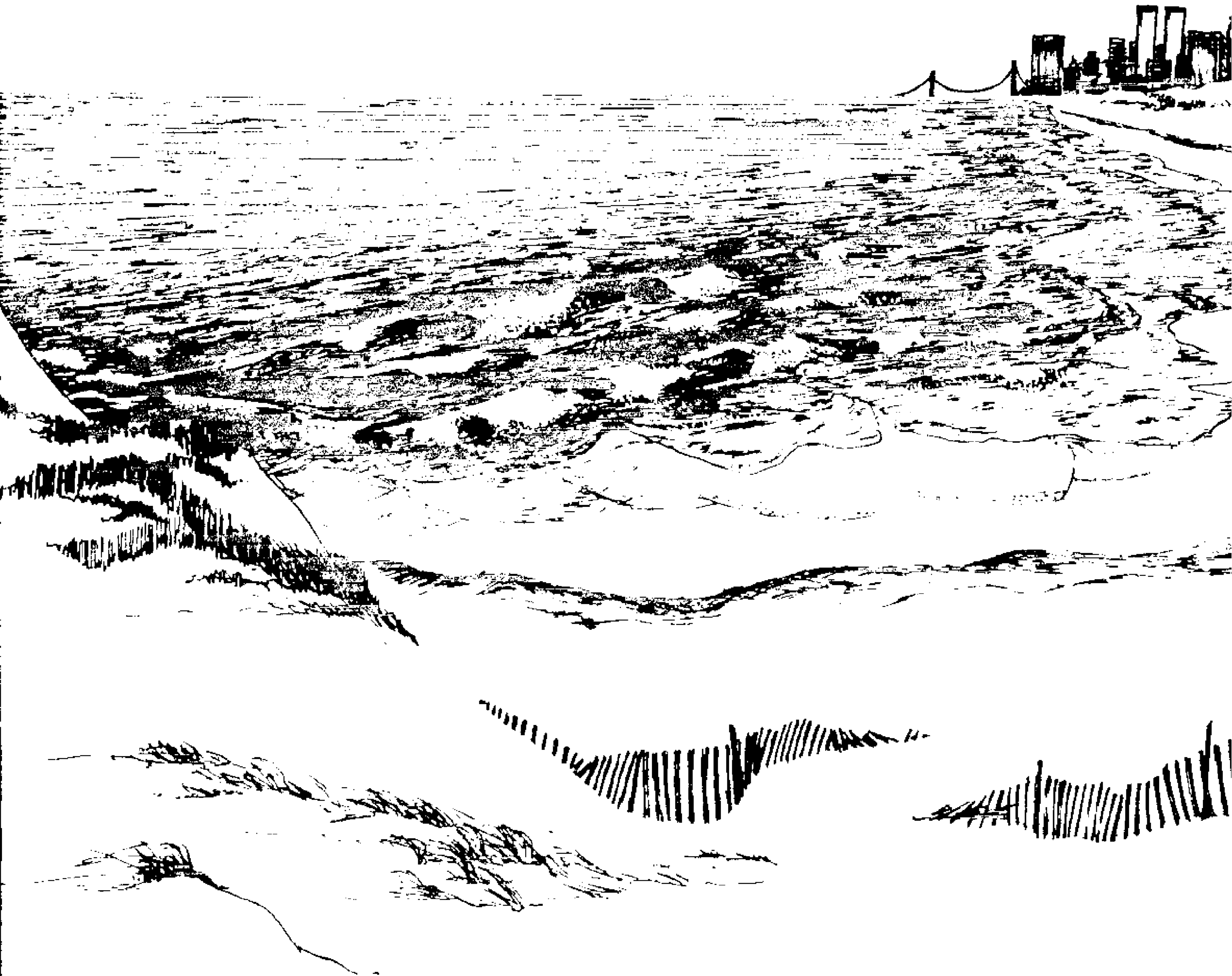
Aquaculture

Orville W. Terry



MESA NEW YORK BIGHT ATLAS MONOGRAPH 17

The offshore water in the bend of the Atlantic coastline from Long Island on one side to New Jersey on the other is known as New York Bight. This 15,000 square miles of the Atlantic coastal ocean reaches seaward to the edge of the continental shelf, 80 to 120 miles offshore. It's the front doorstep of New York City, one of the world's most intensively used coastal areas -for recreation, shipping, fishing and shellfishing, and for dumping sewage sludge, construction rubble, and industrial wastes. Its potential is being closely eyed for resources like sand and gravel—and oil and gas.

This is one of a series of technical monographs on the Bight, summarizing what is known and identifying what is unknown. Those making critical management decisions affecting the Bight region are acutely aware that they need more data than are now available on the complex interplay among processes in the Bight, and about the human impact on those processes. The monographs provide a jumping-off place for further research.

The series is a cooperative effort between the National Oceanic and Atmospheric Administration (NOAA) and the New York Sea Grant Institute. NOAA's Marine EcoSystems Analysis (MESA) program is responsible for identifying and measuring the impact of man on the marine environment and its resources. The Sea Grant Institute (of State University of New York and Cornell University, and an affiliate of NOAA's Sea Grant program) conducts a variety of research and educational activities on the sea and Great Lakes. Together, Sea Grant and MESA are preparing an atlas of New York Bight that will supply urgently needed environmental information to policy-makers, industries, educational institutions, and to interested people.

ATLAS MONOGRAPH 17 looks at the status and future of aquaculture in the New York Bight area. The severity of urban-related environmental problems in the Bight need not always have a negative impact on aquaculture; more rational management of urban wastes and of land use could create a mutually beneficial interaction between the aquaculture industry and other Bight activities. Terry sees the possibility of aquacultural expansion in many areas: advanced hatchery technology for finfishes and crustaceans; extensive ocean ranching of finfishes; and kelp farming. Although these advances currently depend mostly on economic considerations, long-term expansion of aquaculture will also be influenced heavily by water pollution and legislative controls.

Credits

Frances Richardson monograph editor
April Shelford and Kathleen Grove cartographers
Graphic Arts, SUNY Central Administration composition and pasteup
SUNY Print Shop printers
Mimi Kindlon cover and text design

Staff and Consultants

Editorial Board

Marine EcoSystems Analysis [MESA] Program
MESA New York Bight Project

Aquaculture

Orville W. Terry

MESA NEW YORK BIGHT ATLAS MONOGRAPH **17**

New York Sea Grant Institute
Albany, New York
June 1977

Orville W. Terry, PhD, is an adjunct associate professor at the Marine Sciences Research Center, Stony Brook, and an adjunct faculty member, Empire State College, State University of New York. Dr. Terry's research interests include aquaculture, marine algae, tidal wetlands ecology and management, and environmental management. He is a member of AAAS, World Mariculture Society, American Fisheries Society, Marine Technology Society, American Society of Agricultural Engineers, New England Estuarine Research Society, and Phycological Society of America. Dr. Terry is also a former science editor at New York Sea Grant Institute.

Contents

Maps

Tables

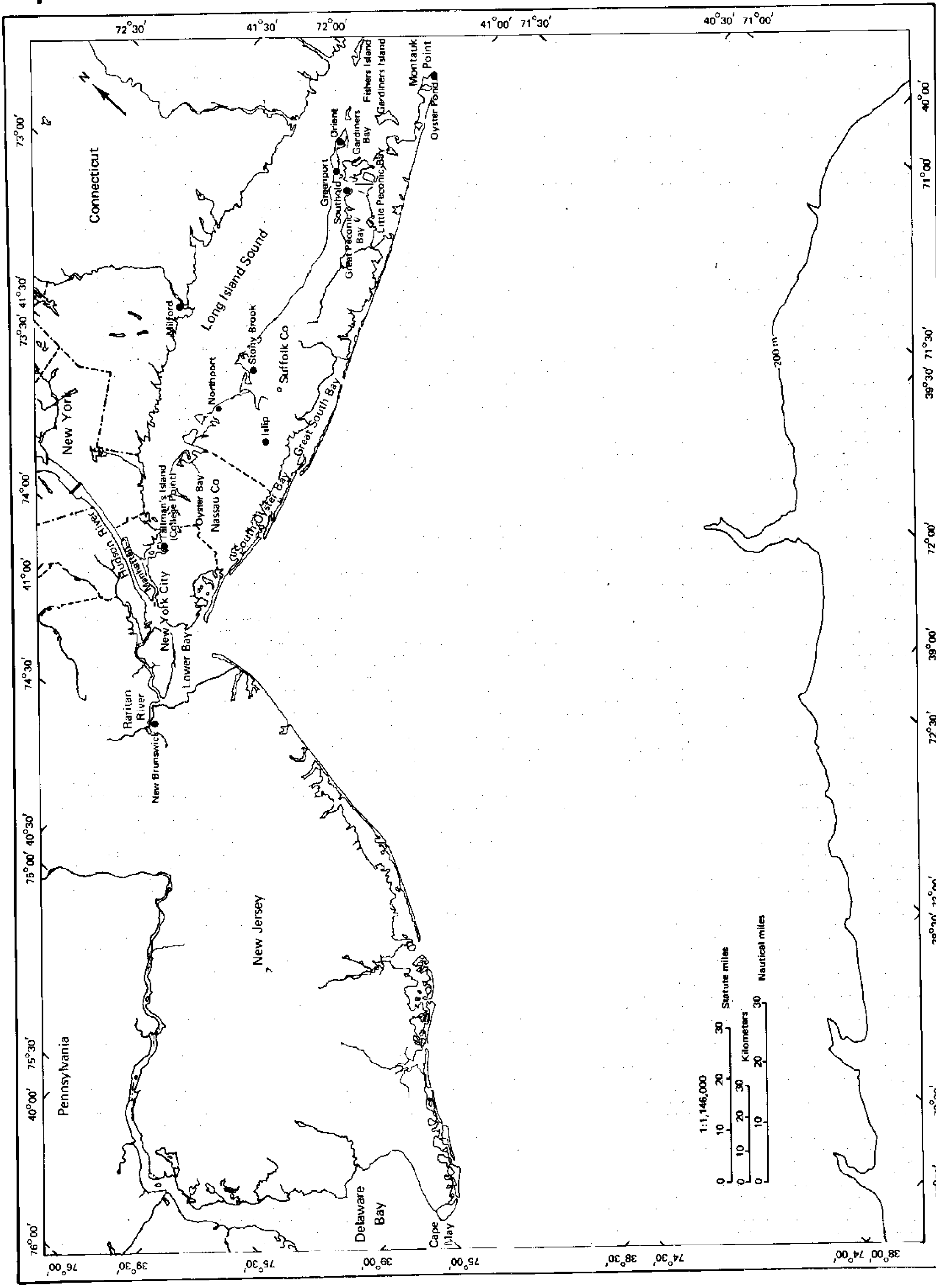
Figures

Acknowledgments

Far more people contributed to the writing of this paper, through publications and personal contacts, than can be listed here. A singling out of the most helpful would be difficult besides implying that others were less generous or knowledgeable. The author has received research support from New York Sea Grant Institute with continuing advice and help from its director Donald F. Squires. The institute's assistance made possible most of the contacts and study without which the monograph could not have been attempted. It has been a real and continuing pleasure to work with so many of the individuals who are making aquaculture a present reality as well as a dream of the future.

Manuscript accepted October 1976

Map 1. Locator



Transverse Mercator Projection

Abstract

The oyster industry, probably the earliest form of American aquaculture, has a long and important history in the various inshore waters adjoining New York Bight. With the introduction of modern technology the future of oyster production is now promising despite the industry's recent difficulties. Similar advances are also beginning to be accomplished in hard clam culture. These in time will undoubtedly lead to commercial aquaculture of other regionally important marine species. In its traditional nearshore location, the aquaculture industry will have to meet ever-increasing pressure from competing uses. But as water pollution is controlled, additional space for aquaculture may well become available. Stricter environmental protection will sometimes work to constrain aquaculture as well as to promote it, but the overall balance promises to be favorable to the industry.

The greatest long-term potential for Bight aquaculture probably lies in sharing worldwide progress toward novel high-technology systems just now beginning to be seriously considered—offshore or open sea mariculture. The opportunities these developments present for augmenting world food and energy supplies are truly revolutionary, although much research and design work is still necessary. The Bight has unique advantages for this kind of aquaculture, which might serve to turn some of the Bight's presently most intractable waste disposal problems into resources through recycling.

Introduction

This monograph is characterized by its frank emphasis on the future—not merely what New York Bight aquaculture is today but what it could become. Aquaculture is a growth industry and ought to be treated as such. In a world of present and impending shortages aquaculture's potential for vast expansion is crucially important. Admittedly no one knows how much of that potential can be actually realized, or how soon, but it can hardly be ignored.

At the same time there is ample justification for the kind of skepticism that various authorities have expressed about aquaculture's more immediate outlook. Mainly it arises from well-founded doubts regarding economic feasibility. Yet enormous progress is being made; there are success stories, some of them from the Bight region. The Bight's urban-related environmental problems are now having a severe impact on aquaculture, but this need not always be a negative impact. With more rational management of urban wastes and of land use the interaction could increasingly become one of mutual benefit. In an ever more crowded and interdependent world the present American trend toward separation of rural food production from urban food consumption cannot continue indefinitely. The Bight is a good place to look for ways to reestablish a more ecologically sound relationship.

Aquaculture, or, in seawater, mariculture, has been defined as "the growing of aquatic organisms under controlled conditions" (Bardach, Ryther, and McLarney 1972). By analogy agriculture might be called "the growing of terrestrial organisms under controlled conditions." Like the land farmer, the aquatic culturist tries to improve the yield or quality of his crop by changing its native wild heredity or environment—sometimes slightly, sometimes drastically. Although farming in water is certainly different from working on land, the basic skills and sciences required to produce a crop are much the same. Aquaculture would benefit from a closer relationship with agriculture than has so far evolved in the United States.

The distinction between aquaculture and fisheries is sometimes fairly minor but still quite definite. A fishery is the hunting of wild organisms in the sea, or in fresh water, whenever and wherever they can be found and successfully collected. Just as game management and regulation improve hunting on land, fishery science and management seek to improve aquatic hunting. Two ways of doing this are to 1) develop better technical methods and equipment for fishermen, and 2) accumulate knowledge about target species and their role in the aquatic ecosystem. The latter kind of information, increasingly essential to successful fishing, begins to make possible the regulation and management of fisheries for maximum overall human benefit, whether measured simply as optimum sustained yield of a particular species or a part of some more general measure of ecosystem productivity. All such efforts are mainly concerned with harvest of a naturally recruited and naturally growing resource. The obvious next step is to aim the actual growing of the anticipated crop in some preferred direction. This is aquaculture.

The objectives and methods of aquatic culture can be classified from various perspectives. The simplest is along a spectrum of culture intensity, based on the physical means by which the crop is contained. When the culture site is an outdoor area with limited environmental control, such as a pond or oyster bed, the operation is called an *extensive* culture. The main advantage is lower cost, the main disadvantage is relative lack of control. An *intensive* culture site could be a tank or perhaps a silo, of much smaller volume but with considerably better control of conditions inside. Because of more effective control, and higher cost, the density of crop organisms in an intensive culture is usually greater than in an extensive one.

The characteristics of the organism and a multitude of other circumstances influence the choice of culture intensity at any particular time and place. Often different stages of a single crop's life cycle are cultured under different conditions—one stage may be intensive, another extensive. For example, oysters may be carried through their early stages in a modern

Figure 1. Modern oyster hatchery, Long Island Oyster Farms, Northport, LI (Courtesy of Long Island Lighting)

hatchery under intensive culture conditions (Figure 1), then moved to outdoor beds for growth to maturity (extensive). Salmonid fishes can be moved from the hatchery (Figure 2) to either silos or cages (intensive) or be released for ocean ranching (extensive). In general, early stages of an organism's life cycle are more likely to be cultured intensively. This approach is aimed at reducing the naturally high early mortality of most marine organisms. Such a partial intensive culture is also more economically feasible because the early stages require less space and food.

