

# A History of Benthic Research in the NMFS Northeast Fisheries Science Center

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## Introduction

Benthic research has been done in northeastern U.S. waters by NOAA's National Marine Fisheries Service (NMFS) since the 1870's (Schopf, 1968), when the agency was titled the U.S. Commission of Fish and Fisheries, known less formally as the U.S. Fish Commission (USFC). The majority of

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**ABSTRACT**—*The Northeast Fisheries Science Center of NOAA's National Marine Fisheries Service has a long history of research on benthic invertebrates and habitats in support of the management of living marine resources. These studies began in the 1870's under Spencer F. Baird's guidance as part of an effort to characterize the Nation's fisheries and living marine resources and their ecological interactions. This century and a quarter of research has included many benthic invertebrate studies, including community characterizations, shellfish biology and culture, pathology, ecosystem energy budget modeling, habitat evaluations, assessments of human impacts, toxic chemical bioaccumulation in demersal food webs, habitat or endangered species management, benthic autecology, systematics (to define new species and species population boundaries), and other benthic studies. Here we review the scope of past and current studies as a background for strategic research planning and suggest areas for further research to support NOAA's goals of sustainable fisheries management, healthy coastal ecosystems, and protected species populations.*

this work was conducted by the NMFS Northeast Fisheries Science Center (NEFSC) which was established formally as the Woods Hole Laboratory of the USFC in 1885 (Galtsoff, 1962). Several other laboratories have been part of the NEFSC since then.

These studies have produced an extensive body of benthic information that addresses a number of marine fishery resource ecology and habitat quality questions, supporting the marine resource stewardship of the National Oceanic and Atmospheric Administration (NOAA). It has also enabled the NEFSC to lead or keep pace with similar research in other regions of the world such as the North Sea.

This review 1) summarizes briefly major benthic research conducted by Federal marine fisheries laboratories in the northeastern United States since the 1870's, including within the current NEFSC, and notes how it has contributed to our understanding of estuarine and marine ecosystems and the management of fisheries or protected species stocks and their essential habitats, 2) describes current benthic research in the NEFSC, and 3) suggests areas in which benthic research is required or can have an important role in strategic planning. This review does not put special emphasis on assessment studies of specific benthic shellfish of fishery value. Instead, it is oriented toward benthic habitat, community, and ecosystem research that supports sustainable fishery management, including understanding the impacts of human activities. The review is not intended to be a comprehensive bibliography of all the diverse benthic work done by the NEFSC, but it is an

overview of the types and range of studies conducted.

## Historic Benthic Research

### New England

The major benthic research conducted in northeastern U.S. waters has been listed or briefly summarized by Wigley and Theroux (1981), Reid and Steimle (1988), Steimle (1990b), National Systematics Laboratory (1993), Theroux (1994, In press), and Theroux and Wigley<sup>1</sup>. Those conducted by Federal marine fisheries laboratories are summarized in additional detail below.

More than a century of benthic investigations at the NEFSC's Woods Hole Laboratory have identified the great diversity of species that live in the Northwest Atlantic, estimated their abundances, and characterized their habitats. These studies were conducted to develop an adequate understanding of the ecosystem needs of fishery resources (Wigley and Theroux, 1981; Theroux and Wigley<sup>1</sup>). Studies were also conducted to assess human threats to the New England fisheries and elements of the ecosystem that sustain them, e.g., *Argo Merchant* oil spill off Nantucket (Bowman and Langton, 1978) and oil and gas exploration on Georges Bank (Maurer<sup>2</sup>).

