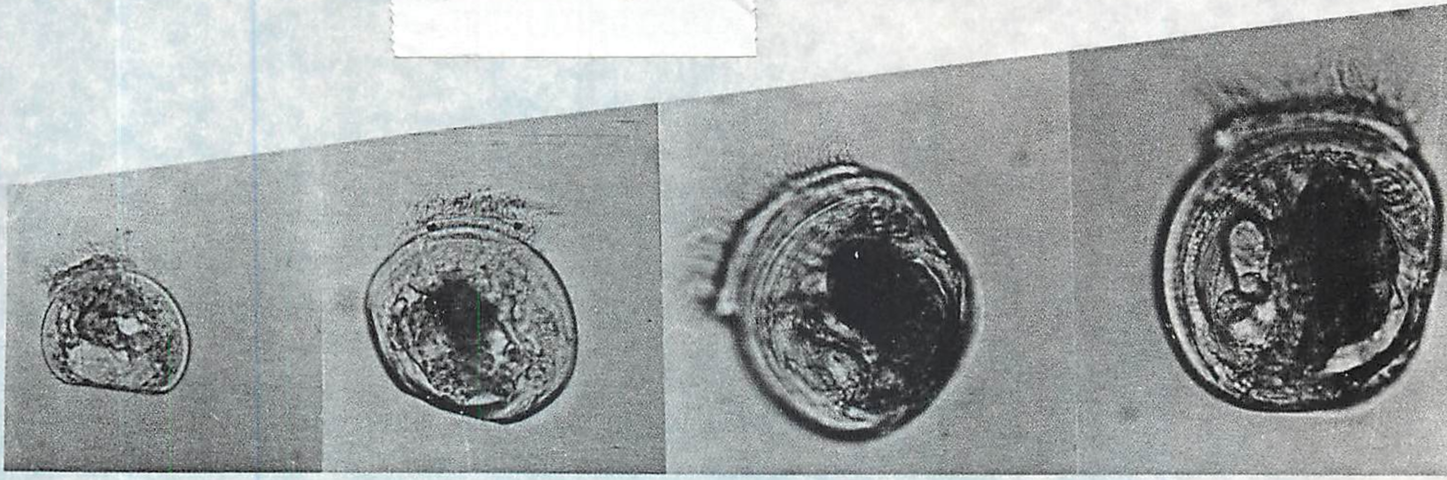
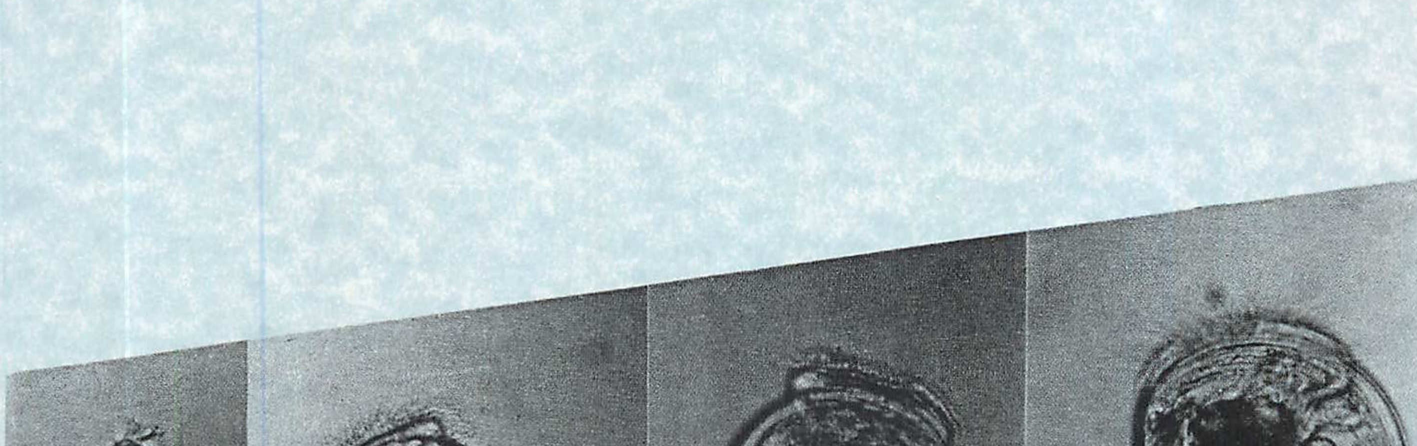


1981-82 Annual Sea Grant Report

Woods Hole Oceanographic Institution



1981-82 Annual Sea Grant Report Woods Hole Oceanographic Institution

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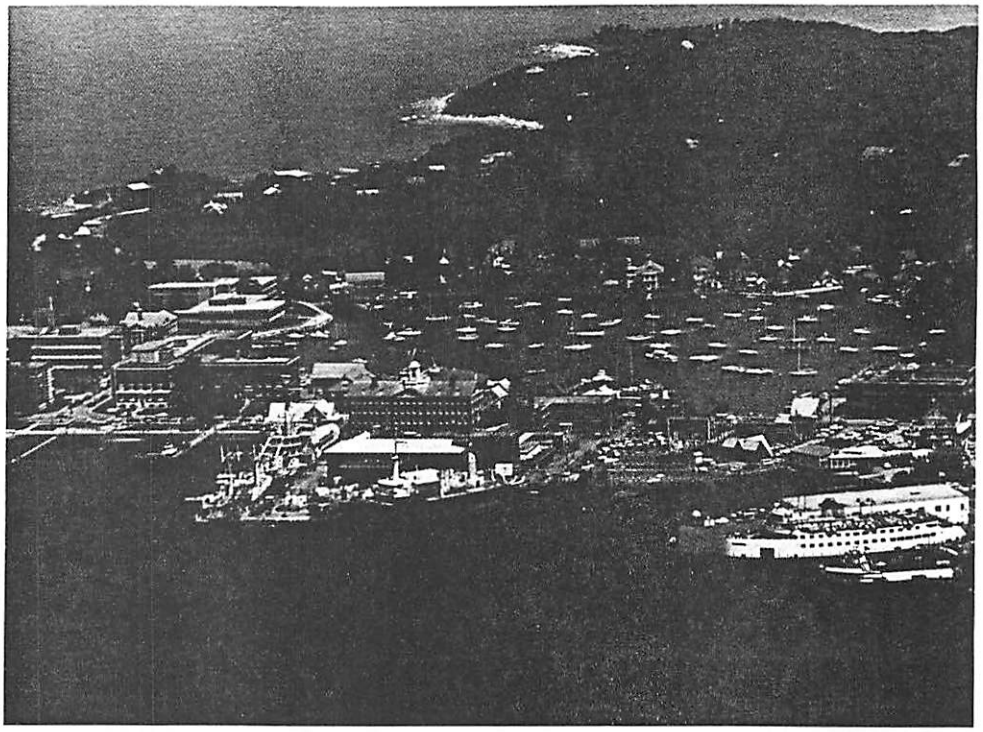
COVER: Larvae of the Quohog Mercenaria mercenaria stained specifically for lipid content(red coloration). Top growth series is of healthy larvae, bottom series is of larvae in poor condition. Lipid specific staining may be used as a diagnostic tool in commercial bivalve hatcheries as an indicator of metabolic health and potential for good growth.

INTRODUCTION



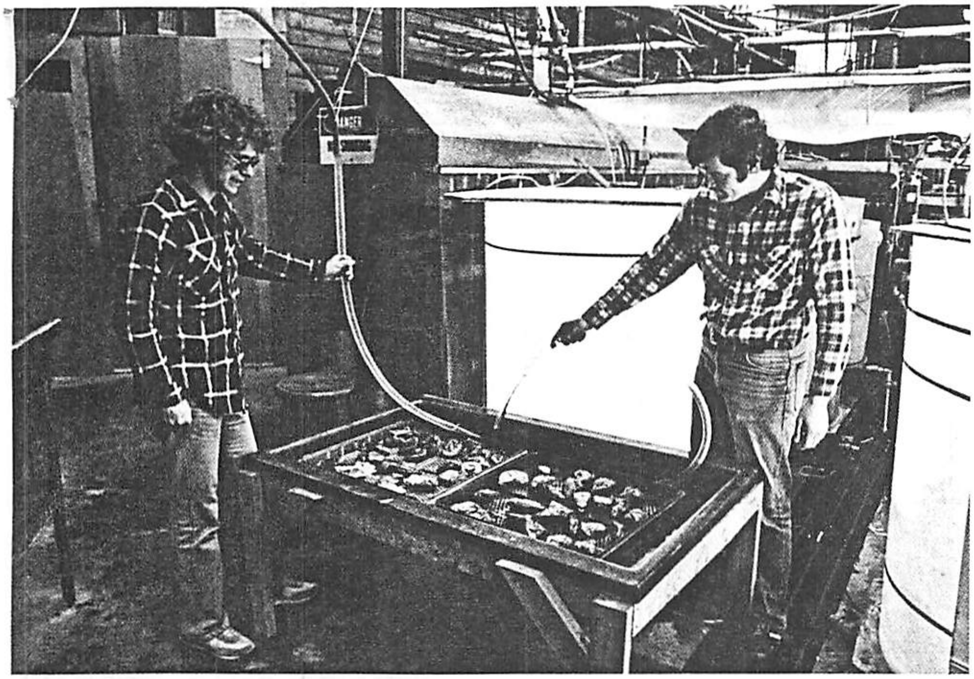
The study of coastal and ocean resources has long been a research theme at the Woods Hole Oceanographic Institution. For the past decade our Sea Grant Program has been especially valuable in this endeavor, and helped develop some new areas of research and expand existing ones. One example is the study of paralytic shellfish poisoning (PSP) caused by the "red tide" dinoflagellate Gonyaulax tamarensis which was unknown to southern New England before 1972. Not only is PSP deleterious to recreational and commercial shellfishing activities, it adds new constraints to aquaculture and sea ranching. A second example is the development of a visual technique for monitoring the lipid reserves of bivalve larvae. Lipids are normally accumulated during the growth of healthy bivalve larvae but are rapidly metabolized and lost by larvae under stress. Assessment of the lipid content of bivalve larvae in hatcheries provides an accurate diagnostic tool for the detection of stress in developmental stages; the technique may hold promise in wild populations as an indicator of pollution or disease.

Although research is our main objective, the transfer of results from our Program and others in the National Sea Grant network, is an important part of our effort. Our Marine Assistance Service maintains interactions with state, county and local environmental agencies and with selectmen and natural resource personnel in the local towns of Cape Cod and the Islands.

During the nearly two decades of its existence the National Sea Grant College Program has played a critical role in the development of a U.S. marine research effort by its encouragement of the understanding, assessment, development, utilization and conservation of our Nation's ocean and coastal resources. The Woods Hole Program has strived during the past decade to meet these ideals.

We hope you find this report informative. Please contact us if you have any questions on the enclosed material or other aspects of our Program.

David A. Ross
Sea Grant Coordinator



Preparing molluscs for lipid staining.

ENHANCED BIOLOGICAL PRODUCTIVITY

Lipid Specific Staining: A Visual Technique for Monitoring Condition of Bivalve Larvae

Scott M. Gallager and Roger Mann
Department of Biology

At present commercial oyster and clam hatcheries do not have a rapid, sensitive, simple technique for assessing the condition of cultured larval forms. The commonly employed techniques of assessing shell growth, mortality, behaviour and signs of disease are valuable but essentially post facto by nature in that excessive changes in larval condition must occur before significant changes are evident. Thus, by the time adverse effects are noted remedial measures may be ineffective or costly to implement.

We have developed and evaluated a rapid, simple, inexpensive, visual technique that may be used to visually monitor the lipid energy reserves of bivalve larvae. Lipids are normally accumulated during the development of healthy bivalve larvae but rapidly metabolized and lost by larvae under stress. Assessment of lipid content provides an extremely sensitive and accurate diagnostic tool for the detection of sublethal stress in larval cultures that would normally proceed undetected until extensive mortality had occurred.

Lipids play an important role in maintaining energy balance in bivalve larvae during stress, starvation and while completing metamorphosis. Standard analytical techniques for lipid analysis are expensive, time consuming and require extensive training of personnel; however, routine monitoring of larval lipid levels in the hatchery for early diagnosis of metabolic dysfunction can be effected by staining whole larvae from culture subsamples with a lipid specific stain and subsequent microscopic examination.

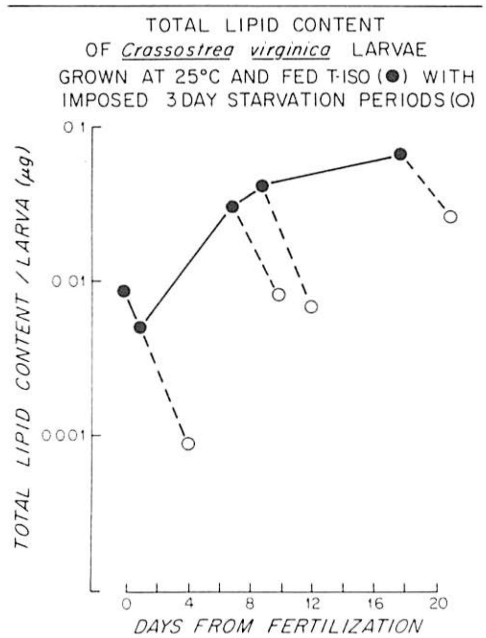


Figure 1.
Analytically measured total lipid content of C. virginica larvae cultured under optimal conditions (0) and after a three day starvation period of each growth stage (---●).

The lipid specific staining technique of Gallager and Mann (1981a, b) was evaluated by culturing the larvae of three species of commercially important bivalves, *Crassostrea virginica*, *Ostrea edulis*, and *Mercenaria mercenaria*, under a variety of food and temperature conditions. Subsamples of larvae were removed from each culture regime at regular intervals and starved for a period of three days. Throughout the culture period, subsamples of larvae were examined with lipid specific stains and analyzed for total lipid content by standard analytical techniques. This protocol allowed direct calibration of visually assessed lipid with quantitative data provided by analytical techniques. Color photographs of the stained larvae were made to provide a permanent record of the stain intensity and lipid localization.

Prior to feeding, newly formed straight hinge larvae contained many small lipid droplets scattered widely throughout the tissues. These gradually disappeared over a period of two to three days when larvae were starved. As the shell of the larvae increased in size greater amounts of stained lipid were observed in the digestive gland and intestines of all three species. Starved larvae showed obvious decreases in number and size of stained lipid droplets . Suboptimal culture temperatures yielded a pattern of lipid storage in the intestines but little accumulation in the digestive gland suggesting a more rapid metabolic turnover of lipid in the latter storage area. Species specific patterns of lipid storage and utilization were observed under all culture conditions. A significant relationship was evident between metamorphosis and spat yield, and prior lipid content of the larvae as visualized by staining and assayed quantitatively.

The total lipid content of developing healthy eggs of C. virginica measured analytically decreased from 10 nanograms (10 x 10^{-9} grams) dry weight at spawning to 7 ng in the first veliger stage (Figure 1). Lipid in larvae fed under optimal conditions increased to a maximum of 80 ng per larva just prior to metamorphosis. An average of 8 ng lipid per larvae was lost during a three day starvation period. The staining method proved to be an extremely sensitive technique for detecting such losses of lipid on an individual larval basis. Reductions in total lipid content of just a few nanograms were easily observed.

A major constituent of our study has been and will continue to be the collaboration with commercial oyster and clam hatcheries. Hundreds of samples removed from larval cultures at two commercial hatcheries have demonstrated that the routine use of lipid staining technique is feasible and very informative when used on a commercial scale. Notebooks containing color photographs of eight larval growth series of the three species under investigation, and a description of the use and interpretation of the staining technique have been supplied to four commercial hatcheries to evaluate the condition of their own cultures on site.

Research in progress has used the staining technique to assess condition of adult brood stock. A relationship has been identified between larval growth and lipid content of newly spawned eggs and one day old larvae as assayed visually by staining. Commercial hatcherymen feel that by assessing egg condition at the time of spawning substantial amounts of time, previously wasted in attempting to rear suboptimal spawns, would be saved.

Future research plans are directed toward providing a better understanding of the biochemical transitions in energy storage material during the process of metamorphosis. The importance of lipid during this critical period makes the staining technique an excellent candidate for assessing potential for metamorphic success and subsequent spat yield.

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Seeding Program for the Bay Scallop: Comparison of Local Bays, Falmouth, MA

Judith M. Capuzzo,
George R. Hampson and
Rodman E. Taylor, Jr.
Department of Biology

The bay scallop, Argopecten irradians, is an important part of the fishery activities on the east coast of the United States. As of 1969 it ranked fourth in importance among bivalve molluscs caught in the U.S. fishery (U.S. Dept. of Commerce, 1969). In 1978 U.S. bay scallop landings were valued at $4.2 million with Massachusetts being the leading producing state (U.S. Dept. of Commerce, 1979). In Falmouth, MA ∿6000 bushels of scallops were harvested in 1978, and ∿4000 bushels in 1979, with a retail value of $200,000-$300,000; the bay scallop fishery is equally important for other coastal towns and the island communities of Martha's Vineyard and Nantucket. Because of its economic importance to local communities, an understanding of the dynamics of local bay scallop populations is necessary for protection and effective management of the fishery.

Although many facets of the natural history and life cycle of A. irradians are well understood, the fishery is hindered by the unpredictable abundance of natural set and the apparent instability of local populations. Factors which may cause the instability of populations of A. irradians include the loss of eel grass and other epibenthic supports for setting juveniles; loss of larvae from local bays by tidal flushing; biological interactions, such as overcrowding, disease, parasites and predation; and harvesting of juveniles prior to maturation.

In our ongoing research program on local populations of the bay scallop we have demonstrated that the interactions of the physical, chemical and biological characteristics of specific embayments are important determinants of the recruitment and survival of bay scallop populations. The most abundant populations were found in bays with stable physical and chemical conditions, low rates of tidal flushing, and low densities of predators; the latter two factors being particularly important for recruitment and survival of newly set seed scallops, respectively. Mortality of both adult and juvenile scallops is attributed to predation by the soft-shelled crab, the green crab and the oyster drill in addition to infestations of the marine worm, Polydora and an unidentified colonial ascidian; in the latter instance, infestation on the outside valve of affected bay scallops may be so extensive as to restrict valve movement considerably. Although the green alga Codium fragile is abundant in local bays, no significant mortality of bay scallops attributable to Codium has been observed in local bays.

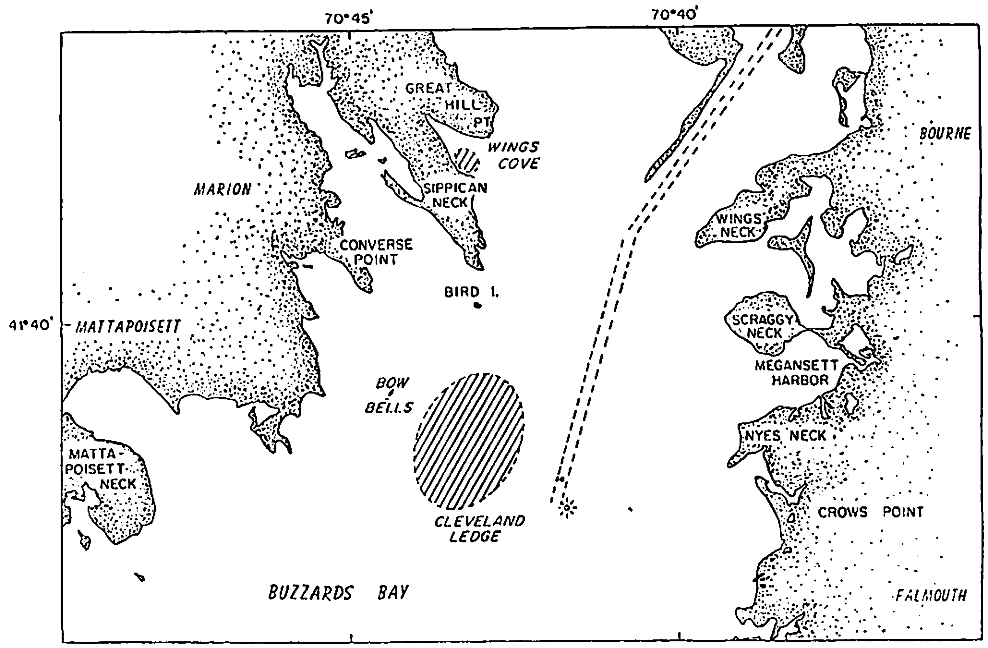

Figure 1. Site of bay scallop bed in Buzzards Bay, southwest of Bow Bell.

