NORTHEAST FISHERIES CENTER

NEWSLETTER

S P E C I A L   I S S U E

FISHERIES MANAGEMENT IN THE NORTHEAST:

ITS SOCIAL, ECOLOGICAL, AND SCIENTIFIC CONTEXT

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US DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE

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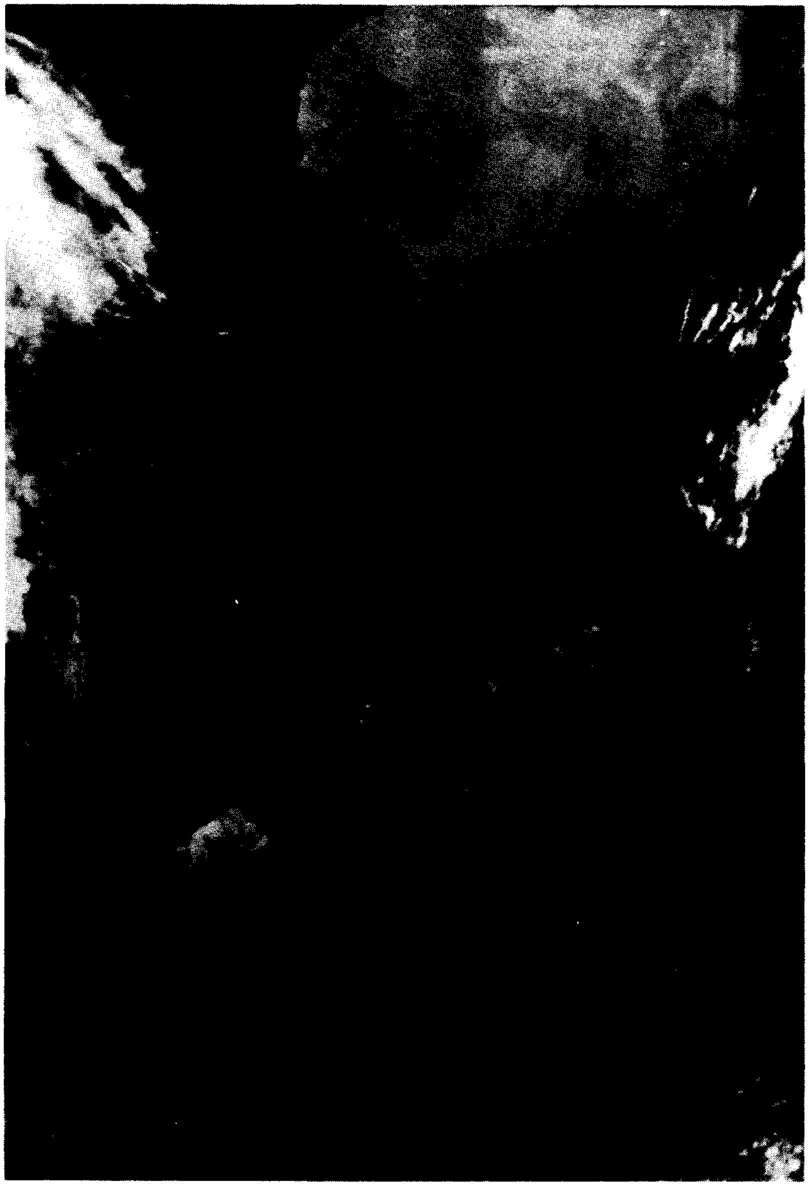


"Warm-core ring" pinched off from the inshore side of the Gulf Stream, revealed by infrared sensors on the TIROS satellite, June 1978. Cape Cod and Long Island appear at the upper left, and Cape Hatteras toward the lower left of the picture, northwest of a cloud. (See page 8 for further information)

PROLOGUE

This special issue of the Northeast Fisheries Center Newsletter has a broader purpose than the usual one of keeping other Laboratories and Centers of the National Marine Fisheries Service informed about the Northeast Center's current activities. The Center produces a wealth of detailed technical reports, but it would take more time than most people have to spare to assemble from these a comprehensive picture of the Center's work. Within the Center most of its members specialize in one aspect of the program or another. It is useful therefore, from time to time to step back, to look at the social, scientific, and political context in which the Center operates, refreshing our sense of how the various special activities interact and where these interactions might be improved.

In the pages which follow, we begin with a brief sketch of the origins of fisheries management, and its relationship to the concept of a common property resource. We then outline the important physical and biological processes that determine production in the sea, and how these, together with social, economic, and technical factors, form the context for research and management. Georges Bank fisheries are used to illustrate some of the issues. We then move southwestward to the Middle Atlantic Bight, an area highly stressed by pollution, to consider non-fisheries impacts on the marine ecosystem.

The motives for fisheries investigations are fundamentally social. Interesting and original science is often done along the way to achieving social objectives, but in the end, science serves the goal of an optimum allocation of the benefits to be derived from the marine environment for ourselves and our posterity.

To achieve this optimum, it is necessary to predict the effects on the marine ecosystem of various events, natural or brought about by human intervention. Closing fisheries after they have collapsed is a form of management, but a costly one, while stopping pollution does not immediately halt pollution's effects, which may persist for an unknown number of years. Management, to yield the greatest long-term benefits from the resources, must be based upon good ecological and economic predictions, and improving our ability to make these is at the heart of the Center's work.

The variability of the marine environment makes accurate prediction difficult. The effects of fishing and other human activities must be added to the natural influences producing this variation. Variability and our efforts to cope with it predictively are a major theme of this paper.

Because of its underlying social mandate, the National Marine Fisheries Service operates in a broader way than most other scientific agencies and institutions do. Others tend to concern themselves with explaining particular processes and their causes, which is often most efficiently done by experimenting in a circumscribed part of the ecosystem, or under controlled conditions in the laboratory. Such work is essential, and its results are often invaluable to the fisheries scientist; we do some ourselves.

But fisheries workers are concerned with whole populations of organisms spread over a broad geography, and with the total impact of their status on the fisheries. This makes monitoring an essential function of fisheries science, the importance of which is sometimes misunderstood.

Monitoring of animal populations and other environmental factors over large reaches of the ocean provides a basis for applying specific research findings, from the laboratory or a particular field site, for the purpose of making practical decisions. Knowing the toxicity of some substance to a particular species of clam, for example, is not of much use to fisheries managers unless the distribution and concentrations of that substance are known throughout the range in which the clam is harvested.

Monitoring has another function, too. It provides a measure of the past and present condition of the resources which can be directly used in management forecasts, even when the reasons for that condition cannot yet be scientifically explained. It is important to realize that managers are not adrift without such explanations. Monitoring the abundance of young fishes, for example, enables managers and fishermen to plan ahead, even though it may not be known why there are more young fish one year than another.

Because of the great impact of fishing and other forms of intervention by man in the marine ecosystem, monitoring cannot be confined to the resources alone. Patterns of behavior in the industry must be kept track of, and related to broader economic factors and the state of the resources. Non-fisheries uses of the ecosystem, ranging from recreation to ocean dumping, must be considered among the benefits we seek from it, however strange the term "benefit" may seem when applied to the latter practice. Practices which pollute have an economic value: the balance remaining when their costs and benefits have been added up. This balance (which may be negative) can be compared with similar cost-benefit analyses prepared for doing a given job of disposal in a less-polluting or a non-polluting way. The importance of projecting costs and benefits into the future becomes increasingly clear. This is certainly the case where short-term economies in disposal are achieved at the expense of long-term degradation of renewable resources. Such conflicts between fisheries and non-fisheries uses are already significant and can be expected to become more acute.

Yet, paradoxically, we are getting less from fisheries resources than we could, despite growing pressures upon them. For most species sought by consumers, the day is long gone in which demand could be met simply by increased and redirected effort in the fishery. But there is much to be done to improve the quality of the yield, both before and after it is caught, and to reduce quite needless waste.

Keeping quality high is not simply a question of getting fish quickly from the ocean to the processor or to the table, though that is essential. It has also to do with the quality of the ocean itself. Where the environment has deteriorated, freshly caught fish may be diseased or chemically tainted, and this, as much as spoilage, is a form of waste. To be sure, what happens to fish after it is harvested remains a major determinant of quality and hence demand in home and export markets. The technology is well developed for insuring freshness, yet it is often not applied despite demonstrations that it pays to do so, and that overall benefits to society are substantial, aesthetically, nutritionally, and economically.

Many excellent fish are thrown over the side of fishing vessels because they are not easily marketed; much of the potentially salable catch and potential profits are wasted by harvesting practices and inefficiencies which could be improved through engineering, through market incentives, or some combination of the two. The importance in reducing waste of this interconnection between engineering and management policy may be traced through from the fishing grounds to the processors and the distribution system.

It should be evident from these few beginning remarks that management of marine resources involves questions which ramify within our social and economic fabric in ways which are perhaps surprising. Many of the questions can only be answered subjectively, or in terms of the relative political or economic strength of contending interests, or of one philosophical view of property rights or another. Fisheries investigators often can furnish help in deciding such public questions, by reporting on the condition of the environment, and by attempting to predict the effects on resources and industry of alternative courses of action. But they will never, by themselves, be capable of supplying objectively "correct" answers to the broader problems of resource management, and they should not be expected to do so.

INTRODUCTION

Man as a Marine Predator

Fisheries science seeks to explain the relationships between living and nonliving elements of the natural environment, relationships which are frequently affected by human intervention. It is a branch of ecology which focuses on whole populations of animals and their interactions, rather than on individuals. Man is a powerful predator on these populations, but at the same time, he stands somewhat outside the system that comprises them. In a natural, closed system, even the ultimate predator eventually succumbs and returns his constitutent elements to it; the predator's welfare is inextricably tied to the health of the populations which support him. Wolf populations, for example, may be "automatically" regulated by populations of caribou they prey upon, and snowy owls by populations of mice and lemmings. When the prey diminish, so do the carnivores -- "prudent predators" in the ecologists' phrase, since they do not overexploit and hence destroy the resource they depend upon. This prudence is not conscious, of course, but the result of long-term, evolutionary selection of successful behavior, co-evolution, and patterns of population dynamics.

In a diffused and global sense, man's predation may also be regulated by the abundance of his prey. In practical terms, the "feedback loops" which transmit the consequences of his actions back to him are tenuous and often difficult to trace. These consequences are usually felt long after remedies should have been applied for greatest effect. Some groups, notably fishermen and their supporting industry, and consumers in places hard pressed for food, are demonstrably tied to the marine ecosystem. But in general, man in the industrialized countries, the opportunistic exploiter par excellence, commonly has options enough to unhook his fate from the fate of the fisheries resources. For us, unlike those predators literally immersed in the marine ecosystem, feedback is an intellectual process based on ecological concepts and the economic and social sciences. The effort we expend on deciphering and regulating our impact on this system is a measure of the value we place on its products.

The "Commons" and the Tradition of Management

Until recently, man's capacity for exploiting sea fishes was strictly limited; in proportion to his feeble fishing powers, the resources must have appeared boundless. The part of the ocean known to coastal dwellers was as narrow as the ink line on a map, and to affect or claim dominion over what lay beyond must have been unthinkable.

It seems fair to speculate that conflicts over resources arise only when they are hard pressed by the people using them. In the marine sphere, this must have happened first close to home, where populations of people had ready access to a large fraction of a given population of animals. Oysters come to mind, or anadromous fishes such as salmon or alewives, whose spawning urge funnels them into rivers where they are easy to get at. Access to such animals is in places which are well defined geographically: bays and river mouths, places encompassed within the borders of a town or two, where the effects of overexploitation become quickly evident and largely unarguable. Consensus on the problem, and a practical basis for addressing it in terms of political geography, seem to have made early fisheries management quite straightforward.

A 13th-century royal edict in England (it helps when the fisheries manager is King, of course) required a gap in salmon weirs big enough for a "sow and her pigs to pass" to insure survival of some spawners. On the same principle, and for the same purpose, colonial New Englanders agreed to close fishing on their alewife brooks certain days out of each week. In short, common rights in a wild resource were asserted early and have continued to be ever since. (Compare this with the farming tradition where stocks, though they might graze in common, were husbanded by individuals. The distinction persists: for example, though there is a common, public interest in our soil resources, it is still left to individuals to conserve them, influenced indirectly by advice and incentive and not by fiat.)

In fisheries, it is not the right of the public to control resources, but the extent of the right which is debatable. As the debate moves out to sea from the river mouths and bays, assertion of control becomes more difficult. William Bradford, first Governor at Plymouth, wrote in 1623:

> *About ye later end of June came in a ship, with Captaine Francis West, who had a commission to be admirall of New-England, to restraine interlopers, and shuch fishing ships as came to fish & trade without a license from ye Counsell of New-England, for which they should pay a round sume of money. But he could doe no good of them, for they were to stronge for him, and he found ye fisher men to be stuberne fellows. And their owners, upon complainte made to ye Parlemente, procured an order yt fishing should be free.*

Bradford cannot have been worried about depletion of the sea fishes, given early settlers' awestruck accounts of abundance; he apparently saw a chance to collect a tax. But the jurisdictional problem is plain to see and uncomfortably familiar.

Whatever Bradford might have thought, depletion was possible, and introduction in the 19th century of more powerful fishing methods proved it. Ignorance of the submarine world early in that century was quite complete once one got beyond coastal waters. (In 1843, for example, the sea was asserted to be lifeless deeper than 500 meters or so.) Under various stimuli, interest in sea exploration grew through the middle 1800's. By 1871, government support of marine biological investigations could be successfully justified by problems perceived to exist in the fisheries. In that year, preliminary work was begun by the newly created U. S. Commission of Fish and Fisheries at Woods Hole, and by the end of a decade, plans were complete for a substantial and permanent laboratory there.

The practical basis of this laboratory's mission was clearly articulated from the start. Implicit in its founding was the recognition of federal responsibility where marine fishery resources were concerned.

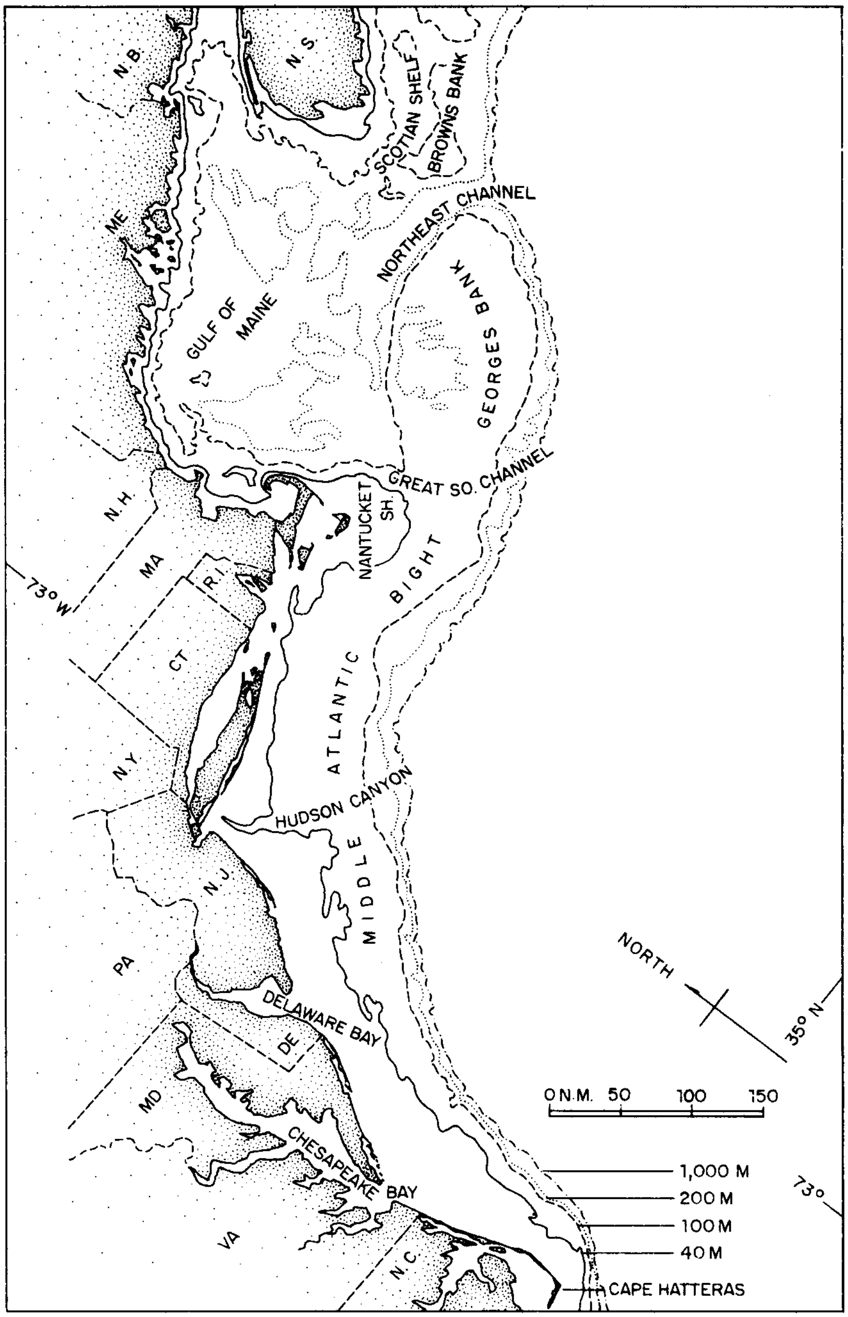
Spencer Baird, the first Commissioner, took the anecdotal experience of fishermen, acute but usually circumscribed, as a starting point, and sought to build from it a systematic science to be used to conserve and manage the fisheries in the public interest. From a quotation like this one from Capt. W. E. Whalley, a Rhode Island fisherman who testified before Baird, it was plain that the sea world was as orderly and integrated with comprehensive natural processes as any other:

> *I always judge by the dandelions; when I see the first dandelion, scup come in; I watch the buds, and when the buds are swelled full, then our traps go in. When the dandelion goes out of bloom and goes to seed, the scup are gone; that is true one year with another . . . .*

Clearly, the scup were not responding to the dandelions. Both fish and flower respond to more fundamental environmental variables. The problem was to find these. From the outset, Baird's investigations focused on the basic ecology of the resources (what he called their "natural history"): food chains, migrations, predation, growth, atmospheric influences, etc.; in short, the subjects which today are still the substance of fisheries investigations.

Baird recognized the conflict between the parochial interests of fishermen from neighboring states and the geography of the resources they sought, which was "apolitical." Today, with fishing fleets of vastly greater power and range, the nature of the conflict remains the same, but the scale and the inherent political difficulties are much greater. The interests of individual fishermen sometimes differ from the public interest, and where resources are in sort supply, competition among fishermen intensifies. The traditions of free access become more difficult to maintain.

The recent evolution of management and its social implications are intricately involved with scientific developments and with international policies and economics. Much of this will be discussed later. What is important here is that the conflict between free access to the "commons" and protection of common property is very old, and that present-day management is part of a continuum stretching back at least to that 13th-century English king.



The North American coast and the continental shelf from Nova Scotia to Cape Hatteras, North Carolina.

THE PHYSICAL SETTING

Some Physical Processes in the Sea

Oceanic waters are imperfectly mixed. Waters with different physical and chemical characteristics are identifiable as distinct "water masses" whose circulation can often be traced over great distances and long periods of time.

