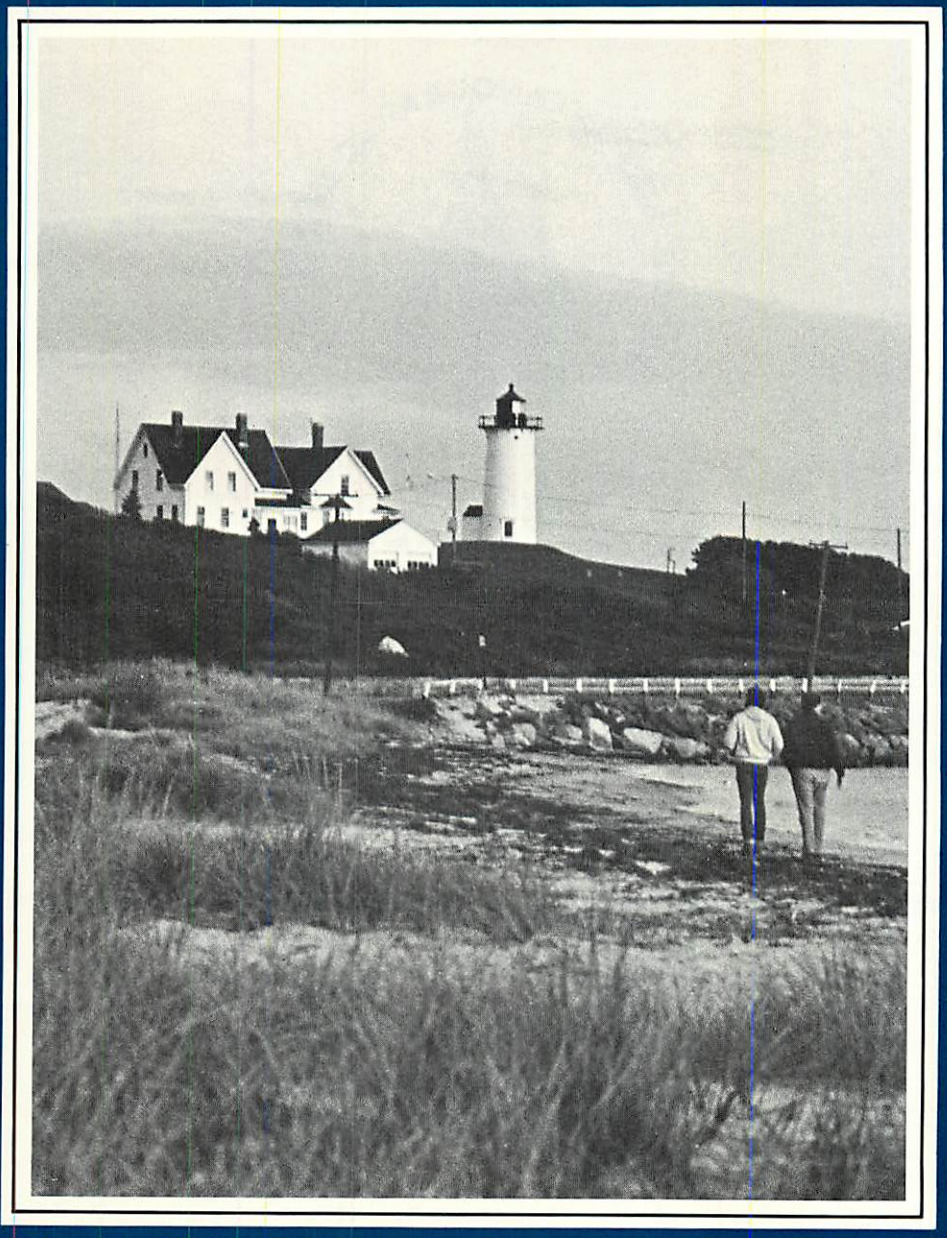
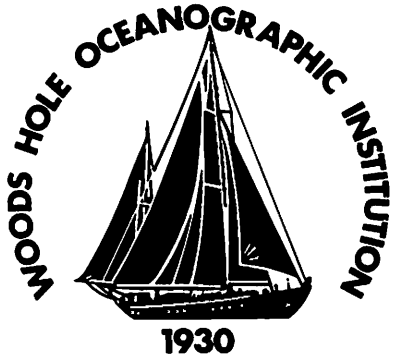


Woods Hole Oceanographic Institution Sea Grant Program Report 1984-1987



1984 - 1987
Sea Grant Program Report

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Alan W. White and
Alexandra W. Petrovits, Editors

Design and Layout, Vicky Cullen

Photos by
Anne Rabushka Smrcina

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Copies are available from:
Sea Grant Office
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone: (617) 548-1400
Telex: 951679

SEA GRANT OFFICE
X2398

January 1988

The attached summarizes the research supported by the WHOI Sea Grant Program during the period 1984 - 1986 and those programs that have continued into 1987.

If you would like additional information, please contact the WHOI Sea Grant office (617-548-1400, ex. 2398) or the specific investigator.

Very truly yours,

WHOI SEA GRANT

David A. Ross
Coordinator

Alan W. White
Marine Science Advisor

Alexandra W. Petrovits
Marine Communicator

DAR:AWP

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Introduction

Recent years have seen a considerable advance in our understanding of the ocean and its many interacting processes. It has also been a time of increased public awareness of the ocean and the need for better dialog between government and the public (including the scientific community). Budget cuts are becoming a way of life and require that priorities in ocean research and management be established. It is under these conditions that a program like Sea Grant has worked and contributed.

This document describes the projects that have been supported by the Woods Hole Oceanographic Institution Sea Grant Program during the period 1984-1986 plus those that have continued in 1987.

A goal of our Sea Grant Program is the evaluation, development, utilization, and conservation of our national ocean and coastal resources. This requires the skill of a wide variety of marine scientists, as well as educational and advisory aspects.

In 1985, the Sea Grant Program was elevated to Institution status. We have presented testimony on several aspects of ocean use and hosted several important meetings and workshops. Among the latter are: "Exploratory Workshop on Fisheries Sociology," "Eelgrass: The Plant the Community and their Possible Decline," "Workshop on Beach Nourishment: Its Future for the Massachusetts Coast," and "Symposium on Hydrodynamics and Sediment Dynamics of Tidal Inlets."

Research during the 1984-87 period focussed on several themes including: Fisheries Biology and Management; Human Impact on the Marine Environment; Coastal Resource Management; and Marine Resource Development. An important effort has been on the pollution problems in Buzzards Bay resulting from high quantities of PCB in coastal waters.

Although research is the main objective of our Program, the transfer of general information and the results of our research are also important parts of our effort.

We hope you find this report informative. Please contact us if you have a question on the enclosed material or other aspects of the Woods Hole Oceanographic Institution Sea Grant Program.

David A. Ross
Sea Grant Coordinator
July 1987

Biological Regulation of Toxic Dinoflagellate Blooms

R/B-56
1984-1986

Donald M. Anderson
Biology Department

The overall objective of this project and those that have preceded it is to develop an understanding of the factors that regulate the timing and location of blooms of the toxic dinoflagellate *Gonyaulax tamarensis* in two distinct hydrographic regimes in the southern New England region. The focus has been on two study areas, one representative of shallow, estuarine sites and the other more typical of deeper, nearshore waters.

In both of these areas, an attempt has been made to determine the coupling between *G. tamarensis* cyst germination and eventual bloom timing or magnitude. Several observations have emerged from these efforts that are important relative to our ability to understand or predict toxic bloom dynamics and to assess the mechanisms and potential for species dispersal.

Historically, the paralytic shellfish poisoning (PSP) caused by *G. tamarensis* first became a problem in 1972 in southern New England following a massive coastal bloom of the dinoflagellate in northern waters. Certain estuaries on Cape Cod were repeatedly toxic in the ensuing years but the toxicity was not widespread and seemed to be localized within, or dispersed from, several key embayments. Our continuing studies of the cysts and motile cell dynamics of this species in Perch Pond, one of these embayments, has documented a dramatic decrease in the peak population size over the past six years. This decrease has been noted in both the number of viable cysts at the sediment surface (representing a potential inoculum for blooms) and the size of the motile population in the water column. Since there have been no concomitant changes in major environmental variables, it appears that the death and burial of *G. tamarensis* cysts in this high-sedimentation environment has decreased the initial "seed" population to a sufficient extent that only relatively minor blooms have developed since 1980. Thus there appears to be a strong coupling between the benthic cyst population and the magnitude of blooms in these estuaries. There is also an indication that this species may not be suited for growth in such waters and that widespread dispersal like that occurring in 1972 may not have long-lasting consequences in certain hydrographic environments.

Another important set of observations concerns the cyst population in the deeper waters of the Gulf of Maine. Our mapping surveys have documented a tremendous number of *G. tamarensis* cysts in those sediments, their distribution correlating well with bathymetry and sediment type. We have also shown that the bottom temperatures are high enough to permit

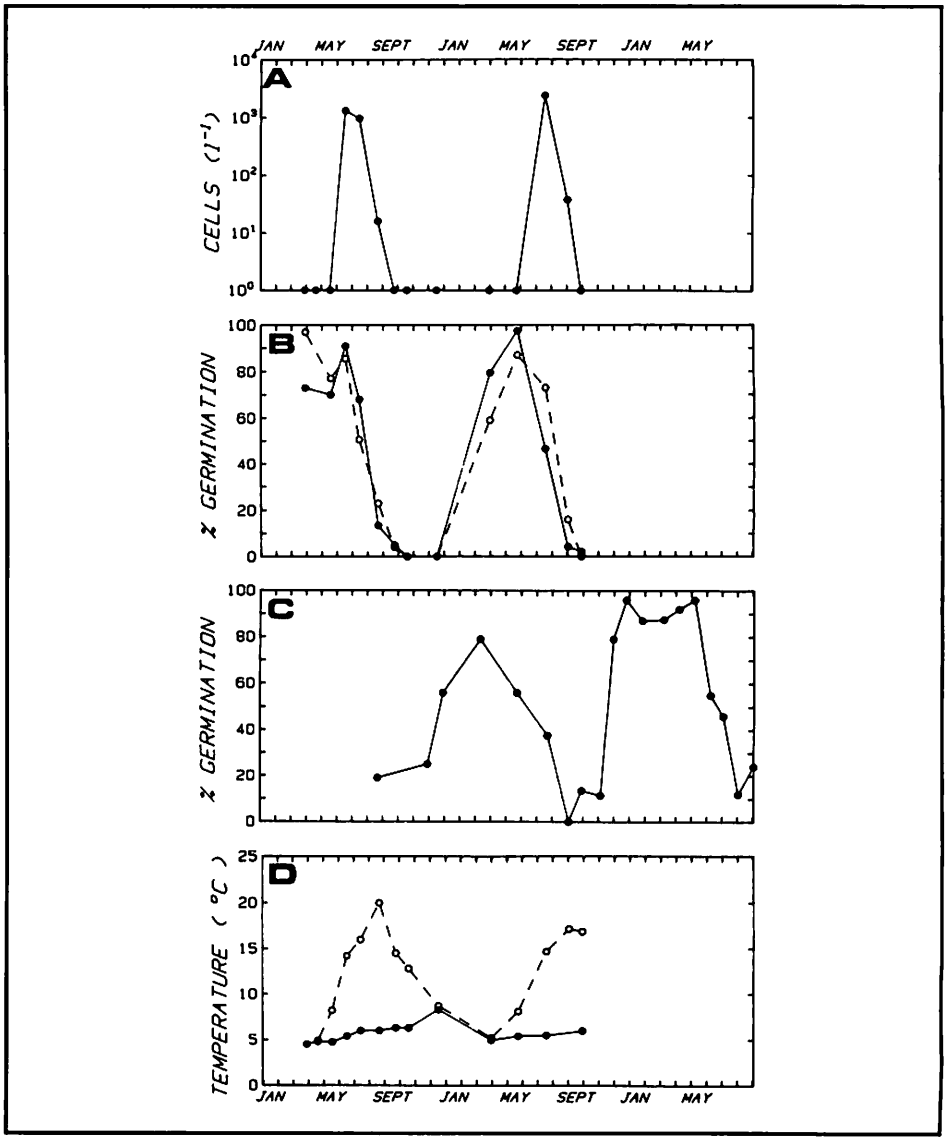

Figure 1. Population dynamics of cysts and motile cells of *Gonyaulax tamarensis*. A, Average motile cell concentration in the top 30m of the water column at two stations in the Gulf of Maine. B, Average germination frequency of cysts isolated from sediments in the Gulf of Maine either from the top 2 cm (●) or from top 5-6 cm deep (O). C, Germination frequency of cysts isolated from Gulf of Maine sediment stored in the laboratory under constant conditions. D, Bottom (●) and surface (O) water temperature where cysts were collected.

germination throughout the year, but that only those cysts in a thin layer at the sediment surface are actually in an environment with sufficient oxygen to allow excystment to proceed. This should still result in a small but steady seeding of the water column throughout the year, but this is not what we observed. Figure 1A shows two years of data describing the timing of the motile cell bloom of *G. tamarensis*. The distinct seasonality of the two blooms is paralleled by a surprising variation in the germination success of cysts from sediments collected fresh on a monthly basis (Fig. 1B). The annual cycle was seen in both cysts from surface sediments and those from 6-cm depths within cores, presumably representing older, mature cells. When one of these core samples was placed in a laboratory incubator, stored under constant conditions, and subsamples removed periodically to test for cyst germination success, it soon became clear that the annual rhythm in germination was not a reflection of the maturation of newly formed cysts, nor was it regulated by the external environment. Figure 1C thus documents an endogenous annual clock in *G. tamarensis* - the first conclusive proof of an annual clock in any marine plant. Examination of the germination success of cysts collected from the shallow Cape Cod estuaries showed no such rhythm-excystment had been possible throughout the year. We then have what in retrospect is a remarkably logical hypothesis, namely that cysts in deeper waters where there are no strong seasonal cues must rely on an internal clock to synchronize their germination, whereas shallow water cysts are apparently better off with a strategy where germination is coupled to the external environment. One objective of our forthcoming Sea Grant project is to examine this hypothesis in more detail, since it has major implications with respect to both toxic bloom dynamics and the population biology of *G. tamarensis*.

The Role of Photosynthetic Capacity in the Initiation, Duration, and Decline of Toxic Dinoflagellate Blooms

R/B-59
1985-1986

Patricia M. Glibert
Biology Department

The primary goal of this project has been to understand the capacity of the red-tide forming dinoflagellate *Gonyaulax tamarensis* to adapt to natural variations in the nutrient regime and in the irradiance regime of the environment in which it is typically found, in order to gain an understanding of how these factors impact its ability to grow. Such an understanding is essential before we can predict its success within a given environment and ultimately devise effective management strategies to minimize the economic impacts of red tides and their spreading to presently unaffected areas.

On Cape Cod, there are a number of small embayments (or shallow salt ponds), which, during the early years of this decade were subject to large outbreaks of *G. tamarensis*, some sufficiently large to cause closure of the shellfishery. To date, many factors have been implicated in affecting population outbreaks and losses, including life cycle events, water column mixing, temperature, salinity, etc. This project focused specifically on light effects, and its interaction with nutrient availability.

Field Results

During the 1985 field season, we were able to document for the first time the individual photosynthetic response to irradiance by the *G. tamarensis* component of a naturally occurring red tide bloom (using single-cell isolations of *G. tamarensis* from ^{14}C-labelled phytoplankton assemblages: Glibert et al., in review). We showed that during the developmental stages of

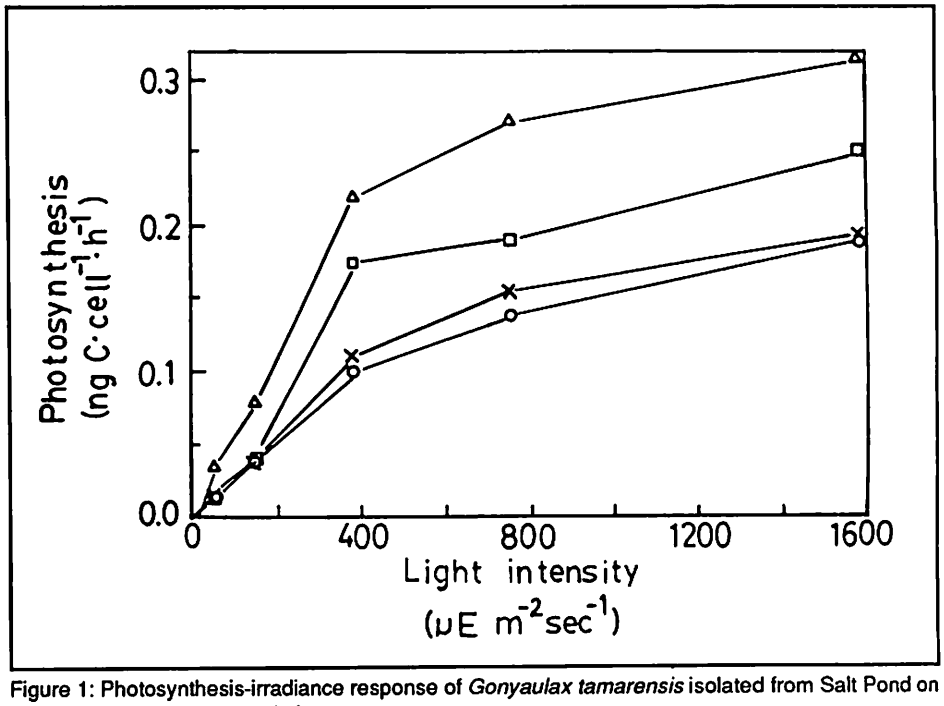

Figure 1: Photosynthesis-irradiance response of *Gonyaulax tamarensis* isolated from Salt Pond on four sampling dates: May 8 (□), May 13 (Δ), May 22 (X), and May 25 (O).

the bloom, the maximum photosynthetic rate that could be maintained by the population increased, reaching a value that matched the maximum growth rate that would be expected at the same temperature for exponentially growing cells of this species in the laboratory (Figure 1). However, as shown in Figure 1, over the following 10-day period, the vigor of the *G. tamarensis* population declined by approximately a factor of two, as determined by the photosynthesis-irradiance response. This decline in photosynthetic capacity corresponded with first, a sharp drop in the concentration of ambient nutrients in the water column, and secondly, with the appearance of planozygotes, the swimming precursors to resting cysts for this species. Based on the photosynthetic patterns shown in Figure 1, and the fact that both carbon fixation and nutrient uptake are required for continued growth, the observed reduction in photosynthetic capacity could be highly significant in understanding how a bloom, or outbreak of red tide, can naturally decline, once it has taken hold.

Our field season during 1986 began, as in other years, with early monitoring of the availability of *G. tamarensis* in several Cape Cod salt ponds. Yet, during the entire monitoring season, there was no evidence of growth of *G. tamarensis* . This observation supports the findings of Dr. D. Anderson (see previous report) that the strength of red tide outbreaks on Cape Cod has been steadily diminishing over the past several years. Thus, we turn our attention to controlled laboratory studies.

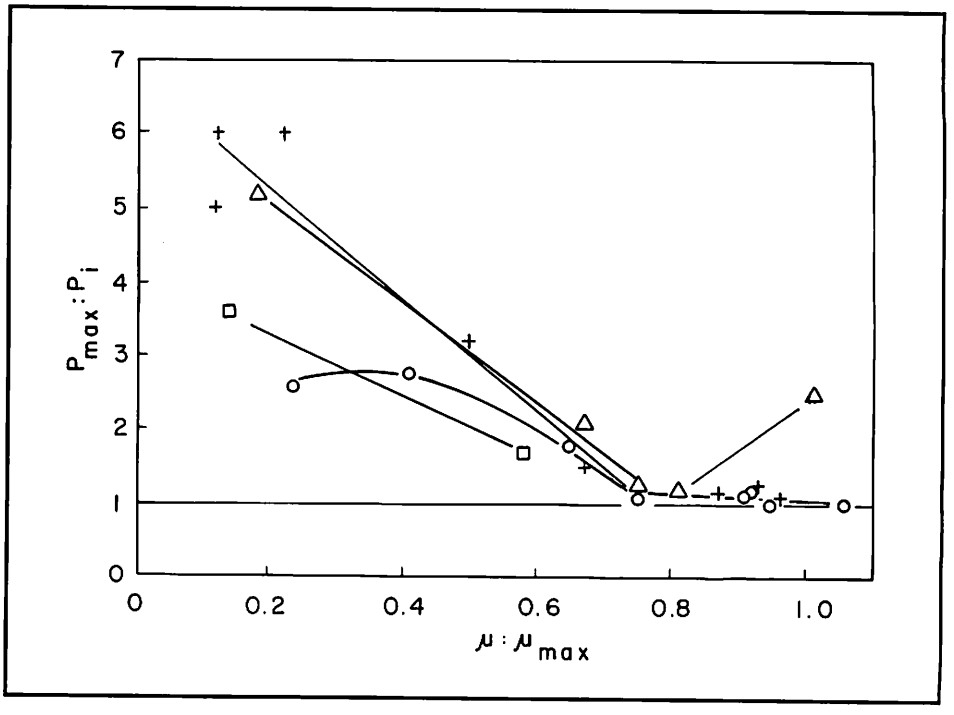

Figure 2: Comparison of the relationship between P_{max}:P_i and μ:μ max for four species of microalgae: *Synechococcus* (O), *Microcystis aeruginosa* (Δ) , *Phaeodactylum tricornutum* (+), and *Gonyaulax tamarensis* (□).

Laboratory Studies

The purpose of these studies was to investigate, under typical bloom temperatures, the interactive effects of nutrient and light limitation on the growth of *G. tamarensis*. The experimental design utilized a batch culture technique whereby multiple individual test tubes containing the cells were grown under varying conditions, with each tube being sacrificed for an individual analysis. This protocol has been shown to be absolutely necessary for growing *G. tamarensis* at rates comparable to those found under field conditions. For some comparative experiments, we conducted similar tests on the blue-green alga *Synechococcus*, because of the ease of culturing this organism and for testing of a more universal occurrence of some of our findings.