Additional mortality of adult scallops during post-spawning periods may be the result of the synergistic effect of a weakened physiological condition and high summer temperatures (28-29°C) at some stations. At stations near the mouth of each embayment, where temperature fluctuations are less severe (maximum temperature = 26-27°C), post-spawning mortality is generally minimal.

Taylor and Capuzzo (in press) have described the reproductive cycle of bay scallop populations from a small coastal embayment on Cape Cod, MA (Waquoit Bay). The results of our study indicate that spawning activity of bay scallops begins in May and continues through July with some minor activity occurring during August and September. Spawning activity is most closely related to changes in ambient temperature and occurs predominantly before the summer maximum temperature is attained. As temperatures decline during the late summer and early fall, increased gametogenic activity is evident. The extensive periods of spawning and settlement coupled with the rapid growth of newly set seed during the summer and early fall result in a wide size range of juveniles by mid- to late fall.

Although A. irradians populations are most abundant in shallow embayments, large populations are occasionally found at depths of 4.5-12 meters in Buzzards Bay, MA. Concomitant with large offshore sets are significant increases in the harvestable yield for towns that exploit them. The offshore harvest of bay scallops in Buzzards Bay, MA was a significant proportion of the total harvest for the towns of Falmouth, Bourne, Marion and Mattapoisett for the period from 1977-1979. Unfortunately little is known of the frequency of offshore sets, the extent of offshore beds or the breeding periodicity, growth rates and other life history characteristics of offshore A. irradians populations. Densities of newly set scallops at Cleveland Ledge have been reported to be as high as $50/m^2$ and other sites within this area may be equally important.

Preliminary investigations of these offshore populations revealed that sig-

(cont'd.)

nificant differences in growth and spawning activity are apparent in comparison with near-shore, shallow water populations. A bay scallop bed at a depth of 9 meters was selected in the northeastern end of Buzzards Bay southwest of Bow Bell (see Figure 1) and, for comparison, an inshore site was selected at Wings Cove at a depth of 2 meters. At both locations collections and measurements were made every 2 weeks beginning in May for analysis of growth rates and gonad development of bay scallops, in addition to monitoring temperature and water quality parameters.

Although the offshore crop was of moderate density, the scallops harvested from this area produced 20-50% greater muscle weight than specimens collected inshore. Also, temperature data and external observation of gonad development suggest that the inshore population attained spawning threshold temperatures several weeks in advance of the offshore population. The sea water temperature at Wings Cove had already reached 21.6°C by June 3 while the temperature offshore remained at 16.1°C.

From comparative bottom temperature data collected during the 1981 season from Bow Bell and Wings Cove, it was apparent that the shallow inshore area was more readily responsive to the spring warming trend than the offshore area which initially remained a few degrees lower, due to the buffering effect of the larger water mass. However, by July 8, the water temperatures were identical and generally remained close except for the occasional higher values experienced in Wings Cove due to an unusual warm air temperature. During the fall cooling period, the reverse was noted and the inshore area was first to experience cooler temperatures.

The energetics of bivalve populations, particularly in relation to the partitioning of energy between gametogenesis and growth, are controlled by temperature. For some bivalves, including bay scallops, the period of gametogenesis and spawning is characterized by high energy expenditures channeled into reproductive effort at the expense of somatic tissue growth. When spawning has been completed, energy is then channeled into somatic growth.

By examining the adductor muscle growth data of bay scallops collected from the two sites in Buzzards Bay, a preliminary assessment of the gametogenic: somatic energy budget can be made. Little somatic growth is occurring in both populations during the early summer as energy is predominantly being used for gonad production. An increase in somatic growth is apparent after spawning has ceased. At Bow Bell, a 41% increase in muscle growth of bay scallops was measured from mid-June to early August, compared with a 245% increase measured from mid-August to October. In contrast at Wings Cove during the same interval, muscle growth of bay scallops exhibited a 124% increase from June to August and a 167% increase from August to October. Differences may possibly be explained by an earlier spawning period in late spring to early summer for the Wings Cove population and an additional short spawning period during the fall. Histological analyses of the gonads taken from these same animals are currently in progress.

In general the Bow Bell scallops generated a 20-50% greater muscle weight for the season than the inshore scallops. After opening of harvesting season on October 1, 1981, the weight from both areas increased appreciably during the first 2 weeks and again in the following 2 weeks. Muscle weights from Bow Bell on November 2, 1981 were 25% greater than October 15 taken at the same site ($P < 0.05$).

It is apparent from our current findings that significant differences in the physiology of the bay scallop exist between inshore and offshore populations, specifically related to reproduction and growth. If the offshore fishery is to be effectively exploited, these differences and their importance to the harvest stock must be determined and further characterized.

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Osmoregulation in the Brook Trout *Salvelinus fontinalis*

Stephen D. McCormick
Robert J. Naiman
Department of Biology

Brook trout (*Salvelinus fontinalis*) often migrate from freshwater to seawater when given free access to the ocean. Movement into comparatively rich marine systems can result in growth rates that are four to five times that of cohorts remaining in freshwater. This fact, in combination with high return rates of brook trout to their parent stream, makes this a potentially valuable species for sea ranching, fish farming and enhancement programs. However, several questions concerning the migratory tendency of brook trout remain unanswered. One important question is the osmoregulatory ability of brook trout, specifically the roles of size, age and photoperiod in determining their ability to osmoregulate in seawater. Current work in our laboratory is designed to answer this and other questions related to salmonid osmoregulation and smoltification.

In order to determine whether size, age and/or photoperiod are important in the osmoregulatory ability of brook trout, we separated several thousand fry of a controlled genetic stock into fastand slow-growing groups using feeding rate to control growth. We further divided the fish into two photoperiods; one is "normal" daylength, decreasing in fall and increasing in the spring, while the second is 3 months out of phase with the normal photoperiod. Every 6 weeks fish from each group are acclimated to seawater using a gradual procedure of one week in 10‰, another week in 20‰ and then exposure to 32‰. Growth and survival of brook trout in seawater is monitored for at least 20 days. To determine the osmoregulatory ability of these fish, plasma levels of Na^+, Cl^-, K^+, Mg^{++} and total osmotic concentration are measured at discrete intervals. Gill Na^+-K^+ ATPase, an enzyme responsible for blood ion homeostasis, is measured in animals exposed to seawater and in a freshwater control group. The circulating levels of the hormone thyroxine is also being measured to determine its effect on osmo-

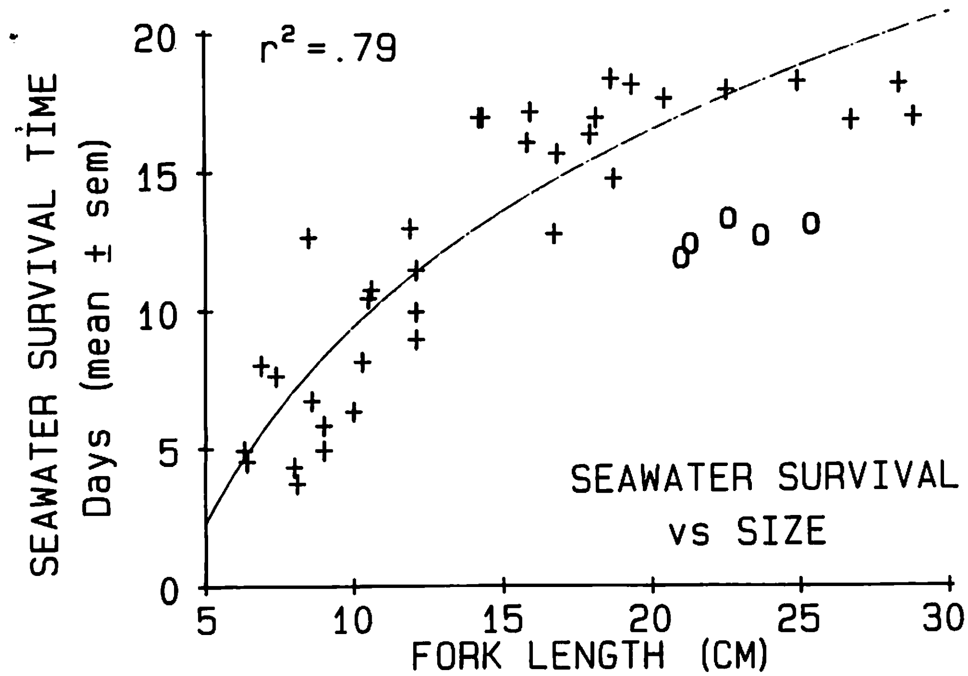

Figure 1.

regulatory ability and seawater survival. Finally, the major osmoregulatory organs including gills, gut and kidney are being examined for histological changes in morphology and ultrastructure that may be correlated with increased salinity tolerance.

Experiments conducted over the past year and a half have shown a strong dependence of seawater survival and hypoosmoregulatory ability on body size. Larger, faster growing fish show greater salinity tolerance than smaller, slower growing fish (Fig. 1). Body size can explain up to 78% of the variation in seawater survival time of brook trout, while age can explain only 62% (Fig. 1).

Photoperiod exerts its strongest influence on hypo-osmoregulatory ability through the maturation cycle. During declining photoperiod a period of normal spawning for brook trout, mature males exhibit poor salinity tolerance relative to immature males and mature and immature females (Fig. 2). Mature males also demonstrate poorer abilities to regulate plasma chloride, magnesium and total osmotic concentration.

In smolting salmonids, increasing photoperiods result in a myriad of physiological changes, perhaps mediated by thyroxine, which facilitate hypoosmoregulation. Although a springtime peak in seawater survival time exists for fast growing fish, it is not significantly different from "summer" photoperiods.

A springtime increase in seawater survival did not occur in slow growing fish (Fig. 3). However, Figure 4 shows that a photoperiod controlled annual cycle in thyroxine does occur, declining in the Fall and rising to a springtime maximum in March. The magnitude of springtime increases in thyroxine levels in the brook trout do not equal those shown to occur in smolting salmonids. An increase in gill Na^+-K^+ ATPase activity, which might indicate preparation for seawater entry mitigated by thyroxine, did not occur and thus the physiological significance of the thyroxine cycle remains unclear.

In the coming months we will be defining our model of hypoosmoregulation in brook trout to include variables such as gonadosomatic index, growth rates and condition factors. With this added information we should obtain even greater accuracy in predicting salinity tolerance and discerning the underlying physiological mechanisms that allow brook trout to osmoregulate in seawater.

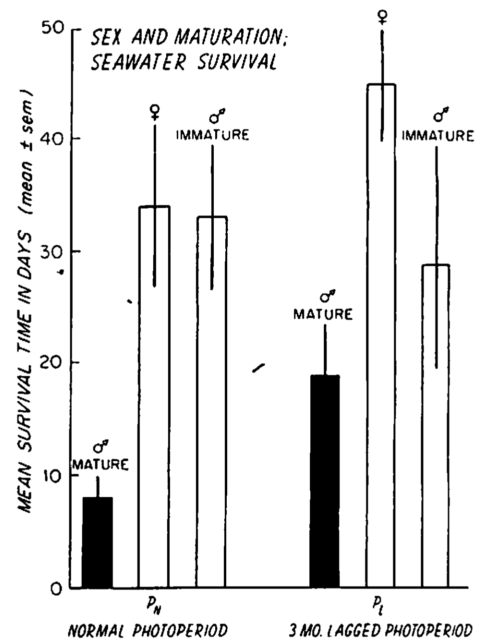

Figure 2.

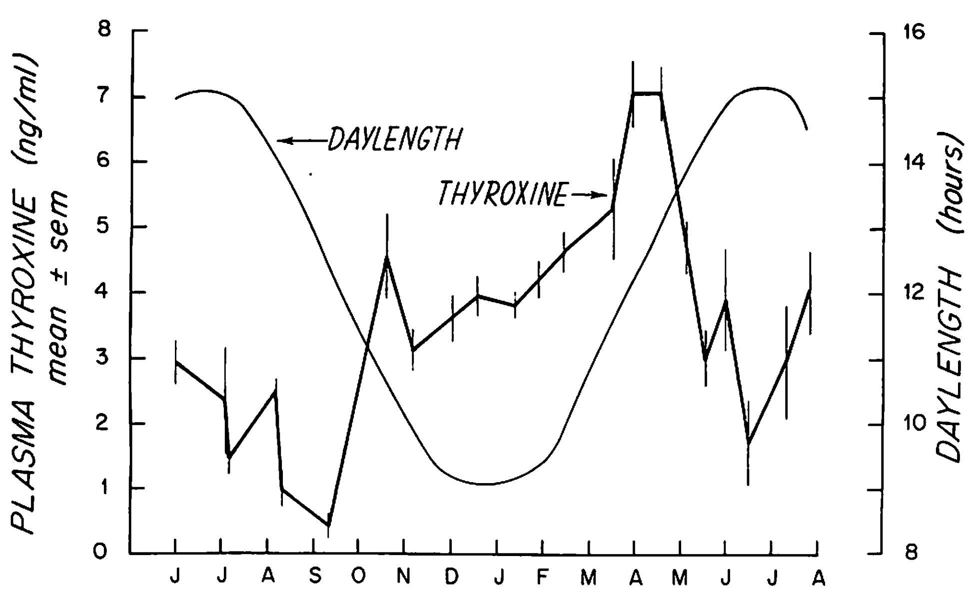

Figure 3.

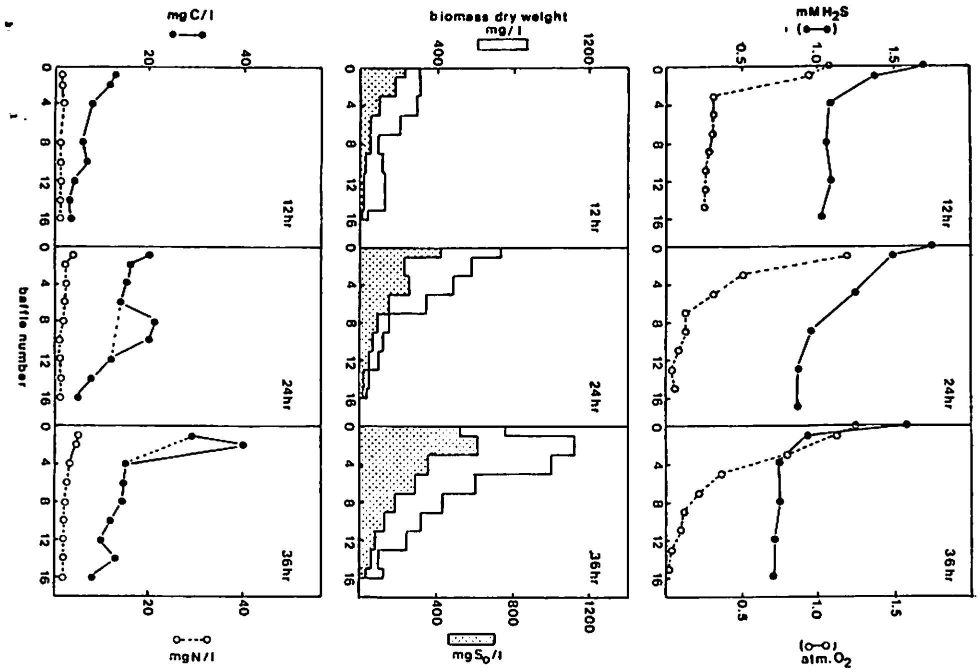

Figure 1. Time-course of hydrogen sulfide generated biomass.

Time course measurements were in three back-to-back endpoint experiments of the indicated duration. Biomass production is restricted to zones within the reactor where hydrogen sulfide and oxygen coexist. Maximal biomass production is favored by high input concentrations of hydrogen sulfide. The reactor, as presently implemented, functions in a state of oxygen limitation. Hence, excess hydrogen sulfide is present in the effluent, and substantial amounts of elemental sulfur are contained within the produced biomass.

Bacterial Chemosynthesis for Aquaculture

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Department of Biology

As high quality natural gas and petroleum become increasingly limited it is inevitable that synthetic and unconventional sources of energy will be emphasized. Coal seems destined to become a major source of energy.

Hydrogen sulfide and carbon dioxide-containing sour gases, derived from various industrial processes for the cleanup of coal-derived synthesis gases and unconventional natural gases, constitute a significant and potentially hazardous by-product of gaseous fuel refinement. Hydrogen sulfide is presently removed from sour gas by chemical oxidation to sulfur or sulfate. However, the energy released during this process is unharvested and unutilized. Carbon dioxide is in significant part released to the atmosphere.

We have proposed that sour gases be considered, not as a waste product (by fuel gas manufacture), but as a resource of biologically harvestable energy and carbon. A unique physiological grouping of microorganisms, the colorless sulfur bacteria, possess the catalytic capacity for the utilization of toxic and bothersome sulfur compounds. The energy derived from these transformations is reclaims (in part) for the conversion of waste carbon (CO_2) into cellular biomass and the sulfur detoxified.

The success of these biological transformations in supporting dense communities of shellfish within hydrothermal vent ecosystems have led us to suggest that hydrogen sulfide-generated biomass might successfully be integrated into the production of mariculture derived products of high commercial value.

Our continuing studies for demonstrating the feasibility of such a plan have proceeded along two lines: a) studies of hydrogen sulfide supported biomass generation and b) the determination of the suitability of such material as a food source for filter feeding bivalves.

Results of studies employing a laboratory scale lamellar reactor have clearly confirmed that continuous and long term (two years) production of attached forms of colorless sulfur bacteria using gaseous hydrogen sulfide as the sole source of energy is possible. Maximal production requires the input of hydrogen sulfide in excess of 1 mM and a means for the continuous input of oxygen (Figure 2).

Since the produced biomass is to serve as a source of food for the type of shellfish to be grown, it is important to analyze the material with respect to its potential nutritional value. Data of this nature are shown in Table 1 where biomass from duplicate reactor units was analyzed for organic matter composition, elemental sulfur and mineral content. For establishing the influence of nitrogen on the composition and quantity of the biomass produced, one of the units was continuously supplemented with 50 uM ammonium.

In keeping with its role as an intermediate in the biological oxidation of hydrogen sulfide to sulfide, elemental sulfur had been a significant and problematic component of the produced biomass, placing organic carbon as a minor component. The presence of exogenous nitrogen, however, dramatically reduced the levels of elemental sulfur present and approximately doubled the production of organic carbon. The organic matter reached a 39-42 percent protein level. These values are within the range expected for actively growing bacteria. The data suggested a significant potential for the production of organic

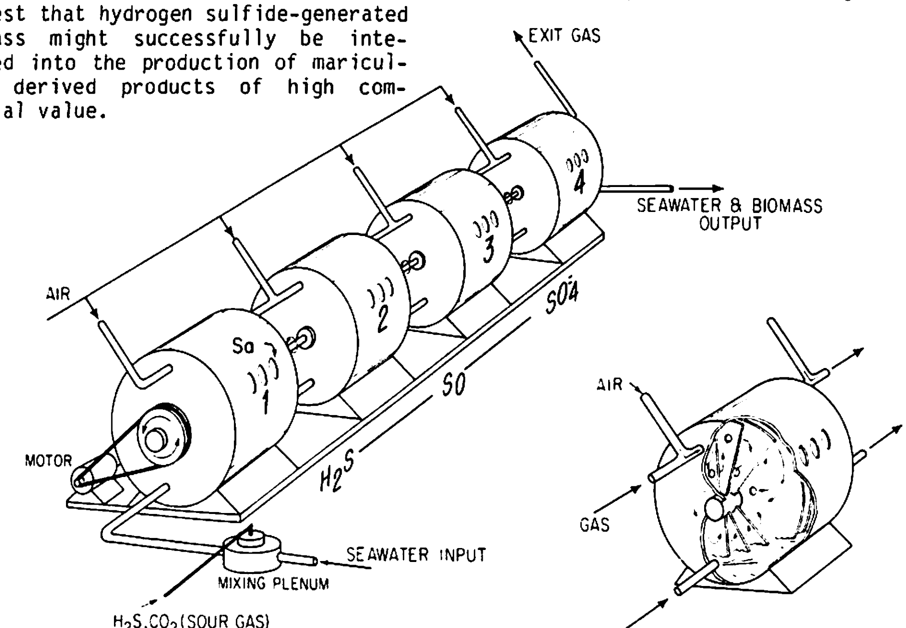

Figure 2. Laboratory Scale Rotating Biological Contactor for growth of sulfur oxidizing bacteria. Symbols: m, small electric motor for slowly driving the rotating discs (d); sa, sample ports. The spatial separation of the sequential oxidation of hydrogen sulfide to elemental sulfur to sulfate is indicated in the upper panel.

carbon of high nutritional quality and that elemental sulfur composition may in part be regulated by the nutrient regime established within the reactor.

