Proceedings of the Third Rhode Island Shellfisheries Conference

Narragansett, Rhode Island

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Proceedings of the
Third Rhode Island Shellfish Industry Conference

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Held at the
University of Rhode Island Bay Campus
Narragansett, Rhode Island
August 18, 1994

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and
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Foreword

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This third Rhode Island Shellfish Industry Conference—now a biannual event—follows up on the conferences held in August of 1990 and 1992. These previous conferences focused on topics of the greatest concern to the shellfishing industry, particularly water quality issues and the management of shellfish stocks in areas of Rhode Island's coastal waters that are certified for shellfishing. There are three main topics of this conference: the current status of quahog stocks in key fishing areas in Narragansett Bay; the economic and marketing trends for quahogs; and the pitfalls and opportunities of aquaculture as a means of maintaining our state's share of shellfish markets.

The crisis in Rhode Island's shellfisheries that was evident in the early 1990s has only deepened. There is evidence that fewer than half of the full-time professional quahoggers that worked the Bay in the 1980s are still in business. The total catch from Narragansett Bay has dropped substantially, and market prices for quahogs have remained at their lowest levels since the 1970s. Although catch per fisherman is not particularly poor, the shellfishermen that choose to remain in the fishery are working longer hours for considerably less pay. As with the previous conferences, our aim is to provide information for fishermen who must make tough decisions about their own economic well-being, as well as to provide information germane to the management of these very important publicly held shellfish resources.

As part of this conference, two studies will be presented that are direct results of suggestions made at the 1992 shellfish industry conference. Najih Lazar, Arthur Ganz, and April Valliere of the Rhode Island Department of Environmental Management present the results of their 1993 summer study of standing crop quahog populations in Greenwich Bay. Also, Joseph Goncalo and I present our data on the bivalve larval abundances in Greenwich Bay during that same summer. Greenwich Bay recently resumed its status as a prime fishing area once nagging pollution closure problems were resolved. Hopefully, resources can be made available so that studies of this type can be expanded to larger areas of Narragansett Bay.

This volume presents the papers and discussions that took place at the third Rhode Island Shellfish Industry Conference, held at the University of Rhode Island's Narragansett Bay Campus on August 18, 1994. This conference is successful only because of the input and support of the steering committee and institutional sponsors. I wish to thank the steering committee—Gerald Carvalho, Arthur Ganz, Neal Perry, and Robert Rheault—for their suggestions of topics and speakers. I also wish to thank our institutional cosponsors—the Rhode Island Shellfishermen's Association, the Rhode Island Shellfish Divers Association, Ocean State Aquaculture Association, Rhode Island Sea Grant, and Rhode Island Cooperative Extension—for their full support of this conference.

Industry Welcome

Edward Agin, President
Rhode Island Shellfishermen's Association
169 Wampanoag Road
Warwick, RI 02818

Good morning, ladies and gentlemen. Thank you for the opportunity to speak this morning. Before we get into the problems of the shellfishing industry, I would like to briefly describe the association that I am currently presiding over. We have been around since 1978. There have been a number of industry organizations that have formed for a single purpose, and have ceased functioning. We have been plodding along for 16 years now, and I believe that we have accomplished a great many things. We have been called a "one-issue association" at times, but we have a recent 10-page report that outlines many of our accomplishments. I invite all who are interested to see me so that I can provide them with a copy. We try to promote shellfish from Narragansett Bay to anyone who will listen. We go to festivals throughout Rhode Island, we have given talks to children in their classrooms, we have taken people out onto Narragansett Bay, we've held social functions, and we have been active in the political process. Additionally, we have been active in the Greenwich Bay bond issue and cleanup program. We feel that we had a major role in the passing of the $13.5 million Greenwich Bay bond issue. We were also active in the *World Prodigy* oil spill issue. We have been a part of a great many good things on the Bay, and I see our role as good stewards of the Bay, or working environmentalists.

The problems we have on the Bay are numerous. We have a diminishing shellfish capacity on the Bay, and our dollar value is sinking down to nothing. Right now, I believe the main thrust of this conference will be aquaculture. More than ever before, there is now a tremendous opportunity to get money from the federal government in the form of the various aquaculture bills, and fisheries disaster relief. These funds can be used wisely by incorporating the scientific knowledge that many of the aquaculturists have, along with potential money for transplants to utilize our vast shellfish resources in uncertified waters. Funding for transplants creates "instant money." I do not know of any other shellfish program where a 10 cent investment will create over $2 in harvestable product. We recently had a transplant opening on Greenwich Bay with a goal of 1 million pounds. Working two hours a day for seven days, nearly 750,000 pounds were moved. The value of this product was somewhere between $3 million and $4 million. This is not a bad return. We have the opportunity now to do our aquaculture and do our transplants. If things are worked out properly, amicable solutions can be proposed to accommodate everybody. I believe that the next three or four years will be a very exciting time for the industry, if the opportunity is there and we take it.

Overview of Rhode Island Marine Outreach Programs

Robert H. Miller, Dean
College of Resource Development
University of Rhode Island;
Director, Rhode Island Cooperative Extension
Kingston, RI 02881

This conference—with participation from the industry and state and federal agencies—exemplifies a typical audience for outreach education at the University of Rhode Island (URI). My role today is to spend a short time telling you about the nature, value, and philosophy of the programs and the people involved in outreach education. I want to impress on you our sincere desire to be of assistance to you to provide information and help. We sincerely believe that we don't fit the negative connotation of the expression, "We're from the government, and we're here to help," even though a considerable portion of our funding for outreach activities is received from the federal government.

The mandate for marine outreach programs at URI has two origins. The first of these goes back to the Morrill Act of 1862, which created the Land Grant universities. URI is Rhode Island's Land Grant university, and has been since its origin in 1892. Land Grant colleges were designed to educate the families of the working class, while addressing research needs for the agricultural and industrial sector of an expanding, dynamic country. The outreach programs of the Land Grant universitie, such as URI, began early, but became official when the Cooperative Extension was established by the Smith-Lever Act in 1914. Cooperative Extension has remained active in Rhode Island and continues today. However, it no longer serves only farmers and homemakers, but a much broader group of Rhode Island citizens. Some of our marine outreach programs are funded in part by federal Cooperative Extension funds, and we are proud of these outreach activities, and we hope you are as well.

In my generation, another program has came into being: the Sea Grant program. In 1969, URI was named a Sea Grant university, one of the original group of universities with this designation. The Sea Grant program has its own outreach program called the Marine Advisory Service. In some states, the Marine Advisory Service is under the same administration as Cooperative Extension. In Rhode Island, the two programs are administered separately, but have developed a very close working relationship. Federal and state funds from both Cooperative Extension and Marine Advisory pay for salaries and program support, in an atmosphere of cooperation with a single mission. That mission is to provide the most effective marine programs based on the assessed needs of our clientele. You in this audience are part of that clientele.

How does marine outreach education occur at URI through Marine Advisory and Cooperative Extension? As mentioned earlier, we have an obligation to assess the need for a program. We work most effectively when there is an audience in need of information that we have the expertise to provide. Information is most commonly provided through workshops, demonstration projects, fact sheets, and one-to-one contacts. It is the responsibility of outreach personnel to be cognizant of the educational need

and make a decision on how to best deliver the information. The best way to deliver information depends on the nature of the clientele, the nature of the information, and the nature of the need. This workshop is an example of an outreach education effort put on by Marine Advisory and Extension personnel. We will let each of you evaluate how effective we have been.

One feature of the marine outreach programs is that they are based upon research findings. Often this research is carried out right here at the university, often by the very same personnel that conduct the outreach program. Often, the ideas for research projects come directly from the clientele we serve. Other times, information comes from wherever it is available. Modern computer linkages, such as Internet, make information transfer rapid and responsive to need, regardless of its source. We cooperate and share information with all of the other Land Grant and Sea Grant institutions in New England and the Northeast.

A final feature of URI's outreach program is that programming is almost always done cooperatively. For example, our very successful Fishing Vessel Safety program is cooperative with the U.S. Coast Guard; fishing gear design programs in cooperation with the National Marine Fisheries Service; harbormaster training with individual towns and cities; seafood safety education in conjunction with the Rhode Island Seafood Council; shellfish and finfish restoration cooperatively with the Department of Environmental Management (DEM); aquaculture initiatives with industry representation (e.g., the Ocean State Aquaculture Association) and DEM; water quality and environmental education with town councils, DEM, the Coastal Resources Management Council, citizen groups, etc. A glance at the list of speakers and responders at this conference is illustrative of the active cooperation of a multitude of public and private agencies and organizations. We're proud of this cooperation, and it is important that we continue, and seek out all stakeholders on an issue.

Before I relinquish the podium this morning, I want to address one last feature of URI's marine outreach programs. In all of the programs mentioned, there is the potential for differing opinions and for conflict. We know we address a diverse audience, but we must always recognize that we serve clientele with different needs and different perspectives on topics. Because we value the breadth of our audience, we must be diligent in how we participate in policy decisions and public-issues education. We strive to be as bias-free as possible. We feel that we can best serve policymakers and the general public by a strong commitment to objectivity. This is not an easy task, nor is our approach always free of controversy. However, we must not disengage and be "shrinking violets" with respect to issues. When controversies are raging is often the time when objective information is most desperately needed. There is a greater potential for progress and mutual respect when we actively work to resolve conflicts.

Finally, in my role as director of Cooperative Extension at URI, I would be very interested in any comments you may have. On behalf of all of the dedicated marine outreach personnel at URI, I wish to express the desire and hope that we are keeping the needs of all the people of Rhode Island first and foremost in our minds. Thank you.

Quahog Stock Assessment and Implementation of an Interim Management Plan in Greenwich Bay, Rhode Island

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Abstract ■ *The quahog fishery of Rhode Island was identified as a priority for development of a species-specific management plan by the Narragansett Bay Project's Comprehensive Conservation Management Plan in 1992. The Division of Fish, Wildlife, and Estuarine Resources (DFWER) received funding to conduct a population assessment in Greenwich Bay as the first step in the development of a bay-wide management plan. The objectives of this study were: 1) to equip a vessel suitable for sampling quahog populations in Narragansett Bay; 2) to develop procedures, techniques, and competencies in estimating population structure and density of quahogs in Greenwich Bay, to be used as a prototype that will be expandable and applicable to the entirety of Narragansett Bay; 3) to determine the current status of fishing pressure in the bay, using catch and effort information supplied by quahoggers through field intercepts; and 4) to develop recommendations for management of the shellfishery in Greenwich Bay when the area is recertified for harvesting. A dredge efficiency study was conducted during this study, and dredge catch ability was calculated to be about 0.67. The mean density of quahogs in Greenwich Bay was estimated to be 5.4 individuals per square meter (SD = 0.422), with predominance of small necks. The total biomass for the entire area was about 10 ± 2.4 million pounds. This represents nearly 75 percent of the average yearly landings (1988 to 1992). However, about 59 percent of this biomass lies behind pollution lines in the coves of Greenwich Bay. The estimated maximum sustainable yield (MSY) is a little over 1 million pounds per year, for natural mortality (M) = 0.2. An interim management plan was established for Greenwich Bay using the results of this study and consisted of the harvest of the quota (1,003,300 pounds) in two periods: 75 percent of the quota for the summer and 25 percent for the winter. Any unused portion of the annual quota is to be carried over to the next year's quota.*

Introduction

Throughout history, Greenwich Bay has been the center of shellfishing within Narragansett Bay, Rhode Island. It is a sheltered estuary fed by four major tributaries—Greenwich, Apponaug, Brush Neck and Warwick Coves—and many small brooks. The bay is an ideal shellfishing ground for many reasons. It is shallow and protected from inclement winds, allowing for easy harvesting. Nutrients, water circulation, and substrate composition are favorable for growth and survival of shellfish. Greenwich Bay encompasses 3,200 acres. The major coves, Greenwich, Warwick, Brush Neck, and Apponaug, cover 750 acres. These coves are widely believed to support the brood stock responsible for Greenwich Bay's quahog (*Mercenaria mercenaria*) population.

Greenwich Bay has supported a substantial commercial and recreational shellfishery, with harvesters targeting quahogs, soft-shell clams, and occasionally, scallops. By 1981, overfishing in Greenwich Bay had resulted in deterioration of the fishery. The area was restored through the combined efforts of the Rhode Island Department of Environmental Management's (DEM) Division of Fish and Wildlife, the R.I. Marine Fisheries Council, and commercial shellfishermen. Greenwich Bay

was declared a shellfish management area, closed to shellfish harvesting for two years, and restocked using uncertified shellfish transplanted from Greenwich Cove. When the shellfishery was reopened during the winter of 1982–83, daily catch limits were reduced, and fishing time was limited. The combined effect of annual transplant restocking and reduced fishing effort s successfully restored the fishery until 1992. Between 1983 and 1991, the annual harvest approached 1 million pounds shell weight annually.

Conflicting uses of Greenwich Bay have challenged its vitality. Shoreside development and pleasure boat facilities have gradually increased bacterial concentrations and the nutrient load in the bay. During December 1992, just prior to its annual opening, heavy precipitation coincided with state water quality determinations that caused a temporary ban on shellfish harvesting from Greenwich Bay. Unexpectedly, continued water quality monitoring showed that the bay failed to recover to a level consistent with a National Shellfish Sanitation Program–approved status, and the area remained closed for a year and a half. During the spring and summer of 1993, a water quality study was carried out by the U.S. Food and Drug Administration(FDA) in cooperation with the DEM divisions of Water Resources and Fish, Wildlife, and Estuarine Resources (Anon., 1993). This study concluded that Greenwich Bay becomes contaminated within a 24-hour period following rain events exceeding 0.5 inches. The data also indicated that during "dry" weather, the water quality in Greenwich Bay is acceptable for shellfish harvesting, and that bay water quality improves rapidly (within three to four days) following a rainfall event. The minimum total closure time following a single rainfall event should be six days; including four days for the effects of the event to pass, and an additional two days for shellfish to eliminate contaminants.

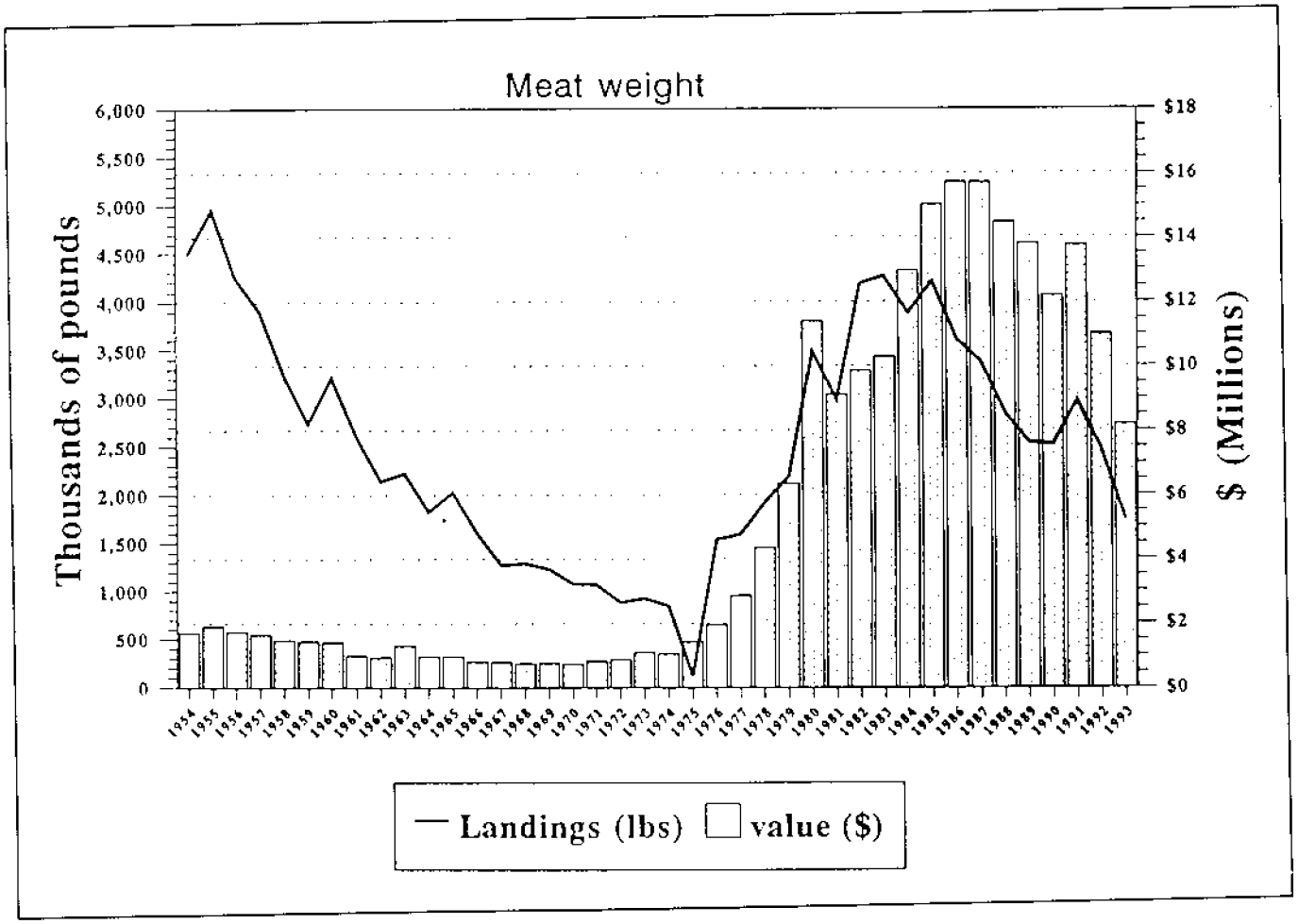


Figure 1. Rhode Island commercial harvest of bay quahogs (*Mercenaria mercenaria*).