Aquatic organisms are as dependent on water quality as air breathers are on fresh air. Extensive culturing depends on natural water exchange, tides, currents, or stream flow, to remove toxic wastes and to bring in fresh supplies of dissolved oxygen, waterborne nutrients, and natural foods. As a culture becomes more intensive, the increasing concentration of crop organisms usually makes artificial water exchange necessary. A system using some large natural water body as its reservoir, from which new water is constantly drawn and to which "used" water is returned, is called an *open* or flow-through (intensive) system. A *closed* or recycling system, in contrast, restores the quality of the used water by sending it through a filter or series of filters, from which it is returned to the culture for reuse (Figure 3). Each method has important advantages, some economic, others biological; various intermediates or combinations of these methods can be developed. Almost all closed systems do, in fact, provide for some water replacement, since complete restoration of water quality by filtration is not practical or even possible outside the laboratory.

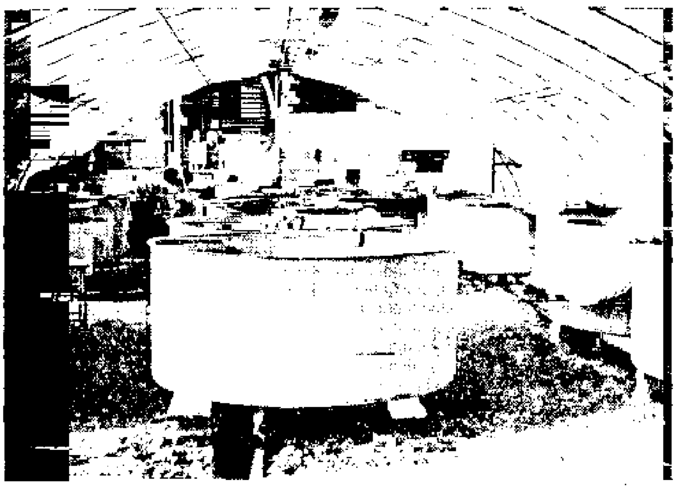
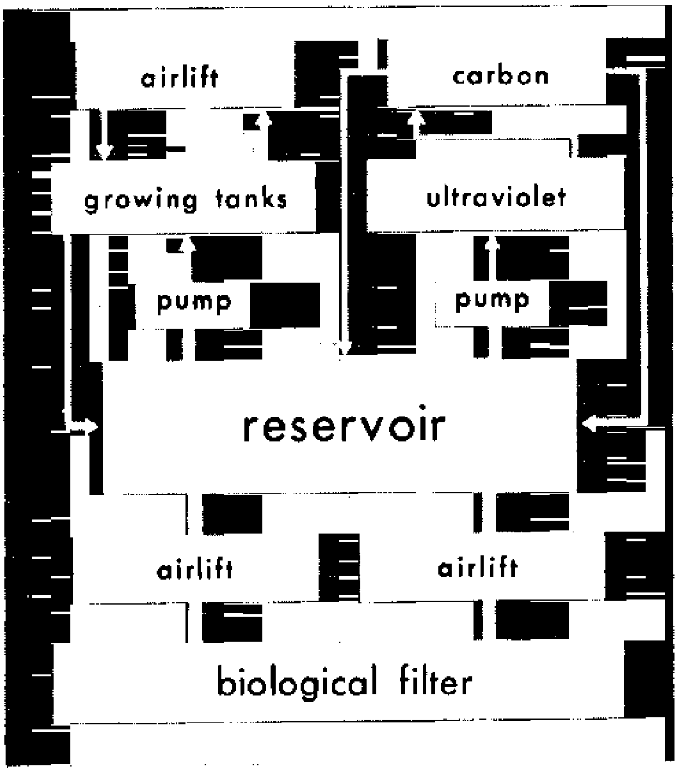


Figure 2. New Hampshire salmon hatchery containing fiberglass tanks in which salmon are raised from eggs (Photo by M. Taylor)

The Bight as Aquaculture Site

American aquaculture, like recent American agriculture, has so far been mostly a high-capital, energy-intensive, labor-saving enterprise, despite the occasional move in a different direction (*Aquaculture and the Fish Farmer* 1975*a*; *New Alchemists Journal* 1973, 1974; Gallese 1976). Under American conditions, and especially those of the Bight region, it is probable that the high-technology trend will continue, only partly for economic reasons. Involved are high prices for almost everything, competition for space on and near shore, and the technical difficulty of offshore expansion. Present aquaculture in the Bight is confined to the more sheltered bays and estuaries, from Long Island Sound on the north to Delaware Bay on the south. A great deal of expansion is physically possible in these areas, but there are also important constraints, mainly water pollution and legal-jurisdictional difficulties. Even if these current industry problems can be effectively disposed of in the future, major expansion will ultimately have to be toward the more open waters of the Bight proper. This will only be accomplished with major capital investments, whether private or public. When the profit opportunity—or the public need—becomes great enough, the investment will be made. Only the timing remains in much doubt.



Source: Epifano and Mootz 1976

Figure 3. Recycling culture system

New York Bight (see Map 1), not surprisingly, offers both advantages and disadvantages as a site for expanding US aquacultural production. The high degree of urbanization of its shorelines means high costs, competition for space and labor, and perhaps most serious, pollution. On the favorable side, urbanization provides markets, high technology, scientific leadership, and the chance for mutually beneficial interaction with various urban activities and services. The current status of aquaculture in the Bight region is not a good indication of its potential there; new technologies, both in culture and in pollution control, can make a vast difference over the years ahead. In the near term the rate at which changes actually come will depend mostly on economic considerations. Anything that makes aquaculture's product more valuable on the one hand or cheaper to produce on the other (or some combination of the two) will tend to expand production. Active support by government at all levels, frequently lacking at present, could also make a substantial difference in the rate of progress.

Significance of Aquaculture

It has become a common observation that American aquaculture is interested only in luxury foods for the rich, making it seem an unnecessary indulgence in an increasingly hungry world. This assessment is not only inaccurate but based on a misunderstanding of the role of price in a market economy. Catfish culture is a good example of large-volume output of a reasonably priced food. There is no apparent reason why culture of various marine species could not reach the same status in due time; none has to date mainly because not enough research and development effort has been invested. Oysters, however, were once a relatively cheap and common food. There are stories from colonial New England of local regulations to prevent masters from feeding their servants too frequently with lobster, which was then plentiful. Which species will constitute the inexpensive food of the future (if any) is impossible to predict. Part of the responsibility for slow development of aquacultural food production in this country lies with the fact that it must compete in the supermarket with a relatively cheap and abundant food supply from American agriculture. As this situation changes, in response to increased demand worldwide for agricultural products and to increased energy costs in producing them, the apparent "luxury food" status of American aquaculture will vanish. Aquatic foods will appear at competitive prices and in larger volume, perhaps pushing some agricultural products into the luxury-priced category.

Another common conception about aquaculture is that we still don't know how to culture marine organisms—that the problem is biological. In many cases this is only too true. For example, despite repeated attempts, no one has yet reported successful culture of the common squid (*Aquaculture and the Fish Farmer* 1975*b*). There are a number of finfishes and shellfishes whose culture has only recently been seriously attempted and many potential food species we know next to nothing about. On the other hand, a considerable body of knowledge does exist about culturing a few species (Bardach et al 1972). Most of these are already being commercially produced somewhere in the world today. Their culture was originally adopted simply because it was easy—and often relatively inexpensive. The oyster is a prime example. Other shellfish, like the American lobster, can be cultured successfully on a laboratory scale but the cost is still too high for commercial production.

Just how important is present-day aquaculture as a factor in world food supply? This is not an easy question to answer. There is no standard global definition for aquaculture; statistics-gathering and reporting methods are not uniform. What is called aquaculture in one country may be classified as part of fisheries or agriculture in the next. Private industry may not wish to release figures while public agencies could have an interest in slanting them one way or the other. As a result, no listing of world aquaculture

Table 1. Estimated world production through aquaculture in 1975

	Metric Tons
Finfish	**3,980,492**
China—all provinces excluding Taiwan Province	2,200,000
Taiwan, Province of China	81,236
India	490,000
USSR	210,000
Japan	147,291
Indonesia	139,840
The Philippines	124,000
Thailand	80,000
Bangladesh	76,485
Nigeria	75,000
Poland	38,400
Vietnam, Republic of	30,000
Yugoslavia	27,000
Romania	25,000
Hungary	23,515
USA	22,333
Italy	20,500
Madagascar	17,392
Germany, Democratic Republic of	16,000
France	15,000
Czechoslavakia	12,222
Israel	12,169
Denmark	12,120
Brazil	12,000
Germany, Federal Republic of	8,900
Sri Lanka	7,659
Egypt	7,000
Mexico	7,000
Malaysia	6,559
Zaire	5,000
Cuba	4,500
Hong Kong	4,019
Norway	3,500
Austria	2,500
United Kingdom	2,000
Finland	1,940
Belgium	1,800
Tanzania	1,500
Burma	1,500
El Salvador	1,208
Canada	1,103
Greece	900
Chile	800
Uganda	700
Singapore	680
Kenya	400
Nepal	400
Venezuela	332
Switzerland	300
Ireland	207
Korea, Republic of	169
The Netherlands	129
Ecuador	90
Central African Empire	43
Cyprus	40
Ghana	40
Zambia	29
Paraguay	23
Ivory Coast	10
Puerto Rico	9
Shrimps and Prawns	**15,663**
India	4,000
Indonesia	4,000
Thailand	3,300
Japan	2,779
Ecuador	900
Taiwan, Province of China	549
Singapore	105
Korea, Republic of	30
Oysters	**591,386**
Japan	229,899
USA	129,060
France	71,448
Korea, Republic of	56,008
Mexico	45,000
Thailand	23,000
Taiwan, Province of China	13,359
Australia	9,200
Canada	5,080
United Kingdom	3,000
Spain	2,289
The Netherlands	1,500
Chile	870
The Philippines	782
New Zealand	700
Senegal	191
Mussels	**328,517**
Spain	160,000
The Netherlands	100,000
Italy	30,000
France	17,000
Germany, Federal Republic of	14,000
Korea, Republic of	5,578
Chile	1,260
Yugoslavia	287
The Philippines	182
New Zealand	150
Tunisia	60
Clams	**38,851**
Korea, Republic of	24,920
Taiwan, Province of China	13,898
The Philippines	33
Scallops	**62,600**
Japan	62,600
Cockles and Other Molluscs	**29,987**
Malaysia (cockles)	28,000
Taiwan, Province of China	1,243
Korea, Republic of	733
The Philippines	11
Seaweeds	**1,054,793**
Japan	502,651
China—all provinces excluding Taiwan Province	300,000
Taiwan, Province of China	7,347
Korea, Republic of	244,795
TOTAL	**6,102,289**

Source: Pillay 1976

production would claim to be precise. The most comprehensive survey is the one assembled by the Food and Agriculture Organzation of the United Nations (Pillay 1976) and reproduced here as Table 1. The 6 million metric ton total (1975) constitutes perhaps 10% of world fishery output (Food and Agriculture Organization of the United Nations 1974). Pillay anticipates a doubling of world aquaculture production in the next decade, based on present technology. Since it appears certain that improved methods will be developed in 10 years, a much greater expansion is probable. It appears unlikely that fishery production will increase at this rate over the same period.

Fish Culture

Historically, two now-traditional aquacultures were probably the first to become significant. These are oyster culture and pond culture of fresh- and brackish-water fishes. Fish culture in the Orient may have been established as early as 1200-1400 BC on the island of Java in the East Indies (Nelson 1971). From there it likely spread to the mainland of Asia and eventually to Europe. Trout, salmonid, and catfish culture in the United States are relatively recent. Nelson estimates that of the 3 million metric tons of finfish produced through aquaculture in 1971, 80% was in the Far East (see Table 1). In this country the original initiative arose from a need to replenish depleted stocks of native fish species, as mainly sport fisheries. Hatchery technology, originally developed to grow fingerlings for release (in fishing streams), provided the foundation from which culturing to market maturity evolved. Farming of salmon (Figure 4) and trout, as well as catfish, is now a well-established, viable industry in the United States.

Bivalve Culture

From oyster culture came the beginnings of culture enterprises for other bivalves, including that of the blue mussel (*Mystilis edulis*). Mussel culture in Spain is relatively recent but now seems to have become well established. The quantity of meat produced per unit area on ropes suspended from rafts is legendary in the aquaculture industry. Transplantation of the Spanish technology to the United States is being actively attempted (Hurlburt and Hurlburt 1975), but substantial production has yet to develop here. However, hard clams (*Mercenaria mercenaria*) are being cultured commercially on Long Island, and culture of the bay scallop (*Argopecten irradians*) is close to being economically feasible (Castagna and Duggan 1971).

Crustacea Culture

Shrimp. The other major group of invertebrate marine food organisms, the Crustacea, are natural candidates for marine farming, but their culture has encountered many problems. In Japan, shrimp have been grown successfully in tanks, on a relatively large scale, but apparently this is economically feasible only because of a Japanese preference for buying live shrimp. This demand cannot be satisfied from fishery harvests. Shrimp farms exist in other nations, including the United States, but have yet to establish their commercial profitability.

Lobster. The history of lobster (*Homarus americanus*) culture is short but colorful. Looking back over that history, it seems likely that efforts will be made to grow in captivity this king of American seafoods. Lobster prices have become almost astronomical in recent years, reflecting a diminishing supply in a rapidly expanding market. Long-established hatchery technology and annual replenishing of wild lobster stocks provided a foundation from which recent widely publicized attempts at farming lobsters to maturity developed (Hughes 1968). Unfortunately the problems involved turned out to be considerably more formidable than most of those concerned with lobster culture research had anticipated. Several major problems still remain essentially unsolved. Commercial lobster culture will eventually become feasible either when the market price rises enough to cover present high culture costs, or when further advances in lobster culture science and technology bring costs down. In other words, when there can be a reasonable expectation of profit (Klopfenstein 1975; *Fish Farming International* 1975*b*). The cost reduction route looks more probable (Rutherford 1973), but is far from assured at this time.

Aquatic Plant Culture

Plant growth is the foundation of virtually all terrestrial food chains, and as far as the human diet is concerned, often their entirety. We simply eat the plants. But the marine organisms we customarily eat are almost all animal. Partly because marine plants are so different in character from land plants, most societies seldom think of them as foods and even tend to overlook their role in primary productivity. Such attitudes are due for a change in future years.

The preponderance of marine primary production comes from microscopic phytoplankton, mainly visible to human eyes only as occasional toxic "red tides." Only limited use has ever been made of phytoplankton cells directly as human food, although many species can be cultured and are routinely used as food for cultured bivalves (Bardach et al 1972). These microscopic plants appear in fact to have an enormous undeveloped potential as cultured crops for a variety of food-related and nonfood uses.

Large benthic seaweeds also have interesting possibilities and these are being at least partially exploited. Japan, China, and Korea use substantial quantities of seaweeds in their national diets and now culture a major fraction of these requirements (Table 1). The idea of seaweed culture is just beginning to be taken seriously in other countries, including the United States. One intriguing aspect of seaweed farming is the sheer scale of its potential for expansion. If we can artificially provide—and this is still a large "if"—two requirements, a supporting artificial substrate and an adequate supply of the major plant nutrients, we should be able to grow seaweeds over a significant fraction of the earth's water surface.