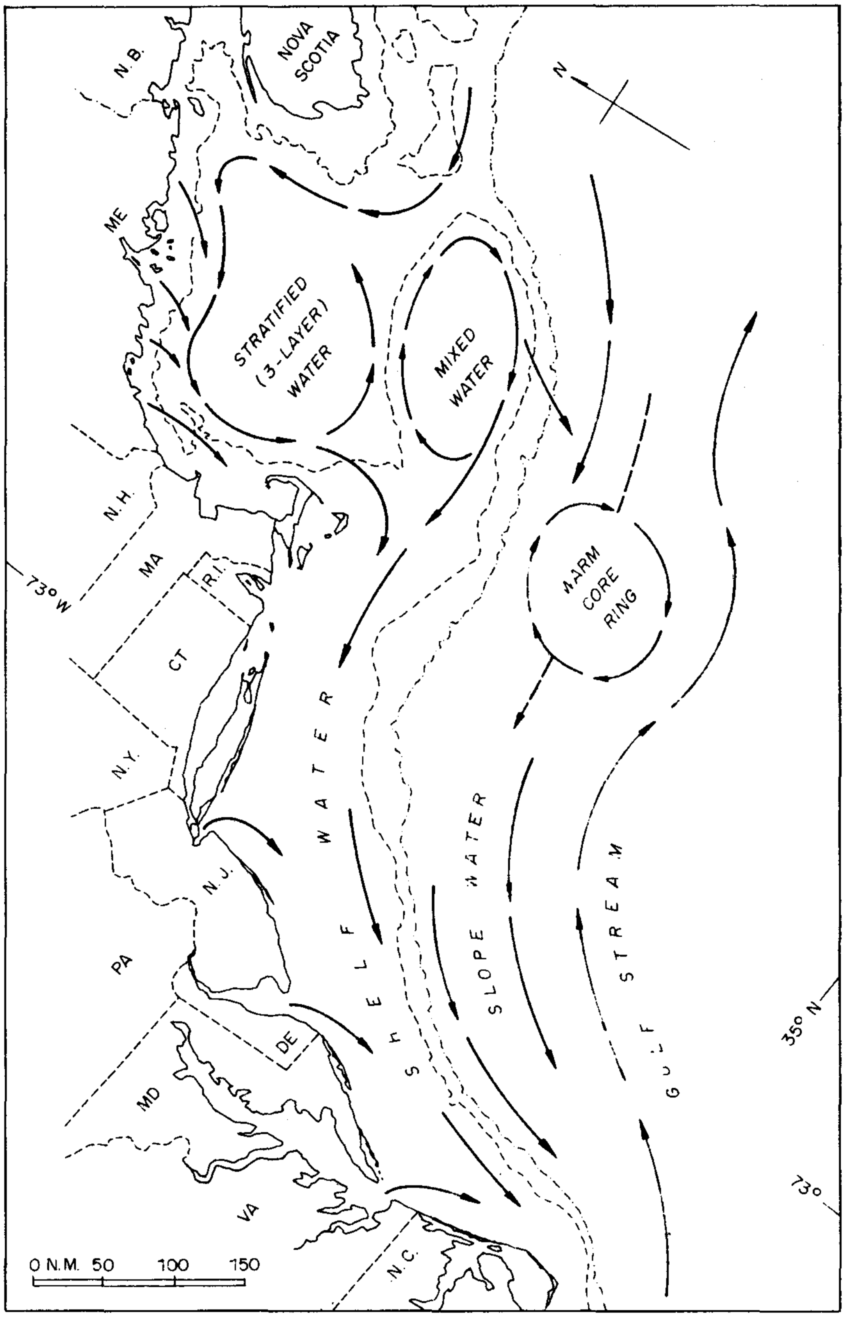
The saltier the water or the colder (down to a point near freezing, which varies with the salt content), the heavier or denser it becomes, tending to sink. (These two properties, salinity and temperature, act together so that very cold freshwater may sink below warmer salty water). In deep waters remote from the influence of wind, the layering produced by these differences in density may be quite stable. Near the surface, winds act to mix the upper strata, while the sun acts oppositely, making them less dense (by warming) and thereby more buoyant.

Bottom topography has its effect too. Deep currents impinging on submarine ridges or slopes may force cold, saline waters upward. This "upwelling" is important biologically since deep waters may be rich in oxygen and dissolved nutrients which, when delivered to the surface where photosynthesis can occur, fuel intense biological activity. Along the coast, runoff of freshwater from the land freshens the surface layers of the sea; wind mixing and upwelling, where they happen, offset this tendency. The runoff brings nutrients, too, and unfortunately, pollutants. Thus, the "shape" and circulation of water masses shift constantly with the seasons as the influences of sun, rain, and wind bring changes on the fundamentals of lunar tide and the earth's rotation. Violent storms bring transient distortions, lasting a few weeks perhaps, while oceanic processes of enormous scale work at a slower tempo--notable in our area are the meanderings of the Gulf Stream and the swirling pools of warm water it periodically gives birth to: the so-called "warm-core rings" which form on the western or inshore side of the Stream.

Hydrographic Domains of the Northwest Atlantic

The physical environment off the northeast coast of the U.S. can be divided into four domains more or less distinguishable by the temperature, salinity, and circulation patterns of their waters (see figure opposite). The first of these, the Gulf of Maine, is a deep basin open to the ocean at the surface, but isolated below about 50 meters, except for narrow passages at each end of Georges Bank. The second domain is Georges Bank itself, a broad shoal only four-meters deep in places, steeply banked on its northern side which forms the southerly rim of the Gulf of Maine, and gently sloping southward. Across the Great South Channel at the western end of Georges, the Nantucket Shoals reach toward Cape Cod.

The remaining two areas are less distinct geographically. A broad shelf with a steeper seaward slope runs westerly, south of New England, from Nantucket Shoals and Georges Bank to the deep dissection of the Hudson Canyon. In the second area, the shelf bends in a more southwesterly direction,



Circulation and major hydrographic features of the waters off the northeast coast of the United States.

narrowing gradually as Cape Hatteras is approached. This concave sweep of coast from Hatteras to Nantucket Shoals is known as the Middle Atlantic Bight. The bottom from Cape Cod to Cape Hatteras is sandy except for a large area south and west of Nantucket Shoals, where silt and clay are found.

In the Gulf of Maine there are three distinguishable water masses: a relatively fresh surface layer, an intermediate layer of about the same salinity but colder (the coldest of the three except in midwinter), and a somewhat warmer but saltier layer of bottom water derived from outside the Gulf through the Northeast Channel. The surface layers take their character from the coastal runoff, and from an influx of water from outside the Gulf, flowing southwest along the coast of Nova Scotia.

Gulf of Maine waters are more stratified in the warmer months than in the winter. On the shoals of Georges Bank the effects of tide and wind prevent this stratification. South and offshore of Georges there is a transition to the slope-water mass which becomes more distinct as spring progresses into summer.

South of New England we find two principal water masses: shelf water and slope water. Shelf water, freshened by runoff from the land, extends beyond the shelf break for some distance in the surface layers. It is generally cooler than the oceanic, slope waters further offshore that are heated by the Gulf Stream. The shelf water meets the saltier slope water at a sharp front which inclines seaward from the bottom to the surface (where it is readily detected by the infrared cameras of satellites). Seasonal stratification of the shelf water resembles the cycles observed in the Gulf of Maine.

The alternating processes of stratification and vertical mixing have important biological implications. Vertical water transport upward resupplies nutrients, generated by processes of decay at the bottom, to the sunlit surface layers of the sea where photosynthesis takes place. Downward transport carries the sun's heat to deeper levels, and mixes fresh water from rain and runoff into the saltier waters beneath, helping to stabilize the physical and chemical environment for its inhabitants.

Water circulation also affects the distribution of organisms directly, and their survival. Over Georges Bank, for example, there is a strong clockwise flow of water mainly due to the tides (see figure opposite) which tends to keep smaller, passively drifting plants and animals contained within the productive environment of this shoal. The spawning patterns of fishes on Georges have evolved to fit its average water circulation, so that their fry tend to be maintained where food is plentiful in their early and critical life stages.

But there are sometimes disruptions of this typical current pattern which have adverse effects on the survival of young fishes. "Warm-core rings" are an example (Frontispiece). These clockwise-swirling water masses, pinched off from the sinuous inner edge of the Gulf Stream, move south along the edge of the continental shelf close to the easterly end of Georges Bank. They may be plainly seen in satellite images. As they pass Georges, the force of their rotational current is added to the easterly component of the Georges circulation, drawing off water that would otherwise cycle around the Bank.

Fish eggs and larvae in the Georges water are likely to be drawn off as well, into the warm and presumably lethal waters of the ring system.

Some of the variation observed in the survival of one year's crop of young fishes (its "year class"), when compared with other years, may be traceable to such disruptions in water circulation; perhaps these are frequent enough to make ideal conditions for survival of a year class the exception rather than the rule. The disruptions cannot be prevented, of course. But their presence or absence at critical times in the planktonic life of fish eggs and larvae may help in forecasting the probable survival of these young, and the eventual success of their year class in contributing to the fishery.

The water masses we have described here are not strictly bounded except where they impinge upon the coast, and even there they infiltrate estuaries and bays and mix with the fresh (and too frequently polluted) waters of rivers. Such masses influence and contribute to each other as elements of a larger, ultimately global, system, and defining each element is a necessary first step to understanding larger-scale relationships. Of the hydrographic domains considered here, Georges Bank has been the most thoroughly investigated. The temperature and chemistry of Georges waters, and calculations of their motion and transfers of energy, permit a "budget" to be drawn up, showing how these waters mix and interact with those of neighboring systems: how much water and energy Georges must be exchanging with these systems to explain what is in fact observed. The Georges system has "free edges" all around, but perhaps the most important, or at least the most complex conjunction, is with the Gulf of Maine system. This opens only to the southward, and because it is otherwise bounded by land, it would appear to be easier to analyze than the open system of Georges, but in fact it is less well studied. Because the Gulf of Maine system and the others we have mentioned act upon one another, it is important that our knowledge of each be brought eventually to the same standard. Marine ecosystems depend ultimately on the "broth" which contains them. Management of marine resources and other uses of the ocean requires a thorough understanding of the behavior of the oceanic medium.

ELECTRONIC TOOLS

At first glance, some basic methods used in modern fisheries investigations appear to be no different than those in use a century ago. We still rely on trawls and nets of various types, on dredges, and on water samplers that our grandfathers in the science would recognize well enough. Such gear has been improved in various ways to be sure, but the basic principles remain unchanged, and they continue in use because they are uniquely effective for certain important purposes. For long-term survey work, moreover, gear "improvements" are to be avoided, since the value of these surveys lies precisely in their consistency over time, which is difficult enough to achieve even when the gear is always built to the same pattern.

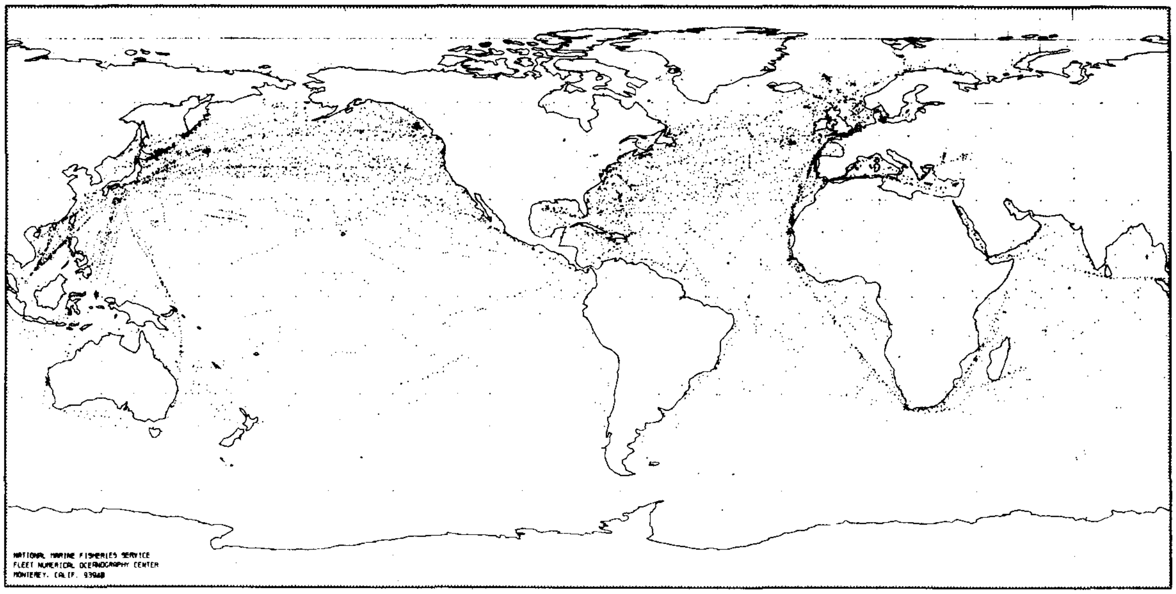
It must not be thought, though, that fisheries investigations are locked into old-fashioned methods. Three techniques with a contemporary flavor should serve to make the point (see also pages 19 and 23).

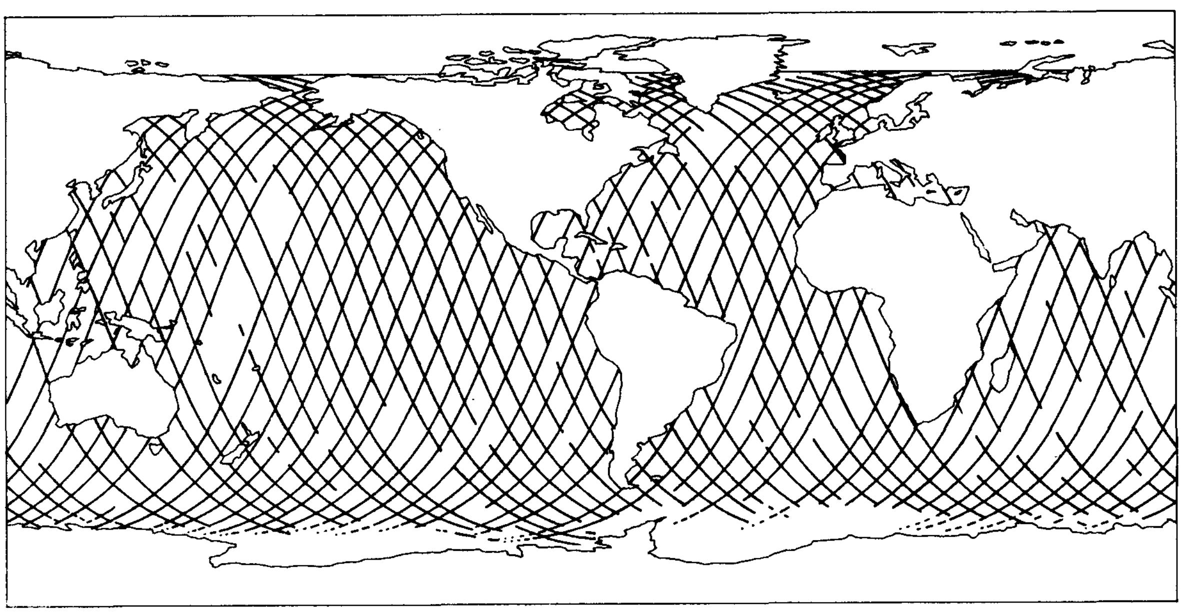
I. Remote Sensing. Images of the sea surface and the coast transmitted from satellites or made photographically by high-flying aircraft furnish information greatly valuable to marine studies. Infrared sensing is used to determine sea-surface temperatures which can be coordinated with information gathered by shipboard sampling to establish the shapes and extent of water masses. Spectral analysis, by which minute differences in the sea's color are discriminated, gives further clues to the source and circulation patterns of the water, and the nature of the suspended matter or plankton it may contain.

By the same computer-aided methods used in medicine and industry, distinctions invisible to the naked eye are intensified, sometimes by "false color" techniques, so that patterns are revealed vividly with a detail that is in practical terms unachievable through shipboard sampling alone. Moreover, the patterns are "synoptic": shown as they existed at a single moment. Even a fleet of ships cannot achieve this (see figures on next page). A series of synoptic maps is much more useful in deciphering dynamic processes than a single map based on data collected over days or weeks. The question of what exactly the flying sensors are seeing is answered by coordinated samples from ships, which can be directed to sampling sites of interest as the satellite passes overhead.

Productivity, dispersal of pollutants, distribution of coastal wetlands (very important to marine productivity), and long-term changes in coastal ecosystems, are among the many phenomena which can be mapped efficiently by these new methods.

Because the technology is new, many problems are still to be solved before we get the most from it. Fortunately, interest in solving them is not confined to our Center, which has been joined by a number of other institutions in planning a Northeast Area Remote Sensing System (NEARSS). This system will serve its associate members in many ways, including data storage and retrieval, communications with the satellites, user training, and data analysis.





Global coverage compared for three days of observations of wind and wave height made by surface ships (upper chart) and by an altimeter mounted on a satellite (SEASAT). Wind strength is derived from the altimeter's measurement of wave characteristics. Surface observations are mainly limited to shipping lanes; 7,600 were made in the period, compared with 131,700 by SEASAT.

PRODUCTIVITY

Primary Production -- Phytoplankton

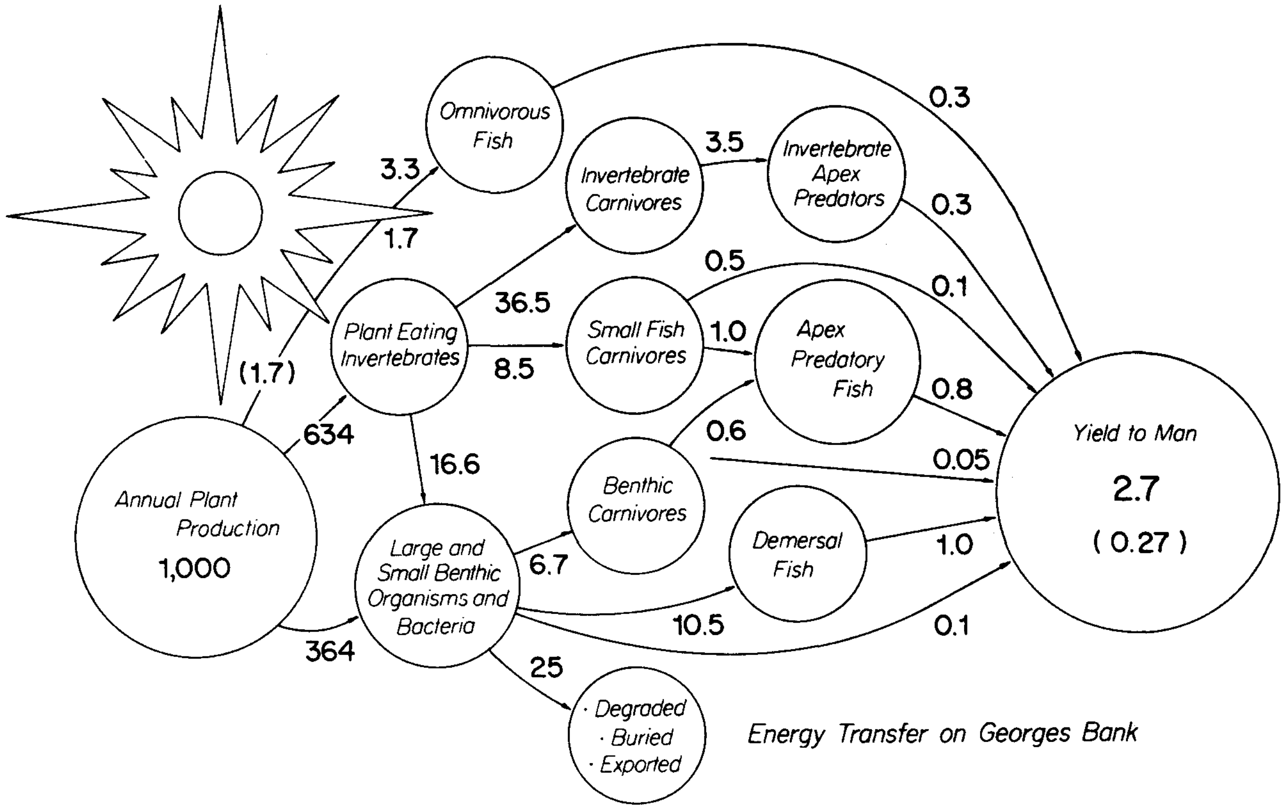
Primary production, the synthesis powered by the sun's energy of simple chemicals into living plant matter, is a conspicuous process in the terrestrial sphere, and at first glance, all but invisible in the sea. Except for seaweeds anchored in shallow waters and certain of their free-floating relatives, marine plant life is, for all its abundance, microscopic, consisting of single cells as small as 1/1000 of a millimeter, sometimes linked together in various ways. One reason for this is physical. Marine plants of the open sea can live and reproduce only in the thin surface layers. Where the upward transport of water is weak, only minute organisms are lightweight enough relative to their surface area to be carried with the flow instead of sinking into the darkness beneath. A second reason for smallness follows from the fluctuating nature of the environment. Populations must grow and reproduce quickly when conditions are suitable, and small size is compatible with quick turnover from one generation to the next.

The ecological role of planktonic marine plants (phytoplankton) is the same as that of the trees, grasses, and other large forms on land. They reconvert the products of organic decay to substances animals can feed upon. Where these products are abundant and the sun can penetrate, rich crops of phytoplankton are generated, capable of sustaining large animal populations. By far the greater part of the world's oceans may be described as a relative desert. Invariably, rich fishing grounds are found in those places where a plentiful supply of nutrients is concentrated by one process or another in waters well lit by the sun.

As the table shows (end of this section), average annual primary production over our northeastern continental shelf is greater than production over most of the world's continental shelves. On Georges, this production is supported by the upwelling of nutrients around the edges of the bank, while along the inner part of the Middle Atlantic Bight, nutrients flow seaward from the Hudson, Delaware, and Chesapeake estuaries.

Secondary Production -- Zooplankton

Marine food chains are often relatively long; compared with terrestrial food chains there are a greater number of links between the primary producers (plants) and the larger consumers. On land there is but one step from a field of grass to a cow for example, but between a field of phytoplankton and an Atlantic cod, by contrast, there might be four, five, or more steps. Conversion of primary production to a form that we as predators can use is less direct in the sea, on the whole, when compared with the land.