There were three direct outcomes of the laboratory studies. First, we were able to demonstrate that during the course of nutrient limitation, there is a progressive drop in the maximum photosynthetic capacity of *G. tamarensis*, and an equal and parallel drop in the ability of these cells to utilize low (i.e., non-saturating) light intensities. This was confirmed in the *Synechococcus* studies as well, demonstrating that as phytoplankton are exposed to progressively nutrient depleted conditions, they slow their photosynthesis rate for all light intensities available. The second finding of our laboratory studies was that *G. tamarensis* cells that were originally grown at a relatively low light intensity (compared with those grown at several-fold higher light intensities) have a capacity for photosynthetic utilization of carbon in excess of that which they actually utilize. This appears to be simply a consequence of their maximizing their cellular photosynthetic machinery for utilizing low light. While this may be advantageous to the cell in the short-term (i.e., if momentarily exposed to higher light regimes), it, for the most part, remains an underutilized capacity in light-limited cells.

The third finding in our laboratory studies, and perhaps the most significant, is that this "excess photosynthetic capacity," found only in low light grown cells, appears to be a universal feature among microalgae (Kana and Glibert, 1987). In Figure 2, we express the excess photosynthetic capacity (relative to *in situ* photosynthetic performance — P_{max} P_i) as a function of relative growth rate (μ: μ_{max}) for *G. tamarensis*, as well as for the cyanobacterium *Synechococcus*, the diatom *Phaeodactylum tricornutum*

(Geider et al., 1985), and the cyanobacterium *Microcystis aeruginosa* (Raps et al., 1983). In each case, excess photosynthetic capacity was inversely proportional to the relative growth rate up to ca. 75% of μ_{max}, or the growth rate within the transitional region between light-limited and light-saturated growth. At near-maximal growth rates, photosynthetic capacity was generally close to photosynthetic performance with the exception of *M. aeruginosa* which exhibited a 2-fold elevation in P_{max} at the highest experimental irradiance.

Thus, in conclusion, during the course of these studies, we have been able to demonstrate the direct effect of nutrient limitation on photosynthetic capacity, and we have been able to define an index of light limitation which appears to be applicable to a wider range of microalgae. This index not only has direct application for the field assessment of the irradiance effects on populations such as *G. tamarensis*, which experience altered irradiance fields during the course of their bloom cycle, but has direct modelling applications as well.

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Raps, S., K. Wyman, H. W. Siegelman, and P. G. Falkowski. 1983. Adaptation of the cyanobacterium *Microcystis aeruginosa* to light intensity. *Plant Physiology*, 72:829-832.

Lipids and Metamorphosis in Marine Bivalve Larvae

R/A-20
1984-1985

Roger Mann and Scott M. Gallager
Biology Department

The bivalve hatchery industry identified their inability to predict larval survival through metamorphosis as a significant economic problem. In previous Sea Grant-funded work we examined the use of lipid specific stains as an assay of larval condition. We continued our studies in response to the industry problem and posed several questions. These included: (1) is there a threshold energy reserve level which a bivalve larva initiating metamorphosis must have to complete that process successfully; (2) how long into post metamorphic growth is lipid an important energy reserve; and (3) can the lipid specific staining technique be successfully applied as a predictive technique in examining success at metamorphosis? In final analysis our studies extended beyond the limited scope of these questions to include the influence of broodstock conditioning on egg quality, lipid utilization during embryogenesis and a comprehensive study of physiological changes accompanying metamorphosis. Such extension was deemed necessary once it became obvious that these processes were all intimately interrelated.

The influence of broodstock conditioning was examined under both laboratory and commercial hatchery conditions. Studies focussed on the clam, *Mercenaria mercenaria* and the oyster, *Crassostrea virginica*. Weekly spawnings were attempted. A significant correlation was observed between parentally derived egg lipid content and survival to both the straight hinge (first shelled) and pediveliger (competent to metamorphose) stages. Embryogenesis was fueled by lipid, in excess of 70% of the egg lipid being utilized during this process.

Good survival to the pediveliger stage was only observed in larval cultures originating from eggs containing >12% lipid (as percent of ash-free dry weight) although high egg lipid content *per se* did not ensure good survival. Clearly, larval development and survival is also influenced by environmental variables. Nonetheless the importance of lipids in larval development was demonstrated as was the value of the lipid-specific stain, Oil Red O, as a sensitive visual qualitative assay of egg and larval lipid content. These results underscore the need for optimal broodstock conditioning prior to spawning.

In addition to its value as a qualitative indicator of egg lipid content Oil Red O was used, in conjunction with classical analytical techniques, to examine lipid accumulation and utilization under varying environmental conditions; e.g., different temperatures or starvation stress. At elevated temperatures (30 v. 25°C) larval shell growth increased but lipid accumulation was 2.5 times slower—the latter contributing to decreased success at metamorphosis. During starvation, lipid was preferentially catabolized with serious consequences for subsequent success at metamorphosis. The described work examining broodstock conditioning and egg and larval lipid content provided a basis for answering questions (1) and (3): indeed there does appear to be a threshold level of lipid required to complete metamorphosis, and yes, lipid-specific staining does have an immediate application here.

Metamorphosis in bivalve molluscs involves significant morphological, anatomical and physiological change. Following our initial focus on pre-metamorphic events and the importance of lipid to them, we proceeded to examine the metamorphic process itself. Physiological studies confirmed our prediction that the ability to feed on suspended phytoplankton was severely decreased during metamorphosis. This observation added further substance to our argument

supporting the requirement for a threshold level of lipid upon initiation of metamorphosis. A surprising finding was the involvement of ciliated tracts on the juvenile foot in limited filter-feeding activity during metamorphosis.

Biochemical studies were used to address question 2. They demonstrated the gradual transition after metamorphosis from lipid to carbohydrate as predominant respiratory substrate. Much of the transition occurs between 40 and 80 days post settlement, a period when hatchery owners noted higher than expected mortalities. Clearly, as this transition occurs the value of lipid specific stains as indices of juvenile condition declines, not to mention the fact that shell development eventually precludes simple observation of stained tissue.

Our studies have added significantly to the understanding of the energetics of larval development and metamorphosis, and have provided the commercial hatchery operator with a powerful, sensitive qualitative tool for evaluating larval and early post larval condition. Furthermore, we have examined options for quantitative, rather than qualitative, lipid assay using specific stains and found this to be tedious, but tractable.

Decision Analysis Applied to Fishery Management Plan Development

R/S-6
1984-1986

Robert E. Bowen, Michael C. Healey, Susan B. Peterson, and Maynard E. Silva
Marine Policy Center

This research examined how the New England Fishery Management Council used scientific and technical information in making decisions. Specifically, we examined whether or not formal decision analytic techniques would improve the Council's decision making process. To do this, we analyzed three fishery management plans - for herring, lobster, and scallops. The results are forthcoming in a book jointly authored by the four principal investigators.

During the period of the grant, Peterson and Silva reviewed and carried out formal content analysis of the Council's documentation regarding development of these three plans. These data were analyzed by Silva and Rosamund Ladner and summarized in a draft chapter for our forthcoming book.

The project principals interviewed all of the key actors in development of the herring plan; less detailed interviews were also done with key actors involved in developing the other plans. These included interviews with Council staff, present and former Council members, advisory committee members, scientists from the National Marine Fisheries Service, and representatives of the fishing industry.

The principals also produced detailed summary records of meetings and discussions held by the Herring Plan Development Team. Healey and Bowen analyzed all interview data and summary records using decision analytic and cognitive mapping techniques. Results of that work are summarized in book chapters currently under review.

Generally, the results of this research suggest that the current plan development process lacks a sufficient goal orientation. Critical stakeholders are consistently ignored and important issues and data appear to play too little a role in final plan evaluation and selection. This results in excessive plan amendments, litigation, unanticipated impacts on stock size and productivity, and lost opportunity costs. The decision analysis framework does provide an opportunity to structure systematically issues relating to resource management questions and to characterize the interests of important stakeholders. Additionally, these methods provide a mechanism to integrate more clearly scientific and technical information into resource management decisions.

Application of Growth Indices to Bay Scallop Management in Southeastern Massachusetts

R/B-57
1984-1986

George R. Hampson and Judith McDowell Capuzzo
Biology Department

The objectives of this project were to compare reproduction and growth of bay scallops collected from seven different areas in southeastern Massachusetts (Figure 1) and to test the feasibility of using these growth data to assist in management of the bay scallop fishery. Simple indices (gonad index and adductor muscle index) were used on samples provided by local wardens. Emphasis was placed on outreach efforts involving a close working relationship with the six southeastern Massachusetts towns involved in the program. Town and state shellfish management has been provided with sound scientific data derived from this study to determine different harvesting strategies rather than relying on a selection of less scientific decisions based upon compromises between noncommercial and commercial interests.

Our data indicate that the general weight yield of scallop muscle can be increased generally between 10-60% based on harvesting delays of one month from October 1 to November 1 (Figure 2). Town awareness of this growth information together with local management information has supported the decision of five of the six participating towns to delay the opening of scallop season from two to four weeks. Other towns not involved directly in the study have also delayed opening the season. During the course of this project it became increasingly apparent that late gonad maturation was noted in second year adults collected in the late fall from the different sites.

It was reported in August, 1985, that excessive rain run-off, causing lowering of salinity, had killed essentially all the scallop population in certain Westport River Estuary embayments. That same year it was noted in late October and November that juvenile scallops were appearing on the bottom and attached to grasses, suggesting that successul spawning had occurred after the mortality caused by salinity alteration in the river. Our data substantiate this observation in that late spawning could occur from individuals showing late gonad maturation in the age range of 15-18 months.

A potentially profitable new research area which could develop from this study would be to determine the spawning contribution of scallops reproducing late in the season. Post-summer spawning coupled with a different set of environmental conditions as observed in the Westport River and changes in the composition of natural predators must be considered and assessed in the final fisheries budget.

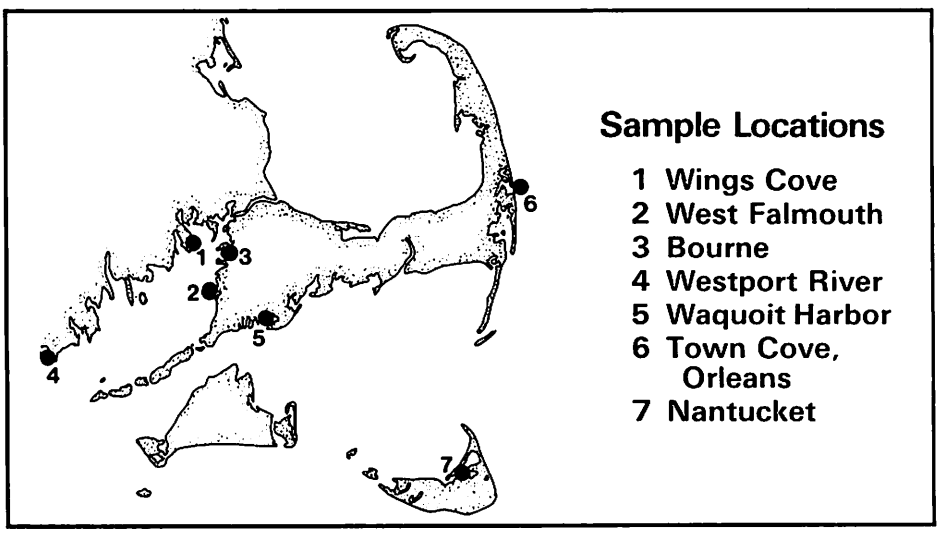


Figure 1. Locations from which bay scallops were collected for measurements of adductor muscle and gonad weights.

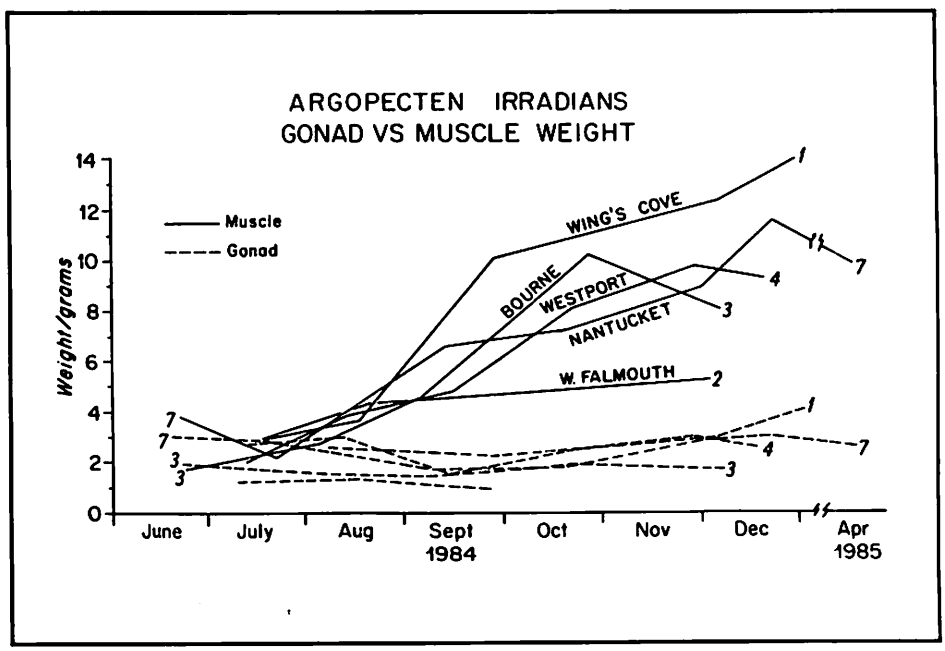


Figure 2. Seasonal change in wet weight of bay scallop adductor muscles and gonads and various locations in 1984. A similar pattern was observed in 1985.

Yield Optimization of Biopolymers in Intensive Cultures of Marine Microalgae

R/B-61
1985-1986

Joel C. Goldman and Mark R. Dennett
Biology Department

Our research has been aimed at developing the biotechnological expertise for optimizing the production of biopolymers from marine microalgae under laboratory growth conditions. This work has been stimulated by the fact that certain marine microalgae can produce copious quantities of high molecular-weight polysaccharides similar in structure and rheological properties to carrageenan, agar, algin, and furcellaran. These biopolymers are produced by some seaweeds and are used extensively in many industries as gelling, thickening, suspending, and emulsifying agents.

The major advantage of using marine microalgae for biopolymer production is that they can be grown in well-controlled and easily manipulated biological systems and they represent a renewable source of these materials. To date, we have focused on two major research areas: preliminary species screening and identification of continuous growth conditions leading to maximum yield of intracellular and extracellular polysaccharides of the most promising species.

We have searched the literature and contacted numerous researchers to identify those species of microalgae that are promising candidates for intensive polysaccharide production. To date, we have ten species in culture that are known to produce copious quantities of extracellular polysaccharides. Some of these species, such as the haptophyte *Phaeocystis poucheti* and the diatom *Nitzschia frustulum*, have been very difficult to grow under intensive culture conditions. We have thus focussed our initial work on two species: the rhodophyte *Porphyridium* sp. and the chlorophyte *Chlorella stigmatophora*, both of which have excellent growth characteristics in mass culture and produce large quantities of high molecular-weight polysaccharides.

A series of continuous culture experiments has been completed on these latter species. The growth system consisted of six, one-liter continuous cultures complete with pH-stat control systems. Artificial seawater contained 2.5 mM NH_4 NO_3 and 0.5 mM PO_4^{-3} as primary nutrients. Culture pH was maintained at 8 by introduction of 1% CO_2 regulated by the pH-stat system, and temperature was held at 20°C by circulating water from a temperature control bath through water jackets on the outside of each culture.

Major emphasis was directed towards determining the effect of dilution rate (medium flow rate/ culture volume = specific growth rate at steady state) on polysaccharide production over a range of dilution rates from 0.05 to 0.75 per day. Both dissolved (X_{EP} in Figure 1A and 1B), and particulate (X_{IP} in Figure 1C and 1D) polysaccharides at steady state decreased with increasing dilution rate. In contrast, bell-shaped curves of production (P) of both chemical constituents (product of polysaccharide concentration and dilution rate) as a function of dilution rate occurred, with maximum production of particulate and dissolved polysaccharide occurring at about 0.25 and 0.15 per day, respectively, for *Chlorella stigmatophora* (Figure IE)

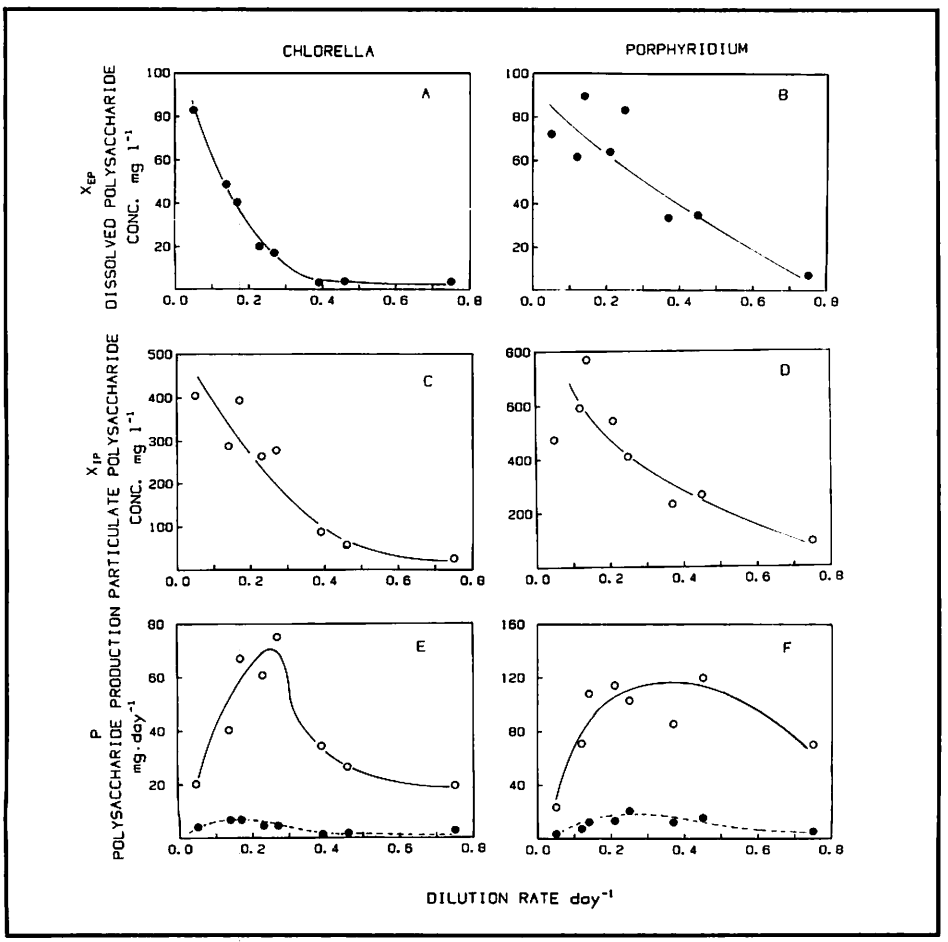


Figure 1. Production of dissolved (●), particulate (O), and total polysaccharides by *Chlorella stigmatophora* and *Porphyridium*.

and about 0.35 and 0.25 per day, respectively, for *Porphyridium*. (Figure 1F). As seen in Figure 1, whereas production of dissolved polysaccharides was comparable for the two species, *Porphyridium* was capable of producing about twice as much particulate polysaccharide as *C. stigmatophora* under equivalent growth conditions. Culture viscosity increased linearly as a function of total ($X_{TOTAL} = X_{EP}+X_{IP}$) polysaccharide concentration, independent of species (Figure 2A). However, when compared on the basis of extracellular polysaccharides, there definitely was a species effect: the rate of increase in viscosity with extracellular polysaccharide concentration was far more pronounced in the *Porphyridium* cultures than in the *C. stigmatophora* cultures (Figure 2B). This result alone suggests that the rhodophyte is a more promising candidate for large-scale polysaccharide production than the cholorophyte.

Another important conclusion from our work so far is that maximum viscosity (which is a reliable indicator of rheological properties of polysaccharides) occurs at a lower dilution rate than that leading to maximum polysaccharide production. In fact, results from preliminary batch experiments confirm that culture viscosities several orders of magnitude higher than the maximum values attained in continuous culture are possible when cultures are maintained for extended periods (weeks) under batch conditions. We are thus left with the distinct possibility that continuous cultivation may not be the best technique for producing biopolymer material of a particular desired quality. Determining the trade-offs necessary in growth conditions to produce biopolymer material of high quality at economical levels of production is a major focus of our continued research.

Mr. Mario Huerta from Miami University of Ohio was a guest investigator on this project during the Spring of 1986 and used some of the results as partial fulfillment for the requirements for a Masters Degree in Environmental Sciences.

