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Status of the Hard Clam Fishery

In Narragansett Bay 94pp

Pratt, S.D. (URI)

Narragansett Bay Estuary Program

Report # NBP-88-07

STATUS OF THE HARD CLAM FISHERY IN NARRAGANSETT BAY

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Final Report for the

Narragansett Bay Project

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FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 and designated an "estuary of national significance" in 1988. The Narragansett Bay Project (NBP) was established in 1985. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a five-year program of research and planning focussed on managing Narragansett Bay and its resources for future generations. The NBP will develop a comprehensive management plan by December, 1990, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

* management of fisheries
* nutrients and potential for eutrophication
* impacts of toxic contaminants
* health and abundance of living resources
* health risk to consumers of contaminated seafood
* land-based impacts on water quality
* recreational uses

The NBP is taking an ecosystem approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among state agencies, governmental institutions, and academic researchers in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement #CX812768 to the Rhode Island Department of Environmental Management. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP. Final recommendations for management actions will be based upon the results of this and other investigations.

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INTRODUCTION

Catches of hard clams in Narragansett Bay have been high for several years. Prices have also been good. We should not assume, however, that this situation is due to good management or that it will last indefinitely. Hard clam landings have fluctuated widely in the short history of the fishery. The reasons for these fluctuations were largely unknown and few management options were available other than allowing fishermen to join or leave the fishery as economic conditions dictated.

At the present time, full-time quahoggers participate in the management of the fishery through membership in the "Quahog Committee," through presentations to the Coastal Resources Management Council (CRMC), and through support or opposition of legislation.

This participation has many advantages including increased compliance with regulations and avoidance of regulations which disrupt working schedules or cause supply fluctuations. Negative aspects of control by fishermen are the exclusion of some management options and lack of consideration for the total economic benefit of the fishery or for part-time and recreational diggers.

To maintain stocks and to produce a high-quality product in the future, it is necessary to consider a wide variety of alternative management practices. This is particularly important at this time when new information is becoming available through the Narragansett Bay Project. In 1985-86 research was carried out on heavy metal levels and histopathology of hard clams throughout the Bay, on the distribution of hard clams in the Providence River and Mount Hope Bay, and on waterborne pathogens. Organic contaminants in clams were determined in 1987-88.

Flexibility in planning will also be required if anticipated improvements in water quality lead to opening highly-productive portions of the Providence River and Mount Hope Bay or if natural causes lead to a decline in recruitment.

This review covers a range of topics on the historical fishery, the biology of the hard clam, and the quality of the Narragansett Bay environment which must be considered in managing the fishery in the future. Each topic is presented in a separate report which is written in "plain English" and which includes information on sources and quality of data and suggestions for additional data collection. Most attention is given to management alternatives which are compatible with the present structure of the Rhode Island fishery.

None of these reviews are definitive. In most areas more information was found than could be included, and areas such as economics are outside the author's field and could only be mentioned in passing. It is anticipated that this report could be supplemented by state agencies and fisheries interests to produce a document for guiding future management of hard clams. Two models for a publication of this kind are the book-length analysis of hard clam management alternatives produced for Suffolk County, New York (COSMA, 1985) and the findings and recommendations on Connecticut aquaculture (Conn. Aquaculture Comm. 1986).

THE RHODE ISLAND COMMERCIAL FISHERY

Landings

In fisheries statistics published by the National Marine Fisheries Service (NMFS), the hard clam catch is given in pounds of meat. This is obtained by multiplying the catch in bushels by the pounds of meat per average bushel (12 pounds previous to 1985 and 10 pounds since). Only the catch sold to dealers appears in NMFS statistics.

Before 1928, annual Rhode Island commercial landings were less than one million pounds of meat. The oyster industry was still important during this period, and much of the Upper Bay was under lease. Hard clams were of secondary importance, both in terms of food and management. Commercial catches increased from 1928 to 1955 with some fluctuation. The greatest increase in landings took place between 1951 and 1953 when they more than doubled to five million pounds (Figure 1). After remaining high for two years, landings decreased rapidly, then more slowly to a low of less than one million pounds in 1974. A second major increase took place between 1974 and 1983, and landings have fluctuated around the four million pound level since then.

The development of the fishery in the 1940s and 1950s was related to the opening of grounds following the demise of the oyster fishery and to increases in demand and price. Peak catches were made a few years after large decreases in the New York fishery. In both Rhode Island and New York the high landing rates were apparently made at the expense of the standing stock and could not be sustained. Failure in recruitment may also have contributed to the rapidity of the decline in both areas. A detailed study of Greenwich Bay showed a reduction of settling of spat between 1952 and 1954 (Stickney and Stringer 1957). We do not know whether this was a Bay-wide phenomena, however.

The increase to the present high levels of landings followed the introduction of the modern bull rake around 1971. This rake made it possible to harvest deeper bottoms and more bottom types. While the density of clams at different depths is not known, it is clear that this gear significantly increases the area available for harvest. Table 1 shows that most of Greenwich Bay is within the reach of tongs (only 8% deeper than 13 feet), but that in other areas an increase in the maximum depth of harvest from 13 to 26 feet doubles the fishable bottom.

Table 1. Areas of portions of Narragansett Bay between given depths (Chinman and Nixon 1985)

area (Km^2) (0.386 square miles)

	code	total	0-4m (13 ft)	4-8m (26 ft)	% increase
Greenwich Bay	3	11.6	10.7	0.9	8
Upper Bay	2	43.3	12.6	23.6	187
Upper West Passage	4	77.9	18.5	27.8	150
Upper East Passage	6	23.8	7.3	7.5	101
Sakonnet Passage	10	50.1	18.4	17.9	97
		206.7	67.6	77.7	115

Although increases in harvestable area and in numbers of fishermen contributed to the recent increase in landings, the high catch rate could not have been sustained without regular recruitment of small clams into the fishery.

Value of Catch

The annual value of Rhode Island hard clam landings is shown in Figure 2. The low peak in the 1950s reflects a peak in catch with little increase in price. The high peak in the 1970s and 1980s is the result of increases in catches and price increases due to inflation. When annual values are adjusted to 1967 dollars, the peak is lower, but still shows an increase in the value of the product. This increase is a function of the larger proportion of valuable small clams in the catch and increased prices in all size categories.

The annual price of hard clams (as pounds of meat) in actual and adjusted dollars is shown in Figure 3. The adjusted price gradually increased by 33% from 1951 to 1970, doubled from 1970 to 1980, dropped to a low in 1982 to 1983, and then increased again.

The 1982 to 1983 dip was caused by a combination of quality problems in New York (COSMA 1985) and an abundance of supply from Rhode Island and other states. Although NMFS statistics are not yet available, it appears that prices have continued to increase in 1986 and 1987 and are now at an all time high in actual dollars.

Numbers of Fishermen

The number of holders of commercial hard clam licenses from 1951-1982 are shown in Figure 4. These numbers give no information of the extent of participation in the fishery of the license holders. Holmsen (1966) and Holmsen and Horsley (1981) conducted mail surveys on two occasions and made the following estimates of number of men deriving different proportion of their income from hard clamming.

Table 2. (Holmsen and Horsley 1981)

	1962-1963		1978-1979	
Proportion of Income	number	%	number	%
none	139	17	113	11
none	139	17	113	11
less than 20%	359	44	297	29
about 1/4	81	10	114	11
about 1/2	65	8	135	13
about 3/4	33	4	31	3
over 90%	138	17	338	33
	815		1,028	

If full-time fishermen are defined as deriving at least 75% of income from clamming, the proportion of full timers increased from 21 to 36% in the two surveys. Holmsen (1966) also found and increase in full timers from the 1950s to 1961, thus the proportion had increased both during periods of decline and expansion of landings. If a high number of 40% is taken, it can be roughly estimated that about 520 of the 1,308 1984 license holders were full time.

The present Rhode Island multipurpose license which allows applicants to check a variety of fisheries and includes all shellfish in one category compounds the difficulty of determining distribution of effort among fishermen.

The number of commercial license holders using different types of gear is also shown in Figure 4. There were about six times as many tongs as rakes in use in the 1950s. A decline in the number of tongers and a switch to rakes preceded the increase in landings after 1974. Presently, about 10 times as many fishermen use rakes than use tongs. The proportion is probably even higher among full-time fishermen.

The annual landings of pounds of meat per license holder and actual and adjusted average income are shown in Figure 5. These show a decrease in pounds landed and no change in adjusted income per license holder over time. It is surprising that adjusted income is virtually level. If the number of full-time fishermen has actually increased over time,income for a given amount of effort has decreased in adjusted dollars. It is clear that more information on status of license holders is required to be able to define the economic condition of hard clam fishermen at this time.

Competing Sources of Clam Meat

Hard Clams—Hard clam fisheries in other states are of interest as competitors with the Narragansett Bay fishery and because they provide examples of the effect of different management strategies.

There are close similarities in the pattern of annual landings in Rhode Island and New York. The two peaks and intervening dip in Rhode Island catches (Figure 1) were proceeded by changes of similar magnitude in New York seven to ten years earlier (Figure 6). In New York the last peak in the 1970s was followed by a rapid decline to a level around one-third of peak catches.

The present condition of the fishery in Suffolk County (the major source area in the state) is discussed in detail in COSMA (1985). It was reported that overfishing is an important cause of the recent decline in landings. In Great South Bay clam density, size of daily catches, and size of clams have all decreased, and the removal of older clams is not being compensated for by increased survival of younger clams.

Water quality has been a problem in New York and New Jersey for a long time. Major outbreaks of shellfish-born disease occurred in 1924-1926, 1961, 1964, and 1982-1983. According to studies cited in COSMA (1985), the decertification of prime growing areas and the general low density of clams in clean areas has lead to significant violation of sanitary control regulations. Mirchel (1980) found that as many as 50% of diggers worked in uncertified waters at times, and Buchner (1984) found that significant quantities of clams from uncertified waters were being harvested. A consequence of this harvest is poor public perception of the quality of New York clams and decrease in demand and price with any rumor of disease outbreak.

Some of the research on ways to increase hard clam stocks in Suffolk County discussed in COSMA (1985) will be presented in subsequent sections of this report.

In New Jersey there was a relatively large hard clam fishery at the turn of the century, and there have been three peaks in landings since the 1930s. The largest annual landings of more than 4 million pounds of meat were made in the late 1940s. Catches declined to 1.4 million pounds in 1962, showed a small increase in the late 1960s and have subsequently decreased.

The largest decline in New Jersey landings during the 1950s was caused by closing of polluted waters. The most recent increase in landings was associated with improved demand, availability of depuration and relay techniques, and re-opening of some areas (McHugh 1977). Although the programs for depuration and relay were developed in an environment of confusion and acrimony, with local watermen or politicians taking the lead rather than the state, these management techniques may help to level out variations in catches in the future.

The coastal lagoons of the southeastern states provide large areas of shallow, clean water with potential for hard clam production. Only Virginia and Florida have significant fisheries, however. Virginia's landings were equal to those from Rhode Island during the 1960s and 1970s, but are smaller in proportion now.

Predation is a major problem in hard clam production throughout the southeast. Aquaculture techniques to protect juvenile clams developed by M. Castagna and associates are gaining acceptance in Virginia (Castagna and Kraenter 1981), but do not yet play a significant role in the fishery. In their analysis of the fishery of wild stocks, Kvaternik et al. (1983) found that fluctuations in landings were due to changes in fishing effort rather than to stock availability. Hard clams are a less desirable target species than the blue crab and is harvested mainly in the winter and where they are locally abundant.

Walker and Tenore (1984) and Walker and Rawson (1985) studied the distribution of hard clams in Georgia and found dense beds only where exposure at low tide inhibited predation. Both Walker and Rawson and Kvaternik et al. (1983) suggest the use of hydraulic escalator harvesters to create a fishery profitable enough to attract participation and which would benefit the regional economy.

There were very successful sets of hard clams in Florida's Indian River lagoon in 1982 and 1983. A rapidly growing fishery harvested over 1.4 million pounds of meat worth $4.4 million in 1984 and 3.8 million pounds worth $8.1 million in 1985. In 1985, landings declined to 1.4 pounds, but increases in prices sustained income to fishermen at $6.6 million.

The Indian River environment and the 1984 fishery are described in Busby (1986). Information on recent developments were obtained from M. Berrigan, Florida Department of Natural Resources. Successful recruitment, such as occurred in 1982-83, appears to be a sporadic event, possibly requiring unusual survival of larvae and reduced levels of blue crab predation. In 1987 stocks were low and declining in certified waters, and the fishery was based on depuration or relay of clams from marginally-polluted areas. Because of the uncertainty of natural supplies and high prices being paid, there was considerable interest in aquaculture in the area. The ability to grow clams to littleneck size in two years makes aquaculture economically feasible. Even with depuration, relay, and aquaculture, Florida may not be able to sustain a fishery as large as the present one. The very large 1984-85 catches appear to be an unusual occurrence.

In 1984, Florida's catch was over 10% of the U.S. total. In that year the shares of Rhode Island and New York dropped by a few percent each (Figure 7). During the fall of 1984, the combination of less expensive Florida clams and large once-a-week catches from the conditional area of the Upper Bay caused low and fluctuating prices. Despite the dislocation, the average price of Rhode Island clams rose 30% in 1984 and has continued to rise since. Apparently the demand for littleneck size clams can sustain prices unless new sources are very large and enter the market very rapidly.

Other Species—The annual U.S. landings of meat from three types of clams are shown in Figure 8 (NMFS 1986). The total supply of hard clam meat was nearly level between 1970 and 1985 despite the large fluctuations which have taken place in regional fisheries. Apparently these fluctuations tend to cancel each other, while rising prices encourage development of substitute sources. Although weight landed has remained level, the harvest of smaller clams has meant a steady increase in the value of the catch throughout the period shown.

The hard clam is almost exclusively utilized by the restaurant and home market. Prepared food manufacturers and large restaurants have utilized the surf clam as a substitute for both hard and softshell clams since the 1940s. When the surf clam stocks were overfished, the ocean quahog fishery was developed. Virtually all of the catch reported as "other" by NMFS consists of ocean quahogs. Surf clams and ocean quahogs are both harvested by hydraulic dredge on the near-shore continental shelf, and the total catch is over seven times that of the hard clam. Because of the differences in harvest technique and market, there appears to be no relationship between the demand and price between hard clams and the deep water species.

Landings of softshell clams are slightly less than those of hard clams, are more variable, and show a decreasing trend over time. Variability and decline are the result of the pollution of their preferred habitat in shallow low-salinity water, closures due to red tide, and overfishing.

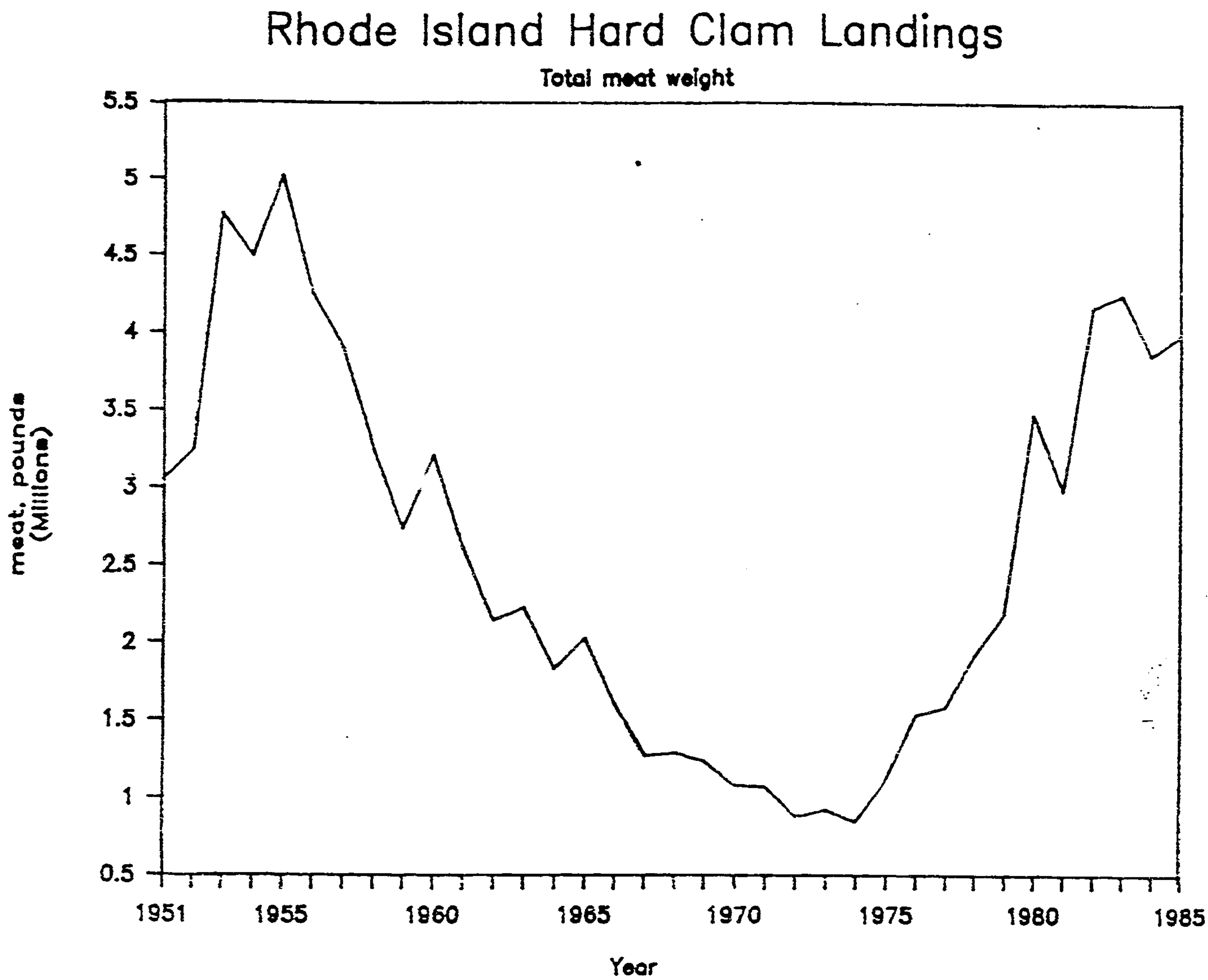


Figure 1. Rhode Island hard clam landings, meat weight, 1951-1985 (various NMFS sources)

