1979-1980 Annual Sea Grant Report Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION
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1979-1980 Annual Sea Grant Report Woods Hole Oceanographic Institution

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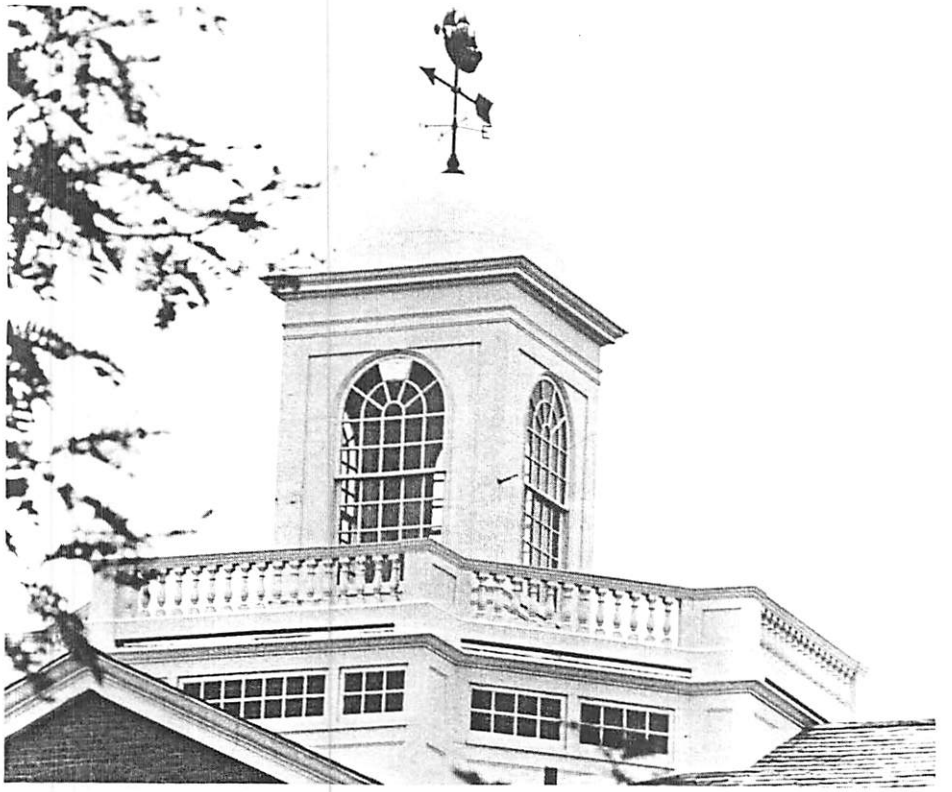

The Woods Hole Oceanographic Institution is a private, non-profit research institution dedicated to broad research and educational programs in all aspects of marine science and technology. We have five departments: Biology, Chemistry, Geology and Geophysics, Physical Oceanography, Ocean Engineering, and a Marine Policy and Ocean Management Program. Our ships and scientists work in all parts of the world's oceans, often in cooperation with colleagues from other institutions and countries.

Introduction

The National Sea Grant Program represents a partnership between the Federal Government and academia whose main objective is to increase the understanding, assessment, development, utilization, and conservation of the Nation's ocean and coastal resources. This goal is achieved by the development of responsive research activities, a strong educational base and broad and prompt dissemination of knowledge and techniques.

The Sea Grant Program of the Woods Hole Oceanographic Institution encourages these objectives by its many research, education and advisory activities. The importance of our coastal and ocean resources has been the theme for much of the research at the Institution and the recent development of our Coastal Research Center has sharpened our focus in the science and policy aspects of this region. We have benefitted in this regard from local, state and federal support and interaction. Sea Grant has been especially valuable to us and has helped develop and expand many new areas of research relative to our use and conservation of our marine resources. The continuing growth of our Sea Grant Program has had positive effects on other research and policy work throughout the Institution. During the past year we had programs in Coastal Zone — Geological and Physical Aspects; Coastal Zone — Biological Aspects; Chemical Processes and Pollution; Aquaculture; and Marine Policy.

David A. Ross
Sea Grant Coordinator
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
December 1980

The Coastal Zone — Physical and Geological Aspects

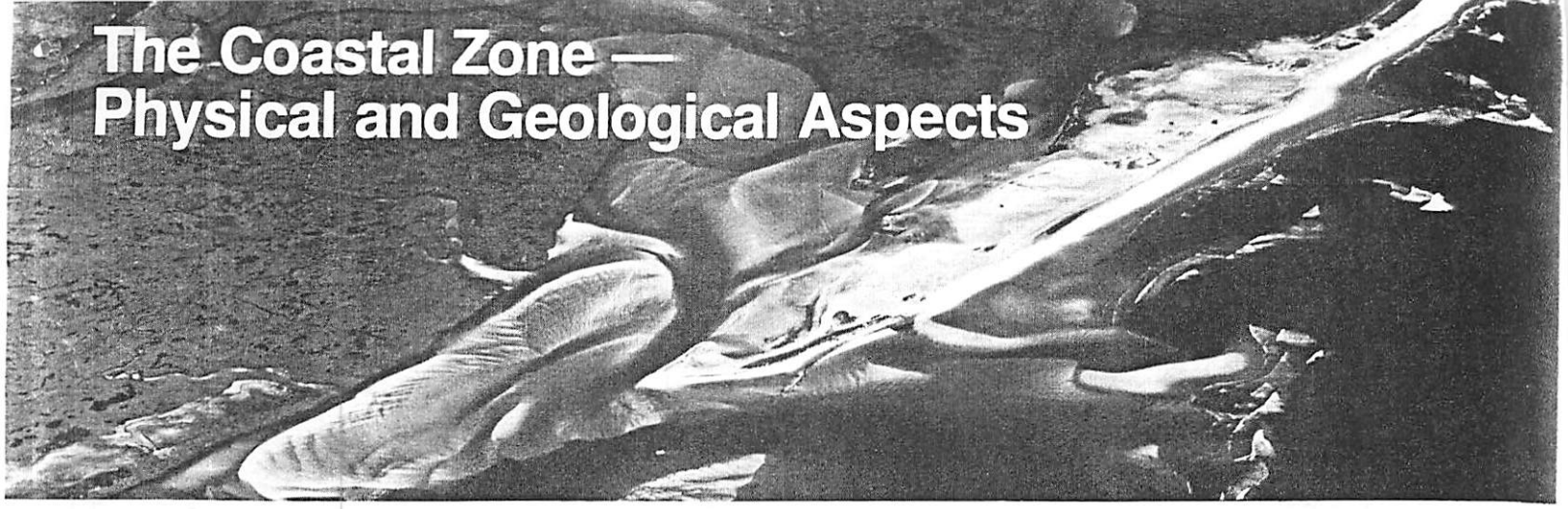

Figure 1. Nauset Inlet, Cape Cod, MA, August 1980.

Sediment Transport in a Tidal Inlet

David G. Aubrey, Department of Geology & Geophysics

The pathways and rates of sand movement around tidal inlets directly affect the navigability of inlet channels in the presence of large quantities of longshore sand movement. The mechanisms by which sand bypasses tidal inlets also have significant impact on dredging strategies and on placement of jetties and breakwaters in an inlet region. The present study is an effort to better define the rates and pathways of sand movement in and around a natural, unstructured tidal inlet, Nauset Inlet, on Cape Cod, Massachusetts. Field and theoretical studies are combined to model the sediment transport in tidal inlets.

For high energy events such as storms, during which instrumentation deployed within an inlet would almost certainly be lost, aerial photos and an offshore directional wave and tide gage are being used to study changes in inlet geometry. For more quiescent periods, intensive week-long experiments are run to measure flow fields and resultant sand movement. Specific quantities measured include sea-surface elevation both on the ocean and bay sides of the tidal inlet, as well as offshore at the wave gage and at two locations within the back reaches of the bay. Vertical arrays of current meters are deployed at different locations within the inlet to examine the vertical structure of the mean flow, as well as to estimate near bottom shear stresses. Bedform and inlet geometries are also accurately measured to better match field data to mathematical models of inlet flows.

In the future, we hope to deploy bedload and suspended load meters to evaluate our estimates of sediment transport based on velocity measurements. These measurements will be compared to a numerical model of water motions and sediment transport in tidal inlets now under development. The results of the study should be of interest to engineers concerned with inlet stability and maintenance of navigation channels, to coastal zone managers concerned with maintaining our barrier beaches, and to the local townspeople who depend on the ocean/inlet/bay system for fishing and recreation.

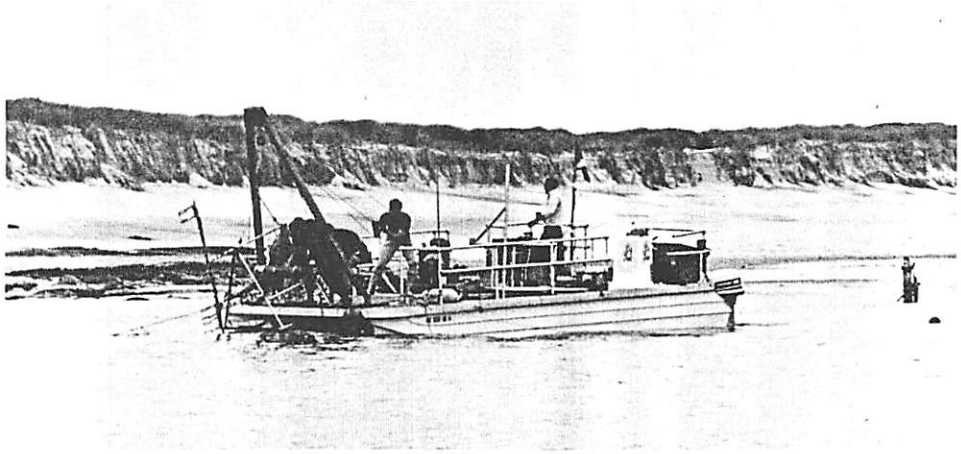

Figure 2. Retrieval of acoustic current meter array — Nauset Inlet, Cape Cod, MA.

Moveable Bed Roughness in the Coastal Zone: Field Study and Model Design

William D. Grant and Albert J. Williams, III, Department of Ocean Engineering

Accurate models of bottom friction on the continental shelf are necessary to understand and predict a wide variety of coastal processes important to solving many applied problems. These processes include sediment transport, coastal currents, near-bottom velocity profiles, and the dissipation of wave energy, as surface gravity waves propagate across the shelf. Over the past two years, we have been studying the bottom friction developed over moveable beds under oscillatory flows on the shelf. Due to the complex nature of the fluid-sediment interaction occurring at the sea bed, we first reviewed existing laboratory studies to help us develop simple models which could be used then to define testable hypotheses for future field experiments. The second phase of the study will consist of field measurements to test and refine our model.

The results of the modeling effort based on laboratory data have been quite revealing. A roughness model has been developed which predicts the roughness over moveable beds in oscillatory flow. The roughness is partitioned into two distinct contributions. The first contribution is associated with the form drag over the wave ripples. From dimensional analysis and similarity arguments, the form roughness is found to be a function of the ripple height and steepness. The second contribution is associated with intense sediment transport near the bed. The roughness is found to be proportional to the thickness of the near-bed sediment transporting layer which is a function of the excess shear stress at the boundary. The results show that when ripples are present they account for a significant proportion of the total roughness. However, for many cases of practical interest, those involving strong wind forcing, the laboratory data indicate the ripples will be washed away. For this latter case, the intense near-bed transport of sediment will be responsible for the major contribution to the roughness. This roughness is typically 7 to 8 gram diameters in magnitude.

Our present efforts are directed at field

verification of this model. The region where friction is important under waves, i.e., the wave boundary layer region, is of the order of 5 to 10 cm thick for typical wind waves. As a result, direct, point estimates of friction under waves are difficult to make. An alternative is to measure the dissipation of wave energy between two points on the shelf. The friction then can be determined from this dissipation and the roughness can be calculated from the friction. The calculations are greatly simplified by picking a site where the bottom is very gently sloping with nearly parallel contours, and only measuring during times when swell alone is present. In addition, the model results indicate that the bed form geometry and sediment properties must be known, as well as the existence of near-bed transport.

To assist in this later task, a 1 MHz remotely recording boundary mapping instrument has been constructed. The instrument is shown in Figure 1. Figure 2 shows a sample of a record of wave-formed ripples taken under mild wave conditions. The large structure in the middle is a set of bricks for comparison of scales. The instrument is capable of indicating, also, the presence of near-bed sediment transport in the return signal.

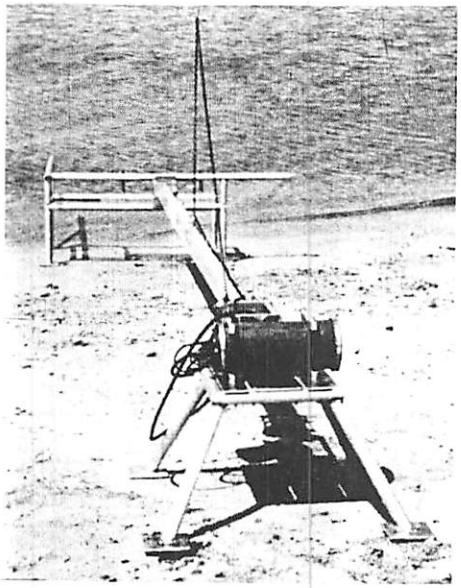

Figure 1. Bed form monitor sled. The 1 MHz transducer moves back and forth along a 5 m long track. The instrument records, internally, height above the bottom, time and position along the track.

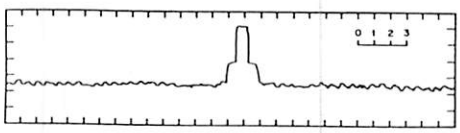

Figure 2. Sample record of wave-formed ripples taken with the bed form monitor. The ripples are approximately 1.5 cm high and 5.4 cm long. The structure shown in the center is two bricks, one laid on its edge on top of the other. The bricks are 11.27 cm wide and 6.19 cm thick.

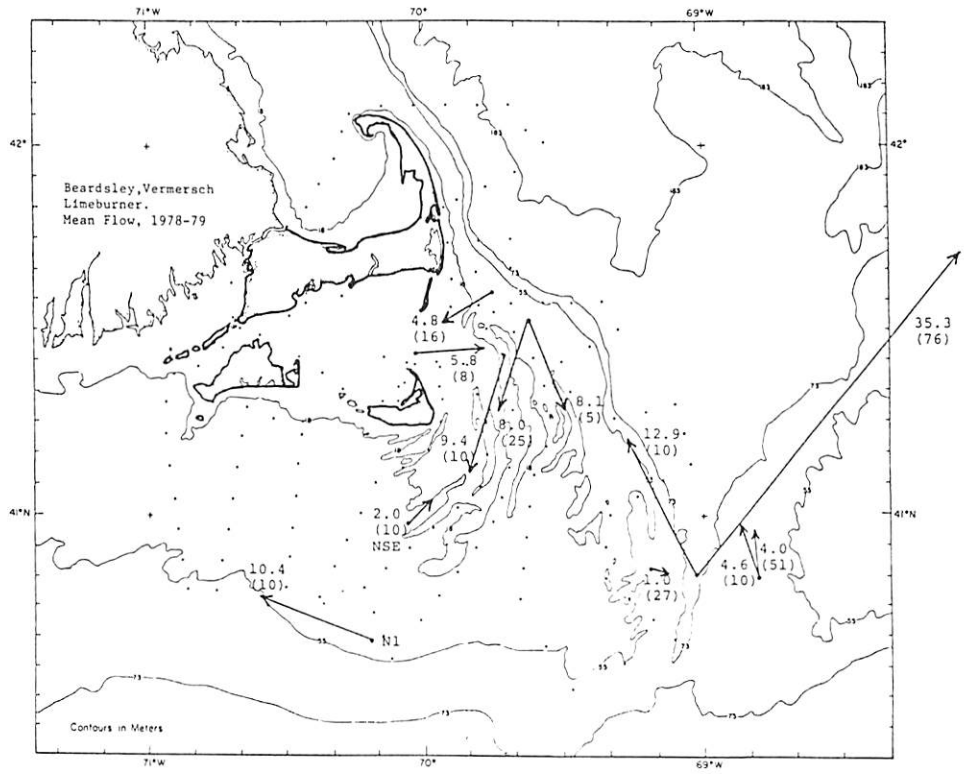

Figure 1. Mean flow measurements from moored current meter arrays in the vicinity of Nantucket Shoals, 1978-79. Upper number is the mean speed in cm/sec, and the lower number in parenthesis is the instrument depth in meters.

Nantucket Shoals Hydrography and Circulation

Richard Limeburner and Robert Beardsley
Department of Physical Oceanography

In May 1978, a field program began to study the physical processes which control the water structure and circulation about Nantucket Shoals, a submerged sand and gravel ridge which extends southeastward from Nantucket Island, Massachusetts. Periodic hydrographic surveys were initiated in May 1978 to measure the spatial structure and temporal variability of the water properties in the Nantucket Shoals region over an annual cycle. A pilot-moored current meter experiment was conducted in January-March 1979 to measure the mean and low frequency current variability over the shoals.

Surface temperature maps obtained in May, July, September, 1978 and in May 1979 show localized upwelling of nutrient-rich mid-water from the Gulf of Maine along the eastern edge of the shoals. The coldest surface temperatures are frequently found in a rectangular zone roughly 15 km x 50 km located 40 km east of Nantucket Island. The temperature and salinity characteristics of the upwelled water indicate the water in the lower seasonal thermocline (20-40m deep) in the adjacent Gulf of Maine to be the source region. The physical mechanism causing this upwelling is not well understood at present. Coastal upwelling is usually attributed to alongshore wind forcing, but meteorological data for the periods prior to and during our hydrographic cruises does not explain the observed localized upwelling.

The mean flow measurements from the moored current meter arrays are shown in Figure 1. These measurements were made at different times at different locations, but represent a circulation pattern consistent with historical data as well as our recent hydrographic measurements. The five moorings over Nantucket Shoals were from our two 1979 Sea Grant deployments, and four other WHOI mean current measurements are shown from experiments near Nantucket Shoals. The circulation pattern shows a diverse pattern of horizontal variability. The mean eastward flow of water from Nantucket Sound becomes a southerly flow over Nantucket Shoals. The mean flow on the shelf to the south of Nantucket Shoals is westward, but some backflow towards the northeast may exist in the nearshore region to the south of Nantucket Island. The Great South Channel region shows a mean inflow to the Gulf of Maine. The low frequency current fluctuations and the local windstress are coherent, but the strong southerly mean flow over Nantucket Shoals is apparent when there is no local wind forcing.

Boston Harbor:

Source and Fate of Urban Estuarine Sediments

Michael G. Fitzgerald*, John D. Milliman,
Dept. of Geology and Geophysics and Marshall Orr,
Dept. of Ocean Engineering
Michael Bothner, U.S. Geological Survey, Woods Hole

Boston Harbor, and its approaches, are a glacially carved, tidally dominated estuary in western Massachusetts Bay. Characterized by low river discharge and significant human impact, the harbor is typical of many bays and estuaries along the New England coast.

The sands and gravels that floor Massachusetts Bay and the harbor approaches are relict glacial sediments, but in areas of fine-grained sediments, Holocene sedimentation rates have averaged 0.015 cm/yr. In the harbor itself, modern organic-rich sediments are accumulating in several depocenters at an estimated rate of 0.2-0.3 cm/yr. The high organic matter content (greater than 10%) of these modern sediments is attributed in part to anthropogenic wastes. Decomposition of this organic material and subsequent production of methane gas render the sediment impenetrable to acoustic energy, and thus not allowing the mapping of these modern deposits.

Wastes rich in trace metals are discharged into the harbor from the sewage treatment facility at Deer Island and from numerous point sources in the Inner Harbor (Figure 1). Organo-metallic complexes and iron oxide coating on suspended particles and bottom sediment appear important in the transport and retention of these metals. Calculations suggest that at least 33% of the metal discharged into the outer harbor is retained. Trace metal profiles in the bottom sediments reflect the increasing use and discharge of these metals during the past 100 years. Large variations in several cores may be related to circulation changes accompanying shoreline construction and landfill operations (such as the closing of Shirley Gut in 1936).

In the water column, silt and clay-sized mineral grains are suspended together in organically-bound agglomerates. The organic film binding these particles is a by-product of biological activity and aids in the deposition of particulates and pollutants.

Tidal activity and differential settling apparently fractionate silt and clay agglomerates forming a very thin, soupy layer of organic, clay-rich material at the sediment-water interface, that carpets portions of the study area. This layer seems to form a transition between the more silty and less mobile subsurface sediments and the suspensates of the turbid water column.

The redistribution of natural sediments (resuspension/advection) is a key depositional process, accounting for as much as 70-80% of the material deposited in the harbor. Harbor circulation indicates that Massachusetts Bay may be an important source for this material. Human activity may enhance the ability of the harbor to retain this redistributed material by stimulating biological production (organic film) and supplying lipid-rich organic material through waste disposal (Figure 2).

Boston Harbor is an efficient sediment trap. Long flushing times and landward bottom drift aid in the retention of the fine-grained wastes, whose impact on the biological and chemical environment of the harbor can be severe. Other estuaries along the coast of New England may operate in similar ways with respect to waste dispersal.

