Woods Hole Oceanographic Institution
Sea Grant Annual Report
1982-83

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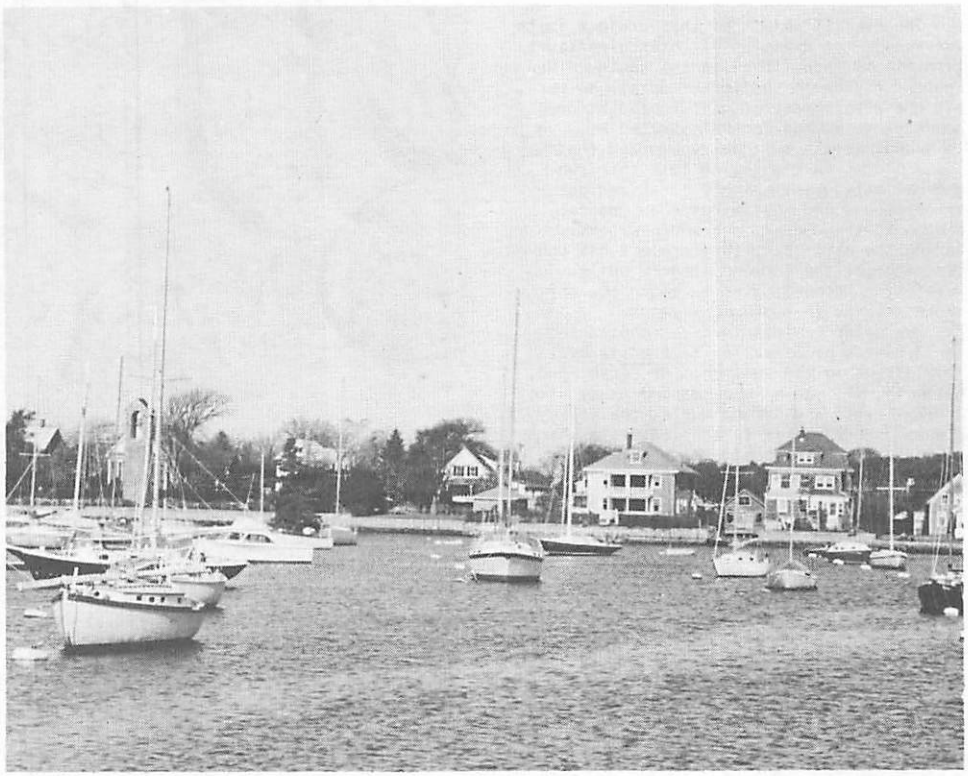
Introduction

The evaluation, development, utilization and conservation of our Nation's ocean and coastal resources is a major theme of the National Sea Grant College Program of the National Oceanic and Atmospheric Administration. The need for such programs will be even greater in the future with President Reagan's recent declaration of a U.S. Exclusive Econmic Zone -- an action that added almost 4 billion acres of marine territory to the United States. To better use and conserve this 200-mile wide zone will require the varied skills of academia, government and industry--a combination that has existed within Sea Grant since its inception.

The coming years will be an especially important period for the U.S. marine effort and the Woods Hole Sea Grant Program is anticipating playing an important role in it. Our Sea Grant Program draws strongly on the strengths of the Woods Hole Oceanographic Institution, which is a private, non-profit institution dedicated to broad research and educational programs in many aspects of marine science, policy and technology.

Some of our projects have addressed immediate problems of the coastal zone, such as the research on tidal inlets and sediment transport by Dr. David Aubrey. His work will contribute to our ability to manage the many navigational channels and inlets of the U.S. coast as well as the beaches and waterfront areas subject to erosion and storm attack. Some of our research looks at issues of even more distant significance. An example is a study of the legal and economic consequences of our Nation's exploitation of recently discovered deep sea polymetallic sulfide minerals, conducted by Dr. James Broadus.

Although research is the main objective of our Program, the transfer of results within the National Sea Grant network is also 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. Continuing interactions with federal agencies is another program objective and we particularly look forward to increased cooperation with the National Marine Fisheries Service.



Eel Pond (Ellen Gately)

The WHOI Sea Grant Program is located on the Village Campus of the Woods Hole Oceanographic Institution and is headed by Dr. David A. Ross, a geological oceanographer and Director of the Marine Policy & Ocean Management Center. Administrative/fiscal and communication responsibilities are handled by Mrs. Ellen Gately who is a member of both the New England and National Sea Grant Communicators and is responsible for production of all reports and proposals emanating from the Sea Grant Office. Dr. Arthur G. Gaines heads our Marine Assistance Service. He is a marine biologist and is actively involved with local and state environmental and natural resource issues. Last year he was appointed by Governor Michael Dukakis to the Massachusetts Coastal Resource Advisory Board.

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
March 1984

Fisheries Biology and Management

Resources Biology

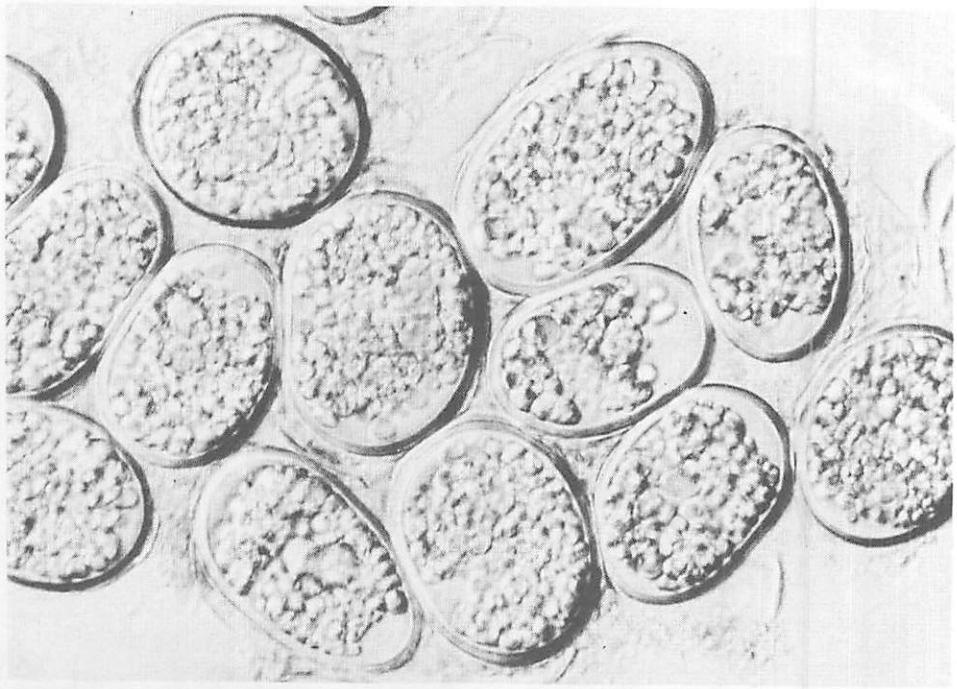
Toxic Dinoflagellate Blooms (Red Tides) in Southern New England

Donald M. Anderson
Biology Department

The overall object of this project is to understand the dynamics of toxic dinoflagellate blooms (red tides) in the southern New England region in sufficient detail to permit the development of useful prediction, monitoring, and/or control strategies. In this context, it must be recognized that toxic blooms in the region fall into two general categories: highly localized estuarine blooms and more widespread coastal blooms in the deeper, nearshore waters. During the past year, this project has concentrated on the former category while developing methodologies to begin the offshore studies in subsequent years.

One major project involved monitoring the dynamics of Gonyaulax tamarensis cyst populations in the sediments of Perch Pond, Falmouth, MA, our main estuarine study site. Dormant cysts are formed during the toxic blooms and deposited in the sediments where they remain until they germinate to re-inoculate the overlying waters in succeeding years. In recent years, we have demonstrated that deposited cysts are quickly buried by benthic animal activity, with viable cysts found 10-12 cm deep. Over several years, we have tabulated G. tamarensis cyst abundance at 20 stations in Perch Pond. These data allow us to quantify the spatial and temporal changes in cyst populations and to see how these variations reflect germination and encystment events during blooms.

Fig. 1A shows the G. tamarensis motile cell bloom sequence in Perch Pond. The logarithmic-scale on the ordinate somewhat obscures the important fact that only 1980 was a "bloom" year with cell concentrations sufficiently high to justify shellfish harvesting closures. Fig. 1B demonstrates how the G. tamarensis cyst population varied through time. When this project began, we expected to see significant decreases in cyst abundance as blooms began, followed by increases when new cysts were deposited as the blooms ended. It is clear from Fig. 1B that this was not the case--that relatively few cysts germinated prior to each bloom and that cyst deposition was minimal relative to the "carry-over" population that remained dormant. Since these cysts could be germinated readily in the laboratory, they were viable but apparently inhibited by unknown factors associated with burial in natural sediments. Work is now in progress to determine the nature of this inhibition.



Resting cysts of Gonyaulax tamarensis (red tide). The presence of these dormant cells in sediment is a useful indicator of the occurrence of motile cells of this species during the year in nearby waters. Photograph courtesy Dr. Donald M. Anderson, Woods Hole Oceanographic Institution.

The long-term trend in Fig. 1B suggests that G. tamarensis cysts are gradually diminishing in number. In actuality, the number has changed relatively little over four years, as evidenced by the open square plotted in August, 1983. That data point reflects cysts tabulated in the top 12 cm of sediment, whereas all solid squares are for the top 6 cm. Previous vertical profiles taken at the start of this project showed essentially no cysts below 6 cm (hence the selection of this depth for integration). We now can see that approximately half of the G. tamarensis cysts in the embayment lie below this level, having been gradually buried over the years. Thus the total number of viable cysts in the pond has not decreased significantly, but the number likely to germinate (i.e., those near the surface) has decreased substantially. Bioturbation can, therefore, have a profound effect on the magnitude of the germination inoculum. This figure also indicates that the cysts are capable of long-term survival (four years or longer) without germination. The lack of major blooms in recent years may reflect this deep burial and may be indicative of a trend towards the eventual "disappearance" of G. tamarensis from Perch Pond.

Two other studies were pursued during the last year--both in collaboration with other Sea Grant projects. In one case, data collected during the spring blooms in two Cape Cod estuaries helped to establish estimates of zooplankton grazing pressure on G. tamarensis. This work, with S. W. Chisholm of MIT, indicates that grazing can be a major factor in bloom decline when larval polychaete abundance is high, but that in most years, blooms ended primarily due to encystment. Additional work is now in progress with the MIT group to model the population development using empirically-

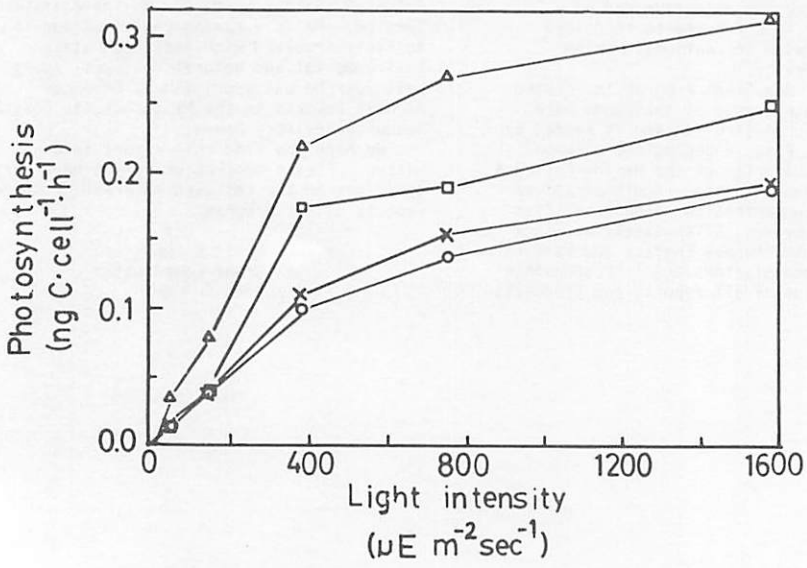


Fig. 1. Photosynthesis-irradiance relationship of Gonyaulax tamarensis at various stages in a natural bloom in Salt Pond, Eastham, MA. Each curve represents a different sampling date: □ - May 9, 1983 (2 x 10^4 cells l^{-1}), △ - May 13, 1983 (1.3 x 10^4 cells l^{-1}), ○ - May 23, 1983 (1.3 x 10^5 cells l^{-1}), and x - May 25, 1983 (2 x 10^3 cells l^{-1})

determined growth and grazing rates and to compare model results with the extensive data set established from our monitoring program over the last few years.

Another study (in collaboration with P. Glibert from WHOI) examined the photosynthetic capacity of G. tamarensis populations at various stages during the 1983 spring bloom. This work (using single-cell isolations of G. tamarensis from ^{14}C-labeled phytoplankton assemblages) provides an indication of the variability in the growth potential of this toxic dinoflagellate under natural conditions, even when other species are far more numerous.

In summary, by focussing on small embayments, this project has been able to contribute substantially to our understanding of the factors underlying bloom initiation, development and decline. In conjunction with planned studies in deeper coastal waters, we hope to document the important processes regulating the toxic dinoflagellate blooms in our region.

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Application of Stage-Classified Demographic Models to Atlantic Salmon Populations

Hal Caswell and Robert Naiman
Biology Department

This is a report on the first year of a two-year effort which focuses on applications of demographic models to the applicability of these models to understanding the dynamics of fish populations, especially those characterized by complex life cycles. More specifically, we are interested in the changes which have been documented in the life cycle of the Atlantic salmon at the WHOI Matamek Research Station, located on the Matamek River on the North Shore of the Gulf of St. Lawrence in Quebec. Since 1967, this population has been monitored continuously, documenting several life cycle shifts: (1) there has been a shift toward returning to the river after only a single year at sea; (2) there has been a shift among the male salmon (but not among the females) toward precocious maturation as parr, without going to sea at all. These shifts are not restricted to the Matamek River population, but are better documented there than elsewhere. The implications of these shifts for the future of the population are unknown, but are of immediate concern to fish farmers, fishermen, and to those involved with the efforts to reintroduce the Atlantic salmon to rivers in New England.

Our approach to this problem has been to apply complex life cycle demographic models which allow individuals to be classified by age, size, location, sex, developmental state, etc. From these models it is possible to project growth rates and population structure for any specified conditions, and to evaluate the effects of changes in parameters (e.g., the parameter describing the probability of precocious male maturation) on these projected rates.

The major thrust of our efforts during the first year of the project has been in the gathering, compiling, and computerization of the Matamek River population data set. Having accomplished this, we are beginning our analyses, focussing on the structure of the life cycle and how it has changed over the last decade and a half.

One reasonable hypothesis explaining the shifts in the salmon life cycle is based on natural selection. If fishing pressure at sea becomes sufficiently intense, while conditions in the rivers remain the same or even improved (and the Matamek is an undisturbed watershed with no human exploitation), a point will eventually be reached at which the loss in fecundity suffered by remaining in the river will be more than compensated by the gain in survival probability. The feasibility of this hypothesis can be evaluated by examining the way in which such a change affects the growth rate (i.e., fitness) of the population. Our preliminary results indicate that the selec-

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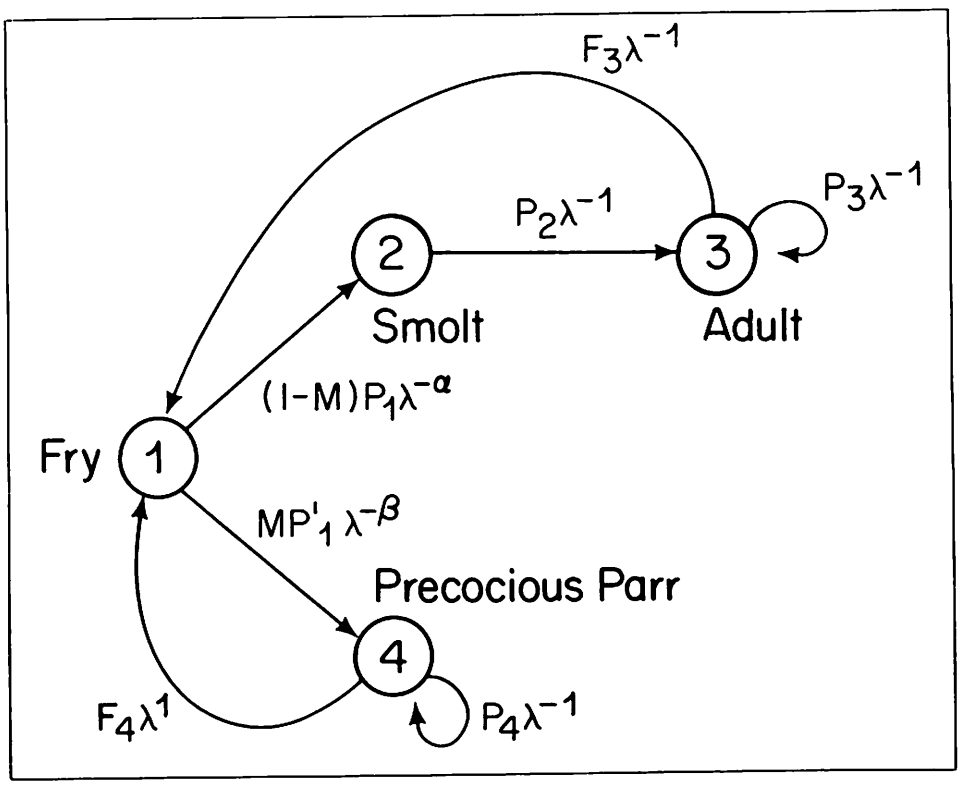
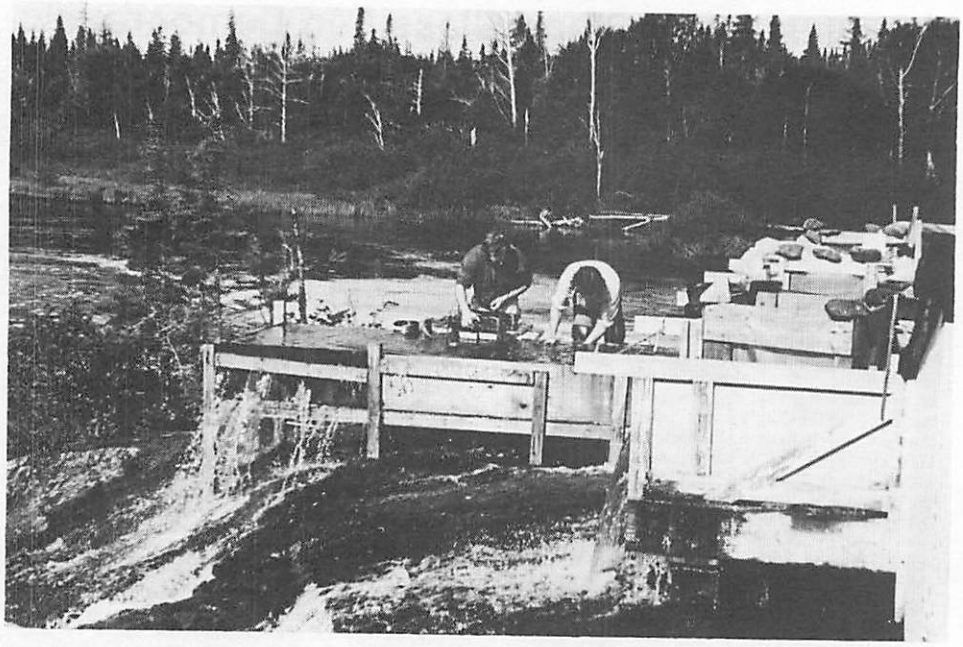


Figure 1. A life-cycle graph for male Atlantic Salmon. In this graph, the P_i indicate survival probabilities, the F_i fecundities, λ the population growth rate, α the time required for smoltification, ρ the time required for precocious maturation, and M the probability of precocious maturation. (From Caswell et al. 1983)



The second falls on the Matamek River near WHOI's Matamek Research Station in Quebec Province. (Vicky Cullen)

tion hypothesis is in fact feasible. We are presently gathering further information on the fecundity of precocious and sea-run males needed to refine this evaluation.

As an example of the approach we have adopted, consider the life-cycle graph in Figure 1 (from Caswell et al. 1983). The parameter M in this graph gives the probability of precocious maturation; we ask for the conditions under which $\partial\lambda/\partial M$ is positive. It turns out that if P_2 (the survival probability at sea) is small enough relative to F_4/F_3 (the ratio of the fecundities of adult and precocious males), increases in M are favored. Figure 2 shows the maximum value of P_2 compatible with this situation, as a function of F_4/F_3 and ϕ (the survival probability for parr in the river). Present estimates from the literature of P_2 are in the range of .01 to .1; from Figure 2 we conclude that if selection is to be a feasible explanation for the increase in precocity, F_4/F_3 must also be in this range. We are now working on improving our estimates of these parameters.

At present, we are continuing these analyses and extending them to consider the effects of sex ratio, frequency dependent interactions between precocious and adult males, density dependent, and environmental variability.

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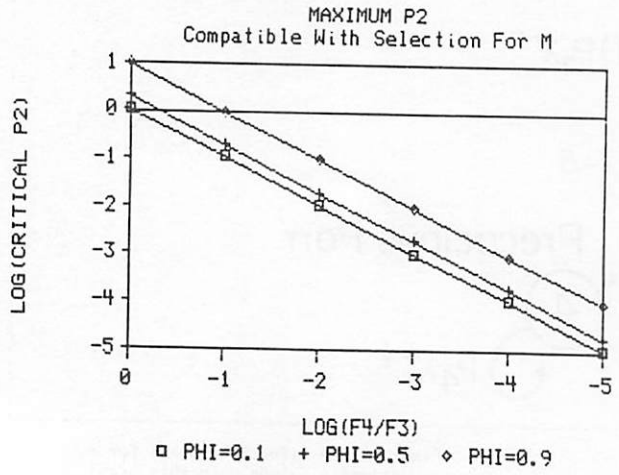

Figure 2. The critical value of P_2 (oceanic survival) compatible with the selection of increased precocity, as a function of F_4/F_3 and , the yearly probability of survival in the stream. (From Caswell et al. 1983)

Effect of Copper on *Favella*

Diane Stoecker
Biology Department

The objective was to compare the sensitivity of the tintinnid, Favella sp., and its dinoflagellate prey to copper. Favella co-occurs with dinoflagellate blooms, including blooms of the species responsible for paralytic shellfish poisoning (PSP), Gonyaulax tamarensis (Needler, 1949; Prakash, 1963; White, 1979; Stoecker et al., 1981). We have no proof that toxic dinoflagellate blooms would last longer and reach higher densities in the absence of Favella, but this is a logical assumption.

We investigated the effects of copper on Favella because changes in the trace metal chemistry of estuaries due to run off, pollution, or alteration of inlets could affect both dinoflagellates and Favella. In addition, one possible control technique for PSP stems from the observation that G. tamarensis is significantly more sensitive to copper than other common phytoplankters (Anderson and Morel, 1978; 1979) and thus that careful manipulation of trace metal chemistry could be a way to control blooms. However, control measures which disrupt natural controls, such as predation, can backfire.

We did our experiments using a culture of Favella sp. which had been isolated from an estuary in which toxic dinoflagellate blooms occur. The bioavailability of copper in seawater is determined by the free metal ion activity. We quantified and controlled the cupric ion activities in our experiments using a copper-nitrotriacetic acid (NTA) buffer system. The zinc, manganese, and cobalt ion activities were held constant at 10^{-11}, $10^{-8.5}$, and $10^{-11.1}$ M, respectively.

In short-term (5 hour) experiments, cupric ion activities as low as $10^{-10.0}$ M caused abnormal motility. The effects of even lower cupric ion activities were detected in 48 hour growth experiments (Fig. 1). Favella were exposed to media and food (the dinoflagellate, Heterocapsa triquetra) grown at the same cupric ion activities as in the media. Cupric ion activities as low as 10^{-12} M (pCu 12) caused decreases in the growth of Favella although short-term effects were not apparent at these low cupric ion activities.

In comparison, Anderson and Morel (1978) found that a cupric ion activity of $10^{-10.4}$ M could inhibit the motility and growth of G. tamarensis. Our studies show that Favella is as sensitive, and perhaps more sensitive, than G. tamarensis to copper. Thus, natural or man-induced changes in cupric ion activity have the potential to disrupt a biological control on dinoflagellate blooms, predation by Favella.

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Adaptation to Irradiance as a Regulatory Factor in the Initiation, Duration, and Decline of Toxic Dinoflagellate Blooms

Patricia M. Glibert
Biology Department

Of critical importance to shellfish management is an understanding of the factors relating to the initiation, duration, and decline of toxic dinoflagellate blooms. Some success has been achieved in using salinity and temperature as principal determinants in the initiation of Gonyaulax tamarensis blooms in several Cape Cod embayments (Watras et al., 1982), but these factors were not as successful in predicting blooms in other New England bays. One factor which has been given considerable attention in the laboratory (Prezelin and Sweeney, 1978; Prezelin and Matlick, 1980; Meeson and Sweeney, 1982), but not in the field, is the response by natural populations of G. tamarensis to varying irradiance levels. It was the purpose of this study to examine the changes in capacity for light utilization by the photosynthetic apparatus of G. tamarensis during the course of a natural bloom.

A field study was conducted in collaboration with the ongoing effort of Dr. Donald Anderson in understanding toxic dinoflagellate bloom development in Cape Cod salt ponds. During spring 1983 a large G. tamarensis bloom developed in only one of the monitored ponds, Salt Pond, Eastham, MA. We sampled the pond from pre-through post-bloom. On each sampling date the photosynthesis-irradiance relationship for the entire phytoplankton assemblage, and for individual cells of G. tamarensis was determined. For the latter, the single-cell isolation technique of Rivkin and Seliger (1981) was used.