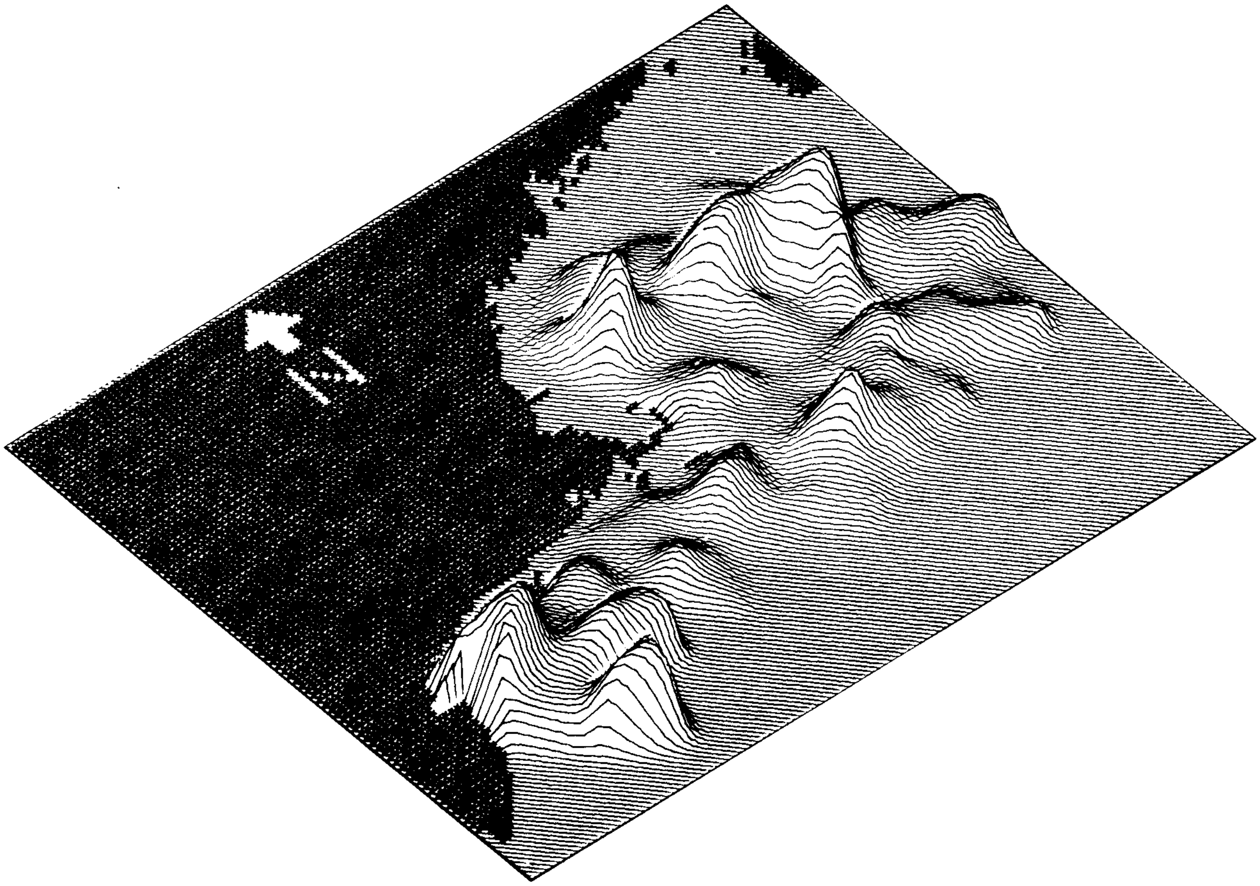


Energy Transfer on Georges Bank

Units of energy, derived from the sun, transferred along various pathways in the marine ecosystem. Primary plant production is arbitrarily valued at 1000 units. Energy available for transfer decreases rapidly from one link in a food chain to the next.

Secondary production refers to the zooplankton: small, often microscopic animals which swim or drift freely in the water. These feed directly on the phytoplankton, and often on other, smaller zooplankton as well. Most of these animals are planktonic throughout their lives, but the zooplankton includes the eggs and larvae of larger animals, such as scallops, sea anemones, and fish, which subsequently change into the familiar, non-planktonic adult forms. While a few animals consumed by man feed to some extent on phytoplankton, many more depend on zooplankton throughout life or at some stage of it.

Secondary production, as one might expect, is usually greatest where primary production is abundant, but its utility in linking phytoplankton with fish production depends also on its timing. From beginning to end, the spawning processes of fish take weeks or months, and they are influenced by a complex of factors such as day length and temperature. For some migratory species, such factors begin to affect the spawners in places remote from the spawning grounds. When the larval fish hatch, plankton of precisely the right kind and size must be ready for them to feed upon, as the last of their supply of yolk is used up.



Relative abundance of zooplankton over the continental shelf from the Gulf of Maine to Hudson Canyon, measured between 3 March and 8 April 1977. Cape Cod is at the center of the map.

Primary production, and the secondary production of zooplankton which depends upon it, do not proceed at an even pace over the year. There are periodic blooms of abundance which come and go year after year according to patterns characteristic of each locality along the coast.

The production of larval fishes and the production of plankton proceed independently, but like the tautog and the dandelions of Capt. Whalley's rule, the two events are no doubt governed by some common factors. The selective processes of evolution, by favoring those spawners whose eggs hatch at times when food is plentiful, have brought the plankton blooms and hatching times for larval fishes into rough coincidence: the average dates of plankton peaks and first-feeding of fish larvae are the same, taking many years together. But these averages do not describe what may happen in any given year, when environmental factors may subtly modify the physiology of the plankton and the fish in such a way that their peaks of production do not coincide as they should at a particular place and time.

This matching or mismatching of larval fishes with their food supply is being given considerable attention as a factor in the success of a given year's crop of young. Outstanding year classes may well result from occasional "perfect" matches of larvae, in space and time, with the proper kinds of zooplankton. Sampling during this critical period, therefore, may enable us to predict the probable success or failure of a year's crop of young fishes.

Production on the Sea Floor

Bottom-dwelling animals and plants, collectively called benthos, are plentiful off our northeast coast around the edges of the Gulf of Maine, on Georges Bank, and on many parts of the shelf of Southern New England and the Middle Atlantic Bight. Most of the smaller benthos are not caught commercially for human consumption (though what is considered edible, or indeed a delicacy, varies from place to place); they are nonetheless important in food chains which culminate in fish and shellfish sought by the fisheries. Larger benthic invertebrates also serve as links in food chains, but alternatively, they may be directly harvested: surf clams, scallops, crabs, and lobsters are examples.

Especially rich populations of benthic animals are found in estuaries, sounds, and bays, and in other areas where there is a flow of nutrient-rich water. Such places are important feeding grounds for bottom-dwelling fish.

Because benthic and free-swimming animals constitute alternative pathways for converting primary production to fisheries products, both groups must be given sufficient scientific attention if we are to have a hope of understanding and hence managing and conserving the fisheries. So far there has been an imbalance; transfers of energy and matter through pelagic food chains are better understood than those involving the benthos.

Many benthic organisms can be far more useful than pelagic ones for certain scientific purposes, because they remain in one place during much of their life, or move only a little. This makes them suitable for demonstrating the effects of natural environmental influences which vary from place to place, or the local impact of pollution and other kinds of disturbance.

Fish Production

Comparisons of organic energy budgets for Georges Bank and the North Sea reveal that Georges Bank is more productive per unit of area at all levels of the food chain, but particularly so at the primary and secondary production levels. Turbulence over the shoals of Georges and the constant upwelling onto these shoals of deeper surrounding waters return nutrients to the sunlit surface waters all the year round, whereas in the North Sea this recycling of nutrients is more dependent on the seasonal rhythms of thermal stratification.

Primary production on Georges is more than four times as great per unit of area as in the North Sea, while production of zooplankton and benthos is two-to-three times as great. Fish production however, taking all species together, is only 30-70 percent greater per unit of area. Georges produces three-to-four times the number of bottom-dwelling fish, but fewer pelagic fish. Fish production for the entire northeast shelf, Maine to Cape Hatteras, is about half that of the North Sea for a given unit of area, but again, the ratio of bottom-dwellers to free-swimming fishes is markedly different in the two places, the bottom fishes being more plentiful on our side of the Atlantic. This suggests strongly that there are important differences in energy pathways through the two ecosystems and that a simple relationship between primary and finfish production does not hold.

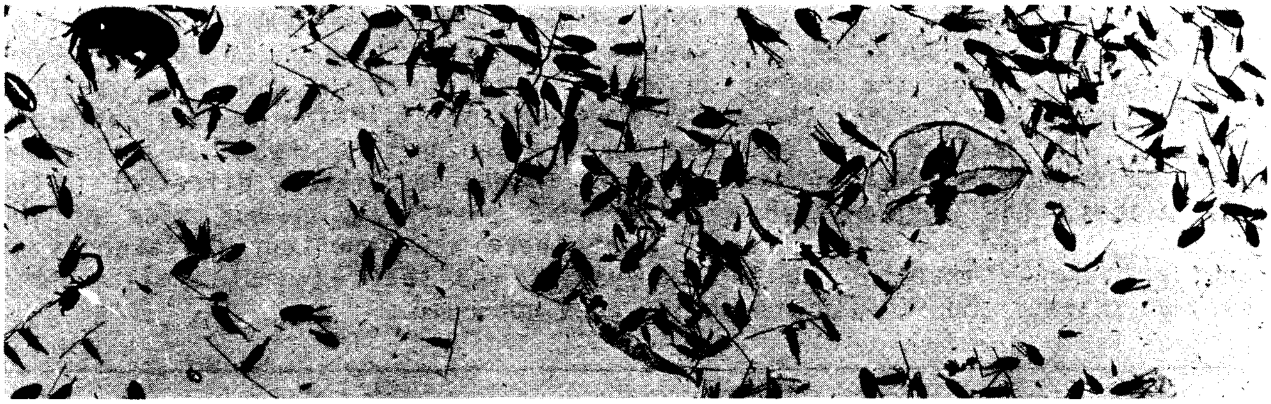
Estimates of annual primary production for Gulf of Maine-Cape Hatteras shelf compared with estimates for other systems worldwide

Area	Grams of carbon per square meter per year
Gulf of Maine - Cape Hatteras	234-449
Eastern Scotian Shelf	102-128
Georges Bank	187-265
Block Island Sound	204
Off Long Island coast, 20-meter depth	233
New York Bight apex	252-326
Raritan Bay*	510-716
Georgia Coast off Altamaha River	547
North Sea	90-100
Northern Baltic	127
Coastal water off India	434
Coastal water off Japan	90
Oceanic	55-70

*Highly polluted.

ELECTRONIC TOOLS

II. Computer-aided Plankton Analysis. Plankton lies at or near the start of marine food chains, and a knowledge of its composition and abundance is basic to working out the flow of energy through the ecosystem. Identifying and counting plankton is ordinarily done laboriously "by hand," under the microscope, by skilled technicians. Since to be useful the number of samples must often be large, sorting is expensive and can be a bottleneck in assembling a comprehensive picture of the ecosystem.



Part of a plankton sample flash-recorded at sea on photographic film. Crustaceans predominate; most are copepods; an amphipod is at upper left.

Once again, computers are being brought into play, in this case using a new technique of image analysis. First, silhouettes of plankton are recorded on photographic film, from fresh or preserved samples, by flashing a light through them, or by photographing living specimens still in the water using a special repeating flash-camera attached to a net. A video camera and image analyzer, attached to a computer, then extracts from these film images information on the size and abundance of the different plankters in the sample. By correlating this statistically with random counts and identifications made in the old way, the process of ecosystem-scale plankton analysis becomes much more efficient and quick (speed is important when management planning depends upon the results).

The "by hand" part of plankton analysis should be reduced still further in the future when computers can be taught to recognize not only the size of the plankton images but their shapes. This development is well under way.

SOME ASPECTS OF FISHERIES ECOLOGY

Fisheries depend on whole populations; therefore, fisheries science is concerned more with populations and the interactions between them than it is with individuals. Populations (many individuals of the same species) and stocks (population subgroups which are somewhat isolated from each other geographically and reproductively) have, at any moment, certain measurable attributes: hatch rate, growth rate, death rate, and age or size distribution (that is, a characteristic percentage of individuals in each of several age or size categories; this may change markedly with time). Fisheries scientists attempt to interpret these phenomena in terms of their effect on fish production: more importantly, the production of "recruits" to the fishery.

"Recruits" and "recruitment" are technical terms from fisheries science for which we could find no efficient substitute. Recruited fish are those large enough to be worth catching. This size is not an absolute; it changes with economic circumstances, and may be affected by cultural values in different places. Recruitment processes are those, collectively, which bring a new generation of fish to the point where it is sought by the fishery. The interval between spawning and recruitment varies with rate of growth, which differs among species and within species. The pre-recruitment interval also depends, of course, on the size-selection made in the fishery. Even in one particular fishery, recruitment of a given crop of young fish may be spread over quite a long period: two or more years sometimes, due mainly to differing growth of individuals.

Fishing success or failure, and fishery management decisions, depend on the size of recruiting populations. Therefore, fisheries scientists attempt to identify and understand the processes that control this size. Recruitment and growth increase the quantity of fish; fishing and all other causes of death decrease this quantity. This is the classic model for describing changes in a recruited stock: recruitment plus growth, less fishing mortality and natural mortality. Unfortunately, this classic model must now be updated by inclusion of another term to account for the effects of pollution.

Even without fishing or pollution, there is a maximum size to which a recruited fish population can grow. As the fish become crowded and compete for food, their growth slows, recruitment declines, and natural deaths increase. In theory, growth, recruitment, and natural mortality tend toward some balance, and the population stabilizes. When fish are caught, the balance among these natural factors is altered. There is less crowding and competition for food, hence less natural mortality and more growth and recruitment. If the theory holds, then there must be some "best" balance where recruitment plus growth minus natural mortality and fishing mortality is at a maximum. The challenge for fisheries scientists is to define this best balance: the point of "maximum sustainable yield."

Unfortunately, this simple theory of fishing is not realistic. Variability rather than equilibrium is the rule for the oceans, and fish populations are no exception. While growth rates are relatively constant, perhaps increasing somewhat when population size decreases, natural mortality rates and especially recruitment are highly variable. "Maximum sustainable yield" is something of an abstraction. Though it may have some significance relative to the long-term average state of a resource, it is of little use as a planning tool in the face of short-term fluctuations.

Among recruited fish, natural deaths are caused by starvation, by contagious and non-contagious disease, and by predation, factors which interact with each other and with the environment. Predation and contagious disease are the principal causes.

Man has many competitors for the fish he consumes, and these vary in their own abundance, with a corresponding effect on mortality of their prey. Changes in predator populations, including changes in average size of individuals within those populations, can affect not only the number of prey consumed but prey size and the species composition of the diet. Such shifts produce further shifts through the food chain, with overall consequences for the ecosystem that are just now being investigated in detail.

The importance which contagious disease may have in fish mortality has generally been neglected. Examination of large numbers of fish reveals an assortment of diseases afflicting them. Epidemics occasionally occur with devastating effect. Pollution and other forms of environmental degradation or change may not always kill directly, but by undermining the vigor of a population of fish, such influences make disease more lethal than it would otherwise be.

Recruitment in a given year depends on the spawning success of the population already recruited (recruitment size, and size at sexual maturity are not necessarily the same, of course, but spawners are generally large enough to be of interest to the fishery). Recruitment also depends on survival of eggs and young fish. But spawning success and early survival are so variable, in fact, that there is usually no obvious relationship between the size of the parent stock and the number of recruits it produces, except perhaps when the stock is reduced to a very low point. (This is discussed in more detail later, in an account of the haddock and herring fisheries.) Due to the combined effects of a great many physical and biological processes, recruitment may vary by a factor of ten, twenty, or even more, from year to year.

Recruitment variability is particularly important to the fishermen and fishery managers of the Northeast. Recruited populations here are heavily fished, and most recruited fish are caught within a few years. Thus, the quantity of fish to be caught each year depends closely on annual recruitment, which in these circumstances far outweighs growth as the source of the fisheries' supply. If management is to be successful in adjusting the harvest to the quantity replenished, there is a clear advantage in being able to predict what is in the pipeline.

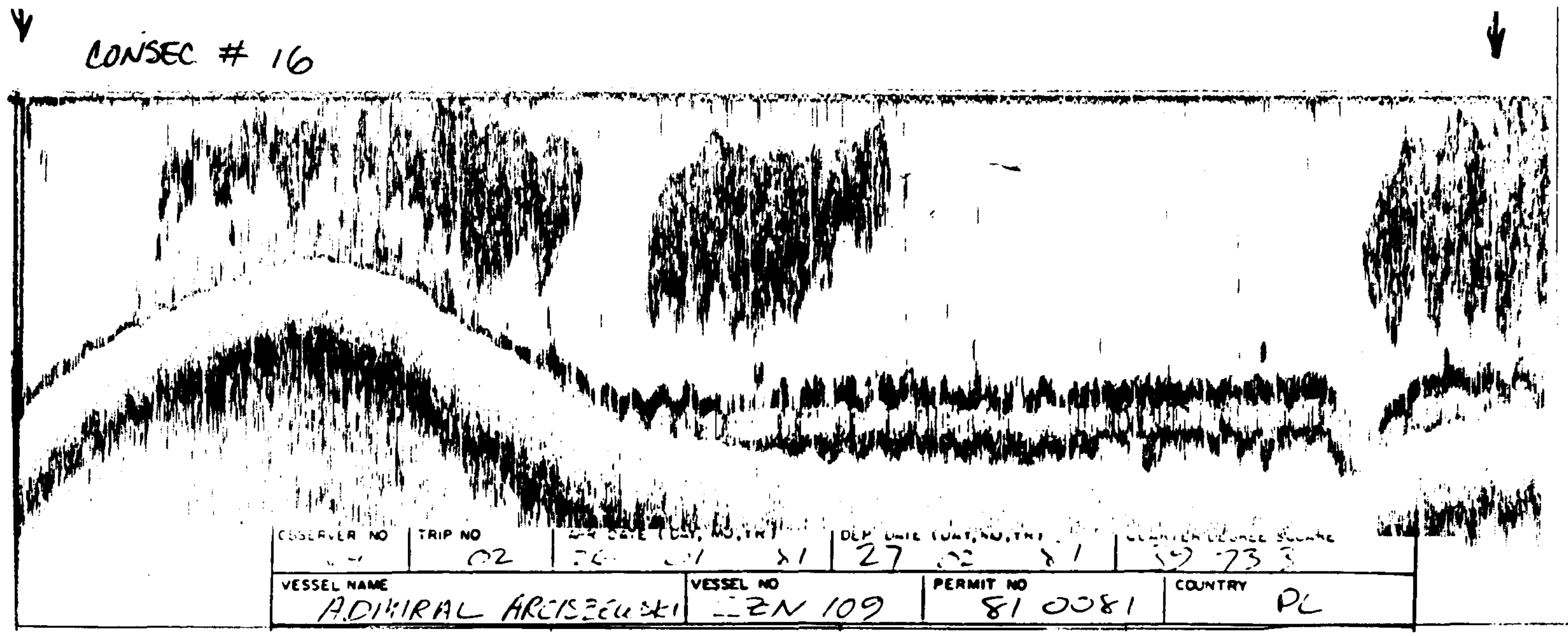
One method is to sample small fishes, pre-recruits, preferably several years before they enter the fishery, using nets with smaller meshes than the commercial gear. Pre-recruit indices are developed in this way, which are related to subsequent catches. A second approach is based on the historical frequency of different size year classes, and the odds that an upcoming year class will fall within a certain range of abundance. Finally, there is a recruitment prediction based on an understanding of the workings of the ecosystem: how its various components interact to determine the success or failure of a given fish crop.

In practice, all three of these approaches are used in a sort of triangulation process aimed at producing a useful estimate. It is unlikely that any single approach can be as accurate as a survey of recruits just prior to entering the fishery. However, an understanding of the ecosystem's functioning should permit those predictions based on historical patterns to be considerably improved and refined. There are many facets to these investigations, ranging from plankton surveys in the open sea to experiments with fish larvae in the laboratory. How they fit together will be suggested in the pages that follow. For now, we will simply underscore the fact that recruitment prediction is a key to efficient management.

ELECTRONIC TOOLS

III. Acoustic Fish Surveys. Objects in the sea whose acoustic properties differ from those of seawater can be detected by an electronic device that sends a sound pulse into the sea and listens for its echo; the depth or distance from the sound source is proportional to the time required for the echo to return, while the nature of the echo pulse can give clues to the size or other properties of the reflecting target. The method is used variously by submarines, by hydrographers mapping the sea floor, and by fishermen hunting for schools of fish (see figure on next page).

The patterns and acoustic properties of the echos contain more information than is ordinarily extracted from them, but modern computer power promises to change this. Methods are being developed, in experiments coordinating conventional sampling with echo-sounding, for determining electronically the distribution and numerical abundance of fish. The theoretical problems are great, and it is unlikely that acoustic sampling will completely replace trawl sampling, which will continue to be relied upon for verifying echo-sounder records. Combining the techniques however, should greatly expand our sampling power, giving some measure of populations between discrete trawl stations, and of pelagic schools that are not as well sampled by the survey trawls.



Ship's echo sounder record (February 1981) showing Atlantic mackerel schools in 55 meters of water, east of New Jersey. Thin horizontal line at top indicates sea surface; bottom includes a prominent ridge or hill. Trawl catch verified identity of the fish; 18,000 pounds were taken in 10 minutes.

SOCIAL AND ECONOMIC ASPECTS OF MANAGEMENT

The issue facing fishery managers is primarily social. Conservation and the ecological basis for achieving it, to be sure, are the immediate problem. But implementation of any regulations to reduce fishing mortality (almost all regulations are aimed at doing this) affects the fishing industry and its social context. The expressed goal of present management legislation is optimum yield, which is defined partly in terms of overall social benefits.

