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TABLE OF CONTENTS

INTRODUCTION

The public's awareness of the importance of the ocean, improvement in the sense of responsibility for ocean resources and the encouragement of greater interaction between government and the private sector have been national goals for the 1984-85 Year of the Ocean — hopefully they will continue beyond this time.

In many ways Sea Grant supports these same ideals with its emphasis on the evaluation, development, utilization and conservation of our Nation's ocean and coastal resources. Likewise, the Woods Hole Oceanographic Institution's Sea Grant Program incorporates these objectives in all facets of its research, educational and advisory programs.

During the past year the Sea Grant Program at Woods Hole has been represented at various national and regional levels. These included testimony to the Subcommittee on Oceanography of the U.S. House of Representatives on the establishment of an Office for International Marine Science Cooperation and the hosting or co-hosting of several important meetings. Among the latter were the 8th annual meeting of the Massachusetts Marine Educators, a meeting of the New England Marine Technology Society, and a conference on major coastal issues for Cape Cod and the Islands, co-sponsored by WHOI Sea Grant, WHOI's Coastal Research Center and the Cape Cod Coalition of Conservation Commissions. Involvement in such meetings aids us in maintaining interactions with state, county and local constituents, as well as environmental agencies, selectmen and natural resource personnel in the towns on Cape Cod and the Islands.

Research during 1983-84 in the WHOI Sea Grant Program revolved around several themes including fisheries biology and management where studies on red tide in southern New England continued along with other projects involving the bay scallop and lipid staining in marine bivalves. An important segment of the Massachusetts coast is Buzzards Bay and we have been studying the physical transport processes which can affect the pollutant, PCB, in this area. The following pages describe some of the highlights of these research projects along with reports on other work. Although research is the main objective of our Program, the transfer of general information and the results of our research is also an important part 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 our Program.

David A. Ross
Sea Grant Coordinator
December 1984

Toxic Dinoflagellate Blooms in Southern New England

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Biology Department

The toxic dinoflagetllate *Gonyaulax tamarensis* can bloom in two distinctly different environments. In southern New England (and Long Island), blooms occur in small estuaries with essentially no input of cells from coastal waters. Further north, widespread coastal blooms are common in the deeper nearshore waters of the Gulf of Maine. One research component of this project focussed on the southern estuarine populations, since it is important to understand the factors that regulate bloom dynamics in shallow water environments. Results to date are available through published articles and past WHOI Sea Grant annual reports. This report will be devoted entirely to ongoing studies on the *G. tamarensis* bloom populations in the deeper nearshore waters of northern Massachusetts.

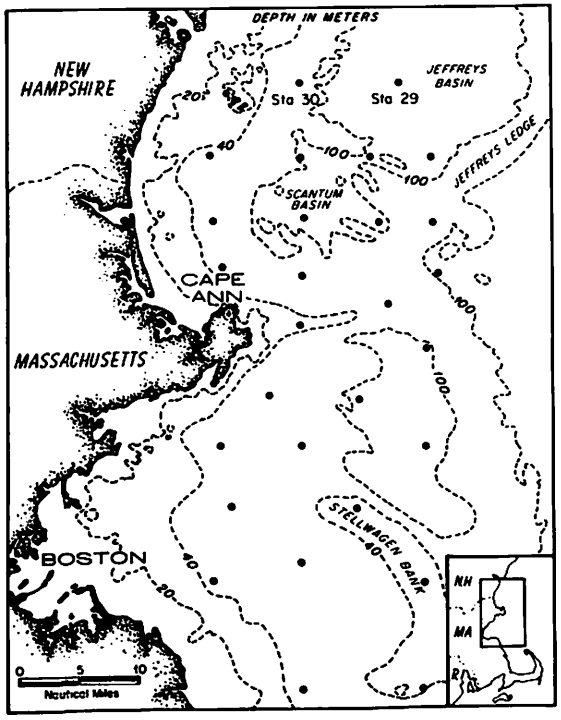

Figure 1. Bathymetry of the study area.

When shellfish filter *G. tamarensis* cells from the water as food, they accumulate the dinoflagellate's toxins, leading to outbreaks of paralytic shellfish poisoning (PSP) that can be fatal to humans. Past research demonstrated that *G. tamarensis* spends much of its life cycle as a dormant cell or cyst in bottom sediments. Cysts can thus germinate after overwintering in inoculate overlying waters. The importance of cyst accumulations as "seedbeds" for bloom initiation is now well established for estuarine blooms, but the origin of the *G. tamarensis* populations in coastal waters remains obscure. Cyst accumulations have been discovered in coastal sediments, but the apparent requirement of relatively warm temperatures for germination (6-8° based on cysts from estuarine sediments) suggests that cysts at 100 meters or greater depths might never warm sufficiently to germinate unless they were physically resuspended. Furthermore, deposited cysts can be rapidly buried by bioturbation, leading to significant subsurface accumulations. This not only affects the resuspension potential of the population, but also places the cysts in anoxic sediments where germination may be inhibited.

The first phase of our project was to determine the distribution and abundance of cysts in the sediments of a study area near Cape Ann, Massachusetts. Vertical profiles of cyst concentrations in sediment cores showed that cysts were scarce in the top centimeters of sediment with most found 4-5 centimeters deep. Figure 1 shows the bathymetry of the area and Figure 2 the corresponding cyst concentrations averaged over the top 6 centimeters of sediment. The region is dominated by several deep basins surrounded by shallow, more heavily-scoured terrain. Cyst abundance was highest in the northern basins, lowest in shallow waters, and decreased from north to south. The low cyst abundance in southern samples is consistent with this species' dependence on estuarine cyst seedbeds for bloom initiation in that region.

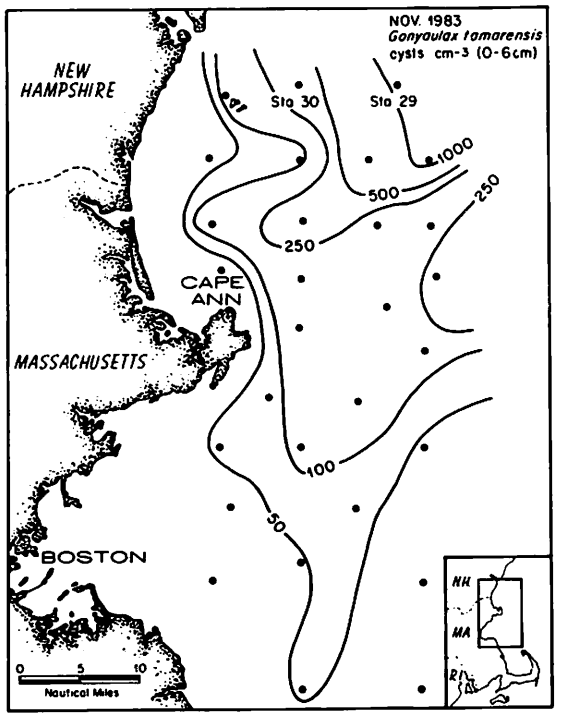

Figure 2. Average G. tamarensis cyst concentrations over the top 6 cm of sediment.

Maximum cyst abundance is high (equivalent to 6×10^7 cysts m^{-2} when all cysts in the top 6 centimeters

are tabulated). If our data are merged with other less quantitative results from surveys of Maine sediments, we see a tremendous reservoir or seed population of *G. tamarensis* cysts stretching far to the north. Very few of these cysts actually germinate, however.

As *G. tamarensis* cysts begin to germinate, their developing chloroplasts fluoresce red when excited by ultraviolet light. This has allowed us to monitor cyst fluorescence to assess the magnitude and duration of germination in deeper waters. Figure 3 shows cyst fluorescence through time at various depths in the sediment. With bottom water temperatures between 4 and 5°C, many cysts show signs of germinating at 150 meter depths, but only those in surface sediments. The percentage of "ripe" cysts increased to over 80% in June, the same time that motile *G. tamarensis* cells were detected in the water column. At this writing, fluorescing cysts have been observed for over 8 months, indicating that the input of new motile cells from the deep water sediments is gradual relative to the short one month pulse of cyst germination that we have observed in shallow estuaries. Fluorescence is only occurring in the oxidized surface sediments (< 1 centimeter deep) — confirming our laboratory observations that anoxia inhibits germination.

The general conclusion at this stage is that despite the massive cyst accumulations in the region, the Gulf of Maine is seeded on an annual basis by the low temperature germination of a small number of cysts in surface sediments. Since this is a gradual process, and involves perhaps 10% of all deposited cysts, the magnitude of a *G. tamarensis* bloom in any given year is probably determined by factors acting on the motile population. It is possible, however, that sporadic episodes of massive, synchronized germination may also occur as major storms expose buried cysts that have accumulated for years. In this context, it is noteworthy that the large 1972 red tide that first introduced *G. tamarensis* to southern New England occurred shortly after a hurricane hit the region. We hope to monitor the effects of such a catastrophic event within the time frame of this continuing project.

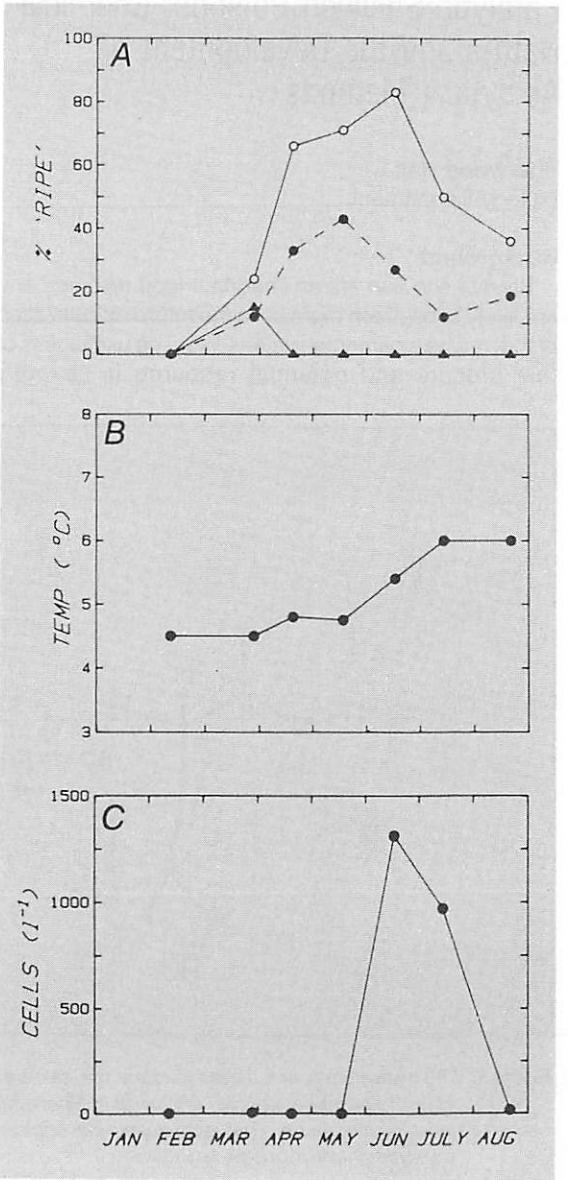

Figure 3. Cyst and motile cell dynamics at Station 29. (A). Fluorescing or "ripening" cysts as a percent of total cysts (o); (●) top 2 cm combined; (▲) 3-6 cm combined; (B). Water temperature (1 m from bottom); (C). G. tamarensis *motile cell concentrations averaged over the top 30 m.*

Paralytic Shellfish Poisons: Chemical Nature and the Development of Analytical Methods

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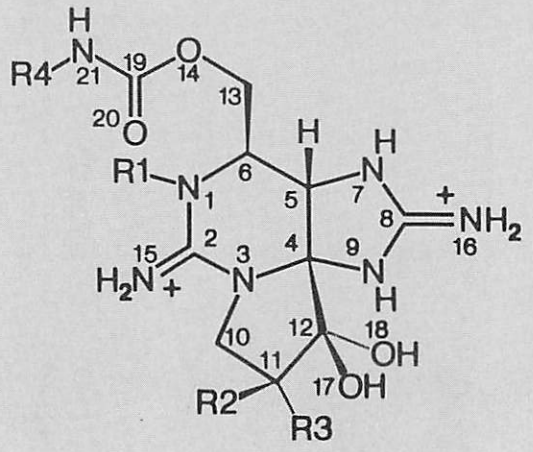
Background:

Bivalve shellfish are an important food resource and are likely to be much more so in the future as cultivation of the marine environment intensifies. The usefulness of this present and potential resource is severely threatened, however, by the sporadic accumulation in shellfish of several potent neurotoxins (Figures 1 and 2). These compounds, saxitoxin (1) and its derivatives (2-12), occur in dinoflagellates of the genus *Protogonyaulax* which may form part of the food of the shellfish. Methods for the assay and analysis of shellfish for these toxins are vital to the management of the problem, yet have been slow to develop, largely because the true chemical nature of the toxins was not understood. Recent work, largely in this laboratory, has advanced the toxin chemistry to a point that the development of such methods is now practical. Work focusses on two areas:



	R1	R2	R3	R4	
1	H	H	H	H	STX
2	H	H	H	SO_3^-	B1
3	H	H	OSO_3^-	H	GTX 2
4	H	H	OSO_3^-	SO_3^-	C1
5	H	OSO_3^-	H	H	GTX 3
6	H	OSO_3^-	H	SO_3^-	C2
7	OH	H	H	H	NEO
8	OH	H	H	SO_3^-	B2
9	OH	H	OSO_3^-	H	GTX 1
10	OH	H	OSO_3^-	SO_3^-	C3
11	OH	OSO_3^-	H	H	GTX 4
12	OH	OSO_3^-	H	SO_3^-	C4

Figure 1. The twelve saxitoxins. These compounds, saxitoxin (1) and eleven derivatives, are found in dinoflagellates of the genus Protogonyaulax, *the origin of paralytic shellfish poison in shellfish.*

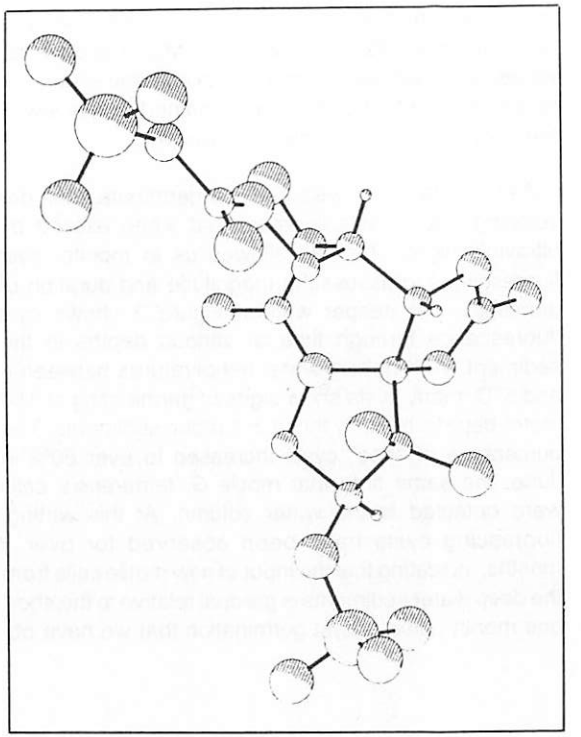


Figure 2. Stereoprojection of toxin C4 (compound 12), from the x-ray crystal structure. This is one of several structures first established by this laboratory.

Derivative Chemistry and Mass Spectrometry

In collaboration with the mass spectrometry laboratory at the U.S. Food and Drug Administration, it was possible to obtain for the first time mass spectra of the saxitoxins. The results are not only of immediate value in current investigations of the toxins, but may provide the basis for a chemical assay useful in the field or in state monitoring laboratories. The FAB/mass spectra of several of the toxins and their derivatives have been obtained.

Adaptation of a Binding Technique for Shellfish Assay

The saxitoxins act by reversible binding to a specific site on nerve and muscle membranes. Using radiolabelled saxitoxin, it is therefore possible to assess the amount of toxin bound to ground cow brain by measuring the amount of radioactivity bound to the tissue fragments or free in solution. Related techniques are well established tools in neurophysiological research, using rat or rabbit brain. If a sample containing unlabelled saxitoxins is added to a standardized mixture of ground brain and labelled saxitoxin, the amount of radiolabel bound to the brain will be reduced in proportion to the kind and amount of unlabelled toxin added.

To determine whether such a technique would provide the basis for a shellfish assay, a suspension was prepared from cow brain. This material was chosen on the premise that it was readily available as a slaughterhouse waste in sufficient quantities for production of a standard reagent if the assay were to be widely used. The cow brain suspension so far appears to be entirely satisfactory as a binding reagent.

For binding experiments, the brain suspension was mixed with tritium-labelled saxitoxin. Figure 3 shows the amount of radioactivity bound to the brain fragments in a series of experiments. The first bar shows the amount of radioactivity bound when nothing else was added to the mixture. For the remaining experiments, an extract was made up from clams purchased at a local market and spiked with varying levels of saxitoxin. These test samples were then diluted 1:10 and added to the brain/radiolabelled saxitoxin mixture. For comparison, the mouse bioassay that is presently the standard method for shellfish toxicity monitoring has a detection limit of about 500 nM saxitoxin, at which it is notoriously imprecise. The highest concentration shown in Figure 3 is half this level, and a clear reduction in bound radiolabel is seen at 50 nM, 1/10 of the mouse assay detection limit.

