing mortality rates on yield and reproductive potential of inshore populations (Anthony and Caddy 1980). Despite large-scale research efforts to define the population dynamics of the American lobster, relatively little is known about the determinants of larval production, survival, and subsequent recruitment to the fisheries. Observations on the occurrence of larval American lobsters have been documented since the latter part of the 19th century (Smith 1873; Herrick 1896); however, quantitative sampling programs have been undertaken only within the last 30 yr.

Larval development of the American lobster is characterized by four pelagic instars. A brief prezoeal stage precedes the first larval stage (Davis 1964). Hatching primarily occurs during late May-early June in New England (Hughes and Matthiessen 1962) after a 10-11 mo incubation period. Larvae typically occur in the plankton from late May to early September depending on location. The larval phase is normally completed in 25-35 d although stage duration is temperature dependent (Templeman 1936). Settlement occurs during the fourth larval stage (Scarratt 1973) and the postlarvae are benthic.

In this review, the distribution and relative abundance of larval lobsters in relation to depth, hydrographic factors, and environmental variables are summariezed and additional information on survival rates and stock-recruitment relationships examined. Phillips and Sastry (1980) reviewed aspects of larval lobster behavior, physiology, nutritional requirements, and ecology. Stasko (1980) and Fair (1980) provided summaries of Canadian and U.S. investigations on the distribution of larval American lobsters in the northwest Atlantic.

VERTICAL DISTRIBUTION

Several studies have indicated that lobster larvae are concentrated at the surface during daylight. Templeman (1937) reported that daytime catch rates at the surface were six-fold greater than at 0.2-4.5 m depth and no lobster larvae were obtained at 5.5-11 m. Smith (1937 cited by Stasko 1980) reported catch rates of 10.0 larvae/tow in surface samples and 0.9 larvae/tow at subsurface depths; larvae in subsurface hauls were primarily collected at night or at dawn. Templeman and Tibbo (1945) concluded that larvae were primarily neustonic in the Gulf of St. Lawrence, however, ambient light levels were found to affect depth distribution and this effect varied with larval stage. In the Gulf of Maine, Sherman and Lewis (1967) reported that catches in surface tows exceeded those in oblique hauls (0-20 m) by a factor of 2.4. Scarratt (1973) noted sharp differences in daytime catch rates between neuston and subsurface nets suspended at 0.6-1.2 m depth; in two series of hauls (34 tows), 876 larvae were obtained in the upper net and 95 in the lower. Further samples taken at 4-18 m depth (13 tows) yielded 14 larvae and no larvae were obtained in tows with the net held 10 cm from the bottom. Stasko[2] reported that few lobster larvae were taken in subsurface collections on the Scotian shelf. Harding et al. (1982) sampled the upper 110 cm of the water column with a three compartment net; 81.4, 14.1, and 4.5% of the larvae obtained were within the 0-30, 30-70, and 70-110 cm depth strata, respectively.

LIGHT INTENSITY

Ambient light intensity has been demonstrated to influence the vertical distribution of lobster larvae. Templeman (1937) concluded on the basis of field observations that first and second stage larvae react positively to low intensity light but respond negatively to increased light intensity. Templeman and Tibbo (1945) noted that third and fourth stage larvae are less sensitive to light levels than earlier stages. Diurnal vertical distribution was apparently related to light intensity and larvae tended to disperse from surface waters during night except under bright moonlight (Templeman 1939). Scarratt (1973) demonstrated significantly higher catch rates at the surface for stage I larvae during daylight, however, no significant differences between day and night samples were observed for second stage larvae. Positive phototaxis was noted for first and second stage larvae under experimental conditions, however, sustained phototactic behavior was not observed and later stage larvae were less responsive to changes in light intensity (Ennis 1975). Harding et al. (1982) noted a dispersal from surface (0-30 cm) waters during bright sunlight, confirming the observations of Templeman and Tibbo (1945).

Early observations under laboratory conditions indicated that phototactic responses differed among larval stages and,

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[2]Stasko, A. B. 1977. Lobster larvae on the Scotian Shelf. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 77/31, 10 p.

to a lesser extent, within each larval stage (Hadley 1905, 1908). First and fourth stage larvae were initially positively phototactic but reversed phototactic responses late in each stage. Second and third stage larvae tended to be negatively phototactic, however, response patterns were highly variable. Huntsman (1924) indicated that direct exposure to sunlight under experimental conditions could be lethal to first stage larvae. Templeman (1936) reported increased survival and growth rates for larvae cultured in darkness. These field and laboratory observations indicate that ambient light levels may directly affect availability of larval lobsters to neuston nets, potentially affecting estimates of relative abundance and survival.

Field investigations demonstrate a predominance of stage I larvae in daylight surface collections (Table 1). The progressive decline in successive stage densities is presumably due to the effects of mortality and behavioral factors, notably phototaxis, which affect availability and catchability of larvae.

TEMPERATURE

Scarratt (1964) found no relationship between surface water temperature and production, relative abundance, and survival of larvae in Northumberland Strait during 1949-61. The period of larval production was, however, extended in cool years. Scarratt suggested that larvae produced in the latter part of the season may be unable to successfully molt into fourth stage before winter. Caddy (1979) concluded that the cumulative temperature sum (degree-days) required for completion of the pelagic phase increases with decreasing water temperature and further suggested that larvae produced in the later part of the season (mid-late August) may not successfully molt if water temperatures decline more rapidly than the accretion of necessary degree-days. An apparent relationship between survival and mean surface water temperature from April through August inclusive was also indicated. Sherman and Lewis (1967) reported mean surface water temperatures of 13.7°-15.0°C

Table 1.—Summary of published accounts of larval American lobster sampling programs conducted from southern New England to Newfoundland in daylight surface tows. (Only daylight tows with complete catch composition data are included.)

Year	Location	Sample period	Percent stage composition I	II	III	IV	Total no. larvae	No. tows	Tow speed (km/hr)	Tow duration (min)	Gear	Source
1936	Nova Scotia	July-Aug.	95.8	3.0	0.6	0.6	324			60	1 m plankton	Templeman 1937
1936	Northumberland Strait	July-Aug.	98.1	1.6	0.3	0	322	50		—	1 m plankton	Smith 1937 (cited by Stasko 1980)
1938-40	Newfoundland	June-Sept.	54.4	13.6	18.9	13.1	5,037			—	1 m plankton	Templeman and Tibbo 1945
1948-61	Northumberland Strait	June-Sept.	77.9	13.8	4.7	3.6	298,872		1.8	30	3.7 × 0.9 m neuston	Scarratt 1964
1962-63	Northumberland Strait	June-Sept.	88.8	8.6	2.1	0.5	11,955	448	1.8	30	3.7 × 0.9 m neuston	Scarratt 1973
1965-66	Gulf of Maine	June-Sept.	80.4	1.9	0.3	17.4	368	218	7.4-11.1	10-30	1 m plankton 2 × 1 m neuston 1 × 0.5 m neuston	Sherman and Lewis 1967
1966-67	Offshore S. New England	June-Aug.	47.9	14.3	28.6	9.2	119	96	5.6-6.5	30	1.5 m plankton	Lund and Stewart 1970
1968	Long Island Sound	June-Aug.	34.7	23.8	23.6	17.9	1,367	145	5.6-6.5	30	1.5 m plankton	Lund and Stewart 1970
1966	Nova Scotia	July-Aug.	94.9	4.4	0.4	0.3	1,984	100	1.8	30	3.7 × 0.9 m neuston	Scarratt 1968
1968	Nova Scotia	July-Aug.	90.2	2.0	0.4	7.4	746	100	1.8	30	3.6 × 0.9 m neuston	Scarratt 1969
1975	Nova Scotia	June-Aug.	91.7	7.8	0.5	0	193	—	7.4	15	0.4 × 0.4 m neuston	Harding et al. 1979
1976	Scotian Shelf	Aug.	8.5	8.5	19.7	63.4	142	—	4.6-9.3	15-30	1 m neuston 1 m plankton Issacs-Kidd Trawl	Stasko (see text footnote 2)
1978	Nova Scotia	June-Aug.	[1]69.6	[1]22.6	[1]6.1	[1]1.7	925	81	5.4-7.2	15-20	0.4 × 1.1 m partitioned neuston	Harding et al. (1982)

[1]Based on production estimates.

at Boothbay Harbor during the period of peak larval density in the Gulf of Maine. Larvae were collected at water temperatures ranging from 12.5° to 28.5°C in Long Island Sound with peak hatching occurring at approximately 20°C (Lund and Stewart 1970).

Hughes and Matthiessen (1962) reported intensive hatching activity at approximately 15°C at a culture facility supplied with ambient running seawater. Hatching occurred at temperatures as low as 9.4°C and peak hatching was noted at 20°C. The time required to reach the fourth larval stage varied inversely with water temperature, ranging from 9 to 33 d at mean water temperatures of 22.3°-16.1°C.

Templeman (1936) reported the cumulative time required to reach successive larval stages (I-V) at temperatures ranging from 7° to 24°C. At 15°C approximately 25 d were needed to reach the fourth larval stage while an increase to 20°C reduced the time required to reach stage IV to 13 d. These data are extremely useful in correcting density estimates for intermolt duration (Scarratt 1964, 1973). The graphical presentation of Templeman (1936) was therefore converted to a series of of power curves relating intermolt period to water temperature for each larval stage (Table 2).

Table 2.—Parameter estimates and degree of fit index for the relationship $D = aT^b$ where D and T represent stage duration (days) and temperature (°C), respectively. Equations derived from the graphical presentation of Templeman (1936) by calculating the difference between the cumulative times required to reach successive larval stages and regressing on temperature.

	Larval stage			
Parameter	I	II	III	IV
a	1,123.542	2,510.476	2,745.043	7,492.117
b	−1.91255	−2.16334	−2.07060	2.11708
R^2	.968	.967	.970	.958

SALINITY

Scarratt (1968, 1969) noted a distinct onshore-offshore salinity gradient during July-August off Nova Scotia; larval lobster densities tended to be greater at higher salinity sampling locations. Scarratt and Raine (1967) reported that first stage larvae avoided salinities of < 21.4 ppt in laboratory experiments. Templeman (1936) had earlier noted that survival rates were adversely affected at salinities below 20 ppt. Above this level, neither survival nor time required to reach fourth stage was significantly affected.

SURFACE CIRCULATION

Vertical distribution studies indicating low concentrations of lobster larvae in subsurface waters have led to speculation that wind-induced surface circulation patterns may influence larval distribution. Templeman (1937) concluded that offshore winds result in dispersal of larvae in surface waters. Templeman and Tibbo (1945) integrated the results of drift bottle investigations, wind pattern observations, and larval lobster distribution studies and suggested that surface hydrography determined the spatial distribution of larvae. Scarratt (1964) considered surface circulation to be a primary determinant of larval lobster distribution and inferred that passive transport may affect catch rates of later stage larvae. However, in an analysis of the same data, Caddy (1979) computed centers of density for each stage within the survey area and concluded that larvae may move against the prevailing surface drift, presumably by vertical migration and transport by subsurface countercurrents. Scarratt (1968, 1969) reported predominately onshore southwesterly winds off Nova Scotia during the period of larval occurrence and suggested that larvae may be concentrated along windward coastal locations by onshore winds. Rogers et al. (1968) noted higher levels of stage I larvae in offshore stations in southern New England while stage IV lobsters dominated inshore stations, implying an onshore drift with time. Coastward surface drift rates of up to 6.4 km/d during the larval period were cited. Evidence for retention of larvae within circulation gyres in western Long Island Sound was presented by Lund and Stewart (1970). Squires (1970) acknowledged the possibility of larval transport in surface waters but postulated that larvae may maintain position during strong winds by descending in the water column. Ennis (1975) indicated that lobster larvae were more sensitive to hydrostatic pressure than light intensity and were capable of depth regulation within broadly defined limits. There was considerable diminution of sensitivity to pressure changes in stage III and IV larvae. Harding et al. (1979) reported that higher densities of larvae in central and eastern St. Georges Bay, Nova Scotia, were due to prevailing southwesterly winds in summer. Stasko (footnote 2) postulated that surface circulation patterns would result in advection of larvae from Georges Bank and Browns Bank toward southwest Nova Scotia. Harding et al. (1982) further proposed that creation of convergent zones through Langmuir circulation may result in concentrations of larvae, explaining the generally observed contagious distribution patterns.

SURVIVAL

Estimates of survival between stages I and IV were derived by Scarratt (1964, 1973) after standardizing larval density estimates for stage duration at prevailing water temperatures. Estimated survival rates ranged from 0.79% to 2.39% during 1949-61 and averaged 1.12%. Harding et al. (1982) estimated a survival rate of 1.0% through the pelagic phase after adjustment for stage duration in St. Georges Bay, Nova Scotia, during 1978. Considerably higher estimates of survival (> 50%) were calculated by Lund and Stewart (1970) in Long Island Sound; however, no attempt was made to adjust for increased stage duration and availability with successive larval stages. Ennis (1975) cautioned that differential response of the larval stages to varying light levels may bias estimates of survival based on surface plankton hauls. Correction for stage-specific larval response to ambient light levels should allow increased precision in estimates of larval lobster density and survival rates, however, the confounding influence of within-stage variability in phototactic responses (Hadley 1908) greatly complicates development of an appropriate adjustment factor. Estimates of survival based on surface samples should be considered preliminary until further information on the effects of light intensity, wind direction and velocity, and other environmental variables on larval lobster distribution (vertical and horizontal) are quantified.

STAGE IV PRODUCTION AND SUBSEQUENT STOCK

In an extensive series of observations, Scarratt (1964, 1973) examined the relationship between stage IV production in Northumberland Strait and subsequent stock size. Stock size was lagged by 6 yr to account for the delay between spawning and recruitment (Wilder 1953). Stock estimates were based on tagging studies conducted off Miminigash, P.E.I. Wide variability in growth rates may result in a single cohort recruiting to the fishery over a 2-3 yr period (Wilder 1953); accordingly, Scarratt (1973) related 3-yr running averages of stage IV larval production and stock size. Scarratt concluded that sampling variability prevented accurate prediction of stock size based on larval production estimates.

Scarratt (1964, 1973) restricted consideration to a linear relationship between larval production and subsequent stock size. However, density (stock) dependent effects may result in a nonlinear functional relationship between larval production and subsequent stock. To further examine this possibility, a modification of the Ricker stock-recruitment model (Saila and Lorda in press) was used to evaluate the relationship between 3-yr running averages of stage IV production (P) and stock size (S) lagged by 6 yr. The generalized model of Saila and Lorda (in press):

$$S = \alpha P^{\beta} e^{-\delta P}$$

was employed in this analysis. The derived curve provided a reasonable representation (r = 0.87; df = 12) of the stage IV production-recruitment observations (Fig. 1). This model may assume either a nearly asymptotic or convex form and therefore retains great flexibility in evaluating stock-recruitment relationships.

Although the many sources of variability in estimating stage IV density and stock size must be recognized, this analysis does provide an indication of a relationship between stage IV production and stock size which merits further investigation.

Stock recruitment relationships have proven difficult to conclusively demonstrate for marine species. Variable survival

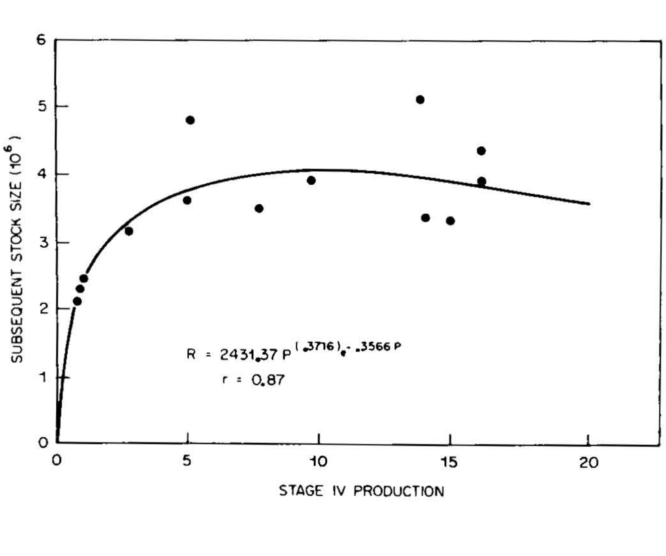

Figure 1.—Relationship between stage IV production (no/3,430 m^2) and subsequent stock size (10^6) 6 yr later. Three-year moving average employed for both variables.

rates for egg and larval stages caused by variability in critical environmental factors tend to obscure any underlying parental stock effect. During the lengthy incubation period typical of many crustacean species, however, the protection afforded to the eggs by brooding behavior of the female reduces mortality and variability in survival rates. Perkins (1971) estimated an average egg loss rate of 36% during incubation for the American lobster; egg mortality would undoubtedly be considerably higher if the eggs remained unprotected.

Although adequate time series of stock and recruitment estimates are not widely available for crustacean stocks (Hancock 1973), recent studies provide evidence for stock-recruitment relationships in two species. Boddeke (1981) demonstrated asymptotic relationships between egg production and subsequent harvestable stock of the European brown shrimp, *Crangon crangon*, in four areas off the Netherlands and Belgium. Morgan et al. (1982) reported an asymptotic relationship between puerulus settlement and recruitment for spiny lobster, *Panulius cygnus*, off Western Australia.

The asymptotic form noted in each of the above investigations indicates that recruitment in crustacean stocks may be relatively stable over a wide range of parental stock sizes. Recruitment curves of this type further imply that the primary population regulatory mechanism is limitation of available resources (e.g., food or habitat). Boddeke (1981) suggested that spatial limitations on the nursery grounds may limit population size. Morgan et al. (1982) cited limitations on food and shelter sites as possible regulatory factors. Although there is no convincing evidence of food resource limitation on American lobster populations, shelter availability is an important feature of lobster habitat (Cobb 1971) and shelter may be a limiting resource, particularly for juvenile lobsters, which are more vulnerable to predation.

CONCLUSIONS

American lobster larvae have been collected most consistently at the surface during daylight. Abundance apparently declines with increasing depth. Although laboratory observations have indicated clear photonegative responses during portions of several larval stages, few larvae have been obtained in subsurface collections. The limited number of samples collected at night do not permit definitive conclusions but do suggest some dispersal from surface waters.

Transport of larvae in surface currents has been widely assumed (Templeman 1937, 1939; Templeman and Tibbo 1945; Scarratt 1964, 1968, 1969, 1973; Rogers et al. 1967; Lund and Stewart 1970; Harding et al. 1979) and higher larval densities along windward coasts tend to support this inference. Vertical migration has been implicated in position-keeping in response to wind-induced turbulence and surface drift (Squires 1970; Caddy 1979), however direct evidence of a behavioral mechanism of this type has not been observed.

Prevailing southwesterly winds along much of the northeastern coast of the United States may result in transport of larvae from offshore locations to coastal sites. Rogers et al. (1968) cited a coastward transport of up to 6.4 km/d off southern New England, implying a possible dispersal range of approximately 100-150 km during a 20-25 d developmental period. Larval transport from offshore areas (which have only recently been exploited) may provide some degree of larval recruitment to coastal populations. Fishing mortality rates in coastal areas are extremely high and current minimum size limits are below the mean size at maturity for many areas (Anthony and Caddy 1980), suggesting that recruitment from less heavily exploited areas may play an important role in sustaining coastal fisheries.

A 15-yr study of stage IV density and subsequent stock size indicated a relationship between larval production and stock size 6 yr later. The derived function is similar in form to stock-recruitment relationships developed for European brown shrimp (Boddeke 1981) and spiny lobster (Morgan et al. 1982), possibly indicating a similarity in population regulatory mechanisms among these crustacean species.

In the context of extremely high levels of fishing mortality for this species (Anthony and Caddy 1980), protection of brood stock by setting minimum size limits to the vicinity of mean size at maturity and prohibition on harvesting ovigerous females would appear prudent. Increases in minimum size limits and reduction in fishing mortality rates would also result in increased yield per recruit (Ennis 1980; Fogarty 1980), providing further incentive for increasing legal size limits.

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An Overview of Larval American Lobster, *Homarus americanus*, Sampling Programs in New England During 1974-79

MICHAEL J. FOGARTY[1] and ROBERT LAWTON[2]

INTRODUCTION

The American lobster, *Homarus americanus*, has long generated intense interest, both for its significance to the fisheries of the coastal New England States and Canadian Maritime Provinces, and its importance in the structure of benthic communities in the northwest Atlantic (Cobb and Wang in press).

Concern over the potential impact of proposed or operating power plants on lobster populations in coastal locations in New England led to several investigations of larval lobster distribution during the last decade. In addition, general studies on lobster population dynamics were undertaken during this period in support of development of a coastwide fishery management program. A lack of adequate knowledge of the distribution of lobster larvae, factors affecting larval production, and annual variation in abundance were recognized as serious impediments to understanding lobster recruitment patterns and to estimating potential losses due to entrainment by power plants.

An ad hoc working group, comprised of scientists from both the private and public sectors, was formed during 1977 to discuss the results of ongoing larval lobster research programs and to provide guidance for the development of future studies. In this report, the results of larval lobster investigations in Maine, New Hampshire, Massachusetts, and Rhode Island by members of the working group are summarized. Aspects of the spatial and temporal distribution of larvae are described and additional information on the diurnal and vertical distribution of lobster larvae and annual variation in production is provided.

SAMPLING METHODS

Larval lobster sampling programs were initiated at several coastal locations throughout the New England region during 1974-79 (Fig. 1). Prior studies indicated that lobster larvae are concentrated in surface waters during daylight (Templeman 1937; Templeman and Tibbo 1945; Scarratt 1964, 1973). Accordingly, sampling effort was directed at the air-water interface using neuston gear (Table 1). An opening-closing Tucker trawl (Hopkins et al. 1973) was used for discrete depth sampling in several studies and for both surface and subsurface hauls in one program (Table 1). Comparison trials between 1 × 2 m neuston gear and a 2 × 2 m Tucker trawl towed at the surface indicated that both nets provided similar density estimates when expressed on an areal basis but neuston net density was approximately 2-4 times higher when expressed on a volumetric basis (Bibb et al. 1983b). These results suggest that larvae are concentrated in the upper 0.50-0.75 m of the water column and that the lower depth strata sampled by the Tucker trawl was nearly devoid of larvae.

Sampling was primarily conducted during daylight hours, however, night samples were occasionally collected in two studies and were consistently taken in Block Island Sound (Bibb et al. 1983a).

Tow speeds ranged from 1.8 to 5.6 km/h and were from 12 to 30 min in duration (Table 1). Tows were often abbreviated during periods of high ctenophore abundance when the filtration efficiency of the nets was reduced. Sampling periods spanned the known seasonal occurrence of larvae, ranging from May through October depending on year and area sampled (Table 1).

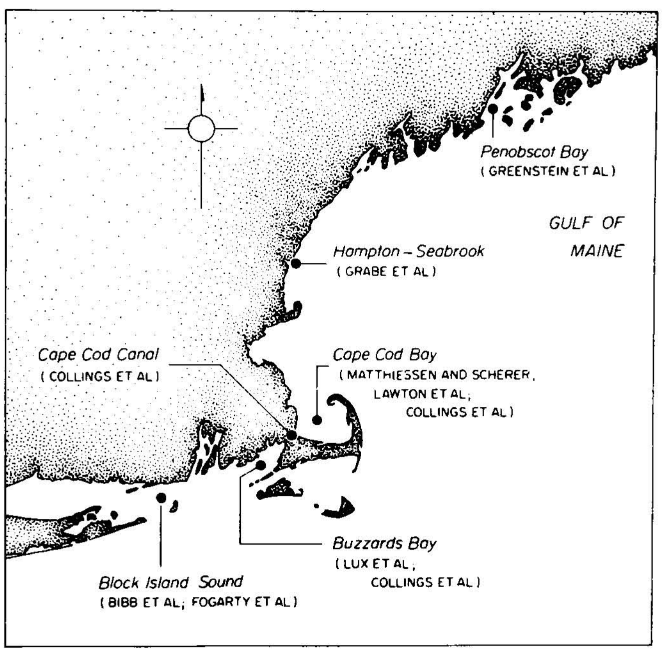

Figure 1.—Sampling locations for larval American lobster, *Homarus americanus*, in New England during 1974-79.

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Table 1.—Summary of larval lobster sampling protocol for New England investigations during 1974-79.

Area	Year	Sample period	Gear	Diurnal period	No. tows	Tow speed (km/h)	Tow duration (min)	Source
Maine Penobscot Bay	1976	May-Sept.	0.9×3.7 m Neuston	Day	213	1.8	30	Greenstein et al. (1983)
New Hampshire Hampton-Seabrook	1978	June-Oct.	1×2 m Neuston	Day	34	3.6	15-30	Grabe et al. (1983)
	1979	May-Sept.	1×2 m Neuston	Day	30	3.6	30	
Massachusetts Cape Cod Bay	1974	May-Aug.	1×2 m Neuston	Day	20	3.7	12	Lawton et al. (1983)
	1975	May-Aug.	1×1 m Neustn	Day	27	3.5-4.6	10-30	
	1976	June-Aug.	1×2 m Neuston	Day	60	4.6	30	
	1977	May-Aug.	1×2 m Neuston	Day	78	4.6	30	
		June-Aug.	1×1.5 m Tucker trawl	Day	48	5.6	20	
Cape Cod Bay	1974	June-Aug.	1×2 m Neuston	Day	58	4.0-5.5	30	Matthiessen and Scherer (1983)
	1975	June-Oct.	1×2 m Neuston	Day (some night)	145	4.0-5.5	30	
	1976	May-Sept.	1×2 m Neuston 2×2 m Tucker trawl	Day	325	.0-5.5	30	
Cape Cod Bay	1976	May-Aug.	1×2 m Neuston	Day	88	4.6-5.6	30	Collings et al. (1983)
Cape Cod Canal Buzzards Bay	1977	May-Aug.	1×2 m Neuston	Day	189	4.6-5.6	30	
			1×1.5 m Tucker trawl		66	6.5-7.4	20	
	1978	May-Oct.	1×2 m Neuston	Day	182	4.6-5.6	30	
Buzzards Bay	1976	May-Aug.	1×2 m Neuston	Day (some night)	50	4.6-5.6	30	Lux et al. (1983)
	1977	May-Aug.	1×2 m Neuston	Day	80	6.0	30	
	1978	May-Aug.	1×2 m Neuston	Day	62	6.0	30	
	1979	May-Aug.	1×2 m Neuston	Day	56	6.0	30	
Rhode Island Block Island Sound	1977	May-Aug.	2×2 m Tucker trawl	Day and night	107	3.6	12	Bibb et al. (1983a)
	1978	May-Aug.	2×2 m Tucker trawl	Day and night	132	3.6	12	
	1979	May-June[2]	1×2 m Neuston	Day	144	3.6	12	
Block Island Sound	1978	May-Sept.	1×2 m Neuston	Day	244	3.7	20	Fogarty et al. (1983)

[1]Samples collected by holding position into current.
[2]Sampling terminated.

RELATIVE ABUNDANCE

Distinctive differences in mean annual density of larvae were evident between the Gulf of Maine-Cape Cod Bay region and southern New England (Buzzards Bay-Block Island Sound). Consistently higher densities were recorded in southern New England (Table 2). Reduced density within the Cape Cod Bay-Gulf of Maine complex may reflect the influence of prevailing southwesterly winds during the period of larval occurrence. Prevailing winds during summer are onshore in

Table 2.—Summary of larval lobster relative abundance, seasonal occurrence, and stage composition for New England Investigations during 1974-79. Data obtained from reports in this volume and personal communication with investigators.

Area	Year	Total no. larvae	Period of peak abundance	Maximum density (no./1,000m^3)	Mean annual density (no./1,000m^3)	Temp. (°C) at 1st occurrence	Temp. (°C) at peak occurrence	Stage composition (percent) I	II	III	IV	Source
Maine												
Penobscot Bay	1976	58	late June	2.9	0.2	[1]10.5	13.5	89.7	1.7	0.0	8.6	Greenstein et al. (1983)
New Hampshire												
Hampton-Seabrook	1978	169	late Aug	53.8	4.3	[1]13.9	[1]13.3	12.5	0.0	1.1	86.4	Grabe et al.
	1979	120	late July	38.3	3.4	[1]7.9	[1]9.6	70.8	2.5	1.7	25.0	(1983)
Massachusetts												
Cape Cod Bay (Plymouth Area)	[2]1974	25	early Aug.	—	—	—	—	4.0	0.0	0.0	96.0	Lawton et al.
	1975	177	early July	19.8	2.0	[1]12.7	[1]14.1	59.9	23.7	8.1	8.3	(1983)
	1976	871	late July	34.9	4.4	[1]9.5	[1]16.0	25.5	19.7	29.6	25.2	
	1977	206	late July	11.2	1.3	[1]11.5	[1]8.5	55.2	16.9	5.3	22.6	
Cape Cod Bay	1974	608	July	7.3	1.6	[1]16.1	[1]20.8	21.0	19.0	25.0	35.0	Matthiessen
	1975	931	June	40.5	2.0	[1]9.0	[1]14.7	56.0	23.0	12.0	8.0	and Scherer
	1976	3,279	June	21.6	2.7	[1]10.5	[1]15.1	52.0	20.0	16.0	12.0	(1983)
Cape Cod Bay (Sandwich Area)	1976	47	late June	3.7	1.3	[1]10.3	[1]13.0	68.1	2.1	6.4	23.4	Collings et
	1977	672	late June	153.5	7.9	[1]11.5	[1]17.5	81.0	4.5	3.4	11.2	al. (1983)
	1978	115	early July	8.6	1.7	[1]13.5	[1]12.5	52.2	5.2	9.6	33.0	
Cape Cod Canal	1976	1,428	June	174.8	15.8	[1]12.5	[1]18.5	34.9	21.6	33.4	10.2	
	1977	654	June-July	47.6	7.4	[1]14.5	[1]14.5	47.4	13.6	9.2	29.8	
	1978	430	June	45.1	3.7	[1]12.5	[1]16.0	48.1	10.2	16.0	25.6	
Upper Buzzards Bay	1976	687	mid-June	79.0	8.6	[1]13.9	[1]16.5	56.6	16.0	17.9	9.5	
	1977	4,035	mid-June	266.2	15.9	[1]17.0	[1]20.0	28.8	22.0	25.8	23.4	
	1978	1,563	mid-June	91.8	10.1	[1]14.5	[1]19.5	36.8	15.2	14.9	33.1	
Lower Buzzards Bay	1976	1,284	late June	35.0	10.1	[1]13.0	[1]18.0	33.7	37.7	22.6	6.0	Lux et al
	1977	3,461	late June	68.7	18.8	11.0	17.0	20.4	30.8	21.9	26.9	(1983)
	1978	1,631	late June	42.4	9.6	11.0	[1]17.0	5.5	6.3	14.9	73.3	
	1979	10,303	late June	449.7	43.7	[1]15.0	[1]19.0	23.4	25.6	38.5	12.5	
Rhode Island												
Block Island Sound	1977	1,661	mid-June	[4]31.2	[4]9.0	[1]13.3	14.0-16.6	59.0	24.0	13.0	4.0	Bibb et al
	1978	761	early July	[4]19.1	[4]4.5	13.6	12.8-14.8	23.0	14.0	11.0	52.0	(1983a)
	[5]1979	1,335	early June	18.7	—	[1]12.6	—					
Block Island Sound	1978	1,030	late June	33.3	10.8	[1]13.0	[1]14.0-17.0	12.3	14.1	10.9	62.6	Fogarty et al (1983)

[1]Bottom temperature (°C).
[2]Preliminary sampling program.
[3]Surface temperature (°C).
[4]Tucker trawl estimates multipled by a factor of 4 to approximate neuston net catches.
[5]Sampling terminated in June.

southern New England, but offshore in Cape Cod Bay, and offshore or alongshore in northern New England. Advection of lobster larvae in wind induced surface currents has been hypothesized as a passive transport mechanism (see review by Fogarty 1983) and dispersal of larvae during periods of offshore winds may result in reduced surface density. Increased catch rates during onshore winds were noted in several studies, lending support to the inference that lobster larvae are transported by surface water circulation. Grabe et al. (1983) reported that 67% of stage IV larvae were collected off New Hampshire when winds were on or alongshore. Similarly, Collings et al. (1983) collected 85% of larvae obtained in Buzzards Bay when winds were from the southwest while only 39% of the larvae collected in Cape Cod Bay were obtained during southwest winds. Lawton et al. (1983) noted that 82% of the larvae in their collections were observed when winds were onshore, however, most sampling (73%) was conducted when winds were onshore. In Block Island Sound, most sampling dates during the period of peak occurrence of larvae corresponded to periods of onshore winds and no significant wind direction effect could be demonstrated (Fogarty et al. 1983).