Changes in the photosynthetic capacity of G. tamarensis were significant over the sampling period (Fig. 1). During the pre-bloom period, the photosynthetic capacity of G. tamarensis (per cell) increased. Under typical daily light conditions, if

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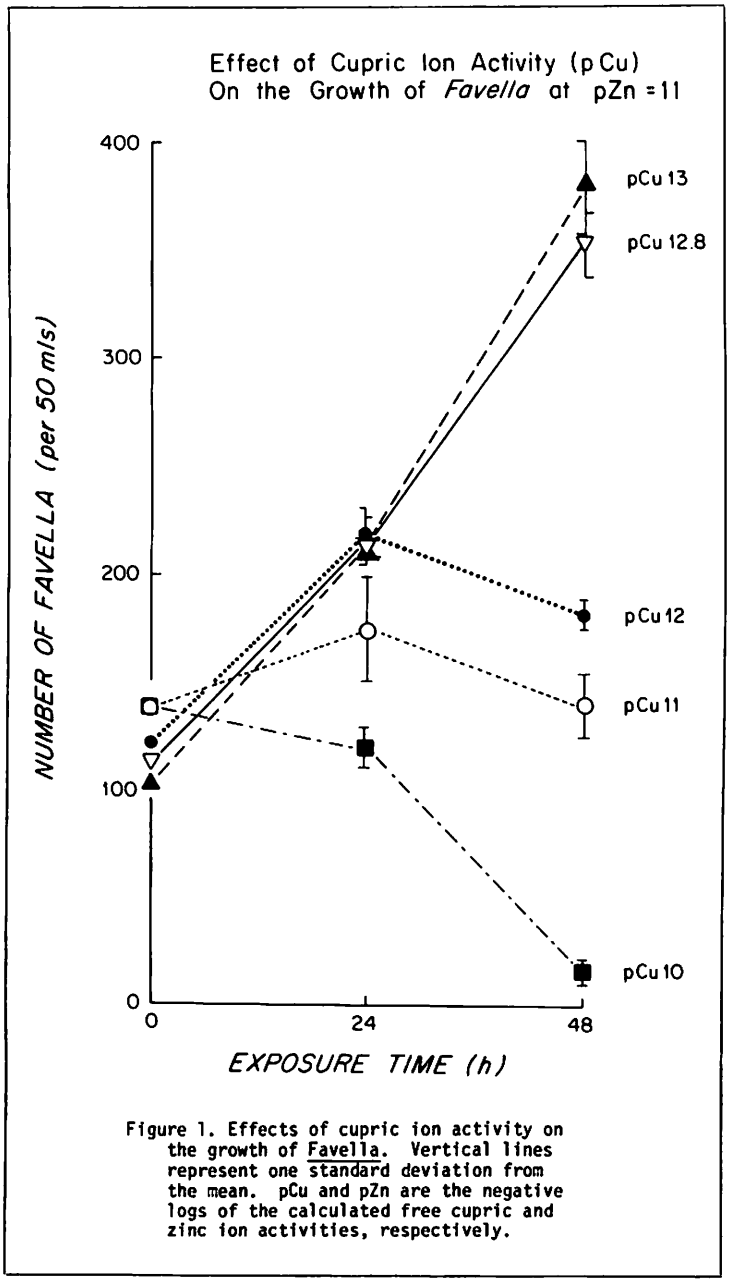

Figure 1. Effects of cupric ion activity on the growth of Favella. Vertical lines represent one standard deviation from the mean. pCu and pZn are the negative logs of the calculated free cupric and zinc ion activities, respectively.

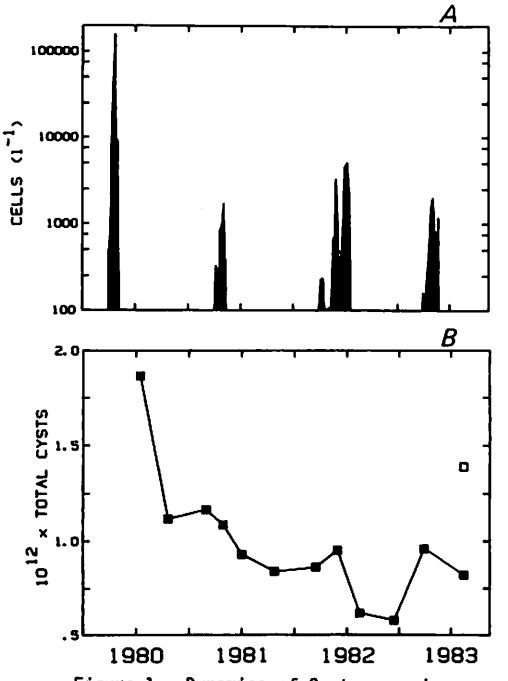

Figure 1. Dynamics of G. tamarensis motile cells and cysts in Perch Pond. (A) Motile cell concentrations through time. Note that only the 1980 bloom was large enough to cause dangerous toxicity in shellfish; (B) Total cyst abundance in pond through time. Solid squares include all cysts in the top 6 cm of sediment; open square represents the top 12 cm. Note the absence of significant changes in cyst abundance immediately before and after the bloom events.

these cells were photosynthesizing at maximal rates, then the amount of carbon taken up would correspond well with maximal growth rates observed for G. tamarensis in culture at 15-20° C (Watras et al., 1982). A growth rate approaching the maximal growth rate would not be surprising during the period of rapid bloom development.

The vigor of G. tamarensis declined shortly after the maximum photosynthetic capacity was attained. The decline in photosynthetic rate was approximately a factor of two over a 10-day period (Fig. 1). Cell density then sharply declined, and planozygotes, the swimming precursors to resting cysts, appeared. These represent the first observations on a natural assemblage of phytoplankton of changes in photosynthetic response of a single species as it progresses through a natural bloom. Despite our present inability to assign a direct cause-and-effect relationship between changes in photosynthetic capacity and phase of bloom cycle (although there is no evidence to think otherwise), the limits to adaptation of the photosynthetic response observed in other dinoflagellates under laboratory conditions suggest that the environmental conditions (e.g. temperature and light availability) of the pond may have changed sufficiently during the bloom period as to exceed the limits within which photosynthetic adaptation is possible. Hence, an understanding of the role of photosynthesis, and its interaction with other potential controlling factors, may significantly improve our ability to predict the intensity, duration, and decline of red tide blooms.

We hope to be able to correlate the observed changes in photosynthetic capacity in the field with similar experiments to be carried out on batch cultures of G. tamarensis; batch cultures simulate relatively well the dynamics of bloom development, nutrient depletion, and encystment in natural waters. Ultimately the photosynthetic parameters will be modelled and included in the larger predictive model of the dynamics of toxic dinoflagellate blooms being developed by Dr. Donald Anderson.

Comparative Reproductive and Developmental Strategies of Populations of the Bay Scallop *Argopecten Irradians Irradians* (Lamarck) in Shallow and Deep Water Embayments

Judith M. Capuzzo and George R. Hampson
Biology Department

Although bay scallop 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 exploiting offshore shellfish beds. The harvest of bay scallops from offshore locations in Buzzards Bay, MA comprised a significant proportion of the total harvest for the towns of Falmouth, Bourne, Marion and Mattapoisett for the period from 1977-1979. Although the offshore shellfish beds are shared by these four towns, 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 their offshore Argopecten 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. An analysis of these offshore populations must be included in any management program for the bay scallop fishery.

Studies on the reproductive cycle, growth and recruitment of offshore populations are currently in progress. A bay scallop bed at a depth of 9 meters was selected in the northeastern end of Buzzards Bay, southwest of the Red and Black Gong and, for comparison, an inshore site was selected at Wings Cove at a depth of 2 meters (Figure 1). At both locations collections and measurements were made every two weeks for analysis of growth rates and gonad development of bay scallops, in addition to monitoring temperature and water quality parameters. For continuous temperature monitoring a microprocessor temperature recorder was deployed.

Histological analysis of bay scallop gonads taken from the offshore station reveals that offshore populations are ready to spawn earlier in the year than inshore populations (Taylor and Capuzzo, 1983) and have an extended spawning season. During 1981 and 1982 offshore populations appeared to be ripe and spawning during early June, whereas inshore animals had just attained maturity. Offshore populations also remained competent for spawning until early September, whereas spawning activity had ceased among inshore populations. Little post-spawning mortality was also noted among offshore populations, unlike inshore populations, and the more stable temperature range at the offshore site probably accounts for this reduction in post-spawning mortality.

The energetics of bivalve populations, particularly in relation to the partitioning of energy between gametogenesis and growth, are carefully controlled by temperature (Giese, 1959; Sastry, 1975). 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 (Sastry, 1969). When spawning has been completed, energy is then channeled into somatic growth.

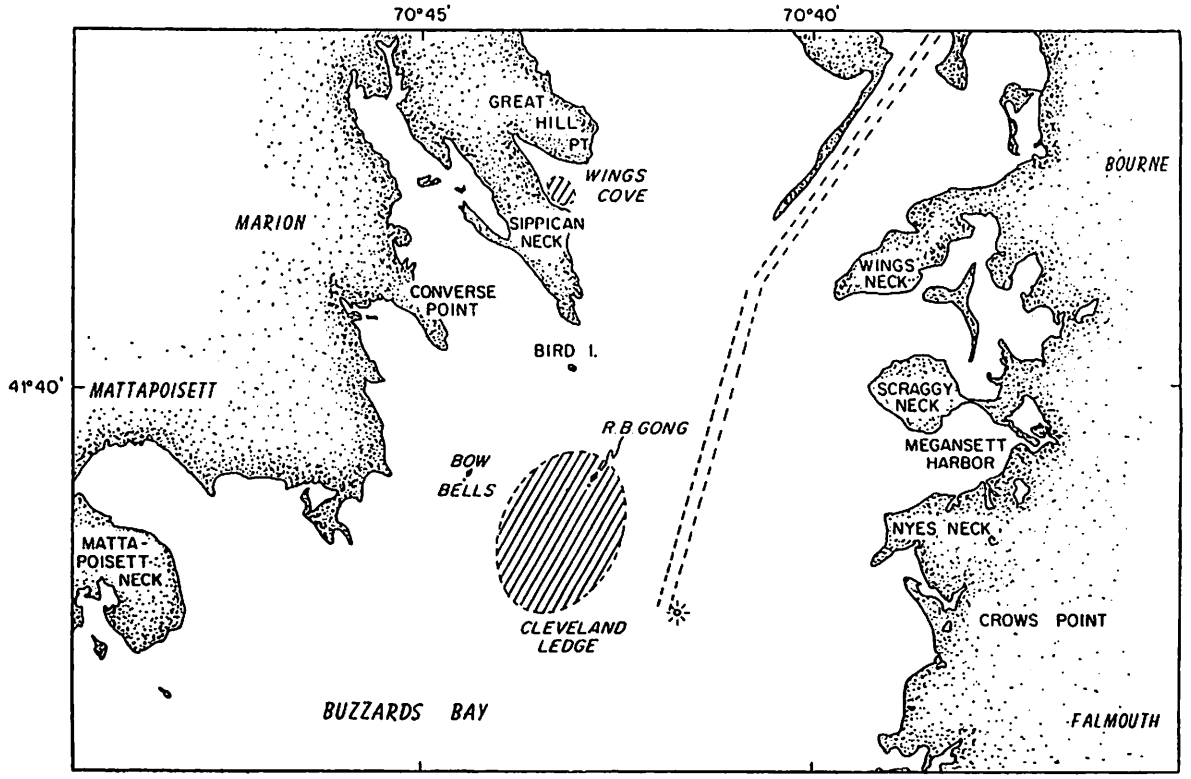

Figure 1. Study Areas

By examining the gonad index,

$$\text{Gonad Index} = \frac{\text{wt of gonads}}{\text{total wet wt. - shell}} \times 100,$$

and the adductor muscle index,

$$\text{Adductor Muscle Index} = \frac{\text{wt of adductor muscle}}{\text{total wet wt. - shell}} \times 100,$$

of bay scallops collected from the offshore and inshore sites in Buzzards Bay, a preliminary comparison of the gametogenic somatic energy budget can be made (Figure 2). From May through June, both inshore and offshore populations showed a marked increase in gonad index and a marked reduction in muscle index, indicating a greater percentage of energy being channeled into gametogenesis in both populations. During early June, inshore populations of bay scallops had a significantly higher gonad index than offshore populations, possibly due to either spawning activity or reduced reproductive output of the latter population. The reduction in adductor muscle index indicates that energy reserves stored in muscle tissue are probably being mobilized for gametogenesis. During the late summer and early fall, a marked decrease in gonad index is noted and a significant increase in adductor muscle weight is apparent. As offshore animals are still spawning during early September, marked increases in muscle weight continue through October, after the opening of harvesting season on October 1. During 1981 offshore bay scallops generated a 20-50% greater muscle weight for the season than the inshore scallops.

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 managed, these differences and their importance to the harvesting stock must be considered.

A workshop on the biology of inshore and offshore populations of bay scallops was held during October 1983 at which representatives of local shellfish groups were invited to discuss and review studies pertinent to exploiting offshore bay scallop beds.

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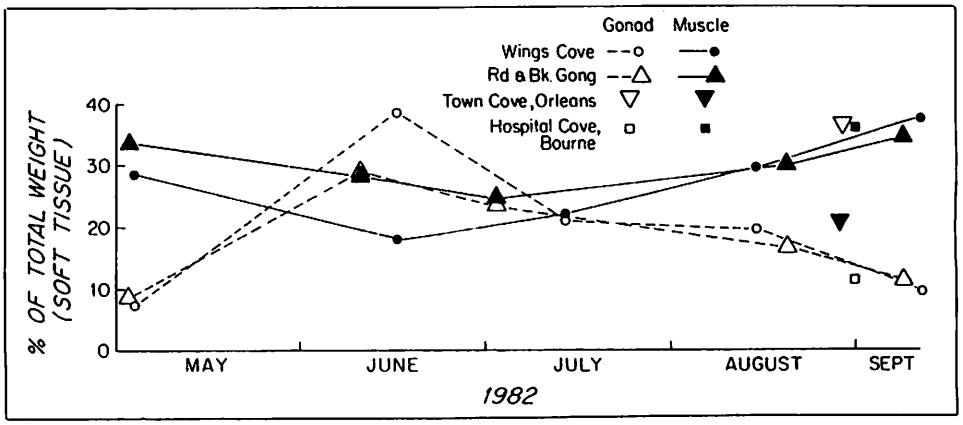

Figure 2. Gonad and muscle indices of bay scallops collected at Wings Cove and the Red and Black Gong, Buzzards Bay, MA and for comparison those of bay scallops taken from Town Cove, Orleans, MA and Hospital Cove, Bourne, MA.

Decision Analysis Applied to Fishery Management Plan Development

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Our research project--to investigate the process by which complex management decisions are made by the New England Fishery Management Council--began in late 1982. The project is designed to examine the Council's use of scientific and technical information in making decisions, and to determine whether decision analytic techniques, such as multi-attribute utility theory (MAUT), would facilitate Council decision-making. To do this, we are testing two hypotheses by analyzing the decision-making process applied to the sea scallop, the lobster and the herring management plans. The hypotheses are: 1) that the decision-making process has been structurally the same for all plans, and similar dysfunctions exist in the use of scientific and technical information and in evaluating trade-offs, and 2) that the application of decision analytic techniques to recurrent fisheries management problems will lead to more effective decisions, more comprehensive use of scientific and technical information, and management strategies operationally acceptable to a wider range of user and interest groups.

At the time of the grant award, the scallop plan had just been put in place, the lobster plan was pending approval, and the herring plan was being completely redesigned. During the first part of the project we have concentrated on the herring fishery because we have the opportunity to observe the process first-hand in addition to relying upon the memories of the Council members, their advisors and upon documentation.

The original herring management plan was one of the first written by the Council. Completed in 1977, it went into effect in 1979, was amended several times in 1979 and 1980, and in August, 1982 was withdrawn by the Secretary of Commerce because "changed fishery circumstances have rendered the plan invalid . . . and . . . the plan's management measures cannot be successfully implemented by NOAA/NMFS . . . (U.S., DOC, 19 Aug. 1982)". In November 1982 the Council decided that development of the herring plan would be the responsibility of the involved states: Maine, New Hampshire, Massachusetts, Rhode Island (and perhaps with consultation from New Jersey). Since that time we have been monitoring the plan development process being carried out by the five coastal states; this has included attendance at the herring plan development team meetings and at Council meetings where herring was discussed, literature reviews and analyses, identification of sources of scientific and technical information, the design and testing of an interview format, and the development of preliminary decision structure based on that information.

The interview structure is important in the application of MAUT; our efforts in the first several months were spent designing and testing the interview schedule and developing the lists of people to be interviewed. We wrote a paper "Decision Analysis in Fisheries Management" which was presented at the Northeast Fishery Meeting in May 1983. Dr. Healey has written a paper based on this preliminary work: "Multi-objective Analysis and the Definition of Optimum Yield," which has been accepted for publication in the Canadian Journal of Fisheries and Aquatic Science. By Fall, 1983, we had interviewed over twenty individuals from among present and past Council members, Council staff, the scientific advisors from the Statistical and Scientific Committee, the National Marine Fisheries Service, the marine fisheries divisions of the States, and representatives of the interest groups affected by fishery management--fishermen, processors, and wholesalers.

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Development of Diets for Crustacean Aquaculture: The Use of Single Cell Protein Sources in Optimizing Protein Utilization

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Biology Department

Single cell protein sources (SCP) are derived from the production of bacterial or yeast biomass, utilizing refinery wastes, petroleum products, methanol or ethanol as a culture medium. Its use as a feed ingredient in diets for aquatic species has received limited attention in recent years in efforts to find suitable inexpensive substitutes for fish and shrimp meals as primary protein sources. Although SCP used in some studies was shown to be limiting in the sulfur-containing amino acids (Spinelli et al. 1979; Bergstrom 1979), several investigators have demonstrated good growth and high protein efficiency ratios with either complete or partial substitution for fish meal in diets for salmon, trout and carp (Atack and Matty 1979; Beck et al. 1979; Ohmae et al. 1979; Bergstrom 1979; Spinelli et al. 1979).

In addition to providing an optimum protein source, SCP may also be manipulated through culture conditions and selection of bacterial populations to provide mineral, vitamin and fatty acid requirements as well. Preliminary experiments have been conducted in our laboratory on the feasibility of using SCP as a protein source in crustacean diets. In conjunction with investigators at Phillips Petroleum Co., Biotechnology Division, Bartlesville, Oklahoma, we have used their petro-yeast product, Provesta(R), as a primary protein source in formulated feeds for the American lobster. SCP was readily assimilated by postlarval lobsters and supported good growth and protein conversion. Further developments in manipulating the amino acid balance to provide higher levels of the sulfur-containing amino acids and fatty acid composition to provide a higher level of ω3 fatty acids are currently being investigated by Phillips Petroleum personnel. Thus, through manipulation of culture conditions and bacterial strains, we hope to develop an optimum SCP, a well-defined yet inexpensive protein source, for use in crustacean diets. In addition, SCP may be used as an experimental medium to investigate various aspects of protein utilization, lipid utilization, vitamin and mineral requirements, and the metabolic consequences of nutritional deficiencies.

Using Provesta(R) as the primary protein source in formulated feeds, we are currently investigating protein nutrition in the American lobster Homarus americanus and the prawn Macrobrachium rosenbergii, specifically focusing on (1) defining an optimum level of SCP in crustacean feeds and (2) comparative aspects of growth, energetics and protein utilization. Figure 1 illustrates the interrelationship of protein utilization and bioenergetics of marine crustaceans and demonstrates the various pathways to be studied.

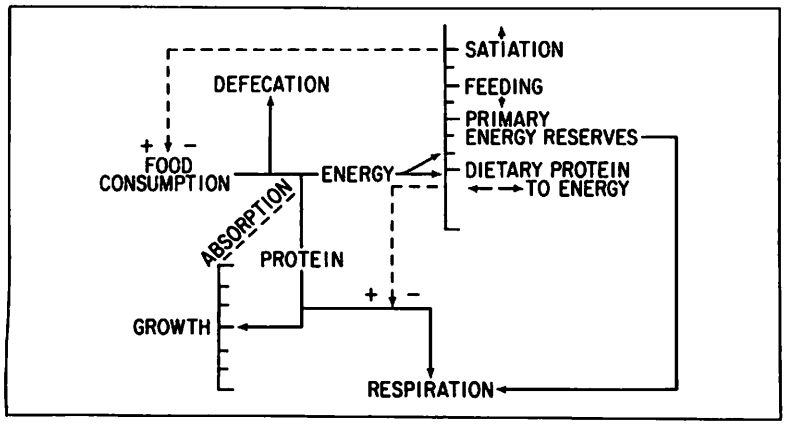

Figure 1. A schematic diagram of the relationship between feeding and utilization of dietary energy and protein sources in crustaceans; solid lines indicate mobilization of dietary energy and protein, broken lines indicate neural or hormonal control.

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Predation on Larval Fish by Coelenterates and Chaetognaths

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Biology Department
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The basic objective of the proposed research was to determine the importance of non-crustacean zooplankton as predators of larval fishes. The research was to be conducted in two locations, 1) on Georges Bank, with the cooperation of the National Marine Fisheries Service (NMFS), Northeast Fisheries Center in Woods Hole, MA, and 2) in the Gulf of Mexico, with the cooperation of the NMFS Southeast Fisheries Center in Beaufort, NC. We will present the results for each location.

Georges Bank

In June 1982, the KNORR (L. P. Madin, Chief Scientist) and the NMFS ship ALBATROSS were scheduled to coordinate sampling on Georges Bank, WHOI scientists were to collect gelatinous zooplankton predators and NMFS was to sample for larval fishes. The expected spawn of haddock did not occur at that time. The WHOI divers collected near Nantucket Shoals where the NMFS had reported eggs and larvae of yellow-tail flounder. Large numbers of the siphonophore Nanomia cara occurred in this location. Gut analysis of the siphonophores did not reveal predation on larval fish. J. E. Purcell examined past samples collected by the NMFS on Georges Bank in which there were high numbers of larval herring and chaetognaths. No evidence was seen for predation by the chaetognaths on the larval fish.

Gulf of Mexico

The groundwork for this research was laid during a NMFS cruise in December 1981, during which J. E. Purcell collected specimens of the siphonophore, Physalia physalis (the Portuguese man-of-war). Participation in two NMFS cruises were planned for 1982-83. However, the cruise dates and tracks were changed in such a way as to make them inappropriate for the present work. Alternatively, cruises aboard the University of Texas ship, LONGHORN, were made during fall (4-6 October 1982), spring (11-13 April 1983), and summer (2-4 August 1983) along a transect offshore from Port Aransas, Texas. Research was conducted at the Port Aransas Marine Laboratory of the University of Texas for 2-6 week periods during each season.

The major results of this research are as follows:

1) Greater than 90% of the diet of P. physalis was composed of fish larvae. As many as 120 larval fish were found in each specimen.

2) Soft-bodied prey were consumed, but not crustaceans. In addition to larval fish, small fish, leptocephalus larvae of eels, cephalopods and large chaetognaths were eaten. A diet of soft-bodied prey is found in all species in the suborder Cystonectae, and may be related to their nematocysts, which differ markedly from nematocysts of the two other siphonophore suborders which primarily eat crustaceans.

3) The relative abundance of Physalia at the Padre Island National Seashore is reported daily by the National Weather Service in Corpus Christi, Texas. The existing records from December 1974 were compiled, and revealed a strong seasonal pattern that appears to be correlated with prevailing wind patterns. Specimens were collected for seasonal comparison of gut contents.

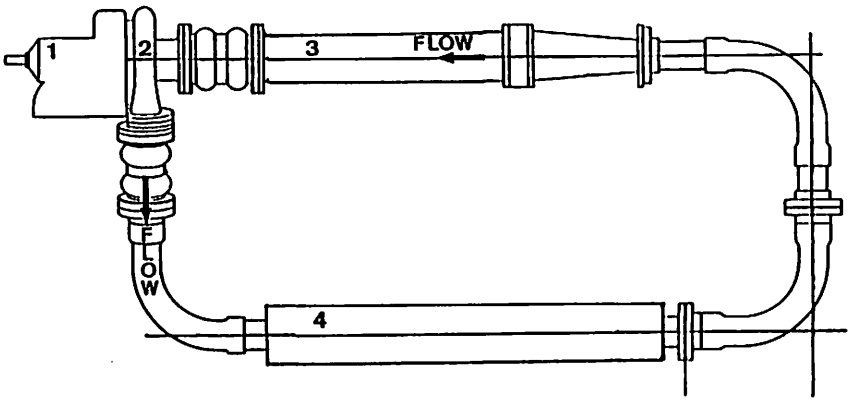
4) The length of time between ingestion of a fish larva and egestion of waste was measured successfully in the laboratory for larval sciaenids about 1 cm in length. Digestion times averaged 7 hr $\pm$ 2 hr s.d. at 21°C.

5) Larval fish densities in the Gulf were roughly 0.1-0.3 larvae/m^3. Further data will be provided once the NMFS samples are counted.

6) The abundance of Physalia as measured by timing the intervals between sightings of specimens while the ship was underway at a known speed. The distribution of Physalia was found to be very patchy. The average abundance over 10 nautical miles was 1 Physalia/200 m^2 at one station.

7) Given the large numbers of prey per Physalia, the short digestion times, the low abundance of larval fish, and the potentially high abundance of Physalia, we believe that Physalia is an important predator of larval fish.

8) During October 1982, three other predators occurred in great abundance. Surface aggregations of the scyphomedusae Stomolophys meleagris and Aurelia aurita, and of the ctenophore Mnemiopsis mccradyi reached 7.4/m^2, 3.3 m^2, and 0.8/m^2, respectively. The diets of these jellyfish contained some fish eggs and fish larvae. However, the diets consisted primarily of small zooplankton of the sizes and types consumed by larval fish. We believe, therefore, that these seasonally-abundant jellyfish are more important as potential competitors of larval fish for small zooplankton foods.



LEGEND:

1. Variable drive, 3 H.P., D.C. electric motor, with controller (variable speed)
2. Centrifugal pump, 316 stainless steel, 9" stainless steel impeller, 6" flange inlet, 4" flange outlet, water cascade type seal on output shaft from impeller (spring and hydraulic pressure activated - from pump action)
3. Swimming tube (bounded upstream and downstream by honeycomb grids), 8" (I.D.) X 30", transparent cast acrylic, with access port
4. Heat exchanger, located on bottom return loop as a sleeve on the outside of the return loop (PVC pipe, 4")

Figure 1. Design of water tunnel treadmill/respirometer.

Water Tunnel Treadmill/Respirometer for Studies on Locomotor Biology of Coastal Fishes

Marvin Freadman
Biology Department

The life history of many fishes is characterized by significant periods of swimming activity. The process of maneuvering in water relates to the swimming capacity of a fish and is essential for activities such as migration, escape from predators and food capture. Knowledge of fish locomotor biology (e.g., metabolic requirements, nature of propulsive movements, swimming stamina) has rapidly increased in recent years due to the development of suitable water tunnel respirometers ("water treadmills") for enforced swimming of fishes at controlled levels of activity.

