LABORATORY REFERENCE DOCUMENT NUMBER 81-19

Larval Fish Trophodynamic Studies on Georges Bank

R. Gregory Lough

☐ Approved for Distribution

☑ Distribution to F/NW/C, F/SWC, F/SEC, F/NWR1, [illegible] (Technical Writer-Editor)

Signature M. D. Grosslein

Date 22 June '81

National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, MA. 02543

June 1981

Larval Fish Trophodynamic Studies on Georges Bank

by

R. Gregory Lough

ABSTRACT

In the proposed study, we will determine the biological and physical mechanisms controlling recruitment processes of major spring-spawning fish species on Georges Bank, focusing on the survival of haddock larvae during its first three months of life. Strong evidence indicates that survival of larvae, and eventual size of the recruited year class, is the result of the temporal and spatial relationship between the larvae, their prey and predators during their early life. This match/mismatch ultimately is determined by climatological advective and turbulent processes of the waters in which they reside.

Our research will describe the fine-scale spatial and temporal distribution (patchiness) of larval haddock, their copepod food prey, and major potential predators in the Georges Bank area. From these field studies and previous laboratory studies with larval haddock, their survival probabilities will be estimated by model simulation. In addition, we will investigate and quantify the linkages between primary and secondary production, and larval fish survival. Our ultimate goal is to relate oceanographic conditions with larval survival as a predictive index of recruitment success or failure. These studies are to be conducted by a multidisciplinary team of biologists and oceanographers at the Northeast Fisheries Center (NMFS), as well as investigators from other institutions, in a series of spring, process-oriented cruises over the next three years. During the first year, the proposed studies will focus on fine-scale spatial and temporal distributions; the second year, advective processes-shelf/slope water interactions in coordination with the NSF funded Warm Core Ring Study; and the third year, primary-secondary productivity studies linked with remote sensing coverage.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
BACKGROUND AND SCIENTIFIC RATIONALE	3
Physical Oceanography of Georges Bank	3
Biology of Haddock	4
Feeding, Growth, and Food Requirements of Larval Haddock	6
Growth and Survival of Haddock Larvae on Georges Bank	8
EXPERIMENTAL PROGRAM	11
General Strategy	11
Operational Plan for 1981	11
Sampling Strategy	13
Processing and Analysis of Data	16
Proposed 1982 and 1983 Activities	16
ANTICIPATED RESULTS	17
ANTICIPATED PROBLEMS	18
MANAGEMENT PLAN	19
Personnel	19
Schedule	22
REFERENCES	23
TABLES 1-2	30-31
FIGURES 1-8	32-39
COSTS	40-41
QUALIFICATIONS OF KEY PERSONNEL	42

INTRODUCTION

The understanding of recruitment processes in marine fishes is critical to the development of long-term predictive management capability of fish stocks. This is because harvestable surpluses of most exploited stocks depend heavily on the strength of recruited year classes. Also the appropriate level of spawning stock needed to maintain high levels of recruitment must be inferred from a knowledge of the mechanisms affecting recruitment. Such an understanding of natural factors which control recruitment are essential in order to distinguish between natural factors and effects of pollution on recruitment.

At present there are a large number of studies which indicate that recruitment fluctuations in fish stocks are caused chiefly by differential mortality during the larval period. Cushing (1972, 1978) proposed three mechanisms governing recruitment in marine fishes: (1) density-independent or physical environmental factors, (2) density-dependent factors, and (3) competition; all are linked to a single process involving the match or mismatch of larvae and their food organisms. Recent theoretical models by Jones (1973), Jones and Hall (1972), Cushing (1973, 1974, 1975), Cushing and Harris (1973), Ware (1975), and Beyer and Laurence (1980) emphasize the link between larval growth and mortality regulated by the availability of food. The major causes of larval mortality are believed to be starvation and predation, which may interact, and the various mechanisms of density-dependent mortality relating to starvation and predation of fish larvae have been set forth in a recent colloquim by Hunter (1976). Trophic (feeding) interrelationships involving both growth and predation are considered to be the basic factors controlling larval mortality. Mortality is thought to be a function of chance encounters by larvae with their predators and zooplankton prey which (like the larvae themselves) are distributed contagiously, or in patches (Lasker 1975, Vlymen 1977). It follows that the degree to which larvae are able to grow rapidly through a succession of decreasing predatory fields, thereby reducing mortality, determines their potential population size. However, this process is a complex function of the density distribution (patchiness) of the larvae, their prey and predators, and possible competitors or other forms (including other larvae) which may be alternative prey for larval predators. Shepherd and Cushing (1980) propose a model involving the intimate interaction of three trophic levels simultaneously (larvae, their food prey, and predators) that produces both a strong density-dependent control of recruitment and a high stochastic variability about average levels of survival caused by external factors. This mechanism leads to the number of survivors depending on the initial numbers with the functional form of a Beverton-Holt asymptotic stock-recruitment curve, given a plausible assumption concerning the density dependence of growth rates.

Since prey abundance will be a critical factor influencing larval survival, it is necessary to know how feeding of larvae in the field is affected by the fine-scale (patchy) distributional structuring of zooplankton communities to understand the biological and physical oceanographic processes which lead to the formation and dissipation of such patches. In this proposal, we will determine the biological and physical mechanisms controlling recruitment processes of major spring-spawning fish species on Georges Bank by focusing on the survival of haddock larvae during its first three months of life. The central goal is to determine whether the survival and growth of larval haddock on Georges Bank is affected by temporal or spatial

variability in the availability of their copepod food prey. The role of predation on the larvae themselves will not be fully addressed in this proposal, but observations will be made to describe the distribution and co-occurrence of the major potential predators of larval haddock.

To achieve the main goal, it will be necessary to determine the critical time and space scales of food availability which are necessary to ensure survival of the larval haddock on Georges Bank. This will require a knowledge of the functional relationships between food concentration and the growth and survival of larval haddock, and of the fine-scale temporal and spatial distribution of the larval fish and their prey on Georges Bank.

Specific objectives of the proposed research program include the following:

1. Conduct intensive field studies to describe the fine-scale spatial and temporal distribution and abundance of larval haddock and their copepod food prey.

2. Investigate the important linkages between primary production, secondary production, and larval fish survival, and quantify the physical and biological processes controlling the spatial and temporal changes in the abundance of these components of the food chain.

3. Identify possible relations between large-scale oceanographic events, such as advective processes and thermocline formation, and larval survival.

4. Determine the survival probabilities of larval haddock populations based on the fine-scale spatial and temporal description of their prey using existing laboratory feeding and growth information and models incorporating encounter rate functions.

In this study, we will be focusing on the haddock, Melanogrammus aeglefinus, because of the commercial and ecological importance of this species, and because we have the best overall base of life history data, including; good laboratory experimental data base, measures of year-class strength at the "0-group" stage, and fecundity and spawning population biomass data. In addition, there is a considerable amount of background field data as to the location of the spawning grounds on Georges Bank and the general movements of the eggs, larvae and post-larval stages (to "0-group" age) on Georges Bank.

Georges Bank, the area of the study, is one of the most productive fishery areas in the world (Grosslein et al., 1980 ; Cohen et al. 1980) and is a principal historic spawning ground for many commercially valuable fish species, notably haddock, cod, herring, hakes, yellowtail, pollock and mackerel (Colton et al. 1979). It has recently been selected as a site for offshore oil and gas exploration. Unlike the petroleum resources, the fisheries on Georges Bank can last independently, so long as man does not alter the environment beyond the point where fish cannot survive or fishermen cannot catch them. At present, information available to evaluate potential resource problems is not adequate. In this regard, we know very little about the causes of fluctuations in the abundance of fish populations and therefore, can do little more than speculate about why some year classes are more successful than others.

At the Northeast Fisheries Center (NEFC), the Marine Ecosystems Division is conducting a broad-based research program on the Continental Shelf, involving both monitoring and process-oriented studies, directed towards a better understanding of the recruitment process (see Fig. 1, Sherman 1980, Grosslein et al. 1979).

BACKGROUND AND SCIENTIFIC RATIONALE

Physical Oceanography of Georges Bank

Georges Bank is a shallow submarine bank along the seaward edge of the Gulf of Maine (Fig. 2). The bank is approximately 300 km long and 150 km wide and is separated from Nantucket Shoals by a shallow (approximately 70 m deep) Great South Channel. Seaward of the 60-m isobath, the Georges Bank shelf is continuous with the New England shelf to the west. To the northeast, Georges Bank is separated from the Scotian Shelf by the deep (220 m) Northeast Channel which cuts across the outer shelf to the shelf bank. The crest of the bank (shallower than 60 m) is shaped into a series of northwest-trending ridges; the tops of some of these ridges are less than 5 m deep.

Surface and bottom drifter studies (Bigelow 1927, Bumpus and Lauzier 1965, Bumpus 1973, Bumpus 1976) of the currents on Georges Bank and in the Gulf of Maine have shown a residual counterclockwise circulation in the Gulf of Maine and a clockwise circulation around Georges Bank at speeds of approximately 10 cm/sec (5 km/day). Westward and northward flow into the Gulf of Maine south of Nova Scotia and southwestward across Nantucket Shoals south of Cape Cod was observed. Bumpus and Lauzier (1965) inferred that the Gulf of Maine and Georges Bank gyres were strongest in summer and that in winter, the near surface flow was primarily offshore, driven by offshore northwesterly winds. More recent studies (Beardsley et al. 1976, Mayer et al. 1979, Beardsley and Boicourt 1980) conducted on the shelf to the west of Nantucket Shoals in the Middle Atlantic Bight have shown a consistent westward subsurface residual drift of shelf water at speeds of 5-10 cm/sec along the middle and outer shelf.

The water on the crest of Georges Bank (depths shallower than 60 m) is vertically well-mixed throughout the year by strong local tidal currents (Bumpus 1976, Colton et al. 1968). In winter, two fronts separate the well-mixed water from adjacent water masses (Figs. 3 & 4). On the southern flank of the bank, the shelf-water/slope-water front intersects the bottom at approximately 80 m and separates cooler, fresher shelf water from warmer, more saline water. The shelf-water/slope-water front is similar in structure and continuous with the front at the shelf break in the Middle Atlantic Bight (Beardsley and Flagg 1976, Wright 1976, Mooers et al. 1979). On the northern flank, a second weaker and deeper front separates Georges Bank water from Gulf of Maine water. In summer, a seasonal thermocline develops over the Gulf of Maine, the slope water, and the water deeper than 60 m in the southern flank. A tidally-mixed front forms at approximately the 60 m isobath. A subsurface band of cool water occurs along the southern flank between the 60-m and 100-m isobaths, bounded by the warmer slope water to the south, the well-mixed Georges Bank water to the north and the seasonal thermocline above.

Butman et al. (1981) have summarized current measurements obtained on Georges Bank and adjacent shelf waters in several field studies conducted from 1978 to 1979 and concluded that the observed mean flow at 10 m has a permanent clockwise circulation around Georges Bank with a mean residence time of approximately 2 months for a particle moving along the 60-m isobath. However, the observations indicated that the circulation is not completely closed and that considerable variability occurs in the trajectory of an individual water particle. They inferred that the clockwise circulation around the crest of the bank may provide a mechanism for partial retention of the pelagic eggs and larvae of the important fish and shellfish, especially within the 60-m isobath. The loss of eggs and larvae south across the shelf/slope front has not been observed to any degree over the extensive time series of plankton surveys conducted by NEFC, but it can be assumed that any eggs or larvae transported off the bank do not survive in the warmer slope water and are lost to the recruited populations. Nevertheless, the development of warm-water eddies north of the Gulf Stream moving near the southern edge of Georges are believed to play an important role in the movement of shelf/slope water both on and off the bank (Mizenko and Chamberlin 1979, Celone and Chamberlin 1980) and the entrainment of organisms residing there.

Biology of Haddock

In the southern part of the Northwest Atlantic, the principal spawning concentrations of haddock occur on northeastern Georges Bank and Browns Bank (Grosslein and Hennemuth 1973). The peak spawning on Georges Bank usually occurs during March or April and it is associated with increasing water temperatures in the spring. Spawning peaks occur in March when temperatures are about 4-5°C, and the peak is delayed until April when March temperatures are below 3°C (Marak and Livingstone 1969). Spawning appears to be more prolonged when the peak occurs in March.