Results of short term feeding studies have clearly demonstrated that the blue mussel Mytilus edulis will actively filter hydrogen sulfide generated biomass from seawater and pass the material through the intestinal tract. In long term feeding studies employing continuous flow aquaria, however, we experienced substantial mortality of the experimental animals in a period of less than one month. Mortality was clearly associated with the feeding of bacterial biomass as both started and algal fed controls remained viable. Toxic hydrogen sulfide was totally absent from the system.

The cause of the difficulty was found to be the presence of elemental sulfur within the produced biomass. The experimental animals either experienced a) chronic toxicity that became manifest upon passage of elemental sulfur through the intestinal tract for prolonged periods or b) a mechanical interference with proper functioning of the mussel's gill system as a result of particle densities too high for the necessary supply of organic carbon. It is evident that a means for minimizing elemental sulfur in the produced biomass is necessary.

To this end we have constructed a new laboratory scale generator that possesses features lending to the production of biomass low in inorganic sulfur. The device is based in concept after the Rotating Biological Contactor (RBC), a low energy, low maintenace alternative to the activated slude digestor and trickling filter in municipal and industrial waste treatment.

Diagrammatically illustrated in Figure 1, the newly constructed RBC consists of a four-stage array of circular discs housed within gas-tight cylindrical tanks and coaxially mounted on a central rotating shaft. The discs are partially immersed in a continuously flowing stream of seawater enriched with hydrogen sulfide. As the discs rotate air enters the lamellar interstices while the seawater medium trickles over a layer of sulfur oxidizing microorganisms that become established on the disc surfaces. Alternate exposure of the attached microorganisms to hydrogen sulfide-enriched seawater and to oxygen in the enclosed gas stream provide conditions more favorable for growth of sulfur oxidizing bacteria than was previously possible. As the bacterial biomass grows it is sloughed from the disc surfaces and carried from one reactor stage to the next in the cntinuous flow of seawater. Within each reactor stage the gaseous and aqueous phases would be homogeneous in composition, with a chemical and biological gradient being manifest between stages in the direction of flow.

Oxygen may be continuously supplied to each reactor stage (Figure 1) as necessary, and the produced biomass continuously and automatically removed from the reactor. The natural tendency for the spatial separation of sequential biological activities (i.e., oxidation of hydrogen sulfide to elemental sulfur and sulfur to sulfate) permits total removal of hydrogen sulfide from the effluent stream and provides conditions favoring continued utilization of elemental sulfur by the microbial biomass.

Studies are continuing for production of hydrogen sulfide-generated biomass of substantially improved composition that will permit its evaluation as food for the growth of Mytilus without the undesirable effects of elemental sulfur.

Table 1. Analytical Characterization of Freeze-Dried Biomass Formed Within the Reactor (Values are given as weight percent)

	Culture grown without exogenous NH_3		Culture grown with added NH_3	
Total organic matter	11.6	(17.6)	18.3	(35.4)
Lipid	1.83	(2.8)	0.41	(0.8)
Protein	4.60	(7.0)	7.66	(14.8)
Remaining organic matter	5.09	(7.7)	10.25	(19.8)
Elemental sulfur	54.4	(82.4)	33.4	(64.6)
Inorganics, mostly sea salt	34.0	(--)	48.3	(--)
Empirical formulae for the non-lipid organic fraction normalized to one carbon atom	$CH_{4.12}N_{0.19}O_{0.69}S_{0.09}$		$CH_{3.60}N_{0.20}O_{0.72}S_{0.08}$	
C:N (by weight)	4.3		4.5	

Aliquots of biomass separately pooled from two reactor units (36 hrs of growth, temperature 25°C) was freeze-dried and kindly analyzed by the Research and Development Section of the Phillips Petroleum Company, Bartlesville, OK. The analysis was overseen by J. Gordon Erdman. Seawater flow rates were 1.5 liter hr^{-1} and hydrogen sulfide input levels 1.1 mM. Ammonium was supplemented at 50 μM. Values in parentheses were computed without contribution of seawater salts which were entrained within the biomass during harvest by centrifugation.

COASTAL ZONE — Physical/Geological Aspects

Sediment Transport in a Tidal Inlet

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Dept. of Geology and Geophysics

The geologic fate of inlet/estuary systems is directly affected by net rates and pathways of sediment transport within them. Prediction of this sand transport requires comprehension of the fluid mechanics of the inlet/estuary system. In particular, one must examine the distortion and frictional decay of the tide as it propagates through the estuary. Modelling the tidal response of the estuary requires proper consideration of the hydrodynamic implications of water depths approximately equal to the tidal range, large amplitude bedforms and complex channel geometry.

The results of our work have implications for a large cross section of interests. Besides the long-range consequences of infilling of estuaries and bays, the study addresses a question central to the design and maintenance of navigation channels and harbors. From one point of view, a channel maintenance program can be directed towards operations which are optimal in a sediment transport sense. From a second point of view, navigation projects which have detrimental affects on the estuary or bay it is serving can be avoided. An example of a potential adverse effect produced by a navigation project is increased tidal propagation due to reduced bottom friction in deeper navigation channels, resulting in higher high water excursions and possible associated shoreline damage.

We have approached the problem of inlet sedimentation in two different ways. The prototype is Nauset Inlet, a natural, unstructured tidal inlet on Cape Cod, Massachusetts. An historical analysis of inlet migration at this

(cont'd.)

Nauset Inlet with adjacent barrier beach and wetlands, Cape Cod, Mass.

site was recently completed (Aubrey et al., submitted; Speer et al., 1982). The study describes patterns of inlet migration and proposes several mechanisms to explain the unusual tendency for Nauset Inlet to migrate against the grain of longshore transport. The effect of extensive inlet migration with consequent flood tide delta development on the historical evolution of the estuary was addressed. We have also conducted field experiments in August 1980 (Aubrey, 1980-1981 Sea Grant Report) and September 1981 to examine the fluid mechanics of the estuary. The field measurements are being complemented by a numerical modelling effort.

The September 1981 field experiment produced measurements of sea surface elevation at many locations within the estuary (Figure 1). The flow field was monitored by Eulerian velocity measurements at several locations and surface drifters. Extensive precision bathymetric work, including repeated profiling of large bedforms over several tidal cycles, completed the experiment. The sea surface elevation measurements enabled us to examine the tidal propagation problem in detail. The measurements revealed significant distortion of the tide as it passed through the system including strong non-linear energy transfers to harmonics of the M_2 tide (fig. 2 and 3). The frictional dominance of this particular inlet/estuary was verified by strong tidal damping and large phase lags associated with tidal propagation over short distances (see also Aubrey, 1980-1981 Sea Grant Report). Large tidal asymmetries, also observed in current meter records, are of crucial importance in understanding patterns and rates of inlet sediment transport.

Based on our field measurements, it is clear that the mechanisms responsible for generation of tidal asymmetries must be investigated. In particular, the phenomena of nonlinear energy transfers and strong frictional

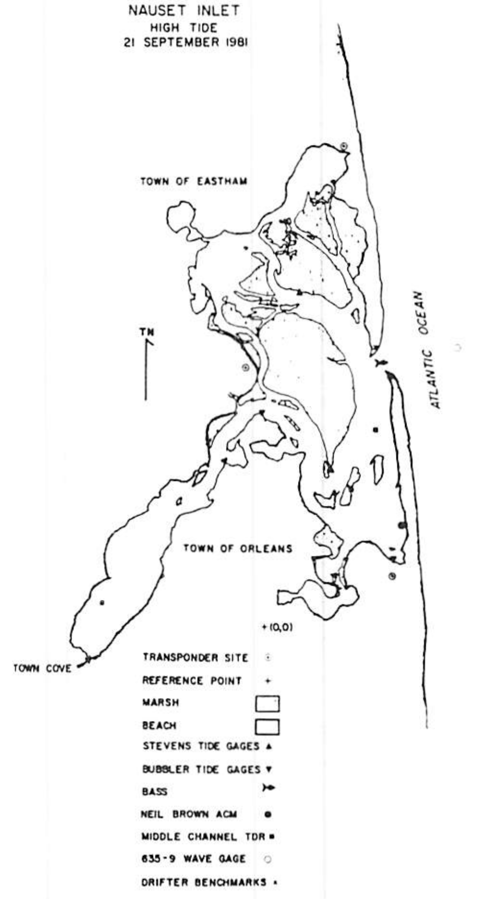

Figure 1.
Instrument deployment for September, 1981, field experiment at Nauset Inlet. Array extended from the ocean, through the inlet, and into the extremities of the estuary.

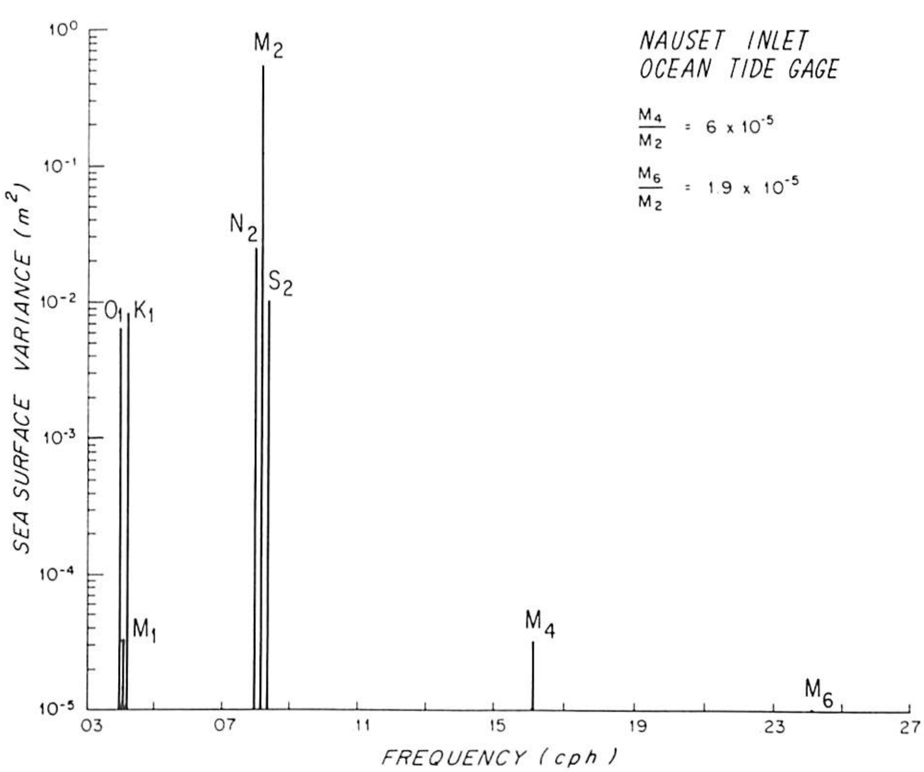

Figure 2. Periodogram derived from a 29-day tide record taken at a 10 m water depth off Nauset Inlet. Dominant tide is semi-diurnal, with low energy in higher frequency harmonics.

effects have been identified as key physical processes. Current tasks for this project include testing several numerical schemes developed to investigate the tidal propagation problem.

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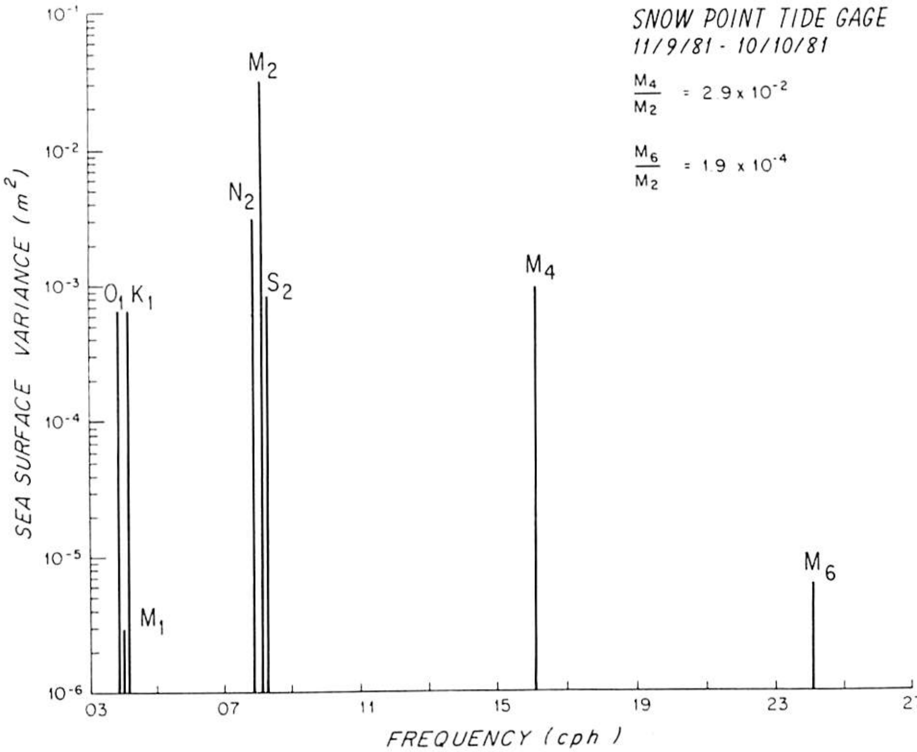

Figure 3. Periodogram derived from a 29-day tide record taken at a 3 m water depth within the estuary, approximately 3 km from the inlet (along streamlines). Note the marked increase in harmonic tides M_4 and M_6 (overtides), which impart asymmetry to the surface tide. This asymmetry results in a flood of reduced duration but higher velocity, increasing net sand transport farther into the estuary.

Development of a Loran-C Drifting Buoy for Coastal Circulation Studies

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Frederick Hess and William Burke
Department of Physical Oceanography

During the past year we have continued our work on the development of the Loran-C drifting buoy and drogue. Early in the year work was focussed on the construction and outfitting of the surface buoy. Built of fiberglass with a foam core, the surface unit is designed to contain and protect the Loran-C electronics package, antenna and power supply (Figure 1). Upon completion, the buoy was anchored in the harbor and its performance characteristics evaluated, a test which the unit successfully passed.

During the summer months, the focus of activity shifted to the drogue unit. Using a design developed and a scale model tested by W. Burke in 1980, plans were drawn up for a new type of drogue which holds potential to significantly improve drifting buoy performance. The drogue was built in late summer, and its performance was tested in two stages. First, the drogue was suspended in the tidal flow past the WHOI pier and its behavior qualitatively examined. The drogue was then taken out on the R/V ASTERIAS and its drag coefficient quantitatively determined. This test indicated that the drogue's drag coefficient was even higher than predicted by the scale model tests.

F. Hess has been working on the development of the electronics package and related hardware and soft ware. It is expected that the electronics can be brought together with the surface buoy and drogue by mid-fall and comprehensive testing of the system can begin. At present, it appears that this drifting buoy system has the potential to successfully fill the need for an accurate coastal Lagrangian drifter and become a valuable tool for coastal circulation research.

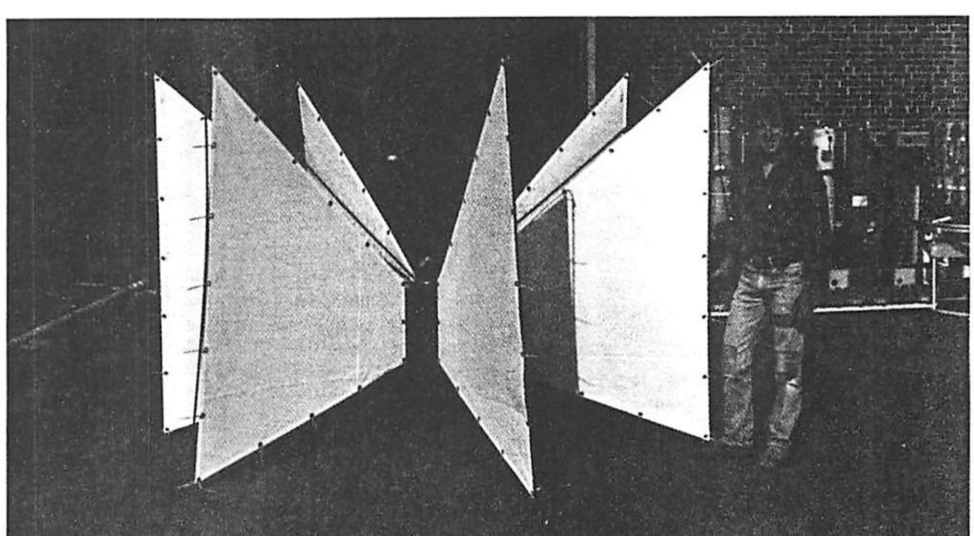

Figure 1. Completed buoy ready for testing.

Laser Doppler Velocimeter for Wave Boundary Studies

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A two-axis backscatter laser Doppler velocimeter (LDV) has been developed to study the region of nonlinear interaction between the surface-wave induced motion and currents in the bottom boundary layer of the coastal seas. In theoretical models on this interaction available to date, increased shear stress on the bottom is predicted when currents and waves are present simultaneously, in comparison with the case of currents or waves acting alone. Established scaling laws assert that the thickness of this region of interaction - leading to enhanced stress, hence mixing and sediment transport - is of order ku_*/ω where K is von Karman's constant, u_* is bottom friction velocity and ω is the radian frequency of wave motion. Thus, this so called wave boundary layer region is of order (2 cm) thick. The laser velocimeter was intended to investigate validity of the available models by making measurements in the wave boundary layer.

The LDV was recently deployed in the coastal waters off Woods Hole, and performed as expected. Scant data obtained due to an inappropriate LDV frequency tracker were of little use scientifically due to the poor data rate achieved. An entirely new Doppler signal processor has since been designed and tested in the laboratory. This processor computes the complete Fourier transform of the incoming optical signal and picks off the peak frequency (i.e., frequency of highest spectral density) which is recorded as the water velocity. This processor is being integrated into the underwater LDV, and will mark the completion of a Doppler frequency processor optimally suited for the weak optical signals characteristic of low-power lasers for oceanographic work. Meanwhile, during the past year, numerous dock tests were conducted to study optical alignment rigidity, the nature of the optical signal, etc.

Several deployments in coastal waters are scheduled in the next few months to collect the data on wave boundary layers dynamics. These will be analyzed in the remaining part of the current fiscal year.

COASTAL ZONE — Biological Aspects

Laboratory and Field Studies of the Larvae of the Ocean Quahog *Arctica islandica*

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Department of Biology

The long term objective of this project is to develop a three dimensional, time-specific model of dispersal of bivalve larvae in the Middle Atlantic Bight and to examine the influence of physical forcing on the dispersal process. Arctica islandica was chosen as a prime candidate species for model development because of (a) its abundance throughout the Middle Atlantic Bight in a well defined depth range, and (b) the value of the species as a commercial fishery crop. Due to their essentially sessile adult form and a habit of recording much significant information on growth and age in their valves (shells) the bivalve molluscs are attractive subjects for comprehensive life history studies. A combination of data on size distribution and age of A. islandica adult stocks (presently being collected by the National Marine Fisheries Service) with a model of larval dispersal for the same species offers the opportunity to develop a comprehensive understanding of recruitment and growth in exploited populations. Model development is, therefore, of both theoretical and practical interest.