Mean size at maturity of female lobsters is considerably lower in the warmer waters of southern New England (Van Engle 1980; Aiken and Waddy 1980), resulting in an increased probability of spawning prior to capture. Templeman (1936a) noted an inverse relationship between size at sexual maturity and water temperature in the Canadian Maritime Provinces. Higher brood stock levels may therefore contribute to higher larval lobster density in southern New England waters. It should be noted, however, that the primary source of lobster landings off the northeastern United States is within the Gulf of Main, implying adequate larval production or transport from other areas.

An association between larval lobster abundance and the occurrence of cencentrations of detached macroalgae and marine vascular plants (primarily *spartina*) was observed off New Hampshire (Grabe et al. 1983). Larvae may avoid predators by seeking refuge in windrows of drifting vegetation. Wind speed and direction may indirectly influence larval lobster distribution by affecting the formation and distribution of windrows. Harding et al. (1982) reported a significant relationship between the occurrence of lobster larvae and floating vegetation in St. Georges Bay, Nova Scotia, Cobb and Wang (in press) have suggested the use of artificial seaweed collectors to monitor abundance of American lobster larvae.

ANNUAL VARIATION IN ABUNDANCE

Despite apparent differences between areas in the availability (catchability) of larvae, relative differences in mean annual density were generally consistent in years for which comparisons were possible (Fig. 2). Increased density in 1977 relative to 1976 and 1978 was noted by Collings et al.(1983) in Cape Cod Bay and Buzzards Bay and by Lux et al. (1983) in Buzzards Bay. Bibb et al. (1983a) reported decreased abundance in 1978 from 1977 density estimates. Matthiessen and Scherer (1983) and Lawton et al. (1983) reported increased relative abundance in 1976 over 1975 levels. Lux et al. (1983) observed a sharp increase in mean density in 1979, although this increase was primarily due to several large catches of stage I larvae. In contrast, Grabe et al. (1983) reported slightly reduced larval density in 1979 relative to the 1978 level, however, the number of larvae obtained was low, possibly obscuring trends in relative abundance.

A striking increase in the proportion of stage IV larvae was observed in 1978 (Table 2). This shift in stage composition was accompanied by generally reduced density levels (Table 2). Increased stage IV composition may reflect an increase in survival through the pelagic phase, accentuated by the longer intermolt duration of fourth stage larvae and hence greater vulnerability to capture (Scarratt 1964, 1973). Positive phototactic responses in early stage IV larvae (Hadley 1908; Templeman 1936b) may render this stage more accessible to capture by neuston gear. However, stage I larvae are also initially positively phototactic (Hadley 1908; Templeman 1937; Scarratt 1973). In addition, production estimates with explicit correction for stage duration still exhibited unexpectedly high stage IV densities (Bibb et al. 1983b; Fogarty et al. 1983). Transport of later stage (III and IV) larvae toward inshore locations in wind-induced surface currents and favorable sampling conditions may also have contributed to increased proportions of stage IV larvae in 1978.

In general, the proportion of stage IV larvae in our studies exceeded those reported by Scarratt (1964, 1973) for Northumberland Strait where the average percentage of fourth stage larvae (uncorrected for stage duration) during 1948-63 was <5%. It is possible that the higher towing speeds in many of the investigations in New England during 1974-79 resulted in the capture of proportionately more stage IV larvae. Increased development of swimming and escape responses in fourth stage larvae may allow avoidance of nets towed at low (<2 km/h) speed.

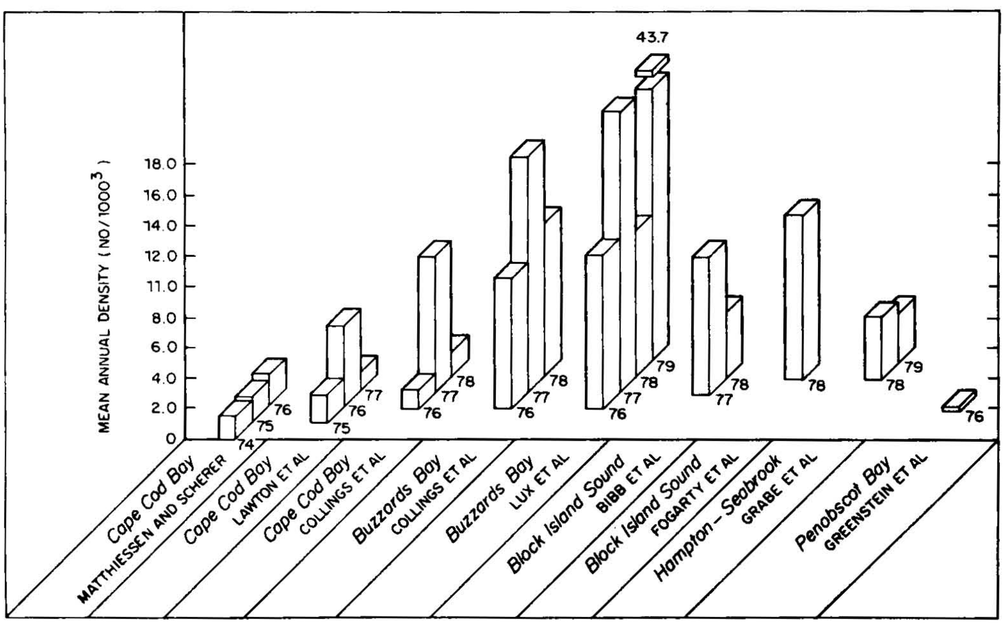

Figure 2.—Mean annual density (daytime surface tows) of American lobster larvae in New England studies during 1974-79. Years of sampling indicated at base. Cape Cod Canal estimates not included since unusual hydrographic features of the Canal may result in biased estimates of density.

TEMPERATURE

Marked differences in water temperature at first occurrence of larvae were noted between the Gulf of Maine and southern New England. Bottom water temperatures at hatching were as low as 8°-9°C in samples collected in northern New England but ranged from 11° to 13.6°C in Buzzards Bay and Block Island Sound (Table 2). Bottom water temperatures at peak larval densities were 8.5°-16.0°C in northern and 12.8°-17.0°C in southern areas (Table 2). Surface water temperatures during the period of highest density were approximately 15°-20°C depending on year and area sampled (Table 2). Hatching is presumably keyed to an increase in water temperature during late spring. Annual variation in water temperature during May-October may affect the onset and duration of hatching, intermolt duration, and survival of larvae.

VERTICAL DISTRIBUTION

Lobster larvae were consistently found in higher concentrations in surface collections in Block Island Sound and Cape Cod Bay (Bibb et al. 1983a; Collings et al. 1983; Lawton et al. 1983). Bibb et al. (1983a) reported significantly higher surface densities of larvae during daylight, however, occasional high larval densities were noted in near bottom samples. Lawton et al. (1983) obtained two larvae in 48 subsurface tows at depths ranging from 3.0 to 7.6 m in Cape Cod Bay in 1977. Significant depth related differences in larval density were observed in Cape Cod Bay with higher abundance at the surface (Collings et al. 1983). These results are consistent with the observations of Templeman (1937), Templeman and Tibbo (1945), and Scarratt (1973).

Discrete depth samples taken within the Cape Cod Canal showed no significant differences with depth (Collings et al. 1983); Matthiessen and Scherer (1983) reported significantly higher larval density at 3 m depth at the eastern end of the Canal. The turbulence and mixing effect of water flow through the Canal were cited as possible factors influencing vertical distribution within the Canal.

DIURNAL DISTRIBUTION

Bibb et al. (1983a) noted significantly higher density of larvae in daylight surface samples in Block Island Sound; however, substantial numbers of larvae were collected both at the surface and in near-bottom waters at night. Lux et al. (1983) reported decreased surface abundance during darkness. A shift in relative stage composition was also noted. First stage larvae were most abundant during daylight while stage III larvae were dominant in night collections. These observations are in accord with known differences in phototactic responses among larval stages (Hadley 1908; Templeman 1936b).

Reduced abundance of larvae in daylight surface samples was observed under completely overcast conditions (Lawton et al. 1983; Collings et al. 1983). Templeman and Tibbo (1945) speculated that some minimum light intensity was necessary to attract larvae to the surface. Greenstein et al. (1983) reported, however, that 84% of larvae collected in Penobscot Bay in 1976 were obtained with cloud cover greater than or equal to 50%; 62% of the larval catch was taken on completely overcast days. Harding et al. (1982) reported that most larvae (95%) were collected in the upper 30 cm of the water column during overcast conditions; during bright sunlight, 73.3% of the larvae obtained were within the 0-30 cm depth interval. Differences in turbidity may alter the effect of light intensity on vertical distribution of larvae among geographical locations (Templeman and Tibbo 1945), possibly explaining some of the discrepancies noted above.

SUMMARY

Larval stages of the American lobster were collected during May-October in New England investigations during 1974-79. Lobster larvae occurred earlier in the southern New England region than in the Gulf of Maine. Lobster larvae were more abundant in southern New England than in the Gulf of Maine (including Cape Cod Bay). Favorable conditions for production of larvae in southern New England (lower mean size at maturity), coupled with the effects of prevailing southwesterly winds which concentrate larvae along windward shores, undoubtedly contributed to higher density estimates in Buzzards Bay and Block Island Sound.

Unusually high proportions of stage IV larvae, accompanied by reduced densities, were observed in several studies during 1978. Increased density dependent survival through the pelagic phase may account, in part, for this result. Alternatively, transport of larvae from offshore locations may have resulted in increased stage IV representation in 1978.

Larvae were most abundant at the surface during daylight hours and some evidence for dispersal of larvae from surface waters during night was obtained. The diurnal and vertical distributions of lobster larvae are, of course, not independent; however, the apparent concentration of larvae in surface waters during daylight offers clear advantages for the development of an appropriate sampling design. Lobster larvae are seldom collected in dense concentrations and factors resulting in further dispersal of larvae should be considered in the development of sampling strategies.

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Distribution and Abundance of Lobster Larvae (*Homarus americanus*) in Block Island Sound

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ABSTRACT

The distribution and abundance of lobster larvae along a transect in Block Island Sound was studied in 1977 and 1978. We examined the seasonal, diel, and vertical distribution of lobster larvae. The study was expanded to four transects in 1979 to examine broader spatial patterns.

Lobster larvae were seasonally abundant, appearing in late May or early June and disappearing by late August. Larvae were generally more abundant at the surface than in near-bottom waters, but occasional high concentrations of larvae were observed near the bottom. Surface abundance tended to be higher in daylight than at night. Stage IV larvae were more abundant in 1978 than anticipated from abundance of stage I larvae, possibly suggesting recruitment from adjacent areas. In the 1979 study, stage I larvae were most abundant in the eastern section of the survey area.

INTRODUCTION

This paper describes an intensive study of the distribution and relative abundance of lobster larvae (*Homarus americanus* Milne-Edwards) in Block Island Sound during 1977-79. The objectives of the study were to provide information on diel variation, depth distribution, spatial differences, seasonal variation, and yearly variation of lobster larvae in Block Island Sound to examine potential impacts of a proposed nuclear power facility at Charlestown, R.I.

METHODS

The 1977 and 1978 surveys consisted of weekly sampling using a Tucker net at four stations along a transect off East Beach, Charlestown, R.I. (Fig. 1). Surface samples were taken day and night at four stations. Bottom samples were taken at two stations only, EB-B and EB-C. In 1977, stations EB-B, EB-C, EB-D, and EB-E were sampled. In 1978, stations EB-A, EB-B, EB-C, and EB-D were sampled. In 1979, the sampling area was expanded to 12 stations along four transects: off Weekapaug (WK), East Beach (EB), Nebraska Shoals (NS), and Point Judith (PJ). Surface samples were collected in daylight every 3 to 4 d using a neuston net along these transects.

In 1977 and 1978, preliminary sampling was carried out at stations EB-B and EB-C to determine when larvae first appeared. During the subsequent weeks, sampling was carried out at all stations and depths described above until no more larvae were observed. The period of sampling extended from May through August 1977 and 1978, and May through mid-June in 1979. Plankton sampling along the same transect was carried out through fall, winter, and spring of 1977 and 1978 and early 1979.

All 1977 and 1978 samples were collected using an opening and closing Tucker net (Hopkins et al. 1973), equipped with a 2 m × 2 m, 0.950 mm mesh, 8 m long net. The mouth of the net sampled at a 45° angle with a resultant 2 m × 2 m effective sampling area. Surface tows were taken with the upper bar of the Tucker net about 10 cm out of the water. Bottom tows were made with the center of the Tucker net about 3 m off the bottom. The net was towed between 0.77 and 1.29 m/s for approximately 12 min. Estimated sample volumes were generally between 2,000 and 4,000 m^3. Triplicate tows were made either in a westerly or easterly direction.

Samples in 1979 were taken with a neuston net having 1 m × 2 m mouth, length of 4 m, and 1 mm mesh. Simultaneous paired tows were made with approximately 10 cm of net out of the water. Sample volumes were generally 1,500 to 2,000 m^3. A paired-comparison of sampling efficiency using the Tucker and neuston nets was performed in 1979 (Bibb et al. 1983).

Samples were reduced in volume to 2 l and preserved in 10% buffered formaldehyde for analysis.

Temperature and salinity measurements were taken during plankton surveys at the surface and bottom at each station in 1977 and 1978 and at the surface in 1979 using a calibrated Beckman Model RS-5 salinometer[4]. The temperature output was calibrated using a NBS-traceable thermometer and the salinity output using standard seawater, and an appropriate correction factor derived. Continuous temperature data was recorded using Aanderaa thermistors deployed at stations EB-A and EB-B (Snooks and Jacobson[5]).

Data were analyzed using analyses of variance (ANOVA) on $\log_{10}(n+1)$ transformed data; the log transform was used to normalize the data and reduce the dependence of the sample mean and variance (Cassie 1968). Data from 1977 and 1978 from stations EB-B and EB-C were analysed by four-way

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[3]Yankee Atomic Electric Company, 1671 Worcester Road, Framingham, MA 01701.

[4]Reference to trade names does not imply endorsement by Raytheon Co. or by the National Marine Fisheries Service, NOAA.

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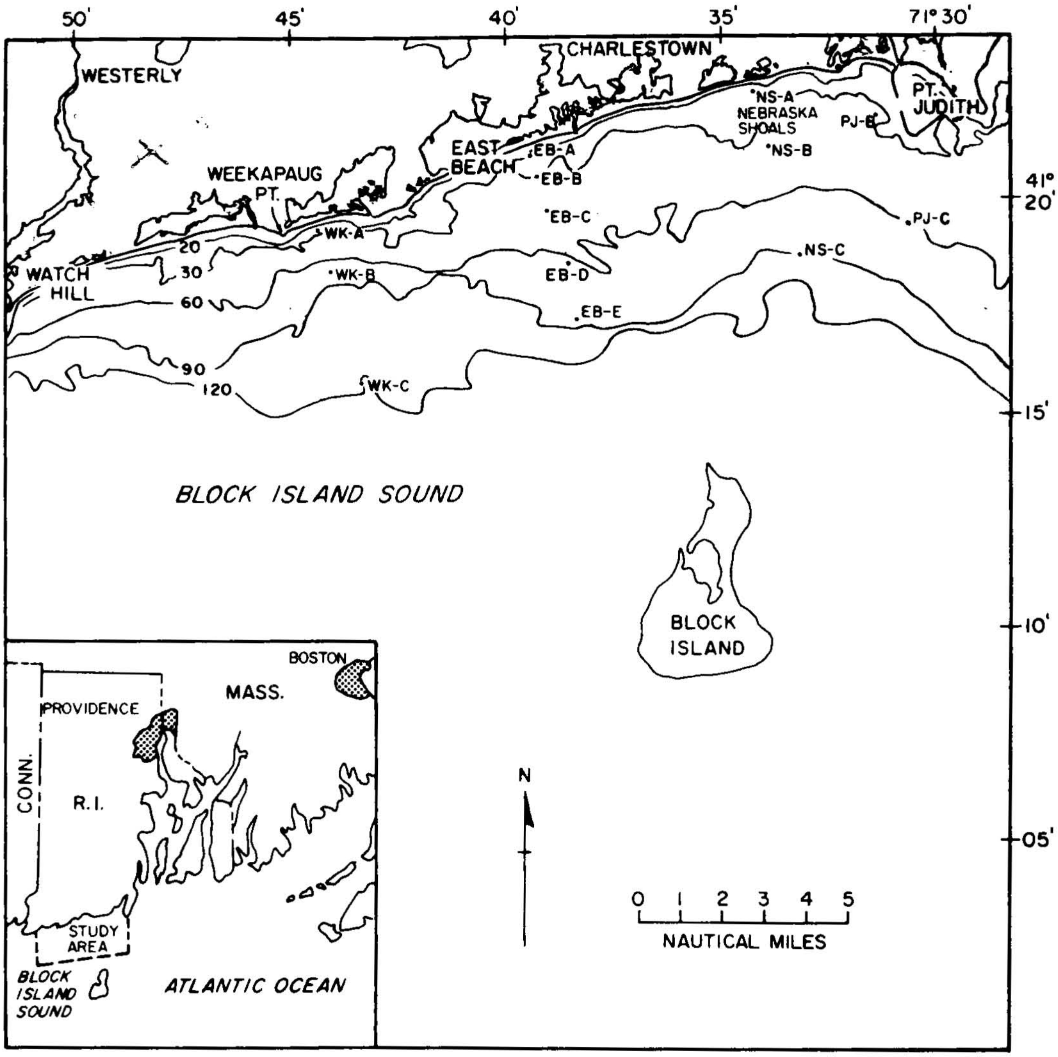

Figure 1.—Station locations in Block Island Sound.

ANOVA with depth, time of day, station, and sample date as main effects. A three-way classification ANOVA was performed on 1977 and 1978 surface data from four stations with station, sample date, and time of day as main effects. One-way ANOVA was performed on 1979 data with station location as the main effect.

RESULTS

Seasonal Abundance

In 1977, lobster larvae were first observed on 31 May, reached peak abundance in mid-June, and were no longer collected after 1 August (Fig. 2). In 1978, larvae were initially collected during the first week of June, and had disappeared by the end of August. In 1979, larvae were first observed on 23 May. Bottom temperatures at station EB-B when stage I larvae were first observed were 13.3 °C, 13.6 °C, and 12.6 °C during 1977-79, respectively.

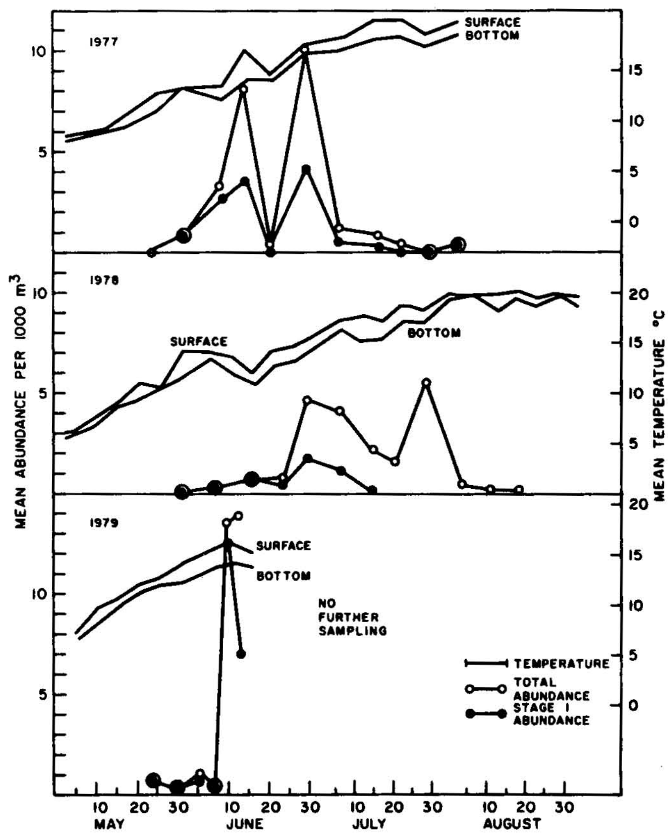

Figure 2.—Mean surface day abundance at stations EB-B and EB-C and mean surface bottom temperature at station EB-B in Block Island Sound. Samples collected in 1977 and 1978 by Tucker net, in 1979 by neuston net.

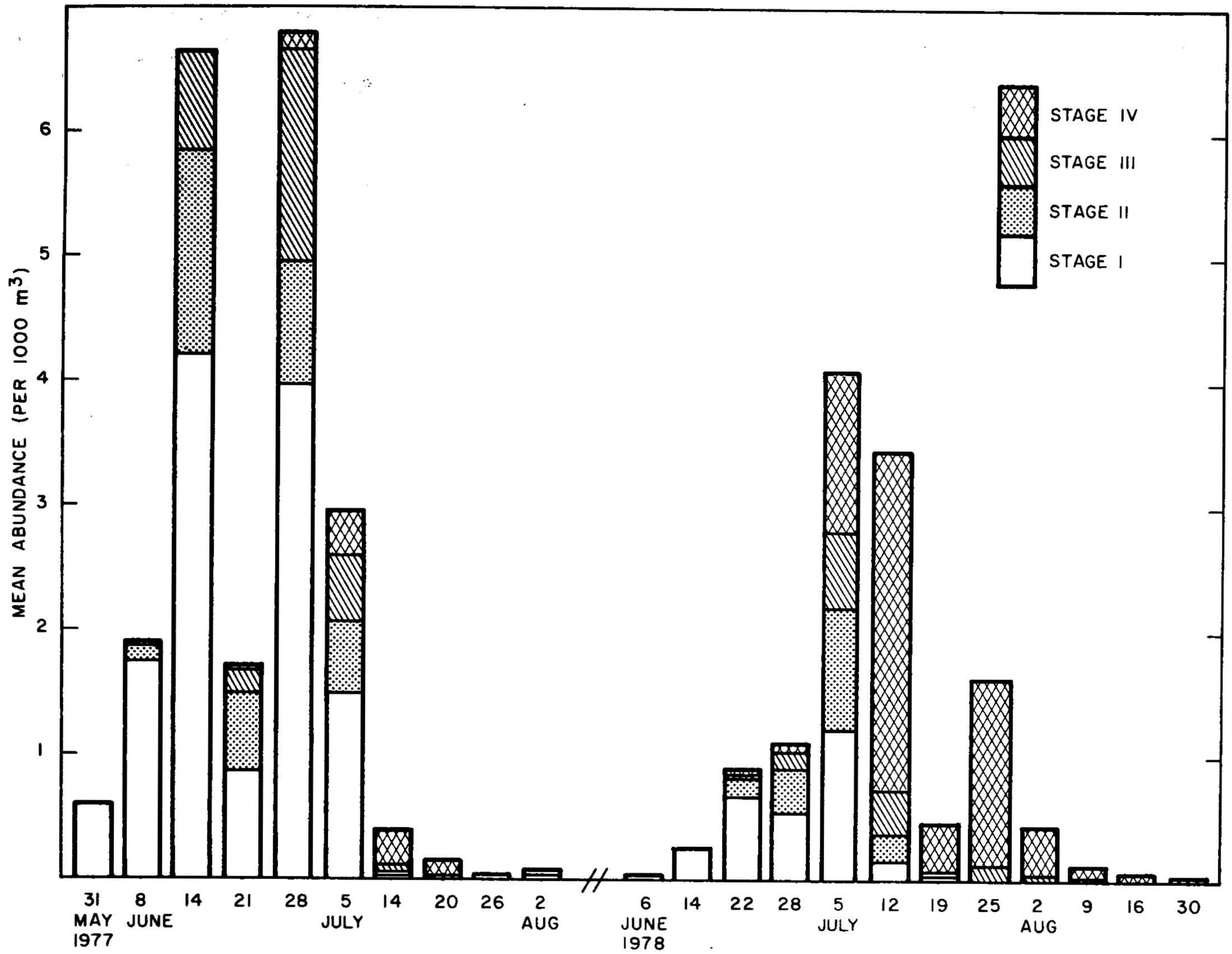

Figure 3.—Stage composition by survey. Mean of all stations, surface and near-bottom, day and night samples.

Stage I larvae were in the water column for a total of 10 wk in 1977 and 8 in 1978 (Fig. 2). In 1977, the maximum abundance of stage I larvae corresponded to maximum total abundance, approximately 3 to 5 wk following the first occurrence of larvae. During the period, mean daily surface and bottom temperatures at station EB-B ranged from 14.5° to 17.5°C and 14.0° to 16.6°C, respectively. In 1978, peak stage I abundance occurred over a 3-wk period from late June to early July. Mean daily surface and bottom temperatures at EB-B during this period ranged from 14.5° to 15.9°C and 12.8° to 14.8°C, respectively.

The appearance of later stage larvae in the water column varied annually (Fig. 3). Stage II larvae were typically found 1 to 2 wk after the first appearance of stage I larvae. Stage III and IV were first collected 2 to 4 wk later. Stage II and III were first found when the bottom temperature at EB-B was approximately 13°-14°C and stage IV at 14°-15°C.

Estimated larval density in 1977 samples declined with each successive stage. In 1978, stage IV larvae, however, were extremely abundant and were observed over a longer time period than in 1977. Stage IV larvae composed 52% of the season total in 1978, but only 4% of the 1977 total (Table 1).

Table 1.—Mean abundance (numbers per 1,000 m³ ± 95% confidence limits) and percent composition by stage of lobster larvae collected off East Beach, Block Island Sound.

Stage	[1]1977 Abundance	[1]1977 Percent of total	[2]1978 Abundance	[2]1978 Percent of total
I	1.33±0.54	59	0.26±0.13	23
II	0.53±0.26	24	0.16±0.10	14
III	0.30±0.14	13	0.12±0.07	11
IV	0.10±0.06	4	0.59±0.38	52
Total	2.26±0.83	100	1.13±0.48	100

[1]107 sampling events 31 May - 2 August 1977).
[2]132 sampling events (15 June - 30 August 1978).

Vertical and Diel Distribution

Four-way ANOVA indicated that mean surface density was significantly higher than near-bottom density at stations EB-B and EB-C in both 1977 and 1978 (Table 2). Relatively high

Table 2.—*F*-value and mean of larval densities for depth and time of day from four-way analysis of variance of lobster larvae data collected at stations EB-B and EB-C using $\log_{10}(n+1)$ transformed abundance per 1,000 m^3.

		Depth			Time of day		
			Mean			Mean	
Year	Stage	*F*-value	Surface	Bottom	*F*-value	Day	Night
[1]1977	I	26.41**	0.18	0.08	11.16**	0.09	0.17
	II	38.29**	0.09	0.02	19.53**	0.08	0.03
	III	31.09**	0.07	0.01	10.99**	0.57	0.03
	IV	26.75**	0.06	0.01	1.34	0.04	0.03
	Total	88.24**	0.28	0.11	1.80	0.19	0.21
[2]1978	I	4.28**	0.11	0.07	0.14	0.09	0.08
	II	1.08	0.05	0.04	4.95*	0.06	0.03
	III	4.98*	0.05	0.03	1.81	0.04	0.03
	IV	104.39**	0.20	0.03	12.83**	0.14	0.08
	Total	67.04**	0.34	0.12	6.50*	0.26	0.20

*Means significantly different at 95% level.
**Means significantly different at 99% level.
[1]14 June through 2 August.
[2]15 June through 17 August.

Table 3.—*F*-value and mean of larval densities for time of day from three-way analysis of variance using $\log_{10}(n+1)$ transformed abundance per 1,000 m^3.

			Mean	
Year	Stage	*F*-value	Day	Night
[1]1977	I	2.18	0.26	0.23
	II	32.78**	0.19	0.11
	III	17.54**	0.13	0.08
	IV	1.10	0.06	0.05
	Total	17.01**	0.41	0.32
[2]1978	I	0.13	0.10	0.11
	II	4.02*	0.08	0.06
	III	0.03	0.06	0.06
	IV	23.19**	0.06	0.14
	Total	15.37**	0.39	0.28

*Means significantly different at 95% level.
**Means significantly different at 99% level.
[1]14 June through 2 August.
[2]15 June through 17 August.

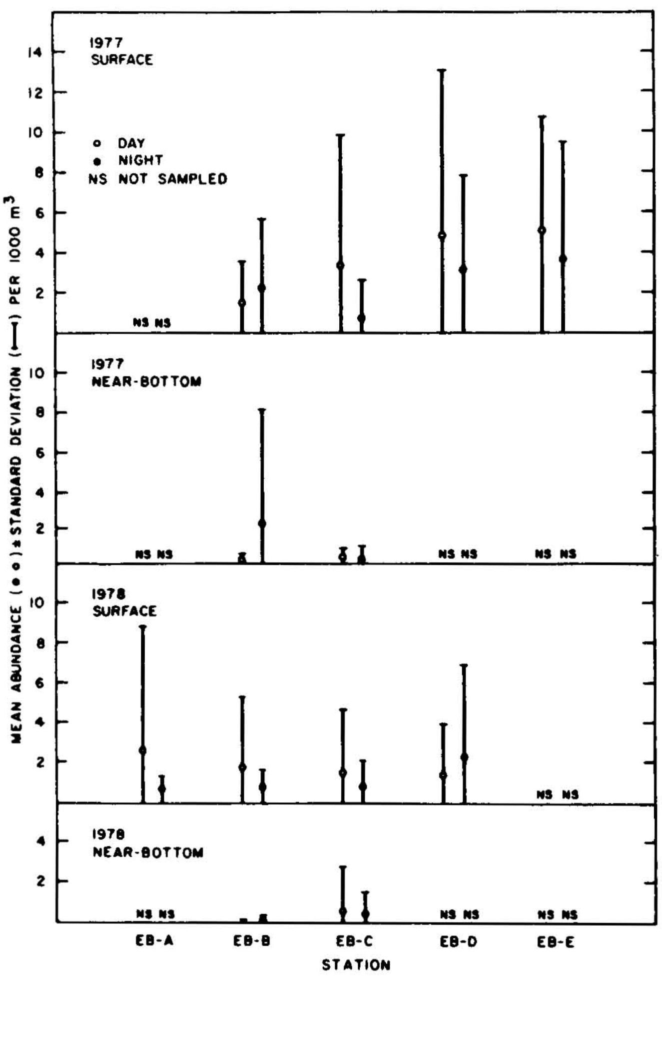

Figure 4.—Vertical and diel distribution of lobster larvae. Mean and standard deviation of all surveys by station, depth, and time of day.

larval densities were noted however in some near-bottom samples (Fig. 4). Day-night differences show no consistent pattern at these stations (Table 2).