Fertilized haddock eggs rise to the surface and hatch in about 2-3 weeks at average spring temperatures (Marak and Colton 1961, Laurence and Rogers 1976) and the larvae are planktonic at least for several months thereafter. The larvae hatch at about 4 mm (Colton and Marak 1969) and yolksac resorption is completed 6-7 days post-hatch at 7°C (Laurence 1974). Dorsal and anal fins are fully formed at 16-20 mm, and they have a general adult appearance at 30-40 mm. The small larvae initially feed upon copepod nauplii, switching to larger copepodites and smaller adult copepods as they grow larger (Marak 1960, Green, pers. comm.). The size of the prey eaten was the most important factor in their utilization as food. These studies indicate that larvae were feeding on the most abundant copepod species present at the time within the selective size range. During this time in their early life history, the dominant species of copepods on Georges Bank are Pseudocalanus, Oithona, Centropages, and Calanus (Sherman et al. 1977, Sherman and Jones 1980, Davis, pers. comm.). Growth of larvae based on Walford's (1938) field data was 0.4 mm/day, or about 97 days to grow from hatch size to 43 mm. Laurence's (1974, 1978) lab-reared larvae metamorphosed[1] in 30 days at 9°C and 40-50 days at 7°C. Figure 5 depicts the principal haddock spawning time and area on Georges Bank (indicated where early egg stages are most abundant) and generalized egg and larval drift and areas where demersal 0-group haddock are most abundant 6-8 months later. Dense concentrations of egg (>10/m^3) have been observed in "patches" on the order of 10-20 miles that retain their integrity over a number of weeks (Colton 1965, Colton and Marak 1962, Walford 1938). Although eggs and larvae

[1]Metamorphosis occurs at approximately 1,000 μg dry weight and 10 mm SL with the development of anatomical and morphological characteristics similar to adults.

can be found throughout the water column, the eggs are concentrated in the upper 10 m and larvae are found principally 10-40 m, and therefore, dispersion depends upon the surface circulation (Colton 1965). The distribution of late stage eggs and larvae indicates that dispersion from the spawning center on northeast Georges follows the general pattern of drift, predominately to the southwest at 3-4 miles/day (Marak and Colton 1961, 1962a, b; Smith et al. 1979). Early larvae are most abundant in areas where concentration centers for late stage eggs occur; generally to the southwest of the spawning grounds. During April-May, high concentrations of larvae (>1/m^3) can usually be found as mesoscale entities along the southern edge of the bank between the well-mixed waters defined by the 60-m isobth and the shelf/slope front. In this area, in May 1958, Miller et al. (1958) found that 80% of the haddock larvae in the 8-21 mm size was concentrated within the depth of the thermocline (20-30 m) which occupied about 25% of the water column. Some portion of these larvae are transported north on the eastern side of the Great South Channel and wind-up back on Georges Shoals, particularly so as the clockwise gyre on Georges Bank intensifies in late spring, and some larvae evidently are transported across the channel into the Nantucket Shoals and Southern New England waters, but we do not have sufficient information yet to determine the relative percentages or the year to year variability. There has been much speculation about the possible loss of spawning products to slope waters south of Georges, particularly in early spring months when the prevailing winds generate an offshore drift on Georges (Colton and Temple 1961). Walford (1938) shows larvae concentrated along the southern edge of the bank in April 1931 with apparently some portion of the larvae caught in the clockwise circulation and moved onto Georges Shoals by May, while in 1932, most of the eggs were believed to have been carried off the northern and southern edges of Georges Bank to the east. However, haddock eggs and larvae have not been found out over slope waters so that further clarification of this problem requires extensive direct measures of surface circulation and egg and larval distributions over a period of years.

Little is known about the distribution of larvae of 2-6 months of age except that substantial numbers were found in mid-water within the thermocline (20 m) about 6 months after normal peak spawning (Colton 1965). 0-group haddock tend to be concentrated on northern Georges Bank (Grosslein and Hennemuth 1973), suggesting that only those larvae transported back to northern Georges, or retained within the well-mixed clockwise gyre on the crest of the bank, reach a favorable environment for optimum survival. The relative abundance of 0-group haddock correlated with abundance of the same year class at later ages strongly suggest that brood strength is determined within the first 6 months of life (Grosslein and Hennemuth 1973). Another interesting feature is the generally good correlation of autumn catches of 0-group haddock between areas (Georges Bank, western Nova Scotia, Gulf of Maine) and years, as well as relative year-class strength, implying a common set of factors controlling survival over a broad area. However, to date, there has been no good predictive index between larval haddock abundance or environmental factors and recruitment success and no firm conclusions have been reached on even a generalized stock-recruitment relation.

Feeding, Growth, and Food Requirements of Larval Haddock

Larval haddock begin feeding about 2 days after hatching, but will survive and grow if first feeding is delayed for 4-7 days at 7°C (Laurence 1974, 1978). A longer period without food will result in high mortality.

When newly hatched larval haddock were fed copepod nauplii at nominal concentrations of 0.1 and 0.01/ml, all of the larvae died within 2 to 3 weeks (Laurence 1974). At concentrations of 0.5, 1, and 3 nauplii/ml there were consistent trends of increasing growth rate and condition factor, and decreasing mortality rate, with increasing food concentration. It should be noted that the two highest food concentrations, 1 and 3 nauplii/ml, are considerably higher than the average densities of nauplii which have been reported in most field studies of zooplankton abundance. The fact that growth and survival of haddock larvae is food concentration-dependent, even at extremely high prey densities, implies that the survival probabilities of haddock in the field will be food-concentration dependent for much (if not most) of the time. This is why it is necessary to determine the factors controlling the distribution, abundance, and production rates of zooplankton on spatial and temporal scales which are relevant to the life history of the haddock larvae. Existing, routine survey data focusing on the broad distributional patterns of the larger zooplankters are insufficient to resolve these problems.

From our laboratory bioenergetic studies the food requirements of larval haddock (R, organisms/day) have been estimated (Laurence 1981), where:

$$R = \frac{\Delta G + kW^n}{(1-\alpha)\beta W}$$

where:

ΔG = change in growth per day (2-6%/day, Laurence 1974, 1978);

W = prey weight and is a variable function of larval size (Beyer 1980; Beyer and Laurence 1981);

β = the coefficient of digestion, a variable changing with larval size based on nitrogen budget data (Buckley and Dillman 1981) and from Beyer and Laurence (1981);

kW^n = the metabolism per day with: k = coefficient of metabolism (Beyer and Laurence 1980, 1981); n = 0.671, a constant exponent (Laurence 1978); and W = larval weight.

Table 1 presents the upper and lower limit values of feeding related parameters for haddock larvae of three different sizes. The 5-mm larvae are first feeding, the 10-mm larvae approximately 8-9 weeks old (7°C), and the 15-mm larvae 11-12 weeks old. The absolute values and ranges of R decrease with increasing larval size because of the increase in preferred prey size, and the fact that as they grow larger, the larvae become more effective predators.

From these estimates of the food requirements of the larvae and an estimate of the volume of water searched per day, we can calculate the concentrations of food required. The total volume (V) of water searched per day is the product of the visual field, the swimming speed (v), and the time spent feeding (t) (i.e., the linear distance swum):

$$V = 2/3\,\pi\,\sigma^2\,v\,t$$

where:

σ = the perception distance and is approximately 0.5 - 1.0 times the body length of the larvae (Beyer and Laurence 1981);

v = the larval linear sustained swimming speed - 1.0 - 2.0 BL/sec (Laurence 1972 and others);

t = the time spent feeding (12 hours since the larvae are visual feeders).

The results of the food encounter and searching capabilities are shown in Table 2. This shows that the number of prey per liter required for larval feeding decreases with increasing size of the larvae. The ranges required for each sized larvae represent maximum and minimum concentrations for growth. Between the concentration ranges there will be different growth rates and probably different mortality rates.

Important results of both the feeding study and the model calculations are the very high food concentrations required for feeding and growth of the first feeding larvae (between 100 and 1000/liter from the experiments and > 73/liter from the model). Food concentrations above the minimum which enhance growth rates of the larvae will not only reduce mortality directly, but will also reduce the time they spend in the stage where they need these very high concentrations. This reduction in time will enhance the probability of survival because they are more susceptible to starvation and predation during this young stage.

The food concentration ranges calculated from the model for the 10- and 15-mm larvae are within the ranges observed on Georges Bank (Sherman et al. 1977, Sherman and Jones 1980) (see Fig. 6 for distribution-abundance data of Pseudocalanus minutus based on 61-cm bongo, 0.333-mm mesh samples). However, the concentrations required for the first-feeding larvae are much greater than reported in these studies. It should be noted that these studies were part of a longer term monitoring program (MARMAP) and did not use mesh sizes sufficiently small to capture the smaller copepodites and nauplii which are the food for the young larvae. Also, the samples were collected with oblique hauls, integrating the zooplankton over space scales greater than those which the larvae see. Present data, therefore, are insufficient to indicate either the abundance or the fine-scale distributional patterns of the small zooplankters which are the food of young haddock larvae. Clearly, there is a need for this information on the fine-scale structure of the zooplankton, and the spatial scales over which variations in food occur which are important to the larvae.

Growth and Survival of Haddock Larvae on Georges Bank

As suggested by Cushing's (1978) match-mismatch hypothesis, timing or the coincidence of larval fish hatching with the availability of the appropriate size and density of prey may be the single most critical influence on the recruitment of fish stocks to the fisheries. This consideration of the coincidence of the prey and predators is affected by factors such as meteorological events and resultant physical oceanographic processes which influence events in the plankton. These events can occur at several different levels of scale. Broad-scale events can affect larval mortality at the population level on a large or perhaps catastrophic scale (advection off Georges Bank, for example). Events controlling fine-scale structure in the plankton will determine larval survival on an individual level. Finally, we need to know rates of processes affecting primary and secondary production in the plankton. The linkages between the different trophic levels, and factors controlling plankton patch formation, structure, composition and duration.

In understanding survival of the early life stages in the field, then, we need answers to the following questions:

(1) Is maximal survival of larvae critically dependent upon successful feeding and growth during the first few weeks after hatching, or at other periods in larval life? Or is it a continual process?

(2) Does successful feeding of larvae depend upon a patchy food environment and the coincidence of larvae within these high concentration food patches?

(3) Since 80% of the larval population (as well as the juveniles) has been observed to reside within the thermocline depth of 20-30 m, does this narrow region also contain a high concentration of suitable food organisms?

(4) Is survival of larvae dependent upon the initial timing and formation of a thermocline over the edge of Georges Bank during the spring?

(5) Is thermocline formation on Georges Bank necessary for water colum stability for the initiation of primary production and does it serve as an optimal spawning region for copepods?

(6) Are there suitable kinds and densities of larval prey in the well-mixed shoal waters of Georges where no strong thermocline develops, and are larvae and their prey vertically stratified in this well-mixed region?

(7) Is there a critical relationship between the stratified water at the edge of the bank and the mixed shallow region which may provide the nutrients for high primary productivity?

(8) Are extensive variations in, or the destruction of the thermocline during the spring associated with the dispersal of larvae and their prey throughout the water column below required concentrations necessary for survival?

(9) If major factors controlling year-class success operate during the larval stage after initiation of feeding and are a result of the interactive process of growth and mortality generated by variation in prey and competitor-predator fields in relation to larval distribution, is the key criterion the number of individuals reaching a critical minimum size at various developmental stages?

The coincidence of match-mismatch of larval fish with their prey can occur spatially and temporally in both the horizontal dimension as they drift around Georges Bank in the clockwise gyre, and in the vertical dimension, particularly in the stratified area where the copepod population may be less abundant.

During spring, most of the copepod population tends to develop along the northern crest of Georges Bank, where they are introduced as overwintering stages from the Gulf of Maine water, or reside in the well-mixed waters (Cohen 1976, Sherman and Jones 1980) where phytoplankton concentrations are about an order of magnitude higher than around the perimeter of the bank (O'Reilly and Evans 1981, O'Reilly et al. 1980, Cura and Magnell 1981). This high primary productivity appears to be maintained by mixing on top of the bank and by the continuous upward transport of deeper nutrient-rich oceanic water along the northern edge by a number of physical processes both continuous and episodic (Cohen and Wright 1979).

Copepod population dynamics appeared to be closely tied to the mean circulation around Georges Bank. Support for this comes from a combined physical-biological computer model developed by Davis (1981) which simulates copepod population dynamics at each of a series of fixed spatial points around a hypothetical clockwise gyre, incorporating both advection and diffusion of copepods. The rates of advection and diffusion were taken from Butman et al. (1981) and life history parameters (developmental rate, fecundity, mortality rates) for Pseudocalanus were estimated from laboratory experiments or taken from the literature. The resulting spatial patterns generated by the model for the December-February period were very similar to the population structure observed on Georges Bank in February 1975 analyzed from fine-mesh (0.165 mm) samples collected on the standard ICNAF station grid (Fig. 7). The generation time of the dominant copepods and the period of time required for the larvae to reach metamorphosis and return to the crest of the bank both match the mean residence time of approximately 2 months (range 1-3 months) for a particle of water moving clockwise along the 60 m isobath. Thus, there will be increasingly larger sized food available to the larvae as both they and their food circulate in the gyre. Coincidence of the development of the spring cohort of zooplankton and the hatching of the larvae may be critical to larval haddock survival.

The possible relation between the formation of a thermocline in the stratified waters around the perimeter of Georges Bank and the survival of haddock larvae and subsequent year-class strength is a second potentially important consideration. The thermocline is a concrete physical entity that can be located (perhaps even by remote sensing) and measured. Its formation is seasonally dependent and its approximate location is known from year to year. Thermocline formation, structure and duration can be interrupted by broad-scale physical events (storms, warm core rings, etc.) whose influence on the hypothesis could be measured. The thermocline is potentially important because biological productivity appears concentrated in this layer and the larval and juvenile haddock appear to be uniquely associated with it.

The dependence of phytoplankton blooms on the vertical stability of the water column and changes in the degree of seasonal stratification and destratification is a well known phenomenon (Riley 1946, Cohen and Wright 1979), as well as the observation of increased phytoplankton concentrations in or near the thermocline. Derenbach et al. (1979) employed an in situ fluorometer and measured distinct, thin layer (ca. 1-m thickness) chlorophyll maxima within and below a seasonal thermocline (30-35 m depth) in the Baltic Sea, with horizontal extensions some 10 meters and having a life time ranging from 2 hours to 2.5 days. The chlorophyll layers were assumed to be a dynamic feature formed or maintained locally. Aggregations of zooplankton have been observed to congregate on density interfaces or thermoclines (Harder 1968, Boyd 1973, Sameoto and Paulowich 1977, Haury et al. 1978, p. 299). These physically stable layers caused by microdensity structure apparently offer colonization sites for formation of larval food patches. A diagrammatic representation of the structural relation between the thermocline and the vertical distribution of chlorophyll, carbon production, and herbivorous zooplankton in the stratified waters on southern Georges Bank is shown in Figure 8.

In the Georges Bank area, while the presence of the thermocline is well known, observations on the vertical structure of phytoplankton within the thermocline have been very limited. Colton (1972) observed a chlorophyll maximum within a well defined thermocline during June 1966 in the northern part of the Great South Channel whose variation was associated with vertical oscillation of the thermocline caused by internal waves. In recent years, O'Reilly (pers. comm.) reports indications of a similar chlorophyll maxima associated with the thermocline in the stratified waters along southern Georges Bank in late spring and summer from NEFC's MARMAP surveys. However, these observations in the Georges Bank area were made from discrete water bottle samples and would not resolve the existence of discrete chlorophyll maxima layers as observed by Derenbach et al. (1979).