The possibility of a major expansion of the world's food and energy supply through the use of the ocean surface for farming seems quite real though certainly not yet generally recognized. At present only coastal (and inland) aquaculture of finfishes and bivalve mollusks make a really important contribution to world food supplies (Table 1). Sea plant and crustacean cultures are still far behind and only beginning to be significant. Yet all have a tremendous potential for improvement based on research and technical development. Together they constitute one of the most promising avenues toward expanding the world's food base (Hanson 1976). If world population control is not effective, and there is little indication that it will be, our descendants could find aquaculture as essential to human survival as ordinary agriculture is today.

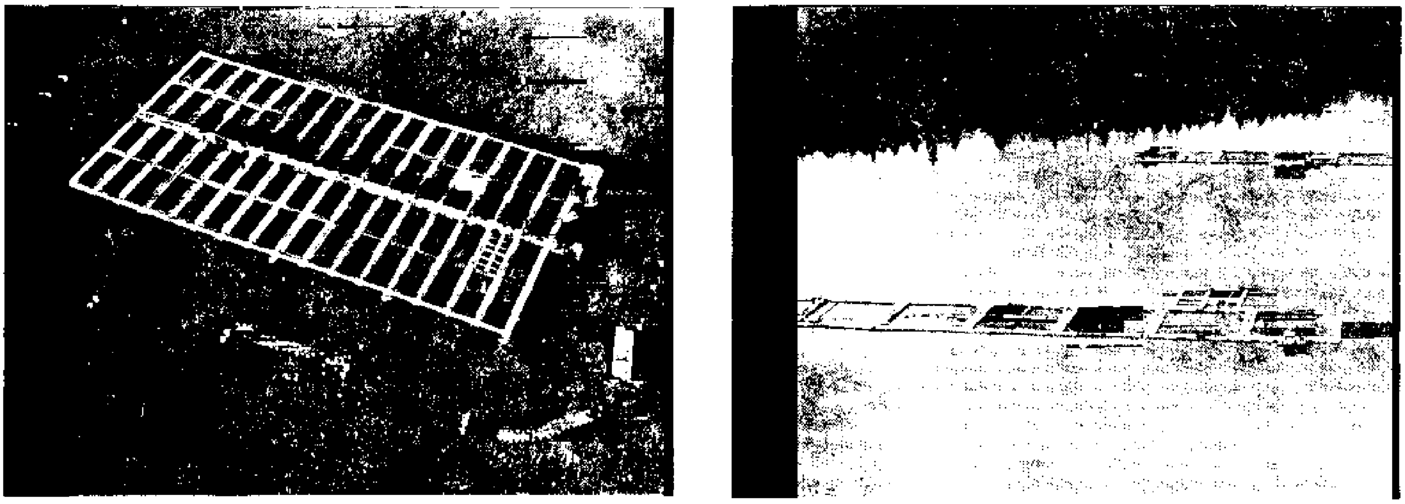


Figure 4. Cage (net) culture facilities of salmonids in Puget Sound (Courtesy of National Marine Fisheries Service, Northwest and Alaska Fisheries Center)

Oyster Aquaculture

Of the various marine resources harvested from the Bight region, only oyster production is as yet based entirely on aquaculture. The industry there is now slowly recovering from its near-collapse in the late 1950s and 1960s (Table 2). Total 1975 oyster production in the Bight's tri-state region is estimated at 1,642 metric tons of meats (McHugh and Williams 1976). Most of the seed (young oysters) used is still of natural origin and wild parentage, though it is exposed to a sequence of culture operations before reaching market. Without this human intervention—which even today still consists mainly of moving the oysters about on the bottom for better growth and of controlling natural predation—harvests would be very much smaller.

Dependence of the oyster resource on aquaculture is not, of course, the way things were originally. At the time of the earliest European colonization there is reported to have been an abundant natural supply of native oysters along the coasts of what we now call New York Bight. They were an important food for the colonists, as they undoubtedly had been for previous Indian residents. Many early reports stress the size and number of oysters then found even around Manhattan Island, where they continued to be harvested for many years (Kochiss 1974). Various local place names are evidence of this natural bounty—Oyster Bay, LI (where cultured oysters now grow), Oyster Ponds, LI (now Orient, and virtually oysterless), and many other water bodies called Oyster

Table 2. Production of oysters, New York landings

	Oyster, American (metric tons)			Oyster, American (metric tons)	
Year	New York	New Jersey	Year	New York	New Jersey
1880	3,313	6,271	1948	3,153	2,716
1887	6,306	8,318	1949	3,690	3,214
1888	6,037	8,016	1950	3,986	3,285
1889	6,635	3,382	1951	4,256	2,613
1890	7,464	3,609	1952	2,958	3,626
1891	8,290	3,486	1953	1,286	3,848
1892		3,650	1954	775	3,324
1897	6,151	4,330	1955	614	2,361
1901	5,616	6,643	1956	485	2,496
1904	9,108	4,157	1957	484	1,234
1908	5,872	2,920	1958	479	376
1921	4,274	5,011	1959	404	94
1926	3,232	5,083	1960	367	76
1929	4,169	7,042	1961	357	499
1930	4,202	5,364	1962	330	705
1931	3,027	6,533	1963	179	234
1932	2,284	3,885	1964	97	498
1933	2,763	3,453	1965	91	237
1935	2,616	3,838	1966	80	315
1937	4,438	2,070	1967	46	466
1938	4,630	2,630	1968	79	599
1939	2,845	2,312	1969	97	480
1940	3,206	2,695	1970	235	303
1942	2,903	2,504	1971	353	385
1943	2,996	2,732	1972	504	778
1944	3,237	2,558	1973	631	634
1945	2,301	3,514	1974	705	458
1946	2,626		1975	956	441
1947	2,624	2,655			

Source: McHugh and Williams 1976

Pond, like the one near Montauk Point, LI. Significant quantities of naturally recruited mature oysters, however, are no longer found in the Bight region. The history of the oyster industry over the years is one of gradual replacement, mainly during the nineteenth century, of a natural crop by a cultured one. The reasons for the change are complex, though they undoubtedly include both overfishing and pollution, as well as technological advances. The result: oyster *fishing* has become unrewarding, but oyster *culture* remains economically feasible as an industry.

The American oyster (*Crassostrea virginica*) is almost uniquely adapted for easy aquaculture. In nature, mature oysters lying on the sea bottom are stimulated by summer temperatures to release their eggs or sperm into the surrounding waters. The eggs are fertilized in suspension and the larvae float, later swim, free in the waters, for up to several weeks. During this period the larvae are extremely vulnerable to predation by zooplankton, to being stranded on the beach or washed out to sea, and to destruction by storms and other unfavorable environmental conditions. The tiny fraction that survive eventually attach themselves, or *set*, on almost any available solid surface and, if conditions happen to be favorable at that spot, they grow over a period of years to adult size. They can also be dredged up by man and moved en masse to some other location. If this is carefully done, there is only slight risk of damage in transit. The crop can be moved from a setting area to a growing area, or succession of growing areas, and finally to a *fattening* ground as it matures. All this moving is not, of course, done at random. Conditions in the various areas are not the same, and different growth stages have been found to proceed best in different locations. The entire sequence, or any part of it, can even be carried out in indoor tanks, for more complete control of growing conditions (Maurer 1973).

Local versions of oyster culture, which are found throughout the world, have often been practiced for centuries. Each version has been developed through experience and observation to capitalize on a particular set of local conditions, although there are many common features. According to Kochiss (1974), the earliest beginnings of an oyster culture enterprise in the Bight region occurred sometime after 1820, on the Connecticut side of Long Island Sound. It consisted of moving young seed oysters from good setting grounds, where natural recruitment

Figure 5. Set of juvenile oysters attached to the inside of an old oyster shell (Photo by A. Longwell)

of set occurred, to good growing grounds, where the juveniles were observed to mature more successfully. The next refinement was to plant clean oyster shells on the bottom in setting areas at times when the naturally-produced oyster larvae in the water column could set upon them (Figure 5). The shells with attached young oysters could then be readily moved to other locations as desired. With increasing experience the methods for harvesting and distributing were gradually improved and have now become highly mechanized. Techniques have been developed for predator control, both mechanical (mop-like devices dragged over the beds to entangle starfish) and chemical (quicklime and other toxic materials that can be broadcast to kill starfish and drills). Only in the last couple of decades have more sophisticated hatchery methods for the production of oyster seed been widely adopted here, the first major break with traditional practices in the industry.

Jurisdiction Over Oyster Grounds

Oysters began to be cultured because there was a ready market for the crop and the cost of culture was low enough to permit price competition with the wild product in that market. Another very important factor quickly became involved, however: the question of ownership or private control of the sea bottom where culturing takes place. Marine resources, including wild oysters, have traditionally been regarded as common property—belonging to whomever was able to harvest them. Under English, and by derivation American, common law the seabed itself below high water mark belongs to the people, being held "in trust" for them by the Crown (federal government), the state, or a local jurisdiction, as the case may be (Kane 1970). The same is generally true of fishery resources, though not necessarily of sedentary shellfish when actually planted by an individual. These would still be considered the planter's private property (Kavenagh, personal communication; Matthiessen and Toner 1966), but he might expect considerable difficulty in defending such rights (Hanson 1974) especially if any naturally recruited shellfish were also present. No private planter would be likely to invest heavily in planting and cultivating an undersea crop unless he could be sure of exclusive rights to the harvest. Some resolution of this problem was absolutely necessary before oyster culture could progress far. Either the planting would have to be accomplished by socialist principles—at government expense and for the use of all—or private rights to oyster grounds would have to be recognized. Historically, the second alternative was generally adopted; by the mid-1800s the states adjoining the Bight had passed laws under which grants and leases of underwater tracts were made to individuals (Kochiss 1974). Most of these laws are still in force. Today's economists commonly support the concept of a lease system because of its greater efficiency and overall productivity (Agnello and Donnelley 1975, 1976). Each of the three states surrounding the Bight developed its own pattern of jurisdiction; New York has the most complex system.

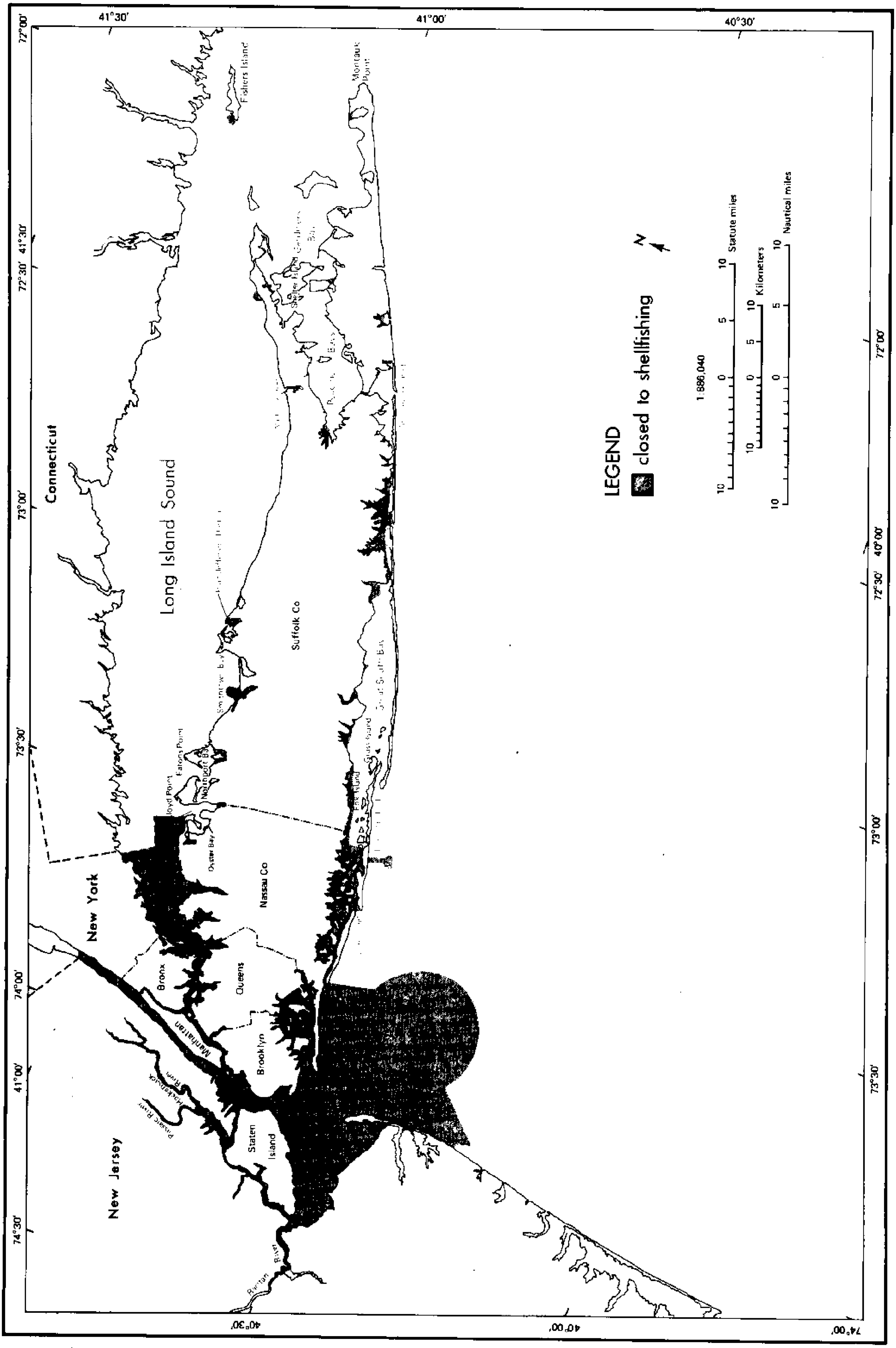
New York Laws. The underwater lands in New York's part of Long Island Sound are under the direct control of the NYS Department of Environmental Conservation (NYDEC) for leasing purposes, but with the restriction that no significantly productive natural shellfish beds may be leased to private individuals. Actually, no leases in the sound have been granted in recent years mainly because of opposition from individual harvesters who wish to retain public access. A citizen's committee has recently been formed to assist the NYDEC in drafting rules and guidelines for leasing and lease management. The state leasing system does not extend to all of New York's shellfish grounds. Jurisdiction over the Peconic and Gardiners bays for this purpose has been assigned to Suffolk County by the state legislature (Chap. 990 of the NYS Conservation Law of 1973). At present the county is engaged in developing methods to precisely locate and map boundary lines for leases in these bays. Old maps of previously leased or granted plots are not considered accurate enough for current needs, even though some of the old grants to private individuals remain in effect and some grounds are still being used for growing oysters.

A different system of jurisdiction applies to the Great South Bay complex of southern Long Island. Here ownership of bottom lands, traced to early colonial grants, is now divided among the several town governments and a private shellfish firm. In one township—Islip—some areas are leased for private aquaculture, mainly of hard clams rather than oysters. The balance is open for public harvest, under rather specific ground rules and a license system. The privately owned grounds are used by their owners for culturing purposes.