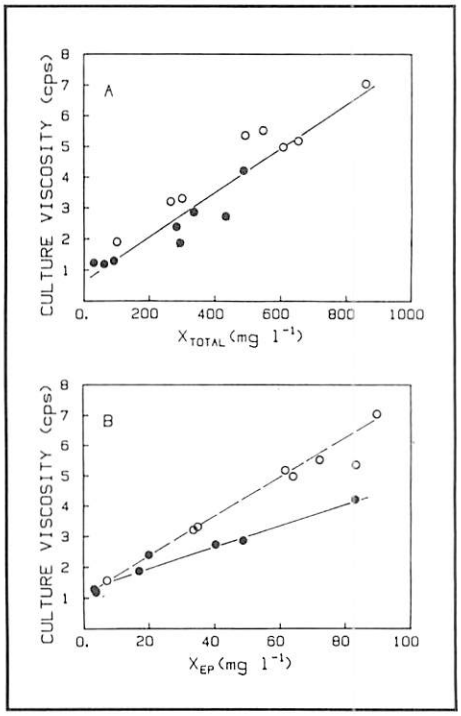
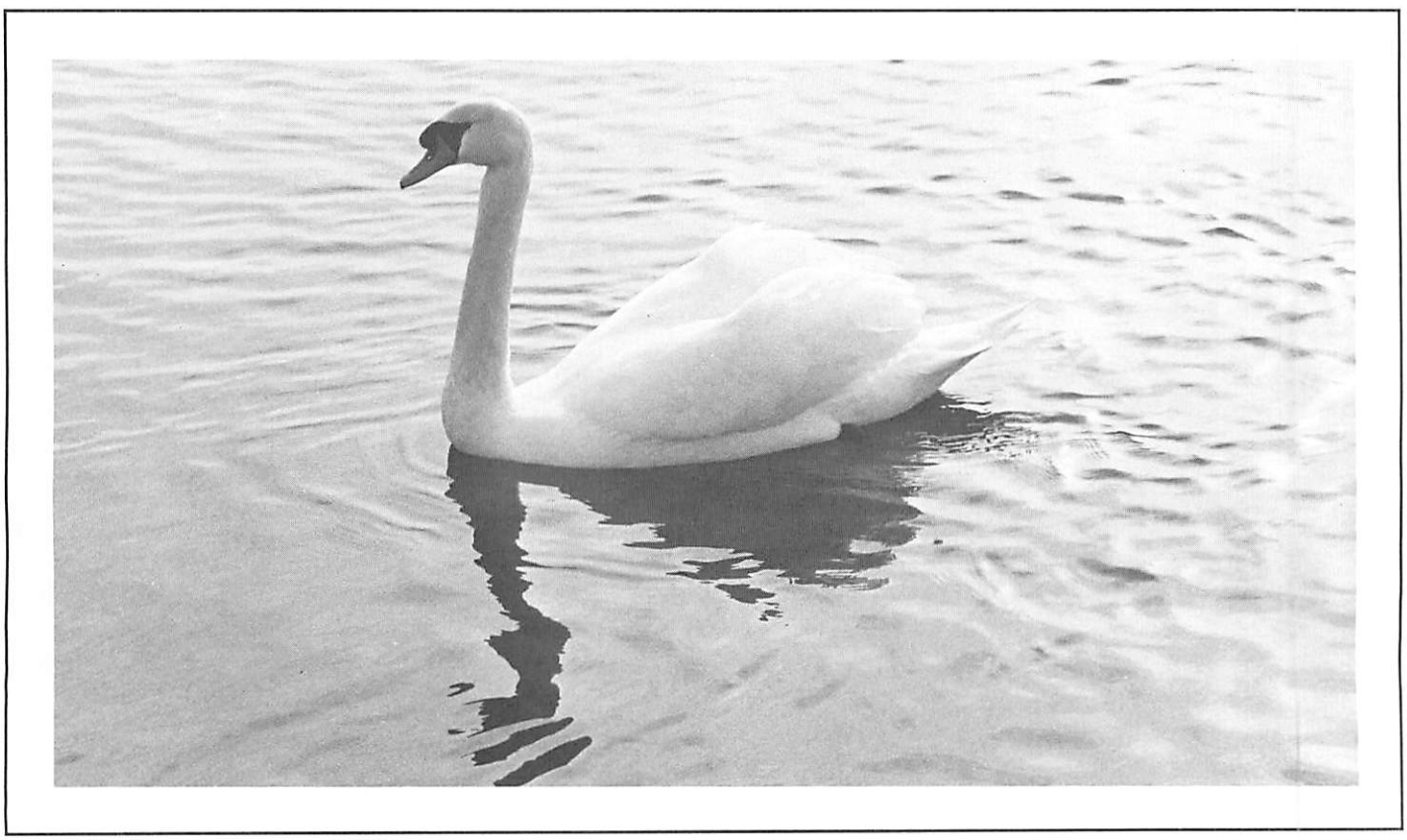


Figure 2. Culture viscosity as a function of total polysaccharide concentration (A) and extracellular polysaccharide concentration (B) for *Porphyridium* (O) and *Chlorella stigmatophora* (●).

Mr. Huerta was sponsored during his stay at Woods Hole by a World Health Organization fellowship.



Biogeochemistry of PCBs in Buzzards Bay, Massachusetts

R/P-17
1984-1986

John W. Farrington and Bruce J. Brownawell
Chemistry Department and Coastal Research Center

The past input of several synthetic organic compounds and fossil fuel hydrocarbons of environmental concern to aquatic ecosystems has resulted in contamination/pollution of aquatic sediments in several areas. Our biogeochemical research on these types of compounds seeks to develop a predictive capability concerning the short-term and long-term fate and bioavailability of these compounds. Several of the compounds of concern are hydrophobic. The results of this portion of our research formed the Ph.D thesis of Dr. Bruce J. Brownawell.

Polychlorinated biphenyls (PCBs) were used as model hydrophobic organic compounds (HOC) to study physical-chemical processes which affect the speciation and fate of HOC in coastal environments. The focus of this study was on the sorption of PCBs with colloidal organic matter in seawater, and the influence of this process on the distribution of PCBs in coastal sediments. Laboratory and field experiments were used to make quantitative estimates of PCB-organic matter sorption, and to test predictions of three-phase equilibrium models.

A static headspace partitioning method was developed to measure the sorption of several individual chlorobiphenyls with colloidal organic matter enriched from coastal seawater by hollow-fiber ultrafiltration. This technique directly measured the dissolved-phase fugacity of PCBs in experimental bottles, and avoided uncertain separation techniques often used in isolating various chemical phases. Colloidal organic carbon normalized partition coefficients (K_{oc}) were determined from linear sorption isotherms, and increased from 1.98×10^4 (L/Kg) for 2,4'-dichlorobiphenyl to 3.5×10^5 for 2,2',3,4,5'-pentachlorobiphenyl. Sorption tended to increase with increasing octanol-water partition coefficients (K_{ow}) of the sorbate, and values of K_{oc} were within the range of those reported in other experimental sorption studies with sediments and dissolved humic substances. Experimental partitioning results support the hypothesis that HOC-organic colloid sorption is similar to HOC sorption by sediment organic matter.

PCBs were measured in the interstitial waters and sediments of three box cores obtained from New Bedford Harbor and Buzzards Bay, Massachusetts. The three sites studied had a wide range of sediment PCB concentrations, and reducing conditions provided environments containing high concentrations of colloidal organic matter. Dissolved organic carbon (DOC) and total sediment organic carbon (TOC) were measured in two cores to test the role of organic matter on the observed partitioning of PCBs. PCB concentrations, particularly those of less soluble chlorobiphenyls, were highly elevated in interstitial waters compared to water column concentrations at all three sites. The measured apparent distribution coefficients (K'_d) of individual chlorobiphenyls did not increase with hydrophobicity (K_{ow}), indicating that a large fraction of PCBs in interstitial waters must be sorbed to organic colloids. A three-phase equilibrium model, in which dissolved PCBs are in a dynamic equilibrium with colloidal and sediment organic matter, accounts for many aspects of the field data. There is good agreement of observed partitioning at New Bedford Station 67 and Buzzards Bay Station M with model calculations based on predictions derived from laboratory experiments of HOC

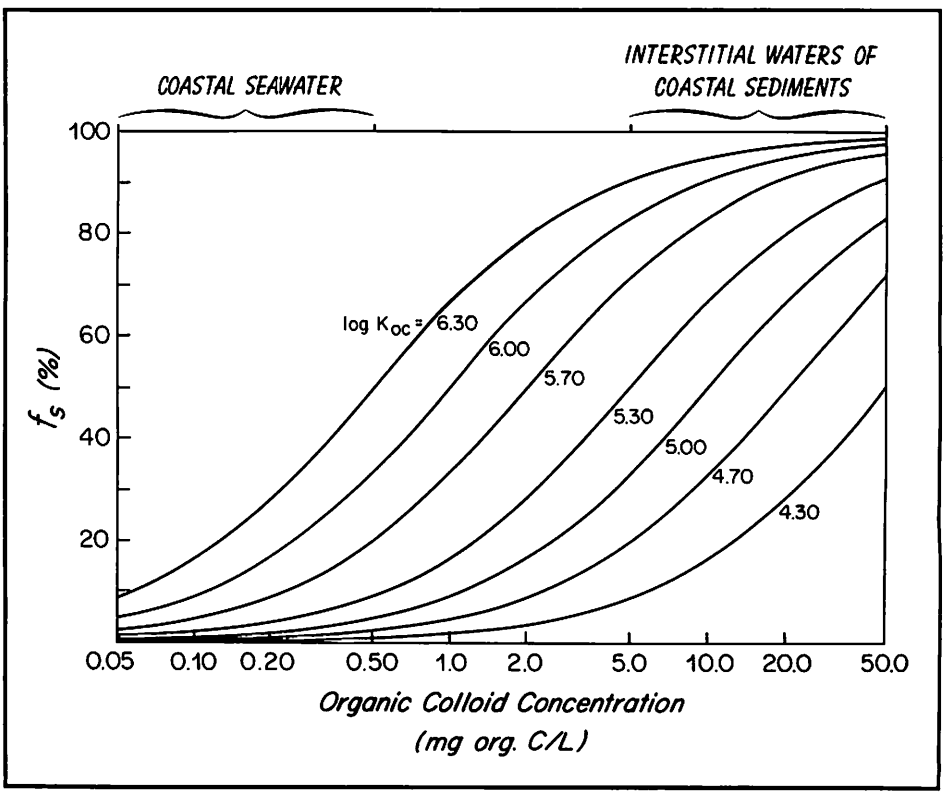


Figure 1. Nomograph providing an estimation of the percentage of a hydrophobic organic compound sorbed (f_s) to a colloid phase from knowledge of the partition coefficient (K_{oc}) and concentration of dissolved organic colloids.

sorption with sediments and organic colloids, but model calculations underpredict K'_d at Station 84 in New Bedford Harbor.

The sediment-interstitial water results were contrasted with results of a study of PCB partitioning in the water column at two stations in New Bedford Harbor. Measured K'_ds of PCBs in the water column increased with K_{ow} and approached predictions based on two-phase, water-suspended particulate partitioning when the effect of organic colloids on high K_{ow}-PCBs was considered.

The effect of a mobile colloid-sorbed PCB phase on a general sediment transport model was evaluated. Enhanced migration of highly sorbed PCBs can be included in an apparent diffusivity term when steady-state conditions exist. Model calculations showed that diffusive migration of PCBs in typical coastal sediments is minor over 20-year timescales. Comparisons with the ^{210}Pb profile provided additional evidence that the solid phase depth profiles of PCBs at Station M were controlled by biological mixing of the sediments and not pore water migration. Predictions based on results from Station M indicate the sediment diffusion and bioturbation of colloid-sorbed PCBs in surface sediments could provide a potentially important flux of PCBs across the sediment-water interface to the water column in Buzzards Bay.

A general application nomograph-type diagram has been prepared to provide a first order assessment of the percentage of a given HOC sorbed to a colloid phase if the K_{oc} of the compound and the concentration of dissolved-colloidal organic carbon in the water are known (Figure 1).

Another focus of our project assessed the uptake of PCBs and PAHs by bivalves (*Mytilus edulis*) transplanted to three locations in Buzzards Bay. These assessments are part of a collaborative effort with Dr. Judith Capuzzo in the Biology Department and are described in her report to maintain a cohesive discussion. Research has commenced on *Mercenaria mercenaria* and will extend our results to a second bivalve species with different life history and habitat characteristics.

We interact in our research with colleagues in the Biology, Ocean Engineering and Physical Oceanography Departments with the objective of providing a quantitative predictive model for biogeochemical cycle processes. Mr. Xiaoping Jia of South China Sea Fisheries Institute, Chinese Academy of Fisheries Science, Guangzhou, China, was a key participant in our studies for two years as a Guest Investigator in the Coastal Research Center and Chemistry Department.

In addition to the generic nature of our research, specific application of our data and results to the New Bedford Harbor-Buzzards Bay Superfund site has attracted considerable attention from several federal and state agencies and our data have been subpoenaed for purposes of resolving litigation. The general applicability of our research has been described in a public evening lecture in July, 1986, at the New Bedford Whaling Museum.

PCBs in Buzzards Bay: Effects on Energetics and Reproductive Cycles of Bivalve Molluscs

R/P-20
1984-1986

Judith McDowell Capuzzo
Biology Department and Coastal Research Center

Uptake and bioaccumulation of lipophilic organic contaminants by marine bivalves are dependent on the availability of specific compounds, the duration of exposure, and the physiological condition of populations. A critical question that remains unanswered is how body burdens of lipophilic contaminants relate to biological effects, particularly at the population level. The objectives of this study were to evaluate the biological consequences of PCB (polychlorinated biphenyl) uptake and accumulation in bivalve molluscs from New Bedford Harbor, MA, specifically focusing on effects on energetics and reproductive potential of *Mytilus edulis* transplanted in cages (from Sandwich, MA) to several sites in Buzzards Bay and Nantucket Sound, MA.

Physiological, biochemical, and histological techniques were used to evaluate the effects of PCBs on growth, energetics, and reproduction. In addition, an extensive series of chemical analyses for chlorobiphenyls and polyaromatic hydrocarbons was conducted by Dr. John Farrington's group of the Chemistry Department and Coastal Research Center. Samples were taken on a bi-weekly basis from November, 1984, through November, 1985. For biological sampling, a mobile laboratory was developed where energetic measurements (feeding, respiration, excretion, assimilation) could be made directly at the field site. Scope for growth estimates were calculated from energetic measurements. Animals were returned to the laboratory for histological, biochemical, and chemical analyses. For chemical analyses, duplicate samples of pooled individuals were analyzed for PCBs and PAHs by glass capillary gas chromatography and gas chromatography-mass spectrometry, after alkaline digestion and column chromatographic isolation of specific classes of compounds.

Mussel transplants in New Bedford Harbor, positioned at the Hurricane Barrier, show considerable uptake initially and then a gradual stabilization of all individual chlorobiphenyls measured. Concentrations are exceedingly high (10^{-6} g/g dry weight range) and there appears to be some fluctuation in concentration of the lighter chlorinated biphenyls during the late spring and summer with a marked decline during autumn, correlated with gametogenesis and spawning activity. Condition indices and scope for growth estimates for mussels at this station are lower than values measured for mussels at other stations during the prespawning period (Figures 1 and 2). Rapid uptake followed by stabilization of chlorobiphenyl concentrations was evident in mussels transplanted at both Cleveland Ledge and Nantucket Sound; concentrations at the two stations are similar (maximum concentration 100 x 10^{-9} g/g dry weight). Condition indices and scope for growth estimates for mussels from the Cleveland Ledge station are lower than values for mussels from the Nantucket Sound station during the first few months of the study, but are equal during the period of gametogenesis and decline after spawning. Reproductive effort (measured as the proportion of energy allocated to reproduction in relation to the total amount of energy assimilated and partitioned to growth and respiratory demands during the entire spawning period) was lowest for mussels from the New Bedford Harbor station. Comparison of bioenergetic estimates of reproductive effort with stereological and biochemical analyses of gonad development confirm these findings.

The composition of the chlorobiphenyl mixture in mussels from the New Bedford Harbor station is markedly different from that observed at other stations. For example, chlorobiphenyls IUPAC 28/31 and IUPAC 95 are present in greater relative abundance than other chlorobiphenyls measured in

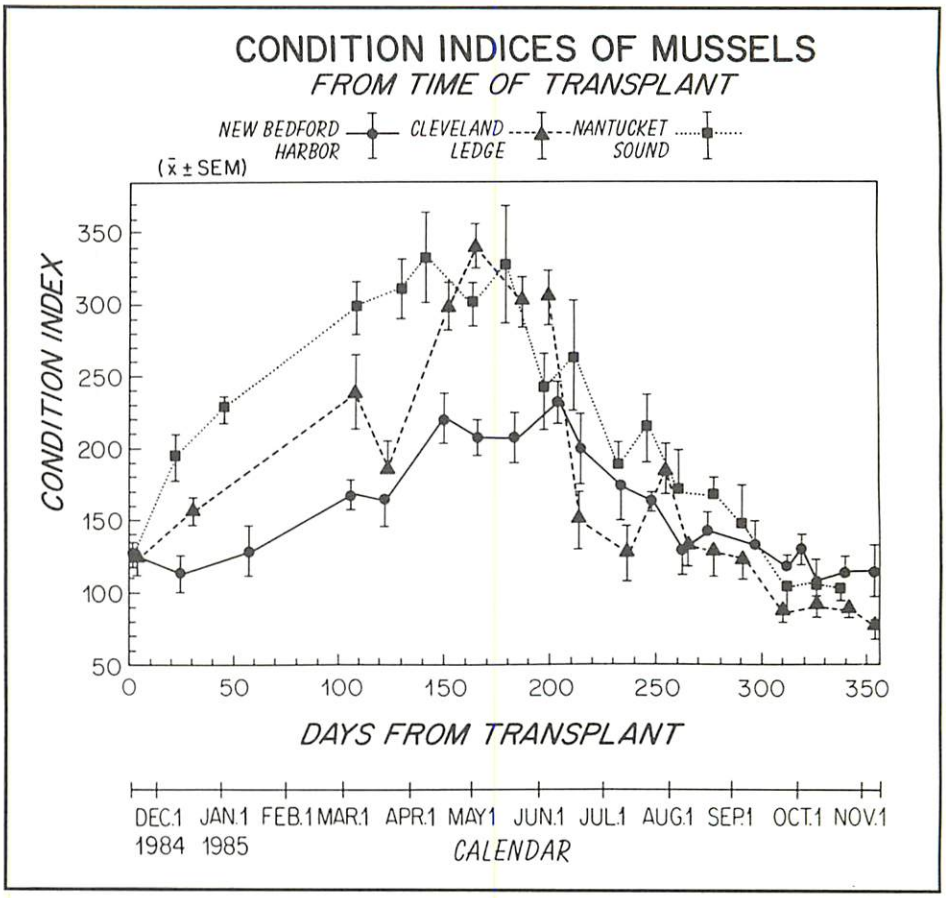


Figure I. Condition indices (physiological index of weight of soft tissue relative to shell weight) for mussels transplanted from Sandwich, MA,to Buzzards Bay and Nantucket Sound.

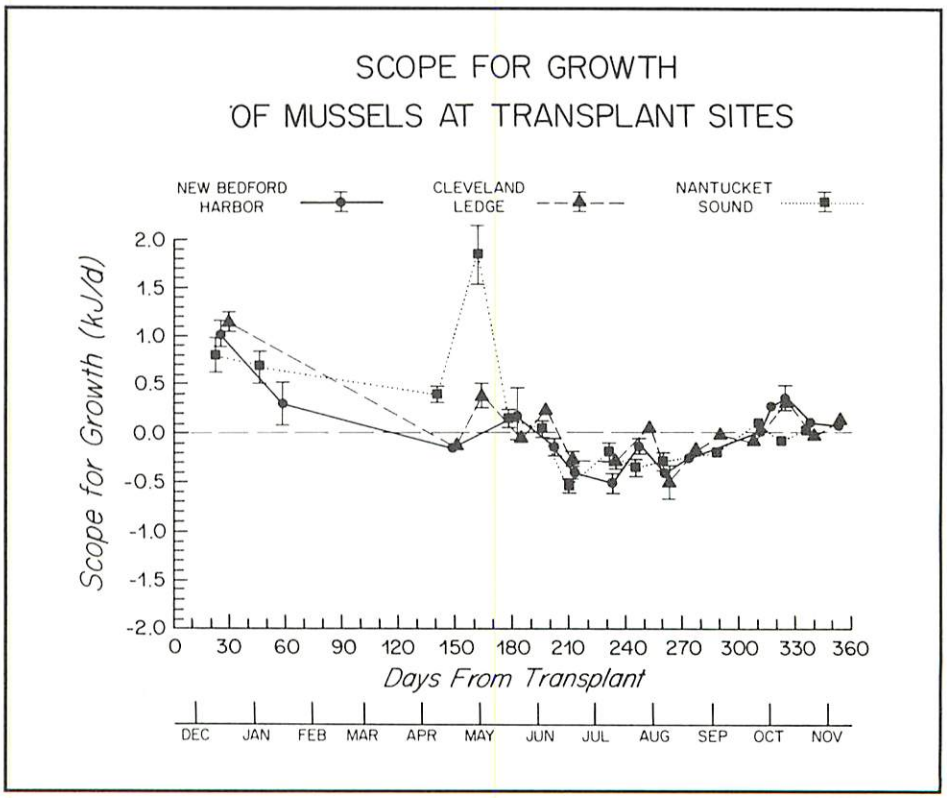


Figure 2. Scope for growth estimates (estimate of energy available for growth and reproduction beyond that required for maintenance metabolism) for mussels transplanted from Sandwich, MA, to Buzzards Bay and Nantucket Sound.

animals transplanted to New Bedford Harbor, whereas these chlorobiphenyls are at intermediate concentrations in mussels from the other two stations. Chlorobiphenyls No. 28/31 are trichlorobiphenyls and have lower K_{ow} (5.69) than several of the other chlorobiphenyls (e.g., No. 95 - 6.55; No. 153 - 7.75). At first inspection we would not expect No. 28/31 to be present in such high concentrations relative to No. 153 because of the direct relationship shown by increasing bioconcentration factor with increasing K_{ow}. If we take into account, however, the high concentrations of chlorobiphenyls No. 28/31 relative to No. 153 in the Harbor water, then we conclude that the more important factor controlling concentration in mussels is the relative concentrations of individual chlorobiphenyls, modified to some extent by differences in partitioning between organisms and water, and possibly selective partitioning into specific lipid pools. The heavier chlorinated biphenyls appear to be persistent, are not lost upon spawning, and have relatively longer half-lives than the lighter chlorinated biphenyls.

Ongoing studies are addressing the bioavailability, bioaccumulation, and biological effects of PCBs and PAHs to bivalve populations indigenous to New Bedford Harbor, specifically the soft-shell clam, *Mya arenaria,* and the quahog, *Mercenaria mercenaria* .