During the period 1978-81 I investigated the seasonal cycle of gonadal development of adult Arctica islandica collected from a depth range of 30-45m on the Southern New England Shelf and, subsequently, cultured and described the larval forms of A. islandica. During the 1981-1982 Sea Grant funding year I have investigated the response of A. islandica larvae to isolated pressure and temperature stimuli in the laboratory. The specific objective of the 1981-82 studies was to

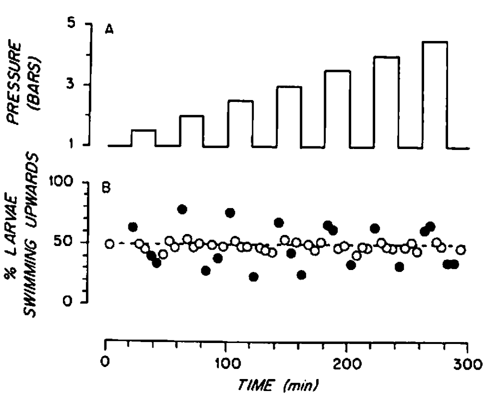

Figure 1. Swimming response of 160 long A. islandica larvae to stepwise increases or decreases in pressure. A: pressure in bars. B: larval swimming response by five minute intervals. ● indicates a significant (5 percent level) difference from response at equilibrium at one bar.

develop, from knowledge of the physical structure of the water column in the Middle Atlantic Bight, a predictive capability describing depth distribution of the larval forms in the field. In combination with knowledge of prevailing horizontal current velocity and direction this approach can then be extended to address horizontal dispersal. A separate program was also initiated to examine seasonal depth distribution of larvae in the field. The field program therefore provides a blind check on the value of laboratory generated data.

A. islandica larvae alternate periods of active upward swimming in vertically oriented helices with periods of passive sinking. Depth regulation is effected by this "sink and swim" behaviour. The larvae cannot swim in the horizontal plane. In laboratory systems, veliger larvae of the animal were exposed to sequential increases and decreases in hydrostatic pressure. Larvae in the length range 160 μM - 196 μM consistently exhibited a net upward movement following an increase in pressure and a net downward movement following a decrease in pressure (Figure 1). The threshold pressure change to elicit a response is <0.5 bars. Larvae of 170 μM length respond to increased pressure by both decreasing the diameter of the helix and increasing the height gain per rotation. Larvae of 196 μM length respond to increased pressure by increasing height per rotation and vertical velocity. Larvae of 202 μM length exhibit no significant change in swimming behavior with increased pressure.

In a thermal gradient from 9 to 25°C trochophores of A. islandica swim continuously and show no aggregation or temperature preference. Early veligers exhibit decreasing maximum and minimum temperature tolerances with preferential aggregation, depending upon size, in the range 12-18°C. Larvae of 204 μM length show no temperature preference in the range 6-20°C.

Laboratory and literature data sets were combined to construct a predicted time and depth specific diagram of density of occurrence of A. islandica larvae at a known station on the Southern New England Shelf. This is illustrated in Figure 2.

During the period April-December 1981 14 cruises, each of one day duration, were made to a station in 43 m of water in Rhode Island Sound. At this station depth specific plankton tows were made, always during the hours of 1030-1430, at 1 m, 10 m, 20 m, 30 m and 40 m with a Clarke-Bumpus net. On collection retained material was stained with Rose Bengal and fixed with buffered formalin. Fixed material was subsequently picked for bivalve larvae under a low power dissecting microscope. On each visit to the station vertical profiles of temperature were made using a sampling interval of 5 m (Figure 3). During the period June-December water samples were collected from the same depths as the plankton tows using a Niskin bottle, a subsample filtered and the retained material assayed for chlorophyll a (Figure 4).

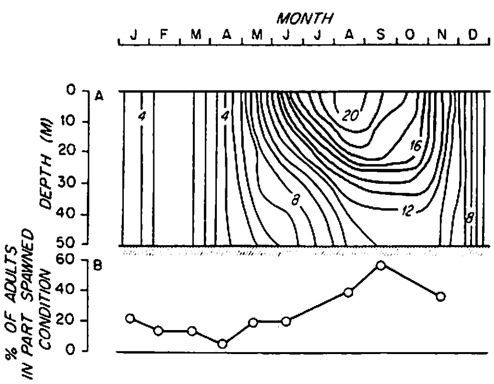

Figure 2. A: Depth versus time isotherm plot of water temperature structure on the southern New England Shelf (replotted from Mann, 1982). Shaded area represents predicted depth range of occurrence versus time of A. islandica larvae. B: Percentage of adult A. islandica in part spawned condition versus time (replotted from Mann, 1982).

Thermal stratification began to develop in May and intensified through June and July. By the end of July an intense thermal gradient (0.5°C/m) was evident between 15 and 23 m. During the period August-September the depth of intense stratification increased as surface temperature gradually decreased. A maximum bottom temperature of 15°C was recorded in mid September. Cooling continued until, by late October, a well mixed water column was again evident.

A weak chlorophyll maximum in mid June was observed at 20 m, immediately below the region of sharp thermal stratification. By early August a chlorophyll maximum (~2 µg/L) extended from 25 to 35 m depth, corresponding to a thermal range of 15-13°C decreasing

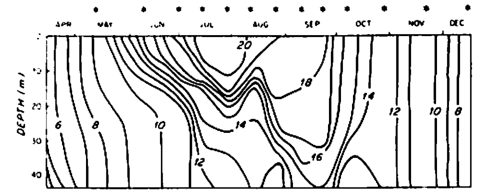

Figure 3. Depth-time isotherm diagram of temperature structure (°C) during the period April-December 1981 based on vertical profiles with a sampling interval of 5 m. * marks a sampling date.

with depth, and again below the region of most intense thermal stratification. In contrast the water column from 0-15m had both the highest temperature (>19°C) and lowest chlorophyll a content (<0.5µ g/L). In spite of some minor thermal stratification from 30-43 m in late August chlorophyll a was, by this time, evenly distributed throughout the water column (~0.4 µg/L). An intense surface bloom of chlorophyll a (>3.0 µg/L) extending to below 20 m (~2.0 µg/L) was observed in early October following the breakdown of thermal stratification and mixing of the water column. This bloom subsided by late October, after which little change in chlorophyll a values, either temporally or through depth, was noted.

A depth versus time diagram for total numbers of all species of bivalve larvae retained per tow is given in Figure 5. Few larvae were evident until early August when a large concentration was recorded at 20 m. This larval concentration corresponds to both the 15°C isotherm (Figure 1) and a high chlorophyll a concentration (Figure 3). By contrast low concentrations of larvae were recorded simultaneously in the higher temperature (> 19°C) surface water and at 40 meters. By early September very high (> 20,000 larvae/tow) concentrations of larvae were recorded between the 17°C and 18°C isotherm at 20-30 m depth. Lower concentrations

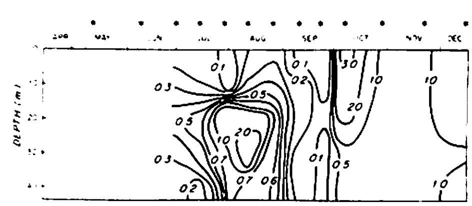

Figure 4. Depth-time contour diagram of chlorophyll a concentration (µg/L) for the period June-December 1981 based on Niskin casts at 10 m depth intervals in the water column. * marks a sampling date.

were again found at the 1-10 m (2000-5000 larvae/tow) and at 40 m (5000-10,000 larvae/tow). By early October, as vertical mixing of the water column began, uniformly high (>10,000 larvae/tow) concentrations of larvae were recorded from 1-40 m. High surface concentrations of larvae were evident until late November. Data for deeper in the water column was unavailable in late October due to net failure; however, larval concentrations (<5000/tow) considerably lower than surface values (>20,000/tow) were recorded from 10-40 m in late November despite a well mixed, isothermal (10.5°C) water column. With decreasing water temperature lower larval concentrations (< 2000/tow with greatest aggregation at 20-30 m) were evident throughout the water column in December.

Despite the fact that the predictive diagram (Figure 2) for occurrence of larvae is specific to A. islandica alone there is generally good agreement between the laboratory generated diagram and the field data (Figure 5). A more rigorous testing of the "Figure 2" data will require further work with the larval samples collected and reported in Figure 5 to identify both species present within the sample, and the size distribution of those species. This will highlight the period when larvae

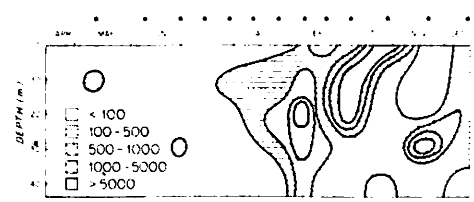

Figure 5. Depth-time contour diagram of numbers of bivalve larvae retained in a standard depth specific plankton tow (see text) during the period April-December 1981. * marks a sampling date.

survive to a size at which metamorphosis can be completed and a sessile, benthic lifestyle initiated. Analysis of species occurrence and size distribution is planned for a future Sea Grant funding year. In the laboratory a further effort to improve the "Figure 2" model will require behavioural experiments that examine multiple environmental stimuli in combination, rather than in isolation, and which better mimic true environmental conditions.

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Toxic Dinoflagellate Blooms (Red Tides) in Southern New England

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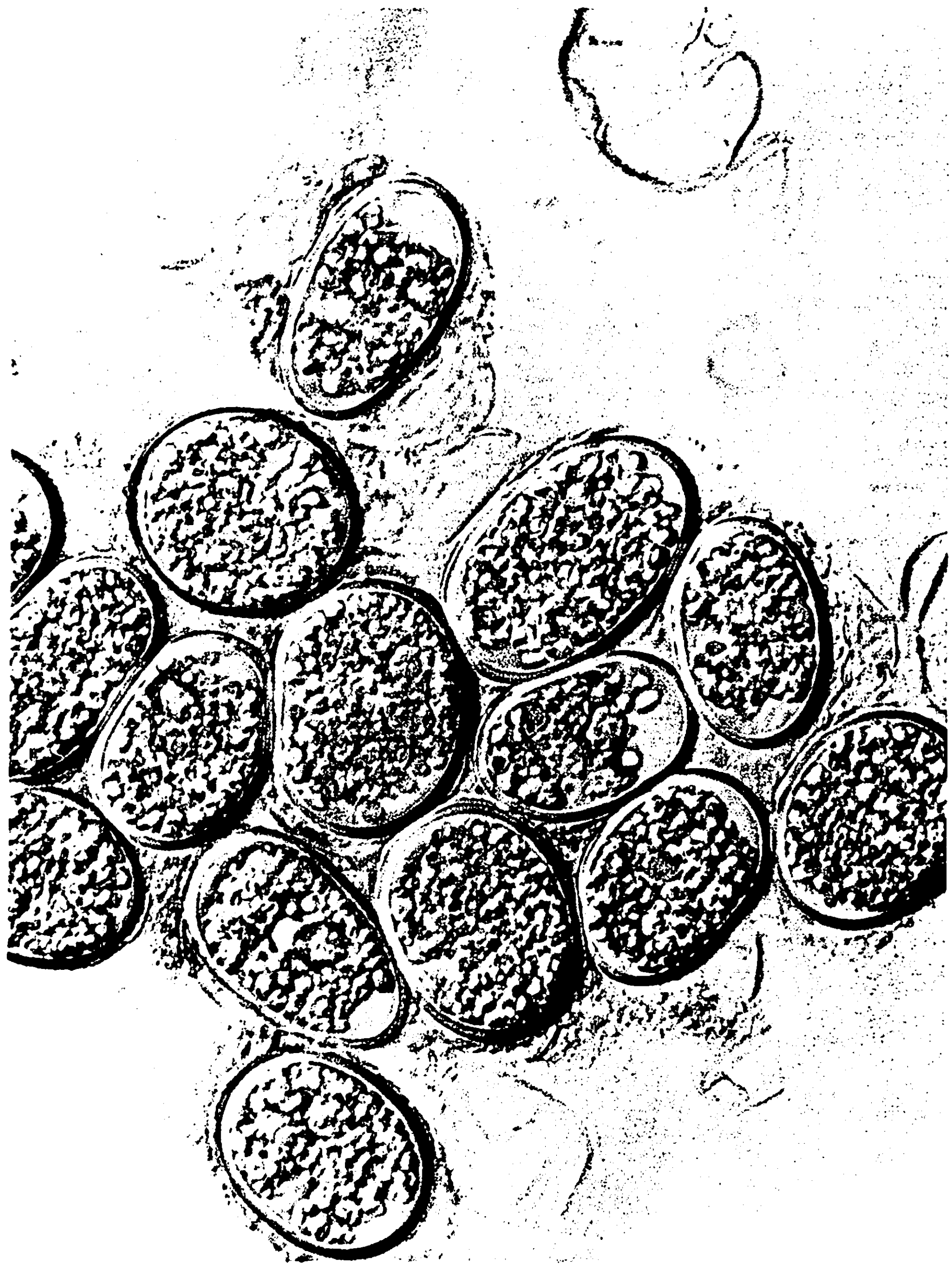
Department of Biology

The overall objective of this project is to understand the dynamics of toxic dinofagellate blooms (red tides) in the southern New England region in sufficient detail to permit the development of useful prediction, monitoring, and/or control strategies. The emphasis over the past several years has been placed on blooms within small embayments, typical locations of paralytic shellfish poisoning (PSP) outbreaks at the southern limit of the geographic range of Gonyaulax tamarensis, the causative dinoflagellate. During the past year, this project has examined three general aspects of G. tamarensis population dynamics.

The first effort was to continue our detailed examination of three Cape Cod salt ponds where G. tamarensis blooms are localized. This involved both the collection of new data and the reduction and analysis of results from the spring of 1980 and 1981 (Figure 1). One important aspect of this data set is that sexual life cycle stages appeared much earlier in each bloom (Fig. 1B) than expected. Not only were nutrient concentrations relatively high, but temperatures had just risen to optimum levels when sexual induction occurred. Thus the common assumption that sexuality (leading to dormant cyst formation) is induced by adverse environmental conditions is not justified from field data. Concurrent monitoring of cyst abundance in pond sediments indicates that a very small percentage of the viable cyst population (<1%) germinated in 1981 or 1982, two years with no significant G. tamarensis population development. Further study is needed to delineate the quantitative importance of cysts in both bloom and non-bloom years.



Resting cysts of Gonyaulax tamarensis (red tide).

This year we also completed a study of behavioral factors which localize G. tamarensis populations within the salt ponds. The combination of a vertical migration study using numerous closely-spaced vertical samples over two 24 hour periods and a dye study with similar resolution indicate that the vertical swimming behavior of G. tamarensis prevents it from being flushed from the ponds under normal conditions. For example, over one 24-hr period, more than half of the pond volume passed through its shallow, narrow inlet channel, while less than 7% of the G. tamarensis population was lost. Dye measurements indicated that the incoming tidal flow displaced stratified bottom water, forcing surface water to leave on the ebbing tide. Thus in the absence of a behavioral accumulation mechanism, G. tamarensis would be mixed and flushed from the pond in the same proportions as the water. We have also obtained data indicating that major storm events are effective in mixing the population and transporting it from the pond. These results have clear implications with respect to the localization and/or dispersal of toxic cells in this region.

The third area of research examined the posibility of geographic localization of the highly sensitive G. tamarensis due to trace metal inhibition. Using a bacterial bioassay technique, we detected significant differences in the total copper concentration, copper complexing capacity, and complexing ligand strength between two locations - one subject to PSP outbreaks and the other with no history of the problem. The net result of variations in these parameters was, however, that both stations had approximately the same level of copper toxicity through time (measured by the activity of the free cupric ion), contrary to our expectation that water in the PSP-prone station would be more suitable for growth. During that year, G. tamarensis did not bloom, despite the presence of small numbers of cells throughout the sampling season. Since our calculated copper activities fell in the middle of the inhibitory section of the dose response curve for this organism, it seems likely that both stations were somewhat toxic during the study. If similar measurements during an active G. tamarensis bloom give indications of non-inhibitory conditions, this research will have made a significant contribution towards our understanding of one factor regulating the distribution and abundance of this toxic dinoflagellate.

In summary, by focusing on small embayments this project has learned a great deal about the mechanisms for PSP development and dispersal in southern New England while also compiling valuable information relevant to outbreaks in other hydrographic regions as well. Future plans call for a shift in research emphasis towards more widespread blooms in the deeper, nearshore waters of northern Massachusetts.

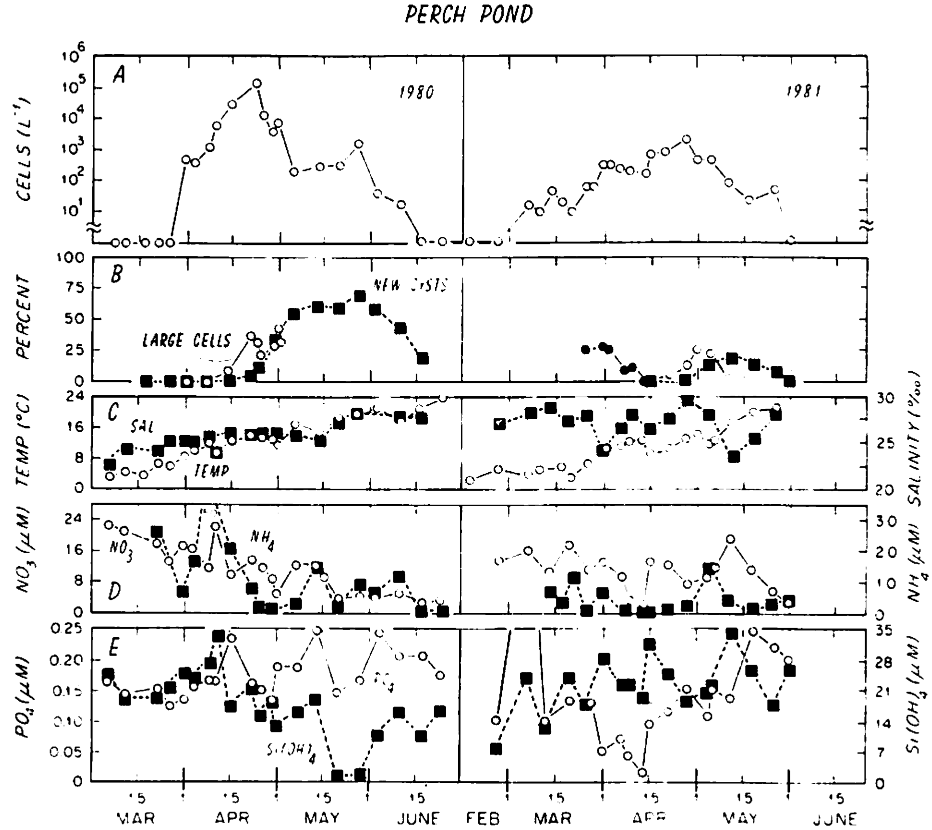


Fig. 1. Spring bloom time series for Perch Pond in 1980 and 1981. A. Gonyaulax tamarensis cell densities: B. new cysts as a percent of total cysts in surface sediments, and planozygotes (the large precursors to cysts) as a percent of total motile cells; C. temperature and salinity; D. nitrate and ammonium; E. phosphate and silicate. Note the appearance of planozygotes (B) well before the 1980 bloom peak, and under seemingly favorable temperature and nutrient conditions.

Impact of *Favella* Predation on Dinoflagellate Blooms

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Department of Biology

Although toxic dinoflagellate blooms (red tides) cause severe economic and public health problems, relatively little is known about the role of natural predation in controlling dinoflagellate populations. For example, Gonyaulax tamarensis is responsible for paralytic shellfish poisoning (PSP) from the coast of northeastern Canada through New England (Anderson and Wall, 1979).