In spring at the time when the larval haddock are present, the thermocline is just beginning to form. At this time, there will be a transition from a vertically homogeneous water column prior to thermocline formation to a more stratified water column as depicted in Fig. 8. The presence of the thermocline with the resulting greater degree of patchiness and structure of the plankton may be critical to the survival of the haddock larvae. There is a need to measure food availability for the haddock prior to, during and following thermocline formation in order to determine the importance of this phenomenon.

In order to predict larval haddock growth and survival, there is also a need to understand production processes within the plankton and the factors controlling them. For example, what are the factors controlling production rates, abundance and distribution of nauplius food for fish larvae? In the spring at the beginning of thermocline formation, there is little structure in the water column and the spring phytoplankton bloom is occurring, with high chlorophyll (4 to 6 mg Ch a/m^3) uniformly distributed. In this situation, reproductive rates of the copepods may be non-food limited and maximal for the observed field temperature. Thus, large numbers of nauplii could be produced continuously and be readily available for the fish larvae. With the development of the thermocline, the availability of food for the zooplankton will change, becoming more patchy and possibly decreasing overall. There is a need to know how this structure in the phytoplankton will affect reproduction by the copepods and the subsequent formation of patches of nauplii. Further, since the zooplankton can adjust their reproductive rates rapidly to changes in food availability, there is a need to know the extent to which there is vertical and horizontal variability in the reproductive rates of the copepods and how these change over time.

EXPERIMENTAL PROGRAM

General Strategy

Our ability to predict early life stage survival and relate to recruitment requires three main components: (1) seasonal population abundance estimates or indices of egg and larval stages, (2) quantitative estimates of larval growth and feeding parameters, and (3) predictive models. Two of these three requirements are currently available as well as portions of the third. Icthyoplankton surveys are conducted routinely by NEFC, at least bi-monthly in the MARMAP mode over a broad area of the northeast Atlantic continental shelf (Sherman 1980), and provide timely abundance estimates of all larval fish. A variety of larval fish growth and survival models exist (Laurence 1977, Beyer and Laurence 1980, 1981, Beyer 1980), some of which have population predictive capabilities. Larval trophodynamics, physiology and behavior have been studied extensively in the lab and field and many factors have been identified and quantified (Laurence 1981). An important missing component is a physical mathematical description of the spatial-temporal bounds of larval prey organisms. Once this is known, prey encounter rate functions in the existing models can be used to predict larval growth and survival on the individual and population level based on the abundance estimates of the eggs or early larvae from ichthoplankton surveys as an initial starting point. In the case of the target species, the haddock, predicted estimates of larval survival can then be correlated with data from subsequent autumn juvenile survey estimates as a validation test.

The general plan is to conduct a series of process-oriented cruises beginning in the spring of 1981 on Georges Bank, concentrating on the feeding dynamics of larval haddock. Special emphasis is being given to a three-dimensional description of the spatial-temporal variability of the distribution of larvae and their prey (copepods) food and factors affecting their production. A field program of this nature attempting to cover at least three trophic levels simultaneously requires sampling on spatial scales ranging from centimeters to kilometers and temporal scales from minutes to weeks.

Our basic field strategy is to compare and contrast their fine-scale distribution in the well-mixed waters on the crest of Georges Bank with the stratified waters on the southern flank using electronically-controlled opening/closing plankton nets, plankton pumps, electronic particle counter, CTD-continuous fluorometry, and a host of other conventional biological and hydrological sampling gear, instruments, and techniques in a multidisciplinary mode. Observations also will be made on the potential predator field of larval fish by sampling the macroplankton and micronekton components on the same cruises. Broad-scale MARMAP icthyo-zooplankton-primary productivity surveys of the Georges Bank area and contiguous waters will be monitored during the haddock season to provide us with the big picture to relate our more intensive fine-scale studies.

Operational Plan for 1981

During spring of 1981, two cruises are planned using ALBATROSS IV to determine the fine-scale vertical and horizontal distribution of larval haddock, their prey and predator organisms and investigate the physical and biological processes responsible for their distribution: Cruise 81-03, 14 April-1 May 1981; Cruise 81-05, 19 May-1 June 1981. ALBATROSS IV is a 187' fisheries research vessel (Class IV) able to stay at sea for two weeks or more, having a crew of 17 and a scientific complement of 13 scientists, and fully capable of handling all our planned and

anticipated scientific operations. A brief description of the key samplers, instruments, and special techniques are listed below.

(1) MOCNESS[1]

NEFC has recently acquired all three MOCNESS units (MOC-½m: 0.064-mm mesh nets; MOC-1m: 0.202-, 0.333-, or 1.000-mm mesh nets; MOC-10 m: 3.0-mm mesh nets) providing us with wide spectrum capabilities of sampling discrete vertical layers, encompassing three trophic levels from microplankton (copepod nauplii), fish larvae-zooplankton, to micro-nektonic predators of larval fish. MOCNESS is a fine-scale to meso-scale sampler which has 9 retangular nets (5 nets - MOC-10 m) which are opened and closed sequentially by commands through a conducting cable from the surface vessel, thus permitting samples of up to 9 discrete depth levels or horizontal series in a single haul. On deck, real-time monitoring includes pressure (depth), temperature, net angle, volume of water filtered, and the number of the net presently filtering water. Other sensors for light, chlorophyll and oxygen are planned to be integrated with MOCNESS.

(2) Plankton Pump

A 1-HP submersible 8-stage well pump (2,750 RPM, 230 V) is used to sample micro-zooplankton at depth. The pump is typically deployed attached to ¼" wire with a 45 kg lead ball. Delivery of water from depth to a deck manifold fitted with fine-mesh nets (0.053- and 0.020-mm mesh) is by a 7.5-cm diameter PVC discharge hose. Pump flow rate is between 24 and 28 gal/min. Water is typically pumped from 5 depth levels in the upper 50 m of water for 10 minutes each depth to filter approximately 1 m^3 water.

(3) CTD-fluorometry

A Neil Brown CTD micro-profiling system with a General Oceanics Niskin bottle rosette is used for rapid continuous profiles of temperature and salinity with depth. The water bottle collections also are used to make discrete observations of micro-plankton, nutrients, and primary production measures using conventional methods. An Aiken-type continuous chlorophyll sensor (Aiken 1981) is on order ultimately to be interfaced with the CTD and MOCNESS units. As a back-up for continuous in situ fluorometry, we have an ENDECO submersible fluorometer (Turner Designs Model) with on-deck read-out of depth, temperature, and fluorescence via conductor cable. All three parameters are recorded simultaneously on a chart recorder.

(4) HIAC Particle Analyzer

A HIAC Criterion PC320 12-channel particle counting and sizing system (Pugh 1978, Tungate and Reynolds 1980) has just been acquired to develop as a real-time tool for the quantification of marine plankton. We have three sensors (CMH-150, CHM-600, E-2500) to count particles in the range of 5-2500 µm. However, at present we can only process samples in the batch mode. We plan to use it in various modes of operations that include an on-line system for horizontal transect-grid studies, and in a remote in situ mode, possibly interfaced with the CTD-fluorometer

[1]Multiple Opening/Closing Net and Environmental Sensing System -after Wiebe et al. (1976).

system for continuous vertical profiles. We also need to acquire a pulse height analyzer and an HP-85 computer to make this system fully operational.

(5) Real-time Plankton Processing

In process-oriented cruise studies, there is a need for real-time results so that decisions can be made to optimize the experimental operations. In combination with the HIAC particle size analyzer, selected plankton samples are processed for real-time identification, enumeration, and measurement of fish eggs, larvae, and zooplankton employing special shipboard subsampling and silhouette photography techniques (Ortner et al. 1979) and a Zeiss MOP in-hand size digitizer. These techniques were used routinely in shipboard operations for the first time during the 1978 Georges Bank Larval Herring Patch Study (Lough 1979).

(6) Larval Otolith Aging and Condition Factor Indices

Special collections of larvae will be preserved throughout the cruise operations and analyzed back in the laboratory for otolith ring deposition (Methot and Kramer 1979, Lough et al. 1980) and biochemical analyses, RNA-DNA ratios (Buckley 1980), as well as the conventional morphometric studies of larval condition indices. These new techniques will allow us to accurately age larvae to the nearest day and assess subtle changes in the growth of individual larvae and nutritional state in relation to feeding conditions. Selected larvae also will be processed for gut content-prey selectivity studies (Cohen and Lough, 1979).

Sampling Strategy

The vessel will begin a station grid of approximately 25 miles square in the Georges Bank area, deploying a bongo-net array (Posgay and Marak 1980) on station every 5 miles to locate and characterize a concentration of haddock larvae. The specific sampling area selected will be based on historical data and the most recent information available from previous and on-going MARMAP I surveys. In the event the distribution of haddock larvae is not known on Georges Bank at the start of the cruise, then a much larger area will be surveyed to locate the center of the larval population. Once a grid has been surveyed, a decision will be made to locate a station within the grid to conduct fine-scale studies for 4-6 days. Once the fine-scale studies have been completed, the bongo grid survey may be repeated. The grid survey and the fine-scale station studies will be alternated in this fashion throughout the cruise period, and depending upon information processed in real-time, the location of the intensive grid study area will be shifted to encompass the drift of eggs and larvae in the gyre and to compare and contrast the well-mixed shoal waters on the northern part of Georges Bank with the more stable, thermally stratified southern part bordering the shelf/slope front. The fine-scale studies, which will sample fish larvae and their copepod prey in terms of meters vertically and 10's to 100's of meters horizontally, will be used to characterize their distributions in the physical environment on order of the scale of rotary tidal currents (8-16 km) observed on Georges Bank. The sequence of the sampling protocols, details, and operational objectives are given below:

I. Intensive grid survey. The objective of the intensive grid survey is to locate and characterize the larval fish, plankton, chlorophyll, temperature and salinity field in an area sufficiently large to encompass the anticipated dispersal of plankton having an estimated residual drift of 5-10 kilometers/day in which fine-scale station studies will be carried out over 4-6 days.

A. A 25 x 25 mile grid with sampling stations every 5 miles will be completed within a 36-hour period.

B. A standard MARMAP double-oblique bongo array (61- and 20-cm bongos) haul will be made at each station; an XBT cast also will be made.

C. Surface temperature and salinity will be monitored continuously by a laboratory in-line thermosalinograph.

D. In situ fluorescence using an Aiken-type fluorometer will be monitored at a depth of 10 m while the vessel is underway at 3-4 knots between bongo stations.

II. Fine-scale studies. The fine-scale studies consist of 3 operations: (A) Drogued-current meter array sampling, (B) Anchored station sampling, and (C) Micro-nektonic predator sampling using MOCNESS 10-m.

A. Drogued-current meter array sampling (2-4 days). The objective of this operation is to measure the vertical variability of larval fish, plankton, fluorescence, temperature, salinity and shear in the water column within the same "parcel" of water on a time scale of 2-4 days.

1. A drogue will be deployed with vector-averaging current meters (VACM) positioned to measure current velocity and temperature at selected depths. Repeated sampling will be made following the drifting drogued array using the CTD-fluorometer, plankton pump, MOCNESS-1 m and -¼ m.

2. MOCNESS-1 m (0.202-mm mesh nets) hauls will be made at 1½ knots. The objective of this operation is to collect a discrete vertical series of samples from near bottom to the surface on the scale of 250 m^3 of water (235 meters horizontal distance) to determine the vertical distribution of larval fish and zooplankton with 10-m strata resolution.

a. Up to eight discrete depth levels will be sampled at 10-m strata, each net filtering approximately 250 m^3 of water (5 min. duration).

b. Total MOCNESS-1 m haul duration will be completed within ½ hour.

3. CTD-Aiken-type fluorometer casts will be made simultaneously with the plankton pump vertical casts. The objective of this operation is to obtain discrete vertical samples (cubic meters, but 10-100's meters sampled in horizontal distance) of the micro-zooplankton in relation to the observed temperature, salinity and chlorophyll a fluorescence vertical structure, over 1½ hours.

a. Typically, 4 casts will be made within a 1½ hour period. Plankton pump water samples will be collected at 4-6 discrete depth levels.

b. A CTD-fluorometer cast will be made during each of the plankton pump water sample collections and, on alternate watches, discrete water bottle samples will be collected at selected depths on retrieval of the final CTD-cast.

c. Plankton pump water samples will be pumped from each selected depth for 10 min. to filter approximately 1 m^3 of water through 0.053- and 0.020-mm mesh nets mounted on deck.

4. MOCNESS-¼ m (0.064-mm mesh nets) hauls will be made at 1½ knots. The objective of the MOCNESS-¼ m haul is to collect a discrete vertical series of micro-zooplankton samples on the scale of 20-36 m^3 of water filtered (94-170 meters horizontal distance) in relation to the temerature, salinity, and chlorophyll a fluorescence structure observed in previous operations.

a. Eight discrete depth levels will be sampled by the fine mesh nets at 10-, 5- and/or 2-m strata. Each net will filter between 20 and 36 m^3 of water (2-3 min. duration).

b. Total MOCNESS-¼ m haul duration will be completed within ½ hour.

B. Anchored station (48 hours) for rapid vertical profiling of temperature, salinity, fluorescence, and microplankton. The objective of this operation is to measure the horizontal variability of various parameters as the water moves past the ship on a scale of approximately 100 meters to 2 kilometers with vertical resolution of ½ - 2 m, depending on the sea state. The same sequence or similar combination of operations as in A. 2-4 (above) will be used at the anchored station study. Sequential measurements are needed through a minimum of 4 tidal cycles for an adequate analysis.