When surface density at all four stations was compared using three-way ANOVA (Table 3), daytime density was significantly greater than night abundance for all stages combined. For the individual stages where significant differences were noted, day abundances were consistently higher (Table 3).

Geographical Distribution

Average surface abundance in 1977 and 1978 was greatest at the offshore stations for stages I-III; and was approximately equal (1977) or greater (1978) at inshore stations for stage IV larvae as indicated by three-way ANOVA (Fig. 5). Distribution of stage IV larvae was patchy, with 41% of all stage IV larvae collected in two samples from EB-A and EB-B in 1978.

The 1979 study was designed to examine broader geographic distribution of lobster larvae in Block Island Sound. The mean abundance of stage I lobster larvae in this study was generally higher along the Point Judith transect and decreased successively along each of the western transects (Fig. 6, Table 4).

A one-way ANOVA indicated that mean density of stage I larvae was significantly different between stations at the 95% level (F = 2.78, df = 11, 108). Station abundance means were ranked and a Student-Newman-Keuls test performed to determine significant groups. Abundance of stage I larvae was significantly higher at stations in the eastern end of Block Island Sound and at the offshore station EB-E. From 1 to 11 June (the last sampling date) the proportion of later stage larvae steadily increased along all transects. Because sampling was terminated in 1979 before the later stages would normally peak, no further conclusions can be drawn with respect to their distribution. However, the proportion of older larvae was greater along western transects while the proportion of stage I larvae remained higher along the eastern transects (Table 4).

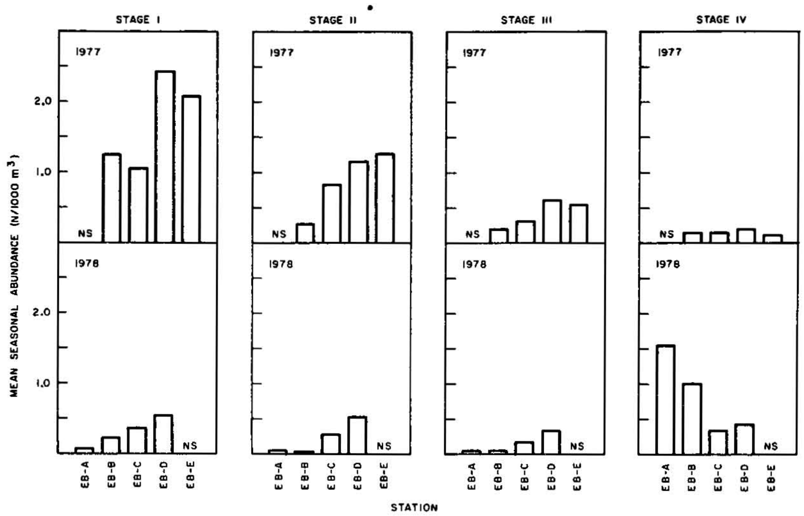

Figure 5.—Distribution of lobster larvae between stages by station in 1977 and 1978.

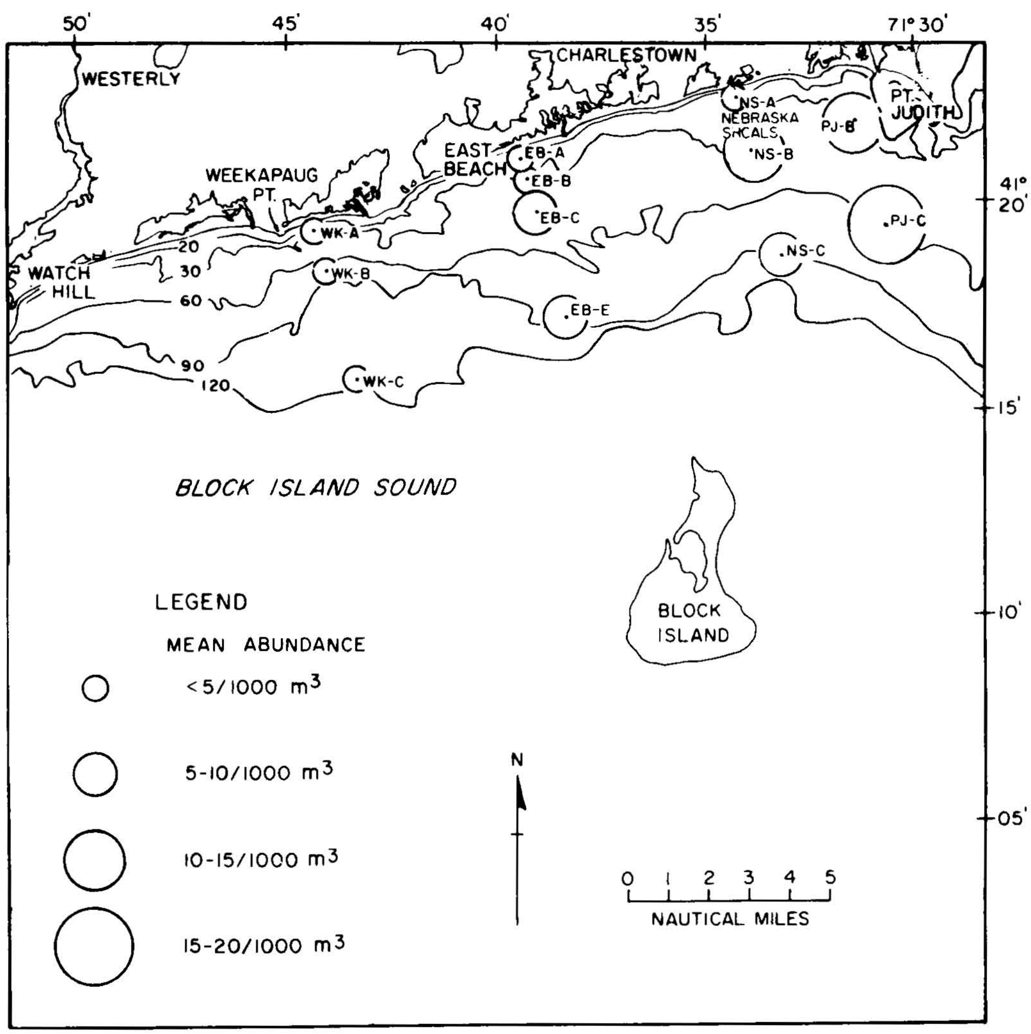

Figure 6.—Relative abundance of stage I lobster larvae by station in 1979.

Table 4.—Mean density and standard deviation per 1,000 m³ of lobster larvae by stage collected along four transects in Block Island Sound during May and June 1979.

	Stage							
	I		II		III		IV	
Transect	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weekapaug	2.9	3.3	1.5	2.2	0.1	0.3	0	0
East Beach	4.9	7.2	1.6	2.3	0.4	0.8	0	0
Nebraska Shoals	7.7	8.3	1.3	1.8	0.2	0.4	0	0
Point Judith	16.4	23.6	2.0	4.1	0.5	1.0	0	0

Observations on surface current patterns indicate westward surface currents from the Point Judith area (Fig. 7), suggesting transport of larvae to the west.

Production

Relative production for the 1977 and 1978 seasons was determined using the method of Scarratt (1964). Weekly production was divided by the time between molts (Templeman 1936) for each stage at the corresponding mean surface temperature for that week. Weekly production estimates were then summed to estimate relative seasonal production. The estimated seasonal production of lobster larvae in 1977 was threefold higher than the 1978 production estimate (Table 5). There was an exponential decrease in production from stages I and IV in 1977. Stage II abundance was 40% of stage I; stage II was 57% of II; and stage IV as 33% of III. A similar pattern was observed for stages I, II, and III in 1978. However, in 1978, stage IV production exceeded that of stages II and III.

DISCUSSION

Lobster larvae in Block Island Sound were abundant in the plankton for a relatively short period in June and July. Observation of stage I lobster larvae in late May or early June is an indication of recent hatching. Since the duration of stage I is approximately 1 to 5 d (Herrick 1911), first hatching occurred off East Beach in mid to late May during 1977-79. The duration of hatching activity was about 8 to 9 wk based on the occurrence of stage I larvae in the water column. Peak hatching apparently occurred in mid to late June in 1977-79.

Herrick (1911) observed that hatching was triggered by rising temperatures. The bottom temperature when larvae were first observed off East Beach was 13.3 °C in 1977, 13.6 °C in 1978, and 12.6 °C in 1979. Peak abundance of stage I larvae occurred in early June in 1977 and 1979 and in early July in 1978. This reflects a later warming trend in 1978. In 1977 and 1979, bottom temperatures at EB-B had reached 12 °C by about 20 May; in 1978, water temperatures did not reach this level until 30 May. Bottom temperatures during periods of apparent maximum hatching were approximately 14°-18 °C. Peak occurrence of stage I larvae was observed at temperatures of 13°-15 °C in Maine by Sherman and Lewis (1967). Intensive hatching was observed in Martha's Vineyard at temperatures of 15°-20 °C by Hughes and Matthiessen (1962).

Hatching was apparently complete by early August in both 1977 and 1978. Stage IV larvae were observed from mid-June until the last week of August in 1978, but only from late June until the first week of August 1977.

Templeman (1939), Scarratt (1973), and Sherman and Lewis (1967) observed highest surface concentrations of lobster larvae during daylight. Our results generally confirm these observations. On occasion, considerable numbers of stage I larvae were caught in near-bottom waters during both day and night.

The distribution of lobster larvae observed in 1977 and 1978 suggests a hatching area near stations EB-C and EB-D. Larvae which hatch in this area may be transported westward and collected at stations EB-C and EB-D.

Currents in Block Island Sound are primarily tidal, with eccentric elliptic patterns generally parallel to the shore (east-west). Velocities are moderate to strong (0.15 to 0.30 m/s). Residual drift is strongly influenced by local winds with strong seasonal variability (Snooks and Jacobson footnote 5). Surface drifters released at stations off East Beach and other Block Island stations in July 1977 were all recovered along the mainland shore to the west of the release point except for those released just off Block Island; some of these were recovered off Block Island and Long Island (Fig. 7).

The 1979 study was designed to identify hatching sites in Block Island Sound and their potential contribution to lobster populations off East Beach. However, the 1979 results are of limited use in identifying hatching areas because the sampling period was abbreviated. Nevertheless, several factors point to a major hatching area near Point Judith. Surface drifters indicate transport to the west during summer. Stage I larvae were more abundant in this area (PJ and NS transects). The proportion of stage I larvae was highest along these transects, with higher proportions of stage II and III larvae observed at more westerly transects.

A summary of observations on lobster larvae for 1976 through 1979 off East Beach in Block Island Sound is presented in Table 6. The time of peak abundance was later in 1978, reflecting a slower rise in bottom temperature. Average surface abundance of larvae at its maximum showed considerable variability, even allowing a factor of two to four for total difference in abundance estimates between neuston and Tucker net samples (Bibb et al. 1983). Abundance of lobster larvae for all stages was higher at offshore stations in 1977. In 1978, stage I through III larvae maintained this pattern, but stage IV larvae were more abundant inshore. In 1976, all stages were more abundant at the inshore station. The high abundance of stage IV larvae in 1978 is perhaps the most remarkable difference among the years of observations, possibly resulting from transport from adjacent areas or differences in survival or sampling efficiency.

ACKNOWLEDGMENTS

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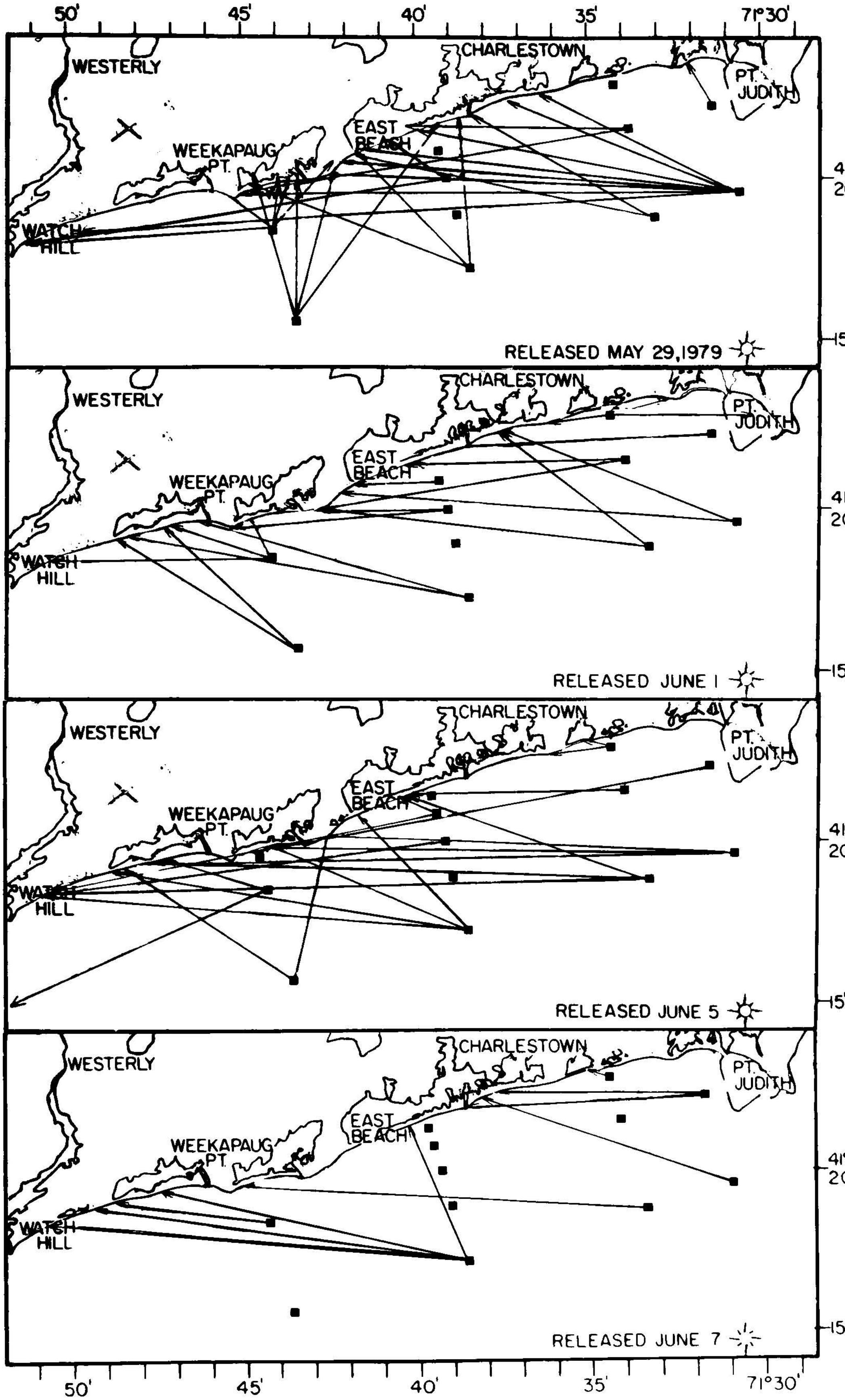

Figure 7.—Surface drifter release and recovery points in May and June 1979 in Block Island Sound.

Table 5.—Seasonal production (number per 1,000 m^3 per season) of lobster larvae collected off East Beach calculated using technique of Scarratt (1964).

	Year	
Stage	1977	1978
I	22.8	4.7
II	4.8	1.7
III	2.0	1.3
IV	0.4	2.3
Total	30.0	10.0

Table 6.—Comparison of lobster larvae observations from 1976 through 1979 along a transect in Block Island Sound.

Parameter	[1]1976	1977	1978	[2]1979
First larvae observed	27 May[3]	31 May	6 June	23 May
Highest station value observed (/1,000 m^3)	65.7	20.81	21.42	21.3
Peak larval abundance (/1,000 m^3) average of all stations, surface	37.2	7.79	4.78	18.7
Date of peak larval abundance	18 June[4]	14, 28 June	5, 12 July	
Relative abundance by stage (over season)	II>I>IV>III	I>II>III>IV	IV>I>II>III	I>II>III
Highest station				
I	nearshore	offshore	offshore	offshore
II	nearshore	offshore	offshore	offshore
III	nearshore	offshore	offshore	offshore
IV	nearshore	offshore	nearshore	not seen
Total	nearshore	offshore	offshore	offshore
Highest time of day	night	day	day	not sampled
Collection method	neuston	Tucker	Tucker	neuston

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[2]Sampling discontinued 11 June 1979.

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Distribution, Relative Abundance, and Seasonal Production of American Lobster, *Homarus americanus*, Larvae in Block Island Sound in 1978

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ABSTRACT

Neuston samples were collected at eight station sites in Block Island Sound at approximately weekly intervals from 3 May through 1 September 1978, and sorted for lobster (*Homarus americanus*) larvae. Larvae were collected between 1 June and 22 August. Fourth stage larvae were numerically dominant, comprising 63% of the 1,030 larvae collected in this survey. Total production of stage I larvae in Rhode Island Statistical Area 4 estimated from survey data was 2.514×10^6 larvae. A minimum estimate of potential stage I production in Area 4 based on population size determined by cohort analysis and relative population fecundity indicated that at least 3.232×10^7 larvae could have been produced. Stepwise multiple regression analysis of hydrographic and climatological variables on total larval density demonstrated that water temperature and wind velocity explained 61.5% of the observed variance.

INTRODUCTION

The American lobster, *Homarus americanus*, is among the most valuable commercially exploited species in Rhode Island. Preliminary commercial landings in 1980 were 1,100 t with an estimated value of $5.6 million. Due to the importance of this species to the economy of Rhode Island, investigations into several aspects of lobster population dynamics were initiated in 1974. These studies provided information on growth and mortality (Russell et al.[5]), local movements and migratory behavior (Fogarty et al. 1980), gear selectivity (Fogarty and Borden 1980), trawl induced injury and mortality (Ganz[6]), and commercial catch statistics (Simon[7]).

Despite the recent attention devoted to the behavior, ecology, and population biology of juvenile and adult American lobster, relatively little is known of the pelagic larval stages. The present study was designed to investigate the seasonal and spatial distribution of lobster larvae in Block Island Sound. We derived a preliminary estimate of larval production in the survey area using stage I density adjusted for development time and mortality. For comparsion, potential egg production was calculated using information on population structure, sex ratios, size at maturity (Russell et al. footnote 5), and relative population fecundity (Saila et al. 1969).

MATERIALS AND METHODS

Neuston samples were collected at approximately weekly intervals from 3 May through 1 September 1978 at eight stations in Block Island Sound (Fig. 1) and sorted for lobster larvae. Replicate samples were collected with paired neuston nets (1 m × 2 m opening; 0.946 mm mesh) deployed from two side booms aboard a 20 m research vessel. When sampling, the nets were positioned forward of the stern wake and outside of the bow wake to ensure an undisturbed sample. The position of the nets was adjusted to sample the upper 0.5 m of the water column. Standard tows were of 20 min duration at approximately 3.7 km/h. During periods of high ctenophore abundance, when the filtration efficiency of the nets was reduced,

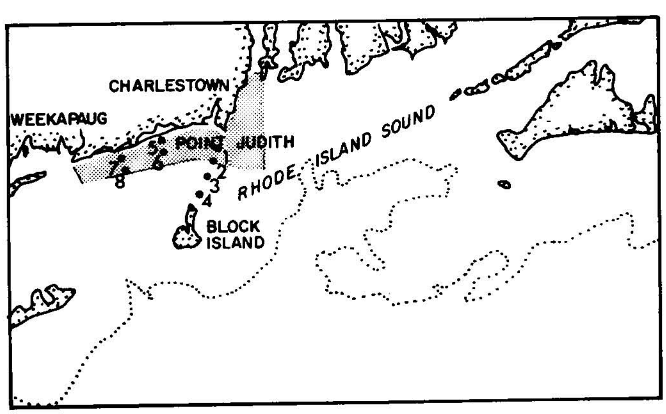

Figure 1.—Location of sample sites in Block Island Sound, 1978. Shaded area indicates Rhode Island Statistical Area 4.

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[5]Russell, H. J., D. V. D. Borden, and M. J. Fogarty. 1978. Management studies of inshore lobster resources. Final report. State-Federal Lobster Management Program Contract No. 03-4-043-360, 78 p.

[6]Ganz, A. R. 1979. Evaluation of otter trawl induced lobster damage. Final report. Commercial Fisheries Research and Development Act Contract No. 04-7-043-44041, 23 p.

[7]Simon, B. M. 1980. Lobster logbook and statistical analysis. Segment report. Commercial Fisheries Research and Development Act Contract 04-78-D01-R1B-B.

tows were shortened. All samples were collected during daylight between 0800 and 1600 h since previous investigations demonstrated that larval abundance is highest at the surface during daylight (Templeman 1937; Templeman and Tibbo 1945; Scarratt 1973). The distance covered by the vessel during each tow was determined from loran-C coordinates recorded to the nearest 0.1μs at the start and end of each tow. Surface water temperature was recorded at each station.

Nets were washed down with seawater after each tow to maintain a standard filtration efficiency. Samples were rinsed in seawater, strained using a 505 μ mesh screen, and placed in buffered 10% Formalin.[8] Samples were sorted for decapod larvae and fish eggs and larvae in the laboratory. All lobster larvae were removed and identified to stage (Herrick 1911) using a dissecting microscope equipped with an ocular micrometer. Since fourth and fifth stage larvae are best differentiated by size (Herrick 1911), larvae identified as fourth stage were measured (total length) to the nearest millimeter and compared with published records of length of stage IV larvae. Larval density estimates were derived using Δ-distribution theory (Aitchison 1955; Aitchison and Brown 1957), a technique in which survey data are classified into zero and non-zero catch values. The conditional distribution of the non-zero class is assumed to be log-normal. A minimum variance unbiased estimator of the sample mean (Aitchison 1955) is:

$$C = \frac{m}{n} e^{y} \psi_m(s^2/2)$$

where m is the number of non-zero observations, n is the total number of observations, y and s^2 are the mean and variance of the log transformed non-zero observations and ψm (Aitchison 1955) is given by:

$$\psi m = 1 + \frac{n-1}{n} t + \sum_{j=2}^{\infty} \frac{(n-1)^{2j-1}}{n^j(n+1)(n+3)\ldots(n+2j-3)} \cdot \frac{t^j}{j!}.$$

[8]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Density estimates for each stage were corrected for stage duration by dividing by development time at prevailing water temperatures (Templeman 1937) for each sample period. Daily production estimates were summed over the entire sampling season to provide an estimate of annual larval production per 1,000 m^3.

RESULTS AND DISCUSSION

Seasonal Distribution

Due to the relatively short duration of the first larval stage, the occurrence of stage I lobster larvae is indicative of recent hatching activity. We initially noted stage I larvae on 1 June and first stage larvae were observed through the beginning of August, indicating that the hatching period in 1978 spanned approximately 2 mo (Fig. 2). Peak abundance of first stage larvae occurred in late June at a mean density of 10.82 larvae/1,000 m^3. The mean seasonal density of stage I larvae was 1.98/1,000 m^3.

Second and third stage larvae were first observed in the 20 June collections and the highest densities for both stages were noted in samples collected in late June (Fig. 2). Stage II larvae were collected through the end of July while third stage larvae were observed through mid-August. The mean seasonal density was 3.11/1,000 m^3 and 1.80/1,000 m^3 for second and third stage larvae, respectively.

Fourth stage larvae were initially collected in the 27 June samples and were dominant for the remainder of the season. The highest mean weekly density of stage IV larvae (26.08/1,000 m^3) was noted in mid-July and fourth stage larvae were collected through the end of August (Fig. 2). Of the 1,030 larvae collected during this survey, 645 (62.6%) were fourth stage. In contrast, the first through third larval stages comprised 12.3%, 14.1%, and 10.9% of the samples, respectively. The dominance of fourth stage larvae is particularly striking since previous investigators observed relatively low densities for this stage (Templeman 1937; Templeman and Tibbo 1945; Scarratt 1964, 1973; Sherman and Lewis 1967). Bibb et al. (1983) also noted a high proportion (52%) of stage IV larvae in 1978 in Block Island Sound, in marked contrast to their 1977

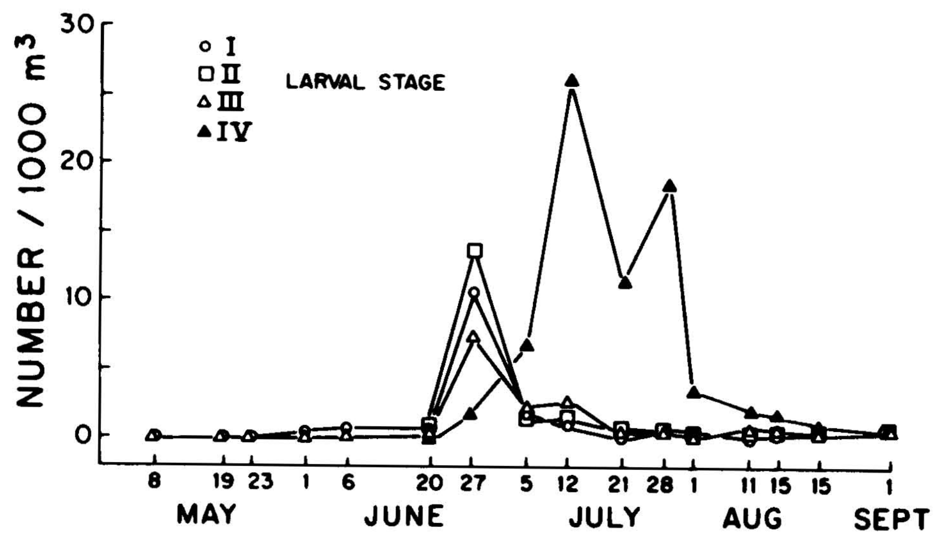

Figure 2.—Density (no./1,000 m^3) of stage I-IV lobster larvae during sampling period (8 May through 1 September).

collections in which stage IV larvae composed 4% of the total larvae obtained.

High stage IV densities may be due to transport into the study area or differential catchability. Phototropic responses differ among larval stages (Hadley 1908; Templeman and Tibbo 1945; Ennis 1975) with first and fourth stage larvae being most strongly phototactic, indicating that these stages may be more vulnerable to surface gear. Since previous researchers, using similar gear, obtained relatively low stage IV densities, it is unlikely that differences in catchability alone are sufficient to explain the high abundance of fourth stage larvae in our samples.

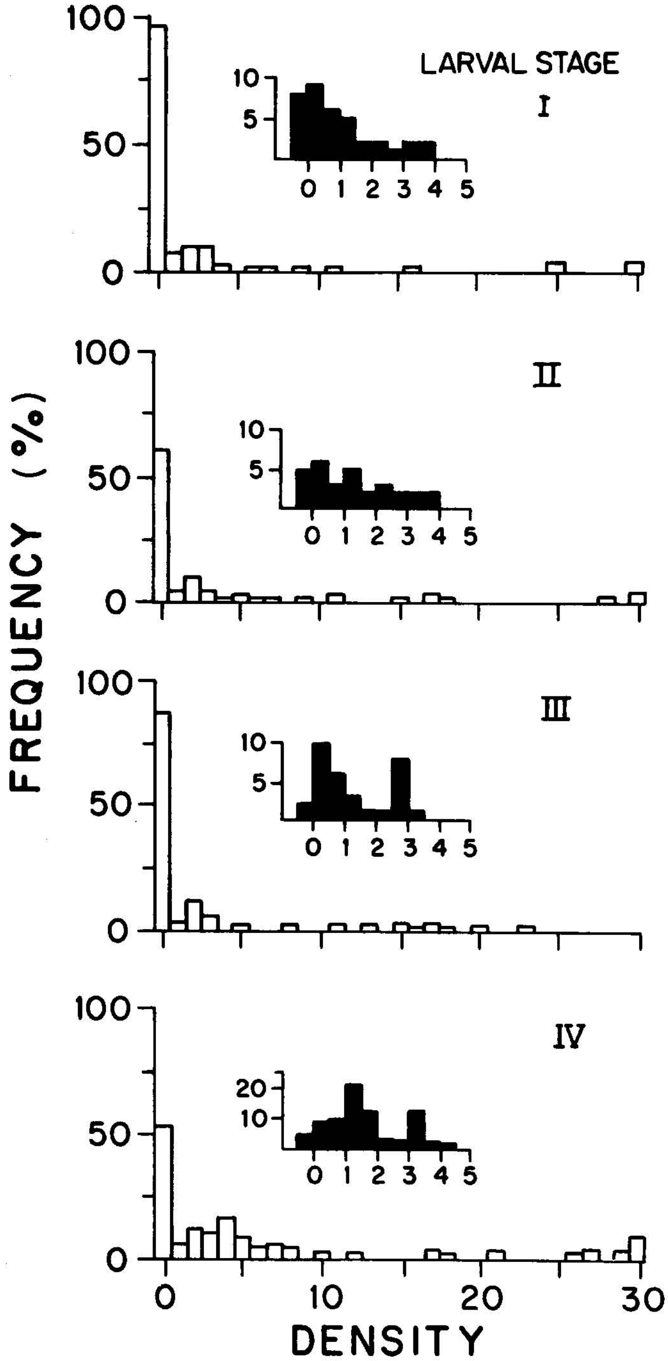

Figure 3.—Frequency distribution of lobster larval catch densities (no./1,000 m³) and distribution of $\log_e$ transformed catch densities (zero catches excluded).

Conditional distribution of the non-zero catches was approximately log-normal for each larval stage (Fig. 3). Contagious distribution patterns have been consistly noted in larval lobster sampling programs (see reviews by Fair 1980 and Stasko 1980). Patch size dimensions are not generally known, however no significant differences in catch between paired neuston nets separated by ≅15 m were observed (Wilcoxon paired rank sum test; $P>0.05$).

Comparisons between larval catches at each of the eight stations (Table 1) indicated no significant differences among stations for stages I-III (Kruskal-Wallis test; $P>0.05$). The lack of significant differences in stage I densities between stations does not permit inference regarding possible spawning locations; however, the area surveyed was relatively small and transport of larvae with prevailing currents may have obscurred source areas. Significant differences ($P<0.005$) were noted, however, between stations for stage IV larvae (Kruskal-Wallis test; $\chi^2 = 20.91$; df = 7). Stage IV densities tended to be highest in the western segment of the study area (Table 1), however, relatively high stage IV density was noted at station 1 in the eastern section of the survey area.

Table 1.—Mean larval densities (no./1,000 m³) for stages I-IV over the entire sampling season.