It should be noted that all these jurisdictions permit harvest for market or home use only on condition that the waters at that location are of approved quality. Essentially all the waters closely surrounding metropolitan New York City are closed to shellfish harvesting (Map 2) under federal/state regulations, thus, *not* approved, because of a high incidence of coliform bacteria. When water quality, as measured by bacteria levels, does not meet prescribed standards, the law bans shellfish harvest from grounds beneath that water, except in special situations where the shellfish are to be placed in clean water for *depuration* (self-cleansing) and later reharvest (Russell 1974). Many areas around other population centers in the three states are also closed. There is long-standing controversy over the details of the testing procedure involved in closing these areas. Many clammers feel the present standards are unreasonably strict. It seems clear, however, that most of the closed areas are in fact sewage-polluted to some extent and that if shellfish from the closed areas were allowed to reach the market there could indeed be a threat to human health. How serious a threat this might be is in dispute. There is little doubt that clams from closed areas actually reach the market illegally, with no reported harmful effects on consumers. On the other hand, reporting procedures are probably less than ideal and may conceal existing problems.

Connecticut Laws. Connecticut's shellfish lands are controlled partly by the town governments and partly by the state (Kochiss 1974). Lands claimed by the towns on the basis of colonial grants are those close inshore, including coastal bays and estuaries. The state controls the grounds under its half of Long Island Sound proper. Some of the grants are perpetual so long as taxes are paid. Most are for a limited number of years (*Connecticut General Statutes* 1975). As in New York, naturally productive oyster beds may not be leased to a private interest, a provision which can obviously lead to some differences of opinion.

Map 2. Areas closed to shellfishing in the inner Bight



Transverse Mercator Projection

New Jersey Laws. The New Jersey situation is somewhat simpler: the State Shell Fisheries Council controls the leasing of all publicly owned shellfish beds. Much of the grounds, including some natural oyster seed areas, are privately owned. Of the total of about 400,000 acres of potential shellfish waters in the state (one-half in Delaware Bay), approximately one-fourth are now closed due to pollution (H. Haskin, personal communication). Present New Jersey oyster culture is based entirely on the use of natural seed relaid on leased beds for growth. Here, again "no exclusive right to natural beds" may in principle be granted (*New Jersey Statutes* 1975), but in practice apparently is in some areas.

Opposition to Leasing. Despite a traditional policy in favor of leasing publicly owned potential shellfish grounds for private culture, such leasing has encountered increasing opposition. At recent hearings on Long Island this opposition appeared to come mainly from individuals with a personal interest in harvesting the natural shellfish crop from public lands. This group has regularly opposed further leasing as a matter of principle even though the lands recently being proposed for lease have been, as required by New York law, *not* natural beds and *not* currently productive (Sammis 1976). In the past, a similar conflict was reported from Massachusetts (Matthiessen and Toner 1966). To what extent this attitude will affect the continued leasing even of established oyster grounds remains to be seen. It could lead to some difficult choices for regulatory agencies, under pressure from both sides, and ultimately for the public.

Opposition to leasing could conceivably also lead to further expansion of public aquaculture, to increase the productivity of public-access grounds. State and local governments have already made and continue to make substantial investments to improve public-access shellfisheries—notably those of seed oysters in New Jersey (*National Fisherman* 1976) and hard clams in Great South Bay (J.L. McHugh, personal communication). Much more can be done along these lines if there is sufficient public interest to support the necessary funding. Federal and state support of aquaculture research, as contrasted with its actual practice has made and should continue to make important contributions to productivity by either culture system.

Hatcheries

Perhaps the most significant recent development in Bight aquaculture has been the introduction of shellfish hatcheries on both sides of Long Island Sound and along Great South Bay. Discussion of oyster farming to this point has involved some variation of extensive culture; hatchery culture, in contrast, is highly intensive. The work is actually carried on indoors, often in greenhouses so that algae can be grown in natural sunlight. Early work by Wells (1920) on Long Island and by Loosanoff (Loosanoff and Davis 1963) and associates at Milford, CT, showed that oysters could be induced to spawn in the laboratory and that the resulting larvae could be cultured in indoor tanks through the setting stage. After being grown there to fingernail size, the young oysters were subsequently planted for growth to maturity in outdoor beds like a natural crop. Apparently the earliest published account of success in such an undertaking was by Wells (1920). The techniques in use then were gradually improved over the years, but adoption by the industry itself was slow in coming. The cost of producing oyster *spat* (seed) by this method is still quite high, mainly because of the large amount of skilled labor required. The young oysters must be almost continuously supplied with microscopic algae as food and these algae must themselves be cultured in the hatchery—generally an expensive operation. Present-day hatcheries are still regarded as only marginally cost-effective per unit of seed produced. The fact that no two hatcheries operate in quite the same way indicates the state of the art. Less than complete understanding of culture requirements is a continuing problem and occasional heavy losses of stock from disease and vaguely known or unknown causes are almost routine.

Despite the present high cost and sometimes limited reliability of hatchery production, most of the industry feels that shellfish hatcheries are here to stay. The problem with natural set has been its even greater unreliability. Oyster larvae are highly vulnerable during their free-swimming period, and natural set, even on recently distributed clean shell, does not always appear when expected and may fail completely. In the hatchery, with patience, a good set can almost always be eventually obtained. A special advantage is that individual oysters can be kept separated from each other, that is, prevented from growing together in clusters as they usually do in nature. These single set oysters are better shaped at maturity and therefore more salable. The time of hatchery setting can ordinarily be arranged to meet the grower's needs. Perhaps most important, true breeding work now becomes possible (Longwell and Stiles 1973). Parent stock can be selected and progeny-tested. The potential for developing a truly domesticated strain of oysters, specifically adapted for culture and for market needs, is thus created. At least some progress toward such a goal is now being made.

Hatchery Culture of Other Shellfish. Other bivalve species have also been found adaptable to hatchery culture, using much of the equipment and techniques originally developed for the oyster. The hard clam, bay scallop, and blue mussel can be hatchery grown with reasonable reliability; various other bivalves can be so grown experimentally (Chanley 1974; Castagna and Duggan 1971; Loosanoff and Davis 1963). Because of their present high costs, hatcheries have so far been built in the Bight region only by the few relatively large shellfish companies operating in Long Island Sound and Great South Bay. The small individual growers like those on Delaware Bay would be unlikely to attempt hatchery operation as it is now practiced. It seems inevitable that eventually hatchery technology will be perfected to a point where the method can be used by small growers. An alternate possibility is to return to Well's (1920) original concept of a state- or federally-supported and operated hatchery which would supply seed either to individuals or for public grounds planting (Matthiessen and Toner 1966). Another promising alternative, already in operation on a limited scale both in New York and California (Rutherford 1975; Chanley 1974), is for private hatcheries to produce and sell seed to other individuals or municipalities at the proper size for planting. A growing market appears to exist for such seed.

Now that hatchery production of oysters and other shellfish seed is on the way to becoming routine procedure the logical next step would be to grow a crop all the way to maturity indoors. There are evident advantages in the much closer control of and accessibility to the growing shellfish possible in this way. The ultimate in control is to use a closed system where the seawater is filtered and recycled, thus excluding all unwanted organisms (except bacteria) and pollutants (Maurer 1973; Epifanio and Mootz 1976). Filtration removes the waste substances added to the water by the shellfish; continuous recirculation of this water maintains oxygen content and carries phytoplankton food to the crop. The chief problem is cost, for equipment as well as for operation and maintenance. The labor involved just in growing and adding food algae (since no naturally grown phytoplankton can enter the system) makes this method seemingly impractical for commercial production at present. For research and other special interests it has great promise and further refinement may in time make commercial application possible.

Off-Bottom Culture

Conceptually distinct from the hatchery innovation, though often used in conjunction with it, is off-bottom culture of shellfish, so far mainly oysters and mussels. There are many practical systems which fall somewhere between culturing oysters to maturity on the sea bottom under relatively natural conditions and growing them entirely by tank culture on land (Figure 6). One such method is to support the growing crop by a structure placed on the sea bottom. Another is to suspend oysters in trays or bags from a raft or similar floating support. The main advantages of raising oysters off the bottom are better water circulation (which increases the oysters' food and oxygen supply), less silting, and relative freedom from bottom-dwelling predators such as starfish, whelks, and drills. Considerably more rapid growth usually results. The main disadvantages are higher costs for equipment and handling, and vastly increased fouling problems, which further increase handling costs. All sorts of unwanted indigenous flora and fauna find the oyster racks a suitable place to settle and grow. In this way they can escape their own natural bottom-dwelling predators. Unless periodically removed, fouling organisms compete with the oysters for phytoplankton food and block circulation of water to the crop, thus wiping out much of the original advantage of the off-bottom method. (Bottom-grown oysters are kept relatively clean by benthic grazers and predators on the fouling organisms). Variations of the off-bottom method are now being used on considerably more than an experimental scale (Matthiessen and Toner 1966). The New York Legislature recently authorized the leasing of underwater lands specifically for off-bottom culture (Section 13-0316 of the NYS Conservation Law of 1973). The method appears to have a promising future in many locations around the Bight. Possibly the greatest long-term potential is in connection with the development of open sea support structures for use in deep water. Almost as promising and perhaps nearer realization is the use of racks, rafts, or floats to support oysters over shoal water mud bottoms (Rhoads 1973) where they would be smothered if spread out in the usual way.

Pond Culture

One other important variation of oyster farming, pond culture, has come into limited use by the Bight's oyster industry. In those fairly rare situations where there is private ownership of a seawater pond it is possible to combine the advantages of off-bottom culture with some degree of control of the water environment. The pond is usually warmer than open water (an advantage during most of the year), can be fertilized more effectively for better growth of algae, may have lower salinity (which inhibits some common predators), and is sheltered from storms. There are at least three important examples of pond culture in the Bight area, each unique in some respects. The largest is carried on in conjunction with Long Island Oyster Farms' hatchery at Northport, LI (Komarek 1973). This modern hatchery is built over the edge of a pond that receives the heated seawater condenser discharge from the Long Island Lighting Company's (oil-fired) steam power plant (Fabricant 1976) (Figure 7). When oysters are ready to leave the hatchery they are placed on off-bottom trays in this pond. Here they have the triple advantage of high water temperatures, high water flow through the tray racks, and consistently high phytoplankton food concentrations. Growth is reported to be extremely rapid. This is perhaps the best-known and apparently one of the most successful projects in the United States for making practical use of the normally wasted heat energy in power plant cooling discharges. The project is, however, highly site-specific. Present thermal pollution control policies of the US Environmental

Figure 6. Oyster tray culture in heated pond, Long Island Oyster Farms (Courtesy of New York State Department of Commerce)

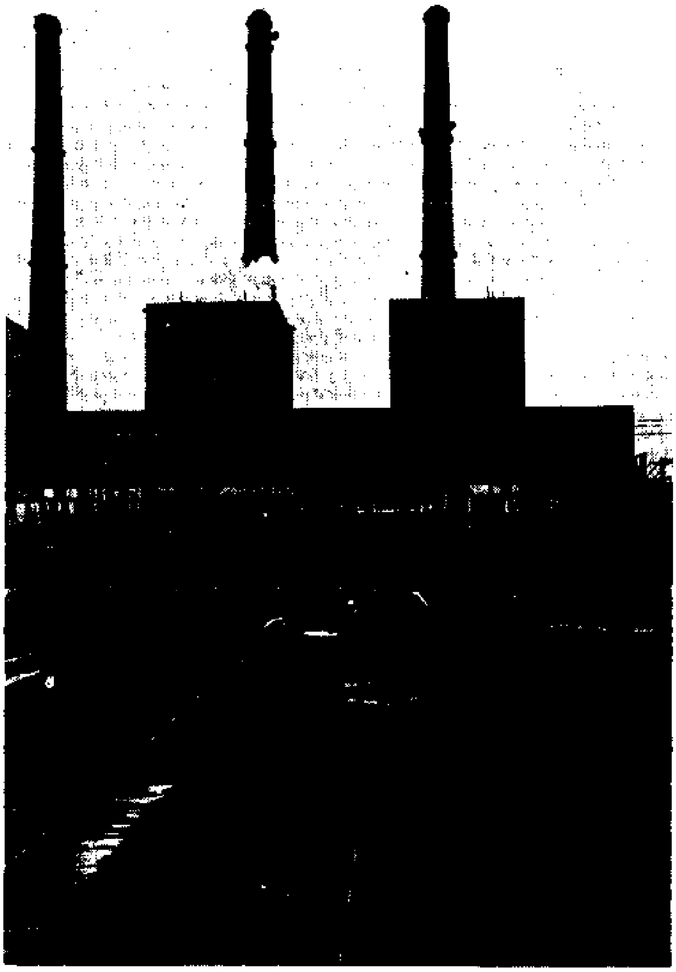


Figure 7. Oyster culture in power plant discharge lagoon, Long Island Oyster Farms (Courtesy of New York State Department of Commerce)

Protection Agency appear to make its duplication elsewhere in the region unlikely even if an appropriate location could be found.

The Shelter Island Oyster Company at Greenport, LI, has made imaginative use of an artificial tidal pond (Chanley 1974; Wacker 1970), by placing tray racks not only in the pond but also in a channel connecting the pond to Shelter Island Sound. The greenhouse built over the channel provides weather protection (Figure 8). Water flow into and out of the pond through this channel provides many of the advantages of the Northport system without dependence on a power plant.

The third system, in use for a number of years at Fishers Island, NY, uses rafts to suspend strings of shells in a tidal pond (Matthiessen 1970). The strings are placed at the proper time of year to receive oyster set produced by brood stock oysters living in the pond. The spat-bearing shell is then harvested for planting elsewhere. This makes the pond in effect an outdoor hatchery for the low-cost production of oyster spat, but again in a special situation which might be hard to duplicate anywhere else.

Pond culture has still to be adequately recognized in aquaculture law and the matter of jurisdiction can be a special problem at each potential site. In theory tidal ponds are part of the seabed and as such publicly owned. In practice, however, many are effectively in private ownership. This is particularly apt to be true of ponds that are artificial in origin; their ownership has been assumed by local government to be the same as that of the upland from which they were dredged—entirely private.

Research in Aquaculture

The fact that oyster and clam production are the only major kinds of Bight aquaculture that have yet "gone commercial" does not preclude active research interest in a number of other species by shellfish companies, occasional private individuals, and various public agencies. Aquaculture research support in the public sector has traditionally been provided by the federal government through the National Marine Fisheries Service (NMFS, formerly the Bureau of Commercial Fisheries), a branch of the National Oceanic and Atmospheric Administration (NOAA). The NMFS laboratory at Milford, CT, has been the source of a very large proportion of current hatchery technology and many other advances in shellfish culture methods. Recent research there has emphasized the culture of shellfish food algae and the genetics of oysters.

New York Sea Grant Institute, also with primarily federal funding through NOAA, has recently supported several small culture research projects with the Marine Sciences Research Center of State University of New York at Stony Brook, LI. These included aspects of lobster culture, the culture of *Arenicola cristata* as a fish bait worm, and the growing of species of red seaweeds from which various food and industrial products are extracted (New York Sea Grant Institute 1974). The lobster work is now being continued under private auspices. An ongoing program in the identification and control of hatchery diseases is also being supported by Sea Grant in cooperation with Cornell University's NYS College of Veterinary Medicine.

NYDEC conducts research on a variety of aquaculture-related problems, usually with partial support from NMFS, at its Flax Pond Laboratory, also at Stony Brook. A feasibility study on oyster seed production at Oyster Pond, LI, was recently completed by NYDEC (Fallon, Brand, and Kilthau 1973), with generally negative conclusions, again illustrating the site specificity of pond culture work. The New York Ocean Science Laboratory at Montauk, LI, with state, county, and other funding, has conducted research on the culture of *Chondrus crispus* (one of the red seaweeds mentioned earlier), on lobster culture, and on the cage culture of striped bass and other finfish species (New York Ocean Science Laboratory 1974). New Jersey supports research, directed from Rutgers, The State University, on the control of MSX disease of oysters (caused by a microbial parasite) and assists the oyster industry directly in numerous other ways.