C. MOCNESS-10 m (3.0-mm mesh nets) at 2½-3 knots. The objective of this operation is to collect a discrete vertical series of day and night micronekton samples on the scale of 7,000-14,000 m^3 of water filtered (705-1,410 meters horizontal distance) to characterize the potential predator field of larval fish and associated zooplankton, within the 25-mile grid.

1. Four discrete depth levels will be sampled at 15-25 meter strata. Each net will filter approximately 7,000-14,000 m^3 of water (15-30 min. duration).

2. A MOCNESS-10 m haul will be completed within 1-2 hours, once every 3 hours over a 24-hour period.

Processing and Analysis of Data

The sample and data processing, quality control, and analysis of the biological and physical data obtained from the experimental program initially will be handled by members of the various participating Investigations within the Marine Ecosystem Division of NEFC (Larval Fish Dynamics, Plankton Ecology, Icthyoplankton, Nekton, Fishery Oceanography Investigations).

Because of the intensive nature of these kinds of studies, large numbers of plankton samples will be collected. We will not want to sort and identify all the samples to the same level and some samples only will be sorted to similar size classes by electronic means (HIAC particle counter) or to similar functional groups. In any case, the samples will be prioritized for sorting; an allotment of the more standard coarse-mesh samples probably will be sent to the Polish Sorting Center, Sczcecin, when they are routinely processing NEFC's MARMAP survey icthyo-zooplankton samples, and other samples requiring more detailed study will be processed at NEFC. Once the analysis of data from the individual research efforts has reached a sufficient level of completion, results from the various investigations will be integrated in an interdisciplinary framework to focus on the biological and physical mechanisms of the recruitment process. Specific data analysis include various time series (spectral) analyses and standard statistical indices of dispersion to determine the patterns and processes in the time-space scales of plankton-larval fish distributions. Larval growth models can be developed based on otolith-aging techniques (Lough et al. 1980) and survival of larvae under conditions observed in the field studies can be simulated in existing models (Laurence 1977, Beyer and Laurence 1980, Beyer 1980, and Vlymen 1977) incorporating prey encounter rate functions. Development of predator-prey and stock-recruitment models will be sought through various members of the Ecosystem Dynamics Investigation and the Resource Utilization Division (Senior Assessment Scientists).

Proposed 1982 and 1983 Activities

During 1981 our experimental program activities are focused on the fine-scale vertical and horizontal distribution of larval haddock and their prey and predators in relation to environmental variations. In 1982, these activities will continue in the spring with better integrated electronic sensing and processing capabilities, but the main focus of our program, and use of ALBATROSS IV vessel time, will be devoted to studying advection of shelf water on Georges Bank (and residing larval fish and plankton populations) across the shelf/slope water front by the entrainment of shelf-water from warm core rings passing westward just south of Georges. NSF has recently funded an interdisciplinary multi-institutional study of warm core rings that will run three years (at about $2½ million yearly) with a preliminary cruise in September 1981 and a major field effort (four month-long cruise periods, each with two or three ships) between April and October 1982. This project provides a remarkable opportunity for NEFC to conduct its own study of the interrelations of warm core rings with the shelf ecosystem and their implications for the fishery against a background of extraordinary rich and detailed investigation of these important features. Remote sensing studies in coordination with NASA Langley Research Center (Dr. W.E. Esaias) will be used to determine the spatial near-surface distributions of temperature, chlorophyll, diversity and suspended solids.

In 1983, our focus will be on the timing, sequencing, and interactions of primary-secondary productivity on Georges Bank using vessel time for studying rates and processes and remote sensing for synoptic coverage of the temperature-chlorophyll fields.

During the proposed study, Drs. E. and A. Durbin (URI) will cooperate, investigating zooplankton secondary production rates, particularly factors controlling production of copepod nauplii, the major food of first-feeding haddock larvae. As a part of these studies, it will be necessary to determine the abundance of nauplii and adult females. Production studies will focus on adult females of the dominant copepods, specifically shipboard and laboratory measurements of egg production rate, and changes in body size and condition factor (weight per unit length). Experiments will be designed to determine how these rates vary spatially and temporally, and the extent to which these variations are related to oceanographic conditions and the availability of phytoplankton food. Physical/biological disperal modeling of copepod population on Georges Bank will be done in cooperation with Dr. C.S. Davis (MBL-WHOI). These studies will serve two purposes: (1) They will provide insight into the factors controlling nauplius cohort initiation, which is relevant to Cushing's match/mismatch hypothesis of larval fish survival. The relevant time scale for these studies will be on the order of days, since first-feeding larvae must find food within about 4 to 7 days at spring temperatures on Georges Bank. (2) Adult females usually make up a considerable fraction of the total copepod biomass, so that measures of their production rates (both somatic and reproductive) will provide an index of production in the entire copepod population.

In addition, we want to promote activity with Dr. J. Walsh and co-workers at the Brookhaven National Laboratory and with scientists of other research institutions in the Northwest Atlantic (e.g., Woods Hole Oceanographic Institution, Bedford Institute of Oceanography). High-frequency acoustics (in conjunction with in situ particle counters) offer considerable promise for providing rapid and quantitative measures of such fine structure and, therefore, their potential should be evaluated. These systems already exist and have been used successfully by Marshall Orr (WHOI), Richard Piper (USC), Douglas Sameoto (BIO) in the field. However, under present funding and personnel restrictions, NEFC cannot construct and adequately test such complicated hardware, and there are still enough R&D problems remaining to advise against purchase of commercially available acoustic hardware until their potential is evaluated further. These scientists may be interested in a grant or contract with NEFC and it would provide an excellent opportunity for evaluating potential of their systems by virtue of the "ground truth" data which could be provided by NEFC.

ANTICIPATED RESULTS

At the end of the first years funding program, we expect to have sufficient new information to address Objectives 1 and 4 on fine-scale larval fish and prey-predator spatial distributions, and partial information on Objectives 2 and 3 to better understand the linkages, processes between oceanographic condition, primary and secondary production, and larval fish survival to formulate more detailed hypotheses and develop specific research programs in the second and third years funding. Ultimately, the information will be used to construct realistic recruitment functions for fishery management and assessment models and to evaluate the potential impact of any environmental alterations.

Specific results in more detail are:

1. Quantification of the fine-scale patchiness of larval haddock and their food prey (copepods) on Georges Bank in terms of spatial scales on the order of meters vertically and 10's of meters horizontally, and of temporal scales from hours to days and weeks.

2. Identification, relative abundance, and distribution, both vertically and horizontally, of potential micro-nektonic larval fish predators as fine- to meso-scale components.

3. Development of a larval haddock growth model based on otolith-aging techniques.

4. Assessment of larval nutritional state (RNA-DNA ratios, etc.) in relation to availability of prey.

5. Model simulation of larval haddock survival incorporating growth and prey encounter rate prey function based on field data.

6. Lagrangian and Eulerian current measurements and an estimate of vertical shear in the water column and their significance to the distribution of larvae.

7. Confirmation of the thermocline formation around the perimeter of Georges Bank as a mechanism for increased biological activity and as a concentrating feature for larvae and their food prey (copepods).

8. Fine-scale vertical structure and variability in temperature, salinity, and chlorophyll on the order of meters and hours in the well-mixed and stratified waters of Georges Bank.

ANTICIPATED PROBLEMS

A major concern by all plankton biologists is the lag time from the collection of plankton samples and its laboratory processing to the point where density estimates can be made for further analyses of the data. Plankton sorting even to dominant categories is a tedious, time-consuming, costly process. At NEFC, this activity is partially a function of the number of skilled temporary employees we hire, which in the present research climate, depends on mandated federal ceiling restrictions and budget allocations to various investigations. Without additional monies for this proposed budget year, our temporary employee sorting capabilities will be seriously reduced. Contracting out samples would be another way to go, but this option is more costly and we tend to lose quality control and interesting observations on a day-to-day basis, as well as the flexibility to have the employees work on a variety of related projects to move the whole program along.

Another problem is the lag time between the purchase of a new instrument or sensor and its full operational capability to meet a desired cruise scheduled. This problem is common and understandable, but it can be minimized by purchasing the gear as soon as the funds are available. These are two reasons whey we are requesting funding in July instead of September 1981. Other than these concerns, we have sufficient permanent employees with the required expertise, and logistical support to pursue the stated goals in our research program. Our Center has made a commitment to process-oriented studies and has insured the availability of vessel time. Vessel time during the spring on ALBATROSS IV is sufficiently flexible to accommodate all our research activities within the Marine Ecology Division as required.

MANAGEMENT PLAN

Personnel

The core of the research program is based on a staff of permanent-employee senior biologists and oceanographers from various investigations within the Marine Ecology Division of the Northeast Fisheries Center since the problem is multidisciplinary in nature. Essentially, all these scientists (listed below) will be working full-time on the proposed project on one aspect or another depending on priority schedules. Each scientist is responsible for the collection and analysis of data for the specific disciplinary experiments and for timely preparation of data reports. The principal investigator will be responsible for the overall collection of data, analyses, and coordinating the multidisciplinary scientific reports and publications.

Dr. R. Gregory Lough - Principle Investigator, NEFC, Woods Hole Laboratory.

Dr. Lough is a Supervisory Biological Oceanographer in the Larval Fish Dynamics Investigation and he will have overall responsibility for the experimental design, at-sea collection of data, and scientific analyses of experimental results.

Dr. Geoffrey C. Laurence - Supervisory Fishery Research Biologist, NEFC, Narragansett Laboratory.

Dr. Laurence is Chief of the Larval Fish Dynamics Investigation and is responsible for the overall review and coordination of the proposed research program within the Northeast Fisheries Center. He will have individual responsibility for the larval fish growth and survival simulation modeling.

Dr. Laurence J. Buckley - Biochemist, NEFC, Narragansett Laboratory.

Dr. Buckley is in the Larval Fish Dynamics Investigation and will be responsible for the analysis and interpretation of the biochemical indices of larval fish nutritional state.

Dr. David G. Mountain - Supervisory Physical Oceanographer, NEFC, Woods Hole Laboratory.

Dr. Mountain is Chief of the Fishery Oceanography Investigation and is responsible for the overall planning, collection, and data analysis of the physical oceanography of the proposed program, as well as coordination of activities within the Northeast Fisheries Center and remote sensing aspects of the problem.

Dr. Ronald J. Schlitz - Physical Oceanographer, NEFC, Woods Hole Laboratory.

Dr. Schlitz is in the Fishery Oceanography Investigation and he will be responsible for the analysis and interpretation of physical data collected from the current meters, drogues, CTD, and XBT.

Gilbert H. Derring - Electronics Technician, NEFC, Woods Hole Laboratory.

Mr. Derring is in the Fishery Oceanography Investigation and he is responsible for the maintenance, calibration and operation of the CTD and current meters.

David C. Potter - Biological Oceanographer, NEFC, Woods Hole Laboratory.

Mr. Potter is in the Larval Fish Dynamics Investigation and he is responsible for the operation of the three MOCNESS units and data processing and analysis of the larval fish vertical distribution collections.

George R. Bolz - Fishery Research Biologist, NEFC, Woods Hole Laboratory.

Mr. Bolz is in the Larval Fish Dynamics Investigation and is responsible for the development of larval fish growth models based on otolith-aging techniques.

Harold G. Merry - Electronics Technician, NEFC, Woods Hole Laboratory.

Mr. Merry is in the Larval Fish Dynamics Investigation and he is responsible for maintenance and calibration of all biological sampling equipment (MOCNESS, HIAC particle counter, fluorometers, plankton pump, light meter, computer systems, navigational positioning instruments, etc.).

Rosalind E. Cohen - Biological Oceanographer, NEFC, Woods Hole Laboratory.

Ms. Cohen is in the Larval Fish Dynamics Investigation and she will be responsible for the larval fish gut content-prey selectivity-morphological condition factor indices, processing and analyses, and specifically, the operation and interpretation of the HIAC particle counter. She has joint responsibility with Mr. Green for zooplankton distribution and abundance.

John R. Green - Physiologist, NEFC, Woods Hole Laboratory.

Mr. Green is in the Plankton Ecology Investigation and will be responsible for zooplankton distribution, productivity, linkages with primary production. He has specific responsibility for operation of the plankton pump system, processing of collected samples and interpretation of data.

Donna S. Busch - Biological Oceanographer, NEFC, Narragansett Laboratory.

Ms. Busch is in the Plankton Ecology Investigation and will be responsible for phytoplankton distributions and production dynamics.

Walter G. Smith - Supervisory Fishery Research Biologist, NMFS, Sandy Hook Laboratory.

Mr. Smith is Chief of the Icthyoplankton Plankton Investigation and he is responsible for the overall planning and conduct of the MARMAP broad-scale plankton-hydrography surveys and analyses of icthyoplankton distribution and abundance studies.

Dr. Kenneth Sherman - Fishery Management Biologist, NEFC, Narragansett Laboratory.

Dr. Sherman is Chief of the Marine Ecology Division and Plankton Ecology Investigation, and he has overall responsibility for our Division research activities. Specifically, he will be responsible for the analyses of zooplankton distribution and abundance from the broad-scale MARMAP surveys.

Robert M. Marak - Supervisory Fishery Research Biologist, NMFS, Narragansett Laboratory.

Mr. Marak is Chief of the Nekton Investigation and will be responsible for analyses of the MOCNESS-10 m micro-nekton collections to determine potential predators of larval fish and distribution-abundance studies of juvenile haddock, etc.

Dr. Marvin D. Grosslein - Supervisory Fishery Research Biologist, NEFC, Woods Hole Laboratory.

Dr. Grosslein is Deputy Division Chief for Marine Ecology Division and Investigation Chief of Ecosystem Dynamics. His group will provide modeling studies of trophic interactions and recruitment functions.