Simple models, taking into account salinity dependent temperature regulation of population growth, can predict the development of G. tamarensis blooms up to the point of peak abundance (Watras, Chisholm, and Anderson, 1982). However, this model does not predict the dramatic population declines seen in the field; grazing may be responsible for this decline.

At least in the areas subject to PSP outbreaks on Cape Cod, macrozooplankton grazing appears to have a minimal impact on bloom dynamics (Turner and Anderson, submitted). However microzooplankton, particularly Polydora sp. larvae and the tintinnid Favella (ciliated protozoa, suborder Tintinnina) may have a substantial impact. Large numbers of Polydora larvae coincident with Gonyaulax tamarensis may be unique to Cape Cod salt ponds but the tintinnid, Favella, appears to co-occur with toxic dinoflagellate blooms in many localities.

Our approach to evaluating the impact of predation by Favella on dinoflagellate blooms includes: (1) field surveys to determine the temporal (diurnal and seasonal) and microspatial (horizontal and vertical) distribution of dinoflagellates and Favella; (2) Laboratory experiments to determine the growth rate and feeding rate of Favella; and (3) in situ caging experiments.

We have surveyed dinoflagellate and Favella populations during seven dinoflagellate blooms in Cape Cod estuaries. Gonyaulax tamarensis was only an important component during two of these dinoflagellate blooms. Favella densities were as high as 3000 cells l^{-1} in integrated surface to bottom samples and as high as 7000 cells l^{-1} at particular depths. In two of the three diurnal vertical distribution studies we made, Favella density was positively correlated with dinoflagellate density. Horizontal distributions within one estuary also showed that Favella was associated with dinoflagellate patches.

Laboratory studies have shown that: (1) Favella is a selective predator on dinoflagellates (Stoecker et al 1981). (2) Gonyaulax tamarensis cells with diameters less than about 35 μm are consumed but larger vegetative cells or zygotes are not consumed (Fig. 1). (3) Under optimal conditions of temperature (15-20°C) and food density (2-6 x 10^9 μm^3 dinoflagellate cell volume l^{-1}), Favella has a generation

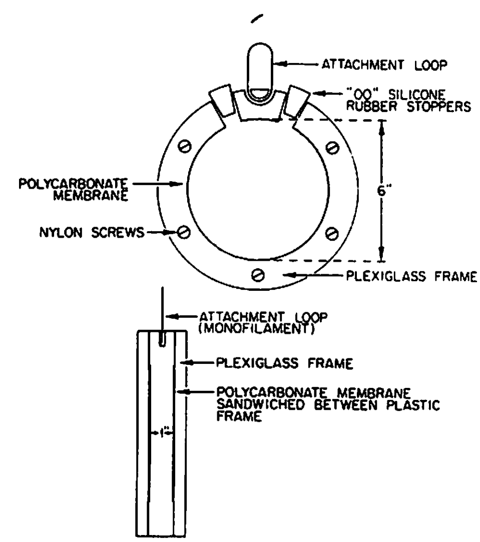

Fig. 1. Changes in the size distribution of a population of Gonyaulax tamarensis exposed to predation by Favella. Favella consumes only the smaller (less than about 35 μm in length) Gonyaulax cells.

time as short as 12 h (Stoecker, Davis, and Provan, in press). (4) An individual Favella can consume 6-8 toxic Gonyaulax cells h^{-1} at dinoflagellate densities within the range found in situ (Stoecker and Guillard, in press). (5) The predation rate of Favella on dinoflagellates is influenced by prey density. Light, by causing aggregation of dinoflagellates, can increase pre-

(cont'd)

dation rates (Stoecker and Guillard, in press). (6) Estuarine copepods prey on Favella in preference to dinoflagellates and thus copepod grazing could, under certain circumstances, reduce the overall grazing pressure on dinoflagellates.

Microzooplankton cages (Fig. 2) were developed to investigate the in situ growth of Favella. Nine caging experiments were done during dinoflagellate blooms. These in situ experiments indicated that: (1) Favella preys on other ciliates as well as on dinoflagellates and that this interaction can partially regulate microzooplankton grazing pressure on dinoflagellate blooms and (2) food availability, parasitism, and life cycle events may influence the net in situ growth rate of Favella (Stoecker, Davis, and Provan, in press) and thus its potential to grow rapidly in response to dinoflagellate blooms. We had planned to use these caging experiments to estimate Favella's in situ grazing rate on dinoflagellates but this was impossible because other microzooplankton predators on dinoflagellates were present simultaneously (Stoecker, Davis, and Provan, in press).

These data suggest that, under certain circumstances, Favella and other microzooplankters may limit the duration and intensity of dinoflagellate blooms. For example, if we assume a Favella density of 1000 cells l^{-1} and a predation rate of 6 G. tamarensis cells $Favella^{-1}$ h^{-1} then the Favella could consume 6000 Gonyaulax cells h^{-1}; this would often be a sizeable fraction of the Gonyaulax population. We have no direct proof that toxic dinoflagellate blooms would last longer and reach higher densities in the absence of Favella predation, but this is a logical assumption given the present data.

By culturing Favella in the laboratory, we have learned that this tintinnid is sensitive to trace metal chemistry. We are now investigating the effects of trace metal speciation (particularly cupric ion activity) on Favella because changes in the trace metal chemistry of estuaries due to run off, pollution, alteration of inlets, or potential control strategies may affect both dinoflagellates and Favella. Sources of copper input to estuaries include leaching of copper from antifouling paints used on boats and land runoff and outfalls, both of which usually are enriched in copper compared of seawater. A variety of control techniques have been considered (Rounsefell and Nelson, 1966 and references cited therein; Archer and Elgavish, 1980; Eng-Wilmot et al., 1979a and b). With respect to the PSP problems, one possibility stems from the observation that G. tamarensis is significantly more sensitive to copper than other common phytoplankters and thus that careful manipulation of trace metal chemistry through changes in water exchange patterns or direct manipulation of chelators plus metals may be a way to control blooms. However, control measures may eventually backfire if they disrupt natural controls such as predation. The value of natural controls is often not measurable until they are removed. Therefore it is important to determine the effects of trace metal perturbations (especially changes in cupric ion activity) on Favella; we are now doing this and these data will be valuable in evaluating potential control measures and in designing integrated management programs such as those which have been successfully applied to the control of insect pests in terrestrial environments (Batra, 1982).

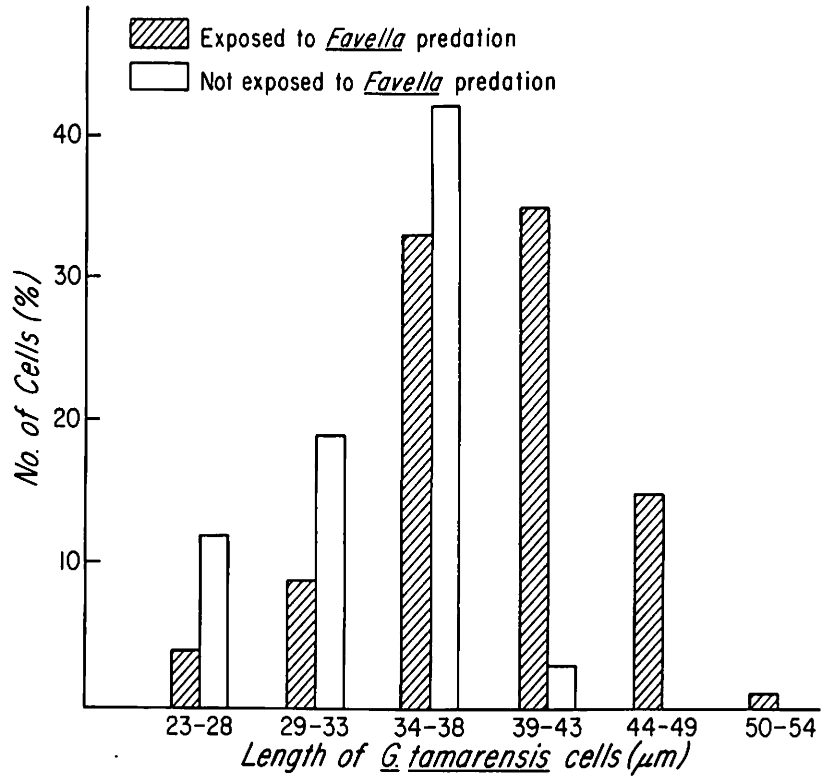

Fig. 2. Microzooplankton cage.

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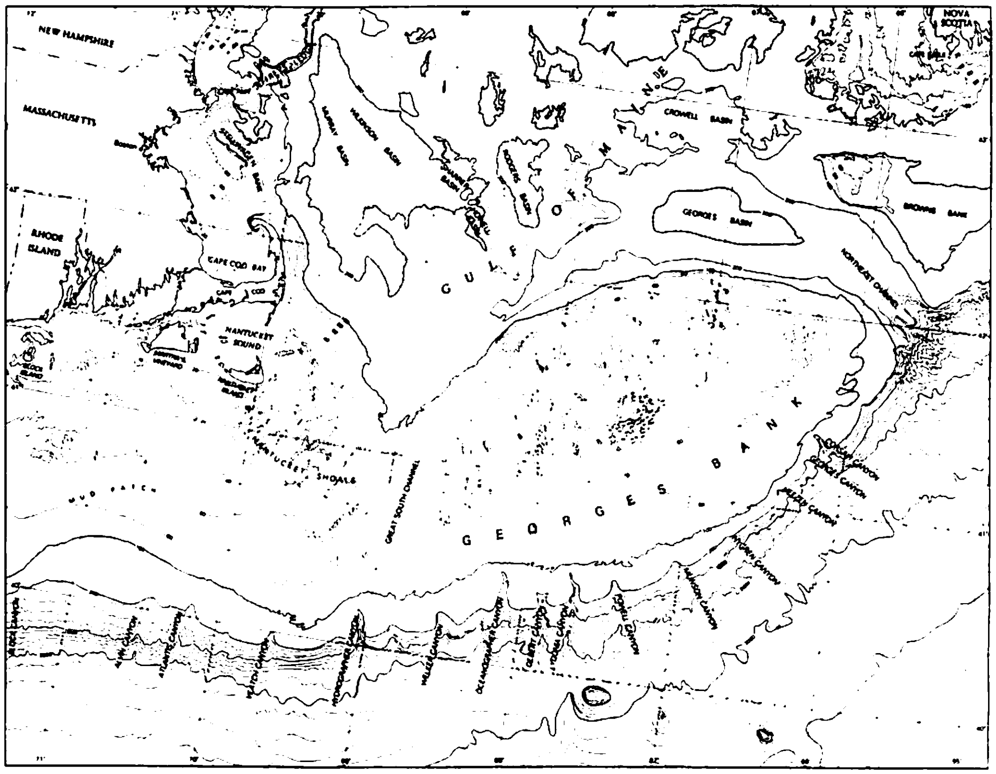
Georges Bank and Its Surroundings: A Book and Atlas

Richard H. Backus
Department of Biology



Standard base map of the Georges Bank area prepared for the upcoming book and atlas.

The Coastal Research Center of the Woods Hole Oceanographic Institution has proposed a comprehensive, multidisciplinary investigation of Georges Bank to supplement the research programs already in progress. The first phase of this effort, underway since 1980, is to collect and interpret existing information about the bank in the form of a book and atlas. The book will be a compendium to which people seeking general information about the bank can refer and an assessment of the current state of knowledge from which scientists working on the bank might get redirection.

The book and atlas are being prepared under the general guidance of the Georges Bank Study Committee of the Coastal Research Center and under the more direct oversight of an editorial board chosen from the committee. Members of the Study Committee during the period reviewed were John Ryther, Robert Beardsley, John Farrington, Richard Backus, all of WHOI, Bradford Butman, U.S. Geological Survey, John J. Walsh, Brookhaven National Laboratory, Marvin D. Grosslein and Michael P. Sissenwine, both of the National Marine Fisheries Service, Judith Spiller, University of New Hampshire, and Robert Howarth, Marine Biological Laboratory. Members of the Editorial Board are Backus (general editor), Beardsley, Butman, Grosslein and Walsh.

A formal description of the book was prepared in April 1981. It was felt that this was a necessary step by the planners of the book for coming to common agreement as to exactly what it was that we wished to produce. A description of the book was also necessary for informing potential publishers, writing-team members, and others whom we wished to enlist. Abbreviated and expanded outlines of the book were updated at short intervals throughout the period as plans proceeded.

A most important function of the Editorial Board was the composing of the writing teams. Section editors for the book were secured for the most part early in 1981. With the section editors' help, chapter editors were chosen and enlisted. The section and chapter editors are associated with the following organizations: Woods Hole Oceanograhic Institution, U.S. Geological Survey, Naval Postgraduate School at Monterey, National Marine Fisheries Service - Woods Hole, Narragansett, and Sandy Hook laboratories, Univ. of New Hampshire, Edgerton Germeshausen and Grier Inc., Brookhaven National Laboratory, State University of New York at Stony Brook, Northeastern University, Erco Inc., Southeastern Massachusetts Univ., Bigelow Laboratory for Ocean Sciences, Manomet Bird Observatory, Univ. of Rhode Island, Marine Biological Laboratory, Associates of Cape Cod, Inc., Swarthmore Collge, and Florida State University. Writers and reviewers come from numerous additional institutions and government agencies in the United States and Canada as well as from the fishing and petroleum industries.

Dr. Richard L. Price, a geographer and fellow in WHOI's Marine Policy and Ocean Management Program, had been designated Cartographic Editor in April 1981. Dr. Price then began meeting with the Editorial Board and other groups having to do with planning for the book. Equipment was purchased and a cartographic laboratory set up. In November 1981 Dr. Price circulated a memorandum and map to section and chapter editors for the purposes of determining scales and areas of coverage for the book's base maps. Also in November 1981, Elizabeth A. Suwijn, who had been Production Manager for the "Atlas of California", was hired to prepare the separations for the book's colored maps under Dr. Price's supervision.

In March 1981 we had begun the process of choosing a publisher for the book. Six commercial presses and six university presses were approached. By summer the choice had been narrowed to two university presses and one commercial press. We went into some detail concerning costs of production, probable list price, and probable subsidy required with these three. Ultimately the MIT Press was chosen, and a letter of agreement between the press and WHOI signed late in November 1981.

Early in 1982 the Editorial Board convened a number of meetings with special groups of contributors for the exchange of ideas and information and for book planning. The meetings were as follows: 1) January 11: Georges Bank Phytoplankton and Its Chemical Environment; 2) January 12: Physical Oceanography of Georges Bank; 3) March 17: Benthic Ecology of Georges Bank; 4) April 12: Chemical Oceanography of Georges Bank; 5) April 29: History of the Georges Bank Fishery and Its Management; 6) April 30: Petroleum Development on Georges Bank. These meetings proved productive for the book and resulted in a number of changes in the book outline, the composition of writing teams, and the content of a number of chapters. These meetings also fostered interaction among scientists working in different fields and brought to light the existence of data sets and analyses of which many individual contributors would not have otherwise been aware.

During April-May 1982 Dr. Elazar Uchupi at WHOI, assisted by Dr. Price, compiled a new base map of Georges Bank at a scale of 1:500,000. This is a large format map that will be folded and put in a pocket at the back of the book. In addition to bathymetry the map will show the protraction diagram used by the Bureau of Land Management (BLM) for its offshore leasing program.

The cartographer's device known as the "color chart" was produced for the book by Elizabeth Suwijn in June 1982 and distributed to contributors and others. It showed contributors the primary base maps and typical page arrangements. Further, it allowed the cartographer to make trial color combinations of the inks to be used on the paper to be used. It will be used as a guide for color map production and as an advance publication announcement by the MIT Press.

The first manuscript was received in April 1982 and several were in hand by the end of June.

CHEMICAL PROCESSES and POLLUTION

The Comparative Toxic Effects of Oil and Oil Dispersants on the Energetics of Larval Development and Metamorphosis of Marine Animals

Judith M. Capuzzo,
John J. Stegeman,
Bruce A. Lancaster,
and Bruce R. Woodin
Department of Biology

Interest in oil and gas exploration in the coastal regions of the northwestern Atlantic has increased in recent years, in efforts to find new petroleum resources. Increased exploitation, however, poses many questions concerning potential toxic effects of drilling and transport operations on commercially important species and the resulting economic impact on established fisheries.

Offshore oil spills such as those caused by the stranding of the Argo Merchant and Amoco Cadiz resulted in high surface water concentrations of petroleum hydrocarbons persisting for several days after the initial spill, thus impacting the pelagic ecosystem. The abundance of the larval stages of many commercially important species of fish and shellfish in surface waters of the northwestern Atlantic dictates our need to understand the effects of oil on the early development of these species. Exposure of planktonic larval stages to oil dispersed in surface waters or through ingestion of oil contaminated food could result in reduced survival, increased susceptibility to other environmental stresses, changes in the rates of growth and development, and reduced recruitment.

With the risk of offshore oil spills, new strategies of oil spill clean up and control have been developed and it has been recommended that the use of oil dispersants may effectively control the movement of an offshore oil slick and prevent its transport into nearshore areas. The application of chemical dispersants to an oil slick will enhance the formation of oil droplets, thus reducing the size of the slick and surface concentrations and leading to rapid dilution and increased distribution of oil throughout the water column. Our understanding of the impact of chemical dispersants in the control of offshore oil spills is limited to the physical characteristics of oil dispersant mixtures under various environmental conditions. The effects of naturally dispersed and chemically dispersed oil on larval and juvenile organisms need to be evaluated with an emphasis on metabolic processes that affect development and recruitment success.

The effects of crude oil and refined oils on the survival, metabolism and energetics of marine animals have received some attention in recent years. Larval stages of marine animals appear to be the most sensitive to hydrocarbon stress. Further, the effects of oil exposure on marine animals are modified by the bioavailability of crude and refined oils, the ability of the organism to accumulate and metabolize various hydrocarbon components and the interference with normal metabolic pathways.

Our current work is focused on the relationship between hydrocarbon accumulation and specific changes in lipid metabolism in larval and postlarval stages of marine animals (including the American lobster, American oyster and winter flounder) with exposure to naturally dispersed and chemically dispersed oil and with ingestion of an oil contaminated food source. The specific goals of our research are:

(1) to relate body burden of hydrocarbon accumulation to observed changes in respiration and lipid utilization and storage in larval and postlarval stages;

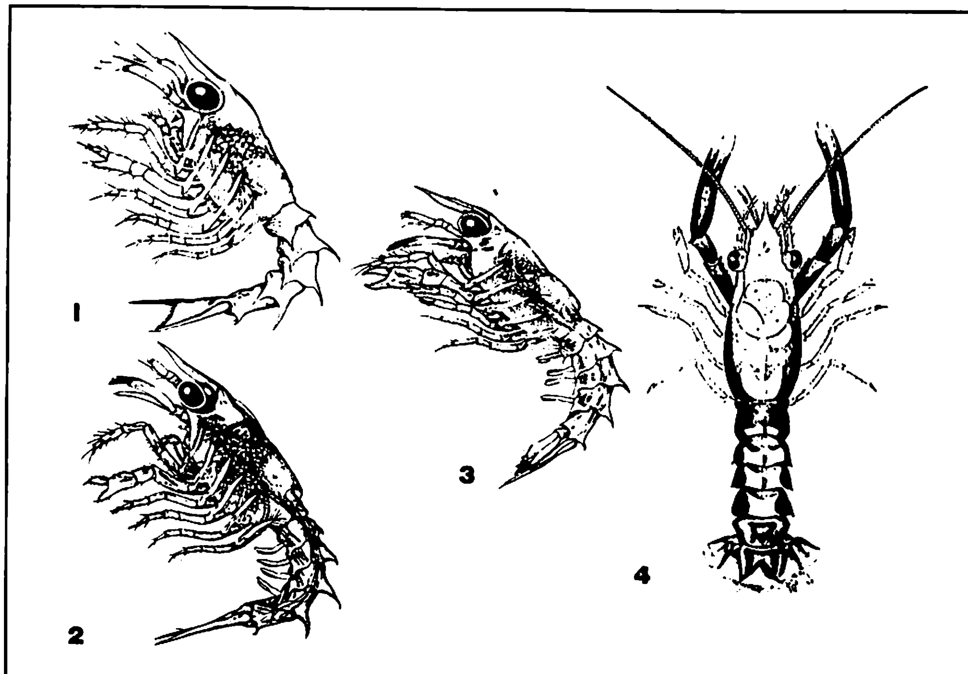
(2) to compare the lipid classes and component fatty acids of control and oil-exposed larval and postlarval stages;

(3) to relate the release of accumulated hydrocarbons (or by-products) to the restoration of normal lipid utilization and storage patterns; and

(4) to determine the capacity for metabolism of hydrocarbons by larval stages and how this capacity changes with exposure to naturally dispersed and chemically dispersed oil.