The several New York town governments whose jurisdictions include shellfish grounds have often supported limited work to improve the productivity of those grounds, as by seed clam distribution (J.L. McHugh, personal communication). Most privately supported aquacultural research is, for obvious reasons, proprietary in regard to both objectives and results, but some information has been published. The Shelter Island Oyster Company has experimented with the culture of scallops, clams, lobsters, and shrimp in its pond system at Southold, LI (Wacker 1970; Chanley 1974). Long Island Oyster Farms has grown a wide variety of species experimentally at its Northport hatchery, including lobsters, shrimp, scallops, and prawns (*Business in New York State* 1971). Power plant effluent aquaculture is being investigated at Public Service Electric and Gas Company's plant on the New Jersey shore, with emphasis on shrimp and trout culture (*The Aquaculture Newsletter* 1975).

The use of treated sewage effluent in aquaculture was introduced to the Bight region by Lamont-Doherty Geological Observatory at the Tallmans Island Pollution Control Facility in New York City. In this pilot-scale research, assisted by New York Sea Grant Institute among other agencies, secondary effluent is mixed in varying proportions with East River seawater to grow marine phytoplankton and seaweeds in concrete tanks. The phytoplankton is fed to bivalves intended to be used as an ingredient in feeds for terrestrial (and perhaps aquatic) farm animals. Such a shellfish protein meal could substitute for an expensive fish meal. The seaweeds (red species) were selected for their commercial value as sources of important carbohydrate extractives. Since neither crop is to be used directly as human food, disease transmission risks should be negligible. The net effect of such a system is to reduce the pollutant load of the effluent by removing plant nutrients as well as various non-nutrient contaminants. In substance the effluent is exposed to a biological tertiary treatment, at low net cost because the products are salable. Since sewage disposal is such a major public problem in highly populated urban areas, this form of aquaculture may have great potential for the Bight region. Whether an activity is classified as sewage treatment or as aquacultural production is unimportant so long as the net effect makes good economic and environmental sense.

The above listing of aquaculture research activities omits one category that could turn out to be far more influential in the long run than its cost and scale of operations might suggest. This is the research performed by private individuals as a hobby, often largely or entirely at their own expense. Aquaculture seems to hold a special fascination for the imaginative person who likes to try things himself (*Aquaculture and the Fish Farmer* 1975*a*; *New Alchemists Journal* 1973, 1974). The potential value of such backyard research should never be underestimated; progress in applied science and technology is seldom in strictly logical sequences, research administrators notwithstanding. Enough people trying out their own ideas may be at least as important in total results as some smaller number of trained scientists. Lobster culture in particular seems to have aroused a great deal of hobby interest among New York, New Jersey, and Connecticut residents, just as it has in other parts of the country. Among them someone just might succeed in making it profitable.

These various research activities together exert an important influence on the progress of Bight aquaculture but still a far smaller one than seems justified by need and potential. Important knowledge gaps are not being filled, and perhaps most serious of all, effective regional and state coordination of research efforts has not been achieved. The writer is insufficiently conversant with research planning in adjoining states to make specific suggestions, but in New York the need for a stronger state role seems clear (Terry 1974). This is not meant to imply that existing agencies—Sea Grant, NYDEC, NMFS, the various organizations of commercial growers—are ineffective. Each has been productive, but each is working in its own sphere toward its own organizational objectives with inadequate knowledge of what others are doing. Only full recognition by government of the agriculture-related nature of the aquaculture enterprise and adequate regular support for research, technical, and information services, comparable on a smaller scale to those provided for conventional agriculture, can meet the evident need.

Figure 8. Pond and "greenhouse" culture of oysters, Shelter Island Oyster Company (Photo by O. Terry)

At this point it may be useful to extrapolate from present trends in aquaculture to likely future developments. Just when these developments are realized seems less important than the need for their potential to be adequately considered in regional planning. Some level of aquaculture is quite certain to continue in the Bight. How fast expansion occurs and the directions of that expansion depend not only on industry choices but also on decisions made outside the industry itself. These should be informed decisions.

Present aquaculture around the Bight consists of field and hatchery production of bivalve seed combined with field grow-out of the seed to maturity. There is an apparent trend toward more intensive methods. Better pollution control in the Bight could slow this trend but probably will not stop it; the advantages of more intensive culture are too great. From a planning viewpoint, although, improving water quality could restore large areas of currently closed shellfish grounds to potential use again. With advanced hatchery technology the productivity of these grounds could become higher than it has ever been. Still further increases in overall productivity are possible by expanded use of off-bottom culture methods—another step toward more intensive culture which the shellfish industry seems certain to take in coming years.

Jurisdictional Questions

Such potential achievements depend on, among other things, favorable solutions to jurisdictional problems. What these solutions will be depend ultimately on public attitudes. At present a definite trend, supported both by increasing numbers of recreational users of the bays and by small commercial harvesters, opposes expanded or even continued leasing of shellfish grounds for private culture. Actual utilization of potentially leasable grounds by such groups may be increasing, in part because the areas previously available are being steadily reduced through pollution-induced closings. Continuing demands of this kind could sharply limit private aquaculture but eventually lead to public-use aquaculture, probably extensive in form. The unit costs of intensive aquaculture appear too high for public support in the near future. The use of intensive, especially off-bottom, methods by private-land growers, however, should be promoted by the recent New York Aquaculture Law (Section 13-0316 of the NYS Conservation Law of 1973), which specifically authorizes raft culture. (It also authorizes the licensing of marine hatcheries—an essential prerequisite for culturing regulated species such as lobster because it allows private possession of juveniles.)

Further expansion of pond culture can also be partly a jurisdictional question. Aquacultural use of ponds where private control can be established is likely to increase. Construction of artificial ponds on privately owned upland (Wacker 1970), generally a high-cost undertaking, may be feasible in some localities. The chief incentive would be the possibility of high productivity under intensive management.

These intensive cultures will continue to develop in the region even if water quality improvements are slow in coming. An important contributing factor may be the availability of recyclable waste materials—waste nutrients for plants and various food wastes for animal feed. At present, large amounts of shellfish and finfish residues are either discarded or sold at nominal prices by local packing plants. Much of this material could be profitably reclaimed as food for animal cultures in intensive systems.

The Future of Plant Aquaculture

Intensive culture of marine plants, like any other plants, is complicated by their requirement of light for photosynthesis. In agriculture this need is normally met simply by outdoor planting, which more or less corresponds to extensive culturing of marine algae. Of course, algae culture is also possible in greenhouses or even in laboratories under artificial light, but at higher cost. Most hatcheries now culture phytoplankton indoors under very intensive conditions. Here the higher cost is justified by the advantages of convenience, better control, and reduced contamination of the cultures. For this kind of production nutrient cost is not yet an important enough factor to warrant using sewage effluent as a nutrient source.

For relatively extensive outdoor cultures, on the other hand, nutrients could be a major cost element—probably significant enough in some cases to justify seeking available open space near sewage treatment plants in order to obtain effluent nutrients. Ryther (1973) and associates at Woods Hole Oceanographic Institution have pioneered in the development of shellfish aquaculture based on the use of secondary effluent as a nutrient source. Practical use of their system on a large scale would be difficult, perhaps mainly because of all the conflicting interests that make most urban planning difficult, but possible nevertheless. For example, some of the presently unused or underused waterways around New York City might profitably be devoted to growing algae, with the added dividend of water quality improvement through pollutant removal.

Such waters often already support large growths of nuisance seaweed species, marine weeds in effect, wherever the concentration of toxic pollutants is not restricting. Their use for seaweed aquaculture, or phytoplankton and shellfish aquaculture, would mean substituting a useful crop for one that is presently of no value. Some danger unquestionably exists that human pathogens could be transmitted through an effluent system of this kind (Vaughn and Ryther 1974) and that danger must be realistically considered. Present indications are that the risk could be largely eliminated by proper choice of crops and culture methods, but further research is needed.

Recently published economic analyses of several types of outdoor "farms" for red seaweeds (Doty 1973; Dawes 1974; Huguenin 1976) suggest that a reasonably cost-effective culture operation, given stable prices for the product, is possible in warm climates. At such farms, seaweed could be attached to nets anchored in shallow water. Considerable hand labor would necessarily be involved. Dawes and Huguenin also analyzed an alternative: tank culture on land at higher cost but with corresponding higher productivity. Adapting either culture system to Bight conditions would require major modifications, but the concept of a seaweed farm in the Bight is by no means purely visionary.

Present Effects of Sewage Effluent. In the absence of baseline information it is not known to what extent and in what ways present shellfish production in the Bight region is influenced by the presence of sewage effluent nutrients. Undoubtedly phytoplankton numbers and species composition are affected to some degree. If some of the currently closed areas can eventually be reopened, through better sewage treatment and storm water control methods to reduce health hazards, the unplanned effluent contribution to shellfish aquaculture could yet prove to be more an asset than a liability. Large-scale depuration of shellfish from polluted areas is another real possibility. Many currently closed areas are known to be highly productive even though their crop is not now legally usable. It should be observed, however, that sometimes pollutants other than bacteria—notably pesticides and toxic metals—can be accumulated to dangerous levels by shellfish. This kind of health hazard must not be overlooked.

Using Thermal Effluent. The issues surrounding use of another major waste resource of urban regions—power plant thermal effluent—are complex indeed. Earlier indications were that such heat could be an important asset in aquaculture and that aquaculture was one of the more promising uses for effluent heat. Reports of early efforts to build aquaculture enterprises around such heat sources were generally optimistic (*Commercial Fish Farmer* 1974). The Long Island Oyster Farms project at Northport was one of the first of these (Figure 7). Current projections, for the United States at least, are not as encouraging. The principal difficulties seem to be the very amount of space needed in large-scale use of effluent heat for aquaculture and the even greater problem of radioactive residues from the nuclear plants now being planned and built. Plant shutdowns during winter could also present a real hazard although probably a manageable one at least for multi-unit installations.

From the point of view of the utility company which designs, builds, and operates a power plant, aquaculture rarely if ever provides an economically or environmentally desirable means for discarding unwanted heat, for several reasons. The utilities' main concern is, must be, the environmentally sound disposal of their excess heat load at minimum cost. An aquaculture unit would have to be tremendous in size (500 or more acres of ponds for a typical plant) to use the entire heat output even in winter. This land must be paid for. Aquaculture would probably want no heat during the summer; yet the power plant must continue to discard the same amount of heat. How would this be done? Generally speaking, aquaculture enterprises do not consume heat—they merely use it and pass it along. The heat disposal problem is not automatically solved (Kildow and Huguenin 1974), unless disposal is incidental to the aquaculture enterprise as in very large-scale ponds used year round. It is the pond system itself that disposes of heat—the utility wants it used for this purpose even through the hottest summer months.

On the other side, aquaculture sees effluent heat as a resource that must be purchased, at best with modifications in its plan of operation, at worst with cold cash. If the price is right, aquaculture may still be willing to buy. To do so, enough space for aquaculture operations near the power plant must be found—frequently a difficult although not always an impossible problem. The large exclusion zones around nuclear plants might sometimes be used in this way (Huguenin and Ryther 1974). Current trends in the thinking of regulatory agencies and in the authorizing legislation itself, however, are not particularly encouraging. The announced emphasis on increased use of cooling towers (*Commercial Fish Farmer* 1975) to replace once-through cooling is not likely to help effluent aquaculture. Even worse, the Food and Drug Administration in the past has actually prohibited the direct use of nuclear effluents in aquaculture, based on the Delany Amendment. This amendment forbids the addition of known carcinogens to food products. All nuclear plants release very small amounts of low level radioactive wastes in the effluent stream. These are, of course, known carcinogens. The logic of allowing them to be discharged to natural water bodies but not to aquaculture ponds has not been explained. Indirect use of nuclear effluent heat, possibly through heat pumps (J. Holm, personal communication) or with intermittent diversion to bypass the contaminants, might under some circumstances be practical for intensive aquaculture if regulatory issues can be resolved. However, unless the cost of more conventional heating becomes truly prohibitive, the large investment required will likely preclude even these uses. What current potential there is for using effluent heat in aquaculture is thus primarily in connection with large flow-through or recirculating pond systems serving fossil-fuel power stations. Aquaculture uses might have to be seasonal. If offshore power plants are eventually built (Bernstein 1975), space for any associated aquacultures would presumably be available, but the mere cost of retaining the heated water at such locations might be prohibitive.

Open Sea Alternative

Although conventional shellfish aquaculture is seen to be capable of major expansion—through both more intensive methods and prospective improvements in water quality—there is an alternative. Aquaculture has the potential for increasing the useful production of the sea surface just as conventional agriculture has increased that of the land surface. Hanson (1974) discussed this alternative, offshore culture, at some length. The principal reason for taking such a seemingly revolutionary idea seriously is that it could provide almost unlimited open space. For animal cultures this means escape from the severe restrictions likely to be placed on the discharge of culture wastes to inshore waters. These wastes would be swept away and diluted to insignificance in the open sea. For filter-feeding crop species, offshore culture means access to vast phytoplankton pastures of the ocean, delivered free by ocean currents. Both considerations are potentially important, but even more significant, in the long run, is simply space, access to sunlight for primary production. All food production ultimately depends on photosynthesis by green plants and therefore on solar radiation, most of which falls on the sea. Aquaculture techniques will supply the plant nutrients needed to increase primary production in the open sea and if necessary to change the species composition of ocean plant populations. Open ocean productivity is generally thought to be limited by nutrient availability (Russell-Hunter 1970). Removal of this limitation can either greatly increase the native phytoplankton crop or support other, more desirable (at least to human consumers) species. Aquaculture can also lead to the production of seaweed—benthic algae—instead of the native unicellular algae. Culture problems are difficult but not insurmountable.

Engineering Difficulties

Open sea aquaculture on a meaningful scale will require answers to some tough engineering questions. Although these are by no means solved yet, more has been accomplished toward their solution than is generally recognized (Wilcox 1975). The major differences from conventional aquaculture introduced by a move offshore are deeper water and much greater exposure to wind and waves. Greater depth means reduced availability of the sea bottom as a culture surface and a consequent need for more expensive substitute structures, whether floating or supported from that bottom. It is not probable that aquaculture interests will soon be able to fund the kind of platforms being developed for open sea drilling sites by oil companies; these are now being designed for depths to hundreds of meters (Yergin 1975). Such giants, however, do establish at least the physical possibilities. Various small aquaculture structures could be, and actually have been (Anderson 1974), attached to the oil-drilling platforms (Figure 9). The question becomes primarily one of scale. Any major add-on facility for commercial aquaculture would probably involve expensive modification of the platform and therefore seems unlikely in the near future. However, structures of the same general type which could be designed specifically for an aquaculture project at somewhat shallower depths may not always be out of the question. There would naturally have to be some reasonable compromise between storm endurance and replacement cost. Exactly the same approach is involved as when, for instance, designing an ordinary pound net for nearshore fishing. It is built to withstand most storms but not necessarily hurricanes.

The alternative to bottom placement is a floating structure which could be anchored semipermanently, maybe moved to shelter on occasion, or even left free-floating (Hanson 1974). Present use of the Dom-Sea and similar salmon pens and wide use by the Japanese of raft structures (Shaw 1971) indicate some of the possibilities. One suggested variant is a culture enclosure that can either be raised to the surface or lowered to the depths for shelter as needed. As exemplified by the giant oil platforms, one key to storm endurance is sheer size and weight; this is as true of floating as of anchored structures. If the aquacultural productivity of a design can be increased in proportion, large size may not always be cost-prohibitive. Floating breakwaters (Kowalski 1974) can moderate rough seas around either rafts or platforms and the larger the installation the more feasible its protection becomes. As size increases, drifting or anchored structures will begin to act as their own breakwaters to moderate passing seas. Until significant design investments are made in facilities of these kinds it is probably pointless to say much about costs, but there is no reason at this time to brand them as prohibitive for all open sea situations.