Commercial Landings

The quahog is a resource of major economic importance in Rhode Island. This fishery, the largest inshore fishery within the state, has provided a livelihood for thousands of commercial shellfishermen until recent years. Figure 1 shows the declining trend in the commercial harvest of this species. In 1993, 1.7 million pounds of quahogs (meat weight), with an ex-vessel value of $8.2 million, were harvested in Rhode Island waters—a decline of 30 percent from 1992. Habitat degradation and pollution have resulted in the increase of uncertified waters throughout the bay. The impact of the loss of grounds available for harvesting has been compounded by excessive fishing pressure on the remaining certified areas, with the result that fewer people are able to sustain a living in this fishery.

Shellfish landings, by month, for 1993 are presented in Figure 2. As expected, landings peak between May and September, when the animals are closer to the surface and mild weather conditions afford easier harvesting. Monthly catch rates vary from 80,000 pounds during the winter to a little over 250,000 pounds in August.

Figure 3 shows the correlation between catch and effort. The data define a classic example of overexploitation, with a rapid increase in effort followed by a decline in the catch per unit of effort.

Quahog Management Plan

The development of a quahog management plan (QMP) started in March 1993, and is an ongoing project for three years. The QMP is divided into two phases, with each phase divided into two sections. One is a fishery-dependent study that deals with commercial landings and characterization of the fishery through dock interviews and sea-sampling data. The second section deals with all fisheries-independent studies. This includes rigging a research vessel for dredge surveys and

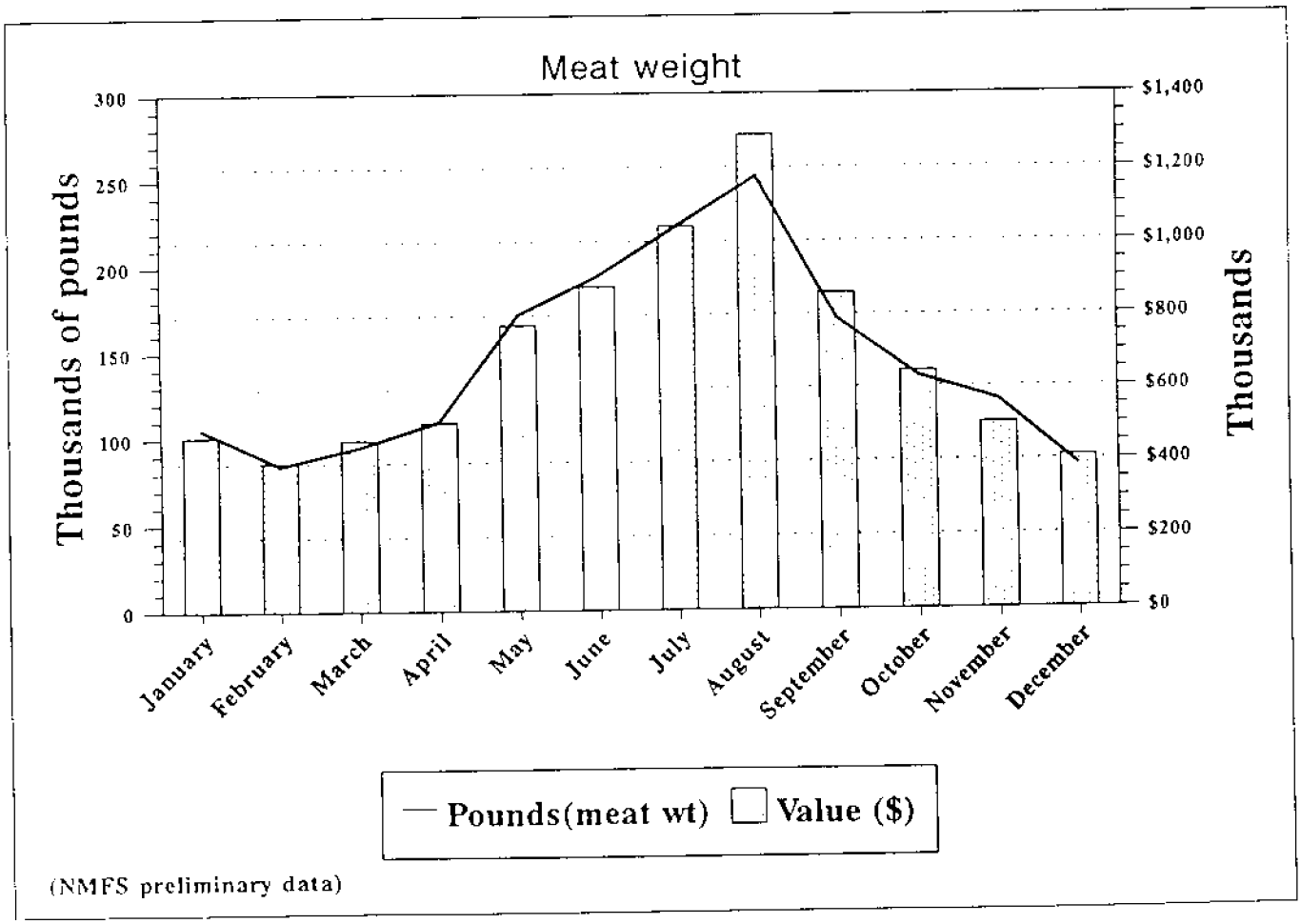


Figure 2. Rhode Island quahog harvest by month for 1993

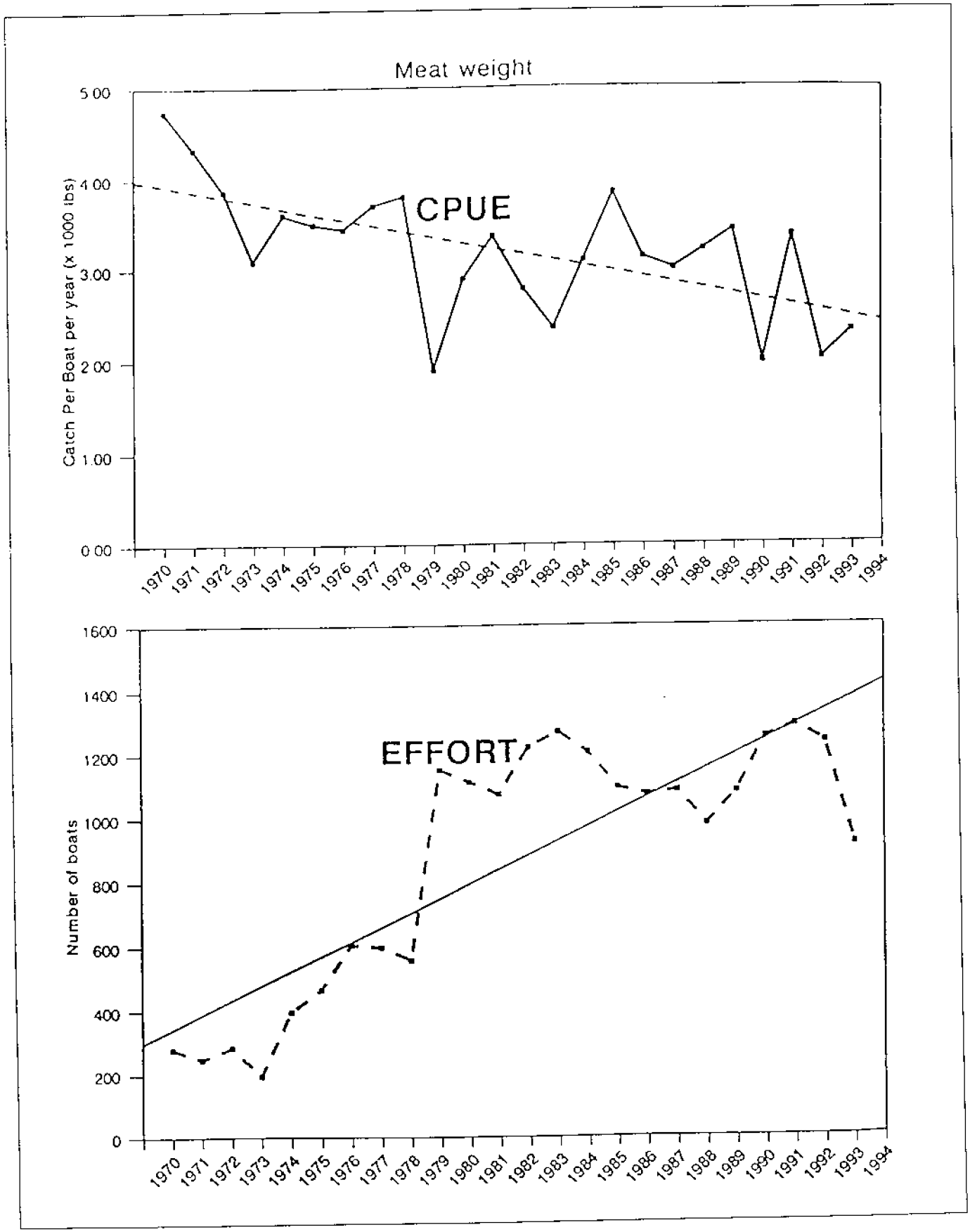


Figure 3. Catch per unit effort (CPUE) and total effort for 1970 to 1994.

related research, and conducting an initial survey of Greenwich Bay (Phase I) to be expanded as a prototype for the rest of Narragansett Bay (Phase II).

At the end of this project, the Division of Fish, Wildlife, and Estuarine Resources, along with the industry, will develop a comprehensive management plan for the quahog fishery in Narragansett Bay.

Dredge Surveys

Great effort has been expended by several researchers to estimate the size distribution of the quahog population in the bay (Stringer, 1959; Saila et al., 1967; Russell, 1972; Sisson, 1977; Pratt et al., 1988; Pratt, 1992; Rice et al., 1989). During the first phase of the Narragansett Bay Project (1985–1990), a series of studies was undertaken on quahog abundance in areas both closed and open to shellfish harvesting.

The first Narragansett Bay–wide mapping of quahog distribution was based on a 1956 to 1957 dredge survey undertaken in response to a proposal for mid-Narragansett Bay hurricane barriers. The map generated from this survey showed three density classes of quahogs (zero, one to two, and over two quahogs per square foot). More extensive surveys have not been done due to lack of personnel and funding, difficulty in resolving problems of spatial heterogeneity, and the constant changes resulting from quahog harvesting.

Since the 1940s, surveys and population studies have been carried out in subareas of Narragansett Bay in response to increased pollution levels and fisheries management issues. Between 1949 and 1950, a dredge survey of Narragansett Bay (123 stations) was done to determine the distribution patterns of quahogs in relation to sediment type (Pratt, 1953), but the data were not mapped.

Quahog population studies were conducted in Greenwich Bay from 1951 to 1957 by the U.S. Fish and Wildlife Service, using a vessel equipped with a construction bucket that took samples of 0.46 square meters (m^2) throughout the bay. Shallow areas inaccessible by boat were sampled with tongs, and the quahog distribution was mapped (Stickney and Stringer, 1957). Density was low on muddy-bottom areas in the center of the bay. High densities were recorded at the mouth of Greenwich Bay, off Mary's Creek, and at the mouth of Greenwich Bay Cove. Rice et al. (1989) provided estimates of quahog densities at the mouth of Greenwich Cove, averaging 190 per m^2 in closed areas and 78 per m^2 in fished areas.

Quantitative surveys of quahogs have been carried out on three occasions, using the same sampling devices (grab and tong)—Providence River and Mount Hope Bay were surveyed in 1956 by Stringer (1959); Providence River was surveyed in 1957 (Stringer, 1959) and in 1965 (Canario and Kovach, 1965a; Saila et al., 1967). In each survey, stations were located on a 274-meter grid: 120 stations in the Providence River, from 700 meters north of Sabin Point to Conimicut Point, and 188 in the Rhode Island portion of Mount Hope Bay. At each station, a single 0.46 m^2 sample was taken with a construction bucket. In the Providence River, shallow stations were sampled with tongs.

A study carried out by the Rhode Island Department of Natural Resources (Russell, 1972) showed that the use of a commercial dredge provided a valid estimate of the population of quahogs because of the nonrandom distribution pattern of this species in Narragansett Bay. It has been demonstrated by Saila et al. (1967) that quahogs occur naturally in a superdispersed or contagious spatial arrangement described by the negative binomial distribution. However, their data indicated that samples collected with the rocking-chair dredge, instead of the grab sampler, exhibit normality. This suggests that aggregate populations of quahogs are relatively small-scale, and that the dredge acts as an integrating device (Russell, 1972). In a study of distribution and population estimation of several species of bivalves, including *M. mercenaria*, Saila and Gaucher (1966) took an approach for refining population density estimates based on negative binomial frequency distribution. Approximate normality was achieved by an inverse hyperbolic sine transformation of the data, supporting estimations of abundance with relatively narrow confidence limits. Stratification of the sample by depth contours increased the precision of the estimates.

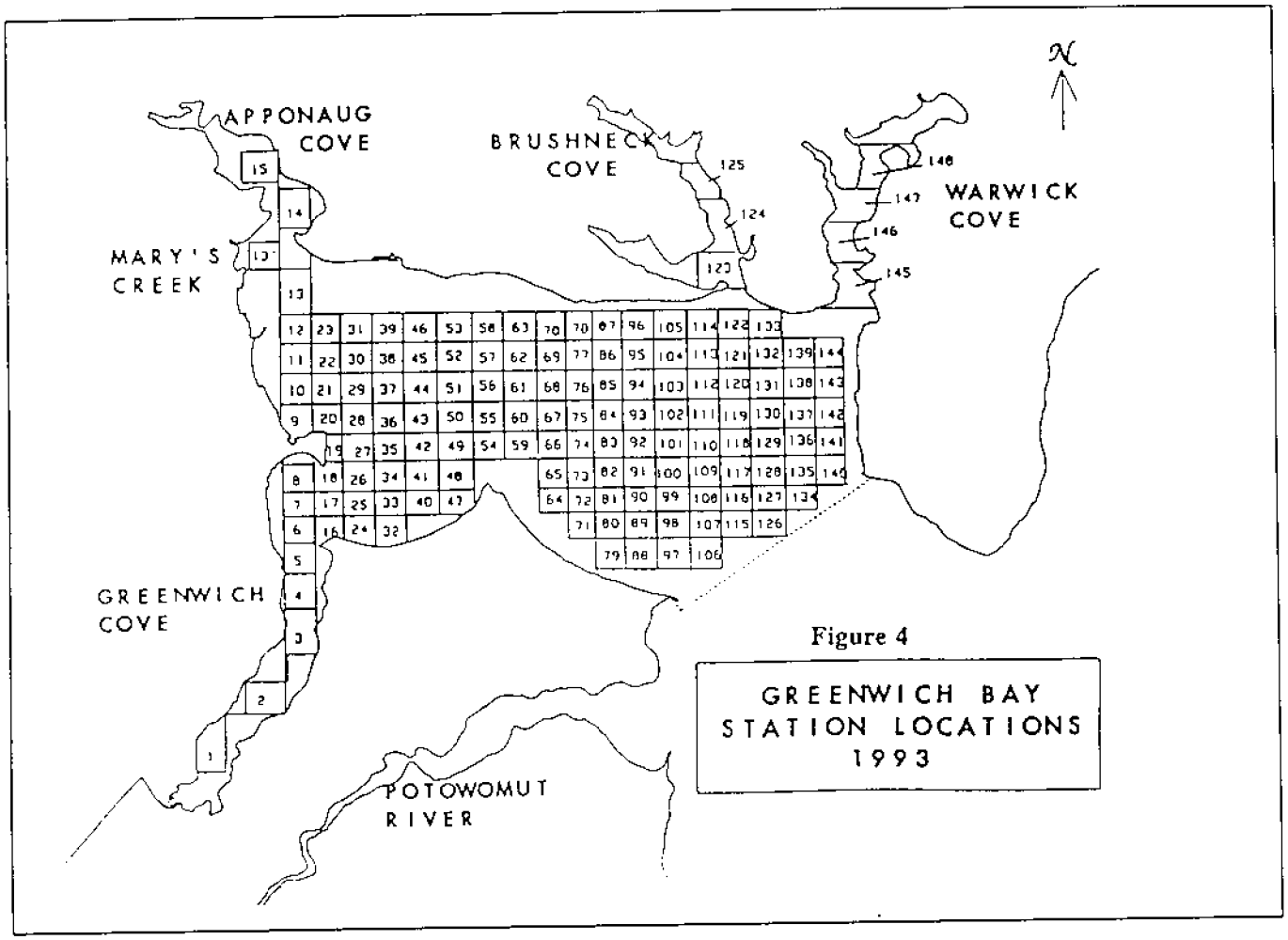


Figure 4. Greenwich Bay station locations in 1993 study.

Several other surveys have been conducted by DEM personnel in various other portions of the Bay, including the East Passage (Canario and Kovach, 1965) and the West Passage (Gray, 1969; Russell, 1972). The entire Quonset-Davisville area was surveyed in 1976 (Ganz and Sisson, 1977). Shellfish were sampled intertidally—in shallow water by bullrake, and in deep water by dredge. This report addresses yet another type of survey to quantify the biomass density of the quahog resource in Greenwich Bay, as well as catch and effort data for Narragansett Bay.

Materials and Methods

Field Sampling

The sampling technique adopted for the Greenwich Bay prototype study is a two-dimensional systematic technique that mixes the simple random and stratified random sampling procedures. This method was carried out by dividing Greenwich Bay into a grid of 250-by-250-m quadrats. Within each quadrat, two replicate samples were taken with the hydraulic dredge. Station locations within each quadrat were chosen randomly, preferably at the center of the quadrat. The grid map consisted of 149 quadrats (Figure 4), from which 143 were sampled. Dredging on the remaining six stations was not possible due to excessive depth.