In studies with the American lobster (Homarus americanus), disruption in energetics with reduced respiration rates and O:N ratios as a result of an inhibition of lipid utilization and delayed molting of larval lobsters has been observed with exposure to both naturally dispersed and chemically dispersed oil. The experimental oil concentrations used in the study are within the range measured in surface waters beneath recently deposited oil slicks (~250 ppb) and thus represent realistic concentrations encountered by surface dwelling planktonic organisms.

Exposure to naturally dispersed and chemically dispersed oil resulted in similar toxic effects for each larval stage and suggests that there is no enhanced toxicity to larval lobsters with the use of Corexit 9527 as a chemical dispersant. Larval lobsters did not accumulate microdroplets of oil within their digestive tracts. Thus, it is apparent that the increased availability of microdroplets in the chemically dispersed crude oil seawater mixture did not influence its toxicity to larval lobsters. Both experimental groups showed significant reductions in the O:N ratio during the 96 h exposure period, indicative of an increased dependence on protein catabolism in comparison with control animals. We have further demonstrated that the increased rates of protein catabolism were complemented by a simultaneous increase in protein content and decrease in lipid content of exposed larvae; although protein was being metabolized for immediate energy needs, less protein was also being channeled



Larval stages of the American lobster
(*Homarus americanus*)

into de novo synthesis of lipid reserves. Thus, both lipid storage and utilization patterns are being disrupted with oil exposure.

Disruption in energetics and development of larval crustaceans as a result of exposure to petroleum hydrocarbons has been reported by several investigators. The mechanisms responsible, however, for developmental and energetic abnormalities are not well understood. It is evident that successful development and metamorphosis of the larval stages of marine crustaceans are dependent on the balance and efficient utilization of energy reserves with lipid reserves being either of primary or secondary importance in the energetics of crustacean development. Accumulation and efficient utilization of energy reserves are critical to the development of larval crustaceans and any alteration in biochemical composition or inefficient utilization of reserves may result in the developmental abnormalities experienced with oil exposure. The reduction in lipid utilization of larval lobsters evident in the present study with oil exposure could account for the sublethal effects on growth and development observed among the larval stages of other crustacean species. It can not be ruled out, however, that decreased lipid utilization may be a defense mechanism against incorporating lipophilic petroleum hydrocarbons in metabolic pathways and disruption in energetics is a consequence of the reduction in energy available for growth and molting.

Hydrocarbon turnover appeared to be rapid in both the tail muscle and hepatopancreas of exposed larval lobsters and little hydrocarbon accumulation was apparent. Physiological effects of oil exposure, however, may be modified by the organism's ability to metabolize various petroleum hydrocarbon components. The relationship between hydrocarbon metabolism, the toxicities of transformed hydrocarbons and disruption in energy metabolism needs further exploration.

The Interactions Between Chemical Species and Phytoplankton Growth In Natural Water Systems

Joel C. Goldman and Mark R. Dennett
Department of Biology

The major objective of this research was to determine the extent and significance of biological influence on the mass transport of atmospheric CO_2 into the aqueous environment in controlled laboratory experiments involving natural seawater samples. The potential enhancement of CO_2 transport into the aqueous phase can occur by three types of processes: 1) photosynthetic assimilation of transported CO_2; 2) possible rate catalysis by extracellular enzymes (ca. carbonic anhydrase) and other chemicals; and 3) alteration of the chemical envirnment (ca. pH and alkalinity changes) caused by photosynthetic activity. To compare the relative influence of each of the 3 processes on CO_2 transport into solution, we developed a unique gas-liquid exchange system. This system consists of both a circulating and closed gas environment coupled through a non-dispersing infra-red CO_2 analyzer and an aqueous phase which is temperature-controlled and mixed to allow moderate turbulent diffusion. Once a steady-state CO_2 partial pressure is established, the gas phase is opened to the aqueous phase and the rate coefficient K, defining the magnitude of CO_2 transport between the 2 phases, is measured over a fixed period. Chemical enhancement of the mass transfer process was then judged to occur when K for the above process was greater than would have occurred had the different between the partial pressures of CO_2 in the 2 phases been the only controlling factor.

We have completed a series of experiments dealing with the effect of pH and temperature on the potential enhancement of CO_2 transport into solution in a variety of natural seawaters. A major part of these efforts was to determine if the enzyme carbonic anhydrase, which catalyzes the conversion of CO_2 to HCO_3, is produced by marine organisms in sufficient quantities to serve in enhancing the mass transport of atmospheric CO_2 into solution.

We first determined the effect of pH on K for artificial seawater (Fig. 1A). Within the pH range 7.8 to 8.2 K remained relatively unchanged at ca. 0.0010 min , but at higher pH values we observed a dramatic increase in K to 0.0044 min^{-1} at pH 9.2. We used this curve as a baseline to gauge the potential for enzymmatic catalysis of CO_2 transport in representative marine waters (Fig. 1B) that included samples from the Sargasso Sea (an oligotrophic water), Vineyard Sound, Massachusetts (a moderately productive coastal water), Wild Harbor, Massachusetts (a productive inlet of Buzzards Bay, Massachusetts), and the outlets of tanks of shellfish and associated large fish that were flushed continuously with Vineyard Sound seawater. There was little difference between the partial presures of CO_2 in these samples and in the artificial seawater at common pH values. Thus any differences in K at a given pH between the natural and artificial seawater samples were due primarily to differences in chemical enhancement potential or other gas transport properties between the 2 types of seawater.

Overall, we could not find any evidence for the presence of carbonic anhydrase in the seawaters we tested. In all experiments the rate coefficient K fell slightly below or close to the baseline curve of K versus pH (Fig. 1B). No discernible effect of depth on K was evident in the Sargasso Sea and Vineyard Sound samples. Moreover,

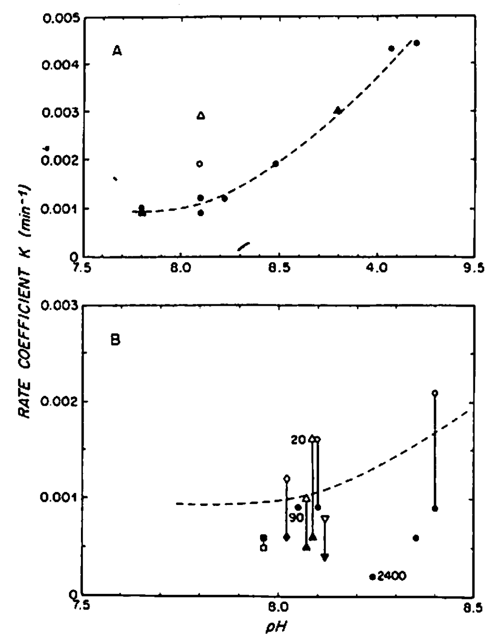


Figure 1. (A) Gas exchange rate coefficient K as a function of pH in artificial seawater (•) and filtered surface water from Vineyard Sound, MA (▲). Data are included for additions of 0.5 (o) and 20 (Δ) mg/liter of added carbonic anhydrase. (B) Gas exchange rate coefficient K as a function of pH in various natural seawaters: Sargasso Sea (•), Vineyard Sound, MA (▲), Wild Harbor, MA (▼), and the outlets of a shellfish tank stocked with the bay scallop, Argopecten irradians, and the hard clam, Mercenaria mercenaria, (■) and a fish aquarium stocked with blue fish, Pomatomus saltatrix, and striped bass, Morone saxatilis, (◆). Open symbols represent effect of carbonic anhydrase additions (0.5 mg/liter additions to the Sargasso Sea samples and 2 mg/liter to the other samples) on K. Dashed line is portion of the artificial seawater curve from Fig. 1A.

(cont'd.)

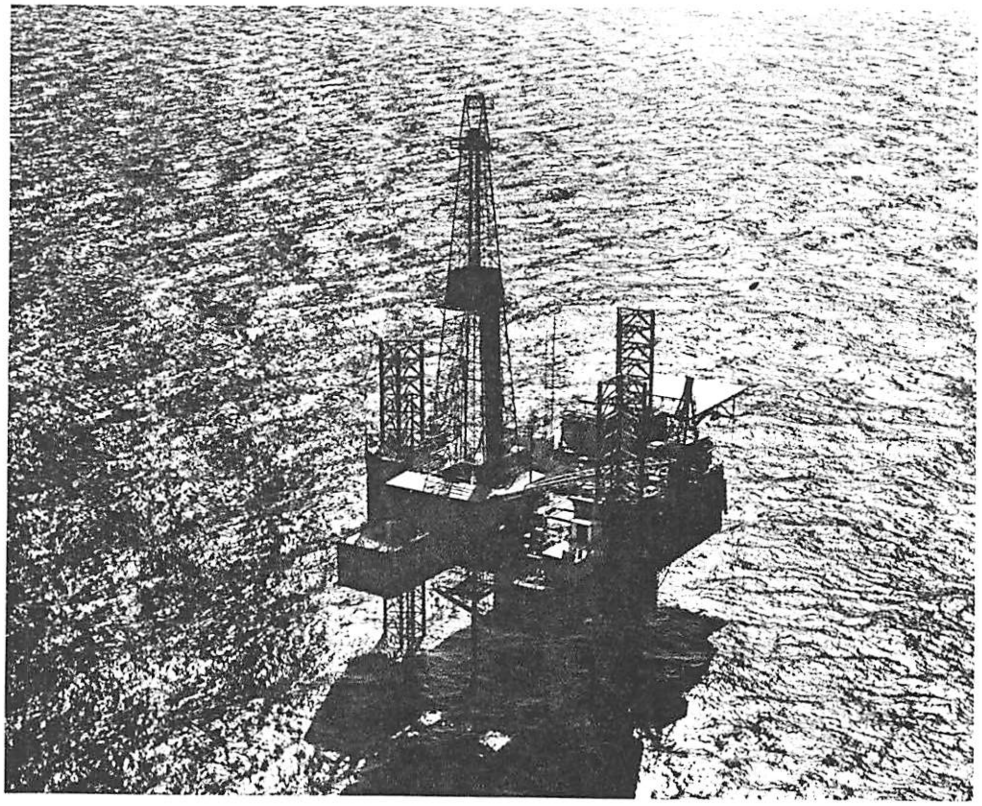
addition of up to 2 mg/liter carbonic anhydrase increased K by a factor of no more than 2 to 3; and in every case when the addition of the enzyme was followed by addition of an equal amount of ethoxyzolamide, an inhibitor of carbonic anhydrase activity, the rate coefficient was reduced to the original value measured before the enzyme was added. Were carbonic anydrase originally present in any of the samples, we would have expected K in the presence of the inhibitor to be reduced below these uncatalyzed values. In particular we could find no indication of biological production of carbonic anhydrase in the waters that were most likely to have catalytic properties, the shellfish or fish tank samples.

The close agreement between CO_2 invasion measurements based on naturally occurring and bomb-produced ^{14}C methods and those obtained with radom methods allows us to place limits on the role of catalysts in the oceans. These results support our overall conclusion that enzymmatic catalysis, even if it does occur, would have little effect on the mass transport of CO_2 into the oceans, given the amount of wind-induced turbulence present.

MARINE POLICY

Marine Policy and Ocean Management

David A. Ross



The Marine Policy Program addresses many ocean resource issues.

Members of the Marine Policy and Ocean Management Program of the Woods Hole Oceanographic Institution conduct research on the problems and activities generated by man's increasing use of the ocean. Understanding these problems and evaluating and establishing appropriate policies and management strategies dealing with them is a complex activity and often requires the data and training of both marine and social scientists. The Marine Policy Program emphasizes three major objectives:

1. providing support and experience to Research Fellows interested in marine-related problems;
2. developing multi-disciplinary marine projects applying natural science, technology and social science;
3. communicating and disseminating the research and evaluation results necessary for development of a rational local, national and international ocean policy.

The Marine Policy and Ocean Management Program maintains a staff of Policy Associates in addition to the Post-doctoral and Senior Research Fellows who are appointed for terms of one to two years. The Policy Program sponsors workshops, conferences, and seminars on important and timely marine policy issues. In 1981-82, the Marine Policy Program included 4 Policy Associates, 1 Senior Fellow, 9 Post-doctoral Fellows, 2 Visiting Investigators, and 2 Special Consultants in Marine Policy. Research activities fell into four general thematic areas: 1) coastal management and marine pollution; 2) fisheries management; 3) marine mining; and 4) cooperative international marine affairs policy.

Specific projects worked on or completed during 1981-82 include:

- Managing the Ocean Resources of the U.S.: The Role of the Federal Marine Sanctuaries Program
- The State: Landlord or Entrepreneur
- Deep Ocean Mining
- Ocean Dumping of Sewage Sludge: The Tide Turns from Protection to Management
- Risk Reduction in Fisheries Management
- Social and Economic Impediments to Artisanal Fisheries Development
- Pitfalls in Third World Aquaculture Development
- Fisheries Research vs. Fisheries Management Research: A Challenge for Social Scientists
- How the Law of the Sea Treaty Will Affect U.S. Marine Science
- The Political Economy of Deep Seabed Mining
- Mining the Deep Seabed: A Complex and Innovative Industry
- Managing the Global Commons
- State vs. Federal Interests in an Expanded Territorial Sea
- Implications of the Law of the Sea Convention for U.S. Oceans Policy

Additional research projects include work on Canada/U.S. issues, including the Bay of Fundy, Gulf of

Maine, Georges Bank Region and Polar research; and the use of scientific information in decision making and policy planning.

Activities within the various thematic areas during 1982 were highlighted by the following accomplishments.

In April we held a workshop in Woods Hole, as part of the Cooperative International Marine Affairs Program (CIMAP), on assisting developing countries in formulating strategies for ocean resource use and management within their 200-mile exclusive economic zones there were approximately 30 participants with a significant number from Latin America and Caribbean countries. The objective of CIMAP is to establish a mechanism whereby a specific developing coastal state will have access to the managerial, technical, scientific and policy expertise required for sound expansion of its economic activities in the coastal ocean.

The Marine Policy and Ocean Management Program and the Ocean Studies Programme at Dalhousie University jointly organized a workshop held in October in Digby, Nova Scotia. The workshop called the FMG Forum, addressed issues concerned with ocean policy and management in the region. The meeting was called by members of DOSP and MPOM in order to initiate discussions on marine management and research in the FMG region during a time when the Canadian and U.S. governments have halted talks pending the outcome of the boundary dispute over Georges Bank. The objectives of the meeting were to review recent research in the region and explore regional ocean management needs; to establish a basis for proposals on collaborative research designed to investigate these issues; and to initiate a continuing forum to consider marine policy in the Bay of Fundy, Gulf of Maine, Georges Bank Region.

The Policy Program sponsored over 23 lectures at the Woods Hole Oceanographic Institution by visiting policy specialists on various ocean policy topics. These lectures continue to be important and help to disseminate information on the substance and method of policy research; they often lay the ground work for future research collaborations. A total of 14 publications (12 articles and 2 books) were generated by members of the Marine Policy Program through September 1982 and a similar number are in press.

Developing an Ecosystem Perspective for the Management of New England Fisheries

Thomas M. Leschine
and Wendell Hahm*
Marine Policy
and Ocean Management

The past several years have seen increasing recognition that the management of complex fisheries like the multi-species groundfish fisheries of Georges Bank requires considerable information on the ecosystem interactions within the fishery. The development and adoption of the Groundfish Management Plan within the past year by the New England Fishery Management Council is a case in point. The plan abandons much of the single-species quota management of the recent past in favor of measures to protect spawning fish, spawning areas, and juvenile fish during critical stages of their development.

To provide information on ecosystem interactions which could aid management decisions, the National Marine Fisheries Service has begun development of a multi-species, age-specific fishery model, GEORGE, designed to simulate the effects of inter and intraspecific feeding among important groundfish species in the North Atlantic. This model, like many models of its type, has a dual purpose. First, it is to serve as a research tool useful for generating hypotheses concerning the effects of feeding and harvest in the fishery, based on the analytical equations which drive the model. Second, it is to provide useful information which could help guide future fishery management decisions.

Such a dual purpose can pose a dilemma for the model's creators, because the model must try both to capture the underlying dynamic of the real world system correctly, and to provide output which is "real" in the sense that it matches estimates of

year class abundance and behavioral characteristics observed in the field. It can be quite difficult to achieve both analytical and empirical validity in the same model.

This research has been aimed at aiding in the resolution of this problem, through the application of an additional analytical tool, "flow analysis", to the model's output. Flow analysis is an empirical data analysis technique originally applied to ecosystem nutrient, biomass, or energy flow models constructed directly from field observations of ecosystem structure and function. The technique can be thought of as an accounting procedures, which in tracing the sources of material which enters any model compartment, accounts for all the direct and indirect pathways by which the material has cycled through the ecosystem.

The figure, which is based on a flow analysis of a trial run of GEORGE, shows the evolution of the cod fish feeding pattern over the course of a season, as both predators and available food fish either are removed by predation or natural mortality, or grow toward maturity. No fishing takes place in this run of the model, but the arrow emerging from the cod compartment is intended to illustrate that the analysis traces the sources, in terms of percentage contributions of all prey sources to cod diet, of a potential unit biomass harvest of cod.

The analysis reveals that the cod's food web can change dramatically through the course of a season, because cod compete with other predators for available food, and surviving prey eventually grow to a size at which they are safe from cod predation. For this model run, a major shift takes place from dependence on herring and non-fish (a category which includes benthos), fish eggs, and plankton, to dependence on the pre-recruits of all species in the model, including young

cod. Dependence on non-fish ranges from a high of near 100% (days 90, 360) to a low of 71% of direct plus indirect dietary contribution (day 270). Pre-recruits vary from a 2% contribution (day 90) to a 79% contribution (78% direct, 1% indirect) by day 360. Only major feeding flows are shown in the model.

The sample run illustrates well the dual applicability of the methods

(cont'd)

*National Marine Fisheries Service,
Woods Hole, MA

employed. Checking these results against dietary information collected by fish stomach contents analysis can lead to adjustments in parameter values or model equations to bring percentage contributions to predator diets in line with levels suggested by the data. At the same time, a comparison of dietary flows across fish species, not shown here, can be used to give a dramatic illustration to fishery management specialists and others of the difference in "value" which one type of harvest removes from the fishery compared to another. For example, cod, which depend heavily on other commercially valuable fish species for food, embody much more exclusively on the benthos.

Future studies may allow for direct construction of flow models of the fishery from the available data on feeding interactions. Flow analysis applied to such models could then provide a way of "bounding" the flows generated by the simulation model, allowing for an exceptional opportunity to develop field and modeling studies hand in hand, in a situation with ramifications both for research and for the future management of an important resource.