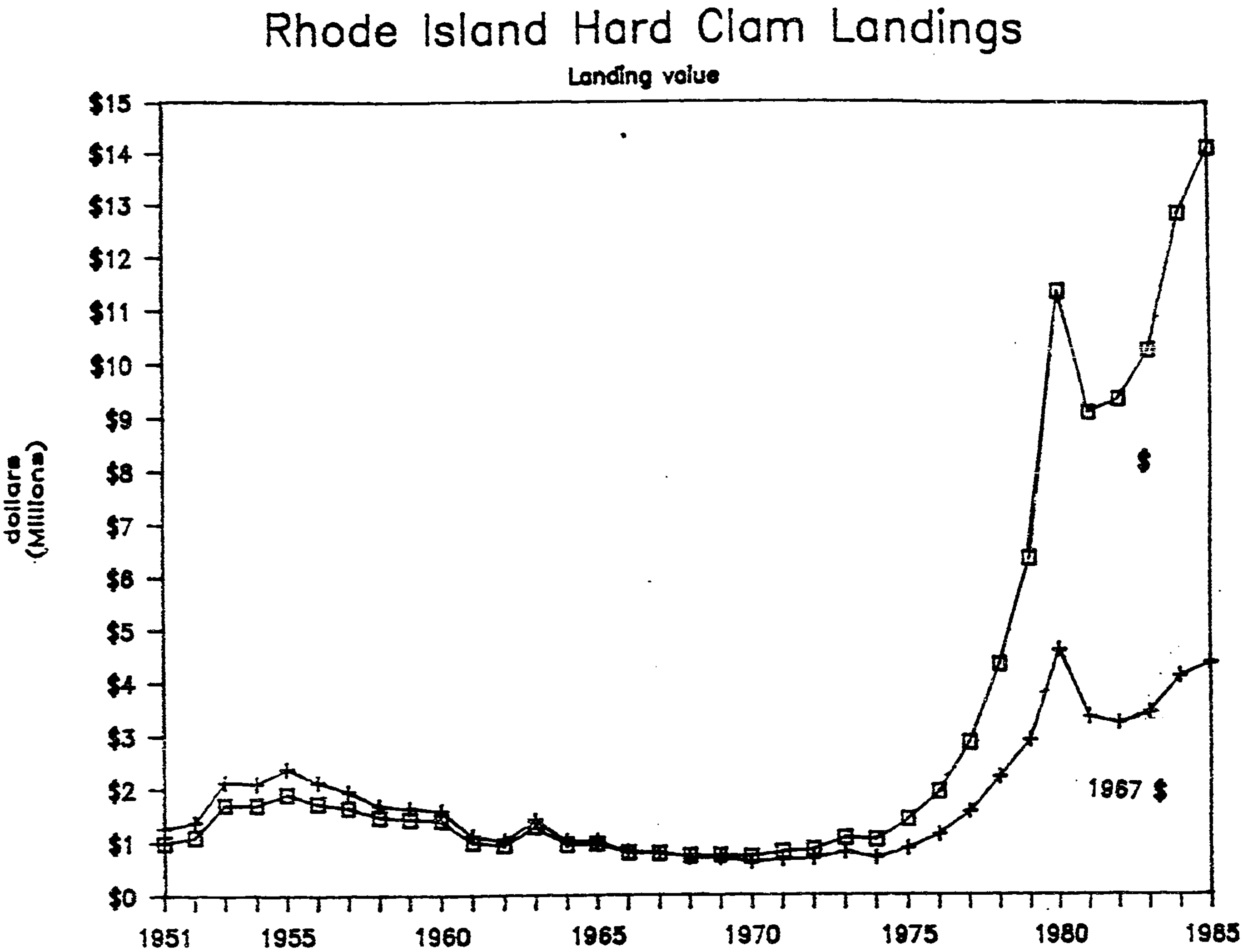


Figure 2. Rhode Island hard clam landings, dollars and 1967 dollars, 1951-1985 (various NMFS sources)

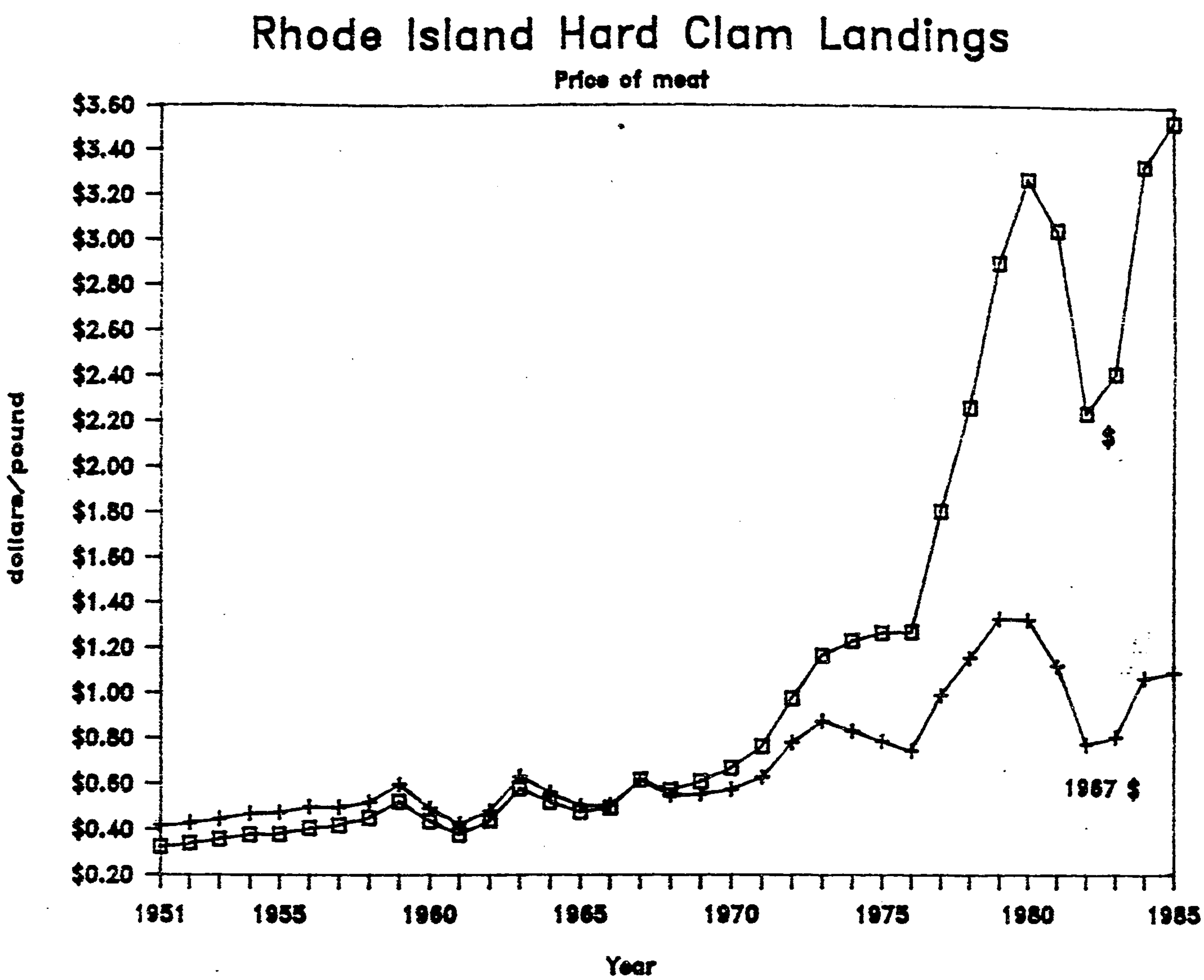


Figure 3. Rhode Island hard clam landings, price of meat in dollars and 1967 dollars (various NMFS sources)

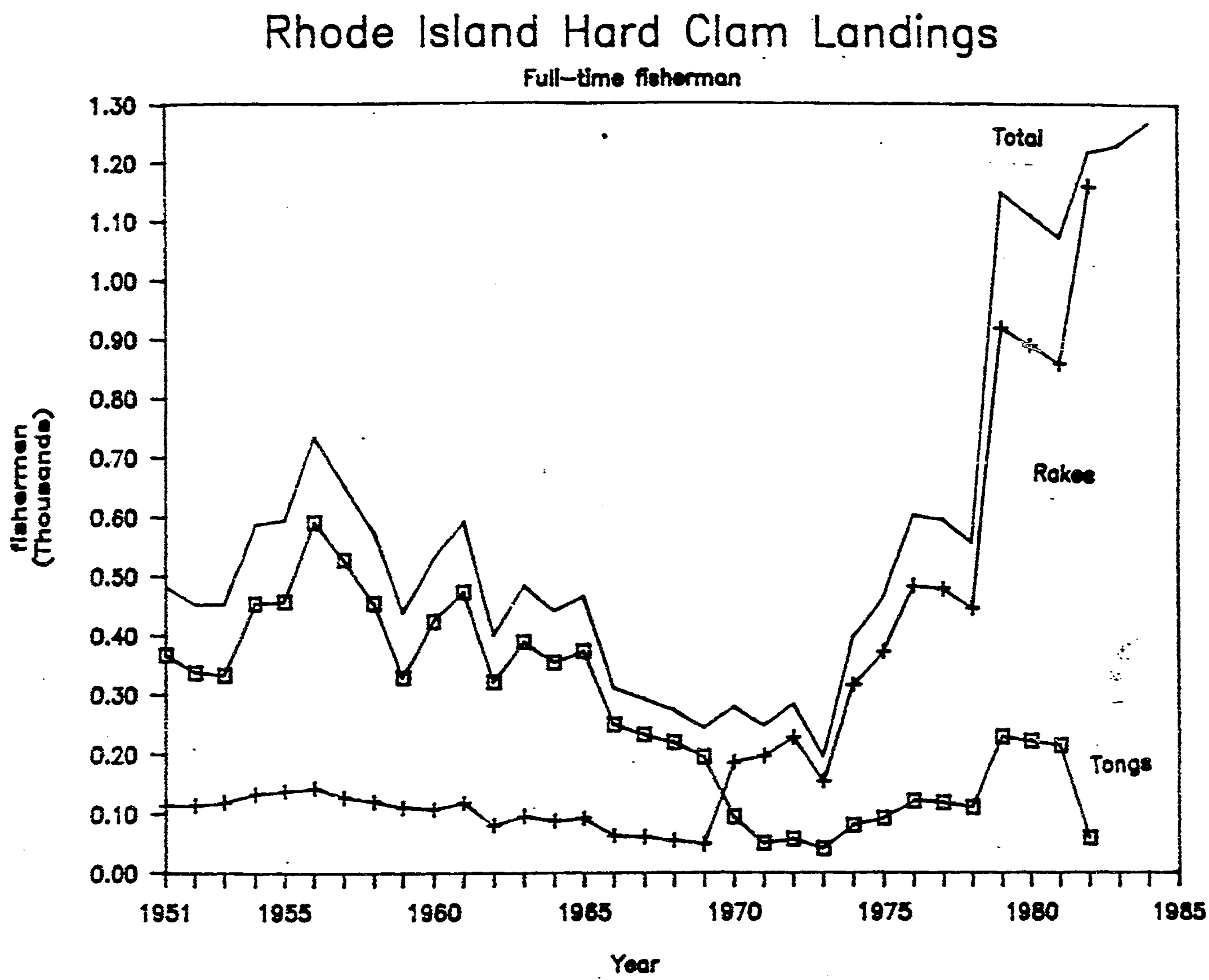
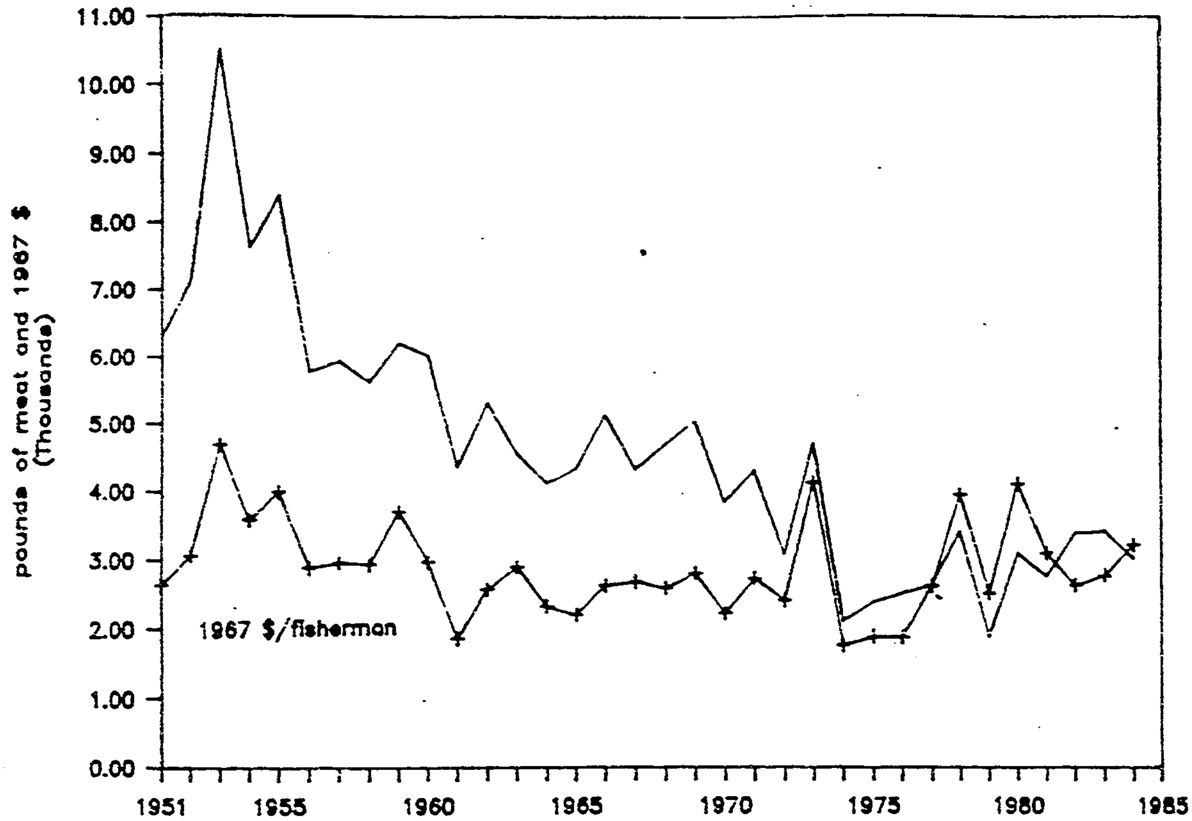


Figure 4. Number of full-time hard clam fishermen utilizing tongs and rakes (various NMFS sources)



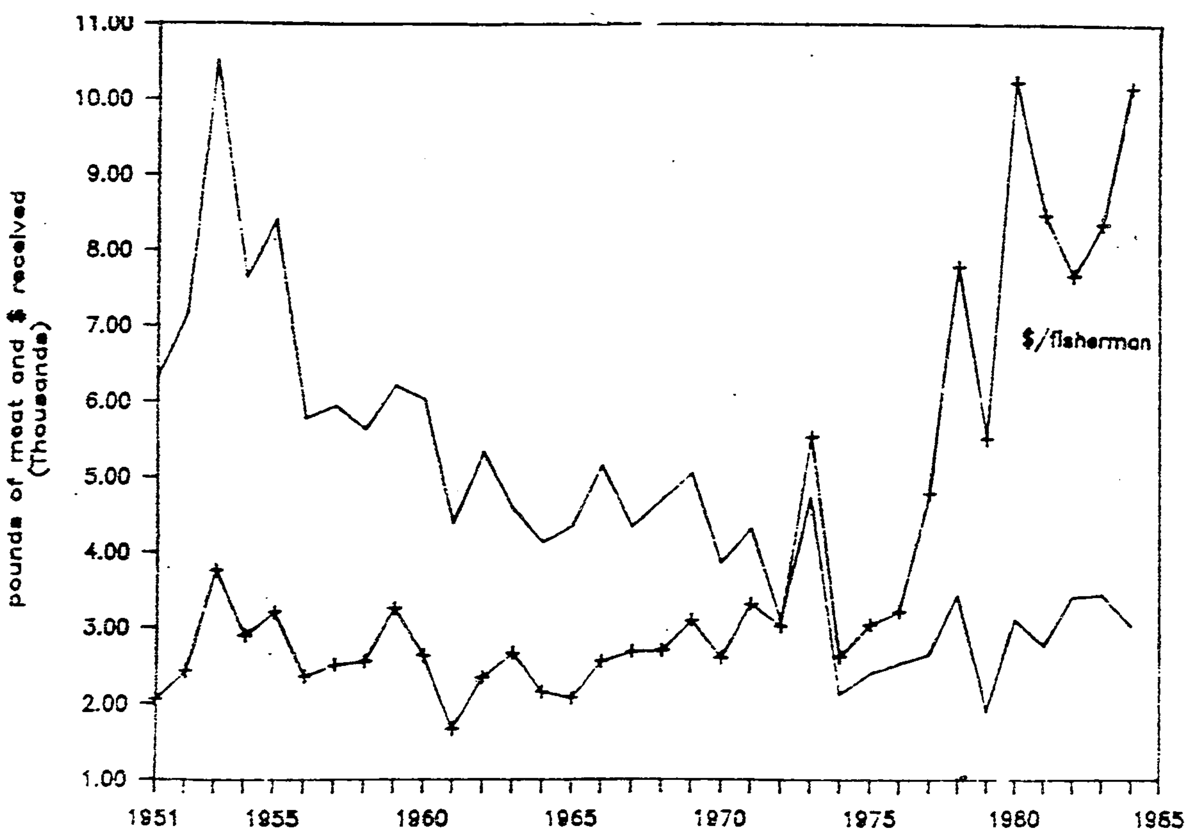


Figure 5. Annual catch per commercial license holder (both graphs) and annual value received per holder in actual dollars (bottom) and 1967 dollars (top) (various NMFS sources)