Sampling was done by the staff using the *R/V Clambo*, a 20-foot skiff, from May 25 to September 30, 1993. Sampling locations were determined by the Global Positioning System (GPS), a hand-held compass, and landmarks. After the position was established, two 100-foot tows were made at each quadrat using a hydraulic dredge with 1-inch-square wire mesh and a cutting blade depth of 3.25 inches. Tows were made into the prevailing current or downwind. A 100-foot line attached to buoys was first set out within each quadrat to measure the distance of the tow. At the end of the measured tow,

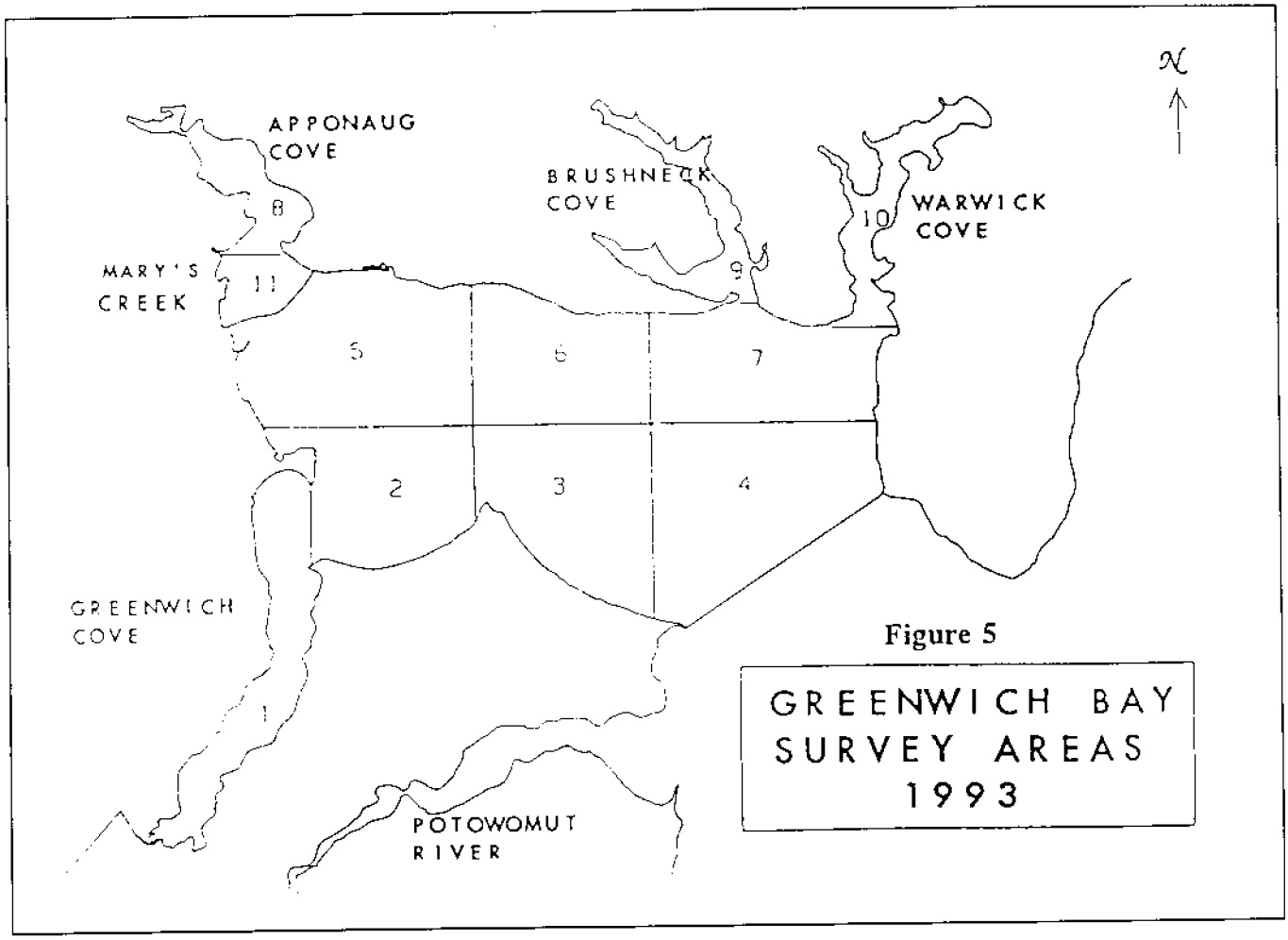


Figure 5. Greenwich Bay survey areas in 1993 study.

the vessel was held as stationary as possible while hauling back the dredge, to prevent sampling in other than the desired area. On deck, the catch was washed and sorted by species. Quahogs were measured widthwise to the nearest millimeter (mm) in order to construct a frequency distribution at each station. For larger catches (more than 150 clams), a subsample (a minimum of 100 animals) was taken and measured. Empty paired shells of quahogs were counted to determine natural mortality, and bycatch was noted on the data sheets.

Evaluation of Dredge Efficiency

Evaluation of efficiency of the hydraulic dredge was a necessary preliminary step. Dredge efficiency was calculated in terms of percentage of clams removed from the area fished by the dredge. Two consecutive 100-foot tows were conducted with both *R/V Clambo* and *R/V Inspector Clambeaux* on different bottom types and depths. At the end of each tow, staff members equipped with scuba collected all clams left in the path of the dredge, down to a depth of about 15 centimeters (cm). Dredge tows were taken as consistently as possible to reduce variability in efficiency estimates. Distinctions in bottom types (hard, shelly, soft mud, etc.) were recorded. Mean catch efficiencies of the dredge were then compared among bottom types and vessels. Previous studies indicated that the dredge took consistent replicate samples when operated in relatively uniform substrates (Saila et al., 1965).

Quahog Population Characteristics

Quahog samples were taken at random from different strata (Figure 5) after the dredge tow, bagged, and brought back to the laboratory on the day collected, for further measurements. This made it possible to conduct a series of observations on the clams, including morphometric measurements on the shell (length, width, and height), total weight,

shell weight and meat (shucked) weight. Sex was determinedby microscopic examination of the gonad.

A total of 1,626 clams were measured and weighed; 329 of these clams were shucked to weigh the meat and determine the sex. Length-weight parameters were calculated using a non-linear procedure using Statistical Analysis Software (SAS), in the following functional relationship:

$$\text{Weight} = \alpha * \text{Width}^{\beta}$$

where α and β are the allometric model parameters.

Several conversion relationships were calculated to characterize the total shell weight-meat weight and the length-width-height relationships for different areas in Greenwich Bay. Data for meat weight and total shell weight were fitted to a linear simple regression. Length, height, and width were characterized by a second-degree polynomial.

Quahog Population Estimates

Plots of hard clam abundance and contour maps of abundance were prepared using several commercially available software packages. A base map of the shoreline was drawn from the Rhode Island Geographical Information System (RIGIS) database, converted to Generic Cadd 6.0, and then saved as a file of pen plotter (HP 7475A) command. This file was later converted to a set of Cartesian coordinates using a program written in SAS. Station locations (latitude and longitude) were converted into Universal Time Metric (UTM) coordinates to match the shoreline contour of the map. These data were combined with the density estimates of quahogs and other species and output into an ASCII format to be used by SURFER (Golden Software Inc., 1991).

Preparation of contour maps in SURFER required a series of steps. The first step was to create a regularly spaced grid array from the original set of irregularly spaced station locations. The contours were established by means of an algorithm that provided abundance estimates within each 250-by-250-m grid cell, by means of inverse-distance without radical searching. The distance between grid nodes was chosen to match the survey's quadrat size.

The specific equation for the inverse-distance weighing procedure is:

$$Z_i = \frac{\sum_{i=1}^{n} Z_i / (d_i)^2}{\sum_{i=1}^{n} 1/(d_i)^2}$$

Where Z_i is a neighboring station,
d is distance between stations, and .
n is the number of Z stations

The value of each data point was weighted according to the inverse of its distance (d) from the grid node, taken to the *n*th power, as shown above. By raising the distance factor in the denominator to a power greater than one, the values of distant data points will exert less influence than nearby points on the value assigned to the grid node. A value of 2 for the exponent was used for this analysis.

In all cases of contour maps of biomass estimates, quahogs collected were graded into the following commercial size categories:

Sub-legals = under 25.4 mm
Small necks = between 26 mm and 34 mm
Top necks = between 35 mm and 39 mm
Cherries = between 40 mm and 43 mm
Chowders = greater than 43 mm

Dredge selectivity was not evaluated in this project, therefore all estimates are likely to be low, especially for sub-legals.

The next step, as described by Cerrato and Wallace (1989), was to modify the grid array in two ways: to smooth the array by applying a cubic spline; and to blank out those nodes lying outside the survey area. The purpose of splining is to produce smooth, less angular-appearing contours. The blanking file was created by the same procedure used for the base map.

Transect, or 'fish-net,' plots were then created from the contour plots using SURF procedure. This plot produced a 3-D diagram that demonstrates the magnitude of quahog abundance in the survey area.

It was evident from the contour plots that populations of *M. mercenaria* are contagiously distributed, and often described by a negative binomial

(variance greater than mean), lognormal, or gamma distribution. Population estimates of quahogs were calculated using a stratified random sampling technique. Strata were defined as areas of relatively uniform abundance of quahogs, taking into consideration regional stratification and the level of pollution in each area (Figure 5). The total area of each stratum was drawn from the FDA Greenwich Bay Study (1993), and then converted to m^2. The sampling unit was estimated in m^2.

The mean catch of quahogs per 100-foot dredge tow is:

$$\bar{Y}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} Y_{hi}$$

and the stratified mean catch per dredge tow, or the mean catch for all strata combined is:

$$\bar{Y}_{st} = \frac{1}{N} \sum_{h=1}^{L} N_h \bar{Y}_h$$

Where N_h = total area in stratum
n_h = total sampling area in stratum h
Y_{hi} = total number of quahogs caught in the dredge in the *i*th tow in stratum h
L = total number of strata (in this case L = 11)
N = total area of all strata (N1+N2+N3+....+N11)

The variance of the estimate of the stratified mean for a negligible sampling fraction in the stratum ($f_h = n_h/N_h$) is:

$$s^2(\bar{y}_{st}) = \frac{1}{N^2} \sum_{h=1}^{L} \frac{N^2_h \, s^2_h}{n_h}$$

where s^2_h is the sample variances from the individual strata, and an unbiased estimate of s^2_h will be:

$$s^2_h = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (Y_{hi} - \bar{y}_h)^2$$

If the f_h terms are significant sampling fractions in the stratum, then the variance of the stratified mean becomes:

$$S^2(\bar{y}_{st}) = \frac{1}{N^2} \sum_{h=1}^{L} N_h (N_h - n_h) \frac{S^2_h}{n_h}$$

with an alternative form of:

$$S^2(\bar{Y}_{st}) = \frac{1}{N^2} \left[\sum_{i=1}^{L} \frac{N_h^2 S_h^2}{n_h} - \sum_{i=1}^{L} \frac{N_h S_h^2}{N} \right]$$

where the second term represents the reduction due to the weight of the fraction f_h.

In order to compute this estimate, there must be at least two sample units drawn from each stratum. The confidence limits were calculated as follows:

Total population:

$$N\bar{y}_{st} \pm tNS(\bar{Y}_{st})$$

Population stratified mean:

$$\bar{Y}_{st} \pm tS(\bar{Y}_{st})$$

The value of t can be read from the tables of the normal distribution. If only a few degrees of freedom are provided by each stratum, the usual procedure to account for sampling error attached to a quantity like $S(y_{st})$ is to determine the t-value from the tables of Student's t instead of from the normal table (Cochran, 1977). The distribution of $S(y_{st})$ is, in general, too complex to allow a strict application of this method. An approximate method of assigning an effective number of degrees of freedom to $S(y_{st})$ is as follows (Satterthwaite, 1946 in Cochran, 1977):

$$n_e = \frac{(\sum g_h s_h^2)^2}{\sum \frac{g_h^2 s_h^4}{n_h - 1}}$$

The value of n_e always lies between the smallest of the values (n_h-1) and their sum. The value of g_h is expressed as follows:

$$g_h = \frac{N_h(N_h - n_h)}{n_h}$$

Results and Discussion

Dredge Efficiency

The efficiency of the dredge was determined by its ability to capture all animals within its swept area. This measure was difficult to estimate, due to the multitude of factors related to the gear, bottom type, depth, water conditions, and the spatial variability of quahogs. Results of the dredge-efficiency study showed no significant difference between the two research vessels when using similar dredges. The overall mean efficiency of the dredge was 67.5 percent for the two research vessels (*Clambo* and *Inspector Clambeaux*), ranging from 61.1 percent to 70.8 percent.

The objective in collecting replicate samples was to evaluate the consistency of the dredge as a sampling tool for quahog populations. Catch variance for each station was plotted as a function of densities, with 95 percent confidence limits (Figure 6). In areas with densities below five individuals per m^2, the dredge catch was quite consistent. However, when dredging in high-density areas, the difference between the first and the second tow was inconsistent, following no clear trend. Depth did not seem to influence the dredge sampling consistency, but diverse bottom types and boat maneuverability due to weather conditions could be significant factors in this discrepancy.

Morphometric Relationships

Width frequency distributions of quahogs in each of the 10 geographic strata showed an overall significant difference in means of the modes and their respective standard deviations (Table 1). Width frequency distribution graphs per geographic area are presented in Figure 7. These width frequency histograms were polymodal, with each peak or mode representing one or more cohorts, due to the fact that recruitment of quahogs is seasonal. Area 2, area 5, and area 11 seem to have fewer and younger

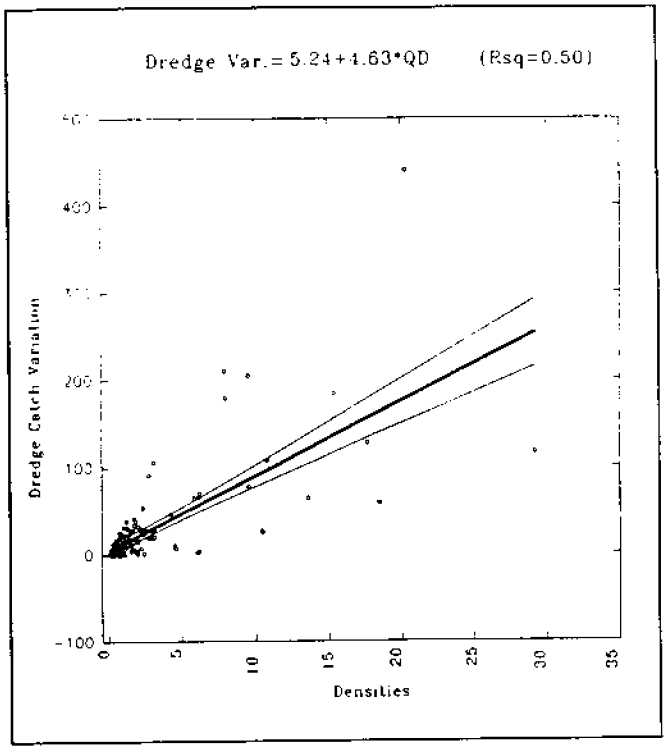


Figure 6. Catch variation of the dredge vs. quahog density (N/m^2).

cohorts with overall mean widths of 27.26 mm, 28.69 mm, and 26.36 mm, respectively. However, area 3, area 4, area 6, and area 7 have more age classes of quahogs, ranging from 20 mm to 66 mm, with respective mean widths of 35.35 mm, 38.71 mm, 39.91 mm, and 41.39 mm. The multimode size distribution in some areas suggests that there were periods of reduced larval recruitment. The reasons for this lowered recruitment and its subsequent recovery are unclear (Pratt et al., 1992).

In the portion of Greenwich Bay open to shellfishing before December 1992 (areas 2 to 7), harvesting pressure is probably the dominant factor in the discrepancy of population structure (Rice et al., 1989; Walker, 1989). This difference in size distribution could also be attributed to predation, since individuals are better able to resist the attack of crabs, starfish, and other predators as they become older. Thus, under natural conditions and in stable environments, quahog populations become dominated by large individuals (Pratt et al., 1992). A morphometric comparison between quahogs in areas open and closed to shellfishing in Greenwich Bay was calculated using the Kolmogorov-Smirnov two-sample test (Sokal and Rohlf, 1981). This test

Area	Mean Length (mm)	Standard Deviation
Greenwich Cove (area 1)	29.00	6.57
Goddard Park (area 2)	27.26	5.07
Bay Ridge (area 3)	35.35	7.91
Middle Ground (area 4)	38.71	8.69
Nausauket (area 5)	28.69	5.37
Buttonwoods (area 6)	39.91	8.12
Oakland Beach (area 7)	41.39	7.76
Apponaug Cove (area 8)	32.70	6.38
Brushneck Cove (area 9)	32.70	6.38
Warwick Cove (area 10)	32.44	5.16
Mary's Creek (area 11)	26.36	3.95

Table 1. Mean widths (mm) and their respective standard deviations of quahogs per geographic area sampled in Greenwich Bay survey of 1993.

revealed a significant difference between length and height distribution of quahogs in certified and closed waters. However, the difference between length and height distribution was more pronounced when width distribution was compared in the two areas with larger and mature quahogs in certified waters. Interpretation of these data suggests that quahogs in closed areas are "blunt," with more widthwise growth, while quahogs in certified areas are "sharps," which grow more lengthwise.

A variety of shell measurements was used in this study to characterize the morphometric differences of quahogs in closed and certified waters. These relationships are as follows:

Open waters

Length = 0.96 + 0.88 (Height) + 0.16 (Width)

Closed waters

Length = 0.27 + 0.95 (Height) + 0.19 (Width)

Shell width and total weight relationship were calculated to estimate potential biomass, in weight, available in certified and closed areas of Greenwich Bay (Figure 8). The total weight can be expressed by the following allometric equations:

Certified waters

Total weight = 0.007 x Shell width$^{2.69}$

Closed waters

Total weight = 0.003 x Shell width$^{2.87}$

Furthermore, a relationship between total weight and meat weight was calculated for the entire Greenwich Bay and can be formulated as follows:

Total weight = 6.53 x Meat weight

Abundance Estimates

Survey data were analyzed prior to plotting contour maps, in order to determine mean quahog densities per m^2, using the sampling theory outlined in the previous section. Contour maps with mean abundance as a single contour level were presented in three different maps for each of the four commercial categories and for sub-legal quahogs. From the contouring results, contiguous groups of two or more quadrats with abundances of 25 percent above the mean were considered high density, areas with abundances within 25 percent of the mean were considered medium density, and areas with abundances 25 percent below the mean were taken for low-density areas. Density distribution of quahogs, as classified above, is presented in Figure 9.