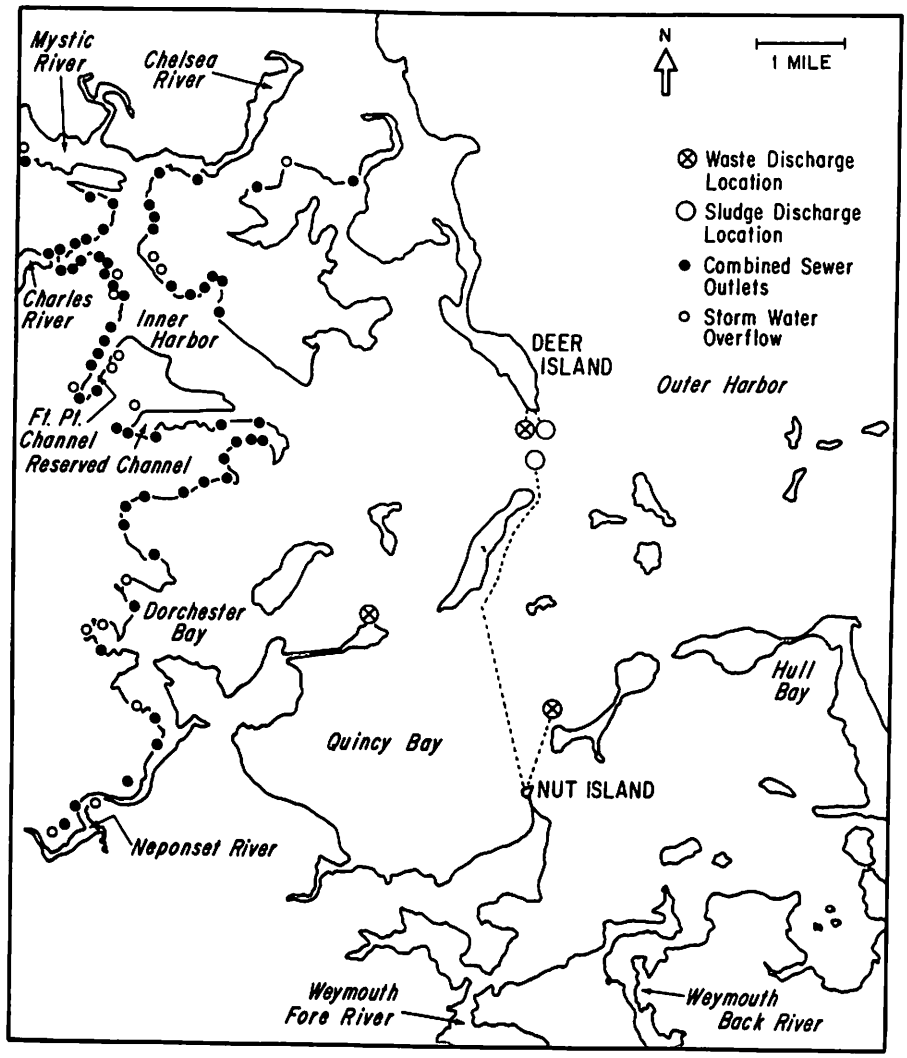

Figure 1. Map of sewer outfalls and storm sewer overflows in Boston Harbor.

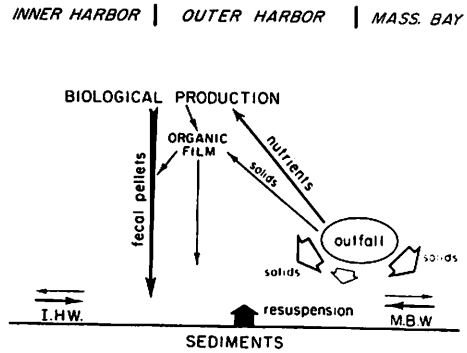

Figure 2. Schematic model of sedimentary regime of Boston Harbor. M.B.W. represents Massachusetts Bay Water; I.H.W. — Inner Harbor Water.

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Influence of Sewage Outfall, Storm Sewers, and Tides on Organic Particles

Jean K. Whelan, Department of Chemistry

Sea Grant funding was used to develop the techniques of gas chromatography (GC) -thermal distillation and GC-pyrolysis as methods of examining small samples (0.1-300mg) of marine organic matter (Whelan, Hunt and Huc, 1980). GC-thermal distillation is used to examine organic matter absorbed by a particle while GC-pyrolysis gives a fingerprint of high molecular weight organic material by cracking the organic matrix of the particle. These techniques were applied to suspended matter collected from the waters of Boston Harbor. The water samples, provided by Mike Fitzgerald, were collected as part of a Sea Grant funded study of Boston Harbor (see Fitzgerald et al., this report). The results of our work demonstrate the usefulness of the methods in obtaining information about organic material in small samples. This data, which is summarized below, would have been difficult or impossible to obtain in any other way.

The total amounts of C_6 to C_{14} hydrocarbons absorbed by particles filtered from Boston Harbor water at various stages of the tidal cycle are shown in Figure 1. The BH-1 samples were taken from top, mid and bottom water samples collected from the inner harbor. The inner harbor is influenced by storm sewer runoff from the surrounding Boston metropolitan area and by tidal flow from the outer harbor (between Deer Island and Spectacle Island). Figure 1 shows that amounts of C_6-C_{14} are relatively constant in all of the BH-1 samples with somewhat higher concentrations being present at low tide. In contrast, the BH-3 samples, taken from the outer harbor, show much larger variations — particularly in the bottom water sample taken at low tide. These samples are strongly influenced by a sewage disposal plant on Deer Island where sludge is dumped daily on an ebbing tide. The high concentration of absorbed organic material in the low tide BH-3 bottom water sample fits with other data of Fitzgerald showing that sludge is collecting in bottom sediments of the outer harbor between Deer Island and Spectacle Island.

Figure 1 also shows the higher levels of C_6-C_{14} compounds in a fish fecal pellet (weight about 0.5 mg) picked out of a mid-water sample from the outer harbor. The hydrocarbon composition of the pellet was different from that of the rest of the sample suggesting that certain particles, such as organic-rich fecal pellets, are more important than others in carrying absorbed organics (including pollutants) through an estuary. The techniques developed in this work give a way of defining which types of particles are most important in carrying particular kinds of organic pollutants.

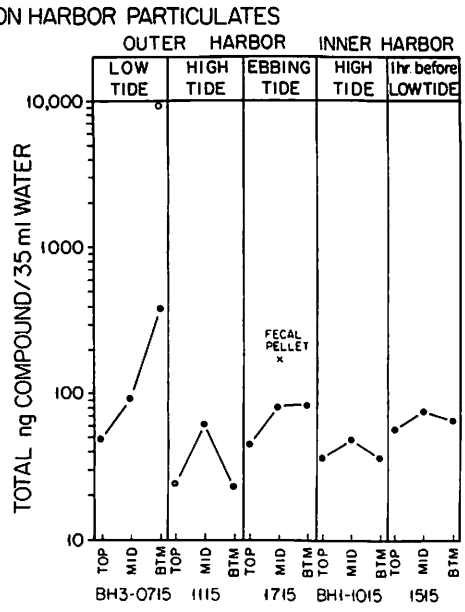


Figure 1. Total levels of absorbed C_6-C_{14} organic compounds (mainly hydrocarbons) absorbed by fine particles filtered from Boston Harbor water samples at various stages of the tidal cycle. BH-3: Taken from outer harbor between Deer Island and Spectacle Island at the times of day indicated. BH-1: Inner harbor samples. Duplicate sample variability; generally less than 15% except for BH-3-0715-BTM where wide sample variability is indicated by the open and closed circles.

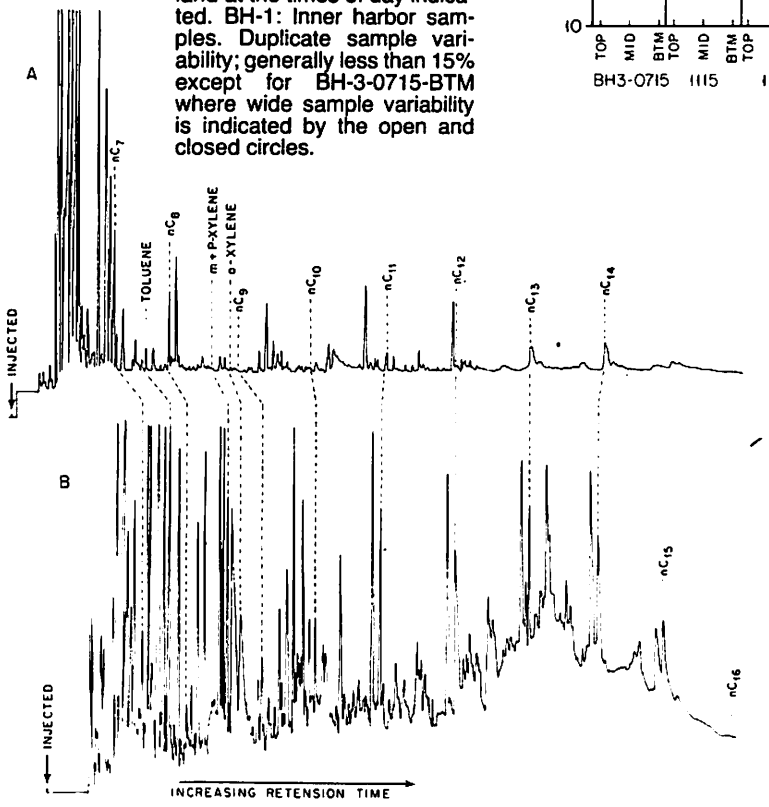


Figure 2. GC-pyrolysis patterns of organic compounds cracked from typical samples: (A) small particles filtered from water, and (B) larger sediment trap particles taken from near the same location.

The GC-pyrolysis technique allows us to conclude that the organic matrix of the small particles filtered from the water is completely different from that of larger particles collected in sediment traps as shown in Figure 2. The pattern of hydrocarbons cracked from each type of particle also suggests a possible reason for the difference. We know from other work that a series of evenly spaced "doublets" in the pyrolysis-GC pattern of the larger sediment trap particles (shown by the dashed circles in Figure 2) is typical of many lipid-rich materials. Thus, we can conclude that the sediment trap particles are more lipid-rich than the smaller filtered particles. The presence of these lipids provides a reasonable mechanism for holding these larger particles together via hydrophobic bonding of long chain lipid hydrocarbon groups similar to that which occurs in many cell membranes. Finally, we observed that the pyrolysis-GC pattern of the sediment trap particles was more similar to that of diatoms (which we have found give very reproducible pyrolysis patterns from one species to another) than to that of Deer Island sewage sludge.

References:

Whelan, J., J. Hunt and A. Huck, 1980. Applications of Thermal Distillation-Pyrolysis to Petroleum Source Rock Studies and Marine Pollution. *Journal of Analytical and Applied Pyrolysis, 2,* p. 79-96.

The North Atlantic Sedimentary Basins

Elazar Uchupi, Department of Geology and Geophysics

A realistic evaluation of the economic potential for oil and gas in the sediment basins of the North Atlantic, including the east coast of the U.S., depends upon deciphering the sedimentary history of the region. A considerable amount of my Sea Grant research time, therefore, has been devoted to this task.

The sediment distribution atop continental (Precambrian/Paleozoic terrain) and oceanic (layer 2) basement in the North Atlantic is illustrated in the isopach map in Figure 1. Sediment accumulation is restricted to the edges of the basin, with little or no deposition on the Mid-Atlantic Ridge (black area). The sediment wedge on the continental margins is made up of two parts — a segment on the shelf and a unit on the continental rise — separated by the continental slope, a complex zone of cut and fill topography and Mesozoic reefal growth. As described below, emplacement of this sediment wedge was not continuous, but was disrupted by changes in plate geometry, in rate of sea floor spreading, and in climate. The present day potential for oil and gas was determined within the context of the ramifications of these events in the sediment column.

Twenty years ago the geologic evolution of the North Atlantic was poorly understood. Yet in the last two decades the application of the plate tectonic concept to geologic field observations, stratigraphic data from wells, DSDP sites and core and dredge samples, seismic refraction and oblique reflection measurements, gravity and magnetic measurements, and acoustic stratigraphic information from thousands of kilometers of single and multi-channel seismic reflection profiles has led to a reasonable reconstruction of the tectonic development of the North Atlantic.

The opening of the Atlantic Ocean occurred in stages. The first segment to open was the region south of approximately 45°N (present latitude) as North America and Africa drifted apart in the Early Jurassic 195 my ago. At this time the edges of both continents were thermally uplifted and eroded (producing the "break-up unconformity") with the material being deposited in topographic lows on the shelf and in a structural low seaward of the plane of continental separation. At the time of continental separation and initiation of sea floor spreading the North Atlantic Ocean was located farther south at a latitude where evaporation exceeded precipitation. This resulted in the deposition of evaporites from Canada to the Gulf of Mexico and along western Africa from the southern Iberian peninsula to Guinea. As sediments accumulated atop this mobile unit, halokinesis (a deformation of salt beds) resulted in the formation of massive diapiric fields along these portions of the margins. As the Atlantic widened and gradually deepened salt deposition came to an end and conditions favorable for carbonate deposition were initiated.

Along the continental edges a complex of carbonate reefs and platforms and lagoons were developed. These carbonate sequences, which have become possible petroleum source beds, graded landward to deltaic or clastic deposits. With time the clastic wedges prograded seaward inundating the carbonate complexes and by earliest Late Cretaceous caused the extinction of the Mesozoic carbonate shelf edge structures.

The opening of the Atlantic north of 45°N is marked by several episodes. The first segment to open was the Bay of Biscay by the counter-clockwise rotation of the Iberian Peninsula 125 my ago. The second segment to open was the Rockall Trough with the separation of Eurasia and Rockall-Greenland-North America 110 my ago. 76 my ago spreading shifted to the Labrador Sea resulting in the separation of North America and Greenland. About 60 my ago spreading shifted to the Reykjanes Ridge splitting Greenland and Rockall Bank. The tectonic history of this segment of the North Atlantic is further complicated by the collision of the Iberian Peninsula with the Aquitainian Platform resulting in the formation of the Pyrenean orogen that extends the length of the northern edge of the Iberian Peninsula.

Similar interactions between Eurasian and African plates produced the Betic and Riff orogens and the volcanic structures of the Canary and Cape Verde Islands. The interaction of these two plates also resulted in the formation of a massive slump block (olistostrome) that can be traced from southern Spain to northern Morocco and occupies much of the western approaches of the Straits of Gilbraltar as far west as 11°W, an area of thousands of square kilometers.

These changes in plate geometry have had a marked influence in the depositional history of the North Atlantic. For example, during the Middle Jurassic (175 to 160 my ago) the margin off eastern North America was inundated with a large wedge of clastics in response to uplift and consequent rejuvenation of source areas. This was due to a westward jump of the spreading axis. Also during the opening of the Bay of Biscay 125 my ago and the opening of the Rockall Trough 110 my ago large portions of the Grand Banks were uplifted, northeast trending structures were formed, source areas were rejuvenated, and large clastic wedges prograded across the shelf. These deposits extend to the base of the shelf and, as indicated above, are at present sufficiently deep for the contained organic matter to have matured to petroleum. This change in plate geometry further results in oceanic basement ridges and seamounts that restricted bottom circulation and led to the deposition of black shales on the continental rise. These deposits may, at present, represent additional petroleum source beds.

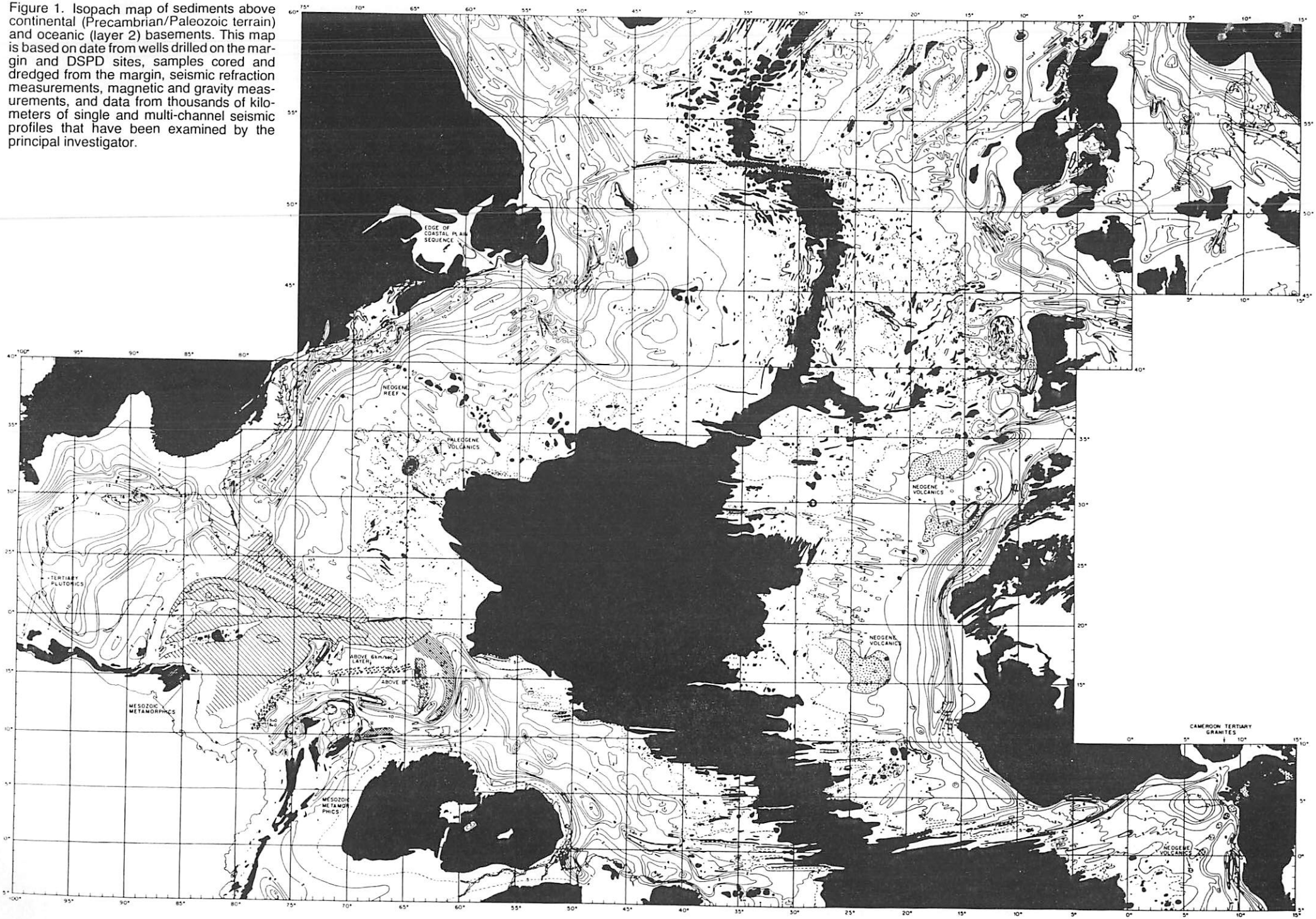
Deposition on the reef slope at this time resulted not only in its near extinction, but also led to the transportation of detritus to the continental rise and carving of submarine canyons along the reef front by turbidity currents. These canyons, which were subsequently filled and partially exhumed several times, in turn served as conduits for sediment transport to the continental rise and the deposition of deep-sea fans. The black shale unit on the continental rise probably represents the distal sediments of these fans.

The North Atlantic sedimentary basins were also affected by an increase in seafloor spreading rate in Late Cretaceous. It resulted in the decrease of the average depth of the oceanic basins leading to the inundation of the oceanic basin margins. This transgression in turn caused the burial and final extinction of the Mesozoic reef complex on the slope.

Another major influence on the depositional history was the onset of continental glaciation in the Paleogene. During glacial periods in late Eocene-late Oligocene, latest Miocene, and Pliocene-Pleistocene the continental shelf and slope underwent considerable degradation by fluvial and submarine processes. Concurrent with this erosion, the abrupt decrease in temperature during the late Eocene-late Oligocene led to the creation of cold abyssal water masses whose circulation caused the erosion of large segments of the continental rise. These sea-level changes also affected the surface currents. For example during times of high-sea level the Gulf Stream migrated landward eroding large areas of the shelf east of Florida and the Carolinas. During sea-level drops the Stream migrated seaward eroding the central part of the Blake Plateau.

Summarizing the economic potential of the Atlantic depositional basins, this overview identifies three possible petroleum source beds: the Cretaceous black shales on the continental rise, the Cretaceous deltaic sequences extending from the shelf to the base of the continental slope, and the lagoonal sediments leeward of the Mesozoic reef beneath the present continental slope. These sources are deep enough for the organic matter to have matured. Petroleum traps (both stratigraphic and structural) also appear to be common, ranging from differential compaction structures over basement highs, growth faults associated with salt diapirs, pinchouts associated with unconformities, facies changes, and folds and faults in the orogens with low temperature and pressure histories. This overview also indicates regions of poor economic potential, such as the high-energy sediment environment of the Bahamas and some segments of plate convergence zones where the strata are highly deformed and intruded by plutons. Gas and oil accumulations in the orogenic belts are probably restricted to post-orogenic basins, structural lows where sediments derived from the orogens accumulate rather rapidly.