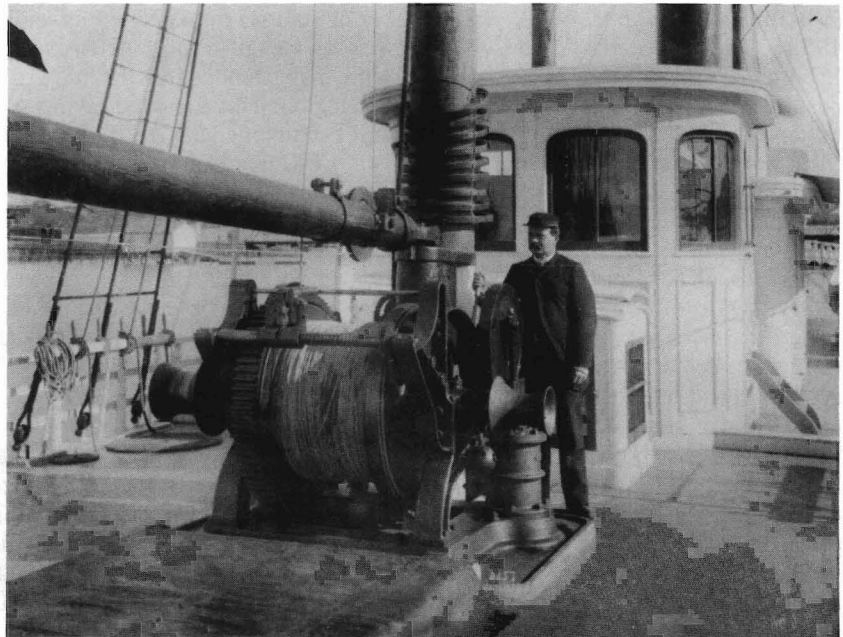
<sup>1</sup> Theroux, R., and R. Wigley. Quantitative composition and distribution of the macrobenthic invertebrate fauna of the continental shelf ecosystem of the northeastern United States. Manuscr. in review.

<sup>2</sup> Maurer, D. 1983. Review of benthic invertebrates of Georges Bank in relation to gas and oil exploration with emphasis on management implications. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Cent., Lab. Ref. Doc. 83-16, 329 p.





**Above and opposite page:** Two views of the second floor of the U. S. Fish Commission's new Woods Hole Laboratory which opened in 1885, with investigators at work. Many benthic studies were performed during this era, especially in the waters adjacent to Woods Hole and the nearby Vineyard and Nantucket Sounds. Identifiable on the opposite page, left to right, are A. H. Baldwin, Sanderson Smith, and Vinal Nye Edwards. All three were active in studying benthic fauna during this period. Baldwin and Smith were summer investigators, but Edwards, appointed by Baird during the first full summer's work of the Commission in 1871 as pilot and collector, became known as the "resident naturalist" for his encyclopedic command of "local knowledge," not only in the pilot's vernacular with reference to natural phenomena concerning weather, tides, and navigation, but more importantly for that pertaining to the local marine flora and fauna. Edwards remained the station's chief collector until his death in 1919.



**Right:** The steam-powered hoisting and reeling engine and dredging/trawling winch on the deck of the USFC steamer *Fish Hawk* used by Spencer F. Baird and Addison E. Verrill in their pioneering explorations to identify and characterize the inhabitants and constituents of the sea bottom and overlying waters of the contiguous New England coast. While this photo dates from about 1885, Baird's efforts began in the early to middle 1860's, and the joint efforts of Baird, Verrill, and several other colleagues began in earnest in 1871 when the U.S. Fish Commission was founded, and they have continued, with but minimal intermittent disruption, to this day.

In the 1860's Spencer F. Baird, then Assistant Secretary of the Smithsonian Institution, became aware of an apparently serious depletion of food fish along the New England coast from his own observations and talking to fishermen. He realized that there was a need to obtain scientific information on the possible causes of the apparent depletion, and other aspects of the fisheries, and he soon persuaded Congress to establish a Federal Fish Commission in 1871 with him as Commissioner. One goal of this Commission was to conduct a program of research in the interest of identifying and preserving the nation's dwindling resources. This program was based on a systematic description of marine organisms, what they ate, how and where they lived and moved, and the influence of disease, parasites, environment, and harvesting on them (Allard, 1978; Cart, In press). Baird's visionary program, which included the need for statistical information on fisheries and ways to increase fisheries resources, continues as a major focus of NMFS today.

The first comprehensive marine benthic surveys of New England waters were mostly qualitative, and they were conducted by Addison E. Verrill in the 1870's at Baird's instructions to determine if a decline in mollusk beds was responsible for the fisheries depletion (Verrill, 1873; Schopf, 1968; Allard, 1978). And today, the Woods Hole Laboratory's benthic data base contains quantitative benthic data obtained intermittently since 1881 (Theroux, 1994). Most of the data are from continental shelf and slope surveys done between 1953 and 1968. Some surveys emphasized the benthos of fishery-productive Georges Bank (Theroux and Grosslein, 1987), while others emphasized selected areas or taxa (Wigley et al., 1975). Studies of sediments and other geological attributes of the benthic habitat were also studied (Wigley, 1961; Emery et al., 1965; Wigley, 1966a; Emery et al., 1967; Wigley and Stinton, 1973; Wigley and Theroux, 1981; Cooper et al., 1987).