Three major areas with high densities were Greenwich Cove, Warwick Cove, and Mary's Creek, all of which are permanently closed to shellfish harvesting. Four other major areas in Greenwich Bay were classified as medium-density strata (Figure 9).

This type of stratification showed a significant gain in variation of the stratified means for high- and medium-density strata, however, there was a substantial loss in variation for the stratified means in areas with low densities. The percentage of the low-density area relative to the total area was too high, which was mainly responsible for high variability of the means. In addition, the irregularity and the shape of these strata would make it imprac-

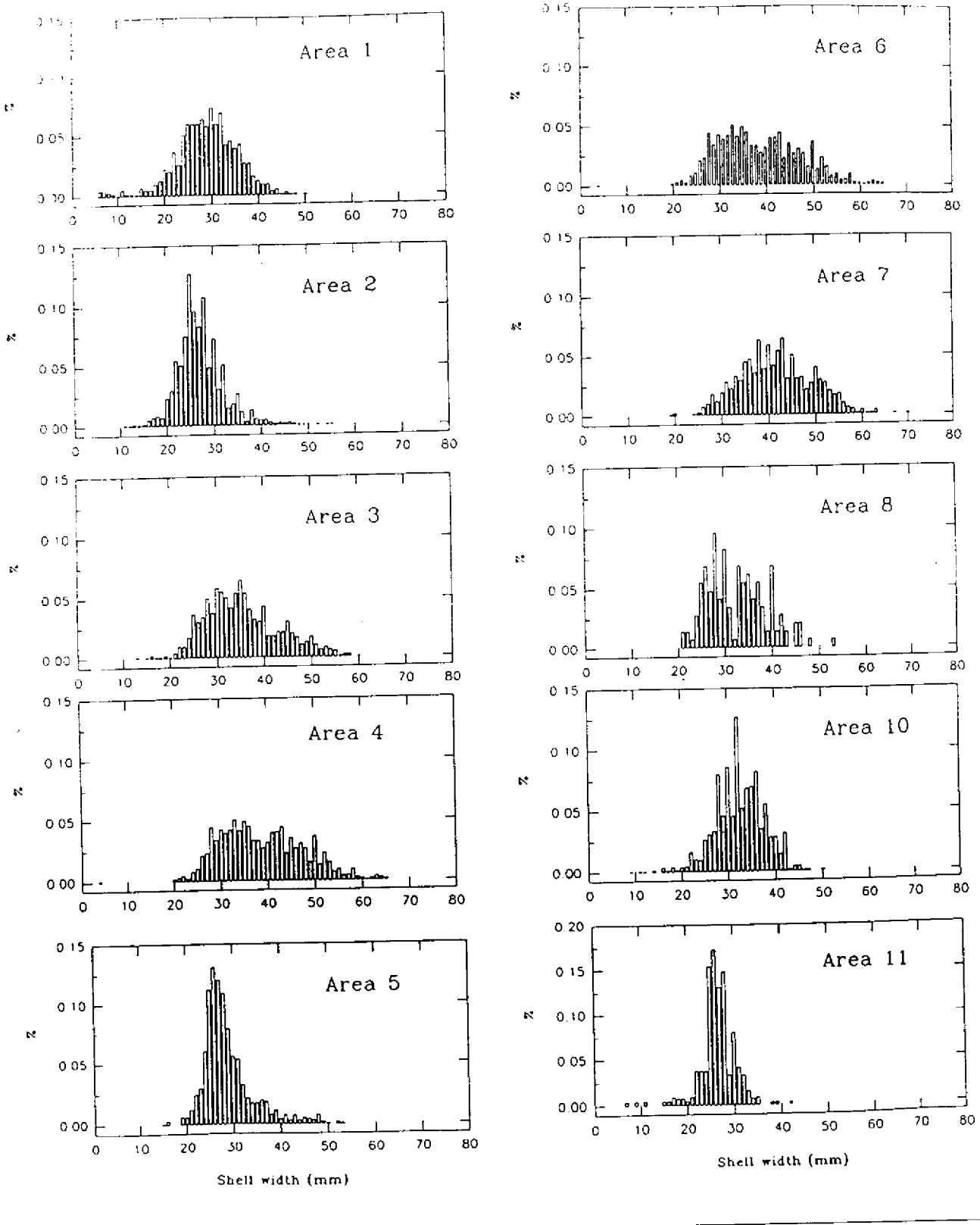


Figure 7. Shell-width frequency distribution of quahogs in Greenwich Bay areas (see map, page 11).

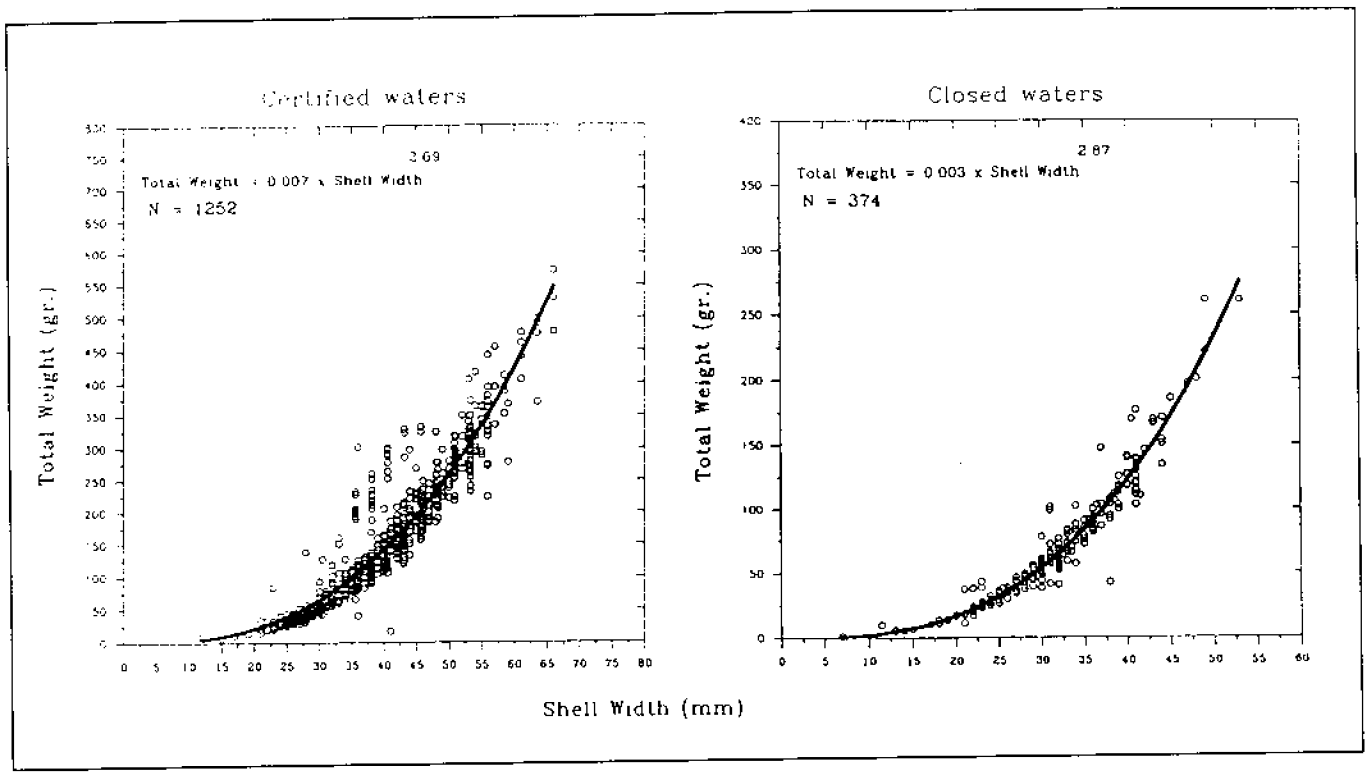


Figure 8. Relationship of shell width to total weight of quahogs in certified and closed waters of Greenwich Bay.

tical for conducting future surveys based on these contours. As a result, the geographic stratification based on sample mean abundance as the single contour level yielded low standard errors. This, coupled with the fact that sample mean abundance varies considerably with time (Cerrato and Wallace, 1989), led to adopting the geographic stratification outlined in Figure 5.

Sub-legals (under 25.4 mm)

Contour maps for sub-legal quahogs, and plots of mean number per tow are presented in Figure 10 and indicate a high distribution of pre-recruits (seed) in the west side of Greenwich Bay, with significant concentrations in Mary's Creek and the north end of Greenwich Cove.

Small necks (26–34 mm)

Small necks were the dominant commercial category in Greenwich Bay, ranging from 0.1 to 22.6 quahogs per m^2 and were distributed generally in all areas of Greenwich Bay. They were highly concentrated in four major areas: Warwick Cove, Mary's Creek, Greenwich Cove, and Middle Ground (Figure 11).

Top necks (35–39 mm)

The distribution of top necks was not as widespread as littlenecks in Greenwich Bay. Mean densities were between zero and 8.8 quahogs per m^2. The contour map and the transect density plot show four major areas of concentration for top necks: Warwick Cove, Greenwich Cove, Buttonwoods, and northwest of Middle Ground (Figure 12).

Cherries (40–43 mm)

The abundance of cherries was very low on the west side, but they were significantly present in much of the east side of Greenwich Bay. Mean densities were very inconsistent, ranging from zero to 5.6 quahogs per m^2. Abundance and distribution of cherries in Greenwich Bay are contoured in Figure 13. The highest concentrations are in Warwick Cove.

Chowders (over 43 mm)

The distribution of chowders in Greenwich Bay is mainly limited to the east side of the Bay. Chowders constitute the lowest portion of all commercial categories, with abundance ranging from zero to

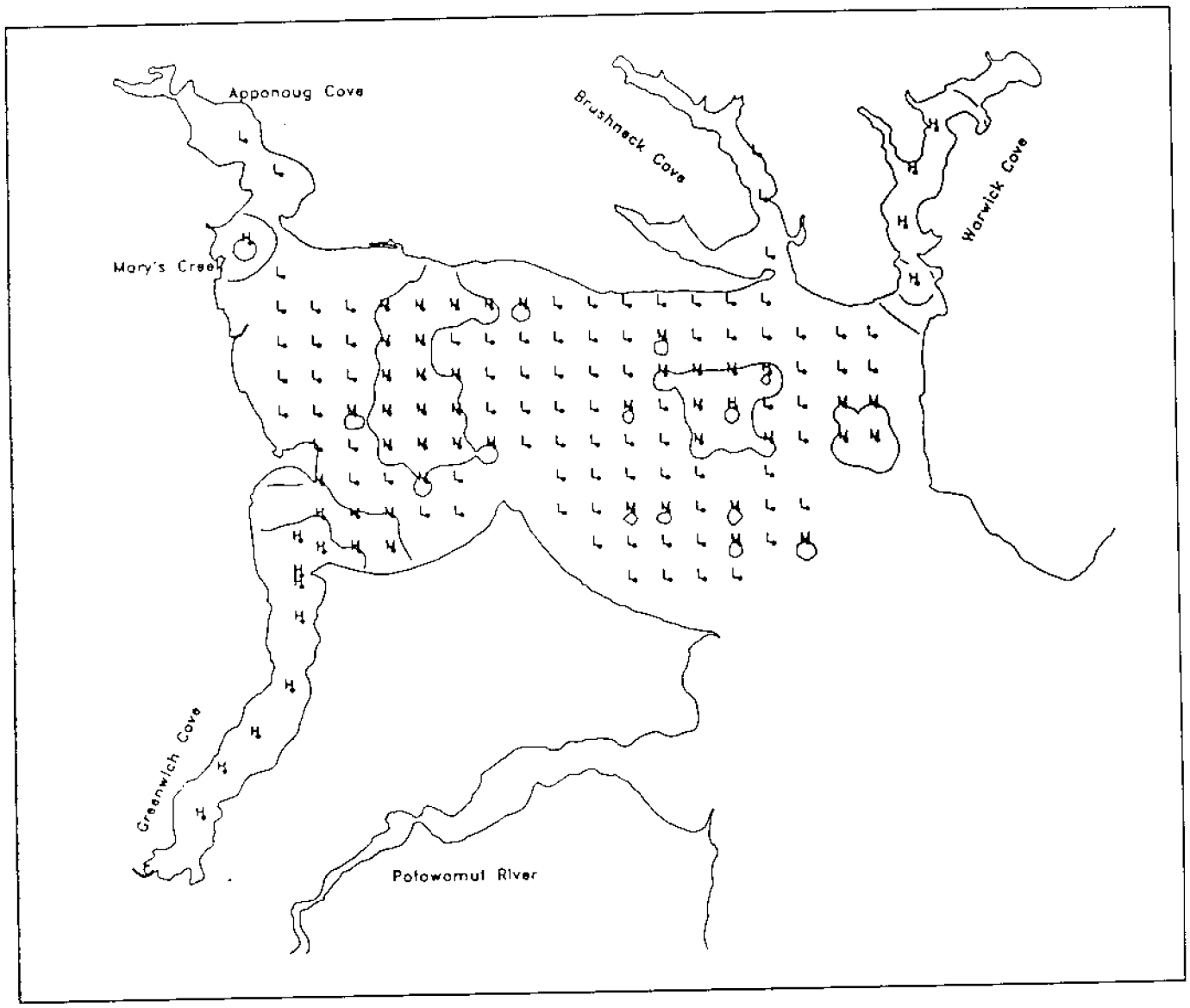


Figure 9. Greenwich Bay high (H), medium (M), and low (L) quahog densities.

3.6 quahogs per m^2, which was about 1.7 individuals per m^2 less than the overall mean abundance. The contour map and the transect density plot are presented in Figure 14.

Total Abundance and Distribution

From the calculated mean densities, contour maps, and transect plots (Figure 15), it is clear that quahog populations are distributed heterogeneously in Greenwich Bay. Total quahog abundance averaged from zero to 17.9 quahogs per m^2 in certified waters, and from 0.2 to 33.9 quahogs per m^2 in closed waters, with the greatest densities in Warwick Cove, Greenwich Cove, and Mary's Creek.

Biomass Estimates

The biomass estimates (in numbers of quahogs) were derived for the entire survey area and for each geographic stratum by commercial categories. These estimates must be considered minimum for all sub-legal quahogs, since the selection characteristics of the dredge (with 1-inch wire mesh) prevented the complete retention of quahogs less than legal size (1-inch width).

Quahogs were caught in all 143 stations sampled (100 percent), and the conditional distribution of the densities was approximately lognormal, or so-called "delta-distribution" (Pennington, 1983). However, this distribution takes into account that

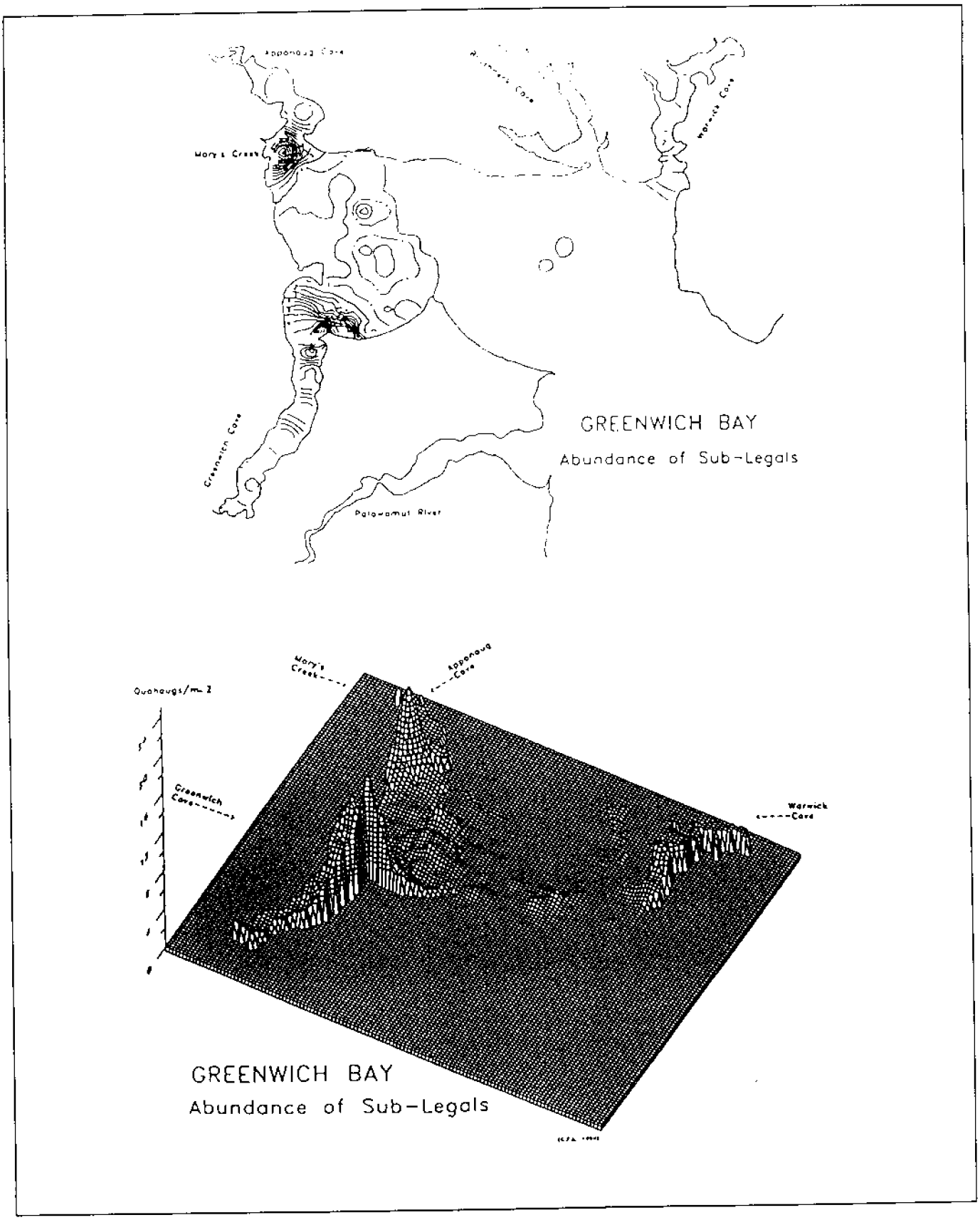
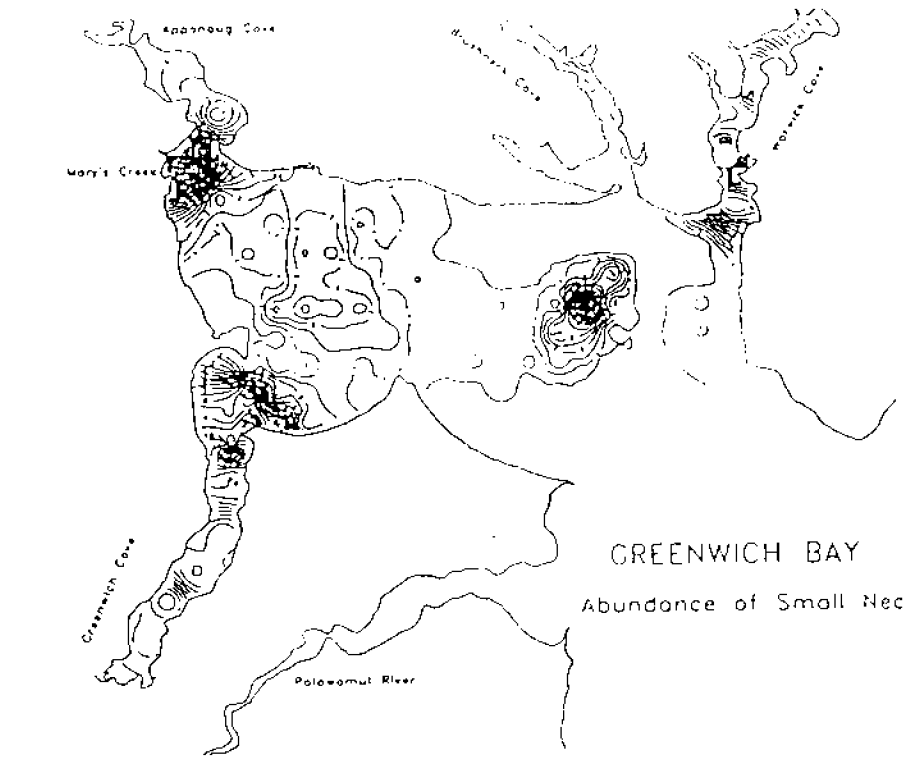