	Larval stage			
Station	I	II	III	IV
1	2.208	4.197	2.560	9.852
2	1.071	2.456	1.995	2.242
3	0.559	0.938	0.331	0.891
4	3.585	9.339	2.099	0.699
5	3.383	5.857	1.035	12.990
6	1.231	1.633	3.957	12.166
7	0.207	0.560	1.533	10.816
8	0.310	1.540	0.790	1.969

Seasonal Production

Seasonal production curves were constructed based on standardized daily production estimates (Fig. 4); annual larval production was then determined by integration. Estimated annual production for stages I-IV was 22.72, 19.80, 12.20, and 32.33 larvae/1,000 m³, respectively. The high production estimate for fourth stage larvae, despite correction for stage duration, is indicative of the unusually high abundance of stage IV larvae in 1978. The adjusted estimates of stage IV production are conservative since settlement occurs approximately midway through the fourth stage and the larvae are no longer vulnerable to the gear (Scarratt 1973). Scarratt (1964) provided stage I seasonal production values for Northumberland Strait which considerably exceeded our estimates.

Stage I density was expanded to provide an estimate of 2.514×10^6 stage I larvae produced in Rhode Island Statistical Area 4 (Fig. 1). The statistical area encompasses 165.01 km² and it was assumed that larvae were confined to the upper 0.5 m of the water column. The stage I total production estimate was corrected for an instantaneous daily mortality rate of $Z = 0.050$ derived by regressing $\log_e$ transformed production of stages I-III on the weighted mean duration (days) of each stage. Due to the many variables influencing the catchability

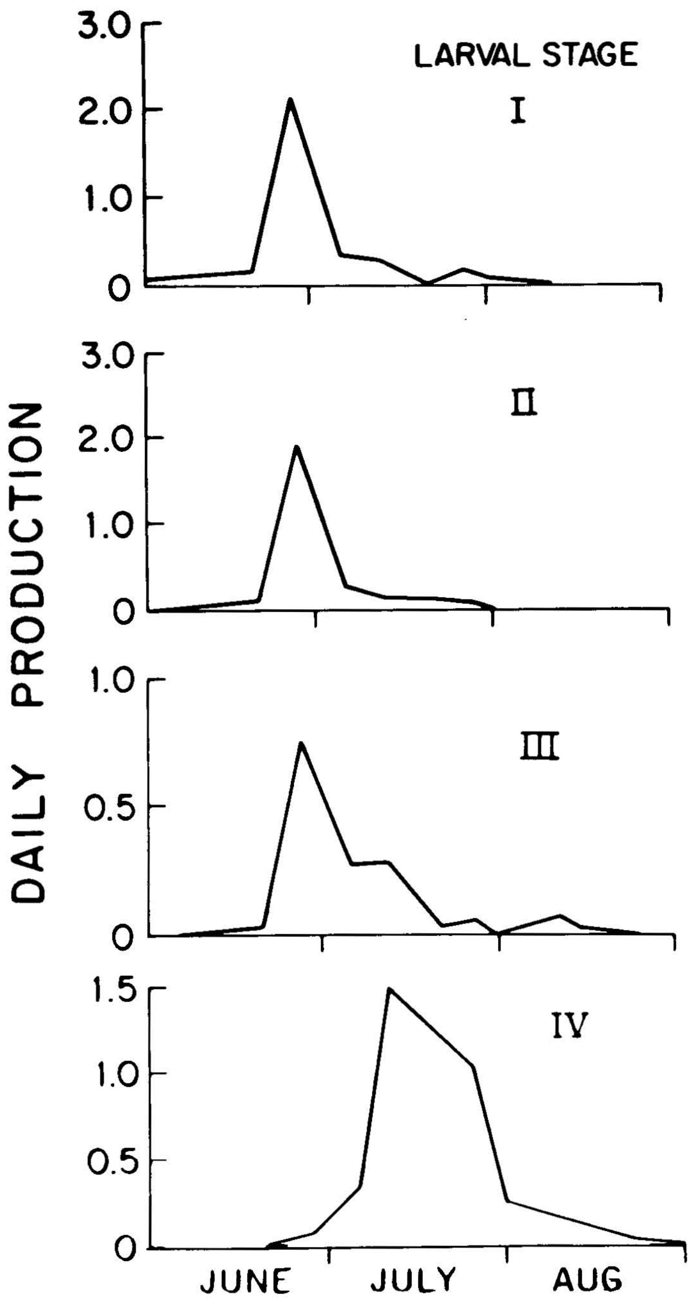

Figure 4.—Daily production (no./1,000 m³) estimates of stage I-IV lobster larvae during period of larval occurrence (1 June-22 August).

of lobster larvae, this must be considered a preliminary estimate.

For comparative purposes, a minimum estimate of potential stage I production in Statistical Area 4 was derived using population size determined by cohort analysis (Jones 1974), size at sexual maturity (Russell et al. footnote 5), and fecundity (Saila et al. 1969). Commercial catch data (B. Simon[9]) for September 1977 to 30 July 1978 were employed in this analysis; this interval spans the egg bearing period for lobsters which would release larvae in 1978. It is implicitly assumed that the catchability of ovigerous females is not altered. Size groupings were arbitrarily defined based on molt increment data using the minimum legal size at the time of this study (78 mm carapace length) as a starting point. Terminal fishing mortality ($F_t = 1.2$) was determined from tag return data (Russell et al. footnote 5) adjusted for the seasonal pattern of catches. Fecundity for each molt class was calculated using the relationship

$$F = 0.02502\ \mathrm{CL}^{2.8647}$$

where F is fecundity and CL is the carapace length (mm) (Saila et al. 1969). Estimated potential egg production for Statistical Area 4 was 3.323×10^7 (Table 2). No estimate of the reproductive contribution of females <78 mm CL was made, however ovigerous females composed < 1% of the 68-77 mm CL female size class in research catches. The expanded survey estimate of stage I production apparently underestimated potential production by an order of magnitude. Nichols and Lawton (1978) noted discrepancies between estimated larval density of *H. gammarus* and potential production. Larvae are not entirely confined to the surface layer (Scarratt 1973) accounting, in part, for this discrepancy. The contagious distribution pattern and behavioral responses to environmental conditions (light intensity, wind factors, etc.) which alter availability compound the difficulty in estimating larval abundance.

Environmental Effects

The influence of several hydrographic and climatological factors on larval density was examined using stepwise multiple

[9]B. Simon, Rhode Island Department of Environmental Management, 150 Fowler St., Wickford, RI 02852, pers. commun.

Table 2.—Arbitrary size classes (carapace length, mm); proportion of each size class, proportion female, and proportion ovigerous in research catches; estimated number of females in commercial catch from 1 September 1977 to 30 July 1978 in statistical area 4; population size of females based on cohort analysis; estimated numbers of ovigerous females in population; and average fecundity.

Size class	Proportion of catch	Proportion female[1]	Proportion ovigerous[1]	Est. no. females in catch	Est. no. females in population[2]	No. spawners	Average fecundity[3]
78-87	0.823	0.529	0.073	24,421	33,683	2,459	7,581
88-99	.162	.522	.143	4,938	6,282	898	10,142
100-112	.011	.444	.375	285	658	247	14,866
>112	.004	.750	.333	175	266	89	20,473

[1]Russell et al. (text footnote 5).
[2]Parameters for cohort analyses by length groups (Jones 1974): $K = 0.0966$, $L_\infty = 184.58$, $M = 0.15$, $F_t = 1.2$ (Russell et al. text footnote 5).
[3]Average fecundity for each size class using mean carapace length of each group and fecundity relationship of Saila et al. (1969).

regression. Independent variables included mean weekly water temperature, mean wind speed and direction on the sampling date, and wind speed and direction averaged over the sampling date and the previous 2 d. Wind direction was treated as a categorical variable with two classes (onshore and offshore). Wind speed and direction data were obtained from the National Weather Service Station at Warwick, R.I. Larval density, water temperature, wind speed, and averaged wind speed were transformed to natural logarithms prior to analysis. Two variables, water temperature and wind speed on the sampling date, were sufficient to provide a significant regression equation (Table 3) with multiple correlation coefficient of R = 0.784. Examination of the squared multiple correlation coefficient indicated that 61.5% of the variance was explained by the derived equation. Inspection of the standardized residuals revealed no departure from the assumption of normality and a Durbin-Watson test (Neter and Wasserman 1974) indicated no significant autocorrelation in the residuals.

Table 3.—Coefficients and associated standard errors (SE), F ratios (df = 2,9), and multiple correlation coefficients (R) for stepwise regression model relating larval density to wind speed and temperature.

Variable	Coefficient	SE	F	R
Wind speed	3.0907	0.8507	13.199**	0.649
Temperature	5.4328	2.5675	4.477*	.783
(Constant)	− 19.6808			

**Significant at $P<0.01$.
*Significant at $P<0.05$.

The lack of a significant wind direction effect was surprising since a positive relationship between onshore winds and larval abundance has been previously noted (Templeman and Tibbo 1945; Squires 1970; Stasko 1980). In the present study, the highest larval densities were generally obtained when winds were onshore. However, low larval densities at the beginning and end of the season, despite onshore winds, tended to obscure this relationship. A vector plot of surface transport was constructed for the period of high larval abundance, 20 June to 28 July, assuming surface drift to be 3.0% of the resultant wind speed and at an angle of 15° to the right of wind direction (Fig. 5). Prevailing winds for the period were southwesterly, however, variable offshore winds dominated from 27 June through 5 July, culminating in reduced larval catches on this date (Fig. 5). High larval densities on 12 July, despite 2 d of offshore winds, do not conform to the general pattern although the effects of strong onshore winds from 6 through 10 July may account, in part, for this result.

The inclusion of surface water temperature in the model reflects the increasing contribution of fourth stage larvae later in the season when water temperatures were also increasing. Lobster larvae were collected in surface water temperatures ranging from 13° to 25°C. Modal temperatures at peak larval densities for stages I and II were 14°-16°C and 17°C for third stage larvae (Fig. 6). Stage IV larvae were abundant at surface water temperatures over 17°C. Lund and Stewart (1970) collected lobster larvae in surface waters ranging from 12.5° to 28.5°C in Long Island Sound. Surface water temperatures ranged from 13.7° to 15°C during peak larval concentrations in the Gulf of Maine (Sherman and Lewis 1967).

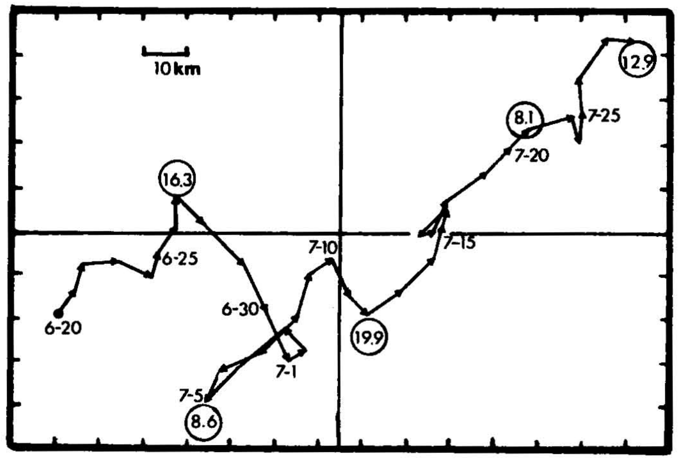

Figure 5.—Vector plot of wind-induced surface drift during 20 June-28 July 1978. Circled figures represent larval densities on sampling dates. Dates provided at 5-d intervals for reference.

The contribution of wind speed to the regression equation may reflect wind-induced advection currents which presumably served to transport larvae into the study area. Wind velocities on sample dates were relatively moderate and apparently did not reach levels at which surface turbulence would result in reduced densities (Squires 1970).

CONCLUSIONS

High fourth stage larval lobster densities were obtained in Block Island Sound in 1978. Adjustment for probability of capture based on developmental times for each larval stage did not eliminate the dominance of stage IV larvae in these collections. Although first and fourth stage larvae may be more vulnerable to surface gear (Templeman and Tibbo 1945), high mortality rates during the pelagic larval stages (Scarratt 1964, 1973) should result in relatively low numbers of stage IV larvae if recruitment is strictly localized. Prevailing winds during the period of larval occurrence are onshore, possibly resulting in a net transport of larvae from continental shelf waters. Larval recruitment from offshore locations may assume particular importance in maintaining inshore populations which are subjected to extremely high fishing mortality rates.

Stage I larval production in Rhode Island Statistical Area 4 was estimated to be 2.514 × 10^6 larvae based on expansion of corrected larval densities. A minimum estimate of hypothetical larval production based on population size determined by cohort analysis, sex ratio, maturity, and fecundity indicated that at least 3.323 × 10^7 larvae could have been produced. Nichols and Lawton (1978) reported similar underestimates of larval production of *Homarus americanus* based on neuston samples.

Larval density was significantly correlated with wind speed on the day of sampling and surface water temperature.

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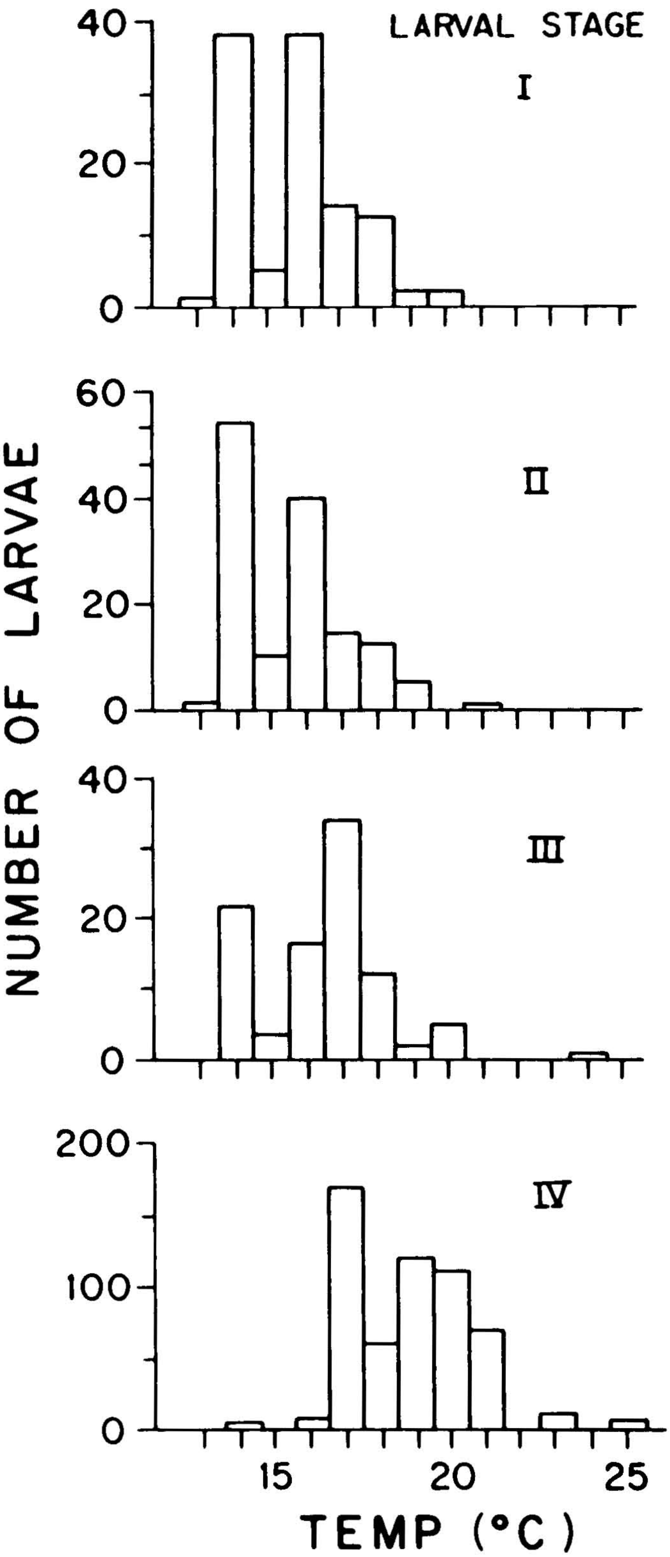

Figure 6.--Frequency distribution of stage I-IV lobster larvae collected at prevailing surface water temperatures.

tion. The critical reviews of M. Sissenwine and S. Saila were very helpful.

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Distribution and Abundance of Larval Lobsters (*Homarus americanus*) in Buzzards Bay, Massachusetts, During 1976-79

FRED E. LUX, GEORGE F. KELLY, and CHARLES L. WHEELER[1]

ABSTRACT

In 280 neuston tows during 1976-79 in Buzzards Bay, Mass., 16,679 larval lobsters (stages I-IV) were collected. The larvae began to appear in catches in late May in each year, reached peak numbers in mid-June, and disappeared from the plankton by early August. The bottom temperature was approximately 13°C when larvae first were caught and about 17°C at the peak of larval production. The mean number of larvae caught per 1,000 m^3 of water filtered ranged from 9.6 in 1978 to 43.7 in 1979. Largest catches were obtained on 18 June 1979 when 6,746 larvae were caught in five 0.5-h tows. The catch of late stage larvae was unusually high in 1978 when stage IV larvae were twice as numerous as the other stages combined. The sampling results indicated that Buzzards Bay is an area of high production of larval lobsters.

INTRODUCTION

The National Marine Fisheries Service (NMFS) at Woods Hole began sampling planktonic larval stages of lobsters (*Homarus americanus*) in Buzzards Bay, Mass., in May 1976. This effort has continued each year with sampling beginning in early May prior to the hatching of lobster eggs and ending in early August after the larvae have settled out of the plankton. The survey was begun as part of a joint study with the Massachusetts Division of Marine Fisheries of the distribution and abundance of lobster larvae in Cape Cod Bay, the Cape Cod Canal, and Buzzards Bay. We sampled the middle section of Buzzards Bay (Fig. 1). This paper reports the results from this work in 1976-79. A general summary of information on distribution and abundance of lobster larvae has been prepared by Fogarty (1983) and therefore is omitted here.

Buzzards Bay varies in depth from < 5 m at the Cape Cod Canal end to about 30 m at the bay mouth. Sediments consist largely of sand and silt, although there are numerous areas of rocky bottom and, along the northwest shore, rock ledge.

The bay, which lies entirely within Massachusetts territorial waters, is closed by State law to fishing with trawls or nets. There are, however, active commercial and recreational trap fisheries for lobsters from spring to late fall. Lobsters <81 mm carapace length and all ovigerous females must be returned to the water. Precise lobster landings from Buzzards Bay are not known, although catch reports filed to the State by lobster fishermen indicate that an estimated 500 tons may be landed per year (Beals et al.[2]).

METHODS

Numerous reports have demonstrated that planktonic lobster larvae are positively phototactic and are found at or near the water surface during daylight (Fogarty 1983). Therefore a neuston net (1 × 2 m mouth, 9 m length) with a mesh size of 0.97 mm was used for sampling. The net was towed from the end of a boom extending 2.5 m out from the starboard side of a 12 m research vessel. Tows were made in a straight line with the net approximately 20 m astern of the vessel and out of the wake; the net mouth was from one-half to two-thirds submerged. Towing speed in 1976, based on distance covered, was estimated at 4.6-5.6 km/h (2.5-3.0 kn) and

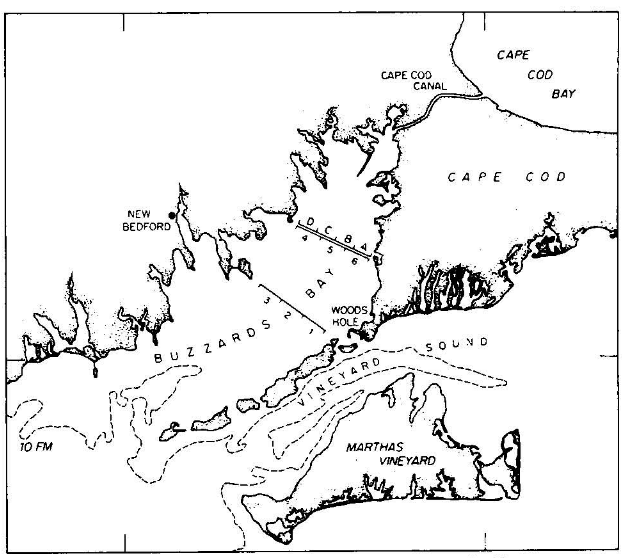


Figure 1.—Sampling stations for neuston tows in Buzzards Bay, Mass., 1976-79. In 1976, stations A-D (upper transect) were sampled; in 1977-79, stations 1-6 (lower and upper transects) were sampled.

[1]Northeast Fisheries Center Woods Hole Laboratory, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

[2]Beals, R. W., C. J. Kilbride, and G. M. Nash. 1978. 1977 Massachusetts coastal lobster fishery statistics. Mass. Div. Mar. Fish. Tech. Ser. 13, 19 p.

6.0 km/h (3.25 kn) as determined by electronic log during 1977-79.

Except where there was significant net clogging, the tows were 0.5 h in duration. At 6 km/h the estimated surface area sampled in a 0.5-h tow was 6,000 m^2, and the estimated volume of water filtered was 3,000 m^3, assuming that the net sampled a surface layer of water 0.5 m deep. At the lower towing speeds used in 1976 the estimated volume filtered in a 0.5 h tow ranged from 2,200 to 2,750 m^3. The volume actually filtered may vary considerably depending on depth of the net in the water, extent of clogging, and the amount of wind and wave action (Scarratt 1973). The water volumes filtered that we have used therefore must be considered approximate.

Where net clogging occurred due to algal blooms or concentrations of ctenophores the volume filtered was reduced. Tows in which clogging was apparent were abbreviated. Clogging often occurred from mid-July to early August, affecting approximately 10% of the tows in a season.

At the completion of each tow the catch was removed from the cod end and floating algae and eelgrass were rinsed free of organisms and discarded. The catch then was strained with a sieve, placed in jars, and preserved in 2% formaldehyde; lobster larvae were sorted in the laboratory.

Weather permitting, all stations were sampled once each week during May-August. In 1977-79 we sampled six stations in two transects, each of which was 9 km in length (Fig. 1). In 1976 we sampled only the easternmost transect, which we divided into four stations (Fig. 1). Sampling began at approximately 0800 h (EST) and was completed by about 1400 h. On one occasion, in 1976, we sampled during early evening hours and after dark.

Surface water temperature was recorded to the nearest 0.1°C at the beginning of each tow, using a mercury thermometer. Surface to bottom temperatures were obtained with an electronic probe in 1977 and part of 1978. Wind and cloud cover observations were noted on each tow log.

RESULTS

Over the 4 yr sampled, 16,679 larval lobsters were caught, averaging 23.3/1,000 m^3 of water filtered (Table 1). Numbers of larvae varied considerably from year to year with totals ranging from 1,284 in 1976, when there were fewer stations, to 10,303 in 1979.

There was a marked variation also in the composition of the catch by stage of development, both within and between years (Table 1). Stage II predominated in 1976 and 1977; stage IV, in 1978; and stage III, in 1979. The large numbers of stage IV larvae in most years seemed unusual, even though the longer duration of this stage increases the chance of capture. In 1978, when this was most pronounced, there were more than twice as many stage IV larvae as the other stages combined (Table 1).

Estimates of the abundance of larvae by sampling date for all stations combined in each year (Fig. 2) indicate that the larvae began to appear in the catch in the latter half of May, reached peak numbers in mid to late June, and had completed pelagic stages by early August. The surface water temperature when larvae first were caught was about 13°-15°C; the temperature at the bottom usually was 1° or 2° lower than at the surface (Fig. 2). The temperature at the peak of larval production was about 19°C at the surface and 17°C at the bottom. These temperatures for initiation of hatching and peak of larval production agree rather closely with the findings of Hughes and Matthiessen (1962). Water temperatures as high as about 24°C at the surface were recorded in July and early August (Fig. 2).

There was no consistent pattern in total abundance by station, although the largest catches generally were made at station 3 (Fig. 1). The water temperature was higher by about 1°-2°C at stations 4-6 (A-D), where the depth was 10-12 m, than at stations 1-3, where the depth was about 15 m, but it was not clear if these temperature or depth differences affected larval abundance.

The high numbers of larvae caught in 1979 were due largely to catches on one sampling date (18 June) when 6,746 larvae were caught in the five tows (Table 1). The mean total catch per 1,000 m^3 of water filtered for 18 June was 450 larvae (Fig. 2). The year 1979 was, however, one of generally high larval abundance in Buzzards Bay (Fig. 2).

The abundance of lobster larvae by developmental stage for each year and sampling date show the general progression of stages through the hatching season (Fig. 3). The abundance of stage I larvae usually peaked around mid-June and stage IV peaked in late June. Larvae were caught from late May to

Table 1.—Total numbers of tows, numbers of tows containing larval lobsters, total numbers of lobster larvae of each stage, mean total numbers per 1,000 m^3, and percentage frequency by stage (in parentheses) for Buzzards Bay neuston sampling in 1976-79 and all years combined.

	Number of tows		Numbers of larvae of each stage					
Year	Total	With larvae	I	II	III	IV	Total number	Number per 1,000 m^3
1976	50	32	433	484	290	77	1,284	10.1
			(33.7)	(37.7)	(22.6)	(6.0)	(100.0)	
1977	80	56	706	1,064	759	932	3,461	18.8
			(20.4)	(30.8)	(21.9)	(26.9)	(100.0)	
1978	62	41	90	103	243	1,195	1,631	9.6
			(5.5)	(6.3)	(14.9)	(73.3)	(100.0)	
1979	88	56	2,413	2,640	3,962	1,288	10,303	43.7
			(23.4)	(25.6)	(38.5)	(12.5)	(100.0)	
All years	280	185	3,642	4,291	5,254	3,492	16,679	23.3
			(21.8)	(25.7)	(31.5)	(21.0)	(100.0)	

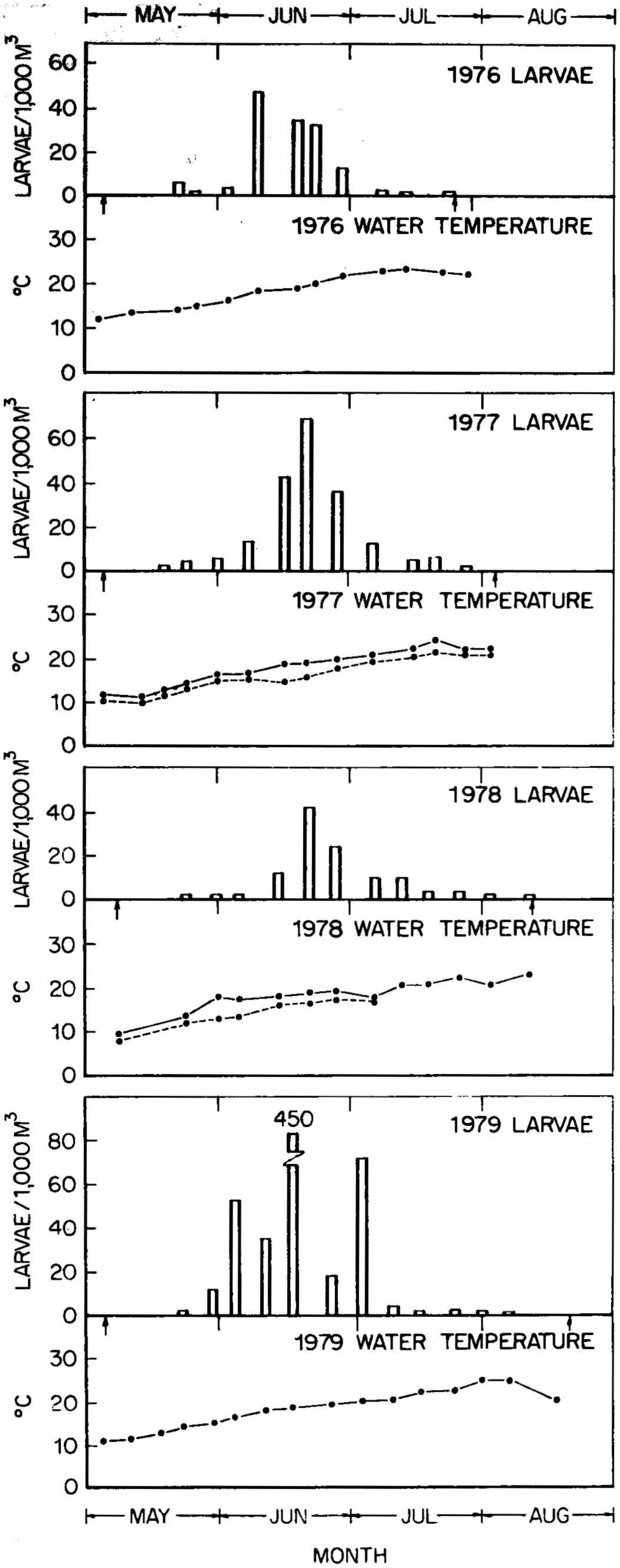


Figure 2.—Numbers of lobster larvae caught per 1,000 m³ of water filtered and average water temperature for each sampling date in Buzzards Bay neuston sampling, 1976-79. Surface temperature (solid line); bottom temperature (broken line); vertical arrows indicate starting and ending dates for sampling in each year.

early August, encompassing a period of about 11 or 12 wk. Generally there was a small peak in abundance of stage I larvae in late May and well before the seasonal peak in mid-June (Fig. 3); this has been noted previously by Collings et al.[3] in the northeastern part of Buzzards Bay.

In 1976 the pattern of larval abundance by stage (Fig. 3) showed early stage larvae to be more abundant than later stages. In 1977 and, especially, in 1978 later stages were as abundant or more so than earlier stages. In 1979 the very high numbers of all stages caught on 18 June greatly altered the pattern of abundance for that year.

In order to examine day-night differences in the larval catch, we made three daylight and three night tows on the evening of 9 June 1976 at stations B, C, and D (Fig. 1). Only the first three larval stages were caught (Fig. 4). Station B, 1820-1850 h EST, yielded 257 larvae, the largest catch of the 1976 season. At station C, 1855-1925 h, 113 larvae were caught, and at station D, 1930-2000 h, 31 larvae were taken. These were the three daylight tows, although the light was fading through the last two of these. Sunset occurred at 1921 h. For the night tows the times and catches were: station D, 2025-2055 h, 45 larvae; station C, 2100-2130 h, 28 larvae; and station B, 2135-2205 h, 17 larvae. Catch dropped rapidly as the light level decreased. Further, the catch composition by stage changed greatly, with stage I larvae dominating during daylight and stage III larvae making up much of the catch after dark.

