Management for Increasing Clam Abundance

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Introduction

Low abundance of the hard clam, *Mercenaria mercenaria*, and soft clam, *Mya arenaria*, in beds of the eastern United States has always had a strong limiting effect on local employment and incomes as well as market supplies of clams. Unlike agriculture, where progressive methods for increasing production have resulted in flourishing crops, the clam fishery is severely handicapped by a complete lack of practicable methods to increase clam abundance in beds through environmental improvement. The beds are wild and yield variable and limited clam quantities, and thus fishermen often have uncertain employment and critically low incomes. Because clam supplies to the market are limited, prices have constantly risen in recent years, with a tendency to price clams out of a broad-base market. The price of the hard clam has soared during the 1970's, producing a strong inflationary effect in the market. The situation, deleterious to the fishery and the market, could be rectified through increased clam abundance in beds. Thus, it is imperative that shellfish researchers and resource managers focus their attention on methods for increasing clam production.

Low clam abundance does not stem from a limited biotic potential of the clams. Indeed, only a minute fraction of the potential is realized as a clam yield to fishermen. The limitations on abundance are to be found in environmental constraints, such as predation, on the biotic potential. General awareness that clam abundance can be increased through environmental improvement has been absent. This paper presents background information on the clam fishery, data on biological and environmental factors that govern clam abundance, and suggestions for developing a strategy and tactics for increasing clam abundance.

Background

Clam Fishery Statistics

In 1977, the year of latest available data, commercial production of the hard clam in the eastern United States totalled about 1.2 million bushels (1 bushel =35.2 l), or 6,045 metric tons (t) of meat, with a landed value of slightly more than $25 million. Approximately 65 percent of the production was from New York, the remainder, in order of descending importance, was from Rhode Island, New Jersey, Virginia, North Carolina, Massachusetts, South Carolina, Maryland, and Maine.

In that same year, commercial production of the soft clam in the eastern United States totalled about 660,000 bushels, or 4,365 t of meat, with a landed value of about $12 million. Approximately 80 percent of the production was from Maine, the remainder was from Maryland, Massachusetts, New York, Rhode Island, and New Jersey (U.S. Department of Commerce, 1978a-i). In recent years, the demand for clams has far exceeded production, bringing increasingly higher prices. In 1977, clam prices reached an all-time high: Hard clams of the littleneck category (longest shell lengths, 5-5.7 cm =2-2.25 inches) brought fishermen more than $30 a bushel; soft clams brought fishermen from $15 to slightly more than $20 a bushel. Hard clams and soft clams within the length range 5-6.5 cm (2-2.6 inches) bring by far the highest demand and prices in the market. Clams are within that length range only about 2 years in most areas, then grow beyond it and have much less value. Ritchie (1977) reported that in 1975 nearly 17,000 part-time and full-time fishermen gathered the hard clam, and 7,000 part-time and full-time fishermen gathered the soft clam.

The Need for More Clams

The condition of uncertain and low clam abundance has consistently dominated the working atmosphere of the

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ABSTRACT–An urgent need exists to increase clam abundance in beds of the eastern United States in order to improve the economic status of clam fishermen and local communities as well as to increase clam supplies at stable market prices. Heretofore, clam fishermen have depended entirely on the vagaries of environmental factors to provide clams in beds, all of which are wild. The hard clam and soft clam each have a sufficiently large biotic potential to stock beds with clam populations of maximum abundance, but environmental factors suppress it, keeping clams in low abundance. In this paper, a strategy and tactics are suggested for increasing clam abundance by at least severalfold through improving environments of setting clam larvae, clam spat, and juveniles. The concept differs from conventional management based merely on gathering controls.

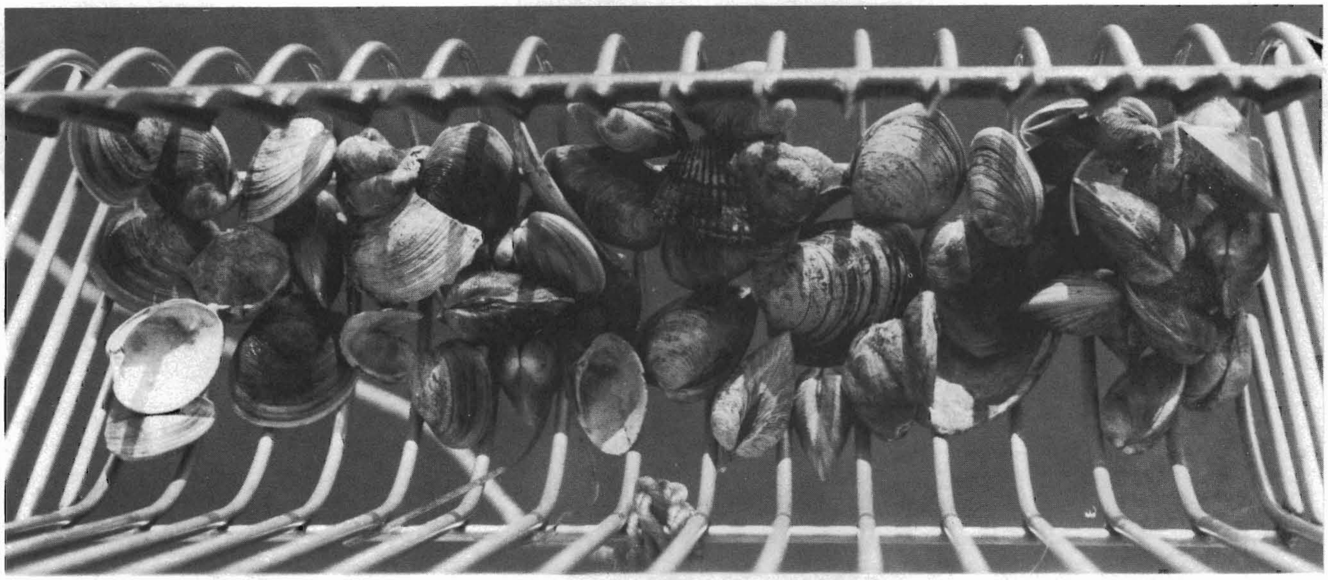

Figure 1.—Hard clams and trash gathered during a 5-minute raking by a fisherman through a bed in Great South Bay, New York, 1975. Small clam shells (the remnants of clams killed by predators), most seed clams, and predators had passed through the rake as it was being pulled. The fisherman gathered only about 1.5 bushels of clams (about 1,000 clams) during the day, showing that clam abundance was low. A fisherman commonly took 5 bushels of clams (3,500 clams) a day a few years earlier.

clam fishery (Fig. 1). The dependence by fishermen on clams gathered makes them hunger for stable supplies and increased abundance of clams. Fishermen fear that clam supplies will become depleted and thus are haunted by insecurity. Moreover, their earnings are usually slightly below that in most other occupations. On the other hand, clam fishermen are autonomous, independent, and somewhat self-sufficient. A scarcity of alternative work that features this freedom, and a lack of skills in other well-paying occupations, binds full-time clam fishermen to the beds. As a result, when clams become scarce, conditions of life become hard for fishermen. Clam fishermen desperately want increased employment security, at least modest prosperity, and the expectation of a good life for their children, all of which can be realized through increased clam abundance.