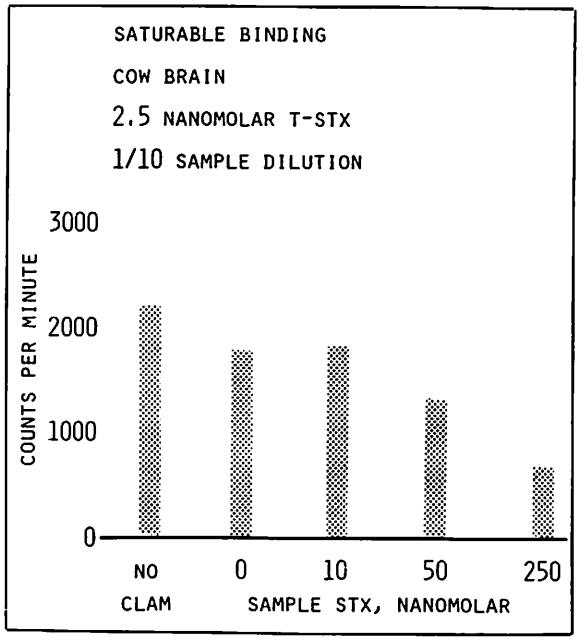


Figure 3. Binding of radiolabelled saxitoxin to bovine brain in the presence of toxin-spiked clam extract.

The value for 10 nM does not differ significantly from that for no added toxin, which means that the clam extract itself interferes with binding. Whether this means that factors intrinsic to clam tissue interfere with the assay, or that the store-bought clams contain low levels of toxin (ca. 1/50 the level detectable by the state monitoring lab with the mouse bioassay) is not yet clear. In any case, this assay clearly has potential as a monitoring technique. Among its advantages over the mouse bioassay are that the reagents can be stored for long periods, the technique is similar to many tests commonly performed in clinical laboratories, it can be largely automated, and the accuracy, precision, and sensitivity are intrinsically better.

Application of Stage-Classified Demographic Models To Atlantic Salmon Populations

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Robert J. Naiman
Biology Department

The primary goal of this project has been evaluation of stage-classified demographic models as a tool to understanding the dynamics of fish populations, particularly Atlantic salmon (*Salmo salar*) populations. Our work over the past year has had three major components.

Data analysis.

Since 1967, the staff of the Institution's Matamek Research Station, on the Matamek River on the North Shore of the Gulf of St. Lawrence, Quebec, has monitored the salmon population of that river. Previous piecemeal analyses of the resulting data base suggested that significant changes had occurred in the life history of this population. There appeared to be an increase in the incidence of precocious maturation by male parr, an increase in the proportion of the population spawning as grilse (i.e., after only a single year at sea), changes in the sex ratio, and a decrease in population size. However, the entire data set had never been subjected to careful statistical analysis, capable of distinguishing genuine temporal trends from the background noise resulting from sampling variation and random fluctuations in population structure.

In collaboration with Dr. W.L. Montgomery of Northern Arizona University, we have carried out such an analysis. We have documented (Montgomery et al., in prep) the existence of the trends mentioned above, and provided estimates of the magnitude of the shifts. These results represent the first time that such trends have

been documented in an intensive study of a single Atlantic salmon population.

Life cycle modeling.

One of the most important life history changes documented in the Matamek River salmon population is the increase in the incidence of male precocity. Since precocious male salmon are not accessible to either commercial or recreational fisheries, their abundance is of some concern to managers.

Given the increase in precocity, the problem arises of explaining its origin. Several hypotheses spring to mind, including the effects of long-term temporal trends in some (unknown) climatic factors, a phenotypic response to decreased parr density resulting from an overall population decrease, and an adaptive genotypic response to recent increases in fishing pressure on the oceanic stages of the life cycle. The latter hypothesis is supported by the existence of genetic variance in the incidence of precocity and by the fact that only males mature precociously. Such a sex differential in selective response to adult mortality would be expected on the grounds that the cost (in fitness) of reproducing at a small size is much greater for females than males, due to the greater energetic investment required to produce eggs.

To evaluate the plausibility of selection as a cause of increased precocity requires a model connecting the incidence of precocity and fitness (λ). Such a connection is provided by a demographic model describing the life cycle of male salmon (Figure 1). From such a model, using the methods of Caswell (1982), we have been able to derive expressions for $\partial\lambda/\partial M$, i.e., the sensitivity of fitness to an increase in the probability of precocious maturation. If $\partial\lambda/\partial M > 0$, selection should favor an increase in M.

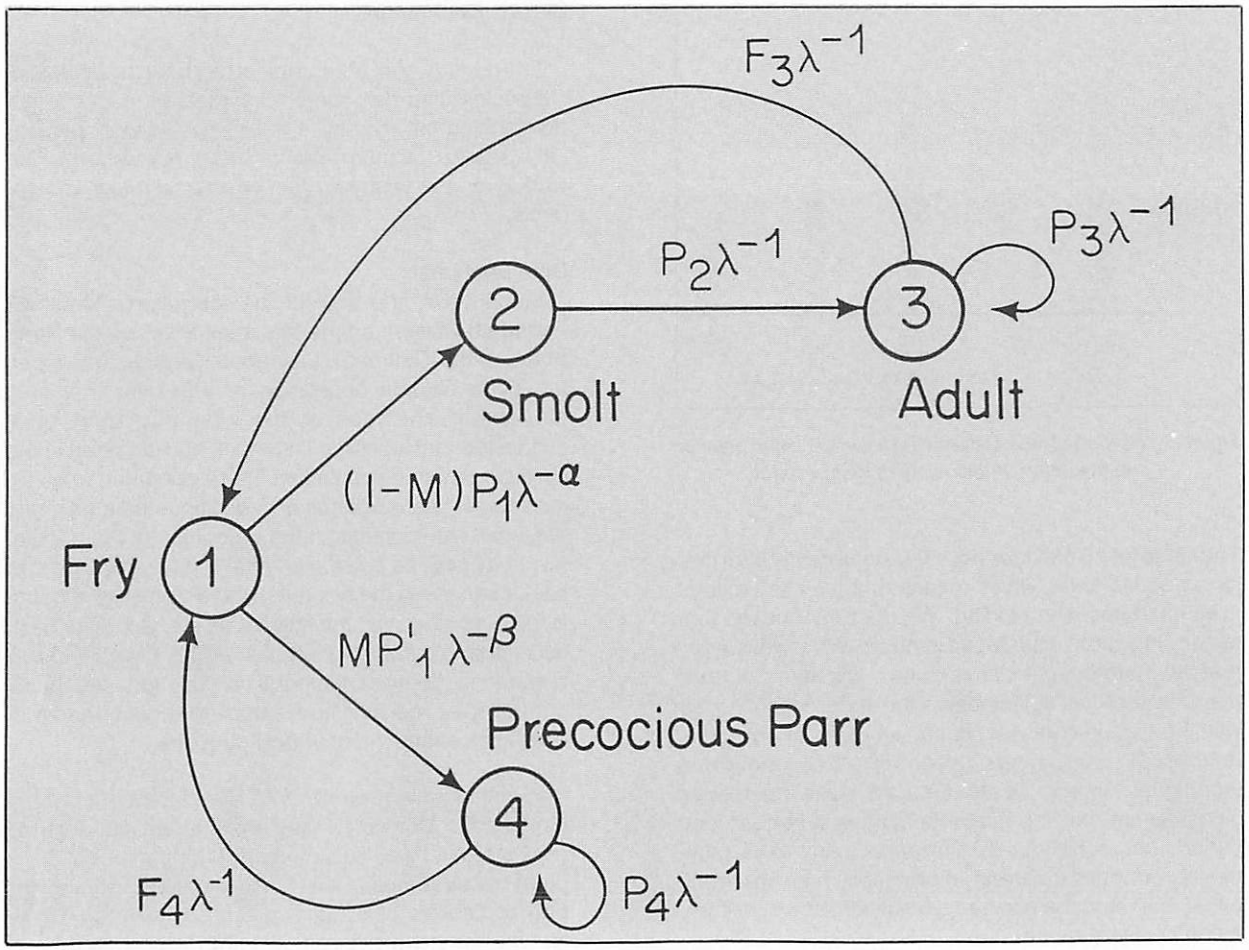

Figure 1. A life cycle graph for the male Atlantic salmon. P_1 and P_1' are the survival probabilities of normal and precocious parr, respectively. M is the probability of precocious maturation. α is the time required for smoltification and β the time required for precocious maturation. P_2, P_3, and P_4 are survival probabilities. F_3 and F_4 are the fecundities of an adult and a precocious male, respectively. The parameter λ measures the ultimate long-term growth rate of the population, and is used as a measure of average fitness.

The results of the analysis (for details see Caswell et al., in press) strongly suggest that increases in fishing pressure over the last two decades have been sufficient to generate selection for an increase in precocity. Thus, this hypothesis needs to be seriously considered as an explanation for the observed changes in the life history.

The dynamic consequences of frequency dependent nonlinearities in fish life histories.

This aspect of our project is concerned with a fundamental theoretical issue arising out of the salmon analysis. Most demographic analyses include only one sex (usually females), assuming that the dynamics of the other sex are sufficiently similar so they may be ignored. However, when the life cycles of males and females diverge, as in the salmon, it may be necessary to consider both sexes. Doing so produces frequency-dependent nonlinearities in the resulting model, expressing the biologically obvious fact that in the absence of either sex, reproduction drops to zero.

The dynamic consequences of such nonlinearities are not well understood. Density dependent nonlinearities, which depend on the absolute abundance of the population but not the relative abundance of the stages within the population, have been well studied and it is known that they can lead to a variety of complex behaviors, including stable equilibria, stable cycles of different periods, quasiperiodic behavior, and eventually purely chaotic fluctuations. One of our goals has been to determine the conditions under which such dynamics may result from the frequency-dependent interaction of the sexes.

We have succeeded in demonstrating for the first time that purely frequency-dependent interactions can result in oscillations and apparently chaotic behavior (Caswell and Weeks, in prep). The crucial parameter determining this behavior is the intensity of competition between stages of one sex for access to mates of the other sex. When the intensity of such competition is low, the population converges to a stable composition; when it becomes high enough, oscillations result. Since behavioral observations strongly suggest that precocious parr compete with each other and with adult males for the fertilization of eggs, these purely theoretical results may well be directly applicable to salmon populations.

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Physiological Consequences of Metamorphosis in Marine Bivalve Larvae

Roger Mann
Scott M. Gallager
Biology Department

Metamorphosis, the sequential transition from one life-history stage to the next, is affected through numerous morphological, physiological and biochemical events in many invertebrate organisms. Ramifications of these events are often cataclysmic in magnitude and interrupt normal life-sustaining physiological functions, such as feeding, necessitating the dependence of metabolism on energy reserves stored prior to initiating the metamorphic process.

Under both laboratory and commercial hatchery conditions, metamorphosis of bivalve molluscs is often coincident with mass mortalities that continue through a critical period of two to three weeks post-settlement. Among possible causative factors, abnormal lipid accumulation and metabolism has been cited in our earlier Sea Grant-sponsored research as being a prime candidate. As a result, we have used the fluctuating lipid levels in developing bivalve larvae as a sensitive indicator of physiological condition and potential success in completing metamorphosis (Gallager and Mann, 1981; 1984a, b,).

Bivalve larvae undergo a transition from a free swimming, planktonic form, complete with a ciliated velum for locomotion, feeding and respiration, to a benthic juvenile, lacking a velum, but possessing gill rudiments that aid respiration but are not capable of capturing food particles. As part of our ongoing studies, we are testing the hypothesis that if a relatively long nonfeeding period

exists between velar resorption and gill activation, the newly settled juvenile will have to depend on lipid reserves accumulated during planktonic life to fuel the transitional period.

Some questions being addressed in an attempt to elucidate the mechanism by which bivalve larvae cope with stress at metamorphosis include the following: (1) If a nonfeeding period does exist, for how long must a larva depend on stored energy reserves?; (2) Is there a threshold lipid level necessary in pre-metamorphic larvae for successful completion of that process?; and (3) If the mass mortalities at settlement reported by commercial hatchery operators are results of suboptimal lipid storage during planktonic life, could the lipid content of pre-metamorphic larvae (visualized by lipid specific stains) be used to predict survivorship to the juvenile stage?

Our approach to answering these questions has been twofold: a detailed laboratory study designed to assess the energetic requirements of metamorphosing larvae and to document post-metamorphic change in energy substrate, and a commercial hatchery component that provides a broad survey of the relationship of pre-metamorphic larval lipid content to the success of metamorphosis itself (i.e., spat yield).

Laboratory reared pre-metamorphic larvae of *Mercenaria mercenaria*, *Ostrea edulis* and *Crassostrea virginica* were allowed to metamorphose under two nutritional conditions — with and without a phytoplankton food supplement. Subsamples were removed at daily intervals for biochemical assay (protein, lipid, carbohydrate), organic content, and physiological rate measurements (feeding and respiration rate).

Since one of our goals was to remove the variability associated with physiological rate measurements on large numbers of organisms, we developed techniques that allow routine measurements of respiration and feeding rates to be effected on individual metamorphosing larvae. Larvae that have attached to the bottom of small tissue culture wells were monitored on an inverted microscope by time-lapse video photography. Analysis of recordings yield the number of algal cells entering the incurrent siphon and exiting the excurrent siphon of the 250mm spat; the difference being the efficiency by which the gill retains the algal cells. Thus, video recordings provide information on the functional morphology of the developing feeding mechanism during morphogenesis that would otherwise be unobtainable by conventional histological techniques.

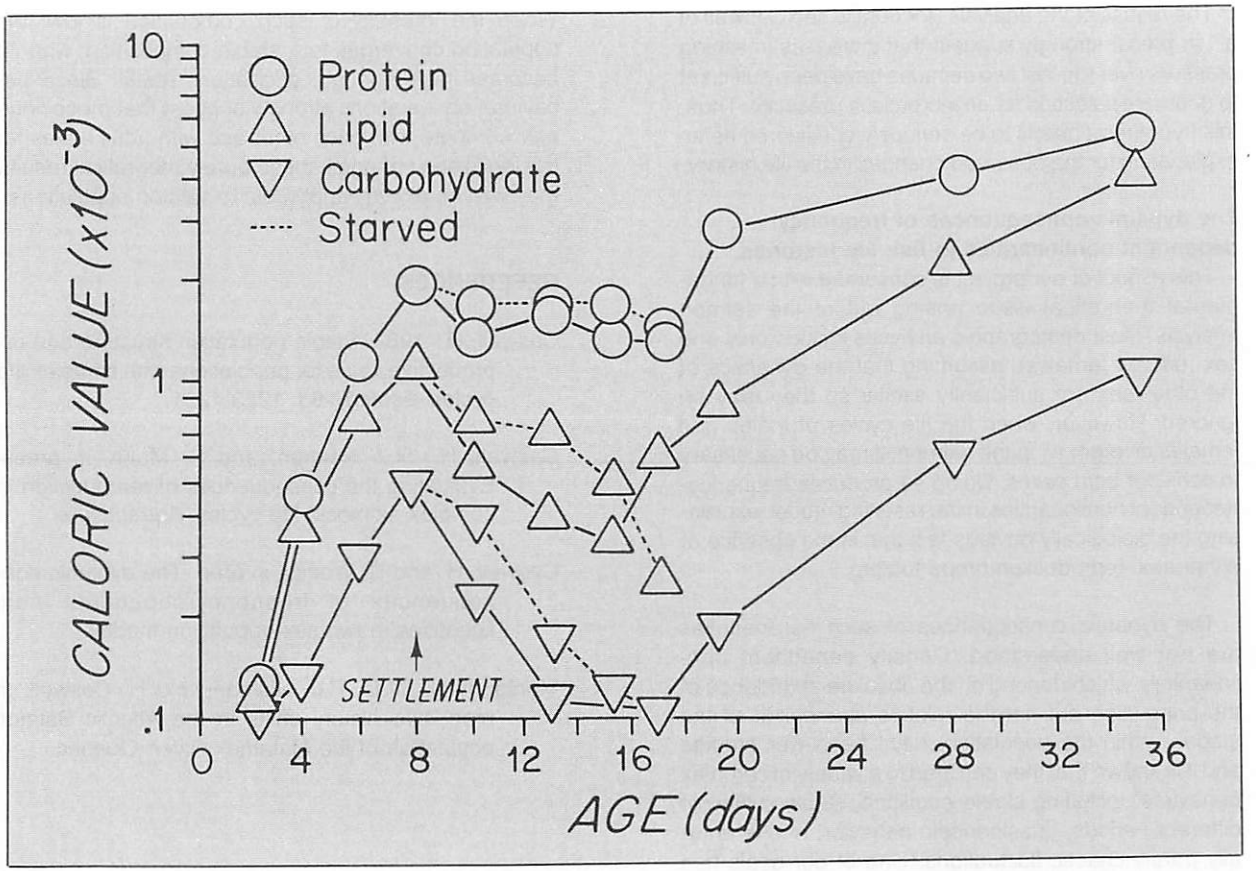

Figure 1. Biochemical changes associated with metamorphosis in Mercenaria mercenaria. *Note rapid decline in lipid and carbohydrate through eight days post-set, irrespective of the absence of a phytoplankton supplement.*

The results of the laboratory-based biochemical studies (Figure 1) on metamorphosing *M. mercenaria* suggest that there is a rapid loss of both lipid and carbohydrate upon settlement, followed by an increase in all components (note the log scale in Figure 1 and the proportionately greater loss of lipid rather than carbohydrate on a caloric basis). Interestingly, the loss of energy substrate occurs irrespective of the presence or absence of a phytoplankton food supplement. From this, it would appear that metamorphosing larvae are not capable of utilizing particulate material and must rely on stored energy reserves during this transitional period.

Figure 2 illustrates the respiration rate, algal retention efficiency, and mode of feeding in transitional *O. edulis* larvae. While there is no discontinuity in the rate at which respiration increases with time after settlement, a precipitous decrease occurs at this point in the percentage of phytoplankton cells removed from suspension. Only 20 to 27% of the cells entering in through the incurrent siphon are retained during the first seven days post-settlement. Video records show that the gill does not function in removing suspended particles until about four days post-settlement, and then only very inefficiently. Involvement of the larval foot in feeding activity has heretofore not been previously reported; ciliated tracts on the ventral surface of the food direct algal cells into the mouth where ingestion takes place. For *O. edulis*, this may be an interim feeding mechanism designed to offset depletion of stored energy reserves.