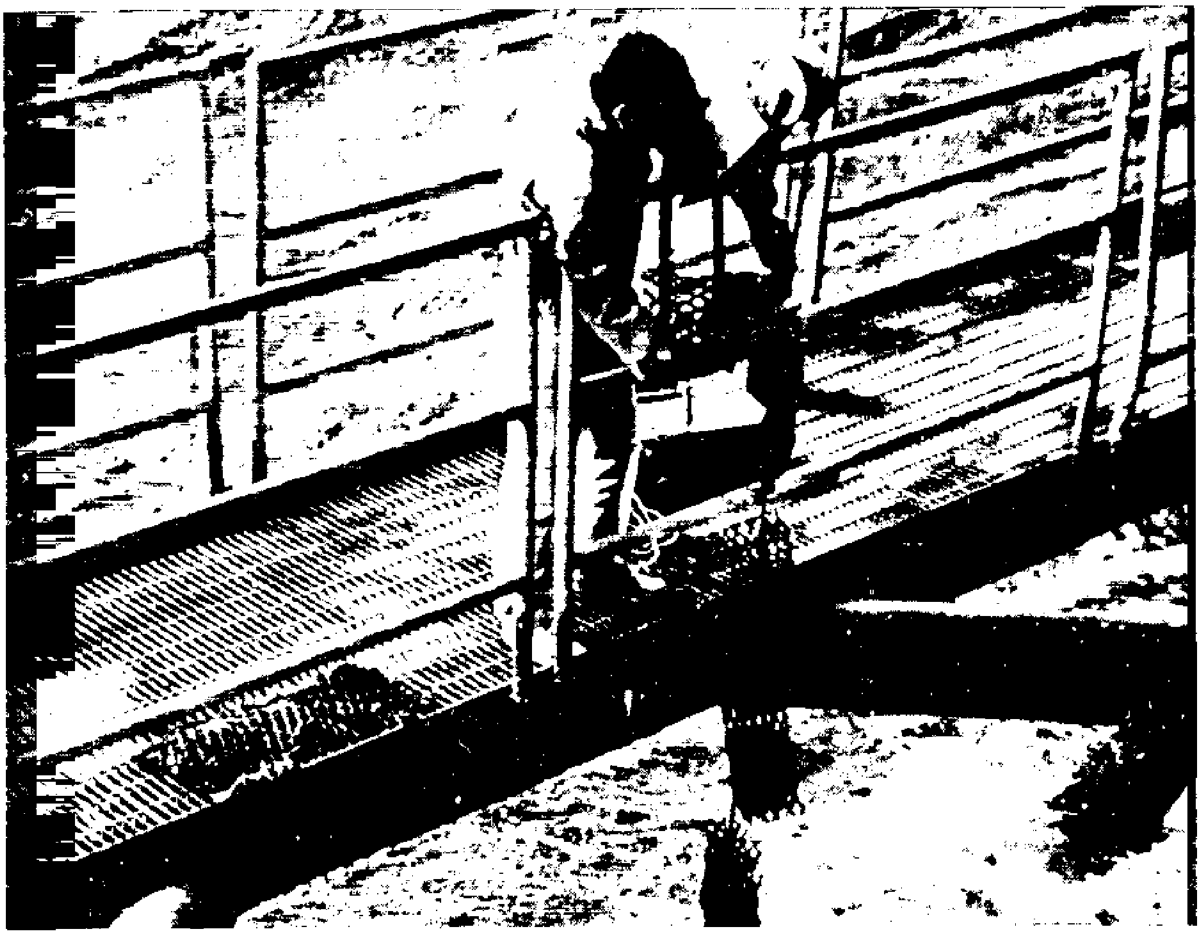


Figure 9. Aquaculture from an oil drill platform, Gulf of Mexico (Photo by R.D. Anderson)

Jurisdictional Questions

Aquaculture cannot expect to completely evade its current legal-jurisdictional problems simply by moving offshore. Control of the Bight waters and the land under them is divided between the states and the federal government, mainly on the basis of distance from shore. State jurisdiction extends in general to a line 3 nmi (5.6 km) from mean low water, the so-called "territorial sea." In New York's part of this zone, grants or easements for aquaculture could probably be obtained if indeed these were even required (New York State, undated). Of course, federal requirements for navigation safety would have to be met, surely not an impossible task outside regular shipping lanes. Existing state regulations authorizing the use of pound nets constitute a precedent for future, more elaborate installations. New York's Environmental Conservation Law (1973) already provides for permits to conduct off-bottom culture of shellfish in state waters.

Beyond the 3 nmi (5.6 km) limit of state jurisdiction the situation for aquaculture is even less defined. In the contiguous zone (3 nmi to 12 nmi or 5.6 km to 22 km), federal control is well established, but apparently no explicit provision for aquaculture has yet been made. There appears to be some legal basis for state control specifically of aquaculture in this zone too, so long as federal regulation is not actually invoked (Kane 1970).

As aquaculture moves beyond the 12 nmi (22 km) limit the situation becomes still more uncertain. The Convention on the Continental Shelf (1958) assigns exclusive jurisdiction over "sedentary species of the continental shelf" to the coastal nation. This would seem to include maricultured species as well as completely undomesticated species (Kane 1970). It might not cover pelagic species confined in enclosures and almost certainly would not include fish that were being ranched in the open sea no matter how dependent they might be on hatchery production in early stages. Incidentally, Kane (1970) believed that this same national jurisdiction extends as well to resources beyond the limits of the shelf in the oceans proper, depending only on the capacity of a coastal nation to exploit them.

Does national ownership of a natural resource convey 1) a right to space for culture to increase that resource, and 2) the potential for private ownership of resource and culture facilities? These questions are apparently unanswerable at this time and may remain so until some initiative toward open sea mariculture actually develops. However, the analogy with open sea drilling for petroleum products is close enough to suggest that mariculture could acquire a comparable status and that the eventual answer to both questions may well be yes.

Legal and other considerations then appear to favor the offshore culture of "sedentary" species—"creatures of the [Continental] Shelf" (Kane 1970). What about other kinds of offshore culture? Recent developments may have made this particular distinction all but meaningless. Strong political pressures, arising in large part from concern over the effect of foreign fishing near US shores, have resulted in new US legislation for this region. Many uncertainties remain as to its ultimate effects (Hedberg 1976), but the 200-mile law is a reality.

Establishment of the 200-Mile Zone. On 1 March 1977 the Fishery Conservation and Management Act of 1976 (Public Law 94-265) went into effect. This law unilaterally establishes a fishery conservation zone outside the 3 nmi (5.6 km) territorial sea to a distance of 200 nmi (370 km) from the coasts of the United States. The act stipulates that the United States shall exercise exclusive fishery management authority throughout this new zone and also over all anadromous fish species throughout their migratory range, unless within another nation's territorial sea or fishery conservation zone. Detailed management plans, one for each individual fish stock, are the responsibility of eight regional fishery management councils. Each council exercises jurisdiction over its own region, subject to approval of the US Secretary of Commerce. New York Bight falls within the Mid-Atlantic Region under this system.

Many details of the act's implementation remain to be resolved, among them the matter of certain international boundaries of the fishery zone. The needs of offshore aquaculture have apparently not even been considered as yet. If Kane's (1970) reasonings on aquacultural jurisdiction were correct, cultured resources will be treated essentially the same as natural populations, possibly even included in regional fishery management plans. The effect of private ownership of such cultured resources on implementation of the act and the possibility that floating or emplaced culture structures may constitute special categories will ultimately have to be addressed. Jurisdiction may indeed remain unclear (Soons 1974) for a long time, but that fact is not likely to bar exploitation when it becomes otherwise attractive. Any resource-exploiting activities will presumably have to be "subject to the requirements of reasonable regard to the interest of the other legitimate users of the high seas" (Soons 1974), but this hardly seems a severe restriction.

Assuming for the moment that the various engineering and legal problems of offshore aquaculture are not insurmountable, what kinds of aquaculture might this be? Conventional bottom culture of hatchery-produced bivalve stock appears unlikely, even though this kind of culture would have the advantage, aside from its familiarity, of not requiring any structures at all. It also has problems, not the least of which are biological. There is no reason to expect that the familiar inshore species—oyster, hard and soft clam, bay scallop—would survive in bottom conditions offshore even if they could be planted there. Two indigenous species—surf clam and sea scallop—now under considerable harvesting pressure might conceivably be cultured by the offshore placement of hatchery-raised stocks. The same conjecture applies to the mahogany clam (ocean quahog) if its use ever reaches the level where stocks are significantly depleted. We don't really know, of course, whether stocking of these species is biologically feasible. In any case, it would be difficult to adequately bound and locate private planting areas under offshore conditions. If these native offshore populations are ever hatchery-augmented, it seems most likely to be at public expense for general (national) access.

Biological Questions

The biological obstacles to offshore bottom culture do not necessarily apply to the use of off-bottom culture techniques. In one respect bivalve shellfish are particularly suitable candidates for open sea growing. They are herbivores, filter feeders, living on a natural phytoplankton food supply which is already present and requires no expensive transportation to the offshore site. In an area as well-supplied with plant nutrients as the Bight it might not be necessary to provide any artificial fertilization, any more than it now is in Long Island Sound or Delaware Bay. Hanson (1974) described a number of possible adaptations of standard off-bottom culture methods that could be used in deep water, whether from bottom-supported structures or from rafts. Culturing mussels on ropes suspended from rafts, as now done in Spain, is a promising possibility. All such off-bottom culture methods serve to concentrate a crop population in a small area while permitting the animals to harvest the primary production (phytoplankton) from a much larger surrounding region of the sea surface. Such cultures are really solar energy collecting devices, and reasonably efficient ones, except for possible nutrient limitations on phytoplankton production.

Species such as the blue mussel and various kinds of oysters can be expected to thrive in high-salinity offshore waters even though they never occur there naturally because of the lack of substrate. Aquaculture provides the substrate. Other inshore species may be less adaptable initially, but chances are good for either finding or developing appropriate strains for the purpose. Hanson (1974) concluded that tray culture of shellfish is at present the most generally promising aquaculture for offshore use on a large scale. Mussels are particularly promising if American buyers ever really accept them (Hurlburt and Hurlburt 1975). The culture of finfish in cages or pens is certainly possible at offshore locations, though the need for bringing in feed supplies makes this alternative less attractive than it otherwise would be. Present net pen culture of salmonids is relatively close to being an open sea operation. If offshore polyculture systems can be developed, starting with algae, which will provide fish feed on site, the problem becomes easier.

Ocean Ranching of Anadromous Fishes. The potential offshore culture systems mentioned thus far are all essentially intensive cultures. Crop animals are confined, even though their food supply may come from the open sea. There is an attractive alternative depending much less on confinement and structures; it capitalizes on the highly developed homing instincts of anadromous fishes. These are species living mainly in salt water but returning to fresh water for spawning, usually to the same stream they left as juveniles.

Previous use of this homing pattern for culture purposes has been limited to salmonids on the US West Coast and overseas. It began with the long-established practice of raising salmon in state-supported hatcheries for release in spawning streams to augment the natural stocks, especially where these were impacted by dams and pollution. The *smolts* (young salmon that have reached the growth stage at which they normally enter salt water) simply join natural populations from the same rivers and migrate to the open Pacific where they spend the balance of their adult lives. At spawning time the survivors seek out and enter the same stream into which they were released as smolts. Naturally, not all survive to return, partly as the result of open sea fishing activities, but enough often do survive to more than justify the costs of hatchery operation. Recently, Washington State law has permitted private hatcheries to use this system for profit—simply as a way to grow fish for harvest.

Joyner (1973) and Mahnken and Joyner (1973) proposed an imaginative adaptation of the West Coast system to New England waters, including Long Island Sound and parts of the Bight. Native Atlantic salmon have almost entirely disappeared from this region because of pollution and industrial damming of streams. Attempts are being made to reintroduce them (*New York Times* 1976), but quick success is not anticipated. Meanwhile Joyner and Mahnken suggested using various Pacific species that could be produced in local hatcheries for a coastal fishery, probably mainly recreational. This is not entirely a new idea; previous attempts have been made to do just this, with mixed results. Joyner and Mahnken emphasized two critical requirements for success. One is a careful study of local seawater temperatures and the seasonal temperature cycle in relation to the spawning habits of Pacific salmon species. The species selected for use here should include only those likely to find our seasonal temperature cycle compatible and therefore to return as and when expected. Failure to make this match with enough precision may have been a fundamental flaw in past introduction attempts.

The second novel feature Joyner and Mahnken proposed is that of holding the salmon smolts in saltwater conditioning pens prior to their release. Accidental escape of fish from pens in Puget Sound revealed an unexpected effect of inshore saltwater confinement on their behavior: instead of migrating to the open sea, as salmon normally would, these fish remained in coastal waters in the vicinity of the pens. They now constituted a coastal fishery, not subject to open sea harvest by foreign nations and readily available for sport fishing. If this system were adapted to the East, the hatchery-grown smolts would be penned for a short time in salt water, perhaps in Long Island Sound. When released they would be likely to remain in Bight waters as they matured and to contribute to a major new recreational fishery there. In principle, with appropriate authorizing legislation, even a private fishery might be feasible, without the penning step. The mature fish would then home to the release point—perhaps a coastal river.

It is more likely that such a fishery would be state supported, possibly through license fees to cover costs. It would not be expected to become self-perpetuating because of the generally poor stream conditions as previously noted. The streams would be unlikely to match the breeding requirements of the introduced species. This fact provides a safety factor for the introduction. If the introduced species had any undesirable effects on local ecosystems or important native populations the stocking could simply be terminated allowing the introduced species to die out by attrition.

Kelp Culture. Phytoplankton may be the most important, but they are not the only marine plants. Primary production can also come from seaweeds, macroscopic algae. The larger, faster-growing species, especially the kelps, are thought to be capable of considerably more production per unit area per year than most phytoplankton communities, ranking them among the most productive plant crops known (Mann 1973). The kelps are important sources of alginic acid and other products wherever natural growth is sufficiently concentrated to make harvesting feasible (at present mainly off California and Australia) (Figure 10). Alginic acid (polysaccharide) extracted from kelp is commonly used as a suspending and stabilizing agent in manufactured food products like ice cream.

The large deepwater California species of kelp (*Macrocystis pyrifera*) has already been cultured to the extent that a hatchery system for augmenting natural recruitment is now in limited use (North 1972, 1973). The main objective of this work is to maintain and augment natural populations in the open ocean off southern California, for eventual harvest. However, an artificially supported "farm" for *Macrocystis* culture is also being developed (Wilcox 1975) (Figure 11).