These data were used to estimate benthic secondary productivity and they supported the development of an eco-

system energy budget for Georges Bank (Cohen et al., 1982; Steimle, 1987) and elsewhere (Rowe et al., 1988). Further, they supported a diversity of ecological studies (e.g., Wigley and Burns, 1971; Williams and Wigley, 1977; Dickinson et al., 1980; Dickinson and Wigley, 1981; Theroux and Wigley, 1983; Maurer and Wigley, 1984; Shepard et al., 1986; Langton et al., 1990; and similar papers in preparation) and have been used to support environmental impact statements and international litigation (Theroux and Wigley<sup>1</sup>).

These benthic investigations are the source of the biological material in NEFSC Woods Hole Benthic Specimen Reference Collection, now available at the National Museum of Natural History in Washington, D.C. This collection is used by taxonomists and systematists from many research institutions and countries for describing new species or species distributions (Bousfield, 1973; Theroux, 1994). Demersal fish food habits, based on benthic macrofauna as important prey, have received increased attention since the 1950's (Wigley, 1956; Wigley and Theroux, 1965; Langton and Bowman, 1980, 1981; Hahm and Langton, 1984).

From 1978 to 1985, the NEFSC's Ocean Pulse environmental monitoring program (within NOAA's Northeast Monitoring Program) monitored a number of stations in the New England region as part of a more extensive program that extended into the mid-Atlantic Region. This included diving studies of submerged banks or ledges in the Gulf of Maine, submersible studies in deep-sea canyons (Cooper et al., 1987), and local surveys of several New England coastal areas, as summarized in Reid et al. (1987). The archived benthic sample and data base was used in other studies, e.g., Steimle (1990a, b) and Frame (1992).

#### Mid-Atlantic

With the exception of broad-scale surveys of the 1950-60's, summarized by Wigley and Theroux (1981), and some intermittent, generally qualitative coastal surveys, benthic studies south of New England were scarce until the 1970's. Studies were mostly focused on

the New York Bight, including its continental slope and rise (Reid and Steimle, 1988). Most of these studies were concerned with providing baselines to assess the potential effects of oil and gas exploration or the effects of waste disposal or hazardous substance spills or discharges.

One of the first environmental-effects studies in the New York Bight was by Redfield and Walford (1951) on the disposal of acid-iron wastes in the Bight apex, the coastal area off the mouth of New York Harbor and Raritan Bay. It sampled only two areas, the disposal site and nearby "mud hole," twice in 1948 with a 24 cm wide bite, "orange-peel" grab. Photographs of the seabed were examined to estimate the occurrence and relative abundance of megafauna.

The next study was during 1966-67 when 12 monthly surveys sampled 39 stations off southern Long Island New York as a baseline for a proposed sewer outfall (Steimle and Stone, 1973). Shortly thereafter, efforts were begun to assess effects of waste disposal in the Bight apex (National Marine Fisheries Service<sup>3</sup>).

Since the 1970's, there has been a proliferation of NEFSC benthic studies in the Middle Atlantic Bight (Reid and Steimle, 1988) that are continuing, at least in regard to data analysis. Most of these were concerned with waste disposal (Pearce et al., 1976, 1979, 1981; Caracciolo and Steimle, 1983; Steimle, 1985; Reid et al., 1991; Chang et al., 1992; Pikanowski, 1992; Reid et al., 1995) or environmental impact statements for proposed projects on the continental shelf such as oil and gas exploration. Certain studies developed baselines, e.g., Reid et al. (1979) and Steimle (1982, 1990b), or addressed other habitat quality issues (Steimle and Radosh, 1979; Steimle and Caracciolo-Ward, 1989; Steimle et al., 1990). A few studies were concerned with the effects of thermal modifications to waterways, such as Young and Frame (1976).

<sup>3</sup> National Marine Fisheries Service. 1972. The effects of waste disposal in the New York Bight. Sandy Hook Laboratory, Northeast Fisheries Center, NMFS, NOAA, Highlands, NJ 07732. Final Rep. to U.S. Army Corps Eng., Wash., D.C., 9 sect., unpagin.

## Specialized Studies

Some NEFSC benthic studies were on the life history and biology of important benthic species, such as harvestable clams (Loosanoff, 1953; MacKenzie, 1961, 1969; Ropes, 1979; MacKenzie et al., 1985), horseshoe crabs (Botton and Ropes, 1989), decapod crabs (Ropes, 1989; Stehlik et al., 1991; Stehlik, 1993), and other taxa (Wigley and Burns, 1971; Steimle, 1990a; Steimle et al., 1990; Packer et al., 1994). This information has been used to understand better the linkages and dynamics of the benthic ecosystem (Steimle et al., 1994a).