Samples of larvae and post-settlement individuals from four commercial hatcheries taken over a two month period are presently being analyzed. The data from Bluepoints Co., W. Sayville, NY on the growth and biochemical composition of juvenile *M. mercenaria* are presented in Figure 3. Once again, a dramatic loss of lipid is evident within seven days of settlement. Since food is always supplied to metamorphosing larvae under hatchery conditions, these results reinforce the

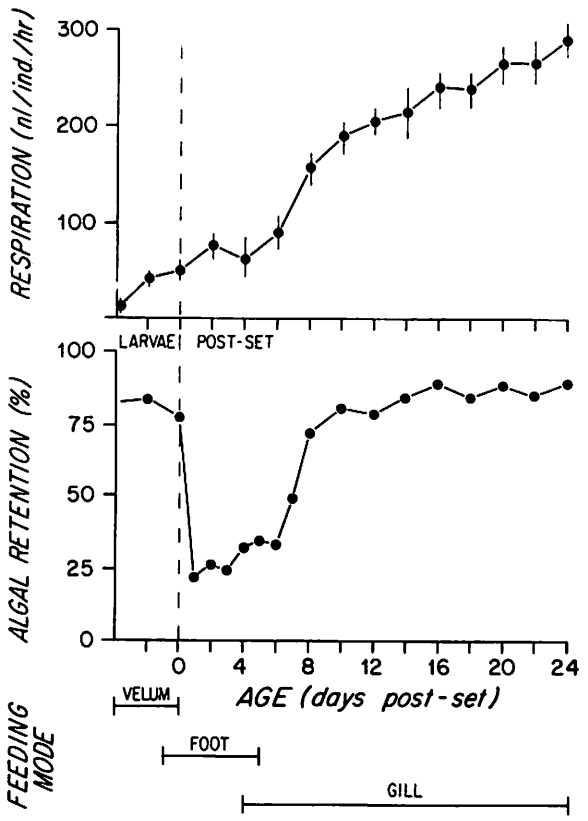

Figure 2. Respiration rate and phytoplankton retention efficiency during metamorphosis of of Ostrea edulis. *Precipitous decrease in the ability to capture food particles is associated with the transition from a velar to a gill mode of feeding.*

data obtained in our laboratory studies, i.e., particulate food consumption is virtually nonexistent during the early days of metamorphosis. After an initial decline in biochemical content upon settlement, the level of all components increases for a period of 40 days. The data of Figure 3 is recalculated on a percentage basis in Figure 4 to illustrate this point more clearly; as the lipid level declines at 40 days, carbohydrate rapidly increases until the age of 80 days. Maturation and initiation of gametogenesis is probably responsible for the observed increase in lipid level at the expense of carbohydrate in young clams beyond this age.

The transition from a lipid-protein based metabolism to that of carbohydrate-protein has previously been documented in *O. edulis* by Holland and Spencer

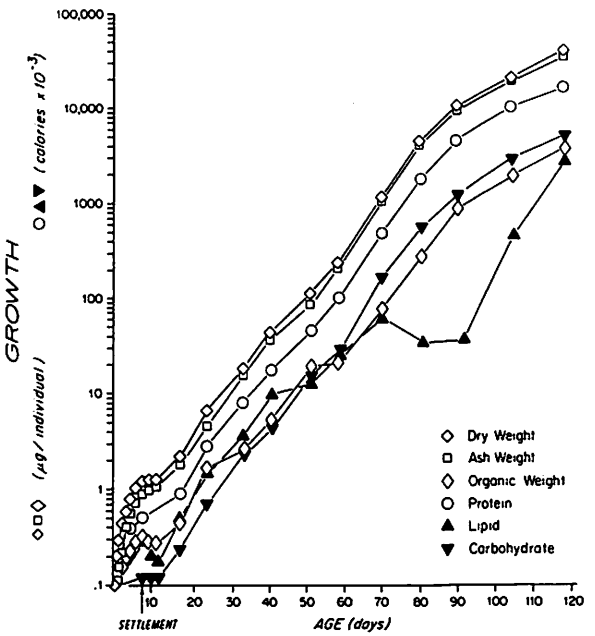

Figure 3. Biochemical content of Mercenaria mercenaria *throughout development under commercial hatchery conditions (Samples from Bluepoints Inc., W., Sayville, NY).*

(1973). This has not been reported in *M. mercenaria*. The biochemical transition is important because a second period of increased mortality usually occurs in hatcheries rearing *M. mercenaria* between the ages of 35 and 60 days. Research directed toward understanding the biochemical complexities of the transition in energy substrate during metamorphosis is pivotal to reducing hatchery mortalities.

In conclusion, the combined laboratory and hatchery results, thus far, point to a possible mechanism employed by bivalves to deal with stress associated with metamorphosis. Once the mortality and survivorship data has been compiled from our experiments, we should be able to develop an index of potential spat yield, similar to that of Gallager and Mann (1981 and 1984a, b), based on the lipid content of veligers initiating the metamorphic process. This will allow researchers and hatchery operators to make real-time estimates of potential metamorphic success and ultimately increase the efficiency of the rearing process.

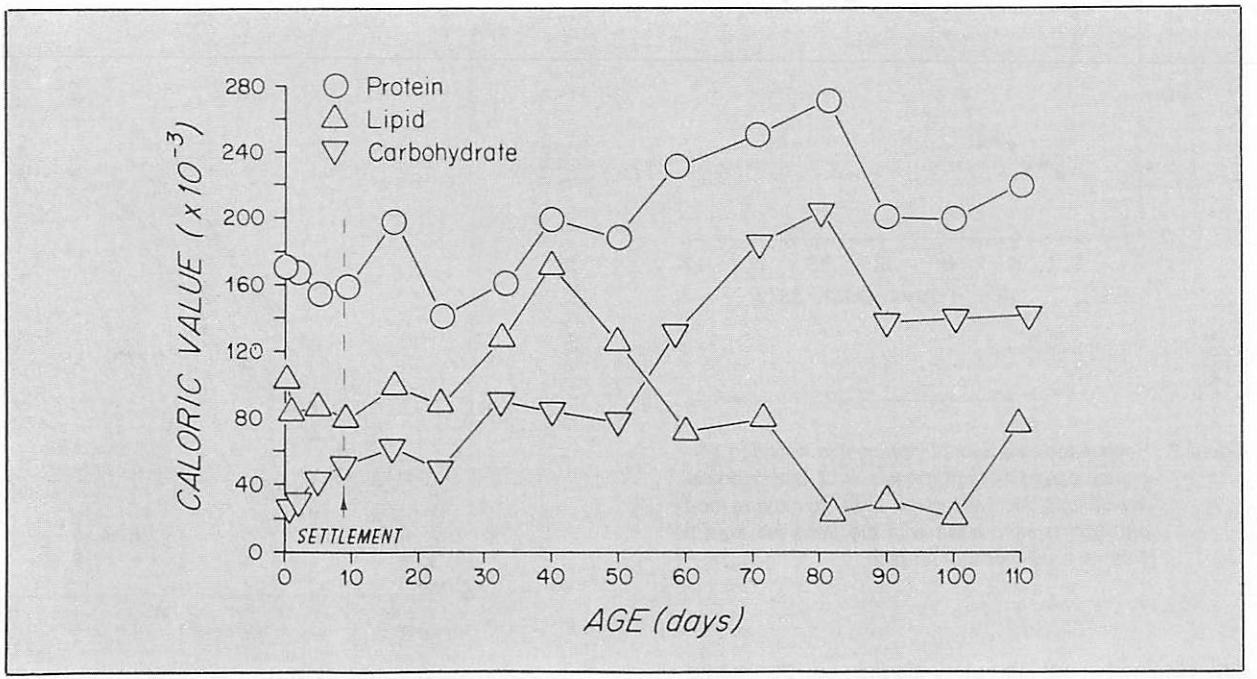

Figure 4. The transition from a lipid-protein based metabolism to that of carbohydrate-protein in Mercenaria mercenaria *40-70 days post-set.*

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Growth and Reproduction of Bay Scallops in Shallow and Deepwater Embayments

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Although bay scallop populations are most abundant in shallow embayments, large populations are occasionally found at depths of 4.5 to 12 meters in Buzzards Bay, MA. Concomitant with large offshore sets are significant increases in the harvestable yields for towns exploiting offshore shellfish beds. Little is known of the frequency of offshore sets, the extent of offshore beds, or the breeding periodicity, growth rates, and other life history characteristics of offshore *Argopectin irradians* populations.

Comparative studies on the reproductive cycle and growth of bay scallops from shallow and deepwater embayments are currently in progress. For comparison, a bay scallop bed at a depth of 9 meters was selected in the northwest end of Buzzards Bay, southwest of the Red and Black Gong, and an inshore site was selected at Wings Cove at a depth of 2 meters. At both locations collections were made every two weeks for analysis of growth rates and gonad development of bay scallops, in addition to monitoring temperature and water quality parameters. For continuous temperature monitoring a microprocessor temperature recorder was deployed.

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

By examining the gonad and adductor muscle indices of bay scallops collected from offshore and inshore stations, a preliminary comparison of the gametogenic:somatic energy budget can be made. From May through June both inshore and offshore populations showed a marked increase in gonad index and a marked reduction in muscle index, indicating a greater percentage of energy being channeled into gametogenesis in both populations. During early June, inshore populations of bay scallops had a significantly higher gonad index than offshore populations, possibly due to either spawning activity or reduced reproductive output of the latter population. The reduction in adductor muscle index indicates that energy reserves stored in muscle tissue are being mobilized for gametogenesis. During the late summer and early fall, a marked decrease in gonad index is noted and a significant increase in adductor muscle weight is apparent. As offshore animals are still spawning in early September, marked increases in muscle weight continue through October, after the opening of harvesting season on 1 October. During 1981 and 1982 offshore bay scallops generated a 20-50% greater muscle weight for the season than inshore bay scallops. More detailed biochemical analyses of the comparative energetics of inshore and offshore populations are currently being evaluated.

A workshop on the biology of inshore and offshore populations of bay scallops *(Argopectin irradians irradians* Lamarck) was held in October 1983 to which representatives of local shellfish groups were invited to discuss and review studies pertinent to management of the bay scallop fishery. Proceedings of this workshop (Capuzzo, 1984) are available from the authors or from the Woods Hole Sea Grant Office.

Bay scalloping in Waquoit Bay, Falmouth, MA (Photo courtesy Rodman Taylor)

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HUMAN IMPACT ON THE MARINE ENVIRONMENT

Physical Processes and Biogeochemistry of Environmental Contaminants: General Considerations and Application to PCB Pollution Problem in Buzzards Bay

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Evaluation of possible solutions to the PCB pollution problem in the Acushnet River estuary (New Bedford Harbor) and evaluation of present and future sewer outfall locations in Buzzards Bay demonstrated the immediate need for a modern, state-of-the-art understanding of the physical oceanography of Buzzards Bay and sediment transport within the bay. Accordingly, a joint effort of the Coastal Research Center of WHOI and Sea Grant was initiated. The effort consisted of (1) seasonal hydrographic studies of Buzzards Bay to provide an idea of vertical and horizontal density structure and some indication of large-scale circulation and mixing; (2) boundary layer measurements of vector velocity to resolve the mean and turbulent flow structure, to determine the primary driving forces of the bottom flow and to contrast storm events with everyday flow for their resuspension potential; and (3) studies of biogeochemistry of PCBs. The major findings are as follows.

Two hydrographic cruises were conducted in 1982 and two more cruises were conducted in January and April of 1983. The data were processed in 1983 and a report issued in 1984 (Rosenfeld et al., 1984). A strong seasonal thermocline appears in the bay in early spring and disappears as the bay becomes vertically well mixed by late October. More saline, more dense water was traced entering the bay on the southeastern side of the mouth near the Elizabeth Islands. Less saline, less dense water was found along the northwestern shore of the bay (Figure 1). A counterclockwise circulation is indicated and is consistent with shoreline geomorphology to the west of New Bedford Harbor and with elevated PCB concentrations in mussels and oysters at a few shoreline locations in the westerly direction away from the harbor. Preliminary analyses of sea level and wind data indicate that the bay responds in two significant modes to wind forcing: (i) a "plunger mode" driven by the along-shelf wind and (ii) a "set-up mode" driven by the local along-bay wind.

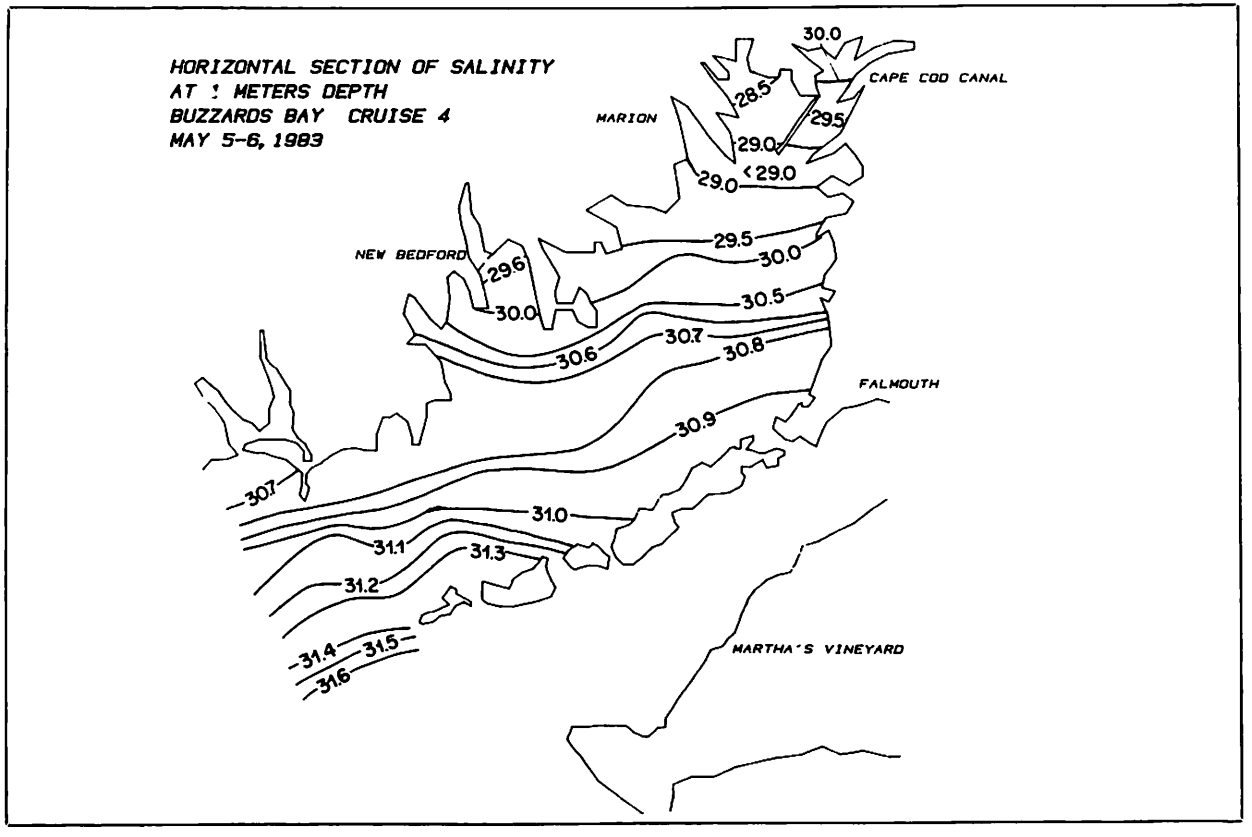

Figure 1. An example of horizontal salinity structure in Buzzards Bay

Instrumented tripods (Figure 2) were deployed near Cleveland Ledge in the eastern part of the bay and in the outer New Bedford Harbor area. These instruments recorded data on water velocity, transmission, wind-waves and temperature for several winter storms as well as during nonstorm conditions and provided estimates of the relative importance of waves, tides, and wind driven currents to resuspend and transport particulate matter. The data also provide estimates of the mean bottom friction term needed in circulation modeling and clearly illustrate the need to account for wave-current interactions in modeling the physical transport processes in the bay. Wave-induced stresses are the most important factor in sediment resuspension during storms; a most important finding relative to transport of polluted sediment particulate matter. Tidal currents and other low frequency currents are not capable of resuspending significant amounts of sediment by themselves.

Concomitant with the above, research on the biogeochemistry of PCBs has continued. Interstitial water profiles of PCBs, DOC, $SO_4^{=}$, salinity, and NH_4^{+} for a carefully collected box core in the outer harbor area have been completed. Concentrations of PCBs are in the μg/L range. Evaluation of the depth profiles of total PCBs and individual chlorobiphenyl isomers in sediments indicates a strong role for colloidal organic matter in the biogeochemical cycle of PCBs in surface sediments. This has important implications to such issues as (i) modeling the flux of PCBs from sediments to overlying waters; (ii) the relative importance of resuspension and transport of particle bound PCBs contrasted to flux of soluble contrasted to flux of colloidal organic matter associated PCBs from sediments; (iii) bioavailability of PCBs in surface sediments.

The above efforts are continuing during 1984-1986. The addition of a significant research effort on the sublethal biological effects of PCBs on bivalves and fish couples biogeochemical cycles and affects research, which will provide findings of generic value. Of equal importance, the research to date has provided significant guidance to the EPA-Superfund efforts, which have moved from planning to field implementation stage in solving the PCB pollution problem in New Bedford Harbor.