Energy Farms

Larger-scale experiments now being conducted in the offshore farming of *Macrocystis* were initiated for a special purpose: the "harvesting" of solar energy. Because of its enormous productivity, kelp is considered a promising source of bulk organic material to be used simply as an energy source. Bacterial (or pyrolytic) digestion of the harvested kelp can produce methane gas, a most useful hydrocarbon substitute for, or extender of, scarce natural gas. Many other products, for example, ethanol, human and animal foods, pharmaceuticals, are also possible. Such a *bioconversion* system is really a means for harvesting and storing solar energy. If culture and processing methods can be refined to cost effectiveness, marine plants will be an attractive potential energy source, nonpolluting and ultimately limited in quantity only by nutrient availability; offshore growing space is almost unlimited. Oceanographers usually regard the benthic seaweeds, including the kelps, as insignificant on the scale of total marine productivity because of their limited distribution compared to phytoplankton (Weyl 1970). The kelps, for instance, can grow naturally only where a firm substrate exists in relatively shallow water and within a temperate or subarctic climate. If a sufficient area of artificial substrate can be provided in the deep ocean, this limitation disappears. Kelps can harvest nutrients from large volumes of ocean water in the same manner that the Spanish mussel cultures harvest phytoplankton. This is the basic reason for their enormous natural productivity (Mann 1973). Nutrient requirements are probably involved in the limitation of kelps to the cooler zones of the earth; most tropical waters are relatively nutrient-poor (Weyl 1970).

Eastern kelps, notably species of *Laminaria*, appear to be about as productive as their Pacific counterparts (Mann 1973) and as useful, but have not yet been harvested on any comparable scale. Their natural growth habit is quite different from that of the surface-floating *Macrocystis*. *Laminarias* lack the gas-filled floats (pneumatophores) which support *Macrocystis* fronds. The *Laminarias*, too, require a solid anchorage site, ordinarily rock; their fronds, much shorter than those of *Macrocystis* (which can exceed 60 m or 197 ft) usually lie near the bottom. The practical importance of these differences is that naturally growing *Laminaria* has been more expensive to harvest than *Macrocystis*, probably accounting in part for the absence of an Atlantic Coast industry. Curiously, the low temperatures of a North Atlantic winter, even with its short days, do not seriously inhibit growth of these subtidal species. Maximum natural production actually occurs in late winter (Mann 1973), probably in response to the annual nutrient peak at that time.

The above facts suggest that *Laminaria* culture for commercial use should have real possibilities in the Bight region. Raft culture of *Laminaria* has apparently not yet been attempted in this country, but has been reported from China (Cheng 1969); many details of raft (or other support) construction and plant attachment will have to be worked out for large-scale offshore use. This culture could become an important primary production enterprise in the Bight, serving most of the purposes already suggested for *Macrocystis* farms in the Pacific—energy and food and pharmaceuticals.

New York Bight is a good location for offshore kelp culture, not only because of its abundant supply of nutrients (originating in part from sewage effluent), but also because its active waves and currents will serve to deliver the nutrient supply for kelp growth. Maximum production may require still more nutrients but if so these might be provided from sewage or as chemical fertilizers, comparable to those used in land agriculture.

Should We Introduce Exotic Marine Organisms? One very serious question is central to the very concept of mariculture and deserves more consideration than it has usually received. This is the dilemma inherent in introducing any exotic (non-native) organism to a culture situation. Should, for example, Pacific salmon be released in East Coast waters? Ecologists generally oppose such introductions, often more as a matter of principle than for specific reasons. Fishery biologists, all too familiar with the havoc wrought by a few of the less fortunate past occurrences of this kind, now also tend to be extremely cautious about exotics. Only the practical businessman/farmer, faced with the necessity for growing a marketable commodity at a profit, is apt to be willing to take a chance. Quite naturally, to the individual grower, the chance for

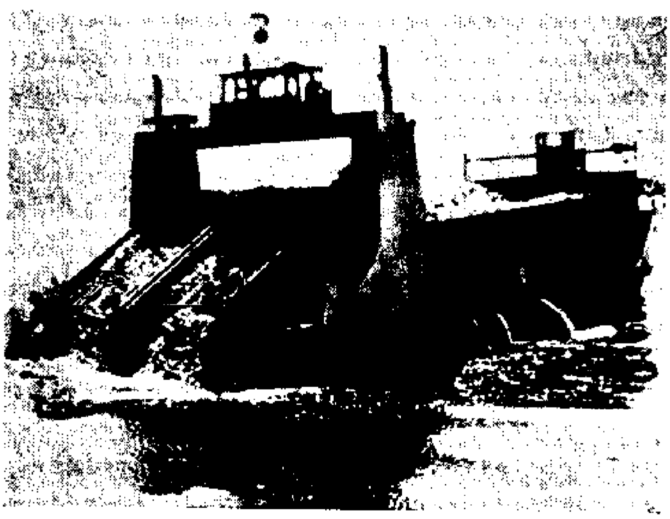
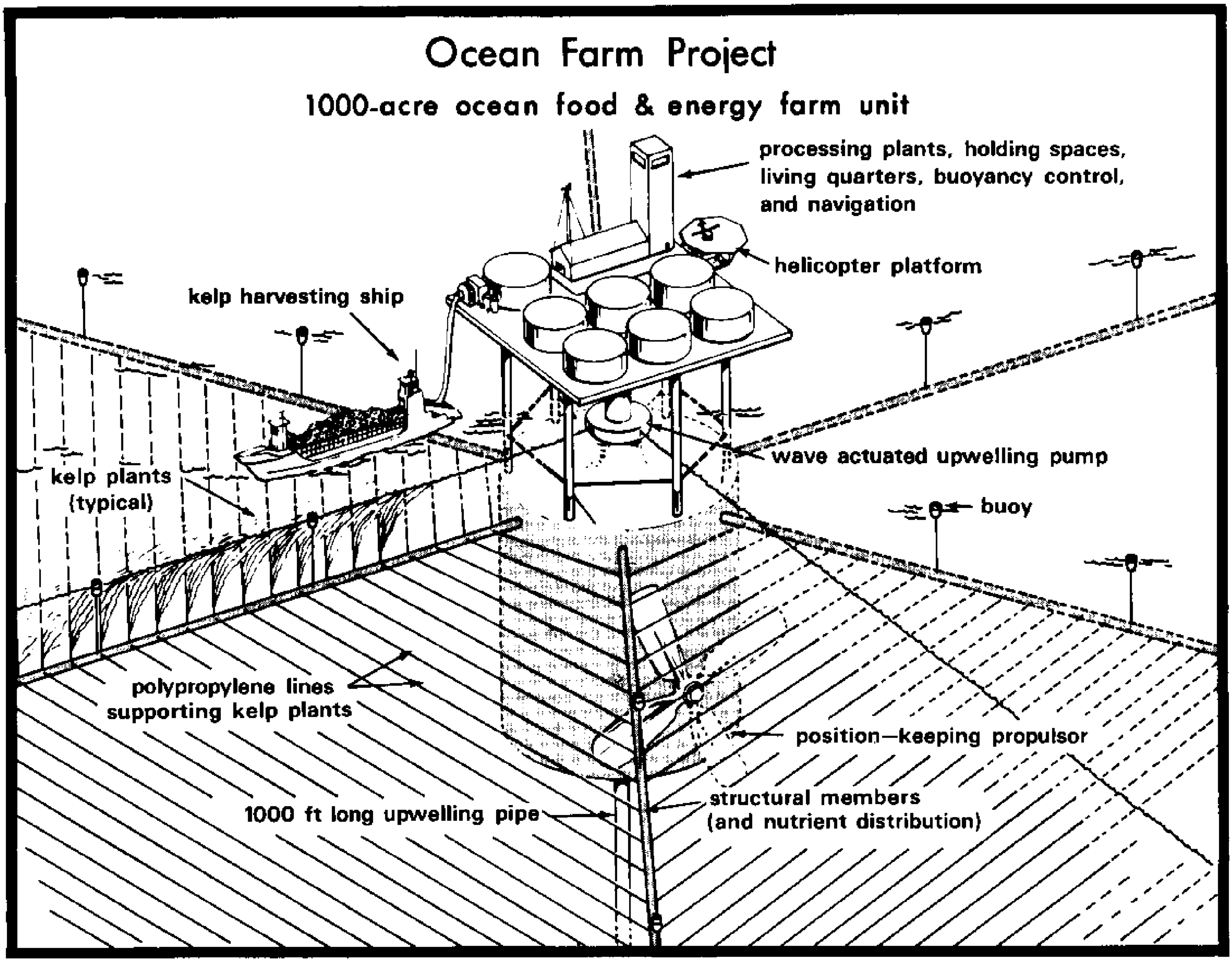


Figure 10. Specially designed kelp-harvesting vessel, Southern California (Photo by H. Wilcox)

personal financial success will tend to overbalance any risk involved. For the individual administrator in the regulatory agencies, the opposite is true: he must risk severe criticism if he allows the introduction and it proves harmful for relatively little personal gain if it succeeds. Credit for the success and profit, if any, will go mainly to the grower. Where does the real public interest lie and how should such decisions be made?

There is no easy answer. We know what damage has been caused by exotic fishes (carp), aquatic plants (water hyacinth), and birds (English sparrow, starling, monk parrot). Yet we also know that modern agriculture would be disastrously less productive if it had to depend entirely on native plants and animals. Can aquaculture accept such a handicap indefinitely? One can argue that the danger is greater in water because ocean currents distribute spores and larvae widely. *Codium fragile*, for example, is an accidentally introduced green alga that is a real pest on northeastern shores. Would *Macrocystis pyrifera* also become a nuisance in the Atlantic?

Conversely, it can also be argued that the danger is actually somewhat less for marine species since all marine waters already mix freely around the globe. Sooner or later any species that can survive in an area is likely to arrive there naturally. The practical approach is to be fully conscious of the dangers, minimize the risks as much as is humanly possible, but not be entirely immobilized. In principle some such risks have to be taken, and will be, when an important crop is involved and there is no advance evidence of negative effects.



Source: Wilcox 1975

Figure 11. Design of ocean food and energy farm

Summary and Conclusions

Aquaculture is already a thriving, if relatively minor, industry in nearshore waters of New York Bight. From this base the aquaculture industry is likely to expand in several directions. Present culture of the oyster, hard clam, and bay scallop is increasingly being built around hatchery technology. As this technology improves—and it is advancing rapidly—culture methods will become more and more intensive, for greater efficiency through better control of crop and environment in a high-cost situation. Food, nutrient, and possibly thermal wastes will be increasingly used, to reduce costs as well as in response to environmental pressures for their beneficial disposal. Off-bottom culture of these bivalves will become an important part of the intensification process. Cultures of other crop species, which could include finfishes and some crustaceans, will be introduced gradually. Seaweed culture is a special case because of its link to the energy problem. The rate of expansion of conventional aquaculture will be influenced by many factors, national and international as well as local, but two will have primary importance—water pollution and legislative controls.

Present indications are that the process of cleansing polluted coastal waters will continue, perhaps even to include the Augean stables of New York City's sewer systems. As this occurs many areas now closed to shellfish culture will again become available for this purpose and, under good management, should reach or exceed their historical peaks in productivity. There will always be problems associated with growing food crops in a heavily populated and highly industrialized region like the one surrounding the Bight. Human pathogens and industrial toxins will continue to pose serious health threats when concentrated by aquatic organisms, but as the dangers are better understood they can probably be controlled.

Legislative regulation of the aquaculture industry will continue to have profound effects as it determines uses for inshore waters. The land-use problems that urban, suburban, and exurban planners now deal with will expand to include underwater lands and the waters themselves. Choices will sometimes have to be made among commercial, industrial, and public uses of space—among marinas, oil terminals, and clam beds. Assuming that food production will continue to be assigned a reasonable share of marine real estate (Landy 1975), a more serious question may involve the balance between private and public aquaculture—or between private aquaculture and wild marine resource.

For more than a century general policy in the states bordering the Bight has favored private enterprise in aquaculture, including the right to exclusive use of assigned underwater culture space (though not the most naturally productive areas). Increasingly, this policy is being questioned, mostly by people who see it as a threat to what they feel should be a public resource. Any decision for aquaculture, given the present climate of suspicion of private enterprise and its methods, will not be an easy one politically. Nevertheless, some kind of inshore aquaculture is inevitable.

A real possibility for the Bight is ocean ranching of finfishes, especially salmon. Established and proven West Coast culture methods for salmon smolt production can likely be adapted without serious difficulty to East Coast conditions. If ranching is successful, an important new inshore fishery would be established, probably on a basis of public-benefit aquaculture. It would be rather optimistic to expect that, in these heavily fished waters, ranched salmon would return in sufficient numbers to a private release point. To what extent the introduction of this exotic predator would perturb the local ecosystems, for privately cultured as well as natural food species, is largely unpredictable. Ocean ranching ought therefore to be tried on a small scale at first.

Open sea aquaculture now sounds like science fiction, but as with so many former science fiction concepts, its time may not be far off. Because of the threatening energy supply situation, the earliest offshore culture to develop may well be kelp farming. Bioconversion of organic material as a means to harvest solar energy is a new idea in name only; this is the way nature made fossil fuels. The use of current biomass production seems certain to increase as fossil fuels are used up. Whether kelp is an economically feasible source of plant biomass for this purpose has yet to be established, but recent projections are promising. Marine production does not draw on limited freshwater supplies or use scarce agricultural land. It does not compete directly with land crops for nutrients or require the substantial energy input necessary to process and transport conventional fertilizers to the point of use.

Frequent reference has been made in this monograph to the central role played by economics in the development of aquaculture. Proposed new ventures in Bight aquaculture face a whole range of problems, most of which can be translated into cost problems. Presently known solutions generally cost too much in relation to probable returns. This being the case, shouldn't a discussion of Bight aquaculture concentrate on operational costs, perhaps in a systems context? The reasons why this direct approach is less practical than it seems deserve a brief statement here. Such reasons are relevant to much of aquaculture at its present stage of development in this country.

The primary reason for limited use of cost data is that most of the proposed cultures discussed have still to be developed in sufficient detail. Enough of the scientific and technical background is known to give assurance they are indeed possible, but detailed production designs do not yet exist. In those few instances where they do—onshore silo culture of salmonids, for example—cost analysis is possible and useful (MacDonald, Meade, and Gates 1975). The recent examination by Huguenin (1976) of tank culture costs for red seaweed is another example. But East Coast kelp farming and off-bottom oyster culture have not yet reached that stage. Detailed specific designs are a necessary first step.

Another main reason for lack of emphasis on cost data is simply the speed of technological change in American aquaculture. Even ignoring inflation, it is of limited utility to list actual costs of an operation or a piece of equipment which is very likely to be displaced by some newer design next year or next week (Anderson 1973). Even bivalve hatchery operation is still in a state of flux; costs today are not what they will be next year, or the year after. The potential culturist has to pull some specific plan off the moving belt of technological change; only then can he cost it and primarily for the one particular situation that immediately concerns him. Having done so he would be well advised to remember that, as Huguenin (1976) pointed out "... systems development is an iterative process" in a fast-moving field.

Commercial expansion of aquaculture is completely dependent on a profit potential, based on a realistic assessment of expected costs and returns. But assuming that expansion does occur, there will be an early need to consider what the economists call "externalities"—the kind of unpriced costs (and benefits) accruing to groups outside the industry and to society as a whole (Anderson 1973; Williams 1975). For example, is the overall effect of oyster culture on water quality such as to improve it for other water users or to degrade it? Would large-scale kelp culture be an environmental asset or an obstacle to navigation or some of both? If both, which is more important? Broad-based cost benefit analyses will be required as mandated by the National Environmental Policy Act of 1969 (PL91-190). An environmentally aroused public will not be as tolerant of any new industry's potential detrimental effects as their grandparents were of steel and paper mill discharges. Fortunately for aquaculture, most of its externalities appear on balance to be favorable, at least to the extent we yet know what they are. This seems especially true of offshore cultures. In the long run environmental considerations may be decisive as aquaculture competes for scarce development dollars and coastal space in the Bight.

References

Agnello, R.J., and Donnelley, L.P. 1975. Property rights and efficiency in the oyster industry. *J. Law Econ.* XVIII:521-33.