Figure 1. Isopach map of sediments above continental (Precambrian/Paleozoic terrain) and oceanic (layer 2) basements. This map is based on date from wells drilled on the margin and DSPD sites, samples cored and dredged from the margin, seismic refraction measurements, magnetic and gravity measurements, and data from thousands of kilometers of single and multi-channel seismic profiles that have been examined by the principal investigator.



Geothermal Studies of Passive Continental Margins

Richard P. von Herzen, Department of Geology & Geophysics

The flux of geothermal heat through various regions of the earth's surface is correlated with the local geologic history and the environment. Recent advances in understanding of passive (rifted) continental margins indicate that they can be explained with tectonic models analogous to those which account for the deep sea floor. In particular, the amount of stretching (thinning) of the continental margin crust associated with the initial rifting process can be deduced from the geologic history of the sediments which infill the subsiding margin. The temperatures over time, and hence the thermal maturation of any petroleum hydrocarbons, within the sediments, is quantitatively related to the parameters of these tectonic models.

For a relatively mature margin, such as the U.S. Atlantic margin, in which the transient effects of rifting have been largely dissipated, the time-integrated thermal effects are largely related to the present-day heat flux. Unfortunately, there exist only a handful of reliable heat flux determinations on all margins of the world. This is because techniques developed for deep sea geothermal measurements are unreliable in shallow, thermally fluctuating waters; and the drilling of relatively deep holes for commercial purposes has only recently begun over some margins.

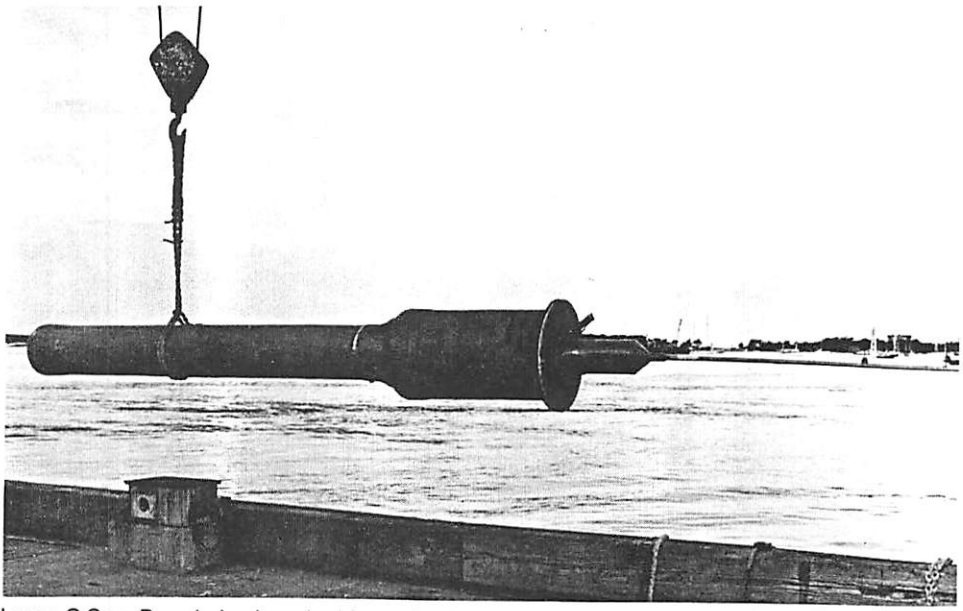
The Continental Offshore Stratigraphic Test (COST) holes, drilled under a cooperative arrangement between industry and the federal government (USGS), have provided an opportunity for obtaining reliable heat flow measurements on passive margins. Downhole logging information, including temperature, are available for scientific purposes over the 3 to 4 km depth intervals of these holes. To obtain heat flow values, the thermal conductivity of the material over which the temperature gradient is measured, is needed. Although coring of the section is done only rather infrequently for the COST holes, drill cuttings are collected at intervals over the entire section drilled. We are measuring the thermal conductivity of selected drill cuttings to estimate the overall conductivity throughout the section.

The hole selected for initial analysis under this grant is the COST B-2 well off the mid-Atlantic continental margin (39° 22′ 32.0″N, 72° 44′ 03.9″W). At this stage we have completed measurements on about 70 drill cutting samples over depth intervals ranging from 1220 to 4870 m below sea level. An interesting result of the measurements is that thermal conductivity is a function of grain size, with sandstones giving the highest values (9 to 12 x 10^{-3} cal/°C cm sec, corrected to zero porosity), and shales the lowest (4 to 8 x 10^{-3} cal/°C cm sec). These differences are probably related to the larger proportion of quartz, a high conductivity mineral, in the coarser grained sediments.

To obtain the mean conductivity required to calculate the heat flux, the various lithologies over the drilled section associated with the measured conductivities have to be combined in proportion to their thicknesses. At this stage it appears that the heat flux at the COST B-2 site is within the range of about 1.4 to 1.6 x 10^{-6} cal/cm^{2}sec, which is somewhat higher than expected for an old passive margin. It is also higher than values measured landward on the coastal plain, and seaward near the continental slope and rise. The higher flux might be due to enhanced radioactive sources in the sediments or in the crust beneath the COST B-2 site, or an edge effect of the margin structure which causes heat to be preferentially refracted in this region. Alternatively, a higher value over the margin may require modification of the simple tectonic models.

Design, Construction and Testing of a Drifting Buoy using Loran-C Telemetry

Robert E. Walden and Clayton C. Collins,
Department of Ocean Engineering



Loran-C Spar Buoy being launched for testing in Vineyard Sound, Falmouth, MA.

This project enabled the evolution of the drifting buoy system from an engineering model to a pre-prototype of the telemetering automatic Loran-C position-fixing buoy.

A low-windage, current-following buoy was designed and fabricated especially for this project, the objectives being simplicity, economy of weight and size for ease of

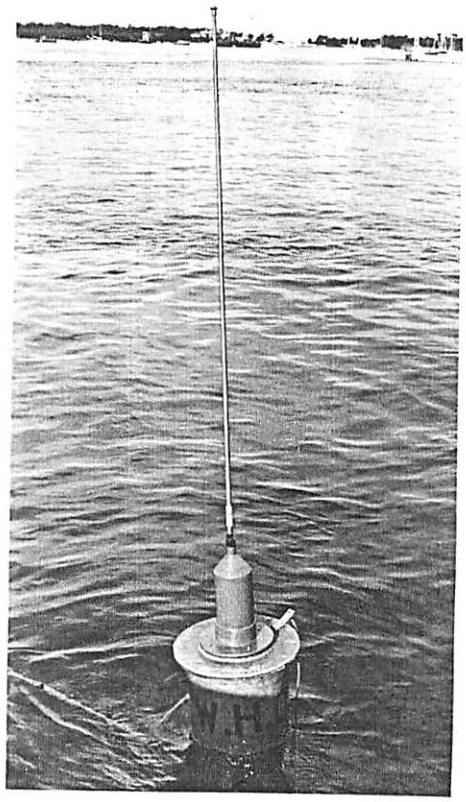
handling, desired performance in the ocean, and compatibility with the existing components of equipment that were used in the engineering model. The buoy is 10 feet long plus an 8-foot antenna and its weight is 430 pounds, assembled and ballasted. The Teledyne TDL-471-C Data Decoder was delivered and tested satisfactorily, enabling the display of data in the laboratory received from the remotely located buoy.

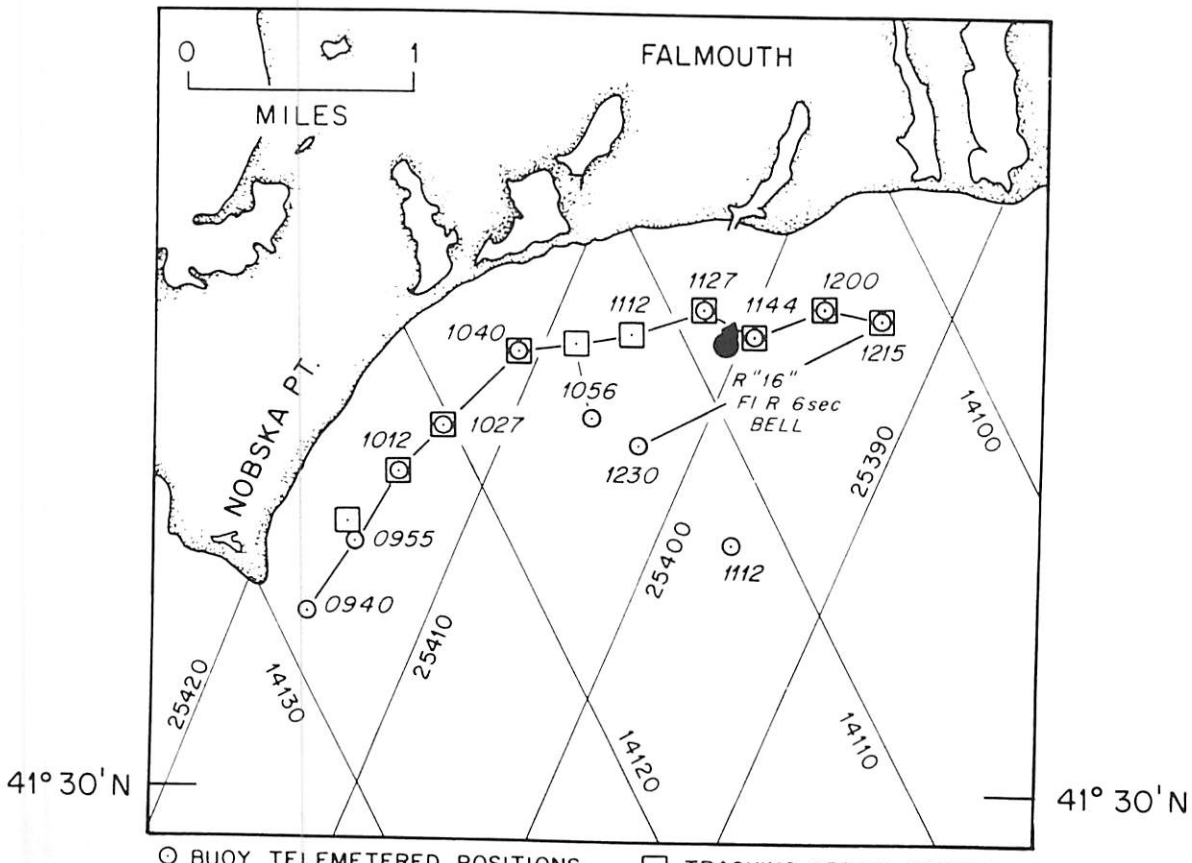
The Clock and Control Unit was completed and tested. Installation of this unit in the buoy along with the Loran-C receiver and single sideband transmitter allowed the functioning of the buoy system to be completely autonomous and automatic. Two rechargeable, sealed Gel Cell Storage batteries were procured for use as the buoy power supply.

Objectives achieved during the period were (1) the integration of the Loran-C receiver, SSB transmitter, and Control Unit into a specifically designed buoy, (2) successful installation and testing of the TDL-471-C Decoder with a communications receiver in the laboratory, (3) completion of the construction and testing of the Control Unit, (4) design and fabrication of a current-following buoy, and (5) deployment and testing of the pre-prototype system in local waters.

The system was turned on, the timing set, and the buoy set adrift off Nobska Point in Vineyard Sound. It was accompanied closely by the R/V ASTERIAS. At each 15-minute data transmission interval, Loran-C readings were recorded in the lab at the base station and compared with simultaneous readings taken on the ASTERIAS' Loran-C receiver. Correlation between the two sets of data was entirely satisfactory.

This final phase has successfully demonstrated the feasibility of telemetering Loran-C position-fixing information from a drifting buoy. A new generation of buoys, based upon these efforts, is currently being constructed for operational use.





Track of Drifting Loran-C Telemetry Buoy, September 12, 1980.

The Coastal Zone — Biological Aspects

Red Tide:

Key Factors in the Initiation, Development, and Geographic Spreading of Toxic Dinoflagellate Blooms (Red Tides)

Donald M. Anderson, Dept. of Biology

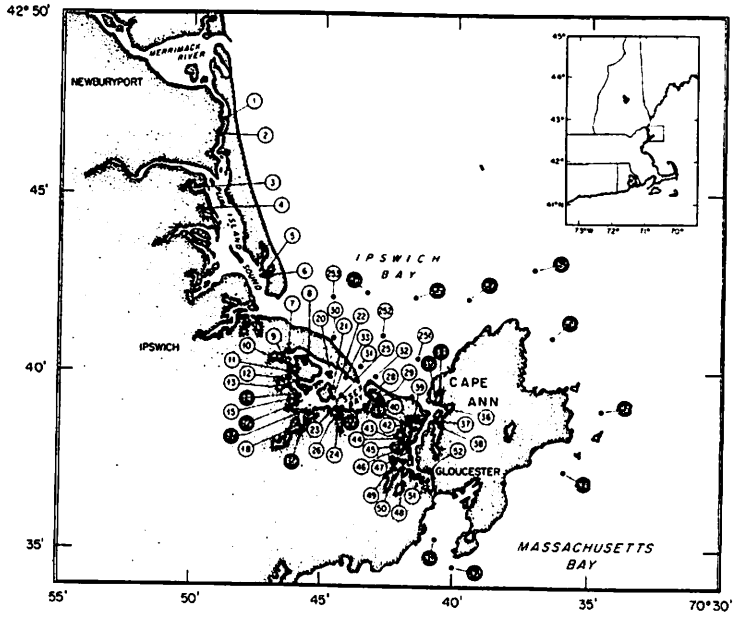
The overall objective of this proposal is to investigate the mechanisms underlying the apparent southward spreading of paralytic shellfish poisoning (PSP) due to *Gonyaulax tamarensis*. Specific projects include: (a) an examination of the mechanisms behind the formation of overwintering cysts of this dinoflagellate (encystment); (b) a study of the toxicity of the encysted stage; (c) a field study of the variations in the trace metal toxicity of estuarine and coastal waters as a possible constraint to the distribution and density of *G. tamarensis*; (d) a mapping survey of the distribution of cysts in near-shore coastal sediments; and (e) a study of red tide bloom initiation and development in estuarine environments having different hydrodynamic and chemical characteristics from those studied to date on Cape Cod.

An important first step in this project was to delineate the existing *G. tamarensis* geographic distribution as a baseline for the evaluation of future red tide events. This has been accomplished by collecting sediment samples from over 260 selected estuarine and near-shore locations in Massachusetts and Rhode Island. Additional samples are now being collected along the coast of Connecticut and Long Island. Only 42 of these samples contained *G. tamarensis* cysts, a finding consistent with the relatively recent appearance of this organisms in southern New England waters. Figures 1 and 2 demonstrate this cyst distribution to the north and south of the toxic organism's known geographic limit in Falmouth, Massachusetts. It is evident from these figures that thus far, no *G. tamarensis* cysts have been found south of this limit. Baseline information of this type is essential if we are to correctly evaluate future toxicity episodes in previously unaffected areas with respect to the spreading hypothesis.

In addition, these data are also useful in evaluating the role cyst accumulations play in the development of shellfish toxicity in widely varying hydrographic and topographic regimes. An example is seen in Figure 1 where cysts were very scarce within the estuarine systems of Cape Ann, Massachusetts, but relatively abundant offshore. The origin of the toxic populations responsible for red tides in that region may well be these offshore accumulations, in marked contrast to the estuarine-generated populations further south on Cape Cod where no cysts are found in nearshore waters.

Since the dormant cyst populations are so important to bloom initiation and population dispersal, a great deal of effort is presently focused on the mechanisms whereby a normal vegetative cell enters the sexual cycle of reproduction that eventually results in cyst formation. This work involves both laboratory and field components. An example of the latter approach is seen in a recent study of three Cape Cod embayments. By carefully monitoring the *G. tamarensis* population and an extensive set of complementary chemical, physical and biological parameters, it has been possible to document the appearance and disappearance of different life cycle states in each of these embayments. Since the time course of population development differed significantly between the three locations, it should be possible to isolate key aspects of

Figures 1 and 2. Locations sampled during sediment survey in Massachusetts and Rhode Island. Numbers in circles are station numbers. Darkened circles indicate the presence of *G. tamarensis* cysts.



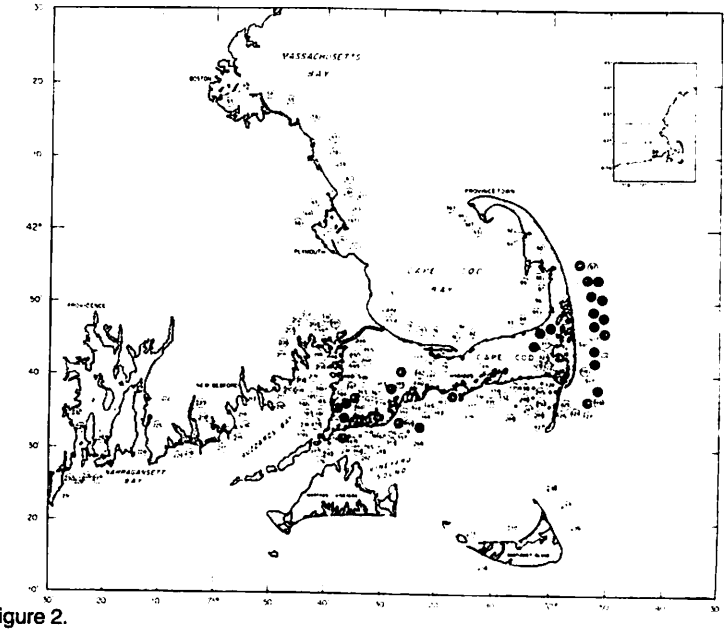


Figure 2.

the physical environment common to each site at the time sexuality was induced.

Another interesting aspect of this field study concerned tintinnid grazing on *G. tamarensis* during these blooms. Collaborative work with Guillard and Stoecker (this report) suggests a close temporal and spatial correlation between tintinnid populations and dinoflagellate blooms and should provide valuable information on natural grazing pressures.

During the spring bloom, another study was initiated focusing on the vertical distribution of *G. tamarensis* in the water column. Our measurements of the flushing characteristics of a small embayment subject to recurrent shellfish toxicity outbreaks indicate that in the absence of a behavioral mechanism to remain well below the surface, the positively phototactic *G. tamarensis* population should be dispersed to the adjacent estuary with ebbing surface waters. Twenty-four hour studies during several stages of the bloom confirm that the population does remain within the embayment without significant advection losses. Although data reduction is still in progress, it is hoped that simultaneous profiles of nutrients, light, temperature, and salinity, will help explain the observed vertical cell distribution.

Another study is using bioassay experiments to examine variations in the copper-complexing capacity of natural waters over time and space as one measure of a potential trace metal toxicity constraint to red tide distribution. Preliminary data during one spring bloom indicate a significant variation in this parameter between estuarine and near-shore locations. Another series of experiments is planned using a slight modification of our former procedure, in hopes of providing more conclusive evidence of the role of trace metals in localizing dinoflagellate blooms in southern New England.

Tintinnid Predation on Toxic Dinoflagellate Blooms (Red Tides)

Robert R.L. Guillard and Diane Stoecker,
Department of Biology

Recurrent episodes of paralytic shellfish poisoning (PSP) cause economic losses in New England. PSP is caused by consumption of shellfish during blooms of the toxic dinoflagellate *Gonyaulax tamarensis* (red tides). Although there has been considerable research on toxic dinoflagellate blooms, little attention had been given to the influences of predation by zooplankton on *G. tamarensis* blooms. If toxins prevent predation by zooplankters on *G. tamarensis*, then predation could select for toxicity (*Gonyaulax* strains vary in their toxicity). However, if zooplankton consume toxic dinoflagellates, then zooplankton predation may limit red tide outbreaks. The objectives of our research were to answer these questions.

The zooplankton predator we choose was *Favella ehrenbergii,* a tintinnid (planktonic ciliated protozoa). This tintinnid is known to be associated with coastal dinoflagellate blooms and has been observed to be abundant during red tides in the Bay of Fundy. In collaboration with D.M. Anderson we sampled salt ponds on Cape Cod for both tintinnids and dinoflagellates. (Figure 1). We found that *Favella* was only abundant during dinoflagellate blooms. However, an important question was whether the *Favella* was eating *G. tamarensis* or other phytoplankton, including non-toxic dinoflagellates, present at the same time. In laboratory experiments we found that *Favella* selectively preys on dinoflagellates including toxic *G. tamarensis* cells (Figure 2). This information answered our first question: *Favella* does not act as a selective agent for *Gonyaulax* toxicity; and partially answered our second question: *Favella* may limit toxic blooms by eating *G. tamarensis* cells.

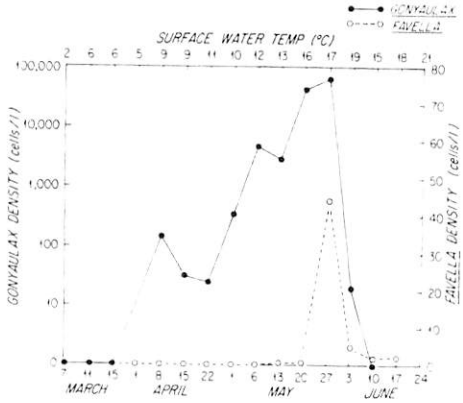


Fig. 1. *Favella ehrenbergii* and *Gonyaulax tamarensis* densities, Station 1, Salt Pond, Spring 1980 (*Gonyaulax* data from D.M. Anderson).