DISCUSSION

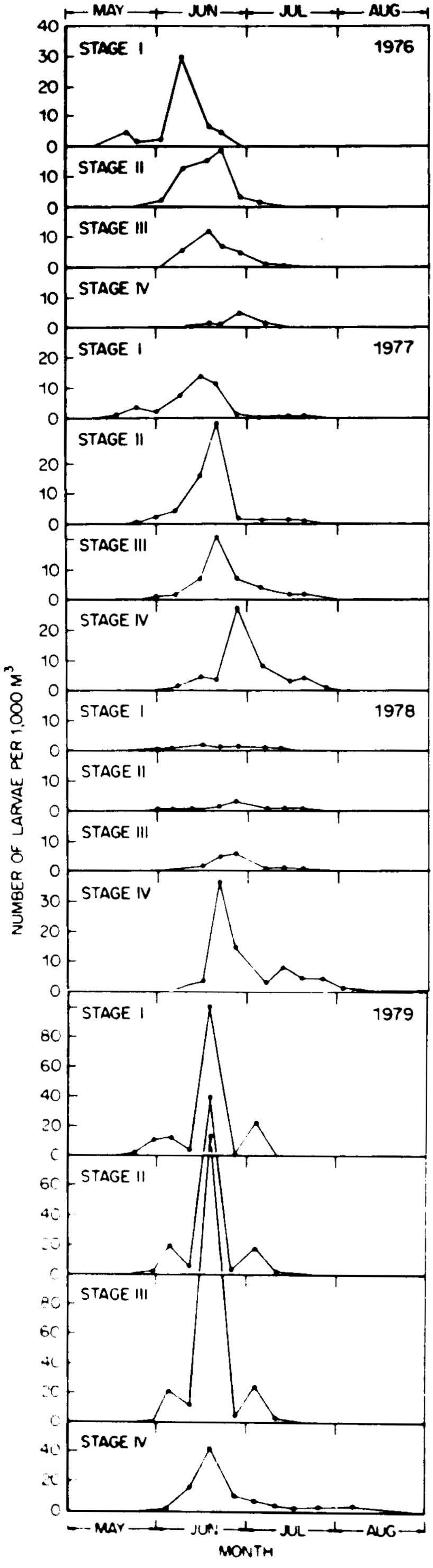
The results from this study and from those of Collings et al. (footnote 3), indicate that the numbers of lobster larvae caught in Buzzards Bay considerably exceed those caught in other New England areas, such as the Maine coast (Sherman and Lewis 1967), Cape Cod Bay (Anderson and Scotton[4]), Vineyard Sound (Herrick 1896), Block Island Sound (Bibb and Hersey[5]), and Long Island Sound (Lund and Steward 1970). Indeed, it appears, when Canadian studies are considered as well, that the larvae are at least as numerous here as in any other location.

The abundance of early stage larvae in an area depends in part on the numbers of ovigerous lobsters present. Collings et al. (footnote 3) indicated that Buzzards Bay lobsters matured at a smaller size than those in Cape Cod Bay, presumably due to higher water temperatures in the former area. This is consistent with the results of Templeman (1936) who found indications that lobsters matured at smaller sizes in the warmer water areas off Canada than in colder areas. Lobster fishermen also have reported a higher proportion of sublegal

[3] Collings, W. S., C. C. Sheehan, S. C. Hughes, and J. L. Buckley. 1980. Biological investigations relative to the effects of a second electrical generating unit upon some of the marine resources of northern Buzzards Bay and the Cape Cod Canal. Unnumbered report, 423 p., append. Canal Electric Co., Sandwich, MA 02563.

[4] Anderson, R. D., and L. N. Scotton. 1978. Marine ecology studies related to operation of Pilgrim Station. Final Rept. July 1969-Dec. 1977, Vol. 1, 407 p., Vol. 2, 217 p. Boston Edison Co., 800 Boylston St., Boston, MA 02199.

[5] Bibb, B. G., and R. Hersey. 1979. Distribution and abundance of lobster larvae in Block Island Sound, 1978. 1978 Final Rept., Raytheon Environ. and Oceanogr. Serv., 89 p. New England Power Co., 20 Turnpike Rd., Westboro, MA 01581.



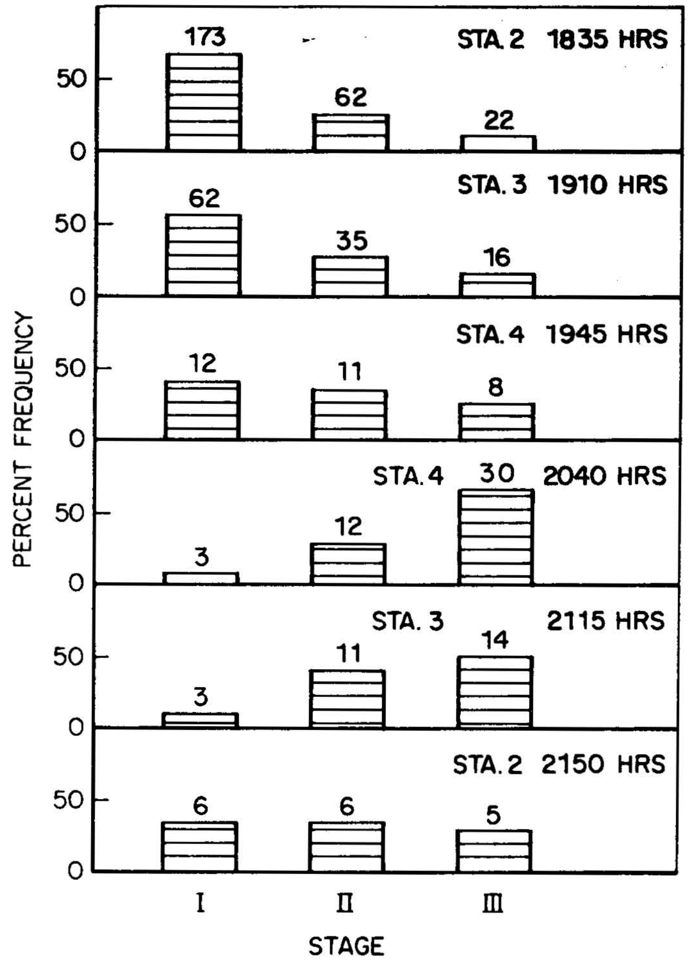


Figure 4.—Percent frequency distributions of lobster larval stages caught during six day-night neuston tows in Buzzards Bay, 9 June 1976. (The times given are EST at the tow midpoints; numbers above each graph are actual numbers of larvae caught; the top three graphs are for the daylight tows, the lower three for those after dark.)

ovigerous lobsters in Buzzards Bay than in surrounding waters, possibly increasing the larval production.

In Long Island Sound, where physical conditions are similar in many respects to Buzzards Bay, Lund et al.,[6] Smith,[7] and Briggs and Mushacke (1979) found that a high proportion of sublegal female lobsters were sexually mature, while in waters south of Long Island (Briggs and Mushacke 1980) this proportion was low. As Lund and Stewart (1970) reported, large numbers of larval lobsters are found in the sound and low numbers, south of Long Island.

All of the above suggests that conditions are more favorable in Buzzards Bay for the production of larvae than in adjacent waters. This bay, which is shallower than adjacent areas and has a slower flushing rate, is warmer from spring to fall

[6] Lund, W. A., Jr., L. L. Stewart, and C. J. Rathbun. 1973. Investigation on the lobster. Completion Rept. for Connecticut Project 3-130-R Comm. Fish. Res. Devel. Act, 105 p. Univ. Conn., Noank, CT 06340.

[7] Smith, E. M. 1977. Long Island Sound lobster management. Completion Rept. for Connecticut Project 3-253-R-1 Comm. Fish. Res. Devel. Act, 97 p. Conn. Dept. Environ. Protect., State Office Bldg., Hartford, CT 06115.

Figure 3.—Numbers, by development stage, of lobster larvae caught per 1,000 m^3 of water filtered for each sampling date in each year, 1976-79.

(the season of rapid growth) than either Vineyard Sound (Sumner et al. 1911) or Cape Cod Bay (Collings et al. footnote 3). The high numbers of larvae caught in Buzzards Bay compared with the lower numbers in Vineyard Sound (Herrick 1896) and in Cape Cod Bay (Anderson and Scotton footnote 4) support this suggestion.

The results in several larval lobster studies have shown that stage I larvae dominated the catches (Templeman 1937; Templeman and Tibbo 1945; Scarratt 1964; Sherman and Lewis 1967; Lund and Stewart 1970; Scarratt 1973). The results from our sampling, however, showed stage II, III, and IV larvae dominating the catch in the 4 yr sampled (Table 1, Fig. 3), a pattern that was similar to that concurrently obtained by Collings et al. (footnote 3) in northeastern Buzzards Bay. Templeman and Tibbo (1945) found that under bright sunlight conditions stage I and II larvae moved from the surface layer. Scarratt (1973) also found considerable numbers of stage I larvae in depths of 0.6-1.2 m on sunny days in the Gulf of St. Lawrence.

Most of our sampling in Buzzards Bay was done under sunny conditions, and it is therefore possible that early stage larvae were missed due to vertical migration in response to light levels. Our data do not cover enough light conditions, however, to draw any conclusions in this regard.

Another possible factor may be the longer duration of the fourth larval stage. Herrick (1896) indicated that stages I and II molted within 5 d and stage III molted in 2-8 d. Stage IV larvae, however, did not molt for 10-19 d and thus were exposed to capture for a longer period.

Surface drift may also result in dispersal of larvae. Scarratt (1964) suggested that the levels of stage I abundance reflected the location of the parent stock. Drift of the larvae could result in a different distribution of stage I relative to stage IV.

High catches of larval lobsters in this study frequently coincided with high catches of zoea and megalops stages of crabs. Similar results were noted by Templeman (1937). Larvae of the rock crab, *Cancer irroratus*, predominated, however larvae of green crab, *Carcinus maenas*, and lady crab, *Ovalipes ocellatus*, also were frequent components of the catch. Larvae of porcellanid crabs were abundant through much of July and into early August.

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The Spatio-Temporal Distribution of American Lobster, *Homarus americanus*, Larvae in the Cape Cod Canal and Approaches

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SALLY C. HUGHES,[2] and JAMES L. BUCKLEY[1]

ABSTRACT

The spatial and temporal distribution of larval lobsters in northern Buzzards Bay, the Cape Cod Canal, and southwestern Cape Cod Bay was examined during 1976-78. Hatching generally began in late May when bottom water temperatures approximated 10°C. Most larvae had settled out of the water column by mid-August, but larvae were occasionally collected as late as October. Larvae were concentrated at nearshore stations by onshore winds in Buzzards Bay and Cape Cod Bay. A higher percentage (71%) of the total larvae were collected when cloud cover was 25% or less. Larvae were collected in water ranging in temperature from 10.3° to 25.5°C. Salinities ranged from 23.3 to 35.5‰. Percent stage composition was comparable with that found in southern Buzzards Bay. The density of lobster larvae in the Cape Cod Canal was similar at all depths, but larvae were associated with the surface water layer in Buzzards Bay and Cape Cod Bay. In 1976, 1977, and 1978, an estimated 13.5, 26.0, and 9.2 million larvae, respectively, were deposited from the Cape Cod Canal into Cape Cod Bay.

INTRODUCTION

Preliminary larval lobster distribution studies carried out in Cape Cod Bay by the Massachusetts Division of Marine Fisheries prior to 1974, and intensive efforts by both the Division and a private contractor (Marine Research, Inc.) from 1974 to 1977, revealed few larvae in Cape Cod Bay. A large commercial fishery exists in Cape Cod Bay and concentrations of egg-bearing female lobsters are occasionally observed in the Cape Cod Canal and Buzzards Bay; accordingly the possible importance of larval transport to Cape Cod Bay and the effects of an additional fossil-fueled electrical generating station on the Cape Cod Canal were investigated. A 3-yr study of the spatial and temporal distribution of larval lobsters in northern Buzzards Bay, the Cape Cod Canal, and southwestern Cape Cod Bay was initiated in the spring of 1976.

STUDY AREA

Buzzards Bay is a marine embayment approximately 46 km long by 19 km wide (Fig. 1) with a maximum depth of 41 m and an average depth of 11 m (Anraku 1964; Gilbert et al.[3]). In upper Buzzards Bay, the salinity varies from 26.0 to 35.5‰ with surface water temperatures ranging from −1° to 28.0°C and bottom temperatures from −1° to 25°C (Collings et al.[4]).

Cape Cod Bay is a nearly circular embayment of the Atlantic Ocean with water depths reaching 91.5 m but with an average depth of 25 m (Parsons 1918; Anraku 1964). Surface salinities range between 29.0 and 36.0‰, and while surface water temperatures can exceed 20°C in the summer, bottom temperatures rarely exceed 15°C. Currents in both bays are weak, seldom exceeding 1.1 km/h (Collings et al. footnote 4).

The Cape Cod Canal is a sea level passage connecting Cape Cod Bay with Buzzards Bay. With a mean tidal range in Cape Cod Bay of 2.8 m and of 1.2 m in Buzzards Bay, the difference in phase and amplitude of the tides produce changes in the slope of the water in the Canal. Consequently, there is a regular reversal in current at approximately 6 h intervals. Currents have an average speed of 6.5 km/h in midchannel, but during spring tides increase to about 7.4 km/h (Anraku 1964). Surface salinity varies from 28.0 to 34.0‰ (Collings et al. footnote 4), and water temperatures range from −1° to 25°C. The lack of thermal stratification in the Canal is due to the strong currents and turbulence (Fairbanks et al.[5]).

METHODS AND MATERIALS

Neuston samples were collected at 7 stations during 1976, 16 in 1977, and 10 in 1978 (Fig. 2). Stations were sampled on a weekly basis from the first week in May until lobster larvae were no longer obtained in neuston samples. Factors that prevented sampling were rough seas and high concentrations of ctenophores (*Mnemiopsis leidyi*) or crab larvae.

[1]Commonwealth Energy, Canal Electric Company, Cranberry Highway, Wareham, MA 02571.
[2]Massachusetts Division of Marine Fisheries, 100 Cambridge Street, Boston, MA 02202.

[3]Gilbert, T., A. Clay, and A. Barker. 1973. Site selection and study of ecological effects of disposal of dredged materials in Buzzards Bay, Massachusetts. Prepared for Department of the Army, New England Division, Corps of Engineers by New England Aquarium under Purchase Order No. DACW 33, 73-C-0024, 70 p.

[4]Collings, W. S., C. C. Sheehan, S. C. Hughes, and J. L. Buckley. 1981. The effects of power generation on some of the living marine resources of the Cape Cod Canal and approaches. Massachusetts Department of Fisheries, Wildlife, and Recreational Vehicles, Div. Mar. Fish., 100 Cambridge Street, Boston, Mass., 212 p. + appendices.

[5]Fairbanks, R. B., W. S. Collings, and W. T. Sides. 1971. An assessment of the effects of electrical power generation on marine resources in the Cape Cod Canal. Mass. Dep. Nat. Resour., Div. Mar. Fish., 48 p. + appendix.

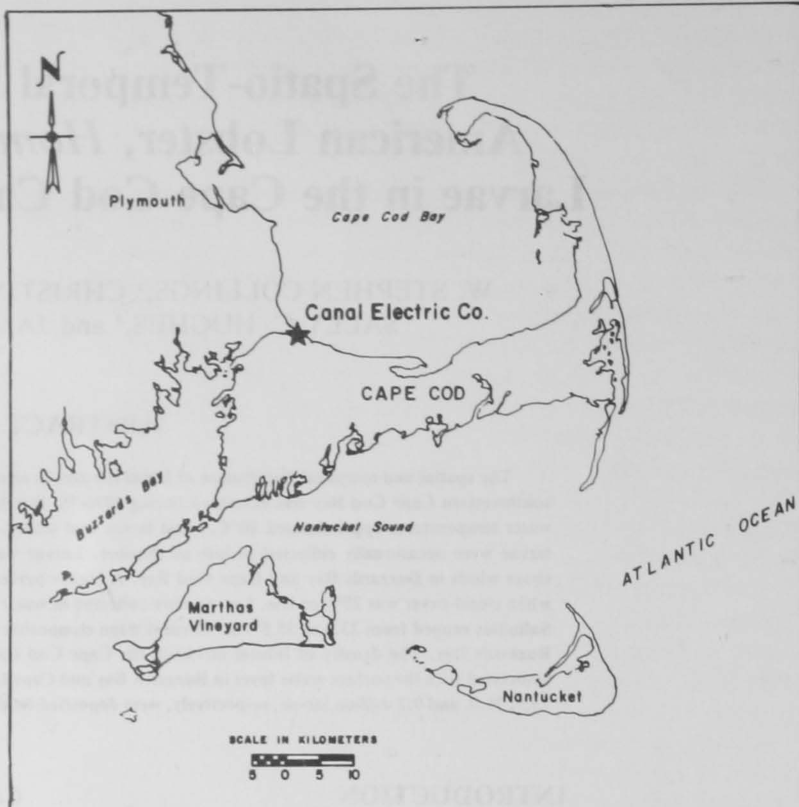

Figure 1.—Map of study area.

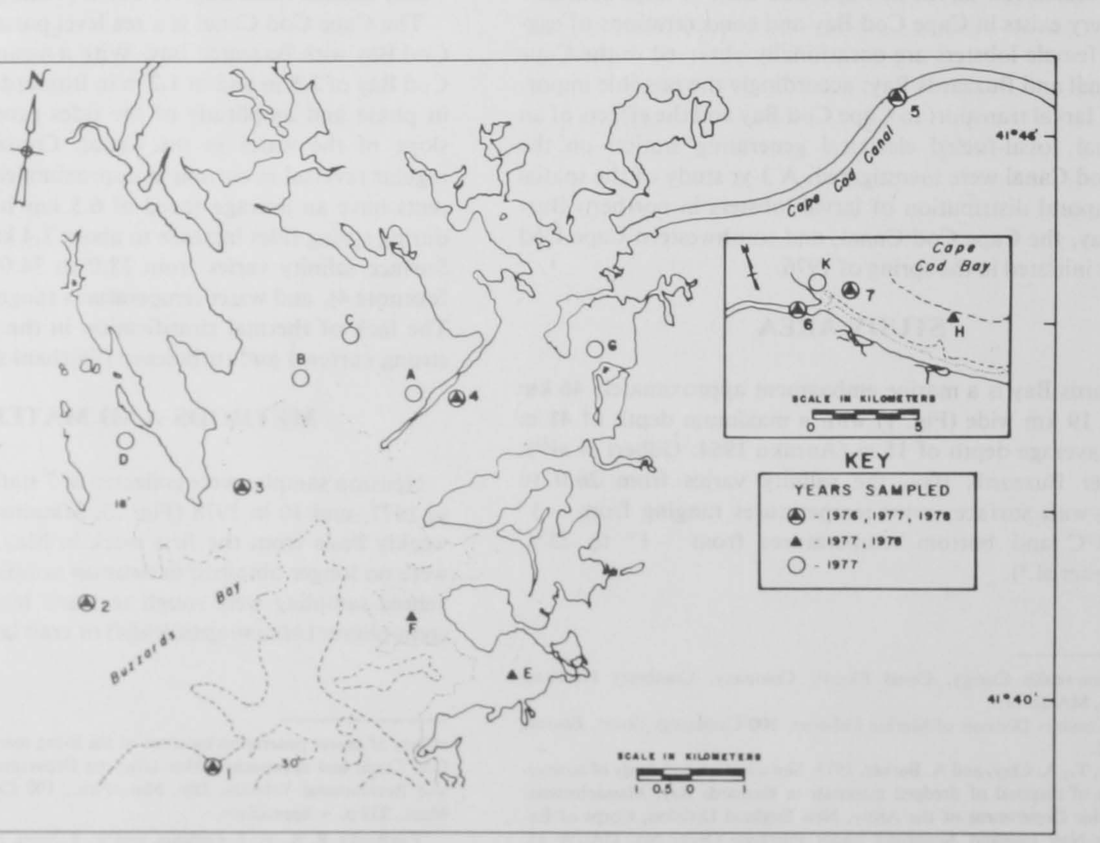

Figure 2.—Lobster larvae sampling locations, 1976-78.

Surface tows were made with a 1 × 2 m neuston net with a mesh size of 1.05 mm. All tows were made during daylight hours at a speed of 4.6-5.6 km/h with the top 20 cm of the net breaking the water surface. Tow duration was 30 min and volumetric measurements were calculated from flowmeter readings obtained from a General Oceanics[6] model S 2030 R flowmeter in the net mouth. The average volume of water strained per tow was 2,793 m^3. This volume per tow decreased over the 3 yr as a result of high ctenophore and larval crab concentrations. The numbers of ctenophores and crab larvae increased rapidly and reached such high densities in 1976, it became impossible to tow for more than 5 min. By mid-August, sampling had to be terminated. While concentrations remained high enough in 1977 and 1978 to prevent full 30-min tows, shorter tows were possible at many stations.

A 1 × 1.5 m opening and closing Tucker trawl with 1.05 mm mesh similar in design to that described by Clark (1969) and Hopkins et al. (1973) was utilized for discrete depth sampling. The net was designed to be fished at a 45° wire angle, presenting an effective opening of 1 m^2. The net was towed at 5.6 km/h for 20 min.

After completion of a neuston or Tucker trawl tow, samples were washed into a pair of nesting sieves with mesh sizes of 1.05 mm and 6.35 mm. Sample concentrate was preserved in a 5% Formalin-95% seawater solution buffered with sodium borate ($Na_2B_4O_7 \cdot 10H_2O$). Samples were returned to the laboratory where all lobster larvae were removed and staged according to the descriptions of Herrick (1911).

[6]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

RESULTS AND DISCUSSION

Neuston Tows

Four hundred fifty-nine tows were made during 1976-78; 9,631 larvae were collected for an average density of 9.9 larvae/1,000 m^3 or water filtered (Table 1). The maximum number and density of larvae collected was 746 (266.2/1,000 m^3) at Station F in Buzzards Bay on 21 June 1977. Mean annual densities were highest in Buzzards Bay during 1977 and 1978 and highest in the Cape Cod Canal during 1976 (Table 1). Highest mean density (12.8 larvae/1,000 m^3) over all years was observed in Buzzards Bay.

Abundance and Temporal Distribution

Hatching in Buzzards Bay commenced during the third week in May and stage I larvae generally disappeared from the water column by mid-July. The peak of stage I abundance in mid-June corresponded to the peak of total larval abundance. An initial small peak of hatching was evident during the last week of May. This peak was consistently observed and may be due to earlier hatching of eggs extruded during summer; ova extruded during autumn appear to hatch later in the season (Perkins 1972). Second stage larvae first appeared in samples by the end of the third week in May and peaked in abundance in mid-June. Stage III larvae were usually found in samples by the first of June and peaked in mid-June. Fourth stage larvae were initially collected by the first week of June, peaked in abundance by 1 July, and could, as in 1978, continue to be collected into September.

Larval abundance patterns in the Cape Cod Canal were quite similar to those found in Buzzards Bay, although a bi-

Table 1.—Lobster larval tow data for three areas for 1976-78.

Area	Number of stations sampled	Total number of tows	Volume of water sampled (m^3)	Number of tows with larvae	Average volume (m^3)	Number larvae collected	Mean larval density (no./1,000 m^3)
1978							
Buzzards Bay	5	90	154,858	40	2,561	1,563	10.1
Cape Cod Canal	3	58	115,972	30	2,686	430	3.7
Cape Cod Bay	2	34	69,085	17	2,442	115	1.7
	10	182	339,915	87	2,578	2,108	6.2
1977							
Buzzards Bay	10	103	257,264	68	2,714	4,035	15.9
Cape Cod Canal	3	50	88,272	23	2,883	654	7.4
Cape Cod Bay	3	36	84,988	23	2,717	672	7.9
	16	189	430,524	114	2,759	5,361	12.5
1976							
Buzzards Bay	3	31	80,137	15	3,343	687	8.6
Cape Cod Canal	3	43	90,353	22	3,170	1,428	15.8
Cape Cod Bay	1	14	35,468	8	3,698	47	1.3
	7	88	205,958	45	3,314	2,162	10.5
All years							
Buzzards Bay	10	224	492,259	123	2,739	6,285	12.8
Cape Cod Canal	3	151	294,597	75	2,889	2,512	8.5
Cape Cod Bay	3	84	189,541	49	2,769	834	4.4
	16	459	976,397	247	2,793	9,631	9.9

modal peak of stage I abundance was not as evident as in Buzzards Bay. The period of exact hatching in the Canal was possibly masked by advection of Buzzards Bay larvae into the Canal with reversal of the tidal cycle.

Cape Cod Bay larval abundance patterns were similar to those of Buzzards Bay, but occurred several weeks later. Stage I abundance was greatest by the last week of June and stages II, III, and IV were not collected until the second week of June. Larval occurrence extended into September in Cape Cod Bay and stage III and IV larvae were collected as late as October.

Percent stage composition of larval catches varied both annually and geographically (Table 2). We noted an increased percentage of fourth stage larvae over the 3-yr study period. Similar patterns in stage IV abundance during 1976-78 were noted by Bibb et al. (1983) and Lux et al. (1983). Ctenophore abundance was relatively high in 1976 and subsequently decreased over the next 2 yr. Lund and Stewart (1970) found that when ctenophore densities peaked, samples were almost devoid of fish or crustacean larvae.

The number of lobster larvae collected is dependent, in part, on the number of ovigerous females within the area. The mean carapace lengths (CL) of ovigerous females in Buzzards Bay and Cape Cod Bay were 81 mm and 97 mm, respectively, (Fair[7]) and the proportion of ovigerous females in research trap catches was higher in Buzzards Bay. Ovigerous females composed up to 14% of the catch in Buzzards Bay but < 1.0% in Cape Cod Bay. Higher larval densities in Buzzards Bay may reflect higher spawning stock levels. Templeman (1936a) suggested that the American lobster attains maturity at a size which varies inversely with temperature. Aiken and Waddy (1976) stated that female lobsters matured at a smaller size in the warmer Gulf of St. Lawrence than off southern Nova Scotia.

Effects of Surface Currents on Spatial Distribution

During the months of May-September, winds in the study area were generally southwest and monthly average speeds ranged from 17.7 to 24.1 km/h (11-15 mph) (U.S. Army Corps of Engineers[8]). Scarratt (1973) noted that winds in excess of 24.1-29.0 km/h (15-18 mph) tend to prevent efficient sampling. Our sampling trips were rescheduled if strong winds were forecast; exposed stations were not sampled if winds increased appreciably during any sampling day.

Wind records for the 24-h period prior to sampling revealed that 68.0% of all tows and 76.4% of the tows containing larvae in Buzzards Bay were made when winds were from the southwest. A total of 85.2% of the larvae was found in samples collected when winds were onshore.

In Cape Cod Bay, 72% of all tows and 73% of all tows containing larvae were made when winds were from the southwest quadrant, however, only 39% of the larvae were collected during offshore winds. When winds were from the northeast-northwest (on or alongshore) 56.8% of the larvae collected in Cape Cod Bay were obtained in 10 tows.

Throughout 1976, the continued occurrence of stage I larvae at Stations 3 and 5 suggests that these sites were primary hatching areas. Large numbers of late stage larvae collected at Stations 1, 2, E, and G were possibly due to larval trans-

[7]James J. Fair, Assistant Director, Massachusetts Division of Marine Fisheries, 100 Cambridge Street, Boston, MA 02202, pers. commun. 4 September 1978.

[8]U.S. Army Corps of Engineers Division, New England. 1973. Final environmental statement, addition of Unit No. 2, Canal Plant. 2.1, 12 p. U.S. Army Corps of Engineers, Trapello Road, Waltham, Mass.

Table 2.—Percent stage composition of lobster larvae for three areas for 1976-78.

	Stage I		Stage II		Stage III		Stage I		All
Area	No.	Percent	No.	Percent	No.	Percent	No.	Percent	stages
1978									
Buzzards Bay	575	36.8	237	15.2	233	14.9	518	33.1	1,563
Cape Cod Canal	207	48.1	44	10.2	69	16.0	110	25.6	430
Cape Cod Bay	60	52.2	6	5.2	11	9.6	38	33.0	115
	842	39.9	287	13.6	313	14.8	666	31.6	2,108
1977									
Buzzards Bay	1,161	28.8	888	22.0	1,040	25.8	946	23.4	4,035
Cape Cod Canal	310	47.4	89	13.6	60	9.2	195	29.8	654
Cape Cod Bay	544	81.0	30	4.5	23	3.4	75	11.2	672
	2,015	37.6	1,007	18.8	1,123	20.9	1,216	22.7	5,361
1976									
Buzzards Bay	389	56.6	110	16.0	123	17.9	65	9.5	687
Cape Cod Canal	498	34.9	308	21.6	477	33.4	145	10.2	1,428
Cape Cod Bay	32	68.1	1	2.1	3	6.4	11	23.4	47
	919	42.5	419	19.4	603	27.9	221	10.2	2,162
All years									
Buzzards Bay	2,125	33.8	1,235	19.6	1,396	22.2	1,529	24.3	6,285
Cape Cod Canal	1,015	40.4	441	17.6	606	24.1	450	17.9	2,512
Cape Cod Bay	636	76.2	37	4.4	37	4.4	124	14.9	834
	3,776	39.2	1,713	17.8	2,039	21.2	2,103	21.8	9,631

port caused by wind driven currents and generally counterclockwise tidal currents in Buzzards Bay (Anraku 1964). The presence of both stage I and stage IV larvae at Station K was an indication of hatching in the vicinity of the entrance of the Canal and possible recruitment of larvae from an area north of the Canal.

It appeared that onshore winds concentrated lobster larvae at nearshore stations. This was substantiated by the higher densities of late stage larvae found in northern Buzzards Bay following southwest winds and at nearshore stations in Cape Cod Bay following northeast winds.

Effects of Cloud Cover

A total of 65.7% of our tows was made when cloud cover was 25% or less and 71% of the total larvae were collected when cloud cover was minimal (25% or less). The average density of larvae collected under clear skies, hazy, 25% cover, 50% cover, and 75% cover was 7.3, 8.2, 7.1, 10.5, and 8.4 larvae/1,000 m^3, respectively. Under completely overcast conditions, the average density decreased dramatically (2.8 larvae/1,000 m^3). Only 6.4% of the larvae collected were obtained when cloud cover was 100%.

Water Temperature, Larval Hatching, and Intermolt Periods

Stage I larvae were collected in Buzzards Bay waters ranging in temperature from 14.0° to 25.0°C. Stages II, III, and IV were collected at temperatures ranging from 16.5° to 25.5°C. Larvae collected in the Cape Cod Canal were found in water ranging in temperature from 12.5° to 23.5°C. First stage larvae were collected at 12.5°-22.0°C, second stage were collected at 14.5°-22.5°C, third stage at 16.5°-22.5°C, and fourth stage in temperatures ranging from 17.0° to 23.5°C. Larvae were collected in Cape Cod Bay at the following surface water temperatures: Stage I, 10.3°-21.1°C, stage II, 14.0°-20.0°C, stage III, 14.0°-20.0°C, and stage IV, 14.5°-20.5°C. The highest water temperature at which larvae were collected was 25.5°C and the lowest water temperature recorded when larvae were collected was 10.3°C.

Estimated average larval intermolt period was determined from the number of days between initial collection of a given stage and first collection of the succeeding stage. Buzzards Bay larvae took an average of 23.2 d to molt from stage I into stage IV in water temperatures ranging from 14.0° to 22.0°C. Templeman (1936b) reported development times of 11-26.5 d for larvae to molt into stage IV at this temperature range. Cape Cod Canal larvae required an average of 25 d to reach stage IV at temperatures ranging from 12.5° to 22.5°C. Based on Templeman's data it would take 10.5-78 d for larvae to complete their third molt when held at these temperatures. Cape Cod Bay larvae averaged 35 d to molt into stage IV at 10.3°-20°C; predicted development times under laboratory conditions were 12-49 d (Templeman 1936b).

Salinity

Observed salinities of 23.3 to 35.5‰ were within the tolerance range of < 20‰ to 42.5‰ (Templeman 1936b; Scarratt and Raine 1967; McLeese 1956).