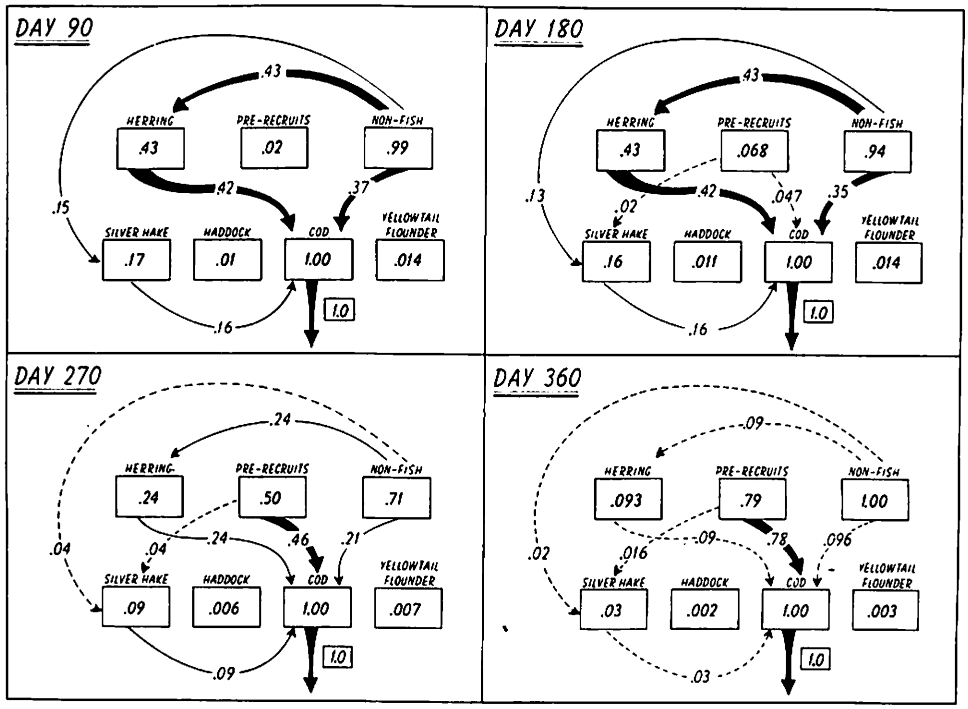


Figure 1. Major percentage contributions to the diet of cod in a multi-species fishery model, over the course of a simulated year. Flow structures for each of the quarters of the season are illustrated, based on total biomass transfers averaged over a six-day period at the end of each quarter. Only flows greater than or equal to 2% of the total contribution are illustrated.

Ecological Theory Applied to Fisheries

Geoffrey T. Evans*

The intention of this project was to determine how sudden shifts in internal behavior of fisheries models could influence the type of management strategy needed, using both theoretical studies and existing fisheries data bases. In pursuing this objective, I reached the disconcerting conclusion that even equilibrium abundances were unlikely to be predictable on the basis of available data: they were extremely sensitive to parameters which basically could not be observed.

The conclusion is based on a model of two fish stocks consuming a common resource. The problem arises because the per capita mortality rates of the fish stocks are taken to be nearly constant, rather than proportional to stock density: this seems in accord with all available evidence. The model behavior is strongly influenced by the nature and magnitude of the deviation from constant per capita mortality, which probably cannot be observed.

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A Comparative Analysis of Large and Small-Scale Fishing in Southern New England

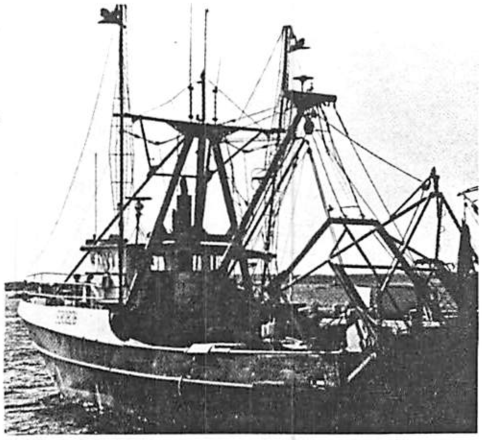
Susan Peterson and Leah Smith*
Marine Policy
and Ocean Management

Havesting, processing and distributing fish caught by Southern New England fishermen is part of a complex industry, shaped by natural, economic, social and political forces. Our research, reported in Chapter 12 of the book and atlas Georges Bank, describes the patterns of harvesting, buying and selling fish in light of seasonal cycles, the boats and gear, the fishermen, the business strategies and financial characteristics of the industry.

Some New England captains choose to fish on Georges Bank in all seasons; many more, particularly those on smaller boats (less than 70') fish offshore grounds only in the milder summer months. Each captain evolves a pattern of fishing which depends upon the seaworthiness of his boat, the skills of his crew and the markets. The pattern of fishing also evolves from the amount of time spent on the fishing grounds: trips to the northeast peak of Georges Bank for scallops last 10 to 14 days; groundfishing trips vary from 1 to 8 days. Typically, an offshore boat in good operating condition would fish about 200 days of the year; in fact, some fish as few as 85 or as many as 288 days. The smaller boats may fish from 50 to 150 days, with weather the major constraint on extending the fishing season.

The offshore boats have an average of 6 aboard, while near shore and inshore boats have smaller crews - 1 to 4 men aboard. The largest crews are on sea scallop boats with 9 to 13 men aboard, although 3 to 6 of them are shuckers rather than experienced fishermen. The captain is in charge of making the day-to-day decisions: when to leave port, where to steam, when to set the gear, how fast to tow in which direction, for how long. The choice of port, species, gear and market are influenced by where the fishermen grew up, family background, aspirations, familiarity with the business. Many of the present fishermen became fishermen because it seemed inevitable - their families had always been in fishing, or they didn't know how to do anything else. Both offshore and nearshore fishermen have families heavily

*Currently at Swarthmore College

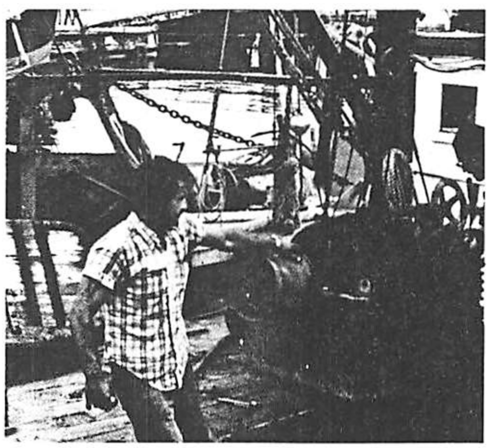


involved in the fishing industry - many of them with records of great-grandfather, grandfathers, uncles as well as fathers, brothers, nephews and cousins working as fishermen. The economic motivations of making a profit, earning a living, trying to make an adequate return on investment in boats and gear are important for most fishermen, but many of them are also attracted by the independence and style of life associted with fishing. While very few fishermen on the offshore boats have other jobs, many (over 75%) of the small boat fishermen have other sources of income during the off-season.

The major New England ports were settled by immigrants from western Europe, some of whom were fishermen before leaving their homelands, and remained as fishermen in the U.S., while others became fishermen because it was unskilled labor, or labor which did not demand formal training or good English. Ethnicity remains important in the New England fishing fleet because the ethnic backbround of the fishermen influences the style of fishing - species sought, boat design, length of fishing trips, grounds fished, innovations in gear and technology, crew composition, family involvement. Ethnic background also influences access to financial and technical information, markets, interaction with fishery managers, fish buyers and other fishermen. The major ethnic groups are Italian, Portuguese, Norwegian and Yankee - the small boat fleet is predominantly Yankee.

Most of the fishing boats are owned by their captains, by retired fishermen, by small corporations made up of family members or local entrepreneurs, or by fish processing companies. Very few boats - less than 2% - are owned by "outside" investors. The smaller boats represent a capital investment that ranges from a few hundred dollars to $100,000; large boats range from $40,000 to over $1 million. Over 50% of the smaller boats are owned outright, while less than 5% of the large boats fall into that category, and most of these are older boats whose 10-15 year mortgages have been paid off. We found that boats bought with personal savings or loans from relatives had a smaller estimated worth than boats bought with the aid of loans supported by government programs or bank loans.

The port communities differ in background and attitudes of fishermen, diversity of the buyers, species processed, and physical capacityof the harbors. Most fishermen sell fish consistently in the same port; offshore fishermen who land large volumes are dependent upon buyers with the physical facilities to offload the fish. Thus, most of them sell in Gloucester, Boston, Provincetown, Sandwich, New Bedford, Newport or Point Judith. The first sale of fish at the dock is part of a long chain of transactions which occur before the fish finally reaches the consumer. The number of exchanges varies, but the major distribution points for seafood landed in New England are Boston and New York. However, little of the fish caught by small, inshore boats enters that distribution network. Smaller boats rarely sell at the auctions or to the major New England dealers. Instead, they have informal arrangements with retail fish markets, wholesalers who



specialize in the local restaurant trade, restauranteurs themselves, and cooperatives in hundreds of small ports along the New England coast.

There are marked differences in the range of species caught by the two classes of fishermen. Offshore fishermen specialize in a small number of species: scallops, groundfish, redfish, herring. Small boat fishermen catch five to twenty different species as they become available in the inshore waters. But even with a broader range of species sought by this group of fishermen, many fish remain "underutilized" because they lack an established buyer, the price is too low to warrant the trouble of packing the fish in ice and transporting it to shore, or the fragile flesh makes it too difficult or too expensive to bring it to port in acceptable condition. Thus marketability and price of various species is more crucial to the decision about which species are sought and brought in than any inherent qualities of edibility of catchability.

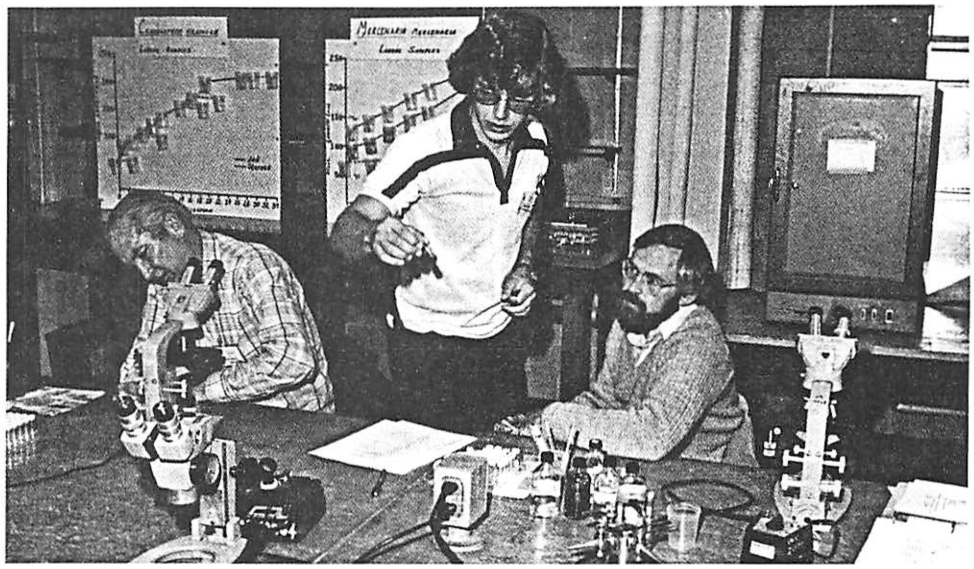
Young men continue to be attracted to fishing as an occupation, in part because of high income, but they are also attracted for the traditional reasons of family involvement in the business and the appeal of the life style. Although present fishermen are generally better educated than their fathers or grandfathers, they still regard fishing as an interesting and rewarding way to spend their lives, but there are serious questions to be asked about the future of this diverse industry. There is a dichotomy developing in the fishing fleet: more of the new boats are quite small (under 50 feet) or quite large (over 100 feet), and fewer in the middle range of 70-80 feet that have characterized the fleet in the last 20 years. Both large and small boats are likely to be flexible in their operations - either from necessity, as in the smaller boats which must catch whatever species are within their limited range, or from opportunity, as with the large boats that can travel rapidly to the farthest reaches of Georges Bank and keep their catch in refrigerated holds until they return to port. However, there is general concern about the future of the occupation. Decreases in earnings per boat accompanied by increasing costs and unprecedented rates of entry ito the fleet make the future of all New England fishermen unpredictable. In the past when fishing was on the upswing, new entrants were able to carve niches for themselves without disturbing other fishing patterns and earnings of boats already in the fleet. Now new entrants threaten the livelihoods of existing fishermen regardless of whether they enter the large or small boat fishery.

The fishery depends upon close cooperating of fishermen, managers and scientists in developing management plans that address the diversity within the industry and within the fishery. This research describes some of the information necessary for wise management of our coastal fishery resources.

PROGRAM ADMINISTRATION
Marine Assistance

Marine Assistance Service

Arthur G. Gaines, Jr.



Shellfish specialists participating in a workshop on lipid staining at Woods Hole.

In addition to funding marine research, the National Sea Grant College Program is committed to providing a means for the non-scientific marine community to benefit from research results and to participate in setting priorities. At the large Sea Grant College programs this effort takes the form of Marine Advisory Programs, patterned after the Cooperative Extension Services operated jointly by individual states and the U.S. Department of Agriculture. At present there are 19 Sea Grant Colleges, for the most part located at state universities in coastal and Great Lake states, each with a large Marine Advisory Program. In New England, Marine Advisory Programs are operated by Massachusetts Institute of Technology, the University of Rhode Island, the University of New Hampshire (jointly with the University of Maine) and, more recently, the University of Connecticut.

The Marine Assistance Service at the Woods Hole Oceanographic Institution (WHOI) represents the advisory element of our Sea Grant Program; it is very small in comparison with Programs mentioned above. Our main objective is to provide a means for individuals or groups outside the scientific community to interact with or benefit from the staff and resources of this Institution. This objective involves defining a basis for interaction that mutually satisfies the requirements of both the scientific and non-scientific participants. We also serve as a link with the national Sea Grant College network, and can make services and products of the larger programs available to people here. The Marine Assistance Service is structured to complement existing institutional efforts in marine education, public information, popular marine publications, etc. (Table 1), activities which in some other institutions fall within the purview of Sea Grant.

Since its creation three years ago, the Marine Assistance Service has interacted with town officials, commercial shellfishermen, businessmen, teachers, state and federal representatives and many others in the public and private sector. Some of the resulting projects are described briefly below.

Popponesset Beach: A Scientific Basis for Management

One of the major areas of concern on Cape Cod and coastal Massachusetts is beach erosion and storm damage, problems that are shared by coastal communities throughout the nation. Although a number of generalizations have emerged from beach studies over the years, these cannot be indescriminately applied to all portions of coast. For example, the concept of longshore drift of river-fed sediments, which applies along much of the U.S. west coast, is of much more restricted application in parts of New England characterized by pocket beaches. Inappropriate application of this concept at Popponesset Beach (Cape Cod) left those responsible for its management in a quandary.

During the past three years we have worked with the Selectmen of the Town of Mashpee on a project involving Dr. David Aubrey, of our Department of Geology and Geophysics. The project aims to define the sources, pathways and sinks of sediment at Popponesset Beach. Now in its final stages, this project has completely altered the previous view of beach processes at Popponesset and offers a number of management implications. For example, longshore drift, once thought to be large, has been shown to be relatively small here. This has strong consequences if the Town wishes to use beach nourishment to enhance the beach. Dramatic loss of sand between 1955 and 1980, previously believed to result from longshore drift, has been shown to result from landward migration instead; sand was "lost" into the channel behind the beach, not downdrift along the coast. This suggests that dune building and beach nourishment would serve better than groin construction to retard movement of sand.

This project has involved funding from our Sea Grant Program, the Town of Mashpee, Massachusetts Coastal Zone Management and Massachusetts Disaster Recovery Team. In the future we hope to more fully develop the management consequences of this research and to involve public and private parties from the town as well as people from our Marine Policy and Ocean Management Program.

Lipid-Stain Advisory

Over the past two years WHOI Sea Grant has supported research by Dr. Roger Mann and Mr. Scott Gallager, of the Department of Biology, dealing with the role of lipids (e.g., fats) in the health of bivalve shellfish larvae, as well as development of a staining technique to estimate the lipid content. This research indicates larval survival correlates strongly with their lipid-content, suggesting lipid-content can be used as an index of the vitality of bivalve larvae. A simple staining method was perfected to measure lipids.

One purpose of the advisory aspect of this project is to introduce this technique to commercial shellfish hatcheries for evaluation under actual working conditions. To effectively accomplish this objective required cooperation from the Sea Grant Marine Advisory Programs in states with significant commercial hatcheries. On October 28, 1982 shellfish specialists from Oregon, Maine/New Hampshire, Massachusetts, New Jersey and Virginia Sea Grant programs met at Woods Hole. In addition, hatchery operators from New York, Massachusetts and Maine attended the workshop and a representative of the National Marine Fisheries Service was also present. Dr. Mann and Mr. Gallager discussed the possible significance of their research and demonstrated the staining method. Participants then practiced use of the method and were given chemical kits to bring home for in-house application.

We used the occasion of this congregation of hatchery experts, in afternoon and evening sessions, to discuss issues of hatchery operation in general. These sessions were opened to local commercial shellfishermen, state regulatory and planning personnel, aspiring hatchery operators, town shellfish constables and other local individuals interested in hatcheries. In all, about 50 people attended these meetings and left with new insight and contacts.

Nitrogen Budget in Town Cove, Orleans

Like many towns on Cape Cod, the Town of Orleans has been wrestling for several years with the issue of sewerage. Federal dollars under the Environmental Protection Agency 201 and 208 Programs, provide monetary incentive for towns to plan and construct sewers, if necessary, before 1984. As in other towns, the issue has been devisive one and aesthetic, engineering, regulatory, political and scientific considerations have tended to become intertwined and confused. During this year the Marine Assistance Service has met with town officials and with scientists from this Institution to help determine if there was an important scientific question involved. We concluded that a crucial question concerns the role of sewage-derived nitrogen in Town Cove (delivered via groundwater), one of the major estuaries in Orleans. Concern over the well-being of Town Cove has been one of the major lines of argument to justify the expenditure of sewering the Town center area.

As a result, the Town has funded a one-year WHOI study to prepare a nitrogen budget for Town Cove, to assess the major sources and sinks of nitrogen, and the relative significance of sewage-derived nitrogen. The study also will provide advice to the Town on the possible impact of leachate from the proposed sewage-septage plant, located at the other side of town at the head of a large salt marsh. The study involves three scientists from our Department of Biology, one from Geology and Geophysics as well as the Marine Assistance Service. To date we have met monthly with the Orleans Citizen's Coordinating Committee, which oversees the project, given several talks on the scientific rationale of the study and presented the first progress report.

In the end it will be the Town's decision whether or not to proceed with sewer construction; however, we feel that decision will be influenced by the best scientific information available.

These projects illustrate something of the active participation by diverse marine interests, possible under the National Sea Grant College concept.

Table 1

Information activities sponsored by the Woods Hole Oceanographic Institution

Public Information Office - Operates public information service; issues news releases on Institution activities; publishes and distributes newsletters; operates a public display center (summer months only); prepares special displays; coordinates institution participation in documentary films and video coverage.

Education Office - Administers a graduate education program; administers summer student fellowships, summer student employment, student volunteer programs and work-study programs; conducts cooperative marine education programs with local school systems.

Ocean Industries Program - Coordinates interactions with member ocean-related industries (primarily oil companies) and transfer of WHOI research results; conducts semi-annual meetings at Woods Hole; prepares and transmits video-taped seminars.

Marine Policy Program - Provides fellowships and other opportunities to social scientists, economists, lawyers, and others outside the earth sciences, to examine policy aspects of ocean resource use.

WHOI Library - Operates a major marine sciences library, open to the public; conducts computer-based literature searches; publishes directories of marine science libraries and marine information centers.

"Oceanus" Magazine - Publishes four issues annually, containing articles written by experts for a lay audience (circulation ca. 15,000).

Lecture and Seminar Policy - Lectures offered at the Woods Hole Oceanographic Institution are open to the public. They are advertised in local newspapers and in a weekly institution calendar.

Development

Marine Natural Products Chemistry: Chemical Ecology and the Role of Phenolic Compounds in Herbivory and in Antibiotic Properties of Seagrasses

Judith M. Capuzzo
and Debby A. Carlton
Department of Biology

Seagrass beds, such as the eelgrass Zostera, the turtle grass Thalassia, and the surfgrass Phyllospadix, often form the dominant bottom and rocky shore communities in many parts of the world. These communities have long been recognized as one of the most productive ecological systems in neritic waters (typically producing 500 to 1000 gC/m^2/yr). Not surprisingly, therefore, seagrasses are concomitantly recognized as harboring a rich biotic assemblage of invertebrates, fish, and algae. Yet, despite this diversity, a striking anomaly is that most animals found in seagrass beds are unable to actually consume the living grass. The potentially critical role of seagrass communities in the secondary productivity of nearshore ecosystems, coupled with major gaps in our knowledge of seagrass dynamics (particularly trophic interactions), thus prompted the present investigations. We focused on establishing the chemical basis of the phenomenon that either inhibits or enhances attraction to seagrass by herbivores.