Other studies assessed chemical contamination of benthic invertebrates, such as those by Greig et al. (1978), Wenzloff et al. (1979), Steimle et al. (1986), Draxler et al. (1991), and Steimle et al. (1994b). The effects of potentially toxic chemical exposure and bioaccumulation on survival, physiology, diversity, and behavior of benthic invertebrates were also studied (Eisler, 1969; Calabrese et al., 1977; Olla et al., 1984; Studholme et al., 1987; Calabrese et al., 1984; Bolgiano et al., 1986; and others). These studies were often complemented with studies of sediment contamination (Carmody et al., 1973; Greig and McGrath, 1977; Koons and Thomas, 1979; Pearce et al., 1979; Reid et al., 1979; Zdanowicz and Gadbois, 1990).

The pathology and parasitology of many benthic invertebrate taxa was examined in several studies. Incidence of crustacean pathology and parasitology, beyond commercial species such as blue crab, were studied by Johnson (1983, 1985, 1986). Crustacean shell disease in the New York Bight and offshore received attention because of a possible relationship with waste disposal, as summarized in Sindermann et al. (1989). Several other NEFSC studies examined crustacean microbial parasites, black gill disease and relationships to pollution, e.g., Sawyer et al. (1984). Murchelano and MacLean (1990) and Sindermann (1990) also summarized crustacean and molluscan pathology with an emphasis on commercially valuable species, but other species are discussed too.

Research was focused also on energetic processes and models that could lead to a better understanding of the ways energy flows in regional ecosystems. To support these models, investigations on benthic invertebrate energy content (Steimle and Terranova, 1985, 1988) and secondary productivity (Howe and Leathem, 1984; Steimle, 1990a; Steimle et al., 1990) were conducted.

There were investigations of other benthic processes such as seabed oxygen consumption, and carbon and nutrient fluxes and dispersion (Thomas et al., 1976; Rowe et al., 1986; Phoel et al., 1995). These addressed important ecological functions that can lead to a better understanding of how anoxic events occur and how environmental variability influences rates, such as nutrient regeneration.

Benthic invertebrates were key elements in several habitat manipulation studies such as the use of artificial reefs to enhance habitat attractiveness to fishery resources, and possibly fishery productivity (Pearce and Chess, 1971; Steimle and Ogren, 1982; Foster et al., 1994).

The systematics of benthic invertebrates are important to understanding complex ecosystems. Definition of species, subspecies, and races help define the zoogeographic limits of species and their relationship to environments. The classification of species is essential to assess and understand the importance of biodiversity. Systematics is used to support regulatory processes, such as to confirm the source of imported seafood. Zoogeographic distributions of certain benthic species were paramount in the U.S.-Canada dispute over fishing rights on Georges Bank. The NEFSC has been involved in systematic marine research since the extensive work done by Verrill before 1900 (Theroux and Wigley<sup>1</sup>). Some recent efforts in this area include those of Wigley (1960, 1966b), Pettibone (1961), Pawson (1976), Bousfield (1973), Williams (1984), Frame (1980, 1992), Theroux and Grosslein (1987), and as summarized in National Systematics Laboratory (1993).

The National Systematics Laboratory has contributed to benthic ecology in more general ways since 1942 by de-

scribing species, providing essential keys for identifying benthic invertebrate species at all life stages, and publishing information on life histories and biogeography. For recent examples, see Perez Farfante (1988), Williams et al. (1989), Williams and Childs (1989), Williams and Wahle (1992), and National Systematics Laboratory (1993).

The NEFSC has also conducted studies to find better ways to sample or survey benthic habitats and communities, or to assess benthic data using more sophisticated statistics (Emery and Merrill, 1964; Wigley, 1967; Uzmann et al., 1977; Patil et al., 1979; Reid et al., 1995).

## Present Benthic Research

There are several ongoing benthic studies within the NEFSC that deal with either archived samples and data or new or ongoing collections. The Woods Hole benthic data base continues to be the source of new scientific research products. These include a summary of the benthic fauna of New England (Theroux and Wigley<sup>1</sup>), and other papers are being prepared.