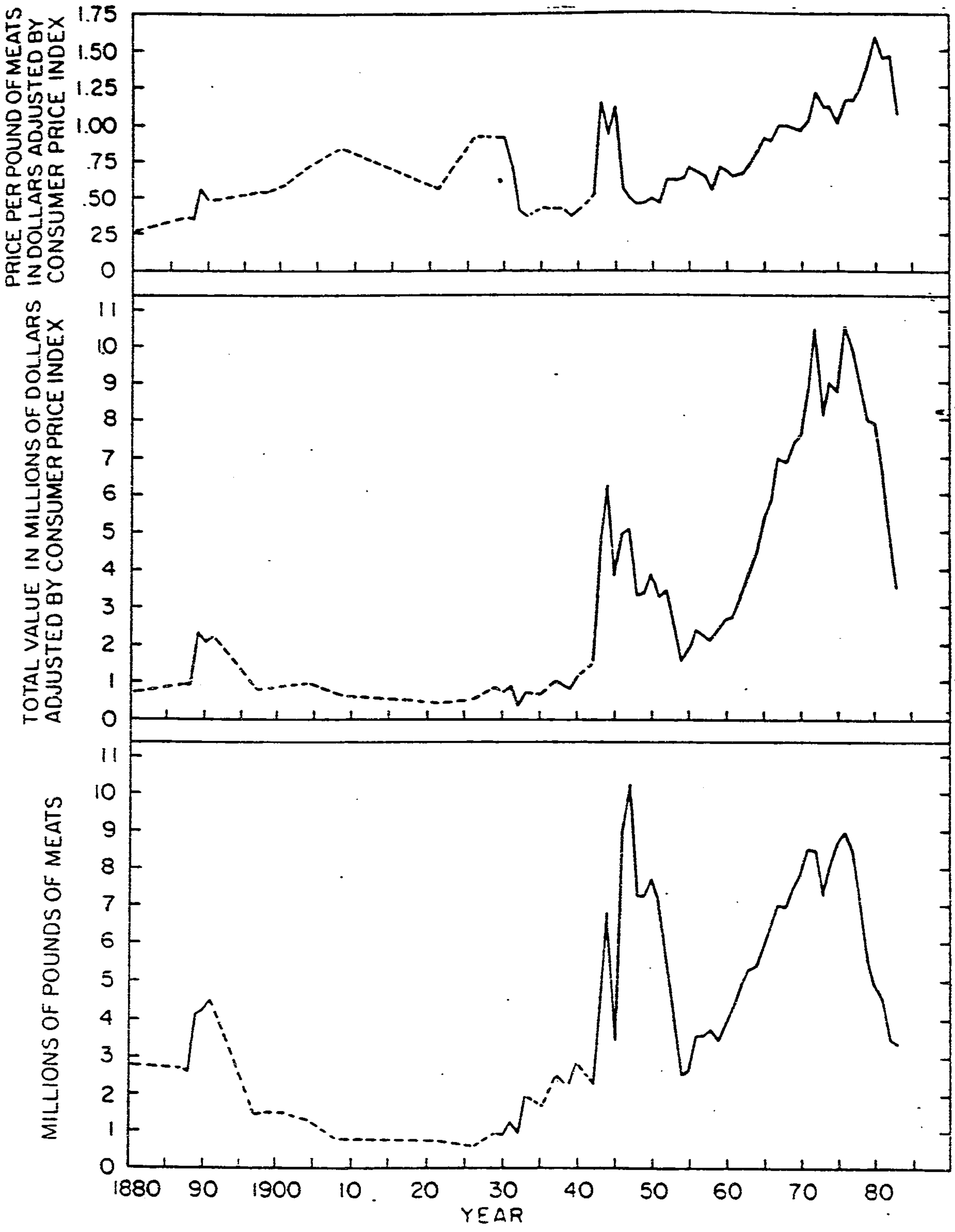


Figure 6. New York state annual hard clam landings, value, and price (COSMA 1985, Figure IV-1)

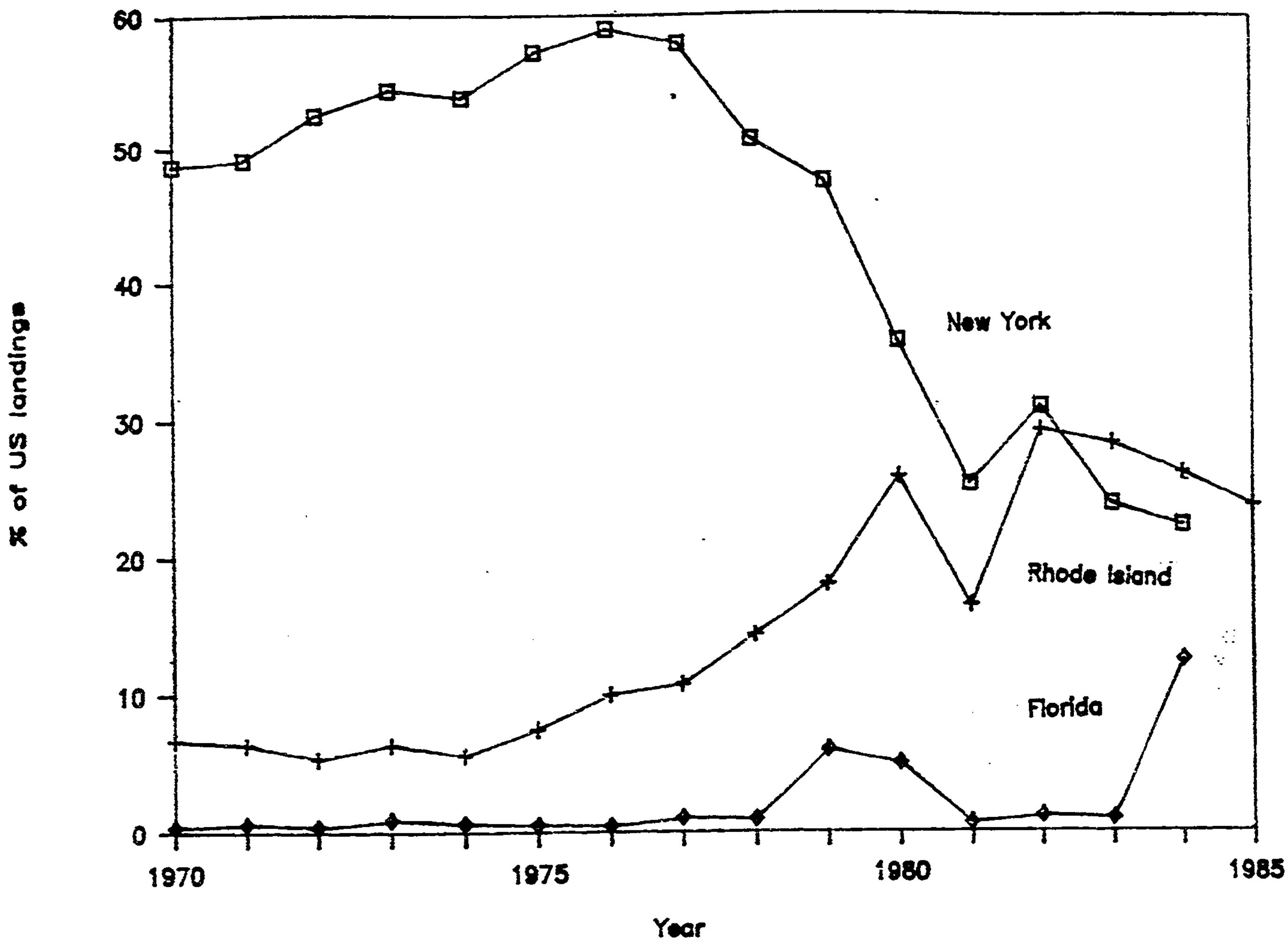


Figure 7. Relative contribution of New York, Rhode Island, and Florida to U.S. hard clam catch, 1970-1985 based on meat weight (NMFS 1987)

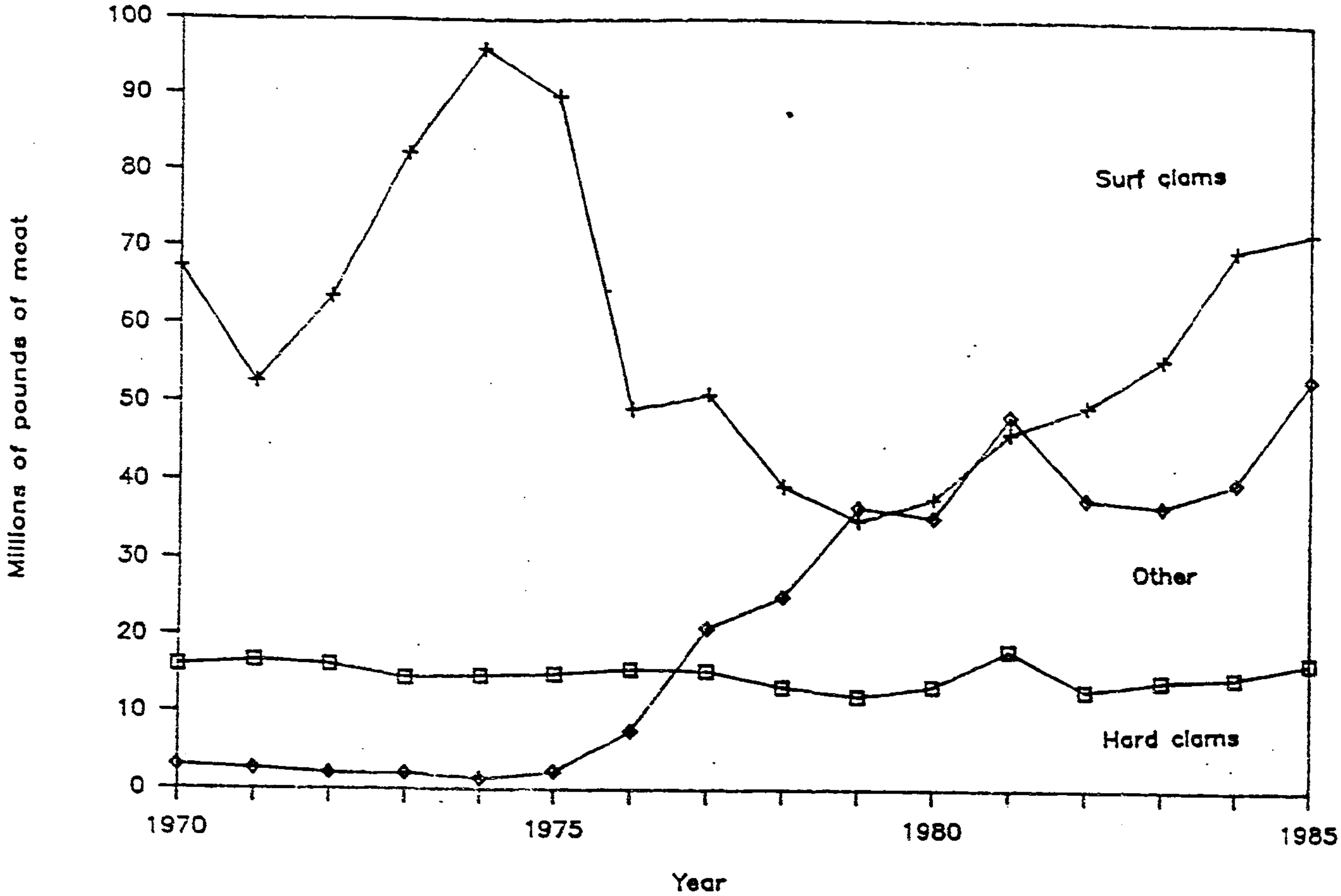


Figure 8. U.S. Landings of major clam categories, 1970-1985. "Other" are largely ocean quahogs (NMFS 1987)

MANAGEMENT STRUCTURE AND OBJECTIVES

A number of different agencies participate in management of shellfish resources in Narragansett Bay. These are introduced below, and the Department of Fish and Wildlife and the Department of Enforcement are discussed separately in more detail. The National Shellfish Program and the Rhode Island laws which govern shellfish management are also summarized.

General Organizations

An organizational chart (Figure 9) shows the divisions of the Department of Environmental Management (DEM) and the Department of Health (DOH) which have a role in shellfish management.

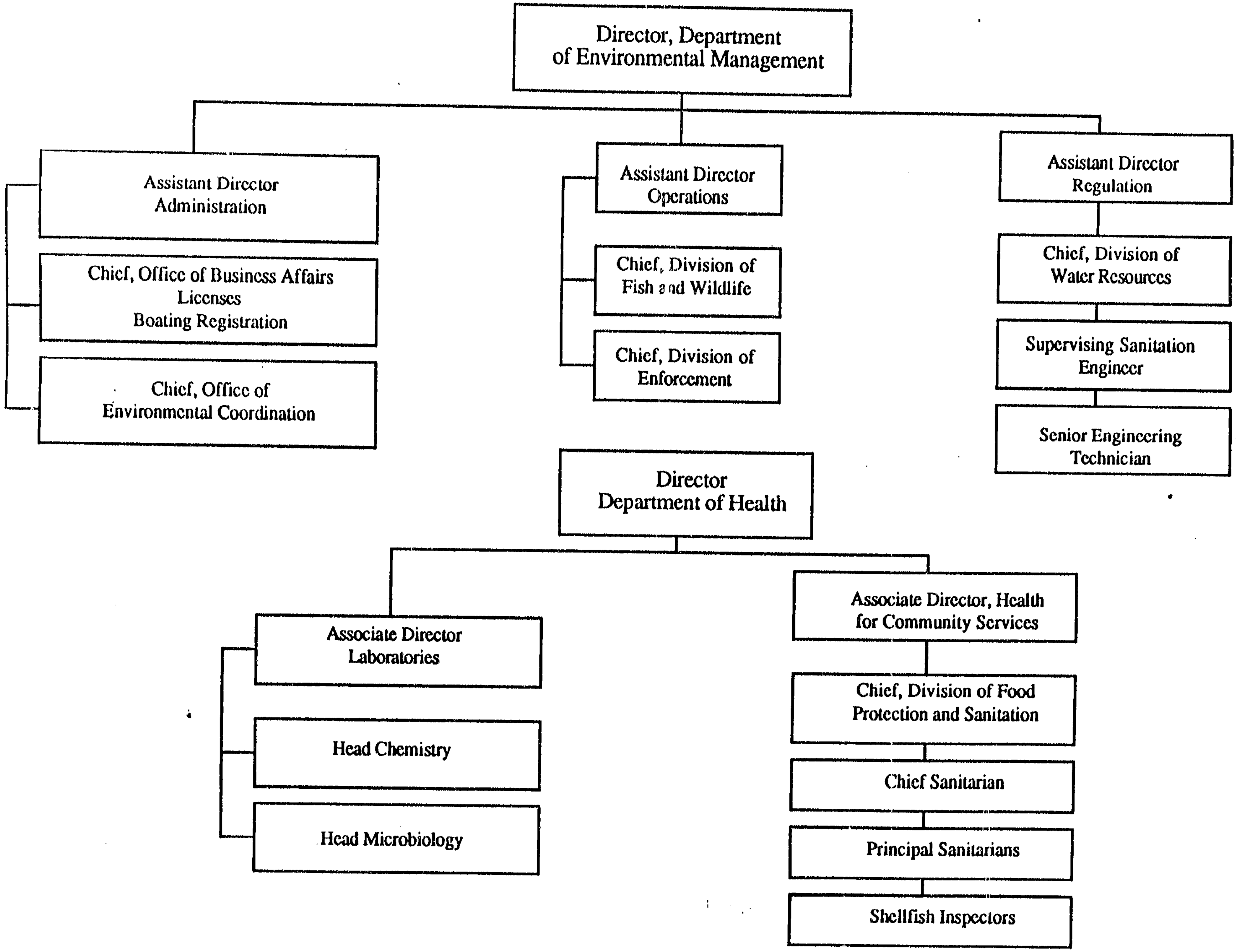
The DEM has three main units. Under the Administrations unit, the Office of Business Affairs handles all fishing licenses and boat registrations. Business Affairs took over this responsibility from the Enforcement Division in 1984. The Office of Environmental Coordination, also under Administration, was created to coordinate departmental response requiring input from more than one division. This office has not participated in decisions involving hard clams in recent years.

The Operational Unit includes the two divisions most concerned with hard clam management—the Division of Fish and Wildlife and the Division of Enforcement.

The Regulatory Unit include the Division of Water Resources which analyzes water quality data and determines open, conditional, and closed areas of the Bay. Laboratory analysis of water is done at the Department of Health microbiology laboratory.

Shellfish tissues from growing areas and markets are analyzed for heavy metals and bacteria in the chemistry and microbiology laboratories of the Department of Health. Data on tissue contaminants are collected and analyzed by a principal sanitarian in the Division of Food Protection and Sanitation. This division also has four inspectors who monitor all aspects of buying, processing, and shipping of shellfish.

Figure 9. Organizational chart for hard clam management in Rhode Island



The Marine Fisheries Council which is chaired by the DEM Director or his designee determine many of the rules and regulations governing fishing, but is independent of the division. The present chair is the DEM Assistant Director of Operations. The Chief of Fish and Wildlife, Chief of Enforcement, and Chairman of CRMC serve as non-voting advisors.

The Coastal Resources Management Council, which is also independent, issues licenses for aquaculture and permits for any shore development. Information on the potential effects of aquaculture leases on existing fisheries comes from the Division of Fish and Wildlife.

The "Quahog Committee," a subcommittee of the Marine Fisheries Council, is made up of representatives of the shellfishing industry who meet with Fish and Wildlife and Enforcement personnel every few months to discuss management of the fishery.

Division of Fish and Wildlife—

The DEM staff carrying out research and management in marine fisheries are under the direction of the chief of the Department of Fish and Wildlife. Staff members are based at department headquarters (Washington County Government Center, Wakefield) (one), at the Marine Fisheries Section, Wickford (five), and at the Coastal Fisheries Laboratory, Jerusalem (four). The crew of the research vessel *T.J. Wright* (two) and the NMFS/DEM port reporters (two) are under the jurisdiction of the department. Major responsibilities of staff members include: administration and liaison (one), fisheries management (three), biological research (two), data analysis (one), facility support (two), data analysis (one), facility support (two), vessel operation (two), and data collection (two).

The Department of fish and Wildlife is being reorganized into sections responsible for game, freshwater fish, and marine fisheries under deputy chiefs. Consolidation of the staff at a single location is also being considered.

The level for research and management of the hard clam in Rhode Island is small when compared with the value of the fishery. At the present time, a single fisheries biologist (A. Ganz) carries out most of the work of hard clam surveys, industry liaison, and management of transplants. Other staff members are able to spend small amounts of time on specific management and biological problems and there is an active research program on another bivalue, the bay scallop. The *T.J. Wright* collects hard clams for contaminant analysis by the DOH and for other studies such as those supported by the Narragansett Bay Project. Port reporters collect data on hard clam sales from shellfish dealers and on numbers of license holders from the Department of Administration.

In the past, officers of the Enforcement Division have participated in surveys of fishing locations (fleet surveys) and catch. The limited size and the multitude of responsibilities of the department make this impractical at this time.

In the State of Rhode Island, fewer than ten persons work full time on mollusk research and management within the Division of Fish and Wildlife, the Division of Water Resources, and in the Department of Health microbiology laboratory. This can be compared with the much larger number of personnel doing equivalent tasks within the Commonwealth of Massachusetts.

In Massachusetts, fifty-five towns have at least one shellfish officer who spends time on both propagation and management. The town of Barnstable has a shellfish staff of seven and a budget of $250,000. Several counties have staff involved in shellfish sanitation. In January 1988, the state established a bureau within the Division of Marine Fisheries with responsibility for all aspects of mollusk management. The present staff includes 24 persons concerned with water testing and classification, biology, and management.

The large number of persons working with mollusks in Massachusetts reflects the large size of the state, the existence of fisheries for scallops and softshell clams as well as hard clams, the maintenance of a large recreational fishery, and the presence of a growing aquaculture industry. The advantages of this large pool of shellfish professionals include advances in culture techniques and the ability to respond rapidly to management problems.

As an example, in the Division of Marine Fisheries as many as 20 individuals can be mobilized for a shellfish resource survey or water sampling operation (F. Germano, Massachusetts, DMF, personal communication).

Division of Enforcement

The Enforcement Division of the Department of Environmental Management monitors the harvest of hard clams in Narragansett Bay. Enforcement is vital to the conduct of this fishery because of the need to prevent the harvest of contaminated product and sublegal size clams and to assure equality of opportunity by regulation of fishing techniques.

A review of the activities of the Enforcement Division was presented by Chief Ernest Wilkinson at the Narragansett Bay Symposium, April 1987. The following section is edited from a written draft provided by Chief Wilkinson.

