To Increase Oyster Production in the Northeastern United States

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Introduction

Estuaries and bays of the northeastern United States currently yield about 5 million bushels of American oysters, *Crassostrea virginica*, per year (USDC, 1980), a quantity which is only about one-sixth as large as the annual yield in the late 1800's, when the yield was at its peak (Lyles, 1969). In 1979 the landed value of oysters was $34 million (USDC, 1980). Despite their value, much of the oyster industry is depressed economically, and an atmosphere of lassitude hangs over a number of oystering communities. The drop in yield, which resulted from a reduction in oyster abundance, was unnecessary and could be reversed at small expense. The process of reversal requires that the quantities of seed oysters be increased. Afterwards, market promotion needs to be accelerated and production costs lowered.

The abundance of seed oysters depends on the number of oyster larvae in the water, and the condition of seed beds for receiving the larvae and permitting the oyster spat and seed to survive. The number of larvae that can set is proportional to the area of clean shell surfaces available. Beds in which the shells or oysters are partially covered with silt or fouling organisms, or are sparce will receive much less spat than those having a continuous layer of clean shells or oysters. Heretofore, in the history of research on the American oyster, the condition of seed beds has been nearly ignored and thus little about it appears in the literature. A few surveys of beds have been made with oyster dredges and hand-held poles, but these implements are inadequate for this purpose; any published results are vague and also optimistically biased (Engle, 1948; Butler, 1949; Maurer et al., 1971). Thus, the important topic of seed bed condition is nearly a blank in the history of research on the American oyster.

Scuba gear is required for accurate determinations of the condition of oyster beds because it permits visual and hand inspection of the bottom. Using scuba gear, I surveyed the condition of seed beds in the northeastern United States (Connecticut, New Jersey, Delaware, Maryland and Virginia) in the 1970's. Many beds were not in good condition to receive oyster sets. This paper reviews production and economic trends in the oyster industry, describes the causes of decline and present condition of the seed beds, and offers a management proposal for increasing oyster production and revitalizing the industry in these states.

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Indicator Statistics for the Oyster Industry

Historical Production Trend

Annual oyster yields from Narragansett Bay, Long Island Sound, Delaware Bay, Chesapeake Bay, and other areas of the northeast declined to about 11,300 metric tons (25 million pounds) of meat (= 5 million U.S. standard bushels) during the 1960's and 1970's (USDC, 1980) from the peak of about 68,000 metric tons (150 million pounds) of meat (= 31 million bushels) in 1890 (Lyles, 1969) (Fig. 1). Chesapeake Bay has yielded from slightly above 50 percent (in the 1930's) to nearly 95 percent (in the 1960's) of the oysters; Narragansett Bay, which had received most of its seed from Connecticut, has yielded negligible quantities since the early 1940's.

Recent Production and Economic Trends

Some oyster statistics for the 1960's and 1970's are shown in Figure 2. Prices are shown in uncorrected current dollars and in inflation-corrected dollars, using 1967 as the base year.

Oyster landings were variable, ranging from about 20 to 30 million pounds of meat per year. A single trend line shows that landings averaged about 25 million pounds per year and were increasing slightly.

Landed prices (inflation corrected) of oyster meat fell substantially. A single trend line shows that the 1979 price, which averaged about $0.55 per pound, was 30 percent lower than early 1960's prices, which averaged about $0.78 per pound. If the data set is divided into two groups, 1960-69 and 1969-79, then a fitted line for the first group has a steeper slope than the single trend line, and a fitted line for the second group has almost a zero slope. Thus, landed prices fell rapidly up to 1969, but thereafter were about level.

In contrast to landed prices, retail prices (inflation corrected) of oyster meat rose slightly: A single trend line shows that 1979 prices, which averaged about $1.68 per pound, were 10 percent higher than early 1960's prices, which averaged about $1.52 per pound. If this data set is divided into two groups, 1960-69 and 1969-79, a fitted line for the first group has a steeper slope than the single trend line, and a fitted line for the second group has almost a zero slope. Thus, prices rose until 1969, but thereafter were nearly level.

A comparison of landed and retail oyster prices shows that the differences between them widened from 1960 to 1979. Thus, the costs to prepare landed oysters for retailing must have increased. Since landed prices fell substantially and retail prices rose only slightly, most of the increase had to have been absorbed by the fishermen and only a small part of it by consumers.

Production Costs

Shoppers find that oysters are relatively expensive in comparison with fish, red meats, and poultry. In supermarkets, oysters are commonly sold as shucked meats, packed fresh and chilled in 8-ounce containers. In this form, oysters are as convenient to handle as most other packaged foods. In 1979, supermarkets in New Jersey sold these containers of oysters for an average of $1.92 each. Thus, on a per pound basis, the retail price of oysters averaged $3.84. The price was $1.32 and $2.06 per pound, respectively, above the average retail prices of flounder (fillets) and beef (chuck roast). Oysters were less expensive, however, than some other seafoods. For example, the retail price of sea scallops was $1.17 per pound above that of oysters (Table 1). Presumably these prices were about the same throughout the northeastern United States.

The cost of producing oysters, flounder, sea scallops, and beef were separated into 1) landed costs and 2) costs from landing to retailing, using data from 1979. The two sets of costs were then compared (Table 1). These other foods were selected for comparison with oysters because, similar to oysters, the entire portion purchased by shoppers can be consumed.

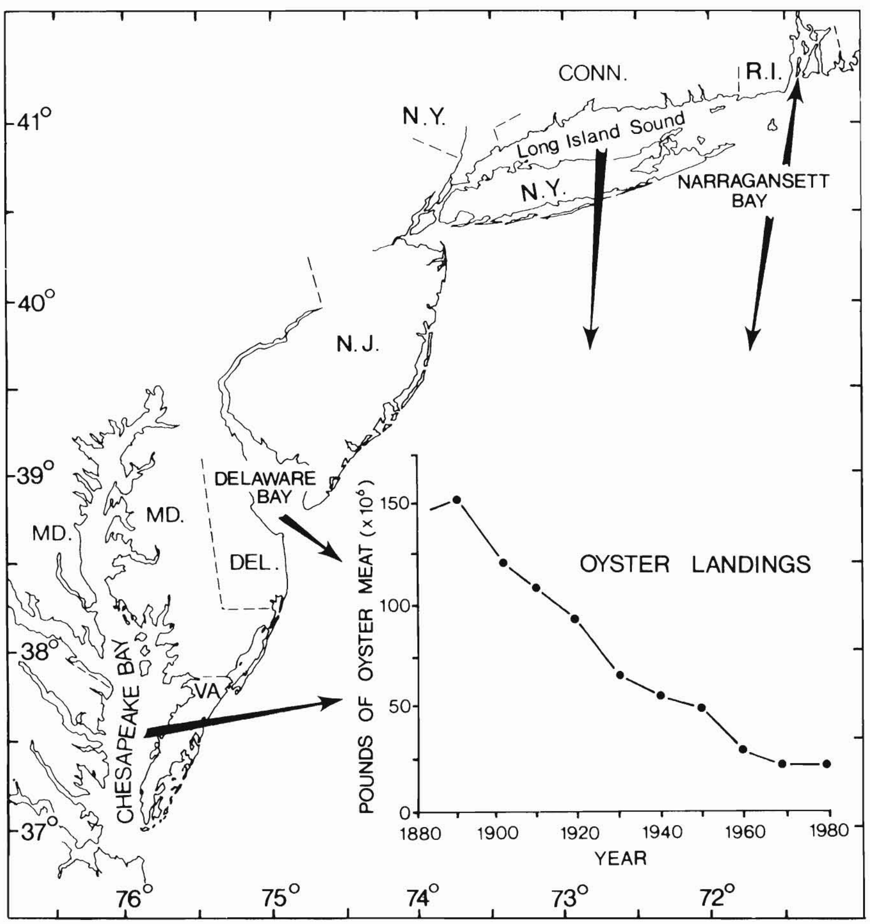

Figure 1.—Historical landings of the American oyster in the Northeastern United States, Narragansett Bay to Chesapeake Bay (Lyles, 1969; U.S. Department of Commerce Annual Landings Summaries, 1970 and 1980; landings from Connecticut and Delaware in 1970 and 1980 were estimated).

Table 1.—Comparisons of landed prices, retail prices, and differences between landed and retail prices of four protein foods in 1979.

	Prices ($) per pound of edible meat		
Commodity	Landed[1]	Retail[2]	Difference
Oysters[3]	1.25	3.84	2.59
Flounder (fillet)[4]	1.07	2.52	1.45
Sea scallops	3.72	5.01	1.29
Beef (chuck roast)[5]	1.08	1.78	0.70

[1]Sources: For oysters, sea scallops, and flounder from Curr. Fish. Stat., U.S. Dep. Commer., NOAA, 1980. Annual state landings for 1979. For beef from U.S. Dep. Agric. Stat. Yearb. 1979.

[2]From *Asbury Park Press*, New Jersey.

[3]The landed price is for unshucked oyster meat; the retail price is for shucked, standard-grade oysters packed in 8-ounce containers.

[4]A medium-sized flounder yields 35-40 percent of fillet; thus, the landed price of $0.40 per pound of whole fish was multiplied by 2.67 to obtain the landed value of the portion sold in retail markets.

[5]A steer yields about 55-60 percent of meat which is later sold in retail stores, and the remainder is discarded; thus, the value of $0.62 per pound which farmers received for live cattle was multiplied by 1.74 to obtain the value of $1.08 per pound. The differences between landed and retail prices of the more expensive cuts of beef are wider than that for chuck roast.

The landed price of oysters averaged $1.25 per pound, or only $0.18 and $0.17, respectively, above the landed prices of flounder and beef. Thus, at this point, oysters were competitive with them; the landed price of sea scallops was roughly three times that of the others. Afterwards, however, oysters were not competitive. The production cost of oysters after they were landed, i.e., $2.59 per pound, was much higher than similar costs of flounder, sea scallops, and beef. The cost per pound of oysters was $1.14, $1.30, and $1.89, respectively, above those of the other three commodities.

The relatively high cost of producing oysters is the result of three factors. One is that oysters require a large amount of handling in processing plants. After being landed on docks, oysters are delivered to a processing plant, where they are shucked by hand, washed in a water tank, packed in 8-ounce containers (11-14 standard grade oysters per container) by hand, a lid is sealed on the can, and then the cans are packed in cartons by hand. The amount of handling is much larger than that for filleting flounder and cutting up beef, and packing them in cellophane for retailing; sea scallops, which are normally shucked aboard the vessels which gather them, require little handling after they are landed to prepare them for retailing.

Another factor is that oysters are a seasonal commodity. Usually the boats and shucking plants are idle between seasons. Thus, the cost of boats and plants per unit of oysters handled is higher than it would be if oysters were a year-round commodity. The industry also slows down or ceases during storms and when ice prevents fishing, which adds similarly to unit costs.