A Possible Biochemical Effect of PCBs in Buzzards Bay Fish

R/D-18
1984-1986

John J. Stegeman
Biology Department

A primary objective of this project was to evaluate the possibility that PCBs are responsible for the induction of cytochrome P-450 in fish in Buzzards Bay. Previous studies indicated that feral scup (*Stenotomus chrysops*) from Buzzards Bay had monooxygenases in many cases strongly induced, presumably by environmental chemicals. Whether the PCB mixtures common in Buzzards Bay, and apparently emanating from New Bedford Harbor, could be responsible for this condition was not known. In this study, we demonstrated that PCBs, like those in Buzzards Bay, can induce cytochrome P-450 in scup.

A PCB mixture designed to approximate the isomer distribution (65% Aroclor 1754:35% Aroclor 1242) in Buzzards Bay was administered to scup. In a separate experiment animals were treated with 3,3', 4,4', 5,5'-hexachlorobiphenyl (HCB). The organ distribution of PCBs was determined and induction of a specific isozyme of cytochrome P-450 (P-450E) was monitored by catalytic and immunological techniques.

Concentrations of mixed polychlorinated biphenyls in scup two days after a single oral treatment were highest in the liver, but the largest percentage of total PCBs was found in muscle and gall bladder. By six days after treatment the PCBs redistributed so that regardless of initial dose the greatest percentage and the highest concentration occurred in the gill. Concentrations of 3,3', 4,4', 5,5',-hexachlorobiphenyl (HCB) did not change as markedly in liver, muscle, or brain between two and six days after treatment as they did for PCBs, suggesting that this single chlorobiphenyl may be reaching a partition equilibrium faster. However, there was redistribution of HCB to the gill like that occurring with PCBs. Hepatic microsomal AHH and ERO-deethylase activities were more strongly induced by moderate (7.6 mg/kg) doses than by higher (38 mg/kg) doses of PCB. Forty mg/kg HCB caused a decline in catalytic activity relative to control values. Immunoquantitation using antibodies to the major MC- or PCB-inducible cytochrome P-450 isozyme in scup, P-450E, revealed that in the PCB- or HCB-treated fish up to 80% of the P-450 was P-450E as compared to 10-20% in control fish. The highest levels of immunoquantitated P-450 occurred in animals receiving 38-40 mg/kg of HCB or PCB.

The results establish that monoxygenase activity in scup can be induced by PCBs and show a time-dependent redistribution of PCBs in scup following a single oral dose. The results also suggest an apparent inhibition or inactivation of the catalyst at high PCB and HCB concentrations and indicate the need for caution in interpretating induction based solely on measures of catalytic function. The mechanism for this decline is yet to be established; demonstrating that mechanism could provide the means to prove whether PCBs are, in fact, responsible for toxic effects in fish liver. This represents an important area for further research.

Scup collected from PCB-polluted waters during field studies were found to have greater monoxygenase activity and a higher percentage of cytochrome P-450E than scup collected from less contaminated waters, suggesting that induction in the field could be associated with PCBs. Analysis of these samples for PCB and PAH metabolite residues is in progress. Levels of chlorobiphenyl previously detected in scup are sufficient to elicit induction, based on residue levels and induction observed in these experiments.

A manuscript describing these studies in detail is being prepared for submission for journal publication.

The Effects of Size Class and Bioturbation on Fine-Grained Transport in Coastal Systems: Specific Application to Biogeochemistry of PCB Transport in New Bedford Harbor

R/P-21
1984-1986

William D. Grant and Cheryl Ann Butman
Ocean Engineering Department

The main objective of this research was to assess the relative importance of size class and bioturbation on the transport of fine-grained sediment in coastal systems for incorporation into a coupled boundary-layer flow and sediment transport model. The research specifically focused on a pollutant transport problem in a shallow-water, coastal embayment: the transport of polychlorinated biphenyls (PCBs) in Outer New Bedford Harbor and other parts of Buzzards Bay, Massachusetts. Since PCBs are known to associate preferentially with organic matter in sediments and fine-grained sediments (silts and clays) tend to be high in organics, PCBs are expected to track with the relatively fine-grained material that is resuspended and transported by the flow. To predict the rates and pathways of PCB-laden particulate transport in Buzzards Bay requires knowledge of the dominant processes responsible for resuspension of bottom sediments. A preliminary analysis of physical measurements from Outer New Bedford Harbor and Buzzards Bay suggested that waves may be required to resuspend bottom sediments and that bioturbation may play a central role in determining the amount and composition (e.g., size-class distribution) of resuspended sediments. Following-up on these observations, this research was directed toward, (1) determining the physical conditions required to resuspend bottom sediments, (2) the depth of the bed that can be eroded by the flow and the composition (grain-size distribution) of these resuspended materials, and (3) the role of benthic organisms in determining the quality and quantity of resuspended material.

Resuspension of Bottom Sediments in Outer New Bedford Harbor

During 1982 and 1983, physical measurements were made of the near-bed flow environment at several stations in Buzzards Bay, using a bottom tripod system. Within 2 m of the seabed, flow velocities were measured at three heights, using an acoustic current meter array (the Benthic Acoustic Stress Sensor, BASS, described in Williams, 1985), and light transmission was measured at two heights; pressure and temperature also were recorded. Preliminary analyses of the tripod data indicated that the bottom stress generated from tidal flows alone was not sufficient to initiate motion of the bottom sediments; transport events were apparently limited to storm periods.

Further analyses during this project concentrated on the storm data and confirmed that the bottom stress associated with waves, together with the stress generated by the steady current, was required to erode the bed. A sampling of the tripod data for non-storm and storm conditions at a station in Outer New Bedford Harbor is shown in Figure 1. For the non-storm case (Figure 1A), the absence of surface waves is evident from the relatively flat pressure record. The tidal current is oscillating about +/- 2 cm/sec around a mean of 6.1 cm/sec and light attenuation is about 2 m^{-1} (61% light transmission). Ten days later (Figure 1B), the pressure record clearly indicates the presence of surface waves with a frequency of about 6 sec. Waves are also apparent in the flow-speed record, where the mean velocity is 7.2 cm/sec, only slightly greater than for the steady current case (Figure 1B), but oscillations are +/- 10 cm/sec and roughly correspond to the wave frequency indicated in the pressure record. In the storm case, light attenuation is almost double, at about 5 m^{-1} (29% transmission), that of the non-storm value.

The physical observations taken with BASS tripod system are limited to relatively short time

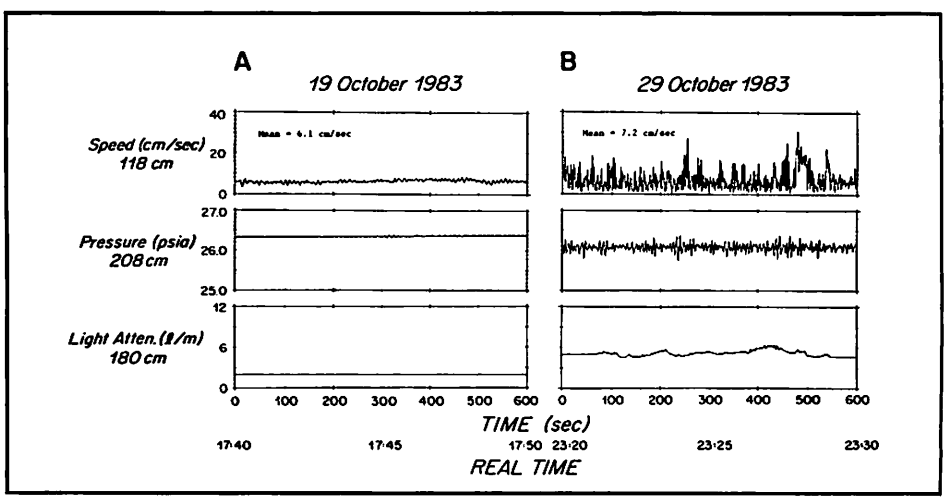


Figure 1. Flow speed, pressure, and light attenuation near the bottom at Outer New Bedford Harbor during non-storm (A) and storm (B) conditions.

periods (days to weeks) due to the high sampling rate. Bottom tripods designed for long-term (months) data acquisition also were deployed at various sites in Buzzards Bay from 1982 through 1985 by Dr. B. Butman (U.S. Geological Survey, Woods Hole). The long-term observations corroborate these findings; resuspension events, as indicated by transmission records, were highly correlated with surface wave activity throughout the Bay. While these results could be predicted theoretically and the theory has been validated in continental shelf environments, this is the first direct evidence that the bed shear stress generated by waves is required to resuspend muddy bottom sediments in a shallow, coastal embayment.

Depth of the Bed Eroded During a Resuspension Event

To predict sediment transport rates using Grant's theoretical model requires a suite of input data from the field, including aspects of the flow, fluid and sediment environments. Critical to accurate model predictions is an estimate of the depth of the bed which can be eroded during a sediment-transport event. This can be calculated from light transmission observations only if the suspended sediment concentration gradient is measured and if the size distribution of suspended material is known. We attempted to determine the erosion depth by direct sampling of the seabed. Sediment cores were carefully taken by SCUBA divers and vertically sectioned at 2-mm intervals using a new core-extruding device; the grain-size distribution of each interval was determined by gently wet-sieving the sediments through nested screens to limit disintegration of natural aggregates. In addition to changes in vertical structure, the core data allowed direct estimates of the size distribution of the very surface material that is available to be eroded by the flow, another important input parameter for the model.

The vertical structure of grain-size distribution varied dramatically between cores taken in the spring and fall of 1985 (Butman and Grant, 1986; Butman et al., in prep.). In April (refer to Figure 2), the top 4-mm of sediment was layered according to grain size, with coarser sediments (90-180 μm) overlain by finer, surface sediments (< 20 μm) and intermediate grain sizes (45-90 μm) dominating every fraction below 6 mm. The 4-6 mm interval contained a very high percentage of 20-45 μm sediment. The simplest explanation for this vertical structure is that the bed is physically graded. Sediments to a depth of < 4 mm were resuspended by the flow and fell to the bottom in layers according to fall velocity, with the smallest particles settling last; the maximum erosion depth apparently is 4 mm, with the coarse sediments in the 2-4 mm fraction armoring the bed from further resuspension, and thus, protecting the fine-sediment layer at 4-6 mm from the flow. In September, such physical grading of the bed did not occur; the grain-size distribution observed below 6 mm in April occurred essentially throughout the 2-cm sediment column in September. This September grain-size distribution is expected to be the result of bioturbation. In this case, it is not possible to determine the maximum erosion depth. The organisms may sufficiently rework and bind the sediments such that they are no longer susceptible to initiation of motion by the same shear stresses which eroded the sediments in the spring; alternatively, the sediments may be eroded and physically graded initially, but are quickly reworked by organisms into the observed size classes.

Fine-scale vertical sections of grain-size distribution provide valuable information on the surface, transportable material. An erroneous representation of the material available to be eroded by the flow results if grain-size distributions from the April core are integrated over 2 cm, as is generally the practice in field sampling of "surface" sediments. Furthermore, these results explain the fact that ripples have been observed on the seabed at the Outer New Bedford Harbor site following some storm events. Sediment samples taken in 1983 and analyzed for grain size using standard sediment analysis techniques and integrating over several centimeters depth indicated that the sediments contained < 20% sand, suggesting that bedload transport resulting in ripples would be unlikely at this site. The more detailed information provided by the fine-scale vertical sectioning technique indicates that the relevant sediment layer (2-4 mm depth in the April core, see Figure 2A) contains > 60% sand after (supposedly) a resuspension event, supplying the necessary high-sand content for rippling.

Bioturbation Effects

To begin assessing the potential effects of bioturbation on sediment transport requires information on the composition of the benthic community and on the bioturbating activities of the dominant organisms. The infaunal community was sampled at 2-3 month intervals beginning in October, 1984. The community is highly numerically dominated by a single polychaete species, *Mediomastus ambiseta*, occurring at densities of 10^5-$10^6/m^2$. Temporal abundances of this subsurface deposit feeder follow a seasonal cycle typical of an annual species, with lowest population densities in the late winter and spring and recruitment occurring during the summer and early fall. *Mediomastus* feeds head-down in a flexible, thin-walled mucus tube and, using its caudal filament, deposits discrete, cylindrical pellets (initially held together in a mucus string) in mounds on the sediment surface surrounding its tube. The worms ingest fine, muddy sediments and egest fecal pellets that are orders-of-magnitude larger in size. The worms apparently do not feed very deep in the sediment; like the other fauna at this Outer New

Bedford Harbor study site, over 90 percent of the *Mediomastus* individuals occurred in the top 2 cm of sediment (at least in the fall). Experiments to determine reworking (pelletization) rates of this organism indicate that rates of fecal pellet production are sensitive (i.e., vary by a factor of three or more) to events occurring at the sediment surface (Butman et al., in prep.) and to the time of the day (Fuller et al., submitted). We estimate that 30 to 100 percent of the top 1 mm of sediment consists of new pelletized material each day (for early fall conditions: *Mediomastus* population densities of $10^6/m^2$ and 20°C water temperature). *Mediomastus* fecal pellets probably constitute the two major grain-size classes observed throughout the sediment cores in September and below 6 mm in April (see Figure 2).

From the data available thus far, we predict that it is a combination of the density of bioturbators in the sediments, their reworking rates, and the frequency of storm resuspension events that determines the vertical structure of grain-size distribution (Butman et al., in prep). When population densities and reworking rates are relatively high, as in the fall when water temperature is at a maximum, and when the frequency of resuspension events is relatively low, then we would expect a completely bioturbated bed as, for example, that observed in September (Figure 2B). However, when population densities and reworking rates are relatively low, as in the spring when water temperature is at a minimum, and when the frequency of resuspension events is relatively high, then we would expect a physically graded bed over the erodable depth (e.g., the April core, Figure 2A).

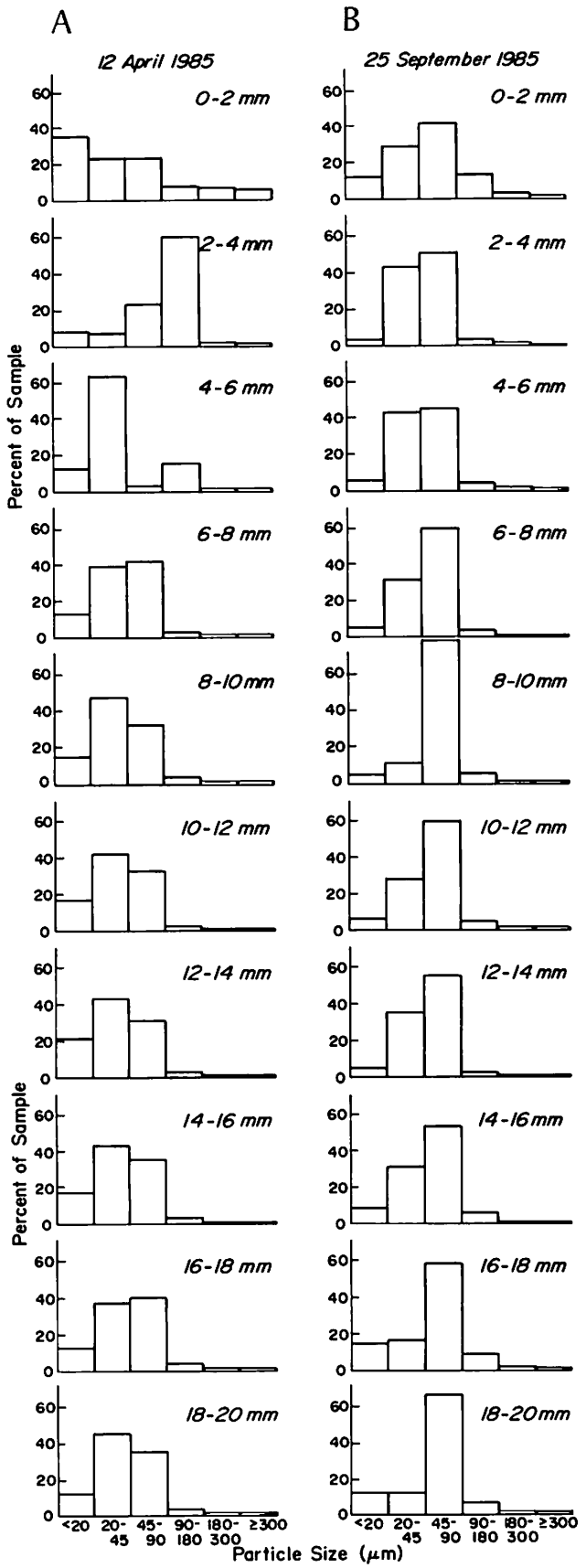


Figure 2. Vertical structure of grain-size distribution of sediments in the spring (A) and fall (B) of 1985 at Outer New Bedford Harbor.

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Natural Tidal Inlet Bypassing

R/B-46
1984-1985

David G. Aubrey
Geology and Geophysics Department

Management of those portions of our nation's shorelines lying adjacent to tidal inlets requires improved knowledge of natural tidal inlet processes. The extent and impact of shifts in unstructured tidal inlets, as well as the deleterious impacts of structured tidal inlets, make proper management of these coastal reaches difficult. Structured tidal inlets are known to create problems by trapping sediment adjacent to jetties and removing sediment from the longshore transport system, causing absolute loss of sediment by moving the sediment farther offshore in a more elongated ebb tidal delta, and by causing sediment to be dumped offshore as continued maintenance dredging takes place. Similarly, unstructured tidal inlets can create temporary (on a geological time scale) interruptions to longshore sand transport and can alter significantly the morphology of adjacent barrier beaches.

Along an unstructured tidal inlet, bypassing of sediment occurs in two fashions: inlet bypassing and ebb-delta bypassing. Inlet bypassing involves the flood and ebb transport of material derived from longshore drift in-and-out of the inlet. Although some sediment may be lost to form the flood-delta shoal, some material is transported out again on ebb tide to be bypassed to the downdrift beach. Bar bypassing or ebb-delta bypassing is thought to be a dominant mechanism along most inlets having large ebb-tidal deltas. There strong ebb currents move sediment seaward until the radiation stress of the waves combined with bottom friction reduces the transporting ability of the ebb tide currents, depositing sediments as an ebb tide delta. This material then is transported downdrift through wave action, along the ebb delta shoal.

The exact mechanisms of this ebb-delta bypassing have yet to be quantified, although some qualitative models for this bypassing exist. Depending on the ratio of momentum flux associated with the ebb delta (related to tidal prism) to the wave radiation stress (related to the wave climate), an inlet will have either a large aspect ratio (lateral versus longitudinal extent of the ebb delta) or a small aspect ratio. These physics dominate the formation and maintenance of natural channels, as well. If the momentum flux of the ebb tide is sufficiently strong relative to the wave radiation stress and bottom friction, a relatively stable navigable channel may result on the ebb tidal delta. However, if bottom friction and radiation stress dominate, maintenance of a navigable natural channel is difficult, and the deep inlet channel rapidly dies out such that the primary egress and ingress along the delta fluctuates markedly.

The present study focused on formation of ebb tidal deltas and natural bypassing along unstructured inlets. Given the complex physics and momentum balances in such an environment, the research effort has not been successful in completing the goal of generating a numerical model adequately representing the complex sediment transport processes. Instead, the primary results derive from elucidation of the driving forces for models of ebb tidal deltas.

As discussed by many authors, the tide is distorted strongly as it progresses over an ebb tidal delta, through an inlet, and into small, shallow lagoons and estuaries. The effects of the inlet and embayment on the ebb tidal current are profound and poorly quantified. Yet, the time history of ebb flow through an inlet is responsible for formation of the ebb tidal delta. With this focus, Friedrichs and Aubrey (submitted) and Aubrey and Friedrichs (submitted) examined in greater detail those factors governing distortion of the tide through these systems. Stability diagrams show the ranges of the dominant parameters responsible for flood- and ebb-distortion, where the important geometric parameters are ratio of tidal amplitude to water depth and extent of tidal flats area to channel area . As a test of these results, numerical model results were compared with data from 11 estuaries and lagoons from throughout the world.

To analyze further the validity of these results, detailed analyses were made of approximately three years of tide-gauge data from Murrell's Inlet, collected during a combined U.S. Army Corps of Engineers and National Ocean Survey study of inlet/estuarine dynamics. These relationships support the strong dynamical ties between geometric and forcing variability and resultant tidal distortion. These ideas can be applied to future models of ebb tidal flows, and subsequently to sediment transport calculations via ebb delta bypassing.

Cape Cod Bay Sediment Transport

R/M-7
1984-1986

David G. Aubrey
Geology and Geophysics Department

The original research proposal was designed to investigate modes and rates of sediment transport along the eastern inner shelf of Cape Cod, Massachusetts, and was intended to be a jointly-funded effort supported by the WHOI Sea Grant Program and the Commonwealth of Massachusetts. When support from the Commonwealth never materialized, the focus of the project was shifted to Cape Cod Bay, where a cooperative research program was conducted using funds and resources from the Commonwealth of Massachusetts, the United States Geological Survey, and Sea Grant. The intent of the cooperative research project was to assess the potential of four sites located within Cape Cod Bay as dredge spoil disposal areas based on a containment strategy. The original project was funded by the Commonwealth of Massachusetts to industry (Marine Geoscience Applications); the participation through the WHOI Sea Grant Program and the United States Geological Survey (Brad Butman, Principal Investigator) permitted an expansion of the proposed work and more thorough analysis.

The focus of this particular effort was on the physical processes responsible for resuspension and transport of bottom sediments at each of four sites within the Bay, emphasizing two sites (B and E; Figure 1). Along with examination of the physical processes, investigations were conducted by other associates on the geology, biology and sediment chemistry of the Bay. Two major field programs were conducted within Cape Cod Bay for studies of sediment transport and water column motion. The first, in the spring of 1985, consisted of two vertical strings of current meters (one each at sites B and E), and a wave gauge at site E. The second experiment, during winter/spring of 1986, consisted of bottom tripods (with cameras, current sensors, transmissometers, and conductivity probes) as well as vertical strings of current meters. This second experiment was conducted jointly with USGS; the first was conducted without their participation.