Twenty-five years of continuous benthic research and monitoring in the Middle Atlantic Bight have provided a data base probably equaled in only a few areas of the world. This data base is actively used to support new hypotheses concerning the fluctuations in abundance and distribution of demersal fishery resources. It is also used with other data to define relationships among benthic habitats and communities, and fishery resources, e.g., Chang et al. (1992), Pikanowski (1992), Steimle et al. (1994a). Archived samples or data are also being used to study the toxic chemical contamination of key benthic prey in the New York Bight apex (Steimle et al., 1994b) and variability in benthic community structure in coastal and continental shelf areas. The benthic community at the former 12-mile sewage sludge dumpsite (12 MDS) in the Bight apex continues to be monitored semiannually to assess long-term recovery trends. These and previously backlogged samples are gradually being processed.

The benthic communities living on or near artificial reefs in Delaware Bay

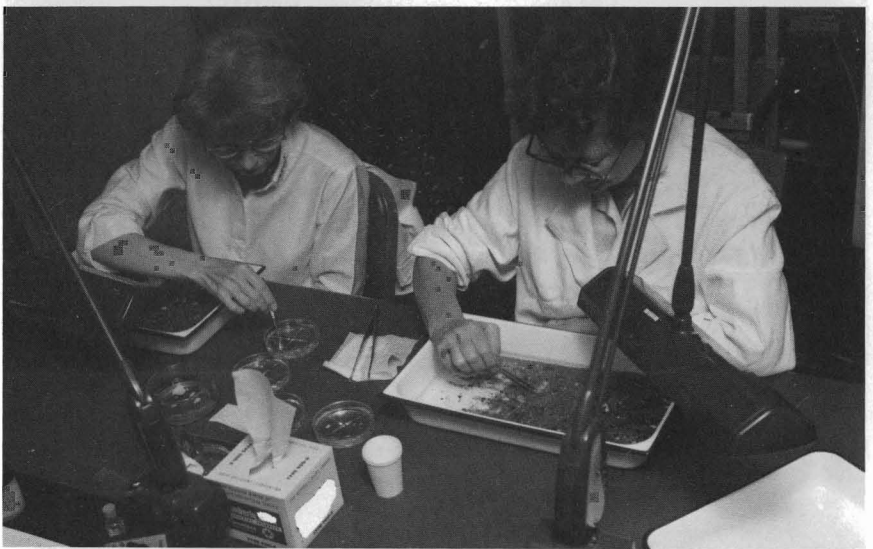


Processing benthic collections in the middle 1960's, above and facing page. The marine biologist above identifies the organisms contained in a collection of bottom material obtained during a major study to characterize the benthic fauna of the continental shelf and slope of the east coast of the United States.

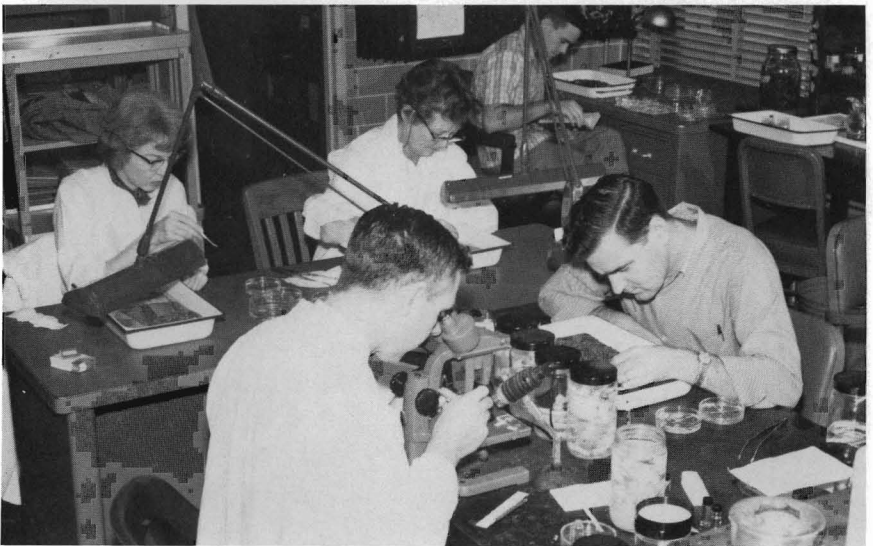
R. B. Theroux identifies and catalogues specimens of benthic fauna from bottom samples from the U.S. east coast continental shelf and slope.