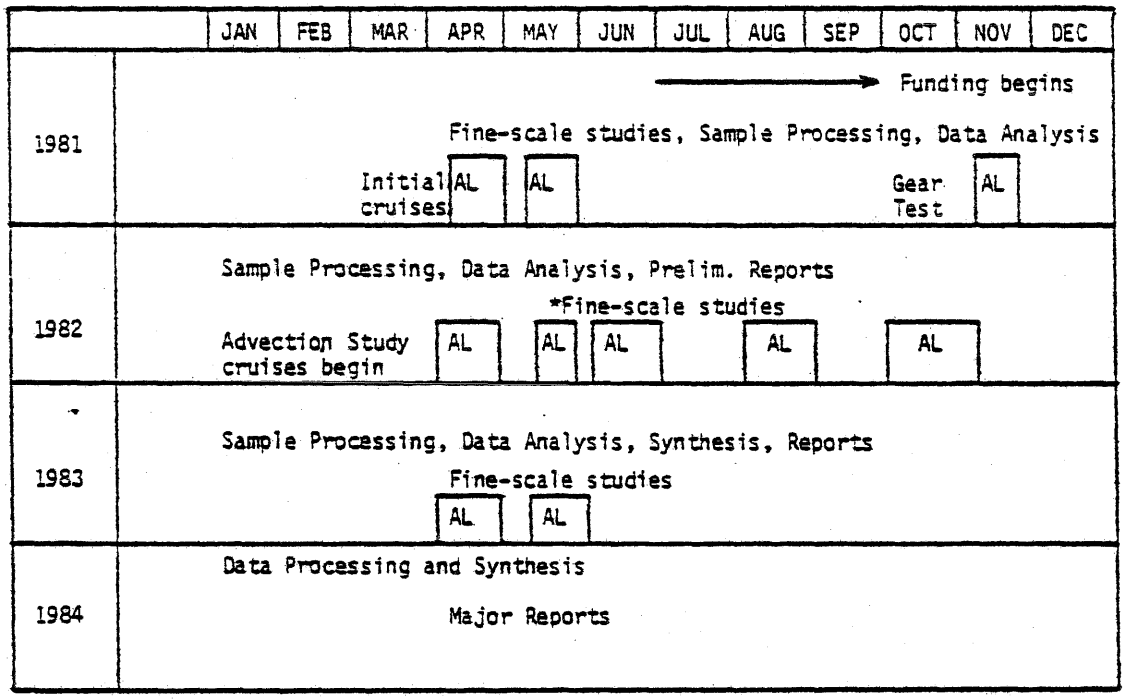
Dr. Michael R. Pennington - Statistician, NMFS, Woods Hole Laboratory.

Dr. Pennington is in the Ecosystem Dynamics Investigation and he will provide advise on experimental design, mathematical and statistical analyses of data.

Schedule

A three-year time diagram showing major milestones in the Georges Bank Larval Fish Trophodynamics Program is proposed below:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981												
1982												
1983												
1984												



* AL = R/V ALBATROSS IV

REFERENCES

Aikens, J. 1981. A chlorophyll sensor for automatic, remote, operation in the marine environment. Mar. Biol. (in press).

Beardsley, R.C., and W.C. Boicourt. 1980. On estuarine and continental-shelf circulation in the Middle Atlantic Bight. In B.A. Warren and C. Wunsch (eds.), Evolution of physical oceanography. p. 198-233. M.I.T. Press, Cambridge, Mass.

Beardsley, R.C., W.C. Boicourt, and D.V. Hansen. 1976. Physical oceanography of the Middle Atlantic Bight. Am. Soc. Limnol. Oceanogr. Spec. Symp. 2:20-34.

Beardsley, R.C., and C.N. Flagg. 1976. The water structure, mean currents, and shelf-water/slope-water front on the New England Continental Shelf. Mem. Soc. Roy. Sci. Liege Ser. 6 10:209-225.

Beyer, J.E. 1980. Feeding success of clupeoid fish larvae and stochastic thinking. Dana 1:65-91.

Beyer, J.E., and G.C. Laurence. 1980. A stochastic model of larval fish growth. Ecol. Modelling 8:109-132.

Beyer, J.E., and G.C. Laurence. 1981. Aspects of stochasticity in modelling growth and survival of clupeoid fish larvae. Rapp. P.-V. Réun. Cons. Int. Explor. Mer 178: (in press).

Bigelow, H.B. 1927. Physical oceanography of the Gulf of Maine. Bull. U.S. Bur. Fish. 40:511-1027.

Boyd, C.M. 1973. Small scale spatial patterns of marine zooplankton examined by an electronic in situ zooplankton detecting device. Neth. J. Sea Res. 7:103-111.

Buckley, L.J. 1980. Changes in ribonucleic acid, deoxyribonucleic acid, and protein content during ontogenesis in winter flounder, *Pseudopleuronectes americanus*, and effect of starvation. Fish. Bull., U.S. 77:703-708.

Buckley, L.J., and D.W. Dillman. 1981. Nitrogen utilization by larval summer flounder (*Paralichthys dentatus*). NOAA-NMFS, Northeast Fisheries Center Narragansett Lab. ms.

Bumpus, D.F. 1973. A description of the circulation on the Continental Shelf of the east coast of the United States. Progr. Oceanogr. 6, Ch. 4:111-157. Appendix.

Bumpus, D.F. 1976. A review of the physical oceanography of Georges Bank. ICNAF Res. Bull. 12:109-134.

Bumpus, D.F., and L.M. Lauzier. 1965. Surface circulation on the Continental Shelf of eastern North America between Newfoundland and Florida. Am. Geograph. Soc., Serial Atlas of the Marine Environment. Folio 7, 4p., 8pl., Appendix.

Butman, B., R.C. Beardsley, B. Magnell, J.A. Vermersch, R.J. Schlitz, R. Limeburner, and M.A. Noble. 1981. The mean circulation on Georges Bank. Sci. (Submitted).

Celone, P.J., and J.L. Chamberlin. 1980. Anticyclonic warm-core Gulf Stream eddies off the northeastern United States in 1978. Annls. Biol., Copenh. 35:50-55.

Chamberlin, J.L. 1978. Temperature structure on the Continental Shelf and Slope south of New England during 1975. In J.R. Goulet, Jr. and E.D. Haynes (eds.), Ocean variability: effects on U.S. marine fishery resources-1975, p. 271-292. NOAA Tech. Rept. NMFS Circ. 416.

Cohen, E.B. 1976. An overview of the plankton communities of the Gulf of Maine. ICNAF Selected Papers No. 1: 89-105.

Cohen, E.B., M. Grosslein, M. Sissenwine, and F. Stemile. 1980. A comparison of energy flow on Georges Bank and in the North Sea. ICES C.M. 1980/L:64. 13 pp.

Cohen, E.B., and W.R. Wright. 1979. Primary productivity on Georges Bank with an explanation of why it is so high. NOAA-NMFS, Northeast Fisheries Center, Woods Hole Lab. Ref. No. 79-53. 9 pp.

Cohen, R.E., and R.G. Lough. 1979. Laboratory and data processing methods recommended for larval fish guts content and condition factor analysis studies using larval sea herring (Clupea harengus L.) as a prototype. NOAA-NMFS, Northeast Fisheries Center Woods Hole Lab. Ref. No. 79-39. 64 pp.

Colton, J.B., Jr. 1965. The distribution and behavior of pelagic and early demersal stages of haddock in relation to sampling techniques. ICNAF Spec. Publ. 6:318-333.

Colton, J.B., Jr. 1972. Short-term variation in estimates of chlorophyll abundance. ICNAF Res. Bull. No. 9: 81-84.

Colton, J.B., Jr., and R.F. Temple. 1961. The enigma of Georges Bank spawning. Limnol. Oceanogr. 6:280-291.

Colton, J.B., Jr., and R.R. Marak. 1962. Use of the Hardy plankton recorder in fishery research programme. Bull. Mar. Ecol. 5:231-246.

Colton, J.B., Jr., and R.R. Marak. 1969. Guide for identifying the common planktonic fish eggs and larvae of continental shelf waters from Cape Sable to Block Island. Bur. Comm. Fish. Biol. Lab. Woods Hole Lab. Ref. No. 69. 43pp.

Colton, J.B., Jr., R.R. Marak, S.E. Nickerson, and R.R. Stoddard. 1968. Physical, chemical, and biological observations on the Continental Shelf, Nova Scotia to Long Island, 1964-66. U.S. Fish. Wildl. Data Rept. 23, 190 pp.

Colton, J.B., Jr., W.G. Smith, A.W. Kendall, Jr., P.L. Berrien, and M.P. Fahay. 1979. Principal spawning areas and times of marine fishes, Cape Sable to Cape Hatteras. Fish. Bull., U.S. 76:911-915.

Corkett, C.J., and I.A. McLaren. 1978. The biology of Pseudocalanus. Adv. Mar. Biol. 15:1-231.

Cura, J., and B. Magnell. 1981. Patterns of primary production on Georges Bank. Third Informal Workshop on the Oceanography of the Gulf of Maine and Adjacent Seas, University of New Hampshire. (Abstract in press).

Cushing, D.H. 1972. The production cycle and the numbers of marine fish. Symp. Zool. Soc. Lond., No. 29:213-232.

Cushing, D.H. 1973. Food and the stabilization mechanism in fishes. Mar. Biol. Assoc. India, Special Publication Dedicated to Dr. N.K. Panekkar, May 1973, p. 29-39.

Cushing, D.H. 1974. The possible density-dependence of larval mortality and adult mortality in fishes. In J.H.S. Blaxter (ed.). The early life history of fish, p. 103-111. Springer-Verlag, Berl.

Cushing, D.H. 1975. The natural mortality of plaice. J. Cons. Int. Explor. Mer 36:150-157.

Cushing, D.H. 1978. Biological effects of climatic change. Rapp. P.-V. Réun. Cons. Int. Explor. Mer 173:107-116.

Cushing, D.H., and J.G.K. Harris. 1973. Stock and recruitment and the problem of density dependence. Rapp. P.-V. Réun. Cons. Int. Explor. Mer 164:143-155.

Davis, C. 1981. Interaction of a copepod population with the mean circulation on Georges Bank. Third Informal Workshop on the Oceanography of the Gulf of Maine and Adjacent Seas, University of New Hampshire. (Abstract in press).

Derenbach, J.B., H. Astheimer, H.P. Hansen, and H. Leach. 1979. Vertical microscale distribution of phytoplankton in relation to the thermocline. Mar. Ecol. Prog. Ser. 1:187-193.

Grosslein, M.D., B.E. Brown, and R.C. Hennemuth. 1979. Research, assessment, and management of a marine ecosystem in the northwest Atlantic--a case study. In J. Cairns, Jr., G.P. Patil, and W.E. Walters (eds.), Environmental biomonitoring, assessment, prediction, and management-certain case studies and related quantitative issues. p. 289-357. International Co-operative Publishing House, Fairland, Maryland.

Grosslein, M.D., and R.C. Hennemuth. 1973. Spawning stock and other factors related to recruitment of haddock on Georges Bank. Rapp. P.-V. Réun. Cons. Perm. Int. Explor. Mer 164:77-88.

Grosslein, M.D., R.W. Langton, and M.P. Sissenwine. 1980. Recent fluctuations in pelagic fish stocks of the northwest Atlantic, Georges Bank region, in relation to species interaction. Rapp. P.-V. Réun. Cons. Int. Explor. Mer 177:374-404.

Harder, W. 1968. Reactions of plankton organisms to water stratification. Limnol. Oceanogr. 13:156-168.

Haury, L.R., J.A. McGowan, and P.H. Wiebe. 1978. Patterns and processes in the time-space scales of plankton distributions. In J.H. Steele (ed.), Spatial pattern in plankton communities. p. 277-327. Plenum Press, New York.

Hunter, J.R. (ed.). 1976. Report of a colloquium on larval fish mortality studies and their relation to fishery research, Jan. 1975. NOAA Tech. Rept., NMFS Circ. No. 395. 5 pp.

Jones, R. 1973. Density dependent regulation of the numbers of cod and haddock. Rapp. P.-V. Réun. Cons. Int. Explor. Mer 164:156-173.

Jones, R., and W.B. Hall. 1974. Some observations on the population dynamics of the larval stage in the common gadoids. In J.H.S. Blaxter (ed.), The early life history of fish, p. 87-102. Springer-Verlag, Berl.

Lasker, R. 1975. Field criteria for survival of anchovy larvae. The relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull., U.S. 73:453-462.

Laurence, G.C. 1974. Growth and survival of haddock (Melanogrammus aeglefinus) larvae in relation to planktonic prey concentration. J. Fish. Res. Bd Can. 31:1415-1419.

Laurence, G.C. 1977. A bioenergetics model for the analysis of feeding and survival potential of winter flounder, Pseudopleuronectes americanus, larvae during the period from hatching to metamorphosis. Fish. Bull., U.S. 75:529-546.

Laurence, G.C. 1978. Comparative growth, respiration and delayed feeding abilities of larval cod (Gadus morhua) and haddock (Melanogrammus, aeglefinus) as influenced by temperature during laboratory studies. Mar. Biol. 50: 1-7.

Laurence, G.C. 1981. Quantitative and qualitative rationale behind the larval dynamics investigation process oriented cruise sampling strategy: spatial and temporal capabilities of larvae relevant to feeding. NOAA-NMFS, Northeast Fisheries Center, Narragansett Lab. Ref. Doc. No. 81-06. 10pp.

Laurence, G.C., and C.A. Rogers. 1976. Effects of temperature and salinity on comparative embryo development and mortality of Atlantic cod (Gadus morhua L.) and haddock (Melanogrammus aeglefinus L.). J. Cons. Int. Explor. Mer 36:220-228.

Lough, R.G. 1979. Larval herring patch study completed. Coastal Oceanography and Climatology News 1:20-21.

Lough, R.G., M.R. Pennington, G.R. Bolz, and A.A. Rosenberg. 1980. A growth model for larval sea herring (Clupea harengus L.) in the Georges Bank-Gulf of Maine area based on otolith growth increments. ICES C.M. 1980/H:65 22 pp. (Submitted to Fish. Bull., U.S.)