The clam fishery has always featured an irregular supply situation: Long periods of dearth may be followed by gluts. Consistently ample supplies would facilitate merchandising and stabilize prices.

Pollution has had detrimental effects on the clam fishery. The clam beds in polluted zones have been legally closed to gathering for direct public consumption, leaving fewer available clam beds (Ritchie, 1977). In some closed beds, clams are more abundant than in clean beds, an invitation to potential poachers. Increased clam supplies in clean beds would obviate that situation.

Coastal towns, counties, and rural areas where a clam fishery constitutes an important factor in their economies, view the fishery as a major supplier of jobs and income. They want the fishery to support as many people as possible in a stable, prosperous condition. Whenever clam supplies become scarce, total gainful employment and earned income drop, resulting in a weakened economy. A management program that supports a stable, prosperous clam fishery should be the aim of a community government. The minor problems and cost involved in establishing it would be far smaller than the problems and costs that stem from scarce clam supplies.

When any environmental factor that contributes to optimum conditions for clam survival begins to deteriorate uncontrollably, it is necessary to find means to remove other limiting factors to maintain or increase clam abundance. For example, deteriorating water quality could lead to reduced numbers of ready-to-set clam larvae, resulting in smaller populations. But this could be offset by an improved setting environment for larvae or an improved survival environment for spat and juvenile clams.

Clams support a sizable recreational fishery, especially in New England and Long Island, N.Y., where the hard clam grows in shallow water and the soft clam intertidally. The recreational clam fishery is a tourist attraction in some localities. Variable and low clam abundance makes the fishery uncertain.

Causes of Low Clam Abundance

The causes of low clam abundance (Table 1) are not hard to identify; they are: low setting densities of spat and predation on spat and juvenile clams (Fig. 2). Descriptions of the factors that

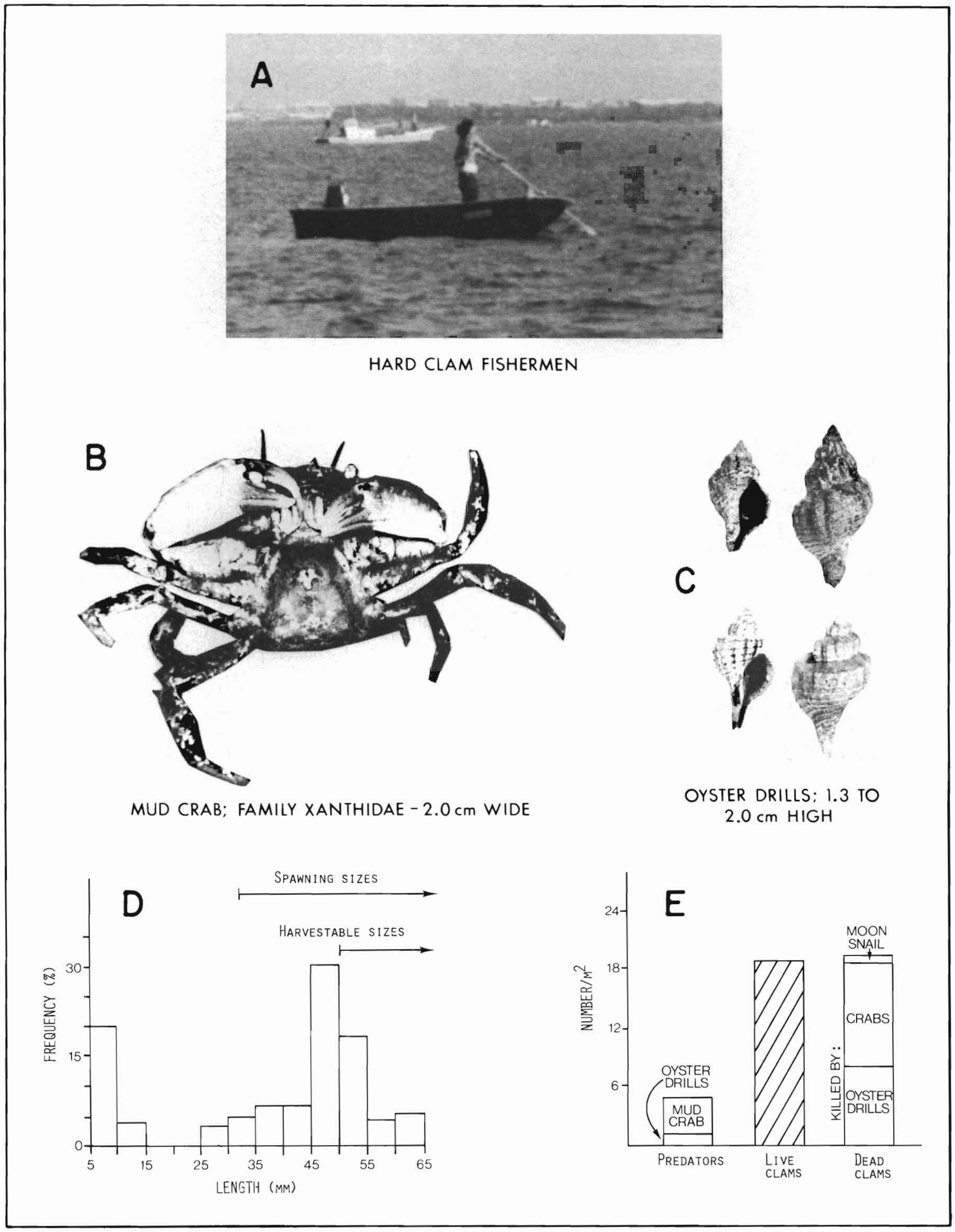

Figure 2.—Observations of the hard clam fishery in Great South Bay, Long Island, N.Y., in June 1975. Fisherman (A) takes the clams which, as larvae, were able to set in the bottom, avoided predators (B, C) and grew to and above the minimum legal gathering length, 5 cm (2 inches) or near equivalent, which is much longer than the smallest length at maturity, 3.2 cm, as shown in the length-frequency distribution of live clams in the Bay (D). Numbers of clam predators and live and dead clams are compared (E); dead clams ranged from 4.5 to 45 mm long. Mortality in clams was not measured in the length group from setting, about 0.2 mm, to 4.5 mm; mortality from predation in the group was probably substantial (MacKenzie, 1977a).

govern clam abundance are presented later in the paper.