It seems fair to say that there will seldom be agreement by all concerned on what this optimum is. We have seen that since the earliest days of the sea fisheries, when resources were limited the demand for conservation has always been opposed by a demand for free access to these resources.

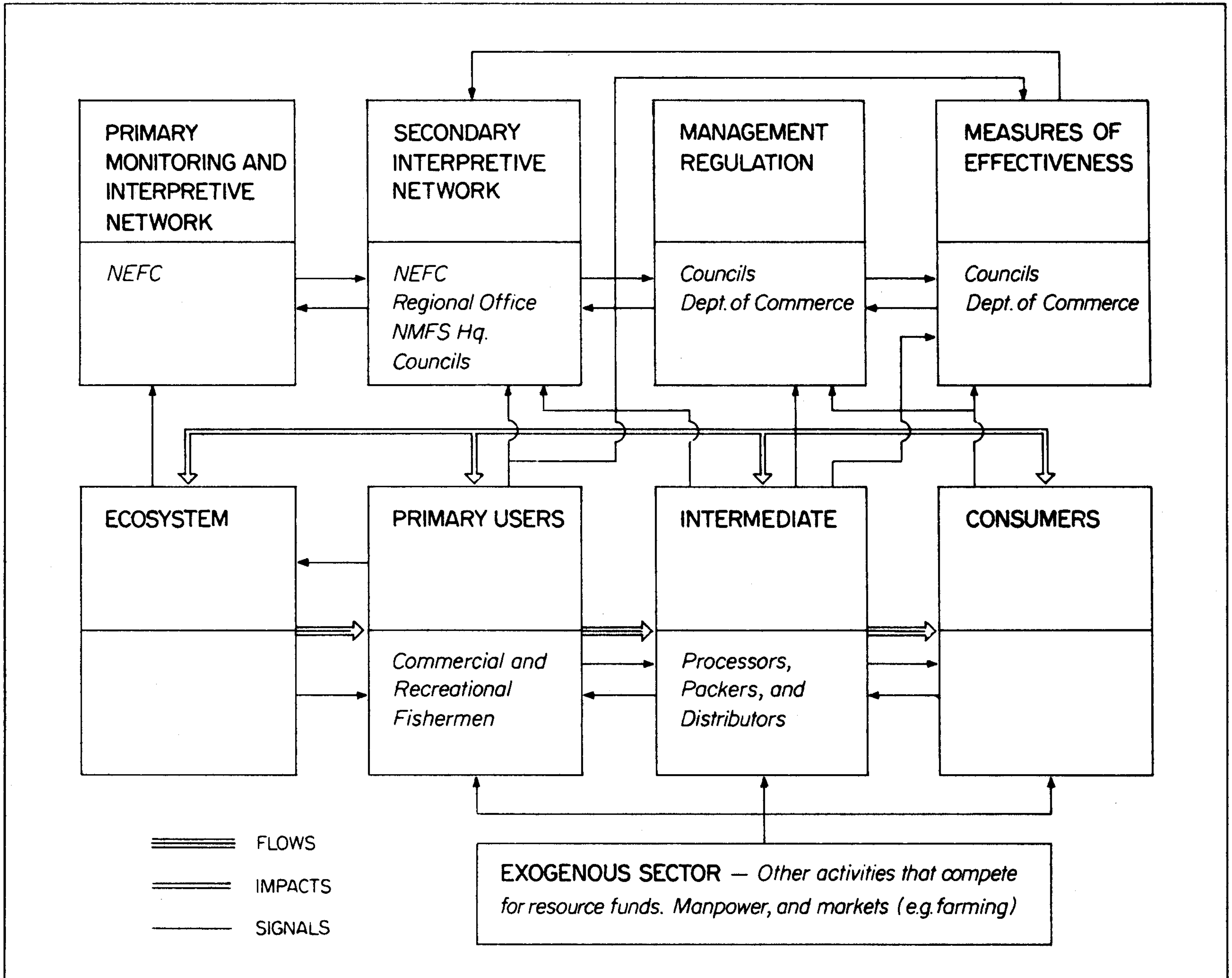
Nevertheless, in the Northwest Atlantic, there is a consensus for some sort of management, because certain problems have become quite clear: varying resource populations, decreasing pay for fishermen, battles between environmentalists and oilmen, and increasing demand for recreational fisheries. Deciding just what sort of management we will have, because of the conflicting demands of various users and the biological constraints of the ecosystem, is an interdisciplinary and political problem.

A primary mission of the Center is to identify opportunities for social benefits to be derived from the resources, and constraints on achieving these benefits. The Center is also called upon to determine, and often to predict, the effects of fishing on the resources. In choosing among alternative management schemes for achieving some objective, the manager will want to know--and is required by law to estimate--the effect of each alternative both on the resource and on the fishery, and it is the Center's job to assess this interaction.

We have tried to make clear in earlier pages how troublesome it is just to define potential resource yields, let alone to predict them. Predicting patterns of behavior in the fisheries, which respond to these factors and to many others, clearly is of a greater order of difficulty. We are not sure that it is practically and usefully possible to make such predictions in many situations. Technical and economic data, which cannot be considered independently, are often not available for the task.

Still, managers are charged with making such assessments, and the Center is committed to supporting them in their task. The framework for analysis is shown on the next page. Signals are generated from sector to sector by human actions, and people within sectors respond by adjusting what they do. For instance, to take a simple case, if consumers want an increase in supply of a particular species, they signal that they will pay a higher price, and fishermen respond by harvesting more. Signals can also come from outside the fishery system itself; inflation, for example, may affect demand and cause the fishermen's volume and price to change.

In the fisheries, the functioning of these signals is complex and often poorly understood. Fishermen "go where the money is" to a large extent, but their preferences for certain kinds of fishing are important too. In other



RESOURCE FLOW AND ECONOMIC SIGNALING

types of industry, signals from the market are expected to control supplies of raw materials, allocation, production, and distribution, before a maladjustment becomes too large. In the fisheries, a demand signal in the form of high prices may indicate resource scarcity while at the same time it may encourage more intense and competitive fishing which only makes the scarcity worse. It is often unclear whether a given signal between sectors is indicating a problem or causing it.

Our aim is to understand better these "feedback" and "feed-forward" signals, and the way in which social and economic factors interact with the ecosystem to drive the entire process. Management which simply reacts as it often does now to perceived emergencies, without understanding the underlying mechanisms, may react inappropriately, with unforseen and possibly unfortunate results.

The Center's perspective is basically ecological, but we do concern ourselves with social and economic aspects of human activity as they relate to what happens on the fishing grounds. It has proved difficult to find satisfactory measures of the costs and benefits of management alternatives, however. When restrictive regulations are proposed, it is reasonable to demand that they serve some objective which has been agreed upon, but in practice this agreement is less a formal matter than the tacit outcome of trial and error. Some "lowest common denominator" (or least objectionable compromise) among the countervailing interests of fishermen, the consuming public, and alternative users of the marine environment is usually what is accepted.

There appears to be a middle range of stock abundance which these groups agree to live with. When stocks decrease to the point of collapse, or are left to increase excessively to high levels, almost all concerned find this less than optimal. There is also some place on a scale of increasingly strict regulation where improved economic efficiency and improved resource yields are no longer perceived as worth the cost in social terms: fishermen's "freedom," for example. It is within the field indefinitely marked out by these high and low limits on yield, and the limit of acceptable regulatory intervention, that the trial-and-error search for optimum benefits takes place. In economic terms, equal benefits may be found at various places within this field, though they will not be perceived as equal by the various groups interested. Moreover, because of natural variability in the stocks, and social variability, optimal benefits within the field of exploitation will not remain fixed over time at any one location, even for individual interest groups.

The role of the fisheries scientist in management is to investigate the relationship between the size and nature of the catch and future yields, considering where necessary such factors as pollution and condition of the stocks. Increasingly, this has meant investigations at the ecosystem level. The economist, given a range of management options, seeks to measure the social consequences of each, not only as they affect the industry, but as they affect the public that consumes its products. The scientist and the economist, however, if they aim simply at a maximum economic efficiency of the system, may indicate management approaches which are unacceptable in terms of social costs, at least to the fishermen. Such approaches cannot qualify as "optimal." The business of the managers, unlike that of the scientists and the economists, is to effect a compromise between the resource factors and the economic and social factors which apply.

Variability in fish production, even when predictable, requires that fishermen either accept periods of low yield within a given fishery, or switch between fisheries. Management seeks to keep the economic pain caused by these fluctuations at tolerable levels, but the limitations of its regulatory tools are not generally well understood. Most difficult to get across, perhaps, is the fact that resources will also fluctuate independently of fishing. At the usual level of sampling effort, fisheries scientists are able to describe this flux quite well over the long term, based on probabilities, but predicting conditions at a particular time and place requires very intensive sampling (which is of course expensive) and a great deal of knowledge.

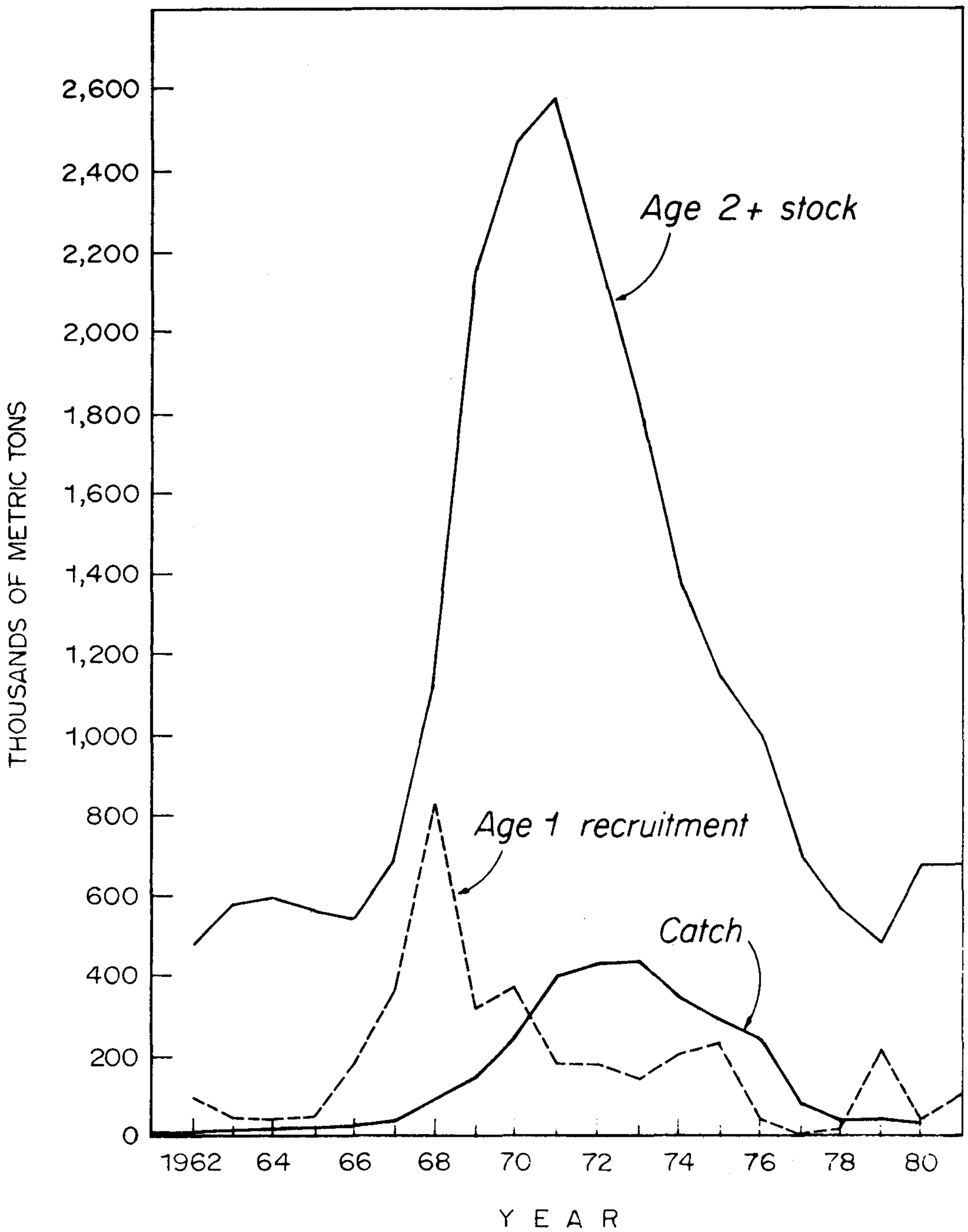
Fishermen are not much interested in the long term if in the short term they go broke, and it is the short-term outlook that determines much of what they do. Production on the fishing grounds may be a "zero-sum game" in which total production is stable, but the components of production constantly shift in proportion to one another. The loser in that game, the man who directs his effort to the wrong component, gets no comfort from the overall stability. Fisheries management is perceived as friendly when it directs effort to profitable alternative resources, but hostile when it obstructs access to traditional ones, even when they become scarce.

Witness the earliest days of management under the 200-mile limit. The overwhelming consensus for "throwing the foreigners out," once it was accomplished, immediately split into the familiar polarities: complete freedom for individual fishermen on one hand, and on the other, a demand for comprehensive control aimed at rebuilding and maintaining the stocks. Management policy reflected the second position, which provoked a furious reaction in much of the U.S. fleet, made worse by the recovery of haddock stocks in the face of quotas which turned out to be expensively restrictive.

Such problems, or "mistakes" if you will, are within the power of managers to rectify. Rigidly specified catch quotas, which make it difficult to respond quickly to observed changes in the stocks, can be replaced with more flexible management tools. But there are two other factors which affect the fisheries and hence the resources, over which the present system of management has little if any influence.

The first of these is the market, which increasingly is worldwide. The effect of market forces on industry operations is obscure; thus any effort to manipulate these forces can be expected to encounter strong resistance, and to produce unanticipated effects. In a worldwide market, economic factors for practical purposes beyond our control, such as foreign-fleet subsidies in the absence of subsidies of our own, may affect our domestic industry profoundly. We saw this happen in the New England groundfishery in the 1960's and early 1970's, and we reacted to it in setting the 200-mile limit, but the point is that decisions affecting "our" resources were made outside our political process. Even if we exclude foreigners from certain grounds, we may not be able to compete in the same markets with them without restructuring our industry in ways presently unacceptable to U.S. society.

Non-fisheries uses of the sea are a second influence on the stocks which lies beyond reach of the Regional Fishery Management Councils--those organizations created by the 200-mile-limit law to manage their respective regions' fisheries. We all participate in this, directly or indirectly, since the sea is used as a sink for wastes discharged from land, or from activities such as dredging or oil drilling which affect the general economy. Fisheries scientists are attempting to discover the extent and effects of such pollution, but the Councils cannot directly limit it.



Relationship between recruitment, stock, and catch in the New England Atlantic mackerel fishery between 1962 and 1981.

VARIABILITY AND SAMPLING

The most dependable attribute of marine ecosystems is their variability. It has been pointed out (see "Sand Lance" on page 44) that fishing can modify natural variability; pollution and other kinds of human intervention may also do so. Sometimes cause and effect seem quite clear-cut. Heavy fishing for haddock in the 1960's and 1970's would appear unarguably to be the main and perhaps the only reason for a striking change in historical patterns of recruitment for this species. But more often, sorting out the separate contributions to variability by different factors observed in nature is extremely difficult.

For example, consider the New England Atlantic mackerel fishery over the past two decades. A major fishery for mackerel began when the Soviet fleet, in 1968, learned of a large increase in the stock of this species, resurgent after many poor years of recruitment. There were good years from 1966 to 1969, with 1967 by far the best. Because the success of these years was not repeated thereafter, heavy fishing reduced the population rapidly, as the figure opposite shows.

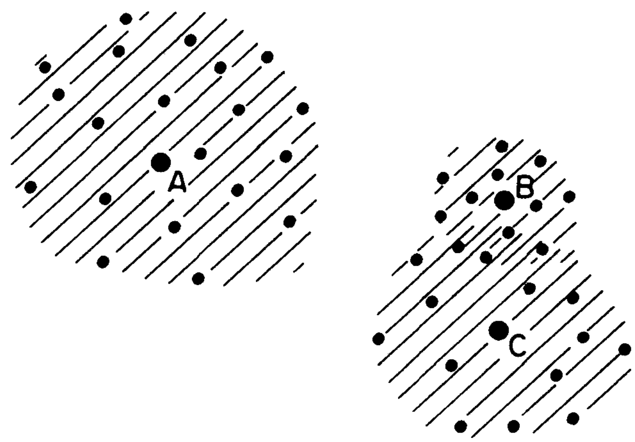
The boom in the mackerel fishery had clearly been touched off by an exceptional rise in the mackerel population, which itself must have come from a nearly perfect conjunction of natural events; a multitude of young had come from a very small parent stock. The question remained, would maintenance of a larger parent stock year after year improve the chances for a series of good year classes? If it would not, then restricting the fishery would be costly to the industry with no corresponding benefit.

Answering this mackerel question requires measurement of the critical factors involved: in this case, more exact measurements than were available after the fact, or possibly measurements of some factors not yet identified. Deciding which of many factors to measure is one problem of ecology. How to measure them is another, for sampling and measurement in the open ocean are difficult, and the statistical error attributable to measurement techniques in certain circumstances may be as large as, or larger than, the actual variation in the phenomenon being measured.

In the next few pages, some aspects of sampling and sampling error will be discussed. Most of us think of science as an exact process, and in the physical sciences this is relatively true, as seen in the astonishing precision with which Voyager II arrived on schedule at Saturn. Fisheries scientists fish for answers with a much coarser net. They are looking for broad trends and tendencies, and even these can be quite expensive in time and money to discover. Still, broad trends are often sufficient for the purposes that underlie fisheries investigations. The fisheries themselves are affected not by minute shifts in population abundance, but by large ones. If these large shifts can be predicted with reasonable confidence, the predictions are of great economic value.

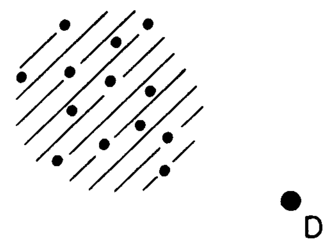
Most sampling at sea is done remotely, using dredges, nets, or other devices operated from the deck of a ship. Because water masses are constantly shifting and mixing, a "sampling station" in the sea (except one on the sea floor itself) is not really definable: successive samples taken at a given geographical spot are ordinarily taken in water that is in transit from one place to another, changing its character from moment to moment. As the water swirls and mixes, so does the plankton it contains, while larger swimming creatures may be there at a station at one moment, and gone the next.

Some idea of the sampling error, the inherent error in the method of measurement, is required for estimating actual variability in a factor or event. Error, as statisticians use the term, is not a "mistake," but the uncertainty which is attached to a given measurement or estimate. It can be thought of as a sort of blurriness, or cloud, surrounding a point of information, as suggested in the sketch below. If the clouds of uncertainty surrounding two such points considerably overlap (B and C in the sketch), we cannot say for sure whether the points are distinct or the same. Obviously, it is desirable to shrink the size of the clouds as much as possible, and this is spoken of as increasing the precision of an estimate (B, here, is measured more precisely).



But of course the thing being measured must remain the same. For the agricultural scientist measuring corn plants, this is likely to be true unless he is careless. For the marine scientist, as we have seen, the condition measured is often changing even as the measurement is being carried out. There are statistical techniques for dealing with this problem, made more feasible with access to great computing power, but the inherent difficulty of distinguishing between real and apparent variability in the marine environment remains very large.

If the center of the cloud of uncertainty mentioned above lies close to the real value of the object measured, the measurement is termed accurate, though if the cloud is large, the measurement is not very precise. If the real value (D in the sketch at the top of the next page) is at some distance from this center, outside the range of uncertainty, the measurements are both inaccurate and biased, no matter how precise they may appear to be. Such would be the case if the corn researcher measured his plants carefully to the nearest sixteenth of an inch, using a folding rule with one joint broken off, though this illustrates only one of many possible kinds of bias.



Many of the gears used for marine sampling, notably nets and trawls, are known to be biased in their capacity to sample all sizes of a population of fishes, as the mesh size of a trawl determines the range in size of the fishes which can be caught, and this varies among species. A trawl with very small mesh, it might be thought, would solve this problem, but it does not, since such a trawl, while better at catching small fishes, is worse at catching large ones. If the corn researcher with the broken ruler is aware of his problem, he can add six inches to each measurement and correct it. Similarly, though with greater difficulty, the fisheries scientist can correct for gear bias if he can quantify it.

In general, the more unbiased (or bias-corrected) measurements one makes of a factor, the smaller the probable error of measurement, and the surer one can be of its true value.

Increasing precision by increasing sampling is practical to a point, but the area of ocean to be sampled is very large, and cost is finally limiting. Sampling becomes more cost-effective if the environment can be subdivided into sections for sampling, based on some knowledge or assumptions about its differences from place to place, so that sampling can be concentrated where it is likely to be most useful for the purposes at hand. Within each section, sampling is done at random, but different sections may be sampled with different intensity.