Marak, R.R. 1960. Food habits of larval cod, haddock, and coalfish in the Gulf of Maine and Georges Bank Area. J. Cons. Int. Explor. Mer 25:147-157.

Marak, R.R., and J.B. Colton, Jr. 1961. Distribution of fish eggs and larvae, temperature and salinity in the Georges Bank-Gulf of Maine area, 1953. U.S. Fish and Wildl. Serv., Spec. Sci. Rept.-Fisheries No. 398. 61pp.

Marak, R.R., J.B. Colton, Jr., and D.B. Foster. 1962a. Distribution of fish eggs and larvae, temperature, and salinity in the Georges Bank-Gulf of Maine area, 1955. U.S. Fish and Wildl. Serv., Spec. Sci. Rept.-Fisheries No. 411. 66pp.

Marak, R.R., J.B. Colton, Jr., D.B. Foster, and D. Miller. 1962b. Distribution of fish eggs and larvae, temperature, and salinity in the Georges Bank-Gulf of Maine area, 1956. U.S. Fish and Wildl. Serv., Spec. Sci. Rept.-Fisheries No. 412. 95pp.

Marak, R.R., and R. Livingstone, Jr. 1970. Spawning dates of Georges Bank haddock. ICNAF Res. Bull. No. 7: 56-58.

Mayer, D.A., D.V. Hansen, and D.A. Ortman. 1979. Long-term current and temperature observations on the Middle Atlantic Shelf. J. Geophys. Res. 84:1776-1792.

Methot, R.D., Jr., and D. Kramer. 1979. Growth of northern anchovy, Engraulis mordax, larvae in the sea. Fish. Bull., U.S. 77:413-423.

Miller, D., J.B. Colton, Jr., and R.R. Marak. 1963. A study of the vertical distribution of larval haddock. J. Cons. Int. Explor. Mer 28:32-49.

Mizenko, D., and J.L. Chamberlin. 1979. Gulf Stream anticyclonic eddies (warm core rings) off the northeastern United States in 1977. Annls. Biol., Copenh. 34:39-44.

Mooers, C.N.K., R.W. Garvine, and W.W. Martin. 1979. Summertime synoptic variability of the middle Atlantic shelf water/slope water front. J. Geophys. Res. 84:4837-4854.

O'Reilly, J.E., C. Evans, V. Zdanowicz, A. Draxler, R. Waldhauer, and A. Matte. 1980. Baseline studies on the distribution of phytoplankton biomass, organic production, seawater nutrients and trace metals in coastal water between Cape Hatteras and Nova Scotia. First Annual Report Northeast Monitoring Program. NOAA-NMFS, Northeast Fisheries Center, Sandy Hook Laboratory. 29pp. Figs., Tables, Lit. Cit.

O'Reilly, J.E., C.A. Evans, and D.S. Busch. 1981. Distribution of phytoplankton biomass (chlorophyll a) and primary productivity in Shelf Water between Cape Hatteras and Nova Scotia. Third Informal Workshop on the Oceanography of the Gulf of Maine and Adjacent Seas, University of New Hampshire. (Abstract in press).

Ortner, P.B., S.R. Cummings, R.P. Aftring, and H.E. Edgerton. 1979. Silhouette photography of oceanic zooplankton. Nature 277:50-51.

Posgay, J.A., and R.R. Marak. 1980. The MARMAP bongo zooplankton samples. J. Northw. Atl. Fish. Sci. 1:91-99.

Pugh, P.R. 1978. The application of particle counting to an understanding of the small-scale distribution of plankton. In J.H. Steele (ed.), Spatial pattern in plankton communities. p. 111-129. Plenum Press, New York.

Riley, G.A. 1946. Factors controlling phytoplankton population on Georges Bank. J. Mar. Res. 6:54-73.

Sameoto, D.D., and S. Paulowich. 1977. The use of 120 kHz sonar in zooplankton studies. MTS-IEEE, Oceans '77, Oct. 1977, Los Angeles, Calif. Session 39: Instrumentation for biological measurements. 6pp.

Shepherd, J.G., and D.H. Cushing. 1980. A mechanism for density-dependent survival of larval fish as the basis of a stock-recruitment relationship. J. Cons. Int. Explor. Mer 39:160-167.

Sherman, K. 1980. MARMAP, a fisheries ecosystem study in the NW Atlantic: Fluctuations in ichthyoplankton-zooplankton components and their potential for impact on the system. In F.P. Diemer, F.J. Vernberg, and D.Z. Mirkes (eds.), Advanced concepts in ocean measurements for marine biology. p9-37. Belle W. Baruch Institute for Marine Biology and Coastal Research. University of South Carolina Press.

Sherman, K., and C. Jones. 1980. The zooplankton component of a Northwest Atlantic ecosystem. ICESS C.M. 1980/L:67. 32pp.

Sherman, K., R. Maurer, R. Byron, and D. Pearse. 1977. Relationship between larval fish communities and zooplankton prey species in an offshore spawning ground. ICES C.M. 1977/L:28. 12pp.

Smith, W.G., M. Pennington, P. Berrien, J. Sibunka, M. Konieczna, M. Baranowski, and E. Meller. 1979. Annual changes in the distribution and abundance of Atlantic cod and haddock larvae off the northeastern United States between 1973-74 and 1977-78. ICES C.M. 1979/G:47. 19pp.

Tungate, D.S., and E. Reynolds. 1980. The MAFF on-line particle counting system. Fish. Res. Tech. Rept., MAFF Direct. Fish. Res., Lowestoft, No. 58. 11pp.

Vlymen, W.J. 1977. A mathematical model of the relationship between larval anchovy (Engraulis mordax) growth, prey micro-distribution, and larval behavior. Env. Biol. Fish. 2:211-233.

Walford, L.A. 1938. Effect of currents on distribution and survival of the eggs and larvae of the haddock (Melanogrammus aeglefinus) on Georges Bank. Fish. Bull., U.S. 49:1-73.

Ware, D.M. 1975. Relation between egg size, growth, and natural mortality of larval fish. J. Fish. Res. Bd Can. 32:2503-2512.

Wiebe, P.H., K.H. Burt, S.H. Boyd, and A.W. Morton. 1976. A multiple opening/closing net and environmental sensing system for sampling zooplankton. J. Mar. Res. 34:313-326.

Wright, W.R. 1976. The limits of shelf water south of Cape Cod, 1941 to 1972. J. Mar. Res. 34:1-14.

Table 1. Larval haddock daily feeding requirements and calculation parameters.

arameter	Larval Haddock Std. Lgth. (mm)		
	5 (first-feeding)	10 (8-9 weeks old)	15 (11-12 weeks old)
ry Wgt (μg)	59.2	1316.0	8084.2
G 6% day^{-1} (μg)	3.6	79.0	485.0
G 2% day^{-1} (μg)	1.2	26.3	161.7
aily Metabolism - Upper imit (μℓO_2)	41.4	347.6	1203.3
aily Metabolism - Lower imit (μℓO_2)	18.3	152.8	529.4
(for a Given Larval gt)	0.290	0.769	0.800
Constant	0.450	0.785	0.800
- Preferred Prey ize (μg)	1.0	7.9	23.0
ange of R, # of Prey ngested day^{-1}, Calculated ith Upper and Lower Values f Above Parameters	69-281	47-110	28-143

Table 2. Larval haddock swimming, searching and food encounter.

arameter	Larval Haddock Size, Std. Lgth. (mm)		
	5 (first-feeding)	10 (8-9 weeks old)	15 (11-12 weeks old)
aily Linear Distance wum @ 1.5 BL sec^{-1} and 2 hr. Activity (Meters	324	648	972
M Sec^{-1}	0.75	1.5	2.25
olume Water Searched n 12 hr. Day (Liters)	9.5	76.2	257.2
ower-Upper Limit # of equired Prey Captures R) day^{-1}	69-281	47-110	28-143
inear Swimming Distance apture^{-1} (Meters)	4.7	13.7	34.7
equired # Prey $Liter^{-1}$ f 100% Capture Rate	7.3-29.6	0.62-1.44	0.11-0.56
0% Capture Rate	73-296	6-14	1-6

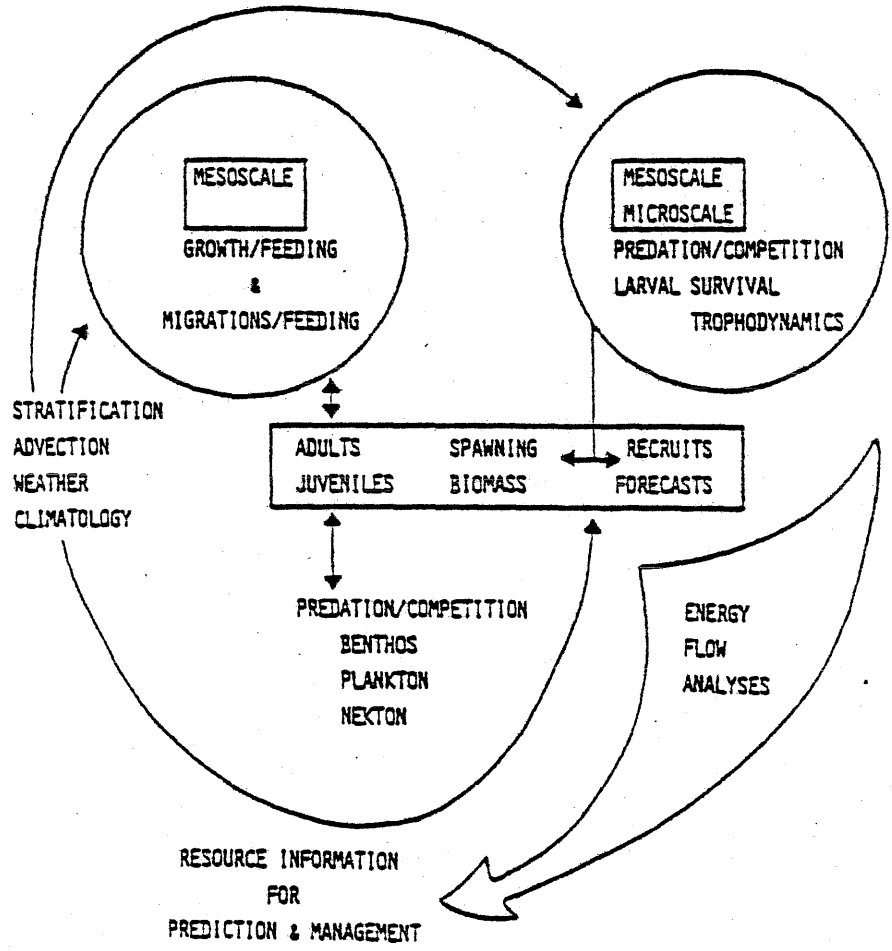


FIGURE 1: Principal focus of the MARMAP ecosystem study of the Northeast Fisheries Center. The rectangle depicts the interactions under investigation to obtain a better understanding of the relationship between the size of a spawning biomass of fish and subsequent year-class recruitment. Studies are underway on the larval, juvenile, and adult fishes within the context of measuring energy flow through the system, and the effects of fishing, pollution and environmental changes on the flow. Macroscale surveys are made up to six times a year to monitor changes of fish, plankton, and hydrography. Mesoscale surveys are conducted from the onset of larval hatching up to juvenile development on target species. Herring sp. has been the target species since 1971 in studies of recruitment processes off the northeast coast. Microscale studies of larval herring growth and predator-prey studies are underway for 1979.

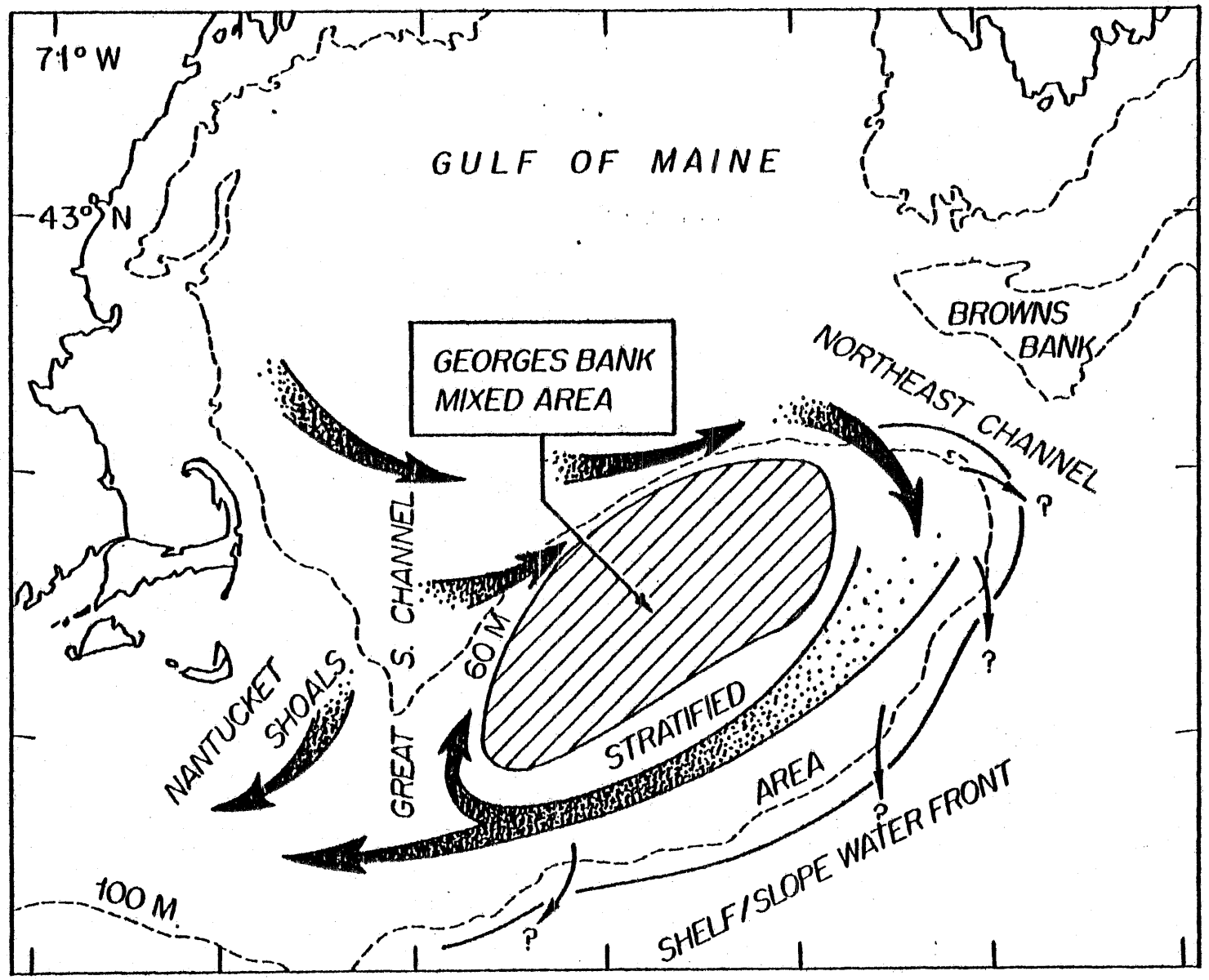


Figure 2. Schematic representation of the well-mixed and stratified waters on Georges Bank and mean circulation flow (arrows) during spring and summer.