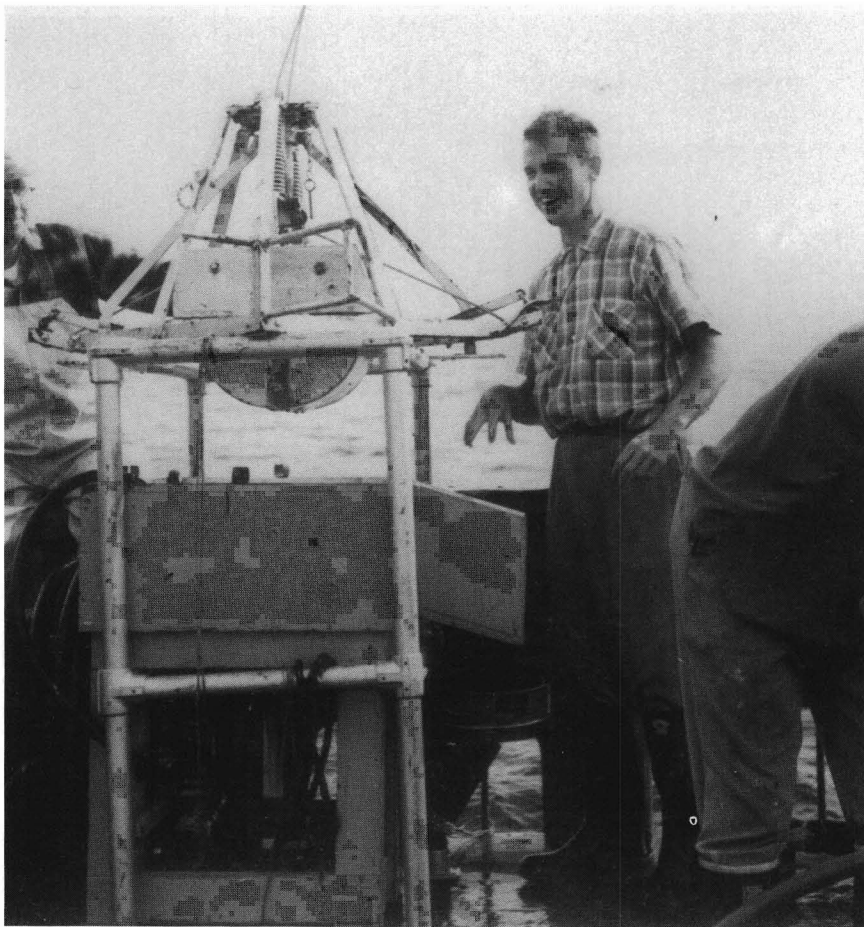


Laboratory technicians sort the contents of samples taken from the sea bottom.



Project leader R. L. Wigley (foreground) identifies organisms sorted out of the sea bottom samples by team members in the background.





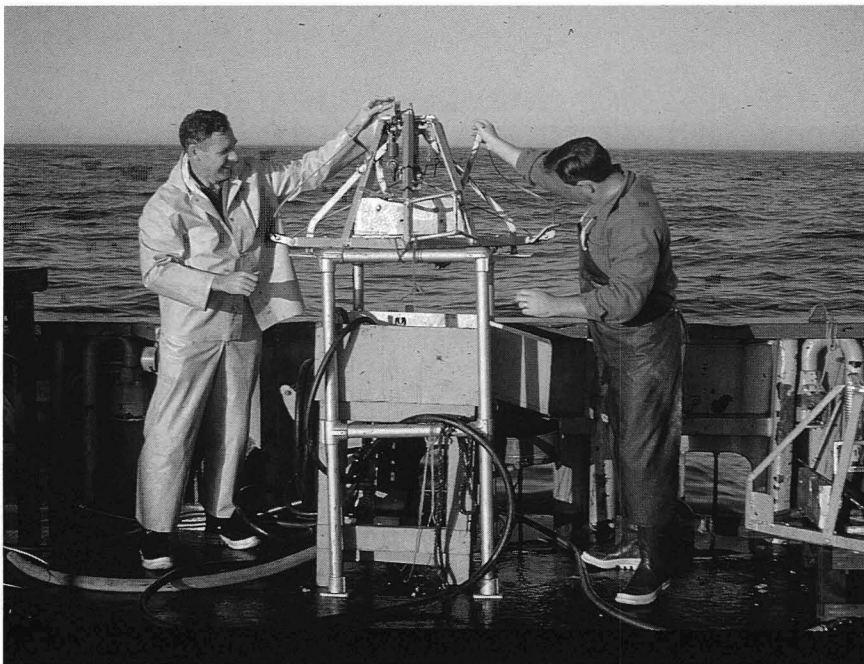
were monitored and studied from 1989 to 1994 to document quantitatively the habitat structure and forage enhancement value of artificial reefs to fishery resources (Foster et al., 1994). Such information is critical to addressing 1) the issue of whether artificial reefs are net producers of living marine resources or whether they aggregate dispersed resource populations and 2) whether artificial reefs are effective tools to restore, enhance, or mitigate losses in benthic habitats and their productivity.