———. 1976. Externalities and property rights in the fisheries. *Land Econ.* 52:518-29.

Anderson, L.G. 1973. An economist looks at mariculture. *Marine Tech. Soc. J.* 7(3):9-15.

Anderson, R.D. 1974. Atlantic Richfield participates in mariculture science venture. *Aquaculture and the Fish Farmer* 1(4):4-6.

Aquaculture and the Fish Farmer. 1974. 1(4), November-December.

———. 1975*a.* One man's family ecosystem. 2(2):9, 12.

———. 1975*b.* Shelter Island Oyster Company: squid grant. 2(3):6.

Bardach, J.E., Ryther, J.H., and McLarney, W.O. 1972. *Aquaculture: the farming and husbandry of freshwater and marine organisms.* New York, NY: Wiley-Interscience.

Bernstein, P.J. 1975. Off-shore N-plants running out of steam. *Long Island Press,* 14 December.

Burchard, B. 1975. Wanted: world action on salmon. *The Aquaculture Newletter,* No. 21. Belleview, WA.

Business in New York State. 1971. Gourmet food of the past returns to today's tables. NYS Dep. Comm. Summer 1971:4-7.

Castagna, M., and Duggan, W. 1971. Rearing the bay scallop, *Aequipecten irradians. Proc. Nat. Shellfish Assn.* 61:80-85.

Chanley, P. 1974. Shelter Island Oyster Company delivering tray grown shellfish to homes. *Nat. Fisherman,* August.

Cheng, T.H. 1969. Production of kelp—a major aspect of China's exploitation of the sea. *Econ. Bot.* 23(3):215-36.

Claiborne, C. 1976. He advocates mussels as a delicious answer to food shortages. *New York Times,* 21 January.

Coffey, B.T. 1972. Aquaculture sustains LI Sound shellfishery. *Nat. Fisherman,* February.

Commercial Fish Farmer. 1974. "Power plant" fish production. 1(1):10-13.

———. 1975. The latest on fish culture in heated effluents. 1(3):34.

Connecticut General Statutes, Annotated. Corr. to 1975. Sect. 26.

Dawes, D.J. 1974. *On the mariculture of the Florida seaweed* Eucheuma isoforme. Florida Sea Grant Rep. 5, pp. 1-10.

Dedera, D. 1974. Jon Lindbergh: young man of the sea. *Exxon, USA,* 2nd quarter, pp. 2-6.

Doty, M.S. 1973. *Eucheuma farming for carrageenan.* Univ. Hawaii Sea Grant Advisory Rep. AR-73-02, pp. 1-21.

Dow, R.L. 1973. Fluctuations in marine species abundance during climatic cycles. *Marine Tech. Soc. J.* 7(4):38-42.

Engle, J.B. 1968. Shellfish culture in Japan and Korea. *Proc. Conf. Shellfish Cult. 1968.* Hauppauge, NY: Nassau-Suffolk Regional Planning Bd.

Epifanio, C.E., Logan, C.M., and Turk, C. 1976. *Culture of six species of bivalves in a recirculating sea water system.* Coll. Marine Stud., Univ. Del. Rep. DEL-SG-1-76.

Epifanio, C.E., and Mootz, C.A. 1976. Growth of oysters in a recirculating maricultural system. *Proc. Nat. Shellfish Assn.* 65:32-37.

Fabricant, F. 1976. Greenhouse oysters yield year-round crop. *New York Times,* 18 January.

Fallon, D.J., Brand, A.R. III, and Kilthau, A.C. 1973. *Pond culture of oyster seed in a controlled natural environment,* pp. 1-37. Stony Brook, NY: NYS Dep. Environ. Conserv.

Fish Farming International. 1975*a.* Firms farm the Pacific salmon in sheltered Puget Sound. 2(1):22-23.

———. 1975*b.* Controlled system farming of Maine lobsters. 2(4):12-15.

Fisher, A. 1975. Energy from the sea. *Popular Science* 207(1):62-5, 116.

Food and Agriculture Organization of the United Nations. 1974. *Yearbook of fishery statistics 1973.* Rome.

Gallese, L.R. 1976. US firms are hoping to net big profits in rapidly expanding fish-farm industry. *New York Times,* 6 January.

Geiser, J. 1976. NJ sea clammers, upset by new size rules. *Nat. Fisherman,* March.

Hanson, J.A., ed. 1974. *Open sea mariculture.* pp. 1-410. Stroudsburg, PA: Dowden, Hutchinson and Ross.

——. 1976. Why fool around with aquaculture? *Marine Tech. Soc. J.* 10(2):49-51.

Hedberg, H.D. 1976. Ocean boundaries and petroleum resources. *Science* 191:1009-18.

Hughes, J.T. 1968. Biologists breed lobsters selectively. *Comm. Fisheries Rev.* 30(10):20.

Huguenin, J.E. 1976. An examination of problems and potentials for future large-scale intensive seaweed culture systems. *Aquaculture* 9:313-42.

——, and Ryther, J.H. 1974. The use of power plant waste heat in marine aquaculture. *Proc. Marine Tech. Soc. 10th Annu. Conf.,* 23-25 September, Washington, DC.

Hurlburt, C.G., and Hurlburt, S.W. 1975. Blue gold; mariculture of the edible blue mussel *(Mytilus edulis). Marine Fisheries Rev.* 37(10):10-18.

Joyner, T. 1973. Salmon for New England fisheries, part I: historical background; part II: effect of the ocean environment on the high seas distribution of salmon. *Marine Fisheries Rev.* 35:1-8.

——, and Spinelli, J. 1969. Mussels: a potential source of high-quality protein. *Comm. Fisheries Rev.,* August-September.

Kane, T. 1970. *Aquaculture and the law.* Univ. Miami Sea Grant Tech. Bull. 2:1-98.

Kildow, J., and Huguenin, J.E. 1974. *Problems and potentials of recycling wastes for aquaculture.* MIT Rep. 74-27:1-170. Cambridge, MA.

Klopfenstein, D.R.I. 1975. A consultant's role in fish farming. *Fish Farming Int.* 2(4):26-27.

Kochiss, J.M. 1974. *Oystering from New York to Boston.* Middletown, CT: Wesleyan Univ. Press.

Komarek, C. 1973. Shellfish thrive in power plant lagoon. *New York State Environment* 3(4):11.

Kowalski, T., ed. 1974. *Floating breakwaters conference papers.* Marine Tech. Rep. Ser. 24:1-304. Kingston, RI: Univ. Rhode Island.

Landy, B.A. 1975. Constraints on aquaculture projects. *Marine Fisheries Rev.* 37(1):33-35.

Longwell, A.C., and Stiles, S.S. 1973. Oyster genetics and the probable future role of genetics in aquaculture. *Malacolog. Rev.* 6:151-77.

Loosanoff, V.L. 1971. Development of shellfish culture techniques. *Proc. Conf. on Artificial Propagation of Commercially Valuable Shellfish—Oysters,* 22-23 October 1969, Newark, DE, pp. 9-40.

——, and Davis, H.C. 1963. Rearing of bivalve molluscs. *Advances in Marine Biology I.,* ed. F.S. Russell, pp. 1-36. New York, NY: Academic Press.

MacDonald, C.R., Meade, T.L., and Gates, J.M. 1975. *A production cost analysis of closed system culture of salmonids.* Marine Tech. Rep. Ser. 41. Kingston, RI: Univ. Rhode Island.

Mahnken, C., and Joyner, T. 1973. Salmon for New England fisheries, part III: developing a coastal fishery for Pacific salmon. *Marine Fisheries Rev.* 35(10):9-13.

Mann, K.H. 1973. Seaweeds: their productivity and strategy for growth. *Science* 182:975-81.

Matthiessen, G.C. 1970. *A review of oyster culture and the oyster industry in North America.* Contrib. No. 2528. Woods Hole, MA: Woods Hole Oceanogr. Inst.

——, and Toner, R.C. 1966. *Possible methods of improving the shellfish industry of Martha's Vineyard, Duke's County, Massachusetts.* Edgartown, MA: Marine Res. Fdn. Inc.

Maurer, D. 1973. The development of closed system oyster culture. *Bull. Amer. Malacolog. Union,* February 1972.

McHugh, J.L., and Williams, A.D. 1976. Historical statistics of the fisheries of the New York Bight. Albany, NY: New York Sea Grant Institute.

National Fisherman. 1976. Delaware oyster beds revived. January.

Nelson, P.R. 1971. Four thousand years of fish farming. *NOAA* 1(4):22-23.

New Alchemists Journal. 1973, 1974. Woods Hole, MA: The New Alchemy Inst.

New Jersey Statutes, Annotated. 1975. Sect. 50.

New York Ocean Science Laboratory. 1974. *Annual Activities Report* 264-360.

New York Sea Grant Institute. 1974. *Program 1974-75.* Albany, NY.

New York State. Undated. *Offic. Compilation Codes, Rules, Regulations.* Part 271.

New York Times. 1976. Salmon "taught" route to Connecticut. 18 April: 1,36.

North, W.J. 1972. Mass-cultured *Macrocystis* as a means of increasing kelp stands in nature. *Proc. 7th Int. Seaweed Symp,* 8-12 August 1971, Sappora, Japan, pp. 394-99.

———. 1973. *Kelp habitat improvement project annual report 1972-3.* Pasadena, CA: Calif. Inst. Technol.

Pillay, T.V.R. 1976. *The state of aquaculture 1975.* FAO Tech. Conf. on Aquaculture, 26 May-2 June. 1976. Kyoto, Japan, pp. 1-13.

Rhoads, D.C. 1973. The influence of deposit-feeding benthos on water turbidity and nutrient recycling. *Amer. J. Sci.* 273:1-22.

Richards, A.F. 1976. Extracting energy from the oceans: a review. *MTS J.* 103(2):12.

Russell, J. 1974. Clam purification plant re-opens New Jersey beds to harvesting. *National Fisherman,* August.

Russell-Hunter, W.D. 1970. *Aquatic productivity.* London, England: Macmillan.

Rutherford, D. 1973. Genetic principles; systems engineering used in continent spanning lobster-farming project. *Amer. Fish Farmer* 4(9):4-6.

———. 1975. California shellfish hatchery supplies world market. *Fish Farming Int.* 2(2):26-29.

Ryther, J.H. 1973. *The use of flowing biological systems in aquaculture, sewage treatment, pollution assay, and food chain studies.* Woods Hole Oceanogr. Inst. Tech. Rep. 73-2. Woods Hole, MA.

Sammis, E.P. 1976. Baymen protest. *Long Island Press,* 15 January.

Shaw, W.N. 1971. Oyster's in 3-D. *NOAA* 1(4):6-9.

Soons, A.H.A. 1974. *Artificial islands and installations in international law.* Occas. Paper #22, Law of the Sea Inst., Kingston, RI: Univ. Rhode Island.

Terry, O.W. 1974. *The New York aquaculture program—past, present, and future.* New York Sea Grant Inst. Rep. NYSSGP-RS-74-018. Albany, NY.

The Aquaculture Newsletter. 1975. PSE and G grows trout in thermal effluent. Vol. 20.

Vaughn, J.M., and Ryther, J.H. 1974. Bacteriophage survival patterns in a tertiary sewage treatment-aquaculture model system. *Aquaculture* 4:399-406.

Wacker, R., Jr. 1970. LI firm nearly ready to market first greenhouse-raised oysters. *National Fisherman,* October.

Wells, W.F. 1920. Decline of the oyster industry. *Conservation Comm. 9th annu. rep.* (for the year 1919), pp. 56-61. Albany, NY: Dep. of Conserv.

Weyl, P.K. 1970. *Oceanography.* New York, NY: Wiley.

Wilcox, H.A., 1975. The ocean food and energy farm project. Paper presented at 141st AAAS annual meeting, 29 January, New York, NY.

Wildman, R.D. 1971. Those versatile weeds from the sea. *NOAA* 1(4):13-17.

Williams, S. 1975. Conflict of interest and its resolution as factors in the commercialization of aquaculture in the Americas. *Marine Fisheries Rev.* 37(1):48-51.

Yergin, D. 1975. Britain drills—and prays. *New York Times Magazine,* 2 November.

The Atlas Monograph Series

1 **Hydrographic Properties** Malcolm J. Bowman, with cartographic assistance by Lewis D. Wunderlich, Marine Sciences Research Center, SUNY

2 **Chemical Properties** James and Elizabeth Alexander, Institute of Oceanography, SUS Florida

3 **Circulation** Donald Hansen, Atlantic Oceanographic and Meteorological Laboratories

4 **Tides** R.L. Swanson, MESA New York Bight Project

5 **Wave Conditions** Not to be published

6 **Storm Surge** N. Arthur Pore and Celso S. Barrientos, National Weather Service

7 **Marine Climatology** Bernhard Lettau, National Science Foundation, William A. Brower, Jr. and Robert G. Quayle, National Climatic Center

8 **Regional Geology** Not to be published

9 **Gravity, Magnetics, and Seismicity** James R. Cochran and Manik Talwani, Lamont-Doherty Geological Observatory

10 **Surficial Sediments** George Freeland and Donald J.P. Swift, Atlantic Oceanographic and Meteorological Laboratories

11 **Beach Forms and Coastal Processes** Warren E. Yasso, Columbia University, and Elliott M. Hartman, Jr., Westchester Community College

12 **Plankton Production** Charles S. Yentsch, Bigelow Laboratory for Ocean Sciences

13 **Plankton Systematics and Distribution** Thomas C. Malone, City University of New York

14 **Benthic Fauna** John B. Pearce and David Radosh, National Marine Fisheries Service

15 **Fish Distribution** Marvin D. Grosslein and Thomas Azarovitz, National Marine Fisheries Service

16 **Fisheries** J.L. McHugh, Marine Sciences Research Center, SUNY, and Jay J.C. Ginter, NY Sea Grant Institute

17 **Aquaculture** Orville W. Terry, Marine Sciences Research Center, SUNY

18 **Artificial Fishing Reefs** Albert C. Jensen, NYS Department of Environmental Conservation

19 **Recreation** E. Glenn Carls, University of Waterloo, Ontario

20 **Port Facilities and Commerce** Alfred Hammon, The Port Authority of New York and New Jersey

21 **Sand and Gravel** John S. Schlee, US Geological Survey, with a section by Peter T. Sanko, NY Sea Grant Advisory Service

22 **Jurisdictional Zones and Governmental Responsibilities** Paul Marr, SUNY at Albany

23 **Demographic Patterns** Charles Koebel and Donald Krueckeberg, Rutgers University

24 **Transportation** Richard K. Brail and James W. Hughes, Rutgers University

25 **Electricity Generation and Oil Refining** H.G. Mike Jones, Harold Bronheim, and Philip F. Palmedo, Brookhaven National Laboratory

26 **Waste Disposal** M. Grant Gross, Chesapeake Bay Institute, Johns Hopkins University

27 **Water Quality** Donald J. O'Connor, Robert V. Thomann, and Henry J. Salas, Hydroscience, Inc.

28 **Air Quality** Volker A. Mohnen, Atmospheric Sciences Research Center, SUNY

29 **The Lower Bay Complex** Iver Duedall, Harold O'Connors, and Robert Wilson, Marine Sciences Research Center, SUNY

30 **Industrial Wastes** James A. Mueller and Andrew R. Anderson, Manhattan College

31 **Marine and Coastal Birds** Marshall A. Howe, Roger B. Clapp, and John S. Weske, US Fish and Wildlife Service

32 **Environmental Health** Joseph M. O'Connor, Chun Chi Lee, and Merril Eisenbud, Institute of Environmental Medicine, NYU Medical Center