Figure 10. Greenwich Bay abundance of sub-legal quahogs.



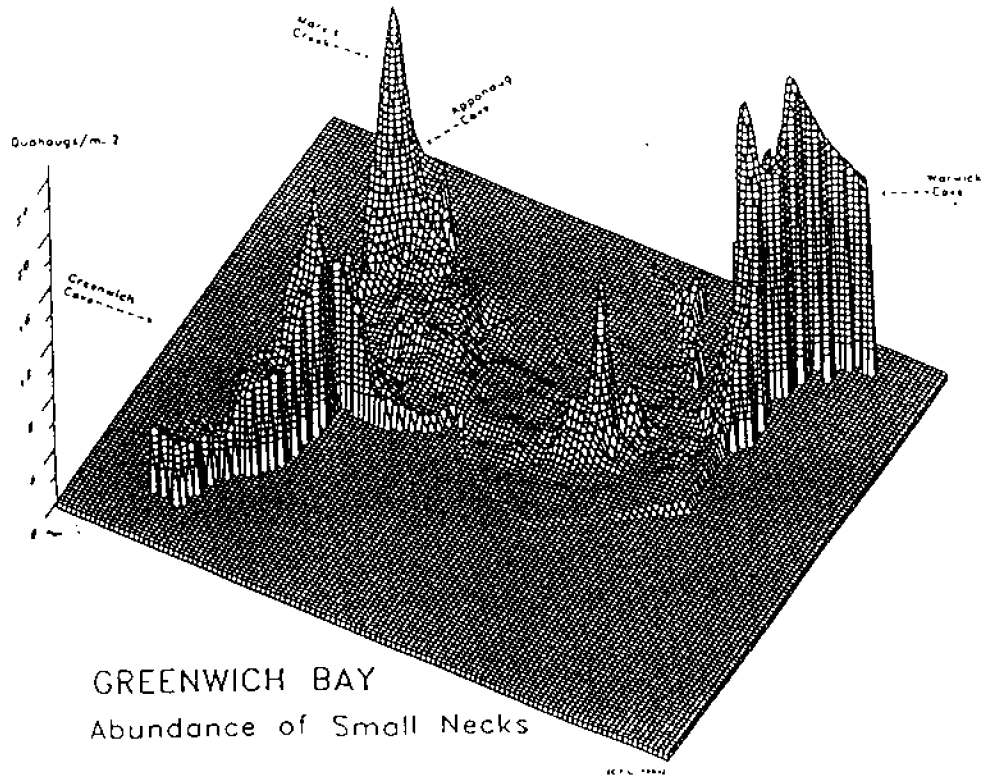
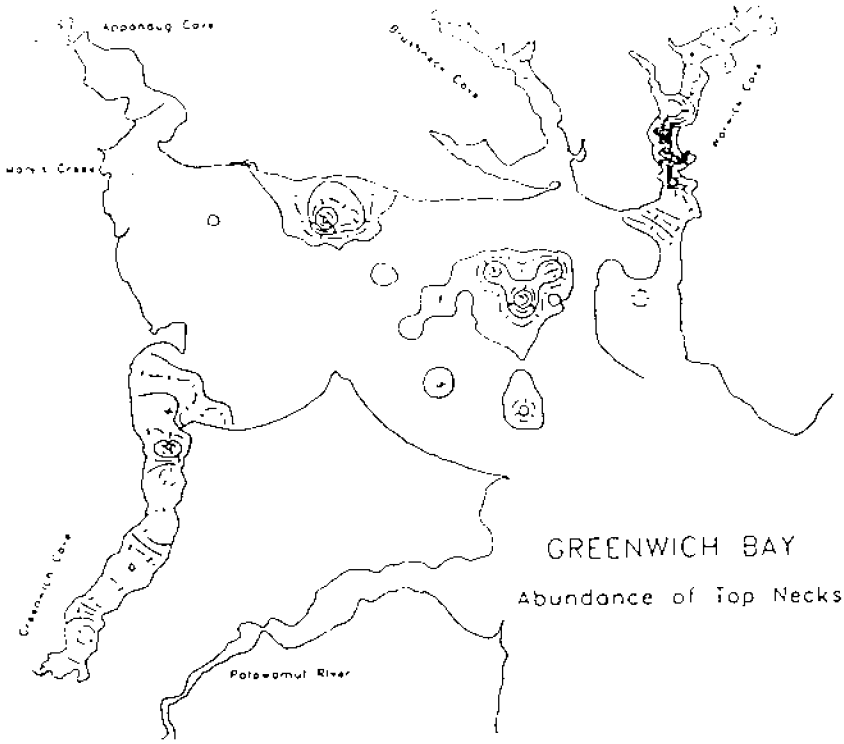


Figure 11. Greenwich Bay abundance of small necks.



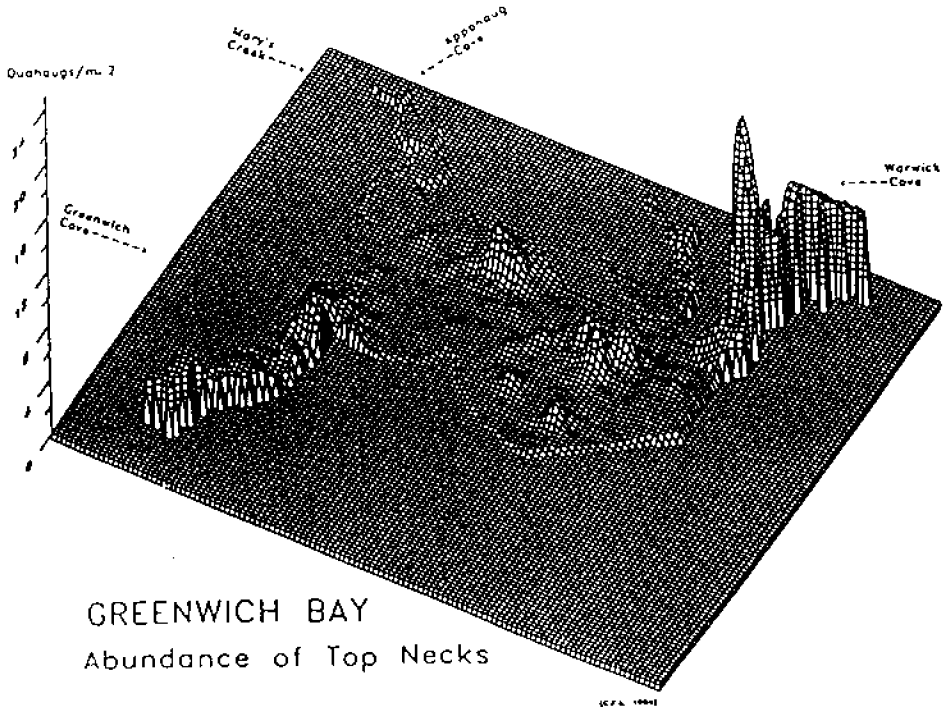
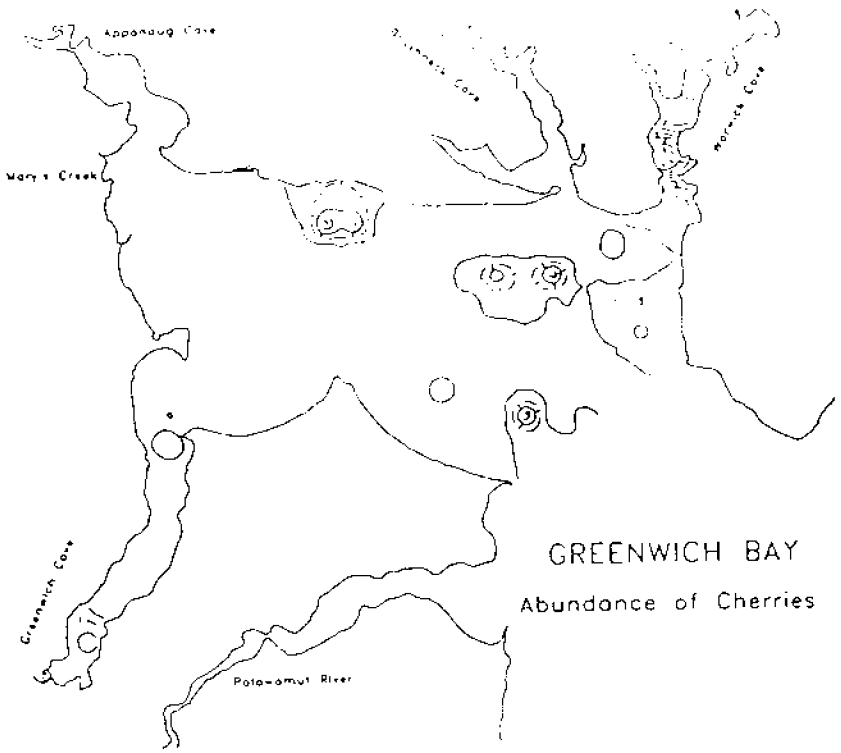


Figure 12. Greenwich Bay abundance of top necks.



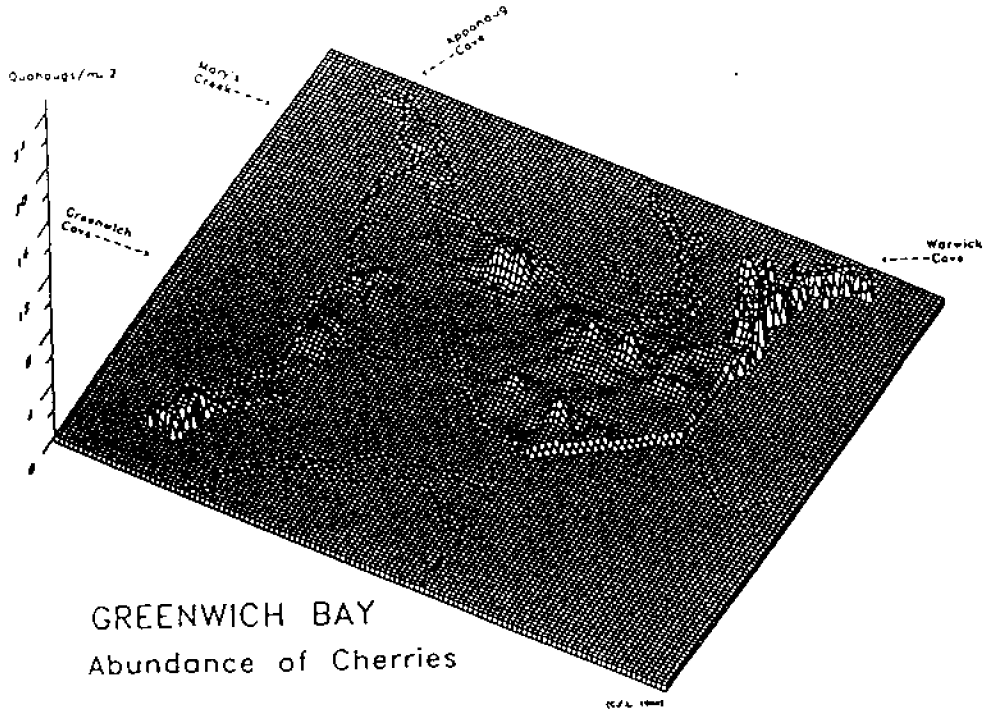


Figure 13. Greenwich Bay abundance of cherries.

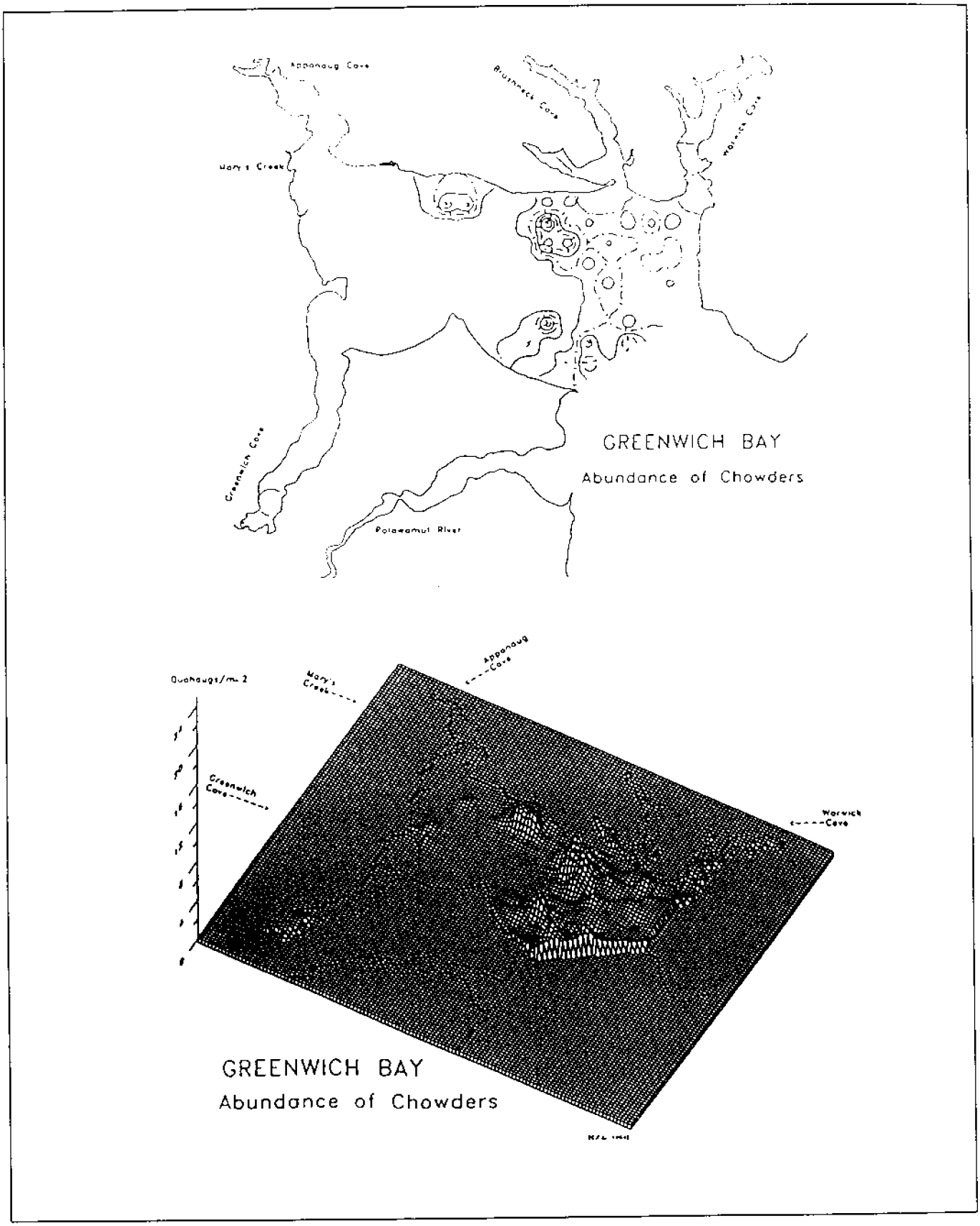


Figure 14. Greenwich Bay abundance of chowders.