A third factor is that the industry now operates at far below its capacity, as would be anticipated in view of the huge drop in production. Usually, oyster boats and plants, many of which were constructed near the turn of the century, and seafood trucks are only partially loaded with oysters, making the cost per unit substantially

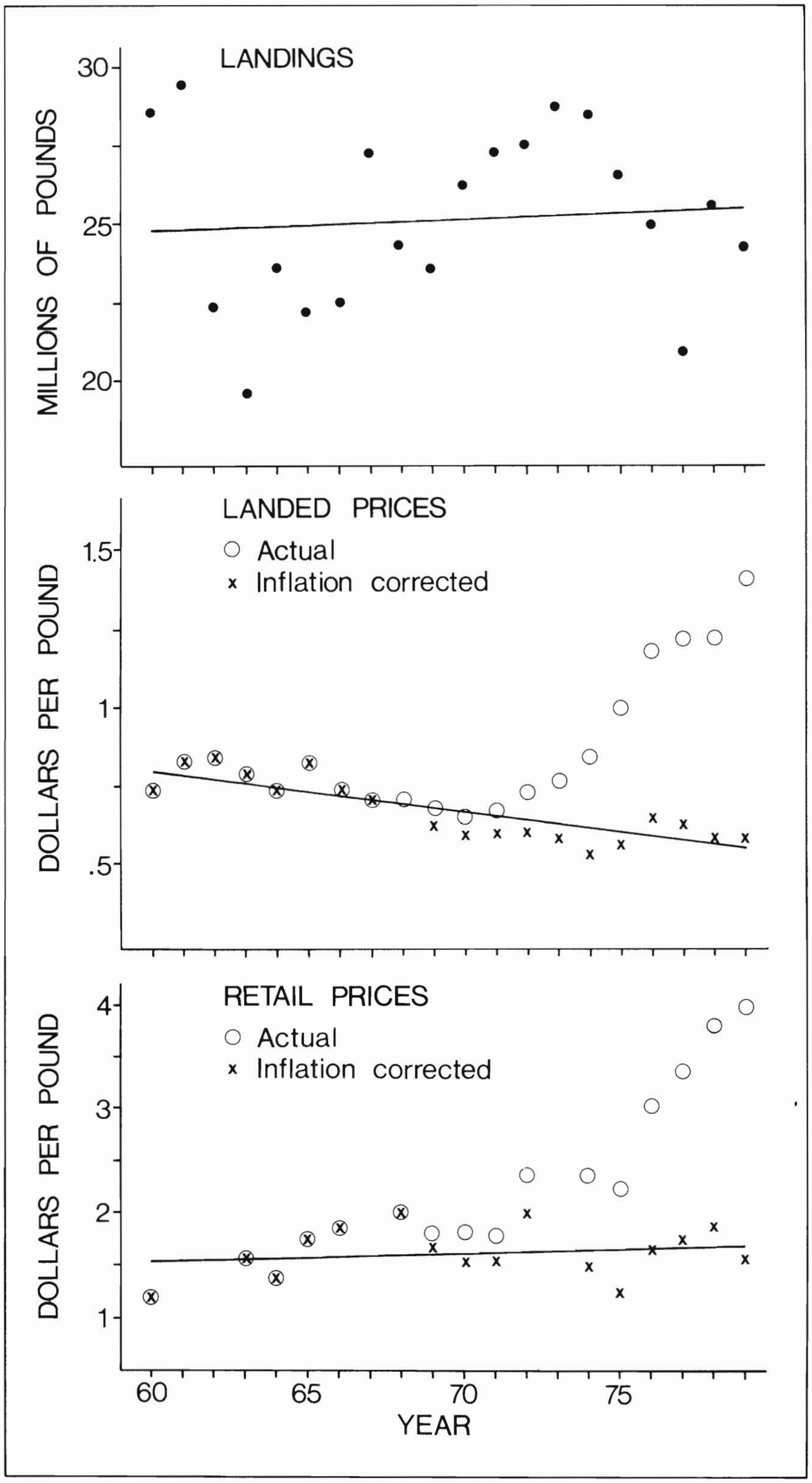

Figure 2.—Trends in oyster landings, landed prices, and retail prices, 1960-79 (trend lines fitted mathematically using the least squares method). Landings and landed prices were from U.S. Department of Commerce Annual Landings Summaries; retail prices were from the *Asbury Park Press*, N.J.

larger than if they were fully loaded. Moreover, boats work longer each day to obtain state limits of oysters than they would have to if more oysters were available on the beds.

Nevertheless, the cost of producing oysters between landing and retailing has been relatively high for many years, and probably since the commercial industry began. Landed and retail prices were compared at about 5-year intervals from 1935 to 1979. The differences between the prices were consistently wide. As examples, in 1935 when fishermen received only about $0.09 per pound for oysters (unshucked meats), the retail price of oysters (shucked meats in chilled 8-ounce containers) averaged $0.35 per pound; in 1955, when fishermen received $0.47 per pound for oysters, the retail price averaged $1.06 per pound. A comparison of retail prices of oysters (shucked meats in chilled 8-ounce containers), flounder, and beef from 1935 to 1979 showed that those of oysters were consistently much higher than those of the other two; oyster prices were usually 1.5-3 times those of flounder and beef (landed prices of oysters from Lyles (1969) and USDC (1970-79); retail prices from *Asbury Park Press*, New Jersey.)

Oysters cost relatively little to raise on the beds. Kennedy and Breisch (1981) reported that the State of Maryland paid an average of about $1.31 million per year for cultural operations (purchasing and spreading shells and transplanting seed oysters) to produce market oysters on its beds during the 1970's: Oyster fishermen, private planters, and processors paid about 60-80 percent of the amount; subsidies from state funds, the remainder. Oyster production in Maryland averaged about 16 million pounds of oyster meat per year during the 1970's (USDC, 1970-79). Thus, it cost about $0.08 to raise each pound to market size on the beds. Korringa (1976) reported that it cost about $1.25 to raise each bushel of oysters to market size on the private beds in Connecticut during the early 1970's. Presumably, the cost was about the same for New York. Oysters in Connecticut and New York usually yield about 7.5 pounds of meat per bushel. Thus, the cost per pound of oyster meat was about $0.16½; these oysters also sell for a higher retail price than those from Delaware Bay and Chesapeake Bay.

Heretofore, it has been commonly believed that the high retail prices of oysters were a result of the consumer demand exceeding the supply. Indeed, in their paper which was a broad review of literature on the oyster, Kennedy and Breisch (1981) implied that this was true. The data presented above show that instead high production costs were responsible.

Consumer Demand

The consumer demand for a commodity can be estimated by analyzing trends in production and retail prices. From 1969 to 1979 the demand for oysters appears to have been good and may have increased because the trends of production and retail prices (inflation corrected) rose slightly (Fig. 2).

Description of Seed Beds

Area of Original Beds

The total area of the original seed beds in the northeastern United States has never been determined accurately. A rough estimate obtained from the available literature is presented in Table 2.

The seed beds in Long Island Sound are mainly leased by oyster companies, whereas those in Delaware Bay and Chesapeake Bay are nearly all public and are under the management of state administrators of estuarine resources.

Environment of Beds

The seed beds are shallow, mostly 1-6 m (3-20 feet) deep, and expansive, commonly more that 40 hectares (ha), or 100 acres, in area. The environment of the seed beds in Long Island Sound, most of which have salinities of 25-28‰, differs from that of the seed beds of Delaware Bay and Chesapeake Bay which have salinities of about 5-15‰.

In Long Island Sound, most of the seed beds lie along the Connecticut coast; the remainder are in the mouths of a few Connecticut rivers. Nearly all the seed beds along the Connecticut coast were man-made. The beds were developed during the late 1800's and early 1900's by oyster growers who spread oysters and shells over bottoms which had been otherwise barren; the bottoms consisted of hard sand and sand-gravel. The oysters were imported from Delaware Bay and Chesapeake Bay, and spread on the bottom for growth and later harvest. The clean shells of shucked

Table 2.—Estimated total area of original oyster seed beds in the northeastern United States.

Estuary	Area: Hectares	Acres	Source
Long Island Sound			
Connecticut[1]	5,600	14,000	MacKenzie (1981)
Delaware Bay			
New Jersey	4,000	10,000	Haskin and Tweed (1976)
Delaware	480	1,200	Maurer et al. (1971)
Chesapeake Bay			
Maryland	50,000	124,000	Brooks (1891)
Virginia[2]	17,400	43,500	Haven et al. (1981a, b)
Total[3]	78,000	192,000	

[1]Includes areas of private beds which were developed by oyster growers.
[2]Includes areas of public bottom which currently have oysters, shelly sand, shelly mud, or buried shells, establishing that they support oyster beds now or did so in the past. The total does not include any leased beds that may have originally been seed beds and is a minimum figure.
[3]Total does not include former seed beds in the Hudson River or Raritan Bay and those in a number of coastal bays.

oysters, which were initially available in huge quantities, were spread on seed beds to collect spat in July each year. Gradually, the practice of importing oysters declined and eventually it ceased. Thereafter, all seed oysters originated on Connecticut beds. The spat set on the shells and growing oysters. In the relatively high salinity along the Connecticut coast, fouling organisms (slipper shells, *Crepidula fornicata* and *Crepidula plana*; barnacles, *Balanus eburneus* and *Chthamalus fragilis*; bryozoa, *Schizoporella unicornis*; and others) and predators (starfish, *Asterias forbesi*; oyster drills, *Eupleura caudata* and *Urosalpinx cinerea*; and crabs, *Cancer irroratus* and xanthids) are abundant. The fouling organisms quickly cover clean shells. For this reason, the shells can rarely collect oyster sets if left on the bottom past the first year; thus, oyster growers have to spread clean shells on seed beds each summer. At present, most beds have shell deposits about 30-60 cm (1-2 feet) deep immediately beneath the bottom surface; the shells are the remains of oysters along with shells buried by storms and hurricanes.

In Delaware Bay and Chesapeake Bay, the beds are nearly all natural, but the yields of many have increased by periodic plantings of oyster shells and seed by public agencies. The oysters grow on oyster shell deposits, some of which are as much as 7 m (23 feet) thick. Oyster beds originated on estuarine bottoms which then were much deeper; afterwards, successive oyster generations set and grew on the older oysters and eventually killed them by overgrowth. The elevation of the beds gradually rose, and the shells of the dead oysters accumulated underneath. Fouling organisms on these beds are much less abundant than they are on beds in salinities above 15‰. Thus, oyster larvae usually can set on oysters and shells which have been on the beds for a year or more. Predators on the seed beds include the bay anemone, *Diadumene leucolena*, which consumes oyster larvae (MacKenzie, 1977c; Steinberg and Kennedy, 1979), and crabs (*Callinectes sapidus* and xanthids), and fish which consume mostly spat and small seed (Van Engel, 1958; McDermott, 1960; Haskin and Tweed, 1976). Oysters grow more slowly than in higher salinities in the same estuaries. It is believed that these beds were covered with dense oyster populations when the Europeans first colonized the northeastern United States.

In areas where salinities are above 15‰, oyster drills and diseases which kill oysters are more prevalent. Little control of predators is practiced in Delaware Bay or Chesapeake Bay.

Setting Potential on Beds

The annual frequency of commercial-density setting of oysters on seed beds in various estuaries has been determined from: 1) Counts of spat on test shells placed on the beds by public agencies, 2) noting the presence of spat on the beds, and 3) records of annual yields of seed oysters from beds in good condition. Commercial-density setting is somewhat irregular in Connecticut (MacKenzie, 1981) and New Jersey and Delaware Bay (Haskin and Tweed, 1976), but it is usually regular in Chesapeake Bay (Engle, 1956; Krantz and Meritt, 1977; Haven et al., 1978). However, Maryland had a series of poor setting years on its beds following tropical storm Agnes in 1972, but setting was good in 1980 and 1981. The James River, Virginia, received light sets from 1961 to 1976 (Haven et al., 1978); it received a good set in 1981. Oyster larvae set randomly wherever clean shells or oysters are present on beds.

The size of the spawning (breeding) stock has little correlation with the number of ready-to-set larvae or spat produced. This fact is illustrated by data from Long Island Sound, where good sets occurred when spawning stocks were relatively small and vice versa (Fig. 3). The number of ready-to-set larvae produced is chiefly governed by conditions in the water for larval survival and growth. Obviously, a minimum size of spawning stock is required to produce a good set, but this has never been determined; apparently, the spawning stock in the James River fell below the minimum for a number of years (see next section). Female oysters become mature and spawn for the first time in their second year when 3.0-4.7 cm (1.2-1.8 inches) long (Galtsoff, 1964).

Decline in Abundance of Seed Oysters

The causes of declines in oyster abundance on the seed beds in each estuary, as reported in the literature, are summarized below.