However, in order to evaluate the effects of *Favella* predation on *G. tamarensis* blooms we needed to know more about our predator. We found that *Favella* has a generation time comparable to *G. tamarensis*, and that the tintinnid *Favella* can eat as many as 10 *G. tamarensis* cells/hour. These data indicate that *Favella* may have a significant impact on toxic blooms in New England.

However, many questions remain. *Favella* may only feed on the smaller *G. tamarensis* cells. D.M. Anderson's research has shown that *G. tamarensis* cell size changes during the course of blooms. Perhaps only certain life cycle stages in red tides are susceptible to *Favella* predation. We found the feeding rate of *Favella* to be influenced by light intensity. We need to know how light influences predation rates in the field given a motile, phototactic prey. We discovered that *Favella* forms cysts (Figure 3) which may synchronize its life cycle with that of *G. tamarensis* which also forms cysts. This may be important in the dispersal of *Favella* to new locations affected by red tides.

By studying interactions between *Favella* and *Gonyaulax* in the field and laboratory we hope to be able to predict, and perhaps control, toxic dinoflagellate blooms.

Figure 2. *Favella ehrenbergii* with ingested *Gonyaulax* cells (bar = 40 μM).

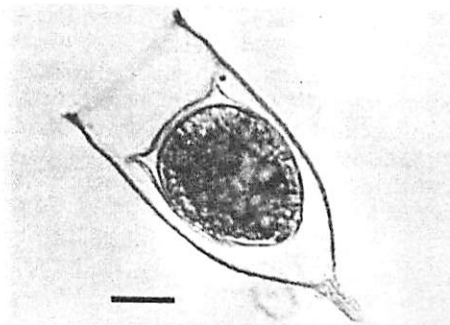


Figure 3. Cyst of *Favella ehrenbergii* (bar = 40 μM).

Stimulated Marine Bioproduction in Great Sippewissett Marsh

John M. Teal, Dept. of Biology
Ivan Valiela, Marine Biological Laboratory

The biostimulation project is a large-scale expansion of ten years of work with small-scale experiments involving addition of nutrients to salt marsh plots. The current work deals with spray irrigation of soluble fertilizer over 1 hectare of marsh, in a regime similar to that commonly used in cranberry bogs. In the second year of irrigation the primary objectives have been to examine (1) to what extent nutrients applied in liquid form are retained by the marsh and available for increasing marsh production and (2) whether the stimulation of primary production significantly increases production of economically valuable end-products in coastal estuaries. In addition, Sea Grant funding has enabled us to continue studies on the effects of sterilized sewage sludge on small marsh plots to evaluate the retention of pollutants and their effects on ecosystem function, concentrating primarily on heavy metals.

Fertilizer specially formulated to imitate secondarily treated sewage effluent (23 N - 19 P_2O_5 - 17 K_2O) was donated by the Ra-Pid-Gro Corporation and is applied to one hectare (2.5 acres) of marsh in dilute solution approximately four hours per day at low tide, five days a week. This translates into approximately 25 kg of nitrogen per hectare in 7.5 x 10^5 liters of freshwater applied per week. Previous experiments have shown nitrogen availability to be primarily limiting to plant production (Valiela and Teal, 1974). The effects of the application of freshwater only are observed in an adjacent area irrigated at the same rate but without added fertilizer.

Increased levels of nutrients appear in the tidal waters during the actual spraying period (Figure 1). Notice, however, that soon after we stop irrigation, concentration of nutrients in the water falls drastically. The marsh sequesters the nutrients and only a small amount is lost to deeper waters in ebbing tides.

The nutrients retained in the marsh sediments promoted increased growth in all five types of marsh plants measured (Figure 2). Note that the effect was a result of the nutrient additions and not due to the addition of freshwater. The increased biomass of plants was low in *S. patens* and *D. spicata* but about doubled standing crops in *S. alterniflora* and *Scirpus americanus*. Based on previous experience we expect that in subsequent seasons continued irrigation will enhance the production even further, up to three times the production in control plots.

We placed several species of commercially important algae in floating cages in the experimental and control creeks. Preliminary results showed that growth of the large algae in the irrigated creek did not differ from that of the control creek, but that there was a great increase in the biomass of microalgae attached to the large algae growing in the irrigated creek. If we could either use the microalgae themselves or find a way to eliminate them so that they would not shade the large algae we could record significant growth rates in fertilized creeks.

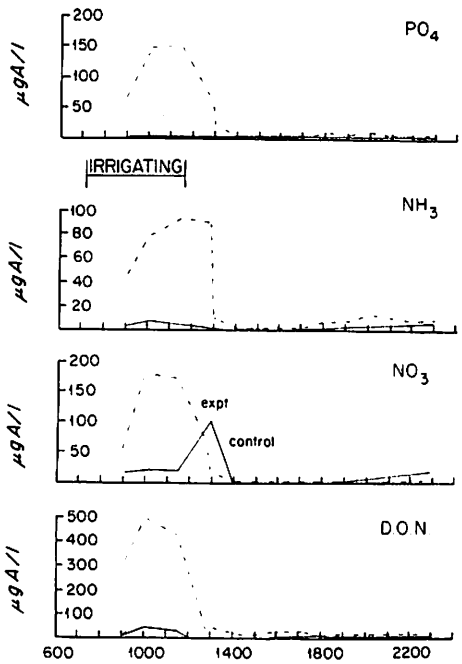


Figure 1. Nutrient levels in tidal waters in experimental and control creeks measured in October, 1979. Period of spray irrigation at low tide is indicated.

We measured the growth of young of *Fundulus heteroclitus*, a very abundant fish in the marsh. These data have not yet been processed but some preliminary observations are that juveniles are more abundant in creeks draining the irrigated area.

Several species of fish reside in the marsh and make use of various kinds of food. These are usually small fish that feed on the smaller-sized particles of food. There is another group of fish species that invade the marsh from deeper waters for short periods of time. These tend to feed on larger fish items. These larger particles are not available to the residents because resident species have small mouths. Although the invader species have a small size similar to that of residents, their mouths are considerably larger. This is due to the fact that the invaders are juveniles of larger species, and head dimensions are proportionately larger for juveniles than for adults of most vertebrates. Thus, even though lengths may be similar, an invader will have a bigger mouth than a resident. Why don't resident species evolve to larger sizes and make use of larger particles? It may be that small size is strongly selected for in salt marsh fish, since large fish stranded in shallow pools of tidal water are either easy prey for the abundant bird predators or may suffer from lack of oxygen in the warm, shallow water.

Both resident and invader species have specialized to use different parts of marsh environments, feed on different foods and perform life activities at different times and places. All these adaptations suggest that there is heavy pressure by these fish on their food resources. Caging experiments whereby benthic invertebrates were protected from predators showed that the standing crop of invertebrates increased within a few weeks up to 5 times the amounts in areas exposed to predation by the fish.

Since we know that the standing crop of benthic invertebrates increases under fertilization, we see that the addition of nutrients affects not only the vegetation, leading to more biomass, but the animals feeding on plant litter. In turn these detrital feeders are consumed by the fish, so that the pulse provided by the fertilization can be felt through the entire food web. Each of the harvestable crops, therefore, can be increased by additions of nutrients.

Studies of the dynamics of heavy metals were performed in our small (314 m^2) plots where we have added sewage sludge fertilizer chronically for ten years. Of three metals shown in Table 1, all show increases in the sediment of fertilized plots over those of controls. Only cadmium seems to be taken up preferentially by the plants and mussels. The deposit feeding fiddler crabs (*Uca pugnax*) incorporated large amounts of lead although we have not been able to measure deletorious effects of this burden. No metal increases were seen in fish feeding in the fertilized areas. No increases in mercury were found, even though additions of mercury in the sewage sludge fertilizer did increase the mercury content of the sediments within treated plots. Although

marsh mud retains some amount of all the metals studied (the three shown in Table 1 are just representative) each metal has its own behavior and needs special attention.

The results briefly mentioned above continue to suggest the ecological feasibility of using marshes as places for conversion of unwanted nutrients into desirable crops. Much information is still needed, both from our ongoing studies and other aspects (pathogens, economic factors, logistics) before realistic trials are possible.

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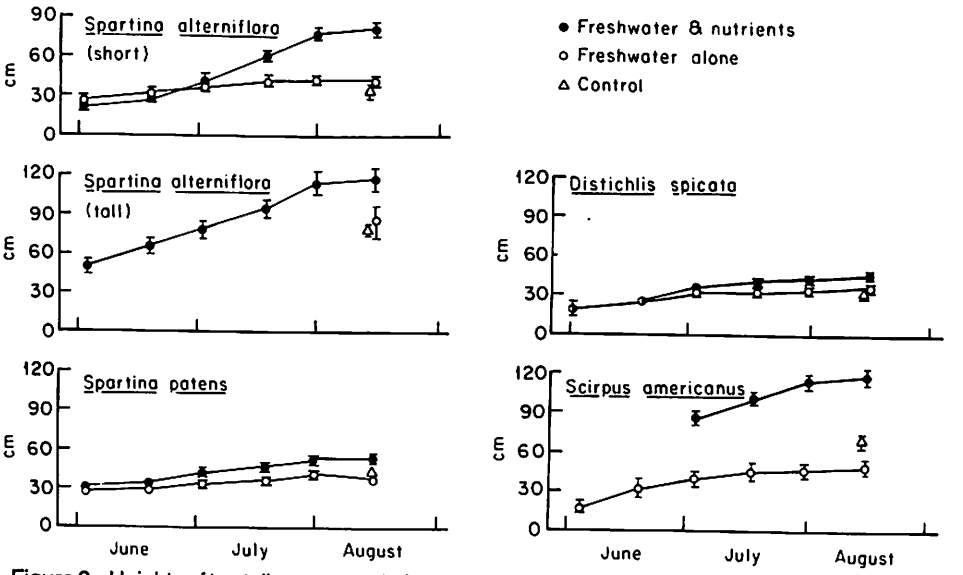


Figure 2. Heights of ten tallest grasses in freshwater plus nutrient, freshwater alone and control areas over three months of irrigation in 1979.

Table 1. Metal analyses from experimental salt marsh plots. Data from Giblin et al., 1980.

		Added mg/m²	Low marsh mg/m²	*Spartina alterniflora* ppm	*Modiolus demissus* ppm	*Uca pugnax* ppm	*Fundulus heteroclitus* ppm
Cd	C	0	8	0.15	3.1	10.7	3.4
	XF	490	94	23	9.7	13.0	4.4
Pb	C	0	187	26	10.1	121	45.1
	XF	1740	1090	20	6.2	116	43.8
Fe	C	0	26,200	2500	217	473	1070
	XF	110,000	105,000	1700	185	303	1080

The Biology of the Ocean Quahog, *Arctica islandica*

Roger Mann and Rodman E. Taylor, Jr.
Department of Biology

Arctica islandica (= *Cyprina islandica*) is a large clam that occurs in European waters from the White Sea to Spain, and in American coastal waters from Newfoundland to Cape Hatteras. In the Middle Atlantic region the species supports a fishery whose catch value is estimated to exceed $21,000,000 by 1982. The greatest concentrations of *A. islandica* are found in depths of 25-61 m with the mean depth of occurrence increasing from 39 m off Long Island to 52 m off Virginia and North Carolina (Merrill and Ropes, 1969). The seasonal temperature structure of the waters of the Middle Atlantic Region were first comprehensively described by Bigelow (1933) and have subsequently been reviewed by Bumpus (1974), and Beardsley, Boicourt and Hansen (1976). Two important features are evident: the first is the occurrence of an intense summer thermocline that builds in May and persists until September, and the second is a "pool" of cold water, surrounded on both the inshore and offshore sides by warmer water, that builds up on the continental shelf below the thermocline during the spring, summer and early fall months. Much of the depth range occupied by *A. islandica* is concurrent with that of this cold "pool" of bottom water.

Previously Loosanoff (1953) described the reproductive cycle of *A. islandica* based upon specimens collected regularly from commercial catches at Point Judith, R.I. He concluded that spawning began near the end of June or early in July and continued through the month of August, and that approximately 50 percent of the sampled *A. islandica* would be totally spent by early October. More recently Landers (1976) has successfully reared the larvae of *A. islandica* to metamorphosis in the laboratory. Fertilization and early cleavage were obtained at 10, 15 and 20°C; however, embryos only survived to metamorphosis at 10-12°C. A disagreement was therefore evident between the data sets of Loosanoff (1953) and Landers (1976) in that if *A. islandica* spawns in July then larvae swimming upwards to the regions of highest primary productivity, and hence phytoplankton food, will encounter both an intense thermocline at 20-30 m depth, and surface temperatures in excess of 20°C (Fig. 1), both of which, according to the data of Landers (1976), will be deleterious to growth or even lethal. Based upon the aforementioned

temperature data and the results of Landers (1976) in isolation it would appear appropriate to hypothesize that spawning in October or November would be more congenial to larval survival in that, following the fall thermocline breakdown and subsequent vertical mixing of the water column, vertical movement of the larvae would not be limited by an intense thermocline. Furthermore, any temperature stratification that did exist at this time would be characterized by widely spaced vertical isotherms and thus form only a weak barrier to horizontal dispersion. Two years ago we set out to both reassess the reproductive cycle of *A. islandica* on the Southern New England Shelf and test our hypothesis concerning the relationship of spawning to the fall thermocline breakdown. Our approach consisted of an histological examination of many adult individuals of *A. islandica,* collected regularly from a variety of depths over a two year period, and an attempt to correlate the observed changes in reproductive status with physical data collected during that same period.

A. islandica were collected at regular intervals during the period September 1978 - May 1980 from depths in the range 27-50 m in the vicinity of Block Island, R.I. Specimens were collected with either a commercial hydraulic dredge or a mechanical dredge. They were subsequently examined histologically for the presence of gonadal material. At each station on each collection date a vertical profile, from surface to bottom at 5 m intervals, was made of temperature and conductivity. On six occasions these data were supplemented by vertical profiles of dissolved oxygen content and pH.

The seasonal temperature structure of the water column is depicted in Figure 1. No significant differences were recorded between the two years of the study, hence data has been pooled. An intense seasonal thermocline begins to form in April-May and reaches a maximum intensity between

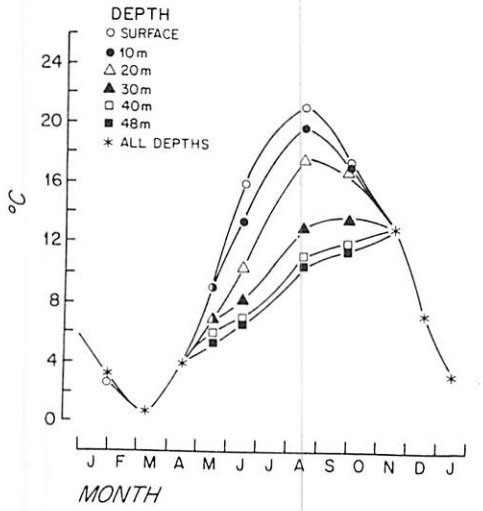
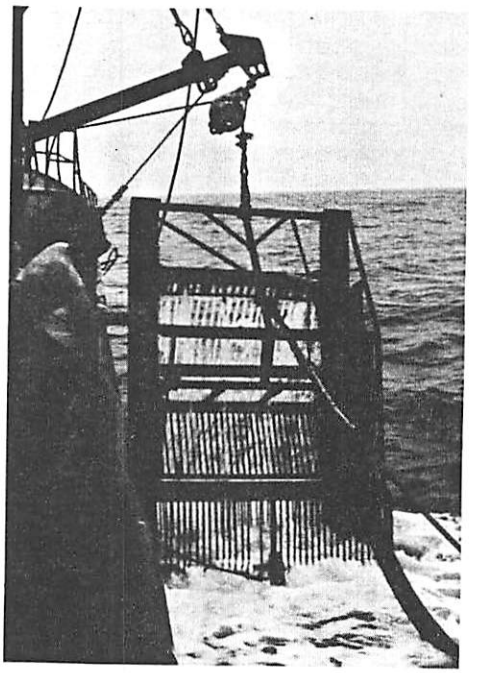


Figure 1. Seasonal changes in sea water temerature at 10 m intervals during September 1978 - May 1980. For simplicity data have been pooled and are presented on a single annual cycle.

20 and 30 m in August. Surface waters cool during the fall months of September and October. A uniform temperature structure throughout the water column is evident from November through April. The intense nature of the thermocline and its relation-



ship to the depth of the stations sampled is illustrated in Figure 2 for August 1979.

The sexes in adult *A. islandica* are separate and stable. Evidence of hermaphroditism was found in only two individuals which contained spatially separate developing male and female follicles. Serial sectioning indicated that gonadal maturation occurs initially in tissues at the dorsal extremity of the gonadal mass, and progressively later moving toward the ventral extremity. Multiple spawnings in the same animal during one annual cycle, originating from tissues in a similar spacial sequence, are suggested by the presence of individuals with gonadal material appearing spent in dorsal sections while ventral gonadal tissue is still maturing.

Figure 3 summarizes data by date for mid-ventral sections taken from animals at all stations throughout the study. Gonadal development is described in five arbitrary stages ranging from the initiation of devel-

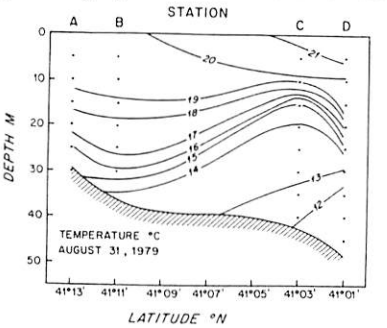


Figure 2. Water column temperature structure along the study transect August 31, 1979 illustrating the intense thermocline and its intersection with the bottom.

opment (early active) through ripe to spent or spawned out.

The onset of spawning activity in both sexes is marked by the transition of ripe to part spawned animals and continues as further spawning results in the eventual predominance of completely spawned individuals. While evidence of the onset of spawning is present in specimens from May and June the data indicate the greatest spawning activity occurs from August through November, that is after the thermocline breakdown. The exact nature of the stimulus to spawn appears complex and probably involves not only any small temperature change associated with the thermocline breakdown but also increases in dissolved oxygen concentration, pH and food levels that accompany this event.

It would appear that the period of the year during which the adults are capable of spawning is probably longer than that during which the larvae are capable of surviving; however, a definitive statement concerning larval development and survival rates in relation to physical parameters must await the completion of recently initiated studies on the larval biology of *A. islandica.* The ultimate goal of our work is to integrate biological data on adult and larval phases of the reproductive cycle with physical data on water current direction and velocity to produce three dimensional, time specific models of larval dispersion in the Mid-Atlantic Bight — a tool which we feel will be of immense value to practical fishery management planners.

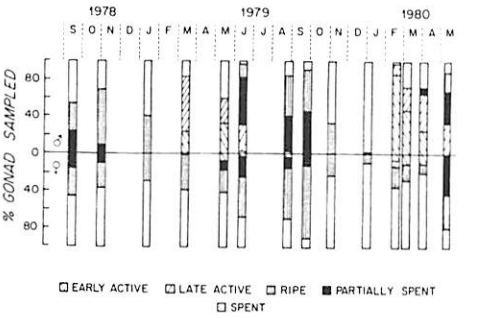


Figure 3. Seasonal changes in gonadal development by sex in *Arctica islandica* for the period September 1978 - May 1980: all stations pooled.

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Biomechanics of Particle Capture by Planktonic Filter Feeders

Timothy J. Cowles, Department of Biology

The results of our investigations address the mechanism of food capture in copepods through two types of analyses. First, movements of the food capturing appendages have been described using high-speed cinematography. A female *Centropages typicus* flaps its second antennae and maxillipeds in a figure-8 motion to create a flow field which brings food particles near the second maxillae. The films document that the second maxillae extend outward rapidly, creating a suction which pulls a food particle into the mouth. The entire sequence of capture takes 10-12 milliseconds. During the food capture process the other appendages keep flapping, maintaining the flow field, bringing chemical and/or physical food stimuli to the animal.

The second portion of the investigation addressed feeding behavior through analysis of the copepod's activity patterns under different food conditions. Feeding experiments were done with two different species of phytoplankton food, the dinoflagellates *Gymnodinium nelsoni* and *Prorocentrum micans.* Table 1 lists the experimental conditions for one set of experiments. The copepod *Centropages typicus* was filmed under each experimental condition and the behavior of the copepod was characterized as shown in Table 2. "Flapping" and "breaks" accounted for at least 95% of the activity time during the experiments, and these two activity modes were selected to further quantify the behavioral response of the organism to changing food conditions. As shown in Table 3, the duration of activities was strongly dependent upon food conditions, with the copepod increasing "break" duration as food concentrations decrease. These results pose two major questions. How does the copepod assess food concentration? Why does it then modify its behavior pattern? Two explanations are possible for the first question. First, the copepod must move its feeding appendages in order to propel itself through the water and eventually encounter the chemical or physical stimulus of a food particle. The frequency of encounter with either the chemical or physical presence of the food could provide the animal with an estimate of food concentration. The interval between stimuli could also influence the duration of particular feeding activities. On the other hand, the physical presence of particles in the mouth or in the gut could provide the stimulus for a particular activity.

Table 1. Food conditions for *Centropages typicus* feeding experiments.