Discrete Depth Sampling

Sixty-six discrete depth tows were made at nine stations in 1977. Four depths (surface, 3, 6, and 9 m) were sampled. A two-way analysis of variance (ANOVA) (Snedecor and Cochran 1967) was performed on data grouped into two categories: Canal stations (4, 5, and 6) and open water stations (Stations 1, 2, 3, F, H, and K). Results showed that at the Canal stations there was no significant difference with depth at the 5% level (F = 1.04; df = 3, 9); the probability of capturing larvae was uniform at all depths due to mixing in the Canal (Collings et al. footnote 4). However, at open water stations, significantly higher surface densities were obtained (F = 6.74; df = 3, 9; P < 0.05).

Scarratt (1973) reported significatly higher catch rates for stage I larvae in surface waters. Bibb et al. (1983) obtained similar results in Block Island Sound in 1977 and 1978.

Larval Deposition in Cape Cod Bay

Tidal patterns in the study area result in transport of significant numbers of larvae hatched in Buzzards Bay and the Cape Cod Canal into Cape Cod Bay. It was conservatively estimated that canal water flows into Cape Cod Bay for 3 h per tidal cycle at a rate of 2,095.4 m^3/s. The average Cape Cod Canal larval density for each year was multiplied by the total volume of water flowing into Cape Cod Bay during each larval season. Estimates of the numbers of larvae entering Cape Cod Bay for the years 1976, 1977, and 1978 were 13.5 million, 26.0 million, and 9.2 million, respectively.

Matthiessen and Scherer (1983) calculated that approximately 7.3 million larvae were deposited in Cape Cod Bay during the period 7-20 June 1976. Our estimate for the same period was 9.2 million larvae.

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Observations on the Seasonal Occurrence, Abundance, and Distribution of Larval Lobsters (*Homarus americanus*) in Cape Cod Bay

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ABSTRACT

The seasonal occurrence, abundance, and distribution of the larvae of the American lobster, *Homarus americanus*, in Cape Cod Bay were studied over a 3-yr period (1974-76). Although larvae were observed during the months of May-September, the great majority were found to occur during June, July, and August. In the neuston net collections, mean larval densities for these 3 mo averaged 3.1, 3.2, and 1.6 larvae/1,000 m^3, respectively. However, densities as high as 62.3 larvae/1,000 m^3 were observed in Tucker net collections near the east end of Cape Cod Canal.

The seasonal occurrence, pattern of distribution, and relative abundance of first-stage larvae near the east end of Cape Cod Canal during June suggest the likelihood that the Canal may contribute significant numbers of larvae to Cape Cod Bay.

INTRODUCTION

Despite the economic significance of the lobster (*Homarus americanus*) fishery in New England, very little is known of the origin and dispersal of larval lobsters and therefore of the primary sources of recruitment to localized stocks.

The increasing number of electric generating plants along the New England coast prompted a series of investigations of the seasonal abundance and distribution of larval lobsters during the 1970's. The primary objective of many of these investigations was to estimate the potential losses of larvae resulting from their entrainment in the power plant's cooling water, the relationship of the numbers of entrained larvae to the population as a whole, and the resultant potential impact upon the local or regional fishery.

The Pilgrim Nuclear Power Station, located in Plymouth, Mass., on the west side of Cape Cod Bay, draws its cooling water from an area that supports a valuable and intensive lobster fishery. The investigation described in this report was initiated to compare the numbers of larvae occurring in the vicinity of the station, and therefore potentially vulnerable to entrainment, with larval abundance in other areas of Cape Cod Bay, and to determine the seasonal occurrence and duration of the larval period in this area.

METHODS

Surface Sampling

Larval lobster were sampled at Stations I-VIII (Fig. 1) biweekly from 20 June through 19 August in 1974; weekly at Stations I-VIII from 5 June through 8 October in 1975; and weekly at Stations I-X from 4 May through 1 September 1976.

Sampling gear consisted of a 1 mm mesh neuston net measuring 1 m × 2 m at the mouth and 10 m in length. The top edge of the net was held just above the surface by large floats. Tows were made at 4-5.5 km/h for approximately 30 min off the side of 12 m (1975 and 1976) and 20 m (1974) vessels. Filtration volumes, estimated with a General Oceanics 2030[2] flowmeter mounted in the mouth of the net, averaged about 3,000 m^3/tow. Surface temperature and salinity were recorded at each station using a Beckman RS5-3 salinometer.

In 1974 duplicate tows were made irregularly at various stations as time and weather permitted. Single tows were taken at each station in 1975. In 1976 two vessels were used, towing in parallel, to collect duplicate tows at each station.

Vertical Sampling

In 1976 samples were taken at 0, 3, 6, 9, and 12 m (near bottom) at Station A located just off the easterly end of Cape Cod Canal (Fig. 1). Samples were taken on easterly tides by holding position into the current which averages about 6.5 or 7.4 km/h on spring tides (Anraku 1964). One sample was taken at each depth during daylight, and in most cases during darkness within the same 12-h period, on a weekly basis 7 June through 8 July.

Gear consisted of a messenger-operated 1 mm mesh Tucker net (Tucker 1951; Clarke 1969) with a mouth measuring 2 m × 2 m. Filtration volumes averaged 3,000-4,000 m^3.

All samples were preserved in 10% Formalin and returned to the laboratory for analysis. Lobster larvae were enumerated and staged following Herrick (1911).

RESULTS

Seasonal Occurrence and Distribution

During the 1974-76 sampling seasons, lobster larvae were found in Cape Cod Bay as early as 11 May (1976) and as late as 28 September (1975). Stage I larvae were found from 11 May

[1]Marine Research, Inc., 141 Falmouth Heights Road, Falmouth, MA 02540.

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

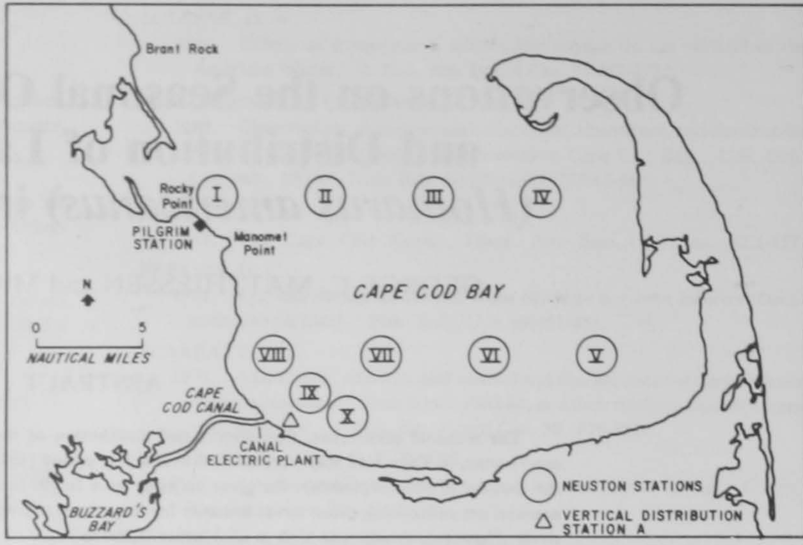

Figure 1.—Lobster larvae stations in Cape Cod Bay sampled in 1974-75 (Stations I-VIII) and 1976 (Stations I-X, vertical distribution Station A).

(1976) to 2 September (1976), stage II larvae from 3 June (1976) to 2 September (1976), stage III larvae from 3 June (1976) to 17 September (1975), and stage IV larvae from 18 June (1976) to 28 September (1975). Larvae were most abundant during the months of June, July, and August (Table 1). Surface water temperatures recorded when larvae were collected ranged between 10.5°C (May 1976) and 21.4°C (July 1974).

Early in the season, highest concentrations of lobster larvae were found in the southern section of Cape Cod Bay (Table 2). A highly significant difference ($P<0.01$) was found between mean densities at stations I-IV and stations V-VIII (X) over all June sampling dates based on a Mann-Whitney U test (Zar 1974). No significant difference ($P>0.05$) was detected for the months of July and August. Although collections were made in May of 1976, few larvae were taken during that period (Table 1). Those that were collected were found in both northern and southern areas of the Bay. Small numbers of larvae were also taken in September 1975 (Table 1); most were found in the northern section of the Bay.

Table 1.—Cape Cod Bay larval lobster collections by month, 1974-76.

Month	Year(s) sampled	Number of tows	Total larvae	Mean number of larvae per 1,000 m³	SD
May	1976	62	61	0.30	0.83
June	1974-76	142	2,005	3.68	5.67
July	1974-76	147	2,340	3.82	4.86
Aug.	1974-76	141	735	1.65	2.84
Sept.	1975, 1976	52	28	0.17	0.26

Table 2.—Mean larval lobster densities, per 1,000 m³ of water, over Stations I-IV (northern section) and V-VIII (or X in 1976) (southern section) by month and year.

		1974[1]			1975			1976		
	Stations	n[2]	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s
June	I-IV	4	0.82	0.69	16	2.82	2.73	20	1.78	2.08
	V-VIII(X)	2	1.53	0.38	16	6.14	9.80	30	4.80	6.33
July	I-IV	8	2.60	2.09	20	1.09	2.30	16	7.10	5.95
	V-VIII(X)	8	2.39	1.93	20	2.66	5.16	30	3.85	4.30
Aug.	I-IV	8	0.87	0.90	16	1.17	1.82	16	1.55	1.79
	V-VIII(X)	8	1.01	0.81	16	2.31	3.29	24	2.03	3.54

[1]Although included, little data were available for June 1974 since sampling did not begin until 20 June and Stations VII and VIII were not sampled until July.

[2]n = number of samples not including replicate tows which were averaged within dates for each station.

Annual Variations in Abundance

Average larval densities were compared by month for each year, 1974-76, to determine if any clear differences in abundance occurred between years. To make this comparison more valid, stations IX and X, sampled only in 1976, were excluded. Comparisons were based on unadjusted mean densities and on mean densities calculated after dividing each density estimate by the temperature-related stage duration for each larval stage obtained from Templeman (1936). Both the unadjusted and adjusted mean densities suggested that larvae were less abundant in 1974 than in 1975 and 1976 (Table 3). The differences

Table 3.—Mean monthly densities of lobster larvae, per 1,000 m³ of water, over Stations I-VIII, for June, July, and August, 1974-76. Mean densities are also shown based on data adjusted for variations in stage duration (see text). Between-station standard deviation in parentheses.

Year		Month			
		June	July	August	June-August
1974	No. sampling periods	1	2	2	5
	Mean/1,000 m³	1.1(0.7)	2.4(1.4)	0.9(0.6)	1.5(1.2)
	Adjusted mean	0.2(0.1)	0.6(0.3)	0.1(0.04)	0.3(0.3)
1975	No. sampling periods	4	5	4	13
	Mean/1,000 m³	4.5(4.2)	1.9(1.3)	1.9(1.0)	2.7(2.8)
	Adjusted mean	0.8(0.6)	0.4(0.3)	0.3(0.2)	0.4(0.4)
1976	No. sampling periods	5	5	5	15
	Mean/1,000 m³	3.3(2.5)	5.8(3.6)	1.3(0.9)	3.5(3.1)
	Adjusted mean	0.5(0.4)	1.2(0.8)	0.3(0.2)	0.7(0.7)

may be exaggerated, however, by the fact that the Bay was sampled only once in June of 1974.

Distribution by Larval Stage

During the early part of the larval season, in both 1975 and 1976 the distribution of larval lobster in Cape Cod Bay appeared to be related to stage of development. Not only the highest densities of larvae but also the highest percentage of stage I larvae were found in the southwest section of the Bay (Fig. 2). A great percentage of larvae collected in the northwest section (Station I) early in the season were also stage I larvae; however, the numbers collected were low in comparison with the southwest collections.

No consistent distributional pattern could be detected among total larvae densities in July and August of each year. No pattern was apparent among stage II or stage IV larvae during these months. In 1974, stage III larvae were most abundant at Station IV on each sampling date of July and August except the last (19 August) when this station ranked second. In 1975 and 1976, however, no pattern among stage III larvae was apparent.

Paired Tows

During 1976, when two vessels, towing in parallel, collected simultaneous neuston samples at each station, a total of 164 paired samples were collected. The mean number of larvae per individual tow was 3.11/1,000 m^3, with a standard deviation of 5.21. The mean of the variation between tows was 1.44/1,000 m^3, with a standard deviation of 2.28. Comparing the catch of the two vessels by means of a Wilcoxon paired sample test indicated that no significant difference ($P>0.05$) occurred.

Vertical Distribution

Results of vertical sampling at the easterly end of Cape Cod Canal from 7 June to 8 July 1976 indicated that highest concentrations of larvae were generally found at a depth of 3 m (Table 4). An analysis of these data using Friedman's test (Zar 1974) indicated a highly significant difference ($P<0.01$) between depths of collection.

The data also indicate that the highest concentrations of larvae tend to occur during periods of darkness (Table 4). However, when the data for dates which included both day and night (1 h after sunset to 1 h before sunrise) sampling within a 24-h period were analyzed using the Mann-Whitney U test (Zar 1974), the results indicated no significant difference in larval density occurred between day and night.

Approximately 96% of the larvae captured in the Tucker net were stage I. This is consistent with the June 1976 data for the nearby neuston stations (Stations VIII, IX, and X) (Fig. 2).

DISCUSSION

It was concluded on the basis of 10 yr of records maintained at the Massachusetts State Lobster Hatchery that hatching of *Homarus americanus* eggs usually begins when water temperatures have risen to 15 °C and is most intensive when temperatures approximate 20 °C (Hughes and Matthiessen 1962). The lowest temperature at which hatching was recorded during 1951-61 was 12.2 °C.[3] The occurrence of stage III and IV larvae in the 20 June 1974 collections was therefore somewhat surprising in relation to both the Massachusetts State Lobster Hatchery data and observations by Sherman and Lewis (1967) and Lund and Stewart (1970) relative to the onset of hatching at 13.7°-15.0 °C and 14.0 °C in Maine and Connecticut, respectively. Surface water temperatures averaged 16.1 °C on 20 June 1974. At this temperature, the time required to reach the third and fourth larval stages is approximately 10 and 20 d, respectively (Templeman 1936). Bottom water temperatures in Cape Cod Bay 14 d prior to 20 June averaged only 7.7 °C (based on 51 ichthyoplankton stations).[4]

In 1975 high concentrations of larvae were found in the collections on the first sampling date (5 June), primarily in the southwest sector of the Bay (Fig. 2). Although the great majority of these were stage I larvae (Fig. 2), bottom water temperatures in Cape Cod Bay at this time, gathered at 18 ichthyoplankton stations on 3-4 June (MRI[5]), averaged only 9 °C. Despite these low temperatures, it was evident from the large numbers of stage I larvae, and moderate numbers of stage II, in the collections that hatching must have been well underway by 1 June.

Cape Cod Canal water temperature records maintained by the New England Gas and Electric Generating Station in Sandwich, Mass., indicate that water temperatures may vary by 5 °C or more in the Canal during a tidal cycle, depending upon whether the water originates from Cape Cod Bay or from the much warmer Buzzards Bay. Stations IX and X and the Tucker net sampling station were added in 1976 for the purpose of establishing whether the large number of larvae found in the southwest area of the Bay in early June samples might originate from Cape Cod Canal, or perhaps Buzzards Bay, where temperatures at that time would be more conducive to hatching.

The June distribution of larvae in the Bay at Stations I-IX (Fig. 2) and the abundance of larvae at vertical sampling station A in 1976 (Table 4) raises the possibility that Cape Cod Canal may contribute large numbers of larvae during June. Data reported by the U.S. Army Corps of Engineers (1973) indicated that water enters Cape Cod Bay via Cape Cod Canal at an average rate of 2,060 m^3/s during an easterly tide, and that most of this water does not return to the Canal during the ebbing (westerly) tide. It is estimated, therefore, that an average of 95.8×10^6 m^3 of water flows into Cape Cod Bay from the Canal each day.

For the period 7-30 June 1976 the mean density of larvae in the water column at the mouth of the Canal was computed for each day of Tucker net sampling. Densities for replicate or day/night tows taken during the same 24-h period were averaged. The total number entering the Bay each sampling day was then estimated by multiplying mean larval density by daily flow. By plotting the numbers of larvae introduced into Cape Cod Bay on each sampling day against time, and computing

[3]This information, in fact, was the basis for the decision not to initiate the 1974 sampling program until the latter part of June since the data collected during previous ichthyoplankton surveys of the Bay (MRI 1974; see footnote 4) indicated temperatures of Cape Cod Bay rarely exceeded 15 °C before this time.

[4]MRI (Marine Research, Inc.). 1974. Cape Cod Bay Study Quarterly Progress Report, March-May 1974. 6 p. + appendix.

[5]MRI (Marine Research, Inc.). 1975. Cape Cod Bay Study Quarterly Progress Report, June-August 1975. 7 p. + appendix.

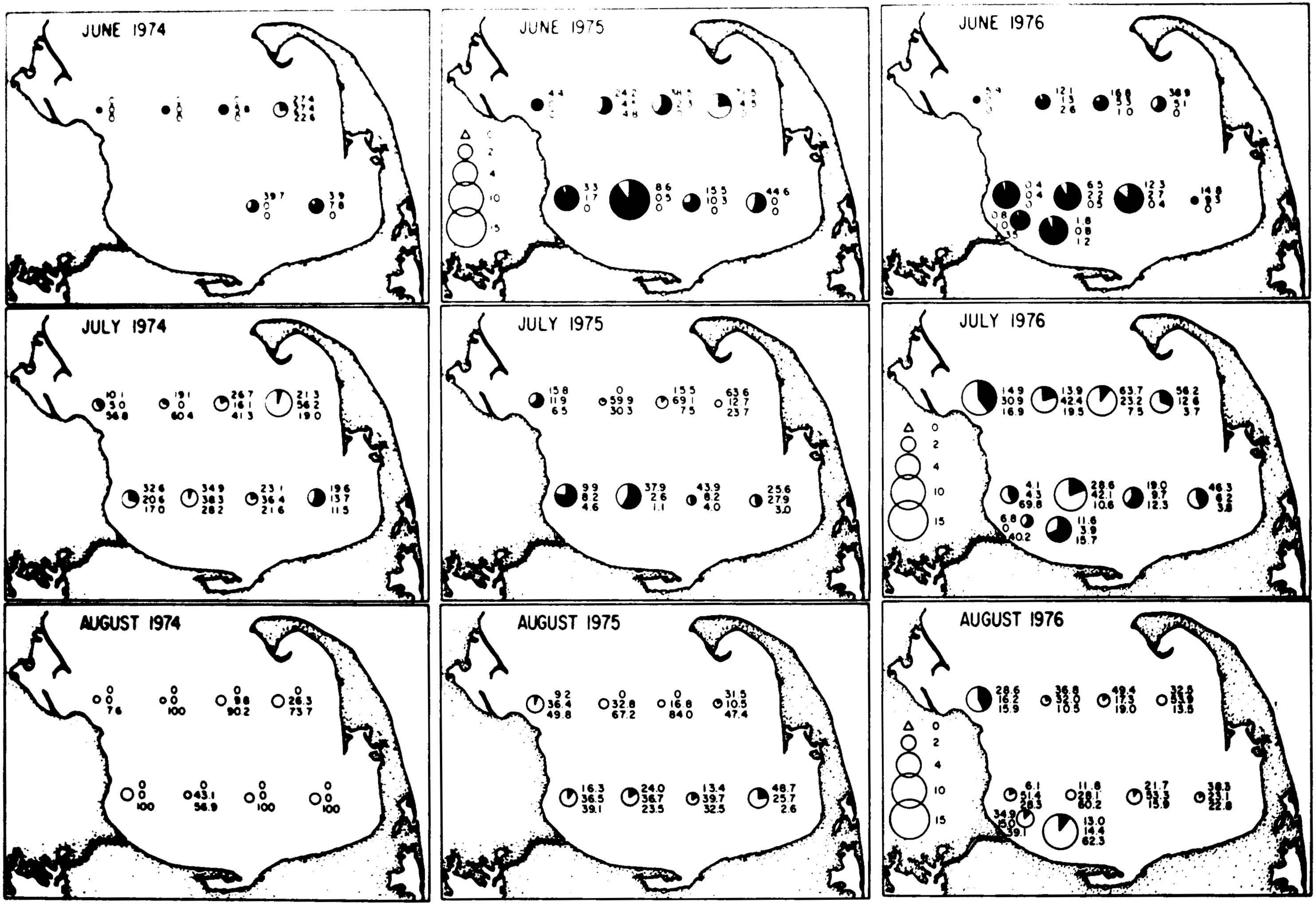

Figure 2.—Distribution of mean monthly larval lobster densities, per 1,000 m³ of water, by station in Cape Cod Bay, 1974-76. Dark areas within each circle represent percent of the mean represented by stage I larvae. Numbers beside each circle indicate (from top to bottom) the percent stage II, III, and IV larvae.

Table 4.—Lobster larvae densities (number per 1,000 m³) in vertically stratified Tucker net samples.

Date	Time	Surface	Depth (m) 3	6	9	12	Mean
7 June	1437-1700	0	1.6	0	0	0	0.32
8 June	0055-0240	0.73	4.0	0.43	0	0	1.03
	0310-0500	9.99	27.13	12.30	2.36	3.01	10.96
10 June	1605-1750	0.34	0	0	0	0	0.07
	1810-2000	0.40	0.62	1.74	1.55	0.50	0.96
11 June	0425-0615	0.56	2.69	0.33	1.24	0	0.96
	0715-0850	0.84	18.50	0	0	0	3.87
19 June	2345-0100	49.49	62.29	10.88	0	0.93	24.72
	0135-0355	1.17	2.16	0.81	0.59	1.09	1.16
	1105-1240	0	0.87	0.41	3.30	0.33	0.98
	1330-1515	0	2.72	5.09	1.90	0.93	2.13
23 June	0215-0410	0	0.55	0.47	0.91	0.48	0.48
	0458-0645	2.27	7.95	2.71	3.35	2.21	3.70
	1430-1635	0.42	0	0.41	0	0	0.42
	1700-1835	0	0	0	0	0	0
30 June	0720-1020	0.76	0.79	0	1.03	0	0.52
	1050-1230	0.35	5.49	1.54	2.72	1.01	2.22
	1940-2135	0	0	0	0	0	0
	2155-2345	3.11	5.26	2.76	1.90	0	2.61
7 July	1355-1538	0	0.32	0.34	0	0	0.13
	1605-1740	0	0	0	0.73	0	0.15
8 July	0115-0255	0	0	0	0	0	0
	0320-0505	0	0	0	0	0	0
Mean		3.06	6.21	1.75	0.94	0.46	
SD		10.34	13.87	3.35	1.12	0.79	

the area under the curve by trapezoidal integration, it was estimated that approximately 7.3 million larvae entered the Bay from the Canal during this 24-d period alone.

Although the fate of these larvae upon entering the Bay is unknown, information on the hydrography of Cape Cod Bay combined with the available field data for 1974-76 suggest the possibility that many of these larvae entering from the Canal may eventually settle in the area of Provincetown or perhaps pass out of the Bay completely before terminating their pelagic period. Drift bottle studies described by Bigelow (1924) indicate a counterclockwise direction to the Bay surface currents, which, according to Ayers (1956), have an average speed of 1.9 n.mi./d. At this rate, it might require a period of 10 d for stage I larvae originating at the Canal mouth to arrive in the area of Provincetown. Although the duration of the larval period varies strongly and inversely with temperature (Templeman 1936; Hughes and Matthiessen 1962), the fact that 22 d may be required for a newly hatched larva to attain stage IV at 15°C (Sherman and Lewis 1967) indicates that most of these larvae would not have settled out prior to reaching Provincetown.

Assuming a counterclockwise drift of the larvae, their projected path from the Canal mouth should pass near Stations VI and then IV prior to passage from the Bay or settlement in the vicinity of Provincetown. This route is suggested by the data in Figure 2 for 1975 and 1976, during which the percentage of stage I larvae in the samples steadily dropped in a northeasterly direction, i.e., between Stations X and VI and between Stations VI and IV. This might explain why stage III larvae were most abundant at Station IV in 1974.

There is some evidence from the 1976 data that a counterclockwise current as described by Bigelow (1924) may also serve to transport larvae from the northwest section of the Bay (Station I) into the southwest sector, notably during the month of July. Large concentrations of early stage larvae found at Station I in 1976 were followed by high concentrations of larvae of later stages at Station VII later during the month (Fig. 2).

The observed vertical distribution of larvae near the mouth of Cape Cod Canal is interesting since most previous efforts to sample larvae have generally relied upon neuston nets in the belief that larvae tend to concentrate at the surface (Lund and Stewart 1970; Scarratt 1973). We suspect, however, that the strong turbulence apparently characteristic of Cape Cod Canal may influence the vertical distribution of the larvae in this area.

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Distribution and Abundance of Larval American Lobsters, *Homarus americanus* Milne-Edwards, in the Western Inshore Region of Cape Cod Bay, Massachusetts

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ABSTRACT

Larval lobster (*Homarus americanus*) abundance and distribution in the western inshore region of Cape Cod Bay, Mass., from 1974 to 1977 are reported. Lobster hatching generally began in mid-June, and the period of larval occurrence ranged from 46 to 62 d over the time and area studied. Maximum densities of larvae were collected in surface waters in July. Considerably more stage IV than stage I larvae were collected. Densities of lobster larvae were similar to levels obtained in several other New England investigations with the notable exception of Buzzards Bay where hatching was substantially greater.

INTRODUCTION

The American lobster, *Homarus americanus* Milne-Edwards, is the most valuable commercial resource harvested in Massachusett's territorial waters. An intensive lobster fishery occurs off Plymouth (Fig. 1) from March to November. The lobster catch reported for Plymouth County amounted to 348 t and was valued at $1.1 million in 1974 (Beals and Phelan[4]). By 1980, landings increased to 918 t, valued at $4.0 million (Anderson et al.[5]).

Inshore lobstering in Plymouth is concentrated within a 5.6 km radius of Pilgrim Nuclear Power Station, located on the western shore of Cape Cod Bay (Fig. 1). Because of the economic value and proximity of this fishery to the power plant and lack of information on site-specific larval ecology, the Massachusetts Division of Marine Fisheries examined the temporal and spatial distribution of lobster larvae from 1974 to 1977. This undertaking was part of an overall ecological investigation to determine plant-related impact on marine resources in Cape Cod Bay.

Our objectives were to determine location of hatching areas, density, and distribution of lobster larvae in the vicinity of the power plant. Work conducted in 1974 was preliminary. We expanded our inquiry in 1975 to investigate effects of wind on larval distribution and to examine the occurrence and density of larvae in shallow water. In 1976, we increased sampling frequency and concentrated efforts from Rocky Point northward to Brant Rock (Fig. 1). Our intent in 1977 was to obtain information on distribution of larvae at depth and further definition of hatching and nursery areas.

METHODS

Study Area

Cape Cod Bay, located at the southern extremity of the Gulf of Maine, is a broad open water body bounded by the landform of the eastward and northward extension of Cape Cod. The substrate in the overall study area, which included stations from Brant Rock to Scorton Ledge (Fig. 1), is primarily smooth sand interrupted by submerged ledges. This habitat may support high lobster densities (Cobb 1971).

Hatching, distribution, and density of larvae are influenced by an interaction of water temperature, salinity, and current patterns. Annual surface and bottom water temperatures generally range from −1 °C in February to 23 °C in August and from −1 °C in February to 21 °C in September, respectively (Lawton et al.[6]). The water column is stratified from June to November with a thermocline evident between 5 and 10 m (Doret et al.[7]). Surface salinities, ranging primarily from 28 to 35‰, are influenced by both the ocean and, to a lesser degree, drainage from watersheds. The overall water move-

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[5]Anderson, C. O., Jr., C. B. Kellogg, and G. Nash. 1980. 1980 Massachusetts lobster fishery statistics. Mass. Div. Mar. Fish. Tech. Ser. 15, 20 p.

[6]Lawton, R. P., W. T. Sides, E. A. Kouloheras, R. B. Fairbanks, M. Borgatti, and W. S. Collings. 1978. Final report on the assessment of possible effects of Pilgrim Nuclear Power Station on the marine environment. Project Report No. 24 (1970-1977). Massachusetts Division of Marine Fisheries. *In*: Marine ecology studies related to operation of Pilgrim Station. Final Report, July 1969-December 1977. Vol. 1, sect. III.9, 19 p. Nuclear Engineering Department, Boston Edison Company, 800 Boylston St., Boston, MA 02199.

[7]Doret, S. C., D. R. F. Harleman, A. T. Ippen, and B. R. Pearce. 1973. Characteristics of condenser water discharge on the sea surface. R. M. Parsons Laboratory for Water Resources and Hydrodynamics. Department of Civil Engineering, Massachusetts Institute of Technology, Boston, Mass., 156 p.

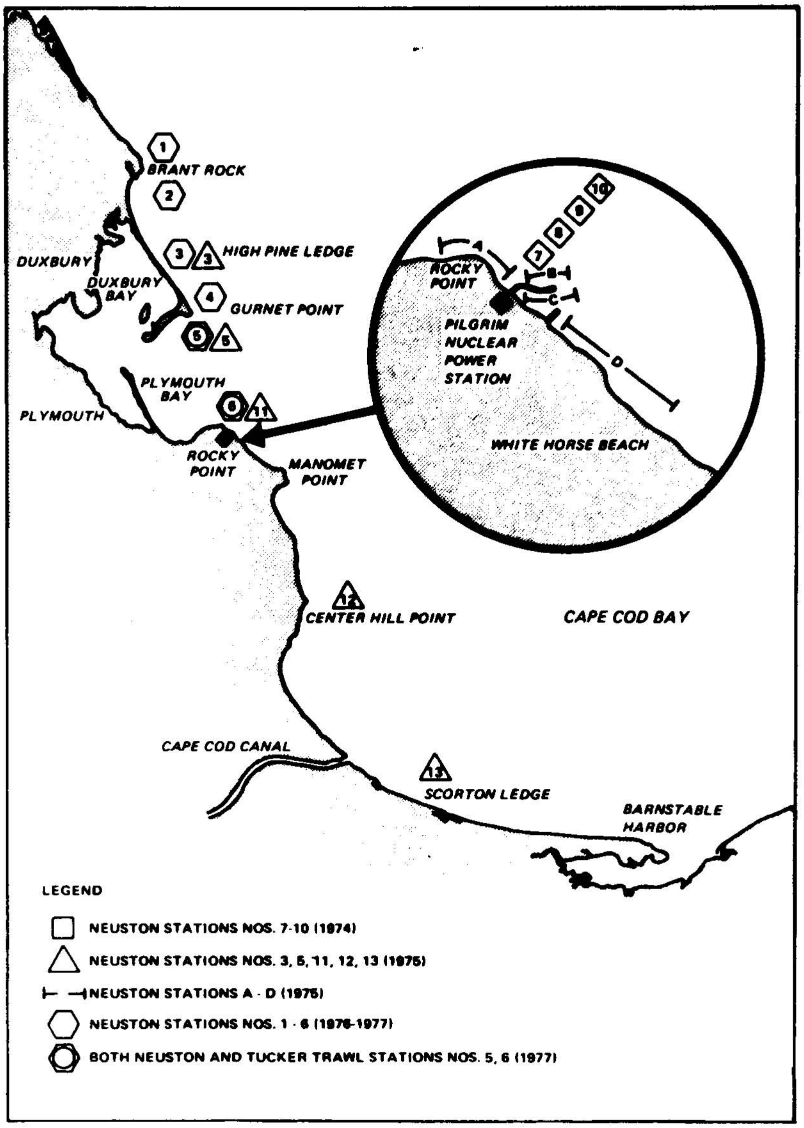

Figure 1.—Lobster larvae sampling stations in western Cape Cod Bay, 1974-77.

ment in Cape Cod Bay is a result of geostrophic, tidal, and longshore currents which have a net effect of producing a flow parallel to the coast toward the southeast (E G and G Environmental Consultants[8]). Movement of surface water nearshore is most influenced by wind-induced currents which are variable in direction (O'Hagan[9]).