Along the Connecticut coast, Long Island Sound, the area of bottom that had clean shells or oysters on which oyster larvae could set has become much smaller. The industry spread increasingly smaller amounts of shells on beds because increasingly larger percentages of market oysters were sold in the shell and fewer as shucked meats, and thus shells became less available; by the early 1970's, a little less that one-tenth as many shells were spread each summer as in the late 1800's (MacKenzie, 1977a). In addition, severe storms and hurricanes occasionally buried many oysters (Sweet, 1951; MacKenzie, 1970). Seed oysters became more difficult to raise for several years after 1957 because the abundance of starfish which had been low for a number of years exploded in that year; the starfish remained abundant and killed quantities of seed oysters until the industry brought them under control beginning in 1966 (MacKenzie, 1981). The industry also declined because some beds used to hold market oysters in Connecticut became polluted.

In the New Jersey portion of Delaware Bay, oysters on the seed beds were originally gathered by dredging with sailing vessels (Rolfs, 1971). The fishermen returned shells to the bottom while retaining seed oysters. Apparently, oyster supplies endured on many beds. In about 1945, motors replaced sails to power the vessels; afterwards, the vessels could remove more oysters from the

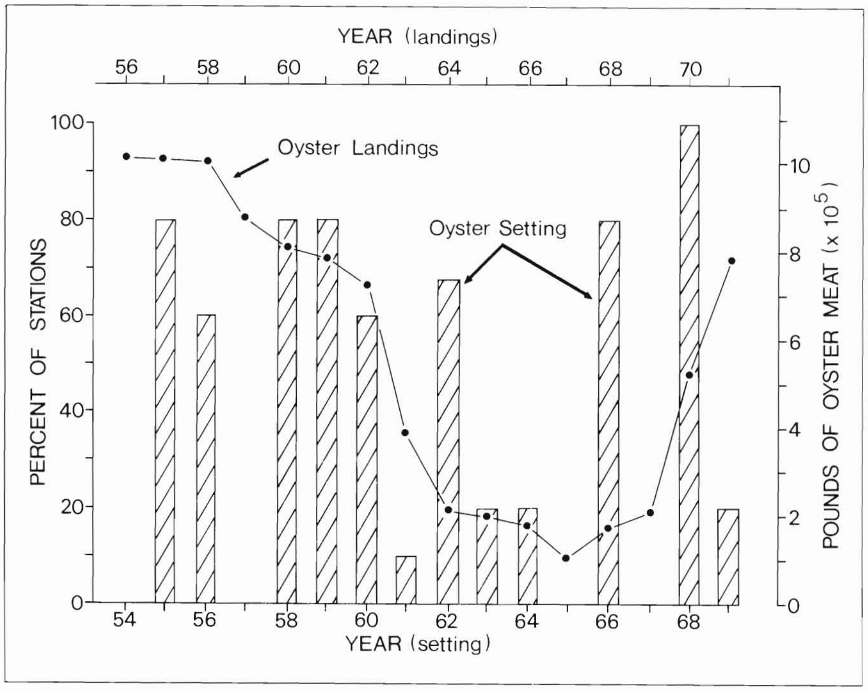

Figure 3.—A comparison of the setting potential of oyster spat (histobars) with the size of the spawning stock of oysters (solid line) in Connecticut, 1954-69. The two sets of data were adjusted to coincide. The percentages of 10-12 stations of test shells having successful commercial oyster sets (i.e., at least 10 spat per shell) show the setting potential of spat (from MacKenzie, 1981). The magnitude of oyster landings from New York was proportional to the size of the spawning stock in Connecticut; most oysters that were marketed in New York had set, grown, and spawned in Connecticut and were later transplanted to New York for a year or two for final growth before being marketed.

beds and reach areas that had been little fished previously. Gradually, the oyster supplies fell (Muldoon, 1981). A drought began in 1949 and continued into the 1960's and salinities over the beds rose substantially; hence, the abundance of fouling organisms growing on oysters and shells increased, reducing spatfall densities. Oyster drills also became more abundant, reducing spat survival. The numbers of oyster larvae and spat on test shells in bags were about equal to those before the drought. In 1968-69 the drought ended and salinities fell. The abundances of fouling organisms and oyster drills decreased and seed abundance increased (Haskin and Tweed, 1976).

In the Delaware portion of Delaware Bay, the history of the seed beds somewhat parallels that of New Jersey. Seed was originally gathered by dredging with sailing vessels, but after about 1945 the vessels became powered by motors and seed abundance declined as in New Jersey. The beds were also affected by drought from 1949 into the 1960's, with a return to normal conditions after 1968-69. Oyster fishermen were allowed to include shells with their seed oysters, however, and the state spread fewer shells on the beds as cultch for oyster larvae than did New Jersey. For these reasons, oyster stocks were not sustained as well as in New Jersey (Maurer et al., 1971). Changes in water circulation from channel dredging and pollution also may have contributed to lower seed abundance (Maurer and Price, 1969).

In the Maryland portion of Chesapeake Bay, oysters have always been gathered by dredging, mostly by sail, and tonging. In the late 1800's the fleet of dredging boats was so large that oyster abundance on beds declined; many beds were fished almost to depletion (Galtsoff, 1943, 1956). In addition, silt accumulated on the beds (Sieling, 1970; Lippson, 1973); many beds in the northern end of the bay were completely covered and thus destroyed by silt (Sieling, 1970). Beginning in 1960 and still continuing, Maryland has had a highly successful program underway to rehabilitate many depleted beds by spreading clean shells over them (Sieling, 1970; Kennedy and Breisch, 1981).

In the Virginia portion of Chesapeake Bay, most production of seed oysters is from the James River; it is the only seed area that will be described here. Seed is gathered from a number of beds in the river by tongers who sell it to private growers, who then plant it on their leased beds in other parts of the state or in Maryland; some tongers plant seed on their own leases. The history and causes of decline are summarized from Haven et al. (1978) as follows. Seed oyster production from the river was 2-3 million bushels a year from 1947 to 1959. Production fell sharply afterwards, however, and averaged only about one-third as much annually from 1963 to 1975. The original cause of the decline is believed to be the loss of nearly all the spawning stock of the oyster larvae near the mouth of the river from a disease termed MSX. The potential for setting, as determined from test shells, declined substantially on all beds. Other factors which contributed to lower abundance of seed oysters were the continuous gathering of the oysters by fishermen and siltation, and perhaps changes in river flow and pollutants.

Heretofore, surveys to determine the condition of seed beds for oyster setting in these estuaries have been rarely made by shellfish biologists. Moreover, they used only standard oyster dredges and hand-held poles for surveying. Thus, little detailed in-

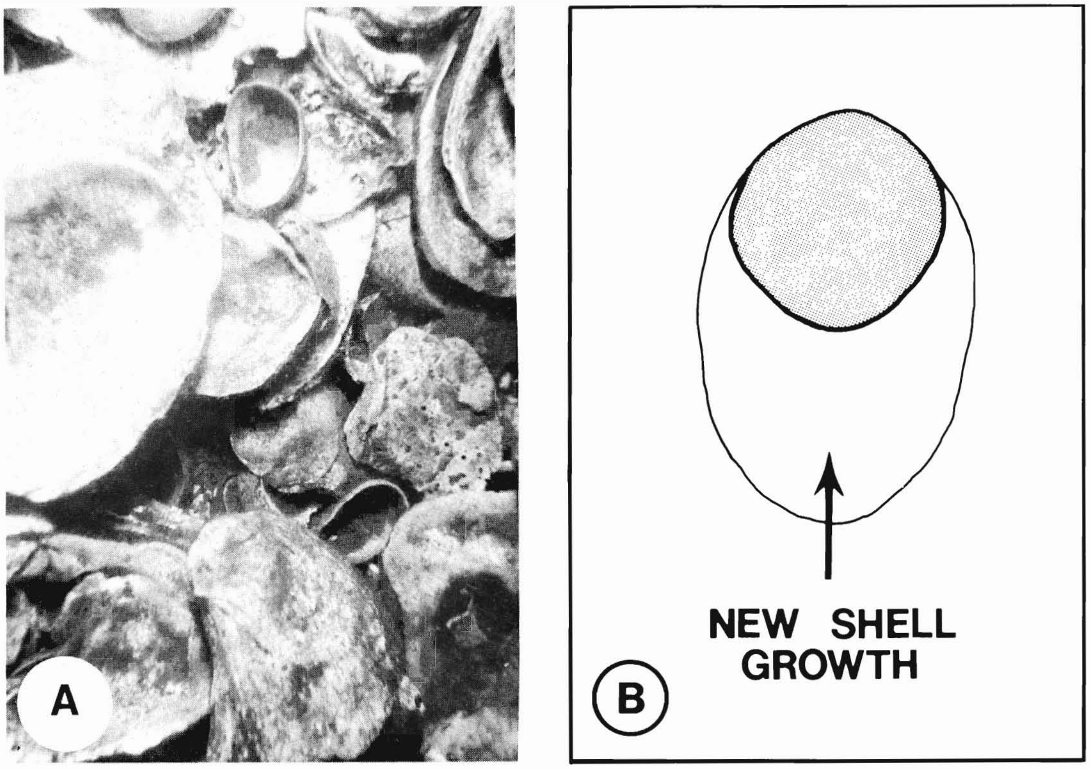

Figure 4.—(A) Bed prepared with clean shells spread immediately before the setting season and in ideal condition for receiving an oyster set in Connecticut. (B) Diagrammatic drawing of a seed oyster, about 5 cm (2 inches) long, at the beginning of setting season. The new shell growth of the oyster, being clean, is an excellent setting substrate for oyster larvae; the older shell growth of the oyster (darkened area) is often an inferior substrate because it may have a cover of fouling organisms or silt.

formation was obtained. The use of dredges cannot accurately determine the density of shells on the bottom, or whether silt covers setting surfaces because silt washes out before a dredge reaches the water surface. The use of poles cannot detect silt deposits less than perhaps 5 cm (2 inches) thick.

Scuba Surveys of Seed Beds, 1970-75

Using scuba gear I made surveys of the condition of seed beds for receiving oyster sets in Long Island Sound (MacKenzie, 1977a) and Delaware Bay and Chesapeake Bay (MacKenzie, 1974) during the normal oyster setting period. The beds selected for surveying had previously been among the largest and most important in each estuary. I swam across the central areas of the beds and examined their condition for about 15 minutes. In Delaware Bay, visibility was poor, and thus the condition of the beds had to be examined by hand and by bringing material to the surface for examination. Photographs using a hand-held camera were taken to illustrate the condition of the beds in Connecticut, Delaware, Maryland, and Virginia, but none were taken in New Jersey. As part of the surveys, some of the beds which I had examined were sampled with an oyster dredge. In every instance, the dredge delivered clean oyster shells from beds where shells were covered with silt or mud. While making the surveys, I noted areas that appeared to be close to ideal for collecting spat and producing seed oysters.

Ideal Condition of Seed Beds

The substrate required for the setting of oyster larvae is a hard surface, such as that of an oyster shell, clean of silt and fouling organisms (Galtsoff, 1964). In Long Island Sound, the ideal setting environment is a continuous layer of clean oyster shells, in a layer 3-5 shells deep; shells that are 7.5-12.7 cm (3-5 inches) long are ideal (Fig. 4a). In Delaware Bay and Chesapeake Bay, the ideal setting environment is a continuous layer of clean shells, 5-10 cm (2-4 inches) long, or growing oysters. Smaller shells are more desirable (and also much more available) in these two bays because the oysters are transplanted only once, if at all. Smaller shells collect fewer spat and thus oyster clusters are smaller, a desirable feature because oysters can grow in a better shape. In Long Island Sound, oysters are normally transplanted two or three times, a process which reduces the sizes of the clusters. Growing seed oysters are good substrate for larvae because their new growth margin provides a clean setting surface, even if the remainder of the shell is covered by fouling organisms (Fig. 4b). On beds covered by less than about 2 m (6 feet) of water, shells that are 2.5 cm (1 inch) long and smaller are a poor substrate for larvae because they are in nearly constant motion during windy periods and thus small spat attached to them cannot survive (St. Amant, 1959; MacKenzie, 1977b; Haven et al., 1978; Gunter, 1979). Beds in ideal condition have low numbers of predators of larvae and spat.