Sequence	Food	Species	cells ml^{-1}	volume (ppm)
2	HP	*Prorocentrum micans*	400	3.50
3	LP	*Prorocentrum micans*	40	0.35
1	HG	*Gymnodinium nelsoni*	100	4.0
4	LG	*Gymnodinium nelsoni*	10	0.4
5	FSW	Filtered seawater	0	0

Table 2. Types of activity observed in *Centropages typicus.*

Activity	Description	Occurrence	Duration of activity
Flapping	Rhythmic motion of second antennae, first maxillae, maxillipeds	Often	Variable, 0.2-10 secs
Breaks	No appendage movement, animal at rest	Often	Variable, 0.15-7.5 secs
Cleaning	First antennae brush across mouth parts, maxillipeds groom maxillae and antennae	Occasional	Variable, 0.15-1.1 secs
Swimming	Rhythmic swimming thrusts with swimming legs	Rare	Variable, 0.1-1.5 secs

Table 3. Activity durations (secs) for *Centropages typicus* ($\bar{X} \pm 1$ SD) n = number of events observed per films.

Food conditions	Flapping	Breaks
HP	2.11 ± 1.80, n = 80	0.38 ± 0.07, n = 57
LP	0.80 ± 0.45, n = 119	0.87 ± 0.34, n = 115
FSW	0.98 ± 0.45, n = 38	4.08 ± 1.52, n = 38
HG	1.38 ± 1.09, n = 76	1.30 ± 0.43, n = 68
LG	2.59 ± 2.10, n = 46	1.75 ± 0.76, n = 43

Why does the copepod modify its behavior pattern? Again, two possible explanations come to mind. First, the metabolic expense incurred during flapping may not be offset by ingestion benefits at low food concentrations. Analysis of fluid motion around copepod mouthparts indicates that these appendages are operating at low Reynolds number (0.1 to 1.0). Viscous drag may therefore impart a high cost to mouthpart movement. An alternative explanation for increased break duration at low food concentrations is that the copepod ceases appendage movements in order to sink *out* of a low food "patch" and sink *into* a "patch" with higher food concentrations. The copepod could thus use the sinking behavior as a mechanism for scanning the fluid for chemical or physical signals.

The results of these investigations have stimulated research into the effects of sublethal concentrations of hydrocarbons on the feeding behavior of copepods, particularly as it applies to chemoreception.

Chemical Processes and Pollution

Biogeochemistry of PCBs in New Bedford Harbor and Buzzards Bay, Massachusetts

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Jacek Sulanowski, Bridgewater State College

The New Bedford Harbor region is severely polluted with polychlorinated biphenyls (PCBs) — presumably as a result of discharges from electrical component manufacturers in the area. During 1974 and 1975 this problem was recognized, serendipitously, when the late Dr. Max Blumer and colleagues of the Woods Hole Oceanographic Institution analyzed a few sediment samples from the harbor for aromatic hydrocarbons. PCB concentrations were so high that they interfered with aromatic hydrocarbon analyses — a rare phenomena at that time for the New England region. Between 1976 and 1978 surveys of the PCBs in sediments and biota by the then Massachusetts Department of Environmental Quality Engineering, the Massachusetts Division of Fisheries and U.S. Environmental Protection Agency contractors led to the realization that the problem was severe. Figure 1 shows the harbor area and indicates the area closed to the taking of lobsters in 1979 and 1980 due to the fact that PCB concentrations in lobsters in that area exceed 5 ppm (parts per million) wet weight. The Massachusetts Department of Health issued a closure order for the area based on the U.S. Food and Drug Administration's recommendation of a limit of no more than 5 ppm in food.

During that same period our research into the biogeochemistry of pollutant organic compounds and in particular the use of bivalves as sentinel organisms in pollution monitoring led us to approach the state agencies to stimulate an in-depth look at the problem. Limited funds and manpower and a broad range of environmental quality problems had severely taxed the resources of the state agencies. They personally could not research the problem of PCB pollution in that area in depth and thus we took on the task of conducting the research into the biogeochemistry of PCBs in this area.

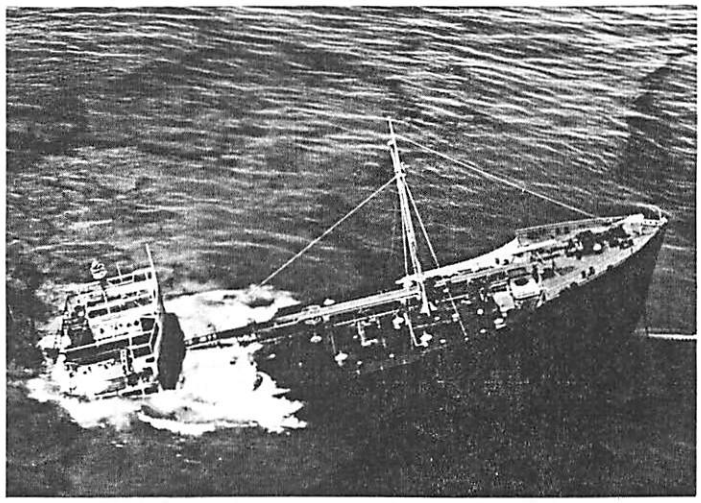
Our objectives were and still are to:

(1) Assess the present state of knowledge of PCB pollution of New Bedford Harbor and Buzzards Bay, Massachusetts.

a. Act as initial coordinating influence to bring together federal, state, city, industrial and university efforts.
b. Assemble and assess available data within the present knowledge of PCB biogeochemistry in coastal areas.

(2) Conduct high resolution trace analyses of selected fish, shellfish, sediment, and suspended particulate samples to more clearly define PCB isomer patterns and to measure polychlorinated dibenzodioxins and polychlorinated dibenzofurans.

(3) Design an effective biogeochemical research and monitoring program for New Bedford Harbor and Buzzards Bay, Massachusetts which will involve federal, state, and local scientists.



Oil tanker *Ocean Eagle* aground in San Juan Harbor. Photograph courtesy U.S. Coast Guard.

We coordinated a workshop in February 1980 which brought together the Massachusetts agencies, federal agencies, several local and state college and university faculty, environmental consulting companies and some local environmental groups to discuss the biological, chemical, geological and physical oceanographic aspects of the problem. Some of the PCB data we compiled from existing data files given to us by participants are given in Table 1. We are now preparing the final draft of the report from the workshop. We have also participated in several meetings of a local steering committee dealing with this problem from the economic, scientific and technical engineering level and convened by State Representative Roger Goyette.

A subset of our own analyses of samples

TABLE 1
PCB Analysis Results of Lobsters, Shellfish, and Fish in New Bedford, Massachusetts and Western Buzzards Bay:

Sample Location	Sample Type	Sample Code	Sample Date	Laboratory Results*
New Bedford Harbor Butter Flats	Lobster	B-1	5/6/77	8.2
Butter Flats	Lobster	B-2	5/6/77	11.7
Fort Rodman	Lobster	C-1	5/6/77	7.9
Fort Rodman	Lobster	C-2	5/6/77	9.3
Egg Island	Lobster	D-1	5/6/77	6.3
North Ledge	Lobster	F-1	5/6/77	4.9
North Ledge	Lobster	F-2	5/6/77	5.8
Clark Point	Shellfish	NB-1	5/77-11/77	1.3
Sewage Outfall	Shellfish	NB-2	5/77-11/77	0.35
Clark Cove	Shellfish	NB-3	5/77-11/77	0.72
Butter Flats	Shellfish	NB-4	5/77-11/77	1.81
Buzzards Bay	Shellfish	NB-5	5/77-11/77	0.41
Buzzards Bay	Shellfish	NB-6	5/77-11/77	0.44
New Bedford Harbor	Blackback Flounder-Fillet	None	5/77-11/77	10.1
New Bedford Harbor	Blackback Flounder-Fillet	None	5/77-11/77	19.0
Fairhaven	Blackback Flounder-Fillet	None	5/77-11/77	7.6
Dartmouth	Blackback Flounder-Fillet	None	5/77-11/77	3.9
Dartmouth	Blackback Flounder-Fillet	None	5/77-11/77	20.0

*PCB reported as mg/kg of 1254 in edible tissue — wet weight.

from the harbor area are given in Table 2. We have used high resolution glass capillary gas chromatography (GC/GC) and GC/GC-mass spectrometry to make many of our measurements. Two important findings have already been forthcoming. First, a substantial portion of the PCBs in the sediments and several organisms are the 1016 and/or 1242 mixture. Thus, the concentration estimates by the U.S. EPA contractors and state agencies were low in many cases by as much as a factor of two or more, because they used state of the art routine monitoring analytical methods which measured only 1254.

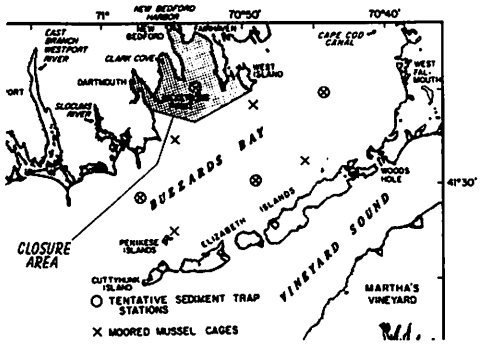


Figure 1.

The second important finding concerns the composition of PCBs in several species of organisms. There is a marked difference in composition when comparing species caught in the same area as illustrated in Figure 2.

We are now pursuing further research into the implications of these data. How can they be used to better understand the processes acting on PCBs in the various components of this ecosystem given the observed distributions. We have set out moored mussel cages to monitor the extent of movement of PCBs from the harbor into Buzzards Bay. Sediment trap, suspended particulate matter, and dissolved PCB measurements for areas of the harbor and Buzzards Bay are planned for the fall, winter and spring of 1980-1981.

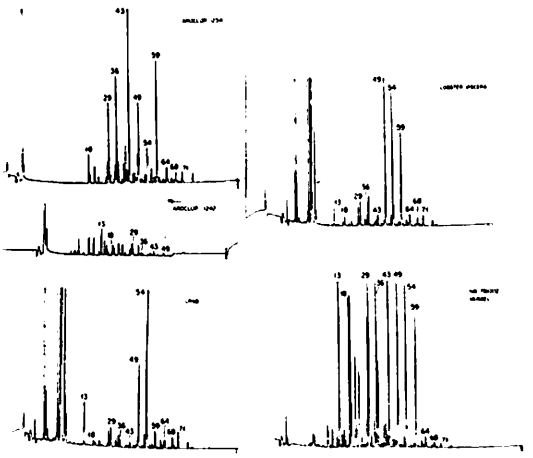


Figure 2. Glass capillary gas chromatograms (electron capture detector) of commercial PCB mixtures and PCB's in selected biota from the New Bedford Harbor area. Numbered peaks correspond to the same compound(s) in each sample.

TABLE 2
Concentrations of PCBs in Organisms and Sediments from New Bedford Harbor and Adjacent Areas of Buzzards Bay, Massachusetts — 1979 Analyses (Farrington and Davis et al.)

Species		Wet Weight	Dry Weight
New Bedford (sampled 7/9/79)			
Outer Harbor, Butler's Flat light			
Parallel with channel or S.E. coast (10^{-6} g, 1254 PCB/g)			
Homarus americanus (lobster)			
Lobster A Muscle		2.2	12.2
Tomale		84	500
Lobster B Muscle		1.0	6.8
Tomale		43	250
Lephopsetta maculata tissue			
(sand flounder), edible flesh			
3 each (20-28 cm) large	A[a]	7.0	39
	B	6.0	33
3 each (12-15 cm) small	A[a]	3.6	18
	B	3.3	17
Pseudopleuronectes americanus tissue			
(winter flounder; blackback)			
e each (15-49 cm)	A[a]	4.0	18
	B	4.1	18
Stenotorus versicolor tissue			
(scup)			
3 each (16-24 cm) large	A[a]	2.5	11
	B	2.2	9.9
Mustelus canis tissue			
(dogfish)			
2 each (35, 33 cm)	A[a]	0.26	1.3
	B	0.24	1.2
Porontus triacanthus tissue			
(butterfish)			
45 each, small (approx. 8-10 cm)	A[a]	1.8	8.9
	B	1.6	7.8
Tautogolabrus adspersus tissue			
(cunner)			
11 each	A[a]	2.3	10.4
	B	2.2	10.1
Neopanogoe texons whole			
(crab)			
16 each		1.4	7
Loligo pealei whole			
(squid)			
3 each	A[a]	1.3	Not
	B	1.1	Measured
Westport River, Sampled April 21-29, 1979			
Pseudopleuronectes americanus			
(blackback; winter flounder)			
	A	.102	Not
	B	.089	Measured

New Bedford Harbor		Wet		Dry	
Mytilus edulis (10/2/78)		1242	1254	1242	1254
(218 homogenized), 10^{-6} g/g					
Duplicates	A	1.8	1.7	16.6	15.7
	B	1.7	1.6	15.6	14.8
Mercenaria mercenaria (3/11/78)					
(from Hatch et al., 1980)					
Station 3		Not		1.59	1.46
Station 10		Measured		0.22	0.20

Buzzards Bay Station B. C.	
0-1 cm sediment	1.8×10^{-9} g 1254 PCB/g dry weight
Mixed polychaetes	62.8×10^{-9} g/g wet weight
Nepthys incisa (polychaete)	44.4×10^{-9} g/g wet weight

[a] Duplicate analyses of homogenized sample of the number of individuals indicated.

Metabolism of Aromatic Hydrocarbons by the Bivalve Mollusc *Mytilus edulis*

John J. Stegeman, Department of Biology

Bivalve molluscs, particularly the blue mussel *Mytilus edulis*, are becoming important as "bioconcentrators" of organic pollutants. Polynuclear aromatic hydrocarbons (PAH), including some known carcinogens, are among those compounds being examined in the context of pollutant monitoring programs using *Mytilus edulis*. One factor that could complicate both qualitative and quantitative assessment of these aromatic hydrocarbons in animal tissue is their metabolism by the animal in question. Oxidative metabolism of polynuclear aromatic hydrocarbons is initiated by a family of enzymes known collectively as cytochrome P-450. Mono-oxygenase reactions catalyzed by these enzymes can lead to detoxication of many foreign compounds, including aromatic hydrocarbons, although such metabolism can also result in the formation of toxic and mutagenic derivatives.

At the beginning of our work there were no data concerning the potential for hydrocarbon metabolism or its induction in the bivalve *Mytilus edulis*, an important food species in many places and the principal species being used in mussel watch programs. Some investigators had suggested that such oxidative metabolism of hydrocarbons was not detectable or did not occur in bivalve molluscs. Thus the potential for metabolic alteration of quantitative and qualitative profiles of polynuclear aromatic hydrocarbons or the production of toxic metabolites in mussels was unknown. Since the inception of this project we have established (using benzo[a]pyrene as a model substrate) that mussels do have the capacity for hydrocarbon metabolism and have begun characterization of the enzyme system responsible.

In our studies to date we have detected benzo[a]pyrene hydroxylase activity in gill, digestive gland, testis, ovary, labial palp and foot tissues. Activity was not detectable in mantle or in posterior adductor muscle. NADPH-cytochrome c reductase activity was localized in the microsomal fractions along with benzo[a]pyrene hydroxylase activity. These results suggest that microsomal electron transport systems similar to those in other animals, may be involved in foreign compound metabolism in mussels, but as yet we have been unable to detect cytochrome P-450 in these samples.

The data collected thus far clearly indicate that the bivalve mollusc *Mytilus edulis* has the ability to metabolize polynuclear aromatic hydrocarbons, whether or not this is the primary function of the enzymes involved. Even though this activity is very low in mussel tissues, pooling the activity in all tissues examined indicated that an overall rate of metabolism *in vitro* of a compound like benzo[a]pyrene might be as high as 0.3 nmol/min, or about 100 μg/day for a 5 gram animal, by no means inconsequential. An *in vivo* metabolic rate even as low as 1% of this could alter the composition of hydrocarbons contained in an animal, and contribute to the accumulation of potentially toxic metabolites. The rates of metabolism *in vivo*, patterns of metabolites, variables affecting activity, and biological functions of mono-oxygenase systems other than foreign compound metabolism remain to be determined.

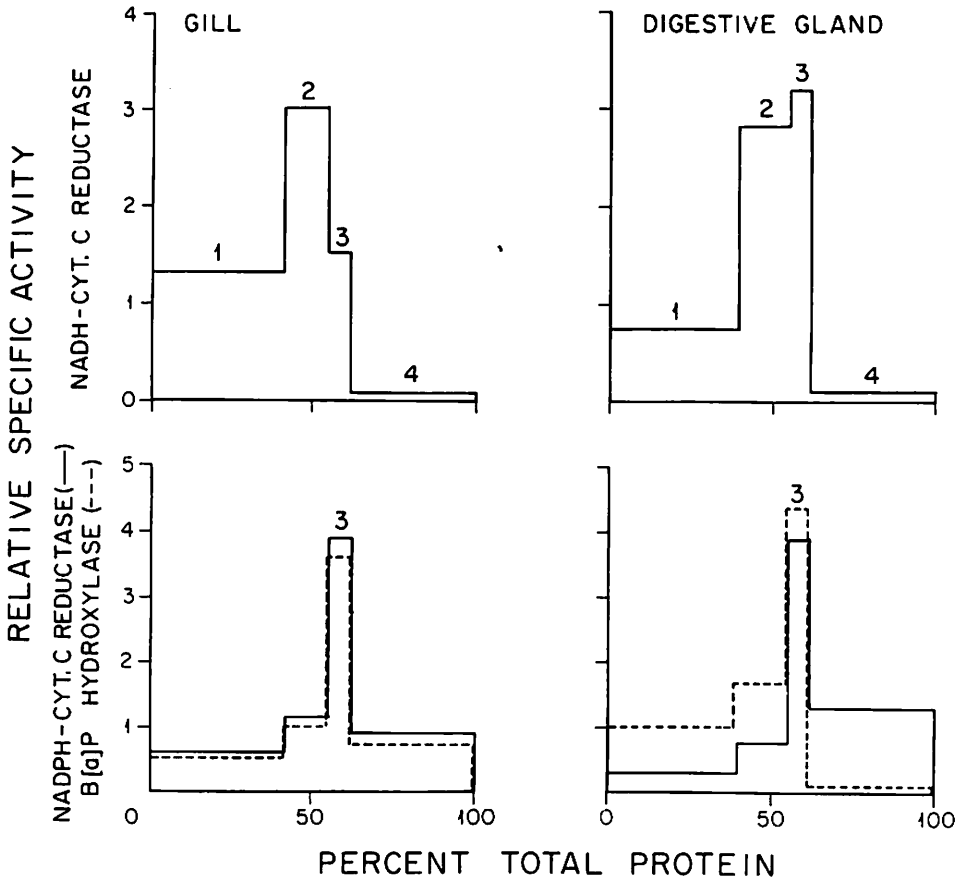


Figure 1. Subcellular distribution of NADH- and NADPH-cytochrome c reductase and benzo[a]-pyrene hydroxylase activities in *Mytilus edulis* tissues. Values are means of determinations on two samples with tissues pooled from more than ten animals in each. Data for benzo[a]pyrene hydroxylase activity were obtained both radiometrically and fluorometrically. 1 = nuclear fraction; 2 = mitochondrial fraction; 3 = microsomal fraction; 4 = cytosolic fraction.

Sewage Sludge and the Marine Environment

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Department of Biology

Conventional wastewater treatment separates raw sewage into a relatively clear effluent and a semi-solid material called sewage sludge. The latter contains the bulk of the organic particles and most of the toxic entities of domestic waste. At the present time only about 15% of the nation's sewage sludge is being disposed of by marine deposition. By the end of 1980, however, the above figure will undergo marked reduction pending implementation of Public Law 92-532, the Marine Protection Act by the U.S. Environmental Protection Agency. Strict enforcement of PL 92-532 will have maximum impact on densely populated coastal communities such as the metropolitan areas of New York, Philadelphia, Los Angeles and Boston.

A perplexing aspect of the planned moritorium terminating sludge release to the ocean is a general failure to identify acceptable non-marine disposal procedures. A further complication is the relentless pressure for more elaborate and extended wastewater treatment on the part of the regulatory agencies which continues to increase sludge generations despite a serious curtailment of disposal options. Current predictions are that there will be a 5-10 fold in total sludge production over the next ten years and that coastal municipalities will be most seriously affected.

A broad and favorable background of information exists in the effectiveness of sewage sludge as a useful resource for agriculture. However, only limited aspects of the potential benefits and deterrents associated with marine sludge disposal have as yet been explored. Traditionally sludge disposal in the oceans has been characterized by an overexploitation of conveniently located coastal sites with little or no attempt to maximize the ultimate assimilitory capacity.

Negative public health and environmental impacts are and must always be a major concern of all waste disposal methods whether on land or at sea. Regarding sewage sludge, potential sources of danger are heavy metals, persistent toxins, petroleum derivatives and pathogenic viruses, bacteria and parasites. On the other hand, sewage sludge also contains generous amounts of amino acids, vitamins and a potentially useful caloric content. Together, these properties, under ideal circumstances, are capable of stimulating the overall fertility of receiving waters. Already dried sewage sludge has proven to be a useful dietary supplement for poultry, sheep and other ruminants (Smith et al., 1977) and the utility of sludge as a soil conditioner is widely accepted. Surprisingly, there has been little or no effort to develop balanced marine disposal techniques more in tune with the realities of marine physics, chemistry and biology. Existing information on the release of sludge in the oceans is dominated by descriptions of monitoring efforts oriented toward shallow water columns within confined areas of the sea.