Studies on the responses of fishes to environmental stresses (natural and manmade) have used testing systems and experimental designs in which locomotor behavior was not considered an experimental variable. Given the importance of locomotion to the life history of many species, this is an area of research which should be investigated. Laboratory and field collected data on known, significant aspects of the life history of fishes (locomotor responses to stresses and perturbations) are required to aid our understanding and management abilities of these important coastal and oceanic resources.

We are constructing a recirculating water tunnel treadmill for studies on the locomotor biology of coastal fishes. The design of the water tunnel treadmill is shown in Figure 1.

Considerable effort and time have been devoted to design details including pump/motor specifications, flow characteristics in the swimming tube, heat exchanger characteristics and piping requirements. We have found a reputable company which fabricates stainless steel centrifugal pumps and is building one to our specifications (see Figure 1 legend). We have consulted Dr. Keith Stolzenbach (hydrodynamicist, Massachusetts Institute of Technology) on the design characteristics in terms of our desired water tunnel working characteristics. The water tunnel treadmill will soon be operational.

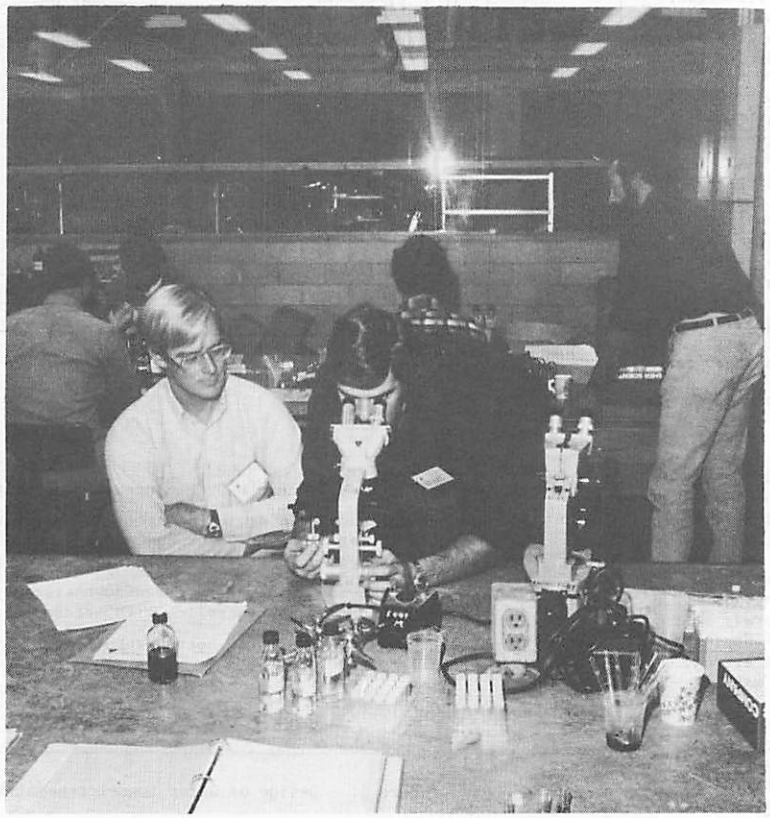


Figure 1. Scott Gallager (at the microscope) demonstrates the lipid staining technique to a workshop participant. (Shelley Lauzon)

Lipid as an Indicator of Bivalve Broodstock Condition

Scott M. Gallager and Roger Mann
Biology Department

The bivalve hatchery industry has been plagued by the inability to predict the survival of larvae from spawning to metamorphosis leading to significant economic losses. Our previous Sea Grant-sponsored research project addressed the problem of larval survival by developing and testing an inexpensive lipid specific monitoring technique that could be used routinely in the hatchery by relatively untrained personnel. The rationale for this technique is predicated by the evidence that lipid, predominantly neutral lipid, is an important energy reserve that is accumulated by fast growing, healthy larvae and rapidly mobilized in larvae under stress. The biochemical transition that takes place in the early stages of stress may be quickly and accurately diagnosed by the lipid specific staining technique described in Gallager and Mann (1981a, b, 1983a).

Dissemination of these results to the shellfish industry in the form of a photographic lipid staining manual, numerous oral presentations and two user-oriented training workshops (Figure 1) generated feedback from commercial sectors that led us to address the following question: could the lipid specific staining technique be used to assess the potential of newly spawned eggs and larvae for rapid growth and successful metamorphosis as related to broodstock condition? Poor broodstock condition has been repeatedly targeted as the causative agent of culture failure. If our lipid staining technique could be used on a predictive basis for determining subsequent culture success at the time of spawning, then precious time and manpower would be ultimately saved by not attempting to rear suboptimal spawns.

We approached the problem by initiating the conditioning of broodstocks of both Crassostrea virginica and Mercenaria mercenaria at two discrete points in their gametogenic cycle. Subsequent spawns of eggs and 24-hour straight hinge larvae were monitored for their initial lipid content by the staining method and total lipid and lipid class composition analytically. The conditioning of one group of oysters and clams was initiated in the late fall when it was expected that residual ova from the previous season had been resorbed and glycogen levels available for subsequent lipid synthesis during gametogenesis would be at a low ebb. The expected low larval viability resulting from conditioning being initiated at this time was contrasted to that of broodstock initiating conditioning during the late winter when glycogen levels are high and gametogenesis naturally begins. Attempts were made to spawn each broodstock on a weekly basis while collecting samples for staining and analytical lipid analysis. Selected spawns were reared through metamorphosis to obtain percent metamorphosis and spat yield. The data from these experiments and from samples collected from commercial shellfish hatcheries throughout their spawning season provided an integrated study designed to test the hypothesis that egg and larval lipid content are strongly influenced by the physiological and gametogenic state of the parental broodstock.

The results will be reported in detail in Gallager and Mann (1983b, c), and indicate that a threshold relationship exists between egg lipid content and subsequent larval growth. Under otherwise identical conditions eggs with higher lipid content give larvae that exhibit higher percentage completion of metamorphosis (Figure 2). It is important to note that although eggs from both our laboratory and commercial hatcheries with a relatively high initial lipid content (i.e., 10-25% of

the ash-free dry weight - a.f.d.w.) may yield cultures in poor condition, excellent cultures with greater than 80% metamorphosis are not possible unless the eggs contain at least 25% lipid. Other factors, most likely with genetic and/or environmental components, undoubtedly influence culture performance, but it is clear that optimal yield must be preceded by high initial egg lipid content. Figure 3 illustrates the effect of broodstock conditioning period on initial egg lipid content for M. mercenaria. Less conditioning time in the hatchery is required as the season progresses to obtain eggs in optimal condition; however, broodstock left to condition naturally produce eggs with variable lipid content from July through September. This illustrates that controlled artificial broodstock conditioning either in the hatchery or laboratory is preferential to relying on natural conditioning processes. Clearly, optimizing egg and larval lipid content, thereby promoting good larval health in culture, necessitates that broodstock be properly conditioned to ensure release of gametes with maximum rearing potential.

Lipid staining of 24-hour straight hinge larvae resulting from these experiments indicated that differences of just a few percent of the total lipid (equivalent to only 2-5 nanograms of absolute quantity) can easily be detected by hatchery personnel. This facilitates and justifies the use of the staining technique for screening young larvae for potential success in culture as a viable alternative to blindly rearing cultures with hopes of a high yield.

Two lipid staining, workshops for hatchery operators, held at WHOI in September 1982 (see Figure 1) and at Batelle Labs, Sequim, WA in March 1983, have generated considerable interest in possible future applications of this technique. Research in progress concentrates on understanding the basic morphological and biochemical transitions that occur during the presently unpredictable (with respect to % survival) process of bivalve metamorphosis. With this data we hope to provide a simple assay of the energy reserves of both cultured bivalve larvae which are initiating metamorphosis and post-metamorphic juveniles. Consequently, a predictive index of the future viability and survival of those animals would be possible.

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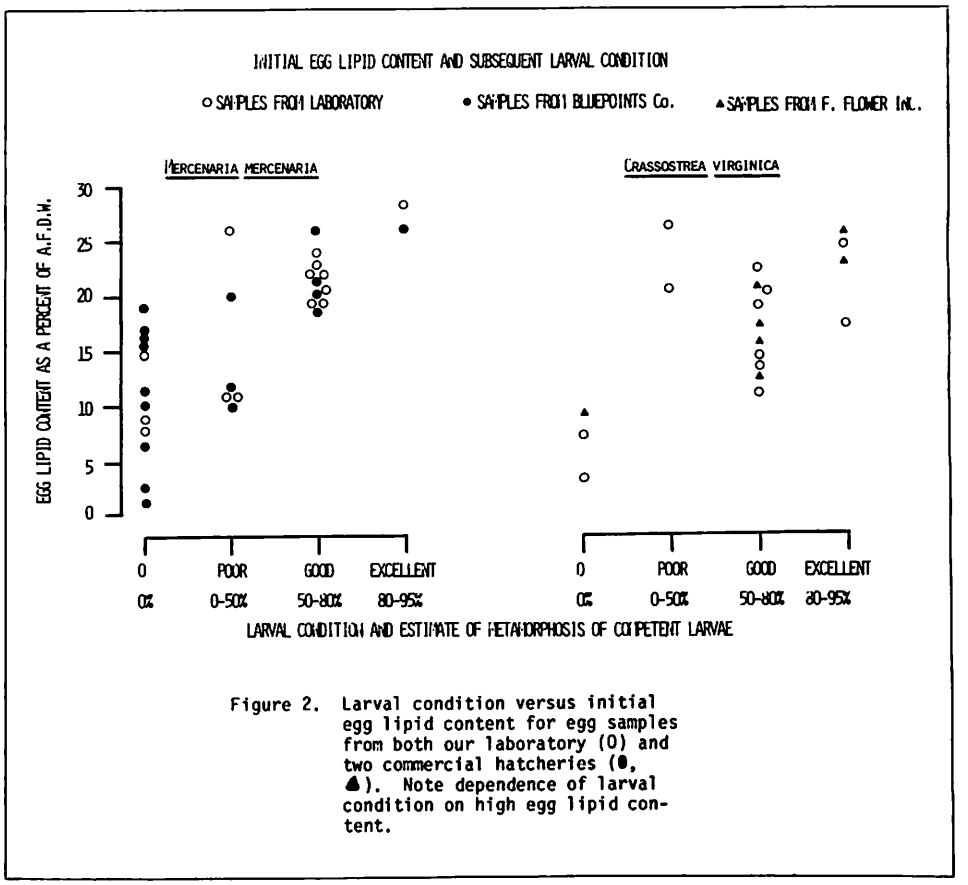

Figure 2. Larval condition versus initial egg lipid content for egg samples from both our laboratory (O) and two commercial hatcheries (●, ▲). Note dependence of larval condition on high egg lipid content.

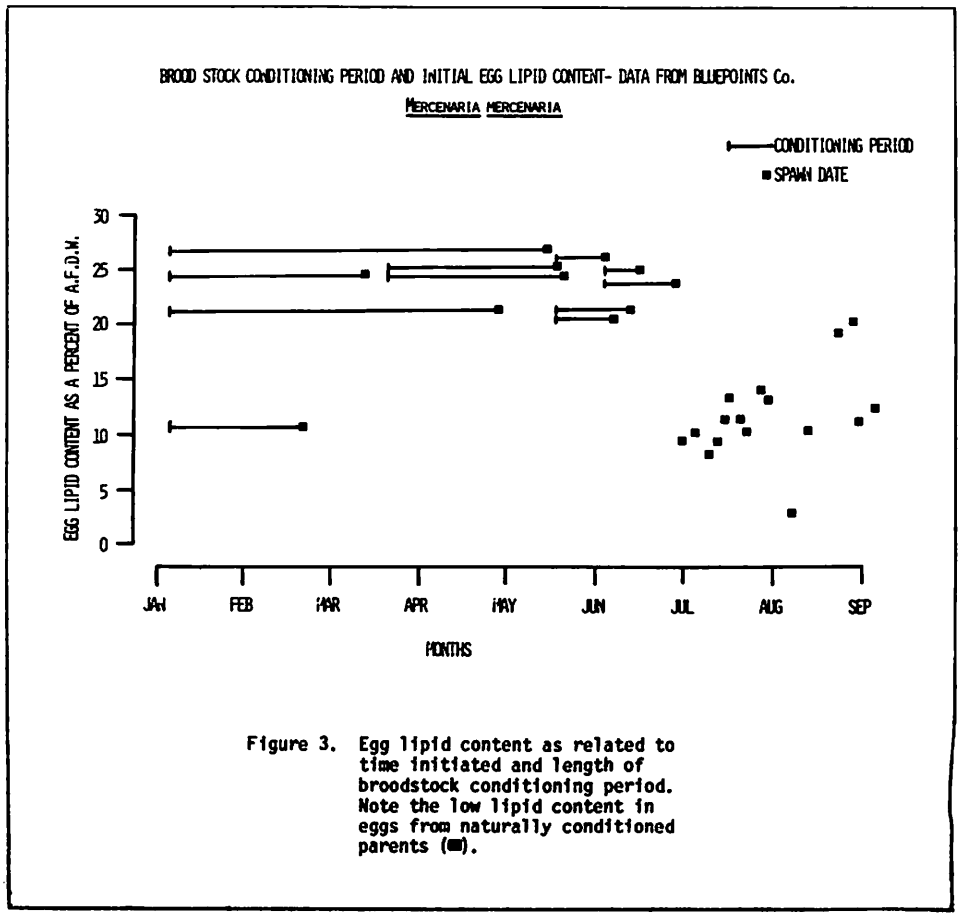

Figure 3. Egg lipid content as related to time initiated and length of broodstock conditioning period. Note the low lipid content in eggs from naturally conditioned parents (■).

Bacterial Chemosynthesis for Aquaculture

Craig D. Taylor, Linda B. Graham
and Holger W. Jannasch
Biology Department

Hydrogen sulfide and carbon dioxide-containing sour gases constitute a significant and hazardous by-product of gaseous fuel refinement and other industrial processes. Through intermediation of the unique capacity of chemosynthetic sulfur bacteria to utilize toxic sulfur compounds and incorporate carbon dioxide into cellula biomass, we have proposed that these industrially-derived waste streams may serv as a resource of biologically harvestable energy and carbon. The success of bacteria chemosynthesis in supporting dense shellfish communities in marine hydrothermal vents has led us to suggest that hydrogen sulfide-generated bacterial biomass may analogously be utilized for the production of mariculture-derived products. Studies have proceeded in two directions: a) investigation of hydrogen sulfide-supported biomass generation, and b) the determinatio of the suitability of such material as food for filter feeding bivalves.

Continuous flow laboratory-scale cultur techniques used for the duration of this project have illustrated that it is possibl to grow stable populations of hydrogen sulfide-utilizing bacteria on a long term basis. In keeping with its role as an intermediate in the bacterial oxidation of hydrogen sulfide, elemental sulfur was a significant and, in view of demonstrated detrimental effects upon shellfish feeding, a problematic component of the produced material. Even though the organic carbon component of the biomass was high in protei and a potentially good source of food, it is clear that procedures will be necessary for the elimination or removal of elemental sulfur. Means to this end would entail a) the input of hydrogen sulfide at high concentrations to maximize biomass production, b) avoidance of oxygen limitation, permitting total utilization of the available energy and detoxification of the effluent stream, and c) separation of the dense extracellularly produced elemental sulfur from particulate organic carbon prior to its use as a mariculture food source.

To test the applicability of bacteria as a food source, separate from potential detrimental effects of elemental sulfur, carbon assimilation studies employing a marine bacterium (Pseudomonas halodurans) were conducted in comparison with a known food algae (Isochrysis sp.). Small specimens of mussels, Mytilus edulis (approximate dimensions 2 x 4.5 cm) were batch fed (Figure 1) with equilibrium ^{14}C-labeled bacterial or algal cells for 7-9 hours followed by 50-280 hours of depuration using several exchanges of seawater containing non-radioactive cells. ^{14}C-labeled cells removed by the experimental animals and ^{14}C-labeled material contained within the feces were measured (typical example, Figure 2). Illustrated by the histogram, depuration was effective in removal of radioactive bacterial (data not shown) cells from the intestinal tracts. Upon completion of the incubation the experimental animals were removed from the shell, rinsed, and dissected into 5 tissue types: a) mantle, b) gills, c) shell adductor muscle, d) foot, and e) digestive system. The tissues were dissolved and analyzed for radioactivity.

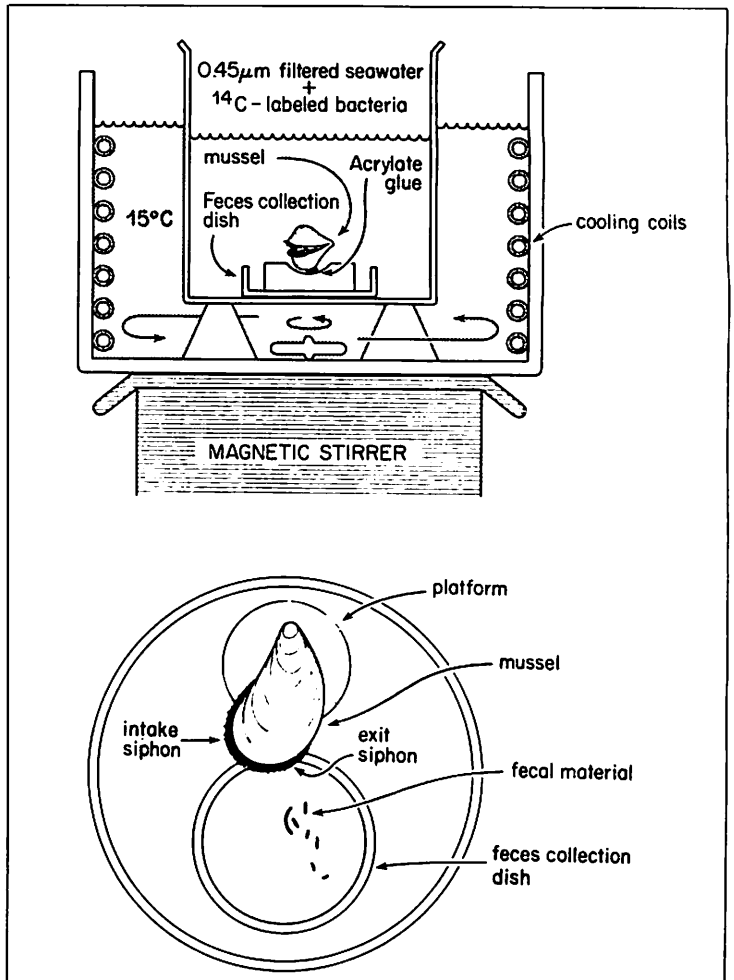

Figure 1. Mussel Feeding Apparatus.

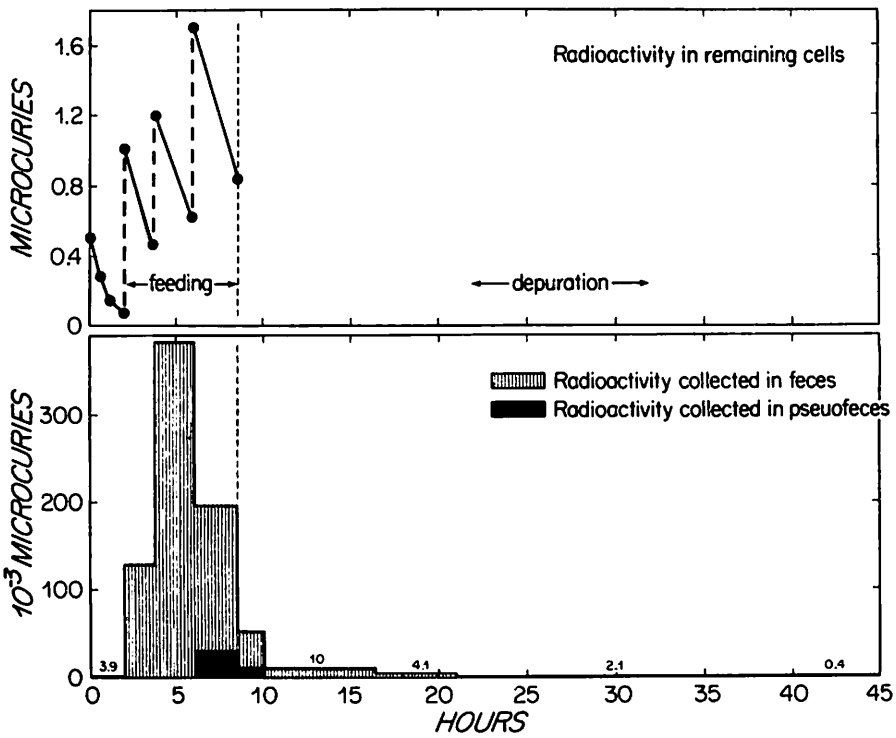

Figure 2. ^{14}C-labeled bacterial cells filtered by Mytilus and ^{14}C-labeled material contained within the resulting fecal material.

The data (Table 1) clearly illustrate that Mytilus is capable of digesting and assimilating bacterial cell carbon. Levels assimilated range from 24-46% of the bacterial carbon filtered from the seawater, values that are lower than but certainly on par with that observed using a classic algal food source (52-76% of algal carbon filtered). In both instances a majority of the assimilated radioactivity was found within the digestive tract tissues (50-70% for bacterial carbon, 47-59% for algal carbon). Since these activities were not removed during depuration, they most likely represent radiocarbon assimilated into the tissue as metabolites and as engulfed food particles that were being actively digested by the phagocytic cells lining the digestive tract.

Subcellular fractionation studies (data not shown) suggest, in fact, that substantial digestion of phagocytic bacterial and algal cells have occurred as revealed by significant differences in the distribution of radioisotope among tissue bipolymers relative to that of the fed material. In addition, the radiocarbon present in the tissues of the foot, mantle, gills, and adductor muscle was transportable only via soluble metabolites, hence reflecting the complete digestion of significant proportions of the retained food materials (30-50% and 40-50% in bacterial and algal fed animals, respectively). Control experiments, where excised mussel tissues were incubated in seawater containing radioactive bacterial cells revealed that less than 1.5% of the observed activities could result from direct contamination by bacteria.

While these short-term experiments do not prove that long-term growth of Mytilus will be supported by bacteria, the observed levels of bacterial cell carbon assimilation are encouraging and are indeed on par with the organic carbon requirements for active growth of mussels.

TABLE 1

RADIOCARBON INCORPORATION BY MYTILUS EDULIS*

Fraction	Food Source: Pseudomonas halodurans (bacteria)						Food Source: Isochrysis sp. (algae)			
	µg ^{14}C in Fraction			% of Total Isotope in Fraction			µg ^{14}C in Fraction		% of Total Isotope in Fraction	
	1B	2B	3B	1B	2B	3B	1A	2A	1A	2A
Cells filtered by mussel	6160	2429	2151	100	100	100	1760	2086	100	100
Fecal material	2090	786	698	34.0	32.3	32.4	200	181	11.3	8.67
Digestive tract	1020	456	472	16.6	18.8	21.9	787	591	44.7	28.4
Foot		44	92		1.8	4.3	156	109	8.8	5.2
Mantle	219	153	237	3.6	6.3	11.0	191	169	10.9	8.1
Gills	176	77	156	2.9	3.2	7.2	158	159	9.0	7.6
Adductor Muscle	33	46	40	0.53	1.9	1.8	43	60	2.4	2.9
Total in Tissue	1448	776	997	24.0	32.0	46.2	1335	1088	75.8	52.2
Total in Feces and Tissue	3538	1562	1695	58.0	64.3	78.6	1534	1269	87.1	60.9
Radioisotope Unaccounted for (Respiration and Experimental Losses)	2622	867	458	42.0	35.7	21.4	226	816	12.9	39.1

*The following further explains experiment parameters pertaining to the mussels 1A, 2A, 1B, 2B, 3B. The animal lengths in cm are 4.44, 4.41, 4.65, 4.79 and 3.4, respectively. The total µCi of cells filtered are 6.07, 5.12, 0.98, 1.11 and 2.45, respectively. Exposure to ^{14}C-labeled cells were 6 hr for mussels 1-2AB and 9 hr for 3B and the depuration times were 280 hr for 1A, 1B; 97 hr for 2A, 2B and 45 hr for 3B.

The Population Dynamics of Infectious Diseases in Mariculture Systems

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This project was a preliminary investigation of the possibilities of applying recent developments in the theory of the population biology of infectious diseases to disease problems in mariculture systems. The literature on mariculture lists the economic impacts of disease as a major problem (e.g., Sindermann 1977). Within the last few years, advances have been made in the development of theoretical and mathematical models of disease systems (reviews by Anderson and May 1982, Anderson 1981, 1982). In particular, these new models include the dynamics of both the host population and the population of the infectious agent, and the ways in which the latter may control the former. The goal of this project was to survey these models with an eye toward potential applications to the specific problems of mariculture systems.

The results of the survey were promising. Several different classes of models have been applied, depending on whether the host population is considered to be static or changing and on the mode of transmission of the parasite. In any of these models, however, given the structure of the life cycles of host and parasite and information on transmission, reproduction, and the dynamics of susceptibility, recovery and immunity, it is possible to calculate two potentially useful statistics.

(1) The reproductive rate (R) of the infection. This number describes, in essence (the details depend on the mathematical structure of the particular situation), the number of secondary cases that a single infected host can expect to produce during its lifetime. Obviously, the persistence of the infection is determined by whether R is greater or less than unity. Since R can be expressed in terms of the parameters of the model, and since in mariculture systems at least some of those parameters are under the control of the manager of the system, it is in principle possible to use this parameter to design systems in which particular infectious agents would be less likely to generate persistent infections.

(2) The threshold host density (N). Most infectious disease models generate a threshold host density, N, below which the infection dies out. One of the factors which make mariculture systems so susceptible to disease is the economic necessity for holding animals at high densities. Given expressions which relate N to the life cycles of the host and the parasite, it may be possible to evaluate the economic tradeoffs between raising animals at different densities.

A large scale study of these models, preferably in the context of one or more specific mariculture systems, should be undertaken in the future.

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Osmoregulation in the Brook Trout, *Salvelinus Fontinalis*

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Biology Department

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, two major questions concerning the migratory tendency of brook trout remain unanswered:

1) Are there physiological adaptations similar to those in smolting salmonids that are preparatory to seawater entry?

and

2) Do size, age, and photoperiod limit the ability of brook trout to osmoregulate in seawater?