Beds with high densities of oysters have much less silt than beds that have had only oyster shells on them for some time. Oysters tend to keep silt from accumulating because they produce external currents while transporting water through their gills for respiration and food collecting, and occasionally squirting away pseudofeces and silt; moreover, they concentrate silt when producing pseudofeces. The presence of certain associated invertebrates which are more numerous on beds of live oysters also reduces silt accumulation.

Table 3.—Condition of oyster seed beds in the northeastern United States.

State	No of beds examined	Dates examined	Condition of beds	Specific remarks
Connecticut[1]	2,000 ha (5,000 acres)	July to October 1971	Nearly all very poor	Former seed beds were examined; most had shell deposits about 30-60 cm (1-2 feet) deep buried in the bottom. Sixty percent of the area had at least 75 percent cover of surface shells, but they were completely covered with fouling organisms which prevented oyster setting. Twenty percent of the area was covered with silt up to 5 cm (2 inches) deep; some of it had surface shells beneath the silt. The remaining area had few surface shells and silt.
New Jersey	Several	13 July 1971 and earlier years	Fair	Beds in the main part of seed area were clean of silt, but were partially covered by algae, barnacles and bryozoa. They also had large bare areas with relatively little substrate for oyster larvae A bed inshore of the main seed area had many shells, but most were covered by silt
Delaware	5	7 July 1971	Poor to fair	Beds had quantities of surface shells, but they were mostly covered by silt. Two beds had seed oysters growing on upper parts of shells that were exposed to water
Maryland[2, 3]	14	8-11 July 1971	Fair to excellent	Beds had quantities of surface shells. The condition of some beds had been improved by towing oyster dredges over them. The dredged beds were mostly clean of silt, but the others had some silt on them. The beds contained many bay anemones which prey on oyster larvae.
Virginia (James River)	4	9 July 1971	Fair to good	Beds in the main part of the seed area were in only fair condition, because quantities of silt were present; silt extended almost to the top of the shells and thinly covered their upper surfaces. The density of seed oysters on which larvae could set was low. A bed farthest upriver was in good condition. The beds may have had bay anemones.

[1]Source: MacKenzie (1977a).
[2]Source: MacKenzie (1974).
[3]Source: MacKenzie (1977c)

Condition of Seed Beds in Each Estuary

The scuba observations of seed beds in each estuary showed that the areas on the beds available to oyster larvae for setting were much smaller than they must have been when the beds were covered with dense oyster populations and oyster production was at its peak. Moreover, the condition of many beds was so poor that they could not receive oyster sets. Thus, from an equivalent number of oyster larvae, the quantity of spat that could set in recent years must be much smaller than set then.

In Long Island Sound, the condition of nearly all beds was too poor to receive oyster sets (Table 3; Fig. 5). In the early 1970's, oyster growers were preparing only relatively small areas out of the total available for oyster setting.

In the New Jersey portion of Delaware Bay, the condition of most beds to receive oyster sets was fair. Beds in the principal seed area had little silt, but the oysters and shells were partially covered with fouling organisms, and the beds had areas with low densities of oysters and surface shells. A bed inshore the area was nearly covered by silt (Table 3). The beds had bay anemones, which are predators of oyster larvae, but the anemones were not as numerous as they were in Maryland (see below).

In the Delaware portion of Delaware Bay, the condition of the beds to receive oyster sets ranged from poor to fair. The beds had quantities of surface shells, up to five deep, but they were mostly covered by silt: Only portions of the uppermost shells were exposed above the silt (Table 3; Fig. 6).

In the Maryland portion of Chesapeake Bay, the condition of the seed beds to receive oyster sets ranged from fair to excellent (MacKenzie, 1974). The state had hired oyster boats to tow oyster dredges with open bags over some beds; the condition of these appeared to be excellent as they had a continuous layer of surface shells which were clean of silt. The beds which had not been dredged had some silt on them (Table 3; Fig. 7a). But the beds contained bay anemones (Fig. 7b), which, it was later discovered, are predators of oyster larvae (MacKenzie, 1977c; Steinberg and Kennedy, 1979). In 1974 the average number of anemones on various beds

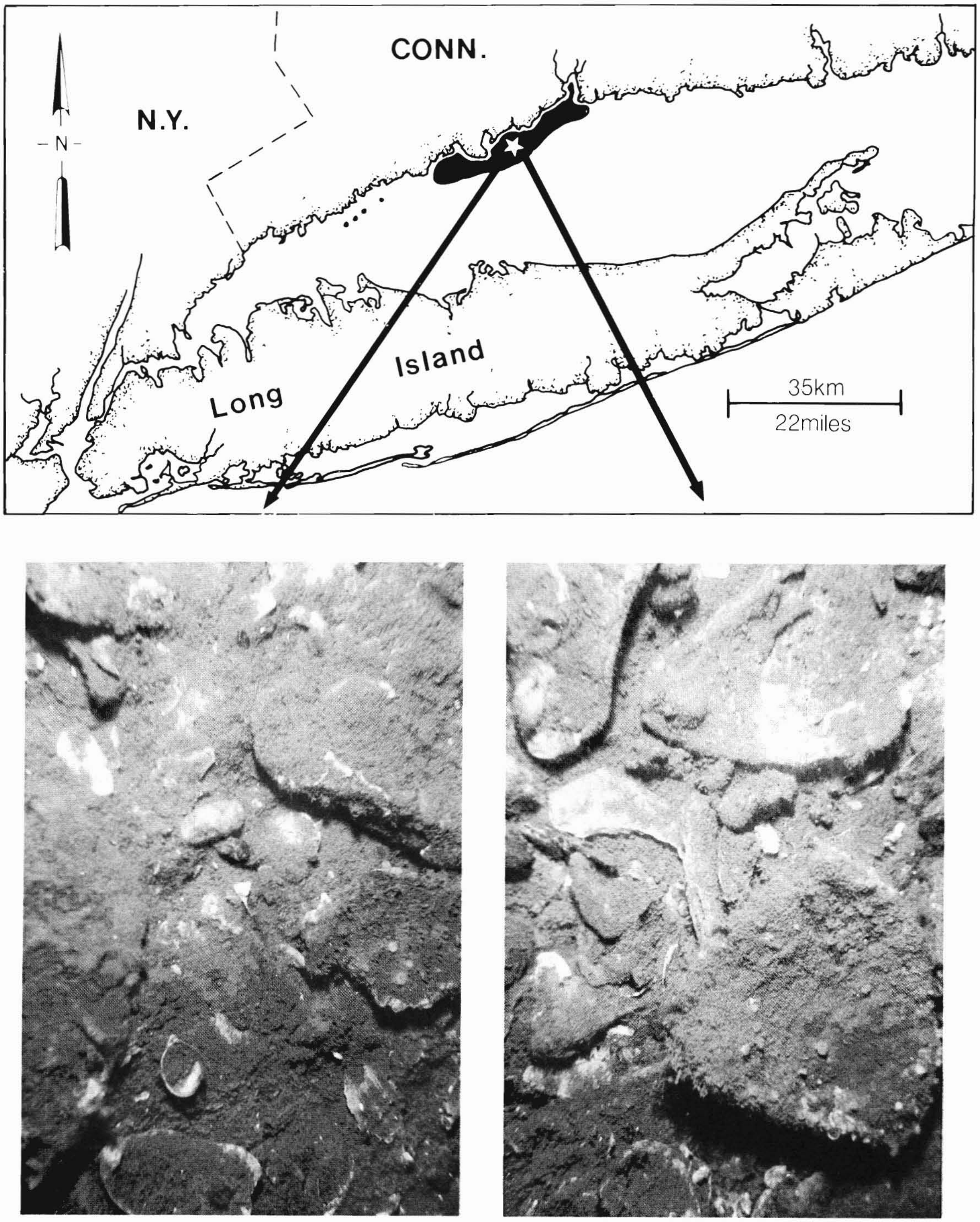

Figure 5.—Location of seed beds (shaded zone) in Connecticut. Photographs illustrate the condition of a bed in location shown. The bed cannot receive an oyster set because fouling organisms and silt cover the shells.

ranged from 104 to 176/m^2 (87 to 147/$yard^2$) (MacKenzie, 1977c), a quantity which is sufficiently large to reduce densities of oyster spat.

In the Virginia portion of Chesapeake Bay, the James River was the

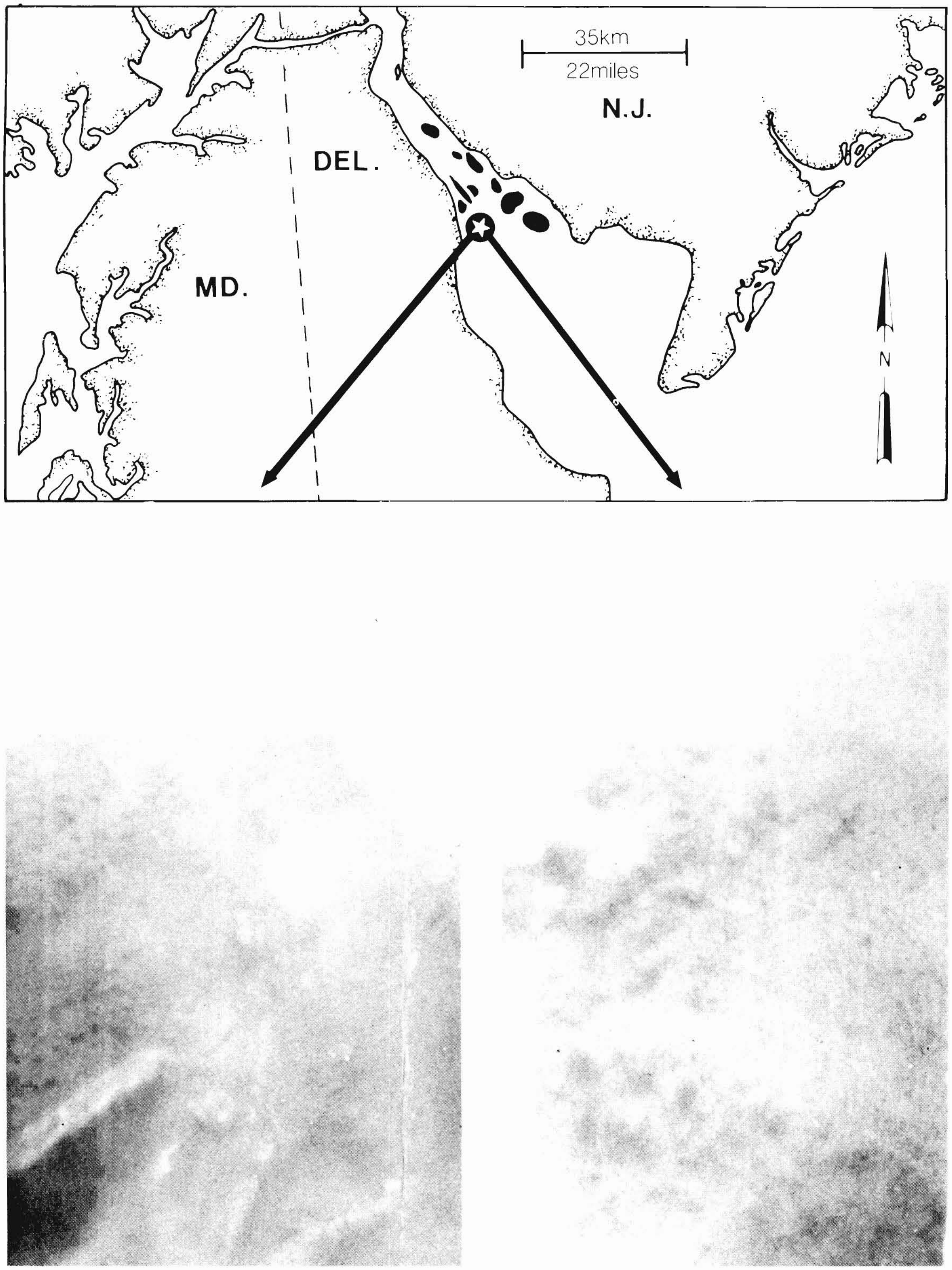

Figure 6.—Location of major seed beds (shaded zones) in New Jersey (from Haskin and Tweed, 1976) and Delaware (from Maurer, 1971). Photographs taken in highly turbid water illustrate the condition of a seed bed in the location shown in Delaware. The bed is in poor condition to receive an oyster set because silt covers the shells; portions of a few shells can be seen projecting above the silt.