Sludge release to the sea can significantly alter normal community behavior. An early impact would be the stimulation of marine heterotrophic bacteria which can utilize many of the soluble organic components of the sludge. A second level of community response could concern the photosynthetic plankton-algae which utilize soluble species of inorganic nitrogen, phosphorus and silica. Given adequate sunlight the standing crops of photosynthetic plankton-algae in the sea are ultimately controlled by the amounts of nitrogen available for protein synthesis and by the grazing pressure exerted by herbivorous zooplankton. The presence of an alternative food in the form of sludge particles might be expected to alter both aspects of this pattern appreciably. The balance of this report describes our preliminary observations on relevent aspects of the interrelation between natural marine populations and experimental quantities of sewage sludge.

Heavy metal exchanges between zooplankton and sewage sludge

Because zooplankton may provide an important link in the transfer of toxic materials to higher trophic levels, the accumulation of contaminants in zooplankton biomass and the removal rates through fecal pellet deposition are interesting questions to consider in the evaluation of sludge disposal in the marine environment. Background levels of Fe, Pb, Cd, Ni and Cu in the copepod *Centropages typicus* are in the part per million range, but the concentrations of these same metals in fecal pellets deposited under control conditions were up to several orders of magnitude higher (Table 1). No enhancement in body levels of these metals were detected with exposure of *Centropages* to sludge suspensions, but slight increases in the metal content of fecal pellets produced by exposed copepods were detected, possibly due to the incorporation of unassimilated sludge particles in fecal pellets. The deposition of metals in fecal pellets by marine copepods provides a rapid means of transport of metals to the deep sea and the importance of sludge deposition via copepod fecal pellets is currently being evaluated.

Zooplankton feeding and sewage sludge particles

In other studies nauplii of the calanoid copepod, *Labidocera aestiva* were offered diets consisting of the dinoflagellate, *Gymnodinium nelsoni* and/or sewage sludge. During the experimental period (3-5 days) the mortality of animals offered *G. nelsoni* was low, whereas the mortality of animals offered the sludge particles was high. There was some indication that survival was enhanced by supplementing the regular diet of *G. nelsoni* with sludge.

Stage II and III nauplii of *L. aestiva* were placed in plastic jars (30-50/jar) containing 400 ml of filtered sea water (glass fiber). *Gymnodinium nelsoni* was added to give concentrations ranging from 0 to 350 cells/ml. Dried sewage sludge that had been pulverized with a mortar and pestle was added to filtered sea water and then placed in a refrigerator for several days. The sludge suspension was then filtered through a series of Nitex mesh screens and the fraction containing particles ranging from 32 to 64 u was retained. This was diluted and offered to the nauplii to give concentrations ranging from 0-350 particles/ml. The size of sludge particles offered to the copepods was comparable to the cell size of *G. nelsoni*. The jars containing the nauplii with experimental diets were kept at 22° ± 1°C on a device that rotated at 1 rpm. After 3-5 days the contents of the jars were siphoned through a Nitex screen to collect the copepods. The number of animals surviving, and

TABLE 1. Metal composition on *Centropages typicus* and fecal pellets produced for 96 h at 20°C.

Metal	Concentration, mg kg^{-1}	
	Body	Fecal Pellets
Fe	3.70	10,800
Pb	2.96	243
Cd	0.60	—
Ni	2.57	50
Cu	32.0	390

Mean values of three replicate samples ashed at 550°C, acid digested and analyzed by atomic absorption spectrometry.

TABLE 2. Mortality, and the developmental stage attained by surviving individuals of *L. aestiva* fed a diet of *Gymnodinium nelsoni* and/or sewage sludge.

Diet Composition (cells or particles per ml)		Mortality (%)	Survival (%)	
G. nelsoni	Sludge		Nauplii	Copepodites
350	0	8	4	88
100	0	13	33	54
		30	7	63
		28	48	24
70	0	40	5	55
		38	48	14
50	0	73	23	4
		40	60	0
0	100	100	0	0
0	350	95	0	5
70	30	17	7	76
		18	60	22
		38	40	22
50	50	50	3	47
		30	66	4
		23	0	87

their stage of development were recorded.

The results are show in Table 2. The mortality of copepods offered a diet of *G. nelsoni* was inversely related to cell density, ranging from a minimum of 8% of 350 cells/ml to between 40 and 73% at 50 cells/ml. A sludge concentration of 100 particles/ml resulted in 100% mortality within five days. At a higher concentration (350 particles/ml) 5% of the individuals (two) did develop to an early copepodite stage. There is some indication that at low concentrations of *G. nelsoni* (50-70 cells/ml) a supplement of sludge particles to the diet results in reduced mortality. It is difficult to assess the influence of the different diets on the rate of development, with the present data. Surviving copepods were classified broadly as either nauplii or copepodites, which may obscure very small differences in development rate. Moreover, to more accurately detect the existence of such differences the stage of development of individuals should be determined at more frequent time intervals.

It is not clear from the present data whether the high mortality experienced by copepods offered the sludge particles was due to toxic contaminants (i.e., heavy metals), poor nutritive value, or a lack of consumption of the particles by the animals. The fact that at high particle concentrations some nauplii did develop to the copepodite stage suggests that they can consume the sludge. We did not test the effects of a sludge diet or supplement on the survival and development of late copepodite stages and adults; nor its influence on egg production.

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Biology of Ships' Ballast Water: Experimental Studies with the R.V. KNORR from Bermuda to Woods Hole and Development of Ballast Tank Sampling Methodology

James T. Carlton and Roger Mann, Department of Biology

The unintentional transport of living marine organisms by man in the seawater ballast tanks of ocean-going vessels, and thus the potential introduction of such organisms into regions of the world where they are not native, may today be the single most important mechanism for the accidental movement of marine life around the world. Although the role of natural current systems in the dispersal of marine organisms along continental margins and across ocean basins has received extensive attention in recent years, few investigations have focused directly upon the role of man in modifying and extending the natural dispersal of planktonic and mektonic organisms, especially for those species whose larval or adult lives are too short for them to be carried, naturally, distances comparable to those of transoceanic ship voyages. An important underlying consideration in this passive transport of marine life is that severe economic, biological, and even geological problems have resulted from the successful movement and establishment of unwanted exotic species around the world. Hundreds of millions of dollars of damage in the United States alone have been caused by introduced boring and fouling species, whose larvae could easily be carried in the ballast tanks of ships, and many other species of invertebrates, fish, and algae may have been transported in ships' ballast tanks to be introduced into, and modify, existing marine communities.

The sequence in time and space of the dispersal and introduction of exotic invertebrates in ships' ballast tanks can be conceived as a series of increasingly smaller survival "filters" (Figure 1). From the naturally occurring community (1) a subset of species is drawn into the ship (II), an assemblage whose composition is highly dependent upon season and time of day. A third stage (III) consists of the assemblage that survives the voyage; those species that do survive (IV) in the new harbor must then be capable of successful reproduction to become components of an established introduced biota (V).

In addition to the problems caused by accidentally introduced non-indigenous species in United States coastal waters, two other considerations prompt us to believe that ships' ballast water may now be playing a critical role in circumventing natural dispersal mechanisms and directions: (1) the significantly increased speeds of modern ocean-going vessels in the past two to three decades, such that the potential survival rate of ballast tank biota may have increased many fold, and (2) what we believe to be the imminent introduction into United States coastal waters, by ballast water, of critical pest species, including the Chinese mitten crab *Eriocheir sinensis*.

No methods or procedures have been previously worked out to frame a large-scale study of ballast-tank biology. Such sampling methodology, procedures, equipment testing and design, and an analysis of the biological, chemical, and physical parameters needed to be considered, as well as other factors, were thus studied in detail in an actual Bermuda-to-Woods Hole leg of an R/V KNORR voyage in March-April, 1980. Under controlled conditions, a main experimental ballast tank was selected, entered, and examined in a dewatered state, and then filled with approximately 3,500 gallons of unfiltered ambient harbor seawater. Shipside plankton tows and plankton tows in the newly-ballasted tank were compared, and these compared to plankton samples taken by tow and pump in the ballast tank upon return of the ship to Woods Hole one month later. Although no copepods survived this long rigorous transit from tropical-to-cold temperate waters (a change in water temperature of 7°C), our new understanding of ballast tank systems has elucidated the procedures necessary for a large fraction of the experimental and observational program that will now be undertaken in a greatly expanded study.

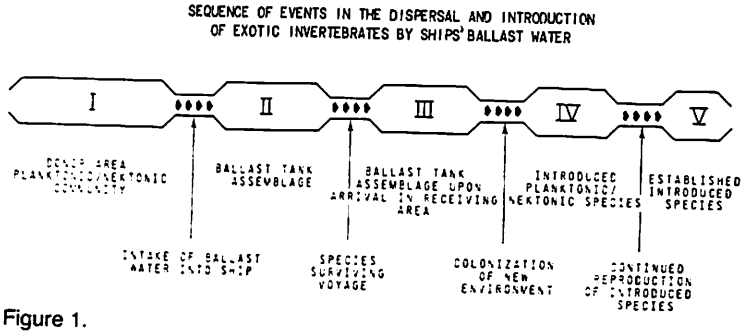


Figure 1.

Aquaculture

Bacterial Chemosynthesis for Aquaculture

Craig D. Taylor and Holger W. Jannasch
Department of Biology

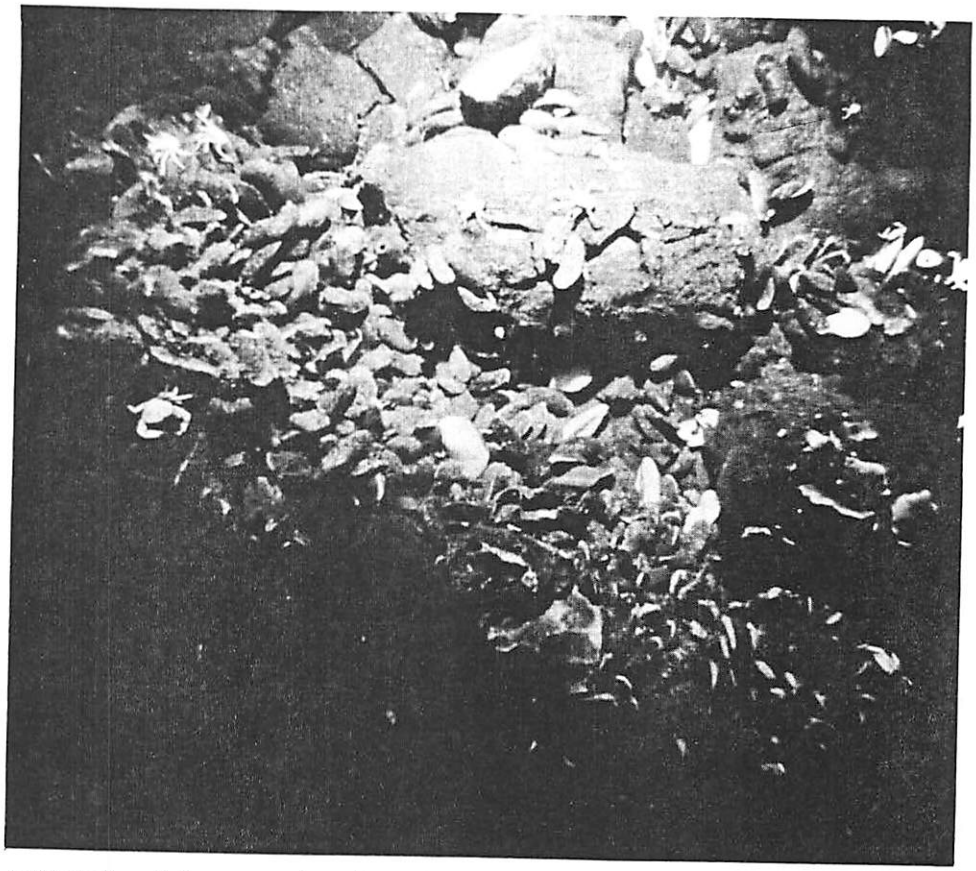
Dense populations of shellfish, recently discovered in deep-sea submarine vents, were found to be supported not by photosynthesis but rather by bacterial chemosynthesis based upon the geothermal generation of hydrogen sulfide. We have proposed to use this chemosynthetic mode of primary production as an energy base for commercial aquaculture.

Illustrated in Figure 1, a chemosynthesis-based system of aquaculture would consist of a continuous flow reactor as a primary stage to provide food, in the form of bacterial cell tissue, to a secondary stage of filter-feeding animals. Hydrogen sulfide would serve as the primary source of energy for the fixation of carbon dioxide into organic material by colorless sulfur bacteria. Other required nutrients are introduced naturally with the incoming seawater or added exogenously (e.g. gaseous ammonia).

Hydrogen sulfide is an untapped, biologically available, and abundant source of energy. It is presently considered a waste product by many industries and is disposed of at great expense. The gas may be introduced into mass culture systems in an uninterrupted fashion, providing a continuous source of energy for maximal production, and its ultimate oxidation product, sulfate, is a non-toxic natural component of seawater. The successful exploitation of hydrogen sulfide for the production of a commercially valuable commodity thus has considerable potential.

The first steps of our work are to establish a stable and continuous production of biomass in the form of sulfur oxidizing bacteria. To this end we have constructed, in collaboration with engineer Clifford Winget, a continuous-flow reactor which will ultimately serve as the first stage of a pilot aquaculture system. The reactor is patterned in concept after submarine vents in that a large surface area is provided for the colonization and growth of surface-attached sulfur oxidizing microorganisms. The continuous production and removal of a fraction of the attached microflora into the flowing stream of seawater would then be fed into the second stage of the aquaculture system.

Illustrated in Panel A of Figure 2, the reactor consists of a frame (AF) which cradles a vertically oriented stack of plastic baffles (B, dimensions 2′ x 3′) that are fitted with rubber gaskets (G). When in use, the gasketed baffles are squeezed together with screw jacks (Sj) forming a sealed rubber tank that is partitioned by numerous plastic lemelli. The top of the reactor is sealed with plastic lids (L). Seawater flows along the axis of the reactor, being alternately directed up and down between the numerous baffles. The manner in which this is effected is shown in Panel B.



Tight clusters of clams, mussels, crabs, and other organisms around the living vents on the Galapagos Rift.

Our initial studies of the inoculation and growth of surface-attached sulfur bacteria were performed in a miniature version (6″ wide x 12″ deep x 34 baffles) of the larger reactor described above. Hydrogen sulfide-enriched estuarine water was allowed to pass through the mini-reactor and the major chemical gradients (hydrogen sulfide, oxygen) assayed in conjunction with studies of the dynamics of colonization. Nitrogen and phosphorous were supplied at the

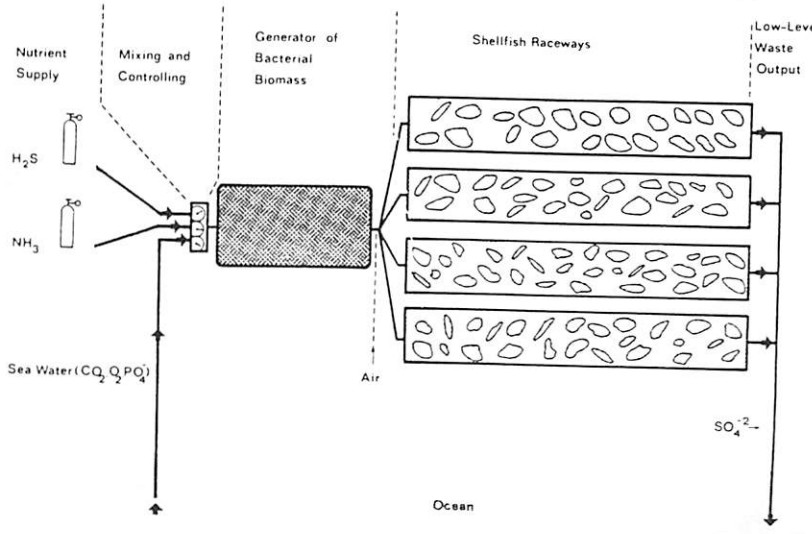


Figure 1. Chemosynthesis based aquaculture facility.

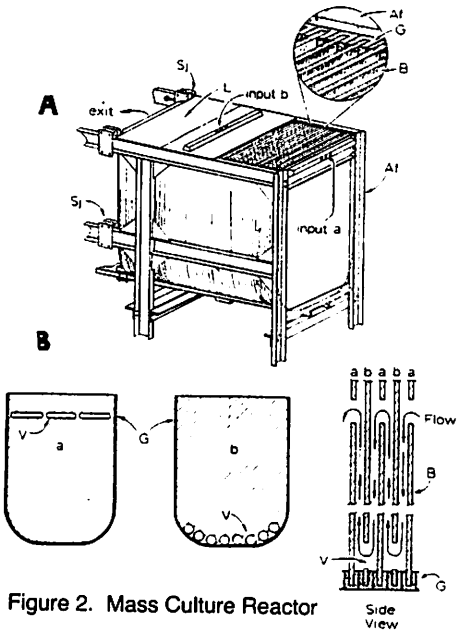


Figure 2. Mass Culture Reactor

natural low levels present in the incoming water. Results from these and other studies permit several conclusions to be made in regard to the practical culture of surface attached sulfur bacteria. A) sulfur oxidizing, chemosynthetic microorganisms are naturally present in aerobic estuarine waters. Estuarine based reactors will therefore be self inoculating. B) Once hydrogen sulfide is introduced into the flowing seawater, colonization of the reactor is rapid requiring only a few days. C) Under the conditions of our preliminary experiments (nitrogen or phosphorous limitation) a filamentous sulfur bacterium predominates within the reactor, along with lesser numbers of more typical rod-shaped bacteria. D) In accordance with our expectations both hydrogen sulfide and oxygen are rapidly consumed by the microflora. Ninety percent of the observed biological activity in fact occurs in the first quarter of the reactor. Production in the remainder of the reactor was limited by oxygen.

These first results suggest that a maximum production is achieved in a much shorter section of the reactor (i.e., fewer panels) than originally assumed. We can now take advantage of the flexible design of the reactor system by dividing it into a multiple set of shorter sections each of which is provided with a separate inlet and outlet.

When natural seawater without an exogenous nitrogen source was used, the protein fraction in the produced biomass was obviously low, however, the high productivity of carbohydratous material still persisted. We are presently investigating the influence of added nutrients upon the establishing populations, the overall productivity, and the nutritional value of the product for its use as food in aquaculture.

Carbohydrate and Protein Utilization by the American Lobster *(Homarus americanus)*

Judith M. Capuzzo and Bruce A. Lancaster,
Department of Biology

Mass culture of commercially important omnivorous species, such as the American lobster, will be facilitated by the use of formulated feeds. The basic features of such feeds would be:

(1) that the animal's nutritional requirements are met, resulting in high growth rates and no significant difference in biochemical composition from that of wild populations;
(2) that the feeds are readily consumed and assimilated by the animal; and
(3) that the feeds are formulated from commercially available feedstuffs, thus reducing the costs of producing the feeds and minimizing the cost of feeding in aquaculture systems.

For an adequate formulation of compounded feeds, however, an understanding of assimilation and utilization of various dietary components by an animal is needed. Protein is an essential but expensive component of an animal's diet: it is needed for tissue growth and maintenance, but may also be catabolized as an energy source by some organisms. Utilization of protein is affected by the nature of the dietary protein source, the dietary level and the ability of the organism to utilize other dietary components as sources of energy.

To maximize both growth and protein utilization in the American lobster, energy sources in addition to protein must be utilized. Energy production from protein oxidation is both nutritionally and economically wasteful and the protein sparing action of other dietary components must be fully investigated. The objectives of our research have been: (1) to identify the effects of low-protein feeds on the bioenergetics of juvenile lobsters; and (2) to define optimum protein:carbohydrate and protein:energy ratios for formulated feeds for the American lobster.

Using formulated feeds with shrimp meal as either the major or supplementary protein source and corn starch or wheat starch as the major carbohydrate starch, we have demonstrated that at protein levels of 23-30% and protein:carbohydrate ratios of 1.00-1.50, growth rates, biochemical composition and energy partitioning of juvenile lobsters were similar to results obtained with lobsters fed a control brine shrimp feed (protein level = 51%; protein:carbohydrate ratio of 5.1, Table 1). Protein efficiency ratios and protein utilization ratios, however, were higher among lobsters fed the lower protein feeds, indicating an increased dependence on dietary carbohydrate as an energy source and increased utilization of protein for growth. Optimization of feeding in lobster aquaculture systems can thus be realized with the formulation of low-protein feeds.