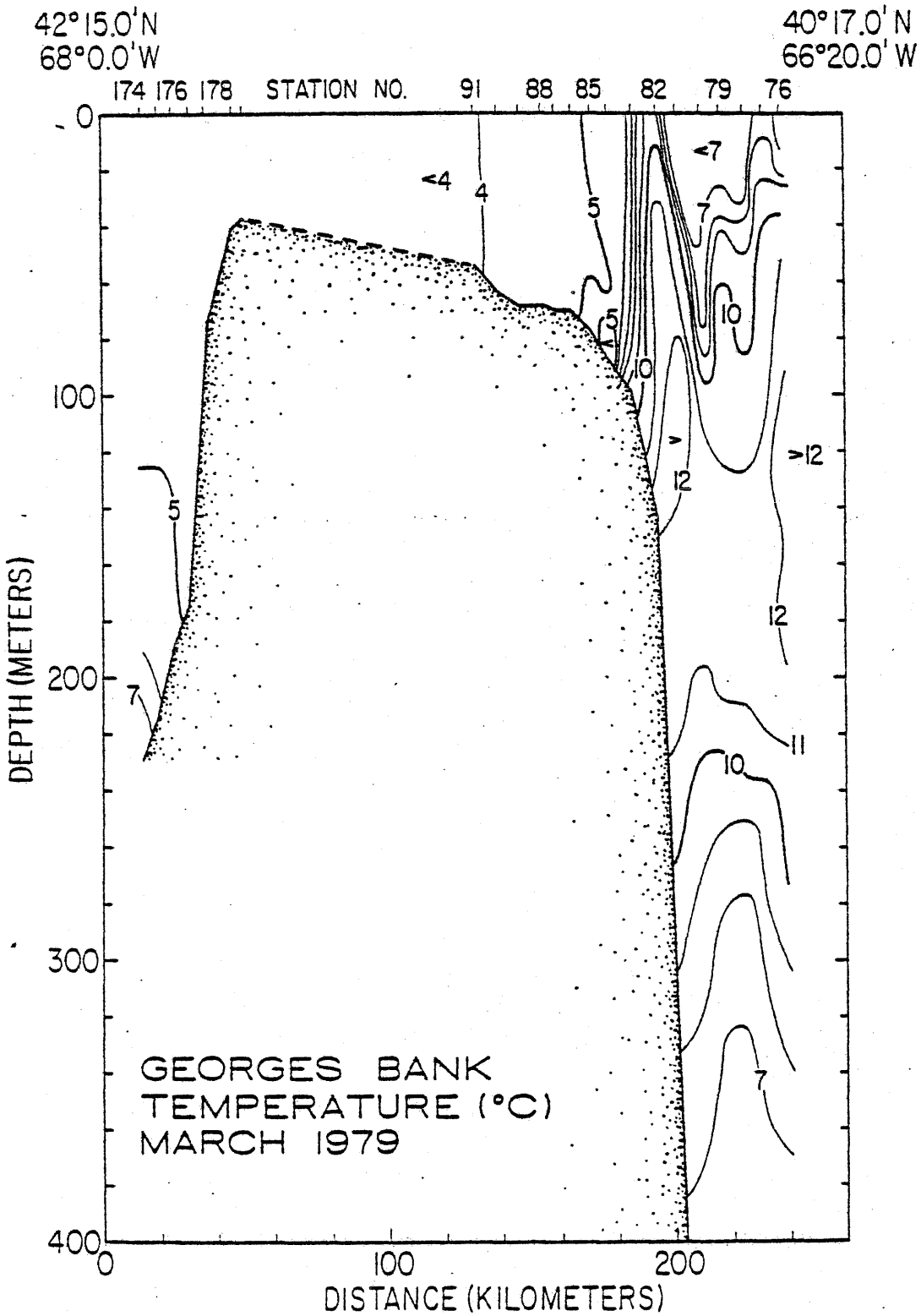


Figure 3. Typical winter section of temperature across the crest of Georges Bank (looking towards the northeast) showing well-mixed water on the crest and on the northern and southern flanks to water depths of 80-100 m. Note the weak temperature gradients along the north flank in contrast to the strong shelf/slope-water front along the southern flank. (Section taken from Butman et al. 1981)

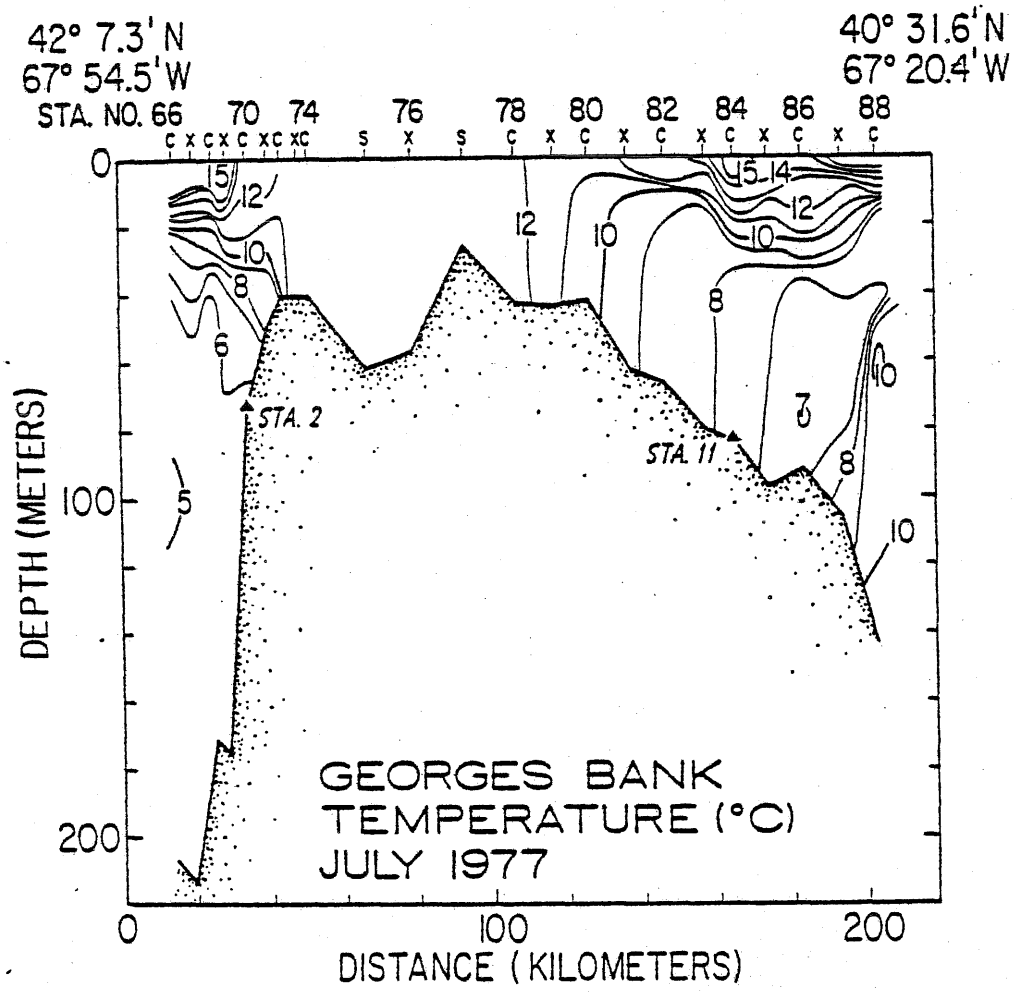


Figure 4. Typical summer section of temperature showing well-mixed water on the crest, tidal fronts at approximately 40 m on the northern flank and at approximately 60 m on the southern flank, the cold band on the southern flank where water core temperatures are less than 7°C, and the shelf/slope-water front which intersects the shelf at approximately 80 m. (Section from Butman et al. 1981)

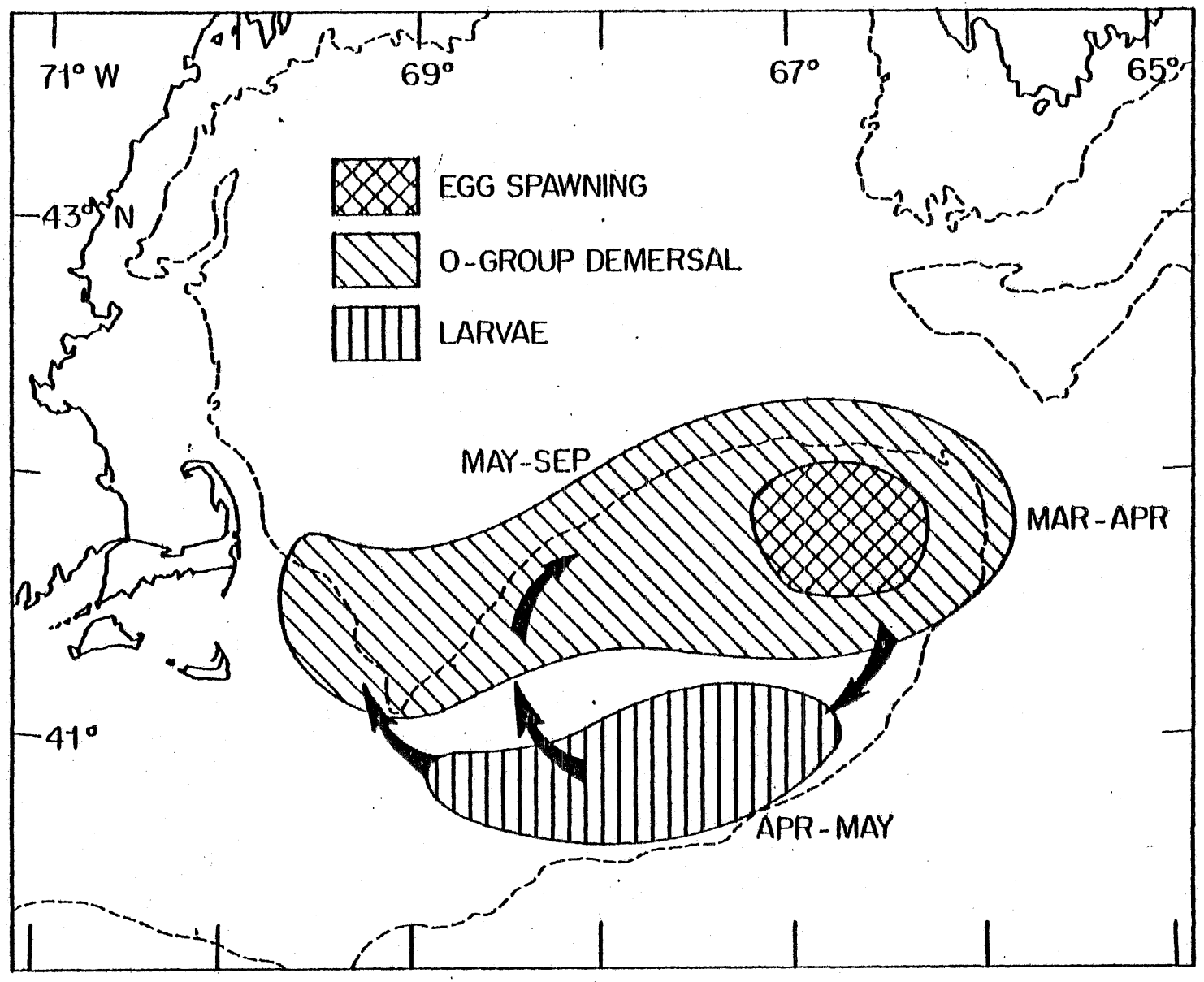


Figure 5. Principal haddock spawning area on Georges Bank and generalized larval drift (indicated by arrows) and areas where demersal O-group haddock are most abundant 6-8 months later.