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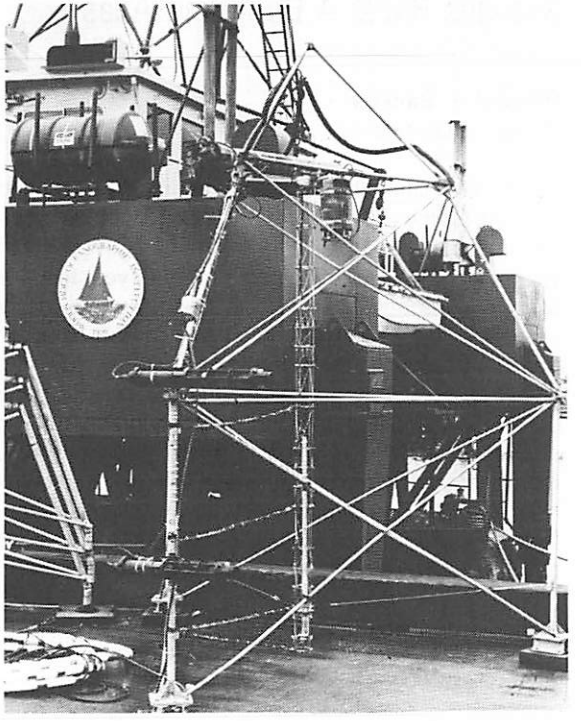

Figure 2. Instrument tripod used near Cleveland Ledge to record data on water velocity, transmission, wind-waves and temperature during storm and non-storm conditions.

COASTAL RESOURCE MANAGEMENT

Georges Bank: A Book and Atlas

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When the Department of the Interior first announced its plans for the leasing of tracts for petroleum development on Georges Bank in 1974, the bank already had yielded rich harvests of codfish year after year for over two centuries and other fish species for some lesser time. It was little wonder, then, that fishing interests became alarmed at the prospect of having to share the bank with oil companies. This dispute drew the attention of the New England public and oceanographers. The oceanographers had already made oceanographic measurements of temperature and salinity and preliminary estimates of currents some 60 years earlier. Also, fishery scientists, from approximately 1930, had been trying to understand the perplexing ups and downs of the fish populations on Georges Bank. Thus, it is not surprising that this dispute over Georges Bank encouraged additional physical, chemical, geological and biological studies on the bank.

Recently, the Woods Hole Oceanographic Institution established a Coastal Research Center for initiating multidisciplinary studies of salt marshes, beaches, estuaries, fishing banks, and the continental shelves. One of three projects initially conceived was a long-term study of Georges Bank. The project originators felt it would be good to start with a summary of what was already known about the bank. Too long to be a good summary, perhaps, this book is the result. The book's planners hoped that the book-making process would foster cross-disciplinary connections.

The book consists of 57 chapters, 10 vignettes and 9 introduction/summaries plus front and end matter. There are about 800 pieces of graphics, many of them color maps, and it is estimated that the book will be about 1,000 pages. Publication is expected sometime in the last quarter of 1985 or first quarter of 1986.

Natural Tidal Inlet Bypassing

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Tidal inlets play important roles in many aspects of coastal processes and human utilization of the shoreline, particularly along the U.S. east and Gulf coasts where barrier beaches are the dominant coastal landform. The permanence and stability of tidal inlets depend on a number of factors, one of which is longshore sediment transport rate. If tidal inlets cannot flush or bypass the quantities of sediment driven alongshore by wave action, they may fill in, or migrate, with possible detrimental effects on estuarine/bay water exchange and navigation. The present Sea Grant work has focussed on the ability of tidal inlets to bypass sediment moving alongshore, both along the ebb tide delta and through the inlet mouth itself. Field work has taken place at Nauset Inlet, MA, where the recent history of tidal inlet behavior is well-understood (e.g., Speer, Aubrey and Ruder, 1982; Aubrey and Speer, 1984).

Modeling and field work has concentrated on two aspects of tidal inlet bypassing. The first phase of the work emphasized the inlet bypassing characteristics of Nauset Inlet (Figure 1) and similar/estuarine systems. The second phase, which is currently underway, examines in more detail the ebb delta bypassing of an inlet/estuarine system, focussing on the relative role of tides and waves in bypassing sediment. The first phase of the work is largely completed, resulting in a number of pages and reports related to inlet bypassing. The emphasis was on examining the nonlinear response of bays and estuaries to tidal forcing, and the resulting distortion of the tide. Tidal distortion either will enhance estuarine flushing or accelerate sediment accumulation, depending on the relative sense of distortion (flood

or ebb-dominant). This work is described in detail in Aubrey and Speer (1983), Speer (1984), Aubrey and Speer (in press), and Speer and Aubrey (in press).

Lately our effort has focussed on ebb delta bypassing, in which ebb tidal currents transport sediment seaward, where incident waves then can influence sediment transport. The relative dominance of ebb currents and incident waves over sediment transport controls the geometry of the ebb tidal delta and the bypassing effectiveness of the ebb delta. In a qualitative sense, this can be summarized as follows (Figure 2). When the ebb currents dominate over waves, the ebb delta tends to be elongated seaward (a large aspect ratio), and a relatively stable channel is formed. As wave influence increases, wave-driven sediment transport fills in the main channel, and smooths much of the morphology associated with a tidally-dominated system. When wave effects dominate, the ebb delta has a low aspect ratio (it does not extend into the ocean very far), and morphology of the ebb delta is wave-controlled. The navigation channel is not stable, with the deepest section limited to the inlet throat, shoaling rapidly as it encroaches onto the ebb delta. This qualitative description of the ebb bypassing problem (similar to one proposed by Hayes, 1979) needs quantification, which is the focus of this second phase of study.

Figure 1. Nauset Inlet with adjacent barrier beach and wetlands, Cape Cod, MA. (Photo courtesy David G. Aubrey).

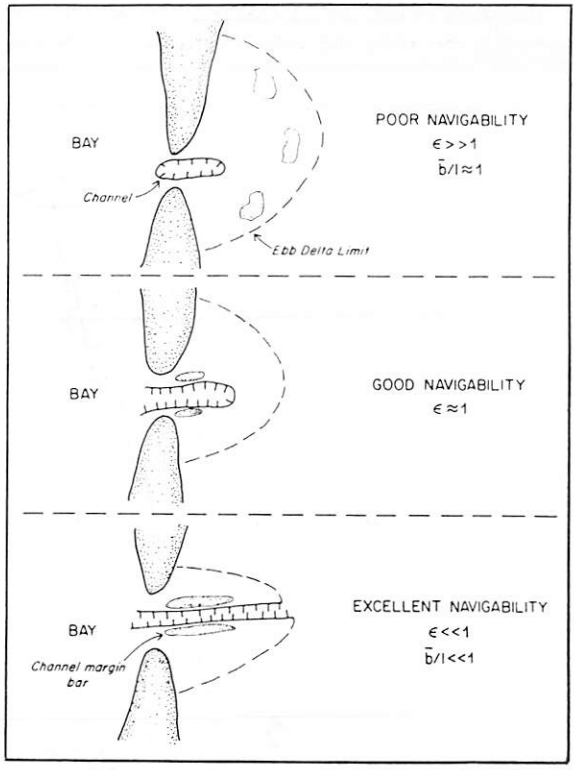

Figure 2. Qualitative framework for modeling ebb tidal discharge and sediment transport. ϵ is the ratio of wave to tidal sediment transport potential. $\bar{b}$ is the mean width of the ebb delta, while ℓ represents its longitudinal scale.

The study of ebb delta bypassing has two phases: numerical modeling and field observation. Numerical modeling centers on the description of the ebb tide jet as it reaches the ebb delta, and is influenced by incident waves. We are implementing a two-dimensional (depth-integrated) numerical model to examine the impact of waves and tides on the ebb tide jet. This will then be coupled with sediment transport models (near-bed transport only) to examine the transport patterns under these conditions. Because of the complexities of wave/current interactions, and the nonlinear shoaling and refraction of shallow water and breaking waves, the wave effects must be simplified. Initially we are representing the wave effects on the ebb jet as a radiation stress, perhaps including the nonlinear wave/current bottom stress interactions at a later time. Field work has focussed on measurement of the characteristics of ebb jets under various wave and tide conditions. Field experiments have included measurements of incident surface waves, Eulerian velocity field within the inlet throat, sea surface variations within the inlet throat and on the ebb delta, and Lagrangian flow patterns in the throat and on the ebb delta (to estimate mixing parameters). To accomplish the Lagrangian observations on a modest budget, we developed a remote observational program using a radio-controlled miniature aircraft, from which photographs were obtained of surface drifters and dye patches (Hess and Aubrey, in press). A network of land and ocean reference marks located in each photograph (Figure 3) enables time series of Lagrangian motion to be constructed from sequential aerial photographs. These data will be used to define jet behavior and estimate entrainment rates for the jets.

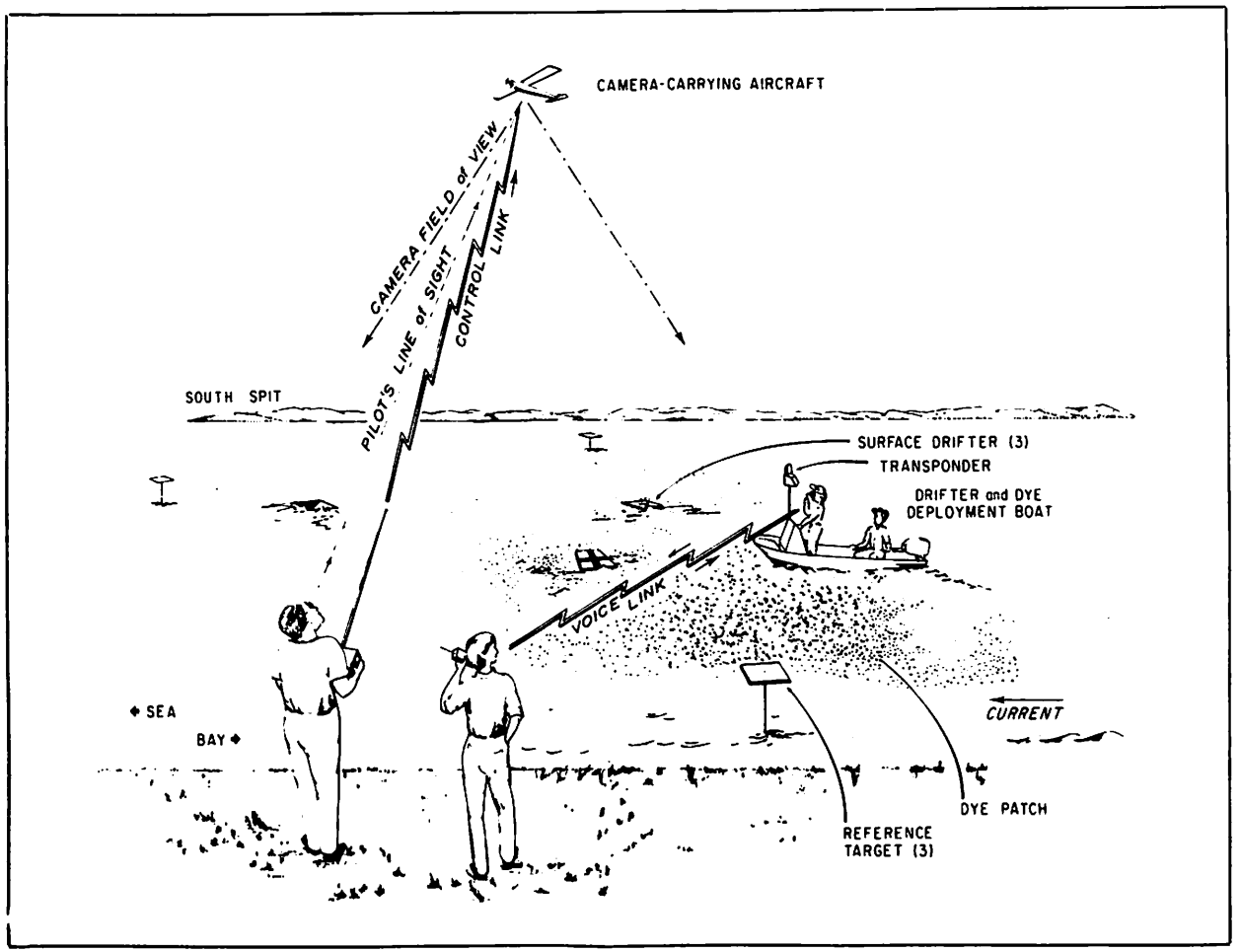

Figure 3. Schematic of procedure for observing drifters and dye patches for Lagrangian flow estimates (from Hess and Aubrey, in press).

This program, in its third and final year, will provide guidance to scientists and engineers concerned with tidal inlets and estuaries. Alternatives to channel maintenance can be assessed from a more quantitative standpoint, and dredging options can be more thoroughly evaluated. This work will be a step towards more quantitative, physically-insightful work on tidal inlet behavior.

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Tidal Distortion in Shallow Estuaries and Bays

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As the continental shelf tide passes through a narrow tidal inlet into a shallow estuary or bay, it becomes severely distorted. This distortion shows as both an amplitude asymmetry (where maximum flood tidal currents either exceed or are exceeded by maximum ebb tidal currents), and a duration asymmetry (where duration of flood tide either exceeds or is exceeded by ebb tide duration). When flood tide velocity exceeds ebb tide velocity, the estuary is called flood dominated; when flood tide velocity is exceeded by ebb tide velocity, the estuary is called ebb-dominated. The sense of tidal asymmetry exerts strong influence on sediment transport, both near-bed and suspended.

To investigate these effects, both field and numerical modeling programs were undertaken. We chose to investigate highly nonlinear tidal estuaries/bays, where the ratio of tidal range to mean water depth is large (order 1), and where freshwater inflow is negligible so we could neglect gravitational effects. For field investigation, Nauset Inlet, Cape Cod, Massachusetts, was selected for study (Figure 1). Arrays of pressure gauges, tide gauges, and current meters allowed us to document the highly nonlinear tides of this bay (Aubrey and Speer, in press). This system is flood-dominated, with flood tides lasting only 5 hours, and ebb tides lasting up to 7.5 hours (Figure 2). This is contrasted to an ebb-dominated system, Wachapreague Inlet, Virginia (which has been studied by investigators at the Virginia Institute of Marine Science), where ebb tides last approximately 0.8 hours less than flood tide (Boon and Byrne, 1981). The Nauset field results show that the nonlinear tidal distortion is phase-locked over the entire embayment, once the tide propagates through the inlet. Although the magnitude of the flood velocity and duration asymmetry change with distance into the bay, the nonlinear growth leading to tidal distortion shows common characteristics (the phase of the overtides and compound tides are locked to the phases of the parent tidal constituents).

Results by numerical modeling (from a one-dimensional numerical model) clarified the hydrodynamic source of the tidal nonlinearities (Speer, 1984; Speer and Aubrey, in press). Using model channel geometries that introduce the lateral dimension implicitly and that are based on a trapezoidal cross section (in the limit either a triangular or rectangular cross section), the effects of varying channel cross section over a tidal cycle were investigated. Similarly, tidal flats were added (serving as storage basins for water, not as momentum-transporting sections) and their effects investigated.

Channels without tidal flats develop a time asymmetry characterized by a longer falling than rising tide. This behavior is enhanced by strong friction and large channel cross-sectional area variability over a tidal cycle. Resulting tidal currents have a shorter, intense flood, and a longer, weak ebb (flood dominant). Addition of tidal flats to the channels can produce a longer rising tide and stronger ebb currents (ebb dominant), if the area of tidal flats is large enough to overcome the effects of time-variable channel geometry. Weaker friction with flats can also produce this asymmetry.

These numerical experiments agree well with the nonlinear response of Nauset Inlet, although the details of Nauset's tidal response cannot be modeled completely with a simple one-dimensional numerical model. In addition, the Wachapreague nonlinear response is also in agreement with numerical model results, al-

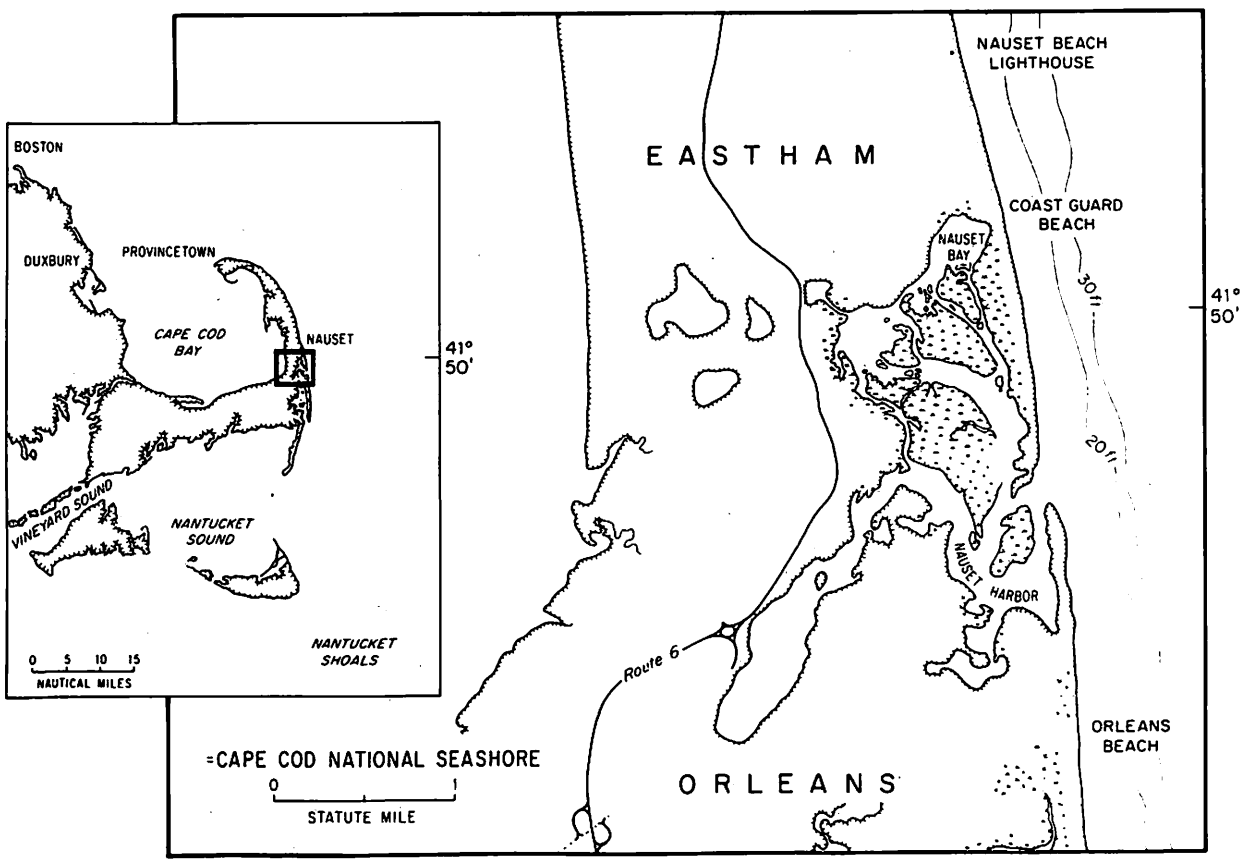

Figure 1. Location of field study of tidal distortion in shallow estuaries/bays.

though the field data for this latter inlet are not as extensive as the data for Nauset Inlet. We plan to continue this work on nonlinear tidal distortion in shallow estuaries and bays, implementing two-dimensional models so we can more correctly represent the momentum effects of tidal flats and marsh bends. In addition, we plan to complete modeling of near-bed and suspended load transport in these vertically-mixed estuaries and bays, with negligible freshwater input. Our final goal is to understand the geological evolution of estuaries and bays.