TABLE 1. Growth and protein utilization of juvenile lobsters *(Homarus americanus)*. [a]

	1	2	3	4
Protein level (%)	16.7	23.3	30.0	51.0
Protein: Carbohydrate (g/g)	0.5	1.0	1.5	5.1
Protein: Energy (g/kcal)	0.06	0.08	0.11	0.16
Initial weight (g) [b]	0.20	0.20	0.20	0.20
Initial protein content (g)	0.028	0.027	0.028	0.028
Final weight (g) [b]	2.00	2.57	2.60	2.49
Final protein content (g)	0.294	0.324	0.325	0.314
Weight increase/day (g/day)	0.015	0.020	0.020	0.019
Food given (g)	3.94	4.53	4.50	4.78
Protein given (g)	0.658	1.055	1.350	2.440
Food conversion ratio [c]	2.20	1.90	1.90	2.10
Protein efficiency ratio [d]	2.70	2.20	1.80	0.90
Protein utilization efficiency [e]	0.45	0.28	0.22	0.12

[a] Feeding period = 120 days.
[b] Wet weight, mean of 20 replicates.
[c] FCR = dry weight food given (g)/wet weight gain (g).
[d] PER = wet weight gain (g)/dry weight protein given (g).
[e] PUE = protein deposited (g)/dry weight protein given (g).

Determining the Osmoregulatory Ability of Anadromous Brook Trout *(Salvelinus fontinalis)*

Robert J. Naiman, Judith M. Capuzzo, Stephen D. McCormick,
Department of Biology

Sea-run brook trout (*Salvelinus fontinalis*) may obtain growth rates that are four to five times that of their cohorts remaining in freshwater. This fact, in combination with an exceptionally high rate of return of brook trout to their parent stream, has generated keen interest in the use of this species in fish farming, ranching and population enhancement programs (Gibson and Whoriskey 1981; Whoriskey et al. in prep.). For any such program designed to grow brook trout in salt water, the determination of optimal size and age for introduction of young brook trout into sea water is an important first step. Research in our laboratory is designed to answer this and other key questions concerning salmonid smoltification.

In order to measure and possibly predict the readiness of brook trout to enter the marine environment, several physiological parameters related to seawater adaptation are being measured. Vapor pressure osmometry, atomic absorption, flame photometry and chloridometry are used to measure the osmotic and ionic concentrations in the blood of brook trout at varying salinities. Equipment for these methods has been purchased, and the techniques for their use have been mastered. Fish from the Massachusetts State Fish Hatchery, that are of the same approximate age but comprised of several size classes, are being used for preliminary examination of blood parameters.

To test the ability of young brook trout to enter sea water it is necessary to grow a large number of brook trout under constant laboratory conditions controlling both feeding rate and photoperiod. The Shore Laboratory at the Woods Hole Oceanographic Institution has been renovated with funds from Sea Grant and the WHOI Education Office to accommodate such a laboratory. At this time a dry lab and main culture room have been completed. The main culture room currently houses brook trout that are being monitored for growth rate and several blood parameters. To date, survival of these fish has been excellent. In early November, when the spawning season begins, 14,000 eggs will be obtained from the State Hatchery and will be raised in the main culture room. These fish will be divided into experimental groups and raised for approximately two years at different photoperiod and feeding regimes.

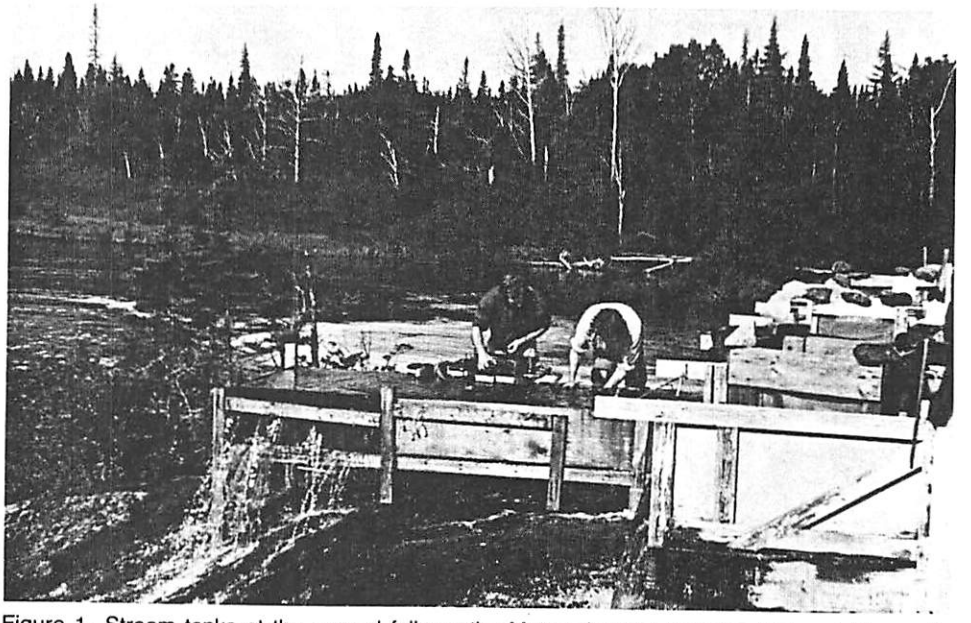


Figure 1. Stream tanks at the second falls on the Matamek River near the Matamek Research Station in Quebec Province.

Currently under construction at the Shore Lab is a constant temperature (12°C) room equipped with photoperiod control that will be used for exposure of brook trout to sea water. In the meantime, brook trout of varying size have been acclimated to freshwater in a similar constant temperature room at the Environmental Systems Laboratory. These fish are being exposed to sea water in order to determine the relative effect of size alone on the osmoregulatory ability of brook trout. Exposure to sea water is accomplished in the step-wise manner over a three day period (10% per day) after which the fish are maintained in full strength sea water. Growth and survival of these fish can then be compared to fish of the same size that remain in freshwater. Data of this nature will serve as preliminary guidelines to later examination of larger groups that will be maintained after hatch out in December. Brook trout hatched in December will be reared under totally constant or controlled conditions. It is these fish that will establish the relative importance of size, age and photoperiod in determining the sea-going capabilities of brook trout.

This initial period of investigation funded with new initiative monies from Sea Grant is an important part of this program. It has allowed us to establish strong contacts with other researchers studying salmonid smoltification, learn state-of-the-art physiological techniques, construct and test new experimental facilities, all of which are a necessary base for the important experiments to be conducted over the next two years.

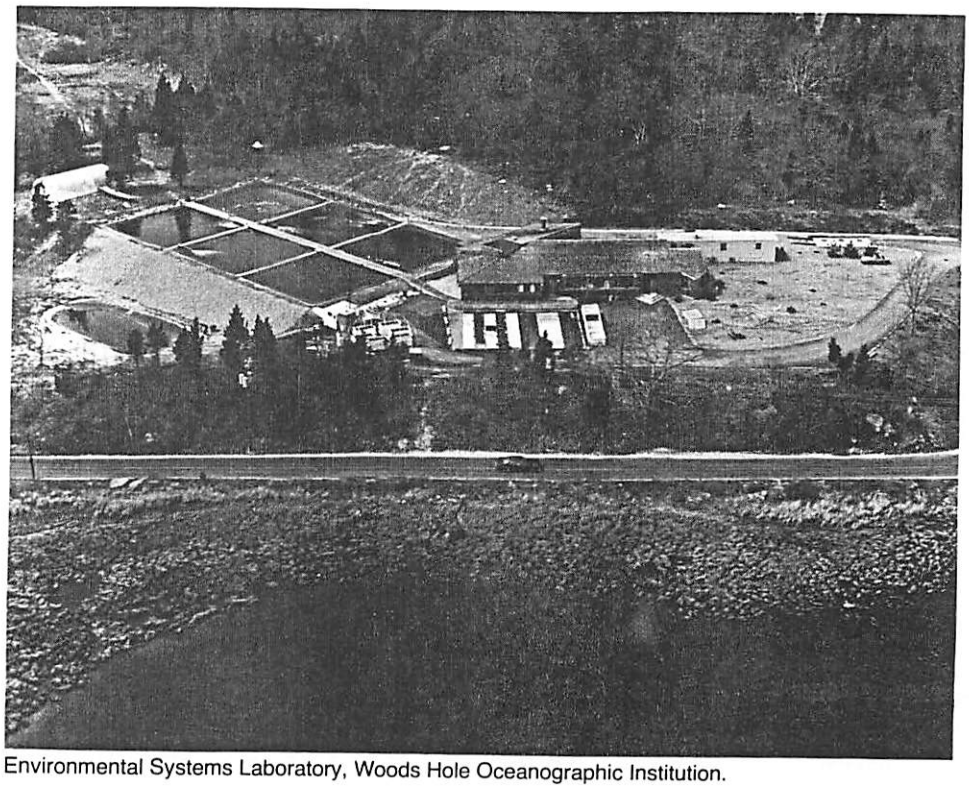
The Role of Compartmental Models in the Designs of Aquaculture and Ecosystem Experiments

Woollcott K. Smith, Department of Ocean Engineering
Thomas M. Leschine, Marine Policy & Ocean Management

Scientific investigations in marine pollution and aquaculture often progress from small, relatively simple laboratory experiments to larger, more complex experiments designed to examine interactions of the system's components. Since these larger experiments are often costly and time-consuming to conduct, it is important to derive as much information as possible from each experiment. In the past two years we have demonstrated how non-linear design techniques can be used to construct efficient experiments to evaluate the important interactions in these complex systems.

Marine pollution experiments, such as those conducted at the University of Rhode Island's Marine Ecosystems Research Laboratory for the EPA, are designed to study the interaction of chemical pollutants with the biota. The processes governing the input of the pollutant into the system and its degradation are generally known, as are the general properties of the ecosystem. The problem is how to best design an experiment to find out the most about the interaction of the pollutant with other elements of the system. The experimental design determines the rate of input of the pollutant into the system as well as the points in time at which measurements will be taken. The optimal design techniques we have developed often result in a large increase in the efficiency of the experiment. The algorithm for evaluating these designs depends on knowledge about the behavior of the isolated processes but it does not depend on knowing the details of the interactions to be studied.

As part of our studies of marine pollution experiments we have shown for two large experimental systems that species diversity is a relatively poor indicator of the effect of transient pollution events such as oil and chemical spills. This has important consequences for field evaluations of oil and chemical spills. From our studies change in species composition is a more sensitive indicator of pollutant effects than diversity for marine ecosystems.



Environmental Systems Laboratory, Woods Hole Oceanographic Institution.

Field experiments that evaluate a marine ecosystem's efficiency in transferring nutrients or pollutants are an important source of information for environmental managers. For example, discharge of treated sewage effluent into a salt marsh may enhance growth of shellfish in an environment enriched by the nutrients in the effluent. The application of flow analysis to compartmental models of marsh nitrogen flow showed that the transfer efficiency for nitrogen added to the marsh surface and processed through the *Spartina* life cycle to the point where it becomes available to shellfish was relatively low. These results suggested several general experimental designs that might be used in future field investigations of nutrient flow in marine ecosystems.

Marine Policy

Marine Policy and Ocean Management

Robert W. Morse and David A. Ross*,
Marine Policy and Ocean Management Program

A major objective of the Marine Policy Program is to provide a framework for the conduct of interdisciplinary research and educational activity dealing with our use of the ocean. The program has several methods of operation: it provides research fellowships for professionals interested in careers related to marine policy; it sponsors a permanent policy staff; it supports new research within the institution that has potential policy appreciation; it develops and supports workshops or projects of broad scope that bear on important national or international policy issues; and it assists in new scientific appointments within the institution that relate to marine policy problems.

The program in 1979-80 included four Policy Associates, five Guest Investigators, nine Postdoctoral Marine Policy Fellows and one Senior Fellow. In addition, the program sponsored one position in the Biology Department. All of these individuals pursued independent projects and in some cases participated in cooperative projects with members of the scientific staff. In 1979-80 these projects included:

- Mitigation, Marsh Creation and Coastal Wetlands Management
- Analyzing Salt Marsh Bioproductivity in Terms of Marsh Nitrogen Flow
- Risk and Uncertainty in Fisheries Management
- The New England Groundfish Industry and the Federal Government
- Defining the Role of Foreigners in the United States Fishing Industry
- New England Small-Scale Commercial Fishermen: Social Research
- The Coastal Energy Impact Program: The Boundaries Dilemma and Policy Problems
- The Basis for Regulation of Drilling Discharges at the East and West Flower Garden Banks, Gulf of Mexico
- Legal Concepts and Economic Foundations in the Management of Global Marine Resources
- Managing the Global Commons
- Federal Organizations for Marine Resource Management
- Oceanic Disposal of Radioactive Waste
- A Critical Evaluation of the Regulatory Potential of the Bioassay
- Prospectus for Analyzing Marine Policy
- U.S. Oceanography in the 1980s
- A Study of the International Decade of Ocean Exploration
- Science: A Source of Technology
- Allocation of Aquaculture Products
- Redesigning the Shipping Regime
- Regulating International Shipping

Workshops sponsored by the Program included one on remote sensing in the coastal zone conducted jointly with the University of Rhode Island.

The program provided partial support to certain projects conducted within the scientific departments. These included: A study of ecological theory applied to fishery management; the use of bacterial chemosynthesis for aquaculture; and a project to measure CO_2 in the ocean.

The Marine Policy Program holds two series of lectures; these include the Seward Johnson Lectures Series and a weekly lecture series involving policy members and the scientific staff. The Seward Johnson Lecture Series is a public meeting and draws its audience from a wide area. During 1979-80 speakers were Ambassador Elliot Richardson who spoke on the current status of the Law of the Sea negotiations; ambassador T.T.B. Koh of Singapore who discussed whether the United States should ratify the new Law of the Sea Treaty; and the late Ambassador Hamilton Shirley Amerasinghe, President of the Law of the Sea Conference who spoke on the Law of the Sea and its contribution to international peace.

*Dr. Ross became Director of the Program in May of 1980.

The Social Impact of Offshore Oil Development in New England: The Case of North Kingstown, Rhode Island

Jane H. Nadel
Marine Policy and Ocean Management Program

Since 1976 the former Navy lands at Quonset Point/Davisville in North Kingstown, Rhode Island have been the primary support base for offshore energy exploration in the Baltimore Canyon region of the mid-Atlantic. If drilling commences on Georges Bank, North Kingstown may experience something of an offshore oil boom. Planners and leaders at state and local levels look forward to the economic benefits, but are concerned about the impact of this new industry on the local community. This research addresses the human, social side of man's effort to draw oil and gas from the outer continental shelf.

The onshore development aspects of offshore drilling projects pose a number of important social issues for the coastal communities involved, including population growth and change, pressure on local resources and infrastructure, and new arenas

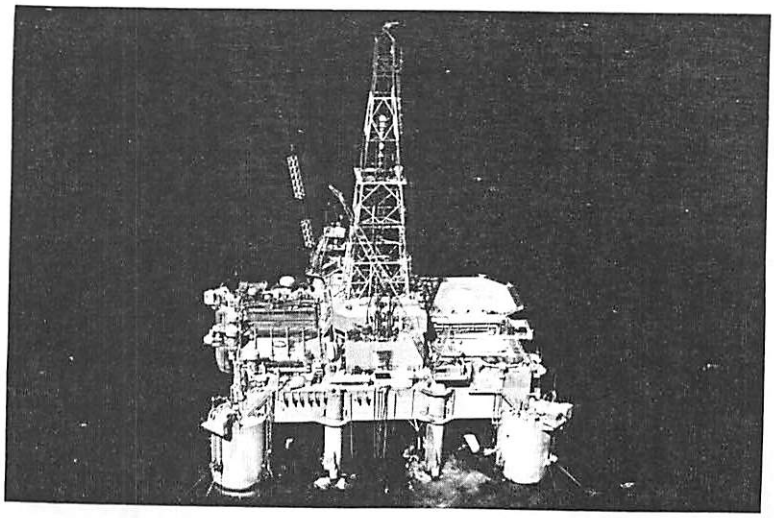


Figure 1. The *Ocean Scout* is the first semisubmersible oil well drilling vessel built on the east coast of the United States.

for planning and management decision-making and the attendant conflicts over jurisdiction. Businessmen and politicians in North Kingstown have become increasingly involved with the offshore oil industry both in Rhode Island and the U.S. Gulf Coast region and have made a number of contacts with North Sea operators as well. The North Kingston Chamber of Commerce hosted its third annual offshore oil and gas Trade Show this October. Local businesses, from carpet salesmen and office suppliers to catering establishments report a slowly growing volume of trade with the offshore industry at Quonset/Davisville. The Town Council has been involved in extensive and occasionally acrimonious negotiations with the State Department of Economic Development and the Rhode Island Port Authority over revenue and jurisdiction questions at the base.

Preliminary analysis of the North Kingstown situation indicates that the Scottish North Sea analogy, often used by planners to estimate impacts in New England, suffers from a number of weaknesses. Among these are the relative proximity of the home base of the offshore industry, the much more highly-developed nature of the New England region, and the very different government and planning institutions regulating development here, as well as striking cultural differences between New England and Scotland.

Wetlands Regulations and Public Perceptions in Massachusetts

Thomas M. Leschine, Marine Policy & Ocean Management

Coastal zone management is often described as the problem of allocating scarce coastal resources among competing and conflicting uses. Coastal wetlands, including such shorefront features as dunes and barrier beaches, are particularly fragile resources which have been eliminated or significantly degraded in many areas as the pace of coastal development has accelerated. Such resources not only have widely recognized aesthetic and recreational values, but also benefit man through the services they provide in flood control and storm buffering, as sinks for many coastal pollutants and as nurseries and feeding areas for fish and shellfish.

Thus the federal government, through the Coastal Zone Management Act of 1972 and related legislation, and many state and local governments have placed increasing emphasis on the preservation and management of wetlands. Massachusetts was among the first states to establish a comprehensive wetlands management program. The Wetlands Protection Act, passed in the mid-1960s, required local communities to set up conservation commissions to administer a permit system for all construction activity that occurred within 100 feet of wetlands. Through this and subsequent legislation the use of wetlands held in private hands came under state control for the first time.

In order to draw a socio-economic profile of the property owners affected by wetlands regulation in Massachusetts and to estimate the socio-economic impact of regulatory programs on them, an interview survey was conducted in two Massachusetts coastal towns in the summer and fall of 1979. Falmouth, on western Cape Cod, and Marshfield, on the south shore near Boston, were selected to represent regions which are growing in response to different pressures for development. Cape Cod has been growing very rapidly for the past twenty years or more; a strong in-migration of retired and semi-retired persons seems to account for most of its growth. The south shore, on the other hand, has grown mainly as a result of a substantial but smaller influx of Boston exurbanites still active in the labor force.

Popponessett, Cape Cod, Massachusetts

In addition to drawing a socio-economic characterization of wetlands property owners, this survey gathered information on the details of property ownership (such as present use, length of ownership, and pattern of use of property). Other information dealt with owners' knowledge of and attitudes toward state and local wetlands use regulation programs, their personal experiences with the regulatory apparatus, their concerns related to wetlands property ownership, and their perceptions of wetlands values and the effects of regulations on those values.

The interviewed Falmouth wetlands property owners differ significantly from their counterparts in Marshfield. They are on average older, much more likely to be retired or semi-retired, have higher incomes and higher valued property, and are much more likely to consider some other place (usually inland) to be their principal residence. They are also more likely to have modified the wetlands or waterfront areas on their properties by filling, diking, building a dock or seawall or some other structure than their counterparts in Marshfield. It is possible that their greater recreational orientation accounts for much of this activity.

The majority of wetlands property owners in both towns believed that the presence of nearby wetlands enhanced the value of their property and that wetlands regulations enhanced the value of wetlands. Though most people interviewed opposed the filling of wetlands, most of those expressing this view also believed that exceptions should be made when a "public benefit" is involved. Wetlands property owners generally favor local control rather than state control of wetlands programs, but knowledge of the goals and workings of all state wetlands programs was very low. Continuing work on this project will concentrate on statistical analysis to test the strength of correlations among those factors examined in an attempt to identify which are of greatest importance in defining the public role in wetlands regulation in Massachusetts.

Small-Scale Fishing in New England

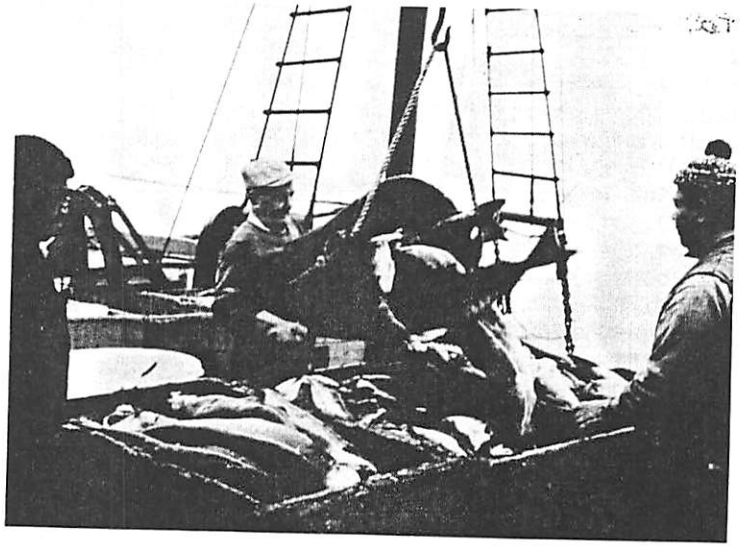
Susan Peterson and Leah Smith,
Marine Policy & Ocean Management Program,

Small-scale commercial fisheries have been a source of concern for the New England Fishery Management Council (established by the U.S. 200-mile legislation) since its inception. The Council, charged with the responsibility for managing fish while considering the complex interaction between the natural and social systems in this region, had use of data collected by the states and National Marine Fisheries Service. For the most part, this data did not provide details on boats less than 50′ or 40 gross tons. Because of the lack of information, small-scale and recreational fishermen are essentially outside the bounds of the current fishery management system. It may be that the Council, as a matter of policy, would not choose to regulate or manage this segment of the industry if it were known that the small-scale fishermen accounted for an insubstantial amount of the catch.