Enforcement of Shellfish Regulations in Narragansett Bay—Currently, there are 32 conservation officers and trainees in the Enforcement Division. Four trainees are either enrolled in the Municipal Police Training Academy or awaiting the start of a new class. Twenty-six field officers include three sergeants, and three lieutenants; while the chief, captain and a prosecutions lieutenant work in Providence. Of the 26 field officers, a number work inland, responding to the Bay only during the summer months or to assist with a violation. The officers are divided to work in three areas: Newport and Bristol Counties, Providence and part of Kent County, and Washington and the remainder of Kent County. In addition to shellfish enforcement, marine officers enforce the boating laws, patrol an active lobster industry, and monitor the fishing ports of Galilee and Newport.

There have been significant inroads in curtailing shellfishing violations in recent years. In 1981, 388 arrests for harvesting in polluted waters (pollution) were made statewide: 341 in 1982; 219 in 1983, and 173 in 1986. In this period, fines have increased steadily from an across-the-board average of $42 in 1981 to a peak of $157 in 1984 (tabulated by dividing total fines for pollution by total number of pollution arrests). In

1981, total fines levied for pollution violations came to $16,355; in 1985 this came to $27,105. Today, a first-time offender will receive a minimum fine of $100.

In addition to these stiffer fines, the court system has shown a willingness to send repeat offenders to the Adult Correctional Institution for periods up to six months. This jail sentence has made a definite impression on those who might be lured back into a polluted area after a first conviction.

Finally, the Rhode Island laws pertaining to shellfishing in pollution include a forfeiture clause which allows the seizure and forfeiture of any equipment used in the violation. Thousands of bullrakes, stales, tongs, and hand digging equipment have been forfeited in recent years. In the six years (1980-1985), 66 boats and 57 motors, along with 7 complete diving suits and 5 scanners or CB radios, have been forfeited. These items are either put to use by the Department of Environmental Management or sold at an annual auction of forfeited equipment. One of the present small patrol boats on Narragansett Bay is a forfeited fiberglass quahog boat. Those boats which are considered unsafe, plus any illegal tongs or bullrakes sized, are destroyed.

The 66 boats forfeited represent only a portion of the total against which forfeitures are filed. Many boats are returned to the offender conditionally upon the posting of a double surety bond and payment of a stiff fine. The conditional return represents a strong deterrent to working in pollution, as the bond is in effect for one year; and if caught again, the digger looses his boat and the bond. In 1983, for instance, forfeitures were filed against 39 boats; 10 of them were forfeited and 21 returned conditionally.

Changes within the shellfish industry have also had a dramatic effect on shellfish law enforcement. The implementation of the credit card license, creation of a shellfish house inspector, and stricter tagging requirements for shipping shellfish has tightened up the dealer end of the industry. The buyer is forced to account more closely for what he purchases and the product offered by the digger can be more closely monitored.

More careful monitoring of shellfish purchases and tougher treatment of repeat offenders have helped to decrease summer enforcement problems with juveniles. In 1981, 168 juvenile petitions were filed in Family Court for shellfish offenses; 21 were filed in 1985, and only 6 in 1986.

In 1986, the one-inch hinge law replaced the old one and one-half inch diameter regulation for harvesting hard clams. Rhode Island became consistent with the key states buying the Rhode Island product. Diggers could use a shaker box to speed up a preliminary determination of legal size. Size regulations for the teeth and baskets of tongs and bullrakes and for mesh size in divers' bags have also reduced the catch of undersized clams.

Implementation of buying on the count system has also reduced undersize harvest. The count machines separate legal and undersize clams. Since dealers are reluctant to take the undersize, the digger must take it out of the shellfish house with him where he may be caught with it in his possession.

While these changes in attitudes and laws have been beneficial towards keeping a healthy industry, there have been some new problems for enforcement personnel in recent years. One example is the use of the "throwaway" boat. Shellfishermen who are making a determined effort to harvest vast quantities of quahogs from polluted waters on a regular basis will use a worthless boat, without markings or registrations, and powered by a valueless motor. If chased by enforcement officers, the digger does not attempt to outrun the state boat, but merely beaches and abandons his skiff. The amount of money to be made in an evening's work in a polluted cove will more than offset the expense of putting together another throwaway.

Another trend has been the organization of groups of diggers to actively and regularly violate pollution laws. These groups employ mobile lookouts, throwaway boats and organized transportation of the shellfish, and connect the operation with small CB radio units. they constantly monitor the enforcement channels and have accessed all DEM frequencies. Therefore, the conservation officers are forced to maintain almost total radio silence, making coordination difficult.

There have been changes in harvesting techniques in the past few years. Shore digging was always considered a recreational activity or one used by juveniles and unlicensed diggers to take shellfish. In recent years, the numbers of commercial diggers who do not employ a boat have grown considerably. The use of dry suits and the new shoulder length insulated gloves developed for the fishing industry allow shore diggers to work year round. The minimal overhead and slight initial outlay provide easy entry into this fishery.

A second change has been the increase in shellfish harvesting by divers. SCUBA diving is an efficient method of recovering shell stock and can be carried out in all areas of the Bay including those where tongers and bullrakers cannot go. One problem with enforcement of diver-harvest is that the fishermen's exact location cannot be monitored.

A final trend has been increased mobility of diggers. As marina prices increase and shell stocks are depleted, increasing numbers of commercial shellfishermen trailer their boats. The most extreme example of this was the 1981 influx of New York diggers to upper Narragansett Bay when very productive beds off Barrington Beach area were opened one day a week. While many of these diggers tried to establish residency, many trailered their boats from Long Island, dug the Bay, and sold their shellfish back in New York. As a result of investigations into this, 37 Superior Court indictments were filed against New York diggers.

The demands being made against the hard clam resource in Narragansett Bay cannot be met by strict enforcement practices alone. The Department of Environmental Management also participates in a transplant program to move clams from productive grounds in polluted coves to clean water areas which are closed to shellfishing until the clams have cleansed themselves. Enforcement personnel monitor these transplant programs and assist in the movement of shellfish and protection of the transplant beds.

The productivity of certain polluted areas is almost legendary. Since 1978, approximately 150,000 pounds of quahogs have been harvested annually from Greenwich Cove. The temptation to work in such an area, where in 15 minutes, a digger can make several hundred dollars, is great. Transplant programs help to remove some of this shellfish from the concentrations in the coves.

The future of a viable shellfishing industry in Narragansett Bay lies in wise management of the resource. Preservation of the quality of the Rhode Island quahog and protection of management programs in the Bay lies in the hands of the men and women who are dedicated to the protection of Rhode Island's natural resources. To guarantee success in protecting shellfishing, the industry itself must police its own ranks and provide the enforcement officers with the information they need to do a successful job.

Table 3. Shellfish citations charged by the Rhode Island DEM Division of Enforcement 1982-1983 (FDA 1985a).

Violation	Number Charged			
	1982	1983	1984	1985
Night shellfishing	68	22	15	14
Implement in pollution	67	83	40	36
Implement in pollution (second offense)	7	7	13	2
Taking shellfish from pollution	198	107	83	94
Taking shellfish from pollution (second offense)	3	0	28	3
Possession of uncertified shellfish	--	--	11	8
Selling shellfish without a license	17	24	3	2
Buying shellfish without a license	1	4	0	3
Shellfishing in a closed management area	--	53	9	59

*Multiple charges may be levied on the same individual

Research on Enforcement

A study of enforcement and compliance in the hardshell clam fishery is being undertaken as part of the 1987-1988 The University of Rhode Island Sea Grant Program

(J.G. Sutinen). The investigators have found from studies of other fisheries that violation rates can be predicted from enforcement levels, rewards of illegal fishing, and the commitment of fishermen to the fishery. The study will use information collected from fishermen interviews and Enforcement Division files to compute the effects of policy changes on compliance and to recommend cost-effective changes to the Department of Environmental Management.

It is likely that the most cost-effective management techniques are those which committed fishermen approve of, or which have been used among themselves informally.

The National Shellfish Sanitation Program

The activities of the various state agencies concerned with shellfish sanitation are guided by the National Shellfish Sanitation Program (NSSP). The following outline of the program comes from the Introduction to the Manual of Operations (NSSP 1965).

> In 1925 State and local health authorities and representatives of the shellfish industry requested the Public Health Service to exercise supervision over the sanitary quality of shellfish shipped in interstate commerce. In accordance with this request, a cooperative control procedure was developed. In carrying out this cooperative control, the States, the shellfish industry, and the Public Health Service, each accept responsibility for certain procedures as follows:
>
> 1. **Procedures To Be Followed by the State.**—Each shellfish-shipping State adopts adequate laws and regulations for sanitary control of the shellfish industry, makes sanitary and bacteriological surveys of growing areas, delineates and patrols restricted areas, inspects shellfish plants, and conducts such additional inspections, laboratory investigations, and control measures as may be necessary to insure that the shellfish reaching the consumer have been grown, harvested, and processed in a sanitary manner. The State annually issues numbered certificates to shellfish dealers who comply with the agreed-upon sanitary standards, and forwards copies of the interstate certificates to the Public Health Service.
>
> 2. **Procedures To Be Followed by the Public Health Service.**—The Public Health Service makes an annual review of each State's control program including the inspection of a representative number of shellfish-processing plants. On the basis of the information thus obtained, the Public Health Service either endorses or withholds endorsement of the respective State control programs. For the information of health authorities and others concerned, the Public Health Service publishes a semi-monthly list of all valid interstate shellfish-skipper certificates issued by the State shellfish-control authorities.

3. **Procedures To Be Followed by the Industry.**—The shellfish industry cooperates by obtaining shellfish from safe sources, by providing plants which meet the agreed-upon sanitary standards, by maintaining sanitary plant conditions, by placing the proper certificate number on each package of shellfish, and by keeping and making available to the control authorities records which show the origin and disposition of all shellfish.

With the Public Health Service, the NSSP is under the jurisdiction of the Food and Drug Administration (FDS), Center for Food Safety and Applied Nutrition, Division of Cooperative Programs, Shellfish Sanitation Branch. The review of the Rhode Island Shellfish Sanitation Program is made by FDA regional shellfish specialists based in Boston, Massachusetts.

The adequacy of state programs are judged by the extent to which they meet procedures described in the NSSP manual. The manual is reissued at approximately ten-year intervals, most recently in 1986. It has two major parts:

I: Sanitation of Shellfish Growing Areas, and
II: Sanitation of the Harvesting and Processing of Shellfish.

These represent two distinct phases of operations of the industry which are overseen by different state agencies. Sanitation of growing areas is the responsibility of the DEM, Division of Water Resources and Division of Enforcement. Sanitation of processing and shipping is the responsibility of the Department of Health, Division of Food Protection and Sanitation (DFPS).

NSSP guidelines for growing areas allow the states to make judgements in such areas as timing and location of water sampling, and tactics of enforcement which will provide the necessary assurance of quality shellfish. The guidelines for processing are much more detailed and specific, describing requirements for construction and upkeep of boats, trucks, and buildings used for storage, shucking, and packing. Procedures for washing, cooling, and opening shell stock and plant supervision are specified. A "public health explanation" is provided to help the plant operator judge whether his procedures are achieving the desired results. As an example of the detail in this part of the manual, the draft section on controlled purification (depuration) is 31 pages long.

A comprehensive evaluation of the Rhode Island shellfish sanitation program (SSP) was made for the fiscal year 1983, a synoptic report in 1984, and an update report in 1985. These reports commend the state for making good use of limited resources, but recommend additional attention to: (1) growing-area sampling and evaluation, (2) deterrence of illegal harvest, and (3) enforcement of processing plant sanitation regulations.

In the recent past, it has been difficult to carry out growing-area evaluations because of changes in staff and understaffing of the Division of Water Resources. The staff size has varied from one to three full-time persons and interns. Continued citations for shellfishing from pollution and from closed management areas up to 1985 were taken as evidence that illegal harvest and selling of shellfish was still taking place (see Table 3). It was concluded that additional officers were needed to cover closed areas 24 hours. The review also suggested dealer surveillance to insure compliance with tagging and record keeping requirements. The problem of repeated violations of processors and shippers has improved over the last few years by: (1) reorganization of the DFPS (effective 10/85); (2) hiring additional shellfish inspectors, and (3) using computer spread sheets to track violations. Firms were also informed that certification would be denied if they have repeated or serious violations.

The two divisions responsible for shellfish quality in Rhode Island collect large amounts of field data from the Bay. The DFPS monitors coliform bacteria and heavy metals in clam tissues from 13 stations Sample trips are made every two weeks, and each station is sampled once a month. Five of the stations in closed portions of the Bay are of particular interest because they show the levels and seasonal pattern of contamination there. The DWR determines the coliform levels of surface waters at 14 subarea within the Bay five times a year and once a week in the upper Bay conditional area when it is open. Field data from this program is being analyzed and discussed in other parts of the present report and in other Narragansett Bay Project reports.

The DFPS analyses mussels collected by the Fish and Wildlife Division at primary monitoring stations at the mouth of the Bay every two weeks from April through October to identify paralytic shellfish toxin. Fortunately, positive results were obtained only once since the start of the program and not in the last ten years.

An additional contribution of the federal government to management of hard clams in Rhode Island comes from the siting of the FDA Northeast Technical Services Laboratory at Davisville. the laboratory is responsible for monitoring shellfish quality in offshore waters and also does research on the effectiveness of NSSP testing procedures and on other aspects of marine microbiology. In 1986 and 1987, the laboratory contracted with the Narragansett Bay Project to conduct sanitary surveys of Mount Hope Bay. Laboratory staff also participates in processing plant inspections and provide expertise in subjects such as depuration.

Laws Relating to the Hard Clam Fishery

The laws relating to the hard clam fishery in Rhode Island are relatively straightforward since most are applicable to public fisheries throughout the state and represent a consensus of managers and fishing interests. Laws within different categories are summarized below. Requirements and penalties which are provided for by separate statutes are combined here.

Marine Fisheries Council—Although many state laws provide specific requirements for shellfish management, the requirements are under the control of and can be changed by the Marine Fisheries Council..

20-3-1 **Composition**—The council is made up of the director of DEM or his designee as chairman and eight private citizens appointed by the governor with advice and consent of the senate. At least two represent the commercial fishing industry and two represent sports fishing. The chairman of the Coastal Resources Management Council and the chiefs of the DEM divisions of enforcement and fish and wildlife serve in an advisory capacity. Terms are four years and members may succeed themselves

20-3-2 **Powers and Duties**—The council has regulatory jurisdiction over all marine animals within state territory. It is authorized after the holding of a public hearing to adopt regulations governing the following activities in taking fish, lobsters, and shellfish:

> fishing method, legal size limits, number and quantities,
> seasons and hours, and opening and closing of areas.

20-3-4 **Shellfish and Marine Life Management Areas**—The council may—in cooperation with the director of DEM—designate land covered by tidewater or portions of the free and common fisheries of the state as management areas to enhance the cultivation and growth of marine species, manage the harvest of marine species, facilitate the conduct by the department of experiments in planting, cultivation,propagation, and managing all kinds of marine life. Designation fishing may be restricted or regulated as required to carry out the goals of the program.

Licenses—All licenses are for one year. commercial licenses expire on December 31. The following licenses can be obtained for hard clam fishing:

	Category	Fee	Limit	Penalty for exceeding
20-2-22	non-commercial resident	none	1/2 bu/day	no more than $50 or 30 days-1/2 bu excess
	non-resident	$15.50 annual $5.50 14 days	1/4 bu/day	$100/bu or no more than 30 days
20-2-20	commercial, over 65	$1	12 bu/day	
20-2-20	commercial	$100	12 bu/day	
20-2-20	multipurpose marine	$150	12 bu/day	
20-2-23	shellfish buyer	$50		
20-6-4	boat registration (commercial)	$2		
20-6-12	shellfish dredging	$100	30 bu/day	no more than $100 or 30 days

20-2-28 **Deposit of Chapter 2 fees**—Monies generated from license fees over $200,000 shall be appropriated to the Department of Environmental Management and can only be used for: (1) protection and propagation of marine fish, lobsters, and shellfish, (2) enforcement of marine fishery regulations, and (3) transplantation of shellfish from closed areas.

20-6-25 **Disposition of Chapter 6 fees**—These are deposited with the general treasurer and appropriated by the general assembly to DEM.

2-2-10
20-2-8 **License holders** must give truthful information on application, endorse the license, and not transfer or loan the license. The penalty is a fine of up to $50 and the loss of the license for one year.

20-2-9 **Licenses** must be in possession when engaged in shellfishing and presented to enforcement officers on request. If this is not done, the individual will be considered to be fishing without a license.

20-6-22 **Minimum size**—For many years, the minimum size allowed was 1 1/2 inches across the smallest diameter. This was determined by attempting to pass the clam through a ring. Effective July 1, 1986, the minimum was changed to 1 inch between the highest parts of the shell perpendicular to the plane of closure or "thickness." This measure which was changed to comply with a directive of the Atlantic States Marine Fisheries Commission for standardization facilitates both onboard culling and commercial grading by machine. The penalty for harvesting undersize is $10-$50/quart.

20-6-26 **Transfer of shellfish from uncertified waters**—The director of DEM is authorized and directed to transfer shellfish to approved areas with necessary safeguards. He may make rules and regulations governing the reharvest to the best economical benefit of the state.

20-6-28 **Cost of transfer**—The director is authorized to hire dredge boats or handrakers. Any transferred shellfish may be sold and the proceeds retained to be used for additional transfers.

20-6-7 **Use of dredges**—Under normal circumstances, any taking of oysters, soft-shell clams, or hard clams by dredges, rakes, or other apparatus operated by mechanical power is prohibited. No such device can be in use while fishing for the above species. If hard clams are caught during mussel dredging, they must be returned to the Bay. Recently, use of winches to return dives-caught hard clams to the surface was banned as the use of mechanical power. Use of small winches to recover bullrakes from deep water was also banned.

Opening areas for dredging—Although there have been no openings since 1969, dredging could be allowed under the following statute.

20-6-8 **Opening areas for quahog dredging**—Pursuant to good conservation practices, the marine fisheries council shall be authorized to open areas of public waters of the state for taking quahogs under license by a registered boat, by dredges, rakes or other apparatus operated by mechanical power or hauled by power boats and shall be authorized to close such areas at any time there is a danger of depletion of quahogs or when flagrant violations of this chapter occur.

20-6-13 **Dredging violations**—The penalties for dredging without a license or violating other provisions of the shellfish laws for which a penalty is not otherwise provided include a fine of $250 and the option of impoundment at the owners expense of the dredge boat and equipment for between 30 and 60 days. For subsequent violations, the penalty is imprisonment for 30 days and the option of impoundment for between 90 and 120 days.

20-149 **Enforcement in waters between states**—When adjoining states have similar fisheries laws, persons of either state who are authorized to make arrests shall have authority on any part of such waters between such states or the shores thereof and to take any person or persons so arrested for trial to the state in which the violation was committed and to prosecute according to the laws of that state.

The following laws provide the enforcement power to deter commercial harvest in areas closed because of pollution or for management purposes.

20-6-29 **Transferred shellfish**—Taking shellfish in closed transfer areas can be punished by a fine of less than $500 or less than 30 days imprisonment.