Sampling Gear Specifications and Procedures

Division of Marine Fisheries research vessels, RV *F.C. Wilbour* and RV *J.J. Sullivan*, were employed for surface towing. Sampling gear consisted of a 1 m × 2 m neuston net, approximately 3 m in length and constructed of 1.05 mm nylon mesh. Net frame was constructed of 12.7 mm steel rod with four floats for buoyancy. Based on knowledge of diurnal lobster larvae distribution (Templeman and Tibbo 1945), we sampled only in the daytime and primarily at the surface from 1974 to 1977. In 1975, we also conducted surface tows at shoal stations employing two 1 m × 1 m neuston nets. These were suspended amidships from a horizontal boom on each side of a 5.5 m skiff to avoid propeller wash.

A General Oceanics Model S 2030 R flowmeter[10] attached to the mouth of the neuston net was used to determine the volumes of water sampled (Table 1). Overall, surface collections averaged 3,522 m^3 of water sampled per tow. We towed the neuston net breaking the water's surface. The vessel was maneuvered to keep the net out of the propeller wash.

In 1977, we conducted subsurface tows aboard the *F.C. Wilbour* using a 1 m × 1.5 m Tucker trawl, approximately 5 m long with 1.05 mm mesh as described by Clarke (1969) and Hopkins et al. (1973). The trawl fished at an angle of 45° producing a net opening of 1 m^2.

Upon completion of each surface and subsurface tow, net contents were washed into the cod end, emptied into a nested set of sieves (6.35 mm and 1.05 mm size mesh), and rinsed. Material retained in the 6.35 mm mesh sieve was rinsed again,

[8]E G and G Environmental Consultants. 1975. Preliminary Phase II Final Report. *In* Forecasting Power Plant Effects on the Coastal Zone, 187 p. E G and G Environmental Consultants, 196 Beak Hill Road., Waltham, MA 02154.

[9]O'Hagan, R. M. 1974. Analysis of 1972-1973 ocean current measurements near Pilgrim Station. *In* Marine ecology studies related to operation of Pilgrim Station, Semi-Annual Report No. 4, sect. III, 38 p. Boston Edison Company, Boston, MA 02199.

[10]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Schedule, stations, gear type, and procedures for lobster larvae sampling in western Cape Cod Bay, 1974-77.

Year	Sampling dates	Station locations (Fig. 1)	Gear type	$\bar{x}$ Tow duration (min)	$\bar{x}$ Volume of water sampled (m^3)	$\bar{x}$ Tow speed (km/h)
1974	5/24-8/20	7-10	1 × 2 m neuston net	11.5	—	3.7
1975	5/23-8/5	3, 5, 11, 12, 13	1 × 2 m neuston net	30	3,774	4.6
	6/20-8/14	A-D	two 1 × 1 m neuston nets	10	1,400	3.5
1976	6/4 -8/11	1-6	1 × 2 m neuston net	30	3,271	4.6
1977	5/5 -8/10	1-6	1 × 2 m neuston net	30	3,001	4.6
	6/9 -8/1	5-6	1 × 1.5 m Tucker trawl	20	1,301	5.6

examined for larvae, and discarded. If large amounts of algae, and/or eelgrass, *Zostera marina*, were present, a third rinse was performed to assure complete removal of larvae. Contents washed into the 1.05 mm sieve were transferred into labeled 1 litre jars containing a preservative of 5% buffered Formalin-seawater solution. Samples were sorted in the laboratory, and lobster larvae were identified and enumerated by molt stage according to Herrick (1911).

Sampling Stations, Schedule, and Data Analysis

Location of sampling stations is presented in Figure 1. We conducted neuston sampling on a biweekly basis in 1974 and 1975 (Table 1). Weekly collections were made in 1976. Biweekly sampling in May and June 1977 was intensified to several days each week in July and August during peak hatching. In June 1977, we initiated biweekly subsurface towing at stations 5 and 6 at depths of 3.0 m, 5.5 m, and 7.6 m. In July and August, we increased the frequency of sampling to weekly intervals. We collected data until ctenophore abundance precluded successful net operations in early August.

The effect of local wind conditions on the concentration of lobster larvae was examined in 1975 and 1976. Mean weekly wind speed, direction, and duration at Pilgrim Station were determined from data provided by Boston Edison Company. Data were grouped into 16 wind directions and by 8.0 km/h wind speed increments.

Density estimates for each larval stage were corrected for stage duration according to Templeman (1936) for each sampling date. Differences in stage I and stage IV density (no./1,000 m^3) by station were examined by Kruskal-Wallis tests (Sokal and Rohlf 1969).

RESULTS

1974 Sampling

We collected only 25 lobster larvae in 1974 (Table 2) in the vicinity of the power plant (Fig. 1). Only nine tows contained larvae. The first larva was obtained on 2 July and was in the fourth stage. Only one first stage larva was found, with other collections consisting exclusively of stage IV individuals. The maximum number (7) captured in one tow was collected at station 7 on 7 August.

1975 Sampling

Expanded spatial coverage in 1975 yielded a total of 177 lobster larvae (excluding shoal water stations A-D). Larvae were first collected on 10 June at stations 12 and 13 (Fig. 1). All were first stage, indicating that hatching had just commenced. On this date, water temperatures in western Cape Cod Bay averaged 14.8 °C at the surface and 12.7 °C on the bottom (Fig. 2). As determined by the presence of stage I larvae in our catch, the hatching period extended from 10 June into the first week of August, or approximately 56 d. Densities of all stages peaked in early July when a total of 137 larvae (65% stages I and II) was captured on one sampling date. The largest number of larvae was collected at station 3 on 8 July.

Table 2.—Larval catch, mean densities, and percent composition for stages I-IV collected in neuston tows in western Cape Cod Bay, 1974-77.

Year	No. tows	Bottom temperature range (°C)	Percent catch composition by molt stage I	II	III	IV	Avg. density (No./1,000 m^3)	Total larval catch
1974	20	—	4.0			96.0	—	25
1975	27	7.7-14.8	59.9	23.7	8.1	8.3	2.05	177
1976	60	5.5-16.5	25.5	19.7	29.6	25.2	4.44	871
1977	78	5.5-15.0	55.2	16.9	5.3	22.6	1.26	206

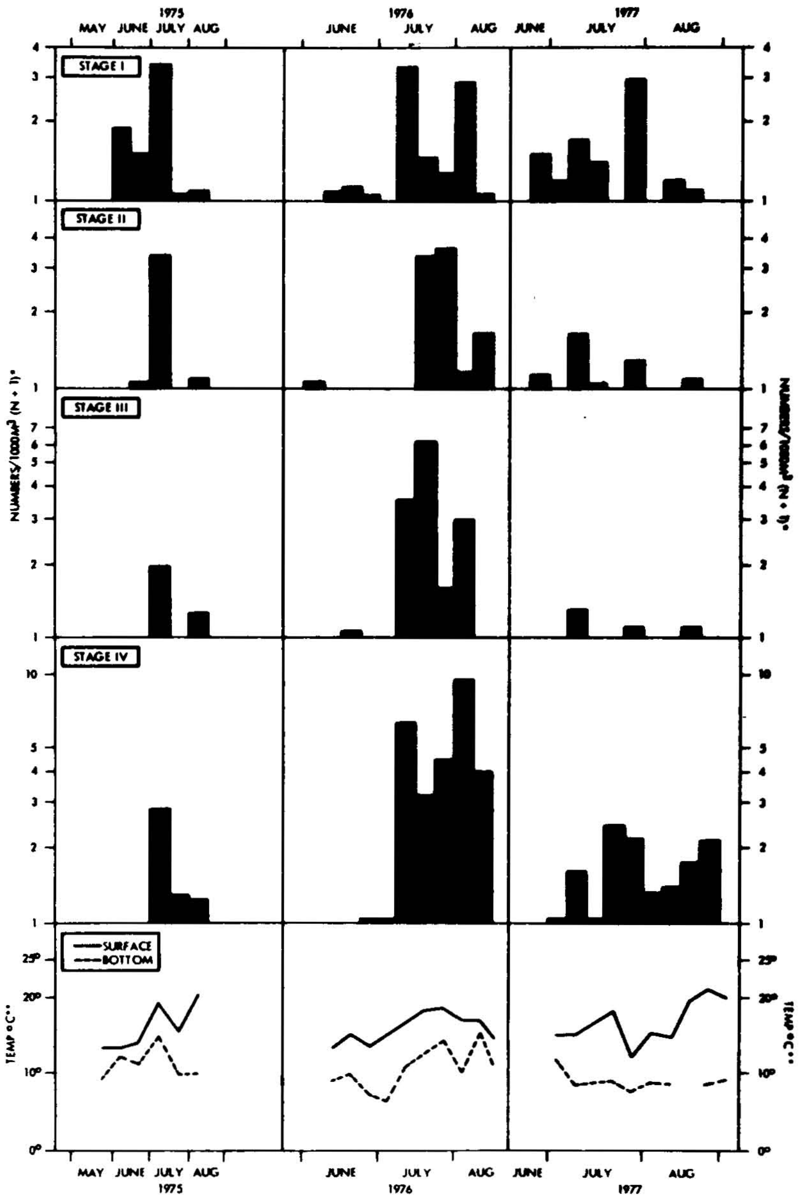

Figure 2.—Temporal distributions of mean lobster larvae pooled density (stations) by molt stage collected in neuston tows, and mean water temperatures in western Cape Cod Bay, 1975-77.

Average density per tow for combined molt stages over the study for all stations was 2.05 larvae/1,000 m³ (Table 2).

Percent composition of total larval catch for 1975 was: stage I - 59.9%, stage II - 23.7%, stage III - 8.1%, and stage IV - 8.3%. Catches at stations 3 and 13 were dominated by first stage larvae which composed 66% and 82%, respectively, of station totals.

At shoal water stations A-D (Fig. 1), we sampled on five dates but collected only eight larvae in 20 tows. Seven larvae were fourth stage, six of which were captured on 25 July.

1976 Sampling

The largest number of lobster larvae was collected in 1976, when we captured 871 larvae (Table 2). Hatching began in June and terminated in August (Fig. 2). Only one larva (stage II) was collected in the first week of June when water temperatures measured 13.7 °C at the surface and 9.5 °C on the bottom (Fig. 2). Ninety-two percent (801) of the total larval catch was taken from 14 July to 3 August at surface water temperatures ranging from 9.5° to 16.5 °C. Catch distribution was bimodal with peak densities occurring on 14 July and 3 August. By 11 August, with one exception, collections consisted exclusively of stage IV larvae. Percent composition of the season's total catch (pooled stations' data) by developmental stage was: stage I - 25.5%, II - 19.7%, III - 29.6%, and IV - 25.2% (Table 2). Catch at all stations contained relatively large numbers of late stage larvae. Mean density per tow was 4.44 larvae/1,000 m³.

Stations 5 and 6 ranked first and second, respectively, in total number of larval lobsters collected (Fig. 3). The combined catch of these stations was 451 larvae, or 52% of the total catch for 1976, consisting of 22.2% stage I, 23.2% stage II, 35.3% stage III, and 19.3% stage IV larvae. Station 1 ranked third in total catch (176 larvae), of which 23% were stage IV. Thirty percent (31 larvae) of all first stage larvae (105) were captured at station 1. Fifty first stage larvae, which constituted 48% of the total stage I individuals collected, were caught at stations 5 and 6 combined.

1977 Sampling

Despite substantially increased effort in 1977, only 206 lobster larvae were obtained (Table 2). We initiated sampling in early May but caught no lobster larvae until 14 June when first and second stage individuals were collected (Fig. 2). Water temperatures averaged 14 °C (surface) and 11.5 °C (bottom) on this date. Hatching apparently terminated in August. On the last sampling date (10 August), surface tows contained exclusively fourth stage larvae. Further sampling was prevented because of net fouling by an unidentified brown alga.

Seasonal catch distribution was bimodal with larval densities peaking on 11 and 29 July (Fig. 2). On 29 July, we collected 73 larval lobsters, consisting of 52% stage I and 29% stage IV individuals. Mean seasonal density (pooled station and molt stage data) was 1.26 larvae/1,000 m^3, well below the 1976 average density level (Table 2). Percent composition of the total catch for stages I-IV was: 55.2%, 16.9%, 5.3%, and 22.6%, respectively.

Stations 1 and 2, in the area of Brant Rock (Fig. 1), yielded the greatest numbers of larvae. At station 1, catch composition was dominated by stage I larvae (74%), while at station 2, first stage larvae comprised about 43% of the station total. Samples were dominated by first and fourth stage individuals (Fig. 3). Of the total first stage lobsters sampled, 49% were taken at station 1. Within the study area, catches of stage I larvae generally decreased from north to south. Only 9.0% and 6.4% of the total first stage larvae were collected at stations 5 and 6, respectively.

We made 48 subsurface tows from 9 June to 1 August 1977. Two larval lobsters were collected at station 6 on 23 June. One was a first molt stage individual collected at a depth of 7.6 m and the other a fourth stage larva captured 3.0 m below the surface.

Effect of Wind Conditions

Analysis of wind data for the spring and summer of 1975 and 1976 indicated that offshore winds from the southwest and south-southwest prevailed. However, an inspection of wind direction for respective sampling days revealed that during the period of peak larval abundance the majority of sampling trips coincided with onshore or alongshore winds. Seventy-three percent of the tows were made during onshore winds, and 82% of the larvae were collected when winds were onshore. Consequently, we could not statistically compare the effect of onshore-alongshore winds versus offshore winds or the dispersion and resultant concentration of lobster larvae in the study area.

Spatial and Temporal Distribution

Kruskal-Wallis tests indicated no significant difference ($P > 0.20$) in density of stage I larvae between stations sampled in 1976 and 1977. There was no significant difference ($P > 0.20$) in density of stage IV larvae between stations for the same 2 yr.

Temporal distribution of mean pooled lobster larvae densities by molt stage and water temperature data are given for 1975-77 in Figure 2. We estimated the period of occurrence of larvae in the water column ranged from 46 to 62 d over the time and area studied.

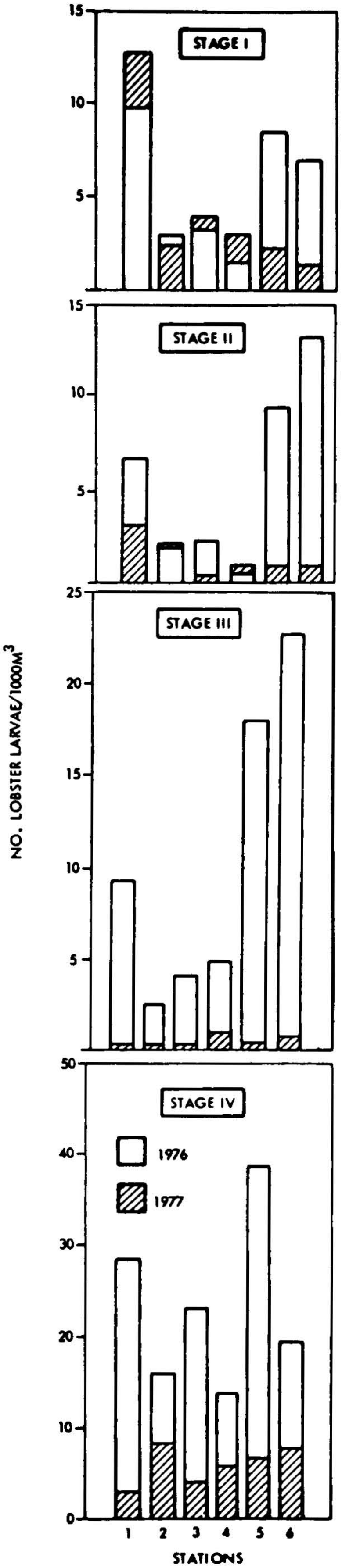

Figure 3.—Lobster larvae density by molt stage collected in neuston tows in western Cape Cod Bay, 1976-77.

DISCUSSION

According to Scarratt (1964), the period of lobster hatching and location of hatching areas may be determined by examining the temporal and spatial presence of stage I larvae. A comparison of station densities in 1975 revealed that substantially more stage I individuals were collected at stations 3 and 13. In 1976, stage I larval densities were relatively high at stations 1, 5, and 6. Our results agreed with those obtained by Marine Research, Inc.,[11] indicating peak larval densities in the environs of Rocky Point. Again in 1977, stage I larval density was highest at station 1. Forty-nine percent of the first stage larvae we collected that year were captured at this site. In contrast to our 1976 findings, the total catch of stage I larvae was less at stations 5 and 6 in 1977.

The relatively high percentage of fourth stage larvae obtained in our study may be due to differential availabilty to capture by molt stage (Herrick 1896; Templeman and Tibbo 1945; Scarratt 1973). Alternatively, high catches of fourth stage larvae may represent transport by currents from other hatching areas. With the existence of a net counterclockwise advection in Cape Cod Bay (O'Hagen footnote 9), late stage larvae may be recruited from areas north and offshore from those studied. In late July 1976, prevailing south-southwest winds with concomitant decline in surface water temperature probably produced an offshore movement of surface water with a possible transport of lobster larvae. A similar situation existed in 1977 during a period of reduced larval density.

Our limited sampling indicated there was minimal depth stratification of larvae during the daylight. Templeman (1937), Templeman and Tibbo (1945), Sherman and Lewis (1967), and Scarratt (1973) reported that the majority of lobster larvae during the daytime are collected at the surface.

Hatching initiated in mid-June at water temperatures of approximately 14°C (surface) and 8°-9°C (bottom) and terminated by mid-August. The period of occurrence of larvae in the water column ranged from 46 to 62 d. There was considerable variability between years in seasonal larval densities and percent composition of molt stages. Maximum abundance of lobster larvae in daytime occurred in surface waters in July. Sampling at shoal water stations yielded few larvae whereas the areas of Brant Rock (Stations 1 and 2), High Pine Ledge (Station 3), and from the mouth of Plymouth Bay to Rocky Point (Stations 5 and 6) produced greatest numbers of total larvae. Higher numbers of stage IV larvae were collected than were expected relative to the number of stage I larvae obtained and considering the expected mortality between stages I-IV.

Wind-generated currents may be an important transport mechanism affecting dispersion of lobster larvae and ultimate distribution in surface waters (Templeman 1937; Templeman and Tibbo 1945; Squires 1969; Caddy[12]). We observed on several occasions over the 4 yr that when a sampling trip was preceded by several consecutive days of offshore winds, e.g., from the southwest, we noted that our catch was comprised of atypically fewer lobster larvae, substantially less crab larvae, and abnormally large numbers of terrestrial flying insects.

[11]Marine Research, Inc. 1976. Entrainment investigations and Cape Cod Bay ichthyoplankton studies. *In* Marine ecology studies related to operation of Pilgrim Station, Semi-Annual Report No. 9, sect. III.C.2, p. 95-104. Boston Edison Company, Boston, MA 02199.

[12]Caddy, J. F. 1976. The influence of variations in the seasonal temperature regime on survival of larval stages of the American lobster (*Homarus americanus*) in the southern Gulf of St. Lawrence. ICES Special meeting on population assessments of shellfish stocks. Paper No. 10, 46 p.

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New Hampshire Lobster Larvae Studies

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ABSTRACT

Lobster larvae, which were collected in coastal New Hampshire waters between mid-July and early October 1978 and early June through mid-August 1979, reached maximum abundance in late August in 1978 and late July in 1979. Stage composition was heavily weighted towards stage IV larvae in 1978, and stage I larvae in 1979. The sizes of larvae at all stages were generally larger than those reported in other studies.

INTRODUCTION

The only quantitative investigations of lobster larvae in New Hampshire waters have been conducted as part of the preoperational ecological studies for Seabrook Station (Public Service Co. of New Hampshire). Preliminary sampling was undertaken during the summer of 1973 (Normandeau Associates, Inc.[3]); formal preoperational studies, described below, were initiated during 1978. Primary questions concerned the seasonal distribution and abundance of lobster larvae in the vicinity of the offshore intake and discharge structures for Seabrook Station.

MATERIALS AND METHODS

A neuston net (1 m × 2 m × 8 m; 1.0 mm mesh) was towed during daylight hours along a north-south transect about 1,850 m offshore from Hampton Beach, N.H. (Fig. 1). Samples were collected from 9 June to 18 October 1978 and 15 May to 20 September 1979. Collections were made weekly until the first larvae were collected, twice-weekly when larvae were present, and weekly again for a few weeks after larvae were no longer collected. Thirty-four collections were made during 1978, 30 during 1979.

Tow duration was 15 min through 18 July 1978 and was increased to 30 min thereafter; tow speed was ≅ 1 m/s. Tows were made from the side of the boat outside of the wake. The net bottom was 0.5 m below the surface to give an effective sampling area of 1.0 m^2. Sample volumes, measured by a digital flowmeter, averaged 1,475 m^3 for 15-min tows and 1,868 m^3 for 30-min tows. If flowmeter readings were suspect (fouled with algae), the average volume calculated for similar tow characteristics (duration and net area) was applied.

Samples were sorted for all lobster larvae in the laboratory, staged after Herrick (1896) and Templeman (1948a), and measured (stage IV only during 1978).

Numerical classification (Boesch 1977) was used to compare the stage composition from New Hampshire with that of other New England areas. A similarity matrix, using percent similarity (Boesch 1977), was constructed for each combination of sites. Group average clustering (Boesch 1977) was then applied to organize these sites into larger groups based on the similarity of larval stage composition.

RESULTS

Seasonality and Abundance

Lobster larvae were first collected in neuston tows on 21 July 1978 and 8 June 1979. Stage I larvae were present from late July through mid-August 1978 and from early June through early August 1979 (Fig. 2). There was no distinct seasonal peak of stage I larvae during 1978; the collection of 53 individuals on 24 July 1979 was coincident with the collection of large amounts of macroalgae. Few stage II (n = 3) and III (n = 3) larvae were collected during 1978-79. Stage IV larvae were collected from 21 July to 3 October 1978 and 17 July to 10 August 1979 (Fig. 3). Peak densities of stage IV larvae

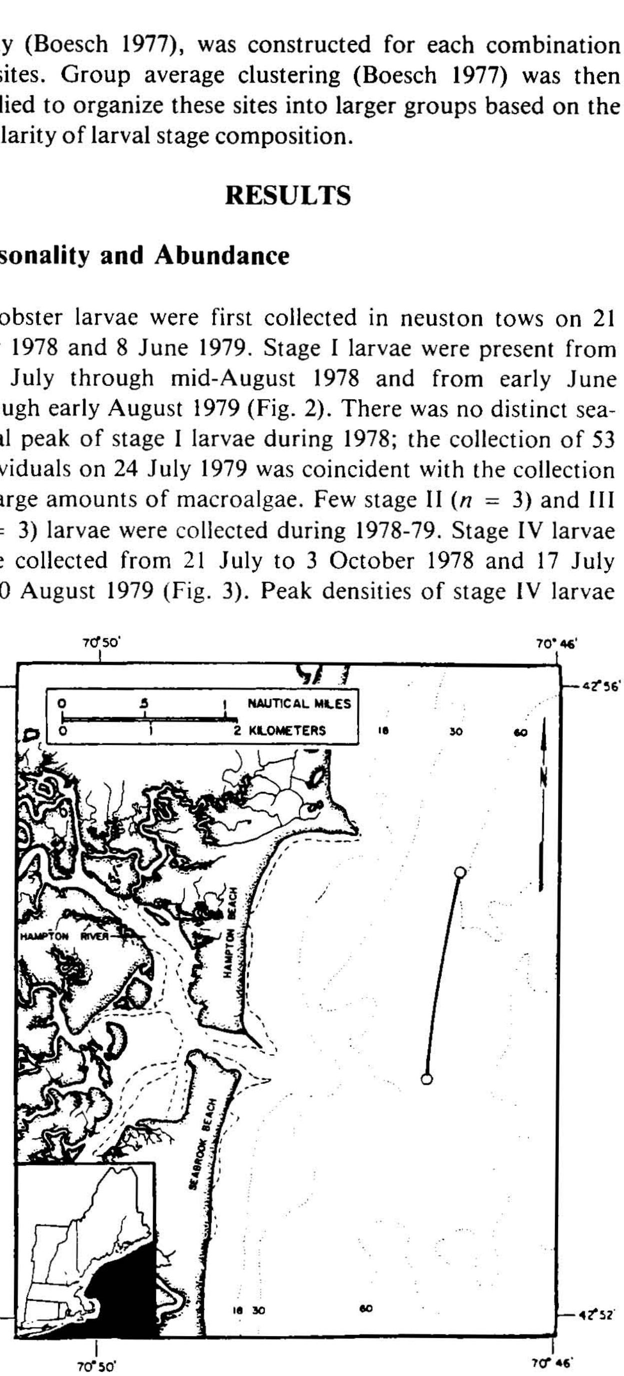

Figure 1.—Lobster larvae sampling station off Hampton, N.H.

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[2]Normandeau Associates Inc., 25 Nashua Road, Bedford, NH; present address: Dames and Moore, 155 N.E. 100th St., Seattle, WA 98125.
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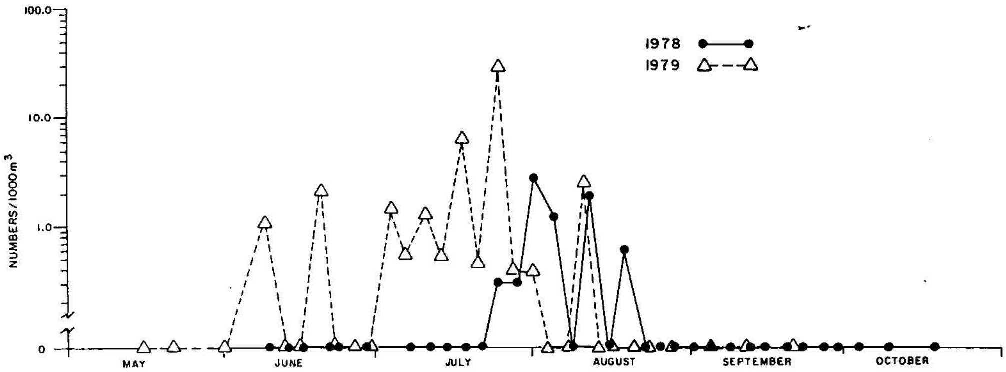

Figure 2.—Abundance of stage I lobster larvae in neuston collections off Hampton, N.H., 1978-79.

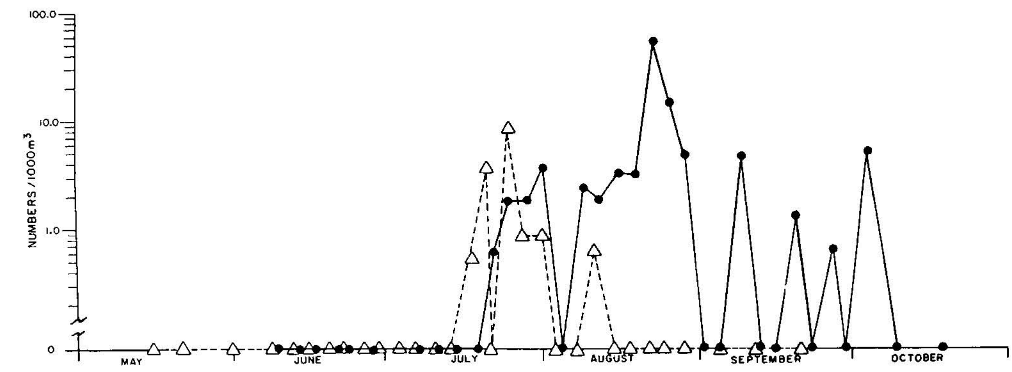

Figure 3.—Abundance of stage IV lobster larvae in neuston collections off Hampton, N.H., 1978-79.

occurred during late August 1978 and late July 1979 and were coincident with large quantities of macroalgae. During 1978, stage IV larvae were collected somewhat more frequently when winds were onshore (Table 1). A total of 169 (1978) and 120 (1979) larvae were collected.

Lobster larvae were also collected during discrete depth plankton sampling conducted in 1978 by Normandeau Assoc., Inc.[4] A third-stage larva was collected in a mid-depth tow on 7 July 1978 indicating that hatching considerably pre-dated the first occurrence of larvae in neuston tows.

[4]Normandeau Associates, Inc., 1981. Plankton studies in the vicinity of Hampton Beach, New Hampshire. Tech. Rep. XI-3, 147 p. Prepared for Public Service Co. of New Hampshire.

Table 1.—Frequency of wind directional vectors (°true) and the percent of stage IV lobster larvae, Hampton, N.H., 21 July-18 October 1978.

Wind direction	All dates	Dates stage IV larvae present in collections	Dates stage IV larvae absent from collections
Alongshore[1]	35.2	33.3	50.0
Offshore[2]	40.6	20.0	33.3
Onshore[3]	24.2	46.7	16.7
	n = 91	n = 15	n = 6

[1]Directional vectors 0°-30°, 150°-210°, 330°-360°.
[2]Directional vectors 30°-150°.
[3]Directional vectors 210°-330°.

Stage Composition

Stage IV larvae were dominant during 1978. Previous neuston sampling conducted off Hampton-Seabrook during 1973 also indicated a disproportionate number of stage IV larvae (Normandeau Assoc., Inc. footnote 3). Stage I larvae, however, were dominant during 1979; stage II and III composed <9% of the larvae collected.

Stage composition in the Hampton-Seabrook area during 1973 and 1978 was dissimilar to that of most other areas of New England for which data were available (Fig. 4). Five clusters were distinguished at varying similarities. Clusters A and B were dominated by stage I larvae, but differed in the contribution of stage II and III larvae (Fig. 4). Stage distribution was somewhat more evenly distributed in Cluster C. Clusters D and E (Hampton-Seabrook, 1973 and 1978) were characterized by stage IV dominance but differed in the contributions of stage II and III larvae.

Size of Lobster Larvae

Mean length of lobster larvae increased almost two-fold from stage I to stage IV (Table 2). At all stages, larvae from New Hampshire appeared to be larger than those reported from areas of Canada and southern New England, with the ex-

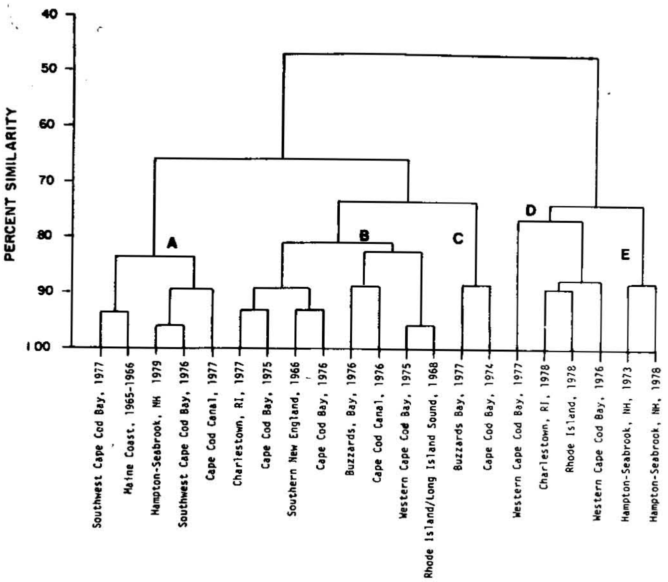

Figure 4.—Dendogram of stage composition in New England lobster larvae studies. Percent stage composition (clustered variable) obtained from reports in this volume and personal communication with investigators; additional data obtained from Sherman and Lewis (1967) and Lund and Stewart (1970).

ception of stage IV larvae from Charlestown, R.I. (Bibb and Hersey[5]).