Fishermen remove most legal-length clams (at least 5 cm, or near equivalent) from beds. Some clam populations can endure, however, under steady and heavy gathering by fishermen. A large number of clam beds along the Atlantic coast have yielded clams to fishermen for many years, some since the 1800's. Hard clam beds in Great South Bay, N.Y., and soft clam beds in Edgartown Great Pond, Mass., have yielded clams continuously to fishermen for at least the past 25 years. Whenever clam supplies have been reduced by fishermen to low densities, they returned when gathering was temporarily postponed and underlength clams grew to the minimum legal gathering length.

Some clam populations do not endure under gathering by fishermen. The populations are characterized by: 1) sparse and sporadic setting; 2) declining setting densities of spat; or 3) increasing predation on juvenile clams. Some clam populations grow gradually over an extended period and eventually are comprised mostly of relatively old clams, to be discovered and gathered by fishermen.

Belding (1930, 1931) reported large declines in hard clam and soft clam abundance in Massachusetts near the beginning of this century. At that time, the market demand was increasing, the number of fishermen increased correspondingly, and thus fewer clams in the regular beds were available to each fisherman. The fishermen discovered virgin hard clam populations in deeper water, which they gradually depleted. It is likely that the virgin populations had grown over a long period and were comprised mostly of old clams. Depletion occurred because the magnitude of subsequent spat setting was insufficient to overcome predation losses and support continuous gathering by fishermen. Belding (1930, 1931) attributed the reduced availability and depletion to "overfishing." The term "overfishing," however, implies that populations of spawning clams are reduced to such low density that reproduction is impaired. If clams below the minimum legal gathering length and some above it are left in the beds, spat setting density cannot be impaired by steady gathering by fishermen. Recruitment of legal length clams in a bed would be nearly the same whether or not gathering occurs.

Table 1.—Some recorded densities of the hard clam and soft clam, Atlantic coast of the United States.

Location	Density (number/m²)	Clam lengths (mm)	Data source
	Hard clam		
Connecticut			
Long Island Sound	0.9	5 to 10	MacKenzie, 1977a
New York			
Northport Bay	6.5	at least five year classes	MacKenzie, 1977a
Great South Bay	18.4	4.5 to 63	MacKenzie, 1977a
New Jersey			
Raritan Bay (Horseshoe Cove)	14.0	4.5 to 105	MacKenzie, 1977a
Lower Little Egg Harbor	34	5 to 84	Carriker, 1961
South Carolina			
Santee River	[1]18 to 24	not available	Rhodes et al., 1977
	Soft clam		
Maine			
Sagadahoc Bay	10.8 to 192.7	10 to 68	Spear, 1953
Massachusetts			
Boston Harbor	[2]320 to 3,200	a few year classes	Turner, 1952

[1]Approximate
[2]Approximate, includes beds with most dense clam populations.

Annual Setting Frequency of Clam Spat

The annual setting frequency of clam spat in beds has not received extensive study. The few existing reports and observations show that nearly every year clam setting takes place in some hard clam beds in New York (MacKenzie, 1977a) and New Jersey (Carriker, 1961; MacKenzie, 1977a), and in some soft clam beds in Maine (Glude, 1955; footnote 1), Massachusetts (pers. obs.), and Chesapeake Bay[2,3]. In other beds, clam setting takes place only when environmental conditions are exceptionally favorable, while in still others, setting rarely occurs (footnote 1; pers. obs). Probably, annual frequencies of clam setting are about the same in beds in other localities.

Clams set during the warm months. In Rhode Island, hard clam spat set from June through September (Landers, 1954a). In Maine, soft clam spat set mostly from June through September with the major portion of setting coming during 1 or 2 weeks out of the season (footnote 1); in Rhode Island, from May through October (Landers, 1954a); and in Chesapeake Bay, from March to November (footnote 2).

Three factors promote or favor regular clam setting in beds. The first is that an ample number of mature female clams is nearly always present in every bed. The number remains ample because each female releases millions of eggs a season (Table 2); thus, a few females can produce sufficient eggs to seed beds with large quantities of clam spat. Usually, large numbers of mature females occur in beds because: 1) Predators do not consume all spat and juvenile clams and cannot take clams above certain lengths; 2) fishermen retain only the hard clams and soft clams

[1]Letter dated 3 October 1978 from W. R. Welch, State of Maine, Fisheries Research Station, West Boothbay Harbor, Maine.
[2]Letter dated 3 October 1978 from H. T. Pfitzenmeyer, University of Maryland, Chesapeake Biological Laboratory, Solomons, Md.
[3]Letter dated 2 October 1978 from D. S. Haven, Virginia Institute of Marine Science, Gloucester Point, Va.

that have at least the minimum legal gathering length and leave in the beds below-length clams, many of which are mature (Fig. 3); and 3) after gathering clams, fishermen leave in the beds a quantity of legal length clams which are impractical to gather, yet capable of spawning. (The minimum legal length for clam retention has been in effect throughout nearly all the present century.)

The second factor is that the spawning season lasts a few months. During some part, if not all, of most seasons, environmental factors that stimulate mass spawning of clams and support some survival and setting of clam larvae exist.

The third factor is that fishermen do not degrade the clam environment while gathering clams; clams can set and grow in beds after, as well as before, gathering.

Figure 3.—Fishermen are required by regulation to return clams less than 5 cm (2 inches) long or near equivalent, termed seed, to the beds. The regulations help to ensure future adequate spawning capacity and yields of the clams from the beds. Shown here is the gathering of soft clams by hydraulic jet and rake on Martha's Vineyard, Mass. Clams are jetted from the bottom by one man, and are then raked up by his partner. Note the 2-inch measure for clams on the handle of clam rake.

Biological and Environmental Factors that Govern Clam Abundance

Biotic potential, environmental requirements, and environmental resistance are the factors that govern the abundance of clams reaching the legal gathering length. The factors are discussed later in this section.