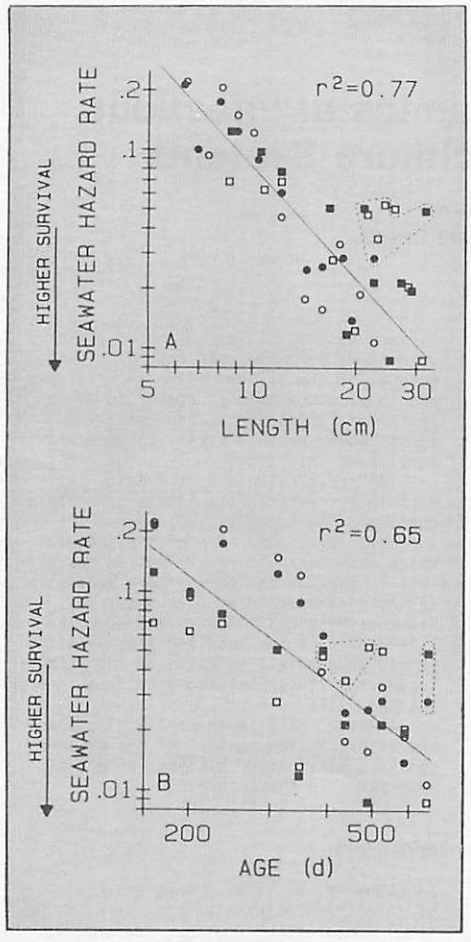


Figure 1. Seawater survival as a function of size and age. Log of seawater hazard rate versus (A) log of fork length and (B) log of age for fish in high feed (squares) and low feed (circles) groups in normal photoperiod (closed symbols) and 3-mo. delayed photoperiod. Points encircled with dashed lines represent experiments with mature males exposed to seawater during autumn photoperiod.

Brook trout raised from eggs under two photoperiod and two feeding regimes were tested for physiological changes preparatory for transition from freshwater to seawater. Size, age growth rate, photoperiod, and diel rhythms were examined for possible influences on plasma osmolarity, $[Na^+]$, $[Cl^-]$, $[K^+]$, $[Mg^{2+}]$, thyroxine concentration, hematocrit, and gill Na^+,K^+-ATPase activity of brook trout in freshwater. Significant diel cycles were found in plasma osmolarity, $[Na^+]$ and thyroxine concentration. Significant size and/or age related changes occurred for plasma osmolarity, $[Na^+]$, $[K^+]$ and hematocrit, but could explain little of their total variation ($0.02 < r^2 < 0.18$). A sexually dimorphic response to photoperiod was observed in hematocrit for both mature and immature fish, with hematocrit of mature females declining in autumn and hematocrit of immature males increasing in autumn. Gill Na^+,K^+-ATPase activity did not respond to photoperiod or feeding treatment and showed no change with size or age. Plasma thyroxine levels responded to feeding and photoperiod treatment. There was a significant correlation between the percent mean difference in plasma thyroxine and the mean difference in growth rate between high and low feed fish ($r^2 = 0.51$), suggesting a relationship between thyroxine and growth.

In 11 experiments over 1.5 years, brook trout were gradually exposed to 32 ppt seawater for 20 days to investigate the ontogeny of salinity tolerance. A single experiment examined daily changes in plasma osmolarity, $[Na^+]$, $[Cl^-]$, $[K^+]$, $[Mg^{2+}]$, thyroxine, hematocrit and gill Na^+,K^+-ATPase during adaptation to 10 ppt, 20 ppt and 32 ppt. Size was the primary determinant of seawater survival ($r^2 = 0.77$, Figure 1); the effect of size on seawater survival slowed after fish reached a fork length of 14 cm. The effect of age on seawater survival ($r^2 = 0.65$) was through its covariance with size. Photoperiod affected seawater survival only through its influence on the timing of male maturation, which decreased salinity tolerance. Hypo-osmoregulation of plasma osmolarity, $[Na^+]$, $[Cl^-]$, $[K^+]$, $[Mg^{2+}]$ and hematocrit increased linearly with size over the entire range of sizes (6-32 cm). Gill Na^+,K^+-ATPase activity after 20 days in seawater decreased with increasing size of brook trout, possibly reflecting decreased demand for active ion transport in larger fish (Figure 2). Plasma thyroxine concentrations generally declined in seawater, but no definitive role of this hormone in seawater adaptation was found. Size dependent survival and osmoregulatory ability of brook trout has been compared to other salmonids and a conceptual model has been developed.

Decreased salinity tolerance and hypo-osmoregulatory ability was found in mature male brook trout and was not found in females or immature males. Lowered salinity tolerance of adult males becomes acute during autumn photoperiod when normal spawning occurs. Plasma $[Cl^-]$, $[Mg^{2+}]$, osmolarity and hematocrit are significantly higher in mature males after transfer to seawater, relative to mature females. It is postulated that reduced adult male hypo-osmoregulatory ability explains skewed sex ratios in anadromous populations, limits the extent of anadromy, and was a significant phase in the evolution of extended salmonid migration.

Anadromous brook trout of Rivière à la Truite, Quebec, were examined for physiological changes associated with salmonid smoltification, and compared to non-anadromous brook trout of the Matamek River. There were no significant differences in plasma thyroxine concentration, gill Na^+,K^+-ATPase activity, hematocrit or osmoregulatory ability of anadromous and non-anadromous brook trout. Moisture content was significantly different between fish from the two river systems, but had the same pattern of declining moisture content as summer progressed. Silver coloration of brook trout in Rivière à la Truite was significantly associated with larger fish and higher gill Na^+, K^+-ATPase activity and hypoosmoregulatory ability than brook trout at low salinity sites. Atlantic salmon (Salmo salar) in high salinity estuarine sites had significantly higher plasma thyroxine and gill Na^+,K^+-ATPase activity than brook trout. The results indicate that smoltification is relatively undeveloped in brook trout and that estuarine residence is important in salinity adaptation and eventual seaward migration.

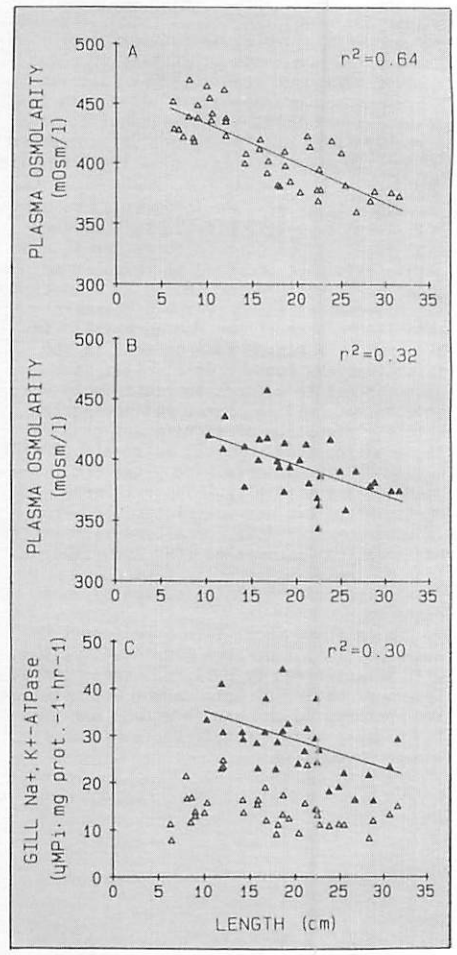
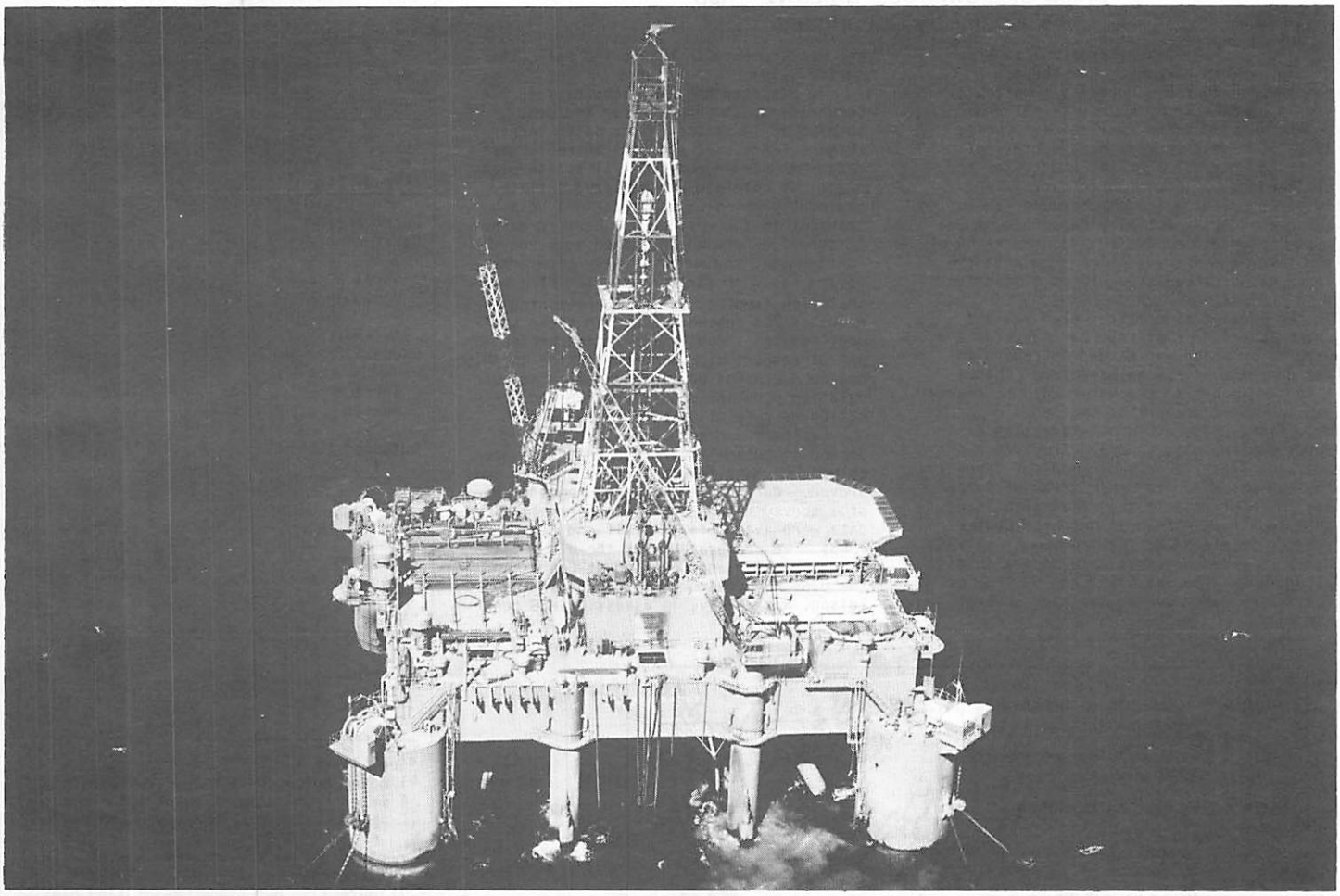


Figure 2. Plasma osmolarity and gill Na^+,K^+-ATPase as a function of brook trout size. (A) Plasma osmolarity after 4 days in seawater, (B) Plasma osmolarity after 20 days in seawater, and (C) gill Na^+,K^+-ATPase after 4 days (open triangles) and 20 days (closed triangles) in seawater, versus fork length of brook trout.

Human Impact on the Marine Environment



The oil well drilling vessel OCEAN SCOUT. The potential for hydrocarbon deposits on Georges Bank has raised many environmental issues, in particular effects on the fisheries in the area. (Bethlehem Steel Corporation)

Georges Bank: A Book and Atlas

Richard H. Backus
Biology Department

The Coastal Research Center of the Woods Hole Oceanographic Institution has proposed a comprehensive, multidisciplinary investigation of Georges Bank to supplement various research programs already in progress. The first phase of this effort, underway since 1980, is the collection and interpretation of 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 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 oversight of an editorial board consisting of Richard H. Backus (general editor) and Robert C. Beardsley, WHOI, Bradford Butman, U. S. Geological Survey, and Marvin D. Grosslein, National Marine Fisheries Service. Dr. Richard L. Price, a geographer in WHOI's Marine Policy and Ocean Management Center and now of Ft. Collins, Colorado, is the cartographic editor, Elizabeth A. Suwijn, the cartographer.

A most important function of the editorial board has been the selection of writers and reviewers. These number about 215 and include private individuals as well as affiliates of about 80 different organizations. The latter include a great variety of private and public academic institutions, industrial and commercial laboratories, and federal and state agencies, both in the United States and Canada. About 80 of the writers and reviewers come from three organizations--the National Marine Fisheries Service (Beaufort, Gloucester, La Jolla, Narragansett, Sandy Hook, Seattle, and Woods Hole laboratories), the U. S. Geological Survey, and the Woods Hole Oceanographic Institution. Other organizations particularly well represented are the University of Rhode Island and the Bedford Institute of Oceanography.

The book consists of 58 chapters, 9 introduction/summaries, 10 special pieces, plus preface, index, and a list of contributors.

About 1100 pages of edited manuscript had been turned over to the publisher, the MIT Press, on 1 March 1984. The remaining 700 pages were in an advanced state of preparation, and manuscript editing will be complete by 1 May. Graphics will consist of about 300 color maps (some of which are in several parts), about 125 other color pieces (half-tones and line drawings), and about 400 black-and-white figures. About 700 pieces had been prepared by 1 March 1984. The book is expected to be about 1000 pages long. Publication late in 1984 is expected.

The Distribution of PCBs in Sediments of an Industrial Harbor; New Bedford, MA

John W. Farrington, Alan C. Davis,
Bruce C. Brownawell, Bruce W. Tripp
Chemistry Department

The Acushnet River Estuary also known as New Bedford harbor or New Bedford-Fairhaven harbor has received substantial inputs of PCBs from two electrical component manufacturing facilities. During 1974-1982 field surveys by a variety of state and federal agencies and their contractors, in addition to surveys and research by a few academic groups (including our own efforts partially supported by Sea Grant) provided sufficient documentation of the severity of the problem such that the inner harbor area was declared a Superfund site in 1982.

Remedial action master plan reviews under Superfund confirmed our concerns that more information was needed in regard to the dynamics of PCB release from contaminated sediments to the water column, resuspension and transport of sediment-associated PCBs, and the interaction of resuspension, with general circulation of Buzzards Bay as a probable mode of spreading the PCB pollution to other areas of Buzzards Bay. Much of this is the focus of a joint WHOI Sea Grant - Coastal Research Center project initiated during the summer of 1983. However, with the assistance of new initiative funds from Sea Grant and WHOI's Coastal Research Center, we made several key measurements in the period fall, 1982 - spring, 1983.

We assisted the EPA's contractor, GCA Corporation, in sampling for sediment samples at locations in the outer harbor (Figure 1-Areas II and III) where further data were needed for remedial action planning. We obtained and analyzed surface sediment samples at key locations on a transect to the west of New Bedford harbor (Figure 1) where we suspected some PCB-contaminated sediment may have been transported based on earlier analyses of shellfish samples. We have documented elevated PCB concentrations in these sediment samples strongly indicating present or past transport of PCB contamination to this region. Present physical dynamics and circulation modeling should provide confirmation or refutation of this conclusion.

Early in our new initiative funding period it became imperative that the water column PCB data for the harbor area be improved. Our few earlier measurements were of a survey nature and few other reliable data were available (Metcalf and Eddy, 1983). We cooperated with the U.S. Coast Guard Research and Development Center and the U.S. EPA Environmental Response Team, Edison, New Jersey, in assessing PCB concentrations in the water column and flux measurements between sections of the harbor (Figure 1). Our higher resolution glass capillary gas chromatography measurements complemented their more numerous, lower resolution methods measurements necessitated by time and expense constraints. Table 1 presents our water column PCB data for the Route 195 and hurricane barrier sites (Figure 1). Much work remains to be accomplished in estimating the flux out of the harbor at the hurricane barrier (Figure 1) and transport throughout Buzzards Bay, but the new initiative funding, in conjunction with other activities, provided for some important new data towards remedial action.

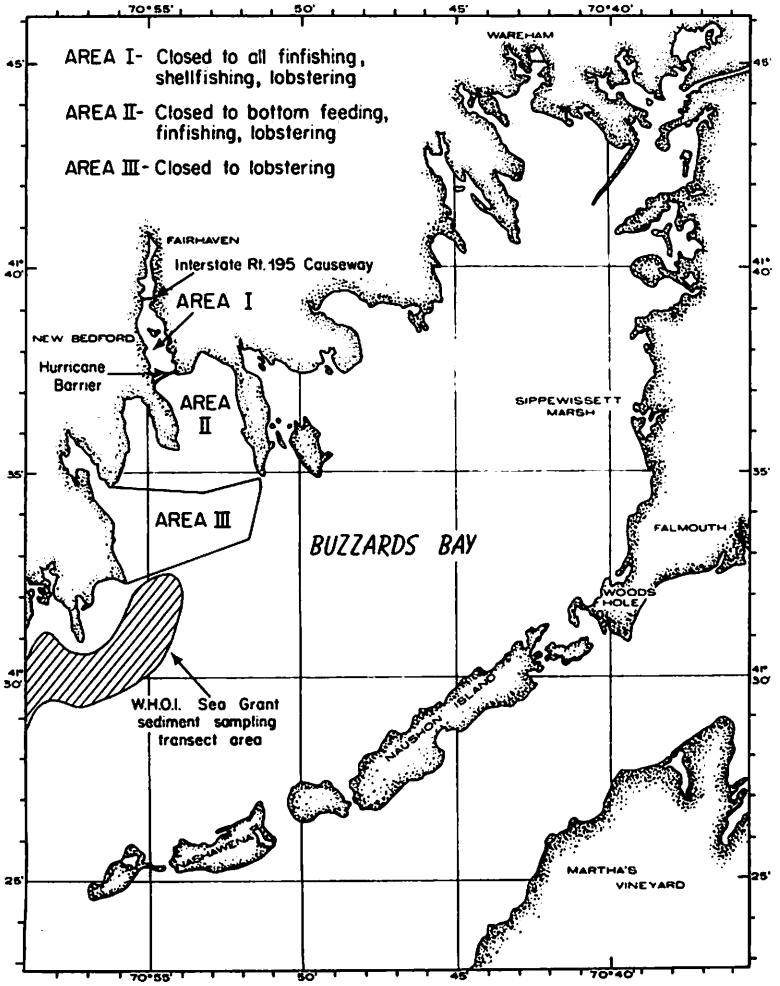


Figure 1. Map showing locations, Areas II and III, where additional data were required prior to remedial action planning and the sediment sampling transect area.

Table 1

PCB Concentrations in New Bedford Harbor Water -- R/V ASTERIAS Cruise 22 September 1982

Aroclor 1242 + 1254 PCB Mixture (10^{-9} g/liter)

	Particulates	Dissolved	Total
Incoming (Flood) Tide			
Hurricane Barrier[a]			
Surface[b]	28	52	80
Bottom[b]	22	28	50
Rt. 195 Causeway[a]			
Surface	183	329	512
Bottom	134	152	286
Outgoing (Ebb) Tide			
Hurricane Barrier			
Surface	27	36	63
Bottom	30	41	71
Rt. 195 Causeway			
Surface	386	289	675
Bottom	232	244	476

[a]See Figure 1.
[b]1 meter below surface and approximately 1 meter from sediment/water interface.

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

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

With the increased interest in offshore oil and gas exploration and the increased risk of offshore oil spills, new strategies of oil spill clean up and control have been developed. 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 (Canevari, 1969). 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 with an emphasis on metabolic processes that affect development and recruitment success need to be evaluated.

During the past year our work focussed on defining the relationship between hydrocarbon accumulation and specific changes in lipid metabolism in larval and postlarval stages of the lobster (Homarus americanus) with exposure to naturally dispersed and chemically dispersed oil. The specific goals of our research were:

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

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

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

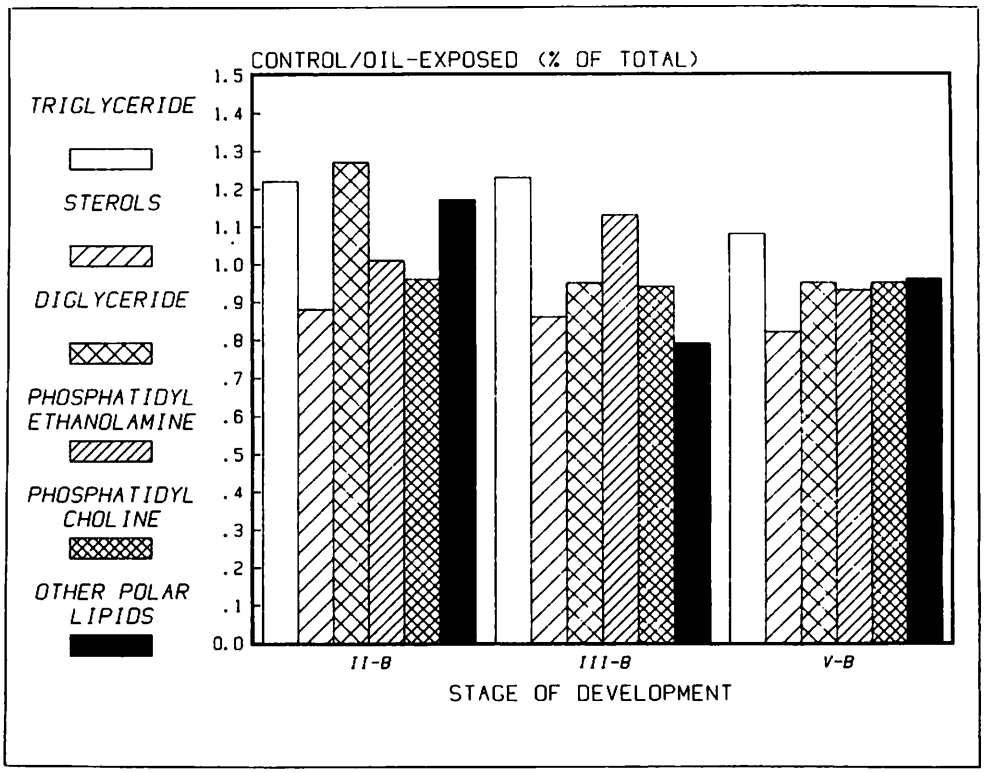

Figure 1. Lipid class composition of larval and postlarval lobsters-ratio of control to oil-exposed values.

The normal patterns of lipid storage, utilization, and synthesis during larval development and metamorphosis of the lobster were altered with exposure to both chemically dispersed and naturally dispersed oil. Increased rates of protein catabolism, delayed molting and reduced growth were also evident among oil-exposed lobster larvae and suggest either deficiency or immobilization of lipid reserves. From analyses of lipid class composition of control and oil-exposed lobster larvae, it is evident that oil-exposed larvae have consistently lower levels of triacylglycerols (the major energy store) and higher levels of sterols than control larvae (Figure 1). Decreased ratios of non-essential fatty acids (both saturated and unsaturated) and increased ratios of essential fatty acids were detected in the neutral lipid pools of oil-exposed larvae that suggest both decreased storage of fatty acids in energy reserves and decreased mobilization of essential fatty acids into phospholipid pools. The fatty acid distribution in the phospholipid pools of oil-exposed larvae, however, varied little from control values and reflect a tendency to preserve the integrity of these structural lipids. Increases in sterol levels may be related to decreased mobilization of cholesterol or other sterols and/or transformation of cholesterol into metabolic pathways including the biosynthesis of ecdysterone.

Oil-exposed animals contained trace quantities of benzene, thiophene, toluene, alkylcyclohexane and alkylbenzenes, detected with GC-MS analyses. No naphthalene, dimethylnaphthalene, higher molecular weight aromatics or their phenolic derivatives were detected; their absence may be related to either the detection limits of the methodology used or extremely rapid metabolism and turnover of these components.

Alterations in lipid metabolism may account for the developmental and energetic abnormalities observed in marine crustaceans. It cannot be ruled out, however, that decreased lipid utilization, synthesis, and mobilization may be a defense mechanism against incorporating lipophilic components of petroleum hydrocarbons in metabolic pathways and disruption in energetics and development is a consequence of the reduction in energy available for growth and molting.

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Stable Isotope Determination of the Origin of Water Types in Buzzards Bay

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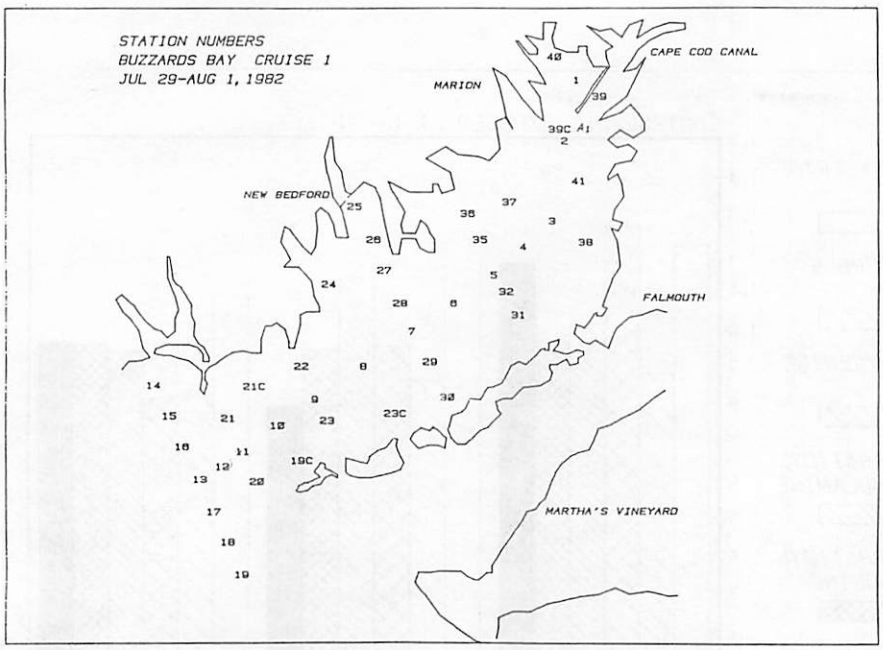

Figure 1. Station locations for Buzzards Bay cruise 1 (BB1), 29 July to 1 August 1982.