Finally, the National Systematics Laboratory is completing a monograph on the mud shrimps of the western Atlantic that will include descriptions and keys to species and their relationship to other fauna. Other crustacean and cephalopod studies are also being pursued.

#### Future Benthic Research

Benthic research will continue to be part of NEFSC's programs in the future. This will include further use of benthic sample and data bases to address fishery habitat issues as they arise and new studies as required. Previous benthic research will be completed and new studies will be started to address new fishery ecology or management issues or marine ecology research opportunities.

Although harvesting mortality will always be a dominant factor in fishery resource population health, subtle effects of the availability, productivity, diversity, or quality (including toxic substance contamination) of benthic food can be a factor in recruitment success and resource distributions. Understanding the degree of this influence on fisheries will require continued benthic studies into the next century.



Top photo, a Smith-McIntyre spring-loaded quantitative ( $0.1 \text{ m}^2$ ) bottom sampler is retrieved onto a wash-stand on the deck of the R/V *Albatross IV* during a middle 1960's benthic invertebrate survey cruise. At bottom, the contents of the Smith-McIntyre spring-loaded quantitative ( $0.1 \text{ m}^2$ ) bottom sampler are emptied into a wash-box on the deck of the R/V *Albatross IV* during a benthic invertebrate survey cruise in the middle 1960's. From the wash-box, the contents of the sample are strained through a 1 mm mesh screen (visible just below the oblique chute at the lower middle right in the photograph), then preserved in a buffered solution of Formalin for later processing ashore in the laboratory.



Although benthic research in support of fisheries, endangered marine species, and habitat conservation has been conducted in the northeastern United States for over a century, there are still many important or critical gaps in our understanding of the roles benthic communities have in fishery ecology. Our knowledge of benthic processes, such as forage production and linkages to fishery resource health, and the consequences of environmental variability or anthropogenic alterations to these processes, is still inadequate. Recent benthic research in other productive fishery areas of the world and by universities or state fishery agencies has focused increasingly on evaluating benthic processes that affect fisheries, and the results of anthropogenic disturbances on these processes.

Some benthic research initiatives or topics to be addressed in the future include:

- 1) We must increase the predictive power of benthic community data by developing a better understanding of the causal mechanisms leading to changes in population size and abundance. Basic information is needed on genetics, biochemistry, pathology, and physiology for most benthic species, e.g. DePledge (1989). Adequate data on energy flow (food uptake, growth, and reproduction) and life cycles, as related to demersal resource species recruitment and survival, or anthropogenic effects, do not exist even for most dominant species.

- 2) Periodic monitoring of sensitive or stressed benthic communities or habitats, such as the former sewage sludge dumpsite in the New York Bight, preferably through interagency research coordination or cooperative agreements, will be required. Such monitoring can use benthic invertebrates as indicators of changes which can ultimately affect other components of associated ecosystems, including fishery resources or endangered species. Ecological models of the role of disturbance on the function and biodiversity of benthic communities need to be elaborated.

- 3) Unanswered questions concerning organic energy or contaminant flux,



Examining, recording, and preserving the contents of a naturalist dredge sample.



The contents of a naturalist dredge haul.



A pair of Digby dredges on a bridle, fine mesh nets streaming behind, is hauled to the forward port gallows of the *R/V Albatross III* during a benthic research cruise in the middle 1950's.

between benthos and fisheries and protected species, must be addressed. Anthropogenic and natural disturbances can change ecosystem productivity, e.g., eutrophication. Changes in food webs or interspecies competition can alter communities and their functions. Changes in the energetics of an ecosystem will be felt, directly or indirectly, in fishery and protected species population abundances, distributions, and health. We should consider further use of stable element isotopes, and their ratios, to explore and define energy flow to fishery resources and endangered species.