Odum (1971) defines biotic potential as the maximum intrinsic capacity in a population to increase, and environmental resistance as the sum total of environmental limiting factors that prevent the biotic potential from being reached. Fluctuations in every aspect of clam productivity, i.e., number of eggs spawned, number of larvae that develop, spat density, and spat and juvenile survival and growth, are governed by environmental resistance; the number of clam spawners has less importance in governing the density of clam spat. Environmental resistance is the difference between the biotic potential and the actual clam quantities which grow in beds. The amount of environmental resistance to which clams are subjected varies constantly. When environmental resistance in a bed increases and endures, clam abundance becomes lower; when it decreases and endures, clam abundance becomes higher. Clam populations increase in relation to environmental resistance because the biotic potential of the clams is always much larger than reached in beds.

Table 2.—Data on biotic potential of the hard clam and soft clam, Atlantic coast of the United States.

Productivity	Hard clam	Data source	Soft clam	Data source
Smallest length at sexual maturity (cm)	3.2	Belding, 1931	1.3 to 1.9	Hanks, 1963
Eggs spawned per year (millions)	25	Davis and Chanley, 1956	[1]1 to 5	Stickney, 1964
Potential setting density of spat	unknown		unknown	
Actual setting density of spat (number/m^2)	[2]up to 125	Carriker, 1961	more than 108,000	Turner, 1951
Annual growth increment (mm)	7 to 13	Belding, 1931	[3]8 to 35	Hanks, 1963
Physiological survival/year	very high	Haven and Andrews, 1956	unknown	
Physiological longevity	More than 25 years	Belding, 1931	More than 10 years	Belding, 1930

[1]Eggs released during a single spawning.
[2]Only a few determinations were made.
[3]Chesapeake Bay only.

The ecological principle of limiting factors, which is commonly used in agriculture, applies to clam populations. It can be explained as follows: if all environmental factors in beds remain optimum for clams, clam populations have maximum and sometimes in the soft clam, excess abundance; if any factor is less than optimum, populations will be reduced proportionately; and if any factor has a value of zero, even if all others remain optimum, the resulting populations will be small or nonexistent.

Early shellfish biologists did not study the causes and magnitudes of mortality in larvae and juvenile shellfish. They confined their investigations to adults. Nevertheless, mortality in clam larvae spat, and juveniles is large, many times larger than in adults. Recently, it has been shown that the magnitudes of setting density and predation on hard clams that are less than 1.5 to 2 cm long determine relative clam abundance, while predation on hard clams longer than 5 cm is neglible (MacKenzie, 1977a). Probably, the same is about true in the soft clam. Spat and juvenile clams suffer large mortality because a new generation of predators appears each summer simultaneously with each new generation of clams, both then being at peak abundance (Turner, 1953). The juvenile predators begin feeding immediately on spat and juvenile clams; moreover, adult predators select juvenile clams when mixed sizes are available. As they grow, the hard clams that survive become increasingly invulnerable to predation because the predators are not then sufficiently large to bore, crack, or swallow them (MacKenzie, 1977a). The largest soft clams may escape most predators by burrowing deeply.

Much remains to be learned about the factors that limit or constrain setting of clams and survival of spat and juvenile clams. Currently, little is known about: 1) The predators of clam larvae; and 2) the effect of associated biota growing on and among bottom sediments on setting density of the clam spat. Only speculative estimates have been made of typical setting densities of clam spat and the percentages of clams that survive from the spat stage to the minimum legal gathering length.

The available information on: 1) Biotic potential, 2) environmental requirements, and 3) environmental resistance of the hard clam and soft clam is summarized below.

Hard Clam

Biotic Potential

Table 2 lists information on the biotic potential of the hard clam. The clam can spawn at least 2 years before reaching the minimum legal gathering length (Fig. 2). Each adult female spawns millions of eggs a year, physiological survival is high, and spat grow to the minimum legal gathering length in 5-6 years. Clam larvae are dispersed in the water and while developing are carried about by currents; when fully developed, larvae set randomly in beds. The biotic potential is sufficiently large to stock beds with at least hundreds of clams over a wide length range per square meter within several years.

The hard clam sets in lower densities and grows more slowly than the soft clam, but the hard clam can live longer. Quantities of full-length empty hard clam shells, the remnants of dead clams, and live clams are about equal in beds, but more full-length soft clam shells than live soft clams occur in beds; the smaller shell quantity shows greater longevity in the hard clam. The contrast between shell quantities in beds of the hard clam and the eastern oyster, *Crassostrea virginica,* is striking. Usually, oyster beds contain oyster shell deposits which are several meters deep; the beds contain a great many more shells than live oysters. The difference in shell quantities shows that the hard clam lives much longer than the oyster, which commonly lives a few years.

Environmental Requirements

The hard clam is adapted to salinities from about 15‰ (Chanley, 1957; Andrews, 1970; Castagna and Chanley, 1973) to 35‰ (Belding, 1931; Davis, 1958), and normally grows in sand, sand-gravel-stone, and mud, at depths from about the low tide mark to at least 7 m. In summer, temperatures must rise above 15°C for spawning, but remain below 33°C for effective larval development (Loosanoff et al., 1951). Larvae seem to prefer bottoms of sand and a mixture of sand and mud which contain sufficient loose material to permit them to burrow as spat (Carriker, 1961). For some clam seed to survive, a bed must have few predators, or some protective cover, such as stones and eelgrass, *Zostera marina;* clams are most numerous in beds in which predators are scarce or cover from predators is available (MacKenzie, 1977a).

Environmental Resistance

The temperature and salinity extremes that suppress growth of hard clam larvae have been determined. Larvae grew slowly at and below 17.5°C and at 32.5°C, and at and below 17.5‰; growth was fastest at 20.0° to 30.0°C and 20.0 to 27.0‰, in laboratory cultures (Davis and Calabrese, 1964).

Some sediment types suppress setting and growth of the hard clam. Bottoms of mud (Carriker, 1961; Keck et al., 1974), coarse gravel, or shell (Carriker, 1961) are less desirable for clam setting and consequently contain fewer clams than sand. Growth is relatively slow in sediments that contain quantities of silt-clay (Pratt and Campbell, 1956).