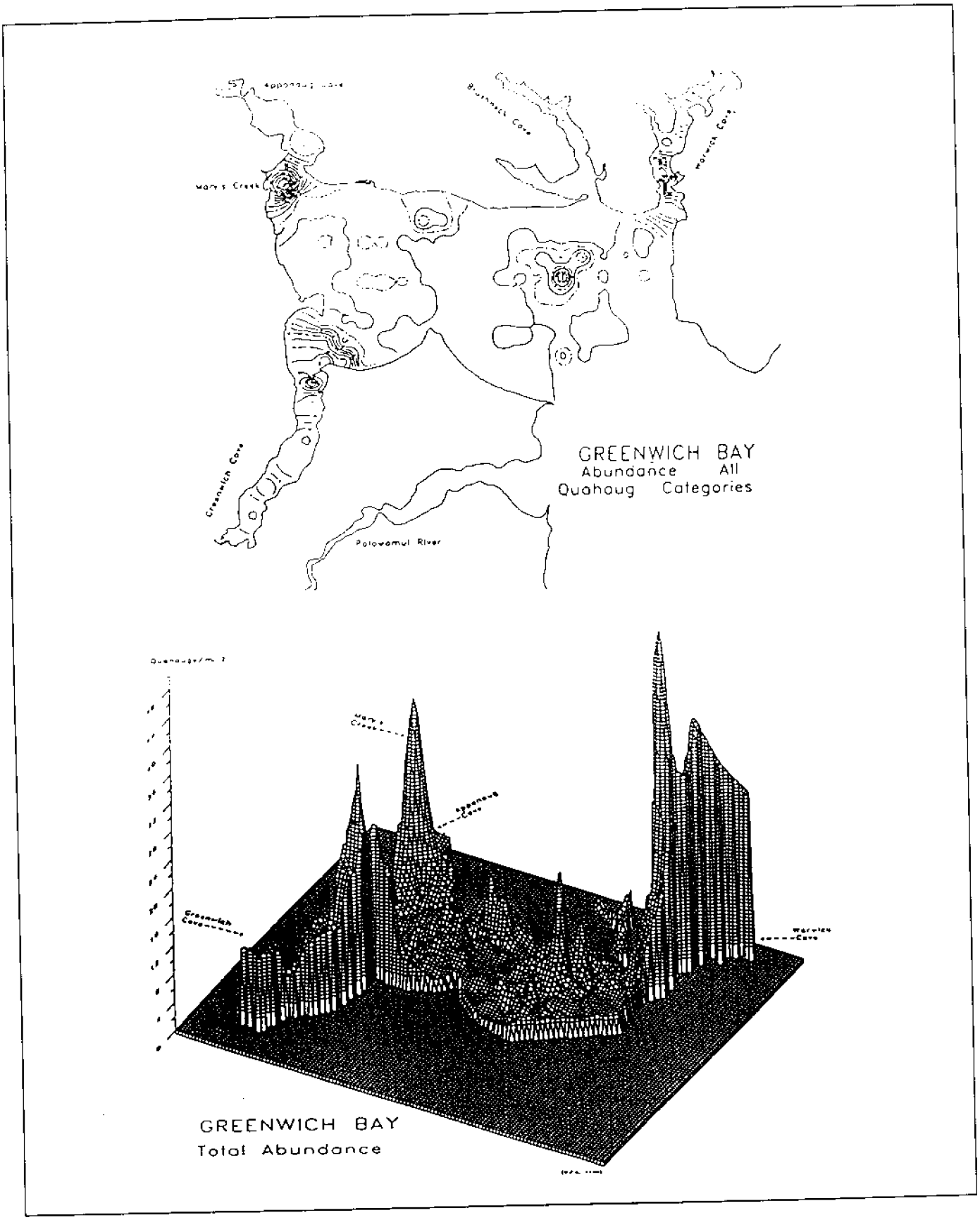


Figure 15. Greenwich Bay abundance of all quahog categories.

survey data often contain a large proportion of zero observations, and that the nonzero observations form the lognormal distribution rather than a normal distribution (Sparre et al., 1989). This distribution was applied to a survey of catch data of ocean quahog (*Arctica islandica*) collected off the coast of southern New England (Fogarty, 1981). Similar distributions could be applied for mean and biomass estimates (e.g., negative binomial) when stratification is not considered.

The stratified mean density per m^2 for the entire survey was 5.435, (SD=0.422). There were no significant differences ($p<0.05$) in quahog density between depth intervals in each stratum within certified waters. A small difference was observed in mean density for different depths in closed waters, probably due to high variance in these strata produced by high densities.

The stratified means (±1 SD) for commercial categories and sub-legal quahogs were calculated, and show the predominance of small necks, with an overall stratified mean of 2.77 (± 0.234) individuals per m^2; followed by sub-legals, with a minimum stratified mean of 1.061 (± 0.134); then top necks, cherries, and chowders, with 0.843 (± 0.101), 0.400 (± 0.070) and 0.352 (± 0.052), respectively.

The total minimum estimated biomass for the entire survey was about 68.3 million quahogs (± 16.7 million), with a corresponding estimated weight of 9.76 million ± 2.4 million pounds (shell weight) in the entire Greenich Bay. This represents nearly 75 percent of the average yearly landings of quahogs (1988 to 1992) in Rhode Island. However, about 59 percent of this total minimum biomass, about 5.8 million ± 1.4 million pounds, lies behind pollution lines.

The distribution of the minimum biomass (in number of quahogs), by stratum and commercial category, is presented in Table 2. The potential fishable biomass, broken down by commercial category, is distributed as follows:

Small necks = 11.171 million ± 3.527 million
Top necks = 4.04 million ± 1.482 million
Cherries = 2.673 milllion ± 1.001 million
Chowders = 4.805 million ± 1.548 million

With their corresponding total shell weights (total weight)

Small necks = 1.396 million ± 440,000 pounds
Top necks = 709,000 ± 260,000 pounds
Cherries = 668,000 ± 250,000 pounds
Chowders = 1.848 million ± 595,000 pounds

Growth parameters were developed using k=0.1, estimated by Rice et al. (1989) for quahogs from Greenwich Cove, and $L\infty$ =130 mm, estimated from Gulland (1969), as follows:

$$L\infty = L_{max}/0.95 = 124/0.95 = 130 \text{ mm}$$

Pratt et al. (1992) found $L\infty$ = 110 mm for the West Passage of Narragansett Bay, and Jones et al. (1989) found $H\infty$ =73.3 mm (shell height) with k = 0.12 and t_0 = - 0.57. The corresponding $L\infty$ in relation to the value for H reported by Jones et al. (1989) would be around 80.9 mm, using the shell length-height relationship developed in this study.

Accordingly, if quahog growth from egg to market size takes about five years in Greenwich Bay, then the maximum allowable catch, or maximum sustainable yield (MSY) annually of the fishable biomass is between 1 million and 1.3 million pounds (total shell weight) per year, assuming natural mortality at 0.2, constant recruitment, and no transplants. Quahogs have relatively slow growth rates in Rhode Island, and are known to live in excess of 20 years. Therefore, it is reasonable to assume a low natural mortality rate (between 0.1 and 0.2) once they recruit to the fishery. Using the shell weight-to-meat weight conversion factor previously defined, the potential harvestable biomass in meat weight is between 153,200 and 199,000 pounds.

Maximum Sustainable Yield (MSY) Estimates Based on the Surplus Production Model

In this section, an alternative method for estimating MSY is suggested, which has the same foundation and application as the Gulland/Cadima estimators (Gulland, 1969). The method is derived from the Fox production model (Fox, 1970), because quahog stocks and the rate of their exploitation would respond better to an exponential model (B = biomass and M = natural mortality).

$$MSY = M\ B\ \exp(Y/(M\ B)-1)$$

Area	Sub-legals	Small Necks	Top Necks	Cherries	Chowders	TOTAL
1	4,699,894	9,542,271	2,495,090	538,752	172,853	17,448,860
2	2,815,210	3,989,453	402,980	96,165	74,160	7,377,968
3	286,658	1,296,117	704,633	355,966	908,112	3,551,486
4	193,907	2,202,406	1,209,954	999,200	1,895,047	6,500,514
5	989,272	2,459,851	285,913	81,999	109,377	3,926,412
6	96,870	662,663	710,682	447,401	622,698	2,540,314
7	22,102	560,702	725,835	691,994	1,195,454	3,196,087
8	170,779	739,515	301,963	180,852	80,258	1,473,367
9	19,092	38,194	19,092	28,641	28,641	133,660
10	1,229,257	9,505,920	4,250,818	1,123,829	158,298	16,268,122
11	1,868,511	3,935,233	80,933	16,171	0	5,900,848
TOTAL	12,391,552	34,932,325	11,187,893	4,560,970	5,244,898	68,317,638

Table 2. Estimated biomass in number of animals, by stratum and commercial category, in Greenwich Bay, 1993.

Area	Sub-legals	Small Necks	Top Necks	Cherries	Chowders	TOTAL
1	1,312,108	1,842,615	556,206	218,123	85,368	4,014,420
2	1,058,190	1,297,122	164,018	50,703	58,702	2,628,734
3	99,702	200,244	131,083	112,513	399,462	943,004
4	112,185	1,112,598	334,423	216,819	337,780	2,113,804
5	249,809	348,800	101,657	47,823	75,871	823,960
6	50,945	179,144	387,236	276,353	353,025	1,246,704
7	26,973	388,737	363,613	296,850	323,561	1,399,734
8	99,122	387,476	54,066	18,022	54,066	612,753
9	16,991	8,496	33,983	29,430	50,974	139,874
10	346,985	2,477,210	2,246,177	842,078	133,276	6,045,726
11	81,100	603,742	18,022	18,022	0	720,886
TOTAL	3,454,111	8,846,184	4,390,485	2,126,736	1,872,085	20,689,600

Table 3. Estimated 95 percent confidence limits in number of animals per stratum and commercial category in Greenwich Bay, 1993.

Because Greenwich Bay has not been open to shellfishing since 1992, but is considered for opening as a conditional area in the near future, it is logical to consider Y as the average catch per year for the last five years. As a result, the MSY for Greenwich Bay would be estimated at 1,003,000 pounds a year for M = 0.2. The value of MSY becomes much smaller if the stock is not exploited (Y = 0). Theoretically, moderate fishing helps remove older and larger clams, leaving a predominance of smaller clams and space for new recruits. This has been observed in many places in the Northeast, including Narragansett Bay (Rice et al., 1989; Walker, 1989).

Implementation of an Interim Management Plan

In June of 1994, legislation was passed in the General Assembly that provided funding for the opening of Greenwich Bay, including water quality monitoring, resource monitoring, and additional law enforcement to operate the area as a rainfall-dependent conditional area.

After meeting with the Rhode Island Marine Fisheries Council (RIMFC) shellfish subcommittee and DEM enforcement, DFWER's preferred alternative for opening the Greenwich Bay shellfishery was presented to the RIMFC. The following regulations were adopted:

1. When declared open by the DEM Division of Water Resources, shellfishing will be permitted between the hours of 7 a.m. and 9 a.m. during daylight savings time, and from 8 a.m. to 10 a.m. at all other times. Shore digging will be permitted only during those specified times.

2. Daily catch limits are 3 bushels for commercial diggers, with a maximum of 6 bushels per boat per day, and the maximum of two license holders per boat. Residents are allowed 1 peck, licensed nonresidents are allowed a half peck. Shore digging is not permitted.

3. All shellfish taken by licensed commercial diggers must be culled, bagged, and tagged according to the new FDA/Health Department regulations before proceeding out of the Greenwich Bay Management Area.

4. A quota of 1,003,000 pounds is set. When 75 percent of the quota (752,250 pounds) is reached, the fishery will close until December 12, 1994. At that time, the remaining 25 percent of the quota (250,750 pounds) can be harvested. Any unused portion of the annual quota will be carried over to 1995.

5. All licensed dealers are required to report shellfish landings weekly to the DFWER. Total pounds of quahogs purchased from Greenwich Bay must be reported via phone or fax each Tuesday for the previous week. If shellfish from Greenwich Bay was not purchased for the reporting week, a report so stating must be submitted.

The Division of Water Resources declared the Greenwich Bay Management Area qualified for opening on a conditional basis for shellfishing on June 27, 1994. Between 350 and 550 quahog boats worked the bay while it was open. The area was closed after seven days, when it was determined that the first portion of the quota had been harvested. Dealer reports indicated a total of 715,195 pounds (95 percent) of the 752,250-pound quota were taken from Greenwich Bay. The remaining 37,055 pounds will be carried over to the winter subperiod quota.

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Questions and Answers

Q: (Peter Canis, Rhode Island Shellfish Divers Association) Am I correct in hearing that you said that Narragansett Bay can support about 900 fishermen?

A: (Lazar) From the data I have, it is about 800 to 900 shellfishermen in all of Narragansett Bay.

Comment: (Canis) It seems to me that there are much less than 800 fishermen working the Bay on a regular basis. Only during well-publicized openings will you see that many people.

A: (Lazar) What I intended to show is that once you reach 800 to 900 fishermen, the catch per unit effort (CPUE) begins to drop.

Q: (Neal Perry, Rhode Island Shellfish Divers Association and Ocean State Aquaculture Association member) Are there studies planned to follow up after the fishing season in Greenwich Bay to actually quantify how much has been taken?

A: (Lazar) We followed the opening of Greenwich Bay, and we are planning a revised management plan once the Narragansett Bay-wide study is completed.

Q. (Perry) Since much of the production from Narragansett Bay over the last 20 to 30 years has been estimates, how confident are you with the data?

A: (Lazar) My model is based on fisheries-related data, which are catch and effort. You have to be careful with this. I do not know how reliable some of the numbers are, particularly the number of fishermen. We hear that there are 1,000 quahoggers on the Bay, but we go out and regularly count 300 or so out there. I'm not saying that the 900 figure is optimum, but it is our starting point.

Q: (Perry) Given the amount of actual catch, is 900 a reasonable number?

A: (Lazar) If you calculate the catch of 900 fishermen, it would be about 2.5 million pounds. In recent years, we have not been near this figure.

Q: (Kim Tetrault, University of Rhode Island department of fisheries, animal, and veterinary science (FAVS)) Have you found correlations between adult numbers and recruitment in any area?

A: (Lazar) The sub-legals and small necks are concentrated on the east side of Greenwich Bay, but we did not do much work in the way of recruitment studies. Dr. Rice did some larval monitoring and will present those data later today.

Q: (Joseph DeAlteris, FAVS) Your catch data is based on landings, and your effort is based on license holders, right?

A: (Lazar) Yes, landings and numbers of shellfishing and multipurpose licenses.

Comment: (DeAlteris) From your recent findings and some studies in the past, it seems that the actual number of fishermen on the bay is about one-third of the licensees. It would seem to me that the shape of your curve is fine, but the effort axis should be lowered by the correction factor.

A: (Lazar) Perhaps you are correct. April Valliere and I are actively trying to analyze these types of effort data.

Q: (DeAlteris) Are there any overflights, aerial photos and the like, to get counts at different times of the year?

A: (April Valliere, DEM-DFWER) We are out on the water constantly throughout the year.

Q: (DeAlteris) So what is your current working percentage of actual fishermen to licensees?

A: (Lazar) This summer there were 200 to 300 boats active on any given day, so the percentage would be somewhere between 20 to 30 percent.

A: (Arthur Ganz, DEM-DFWER) On an average summer day, there are about 200 to 300 boats out there. There are certain well-publicized openings, such as Greenwich Bay, when there were a maximum of 535 boats counted. The catch and effort figures are complicated by the number of multipurpose licenses and the fact that there are active fisheries in the coastal ponds that are often unaccounted for.

Results of a Study of Bivalve Larval Abundance in Greenwich Bay, Rhode Island, 1993

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Abstract ■ *Greenwich Bay, in Narragansett Bay, Rhode Island, is known to be an area that has supported recreational and commercial fisheries of the northern quahog, Mercenaria mercenaria. Sustained annual catches of approximately 1 million pounds of mostly smaller-sized "littlenecks" in the bay suggest annual recruitment, but few studies of early life history stages have been undertaken in this area since 1952. Weekly water samples (100 L each) were taken on an incoming tide from 0.3 and 1.6-m depths at seven locations in Greenwich Bay. Samples were taken using a 30 L/minute, 12-volt electric bilge pump, and water was passed through a 60-μm mesh plankton net. Larvae were fixed in the field with 10 percent buffered formalin in filtered seawater and transferred to a 25 percent ethanol/seawater mixture for storage. Larvae in 1.0 mL subsamples of the preserved samples were identified and counted. Larvae from several vertebrate and invertebrate taxa were identified. Identifiable bivalve larvae were distinguished as to developmental stage: D-hinge veliger, umbonate veliger, and pediveliger. Maximum bivalve abundance occurred June 14 at all sites, with a bay-wide average of 7,800 larvae/100L. A secondary peak of abundance occurred August 3, with 580 larvae/100L. The D-hinge veligers were much greater in number than umbonate veligers, which in turn were greater in number than pediveligers. This suggests predation loss or export of the developing larval stages. Larvae were not uniformly distributed throughout Greenwich Bay. Maximum bivalve larval abundances were found in the open bay sites, rather than in coves and inlets. This is a surprising result, because presumed "spawner stocks" reside in the coves. Further studies are needed to identify the most probable sources of larvae leading to quahog recruitment in Greenwich Bay.*

Introduction

Greenwich Bay is known to be one of the most productive areas for the quahog (*Mercenaria mercenaria*) fishery. A number of studies have focused on adult quahog populations in the bay (Stringer, 1955; Stickney and Stringer, 1957; and Rice et al., 1989), and have shown that the natural adult population densities are among the highest reported. According to Rhode Island Department of Environmental Management figures, annual harvests are approximately 450 metric tons (1 million pounds) from the 1,300-hectare (ha) (3,200-acre) bay (Lazar et al., this volume). These sustained harvests of mostly 48-millimeter (mm) to 55-mm valve-length "littlenecks" from the bay suggest that there is annual recruitment into the actively fished areas.