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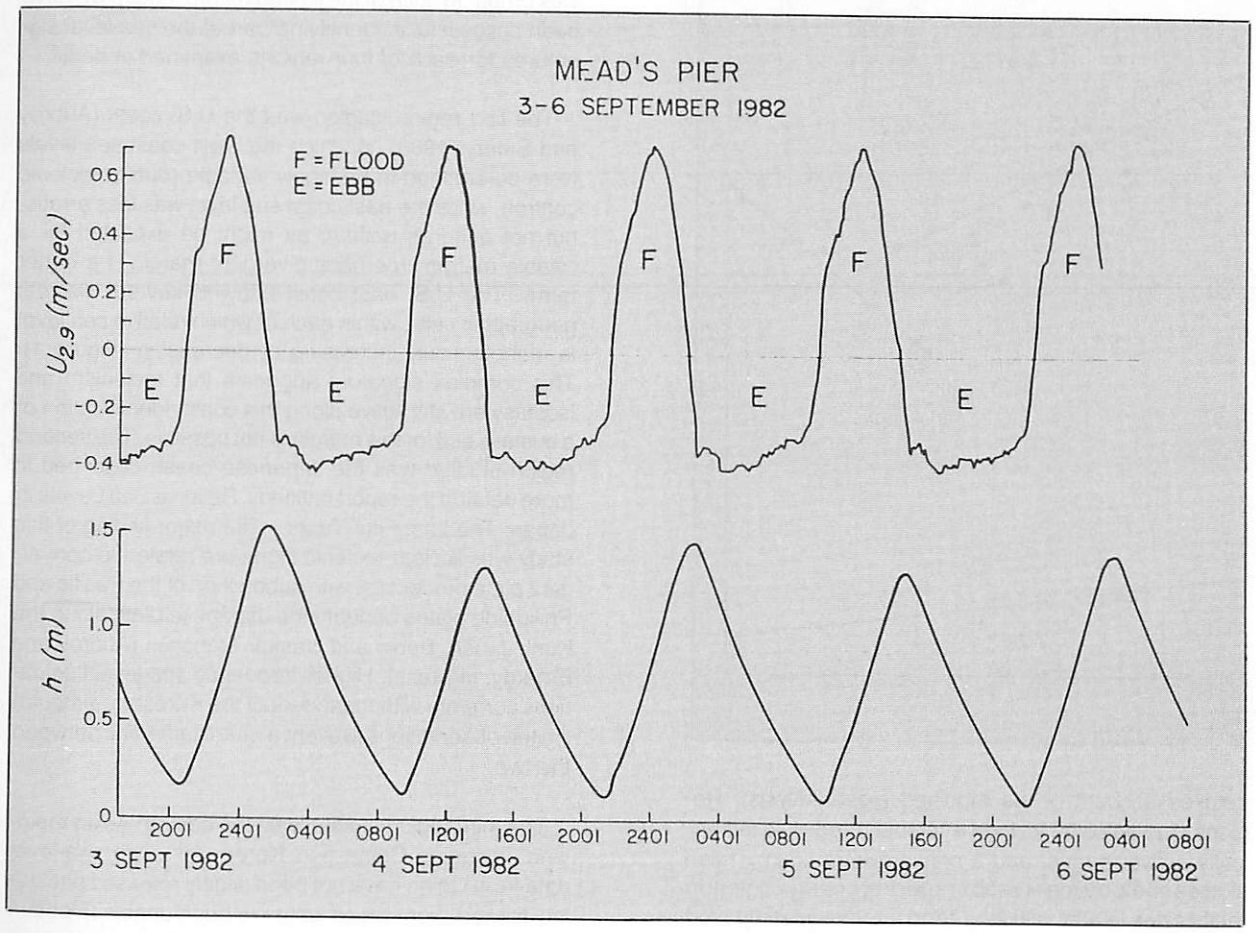

Figure 2. 2.5 day series of sea surface (lower panel) and velocity (upper panel) within the Nauset Inlet/bay system. Tides are strongly asymmetrical within the bay, with flood tides shorter but more intense than ebb tide (see Aubrey and Speer, in press, for details).

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

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Recent concern over the possible effects of increased concentrations of atmospheric carbon dioxide and other trace gases on sea-level rise has provoked a new surge of research into recent relative sea levels (see Aubrey, in press). Emery (1980) and others attempted to define the eustatic rate of sea-level rise over the past century, using tide-gauge data. These analyses were global in scope, making use of nonuniform distribution of stations, which reported for dissimilar time spans. For a variety of reasons, these previous studies had difficulty estimating the true eustatic trend, partly because the eustatic rise has a spatial variability as the increase in water levels attempts to conform to an equi-potential surface.

The purpose of the present Sea Grant project has been to take a closer look at relative sea levels as recorded by tide gauges, first performing regional analyses to define local causes of relative sea-level change, then returning to the global problem to estimate a consistent eustatic signature. Each regional study attempts to separate tectonic effects, isostatic effects, and oceanographic effects, from the larger-scale eustatic signatures. Because of limited station distribution, separation of sea-level causes is more successful in some areas than in others. For regions with dense distributions of tide gauges, the separation is possible with some degree of confidence (Japan, North America, northern Europe, Mediterranean). For other regions, the tectonic signatures cannot be identified with confidence, because of spatial aliasing. In other areas, such as the People's Republic of China, tide-gauge records exist, but have not been released to western sources.

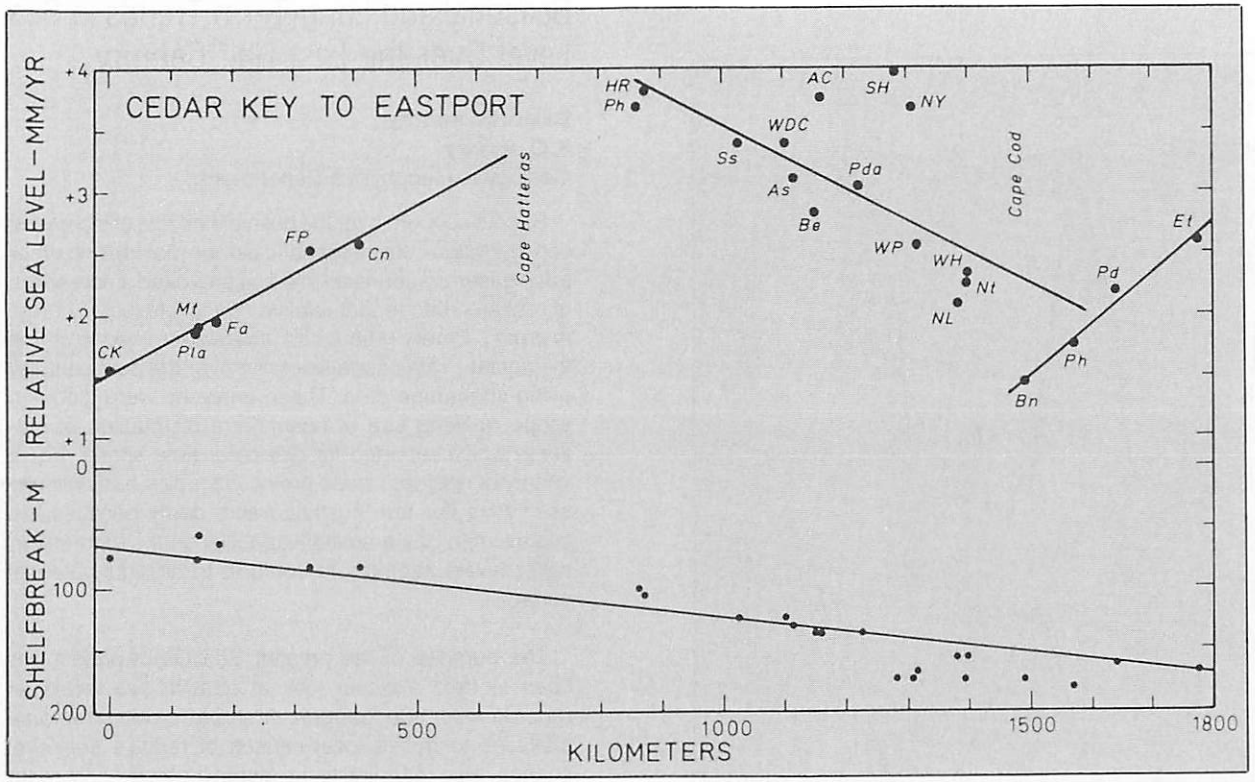

Figure 1. Mean annual relative sea-level changes during 40-year record from eigenanalysis for U.S. east coast stations. Regression lines denote three main segments of east coast having different sea-level trends; these trends are not reflected in depths to shelfbreak at points nearest each station.

Although the analyses have not been completed, some regional studies have been finished. Using a modification of eigenanalysis which allows for data with gaps, coherent patterns of sea-level change have been calculated (see Aubrey and Emery, in press, for a more detailed account of the modified eigenanalysis). Regions studied so far include a "stable margin", a tectonically active margin, and a convergent margin. These studies show a wide spread in spectral energy content in relative sea levels, with long-term trends superimposed on higher frequency relative sea-level oscillations. Our attempt has been to use yearly averaged tide-gauge readings to determine coherent patterns of change on time scales of two years and longer; the seasonal work for much of the coast having sufficient gauge coverage has been undertaken elsewhere, so it was not repeated in this study. Because of limited data record length, spectral resolution is often poor, and confidence intervals broad. In spite of the limited record length, we have been successful in identifying part of the sea-level signatures for each of four regions examined in detail.

The first region studied was the U.S. coast (Aubrey and Emery, 1983), in which the west coast sea levels were determined to be highly variable (due to tectonic control), while the east coast sea level was less erratic, but not quite as uniform as might be expected for a "stable margin" (perhaps divergent margin is a better term). The U.S. east coast showed several discrete geographic cells, within each of which relative sea level is monotonically increasing or decreasing (Figure 1). This complex signature suggests that tectonism and isostasy are still active along this coast. Identification of a eustatic rise for this margin is not possible. The second region studied was the Japanese coast, described in more detail in the report entitled, "Relative Sea Levels in Japan: The Last Fifty Years." The major finding of this study was a clear tectonic signature related to convergent plate processes, with subduction of the Pacific and Philippine plates beneath the Japanese plate along the Kuril, Japan, Bonin and Nankai Trenches (Aubrey and Emergy, in press). Higher frequency sea-level fluctuations correlate with meanders of the Kuroshio, although limited observations prevent a quantitative link between the two.

The third region studied was the eastern Asian mainland, including China and Korea. Although sea-level data from China have not been widely released (including Taiwan, from which we have been unable to obtain tide-gauge records), the 9 stations in China, several in Hong Kong/Macau, and more in South Korea (for a total of 22 stations), allowed us to determine the consistency of records of relative sea-level change with regional geology. Relative sea levels show a consistent rise in Cenozoic basins and foldbelts, while it is falling in areas of massifs and ancient foldbelts (Figure 2). Sparse

tide-gauge data in China are supported by observations of elevated and submerged sea-level terraces (Emery and Aubrey, submitted). We are currently using results from this preliminary study in an attempt to free more tide-gauge results from mainland China and Taiwan.

The final region studied as part of this work is northern Europe, where the Fenno-Scandian and Scottish ice caps depressed the land surface during the last glaciation. Glacial rebound (due to isostasy) determines the major structures of low-frequency relative sea levels in this region (Figure 3; Emery and Aubrey, submitted) with the center of uplift located in the northern Gulf of Bothnia, while a peripheral bulge, now subsiding, surrounds the rebound area. Because of the dominance of glacial rebound, a eustatic signal cannot be identified as it exerts an unknown bias on the isostatic signature. The spectrum of high-frequency relative sea levels is essentially white, in contrast to the sea-level spectra of other regions. Correlations of these high-frequency oscillations with oceanographic and hydrologic factors (sea surface temperature, precipitation, runoff, etc.) are not successful over the entire region of study, largely because of the many water bodies involved (Atlantic Ocean, North Sea, Gulf of Bothnia, Gulf of Finland, Baltic Sea, etc.)

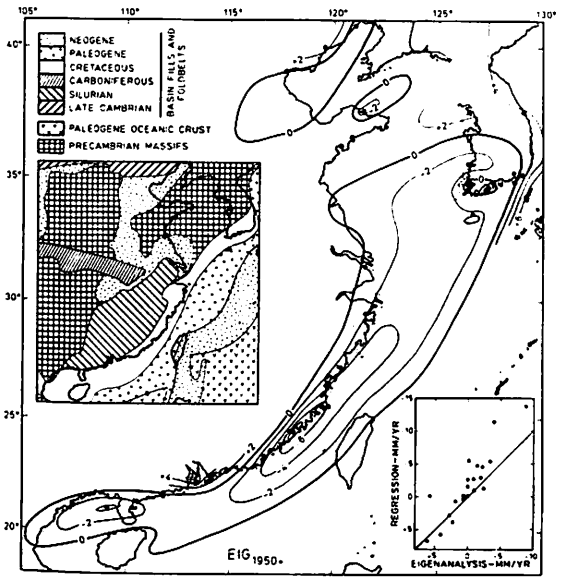

Figure 2. Mean annual change of relative land level in eastern Asia from eigenanalysis. Contours at 2-mm/year intervals depict northeast fabric of relative sea levels. Insert at upper left denotes massifs and foldbelts (see Emery and Aubrey, submitted).

We are continuing other regional studies and hope to address the global eustatic signature in the next year. Because of the nonuniform distribution of tide-gauge stations, we must be careful of our statistical results (as pointed out by many others, including Barnett, 1984). Since the regional studies have been clarifying tectonic and isostatic patterns which are difficult to identify using other types of data, the regional studies serve a dual purpose.

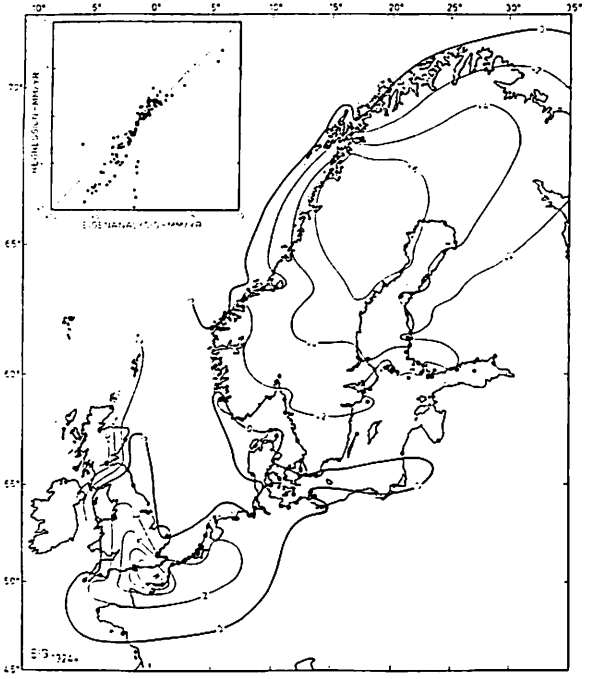

Figure 3. Mean annual movement of land in northern Europe relative to sea level as constructed from eigenfunctions. Contours are in mm/year, positive values indicating relative land uplift.

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Relative Sea Levels in Japan: The Past Fifty Years

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In our investigations of the global behavior of relative sea levels, we have selected specific regions for intensive analysis to identify local causes of sea-level variability, which would be later extracted to improve the signal-to-noise ratio for estimates of global sea-level behavior (see report entitled, "Seasonal and Long-term Trends in Sea Level Over the Last Half-Century"). One of the regions selected for intensive study is Japan, where numerous tide-gauge stations have been reporting over the last thirty years. Previous attempts to clarify relative sea levels in Japan using tide gauges failed to identify any coherent patterns, which are expected to be largely tectonic in origin given Japan's location on a convergent plate boundary.