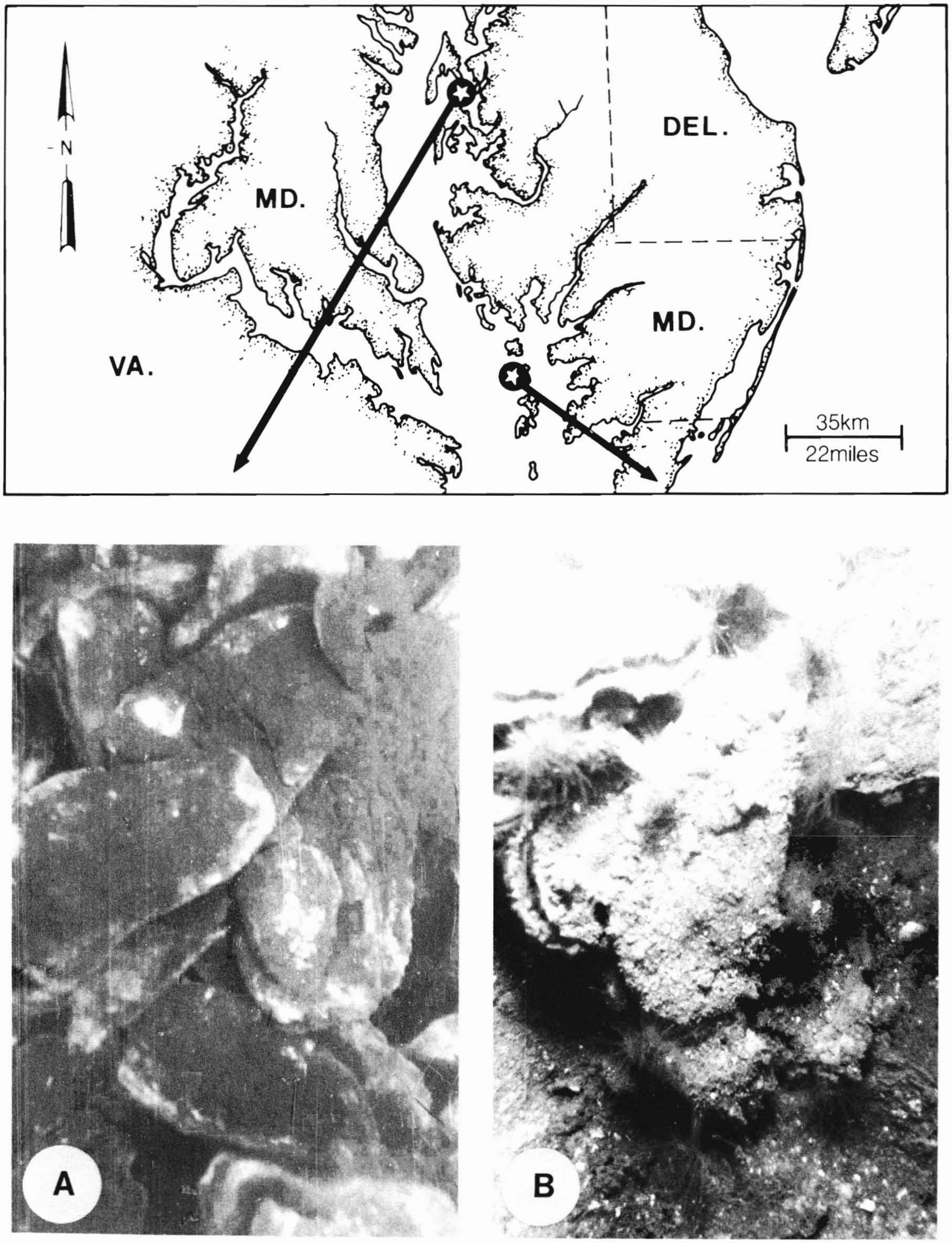

Figure 7.—The Maryland portion of Chesapeake Bay: The oyster beds are scattered over many areas too numerous to show. Photographs illustrate the conditions of beds with silt on shells near Parson Island (A), and with bay anemones and silt on shells near Holland Strait (B).

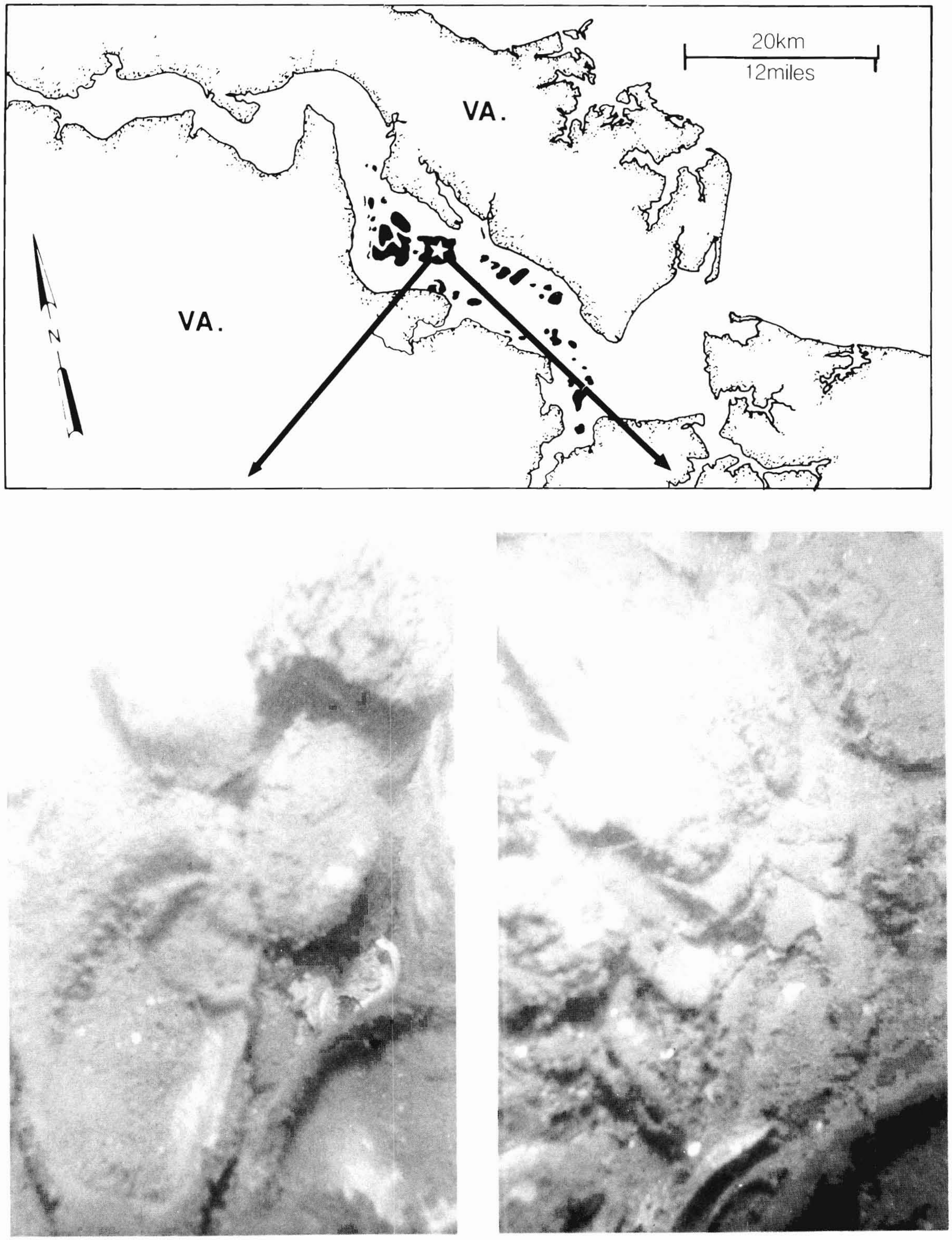

Figure 8.—Location of seed beds (shaded zones) in the James River, Va. (from Andrews, 1979). Photographs illustrate the condition of Wreck Shoal, one of the most productive beds in the river. The bed is in only fair condition for receiving an oyster set because silt and some fouling organisms cover the shells; bay anemones may also be present.

only estuary examined. The condition of the beds to receive sets ranged from fair to good. The beds had quantities of shells, but silt partially covered them (Table 3; Fig. 8). Bay anemones were not noticed during the surveys, but they appear to be present in Figure 8.

Causes of Decline of Seed Beds

In summation, the causes of the decline in the condition of seed beds varied in each estuary, but siltation was a common feature. In Long Island Sound, along the Connecticut coast, the setting area for oyster larvae was much reduced because oyster growers spread far fewer shells, quantities of oysters and shells were periodically buried by storms and hurricanes, and some beds had silt on them. In Delaware Bay and Chesapeake Bay, apparently a combination of heavy oyster fishing and siltation were principally responsible for the decline; in the James River, light setting of larvae and perhaps pollution were additionally responsible.

Oyster beds in the estuaries in the United States portion of the Gulf of Mexico have also declined in number and quality. Many beds are now covered with silt or grit (crumbled shells which are less than about 25 mm (1 inch) in diameter and are a poor substrate for larvae) (Butler, 1949; MacKenzie, 1977b; Gunter, 1979); large oyster shells are present underneath (MacKenzie, 1977b). Freshwater flooding, siltation, sewage and industrial pollution, heavy fishing, hurricanes, and indirectly the construction of levees (because they changed salinities) were responsible for the decline in condition of the beds (Engle, 1948; Butler, 1949; Gunter, 1953; Gunter and Demoran, 1970; MacKenzie, 1977b). Oyster beds in Europe have also declined substantially from heavy fishing and siltation (Gross and Smyth, 1946).

The heavy fishing of seed beds removed too many oysters and shells, leaving the bottom with sparse substrate for oyster larvae. But even when moderate and when few shells are taken, fishing reduces the area of substrate available for larvae, because it lowers the surface relief of beds. Scuba observations have shown that beds which have been recently fished with dredges or tongs have a flatter surface and smaller clusters, and thus a lower relief than beds which have not been fished for a year or more. On the positive side, oysters have a better shape when growing in relatively small clusters. Moreover, fishing, especially dredging, tends to remove silt from beds.

The silt which accumulated on seed beds covered substrates that would have been available to oyster larvae for setting. On many beds, the silt filled any shells that were positioned cup-side-up, and covered shells in low areas in the relief of beds and flat surfaces of shells at the surface (Fig. 8). On some beds, only the margins and undersides of shells at the extreme surface of beds are available to larvae. Some beds have been completely covered by deep silt deposits and no longer have any oysters (Butler, 1949; Galtsoff, 1964; Sieling, 1970; MacKenzie, 1975). The channels in estuaries have accumulated enormous quantities of silt.

The origin of nearly all estuarine silt is land (Fig. 9a, b). An estimated 4 billion tons of soil is eroded in the United States each year (Iowa farmland loses 2.5 cm (1 inch) of topsoil every 12 years); at least 1 billion tons of soil, mostly as silt, settles on the bottoms of ponds, lakes, reservoirs, streams, rivers, estuaries, and oceans every year (Schwengel, 1978). Silt also enters water from road construction, housing developments, and urban streets, and is released when estuarine bottoms are dredged. In the process of sedimentation, the larger particles settle to the bottom first, and settlement is highest where the water flow is least. Thus, much fine silt settles to the bottoms of estuaries where rivers widen and water flows diminish; this is the zone where seed beds are usually located. Paarlberg (1980) believes that trying to reduce the sediment load at its sources on land would be extremely difficult and costly.