4) Mesocosms can be used to conduct controlled benthic experiments to further investigate and support findings from field studies, and fill gaps in our understanding of the behavior and relations between benthic species, including shellfish, and their environment, and benthic processes. Determining thresholds of disturbance or pollution tolerance by benthic species would help environmental regulators protect living marine resources.

5) New technologies, such as remote operated vehicles (ROV's), submers-

ibles, fiber-optic or satellite-linked monitoring stations, and chemical tracers, must be used to better assess and monitor benthic communities and processes. NEFSC benthic data bases must be adequately incorporated into Global Information System (GIS) type data bases for wider accessibility and use.

6) Benthic biodiversity studies and assessments, must be conducted, and the relationship of changes in biodiversity to ecosystem or fishery resource community health evaluated. Also, we know very little about the deep-sea benthic community, and few of the benthic invertebrate taxa have been adequately studied.

7) While maintaining a stable biodiversity, the biochemical assessments of diverse benthic taxa, such as sponges, coelenterates, polychaetes, mollusks, horseshoe crabs, and echinoderms, should be encouraged. These taxa are known to produce substances having pharmacological properties of potential interest to biomedical research and pathological remediation (Baslow, 1977; Scheuer, 1990; Faulkner, 1992). Because, with rare exception, such or-

ganisms presently have little or no commercial value or conservation advocates, it would appear to be NMFS's responsibility to be stewards of these living marine resources, too. This would assure that the current species are available to future researchers to evaluate and to expand their use as a source of biochemical models for various applications.

8) The importance of benthic habitat physical structure (including biogenic) to fishery resources and protected species, and effects of modifications to habitat structure on these species, must be evaluated. Habitat structure modifications can include: bulkheading, piers and pilings, dredged channels and subtidal dredged material mounds, beach sand replacement, dragged fishery gear, loss of a habitat-structuring benthic community (such as a shellfish bed), and the growing number of artificial reefs being built in coastal waters on or over benthic communities. The structure's productivity and other processes affecting fishery resources (especially juveniles) and fisheries (potential overharvesting) must be considered.

9) Ways to enhance the function of benthic habitats or communities for fishery resources, including habitat modifications to mitigate other habitat losses or predation mortalities, must be evaluated.

A major proportion of the fisheries in the Northeast are demersal and depend on benthic habitats as a source for food, shelter, and other essential life support. Benthic habitats and communities are also well known to be degraded by anthropogenic activities such as waste or accidental toxic discharges. Unforeseen events, such as toxic or hazardous material spills or detrimental algal blooms, are unique opportunities to enhance our understanding of how the impacts to benthos are important to fishery resource management or for monitoring fishery resource habitat quality. The maintenance of a core NEFSC benthic research capability is essential to provide an adequate and timely response to these events. We need to know more about the many aspects of benthos, including its natural variability, biomedical value, or inter-

relations with other resources, e.g., protected species.

This capability to continue to manage and study the benthos requires having trained marine benthic invertebrate taxonomists on staff and personnel who have adequate experience in planning and organizing benthic research projects, both for immediate response to an environmental crisis and for more controlled studies and interpretations, as suggested by the NEFSC Research Council<sup>4</sup> and Sindermann<sup>5</sup>. There is a need to assure that our benthic data bases and archived samples are adequately maintained for future use.

### Summary

Since most demersal marine fisheries resources and many protected marine species are dependent on benthos, and because many larger benthic species are harvestable, the NEFSC (and its predecessors) has had a long interest in the abundance, distribution, ecology, productivity, and health of the marine, coastal and estuarine benthic fauna. This interest has resulted in a plethora of studies on these topics and to define associations of importance to managers of living marine resources and their habitats. Despite the wealth of information that past and present studies have provided to managers, many unanswered questions remain about the influence of humans on benthos and of the role of benthos in fishery management. There are also many opportunities to manage the benthos to support future fisheries management goals, including searches for new products or uses for benthic taxa that could lead to new industries and employment.

The benthic taxa are more tractable for management experiments than other taxa because of their sedentary habits (Heip, 1992), as demonstrated from

many successful shellfish culture endeavors and habitat manipulation experiments, such as artificial reefs. To use our extensive benthic data base to its best advantage, it must be managed and developed to adequately address contemporary and future living marine resources management issues. We must maintain a basic benthic research capacity that can fully use our data bases and be adaptable to new issues, research or product-development opportunities, and technological advances. Continued investment in benthic research will maintain leadership in broad-scale and process-oriented studies to support marine fishery and habitat management.

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