This new initiative effort focussed on relative sea levels in Japan over the last fifty years, as defined by tide-gauge records. Japan is a good candidate for regional study, because of its large number of tide-gauge stations (86 stations were used in the present study), yielding dense spatial coverage. Temporal coverage is not as good, as only four stations reported over the

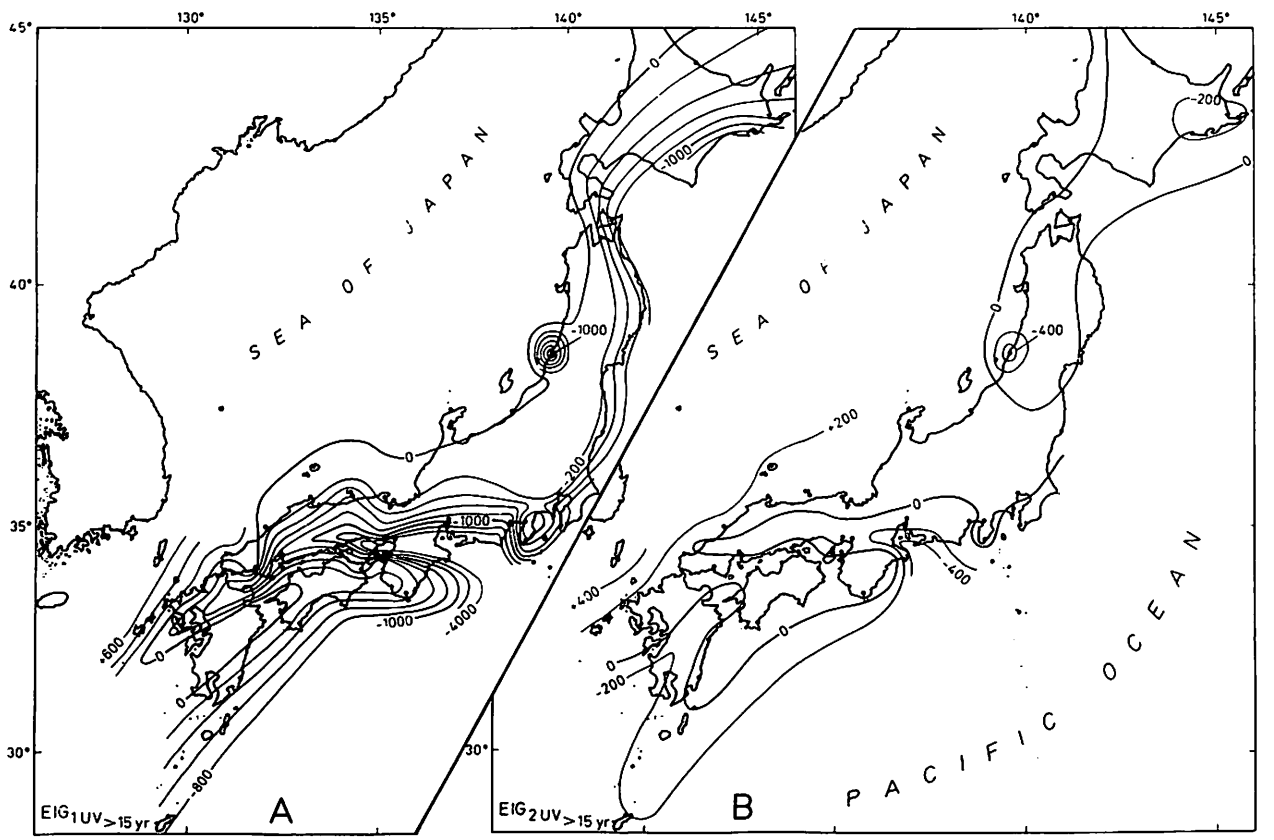

Figure 1. Spatial eigenfunctions for Japan in units of mm at 51 stations, each having unit variance and spanning at least 15 years.
A. First function. Contours are at intervals of 200 units, with 4000-unit contour added. Multiplying this pattern by the temporal eigenfunction trend yields an estimate of sea-level rise in units of mm/year.
B. Second function. Contours are at intervals of 200 units.

period 1930-1954. The remainder of the stations began operations after 1954. In spite of this short period, the study was successful in describing coherent patterns of relative sea levels for Japan (Aubrey and Emery, in press).

Using eigenanalysis, suitably modified to adapt to sea-level records with gaps, the dominant spatial patterns of relative sea levels were obtained. Spatial eigenfunctions (Figures 1 and 2) depict a simple coherent pattern of sea levels, with northern Honshu and Hokkaido tilting towards the east, and southern Honshu along with Shikoku and Kyushu tilting to the south in an imbricate fashion. The spatial eigenfunctions were interpreted as reflecting the tectonic processes occurring along the convergent margin between the Japan and the Philippine and Pacific Plates (Figure 3). Along the east coast of Honshu and Hokkaido, the Japan and Kuril trenches cause tectonic erosion on the overriding Japan Plate as the Pacific Plate is subducted beneath it. This tectonic erosion tilts northern Japan to the east. In southern Japan (southern Honshu, Shikoku and Kyushu), the relative sea-level pattern reflects both present subduction of the Philippine Plate beneath the Japan Plate along the Nankai Trough (Trench), and also former subduction of the Pacific Plate beneath the Japan Plate. Tectonic erosion of the overriding Japan Plate causes the southerly tilt in this case also. Superimposed on this tectonic control of relative sea levels is a eustatic sea-level rise of undeterminable magnitude. Glacial isostasy is negligible in this region, as is hydroisostasy, given the narrow width of the continental shelves.

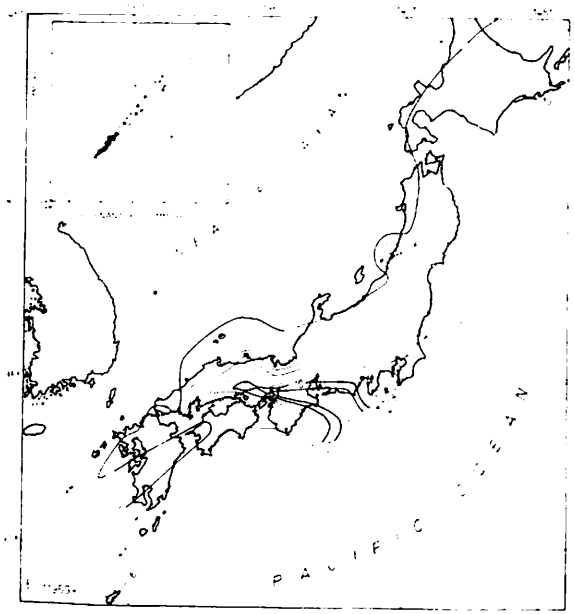

Figure 2. Mean annual relative movement of land in Japan for the period 1953 to 1980 from reconstructed eigenfunction data of Figs. 1 and 4. Contours are in mm/year. Insert shows rates of change in relative elevation at individual stations obtained by both eigenanalysis and regression.

Higher-frequency fluctuations in relative sea levels reflect oceanic processes (Figure 4). Although the record length is short (the pre-1954 records are unreliable as regional averages because only four stations reported prior to 1954), the higher-frequency movements appear to mirror fluctuations in the position of the Kuroshio, particularly meanders of the Kuroshio off southern Japan. Observations of oceanic processes (such as Kuroshio meanders and southern oscillation index) are not sufficiently dense to allow a one-to-one comparison with higher-frequency sea-level fluctuations, but the relationship between Japanese sea levels and oceanic processes appears real.

In regional studies such as this, the emphasis is on defining coherent patterns of relative sea levels, and

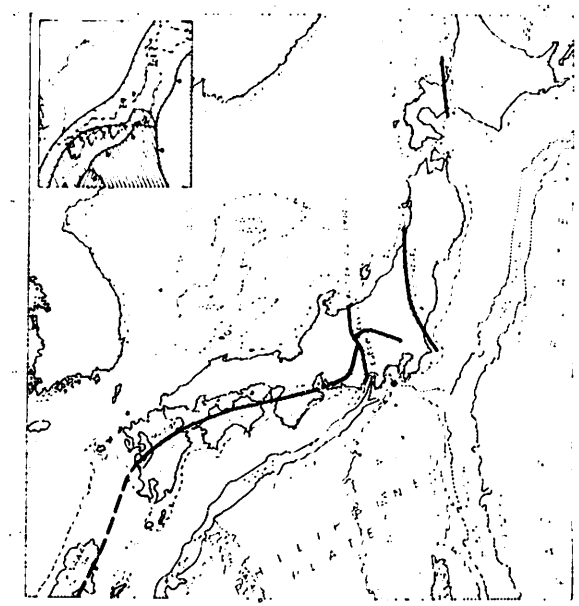

Figure 3. Tectonic trends on land and ocean floor. Insert shows oceanic plates, their present direction of movement, and the areas of overriding crust that have been structurally influenced by the subduction. Approximate shelf break (200-m contour) – dashed line; major positive elements – dotted; trenches and troughs – diagonal lines; plates – named with dates of initial subduction.

separating the tectonic, isostatic, and oceanographic responses of relative sea levels. Once isolated, these regional studies will be used in our global analysis of sea levels, where we try to extract a coherent, eustatic signal from regional behavior. The resulting eustatic signals will be examined for possible trends that may reflect atmospheric warming due to increased levels of carbon dioxide and trace gases in the atmosphere.

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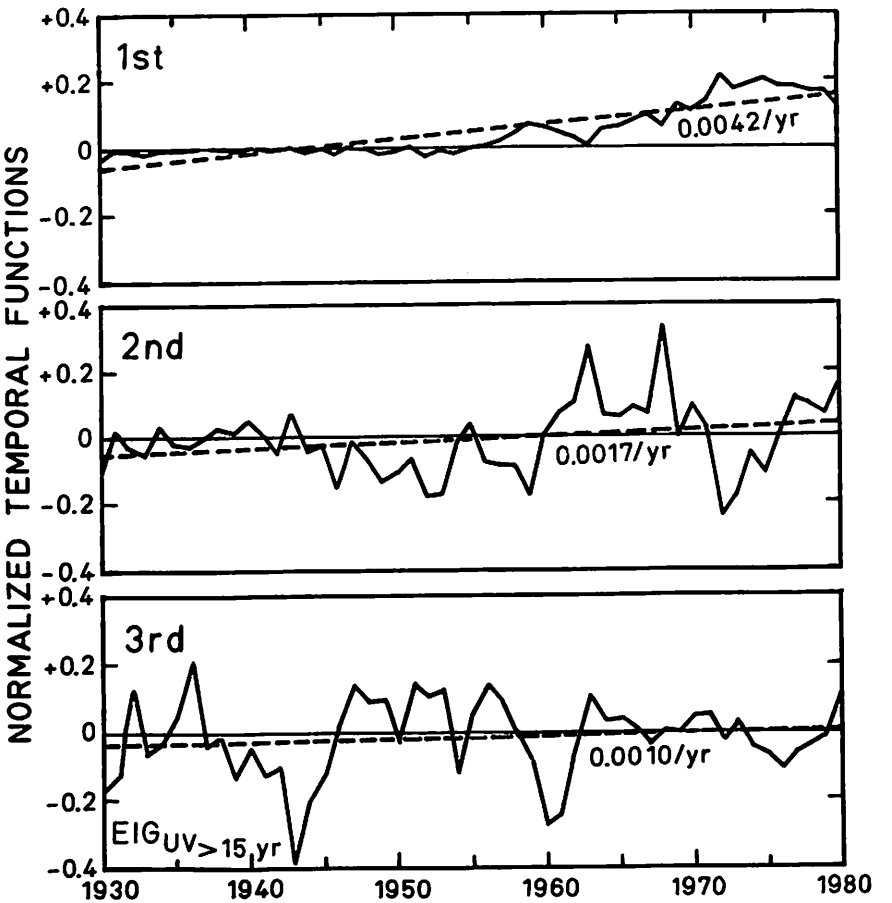


Figure 4. First, second, and third temporal eigenfunctions for same tide-gauge records used in Figure 1. Elevations are dimensionless and normalized. These three functions account for 83, 4, and 3%, respectively, of total variations in records. Note that the best-fit straight line fails to follow the trend of data points, indicating an apparent increase in rate of movement of land or of sea level beginning about 1953 (see Aubrey and Emery, in press, for discussion).

Marine Policy and Ocean Management Center

David A. Ross, Director

The Marine Policy and Ocean Management Center (MPOM) of the Woods Hole Oceanographic Institution (WHOI) supports interdisciplinary research integrating marine science and public policy in numerous important studies. Probably at no time in our country's recent history has the need for objective marine policy research been greater.

Nationally and internationally, the stage is set for rapid policy changes affecting use and management of the marine environment. President Reagan's 1983 proclamation of a 200-nautical-mile U.S. Exclusive Economic Zone adds 3.9 billion acres to U.S. territories and offers incomparable opportunities for the coherent management of living and nonliving marine resources. Also in 1983, the eleven years of negotiation on the Law of the Sea Treaty came to an end and the ratification period began, with the United States indicating that it would not ratify the treaty.

Inevitably, as the United States and other nations around the world begin to assert control over their vast new aquatic territories, the potential exists for jurisdictional and other disputes, especially where important economic or strategic interests are at stake. The complex nature of marine environments and technological or political changes affecting marine policy issues places a premium on objective and timely interdisciplinary research that responds to the informational needs of both policymakers and the broader public.

Because marine environments are highly complex, the process of establishing new marine resource management programs will bring together policymakers and researchers with diverse backgrounds. Policymakers responsible for the design and implementation of effective management programs depend on the availability of adequate scientific information concerning current and potential future impacts of human activities on these highly complex marine environments. Researchers from a wide range of natural and social science disciplines have contributed to a rapid expansion of knowledge regarding marine systems.

Bringing these two groups together in a manner that increases the effective exchange of ideas and information has become exceedingly important in recent years. Dedicated and knowledgeable individuals working at a private research institution with a long-term commitment to marine studies can play a critical role in providing independent analysis and advice, which contributes to the design and implementation of wise public policies affecting use of marine resources.

The Marine Policy and Ocean Management Center is uniquely equipped to contribute to the process of shaping national and international marine policies. The Center's professional staff is comprised of natural/physical scientists, social scientists, and lawyers specializing in marine affairs. We are able to draw on the talents of these individuals as well as on the full marine science expertise of the Woods Hole Oceanographic Institution.

Since its establishment, the Center has sponsored the work of nearly 100 researchers interested in various aspects of marine policy. The majority of these have been scholars just beginning their professional careers who were awarded Postdoctoral Research Fellowships. In most instances these awards have led to continued professional interest and involvement in marine affairs by these Fellows, who have gone on to influential positions in government, academia, and industry.

Individually and as small teams, the Center's staff engages in both specialized disciplinary and broader interdisciplinary research projects. The 16 social scientists presently active within the Center represent the disciplines of anthropology, economics, law, political science, and sociology; combined they constitute, we believe, the largest single concentration within the United States (if not the world) of social scientists working on marine issues. These social scientists often work closely with other researchers from the natural and physical sciences, including the three individuals on the Center's staff who combine such training with interests in policy studies.

Through the publication of research results, the Center's staff has established a solid reputation for research relating to marine resource development, utilization, and protection. The 1983-84 list of completed projects includes, for example, articles on:

- Adjacent State Issues for the United States in Establishing an Exclusive Economic Zone: The Cases of Canada and Mexico;
- Economic Significance of Marine Polymetallic Sulfides;
- Developing a U.S. Research Strategy for Marine Polymetallic Sulfides;
- A Model for Assessing Mean Age-Specific Fecundity in Sea Turtle Populations;
- Preliminary Growth Models for Green, *Chelonia mydas*, and Loggerhead, *Caretta caretta*, Sea Turtles in the Wild;
- The Significance of Signature to the 1982 Montego Bay Convention;
- Economic Evaluation of Ethanol Fuel Production From Agricultural Crops and Residues in California;
- Comparative Maritime Liens: Anglo-Based and Latin-Based Law in the Americas;
- Changing Ocean Policy Horizon for Marine Science;

- The Antarctic Treaty;
- The Problem of Governance of U.S. Ocean Resources and the New Exclusive Economic Zone
- International Jurisdictional Issues in the Arctic;
- Land Grant and Sea Grant: Implications and Limitations of the Model;
- The Law of the Sea and the U.S. Exclusive Economic Zone: Perspectives on Marine Transportation and Fisheries.

These scholarly endeavors, however, reflect only one aspect of the Center's research activities. Equal emphasis is placed on the application of knowledge to national and international marine policy problems. Concern for policy relevance provides unity of purpose to research conducted by the Center's multidisciplinary staff.

Within the broad field of marine policy and the wide range of research interests pursued by the Center's staff, a coherent research program has emerged around the following thematic areas:

1. Law of the Sea issues, implications, and opportunities for domestic and international marine policy;
2. Marine minerals and mining studies;
3. Coastal and fisheries management issues;
4. Interaction of science and policy studies, and
5. Cooperative international marine affairs programs.

These research themes have evolved and will continue to evolve in response to research needs and opportunities posed by social, economic, legal, political, and technological changes affecting marine science and policy. The definition of these research themes is sufficiently broad and flexible to allow the Center's staff to respond quickly to changes in research needs and opportunities. While being responsive to changing in research needs and opportunities. While being responsive to changing circumstances, these themes provide a necessary element of continuity to the Center's research program. As such, they serve to focus our research energies toward a broadly defined set of issues and to indicate for a broader external audience the Center's role and contributions to the field of marine policy.

SUMMARY

Center participants published 5 books and technical reports during the 1983-84 period, as well as contributing 10 chapters to books and 25 articles to scholarly journals. Within the year, MPOM sponsored 19 seminars in Woods Hole by visiting experts on marine policy issues, and the Center's staff participated in numerous workshops and conferences throughout the world.