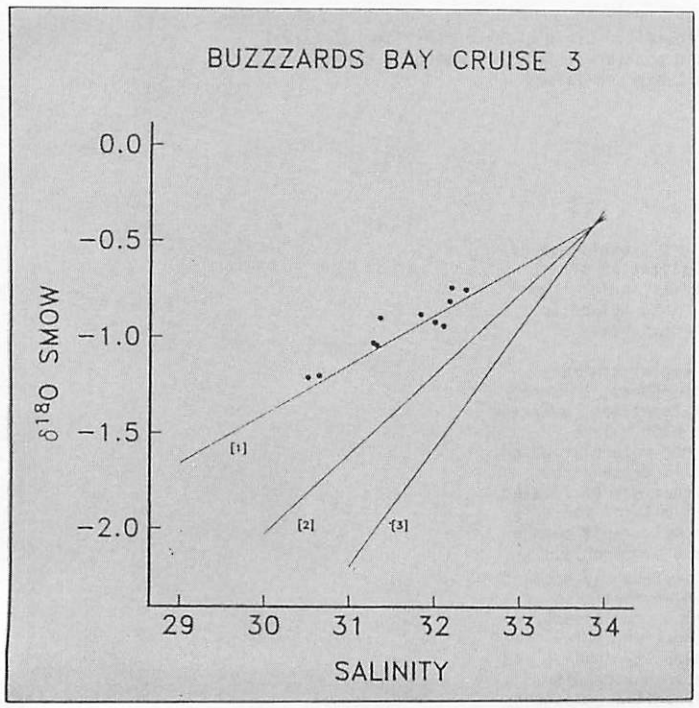

Figure 2. $\delta^{18}O$:salinity distribution for selected stations from the BB3 cruise. The lines on this figure represent the mixing lines observed by Fairbanks (1982) for: [1] New York Bight Water, [2] Gulf of Maine Water and [3] Slope Water.

The utility of characterizing water masses by salinity:$\delta^{18}O$ relationships has been well documented (Epstein and Mayeda, 1953; Craig and Gordon, 1965). Fairbanks (1982) demonstrated that water types from the New York Bight and Gulf of Maine regions are characterized by different salinity:$\delta^{18}O$ relationships which are determined by their respective freshwater and slope water inputs. As a result, these water types can be distinguished based on their salinity and $\delta^{18}O$ compositions. The purpose of this study is to determine the origin of and temperal change in water types within Buzzards Bay by determining the relative contributions of the northern (Gulf of Maine) and southern (New York Bight) sources to the bay. However, since there are small differences in $\delta^{18}O$ between the end-member water types, it is not clear whether the stable isotope tracer method will be useful within Buzzards Bay. A study was undertaken to evaluate the feasibility of interpreting salinity:$\delta^{18}O$ tracer data within such a small geographic region.

A sampling matrix within Buzzards Bay, Cape Cod Canal, and Cape Cod Bay was developed based on previous work by Leslie Rosenfeld, a Joint MIT/WHOI Program student in physical oceanography. In July 1982, she collected samples from surface and subsurface depths at locations within Buzzards Bay (BB1 cruise, see Figure 1) and preserved water samples for salinity:$\delta^{18}O$ analysis. In January 1983, a cruise (BB3) funded by Sea Grant reoccupied these stations and added stations from Martha's Vineyard Sound and Cape Cod Bay. At each station the water column was profiled with a CTD and water samples were collected from the surface and bottom. 46 stations were taken during the 13-14 January 1983 cruise of the R/V ASTERIAS. A subset of 20 samples from the BB1 summer cruise and 10 samples from the BB3 winter cruise were selected for $\delta^{18}O$ and salinity analysis. The $\delta^{18}O$ samples were processed by R. G. Fairbanks at Lamont-Doherty Geological Observatory on a VG Micromass 903E mass spectrometer according to procedures outlined in Fairbanks (1982) and the results are presented in Table 1.

The salinity:$\delta^{18}O$ distribution for the BB3 cruise is presented in Figure 2. The relationship for this cruise is similar to the relationship noted by Fairbanks (1982) for New York Bight water. The lowest $\delta^{18}O$ and salinity values occur at stations 1 and 40 which are located near the mouth of the Wareham River at the eastern end of Buzzards Bay. The similarity of the salinity:$\delta^{18}O$ relationship of these data to the New York Bight data suggests that the isotopic composition of the freshwater input at the Wareham River is similar to that of the Hudson River (-8 to -10 °/oo SMOW: Fairbanks (1982)). The six most saline samples plotted in Figure 2 were collected in Cape Cod Bay (station 49), Martha's Vineyard Sound (station VS1), the western end of the bay (stations 14 and 19), and two stations within Buzzards Bay (30 and 27-B). These stations completely surround Buzzards Bay and their similar salinity and $\delta^{18}O$ values suggest that the water types have a common origin. Thus the mixing occurring within Buzzards Bay at this time is between this water (salinity = ~32.0 to 32.5 °/oo and $\delta^{18}O$ = -0.7 to -1.0 °/oo SMOW) and the freshwater input at the Wareham River.

The salinity:$\delta^{18}O$ distribution of the BB1 summer cruise is presented in Figure 3. The salinity:$\delta^{18}O$ relationship for this cruise differs slightly from the BB3 winter relationship. The lowest salinity and lowest $\delta^{18}O$ values again occur at stations 1 and 40 near the mouth of the Wareham River. The slope of the salinity:$\delta^{18}O$ line caused by this freshwater input appears to be shallower than that noted in the winter data (compare Figure 2 with Figure 3). If the difference is significant, the change in slope probably results from a seasonal change in the $\delta^{18}O$ value of the freshwater end member. Fairbanks (1982) has observed that the isotopic composition of the rivers of northeastern North America are generally enriched in ^{18}O by ~ 2 °/oo during the summer months. This effect would be noted within our data set by the reduced slope of the salinity:$\delta^{18}O$ mixing line. During the BB1 cruise, the most saline samples were collected at the western end of Buzzards Bay (stations 14 and 19). Unfortunately, samples from Martha's Vineyard Sound and Cape Cod Bay were not collected during this cruise. Interestingly, the sample geographically closest to Martha's Vineyard Sound (station 23C-B) is the only sample which falls on the Gulf of Maine salinity:$\delta^{18}O$ mixing line determined by Fairbanks (1982). While this may suggest that a third water type is mixing in Buzzards Bay, only one station clearly shows a difference in $\delta^{18}O$. A better matrix of samples for this summer cruise, particularly from Martha's Vineyard Sound and Cape Cod Bay, would determine if this singular isotopic value is meaningful.

The salinity:$\delta^{18}O$ distribution within Buzzards Bay is dominated by mixing between the freshwater end member of the Wareham River and a seawater end member. The mixing in winter is clearly between two end members: 1) sea water with a salinity of 32 to 32.5 °/oo and $\delta^{18}O$ of -0.7 to -1.0 °/oo SMOW and 2) the Wareham River with a $\delta^{18}O$ composition similar to that of Hudson River discharge. The slope of the salinity:$\delta^{18}O$ relationship appears shallower during the summer, probably as result of a change in $\delta^{18}O$ of the Wareham River discharge. Although the isotopic composition of one sample location suggests the possibility of a third end member mixing within the bay, lack of adequate sample coverage during the summer cruise precludes any definitive statement.

Table 1. Salinity and $\delta^{18}O$ values for Buzzards Bay stations BB1 (29 July - 1 August 1982) and BB3 (13-14 January 1982). "S" indicates a surface water sample. "B" indicates a bottom water sample.

Sample	Station	$\delta^{18}O$ smow	S °/oo
BB1	39-S	-1.22	30.637
	19-S	-1.10	31.505
	11-S	-1.15	31.409
	23c-S	-1.03	31.382
	23c-B	-1.57	31.408
	11-B	-1.26	31.478
	1-S	-1.41	29.718
	1-B	-1.37	29.779
	A1-S	-1.23	30.548
	A1-B	-1.31	30.580
	14-S1	-1.12	31.457
	14-S2	-1.12	31.457
	14-B1	-1.05	31.416
	14-B2	-1.09	31.416
	40-B1	-1.40	29.233
	40-S1	-1.35	29.361
	30-S	-1.11	31.420
	19-B	-1.07	31.738
	25-B	-1.12	30.989
	30-B	-1.09	31.394
BB3	1-S	-1.20	30.641
	14-B	-0.74	32.188
	19-S	-0.75	32.357
	25-B	-0.90	31.363
	27-B	-0.88	31.833
	30-S	-0.92	32.000
	39-S	-1.03	31.278
	40-S	-1.21	30.513
	45-S	-1.04	31.324
	49-S	-0.94	32.098
	VS1-S	-0.81	32.165

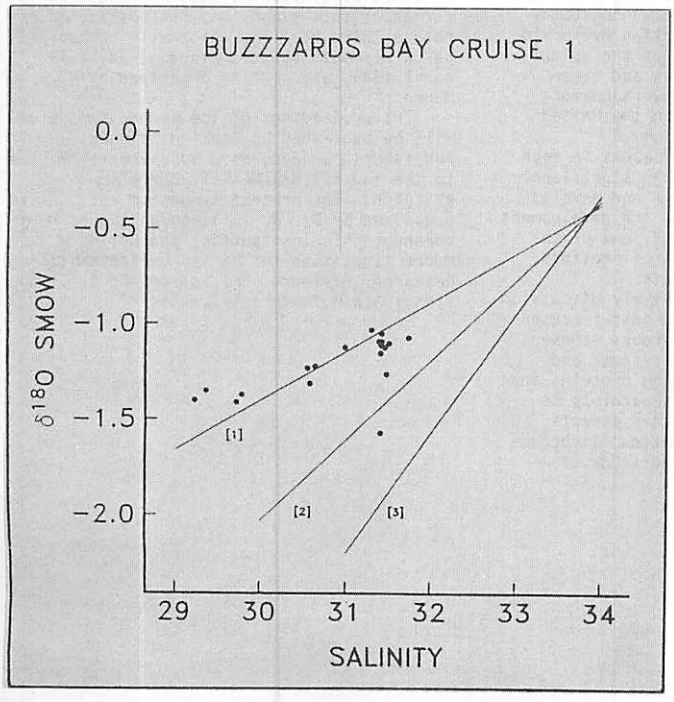

Figure 3. $\delta^{18}O$:salinity distribution for selected stations from the BB1 cruise. The lines on this figure refer to the mixing lines described in Figure 2.

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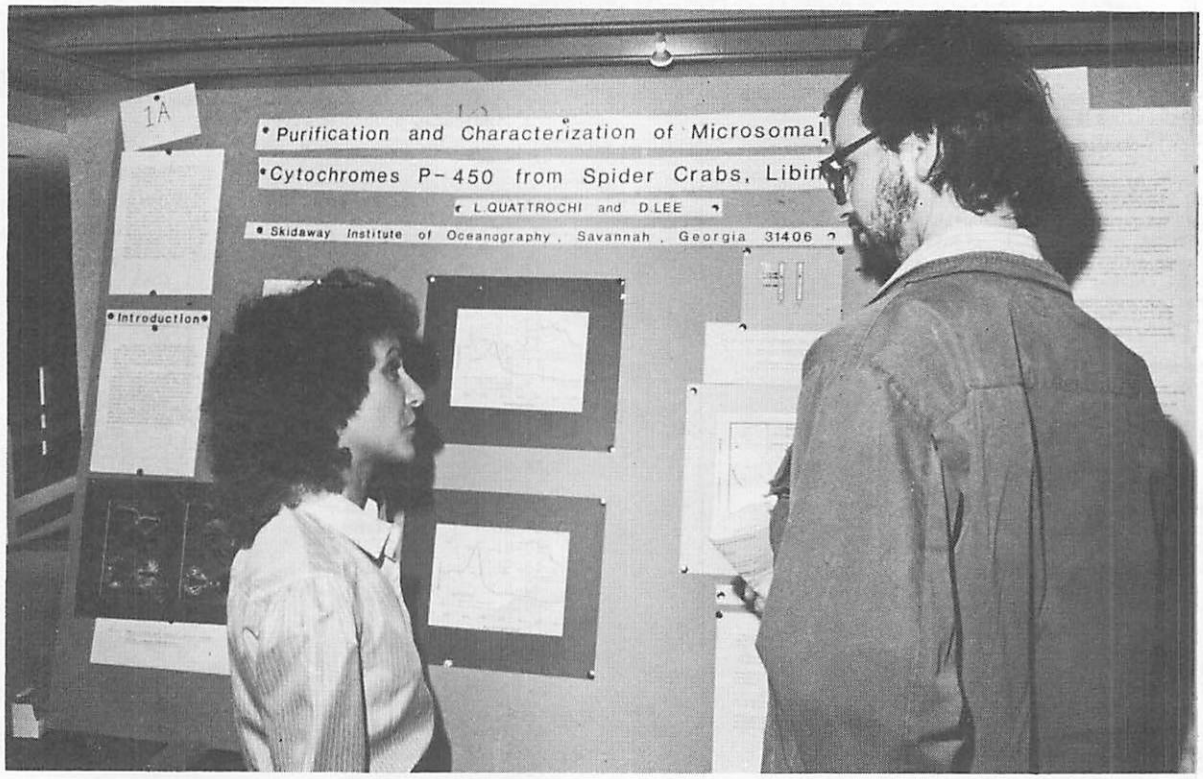

Linda Quattrochi discusses her poster display with Allen Klotz during a break at the symposium. (Shelley Lauzon)

The Second International Symposium on Responses of Marine Organisms to Pollutants

John J. Stegeman
Biology Department

The Second International Symposium on Responses of Marine Organisms to Pollutants was held at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts on 27-29 April 1983. This meeting succeeded in drawing together many of the people actively engaged in research on mechanisms and assessment of biochemical, physiological, cellular and histopathological effects of xenobiotics in aquatic organisms. Although nominally devoted to marine species, relevant comparative research on freshwater systems was an important component of the meeting.

Ninety papers were presented in slide and poster format, covering a comprehensive range of topics. These included cytochrome P-450 and biotransformation systems, metals and metal-binding proteins, more generalized biochemical and physiological effects, effects on immune systems and histopathological changes. The sessions on cytochrome P-450 and biotransformation (24 papers) included presentations dealing with the resolution, purification and characterization of cytochrome P-450 isozymes from fish and crustaceans. The forms now purified from teleost fish include the apparent major hydrocarbon-inducible form of cytochrome P-450. Apparent induction of cytochrome P-450 by environmental chemicals in embryonic and adult vertebrates and invertebrates, interaction between xenobiotics and steroids, and metabolism and activation of procarcinogens in various organ systems were also considered.

Discussion of metals and metal-binding proteins was also prominent, being treated in some 20 papers. These papers had a strong emphasis on the structural characterization and function of metal-binding proteins in fish and invertebrates. A number of papers considered interactive effects of metals and organic xenobiotics, and some 18 papers dealt with the chemistry of contaminated areas and organisms or with bioassays (e.g., incidence of chromosomal aberrations) of environmental samples. The sessions on pathology included consideration of xenobiotic-induced DNA damage, and the occurrence in fish of DNA sequences homologous to the transforming avian myelocytomatosis virus. Description of the epidemiology of neoplastic diseases and other abnormalities in fish and invertebrates from four polluted regions in the United States concluded the symposium.

A substantial number of papers in each of the sessions considered the significance of pollutants to reproductive and developmental processes. Likewise, the development and use of indices of effects, one of the ultimate aims of this series of meetings, received considerable emphasis.

The meeting engendered lively discussion both at the formal slide and poster presentations, and outside. Two groups, those working on cytochrome P-450 systems and those working on metal-binding proteins and metal-induced effects, met separately to consider nomenclature and other aspects of mutual concern. In summation, it became clear at the meeting that the study of pollution effects is benefitting from the application of immunochemical techniques and more sophisticated biochemical and molecular-biological approaches, and that the next few years should see significant advances in aquatic toxicology and environmental assessment. Such advance could well be aided by collaborations that began to be forged at this symposium. It was agreed to hold a third meeting, which will probably be in Plymouth (United Kingdom) on 17-19 April 1985, and will be organized by M. N. Moore.

The proceedings of the second symposium will be published by Applied Science Publishers, London, as a supplemental volume to the journal MARINE ENVIRONMENTAL RESEARCH. The present symposium was organized by Dr. J. J. Stegeman (Woods Hole Oceanographic Institution) and Dr. M. N. Moore (Institute for Marine Environmental Research, Plymouth, UK) and Dr. C. S. Giam (Texas A & M University).

Hydrography and General Circulation in Buzzards Bay

Leslie Rosenfeld
Physical Oceanography Department

The fourth in a series of hydrographic cruises in Buzzards Bay was carried out on a two-day cruise (May 5-6, 1983) on board the R/V Asterias. The CTD performed well and conductivity, temperature and transmission data were collected at over 40 stations. Oxygen data have not been included because of insufficient calibration measurements to determine adequately the coefficients in the algorithm used to calculate dissolved oxygen values.

Surface temperatures from a bucket thermometer and independent salinity measurements are being evaluated to verify the accuracy of the CTD data. One meter averages of temperature and transmission and the derived quantities salinity and sigma-t have been calculated for all stations. Vertical profiles of temperature, salinity and sigma-t will be plotted for each station. In addition, plots of temperature, salinity and density for vertical sections along the axis of the Bay and across the upper, mid-and lower Bay will be generated. Temperature and salinity for the along-axis and mid-Bay sections were also produced (see Figure 1 as an example). Horizontal maps of temperature and salinity at 1 m (see Figure 2) and at 8 m have also been plotted.

The data listings, vertical profiles, and contoured vertical sections and horizontal maps from the May, 1983 cruise will be combined with those from the three previous cruises (July 1982, October 1982 and January 1983) in a data report. The target date for completion of this report is February 1984. Discussion of the general circulation in Buzzards Bay based on this combined hydrographic data set will appear later.

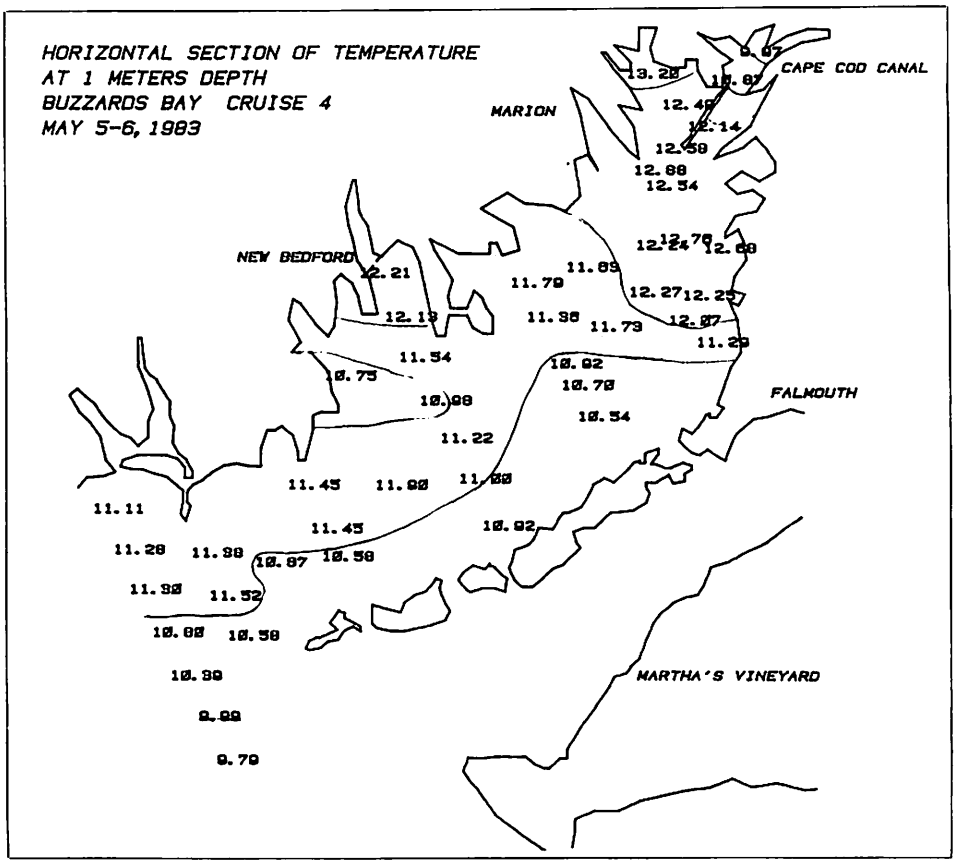

Figure 2. Horizontal section of temperature at 1 m depth.

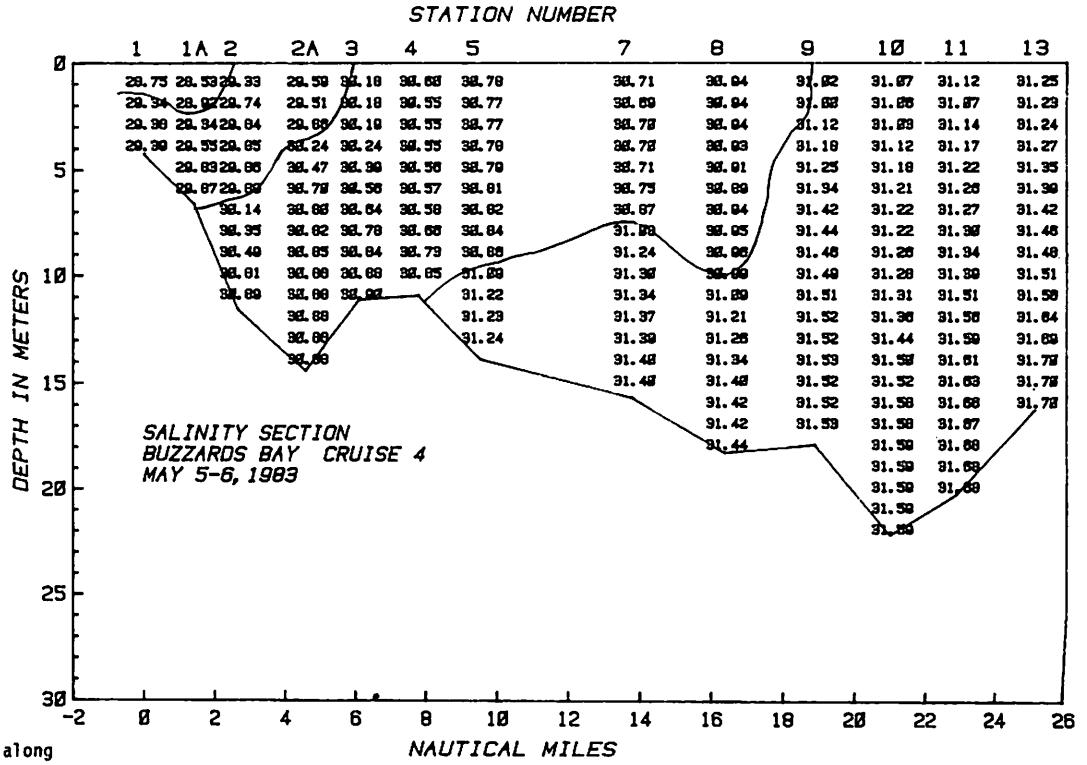

Figure 1. Vertical salinity section along the axis of Buzzards Bay.

Coastal Sediment Transport

Figure 3. Fritz Hess developed the radio-controlled model airplane shown in the figure for Lagrangian flow measurements in a tidal inlet environment. (David Aubrey)

Natural Tidal Inlet Bypassing

David G. Aubrey and Paul E. Speer
Geology & Geophysics Department

A three-year project has been designed to determine mechanisms by which sand carried alongshore in the surf zone bypasses natural tidal inlets. This longshore sand transport is an important factor determining tidal inlet stability; the ability of the inlet to flush itself naturally and bypass the influx of sediment determines its permanence and navigability. Bypassing of sediment brought into the inlet environment can be in one of two modes: either the inlet imports sand on flood tide and exports material on ebb tide (inlet bypassing), or the inlet forces sand to bypass largely along the ebb tide delta (delta bypassing).

Past work has shown that the tidal prism (volume of water exchanged through the inlet over a spring tidal cycle) is an important parameter describing tidal inlet stability, and hence navigability of inlet systems. Other physical factors also come into play, including the character of the offshore tidal regime and the wave climate of the adjacent waters. In addition, the geometry of the estuary served by the tidal inlet plays a major role in bypassing effectiveness. The goal of the present research is to develop a model of tidal inlet bypassing incorporating the elements described above.

Research has focussed on two field measurement programs, addressing different aspects of the inlet bypassing problem, and numerical modeling components to provide a framework for making and interpreting field measurements. The first field and modeling program investigated the distortion of the offshore tide as it propagates into shallow, channelized estuaries generating nonlinear tidal harmonics (overtides). Field observations consisted of an array of ten water level meters distributed throughout the estuary over periods of months (Figure 1, from Aubrey and Speer, 1983), as well as current meter arrays deployed at various sections of the estuary for week-long periods. From these measurements, we extract rates of harmonic growth in sea surface and velocity, as well as local momentum balances to apply to our modelling efforts. Results of our experiments can be summarized in a graph showing rate of decay of the dominant semi-diurnal tide (M_2) and its dominant overtide (M_4), where the ratio of M_4/M_2 is an indication of degree of nonlinearity of the tidal signature (Figure 2). Growth of M_4 is the result of nonlinear interactions extracting energy from the M_2 constituent, and frictional decay through the shallow estuaries. Numerical modelling techniques have been successful in predicting the rate of nonlinear growth of the harmonics, as a function of channel geometry (particularly the ratio of tidal amplitude to mean water depth, and extent of tidal flats). More detail on these results are contained in Aubrey and Speer (1983), Aubrey and Speer (in prep.), and Speer and Aubrey (in prep.). The nonlinearities within the estuaries are felt near the inlet throat, thereby affecting the duration and strength of flood and ebb tides and resulting sediment transport. Flood-dominated inlets (flood flows shorter but stronger) and ebb-dominated inlets (flood flows shorter but stronger) have both been observed along the U.S. east coast, with consequent differences in inlet morphology and inlet bypassing modes.

The second experimental and field effort emphasized flow structure and sediment transport on the ebb tide delta itself. Numerical solutions of combined wave/current flows on the ebb-tide delta are combined with field observations to evaluate the impact of estuarine geometry, offshore tidal structure, and incident wave activity on the nature of ebb tidal flows and hence morphology of the ebb-tide delta. Qualitative descriptions of wave- and tide-dominated inlets have existed in the literature for years, but these processes have not yet been quantified. We are presently taking steps to quantify these complex coastal flow fields. Field experiments have addressed the Eulerian and Lagrangian flow field in the inlet throat and on the ebb tide delta. Eulerian measurements were made with a vertical and horizontal array of current meters, while Lagrangian measurements were made from aerial observation of drifter patterns and dye dispersal (Figure 3-see Hess and Aubrey, in prep.). This aspect of the research is the primary focus of the second and third years of effort.