20-6-23 **Shellfish at night**—Taking shellfish between sundown and sunrise is punishable by a fine of less than $1,000 or less than 3 years imprisonment, and forfeiture of boat, motor, and equipment.

20-8.1-5 **Shellfish from polluted areas**—Taking or selling shellfish taken from
20-8.1-11 polluted waters and possession of shellfish while in a vessel upon polluted waters from two hours after sunrise until sunrise is punishable on the first offense by a fine less than $500 and for less than 1 year imprisonment and on subsequent offenses by a fine less than $2,000 and/or less than 4 years. Any boat, motor, and equipment employed in the illegal fishing can be seized.

20-1-10 **Obligation to heave-to**—Refusal to heave-to on command from a marine patrol boat operated by DEM or disposal of anything overboard when requested to heave-to is punishable by a fine of between $25 and $500.

MANAGEMENT ALTERNATIVES

There are many constraints on change within the Rhode Island hard clam fishery because of its long history and the participation of fishermen in its management. In the following subsections, management alternatives are discussed which have elements which appear to be compatible with the existing fishery. Implementation of any of these alternatives will require additional analysis of the goals and concerns of fishermen. Simple economic models cannot define these goals, since many of the rewards of participation in the hard clam fishery are related to the work environment and degree of independence. The following list of goals for commercial fishing is offered by the author of this report as an outline for expansion or correction. The existence of goals which are contradictory and which oppose changes in the *status quo*, illustrate the difficulty which would be met in introducing significant changes to the fishery.

1) Sustain or increase income of presently active fishermen through sustained catches or price increase.
2) Sustain annual yields at or near the present high level.
3) Develop a stable or predictable price structure with fair division of profits between fishermen and buyers.
4) Avoid sudden entry of large numbers of men into the fishery during employment shortages or temporary high clam abundance.
5) Avoid restrictions on entry or re-entry into the fishery.
6) Improve water quality to allow upgrading of conditional and uncertified areas and build consumer confidence.
7) Avoid alternatives which give buyers control over price.
8) Avoid any limitation of fishable area by closure due to poor water quality, development of the shoreline or aquaculture.
9) Limit the number of part-time fishermen.

10) Be allowed to participate in decisions affecting the fishery.

11) Avoid any technology which is significantly more efficient than hand raking or which will make it more difficult to enter the fishery because of expense.

The economy of the state and the needs of shellfish buyers, part-time fishermen, recreational fishermen, and consumers would all have to be taken into account in a comprehensive plan for managing Rhode Island's hard clam fishery. These needs are outside of the scope of this report, however.

In the following subsections, management alternatives are discussed which will sustain yields while avoiding interference with traditional fishing practices. Additional background information on the natural history and pollution status of Narragansett Bay hard clams is given in previous sections.

Increase in Area of Approved Waters

Among all management alternatives, increasing harvestable waters will give the most predictable increase in yield and cause the least disruption of the traditional fishery. FDA (1985b) reports that out of a total of 97,813 acres in Narragansett Bay, 62,028 were approved for shellfish harvest, 11,447 were conditional, and 24,343 were prohibited. These figures are meaningless since large areas are included which do not support clam populations.

Chinman and Nixon (1985) used a different base line to calculate a total of 84,404 acres within the Bay. They also calculated the area of 1 meter depth intervals for 10 portions (elements) of the Bay. An estimate of the harvestable area of each Bay element is given in the following Table (4) by excluding locations with few clams or deeper than 8 meters (26 feet).

Table 4. Status and size of hard clam producing portions of Narragansett Bay

			Total	Less than 26'
Providence River (Sabin Point-Conimicut Point)	high density	prohibited	3,534	2,650
Mount Hope Bay	moderate density	prohibited	8,578	6,859
Upper Bay	high density	part conditional	10,549	8,972
Greenwich Bay	high density	management	2,836	2,767
Upper West Passage	moderate density	approved	18,989	14,242
Sakonnet River (upper 1/2)	moderate density	approved	6,210	4,353

Lower West and East Passages and the East Passage element south of Prudence Island produce negligible clam harvests. Small prohibited zones throughout the Bay were not considered. The table shows that the two major uncertified portions of the Bay in which hard clams are found is about one-third as large as the portion presently harvested.

It seems reasonable to assume that continued repair of combined sewage overflows and improvements in sewage treatment plant facilities and operation will water quality enough to allow longer periods of opening of the upper Bay conditional area. Recent research, however, suggests that improvement is necessary to provide adequate margins of safety for the public.

Historically, monitoring of microbiological contamination in water has been carried out with counts of fecal coliform bacteria. In two studies for the Narragansett Bay Project still in draft form, Cabelli (1988a, 1988b) used an indicator organism (F - male specific bacteriophage) which more closely simulates the behavior of disease-causing viruses than coliforms. Differences include a greater resistance to chlorination, greater longevity in water and in shellfish, and greater uptake and retention by shellfish—especially when temperatures are low.

The most frequent disease caused by waterborne viruses is acute gastroenteritis. Cabelli points out that the incidence of this disease is not known and in some cases is perceived as acceptable at low levels. He suggests that an epidemiological study in which shellfish are consumed from conditional growing areas harvested in cool weather is the most straightforward way of assessing health effects.

Cabelli also suggests the substitution of measurement of F phage or the long-lived spores of *Clostridium perfringens* within shellfish for measurement of coliforms in water or tissue. Cabelli's results call for a more conservative approach in predicting viral die-off during sewage treatment and after release to the Bay. In the light of these arguments, it is clear that the upper Bay will remain in conditional status and under close scrutiny for some time.

Re-opening Mount Hope Bay to shellfishing would add significantly to Rhode Island's harvestable area. Although hard clams are not as abundant there as in the Providence River: rate of growth (Pratt et al. 1988), condition of tissues (Kern 1986), and content of most heavy metals (Thibault/Bubley 1987; Rhode Island Department of Health) are normal. The major problems to opening this area are sewage pollution and the possibility of mercury contamination.

The Fall River sewage treatment plant (on the Rhode Island-Massachusetts line) was a major source of pollution before its reconstruction was completed in 1982. At one station in Rhode Island waters during 1971 (EPA 1971), median fecal coliform level was 3,500/100 ml. The Rhode Island Division of Water Resources obtained levels as high as 60,000/100 ml in early 1982. The maximum fecal coliform densities allowed in open areas is 15/100 ml and the maximum allowed in areas for transplant or depuration is 50/100 ml.

The Narragansett Bay Project supported a microbiological survey of Mount Hope Bay in 1986-87 by the FDA Northeast Technical Services Unit, Davisville, Rhode Island, with the help of the Wickford Fishermen's Alliance. The following description of the project and its results and recommendations were abstracted from the final report of Rippey and Watkins (1987).

The overall objective of the project was to determine whether the sanitary quality of waters in Mount Hope Bay had improved sufficiently to permit commercial harvesting of shellfish. Specific tasks accomplished included a three-to-four-day screening study, a dry-weather and a wet-weather sanitary survey, two-day seasonal monitoring (all seasons) of three selected stations, sanitary reconnaissance and evaluation of point sources of contamination.

The major sources of contamination input to Mount Hope Bay were found to originate in the Fall River area. Of these, the Quequechan River ranked as the worst polluter during both wet and dry weather. Three combined sewage overflows (CSOs) discharge into the Quequechan, and their inputs result in water quality which is only slightly better than that of raw sewage. Certain other CSOs rank closely behind the Quequechan River by source strength. These include overflows at Birch Street, Middle Street, Mount Hope Street, Alton Street, Williams Street, and State Avenue. Most of these overflows were found to be discharging during both wet and dry periods. Four CSO effluent flows could not be determined. Two of these (Riverview Street and Ferry Street) are probably very significant sources.

In regard to pollution abatement, there is no question that the CSO problem in the Fall River area should receive the highest priority. These effluents account for greater than 95% of the contamination entering Mount Hope Bay as indexed by fecal coliform source strength.

Other point sources impact the Bay to varying degrees. These include several point sources located in Bristol south of the Kickamuit River which were discharging during periods of heavy rain.

Two sewage treatment plants were sampled during the study. The Somerset, Massachusetts, STP has serious problems with a daily flow which significantly exceeds the plant's capacity. The Fall River plant appeared to be operating effectively under all weather conditions since the fecal coliform densities in the finished effluents were quite low. However, if the plant were treating the influents now released by CSOs, it is not known how adequately waste waters could be treated. Moreover, high densities of both bacteriophage and *C. perfringens* were found in the treated effluents at both plants during wet weather, suggesting that disinfection processes should be re-evaluated to prevent release of pathogenic viruses.

The Taunton River was considered a single-point source. While the river contributes a substantial amount of contamination to Mount Hope Bay, it was roughly calculated that the magnitude of the input is only about 3% of that of the Fall River CSOs during wet periods, and about 0.4% under dry weather conditions.

During dry weather, waters west of a line from Touisset Point to Common Fence Point met standards for open growing areas. During wet weather, standards were exceeded throughout Rhode Island waters with mean fecal coliform levels of ranging from 28-266 in the area west of the Touisset to Common Fence Point Line.

It was suggested that the area west of this line could be managed as a conditionally-approved area under the following stipulations:

1) Additional sampling and analyses are performed to supplement data obtained up to this time in order to meet the requirements of the National Shellfish Sanitation Program for reclassifying (15 samples per station). The combined results obtained for the proposed conditional area must continue to meet the sanitary standards for an approved area under defined hydrographic conditions.
2) Shellfish meat samples from the proposed conditional area are analyzed for chemical contaminants (PCBs, mercury) and found below defined action levels.
3) The area can remain open as long as rainfall does not exceed 0.5 inches in a 24-hour period 7 days prior to harvesting.
4) If between 0.5 inches and 1.0 inch of rainfall within a given 24-hour period, the area should remain closed to shellfish harvesting for a period of 7 days following the event.
5) If greater than 1.0 inches of rain occurs within a 24-hour period, the area should remain closed until the results of bacteriological sampling demonstrate

that all stations within the conditional boundary meet the approved growing area criteria.

Additional recommendations were made that a line from Mount Hope Point to Common Fence Point should be considered to make patrol easier, that a dye study be carried out to determine the travel time of water from the Fall River area, and that effective communications be established to assure prompt notification of treatment plant failure

Rippey and Watkins came to the same conclusions as Cabelli in regard to the utility of difference microbiological indicators. They found that the currently used group (fecal coliforms) is inadequate for assessing the market quality of shellstock harvested from cold saline waters and that the two conservative microbiological indicators (*C. perfringens* and F2 coliphage) are probably much more reflective of shellfish quality and, therefore, may better identify potential human health risks.

A dredge survey (Pratt et al. 1988) showed that in deep water west of the Mount Hope Point-Common Fence Point line, hard clams were very large and few in number. As part of the same study, a survey of the Portsmouth shore was carried out with the help of a group of fishermen. They found many large clams along the shore and a dense patch of small individuals in the small bay between Common Fence Point and the Mount Hope Bridge. The only high-density area found in the dredge survey was off Touisset Point on the line between proposed closed and conditional areas.

For an extended period previous to 1974, an industry in Dighton, Massachusetts, released a mercury containing effluent into the Taunton River. Sediments from the dredged channel analyzed by the U.S. Army Corps of Engineers (1976) showed elevated mercury levels from Dighton to the Massachusetts portion of Mount Hope Bay (20 of 31 samples above 2 ppm, maximum 7.5 ppm). In the Rhode Island portion of the Bay, concentrations were much lower (12 of 13 samples below 1 ppm, maximum 2.1 ppm).

Since mercury is often strongly bound to particles, it is difficult to predict to what extent it enters the water column or is taken up by shellfish. Vandal and Fitzgerald (1988) surveyed mercury in Narragansett Bay and its tributaries in April 1986. A single sample in Mount Hope Bay had a concentration similar to that found within the Providence River and about twice the mid-Bay level. On the basis of a dilution model, it was concluded that this level of mercury indicated a large total input from the Taunton River.

Mercury concentrations were determined in hard clams from 13 stations in Massachusetts waters in 1981-82 (DEQE 1982). All of this data is not presently available, but it is known that one sample exceeded the FDA standard of 0.2 ppm wet weight and the proposed Narragansett Bay alert level of 0.21 ppm (Hoffman 1988). The high sample came from the mouth of the Lee River. Mercury was measured in clams from five stations in 1985 (DEQE special analysis obtained from Southeast Regional Laboratory, Lakeville). High levels were found within the Taunton River and a low level of 0.053 ppm was found at the Rhode Island-Massachusetts line.

Mercury was measured in clams from six stations in Mount Hope Bay sampled in November (n = 20) and June (n = 22) 1985-86 (Thibault/Bubley 1987). Mean dry weight concentrations from the two collections were 0.44 and 0.61 ppm. This is approximately 0.09 and 0.12 ppm wet weight, and ~~above~~ below the suggested alert levels. Mean concentrations for all analyses were 2.4 times those at Ohio Ledge and 5.6 times those in Greenwich Bay.

From the data available, it appears that shellfish in the Rhode Island portion of the Mount Hope Bay are safe for human consumption but reflect the input of mercury from the Taunton River. Additional analysis should be made to determine whether: (1) high values are restricted to portions of the Bay, (2) to what extent mercury is moving from the particle adsorbed to dissolved form, and (3) in what form mercury is being taken up by shellfish.

Surveys in Mount Hope Bay showed a predominance of large clams of relatively low value. The present standing crop and size distribution should not be used to project the sustained yield of the bay, however. Mount Hope Bay is similar in depth, salinity, pollutant level, and plankton community makeup to Greenwich Bay and the Upper Bay and should have the potential for production of small clams following removal of the existing large clams and mixing of bottom sediment. The potential for recruitment in different locations could be experimentally determined by removing stock for transplantation and observing recovery of the site. The abundance and effects of predators which are unknown in Mount Hope Bay as they are in the rest of the Narragansett Bay system could also be studied.

The additional surveys and modeling suggested by Rippey and Watkins should be carried out to determine whether the portion of Mount Hope Bay west of Mount Hope Point-Common Fence Point could be opened conditionally. At the same time, pressure must be brought to bear to fund repair of, and eventually elimination of, combined sewer overflows in Fall River.

Preservation of Spawning Stocks

While it is usually assumed that the survival of larvae and juveniles is more important for hard clam repopulation than is the number of spawners, continued high levels of exploitation of small individuals has caused fishing interests to be concerned about the preservation of spawning stocks in the Bay. Conrad (1982) analyzed the hard clam fishery of Great South Bay, Long Island and concluded that revenue would be maximized if only younger, more valuable, "littlenecks" were harvested and sufficient older clams were left to "specialize in regeneration."

Information on the size-specific fecundity of hard clams is necessary to assess the potential contribution of different size classes to repopulation of over-fished areas. Bricelj and Malouf (1980) made a detailed study of hard clam reproduction in Great South Bay, Long Island where conditions are similar to Narragansett Bay. They found equal sex ratios at all ages—first reproduction in a female at 33.1 mm length, 17.6 mm width and in a male at 36.7 mm length, 19.2 mm width (both sublegal), and large variability in egg production for a given size range. The maximum number of eggs produced by any individual in a size class increased from 2,400,000 for sublegal to over 15,000,000 for cherrystones and chowders. No differences could be found in fecundity or larval survival in clams from favorable and unfavorable growing areas.

It has been a traditional management practice to transplant large clams from northern waters into Great South Bay to increase the time larvae were present and increase survival and settlement. However, Kassner and Malouf (1982) found that the source of adults did not effect time of spawning, and that the number of individuals which could be transplanted were such a small proportion of the scattered natural stock that they could have little effect on recruitment. The authors estimated that each transplant only produced 0.08 recruits.

While transplantation of spawning stocks may not be practical, preservation of stocks in "spawner sanctuaries" may be indicated in heavily over-fished areas like Great South Bay. This concept has been defined and analyzed by researchers at SUNY, Stony Brook (COSMA 1985). Their analysis focuses on the importance of locating the planted stocks where setting will be maximized in a preselected target area. Dense deployment of adults is suggested to increase the probability of fertilization and to make protection easier.

The larval period of hard clams is between 14 and 25 days, and in that time they are carried by currents resulting from tides and winds influenced by bottom friction. Particles injected into the water at one point are spread into a patch by variations in transport speed and direction. The Stony Brook group used a computer model of Great South Bay circulation to predict the number of clams entering the fishery from a planting of spawners (1,000 bushels of chowders at a density of $35/m^2$). They found that high rates of settling of larvae and survival of young, and more than one spawning of brood stock were necessary for planting to pay for itself. Nevertheless, it was proposed to carry out on experimental planting of the *notata* variety of clams (having identifiable zig-zag markings) as a test of the ability of the computer model to predict locations of setting.

The Stony Brook investigators suggested that if the sanctuary concept was accepted in Great South Bay, spawners could be protected by placement in uncertified waters, by the relatively low value of chowder sizes and by patrol. (One town's proposal to place obstacles on the bottom was rejected.) An important observation of the study is that larvae would not be retained in small coves where residence time was under seven to eight days.

Preservation of spawning stocks has not been a part of the Rhode Island hard clam management plan, but is implicit in management of Greenwich Bay where transplanted clams are allowed to spawn before they are harvested. One of the reasons for opposition to the development of the Chepiwanoxet area was its potential as a spawning area (Save the Bay 1985). Unfortunately, there is not field data which can be used to judge the need for additional spawners in Greenwich Bay or the effect of transplants on setting of spat.

Larvae from the coves surrounding Greenwich Bay are probably carried to all parts of the Bay and out into surrounding waters in the approximately 20 days they are in the plankton. The flushing rate of Greenwich Cove has recently been determined to be between 21 and 30 hours (Dettman 1987) and tidal currents flow a mile east-west on each cycle.

Just as surrounding coves are potential sources of spat for Greenwich Bay, the Providence River and Mount Hope Bay could provide spat for adjacent certified and conditional areas. The link between the dense beds of hard clams south of Conimicut Point and the very productive area off Barrington Beach is particularly interesting. Gonad development and histological condition of individuals from the lower Providence River were shown to be normal by Kern (1986). However, no information is available on the nutrition and survival of larvae in these waters.

The large numbers of cherrystones and chowders present in closed areas and deep waters throughout the Bay are almost certainly able to supply adequate larvae to repopulate growing areas where conditions are favorable. The role of closed and deep areas would have to be reconsidered if large-scale transplantation, harvest for depuration, or boat dredging were proposed. Knowledge of the source and period of availability of larvae would be valuable in managing areas of high productivity such as East Greenwich Cove, Mary's Creek, or Barrington Beach and in understanding the absence of set in areas such as central Mount Hope Bay.

Existing circulation models of the Providence River and Mount Hope Bay should be used to identify potential sources of spat for the important growing areas. A similar model of Greenwich Bay should be developed which would predict transport from coves to the Bay and to West Passage. Results should be given in stochiometric terms to reflect the highly variable, but important effect of wind-driven circulation (Weisberg 1974).

Knowledge of the availability of clam larvae would be an important prerequisite for any attempt to repopulate "dead bottom." Rapid survey techniques should be developed to delineate sources and seasons of availability and to coordinate bottom preparation and/or predator control.