Significant accomplishments can be cited for each area of research emphasized by MPOM during 1983-84. For example, recent contributions by the Marine Policy Center to national and international marine policy issues associated with Law of the Sea include:

- Publication of a book entitled United States Arctic Interests: In the 1980s and 1990s, edited by two MPOM research fellows.
- Presentations by eight MPOM research staff members in WHOI's two-day Ocean Industry Program, "Marine Policy and Economics, and Our Use of the Sea."
- The initial meeting of the Ocean Policy Roundtable, developed by MPOM as a non-governmental forum. The first meeting and the subsequent report focussed on the establishment of the U.S. Exclusive Economic Zone. Papers resulting from the initial meeting will comprise a special 1984-85 issue of the journal, *Ocean Development and International Law*.

Recent highlights from our international projects include completion of detailed reports for the governments of Ecuador and Colombia. Ecuador's Presidential High Level Commission for the Galapagos Islands invited members of the Center's staff to examine the implications of establishing a coastal zone management plan and a national marine park or protected area in the Galapagos Islands. The final report, "Coastal Marine Resource Management for the Galapagos Islands," has been completed and will be presented to the Ecuadorian government.

In Colombia a team of MPOM researchers assisted in developing a broad diagnosis of the current status and potential for development of a wide range of marine issues from fisheries to transportation. Their final report, "The Management of Ocean and Coastal Resources in Colombia: An Assessment," was presented to Colombian President Betancur in June 1984 by members of the Center's staff who discussed their findings at the Fourth National Seminar on Marine Sciences and Technology, Cartegena, Colombia.

A cooperative program with Brazil was initiated with three individuals from MPOM lecturing in a graduate level course on marine policy and related issues for Brazilian administrators and scientists. The course, held in Porto Alegre, Brazil, was sponsored by Brazil's Coastal Geology Research Center and the Interministerial Commission for Ocean Resources. MPOM hopes to pursue a further project with the Brazilian government on coastal zone management for the entire country.

An Evaluation of Governmental Financial Assistance To The U.S. Fishing Industry

Maynard Silva
Marine Policy & Ocean Management Center

This one year project was designed to analyze certain programs of the federal government that are intended to assist the U.S. fishing industry in financing its growth and development. In particular, the project focussed upon the Fishing Vessel Capital Construction Fund (CCF) and the Fishing Vessel Obligation Guarantee Program (FVOG), which are administered by the National Marine Fisheries Service (NMFS).

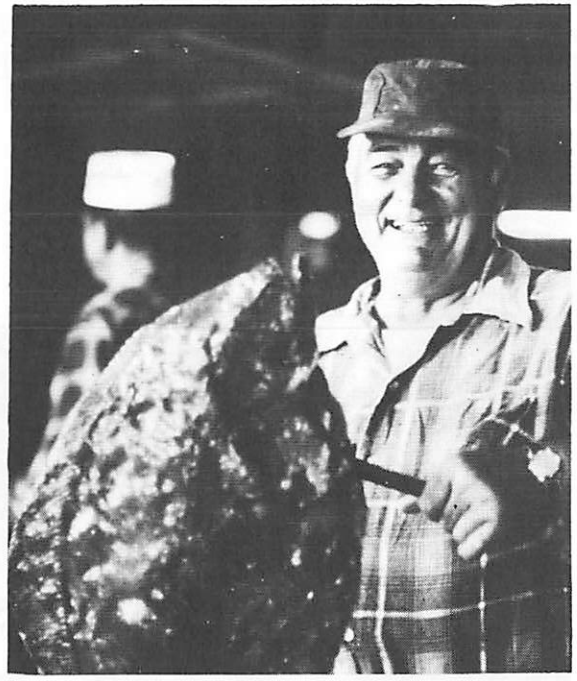
The general questions with which the research concerned itself were: (1) Did these two programs contribute to the growth and development of the U.S. fishing industry?, and (2) Have any externalities, either positive or negative, emerged from the operation of the FVOG and the CCF? These general questions were addressed by asking and collecting data on more specific issues: (1) Who in a socioeconomic sense is taking advantage of these programs?, (2) Are economic impediments to growth and development being removed by these programs?, (3) Have these programs been used by fishermen attempting to move into fisheries for underutilized species?, (4) Has the problem of excess capacity in some fisheries been exacerbated by either of the programs?, and (5) Is participation in either of these programs skewed towards any special segment or fishery of the U.S. fishing industry?

For the CCF, the data was collected from the Washington, D.C. office of NMFS. A random, stratified sample of 487 individuals was drawn from those participants still active in the program at the time of the sample in June 1984. It should be noted that to guard the confidentiality of the participants, the data was collected "blind" — that is, we were given neither the name of the participant nor the vessel names. A participant was defined as anyone who had entered the program from 1977 on. The 487 cases produced data on 1,492 vessels.

The analysis of the FVOG has relied on secondary data. The NMFS commissioned a study by Earl Combs, Inc., of Seattle, Washington, to create a user profile of the FVOG. The Combs' study, based on a sample of 452 vessels in the FVOG program, presented only the aggregated data — it did not attempt to analyze the implications of its findings. This analysis is being completed in the current research and forms the basis for the comparison between the two programs, as well as for the answers to the questions posed above.

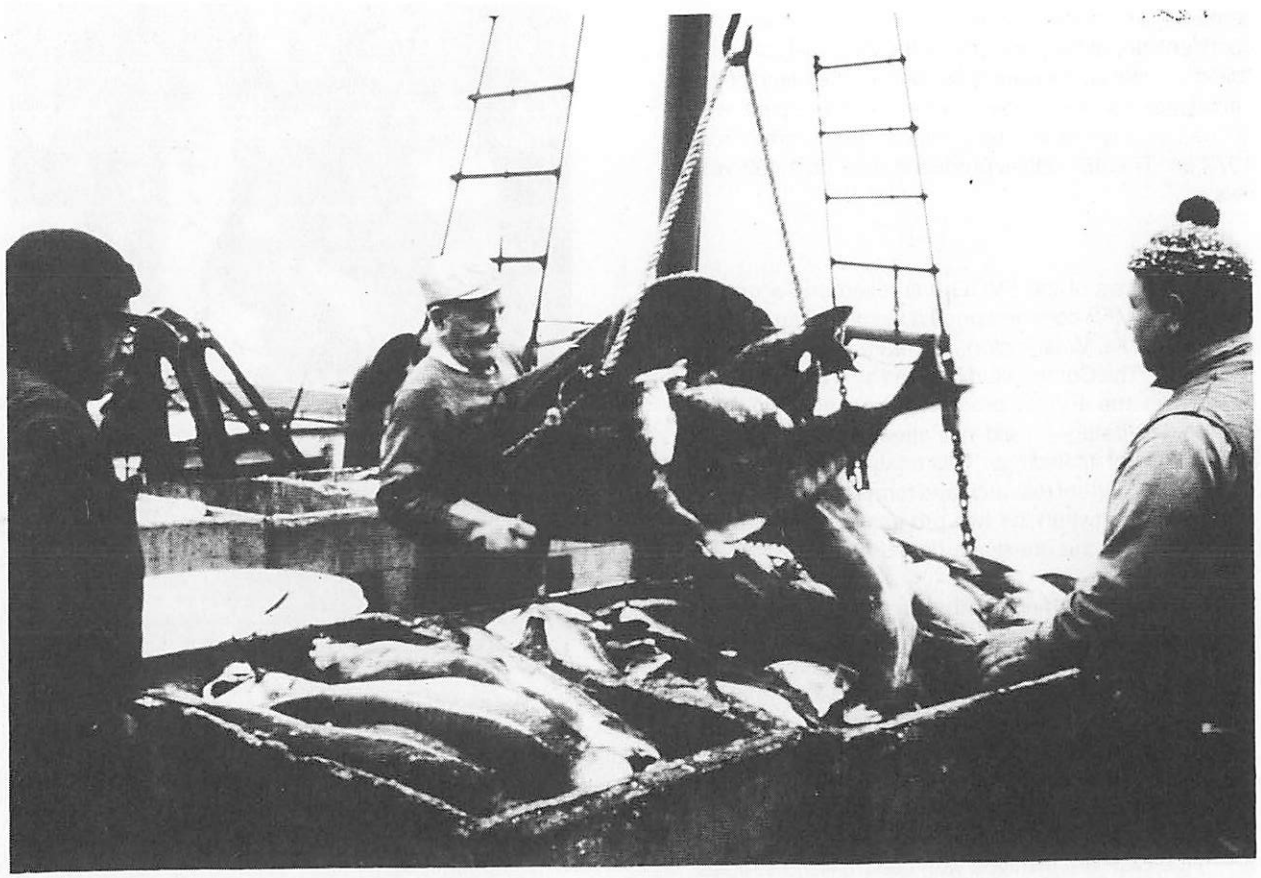
Some of our initial findings that might be of interest are as follows:

1) The majority of participants in the CCF sample fish for salmon in the Pacific Northwest or Alaska. In contrast, the greatest number of FVOG participants come from the shrimp fishery in the Gulf of Mexico.
2) An almost insignificant number of participants in the CCF are involved with underutilized species. The data on the FVOG is less clear, but it would seem that likewise the FVOG is not contributing to the real development of underutilized species.
3) Both the CCF and the FVOG have allowed a small number of fishermen to become owners or to increase their percentage of ownership in the vessels that they operate.
4) It does not appear that either of the programs is being used by non-fishermen to finance tax write-offs.



5) There has been a marked decline in the utilization of the two programs by fishermen, perhaps attesting to the general poor health of the U.S. fishing industry.
6) Relative participation by fishermen from specific fisheries in the two programs may be an indication of the relative health of the fishery. That is, preliminary findings would suggest that fishermen in more economic fisheries are more likely to use the CCF and fishermen from troubled fisheries, the FVOG.

This last point is speculative, and will require more research.



Decision Analysis Applied to Fishery Management Plan Development

Maynard Silva
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Susan Peterson
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Robert Bowen
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and Marine Policy and Ocean Management Center

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During the first eighteen months of a proposed thirty-six, this project has been investigating the process by which complex management decisions are made by the New England Fishery Management Council (NEFMC). One element of this investigation is an attempt to determine whether decision analytic techniques, such as multi-attribute utility theory (MAUT), would facilitate and/or improve the process whereby the NEFMC makes decisions about fishery management plans (FMPs). To make this determination, two hypotheses are being tested against the experience of the herring, scallop, and lobster FMP processes. These hypotheses are: (1) that the decision-making process for each plan, including dysfunctional aspects of scientific information utilization, has been structurally the same; and (2) that the application of decision analytic techniques to recurrent fisheries management problems will lead to more effective decisions, more comprehensive use of scientific and technical information, and management strategies operationally acceptable to a wider range of user and interest groups.

The second element of the research is concerned (as is suggested, in part, by element one) with the utilization of scientific and technical information in regulatory decisions using fisheries as a case study. This element has two phases. The first was the development of hypotheses concerning expected patterns of scientific and technical information utilization by the NEFMC and related fisheries management groups. Completed during the current funding period, the formulation of hypotheses was the product of an extensive literature review, including the compilation of a working bibliography. The second phase, the testing of these hypotheses, will occur during the remaining two years of the research project.

At the time of the grant award, the scallop plan had just been implemented, the lobster plan was pending approval, and the herring plan was being completely redesigned. As a result, the first phase of our study concentrated on the herring fishery FMP because it provided an opportunity to observe the decision-making process firsthand. The in-depth studies of the lobster and scallop FMPs process (based primarily on interviews) will occur during the last two years of the study.

As reported last year, interviews were conducted with representatives from all of the important herring interests. In the current research year we have begun analysis of the data provided by the survey questionnaires. Some initial findings suggest that major evaluative criteria are similar across species, but specific "operational" attributes differ substantially. For example, across species a phenomenon appears that might be called "shifting constituencies." That is, decision-makers are not responding to the interests of consistent groups. Also, the problem of geographical management, in some cases, leads to cognitive dissolution.

With regard to the second element of the study, the literature review has been completed and hypotheses have been extracted for future testing against the examples of the herring, lobster, and scallop FMPs. Those hypotheses that seem most promising, i.e., most conducive to being tested with our case studies, relate to the level of government involved, the saliency of the issue, and the reversibility of the decision. In terms of the instrumental utilization of scientific and technical information, that is, making decisions solely on the basis of what is implied by the scientific and technical information, the literature suggests: (1) that state governments are more likely to directly utilize scientific and technical information, (2) the higher the level of public saliency the lower the level of instrumental utilization, and (3) the higher the perceived level of reversibility the lower the level of instrumental utilization.

During the remaining two years of the study, we will complete the analysis of the survey data collected on the herring management plan, derive general propositions concerning MAUT and FMP development, compare these propositions with the lobster and scallop FMP development processes, test our hypotheses about MAUT, and continue research on the utilization of the scientific and technical information in fishery management decisions.

Science and Public Policy: The WHOI Study of Orleans Town Cove

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Rosamund Ladner
Marine Policy & Ocean Management Center

The Town of Orleans voted at Town Meeting in the Spring of 1981 to appropriate funds for a study of nitrogen loading in Town Cove. Orleans residents were concerned with the possibility that septic systems in town might be polluting Town Cove, a valuable aesthetic and economic resource. If that were the case, sewering of the center of town was suggested as a remedy for the problem. However, townspeople felt that more information about the sources of nitrogen in Town Cove would help them decide among various options for waste disposal. Woods Hole Oceanographic Institution (WHOI) responded to the town's request for a research proposal, and then entered into a contract with the town to complete the study entitled: The Coastal Impact of Ground Water Discharge: An Assessment of Anthropogenic Nitrogen Loading in Town Cove, Orleans, MA. The final report of that study was delivered to the Selectmen in November, 1983.

At Town Meeting on Monday, December 5, 1983, the people of Orleans voted against sewering the center of town and for construction of a septage treatment plant in the Namskaket disposal area. The decision, from the options put forward to the voters, may or may not have been based upon scientific information provided by WHOI. The town's purpose in supporting the WHOI research was to allow townspeople to make informed decisions; the survey reported here was intended to determine whether or not the scientific information influenced public opinion.

We interviewed 87 people, chosen by taking a 10% random sample of the 872 voters who were recorded by the Town Clerk's office as present for part of the December 5 Town Meeting. The interview was designed to a) discover the source(s) of information used by townspeople in coming to decisions about the need for sewers, b) discover what townspeople felt were the most important factors influencing their decisions, and c) elicit background information on the voters so that we could do a proper analysis of the data. Since we were most interested in talking with those people who had voted, the comments of those who left early without voting are not included in this analysis. In addition, eight people, 9% of those telephoned, refused to talk to us.

Sources of Information

Most of the people interviewed said that since the issue had been alive for so long, they were unable to say what their major source of information had been. Everyone with whom we spoke had gotten some information from newspapers: 93% mentioned reading the *Cape Codder,* 59% the *Oracle,* and 39% the *Cape Cod Times.* Summaries of the WHOI report included in newspaper articles were read by 41% of the voters. The second most important sources of information were friends, relatives and/or neighbors; many people differentiated between those with information and those with opinions. Fifty-one percent of the people said that their information came from service on town committees, reports prepared by engineering or consulting companies such as Metcalf and Eddy, experience from other communities in which they had lived, and special information because of professional experience of their own or a family member.

Forty-three percent of the voters were familiar with the report of the Waste Management Cost Distribution Committee; 23% of the voters had learned about details of the issue from town officials, for the most part, from selectmen. Twenty-two percent mentioned Dr. John Teal of WHOI as a source (from his presentation at the Selectmen's meeting, League of Women Voters' meeting or Town Meeting); 18% had read the Cape Cod Planning and Economic Development Commission report on the sewer issue; 14% mentioned the Association for the Preservation of Cape Cod as a source of information. The Orleans Taxpayers Association was mentioned by 10% of the people.

Factors Influencing Decisions

Forty percent of the voters said that environmental issues influenced their decisions most. This is a broad category, so we include some comments from the voters:

"The most important issues that influenced me were evidence regarding pollutants to Town Cove and lack of significant contribution from the core area."

"The most important issue was to protect water quality — not money. We need to plan for the next 30 to 40 years. Families should have a clean environment. I'm not in sympathy with business people who didn't want sewers. I'm willing to pay an increase in taxes to protect the sole source aquifier."

"The most important thing was the necessity for clean groundwater."

"The protection of groundwater and coastal areas was most important."

"The threat to the environment was the most important thing to consider; the present waste processing system is a threat."

"The quality of our water is most important. I guess the WHOI report influenced me to some extent, but I sure hope you were right."

Thirty-two percent of the voters said that the WHOI report was most important because it indicated to them that there was no need for sewers. Again, comments from the interviews:

"My decision was based 90% on the WHOI report."

"The WHOI report was the most important thing that influenced my decision. I was banking on it. The fact that it was an objective report was key to people in changing their minds."

"The WHOI study gave a better understanding of effects on marshland. The charm, beauty of the natural environment, beaches and marshes, are being spoiled. If it is spoiled, the town will have lost everything."

"The most important thing that influenced me was the WHOI report. The reason is simple. Until it came out, I didn't know what to think. But they made two points. First, groundwater does not flow uphill from town center, so why sewer. Second, the nitrogen mostly came from natural causes and if there were a sewer system in town, its results couldn't be measured. But it was still an imperfect decision based on partial data."

Background Information on the Voters

Fifty percent of the sample of Orleans voters have lived in town for less than 10 years, although half of the "newcomers" had spent summers in Orleans for many years before moving there. These newcomers were predominantly (65% of them) over the age of 65. More of the newcomers had read the WHOI report than had the longer-term residents, and more of them cited environmental issues as being the most important factor influencing them about sewers. The longer-term residents did not have significant agreement on the most impor-

tant issue, but they did agree on the second most important thing: cost.