Although there is a considerable amount of information available about populations of adult quahogs in Greenwich Bay, few studies have focused on the early life history stages. Landers (1954) studied the abundance of bivalve larvae in Greenwich Bay between 1950 and 1952. He reported that maximum bivalve larval abundance—assumed to be quahogs—was during the month of June, when water temperatures exceeded 20 C. The sampling protocol of Landers (1954) did not allow for a description of the spatial distribution of the larvae in the bay.

The highest quahog population densities in Greenwich Bay are near the mouth of Greenwich Cove, and at the Mary's Creek area near the mouth of Apponaug Cove (Stickney and Stringer, 1957; Lazar et al., this volume). These dense populations are in areas closed to fishing, and consist mainly of large adults. These large adult quahogs are poten-

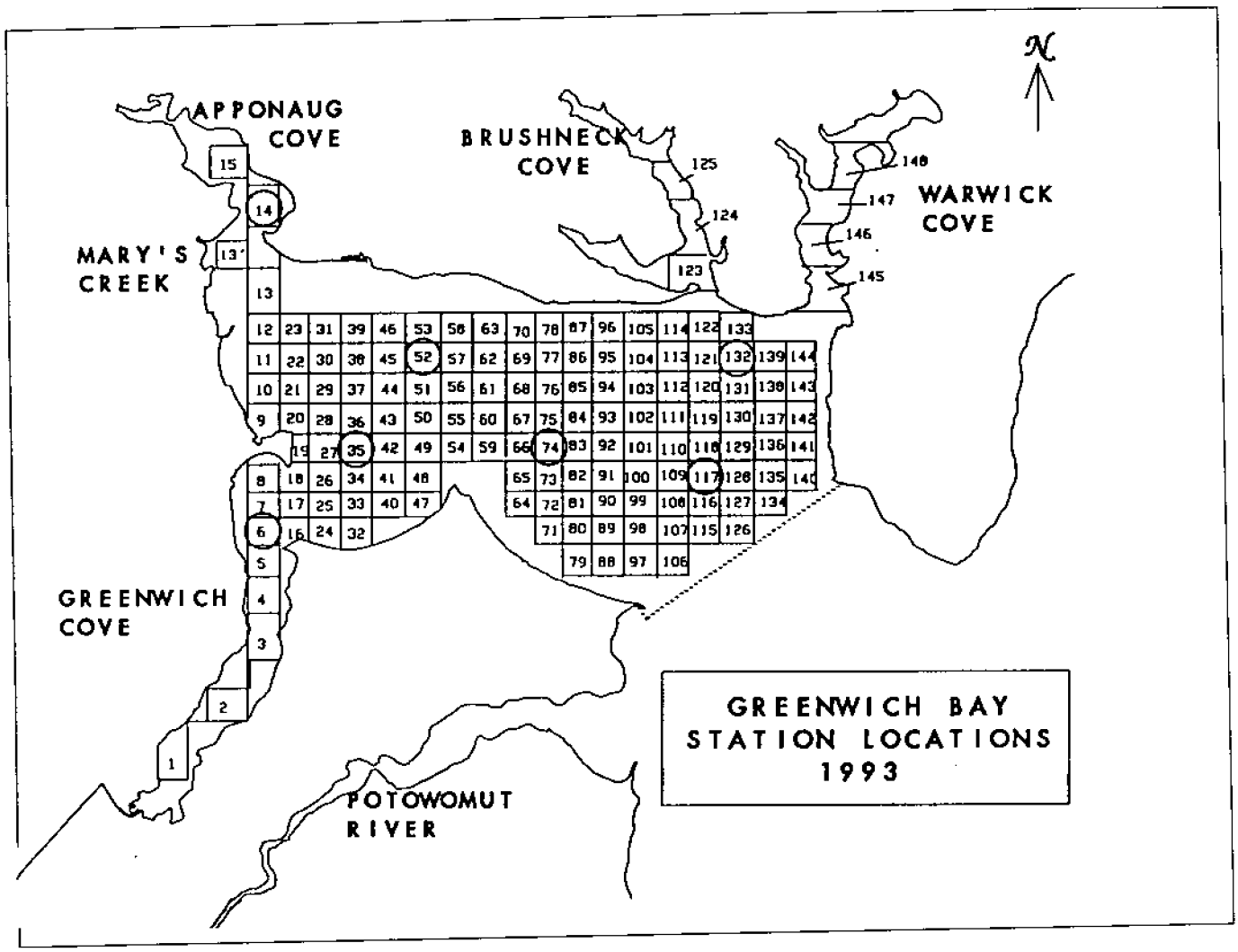


Figure 1. Greenwich Bay station locations in 1993 study.

tially quite fecund (Peterson, 1986), and are assumed to be the parental stocks for Greenwich Bay quahog recruitment (Ganz, 1991). The aim of this study is to describe the spatial and temporal patterns of bivalve larvae in Greenwich Bay, with special attention to areas where adult quahogs are abundant.

Materials and Methods

Zooplankton samples were collected from seven stations in Greenwich Bay on a weekly basis from June 7 to August 3, 1993 (Figure 1). Water sampling and temperature measurements were carried out on an incoming tide, one to two hours prior to high tide. Water samples (100 liter (L)/sample) were collected at 0.3-meter (m) and 1.6-m depths using a 12-volt battery-powered bilge pump with a nominal rating of 500 gallons/hour (approximately 30 L/minute). Water samples were filtered using a 60-micron (µm) mesh plankton net. Materials retained by the net were fixed in the field using 10 percent buffered formalin in seawater. Samples were then transferred to a 25 percent ethanol/seawater mixture for storage prior to examination. Duplicate 1.0-milliliter (mL) subsamples of the preserved plankton were observed and counted using a stereoscopic microscope and a Sedgewick-Rafter counting chamber, and the data presented are the mean of the duplicate counts. The holoplankton and meroplankton in each of the samples were classified to the lowest identifiable taxon, using available references (e.g., Gosner, 1971; Conn, 1991). Rapid identification of bivalve larvae in subsamples was aided by the use of cross-polarizing light filters on a stereoscopic microscope. The developmental stages of bivalve molluscan larvae were

	SITE LOCATION NUMBER							
Date	6	14	35	52	74	117	132	mean ± SD
June 6	17.0	17.0	17.0	17.5	17.5	17.5	18.0	17.5 ± 0.4
June 14	24.0	23.0	24.0	22.0	22.0	19.5	20.0	22.3 ± 1.6
June 23	23.0	22.0	23.0	22.0	21.0	20.0	21.0	21.7 ± 1.1
June 28	24.0	25.0	24.0	23.0	23.0	22.0	22.0	23.3 ± 1.1
July 7	26.0	26.0	25.0	25.0	25.0	24.0	24.0	25.0 ± 0.8
July 13	25.0	25.0	25.0	24.0	24.0	23.0	23.0	24.4 ± 0.8
July 20	22.0	22.0	22.0	22.0	21.0	20.0	21.0	21.4 ± 0.8
July 28	25.0	25.0	24.0	23.0	23.0	23.0	23.0	23.7 ± 0.9
August 3	26.0	26.0	26.0	26.0	25.0	24.0	24.0	25.3 ± 0.9

Table 1. Average temperatures (C) by site and sample date in 1993.

counted and classified as to developmental stage: D-hinge veliger, umbonate veliger, and pediveliger (Loosanoff et al., 1966; Chanley and Andrews, 1971).

Results

Temperature and salinity measurements were taken at the sample-collection sites and depths on all sample-collection days. Table 1 shows the average temperature measurements at all sites. On any given day, temperatures did not vary from site to site by more than 2 C.

Planktonic adults and larvae from several phyla of marine invertebrate taxa were found in the plankton net samples from all areas sampled in Greenwich Bay. Table 2 shows some of the groups of organisms found in the net samples.

Particular attention was paid to quantifying the various larval stages that are particular to bivalve mollusks, namely the D-hinge veligers, the umbonate veligers, and the pediveligers. Figures 2a and 2b show D-hinge and fully developed umbonate larvae, respectively. Pediveligers were relatively large in size, usually greater than 270 µm in length, and have a prominent "foot." Total bivalve abundance was highest during the June 14 sampling day (Figure 3). These samples yielded a total of 119,000 larvae in 14 samples (seven sites and two samples per site). This works out to an average larval density of 8,500 larvae/sample, or 85 larvae /L. A secondary peak of bivalve larval abundance was noted during the end of the sampling period on August 3.

The distribution of bivalve larvae was not uniform by depth or by developmental stage. Figures 4 and 5 show the average number of larvae per sample at 0.3-m and 1.6-m collection depths. On all days sampled, the average number of D-hinge larvae greatly outnumbered the umbonate veligers, which in turn outnumbered the pediveligers. Peak abundance of umbonate veligers occurred on June 28, two weeks after the peak in D-hinge veligers. A first peak in pediveliger abundance occurred on June 28, but this was a relatively small number of larvae, amounting to about 15 larvae/100-L sample in the samples collected at 0.3 m, and 32 larvae per sample in those collected at 1.6 m. A greater peak in umbonate veliger and pediveliger abundance occurred on August 3. Abundances of pediveligers appear to be higher in samples from the greater depth.

The distribution of bivalve larvae was not uniform by sample location in Greenwich Bay. Figure 6 shows a running cumulative total of bivalve larvae at each site. On the initial sampling date, June 7, all sites were almost completely free of

LARVAL FORMS	
Taxonomic Group	**Common Name**
Actinotroph larvae (phylum Phoronida)	
Bipinnaria larvae (class Asteroidea)	starfish
Brachiolaria larvae (class Asteroidea)	starfish
Cyprid larvae (class Cirripedia)	barnacles
D-hinge veliger larvae (class Bivalvia)	bivalves
Gastropod veliger larvae (various species)	marine snails
Megalopa larvae (class Decapoda)	crabs
Nauplius larvae (class Cirripedia)	barnacles
Nauplius larvae (class Copepoda)	
Pediveliger larvae (class Bivalvia)	bivalves
Pilidium larvae (phylum Rhyncocoela)	
Planula larvae (phylum Cnidaria)	jellyfish
Setigerous larvae (class Polychaeta)	bristle worms
Trochophore larvae (phyla Annelida and Mollusca)	nemertean worms
Umbonate veliger larvae (class Bivalvia)	bivalves
Zoea larvae (order Decapoda)	crabs
ADULT FORMS	
Adult harpacticoid copepods	
Adult calanoid copepods	
Adult ribbon worms	

Table 2. Listing of groups of zooplankton present in at least one sample from the sites throughout the study period.

bivalve larvae. A week later, the peak abundance of larvae occurred, but the larvae were confined to samples from sites 132, 116, 75, and 52. These four sites were in the open area of Greenwich Bay, but the three sites in, or near, coves were relatively free of bivalve larvae. As the summer progressed, there was a trend of increasing larval abundance in the coves, but they never reached the abundances of larvae seen in the open bay.

Discussion

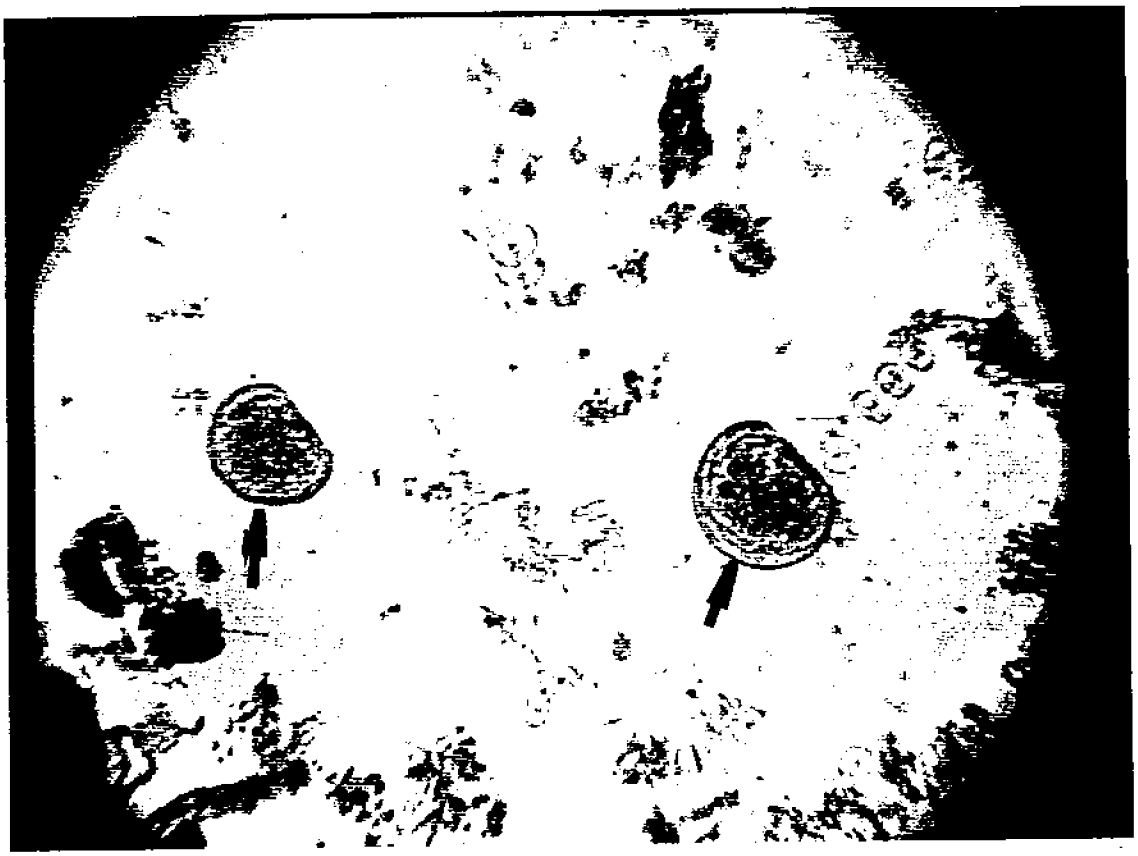
Peak abundances of D-hinge veliger larvae were on June 16, as water temperature reached about 20 C (Table 1, Figures 3 and 4). This result correlates closely with results from earlier studies that suggest that *M. mercenaria* commence spawning as water temperature reaches 20 C (Loosanoff, 1937). Our results also match those of Landers (1954), who showed that peak bivalve abundances were highest in mid-June of 1951 and 1952 in Greenwich Bay.

The high average number of D-hinge larvae in Greenwich Bay can be used to estimate total larvae. The area of Greenwich Bay is 1,299 ha (data courtesy of Peter August, Rhode Island Geographical Information System, University of Rhode Island), and the average depth is 4.0 m (NOAA Bathymetry Chart Number 13221) for a total volume of 5.2×10^8 m^3). Based on this, there would have been about 4.4×10^{13} bivalve larvae in Greenwich Bay on June 16. This considerable number of larvae leads us to conclude that the unavailability of larvae or lack of spawning stock are most likely not the limiting factors in quahog recruitment into Greenwich Bay.

The difference between numbers of D-hinge larvae and the further-developed larval forms can give an indication of the degree of larval mortality in Greenwich Bay. The average number of umbonate and pediveliger larvae in the water column on Julian date 179 (June 28) would be about 4.3 larvae/L (Figures 4 and 5). If we were to assume that umbonate veligers and pediveligers present on June 28 represented the same cohort that were D-hinge larvae on June 14, then there would have been a 95.0 percent natural mortality loss to the larvae. This finding is not out of line with previous studies. Carriker (1961) found that only about 2 percent of *M. mercenaria* larvae settle and metamorphose to become juvenile clams in Little Egg Harbor, New Jersey.

The larvae of *M. mercenaria*, like most bivalves, must spend time in the water column to develop. Typically, bivalve larvae exhibit positively phototaxic (light-seeking) behavior as D-hinge larvae and umbonate veligers, and switch to negatively phototaxic (dark-seeking) behavior once they become pediveligers and are capable of settlement and metamorphosis (Pechenik, 1985, 1990). This behavioral phenomenon may explain the relatively higher numbers of pediveligers found in the 1.6-m samples in comparison to the 0.3-m samples (Figures 4 and 5).