Over the interval of the field study, six hydrographic cruises were conducted within Cape Cod Bay. The first three concentrated on the water column characteristics at the four potential disposal sites, while the final three consisted of a more extensive, bay-wide series of hydrographic stations. Results from these later hydrographic cruises reveal considerable structure in the water column characteristics, including temperature, salinity, density, dissolved oxygen, and light transmission. The bay varies from being totally well mixed, to being highly stratified, and to being a mixture of the two, depending on season and on passage of storms. As an example of winter conditions, the data from the February, 1986, hydrographic cruise can be used. Concentrating on light attenuation, north-south and east-west profiles (Figures 2 and 3) display considerable geographic variation reflecting both local resuspension in shallow or more exposed portions of the bay, as well as advection of material along-shore. The north-south vertical profile shows local high levels of attenuation (higher sediment concentration in the deeper, more exposed northern section of the bay, as well as in a narrow band along the shallower southern portion of the bay). The east-west profile shows high nearshore concentrations of suspended sediments, consistent with a hypothesis of north-to-south advection along the western shore of Cape Cod Bay and a south-to-north transport of material along the eastern shore of Cape Cod Bay.

The data can be summarized briefly. Tidal circulation dominates

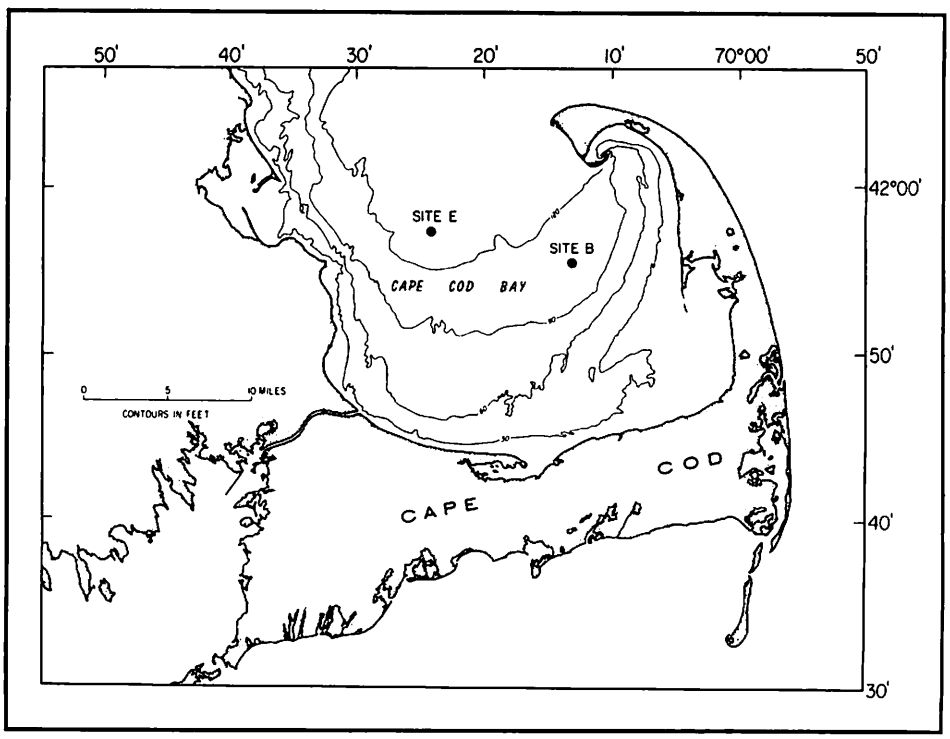


Figure 1. Sites of sediment transport, water motion, and light attenuation studies in Cape Cod Bay.

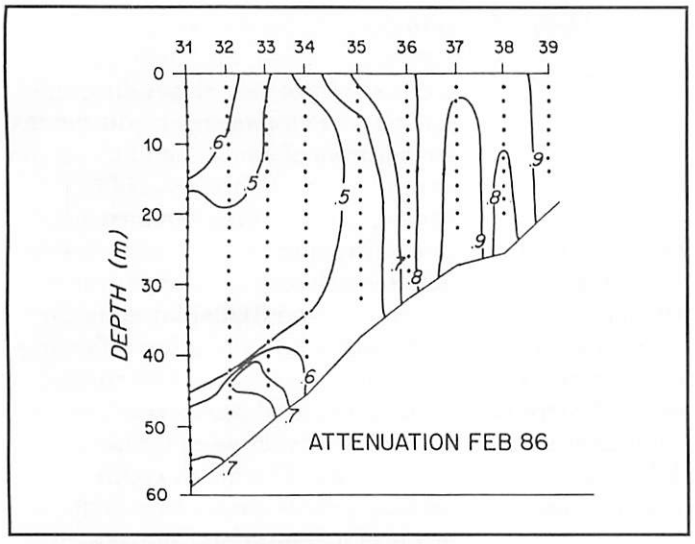


Figure 2. North-South vertical profile of light attenuation in Cape Cod Bay in February, 1986. Station numbers at top.

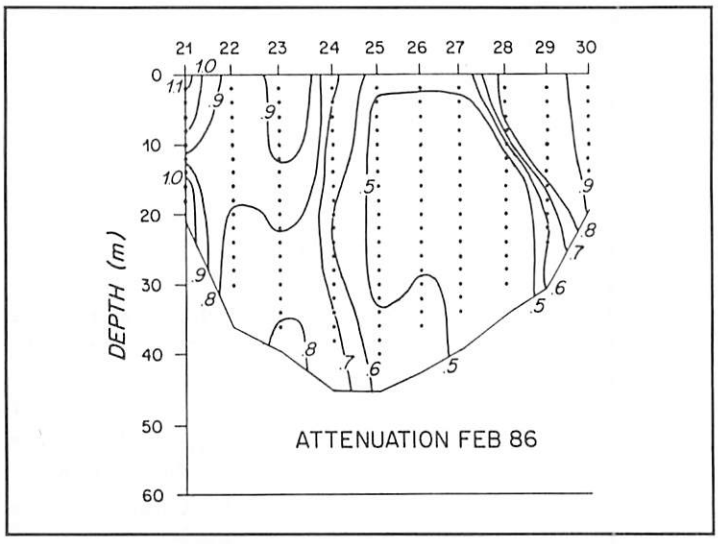
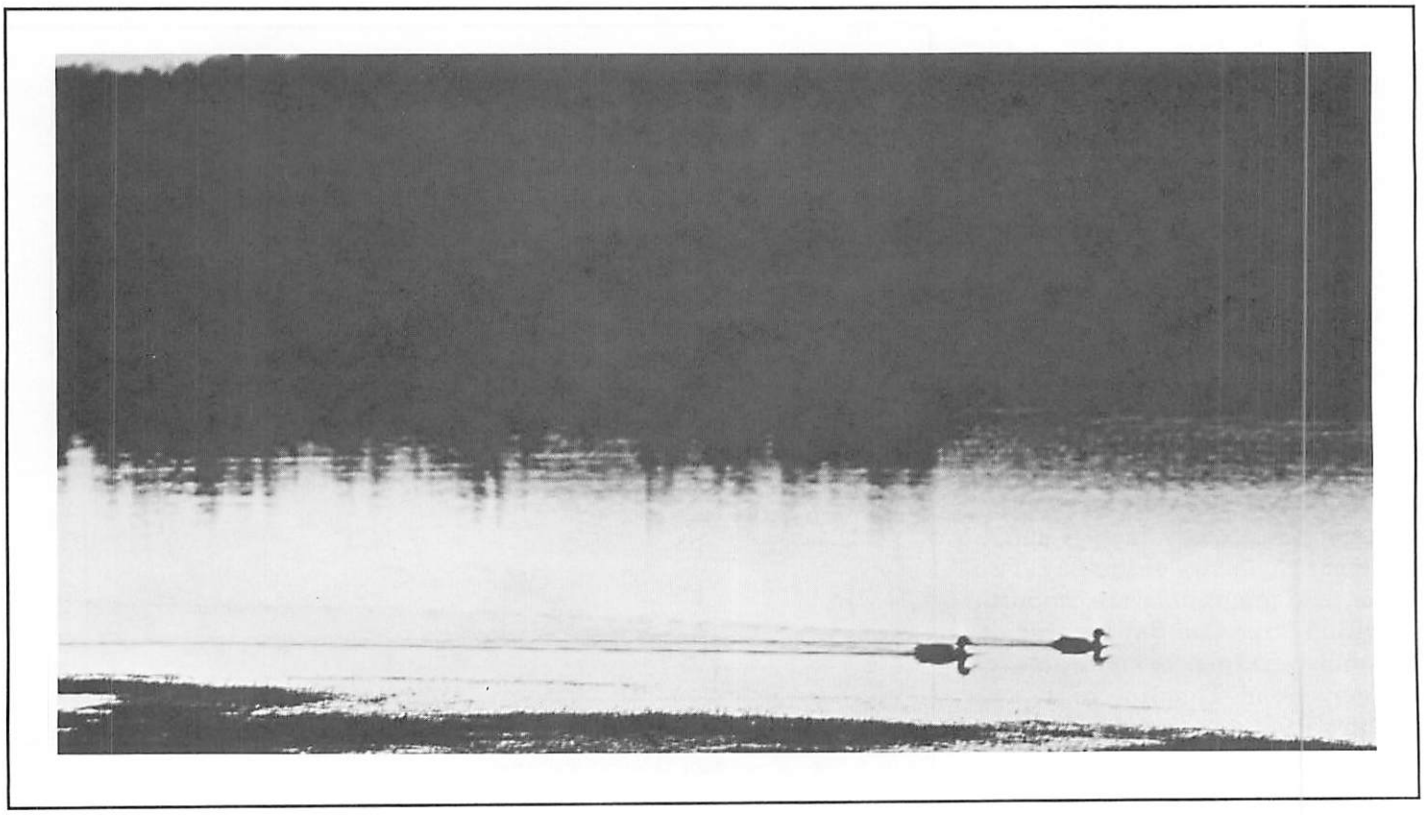


Figure 3. East-West vertical profile of light attenuation in Cape Cod Bay in February, 1986. Station numbers at top.

physical processes in the embayment at frequencies lower than 1 cph. At higher frequencies, surface gravity waves dominate. Because of the sheltering of much of Cape Cod Bay by Cape Cod itself, only the northwestern portion of the Bay is exposed to Atlantic wave action. Site E is included in this region, even though it is deeper than the other three potential sites. Other portions of Cape Cod Bay are exposed either to refracted and less energetic Atlantic wave action, or to local waves generated within the restricted fetch of the embayment. The impact of these waves on sediment transport therefore is governed by degree of exposure to Atlantic storm waves and secondarily by water depth where shoaling waves exert greatest impact at shallower stations. This wave resuspension controls sediment mobility, as tidal and other low-frequency motions only serve to advect and reinforce the wave-induced suspension.

These and other related data are being combined to formulate a draft assessment of potential dredge spoil disposal areas for Cape Cod Bay, to be provided to the Commonwealth of Massachusetts for their designation of such a potential area.



International Marine Science Cooperation Program

E/L-1
1984-1987

David A. Ross
Geology and Geophysics Department

The long-term goal of this program is to enhance international cooperation in the development of marine research projects, information exchange, and management efforts between United States marine scientists and those of other nations. Our 1984-1987 work toward this end has focused on three efforts: Latin American Activities; Programs with Other Countries; and Opportunities Resulting from the Third United Nations Conference on the Law of the Sea (UNCLOS III).

Latin American Activities

Since 1983 researchers from the Marine Policy Center (MPC) have been investigating approaches to improved management of the coastal and marine areas of the Galapagos Islands upon the invitation of the Government of Ecuador. Most notable among the accomplishments of this work is the progress made toward the establishment and effective management of a Galapagos marine reserve. A recent report (Broadus, 1984) was cited by a High Level Ecuadorian Commission as they considered the implementation of a Galapagos Master Plan for Development and Conservation of the Galapagos. In May, 1986, an Executive Decree adopted the Commission's recommendations as national policy, establishing the Galapagos marine area as a Marine Reserve incorporated into the existing terrestrial Galapagos National Park.

Several WHOI researchers visited Colombia in 1984 to discuss and assess the current and potential development of a wide range of Colombia's marine resources, including fisheries, oil and gas, marine minerals, tourism, and marine transportation. After interviews, consultation, and workshop attendance, a final report was presented to Colombian President Becantur in June, 1984, and addressed at the Fourth National Seminar in Marine Science and Technology in Cartagena, Colombia.

Program with Other Countries

Another aspect of Sea Grant-supported international activities has been the exploration for mechanisms of cooperation with countries outside of Latin America. Ross visited Jordan in the spring of 1984 and presented papers addressing marine science and environmental problems and opportunities in the Gulf of Aqaba. A cooperative program for the Gulf was devised with representatives from Yarmouk University and the University of Jordan at Amman and presented to a supportive Queen Noor.

At the invitation of Brazil's Interministerial Commission for Marine Resources, members of MPC and the Geology and Geophysics Department developed a curriculum and taught courses in marine resources management for Brazil. The courses, conducted in October, 1984, in Porto Alegre, focused on: Techniques of Coastal Plan Evaluation; Planning and Managing Uses of the Brazilian Coast; Marine Science Issues and Opportunities; and Environmental Law as an Instrument for Protecting Ocean Resources.

An excellent opportunity has developed with the Government of Portugal for assistance in marine science. In the past year, the Portuguese Luso American Foundation requested that David Ross visit Portugal to reevaluate an earlier report (prepared by a U. S. scientific team lead by Ross) and to assist the Foundation in some decisions concerning a national plan for a "marine science university" and foundation support for the Portuguese national fishing effort (with the Instituto Nacional de Investigaçao das Pescas.) In addition this year, Portugal's Junta Nacional de Investigaçao Cientifica e Tecnologica or JNICT (their equivalent of our National Science Foundation) approached the U. S. National Academy of Sciences through its Board on Science and Technology for International Development (BOSTID), and asked for a U. S. scientist to be designated to act as an official advisory for Portuguese marine efforts. BOSTID has asked Ross to serve in this capacity. JNICT has agreed, as has Ross; the Luso American Foundation also supports this arrangement. It is anticipated that considerable opportunities will develop for cooperative marine work with Portugal in the coming years.

The University of Rhode Island (URI) and WHOI as a primary subcontractor successfully submitted an application to the U.S. Agency for International Development (AID) for a Cooperative Agreement in Coastal Resources Management. The major goals of this agreement, implemented in mid-1985, are: to strengthen developing nations' institutional capabilities in coastal resources management and to enhance U.S. institutions' capacities to respond to the coastal resources management needs of developing countries. The components of the program revolve around research, training, technical assistance and regional outreach, focusing on Ecuador, Sri Lanka, and Indonesia or Thailand.

Opportunities Resulting from UNCLOS III

The U.S. marine science community has long enjoyed productive collaboration with foreign countries in research and education programs. The Third United Nations Conference on the Law of the Sea coupled with economic and technological developments regarding marine resources have encouraged coastal states to pay closer atten-

tion to their offshore areas, placing restrictions on such activities as marine scientific research. It is important to foster international cooperation in marine science to ensure the wise and equitable development of the world's ocean.

Out of the international orientation of the 1984 proposal has grown the concept of creating an Office for International Marine Science Cooperation. We have found support for this concept within the U.S. marine science community and have presented the idea to various forums of representatives, including the House of Representatives Subcommittee on Oceanography, the University-National Oceanographic Laboratory Systems (UNOLS), the National Association of State Universities and Land Grant Colleges (NASULGC) , NOAA, State Department, and National Science Foundation (NSF). The eventual character of such an Office is still undetermined; however, we are pursuing several specific activities in a Program for International Marine Science Cooperation.

These discussions prompted an inquiry into the amount and type of international marine science research projects at Sea Grant institutions. Questionnaires were distributed to and completed by 17 of 29 Sea Grant institutions in order to gather data on the geographic location, source of funding, principal investigators' disciplines, foreign and U.S. agencies and institutions involved, and general categories via keyword identification of international marine science projects initiated at those institutions within the past five years. The survey was not limited to projects sponsored by Sea Grant although many were at least partially funded by Sea Grant. We emphasize that this was a glance at an ever-changing spectrum of scientists and institutions involved in international programs and hence invites updating. The information was published as a WHOI technical report (Ross and Fenwick, 1985) and has been distributed among the participating Sea Grant institutions and elsewhere in the U.S. marine community. This was a new effort not anticipated in our previous proposal.

As a continuation of this Program for International Marine Science Cooperation, we have already completed our first project proposed for the 1986-88 funding period. A 24"x36" map entitled "Marine Scientific Research Boundaries" shows the mosaic of offshore zones of claimed jurisdiction in the world's oceans. The map, in conjunction with a technical report describing coastal state claims with respect to marine scientific research, should provide clear and informative display of international maritime boundaries as they affect restrictions on marine scientific research.

Economic and Legal/Political Aspects of Deep-Sea Polymetallic Sulfides

R/G-7
1984-1985

James M. Broadus
Marine Policy Center

Deep-sea or marine polymetallic sulfides (MPS) are mineral occurrences recently discovered along ridges associated with spreading oceanic crust. The MPS deposits sampled so far contain relatively large proportions of such important metals as zinc, copper, lead and silver. At the time this project commenced, MPS deposits were being reported widely as important new economic resources. The overarching objective of this research was to assess the economic and legal/political implications of MPS, with particular attention to their economic significance and timing of development. Sub-objectives were to characterize in detail the nature and role of the following in MPS resource potential: (1) the international distribution of economic impacts from MPS development; (2) the probable investment policies of national governments most likely to have jurisdiction over the resource; and (3) the structure of the industry most likely to develop MPS and of the markets for MPS metals. In conducting the research, an additional objective was added: (4) a characterization of the relative importance of scientific value versus commercial significance.

All of these project objectives were achieved to our satisfaction. Analysis of the current market conditions for the economically interesting material contained in the MPS deposits and of projected growth rates in demand for these materials and in supply of competing sources led to the conclusion that for the foreseeable future prospects for development of the deposits as economic resources are remote (Broadus, 1984). Only the most speculative designs have so far been presented for recovery systems, and the crucial thickness dimension of the deposits has not yet been sampled because of technological limitations. Consequently, the amount of materials in each deposit cannot be estimated with any confidence. Computer-based mine finance models employed as part of a predecessor project made it clear that even if such deposits were located onshore, they would present only marginal economic prospects unless significant quantities of precious metals could be recovered as by-products. Even if deposits containing such precious metal premiums are eventually discovered in the marine setting (so far they have not been), it would likely take decades before the technological

developments necessary for efficient recovery could be perfected and fielded. Several ambiguities about regulatory conditions that will govern exploration and development of the deposits also impose a constraint on the pace of their investigation and development.

(1) International distribution of economic impacts: Existing patterns of production and trade in zinc and copper were analyzed for evidence about the potential distribution of impacts from MPS development. Premature and exaggerated perceptions about the effects of seabed manganese nodule mining on the distribution of global revenues played a major role in the international Law of the Sea negotiations. In the MPS case, we concluded the distributional concerns will not play so important a role. In any event, substantial changes in the international trade patterns and the distribution of revenue dependency on minerals in MPS can be expected well before any MPS production.

(2) Investment policies of national governments and legal conditions: Analyses of relevant national claims and international treaties, in comparison with the locations of MPS discoveries, show that many MPS occurrences are within national jurisdiction. The investment policies of national governments that might affect the timing of MPS develpment were identified and analyzed (Grodsky, 1986), as were relevant interagency relationships within governments (Broadus and Hoagland, 1984). Concerns we expressed at the commencement of the study, that exaggerated perceptions of MPS resource potential could lead to jurisdictional expansion by national governments, proved to be well-based since exactly such responses have been observed and documented (Ramakrishna, Bowen and Archer, 1987.). Yet, as with trade patterns, governmental investment policies are subject to frequent change with a period much shorter than the probable time horizon for MPS development. We conclude therefore that existing investment policies of national governments will exercise relatively little influence on the eventual timing of MPS development.

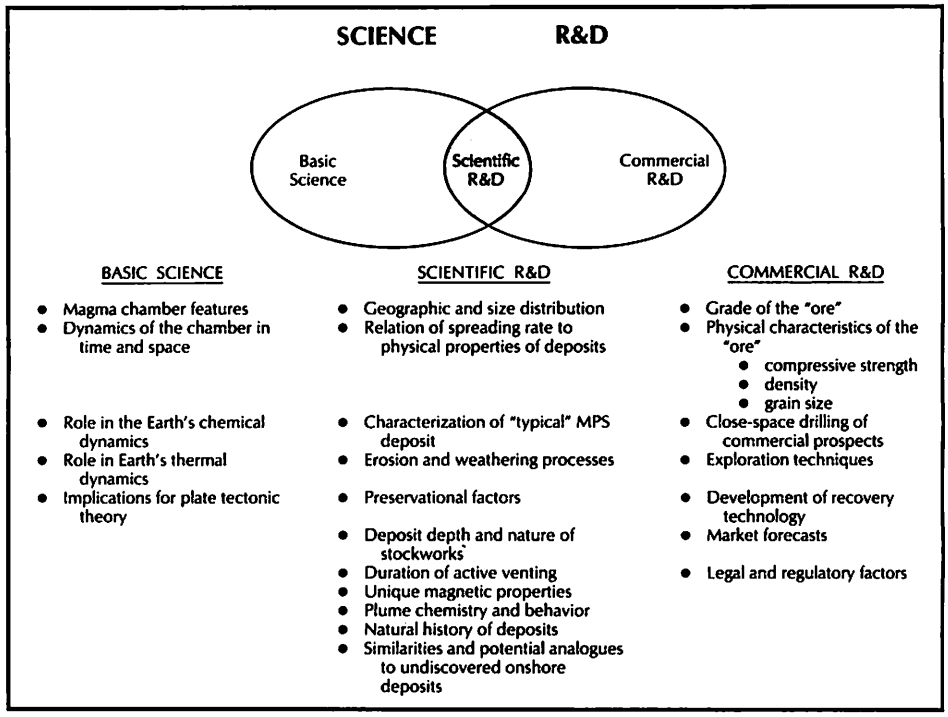


Figure 1. The substance of marine polymetallic sulfide research can be categorized (somewhat artificially) by purpose or objective into science and research and development. The questions addressed will differ, as shown here, depending on whether the research is scientifically or commercially motivated. Some scientific inquiries, however, here called "Scientific R&D," could also provide results useful for commercial development efforts.