We anticipate the final results will be applicable to a number of practical problems, particularly navigation projects in tidal inlet regions, and evaluation of jetty designs for stabilizing navigation channels. This effort complements a new program being instituted by the U.S. Army Corps of Engineers Coastal Engineering Research Center, addressing these problems.

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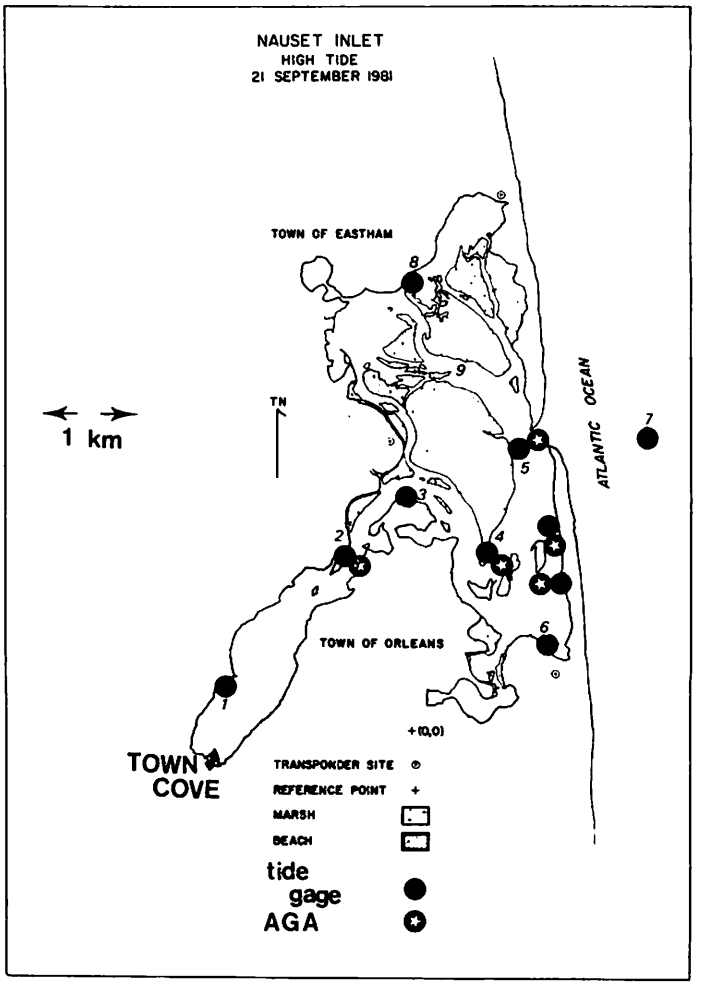

Figure 1.

Location map for Nauset Inlet experiment of August through October 1982. Numbers refer to locations referenced in the text and other figures: 1-Goose Hummock, 2-Mead's Pier, 3-Snow Point, 4-Middle Channel West, 5-Middle Channel East, 6-Nauset Heights, 7-Ocean wave and tide gage, 8-Nauset Bay. Base map was compiled from topography of 1981, referenced to high tide levels showing primary tidal channels more clearly. AGA refers to a current meter array deployed for four days at each location.

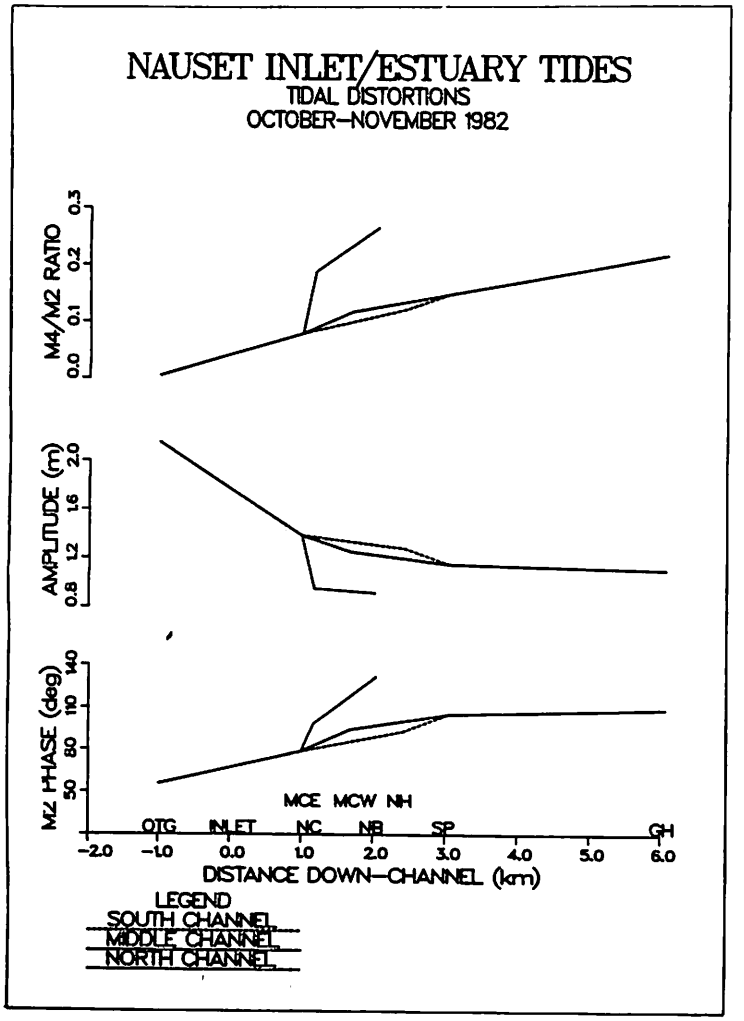

Figure 2.

Tidal distortion from the ocean proper through the three major channels of the estuary. Abbreviations for stations are as in Figure 1. Top panel shows the increase in ratio of M_4/M_2 tidal amplitudes with distances into the estuary. Largest ratio is in Nauset Bay, along North Channel. Second panel shows mean range of total tide as a function of distance into the estuary. Most rapid decay is along North Channel, least rapid decay is along South Channel. Lowest panel shows phase of M_2 tide throughout the estuary, referred to a local tidal epoch. Most rapid phase lags take place in North Channel, least rapid in South Channel.

Coastal Sediment Transport, Popponesset Beach, MA

David G. Aubrey and Margaret R. Goud
Geology & Geophysics Department

Drastic changes in a barrier beach in the Town of Mashpee, MA prompted a study of sediment transport patterns and circulation in this shallow coastal region. A series of three hurricanes impinging on the Massachusetts coastline in 1954 caused a breach in Popponesset Spit which resulted in loss of over a kilometer of beach in the ensuing 20 years, reducing beach area by a factor of two (Figure 1). The development and destruction of this coastal resource were investigated in a preliminary study by researchers at WHOI (Aubrey and Gaines, 1982 a and b), prompting the present study to evaluate in more detail the physical mechanisms responsible for such change.

The study area is dominated by a shallow nearshore platform, approximately 3 m in depth, bordered seaward by an 11 m deep channel, separating it from the remainder of Nantucket Sound. The platform is covered by low amplitude (15-20 cm high), long wavelength (10's to 100's of meters) sand waves (Figure 2), which migrate towards the southwest in response to an asymmetrical, bidirectional tidal flow parallel to the coast. Wave measurements in the area show all waves are locally generated within the Sound, with small periods (3-4 seconds) and low amplitudes (10 cm or so) during prevailing non-storm conditions.

A field experiment was designed to determine the role of offshore sand waves in providing or removing sediment from the beachface. Measurements of waves and currents over a month-long experiment provided data for application to sediment transport models. Using both a Meyer-Peter and Muller model and a Bagnold model, total annual sand transport was calculated. These calculated transports were compared with measurements of sand wave migration over a one-year and ten-year period derived from vertical aerial photographs of the area (Figure 3). Precise bathymetric surveys provided estimates of sand wave volume from which we calculated annual sand transport in the form of sand wave migration. Using only asymmetrical tidal currents as input to theoretical transport models, we found the theoretical estimates to be lower than observed sand wave transport. Since net transport is generally underestimated from bedform migration rates, the effect of storm waves on net sand transport estimates was addressed. Using storm waves hindcasted from meteorological records, we calculated theoretical sediment transport rates using combined wave/current flows for stormy periods, and current flows only for calmer conditions. These combined wave/current estimates were larger than observed transport rates, in agreement with a priori expectations (Aubrey and Goud, 1983; Goud and Aubrey, in prep.).

The sand wave experiment showed that these offshore sand waves had no dominant effect on beach processes, but provide a means for transport of sediment along this shallow glacial platform. The experiment proved the utility of high-quality aerial photographs in studies of shallow sediment transport, and provided a rough test of theoretical sand transport theories for long-term (10 year) sediment transport calculations.

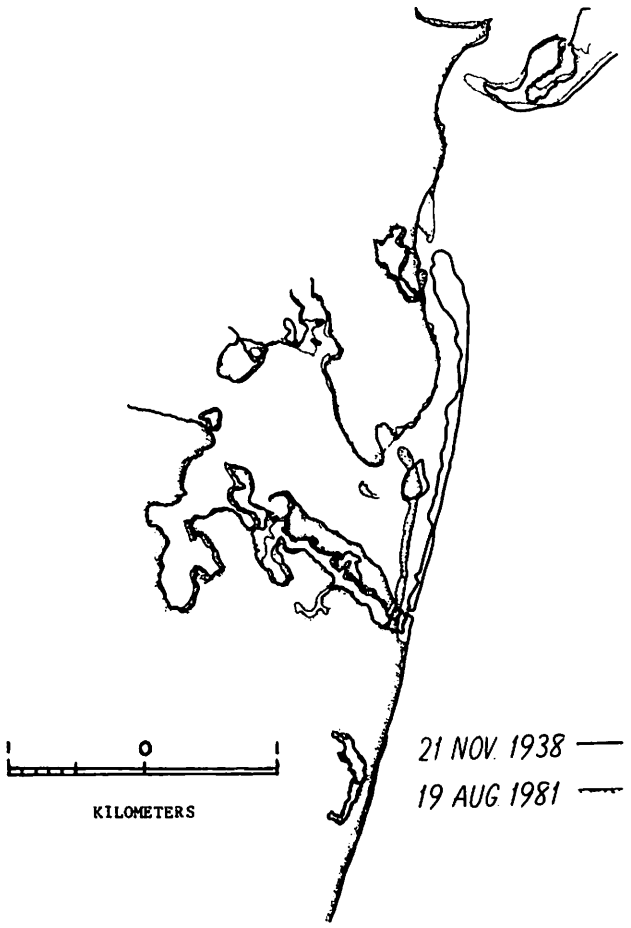

Figure 1. Net shoreline changes at Popponesset Spit, 1938-1981, based on outlines of vertical aerial photographs.

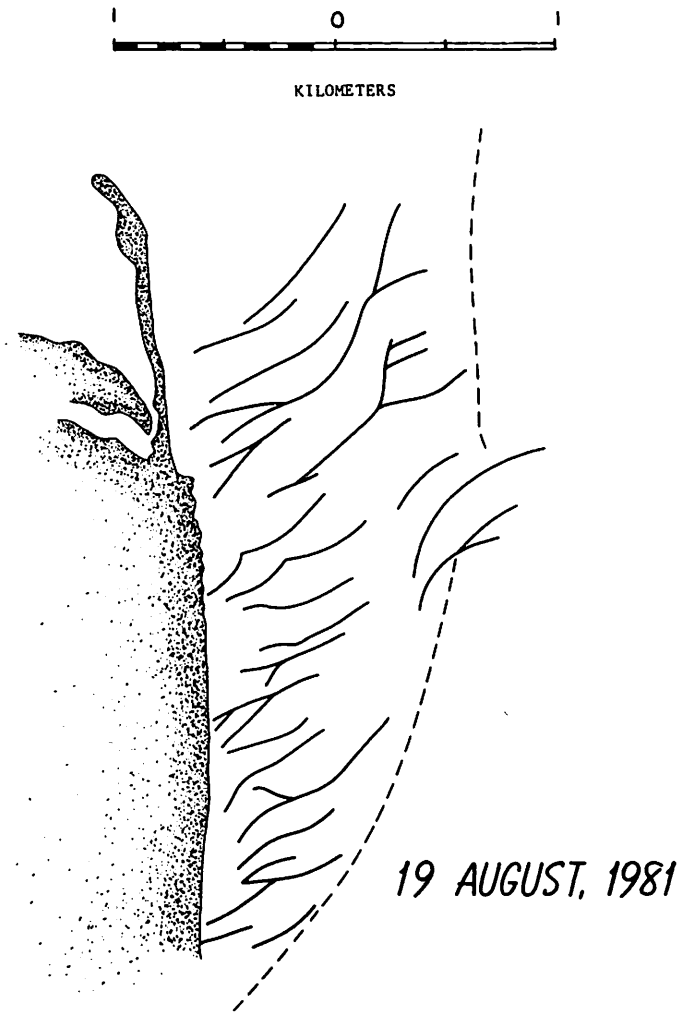

Figure 2. Sand wave crests in the Popponesset Spit study area. The dotted line indicates the approximate position of the 2 m isobath.

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Wave Boundary Layer Studies Using Laser Velocimetry

Y.C. Agrawal and W.D. Grant
Ocean Engineering Department

This project has been driven by the need to understand the hydrodynamics in the bottom few centimeters of the coastal ocean. In this thin region, the nonlinear interaction between steady currents and the orbital motion induced by surface waves enhances the frictional forces which affect phenomena such as sediment transport, boundary mixing and diffusion and, through these, the assimilative capacities of coastal seas to absorb anthropogenic discharge of effluents.

A two-axis backscatter autonomous laser Doppler velocimeter (LDV) has been developed to measure the two horizontal components of velocity in the bottom 0.5 m of the benthic boundary layer. By optical zooming, the time series of velocity is recorded sequentially at several (six) heights off the bottom. The velocity data are read from the instrument and analyzed for the following parameters: bottom frictional stress, effective bottom roughness and turbulence parameters such as turbulent kinetic energy and spectral content.

During the development of the LDV, a few problems unique to the ocean environment were encountered. As an example, particular care in optics was required to enable measurements very close to the bottom, rejecting the intense backscatter from the seabed. Success here can be measured from the ability to make velocity measurements at approximately 3 mm from the bottom. To determine the exact position of the ocean bottom, photomultiplier anode current is sensed by a microprocessor-based controller. As another example, operating a battery-powered low power laser instrument in backscatter at 1 m range, the signals are weak and must be processed with electronics that can deal with low signal/noise power ratios. To overcome this latter difficulty, an entirely new FFT processor has been developed which has the power of burst photon-correlators, but is orders of magnitude simpler (Agrawal, 1983).

The tripod-mounted instrument has been successfully deployed at test sites with bottom cameras to record site-topography with a view to estimating intrinsic site roughness. Data processing has lagged behind schedule, and is currently underway. The measured velocity field, combined with that reported by the Benthic Acoustic Stress Sensor (BASS) 'velocity rake' will illuminate the hydrodynamics of the benthic boundary layer. The hypothesis being tested is twofold: first, the combined presence of currents and wave-induced motion increases the mean frictional stress while increasing the apparent roughness above the wave boundary layer; and second, within the wave boundary layer the effect of a moveable bed is manifested by a stress dependent roughness, first by the development of ripples, and at still higher stresses, by sediment transport. The data analysis will quantify the field behavior.

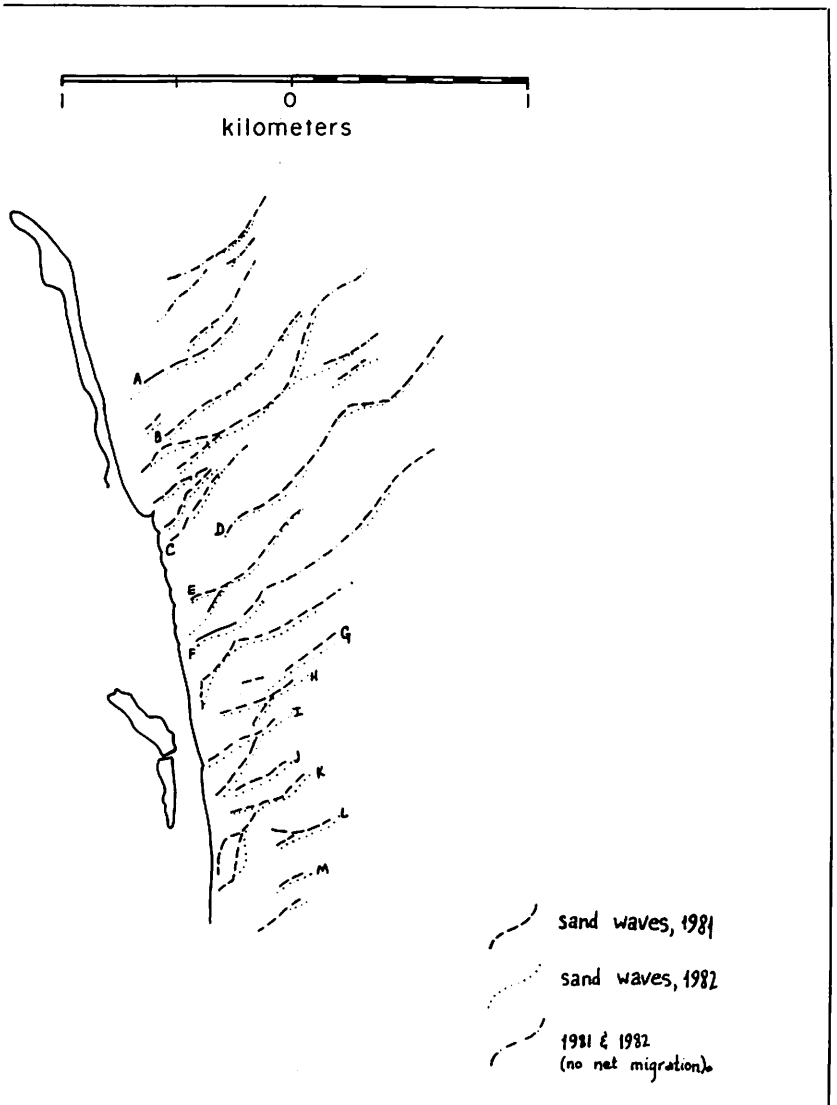

Figure 3. Sand wave migration patterns in the Popponesset study area for the period 1981-1982.

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Seasonal and Long-Term Trends in Sea Level Over the Last Half Century

David G. Aubrey and Kenneth O. Emery
Geology & Geophysics Department

Recent interest in the effects of increased atmospheric CO_2 has renewed conjecture on global trends in sea-level rise and possible impact on coastal erosion, estuarine mixing processes, and shoreline development. Since 1860, atmospheric CO_2 has increased from a level of approximately 290 ppm to 315 ppm in 1959, and 337 ppm in 1979, resulting in an increase in the "Greenhouse" effect. Recent reports by the National Research Council and the Environmental Protection Agency have focussed on the consequences of this trend in the future, and means of detecting such effects.

In a recent article, K.O. Emery (1980) discussed observed global trends in sea levels resulting from increased atmospheric warming, in the process renewing discussion of use of historical tide gage records for determining global sea-level trends. This sparked the present research, which has been directed at careful examination of tide gage statistics, in an effort to determine the historical trend in global sea-level rise, and to provide a basis for detecting differences in these trends which might indicate a statistically significant increase in rate of rise. Two primary effects determine the expected increase in rate of rise of sea level. First, increased atmospheric temperatures (due to the greenhouse effect) will cause a steric change in sea level through warming of the oceans. Second, increased atmospheric temperatures, particularly in the polar regions, may increase the melting of ice caps and retreat of alpine glaciers resulting in net influx of water into the world oceans, thereby raising sea level. Of particular concern is the west Antarctic ice sheet. There is considerable debate about the magnitude of each of these two effects which will be resolved only through ongoing research efforts.

Our research has focused on analysis of tide gage results as indicators of sea-level rise, both to develop methods to detect changes in rate of sea-level rise and to provide input to policy, management and engineering interests concerned with the effects of increases in sea-level rise. The detection problem is particularly difficult because of the wide variety of local causes of changing sea level, including tectonism, volcanism, isostatic adjustment from deglaciation, seasonal heating and cooling of the oceans, and a multitude of high frequency effects (tides, storm surges, surface waves, etc.). Since the signals from these processes are often large compared to eustatic sea-level changes due to global processes, detection must be based on a sound statistical model. Our goal is to develop such a global model of sea-level changes, extracting coherent long-term trends from these higher frequency or spatially incoherent trends.

As an example of the methodology, we have completed a study of the sea-level variations around the shoreline of the United States based on analysis of U.S. tide gage records (Aubrey and Emery, 1983). Using objective statistical techniques to extract sea-level trends which co-vary, we identified several coastal compartments within which sea-level trends are consistent (Figure 1). A closer look at the U.S. east coast reveals three distinct coastal compartments (Figure 2), illustrating the difficulty of trying to extract regional trends from a single tide gage station. These techniques are being applied to several global regions, within each of which sea-level trends are examined in detail. This analysis provides representative regional trends to be used in our global analysis of coherent sea-level changes.

References

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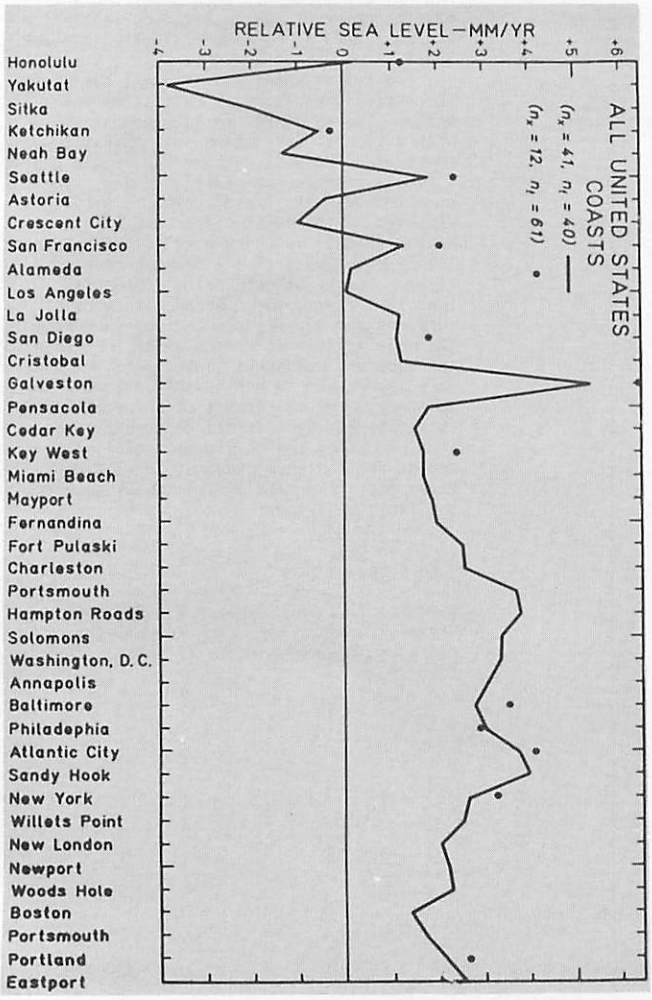


Figure 1.
Relative rate of change of sea level for each of 12 sixty-one-year stations and at each of 41 forty-year stations within the United States.

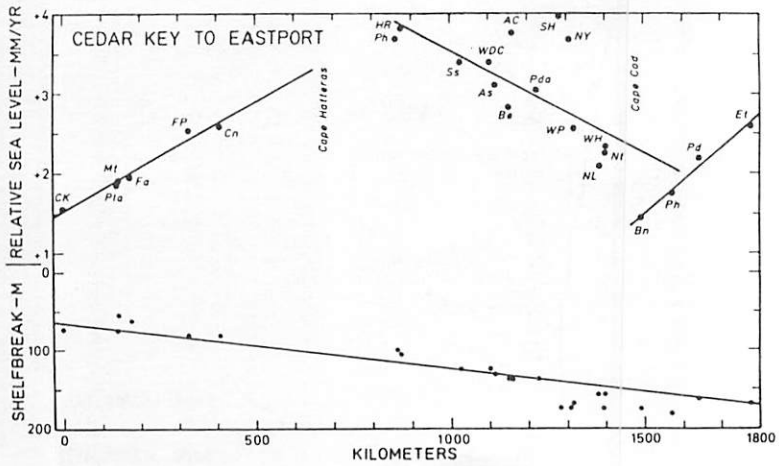


Figure 2.
Mean annual relative sea-level changes during 40-year record for U.S. east coast stations. Regression lines denote three main segments of east coast having different sea-level trends; these trends are not reflected in depths to shelf break or any other obvious geological feature.

Marine Resource Development

Figure 1. Jimmy Stotts, (third from right), President of the North Slope Borough, Barrow, Alaska speaking at the Arctic Workshop on issues of importance to Alaskan natives. Chairman Mel Conant of Conant & Associates, Ltd., and editor of *Geopolitics of Energy* is seated at the far right. (Shelley Lauzon)

Marine Policy and Ocean Management Center

David A. Ross
Director

Wise use and development of the oceans depend on scientific understanding and policy analysis and application. The Marine Policy and Ocean Management (MPOM) Center is the site of a multidisciplinary effort which provides an opportunity for marine and social scientists to conduct research on the social, political, legal and economic problems caused by our increased utilization of and reliance on marine resources.

The Center includes policy associates and research specialists in addition to Postdoctoral and Senior Fellows appointed for varying terms. Marine policy fellowships are offered to individuals in the social sciences, law, or natural sciences to apply their training and expertise to marine policy problems and opportunities in developing countries, policy and management issues concerning fisheries, marine minerals studies, coastal zone use, implications of the Law of the Sea Treaty for ocean activities, Arctic and Antarctic resource issues, and the use of scientific information in decision-making and policy planning. During the 1982-83 reporting period, the policy program consisted of 4 Policy Associates, 1 Research Specialist, 5 Senior Fellows, 8 Postdoctoral Fellows, 1 International Research Fellow, 1 Visiting Investigator, and 2 Special Consultants on Marine Policy.