Our research has shown that, in Massachusetts, small-scale fishermen do not account for large volumes of the traditionally sought groundfish. Instead, they direct their efforts toward a mixed fishery - including a variety of groundfish: cod, haddock, yellowtail, blackback, lemon and summer flounder; lobster; crabs; conchs; shellfish; seabass; bluefish; swordfish; tuna; and sea and bay scallops (see Table 1). Economic independence lies in obtaining the right mix of catch when the market is good and the ability to leave a fishery once the market is saturated.

Small-scale fishermen are important to the coastal communities where they live, sell their fish, and buy bait and equipment. Although, for the most part, small-scale fishing is seasonal work, it does provide income supplements to professional, retired or seasonally unemployed people as well as the entire source of income for a smaller proportion of men. Despite the image of Boston, Gloucester, and New Bedford as fishing centers, fishing is proportionally of greater economic importance to many small coastal towns such as Westport, Chatham, Brant Rock and Rockport.

Better knowledge of the characteristics of the small-scale fishery would improve the basis for managing New England fisheries. Comparative information on large and small-scale fishing has implications for the development of fishery management strategies. A comparison would also allow predictions based on knowledge of industry structure on motivations of the different segments of the fleet. In 1980-81 we are expanding the research to cover all of Southern New England, and in 1981-82 plan to provide the comparative analysis necessary for fishery management.



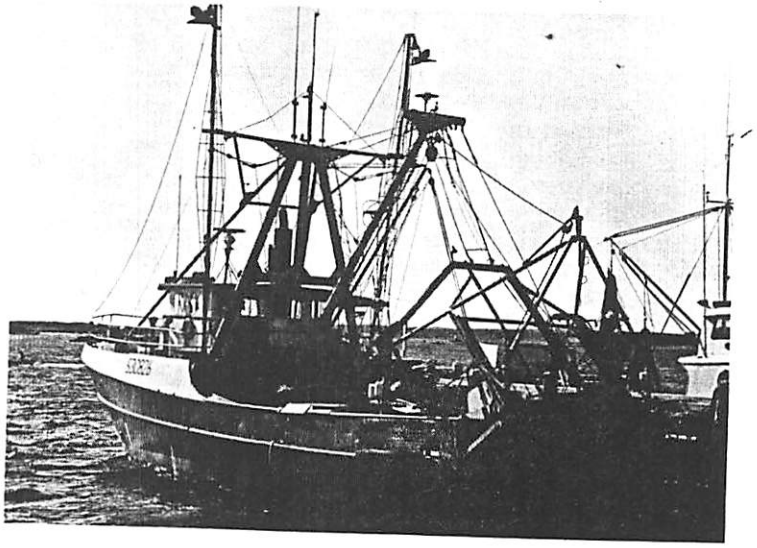


TABLE 1

Fish Species and Percentage of Fishermen* in New England That Fish Given Species at Sometime During The Year

Species	Percentage
Striped Bass	46%
Bluefish	40%
Cod	36%
Bay Scallops	25%
Flounder	19%
Lobster	15%
Quahog	13%
Fluke	9%
Tuna	9%
Swordfish	7%
Haddock	6%
Mackerel	6%
Scup	5%

* Survey based on 111 fishermen.

Marine Assistance Service

Arthur G. Gaines, Jr.,
Sea Grant Program

The Marine Assistance Service is a new element of the WHOI Sea Grant Program. Its principal staff member, Dr. Arthur G. Gaines, Jr. (Marine Science Advisor), joined the program in October 1979. In some aspects of the Service he is assisted by Dr. David A. Ross and Ms. Ellen Gately.

The principal objective of the Service is to assist the towns of Cape Cod and the offshore islands in identifying and solving their marine and related problems. This is accomplished through two complementary objectives: to represent the user community in the WHOI Sea Grant Program by focussing attention on appropriate current local problems; and, to represent the WHOI Sea Grant Program, with its substantial research and problem-solving ability, to the local user community. In our first year the Marine Assistance Service has focussed on three activities, discussed below, which we feel are essential in accomplishing these objectives.

It should be emphasized that the Marine Assistance Service does not replace the existing "advisory" effort of many individual scientists as part of their ongoing research projects. For example Dr. John Farrington has coordinated an information dissemination program among local, state and federal agencies and representatives with regard to the severe PCB pollution problem in New Bedford Harbor (MA), and convened an all-day workshop on the subject. Another example of this built-in advisory effort is illustrated in Dr. Donald Anderson's project. Dr. Anderson has maintained an active exchange with Shellfish Wardens and state officials regarding the findings of his red tide studies; his quick relay of research results at the advent of this year's bloom may well have saved human lives.

1. **Utilize and complement the existing infrastructure of the Woods Hole Oceanographic Institution.**

A number of offices and policies or activities exist at WHOI that can supplement the Marine Assistance Service's objectives, maximize its success and multiply its dollar effectiveness (Table 1). During the first year, cooperative interactions have been implemented with the Public Information Office, the Education Office and with Library staff. We continue to explore possible internal interactions and mutually beneficial activities with persons responsible for other offices or policies.

2. **Utilize and complement the existing Sea Grant network.**

The Woods Hole Oceanographic Institution is geographically close to two Sea Grant Colleges: the Massachusetts Institute of Technology and the University of Rhode Island. These programs offer many services for this region such as full-scale marine advisory services, education programs, a Sea Grant Depository and a Regional Coastal Information Center (jointly coordinated by U.R.I. and New England Marine Advisory Service), which we can augment or tailor to special local needs. We have established increasingly close working conditions with these and other elements of the regional Sea Grant network. We are also striving to identify and interact with elements of the national network, as well. For example, we regularly forward information received or solicited from programs around the nation, on topics such as sea food preparation and K-12 education, to organizations in the Cape Cod vicinity that have active programs in these areas. This illustrates how, through Sea Grant, we can be of local service in areas outside of this institution's main thrust.

3. **Identify and establish interactions with local and regional marine interest groups.**

The number of possible institutional beneficiaries of our service is large. Cape Cod and the Islands, alone, contain 23 towns and three counties. Each town has its own board of selectmen as well as several town agencies with marine concerns, such as shellfish wardens, waterways committees, conservation committees and alewife (herring) superintendents, to name a few. To a large extent these towns and agencies must be dealt with individually as there is a strong sense of home rule in this region and considerable variation in policy even among nearby towns. For example, some towns encourage private shellfish grants while the one next door may have the opposite view, regarding grants as an infraction on the public use of shellfish beds.

In other cases, however, composite associations exist through which many towns and interest groups can be addressed simultaneously. For example, the Cape Cod Planning and Economic Development Commission includes an Advisory Committee composed of representatives of each Cape Cod town. This committee meets monthly to discuss issues of mutual concern, of which a large portion are marine-oriented. Other public and private organizations, numbering more than a hundred in Massachusetts, provide either broad or focused perspective on marine topics of local concern, and from many viewpoints (Table 2).

There were several local coastal opportunities and problems evident during the first year of this Service and they can be grouped into three categories: *coastal erosion, shellfish management,* and *coastal pond management.* Each of these management categories contains numerous questions of significant scientific content and we have begun to identify appropriate key people within and outside of this institution to refine the issues and initiate projects.

— Coastal erosion on Popponesset Beach has been a major concern of the Town of Mashpee for many years. Past studies that addressed specific coastal protection schemes there, were not able to examine broader issues of sediment sources, pathways and fate. Initial contacts with the Board of Selectmen and with the WHOI Geology and Geophysics Department have yielded promising progress toward setting up a project to help resolve this important local management problem. Indeed, we were able to secure a small grant from the Town of Mashpee for one of our scientists to begin a study of this area.

— Shellfish (mainly scallops, quahogs and clams) are an important commercial and recreational resource to the Cape Cod vicinity, with numerous important economic ramifications. We have met with commercial fishermen in the towns of Bourne and Sandwich who are interested in developing new fisheries for these and other species. At present, we are reviewing the status of local shellfish management in order to help identify key obstacles to better use of the resource. Among shellfishermen there appear to be a number of long-held beliefs regarding resource management which have not been subjected to scientific scrutiny. It is possible that some of these beliefs, with objective substantiation and clarification, may provide significant clues for significant improvement of shellfish management.

— Coastal ponds are a focus for human and other activities on Cape Cod and the Islands. They provide residential sites, harbors, shellfishing and boating as well as nursery areas and habitats for numerous organisms. They are subject, therefore, to intense use-conflict. Progress of some projects dealing with coastal ponds is reported elsewhere in this report. During 1979 we initiated a new project on water quality in Siders Pond, Falmouth, which may receive domestic sewage discharge via the groundwater. Hopefully this study will aid the town in formulating sewerage priorities, a topic of considerable current interest.

In order to make past WHOI Sea Grant studies more available to individuals and groups with marine interests we have prepared, published and distributed annotated bibliographies, by subject, of the more than 250 WHOI Sea Grant publications produced to date.

At the close of its first year, we feel the Marine Assistance Service and the Marine Science Advisor are becoming increasingly recognized by individuals, public and private groups and town and state agencies as responsive contacts at the Woods Hole Oceanographic Institution.

Table 1

Activities of the Woods Hole Oceanographic Institution that Complement Sea Grant Advisory Objectives.

1. Public Information Office
   Operates public information service
   Issues news releases on institution activities
   Operates a display center
2. Education Office
   Administers a graduate education program
   Participates in marine education activities with local schools
   Administers summer fellowship and work programs
3. Maintains dialog and information exchange with marine-oriented private institutions
4. Marine Policy and Ocean Management Program
   Sponsors studies of ocean and coastal policy issues from multidisciplinary viewpoints
5. Marine library and library services
   Operates a major marine science library
   Conducts computerized bibliographic searches
6. Lectures and seminars
   Frequent lectures, open to the public, on marine topics, including special general audience presentations
7. *Oceanus* magazine
   Publishes articles on current marine science topics, written by experts for a lay audience.

Table 2

Examples of State and Private Coastal Interest Groups in Massachusetts.

State and County Agencies
Massachusetts Coastal Zone Management
Department of Environmental Management
Department of Environmental Quality Engineering
Division of Marine Fisheries
Division of Water Pollution Control
Division of Waterways
Cape Cod Planning & Economic Development Commission
Martha's Vineyard Commission

Non-profit Associations
Association for the Preservation of Cape Cod
Bourne-Sandwich Shellfish Association
Massachusetts Audubon Society
Trustees of Reservations
Massachusetts Shellfish Officers Association
Massachusetts Marine Educators
Mass. Inshore Draggerman's Association
Martha's Vineyard Shellfish Group
Salt Pond Area Bird Sanctuaries, Inc.

Reports and Publications

Aquaculture

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Goldman, J.C. and R. Mann, 1980. Temperature-Influenced Variations in Speciation and Chemical Composition of Marine Phytoplankton in Outdoor Mass Cultures. **Journal of Experimental Marine Biology and Ecology,** Vol. 36, pp. 29-39.

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Gibson, R. John, 1980. Behavioral Interactions Between Coho Salmon *(Oncorhynchus kisutch),* Atlantic Salmon *(Salmo salar),* Brook Trout *(Salvelinus fontinalis)* and Steelhead Trout *(Salmo gairdneri),* at the Juvenile Fluviatile Stages: Final Report to The Government of Quebec, Ministere Du Loisir, De La Chasse Et De La Peche, 59 pp. plus Appendix.

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Program

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Program Summary

Project/Principal Investigator	Contract Year Ending June 30: 1977	1978	1979	1980
ENVIRONMENTAL RESEARCH				
Stimulated Marine Bioproduction/ Teal, Valiela		N	C	C
Effects of No. 2 Fuel Oil on a Salt Marsh: A Quantitative Three Year Study of Recruitment and Growth/Hampson	N	F		
The Design of Environmental Surveys over Time/W.Smith	C	C	C	F
Biological and Physical Control of Erosion at the Sediment-Water Interface in Estuaries/Rowe, Boyer		NF		
Grain-Size in Laminae of Beach Sand/Emery		NF		
Volatile Organic Compounds in Coastal Waters: Levels, Sources and Sinks/Zafirou		NF		
Source and Fate of Estuarine Sediments — Boston Harbor/Milliman		N	C	F
A New Method for Characterization of Marine Organic Material in the Water Column and Sediments/Whelan		N	C	F
The Interactions Between Chemical Species and Phytoplankton Growth in Natural Water Systems/ Goldman, Brewer	N	C	F	
A Study of the Physical Characteristics of Bourne's Pond, Falmouth/Summerhayes, Ellis		NF		

Project/Principal Investigator	1977	1978	1979	1980
Sediment Dispersal in New Bedford Harbor and Western Buzzards Bay/Summerhayes	N	F		
Stability of a Small Coastal Inlet/Moody	N	F		
The Economic Potential of the East Coast Continental Margin: Blake Plateau to Georges Bank/Uchupi		N	C	C
Paleotemperatures and paleosubsidence of continental shelf sediments/von Herzen		N	C	F
The Hydrography and Circulation Over and Around Nantucket Shoals/Beardsley			N	F
Movable Bed Roughness in the Coastal Zone: A Field Study and Model Design/Grant, Williams			N	C
Sediment Transport in a Tidal Inlet/Aubrey			N	C
Biochemistry of PCBs in New Bedford Harbor and Buzzards Bay, MA/Farrington				N
LIVING RESOURCES				
Populations and Migrations of Certain Large Pelagic Fish/ Mather	*	*		
Effects of Petroleum Hydrocarbons in Marine Fishes/ Stegeman, Sabo	F			
Histopathology of Marine Fish Exposed to Hydrocarbon Contaminants/Stegeman		N	F	
Distribution of Potential Food Resources for Shellfish in Bourne's Pond/Brand	F			
Population of Eels in Cape Cod Waters/Haedrich		N	F	
Reproductive Biology of Wood Boring Molluscs *(Xylophagainae)* on the Continental Shelf of the Eastern United States/Berg			NF	
Quantitative Assessment of Microbial Transformations in Estuarine Waters/Taylor			NF	
Metabolism of Aromatic Hydrocarbons by the Bivalve Mollusc *Mytilus edulis*				N
SOCIO-ECONOMIC AND LEGAL STUDIES				
Limited Effort Programs in the New England Fishery/ L. Smith, Peterson	F			
Draft Legislation for the Massachusetts Lobster Fishery/ Peterson, Friedman	F			
Marine Policy and Ocean Management/Morse, Ross	C	C	C	C
Marine Technology Transfer as Foreign Aid to Less Developed Countries/Sarr	F			
Systems Models and Experiment Design with Application to Marsh Fertilization and Lobster Feeding Experiments/ Smith, Leschine			NF	
A Proposal to Analyze National Marine Fisheries Service Lobster Data for Use in the Outer Continental Shelf Oil and Gas Leasing Process/Spiller			NF	
Small Scale Commercial Fisheries in New England/ L. Smith, Peterson			N	C
Assessing the Impacts of Coastal Zone Management: Wetlands Regulations and Cape Cod Private Property Development/Leschine				NF
The Social Impact to Offshore Oil and Gas Developments in Two Southeastern New England Communities/Nadel				NF
The Role of Compartmental Models in the Designs of Aquaculture and Ecosystem Experiments/ W. Smith, Leschine				NF

Project Principal Investigator	1977	1978	1979	1980
MARINE RESEARCH & TECHNOLOGY				
An Optical Trap for the Use of Diffuse Solar Radiation in Hyperthermal Aquaculture/von Arx	N	F		
Handbook of Oceanographic Engineering Materials/Dexter	F			
Dynamics of the Inclining Spar Current Sensor/Mavor	NT			
Studies for the Development of An Improved Zooplankton Sampling Pump System/Haury	N	F		
Experimental Evaluation of Loran-C Telemetry from a Drifting Buoy/Walden		N	C	F
Dormant Cysts and Trace Metal Sensitivity: Two Key Factors Affecting the Initiation, Development and Geographic Spreading of Toxic Dinoflagellate Blooms/Anderson			N	C
AQUACULTURE				
Bivalve Mollusc Culture in a Waste Recycling Aquaculture System/Ryther	C	T		
Finfish Research at Matamek, Quebec/Gibson	*	*	T	
The Genetic Component of Growth and Survival in Raft-Cultured and Natural Populations of Quahogs *(Mercenaria mercenaria)* on Cape Cod/Grassle	C	C	F	
The Effects of Diet on the Growth Energetics of Postlarval Lobsters *(Homarus americanus)* Capuzzo		N	C	F
Uptake of Heavy Metals, Organic Trace Contaminants and Human Enteric Viruses by the Japanese Oyster, *Crassostrea gigas*, grown in a Waste Recycling-Aquaculture System/Mann		NF		
A Combined Biological and Economic Analysis of the Feasibility of Large Scale, Waste Recycling Marine Bivalve Aquaculture Systems/Mann			N	
The Biology of the Ocean Quahog, *Arctica islandica*/Mann			N	C
Microencapsulated Foods for Rearing Larval Marine Fishes/Capuzzo			NF	
Preliminary Investigations of Local Populations of the Bay Scallop, *Argopecten irradians* Lamarck/Capuzzo, Taylor			N	C
Stimulation of Fish Growth by Detritus Feeders/Connor			N	NT
Effects of Natural Stimulation of Phytoplankton Productivity and Phytoplankton Species Composition on Mollusc Growth/Ryther			N	NT
MARINE EDUCATION & TRAINING				
Coastal Zone Management/Black	F			
Marine Science Libraries Cooperative Network/Winn	NF			
Marine Assistance Services/Gaines				N
PROGRAM MANAGEMENT				
Program Management and Development/Ross	C	C	C	C
Acquisition of Six VMCM's and Check Out Equipment for Use in Coastal Zone Research Projects/Grant				NF

N - New Project; C - Continued Project; F - Completed Project; T - Terminated Project; *-Continued with funds from sources other than Sea Grant.

During FY 80 the Woods Hole Oceanographic Institution Sea Grant Program consisted of:

21 Research Projects (plus 7 new initiatives)
1 Program Management
Personnel associated with the Sea Grant Program were:
Scientific Staff - 29
Technical Staff - 30
Departmental Assistants - 9
Post-Doctoral Investigators - 13
Graduate Students - 7
Undergraduate Students - 1

Budget Summary 1980-81

	NOAA	Matching Funds	Total
The Hydrography and Circulation Over and Around Nantucket Shoals	$ 42,000	$ 000	$ 42,000
Movable Bed Roughness in the Coastal Zone: A Field Study and Model Design	$ 42,000	$ 17,848	$ 59,848
Sediment Transport in a Tidal Inlet	$ 25,000	$ 9,531	$ 34,531
Source and Fate of Estuarine Sediments — Boston Harbor	$ 40,000	$ 9,244	$ 49,244
Design, Construction and Testing of Loran-C Telemetry from a Drifting Buoy	$ 27,000	$ 000	$ 27,000
Geothermal Studies of Passive Continental Margins	$ 15,000	$ 4,948	$ 19,948
The Economic Potential of the East Coast Continental Margin: Blake Plateau to Georges Bank: Continental Rise Off Southern New England	$ 17,800	$ 000	$ 17,800
Stimulated Marine Bioproduction	$ 61,800	$ 41,827	$ 103,627
The Biology of the Ocean Quahog, *Arctica islandica*	$ 50,000	$ 000	$ 50,000
Dormant Cysts and Trace Metal Sensitivity: Key Factors in the Initiation, Development and Geographic Spreading of Toxic Dinoflagellate Blooms (Red Tide)	$ 30,000	$ 5,860	$ 35,860
Biochemistry of PCBs in New Bedford Harbor and Buzzards Bay, MA	$ 31,300	$ 000	$ 31,300
Metabolism of Aromatic Hydrocarbons by the Bivalve Mollusc *Mytilus edulis*	$ 19,400	$ 1,325	$ 20,725
A New Method of Characterization of Marine Organic Material in the Water Column and Sediments	$ 24,000	$ 6,485	$ 30,485
Carbohydrate and Protein Utilization by the American Lobster *(Homarus americanus)*	$ 33,300	$ 10,183	$ 43,483
Small Scale Commercial Fisheries in New England	$ 20,000	$ 20,255	$ 40,255
Assessing the Impacts of Coastal Zone Management: Wetlands Regulations and Cape Cod Private Property Development	$ 12,400	$ 5,081	$ 17,481
The Social Impact of Offshore Oil and Gas Developments in Two Southeastern New England Communities	$ 13,300	$ 14,500	$ 27,800
The Role of Compartmental Models in the Designs of Aquaculture and Ecosystem Experiments	$ 17,000	$ 6,217	$ 23,217
Marine Policy and Ocean Management	$ 19,400	$284,592	$ 303,992
Program Management and Development	$ 96,100	$ 23,000	$ 119,100
Marine Assistance Service	$ 17,500	$ 000	$ 17,500
Acquisition of Six VMCM's and Check Out Equipment for Use in Coastal Zone Research Projects	$ 20,700	$ 29,900	$ 50,600
TOTALS	$675,000	$490,796	$1,165,796