The random procedure of the scientist differs fundamentally from the hunting strategy of the fisherman. Data from both sources, scientific surveys and fishermen's landings, are used in assessing the state of the resources. Scientific sampling gives a measure of the variability of a stock within an area and its average population density and distribution, but unless such sampling is very intensive, it is mainly useful in discovering long-term trends. Commercial catch data are biased from the scientific point of view. The fisherman searches out concentrations of his quarry wherever it may go and avoids thinly populated waters as best he is able. The fisherman's catch, if extrapolated for a whole fishing ground, usually would indicate a population much larger than the one actually present. (The extreme case would be one in which the fisherman caught the very last school in the sea; extrapolation would imply a sizeable population when in fact there were no remaining fish whatever.)

Accurate estimates of absolute size for marine fish populations are difficult to achieve. There are few accurate data, in the sense defined above, available to fisheries scientists. Even the catch is not accurately measured by dockside landings, because many fish are discarded at sea.

Relative commercial catches from year to year can also be misleading, because fishing may become more efficient, with an "inflationary" effect on the data (for instance, the apparent size of a population might increase while its real size is declining). Catch size also reflects changes in consumer demand and shifts in effort among fishermen.

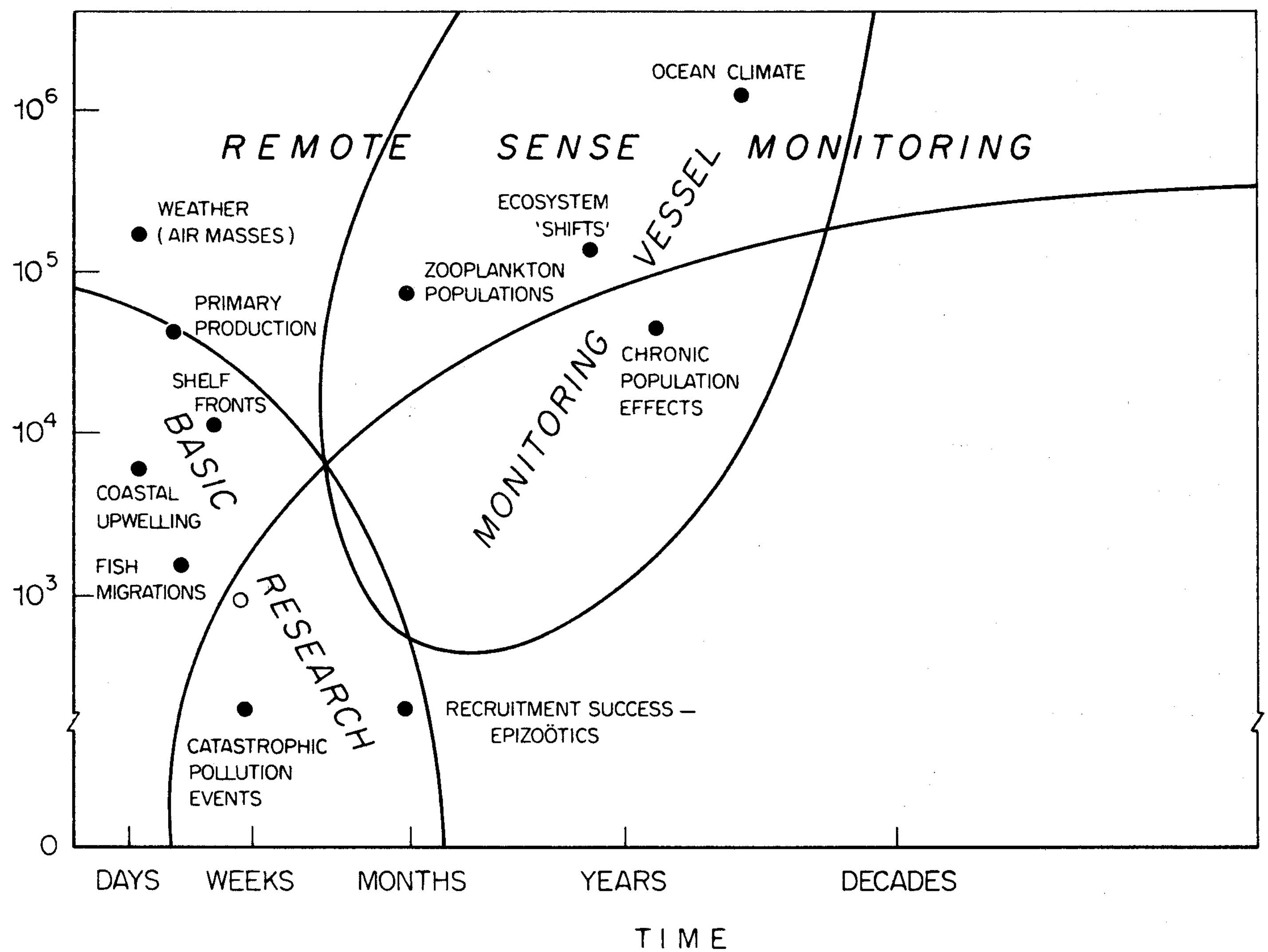
What recourse do fisheries scientists have, if they cannot accurately measure the populations of fishes to be managed? In practice, they rely on a synthesis of information from different sources, correcting probable biases when these can be estimated. Through a variety of statistical procedures, scientific and commercial data can be made to reinforce each other. Measurements taken independently during annual survey cruises are essential, and for these, paradoxically, precision can be more important than accuracy when a high level of accuracy cannot be achieved. Precision here permits changes in populations to be detected and the rates of these changes to be estimated, even if the population's absolute size remains in question. These shifts can then be related to events observed in the fishery and in the natural environment. Precision is achieved by consistency of method year after year. Many technological improvements have been welcomed in fisheries science, but it is not always understood by those outside the field that "improving" methods used in the long-term surveys would largely frustrate the purpose of making them.

Timing

Each of the phenomena that we sample and measure has its characteristic scale in time and space. These dimensions determine the sampling approach: the geographical extent of sampling, and its frequency or interval. In the diagram shown opposite, some of these time and space characteristics are represented for different phenomena. Their positions on the chart, of course, are only the roughest approximations; but still, one can see that different events imply different sampling strategies.

We have stated earlier that absolute population sizes in the ocean are difficult to measure, and that fisheries scientists rely on rates of observed change to predict the probable future status of these populations. For fisheries managers, recruitment and significant changes in species composition of the fish stocks are the most critical aspects to determine. Recruitment is an annual event, and is estimated in the course of twice-yearly survey cruises, each covering about 120,000 square miles of ocean (twice yearly because of spawning time differences among species, and substantial seasonal changes in distribution and abundance). The same sampling interval serves for monitoring species composition.

It is possible statistically to estimate the precision which a given level of sampling is likely to achieve, and to say what increase in sampling would be necessary to improve precision by a given amount. For instance, to make the bottom trawl survey results twice as precise as they now are, would require roughly a 10-fold increase in sampling. Whether to do this, however, is not a scientific question, but a social and political one: does society need that extra precision enough to justify the considerable cost of achieving it? We feel that the twice yearly bottom survey cruises are probably sufficient to furnish managers with the information they need in present



Schematic relationship of dimensions of time and space to various phenomena in the marine environment. Extent and intervals of sampling must be tailored to the time-space scale of a given event.

circumstances.

For other purposes, such as deciphering the processes that underlie such phenomena as recruitment success and failure, the effects of pollution, organic production, and so forth, sampling at other scales of time and space may be required. Plankton blooms, for instance, and changes associated with them, are likely to require twice-monthly sampling to be followed reasonably well. The movements of fronts between water masses may require more frequent observations if we are to understand how they operate. Some phenomena are observed continuously, with such devices as tide gauges and current meters.

These devices are ordinarily fixed in one place and operate at one extreme of the spatial continuum. At the other extreme is the technology of remote sensing from satellites and airplanes. This is limited to studies of what can be seen or inferred from the ocean surface, but such studies can be carried out at a global scale if necessary.

A CHRONICLE OF TWO GEORGES BANK FISHERIES

Georges Bank is in effect an enormously productive food factory, and we can be fairly sure that the quantity of energy flowing into it, in the form of sunlight, bears some direct relationship to the quantity of protein produced. But exactly which products this factory will produce in any given year is far from predictable. As the figure on the next page shows, total landings (at the top) were relatively constant, at least until 1973 or so, when fishing effort finally overwhelmed the productive capacity of Georges, at least in terms of fishes. Even then, energy ordinarily consumed in the maintenance and growth of fishes undoubtedly was diverted to other organisms not represented in the landings (sand lance, for example).

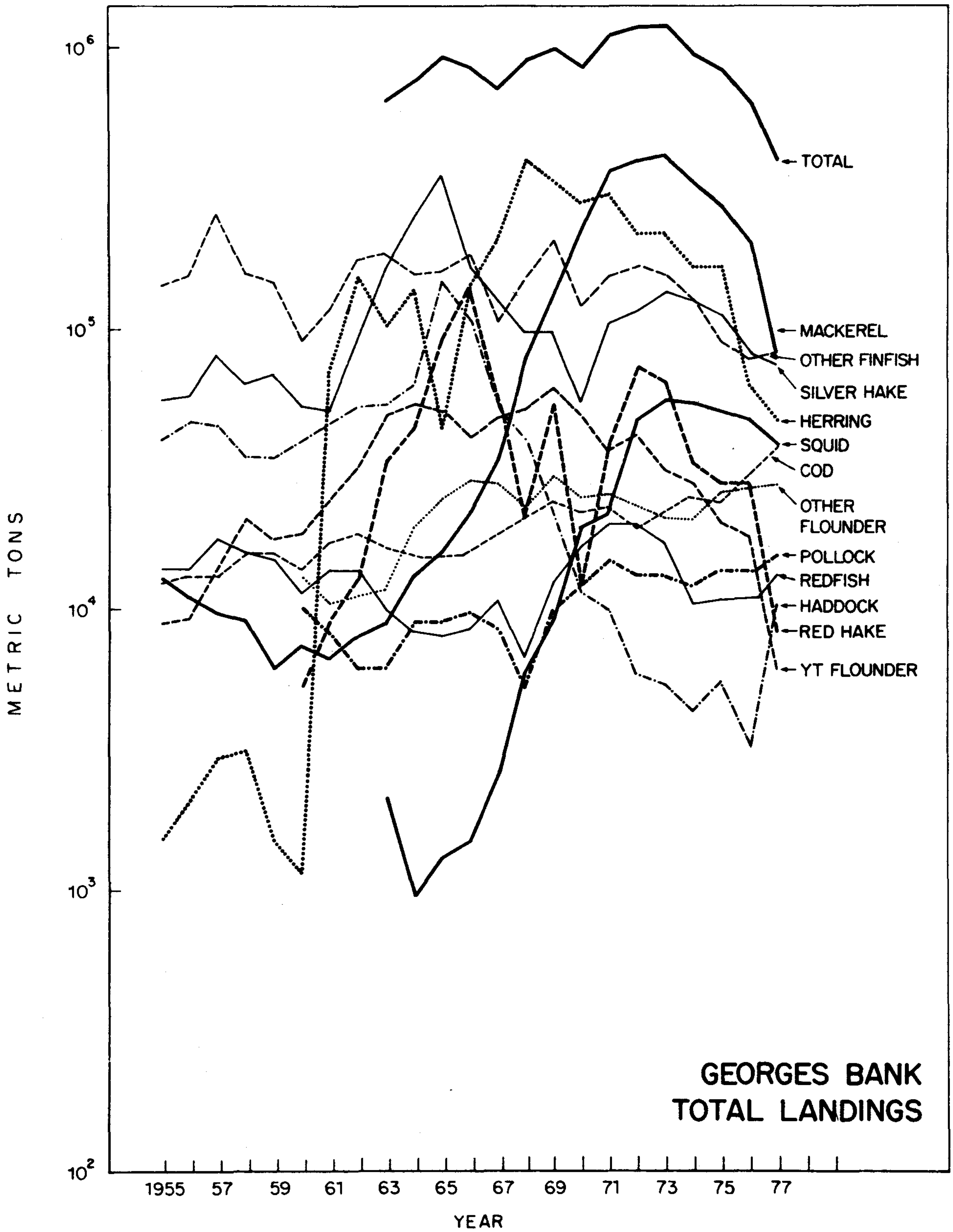
Trends for individual species show wide swings over time, varying by factors of a hundred or more in many cases. How extreme this variation would be in an unfished ecosystem is not clear, and we are not likely to learn the answer for any place as productive as Georges, because we cannot afford the experiment. It is safe to say that both the degree and the rate of change for a given species is strongly affected by fishing; and where fishing is directed at a few species in a mixed-species system, the balance among them is affected also, as the non-target populations expand to use the resources available.

In the following pages, an account is given of two fisheries on Georges Bank where unprecedented fishing pressure appears to have led to significant declines in the stocks. The first of these is the haddock fishery which has had a long history on Georges. Haddock are taken with many other species in bottom trawls, but during the period discussed, effort was aimed at haddock particularly, as a species traditionally prized in the market. The second account is of the Atlantic herring fishery, which was essentially untapped on Georges until the early 1960's. Herring are pelagic and migratory, and a catch of herring is not mixed with other species to any great extent; even more so than for haddock, the herring fishery is a concentrated, single-species effort. Despite superficial differences, what happened in both fisheries is much the same.

Haddock

Haddock have been harvested on Georges Bank since colonial days, but the modern era of exploitation began with the introduction of trawl gear after World War I. Haddock landings peaked in the late 1920's and then began to collapse, spurring federal investigations on the species in the 1930's which set the stage for later management by the International Commission for the Northwest Atlantic Fisheries (ICNAF). Faced with shortages of haddock, fishermen diverted their effort to other species. Landings from 1935 to 1960, almost exclusively by U.S. vessels, averaged between 45 and 50 thousand metric tons annually, close to later estimates of annual sustainable yield. The main problem during this period was the catch of undersized haddock by small-meshed trawls.

The creation of ICNAF in 1951 provided regulatory authority for managing haddock; large-mesh trawls were introduced as a result. Harvesting became


GEORGES BANK
TOTAL LANDINGS
METRIC TONS
YEAR
10^6
10^5
10^4
10^3
10^2
1955
57
59
61
63
65
67
69
71
73
75
77
TOTAL
MACKEREL
OTHER FINFISH
SILVER HAKE
HERRING
SQUID
COD
OTHER FLOUNDER
POLLOCK
REDFISH
HADDOCK
RED HAKE
YT FLOUNDER

markedly more efficient, and discards of small haddock were reduced several fold.

World War II limited fishing on Georges, and haddock stocks remained relatively stable for several years thereafter. Canadian fishermen, next door to Georges, and more distant foreign fleets historically had all but ignored this productive ground, but in the postwar years, driven by increasing world demand for protein, this relatively untapped area was "discovered." The treaty establishing ICNAF in 1949 recognized the need for cooperative international investigations of the Georges Bank resources and the impact of fishing upon them. These led to size restrictions on Atlantic cod and haddock in 1953.

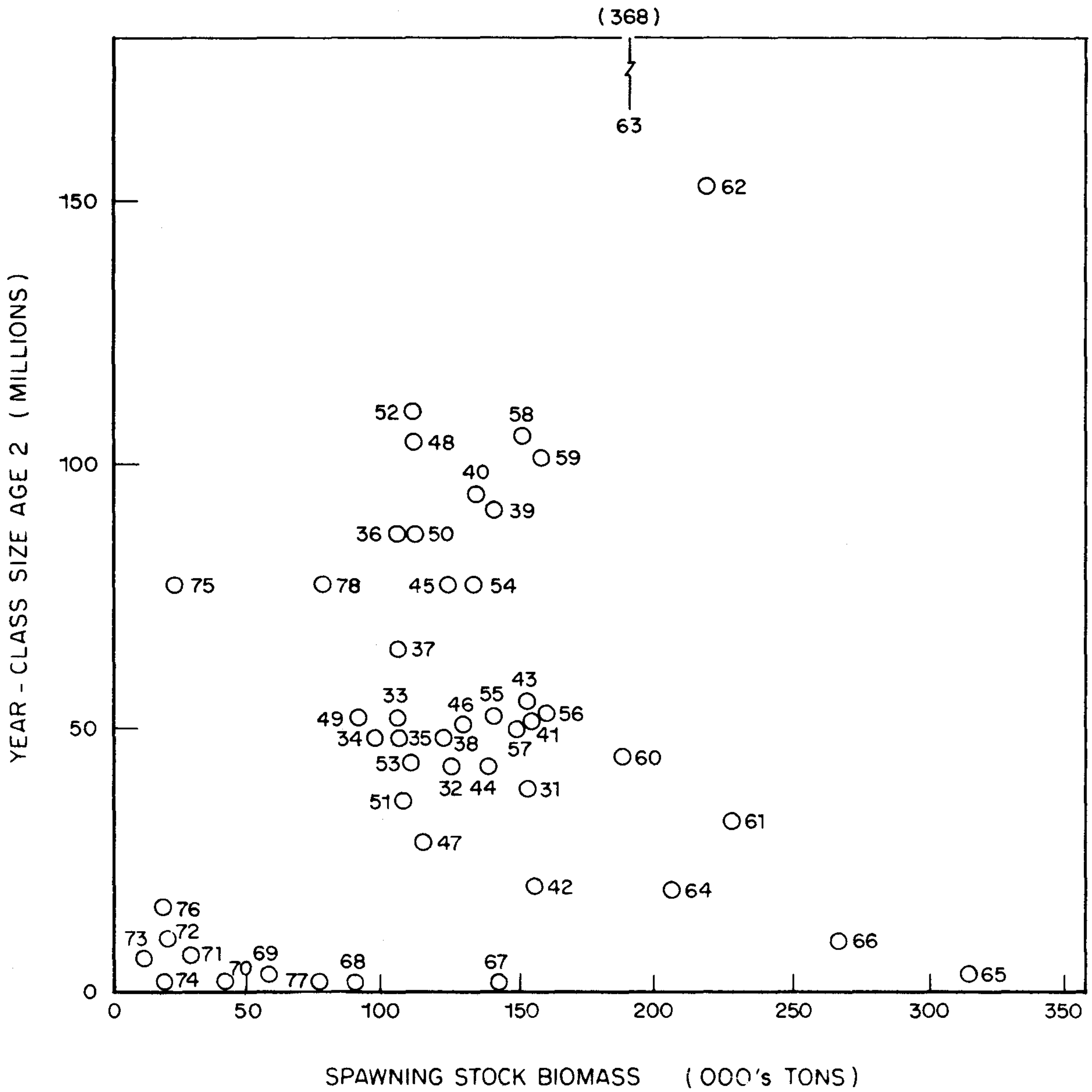
The decade of the 1960's saw Georges transformed from a U.S. to a multinational fishing ground. Canada entered in force, together with the Soviet Union, Poland, East Germany, West Germany, Spain, and Japan. Canada concentrated on groundfish and sea scallops, the Europeans on Atlantic mackerel, herrings, and silver hake. But in 1962 and 1963, an exceptionally large number of young haddock were produced; when these were still a bit small to be caught under the still-existing mesh regulation for haddock, foreign fishermen went after them with their hake and herring gear. At the same time, the United States, finding competition with the Canadians for scallops increasingly unrewarding, expanded its own haddock fishery. The result was an all-time peak catch of 150 thousand metric tons of haddock in 1965: three times the estimated annual sustainable yield. The haddock failed to reproduce fast enough to keep pace with the fishery, which became more intense as the fish grew scarcer. From the mid-1960's onward, the recruitment of young haddock to the fishable population, which in the past had been highly variable year to year, became consistently poor, poorer in fact than ever before recorded, as shown in the figure on the next page.

The Boston fleet, which made its living from the haddock stocks, was devastated. It had been assumed by the U.S. that market factors would "automatically" solve problems of allocating catches to the various fleets, but other nationals were subsidized, and the free-market assumptions did not hold up.

Faced with the desperate condition of the haddock stocks, ICNAF limited catches to 12 thousand tons for 1970 and 1971 (less than one quarter of the maximum sustainable yield). Known spawning grounds were closed to trawling during the spring of those years, and in the following years management under ICNAF became more and more restrictive. Despite all this, the stock remained in desperate condition throughout the early 1970's. Haddock became, in the eyes of New England fishermen, a bitter symbol of ICNAF's ineffectiveness.

Pressure for a new management system became overwhelming. The collapse of the Georges Bank haddock, as much as any other event, led to passage of the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA), which unilaterally declared U.S. control of fisheries within 200 miles of our coast, and brought ICNAF to an end.

Of the eight Regional Fishery Management Councils established by MFCMA, the New England Council was put in charge of Georges Bank haddock, with the task of managing them for "optimum yield." This elusive measure was defined



Relation between recruitment (age 2) and spawning stock size for Georges Bank haddock between 1931 and 1977. (Numerals designate the year.)

as the catch which would provide the greatest overall benefit to the nation with particular reference to food production and recreation, to be prescribed on the basis of maximum sustainable yield modified by relevant economic, social, and ecological factors.

To be sure, the Council was not launched into its management role from a standing start. During the ICNAF years, scientists at the National Marine Fisheries Service lab at Woods Hole had been improving the store of data on haddock, using information from the commercial fishery to which they added results of a new series (beginning in 1963) of standardized bottom-trawl surveys which continue today. Small-mesh liners in the survey gear captured small sizes of fish before they became vulnerable to commercial gear, permitting some predictions to be made of future prospects for the fishery. Standardization of gear and sampling methods avoided the bias inherent in commercial data which reflect constant changes in gear and effort by the fishing fleet as it responds to market and resource factors. A clear-cut link between spawning stock size and subsequent recruitment was sought but not found in the historical data, though a tendency toward poor or highly variable recruitment was seen to be associated with low levels of parent stock. For the first time, all available information was stored in computers, for ready and flexible access and analysis.