The 1982-83 list of completed projects includes papers on:

- Evaluating the Economic Significance of Polymetallic Sulfide Deposits
- U.S. Ocean Policymaking in a Changing World
- Conflictual Interdependence: U.S.-Mexican Relations on Marine Resources
- The Effects of Fish Predation on Aquatic Insects
- Juvenile Pacific Salmon in Estuaries: The Life Support System
- The U.S. Fishing Industry and Regulatory Reform
- State vs National Interests in an Expanded Territorial Sea
- The Case of Ocean Dumping
- Economic Incentives for Environmental Protection: Ocean Dumping Charges
- Evaluating the Risks of Offshore Oil and Gas Development
- An Evaluation of Reagan's Stand on LOS Treaty
- Through a Glass Darkly: Western Europe and the Middle East
- America and the Middle East: Holding the Centre
- Energy at the Summit
- Review of Jeanne Kirkpatrick's "Dictatorships and Democracies"
- Energy and Alliance Politics: Lessons of a Decade
- Oil, Shrimp, Mangroves: An Evaluation of Contingency Planning for the Gulf of Guayaquil, Ecuador
- Prospective Maritime Jurisdictions in the Polar Seas
- International Marine Science: An Opportunity for the Future
- The Shelfbreak: Some Legal Aspects
- The Management of Pacific Marine Resources: Present Problems and Future Trends
- The Politics of Mineral Resource Development in Antarctica: Alternative Regimes for the Future
- Alternative Regimes for Future Resource Development in Antarctica

(cont'd.)

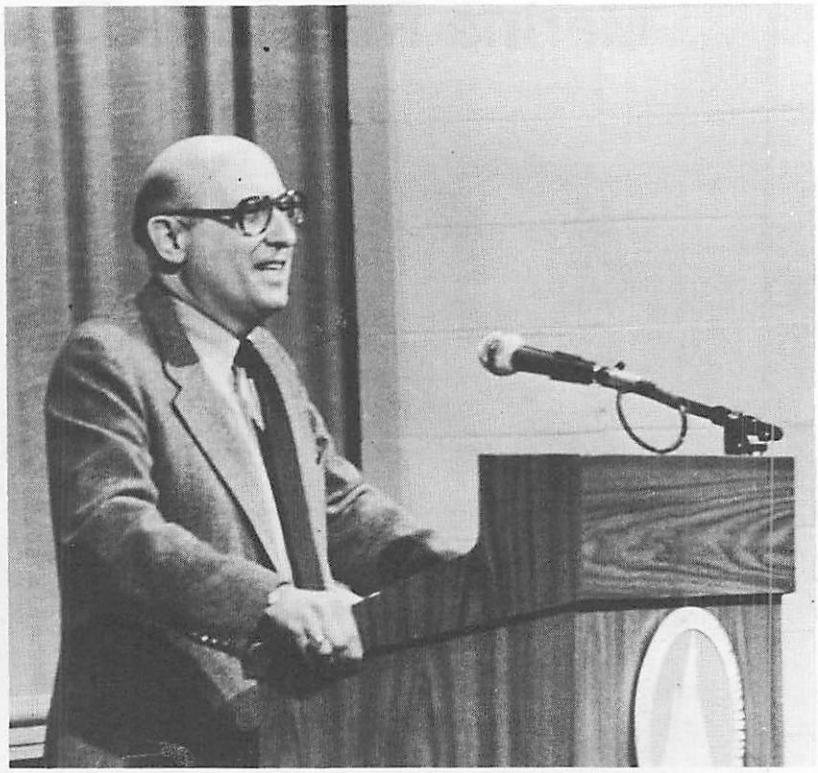
Significant accomplishments can be cited for each area of research emphasized by MPOM during 1982-83. These are highlighted by the following:

U.S. Arctic interests in the 1980s and 1990s was the topic of a workshop May 5-6, 1983 in Woods Hole (Figure 1). The meeting was attended by more than 25 representatives from the State of Alaska, the federal government, industry, academic institutions, and native Inuit groups. Discussion focussed on resource development, the environment, the role of science in the Arctic, socioeconomic concerns, federal-state relations, international jurisdictional issues, security and defense, and transportation. The two-day meeting emphasized the importance of considering the economic, legal, social and institutional implications of Arctic development.

The Policy Center also sponsored the initial meeting of an Ocean Policy Roundtable. The Roundtable provides a non-governmental forum where discussion and debate on key ocean policy issues facing the U.S. can take place on a regular basis, with periodic assessments and policy recommendations on these issues provided to decision-makers. Members of the Roundtable were selected from ocean-related industries, environmental groups, academic and research institutions, public and private groups, and others with broad experience and concern in U.S. ocean policy issues.

MPOM sponsored an additional workshop in connection with its ongoing Cooperative International Marine Assistance Project (CIMAP). The workshop, held in Sasaima, Colombia during June, 1983, fulfilled three functions. It was the source of additional information for the Center's diagnosis of marine sectors in that country. A variety of individuals representing government agencies, government-owned companies, and private groups presented information and offered different interpretations of the current situation in Colombia. The workshop served as a sounding board for preliminary conclusions by the marine sector and enhanced the visibility of the upcoming Colombian "Master Plan for Marine Development" which will be based on CIMAP's diagnosis. Colombia has always been strongly oriented towards the land; it is hoped that the workshop, the diagnosis, and the master plan will focus attention on underutilized marine potential.

MPOM also sponsored over 24 lectures during the year by Policy Center members and visiting experts in the policy field. Included among these talks were two presentations in the Center-sponsored J. Seward Johnson Lecture Series (Figure 2). Dr. Robert Frosch, Vice President, General Motors Research Laboratories, spoke in January, 1983 on "Relevance, Irrelevance and General Confusion: Problems in Science Policy." Dr. Roger Revelle, Professor of Science and Public Policy at the University of California and Scripps Institution of Oceanography, spoke in June, 1983 on "The Future of Ocean Science."



J. Seward Johnson lecturer and Robert Frosch.

An Economic Analysis of Industrial Structure and Behavior in the Emerging Seabed Mining Industry

James M. Broadus
Marine Policy & Ocean Management Center

The objective of this project was to conduct an economic analysis of preproduction structure and behavior in the emerging seabed mining industry. A number of large international companies, as well as several national governments, have invested hundreds of millions of dollars over the last decade in attempts to develop the capability to find and recover metal-rich manganese nodules that litter the ocean floor. Much of this spending has now stopped, but the basic economic conditions that led initially to creation of the nascent industry still favor its eventual success. Whether its pace of development quickens or diminishes in the near future, serious questions about the industry's importance and relationship to national governments and to international organization are now being faced. In this regard, industry structure is likely to be one of the most important factors shaping the scale and direction of the industry's development, behavior and performance over time.

Figure 1 schematically describes the study's primary areas of interest and their interrelationship. Topics represented by boxes 1,2, and 3 in the diagram were the study's principal descriptive and analytic target. Preproduction structure (box 1) includes: the number, size and size distribution of member organizations; their character and scope; the degree of concentration in downstream and competing industries; and conditions of entry, including disposition of primary minesites and the status of potential entrants. Behavior (box 2) refers to investment profiles over time, technological choices, selection of partners, interactions with rivals, and regulatory posture. More generally, it refers to patterns of strategic jockeying, clinging, innovating, imitating, and preempting observed in the preproduction industry. Both behavior and structure are products (as well as part of) the industry's history (box 3). In addition to these primary topics of interest, attention was given to the structure and behavior of closely related industries (box 4), and to the developing legal and regulatory regime for seabed mining (box 5). A secondary objective of the study was a modest qualitative projection of post-start up structure in the industry (box 6), with associated implications for the industry's long-run behavior and performance.

The first step in execution of the study was an extensive survey of the relevant literature on the economics of nodule mining and on the evolution of its legal environment. A systematic search of the economics

literature was also conducted to support an exact and more complete specification of the most applicable theoretical foundation. Simple application of the traditional competitive or monopoly structural models proved inappropriate in this case because of the industry's embryonic stage of development, the small number of players, the intimate involvement of national governments and the muddled legal situation. Since two of the most important decision parameters for producers in a mature industry, namely production cost and market price, are hazy or nonexistent in this case, investment policies, affiliation, and legal tactics take on added significance. Elements of theoretical models developed by Caves and Porter (1977), Spence (1979), Porter (1979), Dasgupta and Stiglitz (1981), and Reinganum (1983) were found to be useful in gaining insights and framing hypotheses.

Probably the most important stage of the study involved the gathering, organizing and interpretation of specific and detailed empirical information about the industry. Included were: consortia histories; investment profiles; decision rules; expectations over time; minesite endowments; nature and extent of government involvement; size, scope and financial capabilities of participating firms; intra- and inter-organizational interaction and communications; and patenting activity. Some of this information was readily available through secondary sources examined in the literature survey, but much of it had to be assembled de novo. This required collection of corporate annual reports and a search of trade journals as well as examination of public reporting documents such as company 10-K's and 4-K's filed with the Securities and Exchange Commission. A great deal of time and effort was devoted to a detailed patent search in an attempt to generate evidence about potential entrants and the relative position of existing firms in the industry.

The most important source of information was a series of standard-format interviews with knowledgeable sources. These included responsible corporate officers from each of the consortia and from nearly all the parent companies. Information and observations were also exchanged with knowledgeable government officials and with foreign colleagues at: Centre National pour l'Exploitation des Oceans (CNEXO, France); Groupe d'Etude et de Recherche de Minéralisations au Large (GERMINAL, France); Bureau de Recherches Géologiques et Minières (BRGM, France); Royal Institute of Geological Sciences (United Kingdom); Kiel Institute for World Economic Studies (West Germany); and the Research Institute for Ocean Economics (RIOE, Japan). The Principal Investigator also was an invited participant in a United Nations Expert Group Meeting on the impact of seabed minerals on the world economy.

A detailed history of each group was compiled along with data on the financial characteristics of parent firms. The current lull in R&D activity created an opportunity for corporate information access that could not have been hoped for in an atmosphere of hard-driving development and high-pressure competition. This permitted the collection of a huge amount of information on company motivations, expectations, and relationships that, together with the financial data file, comprise a valuable asset supporting not only the present study but potential future studies of the industry as well.

Exact investment profiles and descriptions of prospective mine sites were in many cases impossible to obtain because of their proprietary nature. Corporate sensitivity about release of these data was heightened because they are key determinants of equity positions in claims to entitlements for exclusive exploration and mining areas. These claims are currently the subject of intensive international conflict resolution negotiations. This conflict resolution process is crucial to the inception of seabed mining, for without the resolution of area claim overlaps, seabed mining enterprises will not have the security of tenure necessary to prevent claim jumping and to make major mining investments. A careful study of the conflict resolution process revealed that talks are proceeding along two tracks, one leading to certification under the Law of the Sea and the other involving domestic registration and a possible alternative "mini-treaty" regime (see Figure 2). It appears, however, that arrangements achieved through either track could ironically contribute to an eventual convergence between the two legal-regulatory regimes (Broadus and Hoagland, 1983).

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(cont'd.)

Figure 1
AREAS OF INTEREST AND THEIR INTERRELATIONSHIPS

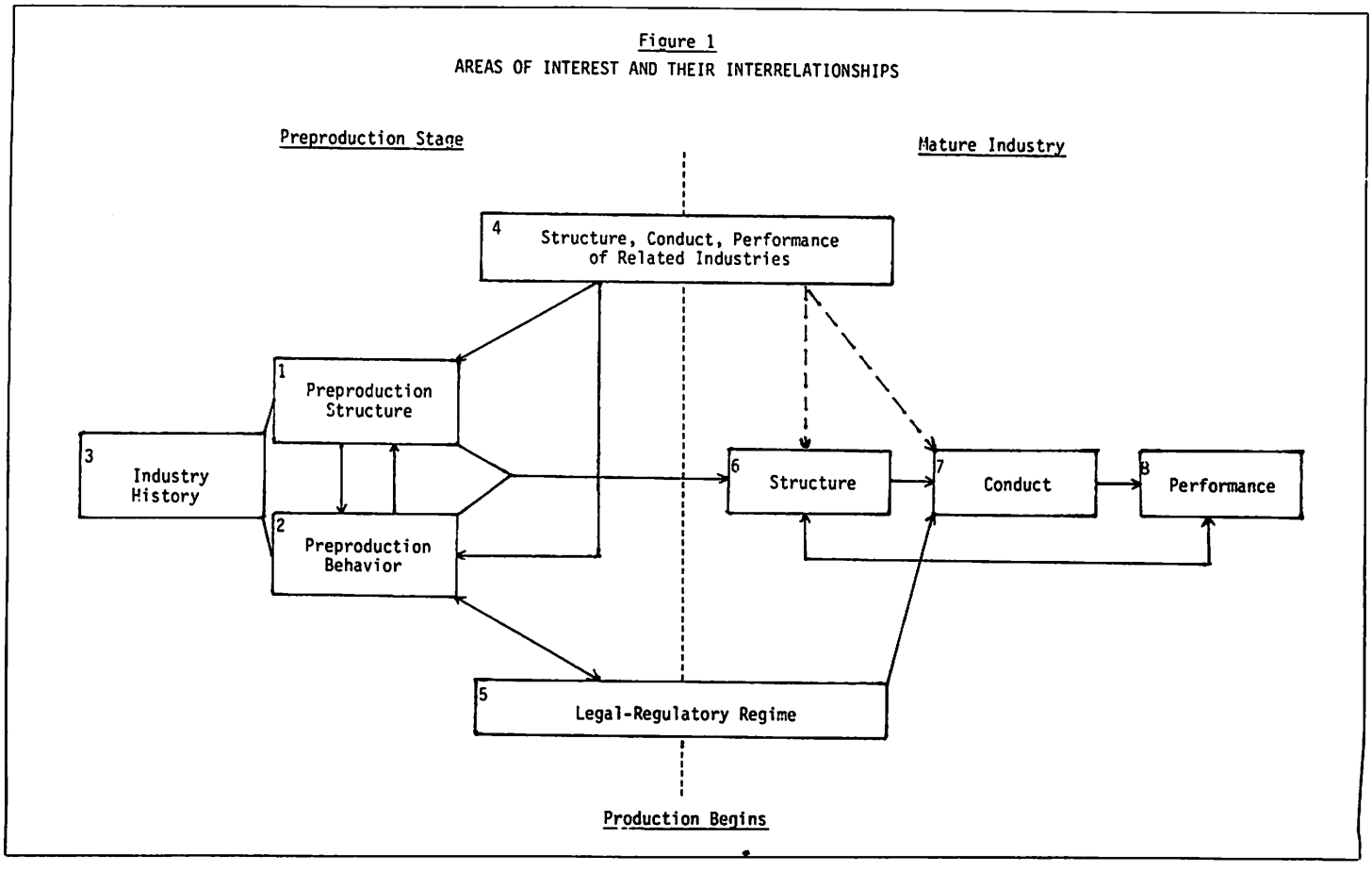

Figure 1. Schematic of this study's primary areas of interest and their interrelationship.

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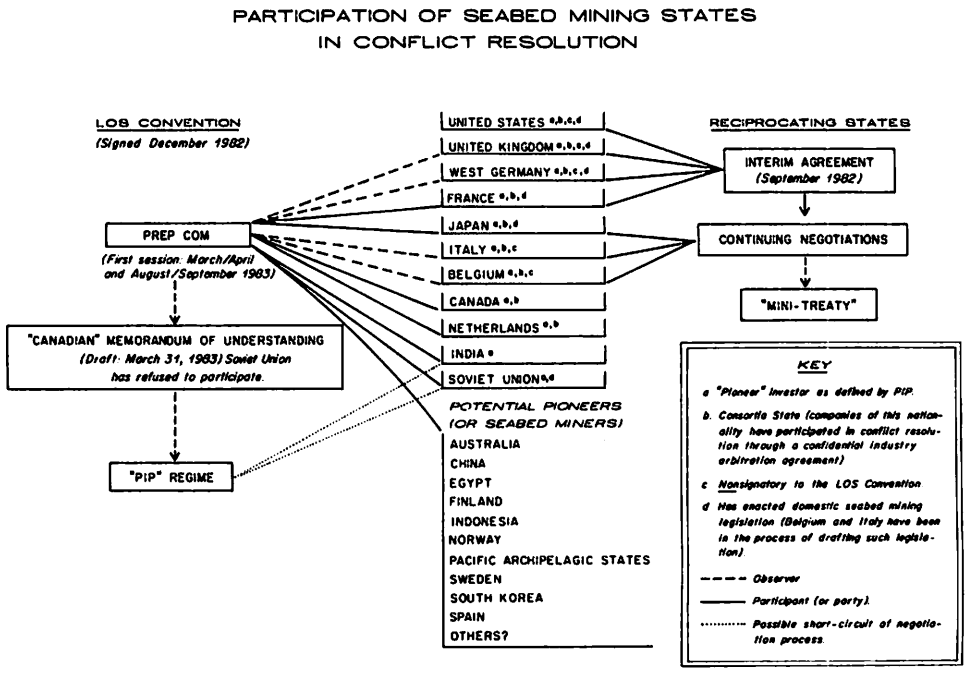

Figure 2. Schematic of the international conflict resolution process, crucial to continued movement toward the inception of seabed mining.

Economic and Legal Aspects of Deep Sea Polymetallic Sulfides

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Marine Policy & Ocean Management Center

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Deep sea or marine polymetallic sulfides (MPS) are mineral occurrences recently discovered along ridges associated with spreading oceanic crust (Figure 1). The MPS deposits contain relatively large amounts of some important metals (See Table 1). They are widely acknowledged to be of intense interest as an immediate scientific opportunity, but their economic importance is subject to question. Grandiose claims have been published about the economic value of the deposits, and some scientists have even suggested that these deposits may offer society a truly renewable source of metals. Misperception of the actual economic significance of MPS, however, could distort not only long-run minerals policies but, more immediately, the jurisdictional claims of national governments and the balance of competing foreign policy objectives. Our work attempts to help resolve issues of MPS economics and policy by systematically developing a first-order approximation of the deposits' current economic significance and by analyzing both their domestic and international legal-political implications.

The project's social scientists, an economist and two political scientists, established and maintained working contact with scientists at WHOI and other institutions as well as with policymakers and scholars involved in MPS issues internationally. Through these and other channels, they gathered data not only on MPS developments but also on minerals consumption and supply projections, on onshore versus offshore mining costs, on uses and substitutes for MPS metals, and on relevant legal and political actions and institutions. They informed themselves also through active participation in such meetings and conferences as: a NATO Advanced Research Institute workshop on hydrothermal processes at seafloor spreading centers; two NOAA-sponsored workshops on MPS; a Department of Interior symposium on hard minerals in the U.S. exclusive economic zone; Underwater Mining Institute meetings; Law of the Sea Institute meetings; United Nations Group Expert Meeting on the Impact of Deepsea Minerals; Offshore Technology Conference; and a Carnegie Institution conference on the problems and prospects for incorporating geologic information into the long-term policymaking process. Along with the Carnegie Institution of Washington's Science Policy Program, a workshop on the status and implications of MPS for the minerals policymaking process was organized in Washington by Drs. Broadus and Bowen.

To assist the analysis at WHOI, by theoretically estimating reasonable physical bounds on the deposits, Associate Investigator M.J. Mottl, a geochemist, prepared a report entitled, "Physical, Chemical and Geologic Constraints on the Formation of Polymetallic Sulfide Deposits on the Seafloor." In the report, Dr. Mottl attempts to assess the potential for MPS formation by identifying the critical constraints that could determine the size, grade, and distribution of the deposits. He evaluated the heat budget and sources for ore metals and sulfur in the oceanic crust and then determined an upper limit for the flux of heated seawater through the crust at mid-ocean ridges and the resulting delivery of ore metals to the seafloor. Using geo-

logic and chemical data from areas of active sulfide deposition, he estimated the likely range in deposit size, grade and distribution and the probable maximum size of deposit which can be produced along the mid-ocean ridge system. He then applied these constraints to submarine environments other than mid-ocean ridges and evaluated the importance of special conditions favorable to ore formation which may exist in these other environments. Although such alternative environments may provide improved prospects for commercial quantities of MPS, Dr. Mottl's estimates appear to indicate greater limitation on size and richness of the ridge deposits than had previously been assumed.

Valuable project input was also provided by the Minerals Availability System (MAS) of the Department of Interior. MAS made available its data base on commercial onshore massive sulfides deposits and also used its sophisticated computer models to conduct a detailed financial analysis of hypothetical onshore deposits with characteristics similar to MPS (MAFO, 1983). That work permits an approximation of the additional costs that hypothetically could be absorbed competitively by remote MPS deposits with sufficiently high ore grades.

Too little is still known about the nature of MPS to permit confident estimates of their economic promise, but approximation of their current significance has been attempted on the basis of: 1) current economic understanding of the dynamics of nonrenewable resource supplies; 2) projections of aggregate consumption of the contained metals; 3) projection of long-run alternative supplies; 4) informed speculation about the sources and relative magnitudes of costs and the relative pace of technological advance; 5) scientific modeling results on geographic, size, and grade distributions; and 6) expressions of commercial interest by profit-oriented firms. The evidence examined suggests that MPS are still largely a scientific phenomenon with little current economic significance (Broadus and Bowen, 1983a). In view of the remaining scientific uncertainties and of the relatively unfavorable market conditions faced by the contained metals, attempts to direct research on the MPS phenomenon toward commercial R&D appear premature. MPS may eventually provide metallogenesis data valuable for onshore exploration, but that remains to be seen. They may someday become a valuable economic resource in their own right, but they do not appear to be now. Evaluation of expenditures on MPS are still most appropriately made through scientific selection criteria rather than through commercial ones (Broadus and Bowen, 1983b).

Analyses of relevant national claims and international treaties suggest that most known MPS areas fall within national marine jurisdiction (Figure 2). Indeed, under the ambiguous language of the United Nations Convention of the Law of the Sea (LOS) all but one known MPS deposit (that found at 20°S on the East Pacific Rise) are arguably within the jurisdiction of at least one coastal state. The most immediate impact of this situation could be on MPS-related marine scientific research. Because of the coastal state consent regime established in the LOS Convention it could become increasingly difficult for marine scientists to carry out MPS studies in foreign waters if that research is viewed by the coastal state as being economically motivated.

Even if MPS deposits do, in fact, prove to be economic, it is now impossible to characterize precisely the regulatory mechanisms that would emerge for their development. However, because deposits appear to exist both inside and outside national jurisdiction, in the most likely scenarios such rules would be diverse and probably idiosyncratic. Within the United States, there is still uncertainty about what law or laws would govern domestic MPS

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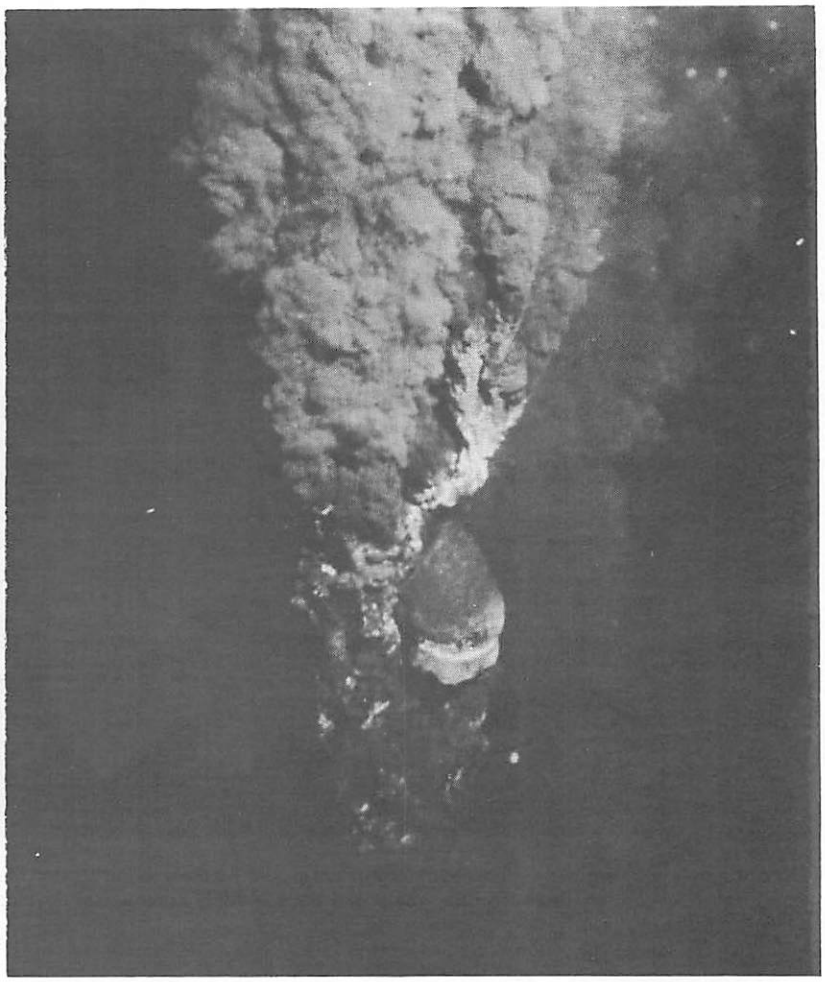


Figure 1. A "smoker" containing marine polymetallic sulfide deposits located at 21°N, East Pacific Rise (Robert Ballard).