Transplantation

In the past, transplantation of hard clams from closed to open waters was an important part of the State shellfish management program in Narragansett Bay. At the present time only a relatively small transplant program is being carried out in Greenwich Cove and Greenwich Bay, however programs for other parts of the Bay are under consideration. In the following sections the various operations which have been carried out by the State of Rhode Island are outlined. This information shows that a surprising diversity of techniques, source areas, and planting areas have been used. It also shows biological and management problems which have occurred. The techniques used in adjoining states (examined in less detail) provide a wider diversity of management alternatives.

Early Programs in Rhode Island—The following information was obtained from Division of Fish and Game annual reports.

Between 1954 and 1975 approximately 480,000 bushes of hard clams were transplanted, mainly by state-owned or hired dredge boats. The following information on these programs was obtained from the annual reports of the Division of Fish and Game and from Holmsen (1966).

In 1954 and 1955, commercial boats were hired from an appropriation of $25,000/year. In 1956 the State obtained an 83-foot dredge boat, *Stormy Weather II*, and conducted most transplants that year and all transplants in 1957. In 1958 transplantation was carried out with *Stormy Weather*, hired boats, and a 32-foot hydraulic conveyor dredge (*Scaup*). *Scaup* harvested clams at a slow rate (10 bushels/hour), but could operate in shallow water and reduce the density of clams which might be harvested illegally. In fiscal year 1958 commercial boats moved 13,098 bushels from Mount Hope Bay to the lower Sakonnet River dredging area under a $10,000 State appropriation. Handrakers moved 2,625 bushels from Mount Hope Bay to the upper Sakonnet River handraking area financed by shellfish license receipts. *Stormy Weather* moved clams from the Providence River to Barrington Beach, Potter's Cove, Rocky Point, and Wickford. *Scaup* planted a bed in the west end of Greenwich Bay.

In 1959-1960 *Stormy Weather* dredged in the Providence River and *Scaup* worked in East Greenwich Cove and Point Judith Pond. Major beds were set up at Rocky Point, Bristol Harbor, and Greenwich Bay; minor beds were set up in Point Judith Pond, Wickford, and Narrow River. In 1960-61 *Stormy Weather* dredged in the Providence River and Mount Hope Bay. Handrakers were hired for one day to move a set of littleneck-size clams from East Greenwich Cove. Average catches were 27 bushels/day, and the largest catch was 66 bushels.

A new management project was introduced in 1961-62. Commercial boats were hired to dredge in Mount Hope Bay and transplant into an area of East Passage off Portsmouth. After two weeks, the boats were paid to reharvest the clams which were then sold to a chowder processing company. Each bushel (85 pounds) produced a profit of around two dollars. It was planned to use the profits to pay back advances from the State and to supplement the existing transplant program for the benefit of handrakers. The total volume moved was 21, 134 bushels for fall and spring programs, and the recoveries were 35% and 62% respectively. During that year *Stormy Weather* transplanted from Mount Hope Bay to Usher's Cove, in Bristol and from the Providence River to Rocky Point and Barrington Beach. Handrakers moved clams out of an area to be dredged in Apponaug Cove. *Stormy Weather* was retired after transplanting Providence River clams along with hired boats in 1962. Handrakers moved 3,800 bushels from two areas to be dredged.

In the fall of 1963 and spring of 1964 a new program was implemented. An association of dredge boat owners arranged to transplant clams to dredging areas for reharvest at no cost and to work one day in six (1963) or one day in seven (1964) planting clams in handraker areas. Clams were collected in Mount Hope Bay, deposited in the lower Sakonnet Passage for dredging, and in Barrington Beach and Island Park for handrakers. The reharvest efficiency of the dredge boats were 62% and 59%.

Payments for transplanting and fees for reharvesting were re-instituted in 1964. This program was set up with a $50,000 revolving fund and included both dredge boats and handrakers. Dredge boats moved 32,538 bushels from the Providence River to a dredging area off Melville and to Rocky Point and recovered 46% after depuration. Handrakers moved 10,000 bushels from Greenwich Cove to Greenwich Bay. Handrakers paid to reharvest clams until Greenwich Bay was reclosed and Rocky Point was opened to free digging. A small profit was made on this operation ($2,953). Similar projects were carried out in 1965-1968. The 1965-66 project ended in the red due to an unprecedented number of starfish congregating on the transplant beds inflicting severe mortality on the newly planted quahogs. Clams were transplanted from the Providence River to Barrington Beach, Goddard Park, and Melville with an average recovery of 27.5%. Handrakers moved 9,950 bushels from Greenwich Cove to Greenwich Bay with funding from a fee paid by dredgers to remove clams from the ship channel between Poppasquash Point and Conimicut Point before it was dredged. Levels of recovery of dredged clams was also low

Table 5. Hard clam transplants in Narragansett Bay in bushels. [These figures from Division of Fish and Game annual reports are subject to some error because sources are not always identified, and it is not always clear whether the fiscal (June-June) or calendar year is referred to.]

	Method of Harvest			Source	
Fiscal Year	State Vessels	Hired Dredge Boats	Handrakers	Prov. River	Mt. Hope Bay
1954	—	32,805	—	?	—
1955	—	26,690	—	?	—
1956	29,335	9,802	—	?	—
1957	28,398	—	—	28,390	—
1958	24,853	15,723	—	40,576	—
1959	26,674	—	—	26,674	15,723
1960	17,757	—	1,500	19,257	—
1961	16,661	—	563	10,777	15,522
1962	22,881	4,660	3,804	8,318	15,658
1963	6,643	—	2,304	6,643	—
1964	—	39,867	—	42,538	—
1965	—	42,538	9,950	40,128	—
1966	—	43,764	9,950	43,764	—
1967	—	36,434	?	36,934	—
1968	—	16,569	2,733	10,756	—
1969	—	—	—	—	—
1970	—	—	—	—	—
1971	1,868	—	—	1,868	—
1972	?	—	—	?	—
1973	"small"	—	—	"small"	—
1974	"small"	—	—	"small"	—
1975	—	—	—	—	—

in 1966-67 (32.5%). In 1967-68 there was a decline in numbers of participating dredge boats, and the volume moved was reduced to 19,302 bushels. The annual report for that year recommends that land-based depuration should be adopted because of the high costs of transplanting and patrol of the beds along with low return rates of transplants.

There was no transplant program between 1968 and 1970. In 1971 the State's vessel *Wanderer* moved 1,865 bushels from the Providence River to the outer harbor of Wickford for a winter fishery. this program was successful and was continued at least through 1974-75.

Recent Operations in Greenwich Bay—The Greenwich Bay Shellfish Management Area is open for harvest only during specific time periods during the winter and with reduced daily catch limits. These measures control overfishing and provide a source of clams in protected waters when work in the open Bay is impossible.

Natural production in Greenwich Bay is supplemented by transplantation from the closed waters of Greenwich Cove. In recent years the operation has been carried out under a legislative appropriation of $10,000/year. Handrakers harvest the clams at $0.10/pound, and the catch is collected and transported by vessels supplied by shellfish dealers. The transplant is carried out in May and takes only one day. Volunteers transplant additional clams one afternoon a week during May and June. A total of approximately 200,000 pounds (about 2,500 bushels) are transplanted each year. Since 1986, shellstock has been spread throughout Greenwich Bay to make them less attractive to poachers. Since the Bay is not opened for fishing until December, there is an opportunity for the clams to thoroughly depurate and to spawn.

The quality of stock in all transplant areas is assured by analysis of both growing waters and clam tissues. Surface water in the transplant source area is tested by the Division of Water Resources five times a year and must meet NSSP standards for restricted waters (less than 50 fecal coliform bacteria/100 ml and not more than 10% of tests over 500/100 ml). One month before transplant and one month before harvest, clams are collected by the Division of Fish and Wildlife and analyzed by the Department of Health for bacteria and heavy metals. In Greenwich Bay, transplants can be identified among the local stock by their chalky shells.

Greenwich Bay transplants have been carried out under the direction of A. Ganz, Senior Marine Biologist, Division of Fish and Wildlife. It is hoped that he can supply additional details on the evolution of the Greenwich Bay program and suggestions for enlargement of that program and development of transplants in other areas for inclusion in an expanded version of this report.

Programs in Other States—In Massachusetts, towns obtain permission from the Division of Marine Fisheries to relay clams from restricted water over which the state has control. Clams are tested for a variety of pollutants by the state before they are transplanted. Most relay operations are carried out by dredge boats contracted by the towns at a cost of approximately $0.15/pound. The towns may have clams placed in areas for either commercial or recreational diggers. Relayed clams are not made available to private aquaculture operations. Clams are not harvested until they have been in place through the spawning season. This assures a high level of depuration during active feeding and metabolism and provides additional larvae to the relay area. Clams are not retested before harvest.

The Taunton River portion of Mount Hope Bay has been a major source of relay stock for Cape Cod towns. About 25,000 bushels/year were relayed from the 1940s-1966; this was reduced to about 8,000 bushels/year in the 1970s and increased in the early 1980s. Presently , the stock is being allowed to recover. Hickey (1984) estimated that the standing stock of depurable clams in 1980-81 was 111,100 bushels and suggested that the sustainable annual yield was at least 22,220 bushels.

In Connecticut areas may be closed to shellfishing if waters exceed 70 total fecal coliform/100 ml or if sewage treatment facilities are found within a six-hour tidal flow range. Commercial Aquaculture companies make extensive use of transplantation of both oysters and hard clams from productive closed areas to certified grow-out areas. The Department of Health Services issues permits for transplant activities. Before harvest, relayed stock must be kept a minimum of 14 consecutive days in water of at least 50°F.

The state encourages coastal cities and towns to conduct transplant operations from the productive beds under their jurisdiction. Some towns have agreements in which commercial agriculturalists are allowed to removed clams from town-owned beds if they place a portion in areas where they can be harvested by recreational diggers.

In Great South Bay, Long Island, relaying was used first to stock large, private-growing areas and later to supplement town-managed areas. In 1964 New York state established a Shellfish Transplantation Fund with the goal of: (1) reducing concentrations in restricted areas which were being poached and were a risk to public health, and (2) making available accumulated stocks for spawning and eventual harvest. After 1973, relays were supported by a federal program (PL.88-309) which provided 50% of project costs. Relay programs were terminated in Great South Bay after 1979 as a result of reduced abundances in source areas and the development of anti-relay sentiment by commercial fishermen. Some relay projects are still carried out in other Long Island waters. The minimum depuration period is 21 days.

The history and operation of the hard clam relay system in New Jersey is described in COSMA (1984). In New Jersey a large portion of landings are depurated in plants or by relaying. In addition to the obvious economic benefits of depuration, the argument is made that it reduced the abundance of polluted clams which could enter the market illegally,. To some extent this strategy fails because production is so high in the closed areas.

Relay depuration is carried out on 1.5 acre lots leased to fishermen. Lots are divided into three half-acre sections and are adjacent to each other. Clams dug by the leasee or other fishermen with a permit to dig polluted waters are dumped into one section, held at least 30 days and until bacteriological tests are satisfactory and reharvested. Fishermen participate in decisions as to the placement of the relay beds and the schedule for opening them. Most New Jersey fishermen are familiar with the use of leases from the period of active oyster fishery. To avoid take-over by large-scale entrepreneurs or corporations, only one lot is allowed per man, and the lease is only valid as long as its holder is active in the relay fishery.

Discussion—Ganz (1987) listed the following potential benefits of transplants from Greenwich Cove to Greenwich Bay.

1) reduction of stocks which might be harvested illegally
2) enhancement of settlement and growth in the source area
3) increase of stocks in certified waters
4) enhanced reproduction in certified waters
5) reduction of effort in overfished portions of certified waters.

In New Jersey continued and possibly enhanced settlement (benefit 2) made it difficult to achieve stock reduction (benefit 1) in relay source areas. Such reduction does not appear to be a substitute for good enforcement.

At least one investigator (Easley 1982) has suggested that non-certified waters be intensively managed as nursery and grow-out grounds for hard clams in a way similar to that used in traditional oyster mariculture. This would involve removal of most of the stock at a young age with retention of adequate spawning population.

Hard clams were surveyed in the major uncertified portions of Narragansett Bay in 1985 (Pratt et al. 1986). Large stocks were found in the lower Providence River and lower densities were found in Mount Hope Bay. While both of these areas could be sources of transplants, it is not present stocks which are of most interest, but the potential for production of valuable small clams. There seems little doubt that the lower Providence River has this potential since it is adjacent to the productive upper Bay, and juvenile clams are found there at this time. Between 1957 and 1965 an average of 26,628 bushels/year were transplanted from the river, while at the same time standing stocks of legal size clams increased from 588,000 to 1,257,000 bushels. This indicates that harvest was well below the carrying capacity of the population and possibly that dredging activity had a positive effect on settlement and growth. This volume is about ten times the size of the present Greenwich Bay transplant.

The 1985 survey of the deeper portions of Mount Hope Bay showed an absence of juveniles where large, old clams were most abundant. The fact that Mount Hope Bay was used as a source of transplants for Rhode Island in the 1950s and 1960s and has been an important source for Massachusetts more recently suggests that it may have been more productive potential than suggested by standing crop. While studies are being undertaken which may lead to the reopening of the Bay to shellfishing, transplant of the standing stock would provide a test of the potential of the area for production of small clams.

Before uncertified waters are opened to heavy exploitation, it would be desirable to determine their importance as sources of larvae for the rest of the Bay. This would require examination of larval abundance in both the upper and lower Bay and examination of transport rates and directions. Studies of larval abundance and transport would also be necessary to determine whether any benefit accrues from allowing transplants to spawn before harvest.

Many shellfishermen consider the Greenwich Bay operation to be very successful and wold like to see it enlarged. They are concerned that license fee money which is available for transplants is not being used and that a decrease in fee income could cut into transplant funds (S. Cote, Rhode Island Shellfishermen's Association).

Some full-time fishermen in New York and Rhode Island are against transplant programs because they disrupt work schedules, reward those with less local knowledge and commitment to the fishery, may lower prices or consumer confidence, and require an increased level of management and enforcement. Transplants create additional work for the DEM in the areas of water quality testing, stock assessment, and enforcement. Since recoveries of transplants are usually less than 100% (recoveries for dredger transplants were always less than 65%), there is often controversy about the fate of missing clams. A major problem with the expansion of the present transplant program is finding a way to allow volunteer harvesters to have priority in reharvesting without contravening the principle of a free and common fishery. It is also necessary to establish whether monies expended on paid transplants are subsidies to fishermen or expenditure of fishing permit funds.

More approaches and a greater level of effort has been used in past transplant programs in Rhode Island than are used now. Programs in adjacent states use additional approaches and benefit different user groups. None of these programs stand out as models for future management of Narragansett Bay. Some, such as transplantation onto leased bottom, are not options in Rhode Island because of the established principle of free and common use of the hard clam resource. All programs suffer from difficulties in administration, uncontrolled natural variability, and perception of unfairness by groups and individuals. It can be concluded, however, that the Rhode Island program could be enlarged, more source and planting locations could be used, and more transplants could be made to benefit recreational diggers. Before the transplant program was enlarged, consideration would have to be given to the relative economic advantage of shore-based depuration, the persistence of organic pollutants in clam tissue, the public perception of quality of transplants, and the role of closed areas as spawner sanctuaries.

Depuration

The term depuration as used here is the purification of shellfish by natural biological processes under controlled conditions such as a recirculating seawater system. Purification also takes place when stock is transplanted from polluted to clean natural growing areas; however, this requires harvesting twice and a long treatment time because of lack of control of environmental conditions. In the United States, depuration is usually used as a way of utilizing shellfish from marginally polluted waters or conditional areas where densities and growth rates are high. Depuration provides an extra margin of safety for hard clams and oysters which are eaten raw.

Two studies of the economic feasibility of depuration in Rhode Island were made during a period when landings were only 25% of the present level. Holmsen and Stanisloa (1966) concluded that controlled depuration would make more economical use of stocks in the closed parts of the Bay than transplantation.

Zakaria (1977, 1978) showed that net profits for depuration plants could vary from 79 to 237% of investment. She also estimated that the value of catches in closed areas would increase about 47% with repeated harvest because the proportion of littlenecks would increase. Zakaria assumed that a single plant could process the catch from the upper Bay and lower Providence River. Zakaria's projections cannot be accepted in detail because some of her area estimates are incorrect, and she did not take into account the heavy fishing pressure in the conditional area during the periods when it was open.

If a new economic study was made, Mount Hope Bay would have to be considered as a source. Increases in the value of hard clams greater than the increase of inflation (Figure 4) have made all elements of the industry more profitable since 1971.

The development of regulations for operation of shellfish depuration plants in Rhode Island was halted by opposition by fishing interests. Other states in this region have approved regulations (Maine, Massachusetts, New York, and New Jersey). Massachusetts has a state-run plant treating softshell clams, and Maine and New Jersey have commercial plants treating softshell clams (five) and hard clams (two). All plants use UV light to disinfect water, either in a recirculated system with seawater or from flow-through salt water wells (Furfari 1975; Furfari, personal communication). Different systems of testing are used depending on the potential pollutant levels of incoming product and the plants.

A major problem with depuration, and a point that will be taken up by objectors to its use in Rhode Island, is the retention of either pathogenic viruses or chemical pollutants after indicator bacteria have been eliminated.

The Narragansett Bay Project has supported research on survival of viruses in sewage treatment effluents, estuarine water, and shellfish (Cabelli, 1988a, 1988b). This research is difficult since pathogenic virus numbers cannot be directly counted, and infective doses are not known. Nevertheless, it appears that viruses are eliminated at a much slower rate than fecal coliform bacteria both under natural conditions and in depuration plants. This means that longer treatment times are needed and that coliform levels do not provide a way of monitoring progress of treatment.

Boehm and Quinn (1977) found that adult hard clams from the Providence River retained accumulated hydrocarbons over a 120-day period. Other investigations have found the PCBs are not depurated from hard clams (Courtney and Denton 1976) and that some fraction of heavy metals are retained for long periods. Information on the levels of pollutants in clams from the cleaner portions of the Providence River (south of Gaspee Point) and in Mount Hope Bay is needed to see whether they are acceptable without reduction by depuration. There are some guidelines for acceptable levels of metals in shellfish, but none for hydrocarbons.

There are strong feelings against depuration by the shellfishermen of Rhode Island. This is primarily because dealers might be able to control price or sources if they could purchase and hold large stocks from upper Bay areas. The availability of depuration might take some impetus away from attempts to clean up the upper Bay and might lead to closure of the present conditional area to regular fishing. Depuration might also lead to the public perception that they are being offered "polluted" clams.

The view of depurated clams being of low quality may be changing, however. Much of the dense set of clams that occurred in the Indian River, Florida, were depurated before sale. It has been reported (Busby 1986) that depurated product has been accepted by buyers as providing more assurance of quality than stock from open waters.

Because of the scientific and political negatives discussed above, the DEM does not consider depuration as a management alternative. Although no research is being made on depuration per se, information on retention of viruses and chemical pollutants in transplants and marketed clams will identify potential problems. The State of Rhode Island should remain in a position so that depuration could be used if it had an economic advantage in the future. This might happen if buyers insisted on purified stock, or if reduced catches in open waters made it desirable to harvest the lower Providence River or Mount Hope Bay.