The predators of hard clam larvae have not been identified. Nevertheless, it has been suggested that one or more bottom-dwelling invertebrate species may consume the larvae (Carriker, 1961). The known predators of burrowed hard clams over the entire range of the clam include: Moon snail, *Polinices duplicatus* (Mead and Barnes, 1904; Belding, 1931; Carriker, 1951, 1961; MacKenzie, 1977a); oyster drills, *Urosalpinx cinerea, Eupleura caudata* (Carriker, 1951, 1955, 1957, 1961; MacKenzie, 1977a); whelks, *Busycon canaliculatum, Busycon carica* (Belding, 1931; Carriker, 1951; MacKenzie, 1977a); blue crab, *Callinectes sapidus* (Carriker, 1951, 1956, 1959, 1961; Castagna and Kraeuter, 1977; MacKenzie, 1977a); green crab, *Carcinus maenas* (Dow and Wallace, 1952; Carriker, 1956, 1961); rock crab, *Cancer irroratus* (MacKenzie, 1977a); mud crabs (Xanthidae) (Landers, 1954b; Carriker, 1956, 1959, 1961; MacKenzie, 1977a); starfish, *Asterias forbesi* (Belding, 1931; Pratt and Campbell, 1956); various rays (Dasyatidae, Myliobatidae, and Rhinopteridae) (Castagna and Kraeuter, 1977); summer flounder, *Paralichthys dentatus;* tautog, *Tautoga onitis;* and puffer, *Sphaeroides maculatus* (MacKenzie, 1977a). The total assemblage of predators never inhabits any one bay or bed.

Various field studies have shown that predation substantially reduces hard clam abundance (Landers, 1954b; Carriker, 1956, 1959, 1961; Castagna and Kraeuter, 1977; MacKenzie, 1977a). Wherever they are numerous, predators eliminate quantities of, and sometimes most, spat and juvenile clams—far more clams than fishermen gather—before the clams reach 5 cm in virtually all beds. The magnitude of predation was partially illustrated in two test areas in New York where clams became seven and eight times as dense (43.6 clams as compared with 6.5 clams/m^2, and to 75 clams as compared with 9.5 clams/m^2) after predator numbers were greatly reduced by a single application of poison as in unpoisoned areas nearby (MacKenzie, 1977a).

Soft Clam

Biotic Potential

Table 2 lists information on the biotic potential of the soft clam. The clam can spawn at least a year before attaining the minimum legal gathering length. Each adult female spawns millions of eggs per year, physiological survival is probably high, and spat grow to the minimum legal gathering length in 2-6 years, depending on latitude. Clam larvae are dispersed in the water and while developing are carried about by currents; when fully developed, larvae set randomly in beds. The biotic potential is sufficiently large to stock beds with at least a few thousand clams over a wide length range per square meter within a few years.

Environmental Requirements

The soft clam is adapted to salinities from about 2.5‰ (Chanley, 1957; Pfitzenmeyer and Drobeck, 1963; Castagna and Chanley, 1973) to 35‰ (Castagna and Chanley, 1973); its larvae grow in salinities as high as 32‰ (the highest point tested) (Stickney, 1964). The clam grows in intertidal flats and to depths of at least a few meters. Fine sand, mud, and pebbly sand are suitable sediments (Turner, 1950). In summer, temperatures must rise to nearly 10°C for spawning, but not greatly exceed 24°C or else the larvae will not develop (Stickney, 1964). A bed must have few predators for some clam seed to survive.

Environmental Resistance

The temperature and low salinity extremes that suppress the biotic potential of the soft clam have been determined. Clam larvae grew little at 8.6°C, but grew at 14.6°C, the next higher temperature tested; larvae were killed at 28.4°C within 14 days, but grew at 22.9°C, the next lower temperature tested, in laboratory cultures (Stickney, 1964). Burrowed clams were killed when temperatures persisted in the high 20°C range and salinities were 2‰ or lower in Maryland (Shaw and Hamons, 1974).

The bay anemone, *Diadumene leucolena,* has been tentatively identified as a predator of soft clam larvae in Chesapeake Bay (MacKenzie, 1977b). The bay anemone is abundant in polluted estuaries of northern New Jersey, which contains soft clam beds, and Delaware Bay; its distribution along the remainder of the western Atlantic coast is incompletely known.

The known predators of burrowed soft clams over the entire range of the clam, include: Moon snail (Belding, 1930; Turner, 1948, 1949, 1950, 1951; Turner et al., 1948a; Sawyer, 1950; Hanks, 1952; Smith and Chin, 1953; Medcof and Thurber, 1959; Edwards and Huebner, 1977); lady crab *Ovalipes ocellatus* (Belding, 1930; Turner, 1948); blue crab (Belding, 1930; Turner, 1948, 1950; Turner et al. 1948b); green crab (Turner et al., 1948b; Turner, 1950, 1951; Smith and Chin, 1953; Glude, 1955; Smith et al., 1955; MacPhail et al., 1955; Ropes, 1968); spider crab, *Libinia* sp. (Turner, 1950, 1951); horseshoe "crab," *Limulus polyphemus* (Belding, 1930; Turner, 1948, 1949, 1950, 1951; Turner et al., 1948a; Shuster, 1950; Smith and Chin, 1953; Smith et al., 1955; Carriker, 1961); starfish (Belding, 1930; Turner, 1948); eel, *Anguilla rostrata* (Wenner and Musick, 1975); winter flounder, *Pseudopleuronectes americanus* (Medcof and MacPhail, 1952); and ducks (Belding, 1930). The total assemblage of predators never inhabits any one bay, river, or bed.

Field studies have shown that predation substantially reduces soft clam abundance (Turner, 1948, 1950; Turner et al., 1948a, 1948b; Dow and Wallace, 1952; Smith and Chin, 1953; Glude, 1955; MacPhail et al., 1955; Smith et al., 1955; Medcof and Thurber, 1959; Hanks, 1963; Edwards and Huebner, 1977), comparable with its effect on hard clam abundance. Probably, the green crab is the most destructive soft clam predator north of Cape Cod, taking most clams in commercial beds when it is abundant (Glude, 1955; Hanks, 1963). During the 1940's, soft clam production declined sharply and became low, and through the mid-1950's, it remained low, in Maine and Massachusetts. The decline was caused by a sharp increase in numbers of the green crab, which destroyed virtually all seed clams (Glude, 1955). During the late 1950's, clam production rose again and remained sizable, at least through the late 1960's, because the green crab became scarce (Welch, 1968). The magnitude of predation on the soft clam in Maine and Massachusetts was further illustrated when the green crab and other predators were excluded with fences in clam beds. Clam densities became many times higher inside than outside the fenced areas during a summer (Turner, 1950; Smith and Chin, 1953; Glude, 1955; Smith et al., 1955; Hanks, 1963).

Some additional types of environmental resistance are present in hard clam and soft clam beds. The circulation between bays and the ocean, weather and climatic factors, currents, and pollution also affect clam abundance.