We hypothesized that place of residence might influence the kinds of information people sought or used. Ninety-seven percent of the sample owned their homes, but only a small proportion of voters lived in those areas that would likely be affected directly by sewers and/or septage treatment plants. We looked at the results to see whether the group that lived/owned in areas likely to be affected were any different than those voters in other areas. We found that the affected group was more likely to have attended the Selectmen's meeting, League of Women Voters' meeting, read the WHOI executive report, read the entire WHOI report, read the *Oracle*, referred to Dr. Teal, and cited *need* as the first factor, and *cost* as the second factor than the unaffected group, i.e. those who did not own property in town center or the Namskaket marsh area.

Was the scientific research done by WHOI useful in helping the townspeople come to a decision about sewers? Eighty-seven percent of those interviewed said it was useful in some way; 52% said it gave specific information that they had not had before; 27% said that it addressed problems about water quality they felt were important; 22% mentioned Dr. Teal's summary as having influenced them or other voters. Naturally some voters were critical of the report; 23% thought it should have been broader, 18% thought it should have been presented to the voters in more detail; 8% said it should have been done sooner.

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Resource Projections, Contingency Planning, and Secondary Investment Targets: The Case of Ocean Mining

James Broadus
Marine Policy and Ocean Management Center

As in other large-scale innovative development projects for extraction of natural resources, decisions to proceed with an investment in seabed mining have been discouraged by high risk imposed by a long period of waiting, or lead-time, for suitable market conditions and technology development. Reduction of this risk would lower the cost of such projects and promote the further development of new marine resources for a broader and more stable resource base. The objective of the research was to identify means of reducing the cost of risk in such projects and improving the project's overall economic prospects through use of contingency planning, increased versatility in systems design, and *ex ante* targeting of secondary investment objectives.

The Principal Investigator was able to draw on extensive knowledge of the emerging seabed mining industry based on his earlier Sea Grant study of its evolving industrial structure. He was joined by Guest Investigator Jan L. Van der Voort, who provided understanding of investment decision-making in the seabed mining industry from her position as Planning, Market Research and Financial Analyst with Deepsea Ventures, Inc. Van der Voort also worked with the Year 2000 Committee, studying the use of natural resources projections and data by private corporations.

A simple four-period model of a proposed seabed mining project's expected lifetime performance was used to determine the value of contingency planning for interim and alternative revenue targeting. The seabed mining consortium is treated as a unified, rationally-acting firm with a well-defined objective to maximize the present value of net returns to its activities. Research and development investment is made in the first period and mining investment in the second. The uncertain lead-time is collapsed into a single third period during which a stochastically-determined "risk penalty" is imposed on the project as an additional cost. In the final period, seabed mining is either achieved and pays fixed revenues with a known probability or forever fails for the firm.

If improved versatility can be designed into the system to make it more suitable to other uses, either during project lead-time or in the event that the primary objective is not achieved, then interim or alternative revenues may be earned to offset the initial investment. These additional revenues are made possible by a supplementary investment in contingency planning and secondary targeting and in designed versatility for the seabed mining capacity. Improved versatility could improve the project's expected economics and increase the likelihood that the investment will be made. The condition for this improvement is that the expected sum of the interim and secondary revenues be greater than the supplementary investment plus the expected value of secondary revenue foregone if seabed mining is achieved. The value of the approach is weakened as the likelihood of success in the primary target is increased, but it becomes more worthwhile as uncertainty about the primary objective increases.

This research has been completed and results are being prepared for publication in a working paper, "Contingency Planning for Interim Revenues and Salvage Values To Reduce the Effects of Risk in Investment Decisions For Large-Scale, Long Lead-Time, Innovative Natural Resource Development Projects: The Case of Seabed Mining" by J.M. Broadus and J.L. Van der Voort.

Marine Assistance Service

Arthur G. Gaines, Jr.
Marine Science Advisor

The National Sea Grant College Program aims to bring the intellectual capability of the U.S. academic research community to bear on improving our use of the coast and its resources. In addition, Sea Grant promotes advisory services and maritime education to disseminate new information, heighten awareness of coastal issues and provide a channel for public feedback to the Sea Grant research and administrative program areas. At Woods Hole our principal Sea Grant focus is on research, the chartered objective of this Institution. Nevertheless, our Marine Assistance Service, though small, provides several of the advisory service elements offered by other Sea Grant Programs and serves as a link with the national Sea Grant advisory network. Beyond our Sea Grant activities, ongoing education, information and public information programs within the Woods Hole Oceanographic Institution (WHOI) represent a major, worldwide contribution (Table 1). Information regarding these activities is available from the appropriate WHOI office or the Marine Assistance Service.

The Marine Assistance Service at WHOI Sea Grant provides an avenue for individuals or groups outside the scientific community to interact with or benefit from the staff and resources not only of this institution, but of the entire National Sea Grant College Program network. Typical of advisory activities elsewhere, our effort takes many forms: telephone and letter response to questions; literature searches; referrals to other research and advisory programs and consultants; seminars, conferences and workshops; cooperative research projects; news releases and feature stories. Three examples of recent or ongoing activities, given below, illustrate our thrust.

Forum on Coastal Issues of Cape Cod and the Islands

In addition to the many state and federal responsibilities and programs in the coastal zone, numerous important decisions fall within the purview of local government, such as aspects of land use (zoning), delivery of public utility infrastructure (water and sewage), solid waste disposal, provision of recreational facilities (beaches, harbors, docks), etc. In Massachusetts, under the provisions of the Wetlands Protection Act, local Conservation Commissions are given statutory authority to administer state laws protecting salt marshes, dune fields, intertidal areas and other coastal environments. With the rapidly growing population of most coastal areas (e.g., Barnstable County population increased by 50% during the 1970s), new and old coastal problems are, in some cases, becoming manifest for the first time. At the same time, local govern-

Table 1
Information and education activities conducted by the Woods Hole Oceanographic Institution.

Public Information Office — Operates public information service; issues news releases on Institution 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 a large number of seminars, annually, to private groups.

ment is increasingly extended in its ability to deal with these responsibilities. In some Cape Cod towns, the principal administrators (the selectmen) are only part-time. Many towns do not have professional planners, and most towns depend heavily upon volunteers to staff planning boards, conservation commissions and special study committees, such as for sewer planning.

On October 13, 1984 we co-sponsored a forum to identify and discuss major coastal issues of Cape Cod and the Islands of Nantucket and Martha's Vineyard (Figure 1). The meeting was geared to local decision-makers, including selectmen, health agents, shellfish officers, building inspectors, conservation commissioners and town planners. Speakers on each topic included an official who has dealt with the topic locally, as well as a technical speaker with expertise in the area. The objective was to identify areas in which available scientific information could help resolve issues as well as areas where new research is needed. The one day forum attracted 40 key officials from this area of Massachusetts. We concur with the participants that this forum should be only the first of a series to update and refine our perceptions of coastal issues and the resources that bear on their resolution.

Figure 1. Mr. Jon Witten, Falmouth, Massachusetts Town Planner, participating in the Forum on Coastal Issues of Cape Cod and the Islands.

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

The shellfish resource of the United States is subject to increasing exploitation as the demand for this seafood continues to rise. At the same time, for inshore species, water pollution has led to closure of many of the best production beds. As a result, considerable effort has gone into aquaculture and depuration techniques to increase or better control the shellfish supply. One technique that has met with particular success in Japan involves culture or shellfish species in tiered nets, so-called "lantern nets", suspended from buoyed lines (Figure 2). This approach maximizes the use of water column space, provides ease in manipulating and cleaning the shellfish, and reduces predation by bottom dwelling organisms, a major source of shellfish mortality.

The purpose of this project is to help assess the practicality of lantern net technology in local waters, and 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, ideally situated for aquaculture, at the mouth of Buzzards Bay. In cooperation with Penikese Island School and with the help of the Barnstable County Cooperative Extension Service, we intend to construct a 100 net shellfish farm, along with the physical infrastructure needed to maintain it and harvest the product. With expertise provided by the Penikese Island Shellfish Project Advisory Board we will select one or more shellfish species for the first attempts. Serious consideration is being given to growing the bay scallop *(Argopectin irradians)*, because of its rapid growth rate, high retail price, and the potential that a harvestable crop could be produced in a single growing season. This would have the advantage that losses during the stormy winter season (when the island is not inhabited) could be minimized, and students could see the fruits of their labor in a shorter term.

At present the lantern nets have been purchased, a servicing raft is in advanced stages of construction, and other needed materials have been assembled at the island. We anticipate the first shellfish will be introduced into the nets in the spring of 1985.

Nutrient Loading in Coastal Ponds

With the burgeoning coastal population of the nation, increasing amounts of nutrients are entering our coastal waters as a result of many human activities producing

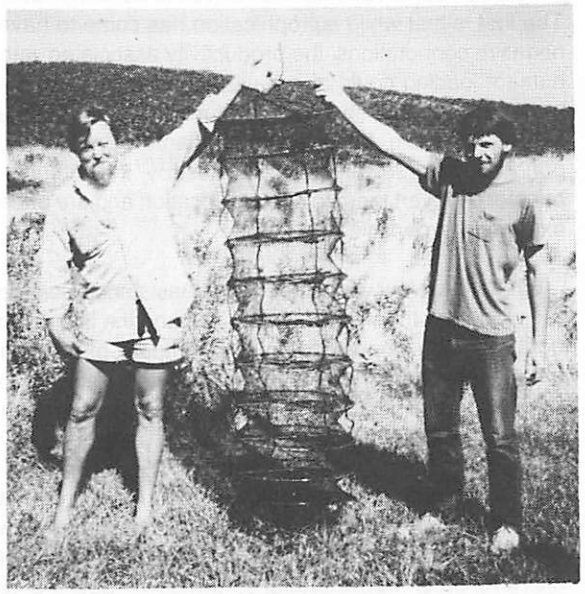

Figure 2. "Lantern nets" for use in the pilot scale facility at the Penikese Island School. (Photo courtesy Arthur G. Gaines).

these substances. The former concern for direct, point-source discharge is now giving way to the realization that regardless of where one "puts" nutrient-containing materials such as sewage, animal wastes and fertilizers, for practical purposes they ultimately will end up entering the sea at the coast, often as nonpoint-source discharge with groundwater. Where the coastline includes embayments or brackish coastal ponds and lagoons, the processes of dissemination characteristic of the open coast are less effective. As a result, the first areas where one may expect to see an impact of nonpoint-source nutrient loading could be these restricted bodies of water, which often are regarded as prime sites for residences and other concentrated human activity.

Two additional considerations need to be recognized. The first is that while eutrophication has come to have negative connotations, the productivity associated with nutrient loading could also have benefits, such as enhanced fish and shellfish production. Second, the means available for diverting nutrients from coastal ponds, such as sewering, do not "destroy" the nutrients, but merely divert them to another location and are often extremely expensive.

For the past few years the Marine Assistance Service has worked with towns on Cape Cod and the Islands in identifying the impact or potential impact of nutrient loading on coastal ponds and estuaries, relative to natural sources of nutrients in these environments. Last year's WHOI Sea Grant annual report described our research in Town Cove, on behalf of the Town of Orleans. The project concluded that natural sources of nitrogen nutrients are relatively large compared with sources from a proposed sewered area. On the basis of this and other considerations, the town decided to forego sewering and to construct a modern septage treatment plant at considerable monetary savings. This plant would eliminate unsightly leach pits from the town dump, eliminate possible public health violations there, and divert the leachate toward an open coastal stretch, where its discharge with the groundwater is less likely to be troublesome. This decision was endorsed by the U.S. Environmental Protection Agency and Massachusetts Department of Environmental Quality Engineering, and federal funding has recently been approved for the construction.

Other towns have expressed similar concern over perceived water quality degradation in their coastal ponds; we presently have cooperative projects with the towns of Oak Bluffs and Tisbury, on Martha's Vineyard, as well as with the Town of Falmouth, to define the issues better, as well as to obtain field measurements to characterize the ponds with regard to certain nutrients levels and inputs, flushing, occurrence of benthic plants, etc. On these projects the Marine Assistance Service is working directly with Boards of Selectmen, Shellfish Officers, Town Planners, regional planning agencies, other town officials and private citizens. Because aesthetics and arbitrary value systems are integral to the perception of water quality (in cases where public health standards are not violated), field measurements play only a partial role in our work.

Our ongoing interactions with government agencies at the federal, state, regional and local levels, and with private groups and individuals provides insight to the Marine Assistance Service into coastal issues of current concern. Through our own program effort, interactions with staff and resources of the Woods Hole Oceanographic Institution, and networking with the National Sea Grant College Program, we hope to continue addressing those concerns to the fullest extent possible.

Program Development

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

During the 1983-84 year the following projects were initiated through this fund. You will find reports on these individual projects elsewhere in this publication.

Relative Sea Levels in Japan: The Past Fifty Years

Tidal Distortion in Shallow Estuaries

Resource Projections, Contingency Planning, and Secondary Investment Targets: The Case of Ocean Mining

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

The Impact of Nutrients on Coastal Ponds with Special Attention to Nitrogen Loading

Paralytic Shellfish Poisons: Fundamental Studies Supporting the Development of Analytical Methods

Science and Public Policy: The WHOI Study of Orlean's Town Cove

Forum on "Major Coastal Issues of Cape Cod and the Islands: A Local Perspective"

PUBLICATIONS

Fisheries Biology and Management

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Program

Gately, E.M., 1984. Woods Hole Oceanographic Institution Sea Grant Annual Report, 1982-83, 40 pp.

SUMMARY OF PROJECT STATUS

Program	1983	1984
Fisheries Biology and Management		
Toxic Dinoflagellate Blooms (Red Tides) in Southern New England, D.M. Anderson	CG	CP
Comparative Reproduction and Developmental Strategies of Populations of the Bay Scallop *Argopecten Irradians Irradians* (Lamarck) in Shallow and Deep Water Embayments, J.M. Capuzzo/G.R. Hampson	CG	CP
Application of Stage-Classified Demographic Models to Atlantic Salmon Populations, H. Caswell/R. Naiman	CG	CP
Lipids and Metamorphosis in Marine Bivalve Larvae, R. Mann/S. Gallager	NS	CG
Decision Analysis Applied to Fishery Management Plan Development, S. Peterson/ M. Healey/ R. Bowen/ M. Silva	CG	CG

SUMMARY OF PROJECT STATUS

Program	1983	1984
Lantern Net Shellfish Culture: A Pilot Scale Facility at Penikese Island School, Mass. A.G. Gaines	NS	CP
Paralytic Shellfish Poisons: Fundamental Studies Supporting the Development of Analytical Methods, S. Hall	—	NS/CP
Human Impact On The Marine Environment		
Physical Processes and Biogeochemistry of Environmental Contaminants: General Considerations and Application to PCB Pollution Problem in Buzzards Bay, J. Farrington/W. Grant/ R. Beardsley	NS	CP
Coastal Sediment Transport		
Natural Tidal Inlet Bypassing, D.G. Aubrey/P.E. Speer	CG	CG
Georges Bank: A Book and Atlas, R.H. Backus	CP	—
Seasonal and Long-Term Trends in Sea Level Over the Last Half Century, D.G. Aubrey/ K.O. Emery	CG	CP
Relative Sea Levels in Japan: The Past Fifty Years, D.G. Aubrey	—	NS/CP
Tidal Distortion in Shallow Estuaries, D.G. Aubrey/P.E. Speer	—	NS/CP

Program	1983	1984
Marine Resource Development		
Marine Policy Initiatives, D.A. Ross	CG	CG
Economic and Legal/Political Aspects of Deepsea Polymetallic Sulfides, J.M. Broadus/R.E. Bowen/ I. Pires/M.J. Mottl	NS	CG
An Evaluation of Governmental Financial Assistance to the U.S. Fishing Industry, M. Silva	NS	CP
Resource Projections, Contingency Planning, and Secondary Investment Targets: The Case of Ocean Mining, J.M. Broadus/J. Van der Voort	NS	CP
Science and Public Policy: The WHOI Study of Orlean's Town Cove, S. Peterson	NS/CP	—
Program Administration		
Marine Assistance Service, A.G. Gaines	CG	CG
Program Administration & Development, D.A. Ross	CG	CG
The Impact of Nutrients on Coastal Ponds with Special Attention to Nitrogen Loading, A.G. Gaines	—	CP
Forum on "Major Coastal Issues of Cape Cod and the Islands: A Local Perspective", B.W. Tripp/A.G. Gaines	—	NS/CP

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

BUDGET 1983-84

	NOAA* Grant Funds	Matching Funds
Marine Resources Development		
Aquaculture	$ 60,700	$ 43,695
Living Resources, other than Aquaculture	87,600	92,040
Mineral Resources	41,300	15,936
Socio-Economic and Legal Studies		
Marine Economics	23,900	5,114
Socio-Political Studies	78,700	105,727
Marine Environmental Research		
Research and Studies in Direct Support of Coastal Management Decisions	60,800	33,140
Ecosystems Research	18,500	41,402
Pollution Studies	143,500	68,165
Advisory Services		
Other Advisory Services	60,300	000
Program Management & Development		
Program Administration	134,700	18,475
TOTAL	$710,000	$423,694

* National Oceanic and Atmospheric Administration

OUTSIDE PARTICIPATION 1983-84

Academia

State University of New York at Stony Brook
Tabor Academy, Marion, Massachusetts
Marine Biological Laboratory, Woods Hole, Massachusetts

Industry

Frank M. Flowers, Inc., Bayville, New York
Bluepoints Co., Inc., W. Sayville, New York
Bristol Shellfish Farms, Round Pond, Maine
Intertide Corporation, No. Hapswell, Maine
Battellè Labs, Sequim, Washington
ALCOA

MATCHING FUND SOURCES 1983-84

Woods Hole Oceanographic Institution	
Education Office	$112,948
Marine Policy Center	112,752
Coastal Research Center	41,402
Mellon Foundation	27,395
Donner Foundation	22,500
Matamek Research Station	65,483
Tabor Academy	10,000
Battelle Northwest Laboratories	1,000
Various industries	4,800
ALCOA	15,554
Pacific Biological Station	9,360