The earlier shellfish biologists believed that the primary cause of decline in oyster abundance in most areas was heavy fishing. Scuba observations have revealed that siltation was also a major cause. Undoubtedly, had the beds not been silted, oyster yields would have declined much less. Silt was largely overlooked as a factor because 1) the beds, being underwater, were hidden from view and 2) it was not collected in samples dredged and tonged from the beds. The appearance of clean oysters and shells in such samples have commonly led biologists and oyster fishermen to believe that the beds were in good condition and that poor oyster sets resulted from a scarcity of oyster larvae. Heretofore, only small numbers of beds which became covered with silt have been rehabilitated.

Seed beds have been destroyed in other ways. Some have been destroyed by the dredging of shipping channels and dockages; others by filling.

Increasing Oyster Production

Woodward (1956) has recommended the following actions to increase oyster production and revitalize the oyster industry: 1) Increase oyster abundance on the beds; 2) promote oyster sales in the market, and 3) reduce production costs. The proposals fit the situation today, but the industry is in a quagmire. Extracting itself from it will not be easy: 1) Consumer demand for oysters is increasing only slightly, and thus a large increase in seed supplies and oyster production without sales promotion would likely depress oyster prices and yield little monetary gain to the oyster industry; 2) promotion of oyster sales has been limited because nearly all available oysters are sold, and it is an expense, and 3) costs of producing oysters are extremely high, but they are difficult to lower without increasing the quantities of oysters handled.

Substantial increases in oyster production with concommitant economic improvement in the industry can be brought about only through a coordinated program to increase seed abundance and promote oyster sales. Measures to reduce production costs would have enormous benefit for the industry and consumers.

Increasing Seed Abundance

The Productive Management Strategy

The productive management strategy for the oyster is the same as that used in agricultural and wildlife management: To increase the productivity of a plant or animal, remove limiting factors from or otherwise improve the environment. As the new environment more closely meets its requirements, the plant or animal will increase in abundance to the limits of that environment. In cultivated agricultural fields, plants can grow and survive at near to their physiological optimum and thus yield much larger crops than they would in wild fields. Management practices include tillage, fertilization, irrigation, and pest control, among others. In the management of game animals, the practices include cutting openings in forests, thus providing an edge effect, providing cover for protection from predators, planting food crops, and providing water, among others. In management of oyster seed beds, the practices should feature improving the condition of the beds to increase setting densities, thereby taking advantage of the widespread distribution of oyster larvae over the beds during the setting season.

The oyster has an extremely large biotic potential: Oyster populations would expand to cover the bottoms of their native estuaries within only a few years, given optimum environmental conditions. Oyster abundance is controlled by various physical, chemical, and biological limiting factors; such factors are collectively termed environmental resistance by Odum (1971).

The biotic potential of the oyster is easily dominated by environmental resistance, as illustrated by the following examples. Oyster larvae cannot develop to the setting stage if conditions in the water are not suitable. Oyster larvae cannot set on a bottom without proper substrates: None can set on shells covered with silt or live fouling organisms, or sand or mud bottoms. Oyster spat, no matter how abundant, can be almost eliminated by a large number of predators, such as oyster drills (Carriker, 1955; Galtsoff, 1964; MacKenzie, 1981) and starfish (Galtsoff and Loosanoff,

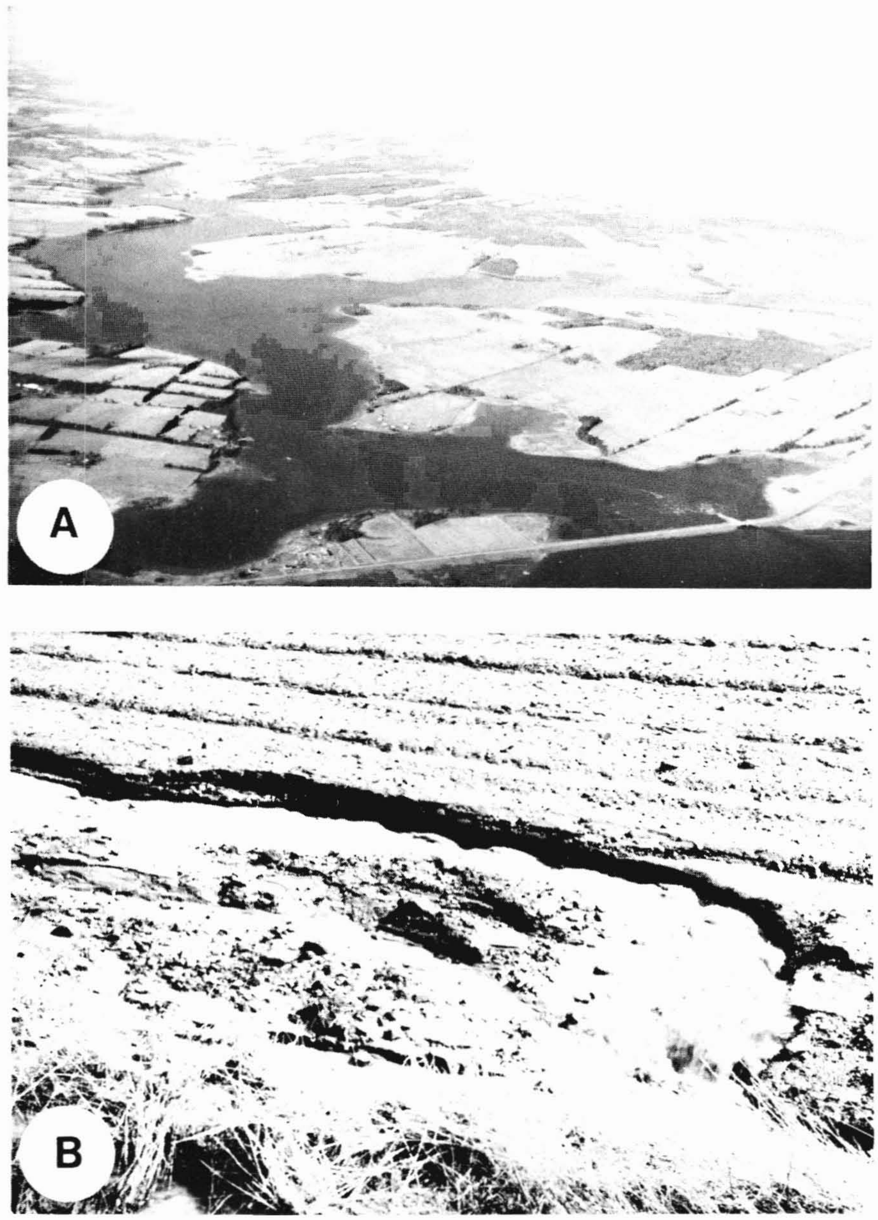

Figure 9.—Views of Prince Edward Island, Canada. (A) An estuary which has oyster beds and is bordered by plowed farmland. (B) The edge of a plowed field following a heavy rain; the water carried silt off the field, through a culvert (bottom, right), and into an estuary where some silt settled on the bottom including oyster beds. Many oyster beds in Chesapeake Bay are similarly surrounded by plowed farmland.

1939; MacKenzie, 1981) in salinities above 15‰. Substantial numbers of, and at times nearly all, oyster seed and adults, no matter how abundant, can be destroyed by a severe storm or hurricane on exposed beds (Engle, 1948; Sweet, 1951; MacKenzie, 1970; Munden, 1975), freshwater floods and unusually low salinities (Butler, 1952; Gunter, 1953; Andrews et al., 1959; Galtsoff, 1964; Zaborski and Haven, 1980; Hofstetter, 1981), and diseases in salinities above 15‰ (Andrews and Hewatt, 1957; Galtsoff, 1964; Haskin et al., 1966; Andrews and Wood, 1967; Farley, 1968; Sindermann, 1968). Thus, it is much more efficient to try to increase the abundance of the oyster by reducing its environmental resistance than by increasing its biotic potential.

A number of examples exist where oyster abundance was increased by improving bed environments, thus reducing environmental resistance. The successful programs of spreading quantities of shells on public seed beds in Maryland (Sieling, 1970), Virginia (Haven et al., 1978), North Carolina (Munden, 1975), Florida (Whitfield, 1973), Alabama (May, 1972), Mississippi (Demoran, 1966), Louisiana (Schafer, 1972), Texas (Hofstetter, 1981), and other oyster states constitute one. The successful but much smaller programs to clean silted shells or move buried shells to the surface in Prince Edward Island, Canada (Morrison[1]), Virginia (Haven et al., 1978), Mississippi (Daly[2]), and Washington, where Pacific oysters, *Crassostrea gigas*, were dragged over and thus cleaned (Sayce and Larson, 1966), among others, constitute another example. The successful programs of spreading shells and controlling predators and other limiting factors on private beds in Long Island Sound (MacKenzie, 1981) constitute yet another example.

In recent years, people have been interested in locating the spawning stocks of oyster larvae for the purpose of maintaining and enlarging them. More concern should be placed on the condition of the seed beds, however, than on the spawning stocks. The principal reason for the relatively low abundance of seed oysters is the relatively small area of suitable setting sites for larval settlement as compared with the past. In most localities, the oysters on the seed beds are themselves the spawning stocks. Thus, increasing seed abundance by improving the condition of those beds would, in itself, increase the size of the spawning stocks.

Rehabilitating Seed Beds

Nearly all seed beds have sufficient quantities of shells, but, as has been described above, the shells on many are covered with silt or fouling organisms or they are buried. The spreading of shells has proven to be a highly effective means of making seed beds more productive, but it might be too expensive for states and companies to increase their shelling programs substantially to rehabilitate more beds. Besides, shell supplies are finite and may become difficult to obtain at some point in the future. Alternative, inexpensive methods are needed to rehabilitate the beds. Seed beds can be rehabilitated by cleaning the surface shells, moving buried shells to the surface, or otherwise improving the condition of beds with specially designed technologies at the beginning of the oyster setting season. After the beds receive a good oyster set and are covered by seed oysters, most will continue as good oyster setting environments, as long as the taking of seed and shells by fishermen is controlled.

A program for rehabilitating seed beds should be large in scope, involving many beds. It should also be inexpensive to keep down production costs and avoid substantial financial losses in the event of a failure: 1) Oyster larvae may be too scarce to produce a good set; 2) the oysters may be killed later by a storm, flood, predators, or disease; 3) the demand for market oysters may be weak; or 4) silt in quantities sufficient to degrade the condition of the beds may accumulate again.

Suggestions for Surveying Beds

It is essential to make accurate assessments of the factors that limit oyster setting and the potential for increasing setting densities on seed beds, and also prescribe appropriate rehabilitative measures for them. Only scuba divers who have experience with oysters can do this. But use of divers without supplementary techniques can be slow and thus expensive; divers can examine 5-10 beds per day in good weather. Conditions on beds can be estimated remotely by using three types of equipment from a boat: 1) A standard oyster dredge can be towed to determine whether shells are present and the quantity of fouling organisms and bay anemones on the shells; 2) an oyster dredge fitted with a scraper blade, rather than a toothed blade, and a close-knit cloth liner inside the chain bag can be towed over the bottom for about a minute to determine whether silt is present, and 3) a pole can be used to determine bottom hardness and the depth of shell deposits. An underwater television camera could also be used where the water is not turbid. Assessments of seed bed conditions from a boat must be spot-checked by scuba divers.

Technologies and Methods for Rehabilitating Beds

Some technologies have been used to rehabilitate seed beds, but little attention has been given to developing them. Oyster dredges with open bags, pressure boards, and agricultural cultivators such as the spring-tooth harrow have been successfully used to clean silted shells and move buried shells to bed surfaces in various states.

The technologies recommended below have never been used exactly as described and may need testing and modifications to be effective on specific beds. They were designed after I had observed, using scuba gear, a

[1]A. Morrison, Provincial Department of Fisheries, P.O. Box 2000, Charlestown, Prince Edward Island, Canada. 1976. Pers. commun.
[2]F. Daly, Mississippi Marine Conservation Commission, Pass Christian, Miss. 1977. Pers. commun.