Management Objective

The management objective of clam beds should be to increase the abundance of clams that reach the minimum legal gathering length (5 cm, or near equivalent).

Developing a Strategy and Tactics for Increasing Clam Abundance

The Basis for Increasing Clam Abundance

Management for increasing clam abundance is based on the fact that clams become more abundant after their environments improve. The avenue to increased abundance is through providing an improved environment for each clam so its setting and survival efficiency can be increased.

Usually, only one or two major abundance-limiting factors exist in commercial clam beds, besides temperature and, in some areas, salinity extremes. If a major limiting factor of clam setting were removed, and a major limiting factor of clam survival in the spat or juvenile stage were also removed through predator reduction, clam populations would irrupt. Furthermore, if the factors were removed every year, thereby improving the clam environment permanently, the beds would then consistently carry clam populations of maximum abundance.[4] Predator reduction, by itself, might produce almost the same result. Adjustments in temperature and probably salinity to accommodate the environmental requirements of clams are impracticable in all beds.

[4]The carrying capacity of clam beds is probably somewhere between 100 and 250 clams, that have a full range of sizes, per square meter; an excess number would need to be transplanted to other beds to allow adequate clam growth. Probably, hard clam beds can carry fewer clams than soft clam beds.

Information Needed From Each Clam Bed

In developing methods to increase clam abundance in beds, the setting regularity of the clam would need to be determined and the factors that limit or constrain clam setting and survival, identified. Only the limiting factors that can be practicably removed need to be identified; thus, studies on effects such as temperature and salinity extremes need not be made.

An estimate of setting regularity can be made from examination of the length distribution of clams. Clams can be sampled from the beds for measuring by using a hydraulic suction sampler with a fine-mesh bag and operated by a scuba diver (Brett, 1964). All existing clam lengths in proportion to their numbers that exist in the beds need to be included. For the hard clam, length groupings of about 10 mm intervals, approximating annual growth increments, are marked off and the number of clams in each is listed. If some clams appear in all groupings, it shows that setting has occurred every year; if gaps exist, setting has occurred irregularly. (Figure 2D shows a gap between 15 and 25 mm; thus, clams did not set in the year represented by the gap, but they did set in the remaining years that were represented.) For the soft clam, appropriately wider length groupings would be used.

The factors that limit setting and survival can be identified and assessed by: 1) Making scuba examinations of the beds; and 2) taking bottom samples for later examination with a hydraulic suction sampler with a fine-mesh bag to collect predators. Soft clam beds should be examined and sampled at high tide. Answers to the following questions will provide the information needed to evaluate bottom conditions for setting of clam larvae and survival of clam spat and juveniles. The questions concerning the bottom condition for setting are as follows:

1) Are predators of larvae present, and if so, in what densities, and will they kill a substantial percentage of larvae?

2) Do grain sizes of surface sediments inhibit setting of larvae, and if so, by about how much?

3) Do biota in surface sediments inhibit setting of larvae, and if so, by about how much?

The questions concerning the bottom condition for survival are as follows:

1) What predator species of clam spat and juveniles are present, during and immediately following the setting period of the spat?

2) What is the density of each predator species, by juvenile and adult? As an estimate, will the assemblage of predators in the numbers present kill a substantial percentage of clams, and if so, about what percentages in defined periods of time?

The following questions concerning management of the beds should be answered:

1) Is it feasible to remove the abundance-limiting environmental factors?

2) What are the costs and benefits of an action such as a reduction in predator numbers?

Resources are then concentrated wherever the chances of increasing clam abundance seem best. Ideally, when a major limiting factor is removed, with little expense or effort, at least a severalfold increase in clam abundance will follow. The methods for removing the limiting factors should be conceived, constructed, and applied with surgical precision.

Possibilities of Increasing Setting Densities

Undoubtedly, predation of soft clam larvae by the bay anemone, which has an unprotected, delicate body, could be greatly reduced by controlling the anemone with a light application of granulated quicklime (CaO). The correct grain size of quicklime has to be used: A screen of 10 meshes/25 mm^2 should retain only a trace of quicklime; and one of 100 meshes/25 mm^2 should retain 98 percent of quicklime. The anemones should be controlled immediately before the setting of clam spat.

Future studies can be made to diagnose and prescribe remedial action to remove other constraints on setting densities of the hard clam and soft clam. It may be possible to increase setting densities by: 1) Removing a shell cover from the bottom; 2) hydraulically jetting the bottom to improve grain sizes; and 3) spreading quicklime to reduce the quantities of biota in sediments.

A major opportunity to increase clam abundance is through controlling predators of clam spat and juveniles.

Predator Reduction Possibilities

The prospects of predator reduction are excellent because most predators, juveniles and adults, remain on the bottom surface, at least during the warmer months, often by day and nearly always by night. On the other hand, the clams are embedded: The hard clam is shallowly burrowed, but has a relatively high specific density; the soft clam is deeply burrowed. It should be possible to remove predators from the bottom without disturbing the clams. Most clam beds have surfaces of sand with only small quantities of shells and stones, which means that shells and stones will not interfere with predator removal.

The frequency of predator removal would depend on whether or not the beds were subjected to recurrent predator invasions. In beds that are not especially subjected to predator invasions, removal of most juvenile and adult predators once or twice during or immediately following the setting period of the clam spat should lead to a severalfold increase in clam abundance. Clams are then at peak abundance, and mortalities of clam spat from predation are substantial. Some predators, such as the oyster drills and mud crab, migrate little, and therefore reinvasions by the two predators would be negligible. In some areas, the blue crab, rock crab, green crab, or horseshoe "crab" may randomly enter beds and destroy many clams. The green crab migrates onto intertidal soft clam beds at high tide and off at low tide, always remaining on the bottom surface (Dexter, 1947; Edwards, 1958), and feeding mostly by night (Naylor, 1958). Crab invasions could be controlled with methods suggested here.

During the late 1940's and 1950's, experiments using low wire fences to exclude predators were conducted in soft clam beds in Maine (Glude, 1955; Hanks, 1963) and Massachusetts (Turner, 1950; Smith and Chin, 1953; Smith et al., 1955). As stated above, the fences excluded most predators and clam densities became many times higher inside than outside the fenced areas; the fences were impracticable to maintain, however, and were not a commercial success. During the early 1960's, a chemical method was tested to control the green crab: Pieces of fish soaked in poison were supported on lines strung across the mouths of creeks, coves, and bays. Crabs entering the areas fed on the fish and died before reaching the clams (Hanks, 1961, 1963). However, the poisoned fish lines also were not a commercial success.