Other MPS occurrences have been discovered beyond national jurisdiction. These include deposits on part of the Juan de Fuca Ridge, on the East Pacific Rise at 21°N, 13°N, 11°N, 7°N, and 20°S and on the Mid Atlantic Ridge at 26°N and 23°N. These deposits would appear to fall under the authority of either the Law of the Sea Convention or some alternative regime that characterizes hard mineral development as a high seas freedom (similar to the Reciprocating States Agreement for the nodule resource). As yet, no specific provisions concerning MPS development have been incorporated into any regime that might apply to mineral occurrences beyond national jurisdiction. It would appear that the same problem facing a characterization of national investment policies also exists for the international case.

(3) Structure of the industry most likely to develop: Industry structure affects industry behavior and can help determine the pace of resource exploitation. The markets into which MPS commodities would trade are well defined international metals markets with well understood structures. Globally these are loose oligopolies with little persistent potential for coordinated price leadership, monopolistic restraint or strategic deferral of development activities. Competitive pressures in this prospective market might be exerted by other marine technology and service vendors, such as firms experienced in offshore oil and gas activities, and perhaps by more sophisticated dredging firms. Evidence examined in this study suggests that access to technical expertise will be available to national governments over the next few years at "bargain" prices (below unit cost). Because the economic prospects of MPS are severely limited, however, national investments in commercial development must be seen as highly speculative and

subject to failure (Broadus, 1986).

(4) **Scientific Value:** Scientific interest in MPS has been intense, and the scientific value of the deposits has so far driven public investment in MPS research (Bowen, 1986). The pace of scientific advance will directly influence the timing of commercial interest and development activities, but the nature of scientific findings to date have not aroused a major commitment of private funds to commercial R&D. Because of the early stage of work on MPS and scant scientific evidence available, expected results of R&D are extremely uncertain. In this context, a sequential scientific approach is favored (Broadus and Bowen, 1986). Such an approach also reduces the danger of distorting the scientific research agenda in premature pursuit of a commercial payoff (Figure 1). Premature commercial expectations also risk imposing burdensome regulatory restraints on scientific research (Bowen, 1985). MPS may someday become a valuable economic resource, but they do not appear to be an economic resource at present (Broadus and Bowen, 1984). Consideration of expenditures on MPS are made most appropriately through scientific selection criteria, rather than commerical selection criteria.

The Relationship Between Natural Resource Characteristics, the Character of Client Industry and Optimal Resource Access Provisions: The Case of Marine Polymetallic Sulfides

R/G-9
1984-1985

David A. Ross, Geology and Geophysics Department
and James M. Broadus, Marine Policy Center

The objective of this research was to provide an economic study of the relationship between the characteristics of an offshore mineral resource and industry expected to develop it, on the one hand, and the features of an appropriate governmental system of access, on the other. In recent months, much public policy attention has been focused on efforts to devise the best arrangements for governmentally-assured access by private parties to explore and develop minerals potential in the U.S. Exclusive Economic Zone (EEZ). Questions have been raised about the adequacy of the bonus-bid leasing provisions in the Outer Continental Shelf Lands Act (OCSLA) administered by the Department of the Interior. Representatives from some commercial firms, mining industry associations, environmental groups, and coastal states have expressed a preference for a licensing system modeled after the provisions of the Deep Seabed Hard Mineral Resources Act (DSHMRA) which governs seabed mining activities by U.S. firms beyond the limits of national jurisdiction (Figure l). Sea Grant support for our application of existing economic knowledge to the offshore access problem has allowed us to provide pertinent and timely information on this issue for the policy making process.

From a public interest point of view, two problems must be resolved, whatever may be the differences between industries involved in offshore activities: (1) one lessee (buyer, claimant, patentee) must be selected from the possible contenders for site access, and (2) a price must be determined. A competitive leasing system permits these decisions to be made at arm's length in the marketplace, while noncompetitive licensing or leasing systems do not. The degree of uncertainty about marine hard minerals plays a central role in access system design. Actually more is known about hard mineral resources in the EEZ than often supposed: it is just that this knowledge mostly indicates little near-term economic promise for EEZ hard minerals, resulting in a general lack of industrial interest and a low level of demand for entitlements to access and developmental rights.

Systems for selecting and allocating access entitlements to the federal mineral estate can range from direct payments from the federal budget or subsidized transfer to first-takers as inducement to generate external economic benefits by expanding and developing frontier regions, through competitive selection and shared risk via profit-share bidding, to competitive bonus bidding to shift risk onto the developer and capture the full expected value of economic rents for the public. As knowledge of the EEZ and its mineral potential grows, then the reasonable terms for these entitlements will shift from one of this spectrum toward the other.

Faced with the expectation of change and uncertainty about its nature, several kinds of response are economically sensible. These are to maintain a high degree of flexibility, to diversify one's bets and avoid committing to a single contingent outcome, to reserve action and learn by waiting and seeing, and to invest in research. Hence, an economically efficient access system would likely be explicitly adaptive, so that learning from exploration and research and changing market conditions can be anticipated in principle and oppor-

tunities for appropriate revision built into the system.

Ross has participated as a member of the U.S. National Academy of Sciences Marine Board's Committee of Technology Requirements for EEZ Utilization. This eight member committee is composed equally of academic scientists and industry leaders. The primary consideration for its study is to develop an appraisal of the state of knowledge and technology concerning survey, assessment, development, and recovery of hard mineral resources, identify participant capabilities and activities and advise on plans and information transfer methods. To achieve these objectives, the committee is focusing on three primary tasks:

1) Review available studies and data to determine the state of knowledge of EEZ hard mineral resources and U.S. mineral requirements.

2) Develop understanding of the state of associated technologies in the public and private sectors and project needed improvements and promising research areas.

3) Comment on available plans and programs and identify government, industry, and academic capabilties and activities, as well as relevant information transfer mechanisms.

The NAS Marine Board Committee's report will be available in early 1987 and should make a contribution to future U.S. marine mineral utilization and policy.

Broadus and Hoagland, through the Marine Policy Center, convened a series of discussions in Washington, D.C., by a "Working Group on EEZ Hard Minerals" moderated by Broadus. This group, composed of leaders from industry, environmental, and coastal states groups addressed questions concerning the design and establishment of a hard minerals management system in the EEZ. Representatives of federal agencies and congressional committees attended as observers, and presentations were made by the Assistant Secretary of the Interior for Land and Minerals Management, the Chairman of the National Materials and Mineral Program Advisory Committee, and the Deputy Director of NOAA's Office of Ocean and Coastal Resource Management. Sessions were held on November 11, 1985 at the American Mining Congress, February 12, 1986 at the Carnegie Institution of Washington, and April 30, 1986 at the National Geographic Society. These meetings were conducted at no cost to the Sea Grant project, but results of the Sea Grant research were instrumental in informing the group's discussions and focusing the issues. Ten consensus "concepts" adopted by core group members have subsequently played a major role in organizing the broader discussion of the topic within federal and state agencies and Congress.

Results of this project were also communicated to the policy making process through congressional testimony. In September, 1986, Broadus appeared as an invited witness before the Subcommittee on Panama Canal/Outer Continental Shelf of the House Merchant Marine and Fisheries Committee to comment on the draft of a "National Seabed Hard Minerals Act" that would create a system for hard minerals in the EEZ separate from the OCSLA.

	*OCSLA**	*DSHMRA*	*H.R. 5464*
Due Diligence	Yes	No	Yes
Bond	$50,000 per lease or $300,000 per "area"	No	No
Rental	$741/km²/year	No	No
Term	5-10 years for exploration, producation limited only by ability to produce in paying quantities (or drilling or well-reworking conducted)	10 years plus extensions for exploration, 20 years for commercial recovery or more if commercially feasible	10 years plus one extension for exploration, 20 years for commercial recovery or more if commercially feasible
Area	23 km² or as determined by DOI	Variable but approx 150,000 km²	Unlimited?
Relinquishment	(Proposed in 1974)	No	No
Expenditure	No	Exploration and Commercial Recovery	Exploration only
Plans	Exploration and Development/Production	Exploration and Commercial Recovery	Exploration and Commercial Recovery
Reports	Monthly operations	Annual	No
Reputation	Yes	No	No

* *Performance requirements for OCS hydrocarbon minerals.*

Figure 1. Performance requirements in U. S. ocean hard mineral entitlements.

Economic and Legal-Political Implications of Mineral Resource Potential in the U.S. Exclusive Economic Zone: An Application of Lessons Learned in the Case of Polymetallic Sulfides

R/S-9
1985-1987

James M. Broadus
Marine Policy Center

The overall objective of this project is to determine and to characterize in comparative terms the economic and legal/political significance of EEZ mineral deposits and to identify the major factors influencing that significance. We are expanding and completing our ongoing efforts to: (1) describe the location of mineral prospects known to exist within the U.S. EEZ; (2) characterize the estimated volume of material and evaluate the robustness of existing estimates; (3) characterize the current economic significance of EEZ mineral resources; (4) evaluate the relevant domestic and international legal/political concerns; (5) characterize those factors most directly related to the timing of EEZ mineral development; (6) identify the potential impact of market structures on EEZ mineral development; (7) evaluate the potential effect of the vulnerability of international supply sources; (8) focus on special problems identified in the first year of work; and (9) monitor and report new developments.

Initial steps in the first year of the project concentrated on a survey of prospective mineral resources, their location, estimates of their magnitude, preliminary characterization of their economic significance, initial evaluation of legal/political status, comparative identification of dependence on and vulnerability of international supply sources, and other important features that will permit these potential resources to be compared in several key economic and policy dimensions (Broadus, 1985, 1986, 1987). In the absence of a more precise measure of increasing natural resources scarcity, the long-term behavior of market price is probably as good a signal as any. If the relative scarcity of a material is increasing over time we would expect to see its real price rising. Trends in real price indices for principal EEZ deposit types have been examined using both linear and quadratic fits (Figure 1). From this limited evidence we cannot conclude that price behavior is signalling increased relative scarcity of these materials.

The work now is concentrated on the resolution of specific problems or areas of special interest that were identified in the first year. Such areas include the effects of environmental concerns on the development process, the effects of multiple-agency involvement in marine hard mineral regulation, the role of the system of federal-state task forces put into effect by the Minerals Management Service of the Department of Interior, the nature of governmental provisions for exploration and development access to the mineral areas by private parties, and the nature of scientific uncertainties about the resources and the distribution of effort to reduce those uncertainties.

Research conducted on this project has permitted and informed the participation of the Principal Investigator on an Advisory Panel for the Office of Technology Assessment of the U.S. Congress project to study "Technology Requirements for Exploration and Development of Hard Minerals in the U.S. Exclusive Economic Zone". This study covers very much the same scope of work as our Sea Grant project, but with much greater emphasis on the status and direction of technology development for offshore hard minerals.

One important distinction that has emerged from early efforts in our first year of research is between deep-sea deposits (including MPS, cobalt crusts, manganese nodules, some placers, some oil and gas, and some phosphorites) and shallower, near-shore deposits (including much oil and gas, sand and gravel, some placers and some phosphorites). Economic assessment of known producing resources that trade in existing markets is relatively simple because observable values are available through the price determination of supply and demand. Production experience and known technologies provide a similar point of reference for some of the shallow, near-shore deposits of the EEZ. However, because several important market signals are absent or must be inferred, evaluation on a consistent comparative basis is more problematic for potential or undiscovered resources, such as all the deep-sea deposits and many of the nearshore EEZ minerals.

Demands are being made in each of these cases for immediate policy decisions on a number of questions relating to research strategies, access provisions, jurisdictional assignments, boundary delimitations, incentives for private investment, environmental issues, and foreign relations (Bowen, 1985; Bowen and Hennessey, 1985; Ross, 1985).

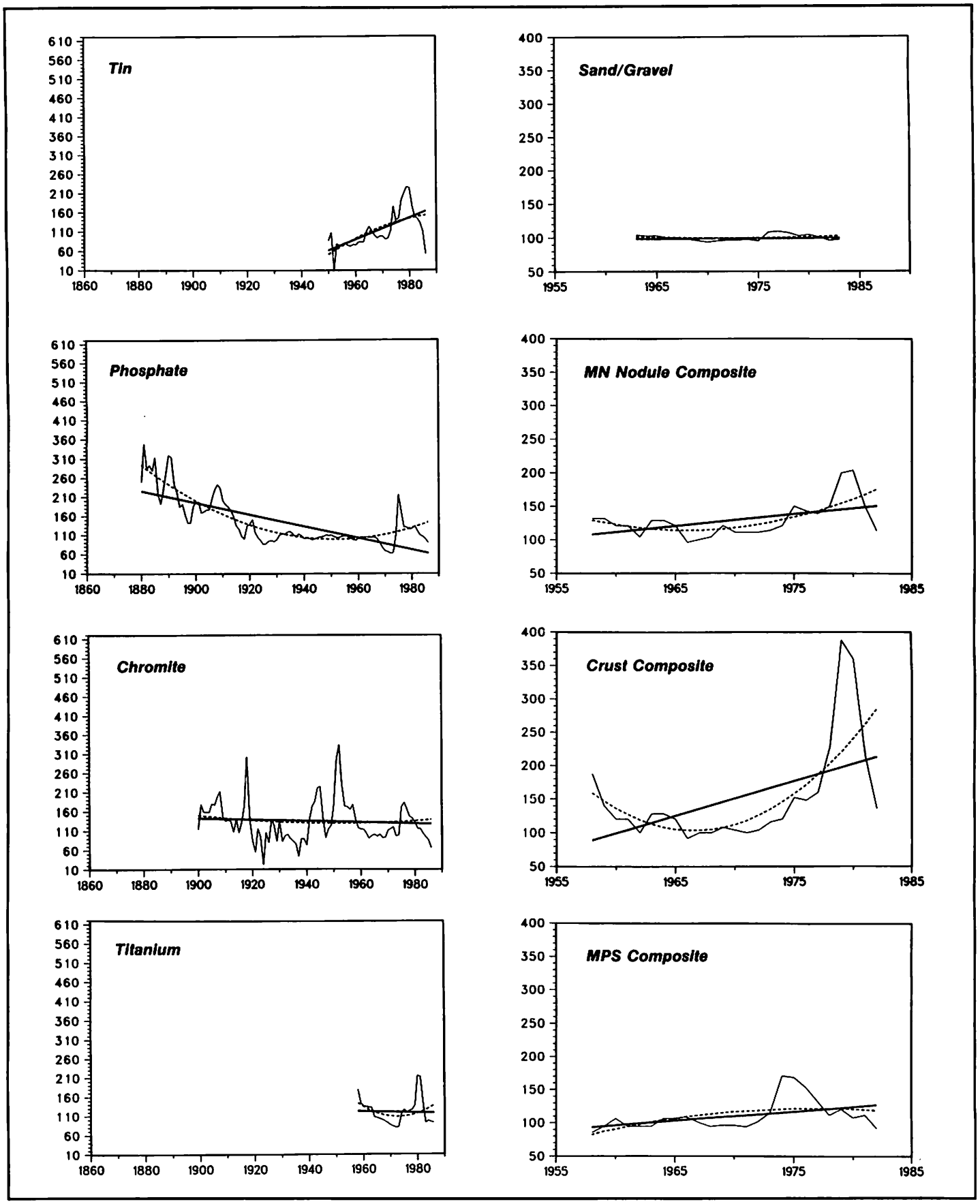


Figure 1. Behavior of real price indices (1967=100) for selected commodities with potential seabed sources, including grade-weighted composite prices of materials contained in typical polymetallic deposits (manganese nodules are: 1.28% nickel, 0.24% cobalt, 1.02% copper, and 25.4% manganese; crust composite is 0.47% nickel, 0.73% cobalt, and 23.06% manganese; MPS is 32.3% zinc and 0.81% copper) and showing linear and quadratic fits.

Program Management

M/O-1
1984-1987

David A. Ross, Sea Grant Coordinator
Arthur G. Gaines, Jr./Alan W. White, Marine Assistance Service
Prudence Stratton /Alexandra W. Petrovits, Staff Assistant

The management team of the Woods Hole Oceanographic Institution Sea Grant Program is composed of three individuals: David A. Ross, Sea Grant Coordinator; Prudence Stratton, Staff Assistant from June 1985, until March 1987. (As of March 1987, Alexandra Petrovits has been Sea Grant Communicator and Staff Assistant); and Arthur G. Gaines, Jr., head of the Sea Grant Marine Assistance Service since 1979. (In September 1986, Arthur Gaines left his position and was replaced by Alan W. White.)

The key objectives of the program management team are:
1. Quick response to immediate problems and better application of Sea Grant results.
2. Improve quality of on-going programs.
3. Initiation of important new projects.
4. Explore and develop new areas for future research.
5. Support special information dissemination activities, such as workshops, conferences, and special publications.

In the 1984-1986 grant period several important efforts have been developed by using New Initiative funds (described in the following section), and over 60 Sea Grant-sponsored publications were produced. Since 1985 Sea Grant at Woods Hole has supported research leading to 341 scientific publications; 103 technical reports (including several theses); and 6 books for a total of 450 publications.

Marine Assistance Service

M/O-2
1984-1987

Arthur G. Gaines, Jr./Alan W. White
Sea Grant Marine Science Advisor

The Marine Assistance Service has continued to reach more members of the non-scientific community interested in marine problems. This effort provides a number of services that do not change in large part from year to year. For example, we respond to verbal and written questions, provide bibliographic searches, and give talks at local clubs, associations and schools on marine-related topics; based on interactions with marine interest groups in the Commonwealth, we promote research within the Program to address important aspects of marine resources, coastal management and other marine-related topics affecting the public and private sector. The Marine Assistance Service organizes conferences and workshops on topical research issues and writes news releases. One important function of the Marine Assistance Service is to provide a link with the national Sea Grant network, making products of the national effort available to people in our region.

It is important to realize that beyond our Sea Grant activities at the Woods Hole Oceanographic Institution, the Institution has for many years sponsored ongoing education, information and public information programs (not to mention its internationally famous research program) that represent a major asset to the Commonwealth and the Nation (Table l). Because of our location on Cape Cod, these functions and services are a particularly valuable and unique asset for neighboring towns, counties and planning districts. It should also be realized that there are many other marine research and marine-related organizations in the Commonwealth, giving this state perhaps the greatest concentration of marine experts in the world.

One aspect of the Marine Assistance Service that does change from year to year falls in the category of Advisory Projects. This part of our program attempts to address needs of local groups through advisory services tailored to their specific requirements. Some examples of recent or ongoing activities, given below, illustrate this aspect of our thrust:

Lantern Net Shellfish Culture: A Pilot Scale Facility at Penikese Island School

The 1983-84 WHOI Sea Grant Report described early stages of this project, designed to test the suitability of "lantern net" technology as a means to enhance shellfish production in local waters. The project was also intended to provide an education activity and aquaculture work experience for youngsters at Penikese Island School. This school for troubled boys and girls operates a partly self-sustained island farm at the mouth of Buzzards Bay, a site in many ways ideally suited for aquaculture. Our objective was to establish the working facility which, once operational, would then be turned over to Penikese Island School.

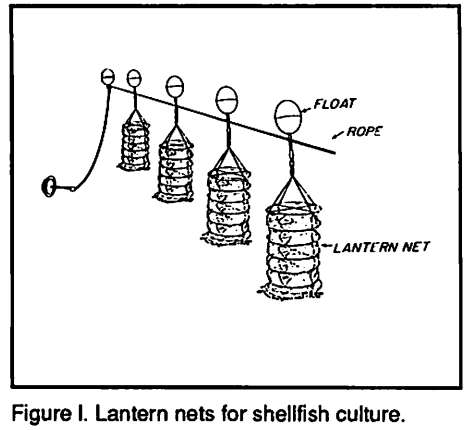


Figure I. Lantern nets for shellfish culture.

During the spring of 1985, assembly of the shellfish farm was begun. It consisted of four and five-tiered lantern nets (Figure 1), each suspended from a surface buoy and strung in four parallel rows on ropes anchored at each end. Although consideration was given to several shellfish species, the availability of seed oysters (*Crassostrea virginica*) made this species an easy one with which to begin (the seed was donated by Ocean Pond Corporation, Fishers Island, NY and the Cotuit Oyster Company, Cotuit, MA). The potential for growing bay scallops (*Argopecten irradians*) had been considered earlier, because the rapid growth of this animal could permit harvesting a crop after a single growing season, thus avoiding the problems of overwintering. However, seed of this species was not readily available.

Approximately 50, year-old oyster seed per tier, as singles and in clumps of up to four animals, were placed in the nets in June, 1985, for a total of more than 5,000 oysters. Data on the size and weight of the oysters were collected to provide a basis for future assessment of growth. Six weeks later we visited the facility to determine early mortality and initial growth rates. To our delight, the mortality rate was zero—not a single dead oyster. Average growth in length was about 9.3 mm, or 6.2 mm/month. While this is not considered an extremely fast rate, it is acceptable, and the low mortality suggests the site has promise. After a year we have heard from Penikese Island that the growout facility is operating satisfactorily. Expert assistance is provided by the shellfish warden in the neighboring island of Cuttyhunk.

MSX Disease in Oysters

One favorable aspect of the Penikese Island site is the absence of MSX disease there. This fatal affliction of oysters, caused by a protozoan, has recently appeared elsewhere in Massachusetts waters, possibly as a result of oyster seed imports from other states. Only recently the most promising shellfish aquaculture industry in Massachusetts, the oyster industry has suffered catastrophic losses in this area for the past two summers and is now threatened with bankruptcy.

In response to discussions with oyster growers in the spring of 1986, the Marine Assistance Service initiated a small project to better define the seasonal occurrence and pathology of MSX in local waters. Dr. Louis Leibovitz, Director of the Laboratory for Marine Animal Health at the Marine Biological Laboratory in Woods Hole, directed this project in cooperation with the Cotuit Oyster Company. The research involved monthly examination of oysters for symptoms of MSX disease, histological examination of the oyster tissues and correlation of pathology with environmental conditions.