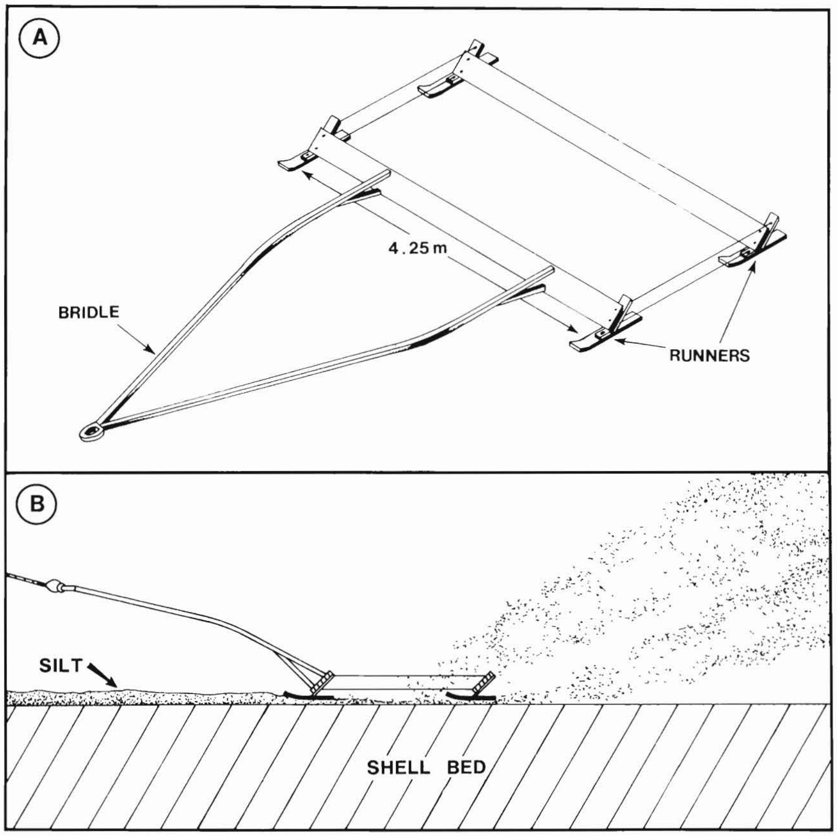

Figure 10.—Conceptual model of two pressure boards arranged one behind the other for removing silt from seed beds. Each board would ride on runners to maintain it above shells and oysters. Rigid teeth about 12.7 cm (5 inches) long and spaced 12.7 cm apart could be attached to the boards to loosen silt if it is compact. The boards, about 4.25 m (14 feet) wide, would be towed at a 45° angle, and at a speed of at least 3 knots. A typical oyster dredge boat in the northeastern United States has the size and power to pull such a pair of pressure boards. Panel A shows details of the boards. Panel B shows the boards removing silt from a bed.

number of oyster dredges and pressure boards being used on various bottoms, and with advice from several oyster growers and agricultural specialists. Their purpose is to rehabilitate seed beds quickly and at low cost. The gear is inexpensive to construct or produce, and can be towed from, or used on, existing oyster boats with regular captains and crews. The cost to operate an oyster dredge boat with crew is $300-350/day (1981 prices, Connecticut).

Seed beds that are candidates for rehabilitation fall roughly into five categories. The values given of the areas that can be rehabilitated per day and the costs per unit of area are estimates for optimum conditions.

Category 1: Beds with adequate quantities of surface shells covered with silt up to a few inches deep; such beds are common in all oyster producing states.

The beds can be rehabilitated by towing pressure boards to lift off the silt, which would be carried from the bed by tidal currents; teeth could be used on the boards if the silt is compact and viscous; runners to maintain the boards slightly above the bottom would be required if oysters were present on the beds. An oyster dredge boat has the power to pull two boards which are 3.7-4.6 m (12-15) feet) wide and arranged in tandem (Fig. 10). The boards would be towed at a speed of 3-4 knots. If the silt on a bed was no more than 5 cm (2 inches) deep, one boat pulling two boards could clean the silt off about 10-12 ha (25-30 acres) per day. Thus, the cost would be $25-37/ha ($10-15/acre).

Depending on the arrangement of seed beds and barren bottom, some suspended silt might settle on nearby beds including those previously cleaned. If so, the silt would have to be removed, thus increasing the cost of silt removal somewhat. It is suggested that silt be removed during ebb currents.

Category 2: Beds consisting of firm sand or grit, with insufficient quantities of large shells on the bottom surface, but with quantities of large shells underneath; such beds are common in all oyster-producing states.

The beds can be rehabilitated by moving the large shells to the bed surface. A cultivator, which has rigid teeth about 10 cm (4 inches) long and attached to three or four rows of cross bars, would raise the shells effectively (Fig. 11). An oyster dredge boat could pull two-six cultivators, each about 2.4 m (8 feet) wide; the cultivators would be towed at a speed of 3-4 knots. Thus, about 3.2-4 ha (8-10 acres) or more could be rehabilitated per day, at a cost of $75-100/ha ($30-44/acre). This new design could be tested alongside the spring-tooth harrow and other common agricultural cultivators to determine which is the most effective.

The cultivator might also be used to increase oyster abundance on beds with low stocks of oysters by moving buried shells to bed surfaces. Trials would have to be conducted to determine whether they would adversely affect oysters; if they do, probably the method could not be used.

Boats would tow the pressure boards and cultivators continuously over the bottom, with periodic checks of equipment condition.

Category 3: Beds consisting of shells on the surface which are covered with fouling organisms and with buried shells beneath the surface; many beds in Long Island Sound and those in areas of relatively high salinity in other estuaries are in this condition.

The beds can be rehabilitated by one of two methods.

Method 1: Spreading granulated quicklime on shells to control fouling organisms (MacKenzie, 1977a) (Fig. 12). The quicklime kills fouling organisms on the upper side of shells as well as starfish and embryos and juveniles of oyster drills. The spreading rate of quicklime should be about 6.75 metric tons/ha (3 U.S. tons/acre). The grain size of quicklime to be used is as follows: A screen of 10 meshes/25mm^2 should retain only a trace of quicklime, and one of 100 meshes/25mm^2 should retain 98 percent of quicklime; this is a standard grain size sold by commercial companies. The ideal time for spreading would be about 2 weeks before the normal season of oyster setting, to allow time for the quicklime to dissolve and the killed organisms to slough off the shells. Quicklime must be spread at slack current.

Oyster boats in Connecticut can carry a tank which holds about 8.2 metric tons (9 U.S. tons) of quicklime, a quantity which can treat 1.2 ha (3 acres) and be spread in about 45 minutes. Quicklime costs about $75/U.S. ton, delivered to a dock. Thus, the cost would be $556/ha ($225/acre), plus the spreading cost.

Method 2: Removing the fouled shells with dredges made with scraper blades or suction dredges and transporting them to land for storage, and then moving the buried shells to the bed surface with cultivators. The initial cost per unit of area would be higher than the single procedure of moving shells to the surface, but the stored shells would be available for respreading later on seed beds; while stored on land, fouling organisms die and slough off shells, which thus become cleaned.

Figure 11.—A cultivator for moving buried shells to the surface of seed beds. The cultivator has four rows of rigid tines which are staggered; the tines are adjustable and reversible. The cultivator would be towed at 3-4 knots, and might have to be fitted with a pressure board to hold it down. A typical oyster dredge boat has the size and power to pull 2-6 cultivators, each about 2.4 m (8 feet) wide.

Category 4: Beds with quantities of relatively clean shells which have few oysters, but many bay anemones; such beds were observed

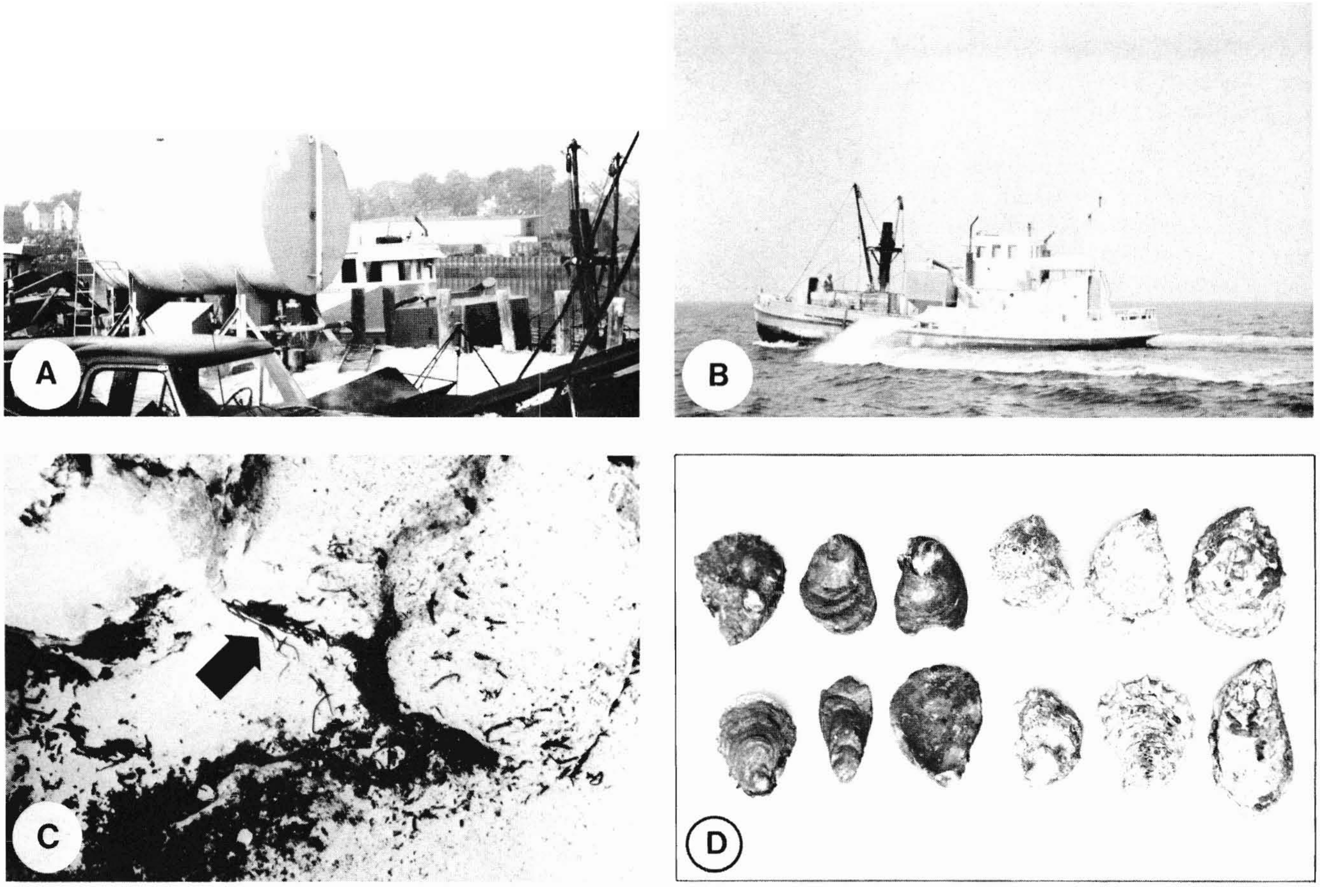

Figure 12.—Use of granulated quicklime to control fouling organisms which cover shells on seed beds. (A) Tank on dock which can hold 50 tons of quicklime. The tank is filled from a delivery truck through a hose by air pressure; quicklime is loaded into a tank on an oyster boat through a hose also by air pressure. (B) Quicklime being spread from a tank, 9 tons capacity, located amidship on an oyster boat. The boat spreads 9 tons of quicklime in about 45 minutes. (C) Quicklime covering oysters in a laboratory tray (running water at 15 °C), roughly as it appears on an oyster bed a few hours after it has received 6.75 metric tons/ha (3 tons/acre) of quicklime. The oysters were open and transported water through their gills; arrow points to pseudofeces being discharged from an oyster. (D) Left, oyster shells with a layer of fouling organisms from outside a test plot on a bed in Connecticut; right, clean oyster shells from the test plot 2 weeks after it had been treated with quicklime at a rate of 6.75 metric tons/ha (MacKenzie, 1977a).

mostly in Maryland, but also in New Jersey and Virginia.