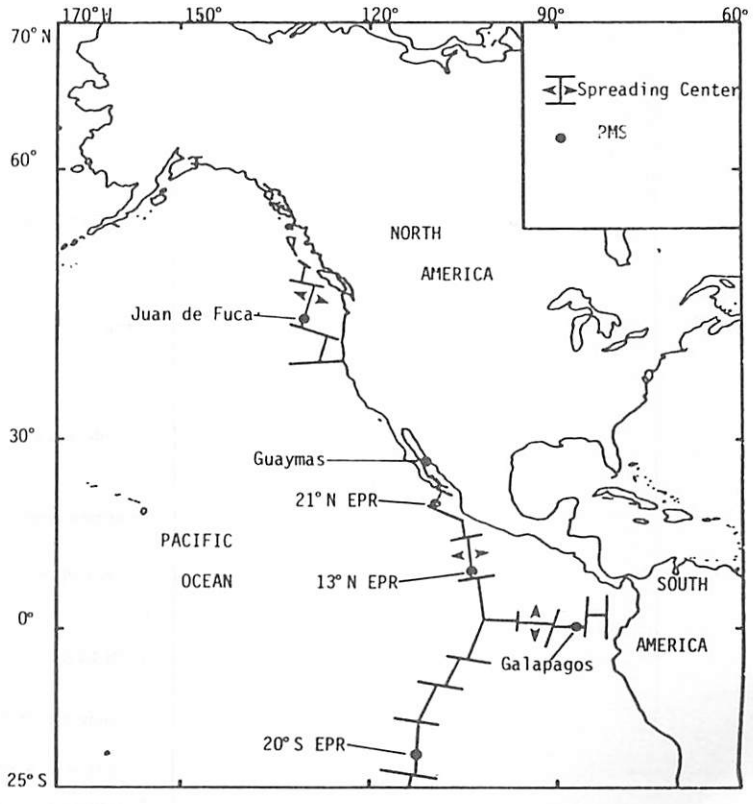
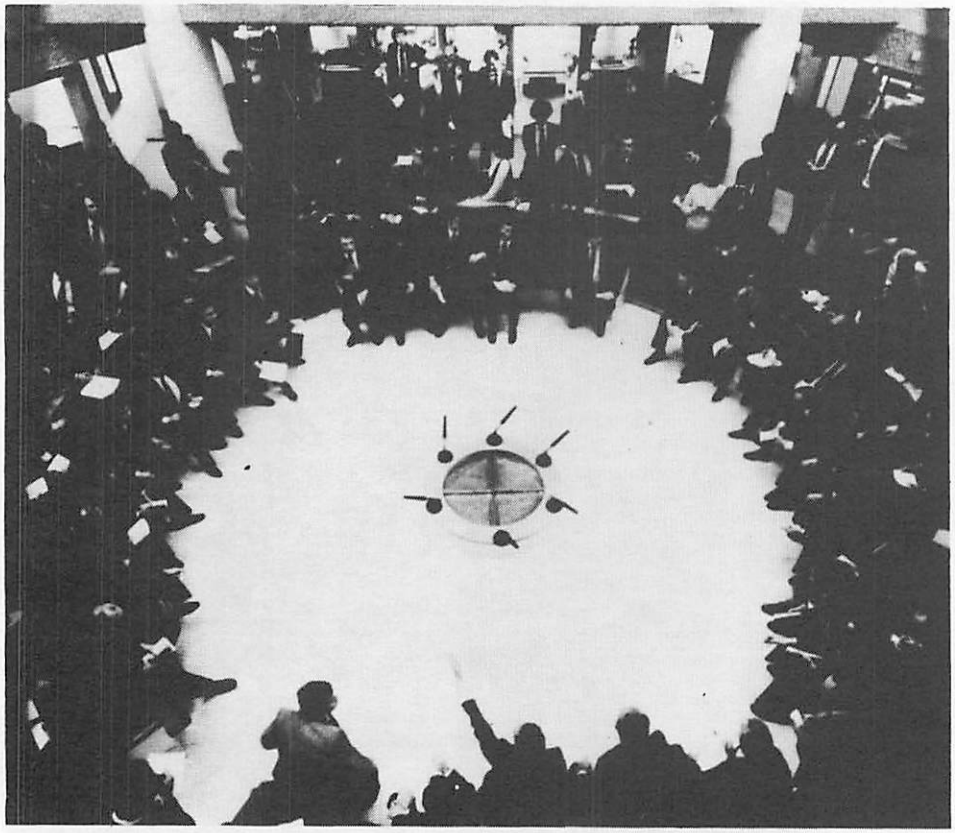


Figure 2. Location of known marine polymetallic sulfide deposits.



Forces of supply and demand, expressed through trade in such markets as the London Metal Exchange (shown here), will largely determine the value and pace of MPS commercial development. (From *Metallgesellschaft,* 1981)

exploration and development. A 200-mile exclusive economic zone was established in March by Presidential decree, but the details of supporting legislation have not yet been settled. Some ambiguity exists, for example, about the division of responsibilities between NOAA and the Department of Interior.

Results of the year's work have been, and are being, disseminated through publication of papers, presentation of lectures, and continuing consultations with government decision-makers and other researchers. Investigation of this subject will continue through a subsequent Sea Grant project focussing on factors that will influence the timing of MPS development.

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Metal Concentrations from Selected Marine Polymetallic Sulfide Sites

Area	Zn%	S%	Fe%	Cu%	Pb%	Ag(ppm)	Cd(ppm)
Juan de Fuca [a]	0.63-54.0	n.a.	1.8-50.5	0.0003-0.32	0.06-0.25	3-290	0-490
Guaymas Basin [b]	30	n.a.	n.a.	1.0	.10	300	n.a.
21° N EPR [a]	0.12-41.8	0.74-39.7	0.61-26.2	0.13-1.3	0.04-0.61	1.6-241	20-890-
13°N EPR	No compatible date is as yet available						
Galapagos Rift [a]	0.14	52.2	44.1	4.98	0.07	10	31

[a] *Source: Bischoff, et al., 1983*

[b] *Apparent average concentrations based on limited existing samples. Source: Cruickshank, 1982*

Program Administration

Figure 3. Dr. David A. Ross, Sea Grant Coordinator (right) welcomes Massachusetts Governor Michael Dukakis (center) to the Woods Hole Oceanographic Institution for a day of talks on the role of marine sciences in the economy of Massachusetts. Legislative liaison, Mr. Richard Kendall, is at the left. (Amy Rader, *Falmouth Enterprise*)

Marine Assistance Service

Arthur G. Gaines, Jr.

An integral part of the National Sea Grant College Program is to promote interaction between academic research institutions and the general community. One purpose of this Sea Grant effort is to focus the intellectual capacity of our nation's colleges and universities on improving our ability to use the sea, particularly with regard to coastal resources. More specifically, it is an attempt to involve priorities and needs of potential users of the Sea Grant research effort in the research planning process. At most Sea Grant College Programs this effort emanates substantially from Marine Advisory Services, sometimes patterned after the Cooperative Extension programs (operated jointly by individual states and the U.S. Department of Agriculture).

The Marine Assistance Service of the WHOI Sea Grant Program represents our advisory element; though small compared with others, it serves a similar essential function. 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 not only this institution but of the National Sea Grant College Program as a whole. Our effort involves defining a set of approaches for interaction which mutually satisfy the needs of both the scientific and nonscientific participants. The Marine Assistance Service is structured to complement, rather than compete with, existing efforts in marine education, public information, popular publications, library services, etc., at WHOI (see Table 1) and in the Commonwealth of Massachusetts in general. Three examples of focus during the past year illustrate our approach:

Workshops on Shellfish Biology

Shellfish in New England represent a source of food, employment, and recreation and provide part of the ambience that makes this area attractive for summer homes and tourism. Hence, the inherent value of the shellfishery far exceeds such indices as the dockside or retail value of the catch. The WHOI Sea Grant Program has sponsored a number of projects over the years dealing with such shellfish as the quahog (Mercenaria), the ocean quahog (Arctica), the bay scallop (Argopecten) and the soft clam (Mya). For the past two years we have sponsored special workshops to convey the results of these projects to commercial and recreational fishermen, shellfish officers and biologists from local, state, private and federal laboratories. The workshops have attracted from 60-80 participants, largely from the northeast but occasionally from the Pacific and mid-Atlantic areas as well, and have served as an effective means for the exchange of ideas and concerns among people who do not often meet or have this opportunity.

Our shellfish workshop this year focused on the bay scallop (Figure 1), a shellfish species which thrives in the waters of southern New England, providing up to 30% of the U.S. annual catch. The bay scallop is always one of the three top shellfish landings here, the others being quahogs and soft clams. Unlike other species, however, the scallop fishery undergoes very large annual fluctuations in yield. This sharp fluctuation presently prevents a reliable supply to markets and adds instability to the already tenuous existence of the com-

mercial shellfisherman. WHOI Sea Grant projects have addressed this problem in terms of assessing environmental factors that appear to control scallop productivity and the effectiveness of culture-based seeding programs to enhance the natural set (Capuzzo/Taylor, 1980, 1981), as well as through identification and characterization of underutilized and relatively unknown bay scallop beds in offshore waters (Capuzzo/Hampson, 1981; also see this report), such as in Buzzards Bay. At this year's bay scallop workshop, chaired and largely planned by Dr. Judy Capuzzo, Mr. George Hampson presented results of his work on the deep water scallop beds. Other speakers included Dr. Louis Leibovitz, a shellfish pathologist (New York Sea Grant); Mr. Jim Widman, an aquaculturist (National Marine Fisheries Service, Milford); Mr. Dennis Walsh, a biologist at a commercial hatchery; and biologists and shellfish officers from five towns on Cape Cod and Martha's Vineyard who talked on topics from mass mortality of scallops to field and culture programs in scallop propagation.

In addition to the verbal exchange of information, Dr. Capuzzo has prepared a proceedings for the meeting containing abstracts of the papers, a transcription of a formal discussion session, and a synopsis of a questionnaire prepared by the Sea Grant Office, distributed at the workshop. Because of the very positive feedback on these workshops, we anticipate holding them on an annual basis.

Nitrogen Budget for Town Cove, Orleans, MA

Like many towns on Cape Cod (and around the nation), Orleans has been wrestling with the issue of whether sewers are needed in town. Federal dollars under the Environmental Protection Agency 201 and 208 Programs (Clean Water Act) provided monetary incentive for towns to plan and construct sewers, if necessary, before 1984. As in other towns, the issue in Orleans has been a divisive one , where aesthetic, engineering, regulatory, political and scientific considerations have become intertwined and confused. Aside from technical aspects, the perspective on the need for sewers depends in part on how residents feel things in Orleans should be done and what is valuable.

On the technical side, concern had been expressed that nitrogen from on-site septic systems was damaging Town Cove, a nearby estuary. Certain forms of nitrogen, viz. nitrate, tend to pass directly through septic systems and enter the groundwater, which then can be discharged into swamps, lakes, streams and estuaries. Since nitrate is a plant nutrient, it can result in algal blooms and undesirable conditions when entering surface water bodies.

In 1982 we met with representatives of the Town to discuss the possible role this Institution might play in clarifying issues surrounding the sewerage debate. We decided a pivotal issue requiring further clarification was the impact of sewage-derived nitrogen on Town Cove, relative to natural and other man-made sources, i.e., we proposed preparation of a nitrogen budget for Town Cove. Early stages of this research were begun using WHOI Sea Grant Development funds and eventually the bulk of the funding, from the Town of Orleans, was approved by a vote at the Orleans Annual Town Meeting.

Principal investigators on the study were Dr. John Teal, Dr. Joel Goldman, and Dr. Anne Giblin of the Department of Biology, Dr. David Aubrey of the Department of Geology and Geophysics, and Dr. Arthur Gaines of the WHOI Sea Grant Program. The results of the study (Figure 2) indicated that nitrogen from on-site systems in the proposed sewered area accounted for about 10-20% of nitrogen entering the Cove. Adding this information to other elements of the decision-making process, the voters decided not to construct sewers at the present time. The role of the Marine Assistance Service, in addition to helping define scientific aspects of the issue, involved regularly appraising a town committee of progress in the research, answering questions about the progress reports and the final report and presenting results at other public meetings.

As follow-up to the project, Dr. Susan Peterson, a member of the WHOI Marine Policy and Ocean Management Center, conducted a survey of voters to evaluate the impact of our study. This survey, also sponsored by WHOI Sea Grant, is currently in preparation and will be available in the near future. We are also looking into the potential significance of this research to the many other towns facing a similar decision.

Coastal Sediment Transport

Changes in coastal configuration, whether erosion or deposition, can be an important source of uncertainty and expense in coastal management, for the private waterfront homeowner, for the boater or for government agencies at all levels, to name but a few. For several years WHOI Sea Grant has sponsored research on coastal sediment transport, including several projects by Dr. David Aubrey of the Department of Geology and Geophysics and his co-workers. In response to a request by the Town of Mashpee, MA the Marine Assistance Service helped coordinate planning and funding of a research project to provide a scientific basis for coastline management in Mashpee, with particular emphasis at Popponesset Beach. Portions of the project were supported by Sea Grant, the Town of Mashpee, and Massachusetts Coastal Zone Management. The research was completed this year and several meetings have been held with the Selectmen, private coastal interest groups and with the public at large. Press and radio coverage further disseminated the results of this work, with emphasis on the management aspects--of special focus during the latter parts of the project. To date, the results have been used in assessing and planning proposed navigational improvements, a beach nourishment project and short term evolution of the barrier beach at Popponesset Bay. We anticipate this project can also serve as a basis for management of a recently purchased state recreation beach.

Ongoing projects include preparation of a computer-based environmental bibliography for Cape Cod and the Islands' inshore waters; and a shellfish farming demonstration project in cooperation with Penikese Island School and Barnstable County Cooperative Extension Service. The Marine Assistance Service devotes a substantial continuing effort to identifying new marine-related issues and problems of concern to the non-academic sector: we welcome communications from all interested parties.

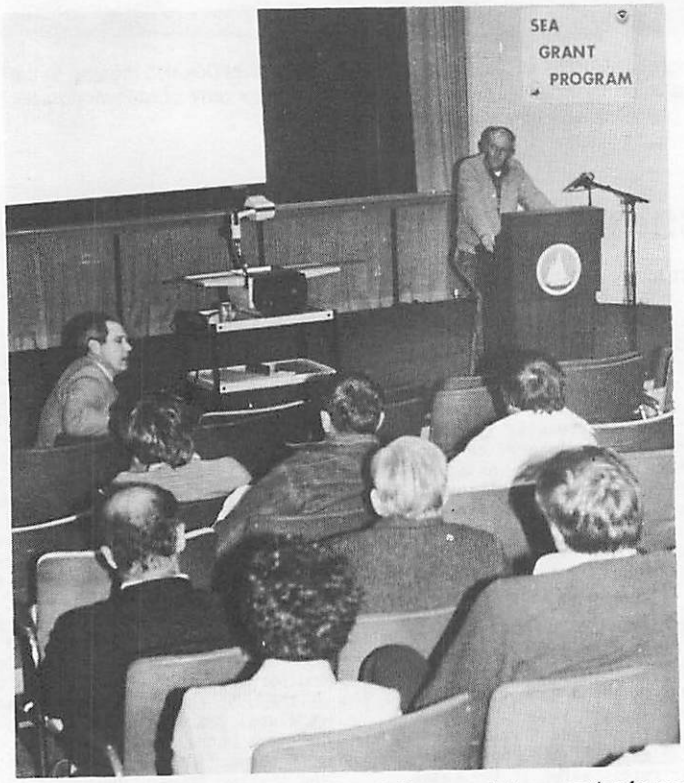

Figure 1. Mr. George Hampson (upper left) responds to a question from a participant at the bay scallop workshop. Mr. Burke Limeburner, Shellfish Warden from Bourne, MA and President of the Massachusetts Shellfish Officers Association, is at the podium. (Shelley Lauzon)

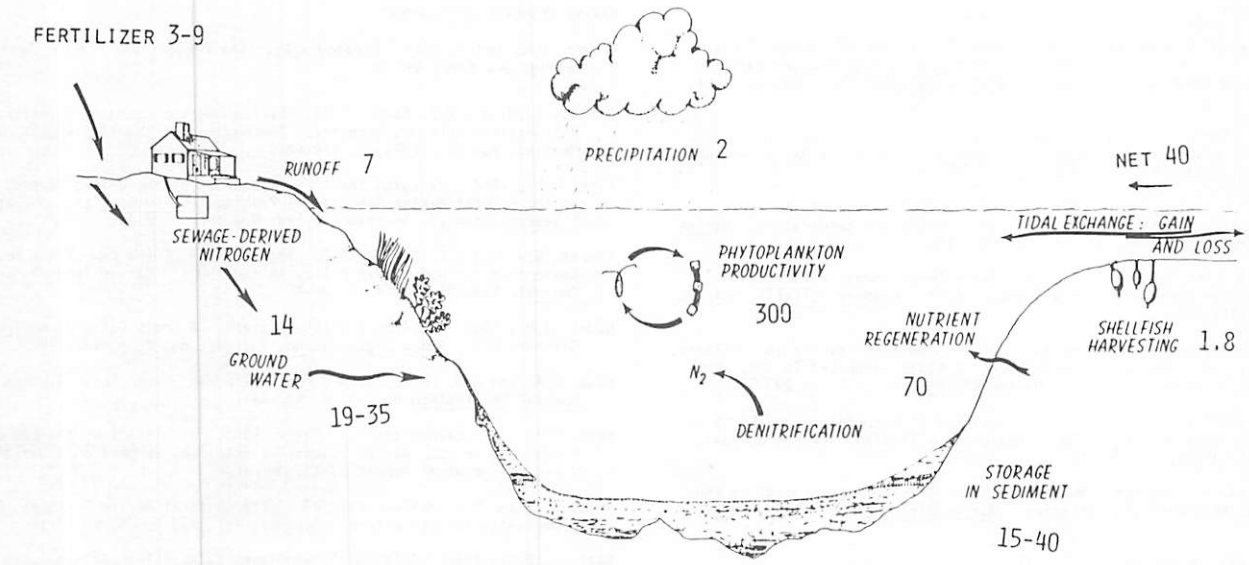

Figure 2. A NITROGEN BUDGET FOR TOWN COVE, ORLEANS, MA. VALUES ARE IN KILOGRAMS NITROGEN PER DAY.

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 progarms 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.

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.

Program Development

Program development funds are an especially valuable source of support as they provide the WHOI Sea Grant Program the opportunity to expand and develop its Program as well as make rapid responses to immediate and important scientific opportunities.

During the 1982-83 year the following projects were initiated through this fund. You will find reports on these individual projects elsewhere in this report.

Seasonal and Long-Term Trends in Sea Level Over the Last Half Century

The Distribution of PCBs in Sediments of an Industrial Harbor: New Bedford, MA

Adaptation to Irradiance as a Regulatory Factor in the Initiation, Duration, and Decline of Toxic Dinoflagellate Blooms

Effect of Copper on Favella

Development of Diets for Crustacean Aquaculture: The Use of Single Cell Protein Sources in Optimizing Protein Utilization

Water Tunnel Treadmill/ Respirometer for Studies on Locomotor Biology of Coastal Fishes

The Second International Symposium on Responses of Marine Organisms to Pollutants

Decision Analysis Applied to Fishery Management Plan Development

The Population Dynamics of Infectious Diseses in Mariculture Systems

Stable Isotope Determination of the Origin of Water Types in Buzzards Bay

Hydrography and General Circulation in Buzzards Bay

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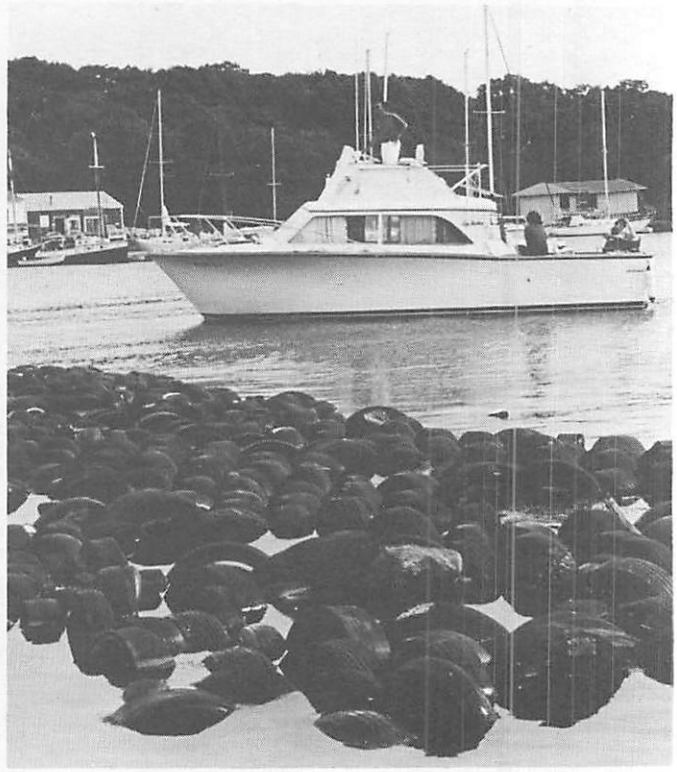


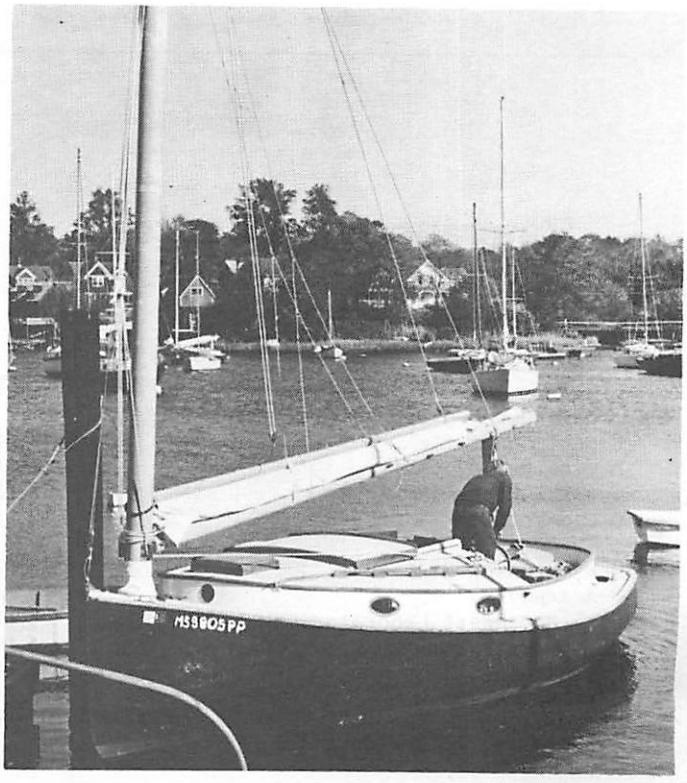
(Paul Gately)

Summary of Project Status

Program	Year Beginning '82	'83
FISHERIES BIOLOGY & MANAGEMENT		
Resources Biology		
Toxic Dinoflagellate Blooms (Red Tides) in Southern New England, D.M. Anderson	CG	CG
Comparative Reproductive and Developmental Strategies of Populations of the Bay Scallop Argopecten Irradians Irradians (Lamarck) in Shallow and Deep Water Embayments, J.M. Capuzzo/G.R. Hampson	NS	CG
Application of Stage-Classified Demographic Models to Atlantic Salmon Populations, H. Caswell/R. Naiman	NS	CG
Predation on Larval Fish by Coelenterates and Chaetognaths, L.P. Madin/J.E. Purcell	NS	CP
Development of Diets for Crustacean Aquaculture: The Use of Single Cell Protein Sources in Optimizing Protein Utilization, J.M. Capuzzo	-	CG/CP
Adaptation to Irradiance as a Regulatory Factor in the Initiation, Duration, and Decline of Toxic Dinoflagellate Blooms, P.M. Glibert	NS	CP
Effect of Copper on Favella, D. Stoecker	NS/CP	-
Water Tunnel Treadmill/Respirometer for Studies on Locomotor Biology of Coastal Fishes, M. Freadman	-	NS/CP
Decision Analysis Applied to Fishery Management Plan Development, S. Peterson/ R. Bowen/ M. Silva	-	NS/CG
Sea Ranching & Culture-Based Fisheries		
Osmoregulation in the Brook Trout, Salvelinus Fontinalis, S. McCormick/R.J. Naiman	CG	CP
Bacterial Chemosynthesis for Aquaculture, C. Taylor/ L. Graham/ H. Jannasch	CG	CP
Lipid as an Indicator of Bivalve Broodstock Condition, S.M. Gallager/R. Mann	NS	CP
The Population Dynamics of Infectious Diseases in Mariculture Systems, H. Caswell	NS	CP
HUMAN IMPACT ON THE MARINE ENVIRONMENT		
Georges Bank: A Book and Atlas, R.H. Backus	CG	CP
The Comparative Toxic Effects of Oil and Oil Dispersants on the Energetics of Larval Development and Metamorphosis, J.M. Capuzzo/ J.J. Stegeman/B.A. Lancaster/B.A. Woodin	CG	CP
Stable Isotope Determination of the Origin of Water Types in Buzzards Bay, W.B. Curry	NS	CP
Hydrography and General Circulation in Buzzards Bay, L. Rosenfeld	-	NS/CP
The Distribution of PCBs in Sediments of an Industrial Harbor; New Bedford, MA, J.W. Farrington/ A.C. Davis/B.C. Brownawell/B.W. Tripp	NS/CP	-
The Second International Symposium on Responses of Marine Organisms to Pollutants, J.J. Stegeman	NS	CP

Program	Year Beginning '82	'83
COASTAL SEDIMENT TRANSPORT		
Natural Tidal Inlet Bypassing, D.G. Aubrey/ P.E. Speer	NS	CG
Coastal Sediment Transport, Popponesset Beach, MA, D.G. Aubrey/M.R. Goud	CG	CP
Wave Boundary Layer Studies Using Laser Velocimetry, Y.C. Agrawal/W.D. Grant	CG	CP
Seasonal and Long-Term Trends in Sea Level Over the Last Half Century, D.G. Aubrey/ K.O. Emery	NS	CG
MARINE RESOURCE DEVELOPMENT		
Marine Policy Initiatives, D.A. Ross	CG	CG
Economic and Legal Aspects of Deep Sea Polymetallic Sulfides, J.M. Broadus/R.E. Bowen/ K.M. Shusterich/M.J. Mottl	NS	CP
An Economic Analysis of Industrial Structure and Behavior in the Emerging Seabed Mining Industry, J.M. Broadus	NS	CP
PROGRAM ADMINISTRATION		
Marine Assistance Service, A.G. Gaines	CG	CG
Program Administration & Development, D.A. Ross	CG	CG

NS - New Start; CG - Continuing Project; CP - Completed Project;
TM - Terminated Project



(Ellen Gately)

Activity Budget

1982-83

	NOAA* Grant Funds	Matching Funds
Marine Resources Development		
Aquaculture	$ 113,200	$ 121,959
Living Resources, other than Aquaculture	130,900	23,092
Mineral Resources	29,900	15,003
Socio-Economic and Legal Studies		
Marine Economics	24,900	000
Socio-Political Studies	26,400	132,590
Marine Technology Research & Development		
Ocean Engineering	57,100	38,714
Marine Environmental Research		
Research and Studies in Direct Support of Coastal Mangement Decisions	63,700	30,553
Ecosystems Research	24,900	103,895
Pollution Studies	55,900	25,683
Advisory Services		
Other Advisory Services	58,500	000
Program Management & Development		
Program Administration	124,600	34,906
TOTAL	$ 710,000	$ 526,395

*National Oceanic and Atmospheric Administration

Matching Fund Sources

1982-83

Woods Hole Oceanographic Institution	
Education Office	$142,620
Marine Policy Center	147,595
Coastal Research Center	123,684
Ocean Industries Program	12,255
Matamek Research Station	72,941
Tabor Academy	10,500
Battelle Northwest Laboratories	5,000
Various industries	4,800
Town of Mashpee	4,500
Phillips Petroleum	2,000
Town of Marion	500

Outside Participation

1982-83

Academia

Tabor Academy
Cornell University
San Diego State University

Industry

Battelle Northwest Laboratories
Wiegart & Sons, Inc.
Bluepoints Company, Inc.
Phillips Petroleum