Associated Species

In addition to lobster larvae, 15 invertebrate species and 12 fish species have been identified from summer neuston tows (Table 3). Although quantitative data are not available, *Cancer* spp. megalopa and the copepod *Calanus finmarchicus* appeared to be the most abundant invertebrates. Dominant larval and juvenile fish during 1979 were *Enchelyopus cimbrius*, *Urophycis* spp., *Ulvaria subbifurcata*, and *Tautogolabrus adspersus*.

DISCUSSION

The periods of occurrence of lobster larvae in the Hampton-Seabrook area generally agree with that reported elsewhere (Wilder 1953; Scarratt 1964, 1973; Lund and Stewart 1970; Sherman and Lewis 1967). Peak densities occurred between 1 and 2 mo later than that found in southern New England (Lund and Stewart 1970) but agreed with Canadian studies (Wilder 1953; Scarratt 1964, 1973).

Table 2.—Mean total length and range (mm) of lobster larvae from Hampton, N.H., compared with larvae from Canadian and southern New England waters.

Area	Stage I	Stage II	Stage III	Stage IV
Hampton, N.H. (this study)[1]	9.1 (7.6-10.7)	11.1	13.8 (13.5-14.0)	16.7 (13.6-22.0)
Northumberland Strait, Can. (Wilder 1953)	—[2]	—	—	14.4
Northumberland Strait, Can. (Wilder 1953; computed from Templeman 1936)	7.5	—	—	14.6
Woods Hole, Mass. (Herrick 1896)	7.8 (7.5-8.0)	9.2 (8.3-10.2)	11.1 (10-12)	12.6 (11-14)
Wickford, R.I. (Hadley 1906)	8.2	9.6	11.4	13.5
Southern New England (Rogers et al. 1968)				
Inshore	8.3	10.4	12.9	15.6
Offshore	8.6	10.8	13.1	15.9
Charlestown, R.I. (Bibb and Hersey 1979; see text footnote 4)	7.9 (6.5-10.0)	9.5 (8.0-11.0)	12.1 (10.5-14.0)	16.3 (14.0-19.5)

[1]Number measured by stage: 26(I), 1(II), 2(III), 162(IV); stages I-III, 1979 data only; stage IV, 1978-79.
[2]—Data not available.

Table 3.—Species associated with lobster larvae in neuston collections from the vicinity of Hampton, N.H.

Cnidaria	Decapoda
Hydrozoa	*Cancer* spp. (zoeae, megalopa)
Bougainvillia sp.	*Carcinas maenas* (zoeae, megalopa)
Halitholus cirratus	*Pagurus arcuatus*? (zoeae)
Scyphozoa	*P. longicarpus*
Cyanea capillata	Chordata
Arthropoda	Pisces
Copepoda	*Cyclopterus lumpus*
Anomalocera opalus	*Enchelyopus cimbrius*
Calanus finmarchicus	*Gasterosteus aculeatus*
Caligus (*elongata*?)	*Liparis* (*atlanticus*?)
Mysidacea	*Peprilus triacanthus*
Neomysis americana	*Pseudopleuronectes americanus*
Isopoda	*Scomber scombrus*
Idotea balthica	*Scophthalmus aquosus*
Amphipoda	*Syngnathus fuscus*
Calliopius laeviusculus	*Tautogolabrus adspersus*
Gammarus lawrencianus	*Ulvaria subbifurcata*
Parathemisto gaudichaudi	*Urophycis* sp(p).

Stage composition of lobster larvae in 1973 and 1978 was heavily weighted toward stage IV larvae with few intermediate stages present. Stage I larvae have been dominant in Canadian studies, composing between 72 and 95% of the larvae collected (Wilder 1953; Scarratt 1968, 1969, 1973). Stage IV larvae never composed more than 7.5% of total larval abundance in Canadian studies. The other New England studies described in this report generally showed higher percentages of stage II and III larvae or very high contributions by stage I larvae.

The 1973 and 1978 data suggest that recruitment of juvenile lobsters in the Hampton-Seabrook area may not be dependent upon a local spawning population. Three lines of evidence tend to support this contention: 1) Stage composition showed low proportions of stage I-III, relative to stage IV, indicating

[5]Bibb, B. G., and R. Hersey. 1979. Distribution and abundance of lobster larvae in Block Island Sound, 1978. Raytheon Co., 88 p. Prepared for New England Power Co.

little contribution from resident spawning stock. 2) There was a tendency during 1978, for stage IV larvae to be collected when winds were onshore. Winds in the Hampton-Seabrook area tend to be from the west and southwest during summer months, but due to thermal differences between air and water, are more likely to be onshore during the day and offshore at night (Normandeau Associates, Inc.[6]). Tidal currents in the area average 0.05-0.1 m/s; these effects are more pronounced during summer months when wind velocities are somewhat below average. Net drift tended to be predominantly southward and was generally 1.8 to 3.8 km/d (Normandeau Associates, Inc. footnote 6). This suggests that larvae may be derived from a more northern spawning population, are moved by tidal currents into New Hampshire coastal waters, and are then transported onshore by winds. 3) Catch data for adult lobsters (Normandeau Associates, Inc. footnote 3) showed that during 1972 and 1973 ovigerous females never made up more than 1.5% of the monthly catch; Public Service Co. of New Hampshire (unpubl. data) found that ovigerous females never exceeded 2.4% of the monthly catch during 1974-78, even though females made up 60% of the catch. Also, fewer than 5% of the females in the nearby Piscataqua River were found to be ovigerous (Normandeau Associates, Inc.[7]).

Ennis (1980) and Squires (1970) found between 2.6-30.4% and 10-35% of females were ovigerous, respectively, in Newfoundland waters. Skud and Perkins (1969) reported that 22% of females collected were ovigerous in trawl catches from the continental shelf off New England. Ovigerous females, however, may not be as easily trapped as non-ovigerous females (Templeman and Tibbo 1945).

The association between large amounts of drift macroalgae and increased catch of larval lobsters requires further investigation. For example, virtually all of the stage I larvae collected during 1979 occurred in a single sample which contained a large amount of algae.

Stage IV larvae from the Hampton-Seabrook area appear to be considerably larger than those from Canadian and southern New England waters. Stage IV larvae in our collections were within the size range of Herrick's (1896) stage V-VIII larvae. However, both Herrick (1896) and Hadley (1906) reared their larvae in the laboratory. Templeman (1948b) noted that larvae collected in the warmer waters of Northumberland Strait were smaller than larvae collected from cooler waters, but did not provide temperature data. Wilder (1953) compared larval and juvenile growth in the cooler Bay of Fundy with that in the warmer Gulf of St. Lawrence, and made similar observations.

Species associated with lobster larvae in our collections may be categorized as true neuston species or as near-surface species which may be associated with floating macroalgae. *Anomalocera opalus* and *Enchelyopus cimbrius* are common neuston species in the Gulf of St. Lawrence (Pennell 1967). The majority of species, such as *Cancer* spp. larvae, the hydrozoans and their associated hyperiid amphipods, may be inhabitants of the near-surface waters for either a particular part of their life cycle or for a particular part of the day, but are not adapted for a neuston existence per se. The third assemblage, which lives among the floating algae, includes *Idotea balthica* (Schultz 1969) and larvae and juveniles of *Gasterosteus aculeatus*, *Cyclopterus lumpus*, *Liparis* spp., and *Sygnathus fuscus* (Bigelow and Schroeder 1953; Leim and Scott 1966).

[6] Normandeau Associates, Inc., 1979. Annual summary report for 1976 hydrographic studies off Hampton Beach, New Hampshire. Tech. Rep. VIII-1, 184 p. Preoperational ecological monitoring studies for Seabrook Station. Prepared for Public Service Co. of New Hampshire.

[7] Normandeau Associates, Inc., 1979. Newington Generating Station, 316 Demonstration. Vol. I. 398 p. Prepared for Public Service Co. of New Hampshire.

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Abundance and Distribution of Lobster Larvae (*Homarus americanus*) for Selected Locations in Penobscot Bay, Maine

DANIEL M. GREENSTEIN, LEIGH C. ALEXANDER, and DARYL E. RICHTER[1]

ABSTRACT

Larval lobster (*Homarus americanus*) abundance and distribution were compared at three locations in Penobscot Bay, Maine, from May through September 1976. For the areas in which larvae were found, abundance was low (0.30 larvae/1,000 m^3) during the hatching and development period (mid-June through July) when over 98% of the larvae were collected. Hatching initiated when bottom temperatures were as low as 10.5°C (Station 2). The abundance of lobster larvae decreased from the mouth to the head of the bay. The absence of larvae at the upper bay station was attributed to low salinity surface waters in the area. Almost all stage I larvae (92%) were found on days when cloud cover was 50% or greater.

INTRODUCTION

American lobster, *Homarus americanus*, larvae were collected in Penobscot Bay from May through September 1976 as part of a regional environmental survey related to a proposed power plant site in the upper bay. The principal objective of the study was to estimate the relative abundance and temporal distribution of lobster larvae at three locations in Penobscot Bay (Fig. 1). These stations, distributed over the length of the bay, had similar benthic topography. Furthermore, the lower bay station was selected as an area of relatively high lobster density (as indicated by lobster trap densities).

The study also provided a data base which would contribute to estimates of power plant entrainment impact.

MATERIALS AND METHODS

Lobster larvae were collected with a 1 mm mesh net similar to the type developed and used by Wilder (1953) and Scarratt (1964, 1968, 1973). The net measured 3.7 m × 0.9 m at the mouth, extending 7.6 m to a 0.4 m cod end, and was rigged and buoyed horizontally to expose the upper 0.15 m above the air-sea interface with the remaining 0.85 m underwater. A flowmeter was mounted in the mouth of the net. The net was towed 90 m astern of the boat to avoid towing in the propeller wash. Each tow was 30 min at approximately 1.8 km/h and filtered about 2,650 m^3 of water. Generally samples were collected 3 or 4 d per week. On sampling dates two or three tows were made at each of two stations on a rotating schedule. All samples were collected during the daylight hours.

RESULTS

Total Catch

A total of 58 lobster larvae was collected in 213 surface net tows (Fig. 2). Only 23 of the tows (11%) contained larvae. All

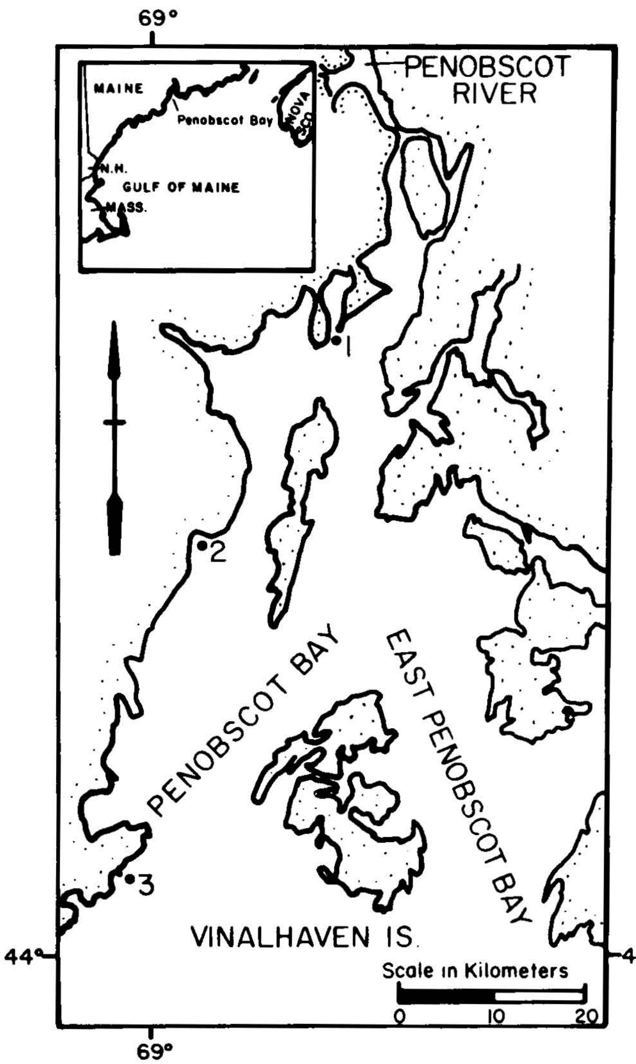

Figure 1.—Sampling stations for lobster larvae, Penobscot Bay, Maine.

[1]Environmental Studies Department, Central Maine Power Company, P.O. Box 53, Yarmouth, ME 04096.

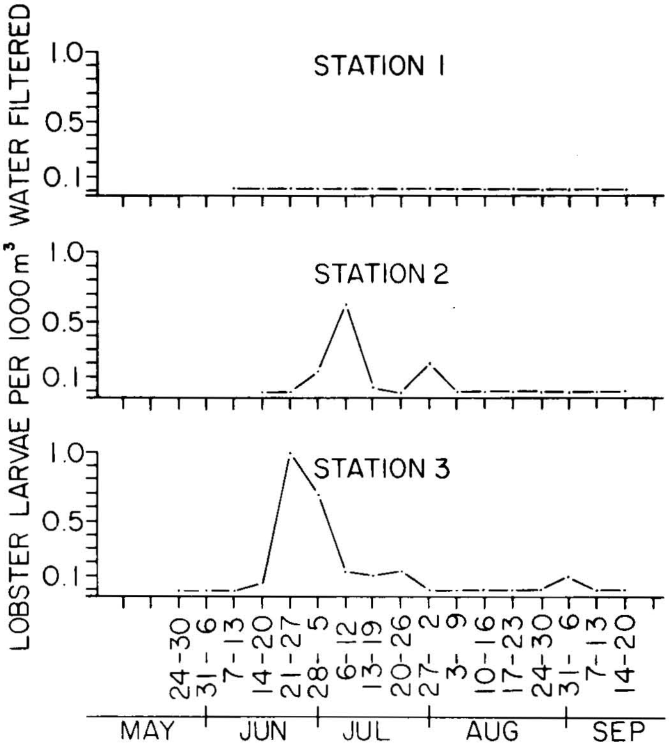

Figure 2.—Weekly lobster larval densities at Stations 1, 2, and 3 in Penobscot Bay, Maine, May-September 1976.

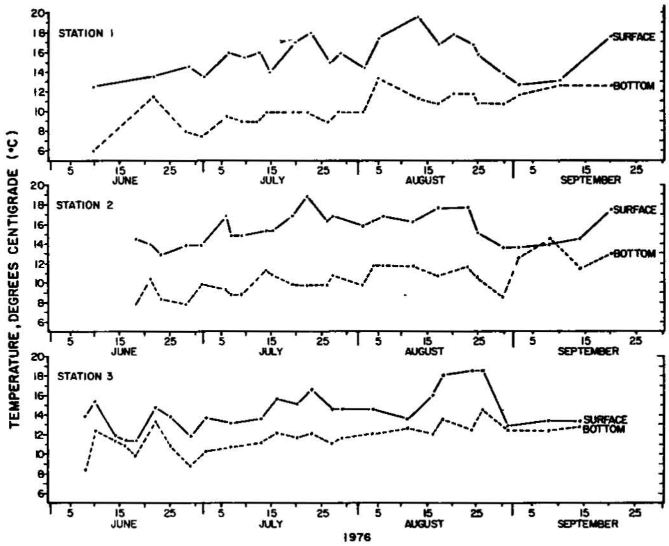

Figure 3.—Surface and bottom water temperatures at Stations 1, 2, and 3 in Penobscot Bay, Maine, June-September 1976.

but one larva were collected from 16 June through 26 July. Stage I larvae dominated the catch, initially appearing at the southernmost station (No. 3) followed by their appearance at station 2, 2 wk later. Only one stage II larva and no stage III larvae were collected during the study. Stage IV larvae were initially found during the later part of July.

Catch by Station

Throughout the sampling period no larvae were found at station 1. At station 2, 17 larvae (14 stage I; 1 stage II; and 2 stage IV) were collected during 1 through 26 July. The 2 stage IV larvae were found in near-surface waters at the end of this period. A peak density of 1.62 larvae/1,000 m^3 occurred 8 d after the first occurrence of larvae in neuston samples.

Highest densities of larvae were recorded at station 3 where 38 stage I and 3 stage IV lobster larvae were collected. Stage I larvae were initially found on 16 June. Higher bottom temperatures were recorded at station 3 (Fig. 3), resulting in earlier hatching at this station than station 2. Hatching intensity, as reflected by the presence of stage I larvae, peaked at a density of 2.89 larvae/1,000 m^3, 9 d after the initial occurrence of larvae (bottom temperature = 11 °C). Hatching apparently ceased after 16 July, after which 2 stage IV larvae were found 1 wk later and 1 stage IV larva was collected on 31 August.

Relation to Cloud Cover

A relationship was noted between the number of larvae taken and the degree of cloud cover. Ninety-two percent of the stage I larvae were collected on days of cloud cover $\geq 50\%$ while all stage IV larvae (n = 5) were taken on days of $<50\%$ cloud cover. For all larvae, 84% were collected when cloud cover was $\geq 50\%$ and 62% of the larvae were obtained on completely overcast days. Approximately 45% of all tows were made on days when cloud cover was $\geq 50\%$.

DISCUSSION

Overall abundance of lobster larvae at the Penobscot Bay stations was low when compared with similar studies conducted in New England coastal waters (Sherman and Lewis 1967; Lund and Stewart 1970) and along the eastern Canadian coast (Scarratt 1964, 1968, 1973). We noted an average density of 0.30 larvae/1,000 m^3 of water for the observed hatching and development period (16 June-31 July) and 0.19 larvae/1,000 m^3 for the entire period of larval occurrence at stations 2 and 3. Based on the temporal distribution of larvae, it appears that the majority of lobsters in Penobscot Bay spawned from early to mid-June through July in 1976.

Stage I larvae from the lower bay (station 3) showed the earliest evidence of hatching (16 June) and the longest period during which larvae were found (16 June through 31 August). Scarratt (1964) suggested that stage I abundance is indicative of underlying parent stock size. Thus, the higher stage I larval abundance observed at station 3 possibly reflects a larger parent stock at this location.

An early warming of the Maine coastal waters in 1976 (Welch[2]) stimulated hatching in mid-June. During the previous year lobster larvae were first observed in Penobscot Bay during early July (Central Maine Power Company[3]). Hatching at station 3 apparently began within 6 d after bottom temperatures rose to 12.5 °C. Not until 21 June did the bottom temperature at station 2 exceed 10°C and become warm enough to stimulate hatching at this site. At station 2, stage IV larvae

[2]W. R. Welch, Maine Department of Marine Resources, Fisheries Research Station, W. Boothbay Harbor, ME 04575, pers. commun. October 1976.

[3]Central Maine Power Company, Environmental Studies Department. 1976. Lobster larval distribution in Upper Penobscot Bay, Maine. Unpubl. rep., 4 p. Central Maine Power Company, Augusta, ME 04336.

appeared approximately 4 wk after the first stage I larvae was found, while at station 3 the corresponding development period lasted more than 5 wk possibly due to lower mean surface water temperature at this site. Average surface temperatures were 15.0°C and 16.2°C at stations 3 and 2, respectively, during the period of larval occurrence. At both stations the appearance of stage IV larvae accompanied by the absence of stage I larvae in late July, signaled the end of the spawning period. The single stage IV larva collected on 31 August was attributed to a random late hatch.

Salinities of 19.4‰ or less are unfavorable to larval growth (Templeman 1936). Scarratt and Raine (1967) have shown larval avoidance of salinities as low as 21.4‰. Station 1 was subjected to frequent periods of low salinity caused by freshwater runoff from the Penobscot River, possibly explaining the absence of larvae at this site. Larvae may have avoided lower salinity surface water at station 1 and were therefore not vulnerable to neuston gear.

It is well documented that early stage I lobster larvae exhibit positive phototaxis (Hadley 1908; Herrick 1911; Ennis 1973), concentrating in the near-surface waters during daylight. However, young larvae are subject to mortality from ultraviolet radiation (Huntsman 1924; Templeman 1936) and tend to move from surface waters during periods of bright sunlight (Templeman and Tibbo 1945). Based on cloud cover observation recorded during the present study it appeared that the larvae adjusted their depth in response to ambient light intensity. Larvae apparently moved to surface waters during partially to totally overcast days when sunlight intensity was reduced. During periods of high light intensity, lobster larvae may have descended to avoid possible harmful levels of ultraviolet radiation. During periods of intense sunlight, the larvae may have been below the net sampling depth, accounting for the capture of 92% of stage I larvae when cloud cover equaled or exceeded 50%. Stage IV larvae, which are not as susceptible to ultraviolet radiation, were found at the surface on days of <50% cloud cover although the number of stage IV larvae collected was low.

SUMMARY AND CONCLUSIONS

Data analysis from this program, designed to study American lobster larvae abundance and distribution at three locations in Penobscot Bay, Maine, from May through September 1976, revealed the following:

1) Abundance of American lobster larvae for the three areas of Penobscot Bay studied appeared to be relatively low compared with Canadian waters such as the Northumberland Strait and various New England areas.

2) The hatching period for the American lobster in Penobscot Bay extended over a 6-wk period from mid-June through late July in 1976 when coastal water temperatures rose more rapidly than in previous years, resulting in a correspondingly early hatching period.

3) Low average salinities as found in surface waters near station 1 in early summer may have been detrimental to larval development resulting in either the avoidance of the area by larvae or mortality of larvae.

4) Early planktonic stages which are more vulnerable to ultraviolet radiation than stage IV larvae were most abundant in the near-surface waters on cloudy days.

ACKNOWLEDGMENTS

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A Comparison of Lobster Larvae Sampling Using Neuston and Tucker Nets

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ABSTRACT

A series of paired surface tows with a 1 m × 2 m neuston net and a 2 m × 2 m Tucker net were made to compare sampling efficiency for lobster larvae. The neuston net collected two to four times more larvae per unit volume than the corresponding Tucker net. Both nets collected similar numbers of larvae if numbers are expressed per unit area. This indicates that larvae were concentrated in the upper 0.75 m of the water column.

INTRODUCTION

Both neuston and Tucker nets have been used to collect lobster larvae along the New England coast. Neuston nets were used in a study of geographic distribution of lobster larvae in Block Island Sound (Fogarty et al. 1983) and Tucker nets in a study of distribution and abundance off East Beach, R.I. (Bibb et al. 1983). Because of the different nets used, the results of these surveys are not directly comparable. This study was conducted to compare the sampling efficiency of the neuston net with that of the Tucker net to determine whether lobster larvae data collected using these two techniques are comparable.

METHODS

Paired tows were made with a neuston net off the port side and a Tucker net off the starboard side of the survey vessei. About 25 cm of the neuston net and 10 cm of the Tucker net were kept above the water's surface while towing. All tows were made into the current at 1 m/s for 15 min. Sample volume and boat speed were estimated with a calibrated General Oceanics Model 2030 flowmeter.[4] Volumes for each tow ranged from approximately 2,000 to 4,000 m^3 (Tucker) and 1,500 to 2,000 m^3 (neuston).

The neuston net had 1 m × 2 m opening and 4 m length with a 1 mm mesh (Fig. 1). The opening and closing Tucker net was 8 m long with a 0.950 mm mesh (Fig. 1). The mouth of the Tucker net was designed to sample at a 45° angle with a resultant 2 m × 2 m sampling area.

Samples were collected 14, 18, and 21 June 1979 at two stations in Block Island Sound, NS-B and PJ-C (Fig. 2). Triplicate paired tows were made at each station. Mean surface temperatures for each sampling date were 15.4°, 16.7°, and 16.1 °C, respectively. During sampling, the sky was clear and seas were calm.

Data comparisons were made in two ways: Per unit volume (1,000 m^3) and per unit area (1,000 m^2). Abundance per unit volume was calculated using the volume filtered as indicated by the flowmeter. Abundance per unit area was calculated by dividing the flowmeter volume by the depth sampled by each net. These depths were 0.75 m for the neuston net and 1.9 m for the Tucker net.

RESULTS AND DISCUSSION

A comparison of the total number of lobster larvae collected in paired triplicate surface tows using neuston and Tucker nets is shown in Table 1. These results indicate that

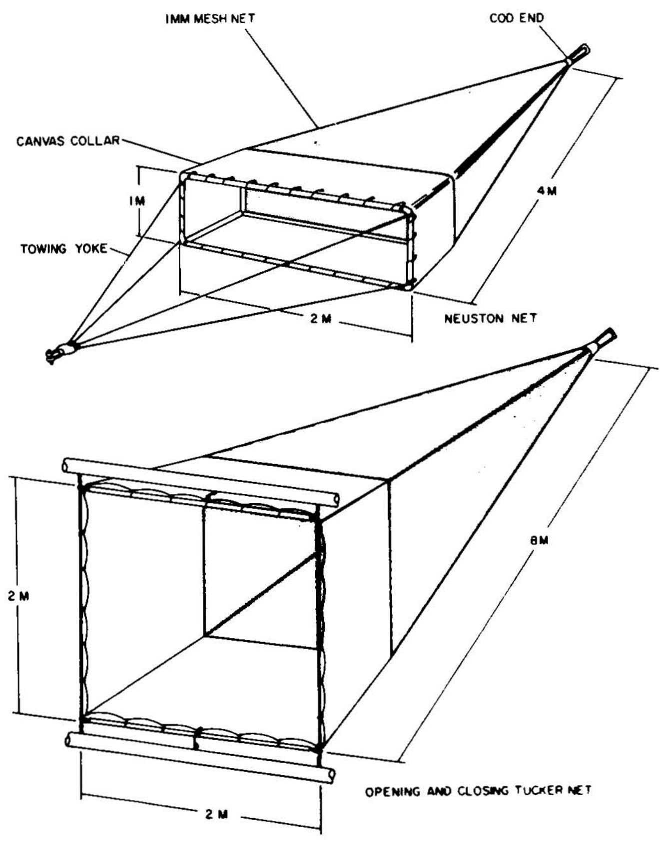

Figure 1.—Diagrammtic representation of neuston and Tucker nets.

[1]Raytheon Company, P.O. Box 360, Portsmouth, RI 02871.

[2]Raytheon Company, P.O. Box 360, Portsmouth, R.I.; present address: 124 North Road, Kingston, RI 02881.

[3]Yankee Atomic Electric Company, 1671 Worcester Road, Framingham, MA 07101.

[4]Reference to trade names does not imply endorsement by Raytheon Company or by the National Marine Fisheries Service, NOAA.

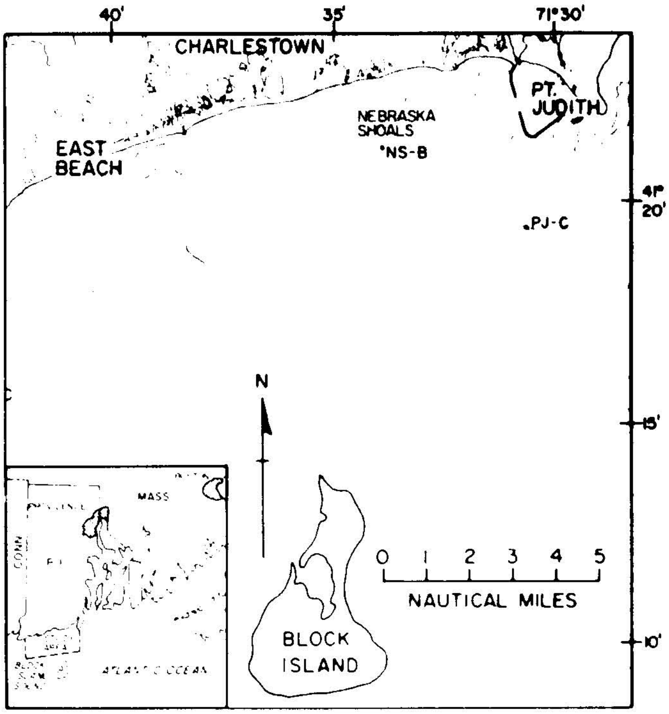

Figure 2.—Sampling locations for net comparison study.

Table 1.—Mean abundance ± standard deviation of lobster larvae (all stages) in paired triplicate surface tows using a 1 m × 2 m neuston net and 2 m × 2 m Tucker net.

		Abundance per 1,000 m^3		Abundance per 1,000 m^2	
Date	Station	Neuston net	Tucker net	Neuston net	Tucker net
6/14/79	NS-B	37.1 ± 44.1	14.4 ± 14.2	27.9 ± 33.0	28.8 ± 28.4
	PJ-C	34.6 ± 18.6	14.3 ± 15.7	25.9 ± 36.5	28.7 ± 26.8
6/18/79	NS-B	6.4 ± 4.1	1.4 ± 0.8	4.6 ± 3.0	2.9 ± 1.7
	PJ-C	177.3 ± 181.3	47.3 ± 33.7	133.0 ± 135.9	94.5 ± 67.3
6/21/79	NS-B	6.1 ± 5.2	3.2 ± 2.6	4.5 ± 3.8	6.5 ± 5.3
	PJ-C	6.2 ± 4.2	3.1 ± 0.8	4.7 ± 3.2	6.3 ± 1.5
Grand mean and standard deviation		44.6 ± 91.1	14.0 ± 21.3	33.4 ± 68.3	27.9 ± 42.5

when expressed on a volume basis (number per 1,000 m^3) the neuston net collected two to four times as many larvae as the Tucker net.

The sampling variance was high and proportional to the mean as is characteristic of lobster larvae data and most plankton data (Cassie 1968). Consequently, the data were normalized with a log (n + 1) transformation and a paired t-test was performed on the complete data set. The mean difference of total larval abundance from neuston net samples versus Tucker net samples was significantly different ($t_S = 6.42$, $t_{.01(17)} = 2.90$).

When abundance is calculated over the area sampled (number per 1,000 m^2), the neuston and Tucker nets collected approximately equal numbers of larvae (Table 1). The mean difference in total abundance was not significantly different ($t_S = 0.93$; $t_{.05(17)} = 2.11$).

The Tucker net used in this study has a sampling volume approximately 2.7 times that of the neuston net. The observed ratio of abundance in Table 1 is approximately 2.9, indicating that larvae may be concentrated in the uppermost 0.75 m.

These observations indicate that densities of lobster larvae (per 1,000 m^3) estimated from Tucker net samples can be compared with neuston densities by considering ratios of volumes filtered. However, such a factor would be applicable only to samples collected under similar conditions. All samples in this study were taken on sunny days when seas were relatively calm (< 1 m). Larval distribution in rough seas and on cloudy days may be more dispersed and differences observed would be smaller.

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