In connection with this research, the Marine Assistance

Table 1
Information and Education Activities Conducted by the Woods Hole Oceanographic Institution

Public Information Office - Operates public information service; issues news releases on Instituion activities; publishes newsletters; operates a public exhibit center; prepares special-purpose displays; coordinates Institution participation in documentary film and video coverage.

Education Office - Administers a graduate education program, including a joint doctoral program with M.I.T., post-doctoral fellowship program, summer student fellowship, employment and volunteer programs; conducts special programs in secondary level education and training.

Oceanus - A marine science magazine written by experts for a lay audience. Published four times annually; circulation is about 13,000, internationally. Full-time editor and staff.

WHOI Library - Operates (in conjunction with the Marine Biological Laboratory) one of the premier marine science libraries in the world, open to the public; conducts computer-based literature searches on request; publishes international directories of marine science libraries and information centers; hosts international symposia on marine library science and information retrieval systems.

Ocean Industry Program - Operates an industrial liaison program, open by subscription. Sections on Geosciences, Ocean Dynamics & Engineering, and Policy & Environmental Studies.

NOAA Liaison Office - One of five NOAA offices nationally, providing scientists and the public with access to marine environmental data files for retrieval or storage of data and reports.

Lectures and Seminars - Lectures offered at the Woods Hole Oceanographic Institution are open to the public and advertised in a weekly calendar and in local newspapers. On a volunteer, special-request basis, members of the scientific and technical staff give seminars to many private groups.

Service held a workshop in Woods Hole in February, 1987, on diseases of shellfish. In addition to initial results of Dr. Leibovitz's research, experts from around the country addressed significant diseases of shellfish before an audience of growers and hatchery operators from southern Massachusetts and elsewhere in New England. An active exchange between growers and scientists helped define future research needs in this important area of shellfish husbandry and gave growers a better perspective in formulating a strategy for minimizing disease in their facilities.

Eelgrass: The Plant, the Community, and Their Possible Decline

Another area of concern for wild shellfish stocks is habitat quality. One of the principal concerns of environmental agencies, such as the Environmental Protection Agency and the National Marine Fisheries Service, is protection of critical marine and estuarine environments. One such environment, the eelgrass community, is known to be essential for early life stages of shellfish, such as the bay scallop, as well as for many commercial fish species which use the shelter of eelgrass beds and the food produced in this environment during juvenile life stages.

As a result of our concern for protection of eelgrass beds in Massachusetts, we convened a meeting in October, 1985, to discuss the status and importance of eelgrass beds and learn from experience of scientists in neighboring areas. Unfortunately, the news is not good. For example, during the late 1960's and 1970's scientists observed a sharp decline of submerged aquatic vegetation, including eelgrass, in Chesapeake Bay. Vast areas of eelgrass beds, formerly comprising habitat for blue crabs and other estuarine species, were laid bare. While initially the culprit was believed to be herbicides widely employed in the Chesapeake Bay watershed by farmers, current thinking is that increased turbidity of Bay water blocked sufficient sunlight to kill the bottom-dwelling grasses. The increased turbidity, in turn, has been related to nutrient enrichment that produced blooms of microscopic algae, as well as to land runoff containing suspended sediments.

To the north of our area, eelgrass appears to be dying from Cape Ann to at least Great Bay (New Hampshire). In this instance, however, the causative agent is believed to be a disease similar or identical to that responsible for the eelgrass epidemic of the 1930's which devastated grass beds on both sides of the North Atlantic. The disease characteristically first appears at the mouth of estuaries where salinity is high, and is manifested by the black spots it produces on leaves of the plant.

Thus both to our north and our south, eelgrass beds have shown significant decrease in recent years (some evidence suggests partial recovery in Chesapeake Bay); to date, however, there have been no published reports of overall eelgrass decline in our waters. A Sea Grant-sponsored study by Joseph Costa (of the Boston University Marine Program) indicates both areas of increase and areas of decline in Cape Cod and Buzzards Bay waters. Decline is generally associated with urban harbors and upper reaches of coastal ponds (a pattern similar to that in Chesapeake Bay). However, there is now mounting evidence of increased turbidity in Long Island Sound and Narragansett Bay that could have serious consequences for eelgrass in these waters. The causative agent for the turbidity is a microscopic alga, previously unknown to scientists in this area, which for the past two summers has caused extensive dense murky blooms, known as "brown tide."

Issues surrounding shellfish and their habitat, as illustrated above, are highly complex and involve numerous interacting elements and processes. It is clear that no single specialist will be able to resolve these problems and no simple management step alleviate them. These transdisciplinary issues are ones for which Sea Grant is ideally equipped, combining the talents of academic researchers of many backgrounds and specialities with the insights and coordination abilities of advisory personnel to serve the needs and concerns of resource managers and the coastal private sector.

Nutrient Loading in Coastal Ponds

Many of the environmental quality concerns expressed today, including the deterioration of eelgrass beds described above, can ultimately be related at least in part to increased nutrient input to our coastal waters. In a conference held at Woods Hole last year, scientists from around the nation agreed that the principal widespread pollution problem in our coastal waters is eutrophication resulting from nutrient inputs, even though at a localized scale other pollutants present severe problems.

For the past few years we have been helping local towns in their attempt to sustain multiple uses of the coastal ponds and estuaries that dot the coast of Massachusetts. Through the complex geometry they impart to the coastline, these water bodies increase by many times Massachusetts' nominal 1,900 mile coast—at the scale of residential lots, public access points and coastal wetland frontage. Coastal ponds are sites of intense human activity for residential use, active and passive recreation, and recreational and commercial shellfishing, to name but a few. They are also intensely used by wildlife, including larval and juvenile stages of commercially important fish species.

In many instances, coastal ponds represent the primary discharge site of land runoff and groundwater as these sources of freshwater (and contaminants contained therein) make their way to the sea. Thus it is in coastal ponds that we expect the first symptoms of eutrophication and it

is here that studies of the impact of pollutants are often most tractable. Surprisingly, there is little information available to document perceived changes in water quality in Massachusetts' coastal ponds, and even less regarding interactions or interrelationships such as that between land use and coastal water quality or, more specifically, regarding the dose/response relationship between nutrient (e.g., nitrogen) loading and estuarine ecosystem response. Thus, planning or appeals boards faced with assessing the potential impact of proposed coastal development have little scientific basis for their response.

To help provide baseline data to evaluate perceived changes in coastal ponds and contribute to the process of defining the relationship between land use and estuarine water quality, we have initiated a Coastal Pond Project on Cape Cod and the Islands. Past Sea Grant reports have described our project in Town Cove, Orleans, a coastal pond which was believed threatened by sewage-derived nutrients from Orleans town center. Although the principal objectives of our project there were short-term ones, the appreciable quantities of data collected provide a reference and baseline for the future in assessing changes in water quality and biological activity.

More recently, the town planner in Falmouth requested assistance in preparing a bylaw to require builders to assess the impact of nutrient loading of neighboring ponds and estuaries, associated with the proposed construction. Since the dose/response relationship for nutrient loading of natural water bodies, especially estuaries, is not in our opinion firmly established, we feel this bylaw is at the moment premature, however well intended. Regardless, to contribute to progress in this area and provide baseline data, we have initiated a series of measurements in a Falmouth coastal pond—Green Pond.

The third, coastal pond included in our project is Lagoon Pond, on Martha's Vineyard. In this instance the regional planning agency (Martha's Vineyard Commission) requested help in addressing perceived water quality changes, not specifically associated with any particular activity. As elsewhere, water quality on Martha's Vineyard can be an emotional issue, but in the case of Lagoon Pond the presence of two hatcheries on its shore, a lobster hatchery and a shellfish hatchery, gives added reason for concern over water quality.

We hope that by obtaining data on dissolved nutrients, algal productivity, turbidity, flushing and other water quality-related variables in these three ponds and characterizing land use in the adjacent areas, we can contribute to more experimental studies in establishing a practical relationship between human shoreline activites and impacts in coastal waters. A report on early results on this work (Gaines, 1986) is available through this office.

Program Development

M/O-5
1984-1987

David A. Ross
Sea Grant Coordinator

The Sea Grant Program at Woods Hole receives some modest funds for new initiatives in various areas. These new initiatives funds are an especially valuable source of support as they provide us with the opportunity to expand and develop, as well as make rapid responses to immediate and important scientific or advisory opportunities.

During the 1984-1986 period, the following projects were initiated:

***Administrative Support for the 3rd International Conference on Toxic Dinoflagellate Blooms**

*** Exploratory Workshop on Fisheries Sociology**

*** Symposium on Photoperiodism in the Marine Environment**

*** An *In Situ* Gas Extraction System Suitable for Petroleum Exploration**

*** Institutional Response to Sea Level Rise**

*** Mapping Historical Changes of Eelgrass Distribution in Response to Human and Natural Disturbances**

*** Thematic Mapper Study of the Malawi Region, East African Rift**

*** Radiocarbon Dating by Tandem Accelerator Mass Spectrometer**

*** An Economics Primer for the Analysis of Coastal Zone Development Issues on Cape Cod and the Islands**

*** Standard for Bioassays: Marine Copepods that Produce Diapause Eggs**

*** Ciguatera Dinoflagellates: Population Dynamics and Life Cycles**

*** Immunological Techniques for the Identification of Marine Bivalve Larvae**

*** Environmental Mutagens and Tumorigenesis in Massachusetts Fish**

*** The Origin of Tumors in Boston Harbor Winter Flounder**

*** Buzzards Bay Reference Collection: A Bibliography of Scientific Publications for Buzzards Bay, Massachusetts**

*** Shaded Relief Maps of the Seafloor**

*** Improvement of WHOI SEM Capabilities**

***Workshop on Beach Nourishment: Its Future for the Massachusetts Coast**

*** Eelgrass: The Plant, the Community, and Their Possible Decline**

*** Inland Wetlands Workshop**

*** Benthic Biological Effects on the Transport of PCB-Laden Particulates in New Bedford Harbor and Buzzards Bay**

*** Seagrass Herbivory by Parrotfish and the Production of Dimethylsulfide**

*** Acoustic Monitoring of Hydrothermal Mineral Deposits**

*** Groundwork for a Benefit-Cost Analysis of Protecting Potable Groundwater in the Coastal Zone**

*** Symposium on Hydrodynamics and Sediment Dynamics of Tidal Inlets**

*** A Pilot Study of Oyster Mortalities During an Annual Growing Cycle at the Cotuit Oyster Company in Southeastern, Massachusetts**

A brief statement on each of the above new initative projects follows.

Administrative Support for the 3rd International Conference On Toxic Dinoflagellate Blooms

R/B-65, 1985
Donald M. Anderson
Biology Department

This conference was held in June, 1985, in St. Andrews, New Brunswick, Canada. Judging by the comments from the 175 participants and the written evaluations submitted after the meeting, it is clear that registrants were very pleased with the organization and content of the meeting. This is especially gratifying because we deviated from the typical conference format by emphasizing poster presentations. This meeting had 4 invited speakers, 20 contributed papers (oral), and nearly 100 posters. The information exchange on techniques and concepts will do much to shape the progress and direction of numerous research programs, including those sponsored by Sea Grant here in the U.S. The proceedings, published at the end 1985, make the current status of many research programs available to scientists throughout the world. Twenty-two countries were represented at the conference, but the proceedings extend this impact to many others as well.

Exploratory Workshop on Fisheries Sociology

R/S-12, 1985
Connor Bailey
Marine Policy Center

This workshop, held on April 26 and 27, 1985 at the Woods Hole Oceanographic Institution, was a tremendous success. The 24 participants represented the bulk of fisheries sociologists in North America. The level of active participation was exceptional. The discussions were lively and the papers of sufficient quality to justify inclusion in the WHOI Technical Report series. These papers will be supplemented by material based on the discussions which followed. The report will stand as a useful document representing the state-of-the-art in fisheries sociology.

Symposium on Photoperiodism in the Marine Environment

R/B-62, 1984
Nancy H. Marcus
Biology Department

The symposium was held on Thursday, December 27, 1984, in Denver, Colorado at the annual meeting of the American Society of Zoologists. The meeting was held jointly with several other societies. The symposium was co-sponsored by the Western Society of Naturalists, and the Divisions of Invertebrate Zoology, Comparative Physiology and Biochemistry of the ASZ. It was well attended and a diversity of topics relating to photoperiodism were discussed. The papers and discussion stressed the widespread occurrence of photoperiodic responses in marine organisms and the need for considering this phenomenon in interpreting field and laboratory data.

An *In Situ* Gas Extraction System Suitable for Petroleum Exploration

R/E-14, 1984-1985
Jean K. Whelan
Chemistry Department

The objective of this work was to determine the feasibility of building an *in-situ* hydrocarbon gas extraction system which could be used to monitor continuously oil and gas seeps in the deep ocean. A fully developed system would allow better evaluation of suspected but unproven offshore petroleum source areas. Potential users would be oil companies and government. In addition, the system could also provide valuable data on amounts of natural (including biogenic) gas present *in situ* in the ocean. There is considerable evidence the methane available to the upper atmosphere may have important effects on global climate and the ozone layer. There are also good reasons for believing that most areas of the ocean contribute very little methane to the atmosphere. However, there are currently no reliable *in situ* sediment gas data available to rule out a significant methane source

from localized high-productivity areas (such as the Peru upwelling or polar regions).

Institutional Response to Sea Level Rise

R/S-13, 1985

Maynard E. Silva
Marine Policy Center

All three primary objectives of the study—(1) literature review on social implications of sea level rise; (2) review of "policy metaphor" literature; and (3) evaluation of coastal land loss in Louisiana as a metaphor for sea level rise—were successfully completed.

One aspect of the research which was not fully anticipated was the role of deltas in counteracting the effects of sea level rise. Work on this has led to participation in a research project funded by EPA looking at the socio-economic aspects of sea level rise/river delta interaction for five river systems around the world: the Nile, the Magdalena, the Yangtze, the Indus and the Ganges-Brahmaputra.

The major finding of this research was support for the contention that present "metaphors" for sea level rise can be identified and studied. Further, studies of these metaphors can provide insight into the decision-making processes that will be employed and the problems encountered in responding to sea level rise in the future. Also, this research has demonstrated that the "metaphor" approach to policy analysis is useful in studying phenomena which are known today but which will not impact society until some time in the future.

Mapping Historical Changes of Eelgrass Distribution in Response to Human and Natural Disturbances

R/B-68, 1985

Joseph E. Costa
Boston University Marine Program

The original objective of this work was to map the current and past distribution of eelgrass in selected embayments around southeastern Massachusetts, using aerial photographs coupled with field verification, published accounts and oral reports. The sites were chosen because they had different histories of distribution.

The current distribution of eelgrass beds in this region was mapped. Eelgrass is very abundant. In Buzzards Bay alone there are over 25 km^2 of eelgrass beds, roughly twice the area of saltmarshes in this region. These eelgrass beds contribute at least 10^{10} g carbon fixed per year to local primary productivity.

The analysis of historical changes of eelgrass distribution in 12 embayments is still in progress, but certain trends are apparent. It has been well documented that in 1932 and 1933, 90% of the eelgrass in the Atlantic was destroyed by a wasting disease. Costa has found that eelgrass beds in southeastern Massachusetts took decades to recover from this disturbance. For most sites in this region, eelgrass made its greatest advance in the 1950's to 1970's and is still showing some expansion.

Maps resulting from this study will be of use to both managers and biologists concerned with the coastal environment. Costa's preliminary work together with other research in this field suggests that changes in eelgrass distribution may be a useful indicator of human disturbance, and several areas of future research appear to be worth pursuing.

Thematic Mapper Study of the Malawi Region, East African Rift

R/G-11, 1985

Jeffrey A. Karson
Geology and Geophysics Department

Three hard copies of Landsat TM images and one image on magnetic tape were obtained from EROS. One objective was to locate hydrothermal areas using these images. Due to their small size relative to pixel size (~30m) and erosion of surrounding hydrothermal deposits, we could not locate these on our images. These problems were not obvious until a trip to the region was made. Lineament analysis of the hard-copy images has been done by Ms. C. J. Ebinger of the WHOI-MIT Joint Program in order to help constrain the regional tectonic history relevant to petroleum exploration. These data will be incorporated in papers in preparation by Ms. Ebinger.

An important new research direction was developed during field work in southern Tanzania. Several large, economically important carbonatite bodies were visited and sampled. Distinctive spectra of the rocks there should allow us to find and map the distribution of such bodies in Tanzania and elsewhere. These are the subject of active prospecting by the Tanzanian Geological Survey as they are important sources of phosphates. Spectral studies of carbonatites and related rocks are underway and should suggest some new processing methods.

Radiocarbon Dating by Tandem Accelerator Mass Spectrometer

R/G-10, 1985

Glenn A. Jones
Geology and Geophysics Department

The major short-term goal of this proposal was to evaluate the potential of accelerator mass spectrometry for radiocarbon dating deep-sea sediments. This was accomplished by directly comparing this new method with the well-established beta-decay counting method of radiocarbon dating. The long-term goal is to be able to use this new dating method to obtain more accurate age-dates for sediments from continental margin environments. The continental margins are important for mineral and food resources, as well as important dumping grounds for wastes derived from heavily populated coastal cities. Many important questions about the continental margin environment need to be answered, and many of these require a knowledge of the rate of sediment accumulation.

The great advantage of the accelerator mass spectrometer method is that samples can be dated that are 1-2000 times smaller than can be dated by conventional methods. For continental margin studies this means that specific fractions or non-reworked components can be dated, rather than the bulk sediment. Before attempting to use this new methodology for continental margin sediment studies, we compared the precision and accuracy of these two methods of radiocarbon dating in deep-sea sediment core (V30-41K). The most significant finding is that for sediments younger than approximately 17,000, years there is no statistical difference in the ages determined by either method, whereas for sediments older than approximately 17,000, years there is a significant divergence in the ages.

An Economics Primer for the Analysis of Coastal Zone Development Issues on Cape Cod and the Islands

R/S-14, 1985

Steven F. Edwards
Marine Policy Center

As conflicts over use of the coastal zone increase, and as the adverse social and environmental impacts of man's action accumulate, better management will become critical if coastal resources are to be allocated efficiently among market and nonmarket interests. Although economics pervades all issues related to resource allocation, including those involving pollution, preservation, and outdoor recreation, most coastal managers lack even a basic understanding of economic concepts and applications. Indeed, economics often is construed narrowly in terms of costs and markets, and as a threat to broader interests in overall well-being. An Economics Primer for Coastal Zone Management confronts these misconceptions and begins to lead planners, policymakers, scientists, students, and concerned citizens to a deeper understanding of economics and of its wide, but unappreciated, applicability to resource management.

The primer consists of two parts. In Part One, the reader is introduced to basic concepts and methods from microeconomics, welfare economics, public finance, and environmental and resource economics. As the foundation for monetary valuations become apparent, one understands why neither markets nor prices are required for economic analysis. Thus, tradeoffs among market and nonmarket uses of coastal resources can be assessed in commensurable units.

Part Two reinforces the teachings in Part One by critiquing several familiar "economic" arguments about coastal resource use and by reporting on two case studies. The case studies demonstrate the application of economics to outdoor recreation.

Standard for Bioassays: Marine Copepods that Produce Diapause Eggs

R/B-69, 1985

Nancy H. Marcus
Biology Department

Results of this study indicate that the sensitivity of *Labidocera aestiva* nauplii derived from diapause eggs is comparable to that of *Acartia tonsa* and *Eurytemora affinis* (data supplied by Dr. Stephen Schimmel). The results were consistent among tests that used eggs produced by different generations of laboratory-reared animals. These findings suggest that *L. aestiva* represents an excellent test organism for toxicity studies. Moreover, since the survival of control nauplii in short-term tests without food can be quite good, it seems possible that a test could be developed that requires little more than a vial of diapause eggs, seawater, and test material.

We believe that further testing of *L. aestiva* is warranted and suggest the following modifications to improve the protocol used in the present study. Due to the small size of the nauplii, much smaller dishes should be used. This would also allow for greater replication. In addition, to reduce mortality arising from nauplii getting caught in the surface film, dishes could be covered with dark lids or illuminated from below. We routinely use cetyl alcohol to alleviate this problem and would suggest its use if regulations allow it.

Ciguatera Dinoflagellates: Population Dynamics and Life Cycles

R/B-71, 1985

Donald M. Anderson
Biology Department

The general objective of this project was to establish cultures and facilities needed for a planned research program on the physiological ecology of the ciguatera dinoflagellates. The project also included an evaluation of the coral reef exhibit at the Pittsburgh Aquazoo as an experimental facility free from much of the variability associated with the natural reef environment.

All of the objectives were satisfied. Visits to the Aquazoo verified that numerous experiments are possible using the ciguatera community resident in the coral reef exhibit that would not be possible in the field. The benthic dinoflagellate community in the exhibit is diverse and flourishing, and representative isolates were established in culture for future work.

Immunological Techniques for the Identification of Marine Bivalve Larvae

R/B-70, 1985

Scott M. Gallager and Judith McDowell Capuzzo
Biology Department

Although adult bivalve molluscs constitute both an economically and ecologically important resource of coastal benthic communities, detailed studies of the distribution, transport, behavior, mortality and recruitment of larval stages have been hampered by the lack of

taxonomic tools for their identification in plankton samples. Classical approaches to larval identification on the basis of shell morphology have yielded a number of excellent taxonomic keys. However, identification of young veligers (prodisoconch I shell) and embryos prior to shell secretion remains difficult, if not impossible, for most bivalve species. Ironically, the dynamics of these early stages of larvae are crucial to sustaining adult bivalve populations, yet they are the least well understood.