Previous economic studies of depuration have focused on the profits available to the processor. At this time, projections are required of the consequences of different systems and regulations on the shellfishermen's income and pattern of fishing.

Aquaculture

History of aquaculture in Rhode Island—Seventy years ago oyster aquaculture was by far the most important fishery in Narragansett Bay. Approximately 20,000 acres were leased, almost all in areas where hard clams are presently harvested. Hundreds of fixed fish traps along the shoreline were an additional restriction on public use of Bay waters. The hard clam fishery was of minor importance, and in some cases payment was made to oyster lease holders for the right to fish.

As the oyster industry declined and disappeared from the 1930s to the 1950s, the hard clam fishery increased in areas harvested and in yield. Both hand collecting and dredging by boats was utilized until the late 1960s. Since then hand collecting (tongs, rakes, and diving) has been carried out in all certified waters without restriction from leases or competition from dredgers.

Overfishing of natural stock, increases in demand and prices, and advances in culture techniques caused a renewed interest in marine aquaculture throughout the United States in the 1970s. In Rhode Island, the concept of aquaculture came into direct conflict with the free and open fishery of hand collectors. The following description of the resolution of this conflict has been condensed from Nixon (1981).

> When the state began its coastal management program in the mid 1970s, control over aquaculture was given to the newly created Coastal Resources Management Council. Two permits were granted under their

authority, despite a lack of implementing regulations: the Blount Oyster Farm on Prudence Island and the Blue-Gold Sea Farms of Middletown. Blue-Gold received a permit to culture mussels in an off-bottom system over sixty acres in the East Passage. Fishermen objected to this proposal because the regulatory program was not yet in place. They feared that this would be ... the beginning of a series of projects which would once again monopolize the bay's most productive areas.

In an effort to clarify the regulatory program, the General Assembly passed a new aquaculture law in its 1980 session (G.L.R.I. 20-10-1) which repealed the oyster leasing laws of the 19th century and recognized the potential for conflict between bay fishing and aquacultural interests. Regulations implementing the new law were not in place by the fall of 1980 when the Narragansett Mussel Company submitted an application for a site in the West Passage of the Bay in an area utilized by a variety of fishing and recreational interests.

In October of 1980, the Rhode Island Shellfishermen's Association requested a meeting with Governor J. Joseph Garrahy to seek his intervention in what was perceived to be a serious threat to the future of fishing in the bay. The Governor responded by declaring a moratorium on new aquaculture permits and appointed a Task Force representing fishing, aquaculture, environment, regulatory, and scientific interests. The Task Force was to develop recommendations by June 1, 1981 to resolve the dispute.

The Task Force began its deliberations in January of 1981 with friction between aquaculture and fishing interests high. Research, hearings, and studies were conducted for seven months in an effort to find a common ground for the parties to agree upon. At the outset, the parties were diametrically opposed: fishermen maintained that aquaculture should not be allowed within the bay while aquaculturists argued that they should be allowed to operate wherever environmental conditions allowed since their use was the most intensive and beneficial use of the water column.

By July 14, 1981, consensus was achieved on a number of significant points: (1) fishermen softened their position that aquaculture should not be allowed in the bay at all and recognized that limited efforts of a relatively small size would not necessarily be harmful to their operations; (2) aquaculturists acknowledged that they should seek locations which are not actively exploited by commercial fishing operations; (3) the State Division of Fish & Wildlife developed a draft Aquaculture Management Plan which maps the location of existing fishing areas and excludes aquaculture from potential high conflict areas; and (4) the Coastal Resources Management Council announced that regulations implementing the aquaculture law would ... set fees for aquaculture leases, and bonding requirements ....

One of arguments against establishment of aquacultural leases was that mussel farms would produce spat which would settle on hard clam beds smothering them and leaving shells which would "destroy the ground" (Commercial Fisheries News 1980). It is clear that mussel farms and hard clam farms will be very minor sources of spat as compared to the very large natural populations. It is also known that colonization of soft bottom by mussels varies by year and location.

More important is concern about loss of access near aquacultural ventures, deleterious changes in price structure and loss of ease of access into an open fishery.

During the development of the program, arguments were made that aquaculture would provide information on shellfish of use to all and that aquaculturists would join with other fishermen to fight for cleaner water.

Regulation of aquaculture—The Coastal Resource Management Council's program on aquaculture is described in a 1983 report (Olsen and Seavey 1983). Policies are that: (1) aquaculture is a viable means for supplementing the yields of marine fish and shellfish food products and will be supported where it can be accommodated among other users; and (2) applicants will be granted exclusive use of submerged lands and water column when such use is necessary, otherwise the public will be allowed use of the area for traditional water activities.

Prior to issuing a permit, the Council will ask the director of DEM to determine that the proposed activity will not adversely affect marine life outside of the proposed area and the continued vitality of indigenous fisheries. The chairman of the Marine Fisheries Council will be asked to determine that the activity is consistent with competing uses of marine fisheries.

Permits must be obtained from the director of DEM for possession, importation, and transportation of species used in aquaculture.

Applicants for aquaculture permits must:

1) describe the location;
2) identify the species managed;
3) describe methods used and whether they are experimental, commercial, or for personal use; and

4) provide information required to determine:

   a) compatibility with existing and potential uses;

   b) degree of exclusivity required;

   c) safety and marking of the lease area;

   d) projected yield per unit area;

   e) cumulative impact on the area;

   f) capability of the applicant, and

   g) impact on scenic qualities.

Permittees are charged an annual fee ($75 for 1/2 acre or less; $150 for 1/2-1 acre, and $100 for each additional acre) and are required to submit an annual report to receive a renewal. Leases can be renewed for ten years.

Practice of aquaculture—Annual reports from aquaculture permittees are summarized in a report by the DEM Fish and Wildlife Division. The most recent report (Ganz 1987) states that:

> Aquaculture continued to decline in 1987. Only three operations marketed their cultured products; this amounted to 116 bushels of oysters. The other operations were active in producing shellfish, but did not sell product. There does not appear to be any desire by operators to expand their projects.

Specific projects which were active in 1987 include four oyster culture operations in salt ponds, the Blue Gold mussel farm in East Passage, and a quahog "clam box" experiment in Charlestown Pond. No mussel harvest or new planting was reported for 1987 by Blue Gold which presently spends most of its effort marketing product from other sources. The "clam box" operation, an attempt to attract quahog settlement in various configurations of boxes, has apparently not succeeded in producing or concentrating seed. One oyster operation has made plans to start grow out of hatcheries-reared softshell clams during 1988.

It is clear that fishermen have not been "squeezed in smaller and smaller areas of the Bay" by aquaculture as feared in 1980 (Commercial Fisheries News 1980.

Commercial aquaculture of hard clams has been slow to develop in the United States. However, it is now possible to see different types of operations becoming practical under different conditions. In the southeast, hard clams grow fast enough so that planted seed clams can be held until they reach marketable size (two years). A high level of predator control is necessary, however. In Connecticut, leased beds are prepared by removal of old individuals and some predators in preparation for seeding by natural set.

Much hard clam aquaculture is devoted to production of seed which is in demand by towns to plant for recreational use. In Massachusetts, seed is provided by operations varying from large commercial to small town operated. A problem in production and use of seed clams is that it is easy to produce large numbers of very small clams (1-2 mm) which have low survival rates; while more time, space, larval food sources, and disease control are required to produce more desirable larger seed (8 mm).

Over a period of 13 years, a system of intensive hard clam aquaculture has been developed in Wellfleet, Massachusets (Chapman 1987). Presently 50 persons have grants on 80 acres of tidal flats. Most operators stock 4 feet x 8 feet net boxes with 10,000 or more seed from a local hatchery ($12-$16/1,000), allow them to grow to 19-24 mm, and then transfer them to narrow net-covered plots for grow out at a density of 100-00/m^2. Clams are harvested at a length of 51-63 mm (2-2.5 inches). Individuals have reported gross sales of $30,000/acre in recent years (J. Fox, personal communication to R. Rheault, URI). Wellfleet grant holders stress the potential contribution of their operations to the spawning stock (Chapman 1987).

Malinowski (1986) has prepared an illustrated manual on "small-scale farming of the hard clam on Long Island, New York." His concept is of leases of less than five acres worked with light equipment by a few individuals. Most of the clams produced would be sold as seed, but some would be kept until they were of harvest size. The suggestion is made that since overfishing and environmental deterioration have severely reduce clam harvests on Long Island, clam farming would be a way that baymen could continue using their skills to make a living on the water. Interference with the remaining open fishery would be reduced by only utilizing areas where clams do not naturally occur.

Although the potential for significant profit from aquaculture is questionable, the reasons for the low level of activity in Rhode Island are legal and political obstacles erected for protection of the open fishery. The commitment to an open fishery does not preclude the use of techniques developed by aquaculture, however. Techniques of induction of set, transplantation, and predator control should be examined for use on public ground. The existence of shellfish management areas and the availability of license fee (804) monies for shellfish propagation would make such projects possible.

In 1988 research will be carried out by investigators at URI (M. Rice, J. DeAlteris) and DEM Fish and Wildlife (A. Ganz) on the effect of bottom cultivation on setting and growth of had clams in the field. This research may indicate a way to induce set in public or private bottoms. It may also provide a test of the widely-held believe that working the bottom encourages continued setting.

Predator Control

Predation has been recognized as a problem in the Bay during cycles of high starfish abundance in the past, but in recent years there has been little perception that predation is a threat to the fishery. Nevertheless, on the basis of research in other regions, it can be assumed that predation is an important determinant of the survival of spat and small clams in the Bay. Control of predation could be a valuable management tool at this time. Concerns about retention of an adequate spawning stock would be relieved if the need for very large numbers of setting larvae were reduced. Predator control could even out the effects of annual variations in larval supply and might increase clam supply on chronically unproductive grounds.

Levels of control range from allowing predators caught while clamming to die before returning them to the water, to the use of toxic chemicals and mechanical mixing of the bottom. Before a predator is targeted for control, it is necessary to determine what damage it is doing, whether other predators will take its place, and whether other species such as those which compete with clams will increase without control.

In the following subsections, information is given on predators which may effect hard clam abundance in the Bay. In no case is it possible to quantify their effect on natural populations of clams in the field.

Crabs—The xanthid crabs are small estuarine species with large crushing claws marked by dark tips. They prefer muddy bottom with shells or pebbles, but are found in most habitats. One of this group, *Neopanope sayi* (*texana* in older literature) is very abundant in the Bay and is probably a major predator of small bivalves including hard clams.

The first report on the rate of predation by *N. sayi* on small hard clams was published by Landers (1954) from work done in Wickford, Rhode Island. In laboratory experiments, he found that crabs 15 mm (0.6 inch) across consumed clams less than 10 mm long (0.4 inch) at a rate of 5/day at summer temperatures. Little or no predation was observed if the clams were more than 15 mm long or if temperature was below 12°C. In a field planting of 2,000 seed clams, there was circumstantial evidence that mud crabs ate 86% within a year. Oyster drills appeared to have eaten only 0.6%.

MacKenzie (1977) found that adult crabs could eat seed clams at a rate of 14/hour in the absence of sediment. In sand, the crabs would bury themselves to reach clams which they ate at a rate of 1.6/day.

The closely related *Panopeus herbstis* is present in small numbers in the Bay. Whetstone and Eversole (1981) determined that the ability of *P. herbstis* to crush clams decreased rapidly with clam sizes over 20 mm (0.78 inch) and at temperatures below 17°C.

Flagg and Malouf (1983) calculated that the existing population of *N. sayi* in Great South Bay, Long Island, could consume about 20 seed clams/m^2/day which would soon destroy any aquaculture planting. Experiments with gravel overlays, which are effective in protecting clams from blue crabs in the Virginia area, resulted in attraction of mud crabs and increased predation. Oyster toadfish living near the experimental plots eat crabs and increased clam survival from 5% to 80%. Gibbons and Castagna (1985) found toadfish to be useful in crab control in net-covered seed-growing areas. In Narragansett Bay, *N. sayi* are eaten by toadfish and probably also by tautog.

The green crab, *Carcinus maenas*, has been very destructive to intertidal softshell clam stocks in northern New England. It does not appear to be as destructive to hard clams in the Bay. It is found in the salt ponds and in the Narrow River (A. Ganz, personal communication) and on mussel beds.

The rock crab, *Cancer irroratus*, is found on sandy and silty sand bottoms, especially in the lower Bay. MacKenzie (1977) found that in the absence of sediment, juvenile crabs could eat 30 1 mm seed clams in an hour, while adults could eat 29 8-10 mm clams/hour. In sand, the crabs dug up small clams and ate them at a rate of 100/day.

Where blue crabs,*Callinectes sapidus*, are abundant on the mid-Atlantic and southeast Atlantic coasts, they are the major predator of small hard clams. Because Rhode Island is near the northern edge of their range, they are less abundant here and their numbers vary from year to year. Blue crabs are most abundant in the summer in warm shallow areas with freshwater input and move into deeper parts of the Bay in the winter.

The lady crab or calico crab, *Ovalipes ocellatus*, a close relative of the blue crab, lives on fine sand bottoms, especially in the lower Bay. Like the blue crab, it has a very high level of activity and rapidly consumes seed clams in laboratory tests.

Starfish—The starfish, *Asterias forbesi*, has been an important predator of shellfish in the Bay in the past, and its control was a major expense in oyster farming operations.

Starfish have great destructive potential even as very small individuals. In 1898, Mead (1901) studied starfish on softshell clam and oyster beds in the upper Bay. He describes the "reign of terror" of a 1 mm wide starfish which ate 50 softshell clams in six days and increased in size by 300%. An illustration in Mead's report of a two-day old starfish attacking a softshell clam larger than itself emphasizes the threat of this predator. He found that starfish settled from the water column several weeks before their prey so that they were prepared to feed heavily on spat and that they could complete their life cycle in one year. The rapid growth of starfish helps to explain the sudden shifts in concentrations reported by oystermen and found in state surveys (see section on management surveys).

Doering studied hard clams from the Bay in laboratory experiments. He found peaks of feeding in the fall and spring, a short period of inactivity in the winter and a longer period of inactivity throughout the summer (Doering 1981). In the same study, he observed that large clams could be opened by groups of starfish. He found that deep burrowing gave measurable protection from starfish (Doering 1982).

Burkenroad (1946) concluded from oyster company records and newspaper reports that starfish followed a regular cycle of abundance of about 14 years. Apparently, starfish densities were relatively high from 1959-1962 when state surveys were made, but the program did not continue long enough to establish whether this was the peak of a cycle. Long-term weekly otter trawl data from the West Passage (Terceiro 1985) shows a low density of starfish from 1966-1968, a steady increase until 1976, and then a rapid decline. Starfish catches have remained low from 1976 to the present time.

If starfish abundance is cyclic, an increase may be overdue. At this time, studies should be made to understand the factors controlling densities, and a monitoring plan designed to provide early warning of increase. Surveys should be made in local areas before transplants are carried out.

It is not clear that any control measures are available in case of future outbreaks. The starfish removed during hard clam fishing have already had the opportunity to feed heavily on spat and juvenile clams. In Long Island, operators of leased beds hydraulicly dredge with the hope of making the bottom unsuitable for recently metamorphosed starfish. Starfish have few natural enemies, however, it has been shown that the spider crab, *Libinia emarginata*, eats them one leg at a time (Aldrich 1976). The low level of activity of the spider crab probably keeps it from being a controlling predator. Nevertheless, their possible beneficial effect would make them worth preserving.

Gastropod Mollusks—In the Bay the whelk or channeled whelk (*Busycon canaliculatum*) feeds almost exclusively on hard clams as an adult. It feeds by rasping or breaking the clam shell with its own shell and is most active at night. Conchs are found on fine sand and silty sand bottoms in open parts of the Bay where they are subject to a pot fishery. Sisson (1972) studied conchs off Wickford where he found a small inshore-offshore seasonal movement. He found that they were inactive in the winter and remained buried and inactive over long periods of time in the summer as well.

Conchs, unlike crabs and drills, are able to attack adult clams. Peterson (1982) found that they actually selected the largest size of prey available. Scattered adult conchs seem to be little threat to the clam fishery since they attack less valuable large clams and eat at a slow rate (1/20 days, Carriker 1951). However, in areas where they are abundant such as Great South Bay, conchs can rapidly destroy 25 mm clams that are safe from other predators (Flagg and Malouf 1953).

The rough oyster drill (*Eupleura caudata*) and the smooth oyster drill (*Urosalpinx cinerea*) were serious predators of oysters when they were grown in the Bay, and they attack small hard clams in Long Island and New Jersey (MacKenzie 1977). In the Bay, they are presently more abundant feeding on barnacles in the rocky intertidal than on clam beds.

The moon snails, *Polinices duplicatus*, and *Lunatia heros*, are important predators on sandy bottoms. The holes that they drill in a clam's shell can be differentiated from those made by oyster drills because they are "countersunk" rather than straight-sided.

Discussion—Research on hard clam predation in the Bay is needed to be able to understand annual variation in recruitment into the fishery and the density of clams in different habitats. High densities in areas like the lower Providence River and East Greenwich Cove may result from exclusion of predators by salinity, high temperature, or low oxygen. The low density of clams in the lower Bay could be the result of predation by species adapted to marine conditions.

Many management proposals have elements which relate to predation. Seasonal closures, clam collection techniques, and closures to fish trawling could effect predators. Transplants should not be made at temperatures when hard clams are inactive and starfish are active. Encouragement of fisheries for conch, green crab, blue crab, lobster, and horseshoe crab will have a positive effect on clam abundance.

Some control techniques such as retention of predator species and return of beneficial species by shellfishermen are very simple. Another simple technique which has not been tested is attraction of toadfish to bottom areas by provision of containers to breed in.

Control techniques are most effective where spat is abundant. The initial density of spat set in the Bay is not known, but probably does not reach very high levels. Pratt (1977) found a maximum of 140 seed clams/m^2 in samples from off Calf Pasture Point, and Carriker (1961) found up to 125 spat/m^2 in Delaware Bay. This is much less than the maximum densities of natural beds of softshell clams, and less than the densities at which aquaculturists grow hard clams for harvest (540/m^2; Malinowski 1986).

Quantitative surveys have found patches of harvestable clams in the Providence River of 50/m^2 (Canario et al. 1965). The densities of clams in the rest of the Bay are not known, but probably average around 5/m^2 in the upper Bay. While the upper Bay could support clam densities at least two times higher than it does not, a low initial density would make this impossible without complete predator control by hand picking, enclosure, or poison. Induction of additional spat setting through bottom preparation would reduce the requirement for complete control.

Before control is discussed, it will be necessary to determine the importance of predation to the hard clam resource. Ths is a complex problem since many species are involved, many show cycles of abundance, and other factors effect hard clam set and success. With limited resources, the Division of Fish and Wildlife could obtain semiquantizative records of predator abundance when clam stocks are assessed. Information on the density of predators in productive areas of the Bay—such as Greenwich Cove and Barrington Beach—would be especially interesting.