The store of information was growing but still limited, and the New England Fishery Management Council, faced with poor haddock stocks and an immediate need to forestall unrestricted fishing, acted conservatively. They continued in effect previous ICNAF catch levels: 6200 tons of haddock for the Gulf of Maine and Georges together, to be taken only incidentally (as "by-catch") in fisheries for other species. The idea was to keep the catch at the lowest possible level, and let the stock's spawning potential increase as the 1975 year class matured. But this year class, entering the fishery just as the catch edicts were being laid down, proved to be very large. Indications of its great numbers had been detected by the fall survey cruises of 1975 and 1976, but the Council kept conservative quotas in effect in order to rebuild the spawning stock, because the abundant 1975 year class, though vulnerable to fishing in 1977, would not spawn until 1978.

Recruitment of the 1975 year class to the fishery in 1977 was estimated at 165 million fish, nearly three times the long-term average, and more than thirty times the number during the years of collapse. This sudden increase amounted to a management crisis for the Council, because the status of haddock as a by-catch species was "locked in" by the Council's Fishery Management Plan, difficult to change quickly under the terms of MFCMA. Haddock are normally taken with Atlantic cod, yellowtail flounder, and other species in the mixed trawl fishery, and when their numbers became enormous, it was next to impossible to avoid catching them except by closing or severely limiting the fisheries for other species. The prescribed yield for haddock had suddenly become quite unrealistic. The result was massive discarding at sea, and misreporting of haddock as other species to circumvent the rules.

Not until November 1977 was the management machinery able to effect the necessary changes, and by this time much damage had been done. Thousands of tons of haddock had been wasted in trawling operations, and masses of data vital for management planning had been lost.

The flow of information to the Council and the Council's ability to use it have both improved and been put to good use in guiding the haddock stocks and the fishery toward recovery. Haddock recruitment is affected by the fishery, by the condition of the spawning stocks, by other species, by disease, and by environmental factors. These interactions are becoming better understood now as the store of data necessary for exploring them becomes larger and more accessible. A "fishing year," beginning in October, has replaced the calendar year as a basis for management, permitting more timely incorporation of fall survey results in planning the next year's fishing. The states are cooperating, supplying information from their work inshore. In short, an orderly management process is in place and is being constantly improved, and its effects have become quickly evident. In 1978, optimum yield was set at 20 thousand tons of haddock, and the next year at 32.5 thousand tons, a promising recovery from the dismal circumstances of 1976, when the fishery was effectively closed.

Atlantic Herring

Atlantic herring range, on our side of the Atlantic, from Cape Hatteras to Greenland, usually in waters shoaler than 200 meters. Distinct stocks exist, with a major division at the latitude of northern Nova Scotia. Herring south of that are further divided into Nova Scotia, Gulf of Maine, and Georges Bank subpopulations or stocks which in the course of their seasonal migrations overlap geographically.

The European herring fishery is ancient, and our earliest settlers pursued these fish on this side of the Atlantic too. As early as the 1600's, a fishery for trade in herring developed from North Carolina and Chesapeake Bay to Newfoundland. But an industry whose impact on the stocks could be considered in any way significant did not begin until much later. A coastal, fixed-gear fishery for juvenile herring, the "sardines" of Maine and New Brunswick, began in 1875 and remained the leading fishery for this species until the middle of our century.

Adult herring began to be caught in large numbers in the Gulf of Maine and on Georges Bank in the early 1960's. Powerful mobile gear--various trawls and purse seines--were brought to bear on the herring stocks as the Soviets, followed by the East Germans, West Germans, and Poles, crossed the Atlantic to tap this virtually untouched resource. They were joined by other foreign fishermen, and by 1968 landings exceeded 370 thousand metric tons. Not surprisingly, this level of exploitation led to a crash in the fishery. Despite increasingly severe catch restrictions beginning in 1973, the population continued to fall. There has been almost no herring yield from Georges Bank or its neighboring waters since 1977, when the Georges catch amounted to about 1000 metric tons, roughly one-third of one percent of the yield a decade before.

Heavy fishing explains some of what happened, but not all. The trawl and seine fishery in the first half of the 1960's was based on some exceptionally good year classes (1956, 1960, and 1961) which swelled the estimated spawning stock four-fold, despite growing fishing pressure, between 1963 and 1967.

The importance of recruitment, the potential resilience of the herring stocks in the face of heavy fishing pressure, is illustrated by the decline in catches during a period of poor recruitment in the late 1960's, and the subsequent, if transient, recovery of both stocks and catch levels, despite continued heavy fishing, when a good year class came along in 1970. Stock abundance (not landings) decreased eight-fold between 1967 and 1973, but it was again on the rise in 1973 and 1974 (1970 year class), even though the restricted fishery continued to harvest a large fraction of what was available.

Systematic collection of data on the Georges Bank-Gulf of Maine herring stocks was begun in the 1950's under the impetus of the International Passamaquoddy Fishery Committee. As serious declines in herring became evident in the early 1970's, investigations were stepped up by the U. S. and other member countries of ICNAF.

Since there was gathering evidence of trouble in the fishery and some attempt to manage it, why did the virgin stocks of herring collapse within 17 years? To start with, the year classes on which the fishery began were unusually large, but the assumption was made by managers that they were typical. At the outset, stocks actually increased in the face of an intensifying fishery: 272 thousand metric tons were landed in 1963, and 1140 thousand in 1967. It is now felt, looking back on the situation, that even without fishing, stocks would have come down from their exceptional mid-1960's levels to some lower level through natural causes and more normal recruitment. But there was excessively heavy fishing, and after 1967 (with a respite in 1970) stocks came down precipitously. Allowable catches had been set too high to maintain the stocks, and on top of this, the allowances which had been set were routinely exceeded. ICNAF's objective had been maximum sustainable yield, but in their yield models, they used data from an expanding fishery based on two aberrantly large year classes. Yields declined, but a large international investment had been committed to the fishery and pressure grew upon ICNAF's Commissioners to base quotas on the most optimistic assessments of sustainable yields. Finally, quotas were set higher than any scientific opinion could justify. The following table shows what happened.

Recommended, adopted, and actual catches of George Bank herring in 1972, related to the targeted and achieved spawning stock size in 1973.

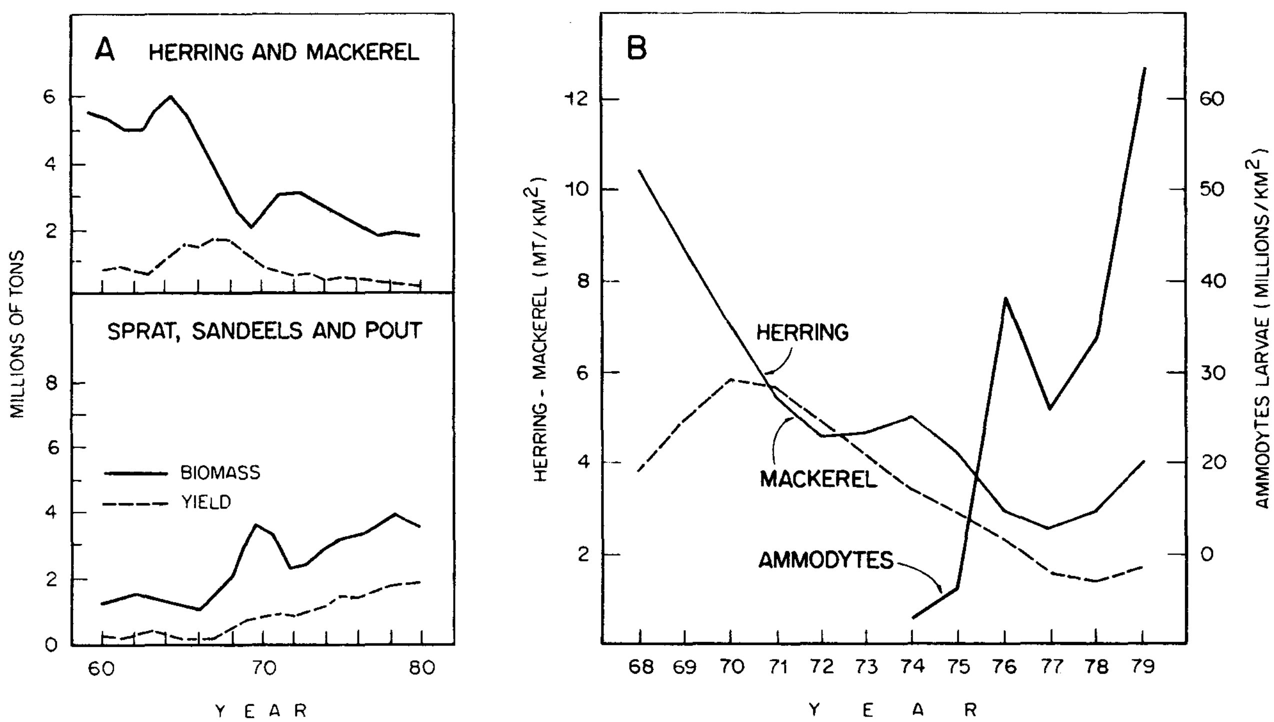
1972 catch (in thousands of tons)		1973 spawning stock size (in thousands of tons)	
ICNAF Herring Group recommendation	= 50-95	ICNAF target	= 310
ICNAF adoption	= 150	Achieved stock	= 144
Actual catch	= 172		

The future of the Georges herring stock is interesting to contemplate. In economic terms, it is right now effectively non-existent. In the Gulf of Maine, reasonably strong year classes (1976 and 1977) were recruited to the fishery in 1979 and 1980, but this had no effect on Georges. The hypothesis long held by many, that the Georges stock was recruited from inshore, has been as a general rule discarded. For Georges to be replenished with herring, it appears that we must now wait for some nearly ideal conjunction of factors affecting recruitment success, and this may be years in coming.

SAND LANCE

Field observations, supported by modeling studies, suggest that heavy impacts (as by fishing) on a few species can have substantial and broadly ramifying consequences on other species in an ecosystem, at other levels in the food chain. Such impacts parallel, in scale, effects of changes in the physical and chemical environment, and can be potentially as significant.

Commercial fisheries landings from the North Sea over two decades (1960-80) have shown a decrease in the quantity of herring and mackerel to be accompanied by an increase in certain small, fast-growing, plankton-feeding species: sand lance, sprat, and Norway pout (Figure A). Such fish are an important link in marine food chains between the zooplankton and the larger, commercially valuable, predators. Presumably, when fishing removes these predators in large numbers, populations of sand lance and other small fishes are free to explode. One practical consequence is that the commercial fishery is forced to switch to these less-desirable forms which, though they have some value as food, are mainly suitable for industrial use only.



A. Biomass and yield decline (upper graph) for North Sea herring and mackerel.
B. Herring and mackerel decline in the Northwest Atlantic while larval sand lance (<u>Ammodytes</u> sp.) increase.

Six years of records from the MARMAP surveys of the National Marine Fisheries Service, carried out on Georges Bank, combined with stock assessments from a longer period documenting declines in mackerel and herring on the same grounds, present a striking parallel to the North Sea experience. Larval sand lance in the MARMAP samples increase sharply as numbers of herring and mackerel fall (Figure B).

While environmental factors, such as temperature, may have contributed to the phenomenon, man's predation on the mackerel and herring appears to have been a significant cause.

It is now suggested that the effects of this predation by man reach out of the sea to the breeding colonies of Atlantic puffins, historically one of the most plentiful of North Atlantic seabirds. Wholesale reproductive failure on islands off the Norwegian coast has been tentatively ascribed to starvation of the puffin chicks. Analysis of food brought to them by their parents shows that their diet has become increasingly meager. It is argued that predation on sand lance by the commercial fisheries, which lack a supply of herring and mackerel, has removed larger sand lance from the populations preyed on by the puffin, so that only juvenile sand lance are available to them: the parents "would not collect such unrewarding dross unless there were a shortage of suitable food."

Whether this explanation is partly or wholly correct remains to be learned. The fact that it is seriously put forward should alarm us.

MODELING

We have seen how two important stocks, haddock and Atlantic herring, reacted to a massive increase in fishing pressure during periods of variable recruitment. These species were considered more or less in isolation from others, and from many other influences that might have had a bearing on their status. In fact, the western North Atlantic fisheries as a whole are based on an unusually large number of species directly, and indirectly on a bewildering, additional number of factors which interact in constantly changing ways. The number of such factors soon becomes too large to organize conceptually without the help of a process called "modeling," which serves to identify critical elements, and as an aid to exploring their function. "Modeling" is presently a vogue term in a number of professions, and when prefixed by "mathematical," tends to numb the attention of the non-mathematician. But it refers to what is, nonetheless, a useful process. Each of us since birth has been "model-building," however unconsciously: inferring from experience rules for predicting the behavior of our world, and testing these rules against subsequent observations of our own and the experiences of others.

Simple models can be carried in the mind, but models of ecological relationships, though they may be built up from such simple models, usually require some sort of diagrammatic or mathematical expression, becoming, if correct, more useful accordingly.

Take the statement: "Bullfrogs eat flies"; it constitutes a "conceptual" model of the simplest sort. Suppose, next, that a certain frog eats twice its weight in flies in a given week. The model, involving quantities now, has become "mathematical":

$$\text{Weight}_{\text{flies}} = 2\,(\text{Weight}_{\text{frog}}) \times \text{No. of weeks}$$

If the feeding rate depends on some variable factor, temperature say, this can be incorporated into the model, changing it to a form capable of accounting for continuously fluctuating processes. If not all frogs behave the same, the feeding of the whole population can be calculated in a "probabilistic" model based on the frequency of occurrence of different feeding rates observed in a sample from that population.

All of these models state that in described circumstances, such-and-such will happen in a predictable way; cause is explicitly related to effect. In nature, the relationships are seldom so simple as those suggested here. Feeding may be directed at several different prey species, with the rates dependent on the abundance of each of these, for example. Nevertheless, in principle, each element can be incorporated in a complex model, if its relationship to certain other elements is known.

All too often in practical ecology, many of the relationships are not known, because the chain of cause and effect is too subtle to be easily detected by methods available to us, or because a significant factor occurs so rarely or randomly, relative to other factors, that we are unlikely in a lifetime to get the repeated set of circumstances allowing us to prove its influence. Factors either have an effect or they do not, and in principle, effects, when present, can be explained. But in practice, some effects have to be treated as random and unexplained--what is "left over" after all of the explainable phenomena have been accounted for. Models can be devised that attempt to incorporate or predict the effect of this apparently random behavior of the ecosystem.

Models need not be of one pure type. One part of a model, for example, might determinately relate cause and effect, while another part might assume that random factors are operating. Moreover, complex models are not necessarily "better" than simple ones, any more than a turret-lathe is better than a screwdriver. Models are tailored to particular tasks.

At one extreme, in fisheries work, one might devise a comparatively simple model to explain the relationship between prey density and the growth rate of larval fishes maintained in a laboratory culture. At the other extreme are multispecies ecosystem models designed to utilize field data of various degrees of imperfection. Such models are likely to be based on randomness as an interpretation of observed events, at least in part, and to require a number of hypothetical assumptions about natural processes which have not yet been fully quantified by experiment. A great value of such models is in helping to sort out significant processes from insignificant ones, directing future study where it will count.

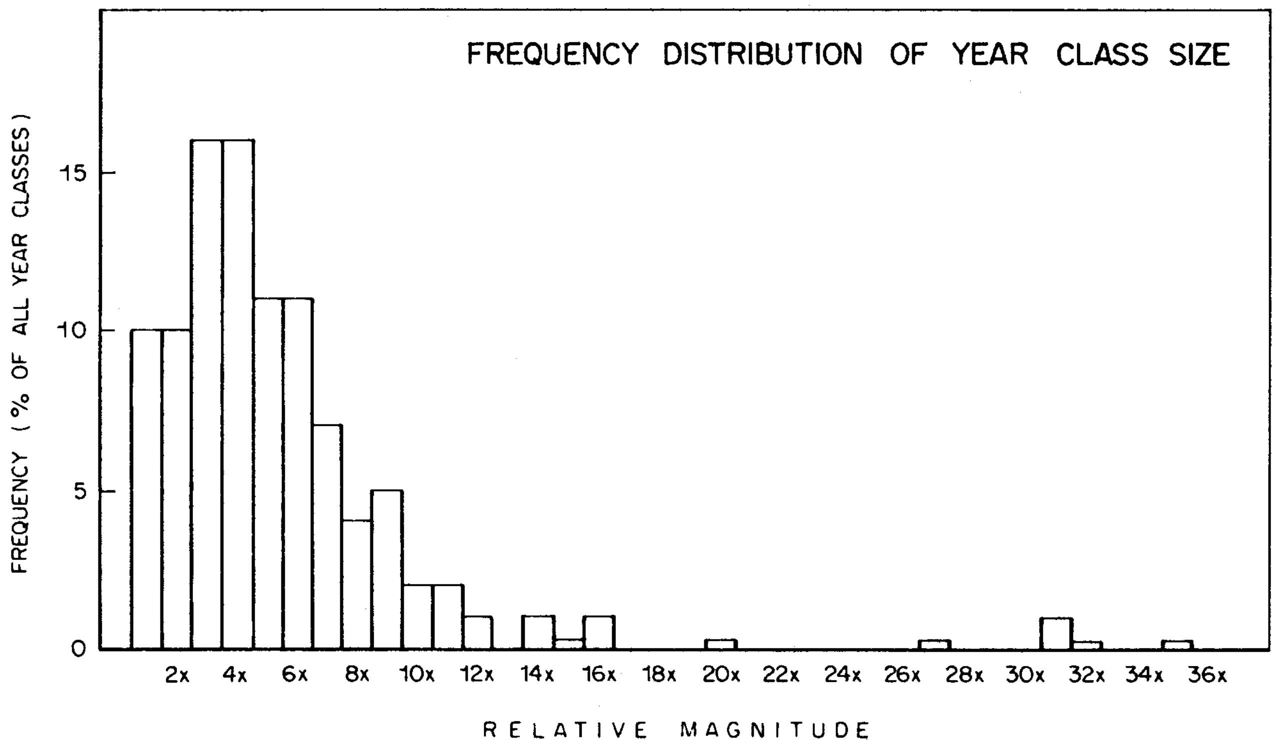
It is sometimes thought that a perfect description of an ecosystem is the final goal of modeling, and that since this is unlikely to be achieved, the effort might well be abandoned. Think instead of a hierarchy of model types, and a sort of dialogue among its different levels, in which conclusions at one level can be tested at another. By looking at problems from different sides in this way, one gains insight into how the system works, even if these workings will never be perfectly predictable.

In the next few pages, a brief account will be given of two models currently in use for research on Northwest Atlantic fisheries problems. The first of these, which predicts the probability of different levels of recruitment based on historical data, is very simple, but nevertheless powerful, since it shows convincingly that assumptions about recruitment among fishermen are often more optimistic than they should be, and that a more conservative outlook might prevent wasted investment. The second model, GEORGE, is of the complex, multispecies ecosystem type, which is used to direct and interpret investigations on Georges Bank. Only a few elements of this model will be discussed, enough to give the reader some idea of the nature of an ecosystem model.

A Probabilistic Recruitment Model

Much effort has been spent in trying to show cause-and-effect relationships between spawning stock size and subsequent recruitment, and as we have seen earlier, it has not been very productive. Observations of the annual ratio of year-class size to parent stock size have been made for different stocks over many years. From these data, we must conclude, given the large number of factors involved and our limited ability to measure many of them, that recruitment for practical purposes at present must be considered a random event, the result of a complex of processes.

But there are discernible patterns. If we have data gathered over a long period, which we do for many species, we can plot the frequency with which differently sized "crops" of annual recruits occur. This approach is illustrated here using combined data from 22 fish stocks. So that comparison between stocks is uniform, the smallest observed crop for each of the species has been related to larger crops in this way: a crop twice as large is indicated by "2X," four times as large by "4X," etc. The graph shows, for instance, that crops three times and four times the minimum size each occur about 16 percent of the time over a long period, while crops eight times as large occur about four percent of the time.



Frequency of occurrence of differently sized year classes, based on 22 fish species from Georges Bank. Bars indicate percentage of all years in which classes of particular sizes occurred. Size is measured as a multiple of the smallest year class observed (2X the smallest, 6X the smallest, etc.).

Typically, a very large year class in a stock draws the attention of the fishermen, and as that stock declines under fishing pressure, effort is increased to maintain catches. If another large year class does not occur soon enough, the stock may collapse with great cost to the industry.

In the case shown here, recruitment is 10 times the minimum level or more about 10 percent of the time (add the percentages for "10X", "11X", "12X", and all larger crop sizes). As we have said, it is these large year classes that tend to touch off new or expanded fisheries; there is an optimistic if not historically supportable tendency among fishermen to suppose that such recruitment levels are "normal." But the recruitment model here argues against this; it says that over a long period, recruitment will be no more than six times the base (or "worst") level about two thirds of the time, no more than four times the base level half the time, and no more than twice the base level 20 percent of the time. From an investment point of view, this is useful to know, offsetting the enthusiasm which may be generated in a fishery by an aberrantly large year class.