We have made substantial progress in a multiple-phase experimental system designed to establish causal relationships between plant chemistry and direct or indirect herbivore utilization of the plants. Samples of the Northeastern Pacific temperate surfgrass Phyllospadix scouleri were maintained in flowing seawater at the Environmental Systems Laboratory, along with their natural assemblage of invertebrate associates. Two herbivorous mollusks, the limpet Notoacmea paleacea and the snail Lacuna marmorata were isolated from Phyllospadix samples. The limpet is found only in association with the surf-grass while the snail is a more generalized species, occurring in a variety of intertidal and subtidal substrates. Both gastropod species were recombined experimentally with individual grass blades to test the differential predation by these mollusks on blades of different ages. Replicated experiments were conducted under day-night (16L-8D) cycles for 48 to 72 hours. These experiments yielded both between and within blade differences in herbivore utilization. Following the experiments, each grazed blade was subdivided into the sheath and, proceeding distally, into 10 cm segments. Grazed areas on each segment of each blade were then graphically traced with the aid of a camera lucida system mounted on a Wild M5 binocular microscope.

These data are now being analyzed by measuring the precise surface areas grazed on each part of each blade with the aid of a computer-interfaced HIPAD digitizer. In turn, chemical studies in progress will correlate areas grazed with the biochemical structure of each area. These chemical studies are based upon replicated grass samples from plants of the same population (of the same time) as used in herbivory experiments. Nutrition, digestion and microbial experiments will complement these studies. Our preliminary results provide further evidence that the snail Lacuna consumes older, and the limpet Notoacmea consumes younger, parts of the seagrass blades, and that this behaivor is directly associated with plant biochemistry. The ability of Notoacmea to consume regions of the plant with high phenolic contents (inhibitory to most plant herbivores) suggests that this limpet is either physiologically (postconsumption) or behaviorally (preconsumption) circumventing these phenolic compounds, and provides important clues in reconstructing the evolution of seagrass herbivores.

Seagrass beds are recognized as rich nursery grounds for a wide variety of commercially important species, yet the dynamics of seagrass communities are not well understood. Our study contributes important data sets to current questions of natural products chemistry in the marine environment, and provides a foundation for the complex relationship between plant chemistry and herbivory in seagrass ecosystems.

Directory of Marine Sciences Libraries and Information Centers

Carolyn P. Winn
Research Librarian

This directory represents a network of cooperating libraries and information centers which are willing to provide assistance not only to other cooperating members, but to any library or organization seeking information in the marine sciences. The intent is to foster the smooth flow of information from the scientist to the person seeking a solution to a problem. Librarians and information specialists are the traditional liaisons between the generator of information and the user of that information. This directory identifies access points to repositories of specialized marine information. Each entry includes names of information specialists, telephone numbers and addresses; descriptions of collections, services available and library publications. There are 137 entries in the directory, primarily from the United States and Canada, with representation from the United Kingdom, Bermuda, Panama and the Fiji Islands.

Publication of the directory was made possible by a grant from the Sea Grant Program at WHOI. The Marine Assistance Service of the WHOI Sea Grant Program distributed copies to marine-interest groups in New England. This directory has been used as a model for a directory of aquaculture information resources currently being compiled under NOAA sponsorship.

The first edition of the directory was published in 1976 as the Directory of Marine Science Libraries on the East Coast of the United States and Canada. During the intervening years, the organization, now known as the International Association of Marine Science Libraries and Information Centers, expanded its membership and increased its international scope. From its beginning in 1975, the development of this group has been encouraged and suppoted by the WHOI Sea Grant Program. Active membership is now 140, including the Library of Musee Oceanographique in Monaco, with an additional list of 100 individuals and organizations that maintain an interest in the Association's activities.

Coastal Sediment Transport, Popponesset Beach, MA

David G. Aubrey
Dept. of Geology and Geophysics

This new initiatives project was designed to advance our state of understanding of beach and nearshore processes along a tidally-dominated coastline, exposed to low wave activity. A study site (figure 1) was chosen along the south shore of Cape Cod, MA, where recent shoreline changes have been both dramatic (figure 2) and perplexing. The site is of particular state and local interest, since it concludes an area to be purchased by the state for recreational purposes (South Cape Beach). Recent storm damage in 1978 has focussed federal attention on the area, as well. Popponesset Bay, protected by the barrier spit, has supported an historically important shellfishery, which has declined in recent years.

The study has progressed along two lines: an historical survey and a field study. The historical survey has clarified the evolution of Popponesset Barrier Spit, with two phases of particular interest. From 1860 to 1954, the barrier spit elongated one kilometer to a point just north of its position in 1938 (figure 2). Following serious hurricane damage in 1954, the spit has progressively disappeared and migrated landward, to the position indicated for 1981 (figure 2). Both the historical documentation and a qualitative model describing the sequence of change have been presented (Aubrey and Gaines, 1982a and b, figure 3).

The field portion is directed towards evaluating hypotheses formulated during the historical phase. Of particular concern is the onshore/offshore exchange of sediment between beaches and shoals. Active tidal inlets and strong (50 cm/sec) longshore tidal flows provide a mechanism for diverting beach sands (transported alongshore by wave activity) to deeper waters offshore where it becomes entrapped by offshore shoals (such as Succonnesset and Wreck Shoals). Other bedforms (such as the sand waves found on the shallow platform between Succonnesset and Osterville Points) may also contribute to the beach sediment budget in either a positive or negative manner.

The results of this study are being incorporated actively into management considerations for this coastal area. We are working closely with the Massachusetts CZM, Massachusetts Disaster Recovery Team, and town officials at creating a coastal management program built on a sound scientific basis.

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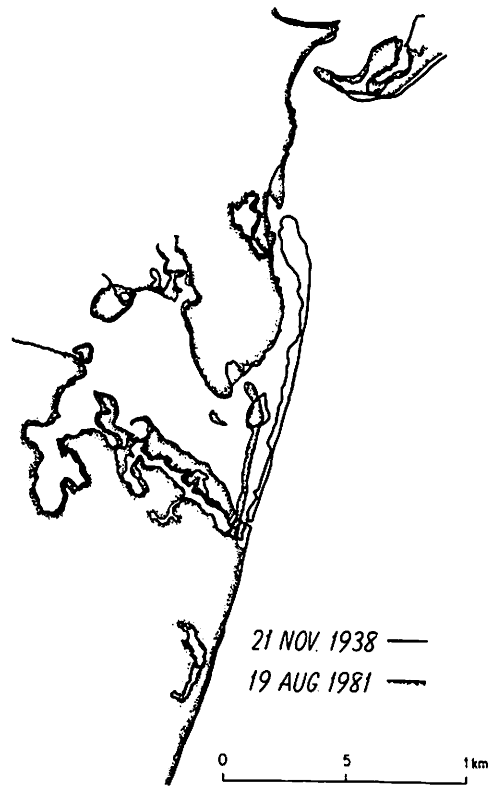

Figure 2. Forty-three years of beach change at Popponesset Spit. The barrier has shortened by one kilometer and migrated 100 m shoreward following a hurricane breach developed in 1954 near the present inlet location.

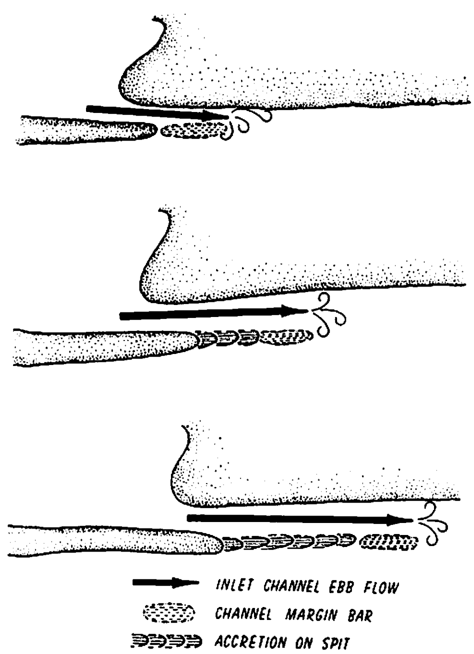

Figure 3. Schematic of the process whereby Popponesset Spit elongated from 1860 to 1954, when little longshore sand transport occurred. The mechanism is explained in Aubrey and Gaines, 1982a.

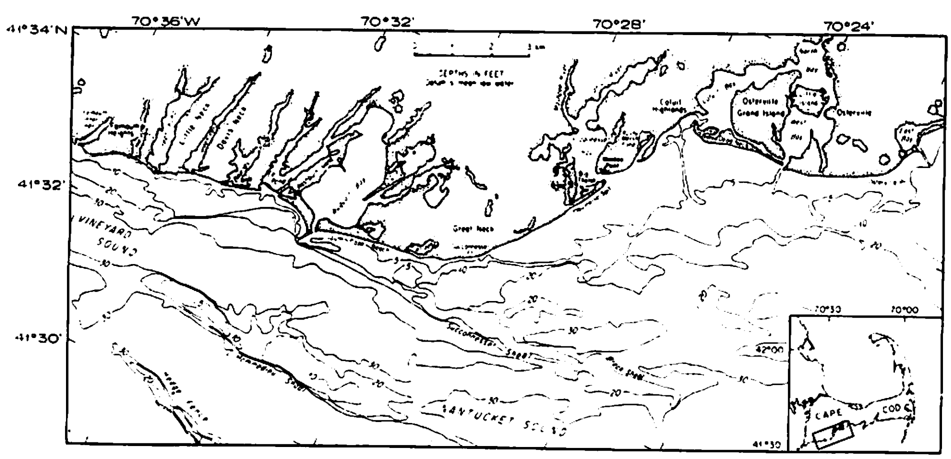

Figure 1. Location map for the study of a tidally dominated nearshore. Popponesset Spit is near the center of the chart. Tidal flows are east-west in Nantucket Sound.

The Transport of Dissolved Trace Metals in Coastal Sediments

William R. Martin
Department of Chemistry

This study has been undertaken to determine the factors affecting the transfer of several first row transition metals across the sediment/seawater interface in a coastal environment. Both chemical processes (inorganic and microbial) and transport processes (physical and biologically-driven) are believed to be important, and we have taken an integrated approach, calling for measurement of transport and chemical parameters at the same sites and times, to the characterization of sediment/seawater exchange. The study is proceeding along two paths. (1) A sampling program involving measurement of dissolved and solid phase metals (Mn, Fe, Ni, Cu, Co), redox indicators (nitrate and sulfate), and pore water components which may precipitate with metals (CO_2 and alkalinity, reactive phosphate, sulfide) is underway; measurements of sediment mixing by bioturbation have been carried out using excess ^{234}Th as a tracer; and measurements of biological irrigation using the ^{222}Rn deficit as a tracer have also been made. (2) Initial designs for a probe through which radiotracers can be released into the sediment for subsequent direct determination of the transport of Mn, Fe, Ni, and Co have been made; laboratory tests of the experiment system are to begin in December, with initial field experiments scheduled for May.

Sampling and Analysis. Because it is essential to avoid disturbing cores during sampling and to sample pore waters quickly, considerable effort has been devoted to developing the sampling scheme, which is summarized in Figure 1. A station in Buzzards Bay, just north of the Weepecket Islands and characterized by silt-clay sediments, has been occupied since May and sampled several times, both to begin measurement of seasonal variations and to develop sampling and analytical methods. Cores are emplaced by divers and remain sealed until extrusion, with overlying water in place, to avoid disturbance and air contamination. Core sectioning is comleted within 5 to 10 hours of coring; pore water sampling, acidification of metal samples, and analysis of unstable pore water components are completed within 24 hours of coring. Pore water ^{222}Rn analyses are completed within 48 hours; two to three weeks are typically required for completion of ^{234}Th analyses.

Results. The positioning of redox boundaries in the sediments, and their changes during the summer months, are illustrated in Figures 2 through 4. Mn reduction takes place in the upper 0.5 cm, with Fe reduction apparently occurring between 0.5 and 1.5 cm from the interface. The first appearance of sulfide in pore waters is at 12 cm in late May; sulfide appears at about 3.5 cm below the interface during the warm water months. The concentrations of pore water components with which metals may precipitate have been monitored during the summer months. Sulfide, reactive phosphate, and carbonate ion (calculated from alkalinity and total CO_2 measurements) concentrations are presented in Figures 4 through 6. Simple ion activity product calculations carried out for the 20 October core indicate that the pore waters are satured or supersaturated with respect to vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$) throughout the core and with respect to iron monosulfides below a depth of 4 cm from the interface. Similar calculations indicate that pore waters are saturated with respect to reddingite ($Mn_3(PO_4)_2 \cdot 3H_2O$) in the upper 4 cm, and with respect to alabandite (MnS) below; while the pore waters do not appear to be saturated with respect to rhodocrosite, they are saturated with calcite. Ni and Cu (Figures 7 & 8) are very insoluble in the presence of sulfide; their pore water concentrations appear to be somewhat greater in the upper 4 cm than below.

Thus, the presence of transfers of the metals under study between solution and solid phases has been demonstrated: Mn and Fe are reduced to soluble forms near the sediment/water interface, and Ni and Cu appear to be solubilized as well; pore waters are saturated with respect to several solid phases containing these elements below the upper 2-4 cm of the sediment column. Preliminary measurements of the bioturbation tracer ^{234}Th, and of the irrigation tracer, ^{222}Rn (Figures 9 & 10), show that bulk sediment mixing occurs in the upper 2 cm of the sediments and that irrigation may be occurring to depths of 10 to 15 cm. Thus, exchange of metals with the overlying seawater is likely to be important. Measurements of solid phase components for the calculation of mass balances confirming exchange with overlying water are also underway. Initial experiments involving treatment of wet sediment with acetic acid/hydroxylamine hydrochloride to determine a fraction of the solid phase which is in some sense "labile" show promise, and indicate that Mn and Fe are lost to the overlying water in the upper 2-4 cm and that Fe is lost to a more refractory phase (probably pyrite) deeper in the sediment column. Further measurements are needed to confirm these preliminary results and to extend them to Ni, Cu, Co. and sulfur.

Conclusions. In summary, measurements of pore water and solid phase concentrations of the metals under study have been made. They have been coupled with measurements of other relevant pore water components to indicate the presence and position in the sediment column of transfers between solution and solid phases; they have been coupled with measurements of mixing rate indicators to predict that transfers from the sediments to the overlying water are occurring. Quantitation of results awaits further measurements. Planned for the immediate future are the Mn, Fe, Ni, and Co tracer experiments which will build on the measurements already made by providing direct estimates of the transport of these metals in the sediments under study.

Effects of Chemical Pollutants in Benthic Sediments on the Viability of Copepod Eggs

Nancy H. Marcus
Department of Biology

During the last ten years it has been shown that the eggs of many pelagic copepods occur in the bottom sediments of coastal waters. These eggs may represent an important source for the recruitment of nauplii into the planktonic population. The ultimate goal of our research is to elucidate the influence of the benthic environment on the viability and subsequent development of eggs of these copepods.

To date we have focused our efforts on determining the most accurate and efficient methods for collecting sediments in the field so that egg loss from the sample is minimized, and for assessing the number and viability of eggs present in each sample.

We have obtained sediment cores by divers using SCUBA at several sites in New Bedford Harbor and Buzzards Bay. In the laboratory each core was divided at 1 cm intervals, to a maximum depth of 10 cm, and from each layer small sub-cores were taken. These subsamples were analyzed for the number of eggs present or the number of nauplii that hatched after incubation of the sediments at 19°C. We found viable eggs (i.e., hatched nauplii) in each layer. The greatest number of eggs ($5 \times 10^5/m^2$) usually occurred in the top centimeter, although peaks were observed at 4-6 cm. The eggs of Labidocera aestiva, Centropages hamatus, Acartia spp., and Eurytemora spp. were positively identified by rearing the hatched nauplii to the adult stage. We found that by placing the sediment sample in an ultrasonic water bath for 5 minutes, and then filtering the material through a 70 u mesh screen, the eggs of Labidocera aestiva could be readily observed under a microscope. The eggs were counted and removed from the sample to determine viability. Viability did not differ between sonicated and untreated eggs. The numbers of other types of eggs (e.g., spiny) was more difficult to determine by this method since the eggs were often caught-up in fibrous material.

During the next few months we will compare the number of eggs and nauplii obtained from cores collected by SCUBA divers with that obtained by using an Ekman dredge. If the values are comparable, the dredge would be used for all future sampling. We will also compare the viability of eggs from various sites in Buzzards Bay and New Bedford Harbor that differ in terms of grain size composition and pollutant contamination. The data obtained from this work will indicate the most valuable directions for further field and laboratory studies that will focus on the effects of chemical pollutants in bottom sediments on the viability of copepod eggs.

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PROGRAM SUMMARY

Project/Principal Investigator	7/1/79	7/1/80	7/1/81	6/30/82
	Project status as of:			
COASTAL ZONE - PHYSICAL/GEOLOGICAL ASPECTS				
Sediment Transport in a Tidal Inlet/ Aubrey	N	C	C	F
Development of a Loran-C Drifting Buoy for Coastal Circulation Studies/ Beardsley	-	N	C	F
Laser Doppler Velocimeter for Wave Boundary Layer Studies/Agrawal	-	N	C	C
COASTAL ZONE - BIOLOGICAL ASPECTS				
The Biology of the Ocean Quahog, *Arctica islandica*/Mann	C	C	C	F
Toxic Dinoflagellate Blooms (Red Tides) in Southern New England/Anderson	-	-	N	C
Tintinnid Predation on Toxic Dinoflagellates/Stoecker	-	N	C	F
Georges Bank and Its Surroundings: A Book and Atlas/Backus	-	-	N	C
CHEMICAL PROCESSES AND POLLUTION				
The Interactions Between Chemical Species and Phytoplankton Growth in Natural Water Systems/Goldman	-	N	C	F
The Comparative Toxic Effects of Oil and Oil Dispersants on the Energetics of Larval Development and Metamorphosis of Marine Animals/Capuzzo, Stegeman	-	-	N	C
ENHANCED BIOLOGICAL PRODUCTIVITY				
Bacterial Chemosynthesis for Aquaculture/ Taylor, Jannasch	N	C	C	C
Seeding Program for the Bay Scallop: Comparison of Local Bays, Falmouth, MA/ Capuzzo, Taylor	N	C	C	F
The Role of Size and Age in Determining Osmoregulatory Ability by Sea-Run Brook Trout (*Salvelinus fontinalis*)/ Naiman	-	N	C	C
The Use of Lipid Specific Staining Techniques for Assaying Condition in Cultured Bivalve Larvae and Field Zooplankton Populations/Mann, Gallager	-	-	N	F
MARINE POLICY				
Marine Policy Initiatives/Ross	C	C	C	C
Developing an Ecosystem Perspecitive for the Management of New England Fisheries/Leschine	-	-	N	C
A Comparative Analysis of Large and Small-Scale Fishing in Southern New England/Peterson, Smith	N	C	C	F
Ecological Theory Applied to Fisheries/ Evans	-	N	C	F
PROGRAM MANAGEMENT				
Program Management and Development/Ross	C	C	C	C
Marine Assistance Service/Gaines	N	C	C	C

N - New Project C - Continued Project F - Completed Project

BUDGET SUMMARY
(by W.H.O.I. Program Activity)
1981-82

	NOAA	Matching Funds	Total
Coastal Zone - Geological/Physical Aspects	$147,900	$ 53,558	$ 201,458
Coastal Zone - Biological Aspects	116,600	120,043	236,643
Chemical Processes and Pollution	81,300	22,323	103,623
Enhanced Biological Productivity	109,800	80,464	190,264
Marine Policy	98,100	215,286	313,386
Management	161,300	33,970	195,270
TOTALS	$715,000	$525,644	$1,240,644