Other Management Options

Minimum Size—The present minimum size of one inch thickness has been adopted by most hard clam producing states and by the retail industry and no change is suggested. Since clams harvested at one inch have just reached maturity, it is desirable to retain spawning stocks within harvest areas or within larval-transport range. The role of "spawner sanctuaries" is discussed earlier in this report.

Seasonal Limits—The seasonal closure of the Greenwich Bay Management Area to fishing from boats allows depuration of transplants, recovery of natural stock, and provides safe fishing and increased catches/effort in the winter for commercial fishermen. Areas which are closed during the summer because of extensive use by moored boats such as Wickford Outer Harbor, and Potter Cove (Prudence Island) also provide winter fishing. Although recreational shore digging is allowed year round in Greenwich Bay, the seasonal closure to boat harvest excludes some potential summer recreational users from the densely populated surrounding towns.

Seasonal closures have many benefits to the commercial fishery and provide opportunity for development of techniques of stock enhancement. Other closure areas should be considered along less populated shorelines such as off Quonset/Davisville.

Gear Restriction—The present allowed harvest techniques are handraking and diving. Divers do not appear to have an unfair advantage over handrakers, since more expense and discomfort is involved although catch/hour on the water may be higher. Regulations may be needed to reduce competition for space when reopenings or transplants draw large numbers of boats into small areas.

Divers can remove a larger proportion of clams from a given bottom area than can handrakers. At this time, there is no way of judging whether this is undesirable, since the effect of the presence of adults on setting of spat are not known. The effects of divers and handrakers on tilling of the bottom and on predators are probably similar.

Catch Limits—Catch quotas and limited entry can both be used to limit catches to a sustainable level. At this time, such limits would be unacceptable to commercial fishermen. If the need for limits was recognized in the future after a decline in catches, the information to predict sustainable yield would be hard to obtain. Little is known concerning variations in survival of larvae and juveniles, the productivity of different habitats, or the effect of fishing on growing areas. Since the beginning of the fishery, annual catches have been determined as much by harvest technique and market forces, as by stock availability.

Catch limitation as a tool is discussed in COSMA (1985) and by Conrad (1985) who made the following observations and suggestions. Limitation of numbers of license limits total catch as long as gear restrictions are retained. Licenses are awarded to active fishermen, and those not receiving a license are compensated. Licenses are transferable and would become more valuable as stocks increase. A limited entry system benefits full-time fishermen to the detriment of part-timers. Direct catch quotas are set on a seasonal, annual, or area basis. Quotas give good biological control of stocks but are not compatible with a full-time fishery with no alternative target species.

RESEARCH ON HARD CLAMS IN NARRAGANSETT BAY

In this section surveys and research which have been carried out in the Bay are identified and described. If in the future, Rhode Island's hard clam resources are more actively managed than at present, historical studies will show the potential and problems inherent in different types of surveys. Although the natural history of the hard clam has been extensively studied throughout its range (McHugh et al 1982, lists 2233 articles), research carried out in the Bay is of special interest because no adjustments are necessary to project conclusions to this location. The effects of variables such as circulation, bottom types, location of brood stocks, predators, and pollutants are all specific to the growing area and require study within the area of concern.

Surveys for Management

Distribution of stocks—It may seem surprising that the only map which shows hard clam density throughout the Bay was made from a 1956 survey. The major reasons why more extensive surveys have not been made are expense, difficulty in resolving problems of spatial heterogeneity, and the constant changes which take place due to fishing pressure and growth of clams. If a bottom grab is used, it must be large enough to recover more than a few clams per station, and stations must be close enough together to define areas with different abundances, and numerous enough to provide good estimates of standing crop. Taking large numbers of grabs is slow and expensive. Dredges have the advantage of sampling large bottom areas, integrating small scale patchiness, and do not require sieving aboard the boat. The major faults of dredge samples are variation of efficiency with bottom type and vessel operation, and failure to recover small clams.

Since the 1950s, a number of surveys have been carried out in sub-areas of the Bay as part of studies of populations and responses to pollution, and to manage fisheries . When these surveys are examined together, they show the general distribution of hard clams and changes which have taken place over time. The areas studied and the techniques used are summarized below.

In 1949-1950, a dredge survey of the Bay (123 stations) was made to determine the distribution patterns of hard clams in relation to sediment type (Pratt 1953). The data was not mapped. Findings on the effects of substrate are discussed later in this section.

Hard clam population studies were conducted in Greenwich Bay from 1951-1957 by the U.S. Fish and Wildlife Service and the Rhode Island Division of fish and Game using a construction bucket that took a large (5 square foot) sample. Shallow areas were sampled by tongs. All clams at least 15 mm (0.6 inches) long were counted. While short annual reports were made, most of the data was not analyzed or mapped in detail. The data has been obtained by the Bay Project for possible use for historic comparisons. The period covered includes the all-time high Bay landings of 1953, and 1955 and precedes a period of decreasing landings which continued until the mid-1970s. This series of surveys are of particular interest because they were supplemented by a study of other bottom animals in Greenwich Bay (Stickney and Stringer 1957).

The only quantitative survey made which covered most of the growing areas in the Bay was carried out in 1955-56 in response to proposals to build mid-Bay hurricane barriers. This survey was made by the U.S. Fish and Wildlife Service and the State using techniques developed in Greenwich Bay. A total of nearly 2,800 samples was taken on a 900-foot grid. In 1957, the lower Providence River, Bristol Harbor, Greenwich Bay, and one mile square areas of Ohio Ledge and "High Banks" were re-sampled. A description of the project and data on mean densities of four size classes in ten areas are given in Stringer (1957). A map of three density classes shows that the areas of high abundance were very similar to those found today.

Campbell (n.d.) gives more detail on the results of the 1956 surveys of the Providence River and the Rhode Island portion of Mount Hope Bay and provides contour maps of six density classes of "chowder," "neck," and undersize clams.

In 1965, the Providence River was re-sampled by the Rhode Island Division of Conservation using the same samples, station location, and mapping technique (Canario and Kovach 1965). It was found that the standing stock had increased from 588,000 to 1,257,000 bushels although about 240,000 bushels between 1956 and 1965 had been removed for transplant during that time. The map for total density of legal size clams in the Providence River shows that many areas had more than 50 clams/m^2 (5/ft^2). Factors affecting the relative abundance of the clams from the 1965 survey were analyzed in a paper by Saila et al. (1967).

The lower Providence River and the upper Bay were surveyed in 1976 by the Division of Fish and Wildlife (Sisson 1977) using a dredge for which efficiency values had been determined in five sediment types. Results are given as potential yield to dredging of three size classes in each sediment type, rather than as mapped densities.

The Providence River and Mount Hope Bay were surveyed by dredge in 1985 as part of the Bay Project. Maps of relative abundance and the size distributions of populations in different strata are provided by Pratt et al. (1987).

In 1983, the Massachusetts Division of Marine Fisheries surveyed the northern portion of Mount Hope Bay with a dredge for which efficiency had been determined by diver sampling (Hickey 1983). This survey confirms the low abundance and large size of clams in the central portions of the Bay found in 1985 by Pratt et al. (1987).

Deeper portions of Narragansett Bay were opened to a dredge fishery for limited periods during the 1960s. Surveys were conducted to determine the resource present before the openings and research was done on use of dredge results for stock assessment and the portion of the stock which was recoverable by dredging. Results of surveys in the West Passage are given in Canario and Kovach (1965a), Division of Conservation (1968), Gray (1969), and Russell (1970). Population estimation technique is discussed in Russell (1972). The Sakonnet River was surveyed in 1968 (Division of Conservation 1968).

The area of Quonset Point closed to shellfishing was surveyed by bucket sampler in 1967 (31 stations)(Kovach and Canario 1968). The entire Quonset-Davisville area was surveyed in 1978 (Ganz and Sisson 1977) for an environmental assessment of redevelopment of former Navy land (CRC 1977). Shellfish were sampled intertidally, in shallow water by bullrakes, and in deep water by dredge (32 stations).

The following coves and harbors have also been surveyed: Nausauket-Buttonwoods 1955-1958-1959 (Campbell 1959a); Potowomut River (Campbell 1959b); Kickamuit River (Campbell 1959c)(Canario 1963); Warren River (Canario and Kovach 1966); and Wickford Harbor (Kovach 1969).

Location of Fishing Effort—The location of tong and bullrake fishing effort was mapped intermittently by the State of Rhode Island between June 1955 and August 1960. The initial object was to obtain area-specific data on catch, catch/effort, and size distribution of clams for research in the productivity of the bottom (Campbell and Dalpe 1960). After a hiatus, the project was reactivated to be able to establish dredge boat harvest areas where they would not conflict with hand collectors (Campbell 1961). The locations of bullrake and tong fishermen were recorded on 40 days between September 1959 and August 1960. Campbell provides maps of bullrake and tong locations for all observations and also provides separate maps for winter and summer. The areas of productive fishing have changed very little in 28 years. Wickford, the upper West Passage, Greenwich Bay, the upper Bay, and Bristol were all locations of concentrations of boats. Bullrakers were able to fish in areas of intermediate depth in upper West Passage and the upper Bay which were denied to tongers.. Although the plotting operation was supposed to take into account "all the known areas ... frequented by fishermen," no locations are shown in the Sakonnet River. It appears that that area was not surveyed, possibly because much of it was assigned to dredge boats.

In 1960, four times more tongers were licensed than bullrakers. However, the number of tongers observed fishing was only a little larger than the number of rakers. At the present time, ten times more bullrakers than tongers are licenses, emphasizing the importance of deeper growing areas in sustaining high levels of landings.

Site-specific information of harvest is necessary for detailed analysis of productivity and of the effects of modification of fishing practices or treatment of the bottom. It is doubtful that such data could be obtained from parts of the Bay where there is an open fishery. The number and size of clams removed from a given area depends on fishing technique, weather, amount of the Bay open, and many other variables. The number of fishermen who might utilize an area is large, and land at a large number of harbors and ramps.

Estimates of yield could probably be made for the Greenwich Bay Management Area because of the limited periods which it is open to harvest. Information on catch and estimates of the proportion of transplants and "native" clams could be used to assess changes in annual yields and the benefits fo the transplant program. In the 1960s, unfished areas were sought for dredge boat areas. It seems reasonable to identify some areas with no hard clams present for possible aquaculture experimentation.

Starfish Surveys—Starfish distribution in the Bay was mapped in the fall and winter of 1935 (Galtsoff and Loosanoff 1939)(103 and 80 dredge stations). Starfish were only caught within the boundaries of the Bay, and they were concentrated in the East Passage near Dyer Island, Hog Island, and Mount Hope Bridge.

During a period of relatively high starfish abundance, the State of Rhode Island conducted four annual surveys to plan possible predator control measures and to learn about their natural behavior patterns. Collections were made at 84 stations throughout the Bay during the winter (when starfish are inactive) using a sea scallop dredge. The width of each starfish caught was recorded in centimeters. Survey data is given in Campbell (1960) and Canario (1962).

In 1960, starfish concentrations were found off Wickford, Davisville, Colt Drive, east of Hog Island, south of the Kickammut, south of Old Stone Bridge, and off

Portsmouth. As many as 2,523 were caught in one five-minute tow. Starfish were not abundant in Greenwich Bay and the Providence River. In 1961, populations were generally more dispersed, although concentrations were noted in Dutch Island Harbor and off Fogland Point. In that year, densities throughout the Sakonnet River had increased.

Starfish surveys were discontinued by the state after 1962, presumably because of decreased densities. Weekly otter trawl surveys off Fox Island and Whale Rock in the West Passage conducted by the Graduate School of Oceanography since 1966 (Jeffries et al. 1986) provide a good record of major changes over time. These showed a low density from 1966-1968, an increase to 1975, and a rapid decline to a low level which continues to the present time.

Condition Index—The ratio of tissue volume to internal shell volume is a traditionally used measure of condition or "fatness" of bivalves. This index provides a method of tracking development of gonads and time of spawning.

Only two studies of measured condition of Bay hard clams have been reported. Green (1965) recorded an index based on displacement volume for: (1) clams from East Greenwich Cove, (2) Cove clams which had been transplanted to Greenwich Bay, (3) clams from Bullock Point, (4) Bullock Point clams transplanted to the East Passage (Melville), and (5) clams from Longmeadow. Observations were made from July to December 1965. Green found that in general, populations had high index values in spring and early fall and low values in late summer (after spawning) and in winter (with reduced feeding activity). The natural Greenwich Cove population had the highest range of values (0.3-0.6) and transplants had lower values than source populations.

The late summer low in East Greenwich Cove may reflect the effect of high temperature or low oxygen as well as spawning stress. High index levels in October may indicate a period of tissue growth without equivalent shell growth. Pratt (1953) found little shell growth after September in experiments at Wickford. The delay in recovery of transplants from East Greenwich Cove may mean they are of lower quality when harvested in the winter.

Condition index was not a good indication of pollution level in Green's study. Cooper et al. (1964) reached this same conclusion in a study of hard clams from polluted and clean areas of Point Judith Pond.

Diamond (1981) calculated indexes from the ratio of tissue weight to shell length and tissue weight to the product of shell length, width, and height for clams from Sabin Point and Dutch Island Harbor in monthly samples over a year. She reported a statistically significant difference in mean index values between the two populations.

Kern (1986) assigned a visual index of condition for hard clams collected from the Providence River, Mount Hope Bay, and upper Bay in late November and mid-June. The index did not show any significant variation between sites. However, clams collected in June were judged to be in poorer condition than those collected in November.

The November populations may reflect the good fall growing conditions reported by others, while June populations may show a combination of winter and spawning stress.

Natural History

A summary of data on the life history and environmental requirements of the hard clam is provided in Stanley (1985). The effect of some key variables are reviewed here, making use whenever possible of research which was carried out in Narragansett Bay.

Effect of Temperature—The hard clam is adapted to temperate waters, and many of its physiological functions have maxima between 25 and 30°C and decrease below 20°C.

The research of Savage (1974-1976) on Narragansett Bay clams showed that in the summer it took 10-20 minutes to burrow into the bottom after being left on the surface, while at 10°C it took an hour. This means that between mid-November and early May, clams left on the surface by rakes or transplantation would be subject to attack by predators. Savage also showed that the decrease in metabolism at low temperatures decreased the effects of low oxygen concentration.

Davis (1969) measured highest rates of larval development at 25-30°C. In the Bay, some larvae are released at temperatures as low as 13°C (Landers 1954) Peak densities of larvae in July would be exposed to temperatures between 20 and 23°C (Hicks 1959). Davis and Calabrese (1964) found no growth in the laboratory below 12.5°C. In the Bay, Pratt and Campbell (1956) found growth rates to be very variable at a given temperature, but that no shell growth took place below 10°C. The absence of growth below 10°C leaves a break on the shell which can be used for aging unless obscured by other breaks. At low temperatures, clams are not active enough to clear themselves of pathogenic microorganisms.

Growth Rate—Pratt and Campbell (1956) found the following mean annual growth rates for different size hard clams in boxes placed in the Bay.

initial length (mm)	30	40	50	60	70
annual increment (mm)	12.5	10.5	8	6	4

In these experiments, up to a third of annual growth took place in the spring and early summer and very little after mid-September.

Growth rate in the Bay is lower than in warm water parts of the Cape and in southern states and higher than in areas north of Cape Cod (Ansell 1968). On good growing ground in the Bay, clams reach legal size in their third year.

Within the Bay, growth is effected by food supply. Pratt and Campbell (1956) found that clam growth was higher when small diatoms were abundant than when flagellates dominated the plankton. Attention was drawn to food value of different phytoplankton species during the 1950s when it was found that small *Nannochloris* growing in nitrogen-rich, duck-farm effluent in Long Island had little nutrient value. Bass (1983) determined that *N. atomus* passes through hard clams undigested. The summer phytoplankton of the Providence River was characterized by intense blooms of

Nannochloris in 1968-69 (Mitchell-Innes 1973). Pratt et al. (1987) suggested that the slow growth rate of hard clams which they observed in the Providence River could be due to food quality rather than to the direct effect of pollutants.

In 1985, there was a mid-Bay bloom of a very small "brown tide" algae. In high densities this organism causes the shutdown of bivalve feeding activities. During the bloom, large numbers of blue mussels died when they could not satisfy their metabolic demands (Tracey et al. 1988). The slow metabolism of hard clams appeared to reduce the effects of the bloom. No mortality or significant decrease in condition was observed in monitoring by the Division of Fish and Wildlife during the bloom (R. Sisson, personal communication).

A large amount of research has been carried out on the food value of phytoplankton to bivalve larvae (a recent review is provided by Webb and Chu 1982). Much less is known about the role of algal species makeup and density on growth of post-larvae.

In very turbid estuaries and where dredging is taking place, there is often concern as to the effect of suspended sediment on bivalves. Bricelj et al. (1984) found that seed clam growth was not affected by the presence of as much as 25 mg/l suspended silt. Suspended loads were rarely more than 5 mg/l in the upper Bay water column (Bisagni 1975). Although levels directly over silty bottoms are not known, it is clear that suspended sediment is not an important problem in Narragansett Bay.

Reproductive Cycle—Diamond (1981) examined gametogenic cycles in clams from the upper and lower Bay in monthly collections over a year. She found evidence of peak egg release in May and September at Sabin Point and in June and September at Dutch Island Harbor.

Landers (1954) followed larval density in weekly samples from Wickford Harbor and Greenwich Bay over two summers. He found that larval release usually began in May, peaked in July, and lasted until August-October. Only about one-tenth of early larvae survived to the pre-settlement stage. The density of mature larvae varied from 16/l-0.3/l depending on season and location. Two peaks of abundance were found in one year but not the other.

The observed variability of hard clam larval supply will complicate any surveys to determine sources and transport. Samples will have to be taken at close intervals in space and time to be able to follow the development of a single population of larvae. The extended period of supply explains to some extent the large variation in sizes of first year clams found in field samples.

Effect of Substrate—Pratt (1953) compared the abundance of hard clams and widgeon clam or ducks feet (*Pitar morrhuana*) in different sediment types from a dredge survey of the Bay. He found that hard clams were most abundant in fine sediments which had shell and rocks as minor constituents. *Pitar* were most abundant in fine sediment which had the smallest number of hard clams. The partitioning of the Bay into hard clam and *Pitar* habitat has been observed in other studies. Seavey and Pratt (1979) conclude that dredging in the Quonset/Davisville area has created conditions favoring *Pitar*.

Pratt (1953) postulated that sediments containing shell and rock induce planktonic larvae to set and also afford spat protection from predators. Wells (1957) confirmed the positive effect of shell on clam abundance in coastal Virginia.

Sediment type also appears to effect growth rate. Pratt (1957) found a 24% increase in growth in sand versus sandy silt in experimental boxes. Additional experiments carried out throughout the Bay (Pratt and Campbell 1956) corroborated this finding. They list as possible reasons: (1) inability to pump water when the burrow is covered by impermeable sediment, (2) presence of injurious chemicals, and (3) interruption of feeding to expel fine material taken in with bottom water.

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