Mechanical methods need to be developed for removing predators from clam beds.

Developing Mechanical Methods for Predator Removal

The methods should remove juvenile and adult predators, and should do so without damaging or removing clams, or otherwise disturbing the bottom. The methods should be simple, inexpensive, and capable of removing predators from extensive areas within a short time; anything which adds to the complexity and expense of the methods should be avoided.

Some predators, such as crabs and the starfish, have relatively low specific density and can be easily lifted from the bottom by a slight water current which will not disturb clams. A board-net array which consists of a pressure board towed over the bottom followed by a net could remove predators that have low specific density. Using scuba, we have observed that the turbulence created behind a wooden board, held in a bridle and towed at a 45° angle over the bottom, lifts crabs and starfish off the bottom. The board was 4.25 m (14 feet) long, 30.5 cm (12 inches) wide, and 5 cm (2 inches) thick. A fine-mesh net towed behind the board might then catch the suspended predators (Fig. 4). Most small clams which were lifted from the sediments by the board would likely pass through the net. The net would have to be retrieved periodically for emptying. The board-net might also remove some predators that have high specific density such as the oyster drills and moon snail; trials would have to be conducted when the moon snail was on the surface. Before the board-net could be used, the bottom would have to be cleaned of loose algae, such as sea lettuce, *Ulva lactuca,* and any shells which would plug the net. A wide dredge could be used for such prior cleaning.

A more elaborate possibility is a collector having two tandem components. The first would lift the predators by directing a water current at the bottom and the second would catch them above the bottom on a screen. The predators could be brought to the surface by suction hose for disposal.

The moon snail which surfaces in larger numbers by night than by day (Medcof and Thurber, 1959) could be removed by night with a wide surface dredge or skimmer having a sufficiently fine screen bag to hold the snails.

In some clam beds, oyster drill abundance appears to be limited by the availability of surface shells to which the drills attach their egg cases when spawning. The beds, e.g., those in Great South Bay, N.Y., have scattered, mostly small, shells on their surfaces. Probably, shell removal would lead to a reduction of oyster drill abundance. The predator board-net could be used for removing the shells.

Any biological researchers and resource managers who decide to specialize in clam production should be able to develop effective tactics for removing predators from clam beds within a few months. The clam production specialists should have imagination, mechanical ability, a feel for working with nature, and probably have the capability to use scuba. They would need a vessel, testing equipment, and testing beds, besides the

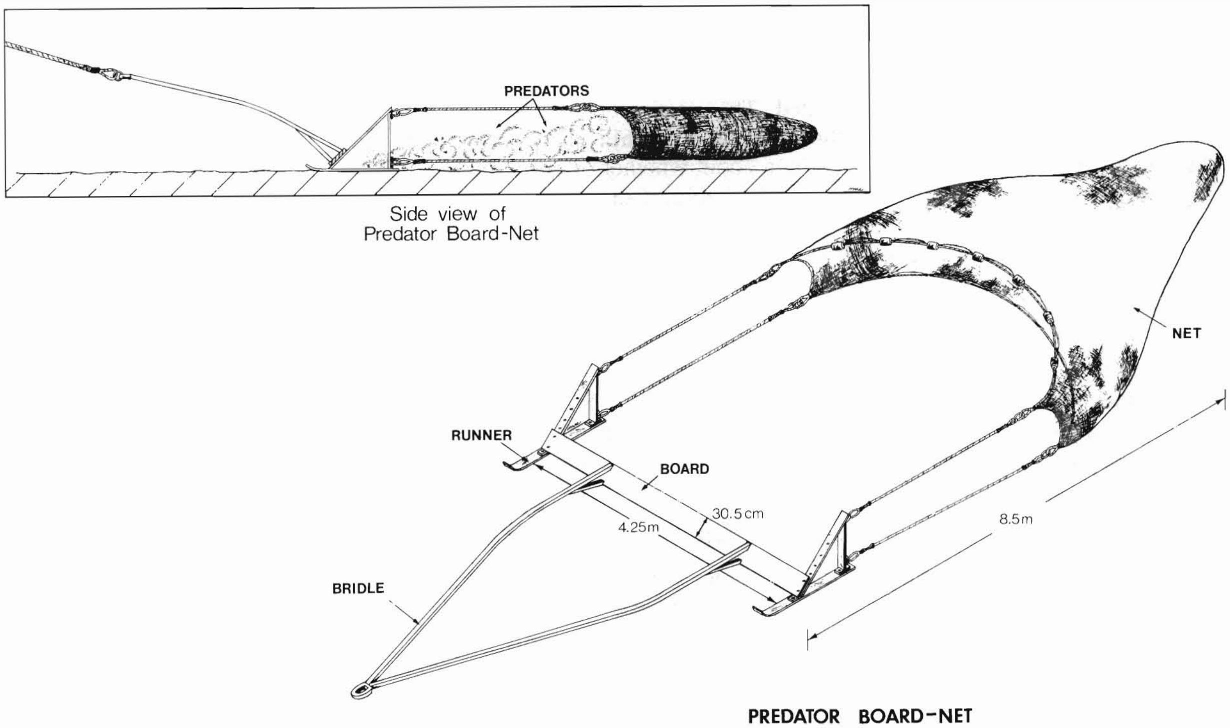

Figure 4.—Conceptual model of a board-net which could be tried for removing predators from clam beds. Adjustments in board distance from the bottom, distance between board and net, size of floats and weights on net, mesh size, and towing speed, and possible addition of small doors on net, could be made while testing the board-net to remove predators, but not remove the clams. Inset shows side view of board-net being towed and how predators might be lifted by board and enter net. A board-net of this width has the potential to remove predators from a few hectares (several acres) of bottom in an 8-hour day. In 1979, the cost of its construction would be about $600; $300 for the board and supporting structures, and $300 for the net.

necessary time. Development of predator-removal methods will involve trial and error testing, by night as well as by day, followed by sampling of predator and clam densities. After the predators have been removed from the beds, clam densities would be compared periodically with those in control beds. A hydraulic suction sampler with a fine-mesh bag and operated by a scuba diver can be used to measure the densities. Eventually, documentation of costs and benefits of using the methods would be needed. As a precaution against damage to commercial beds, methods should be tested, perfected, and proven effective on small areas.