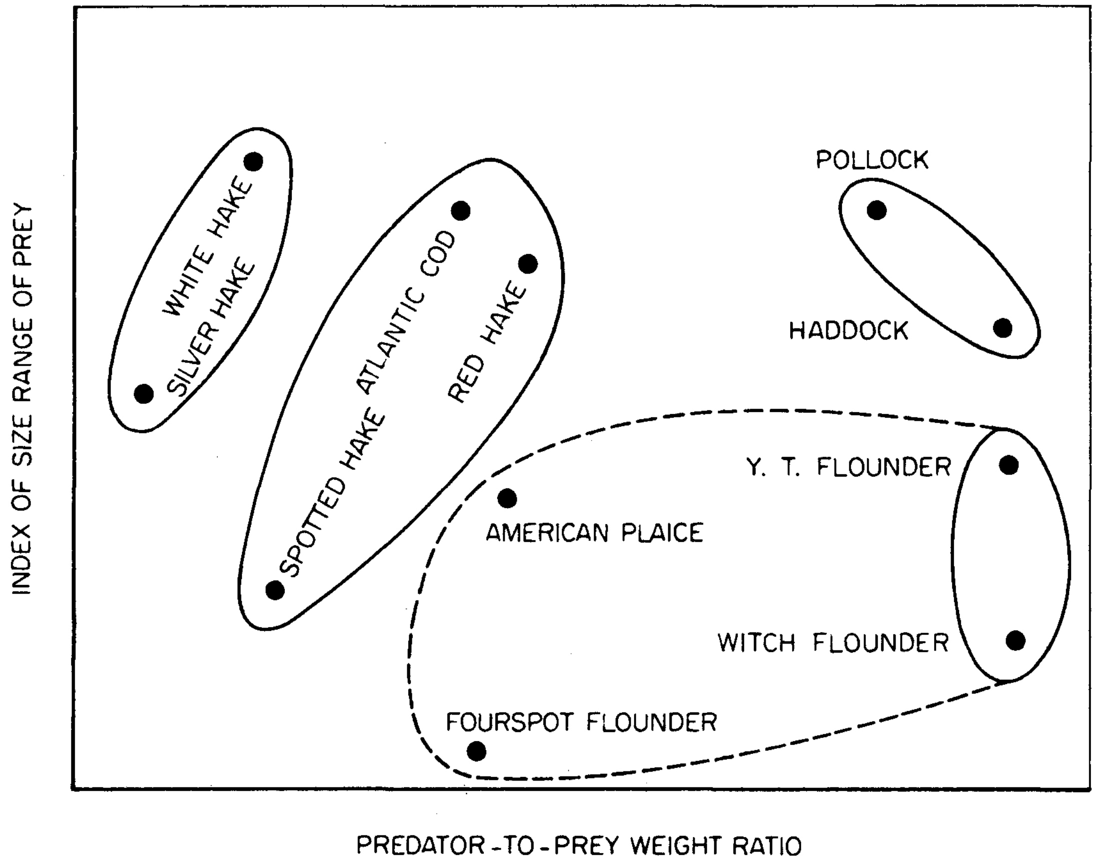
Useful results have been achieved economically in this model, and the historical records of recruitment necessary for devising it were already at hand. The multiplicity of factors that affect recruitment did not have to be separately analyzed; they are effectively integrated in the model. Its defect is that, as it stands, it applies to the long term only; it cannot tell us what is likely to happen in any particular year to come.

For prediction at shorter range, it is usually necessary to dissect the general problem of recruitment success further, to look at components that influence it. What is sought is a series of variables which are readily measured and whose interactions sufficiently explain (or predict) recruitment variability for management purposes. These variables themselves represent the summed effects of many biologically significant factors, which fortunately for the sake of economy, need not all be analyzed.

GEORGE--An Ecosystem Model

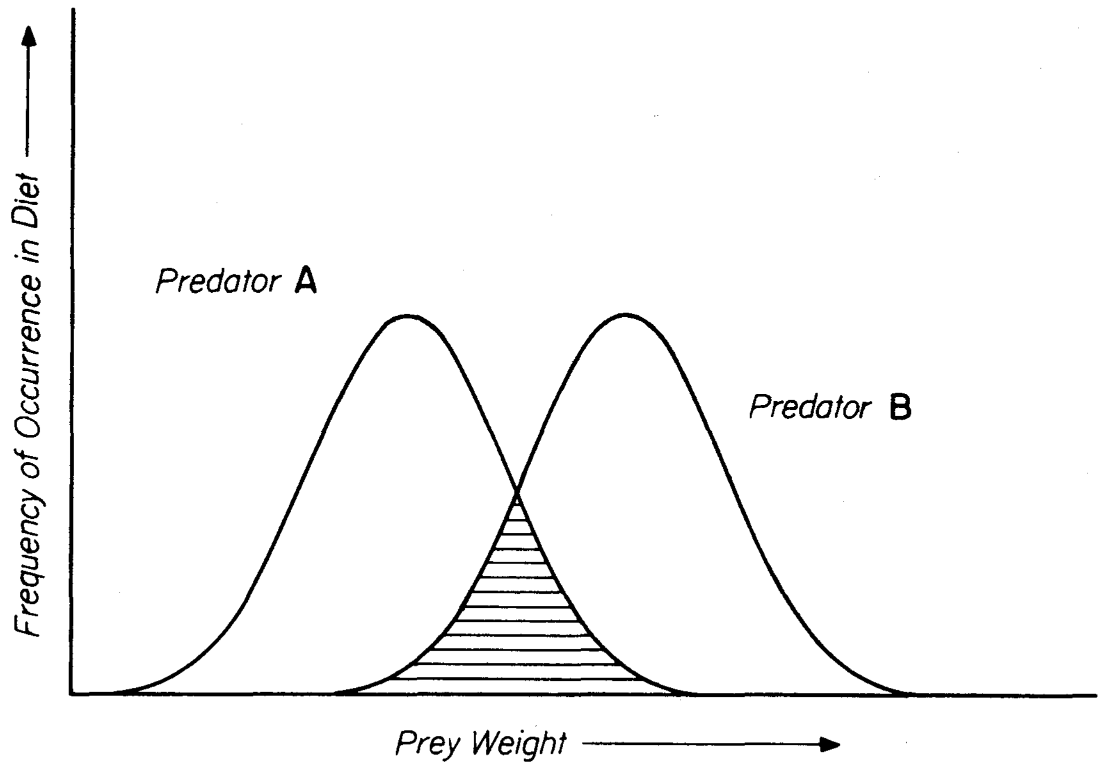
GEORGE was designed initially to explore joint effects of different fishing strategies and predator-prey interactions on Georges Bank. The model contains "compartments" for fish, zooplankton, and benthos. Phytoplankton, the primary producers of living matter by means of photosynthesis, are not yet included as very little is known about the linkage of phytoplankton with fish production. The flow of living substance (biomass) from zooplankton and benthos to fish, and the flow between different species of fish, is based on a number of empirical "rules." These rules are based on the relationship between predator size and preferred prey size, prey species preference, prey availability, seasonal feeding patterns, etc. The empirical relationships have been derived in part from actual counts and measurements of the stomach contents of fishes of different sizes and kinds.

Some differences in feeding behavior among species which have been incorporated in the model are illustrated in the figure at the top of the next page. The vertical axis of the graph gives a measure of the range in prey size acceptable to a predatory species: the higher up on the graph the predator's name appears, the less choosy it is about size of prey. The horizontal axis reflects the ratio of predator weight to average prey weight. Species toward the right select smaller prey relative to their own size than species on the left. The diagram is based on mean ratios of predator and prey weight, and shows how detailed analysis can demonstrate ecological distinctions among animals sharing a given habitat.



Two aspects of feeding selectivity related for 11 fish species from Georges Bank. The higher up a species appears, the less selective it is for a particular size of prey. The farther to the right a species, the larger it is relative to the prey it eats.

A second type of analysis used in the model, also based on the stomach contents of predators, expresses the range in prey size for each predator species as a curve of probability. At the top of the next page are two such curves for two hypothetical predators whose prey size preferences differ, but partially overlap. The preferred prey for Species A is of little interest to Species B, but there is a size for which they compete (shaded area). The frequency of different sizes among a prey population may be used to predict, based on probability, how it will be apportioned among predators. These probabilities are factored into the model.



Range of preferred prey weight for two hypothetical fish species, A and B. The shaded area shows the range for which both species compete; for the most part, they are not competitors.

Conceptually, since the model concentrates on predator-prey interactions, these can be considered "inside" the model, driven by certain processes "outside" it. These outside, driving processes are: production of benthic (bottom-dwelling) organisms, production of animal plankton (that is, secondary or zooplanktonic production), and recruitment of fishes into the Georges Bank population. (Because changes in recruitment from year to year have not yet been causally explained, the size of recruiting year classes is computed by probability statistics, based on recruitment data gathered over many years; see the diagram on page 49.)

In its present version, GEORGE assumes that Georges Bank is isolated, and that predators and prey are evenly distributed over its entire extent. In the future, the model will be refined further to reflect unevenness in the distribution of animals, and patterns of migration into and out of the study area. The model will also eventually consider other biological, physical, environmental, and economic factors affecting stock size and fishing.

A full and technical account of GEORGE is not our objective here. We merely try to suggest how this multispecies model addresses a complex ecosystem in terms of a limited number of variables, using empirical data from field and laboratory work gathered over a long period. Data which are unavailable or questionable can be estimated, and the model can be run to see how different estimates affect results. Where a wide range of estimates affects output but little, that factor probably need not be measured empirically. Sensitive factors identified by this process become subjects for future investigations.

THE MIDDLE ATLANTIC BIGHT--A STRESSED ENVIRONMENT

It is widely known that continental shelf waters yield most of the sea's produce: about 90 percent of that consumed by man. It follows that fisheries management is mainly concerned with the continental shelf. Traditionally, in considering the various factors that affect the shelf's resources, managers have focused on fishing, particularly as a component of mortality. Other components have been considered "natural," and have been assigned relatively low, constant values in the fisheries scientists' computations. These components: predation, starvation, disease, etc., have always been present after all, and flourishing wild populations have existed nevertheless.

So far in this report, we have mainly discussed fishing and predation. In the pages which follow, we will turn to disease and environmental stress as determinants of mortality and variability in fish populations. These components cannot be isolated for study as neatly as the effects of fishing can be. Disease may interact with environmental stress and with various factors that determine competitive fitness, such as vulnerability to predation. An infected fish might survive reasonably well in a healthy environment, for example, but succumb quickly when the environment itself becomes a source of stress. It might die directly from its disease, or be so weakened that it cannot escape a predator.

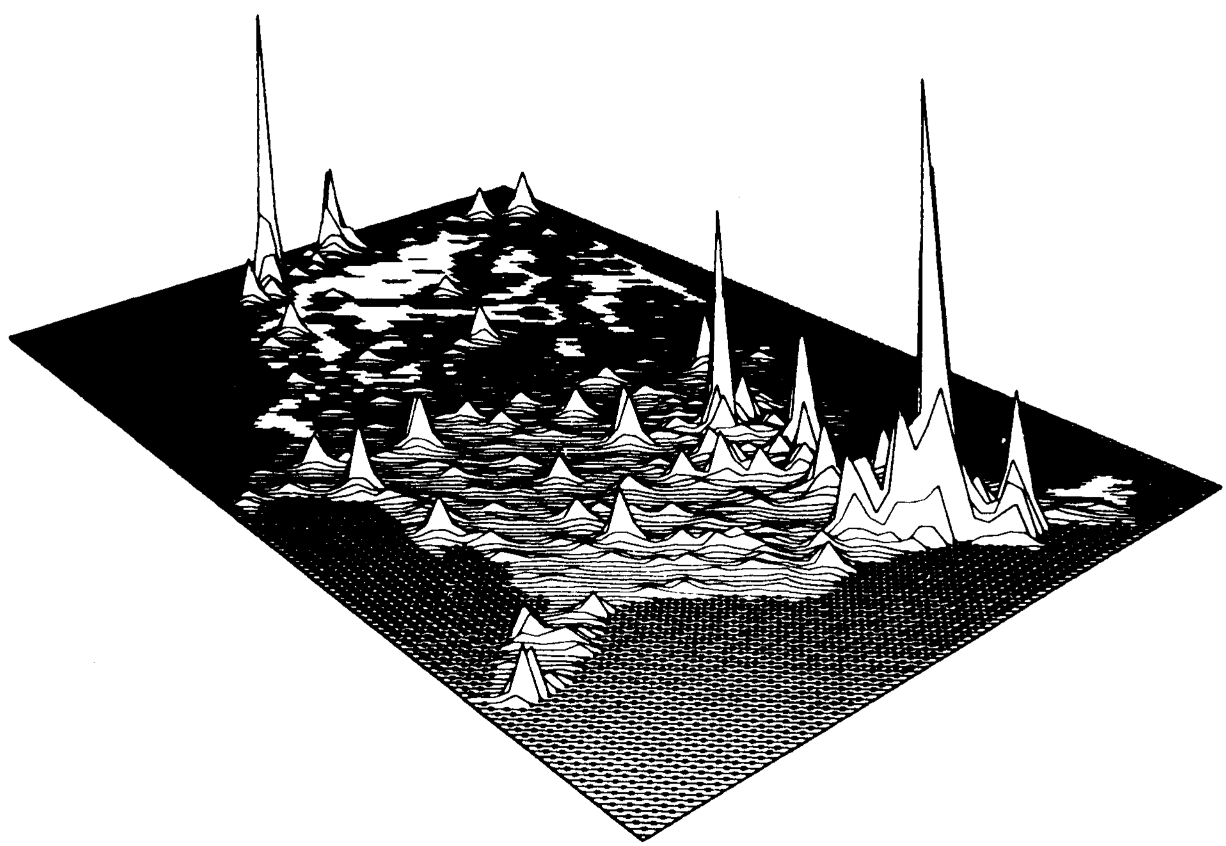
Because fisheries are concentrated on the continental shelf, and because this is the part of the marine ecosystem most affected by pollution, we can no longer simply assign some "standard" values to the non-fishery components of mortality. These components influence the resources dynamically, and in many cases with increasing seriousness.

In our region, the East Coast megalopolis is backed by a watershed which in places reaches hundreds of miles inland. This watershed pours its burden of runoff and drainage into the Middle Atlantic Bight. There, this runoff and drainage join the fallout from contaminated air, dumped bargeloads of wastes of all kinds, and miscellaneous leaks and spills, to furnish a grim laboratory in which we can and must study the effects of environmental degradation on the marine ecosystem. Where degraded conditions (contaminated sediments, ulcerated fishes, water too poor in oxygen to sustain life, etc.) are found, a map of their extent mirrors the density of human populations on the tributary land, and the massiveness of industrialization.

Predictably, the mouths of great estuaries such as the Hudson and the Chesapeake, which collect and concentrate the polluted product of thousands of square miles, are among the worst places. Studies show that in most major harbors and estuarine areas, the inner parts began to be affected during the early phases of the industrial revolution. Analyses of sediments in Narragansett Bay, for example, indicate that in the late 18th century, heavy metals had begun to accumulate because of discharges from metal refineries. The lower Hudson estuary had become so heavily polluted by the time of the Civil War that fish and shellfish taken there could not be sold because they tasted of kerosene leaked from early petroleum refineries located on Newark Bay. As decades passed, and especially after the turn of the century, the effect of pollution spread seaward; evidence of contamination can now be found in waters hundreds of miles from its probable sources.

To be sure, not everything the waters carry is harmful. Intensely productive coastal waters may be made so by replenishment of nutrients from the land. Even sewage, properly decomposed and distributed, can be beneficial. But it is inescapably true that the summed effects of what we have put into the water are not beneficial. At best they may be neutral in their consequences, but as we are becoming aware, the situation is far too often worse than that.

The Middle Atlantic Bight is not yet a disaster zone. As we have remarked elsewhere, it embraces some of the most generously productive waters to be found along our coasts. But danger signals are now plainly visible, and we believe that they can become only more alarming if we continue to perceive the sea as an "other" place where we can throw our civilization's garbage, resting easy that it will somehow go away.



Computer-generated graph of population concentrations in the contiguous United States, based on the 1970 census. The tallest spike at the right represents population in the Boston-Washington megalopolis.

The problem has both economic and technical aspects. Sea interests and land interests compete with each other not to be burdened with these wastes, because accepting them has a cost. But even if money enough were available for disposal, provably safe methods often are not. The size of the sea deceptively suggests that it will forgive any insult, so it has tended to lose out in this competition with the land, except in certain coastal places, easily defined, where benefits of protecting the marine environment are readily translatable into social and economic assets.

Industrial contaminants present the greatest long-term danger. Many of them are extremely persistent, and they may be biochemically alien to biological systems which have not evolved means of decomposing them. There are thousands of different compounds, and a still greater number of possible interactive effects which these may have on living organisms. Any massive lethal effect is likely to be detected, and in time its cause can probably be worked out scientifically. The sublethal effects are much more difficult to detect and trace, particularly because they may act cumulatively through the food chain, and may manifest themselves, for instance, only as a somewhat mysterious decline in predator populations.

Not all "industrial" pollution is discharged directly from industry (though these wastes do a major part of the damage); such substances reach the marine ecosystem by every conceivable pathway: in sewage, which includes whatever might have been poured down the kitchen sink; in dredge spoil containing chemicals dumped by industries dead perhaps for 50 years, or leached from the antifouling paint on ships' bottoms; in the runoff from farmers' fields and from highways (fertilizers, pesticides, petrochemicals, and lead); and in the microscopic rain of particles from the air.

Organic sewage, leaving aside for the moment "industrial" additives, is a problem in itself. As we have said, sewage properly distributed can enhance productivity. But in excessive amounts, which is usually the way it is introduced into the ecosystem, it may cause productivity so abnormally intense that the habitat becomes unlivable for the species we seek; or it may create such a demand for oxygen, required for the processes of decay and regeneration of nutrients, that in effect the animals inhabiting the locality are suffocated. Given time and oxygen enough, and sufficient water circulation, organic sewage will eventually "go away." The effects of the "natural" components of sewage pollution are usually fairly local and potentially tractable, because we can alter the way we introduce this pollutant into the ecosystem. This is not true for many chemicals that may be introduced with sewage, and for certain disease-producing organisms which it may contain; such organisms, we begin to learn, can persist dangerously in the marine environment. There is an aesthetic aspect too, which any community privileged to live by the sea must value (and this value can be expressed in dollars): sewage, apart from its chemical and pathogenic burden, is not pleasant to swim in. While we are waiting for it to go away it may be washing up offensively around our ankles.

Dredge spoils, again leaving aside their chemical additives, usually have a local effect. Dumping loads of silt, sand, or mud on top of a settled benthic habitat is bound to alter it, and if the dumping rate is excessive, the place will probably become, locally, a desert. Probably the main danger in dredge spoils, given the small volume of dredgings and the great expanse of the sea floor, is precisely in the "unnatural" substances they contain. Dumpsites become leaching fields which export toxic substances over tens, hundreds, or thousands of square miles. The effects, except locally, may be insidious and not specifically detectable.

Runoff of surface waters, directly or through rivers and streams, is analogous to the circulation of the air in the breadth and uncontrollability of its effect as a vehicle for pollutants. The most practical place to control pollution introduced by these means is at the source.

Offshore oil operations represent a threat to living marine organisms which has been widely and heatedly debated. Exploratory drilling has just started on Georges Bank, while in the Middle Atlantic Bight it has been going on for several years. Oil transport and the attendant risk of spills is increasing on land and sea all along the coast. Oil operations may have a gradual, chronic effect on an ecosystem that is nearly impossible to quantify, or in the case of a major spill, a sudden and catastrophic effect with immediately obvious consequences.

Danger to marine ecosystems comes from three main sources: drilling muds and cuttings dumped on the bottom; the physical barrier which pipelines present to the bottom fauna and to trawling operations; and spilled oil.

Muds and cuttings produce a cloud of suspended particles and a layer coating the bottom. Studies indicate that the suspended fraction, including any toxic materials, is rapidly dispersed and diluted, and no adverse effects have been observed on pelagic animals. The fraction that falls to the bottom forms an elongated heap, trailing down-current from the drilling site. Toxic materials appear to be rapidly diluted, and while the dumped material is temporarily unproductive in biological terms, productivity shows evidence of recovering.

Substantial losses could occur for the trawl fisheries if pipelines are left exposed in certain places, but the impact of burying pipeline should be temporary; the hydraulic jets used for the purpose are compared in their effects to several passes of a hydraulic clam dredge--a popular fishing gear.

In relatively shallow environments, oil spills contaminate not only the water column but the sediments, producing a wide range of lethal and sublethal effects. Plankton and the early life stages of various organisms are most sensitive, which may decrease future recruitment. Thus, spills during reproductive seasons are especially threatening. Once oil invades the sediments, it persists, and bottom-living animals are slow to recover. Oil may be ingested by various animals, filter-feeding copepods for example, so that its toxicity is passed through the food chain.

Chronic leakage of oil into the environment can be expected to cause different problems from a one-time, major spill. The problems are not necessarily less, but they can be addressed more deliberately. A spill is a catastrophic event, requiring an emergency response.