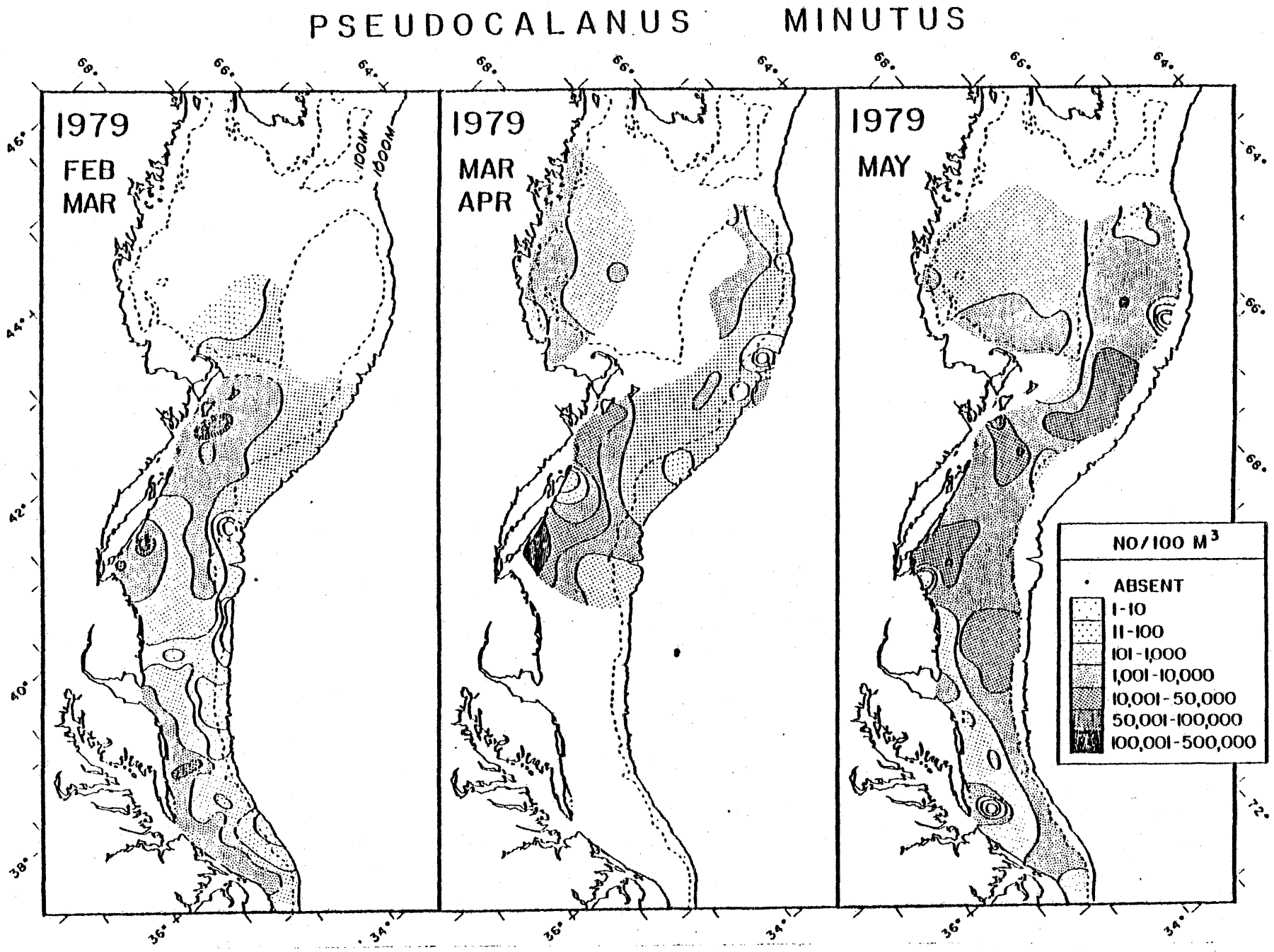


Figure 6. Spatial trends in abundance of Pseudocalanus minutus in the continental shelf off the northeast United States coast in Feb-Mar, Mar-Apr, May 1979. The four subareas sampled -- Gulf of Maine, Georges Bank, Southern New England, Mid-Atlantic Bight (Sherman and Jones 1980). (61-cm bongo, 0.333-mm mesh)

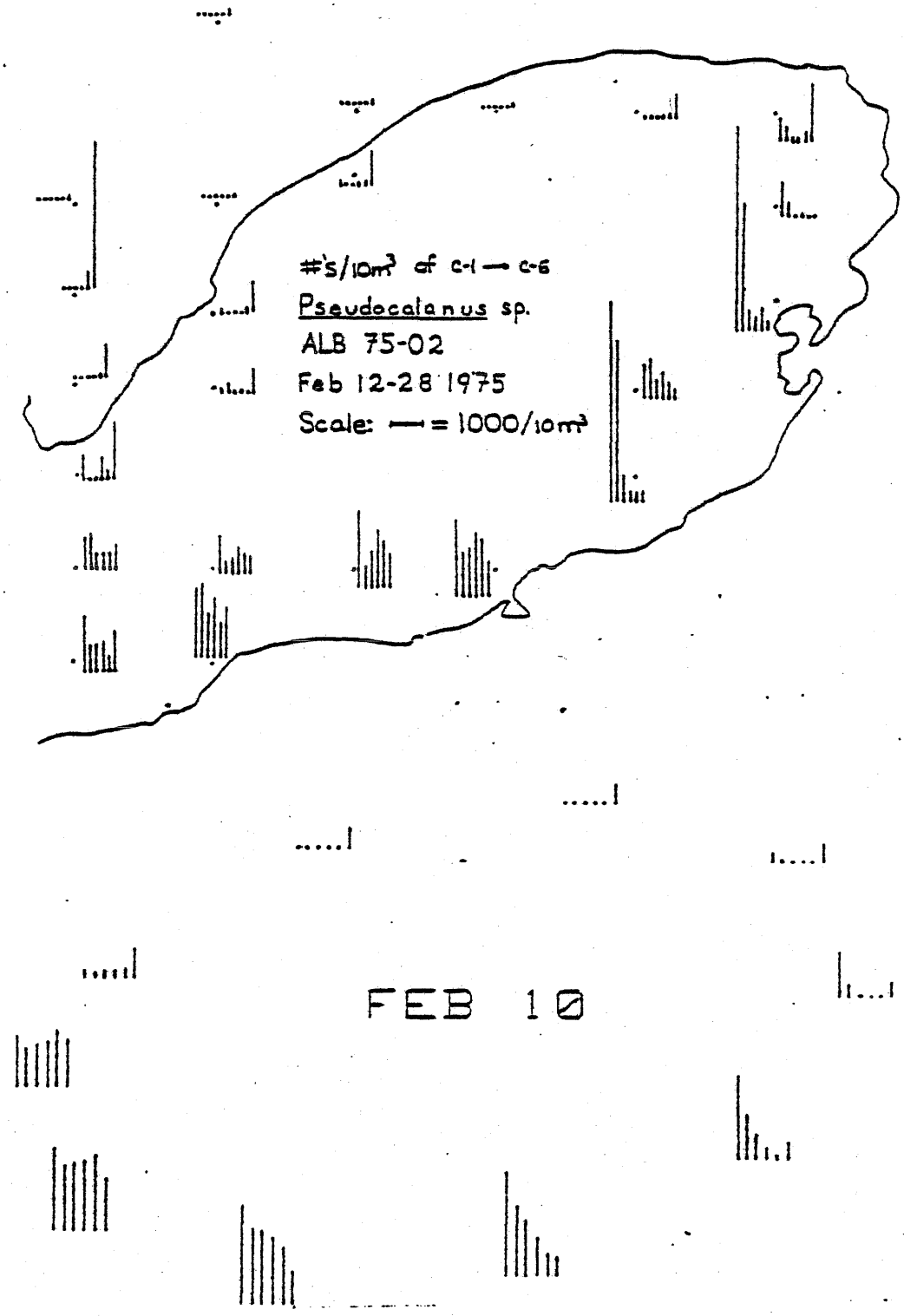


Figure 7. Population structure of Pseudocalanus on Georges Bank in February 1975 analyzed from fine-mesh (0.165 mm) samples (top figure) compared with a computer generated combined physical-biological model (lower figure) which simulates copepod population dynamics at each of a series of fixed spatial points around a hypothetical clockwise gyre (Davis 1981).

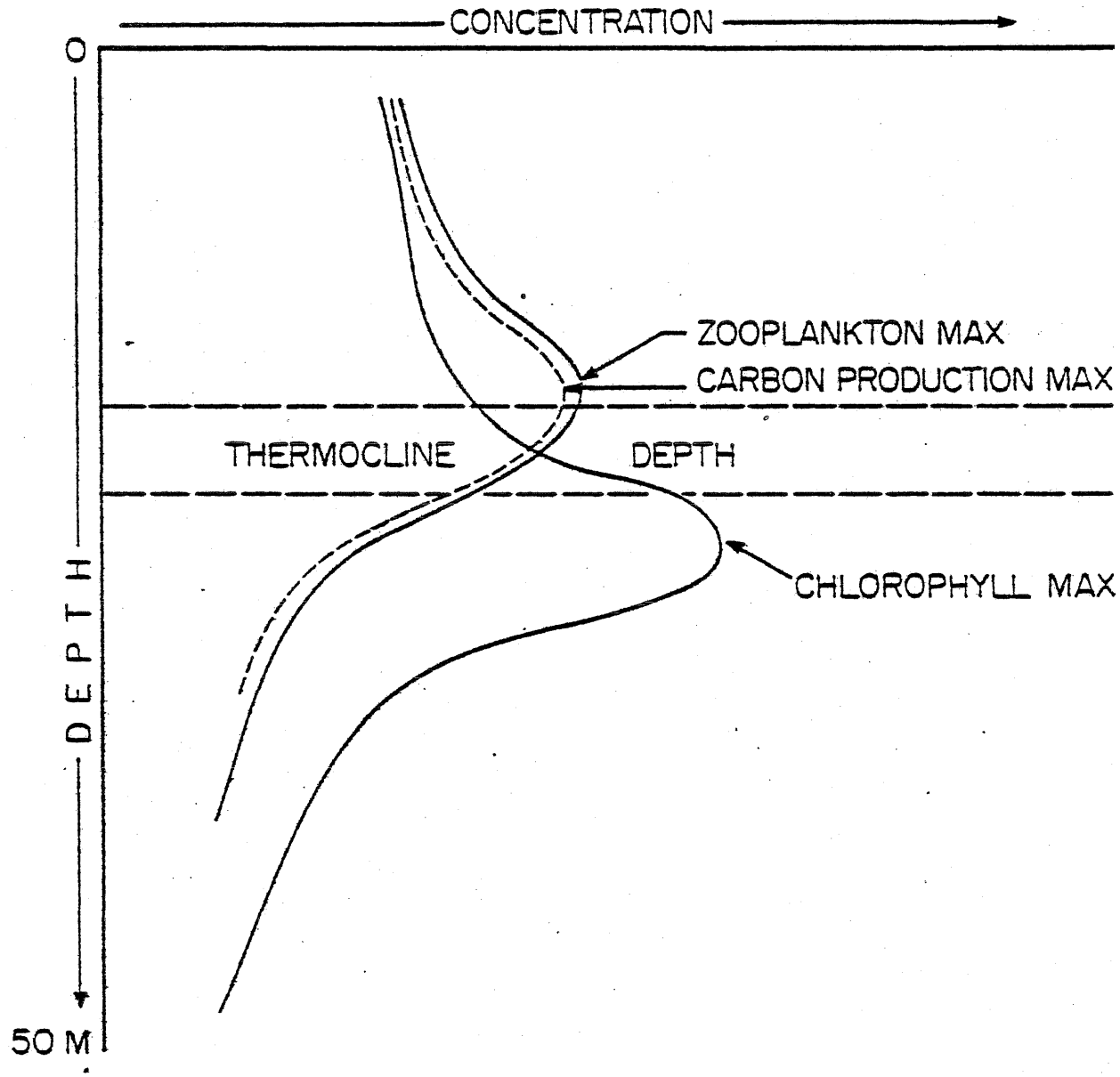


Figure 8. Diagramatic representation of the possible relation between the depth of the thermocline and the vertical distribution of chlorophyll, carbon production, and herbivorous zooplankton in the stratified water on the southern flank of Georges Bank.

COSTS

(Thousands of Dollars)

	YEAR 1	YEAR 2	YEAR 3
Salaries[1]	68	68	69
Fringe Benefits[2]	7	7	7
Equipment			
Pulse Height Analyzer-(HIAC)[3]	5	-	-
HP-85 Computer System-(HIAC)	30	-	-
Fluorometer, Aiken-type (in situ unit)[4]	15	-	-
Lasker-Brown Free-falling Particle Counter[5]	5	-	-
Fluorometer, Turner Designs (Lab unit)	-	10	-
Undulating Oceanographic Recorder[6]	-	30	-
MOCNESS-10m[7]	-	--	50
Light Sensor (MOCNESS)	-	--	10
Travel[8]	15	15	15
Publication Costs	2	2	2
Other Direct Costs			
Computer data processing	10	10	10
Nutrient sample analysis[9]	22	36	15
Fluorometer-CTD electronic integration[10]	5	--	--
Drs. Edward G & Ann G. Durbin (URI)[11]	34	34	34
Dr. Cabell S. Davis (MBL-WHOI)[12]	30	30	30
Dr. Marshall H. Orr (WHOI)[13]	20	--	--
Indirect Costs	--	--	--
Total Costs	268	242	241
Federal Share[14]	1,348	1,636	1,312
Non-Federal Share	-----	-----	-----

Footnotes:

1. Temporary technical and biological employees.
2. Employee benefit contribution.
3. Tungate and Reynolds (1980).
4. Aiken (1981).
5. Lasker and Brown (1980). CalCOFI Repts. 21

Footnotes to COSTS (cont'd):

6. Bruce and Aiken (1975). Mar. Biol. 32: 85-97.
7. Wiebe et al. (1976).
8. Includes costs of visiting scientists on a per cruise basis and meetings.
9. Contractual services estimated at 7.3K per cruise.
10. Contractual serice estimated with Brown Neil Instrument Systems, Inc., Falmouth, Massachusetts.
11. Primary-secondary production experimental studies.
12. Biological-physical dispersal modeling of plankton populations.
13. High-frequency acoustical studies of larval fish-zooplankton distributions.
14. Includes full-time permanent employees plus ALBATROSS IV vessel time in proposal.

QUALIFICATIONS OF KEY PERSONNEL

(NOT INCLUDED)