As part of a new initiative project, we are evaluating the possibility of using immunological techniques to produce a species-specific fluorescent antibody tag for direct application to whole eggs and larvae of the bay scallop *Argopecten irradians* and the quahog *Mercenaria mercenaria* from field-collected plankton samples. Using methods similar to those described by others, antibodies produced in rabbits against antigens derived from adult bivalve adductor muscle and gonad tissues are being used to determine the degree of cross-reactiveness of antigenic proteins from sympatric bivalve species. To date, antisera to adductor muscle and gonad tissues of both *M. mercenaria* and *A. irradians* have been produced and analyzed for the presence of cross-reacting proteins to antigens from 11 sympatric species.

Much work is still to be done, but the results to date are encouraging. We are using the immunological tag as a supplement to more classical methods of larval identification in our ongoing study of larval recruitment in local estuaries. Coupled with our recently developed optical technique for assessing lipid content of single bivalve larvae, it should be possible in the near future to obtain concurrent physiological, biochemical and taxonomic data on individual organisms from field-collected samples.

Environmental Mutagens and Tumorigenesis in Massachusetts Fish

R/P-19, 1985

John J. Stegeman
Biology Department

We have studied the activation of a variety of carcinogens known to be present in sediments in Boston Harbor, particularly at Deer Island, or which could be present in other urban environments. The most interest at this point is on aromatic hydrocarbons and we have confirmed an activation of benzo[a]pyrene by winter flounder, in this case using fish taken from Boston Harbor at Deer Island. Several other hydrocarbons, particularly two of three isomeric benzofluoranthenes are activated by winter founder. However, one very common compound present in the sediments there (i.e., fluoranthene) is not activated by the flounder microsomal preparations, nor by scup liver. This is an interesting finding, given the fact that fluoranthene is a dominant component of soot and is readily activated to a mutagen and is carcinogenic in mammals.

The Origin of Tumors in Boston Harbor Winter Flounder

R/P-28, 1986

John J. Stegeman
Biology Department

Subsequent to initial difficulties in isolating DNA from winter flounder, we have been working on methods for obtaining DNA from these fish. The methods have involved attempts to overcome a severe problem with recalcitrant endogenous nucleases, and in eliminating the "contamination" by some co-purifying material. This effort has not been trivial. Results showed that the nuclease problem appeared in some (winter flounder, scup, *Fundulus*) but not all fish analyzed. Rainbow trout did not show such nuclease activity. The "contaminant" was identified as glycogen, and it occurred in all species. Both problems have been overcome, and we are able to obtain high molecular weight DNA preparations with a minimal amount of interfering materials. Such DNA preparations are being used for study of specific flounder genes involved in carcinogenesis.

Buzzards Bay Reference Collection: A Bibliography of Scientific Publications for Buzzards Bay, Massachusetts

R/B-73, 1985

Bruce W. Tripp
Coastal Research Center

Buzzards Bay is an important segment of the Massachusetts coast that is heavily used for industrial, commercial and recreational activities. The full range of multiple use demands found elsewhere in the urbanized northeastern U.S. are found in and around Buzzards Bay, yet few systematic scientific studies have been done in this area. This bibliography represents a first step in an assessment of the available published information.

The search for published information found herein included library collections, computer compilations, review articles, bibliographies and personal files. This search has been an identification process for the most part and many of the entries in this bibliography are derived from secondary sources. The main body of the bibliography includes a list of published studies addressing biology, chemistry, geology and physical oceanography, and is organized by senior author, listed alphabetically. Several appendices are included to make the information more useful.The bibliography is stored on a floppy disc and can be updated easily if a second edition is published.

Shaded Relief Map of the Seafloor

R/G-12, 1985

James R. Heirtzler
Geology and Geophysics Department

Printing of the three-page atlas entitled "Relief Of the Surface of the Earth" was completed in December, 1985. Initial copies were sent to the principals of the project and to of-

ficials in the U. S. Navy and NOAA. Two thousand copies were shipped to the National Geophysical Data Center in Boulder where they are being assembled and priced for distribution. A small version of one of the color sheets will be displayed on the front cover of EOS, and their general availability will be announced there.

Improvement of WHOI SEM Capabilities

R/B-72, 1985

Kozo Takahashi
Geology and Geophysics Department

We have accomplished the strengthening of the scanning electron microscope (SEM) research capability at WHOI with new iniative funds. We were able to purchase a sputter coater system which is necessary for SEM sample preparation. This brings our sample preparation levels to state-of-the-art capability.

Current and past SEM users including Sea Grant workers have benefited from the improved capability. We anticipate an increase in the frequency of use and the number of users due to its enhanced capability and simple operational procedures.

Workshop on Beach Nourishment: Its Future for the Massachusetts Coast

R/B-74, 1985

David G. Aubrey
Geology and Geophysics Department

On October 10, 1985, a workshop on "Beach Nourishment: Its Future for the Massachusetts Coast" was held in Woods Hole, hosted by the Woods Hole Oceanographic Institution and the Massachusetts Coastal Zone Management Office. The one-day workshop, an activitiy of Coast Week, was designed to promote open discussion of various alternatives for beach nourishment along the coast, including potential uses and problems arising from such a management tool.

The meeting proved to be a useful forum, bringing together federal, state, and local representatives, as well as the research community and the users. As is expected from such a complex issue as beach nourishment and its myriad of engineering and environmental facts, no final solutions were derived, but some framework was established for future interaction and planning.

In summary, the workshop pointed out that Massachusetts, with its abundant offshore sand supplies and large coastal stretches exposed to benign wave conditions, is a likely candidate for large-scale beach nourishment programs as a primary tool for erosion control and upland flooding. By increasing the extent of the beach and dune system, storm damage protection is effected while enhancing the recreational and wildlife use of these coastal resources. For those portions of Massachusetts where wave exposure is limited and sand supply is abundant (primarily the southern shoreline of Massachusetts), beach nourishment promises to be a cost-effective management tool to be encouraged in the future.

Eelgrass: The Plant, the Community, and Their Possible Decline

A/S-5, 1985

Arthur G. Gaines, Jr.
Marine Science Advisor

A two day meeting was held (October 24-25, 1985) to discuss the status of and issues surrounding submerged aquatic vegetation, with emphasis on eelgrass (*Zostera marina*). Experts from federal, state, local and private institutions from east coast states met with about 40 interested biologists and local resource managers for formal talks, informal discussions and a panel session. Among the conclusions of the meeting were:

- Eelgrass and the eelgrass community of associated plants and animals constitutes an important estuarine and nearshore habitat. The community has high primary and secondary productivity and is critical for certain life history stages of commercially important animals, such as the bay scallop.
- Up to the occurrences of the recent "brown tides" in Long Island Sound, eelgrass is not believed to be declining in the area between New York and Cape Cod. In the Buzzards Bay area, eelgrass has shown both increases and decreases, depending upon the specific site. Urban areas and heads of coastal ponds are examples of sites where decrease has predominated.
- North of Cape Ann (Massachusetts), at least as far north as Great Bay (New Hampshire), eelgrass has been declining in recent years. In these areas there is evidence that "wasting disease," similar to that which caused the epidemic of the mid-1930's, is responsible. In this instance decline begins at high salinity regions near the mouth of estuaries and proceeds up estuary.
- While the concensus among scientists was that the eelgrass beds can only improve the estuarine environment as a productive habitat, certain resource managers expressed the opinion that dense eelgrass beds are harmful to scallop growth and should be thinned. The problem of obstruction to navigation posed by eelgrass was also cited.
- Proceedings of the meeting, consisting of abstracts of the 10 papers given and a bibliography of over 100 principal papers on eelgrass and the eelgrass community is in preparation. Participants at the meetings and representatives of a west coast group interested in eelgrass have expressed the desire to hold another national meeting on this topic.

Inland Wetlands Workshop

R/B-84, 1985

Dean E. Cycon
Marine Policy Center

A workshop was held on December 14, 1985, sponsored by the Marine Policy Center, WHOI Sea Grant, and the Coastal Zone Management Advisory Committee of the Cape Cod Planning and Economic Development Commission. The workshop brought together persons and organizations that have mana-

gerial or technical expertise or are otherwise concerned with the fate of the inland wetlands of Cape Cod.

The inland wetlands on Cape Cod are rapidly being filled, polluted or otherwise impacted. Yet there are very different opinions on the significance of these wetlands to the Cape's freshwater supply, and other functions that they may or may not serve. The regulatory system treats wetlands statewide in one regulatory framework; there is some question whether the inland wetlands on the Cape should be treated differently from wetlands in other areas, given what may be their special relationship to Cape freshwater flora and fauna.

Benthic Biological Effects on the Transport of PCB-Laden Particulates in New Bedford Harbor and Buzzards Bay

R/P-26, 1986

Cheryl Ann Butman
Geology and Geophysics Department

The purpose of this study was to explore techniques for determining hydrodynamic characteristics of the dominant biological bedform (at a study site in outer New Bedford Harbor) - fecal pellets of the polychaete worm, *Mediomastus ambiseta*. Estimates of pellet size, fall velocity and density in relation to hydrodynamic characteristics of non-bioturbated sediments at the study site allow comparisons of estimated sediment-transport rates, using a theoretical model for the bioturbated and non-bioturbated cases.

This exploratory study of hydrodynamic characteristics of the fecal pellets of *Mediomastus ambiseta* has provided some intriguing results for further study. It is particularly important to determine the actual density of the pellets, since this is one of the critical variables for estimating μ^*crit from empirical curves such as Shields. It is also necessary that μ^*crit of the pellets be measured directly, using a laboratory flume. If the pellets do, in fact, move before the surrounding sediments, then sediment-transport rates estimated for the non-bioturbated bottom (i.e., the free sediments) may be underestimates of the actual transport at the site. However, it is unknown for what period of time the pellets remain intact during the transport process.

Seagrass Herbivory by Parrotfish and the Production of Dimethylsulfide

R/B-86, 1986

John W. H. Dacey and Phillip S. Lobel
Biology Department

This research had three primary objectives:

1. Establish the presence of dimethylsulphoniopropionate (DMSP) in marine plants which had not yet been investigated in this regard.
2. Examine the decomposition of DMSP to dimethylsulfide (DMS) and acrylic acid in herbivorous fish.
3. Evalute the impact of DMSP on the marine food web and its potential consequences to fisheries.

The project centered on a field trip to the West Indies Laboratory, St. Croix, U.S.V.I., between March 27 and April 10, 1986. This trip represented the first field use of a prototype gas chromatography (GC) system employing a small column oven and HNU photoionization detector. This GC system was used for analysis of DMS and DMSP on specimens of plants and fish immediately after collection. We performed more than 800 GC analyses at St. Croix and several dozen more on return to Woods Hole.

Acoustic Monitoring of Hydrothermal Mineral Deposits

R/G-14, 1986

G. Michael Purdy and Sarah A. Little
Geology and Geophysics Department

The purpose of this project is to design a technique for monitoring the long-term behavior of sulfide forming hydrothermal vents by recording and analyzing the sound produced by the vent's hot, turbulent jets of water.

In the spring of 1986 we used New Initiative funds to emplace a hydrophone, pressure transducer and recording package (borrowed from S. Webb and others) on the seafloor near a hydrothermally active area at 26°N on the Mid-Atlantic Ridge. The operation was conducted on a non-interference basis by the scientists aboard the *Atlantis* II/*Alvin*.

Although this sort of procedure costs very little, the risks involved center around the lack of control one has in unforeseen circumstances at sea. Unfortunately, the instrument was not recovered because 1) the acoustic release malfunctioned, 2) the recovery *Alvin* dive was aborted (battery leakage), and 3) a second dive to the site was cancelled at the discretion of the chief scientist. The possibility for instrument recovery, although remote, still exists.

The remainder of the New Initiative funds has been used to procure parts and assemble another instrument for recording vent sounds. The instrument has been designed for flexibility because there is at present a lack of constraints on the power spectral levels for hydrothermally generated sound.

A laboratory experiment proceeds in parallel with the field work. The initial set up of a 2m x 2m x 1.5m tank, a variable temperature jet, and digital recording apparatus using a personal computer was completed this summer at the MIT Parson Laboratory in the Department of Civil Engineering. Experiments are in progress to determine the variation of sound with such jet parameters as velocity, temperature, and orifice diameters.

Groundwork for a Benefit-Cost Analysis of Protecting Potable Groundwater in the Coastal Zone

R/M-11, 1986

Steven F. Edwards
Marine Policy Center

The support was used to write, design, and mail a questionnaire on water quality benefits. The study began with a pilot study that tested

the questionnaire and specific features of the "contingent market" which were described to elicit valuations of potable groundwater. Based on the results of this query, the final questionnaire was written and mailed to nearly 1,000 residents and property owners in Falmouth. After three follow-ups, 80% of the respondents returned their questionnaires.

These steps conclude the groundwork described for New Initiative support. With additional funding from the U.S. Geological Survey, the data are being analyzed. All accomplishments and benefits pend completion of the larger study.

Symposium on Hydrodynamics and Sediment Dynamics of Tidal Inlets

R/M-13, 1986

David G. Aubrey
Geology and Geophysics Department

In December, 1986, a symposium on Hydrodynamics and Sediment Dynamics of Tidal Inlets was hosted at the Woods Hole Oceanographic Institution by the Woods Hole Sea Grant Program and the U.S. Army Waterways Experiment Station's Coastal Engineering Research Center. The intent of the workshop was to bring together workers from diverse disciplines representing state-of-the-art research on topics related to tidal inlets. Over the past decade there has been no lead agency funding tidal inlet research; this has led to a dearth of new work in this important field and a lack of research focus.

The symposium consisted of a series of invited talks in each of three fields: hydrodynamics of tidal inlets; sediment dynamics of tidal inlets; and historical and geological inlet change. In addition, a keynote speaker, Dr. Robert Dean of the Universityof Florida, participated. Following the invited talks were talks submitted by symposium participants. A discussion session followed during which plans for future meetings and possible large-scale inlet experiments were discussed.

The workshop product will be a symposium volume, which is projected to be printed by the end of 1987. Papers from the workshop have been submitted and are currently under review. It is intended that this workshop volume will represent a status report of ongoing inlet research and help point the way for future inlet research. The symposium volume, to be published by Springer-Verlag, will represent the first major publication on tidal inlets over the past decade.

A Pilot Study of Oyster Mortalities During an Annual Growing Cycle at the Cotuit Oyster Company in Southeastern Massachusetts

R/A-22, 1986

Louis Leibovitz
Marine Biological Laboratory

A study was undertaken to determine the patterns and causes of oyster mortality on a commercial oyster farm known to be infected with MSX during a normal growing season. Sibling MSX-free seed oysters, approximately two years of age, were obtained from a hatchery at Fishers Island, New York, and planted monthly from April to November in trays containing 100 seed oysters each in the oyster growing beds of the Cotuit Oyster Company. The trays were raised and sampled each month and examined for the number of dead and live oysters present. The valves were examined for signs of predation. During each month of tray examination, 25 oysters were removed from the group planted on the bottom in April. Each of these planted oysters was examined at the laboratory and sections of tissues were taken for histological examination.

Preliminary results suggest that the most important causes of mortality to date were MSX disease and predation. The earliest MSX mortality in oysters planted during 1986 were found in July. A minimal period of two-months in the infected bed was required, with the exception of the April planting for which three months were required, before detectable mortality or signs of the disease in planted oysters could be found in either tray or bottom samples examined, regardless of seasonal changes in water temperature or salinity. The highest monthly percentage mortalities were recorded in July through September. The causes for the uniform peak mortality period and the uniform latent period, despite the variable planting time, needs further study. The presence of the infection in resident oysters throughout the entire growing season suggests that once the oyster becomes infected, it remains so. The study offers an opportunity to examine the induction period of the disease, including the possible role of intermediate hosts during a defined period of time. The study also offers an opportunity to examine the influence of management of shellfish beds to reduce or avoid the disease. For example, tray cultures experienced less mortality than bottom cultures.

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R/P-20

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R/P-21

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Coastal Resource Management

R/B-46

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E/L-1

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M/O-2

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Program Development

R/B-65

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R/B-70

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R/B-73

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R/B-74

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Project Status Summary 1984 - 1986

	FY 84	FY 85	FY 86
Fisheries Biology and Management			
Biological Regulation of Toxic Dinoflagellate Blooms (R/B-56, Anderson)	NS	CG	CP
The Role of Photosynthetic Capacity in the Initiation, Duration, and Decline of Toxic Dinoflagellate Blooms (R/B-59, Glibert)	-	NS	CP
Lipids and Metamorphosis in Marine Bivalve Larvae (R/A-20, Mann and Gallager)	CG	CP	-
Decision Analysis Applied to Fishery Management Plan Development (R/S-6, Bowen, Healey, Peterson, and Silva)	CG	CG	CP
Application of Growth Indices to Bay Scallop Management in Southeastern Massachusetts (R/B-57, Hampson and McDowell Capuzzo)	NS	CP	-
Yield Optimization of Biopolymers in Intensive Cultures of Marine Microalga (R/B-61, Goldman and Dennett)	-	NS	CP
Human Impact on the Marine Environment			
Biogeochemistry of PCBs in Buzzards Bay, Massachusetts (R/P-17, Farrington and Brownawell)	NS	CG	CP
PCBs in Buzzards Bay, Massachusetts: Effects on Energetics and Reproductive Cycles of Bivalve Molluscs (R/P-20, McDowell Capuzzo)	NS	CG	CP
A Possible Biochemical Effect of PCBs in Buzzards Bay Fish (R/P-18, Stegeman)	NS	CG	CP
The Effects of Size Class and Bioturbation on Fine-Grained Transport in Coastal Systems: Specific Application to Biogeochemistry of PCB Transport in New Bedford Harbor (R/P-21, Grant and Butman)	NS	CP	-
Coastal Resource Management			
Natural Tidal Inlet Bypassing (R/B-46, Aubrey)	CG	CP	-
Cape Cod Bay Sediment Transport (R/M-7, Aubrey)	NS	CG	CP

NS-New Start CG-Continuing Project CP-Completed Project

Marine Resource Development

	FY 84	FY 85	FY 86
International Marine Science Cooperation Program (E/L-1, Ross)	CG	CG	CG
Economic and Legal/Political Aspects of Deep-Sea Polymetallic Sulfides (R/G-7, Broadus)	CG	CP	-
The Relationship between Natural Resource Characteristics, the Character of Client Industry, and Optimal Resource Access Provisions: The Case of Marine Polymetallic Sulfides (R/G-9, Ross and Broadus)	NS	CP	-
Economic and Legal/Political Implications of Mineral Resource Potential in the U.S. Exclusive Economic Zone: An Application of Lessons Learned in the Case of Polymetallic Sulfides (R/S-9, Broadus)	-	NS	CG

Management and Development

Program Management (M/O-1, Ross)	CG	CG	CG
Program Development (M/O-5, Ross)	CG	CG	CG
Marine Assistance Service (M/O-2, Gaines/White)	CG	CG	CG

NS-New Start CG-Continuing Project CP-Completed Project

Budget 1984-1985

	NOAA Grant Funds	Matching Funds
Marine Resources Development		
Aquaculture	$ 44,900	$ 15,332
Living Resources other than Aquaculture	83,900	31,307
Mineral Resources	99,400	39,192
Marine Law and Socio-Economics		
Socio-Political	78,900	86,048
Marine Environmental Research		
Research and Studies in Direct Support of Coastal Management Decisions	43,400	145,903
Pollution Studies	155,500	144,827
Advisory Services		
Other Advisory Services	60,600	0
Program Management and Development		
Program Administration	153,400	191,119
TOTAL	**$720,000**	**$653,728**

Matching Funds Sources 1984-1985

Woods Hole Oceanographic Institution Education Program Marine Policy Center Coastal Research Center	$338,671
Woods Hole Oceanographic Institution Ocean Industry Program	170,400
Massachusetts Department of Enviromental Quality Engineering	122,107
Brigham and Women's Hospital	9,000
Battelle Laboratories	8,000
Shellfish Hatcheries	4,800
Shellfish Departments (various Massachusetts towns)	500
Town of Marion, Massachusetts	250

Outside Participation 1984 - 1985

Academia

Marine Biological Laboratory
Woods Hole, Massachusetts

Massachusetts Institute of Technology
Cambridge, Massachusetts

University of Washington
Seattle, Washington

Boston University
Boston, Massachusetts

Columbia University
New York, New York

Industry

Battelle Laboratories
Sequim, Washington

Bluepoints Company, Inc.
West Sayville, New York

Brigham and Women's Hospital
Brookline, Massachusetts

Bristol Shellfish Farms
Round Pond, Maine

Coast Oyster Company
South Bend, Washington

Frank M. Flowers & Sons, Inc.
Bayville, New York

Intertide Corporation
North Harpswell, Maine

New England Nuclear
Boston, Massachusetts

Budget 1985-1986

	NOAA Grant Funds	Matching Funds
Marine Resources Development		
Living Resources, other than Aquaculture	$132,600	$ 38,117
Marine Biomedicinals and Extracts		
Marine Extracts	42,300	0
Marine Law and Socio Economics		
Marine Economics	57,200	13,509
Socio-Political Studies	77,100	99,686
Marine Environmental Research		
Research and Studies in Direct Support of Coastal Management Decisions	43,700	19,350
Pollution Studies	134,500	87,879
Advisory Services		
Other Advisory Services	65,300	0
Program Management and Development		
Program Administration	162,300	201,435
TOTAL	**$715,000**	**$459,976**

Matching Funds Sources 1985-1986

Woods Hole Oceanographic Institution Education Program Marine Policy Center Coastal Research Center	$263,226
Woods Hole Oceanographic Institution Ocean Industry Program	180,000
Brigham and Women's Hospital	9,000
Battelle Laboratories	7,000
Shellfish Departments (various Massachusetts towns)	500
Town of Marion, Massachusetts	250

Outside Participation 1985 - 1986

Academia

Marine Biological Laboratory
Woods Hole, Massachusetts

Massachusetts Institute of Technology
Cambridge, Massachusetts

University of Washington
Seattle, Washington

Boston University
Boston, Massachusetts

Columbia University
New York, New York

Industry

Battelle Laboratories
Sequim, Washington

Brigham and Women's Hospital
Brookline, Massachusetts

New England Nuclear
Boston, Massachusetts