THE POISONING OF THE BALTIC

The Baltic Sea is bordered by five fishing nations. Information from these nations is hard to come by, but it is reported through Polish sources that massive fish kills are occurring near Gdansk and that fishermen, to sustain their livelihood in some degree, are being paid to destroy catches which are so diseased or contaminated with sewage and chemicals that they are not fit for consumption. Official Polish figures from 1978 state that 37 percent of fishery products are in this category, though many of these products continue to find their way to consumers. In the 1970-80 period, pollution levels in this part of the Baltic increased four-fold. Most beaches have been closed to the seven million seasonal visitors seeking to use them.

It is estimated that 10 million metric tons of polluting mineral salts are discharged annually into the Baltic, more than 20 times the amount which the Rhine, described as the "sewer of western Europe," discharges into the North Sea.

The bulk of the pollutants are being stored on land, but much of this material will eventually find its way to the sea after working injury upon surrounding farms. (In Poland, one fourth of all food products cannot meet health standards.)

Swedish researchers have found strong concentrations of polychlorinated biphenyls, or PCB's, all along the Soviet Baltic coast. Every body of water discharging into the Baltic contains them.

The fragmentary information we have from Poland only begins to suggest the enormity of the problem throughout the Baltic, which is not well advertised by the polluters. This secrecy cannot be long sustained, however, as more and more evidence rises stinking to the surface.

Multiple Use and "Assimilative Capacity"

As deteriorating drinking water is traced to toxic substances in landfills and the costs of purification rise, the pressure builds in favor of ocean dumping. The scramble for domestic oil supplies makes us more willing to risk the dangers of offshore drilling. Antiquated harbor facilities need dredging which will inject long-buried contaminants into coastal ecosystems. However we might choose to do otherwise, the critical condition of municipal finances seems to offer no alternative to dumping sewage and other wastes into the sea.

Inshore waters are particularly hard-hit by these practices. Recreational fisheries are almost entirely inshore and are economically very important to many coastal communities. Local economies can be devastated. Commercial fishermen are forced further offshore, where the species to be caught may have much lower market value than the inshore species, and where the cost in fuel and time for catching them is much greater. Fish products may become unfit to eat, or public fear of contamination may spoil the market.

There is no doubt that there can be real and fundamental conflicts between various uses to which we put the ocean. The attempt to resolve them rationally revitalized the old concept of "assimilative capacity:" the idea that there is some level of waste which an ecosystem can absorb without danger to its resources and to human health. This concept is attractive, and has much in common with the concept of "multiple use" that has been applied in managing terrestrial habitats, so that industrial uses do not unduly affect those outdoor activities deeply ingrained in our culture--fishing, hunting, camping, etc.

Multiple-use practices have worked well in some places, but in others they have not. Assimilative capacity in the ocean requires rigorous and skeptical testing against the hypothesis that the most productive ecosystem is an uncontaminated one. In the short run, the oceans will continue to be used for dumping wastes, and as new emergencies are perceived arising from land dumping, disposal in the oceans may increase. Certainly the pressure for doing it will increase. But "assimilative capacity" must not become a code for shifting costs and problems from one economic sector to another. Evidence from the Baltic and from many of our own coastal waters shows plainly that these costs and problems may catch up with us eventually, perhaps in new and even less manageable forms.

Clearly, we are confronted by a scientific problem of great scope: determining how much contamination is too much in a vast and constantly varying ecosystem. It is an "uncontrolled" experiment...there is no pristine ecosystem available for direct comparison. The best we can do is to establish what the normal (or at least the present) "envelope" is within which marine populations vary, in terms of their important characteristics (population size, growth rate, incidence of disease, etc.). We can then use this range as a reference for evaluating what happens (if anything) when alien substances are discharged into the sea.

This work goes forward on many fronts, much of it in the context of our own monitoring program, but involving as well other federal and state agencies in a cooperative process.

When the <u>Torrey Canyon</u> sank in the English Channel and a well-head blew in Santa Barbara, the public demanded to know what the long-term dangers might be, as it did when the <u>Argo Merchant</u> went down in our neighborhood. There was no very satisfactory way of answering these questions because we had so little knowledge, in the broad geographic and historical sense, of natural flux and regenerative processes. The sites where accidents might occur in the ocean are innumerable, and we cannot have close knowledge of each one. To prepare ourselves for responding to specific events we need to combine the "close-up" and the "long-shot" in our overall scientific perspective. We can study only a limited number of phenomena in detail, and to generalize from our findings we need to know whether they are roughly representative at a larger scale.

Monitoring patterns of variation in time and space is tedious work, and only the sudden aberrations in these patterns make the newspapers. The aberrations, of course, cannot be seen as such unless the basic patterns have been established. It is a crucially important part of our public function to provide this framework whose importance is often recognized only when it is missing.

Pathology

Sickness, either in its plainly evident form or in the subtler form of diminished vitality, is found wherever life is found: in domestic and wild populations, in "unspoiled" and polluted circumstances, among animals and plants. Because much of the marine environment is inaccessible, and because in most cases only the more obvious manifestations of disease have been studied in marine organisms, we know relatively little about the role it plays in the growth and decline of populations. But there is no reason to suppose, based partly on analogy with terrestrial phenomena, that disease is not a major cause of the variability found in the sea.

Atlantic herring stocks of the western North Atlantic have been ravaged periodically by outbreaks of a fungus disease. These occurred in the Gulf of Maine in 1932 and 1947, and in the Gulf of St. Lawrence in 1898, 1916, 1940, and in the 1950's. It has been estimated that at least half the Gulf of St. Lawrence herring were killed in that most recent outbreak. There is an interesting suggestion that good year classes in 1958 and 1959 followed as a result; with spawning diminished, there was less competition among herring larvae, and unusually high rates of survival. The effects of the original disease continued to reverberate when these large year classes grew to maturity and crowded the environment with their young. Survival and recruitment was poor for several years, it is thought due to intense competition among the young herring.

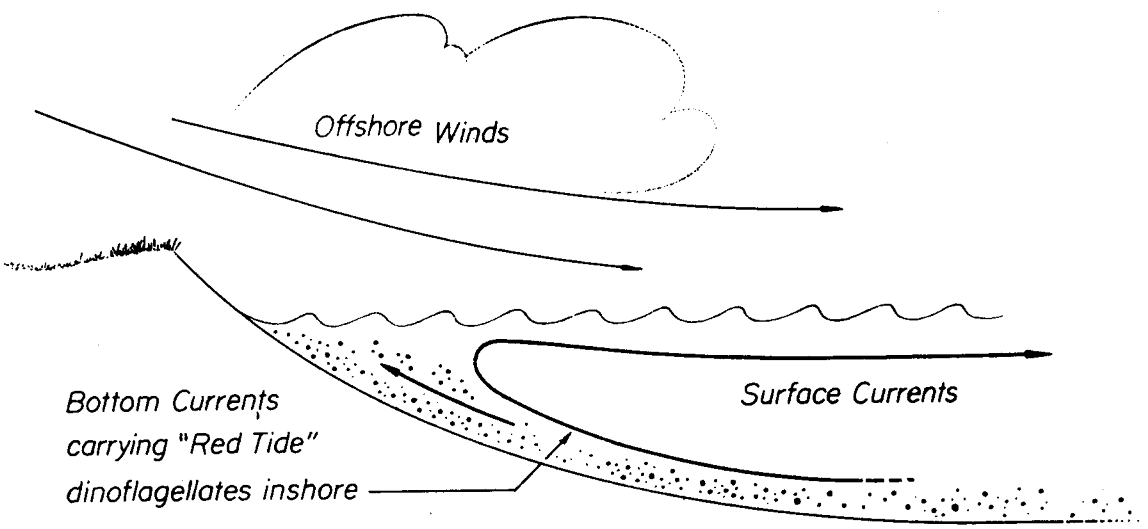
It is difficult, of course, to prove the role of disease in determining variability in wild fish populations, because it interacts with other factors as we have just seen, and we have tended to assume that among these factors, fishing has been overwhelmingly important. But the widespread incidence of infectious organisms in fish populations that are notorious for wide swings in abundance suggests that "natural" determinants may sometimes be at least as significant. Atlantic mackerel populations show such swings for instance, and it is considered that a blood parasite may be partly responsible.

One fact is clear: organisms exposed to pollution are likely to suffer higher rates of morbidity and mortality from disease. The causes are many, ranging from lethal genetic changes (these have been observed, for example, in mackerel eggs from the Middle Atlantic Bight), to bacterial infestations which ulcerate the flesh of fishes, viral infections, and increased vulnerability to parasites. When instances of these sicknesses are mapped, it is clear that they are worst in the most polluted places. Abnormally large numbers of diseased organisms thus direct our attention to danger spots. But to identify the abnormal we need a better understanding of the normal flux in disease and other disturbances, for we know that such phenomena, when they do occur naturally, are often effectively self-regulating (see "Red Tides and Anoxia" below).

Environmental stress, including pollution, can weaken or kill organisms directly or by reducing their resistance to disease-causing agents in their habitat. There is evidence that a herpes-type virus in oysters may kill them if they are removed to an environment warmer than they were accustomed to. Many chemical agents have a direct effect, causing genetic damage, physiological malfunctioning, or various kinds of tumors. Chemicals may interfere with vision or the sense of smell important in reproduction or migration.

RED TIDES AND ANOXIA

Not all of the biological events which occur in the sea that are calamitous from man's point of view are due to our interference. "Red tides," for instance, which are periodic blooms of certain planktonic algae that make inshore fish and shellfish poisonous for us to eat, have not been clearly tied to pollution or other human disturbance of the habitat. These eruptions on shoal water fishing grounds occur, it appears, when strong offshore winds coincide with blooms of these toxic algae in their normal deepwater environment. The wind blows surface water away from the coast, and this is replaced by deeper water together with the algae it contains: a manifestation of the "upwelling" process (see page 9).



To take another case, periodic large-scale deaths of fishes and benthic animals (most recently in the New York Bight in 1976) have been traced to anoxia: abnormally low levels of dissolved oxygen in the water. Because decomposition of sewage consumes large quantities of oxygen, it was first supposed that sewage pollution was the cause of these kills. But an unusual combination of wind and weather seems to have been mainly responsible; the water became stratified, and the free diffusion of oxygen into deeper layers was prevented.

There are plenty of disturbances in the marine ecosystem which can be correctly blamed on pollution, but in these two cases that would have been wrong, and an attempted cure based on that diagnosis would have been wasted effort.

Investigations of the relationship between disease and possible causative agents are carried out both in the laboratory and the field. Diseased states can be produced in the laboratory under controlled conditions, while in the field, high incidence of diseased organisms can be correlated with measures of environmental quality. The problem in the second case is to sort out the specific causes, because they may be complex, and might have had their damaging effect at some earlier place and time in the organism's life history. Many sublethal effects can be particularly hard to detect. Fish, for example, may appear quite normal as they are dumped on the deck of a trawler, but they may have been damaged in subtle ways (in their reproductive capacity perhaps), which have serious implications for the population.

Laboratory studies are useful and necessary because they are the only way we know to test one by one, or in relatively simple and controllable combinations, the effects of influences which we suspect to be significant. Extensive winter kills among summer flounder, for example, have been shown by laboratory experiment to be due to a combination of cold temperature and infection by a blood parasite. Similarly, tumors in clams result from the combined effects of a viral agent and stress; the stress can be induced in different ways: by preventing the clam from burying itself in the bottom, for instance, or by exposing it to petrochemicals.

The drawback of lab studies is that in their simplicity they may bear only a remote relationship to what happens in the natural environment, because in practical terms all of the variables which operate in that environment cannot be reproduced. Among such variables is the behavior of organisms, which may be most "unnatural" in the lab, and which in nature can provide a "microenvironment" for a wild animal which can be very different from what we suppose it to be when we measure average conditions.

Explaining such apparent contradictions requires a careful combination of field and laboratory studies, which may involve exposure of test animals to physical and chemical stress and the study of their behavioral responses. In the laboratory, an animal given a choice may successfully avoid harmful conditions, but in the more complex natural environment, this behavior may not be sufficient for survival.

WHY FIELD STUDIES MUST BE BACKED UP BY LAB STUDIES

I. When given a choice in a laboratory tank between a bottom contaminated with oil at one end, and a clean bottom at the other, juvenile red hake avoid the oily bottom. From this alone, we might conclude that they would flee the area of an oil spill, and so save themselves. But in nature, these little hake are intimately associated with the sea scallop, hiding within the living scallop's shell secure from predators. So strong is this tendency that the young hake will choose shelter on a contaminated bottom rather than exposure on a clean one. Thus the initial conclusion about self-protective behavior, when tested in the more complicated circumstances of nature, proves to be wrong.

II. Certain clams respond to oil-contaminated sand by burrowing upward to cleaner surface layers of the bottom. This would appear to reduce their danger from chemical contamination, and it does. But it has been shown in field studies that what they gain in protection from the oil by this behavior they may lose by exposing themselves to predators. Again, to determine the effect of a pollutant on a species, mere exposure to it is not a sufficient test; a spectrum of ecological interactions must be taken into account.

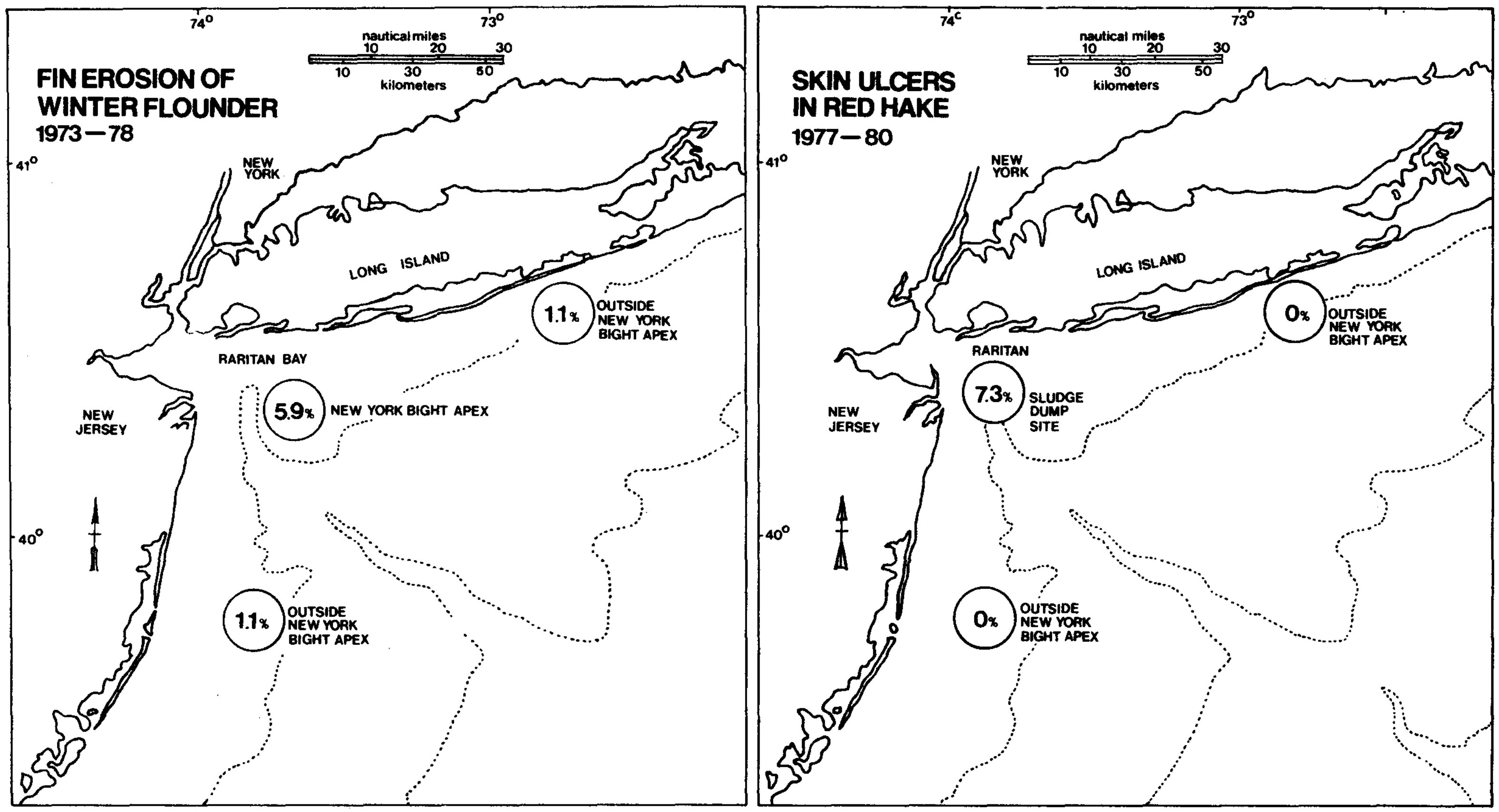
So far, we have been looking at disease and pollution, and the way in which these factors may interact. Once this interaction is understood, population variability and the incidence of disease can be viewed together as a sensitive indicator of pollution. This approach is important because ultimately it is the biological effects of pollution that concern us economically; pollutants are so widespread and various in kind and concentration, and there are so many possible ways in which they can interact, that without evidence of biological effects to point the way, it would be most difficult to decide where to direct finite resources for investigation.

The geographic distribution of three types of disease: "fin-rot," skin ulcers, and deformities of the skeleton, have been useful in this respect. The accompanying maps show the distribution of two of these diseases in the New York Bight, where the association of the problem with the principal pollution source is plain to see.

Once the distributions of these "biological effects" of pollution are mapped in more detail than at present, it should be possible to correlate them with data gathered by other means on transport of pollutants. If we know where the biological effects are serious, and how the causative agents got there, we may be in a position to alter the way in which we introduce these agents and so reduce their harmful consequences.

Conditions at the so-called 106-mile dumpsite in the Middle Atlantic Bight off New York may be right for such an approach to waste management. Infrared photographs made by satellites (see "Electronic Tools. I. Remote Sensing," page 12, and frontispiece) show that continental shelf water extends over the dumpsite about one-third of the time each year, where it may absorb about 200 thousand tons of hazardous material into an ecosystem of great importance in fish production. The fact that the shelf water does not always extend to the dumpsite suggests an alternative to regular, year-round dumping there. Dumping could be tailored to the distribution of water masses in time and space. Oceanic processes are slow enough, and overflights of satellites frequent enough, to permit such a flexible and reactive system of disposal. The eddies that pinch off from the Gulf Stream as it meanders through the 106-mile dumpsite might serve to carry waste material away from the shelf, diluting it in the process.

We are favored with productive water, open at its edges to influxes of nutrients which fertilize our harvest, but open, also, to countervailing poisons which we hope the sea will absorb. The open ocean has not yet given us a clear-cut example of its irreversible vulnerability to our practices, but some of its larger tributaries threaten to do so, and these are big enough in geographical extent to warn any sensible observer that to throw something into the sea is not necessarily to throw it away (see "The Poisoning of the Baltic," page 59).



Incidence of two diseases of fish in the vicinity of the New York Bight.

EPILOGUE

> *A systematic plan of inquiry was therefore drawn up...a series of questions was devised, answers to which, if satisfactory and complete, would leave little room for future inquiry. These...include queries in reference to the local names of each kind of fish, its geographical distribution, its abundance at different periods of the year and in different seasons, its size, its migrations and movements, its relationship to its fellows or to other species, its food, its peculiarities of reproduction; also questions relative to artificial culture, to protection, diseases, parasites, mode of capture, and economical value and application--eighty-eight questions in all, covering the entire ground.*
>
> *S. F. Baird, 1873*

Spencer F. Baird was a man of vision, and if he foresaw prompt answers to his eighty-eight questions, he was an optimist as well. For more than a century after he posed them, many of his questions hold the attention of modern fisheries investigators, and many new questions have been added to his list.

Given time to catch up with developments, Baird would doubtless feel at home in a fisheries laboratory today or on the deck of the ALBATROSS IV. He would see that enormous progress had been made, that the underlying cycles which bring scup into our coast when the dandelions bloom had been largely explained. But there are problems addressed now which he could not have set out to solve. Even had he guessed at the great scale and complexity of ecological patterns in the sea, the data-gathering and computational power now at hand for investigating them must in Baird's day have been unimaginable. Unforeseen, too, would have been the extent of man's influence on the oceanic system.

Baird might today blush a little at having once supposed some of his questions answerable with the tools he had to use, but his achievement needs no apology. Before the term was coined, he built for fisheries ecology a framework which his successors still depend upon as they make clearer in each generation the governing processes in the ocean. And he would endorse the reason for continuing this work, for it was his own: to insure for each generation its share of the ocean's yield.

EVERYBODY IN THE CENTER AND SOME OUTSIDERS AS WELL PROVIDED MATERIAL AND HELP TO PREPARE THIS DOCUMENT. IN THE LAST ANALYSIS IT WAS MADE COHERENT BY MR. DONALD W. BOURNE, AN INDIVIDUAL WITH CONSIDERABLE KNOWLEDGE AND EMPATHY FOR THE FISHING INDUSTRY, MANAGEMENT PROBLEMS, AND THE WORK THAT IS NECESSARY TO GET ON WITH THE BUSINESS AT HAND.--RLE