Side Effects of Predator Reduction

Predator reduction on clam beds would not impinge on other interests. The ingredients of quicklime are natural components of bay and estuarine water and shells, and also flow into the water from farmland treated with lime. A light bottom application of spread quicklime dissolves in 2-3 days. The mechanical methods for removing predators would be used for only brief periods, and thus would not interfere with navigation. Predator numbers would become greatly reduced, thereby shifting typical numerical ratios of predator to prey in wild beds; the new ratio would be similar to one that occasionally occurs in beds when predators become scarce from natural causes and where afterwards clam populations irrupt. Predator reduction in clam beds would be followed by large increases in numbers of polychaetes, other mollusks, and other invertebrates, along with the clams. Predator and invertebrate numbers would not be affected in areas other than the clam beds.

Incorporating Methods Into Practice

It will do little good to develop effective methods for removing predators from clam beds unless they are put into practice. The development process will not be complete until the new methods result in increased abundances, yields, employment, incomes, and supplies. Any effective method to be successfully put into practice must qualify as follows: 1) Meet an urgent need; 2) be technically and operationally feasible; 3) offer no damaging risks to the beds; 4) will not impinge on other interests; and 5) will yield a return that exceeds the investment which, primarily, should be low. Probably, with clams, a method would have to produce at least a twofold increase in clam abundance at an annual cost within the range of about $75-$125 per hectare ($30-$50 per acre) to be attractive enough to implement. An effective method, which has been conceived, constructed, and applied with precision, would undoubtedly yield much larger increases for roughly the same cost.

It should be recognized that implementation of a method on commercial clam beds will be one of the most difficult hurdles in the translation of an idea into more clams. Implementation is difficult because it means impingement directly upon the livelihoods of clam fishermen and other people in local communities. Accordingly, when the time gets close to implementation, an uncertainty will likely develop within fishermen and local people concerning whether the use of a method will be beneficial; they will not want to risk the little security and the employment and incomes that the fishermen already have. The fact that no such method has ever been used on any clam bed will amplify the uncertainty.

Naturally, clam production specialists would be at first eager to implement their method, especially if they have been deeply committed to its development. However, they may come to fear that negative reaction will arise among the fishermen and local people, which could lead to criticism of their work, damage to their reputations, and permanent loss of their credibilities. If it happens, specialists should not leave the development process at this point. Specialists make a mistake by leaving a designed and developed system before it has been properly implemented, because subsequent implementation by others than the developers is rarely successful.

The decision about whether to implement a method lies with the fishermen and local people because they have community responsibility over the beds. Accordingly, the specialists must thoroughly demonstrate the method on the testing beds and supply convincing evidence of its effectiveness by showing them samples of higher abundance of juvenile clams. The fishermen and local people should have ample opportunity to examine all features and performances of the method; all angles should be freely discussed, criticisms aired, or alternative methods suggested. Then, after such deliberations, the specialists should sample public opinion about whether or not to implement. Probably, fishermen and local people will respond favorably to a new method which clearly promises increased production and monetary gains, and will urge the specialists to go ahead. If not, the specialists should consider whatever revisions were suggested.

During the implementation phase, personnel who will use the method will have to be trained.

Political Support for Program

A management program, of whatever size, for maintaining high clam abundance in beds would be under the sponsorship of the governing body of a community. Such a program would have to be established by the respective civic authority which is fiscally empowered to undertake such a project. It would entail the will, determination, and commitment of those involved, who are entrusted to make such decisions. The production specialist would have to meet with the civic body to explain the designed process for increasing clam yields, and submit evidence of its potential effectiveness. Computed evidence of tangible increases in yields, concomitantly increased employment and incomes, will be highly influential in winning support for, and later maintaining, the program.

Clam Production Specialists Guide Program

After the establishment of a management program to increase clam abundance in a locality, it is advisable for production specialists to consult, at least 1 or 2 days a year, with operating personnel on the beds. Such consultations would include an examination of the beds and pertinent discussions to keep the program on track and improve efficiency. A program may gradually fail to function if not stimulated by such consulting.

Increasing Abundance of Ocean Clams

Ocean clams inhabit an environment which is probably far from optimum for maximum clam setting and survival efficiency. Thus, it may be possible to increase abundance of clams by improving their environments. The commercial ocean clams off the Atlantic coast of the United States are the surf clam, *Spisula solidissima,* and ocean quahog, *Arctica islandica*. The clam predators include gastropods, crabs, and starfish. Application of methods to remove any major factors that limit clam setting and reduce predator numbers to improve clam environments may not be practicable in the ocean. Nevertheless, the idea should be tested.

Conclusion

The objective of clam management, to increase clam abundance in beds and consequent yields and supplies, can be achieved when practicable, low-cost methods are developed and used for removing predators from clam beds. The examples from test areas in wild clam beds of substantial increases in abundance of the hard clam and soft clam following poisoning and fencing-out, respectively, of predators show that clam abundance will also increase substantially after predators are removed from other wild clam beds. Studies should be undertaken to determine whether or not setting densities of clam spat can be increased with practicable methods. A permanent increase in clam abundance and yields will vitalize the clam fishery and thus meet basic human needs by: 1) Increasing the economic security, stability, and prosperity of clam fishermen; 2) stimulating the economy of local communities; and 3) increasing clam supplies at more stable prices in the market, without substantial cost in money or time.

Heretofore, clam management has been designed to conserve clam populations and ensure continuous clam yields. As stated above, various state and local regulations restrict the clam sizes and quantities to be gathered and the types of gathering gear. The conservation management concept somewhat parallels management of many of the wildlife resources, such as freshwater fish, waterfowl, and upland game of our nation. It differs in that attempts have been made to increase wildlife abundance within the three categories through environmental improvement. The management goals have been successfully reached through the legal restrictions on clam gathering, but under the conservation concept, clams can and do become scarce for years. No attitudes and solutions within the concept exist to increase clam abundance. Imposing increased restrictions on gathering clams will never create increased clam abundance. This has been evidenced when freshwater fish, waterfowl, and upland game did not increase with the imposition of increased restrictions on fishing and hunting.

Conventional management for the conservation of clam populations should be replaced with a management concept which embraces conservation and increased clam abundance through environmental improvement. Permanent increases in clam abundance can be brought about through a combination of: 1) a continuation of the regulations prohibiting the gathering of small clams; 2) problem-oriented research and development, and implementation of methods and programs for improving clam environments by clam production specialists; 3) establishment of the programs by decision-making civic bodies, authorized and willing to do it; and 4) guidance by the production specialists in the years after programs have been established.

Removing the constraints on clam abundance in beds, which have heretofore consistently deprived clam fishermen, local communities, and the market, will benefit everyone.

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