The number of anemones on a bed can probably be substantially reduced by spreading about 1.1-2.2 metric tons/ha (0.5-1 U.S. tons/acre) of quicklime over the beds. Thus, a boat carrying 9 U.S. tons of quicklime could treat 7.3 ha (18 acres) with 1.1 metric tons/ha during a period of slack current; the cost of anemone control would be $93/ha ($37.50/acre), plus the spreading cost.

Possibly, control of anemones would not result in more seed oysters. The anemones consume the larvae of other species besides oysters, probably including those that foul shells. A reduction of anemones might result in a profusion of fouling organisms, whose detrimental effect could be larger than that of anemone predation on oyster larvae.

Category 5: Beds with low densities of oysters and with quantities of shells on the surface, but with enough silt and fouling organisms to substantially reduce setting densities of spat; such beds are mostly in the James River, Va.

The beds can be partially rehabilitated by removing the silt with pressure boards; the boards should have runners to keep them above the oysters. Another method would be to treat the beds with quicklime to control fouling organisms on the shells and then remove the silt with pressure boards. In the James River, which has relatively shallow beds (a number are about 2 m (6 feet) deep), perhaps 4.5 metric tons of quicklime/ha (2 U.S. tons/acre) would control the fouling organisms. At this dose, the cost would be about $370/ha ($150/acre), plus the spreading cost.

Beds rehabilitated with the methods and technologies suggested above should be spot-checked by divers after any operations are completed to ensure that they are in good condition for oyster setting.

The technologies and methods described will probably not be suitable for rehabilitating all types of seed beds. Those that had been abandoned and unproductive for many years were not surveyed, except in Connecticut; thus, their potential for rehabilitation was not determined. Undoubtedly, many have conditions similar to those in categories 1-3. To design rehabilitative technologies for beds having conditions that are not described above, the limiting factors would have to be identified first. If the limiting factors were not evident during visual examinations using scuba gear, test plots established in the beds at the beginning of the setting season might help to identify and characterize them. Each plot would consist of a layer of clean shells or seed oysters and have an area of about 1.5 × 1.5 m (5 × 5 feet). Four such plots should be sufficient for each bed. The limiting factors might then be identified by comparing conditions visually in the beds and the test plots during the setting season.

Environmental Effects of Rehabilitation

Seed beds occupy from 1 to 10 percent of the bottom area of estuaries; these beds harbor much more algae, and many more invertebrates and fish than the remaining bottom (Arve, 1960; MacKenzie, 1981). Thus, rehabilitation of seed beds produces an increase in the abundance of oysters and associated species.

Rehabilitation of seed beds by silt removal would result in some silt deposition on bottoms near the beds. But the quantity of silt deposited would probably be no more than that raised from the bottom during high winds and redeposited, or washed from land by rain and deposited on the bottom. Thus, the effect on benthic organisms would be no larger than it is from these events. The effect would be negligible compared with that at sites where mud from the dredging of river channels is dumped. Mud does destroy the benthic communities, but sites may recolonize within 30-60 days during the breeding season of the organisms (Anonymous, 1976).

The use of quicklime to control fouling organisms on seed beds has raised questions in the literature about its side-effects on the reproductive organs of oysters, growth of oyster spat, and long-term effects on fouling organisms (Anonymous, 1977). Quicklime originated in and contains the same chemicals as sea water. It is composed mainly (94-96 percent) of calcium oxide (CaO) with small quantities of calcium carbonate ($CaCO_3$), magnesium oxide (MgO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and ferric oxide (Fe_2O_3). Thus, spreading it over oyster beds is not adding any unusual chemicals to sea water.

Using scuba gear, I have observed several seed beds immediately before, during, and after quicklime treatments. Quicklime, an alkali in water, kills the exposed cells of algae and animals such as diatoms, starfish, and boring sponges, which it contacts. It does not harm exposed cells which it does not contact, or animals with tissues protected by shells or scales, such as oysters; hard clams, *Mercenaria mercenaria*; crabs, and fish. In treatments as heavy as 6.75 metric tons/ha (3 U.S. tons/acre), quicklime dissolves within 18 days. Whenever beds of oyster spat were treated with quicklime to control starfish, the growth of spat was the same as that of spat on beds not treated with quicklime.

No effects on oyster gonads were apparent from quicklime treatments. Quicklime has been used in Connecticut every year for over 40 years with no evident adverse effect on the density or annual regularity of potential oyster setting.

Community changes in a bed treated with quicklime would likely be temporary. The sequence of events are as follows. The upper side of shells and other substrates on a bed would be cleaned, oyster larvae would set on these surfaces, fouling organisms would set on the spat and shells and then spread over the surface area. The bed would be roughly the same as before the treatment, except that the upper surfaces of substrates would have many oysters and the fouling organisms would be younger. A year or two later, the community of fouling organisms would be about the same climax stage as before the treatment.

Making Seed Beds for Divers

In Maryland, many oysters are now being gathered for market by scuba divers. Heretofore, it has been desirable to maintain the oyster beds nearly flat so boats could tow dredges to gather the oysters. But flat beds are not a requirement for divers. Beds for divers could be made of conical piles of rubble which could then be covered with clean oyster shells.

Increasing Seed Survival on Growing and Market Beds

The oyster growers in Long Island Sound have achieved reasonable control of starfish and oyster drills by using quicklime and suction dredges in recent years. Thus, their yields of oysters have increased substantially (MacKenzie, 1981). Effective methods for controlling oyster drills and diseases have not been developed for beds in salinities above 15‰ in Delaware Bay and Chesapeake Bays. Oyster production would increase substantially there if either or both could be controlled since they kill many oysters. Continued work to devise control methods is encouraged.

Seed from Oyster Hatcheries

The presence of several private

oyster hatcheries along the Atlantic coast makes it possible to obtain seed if it were to become scarce. If oysters were scarce on beds that are believed to be a source of larvae for seed beds, seed from a hatchery could be purchased and placed on the beds to increase the size of the spawning stock. In the future, improved genetic strains of oysters including those that are disease-resistant may be developed. They could be mass-produced in a hatchery and placed on spawning beds to produce a better oyster strain on the seed beds.

Promoting Oyster Sales

It can be anticipated that a sudden, sharp rise in oyster supplies to an unprepared market will result in a further drop in landed prices of oysters. Thus, promotion of market sales should be accelerated before oysters reach the market. Retention of high quality of oyster products should also be a goal.

Heretofore, oysters and many other seafoods from the northeastern United States have been awkward to promote because fishermen gather and sell nearly the entire available supplies that are practicable to gather or allowable to gather under quotas set by the Fishery Management Councils. Except for the oyster, no means has been used to increase them. Seafoods contrast with agricultural commodities whose supplies can be increased through increased planting and breeding when their market demand increases. What is the purpose of extensive promotion of seafoods whose entire supplies are sold? It would increase consumer demand and thus prices, but not necessarily sales volume.

Extensive rehabilitation of the oyster seed beds will result in much larger supplies of oysters which will then make promotion of oysters feasible and desirable. Small-scale promotion includes advising wholesalers and retail stores that larger supplies will become available, sending recipes to newspapers, sending items to cooking programs on public television, and distributing public information leaflets, among others. For more extensive promotion, state economic development agencies could use the conventional methods for promoting agricultural commodities: Consumer publicity, trade shows, and recipe mailings. An oyster industry development program that does not contain promotion of market sales may lose much of its spirit when increased supplies of oysters become available, because prices will inevitably drop.

Reducing Production Costs

The high costs to prepare landed oysters for retailing constitute a major depressant to increasing oyster production because they keep retail prices extremely high. Strong efforts should be made to lower them. The most urgent need would seem to be for a mechanized process which can remove oyster meats from live oysters and then wash and pack them, and which is inexpensive, fast, and maintains a high product quality. Some inventors have tried to develop processes for shucking oysters, but thus far their prototypes have not been a substantial improvement over hand shucking. Probably, a reason that more effort has not been expended in developing mechanized processes is that the industry is now relatively small; the use of any new improved technology would be limited, and thus any return on investment in the development, manufacturing, and sales of it would be marginal. If much larger quantities of seed are produced on the beds and the market for oysters is good, the incentive to develop the needed technologies would be much larger.

A shortage of people to shuck oysters has been a problem for the oyster industry for many years. Labor for shucking has been getting scarcer. Thus, a mechanized shucking process may be essential if production is to increase substantially.

Recently, improvements in the gathering of oysters have been made. For example, in the late 1970's an oyster grower (L. Jeffries) in New Jersey developed a cheaper method for culling oysters from shells on boats by replacing human labor with rotary drums. Now, nearly all New Jersey oyster boats have these drums.

Production costs would fall somewhat when more oysters become available on the beds and more oysters are sold, because more would be handled during each production step. Oyster boats would gather oysters more quickly, and thus carry more oysters and perhaps work fewer hours each day on the beds; plants would process more oysters; cold rooms would be fuller, and trucks would carry larger loads.

The Role of Administrators

The elements essential for increasing oyster production are as much political and psychological as they are technical. Oyster production can be increased only under the direction of state administrators of estuarine resources and administrators of private companies. The solutions offered in this paper will be implemented only if the administrators believe they are beneficial.

The solutions appear to be an attractive investment opportunity because: 1) They have sound, unquestionable premises and no social tangles; 2) they mean reestablishment of oyster populations on extensive areas and, on most beds, oyster populations should endure for many years after they are reestablished under a system of sustained management and controlled gathering by oyster fishermen; 3) while they have large potential for high return, the risks to the beds and the industry are negligible; 4) they are achievable at low cost; and 5) an increase in production would generate employment and higher earnings, thus producing higher living standards in oystering communities as well as company profits.

Currently, state administrators have jurisdiction over laws that regulate oyster fishing and sponsor projects to spread shells and transplant oyster seed within public oyster beds. To increase oyster production, an administrator will, in addition, have to: 1) Obtain opinions about any proposed projects from oyster fishermen and other representatives of the oyster industry; 2) have the conditions of the seed beds surveyed; 3) have technologies developed and constructed for rehabilitating the beds; 4) hire boats to employ the technologies; 5) define institutional limits for the projects; and 6) while seed is increasing in abundance on the beds after they have been rehabilitated, prepare a program to promote oyster sales. State administrators would find that increasing production of oysters and other shellfish would be substantially facilitated if they had a qualified person working fulltime and doing the following: 1) Surveying seed beds to identify limiting factors; 2) devising better methods to rehabilitate the beds; 3) developing measures to control oyster predators and diseases; 4) arranging market promotion; 5) helping the industry to reduce production costs; and 6) handling related problems. Because the oyster industry is characterized by providing many jobs, the benefits from increasing oyster production substantially would far outweigh the cost of employing such a person.

Predicted Extent of Production Increase

Possibly, oyster production could be raised to its highest point of the past, i.e., to about 31 million bushels, but during the previous 90 or so years many beds have been destroyed beyond the possibility of rehabilitation, diseases now kill quantitites of oysters in high salinities in Delaware Bay and Chesapeake Bay, and some beds formerly used to hold market oysters have been polluted. Thus, it would be difficult. Control of oyster drills and diseases in Delaware Bay and Chesapeake Bay and pollution on former market beds would have to be achieved beforehand.

Production of seed oysters would at least double if the seed beds that are candidates for rehabilitation were all rehabilitated. Thus, a realistic prediction is that at least doubling of current production to 10 million bushels of market oysters could be achieved once a coordinated program of seed bed rehabilitation and market promotion is completed. The benefits for society would be that 1) gainful employment in the oyster fishery would increase, 2) profits of oyster processing plants would increase, 3) retail supplies of oysters would increase, and 4) retail prices of oysters would decrease.

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