The distribution of bivalve larvae was not uniform throughout the seven sample stations (Figure 6), with most larvae present in the open bay, rather than in the coves. This is a surprising result, in that three studies have indicated that major assemblages of adult



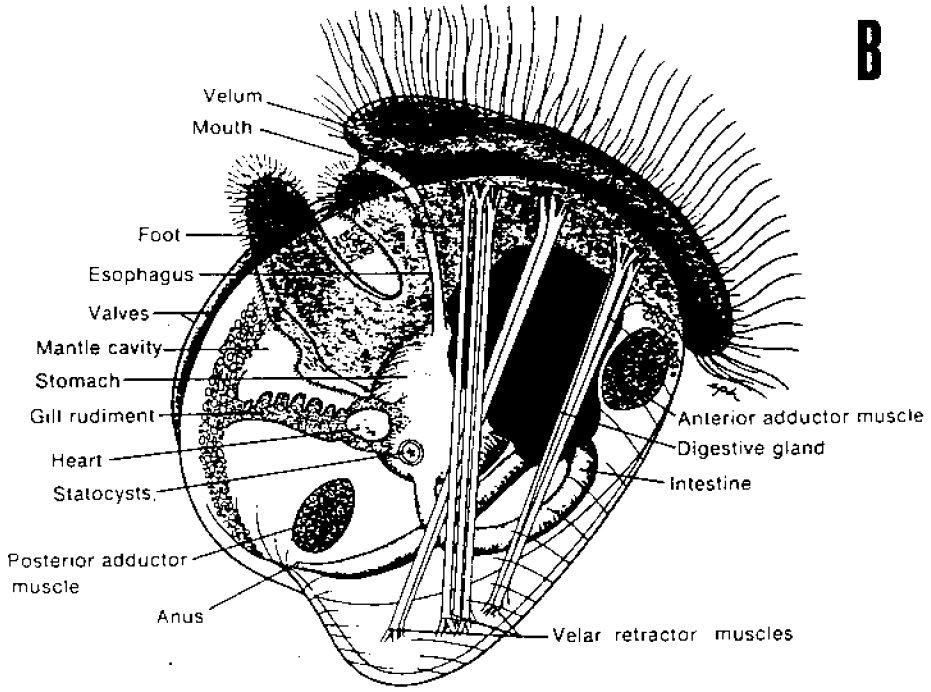


Figure 2. (a) Two D-hinge veligers (arrows) from station 132, taken on June 14, 1993, from a depth of 1.6 m. (b) A drawing of a fully developed pediveliger larva, showing prominent umbo and developed "foot." *Drawn from Galtsoff (1964).*

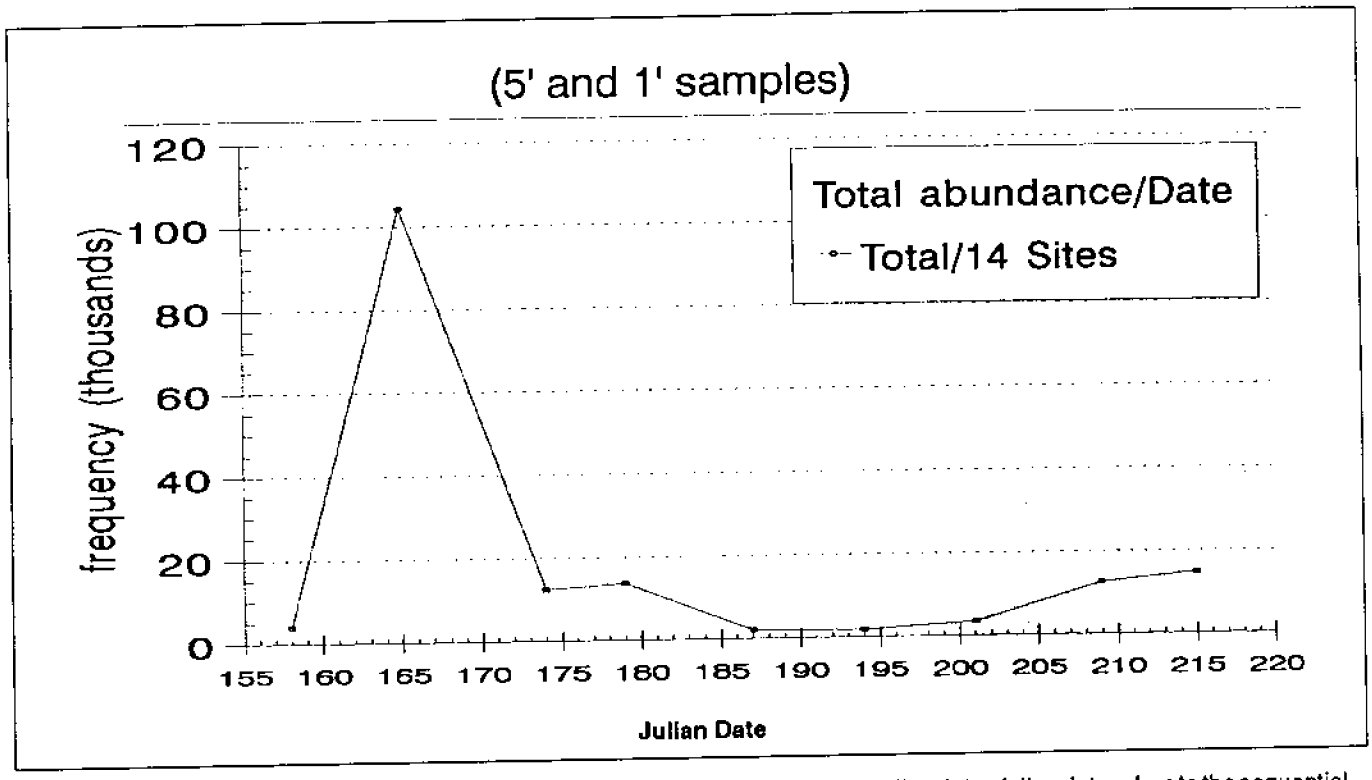


Figure 3. Cumulative total of bivalve larvae in all samples taken on the indicated sampling date. Julian date refers to the sequential date of the year (January 1 is day 1, and December 31 is day 365). The frequency is total larvae in a 1,400-L volume.

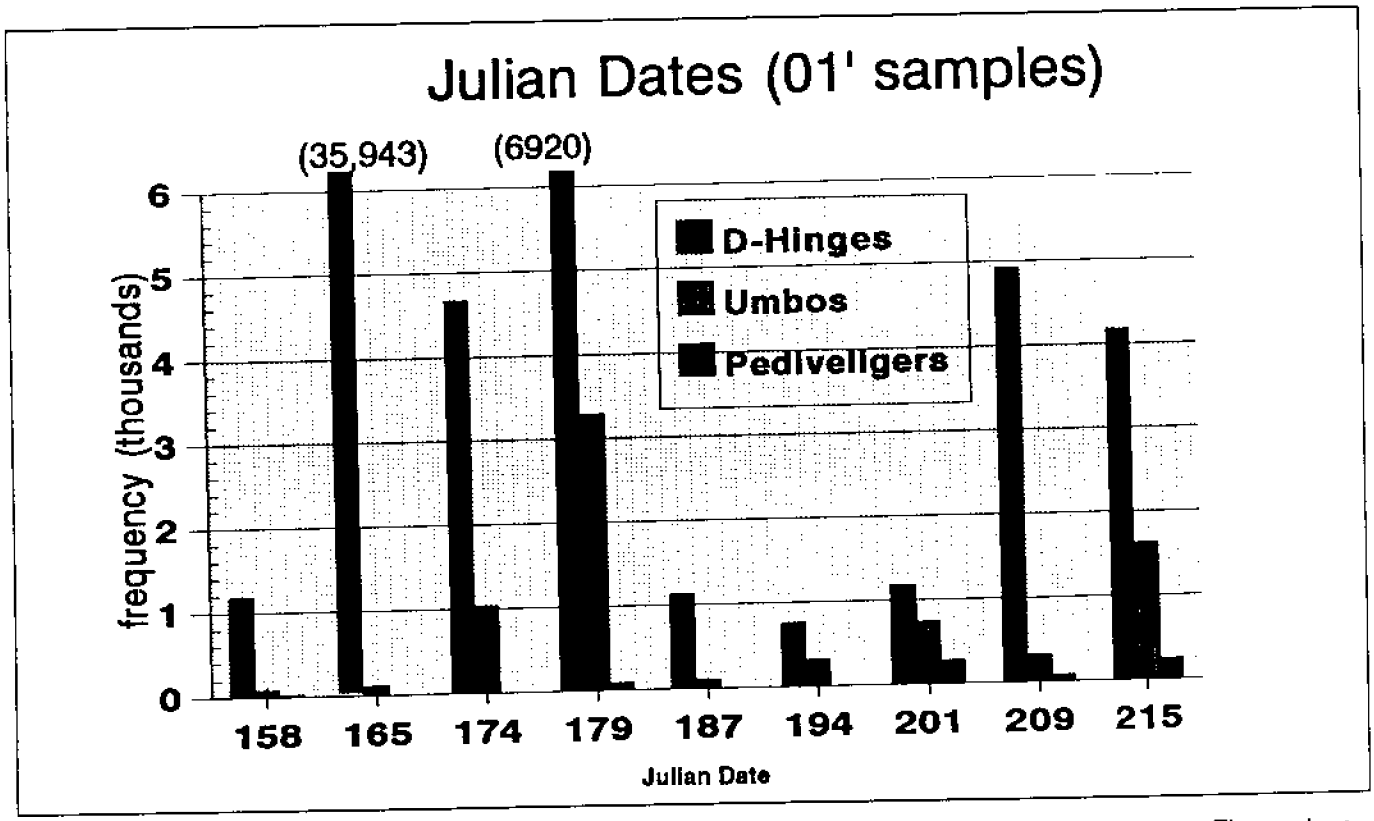


Figure 4. Cumulative total of bivalve larvae at all sites from a depth of 0.3 m, and sorted by developmental stage. The numbers of D-hinge larvae in June 14 and June 28 samples exceeded graph scale, so total numbers are indicated in parentheses. Frequency refers to total numbers in a 700-L volume.

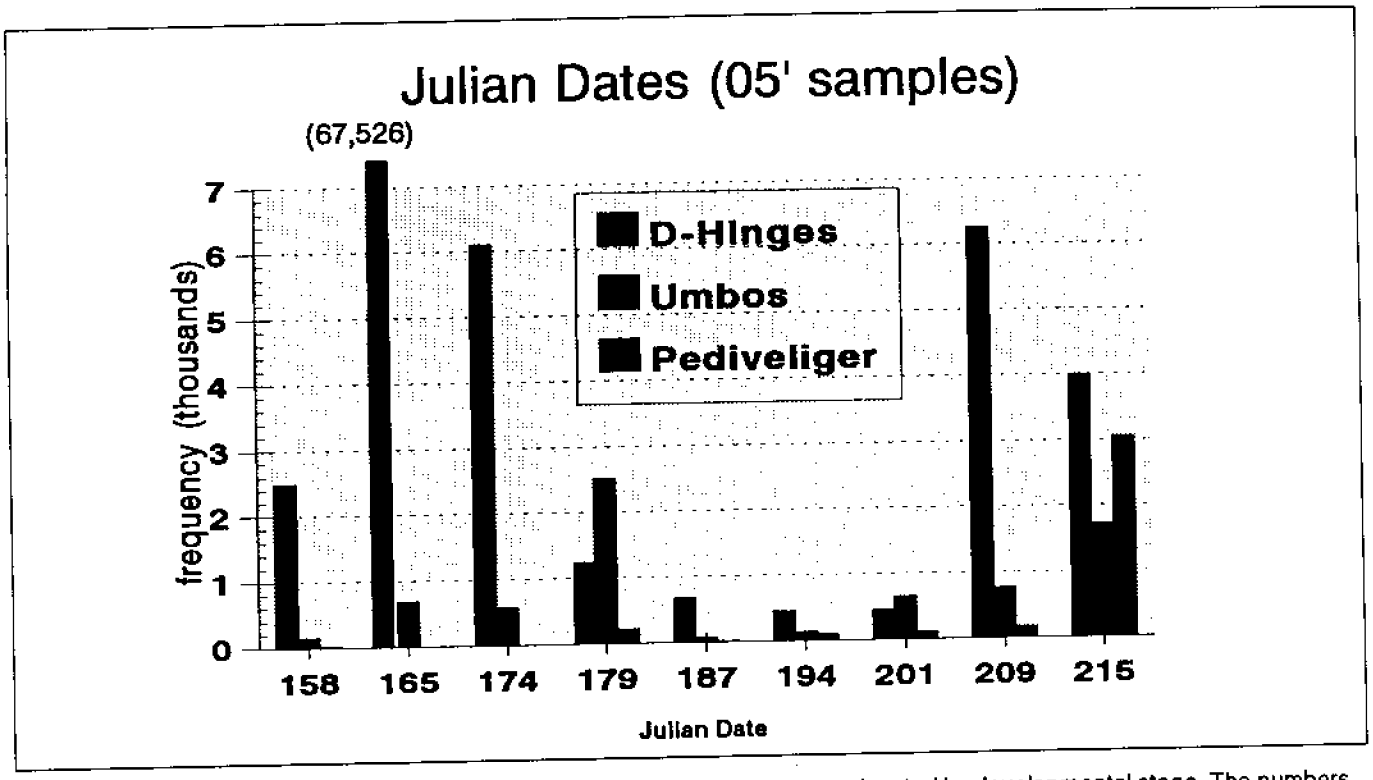


Figure 5. Cumulative total of bivalve larvae at all sites from a depth of 1.6 m, and sorted by developmental stage. The numbers of D-hinge larvae in the June 14 sample exceeded graph scale, so total number is indicated in parentheses. Frequency refers to total numbers in a 700-L volume.

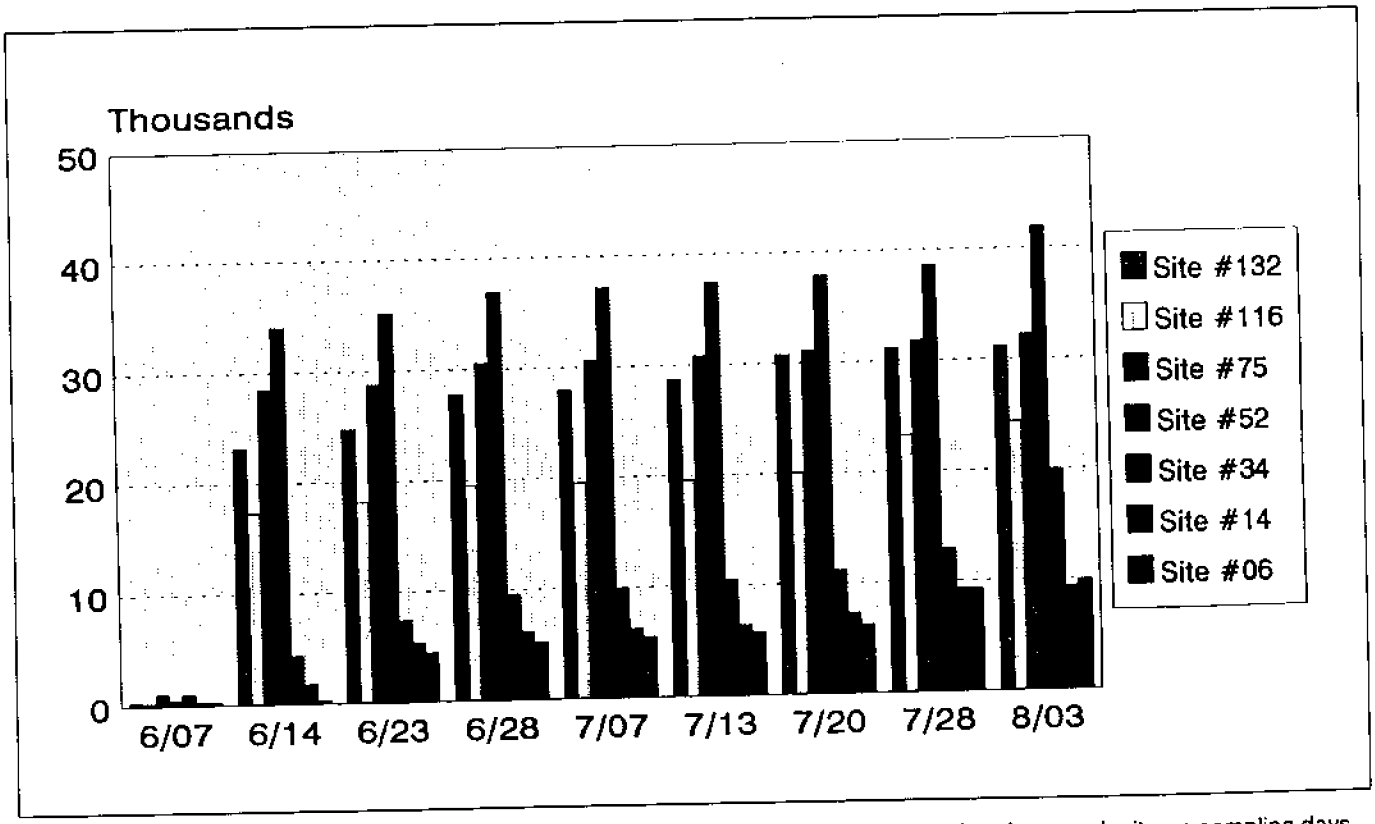


Figure 6. Running cumulative larval totals, by time and site. Two 100-L samples were taken from each site on sampling days (0.3-m and 1.6-m depths). The frequencies reported are the total number of larvae collected at each site, up to the date indicated.

quahogs occur near the mouth of Greenwich Cove and the Mary's Creek area near Apponaug Cove (Stickney and Stringer, 1957; Rice et al., 1989; Lazar et al., this volume). Samples from stations 6 and 14 remained relatively free of bivalve larvae throughout the summer, despite their location, which is in close proximity to these dense adult assemblages. We collected all of our samples on an incoming tide, usually two hours prior to high tide, so a tidal "washout" explanation is unlikely. Likewise, the summer of 1993 was relatively dry, making the "freshwater washout" explanation unlikely. Alternative explanations, such as mortality of larvae due to some unknown pollutant, or filtration of the larvae from the water column by the dense adult assemblages, have not been ruled out. Kurkowski (1981) reported that adult quahogs can filter their own larvae out of suspension in the laboratory, but this phenomenon has not been clearly demonstrated by field studies.

Care must be taken with the interpretation of the bivalve larval identification. We—as did Landers (1954)—assumed that the majority of the bivalve larvae sampled and enumerated were larvae of the northern quahog, *M. mercenaria*. This is based on the fact that, in terms of biomass, quahogs are dominant in Greenwich Bay. But in spite of the existence of materials to aid in the identification of various species of bivalves from their larvae (e.g., Chanley and Andrews, 1971), the visual discrimination of species—especially in early stage larvae—remains problematic. The bivalve larvae found in Greenwich Bay could conceivably be one of a number of species other than quahogs. These possibilities include oysters (*Crassostrea virginica*), scallops (*Argopecten irradians*), soft-shell clams (*Mya arenaria*), false quahogs (*Pitar morrhuanus*), mussels (*Mytilus edulis*), gem clams (*Gemma gemma*), or nut clams (*Nucula annulata*), among others.

A number of new approaches are being attempted to differentiate larval species. Use of computer-imaging software to accurately measure length and shell-height ratios from microscopic images may make the use of published identification aids more useful. Recently, fluorescent antibodies have been developed that are specific for detecting scallop (*Placopecten magellanicus*) larvae (Demers et al., 1993), and this approach may be useful for identifying quahog larvae (Feller, 1986). Scanning electron microscopy of larval hinge structures has been shown to be useful for identifying individual species, but the key drawback is that it is too cumbersome for routine identification of large numbers of larvae (Lutz et al., 1982; Tremblay et al., 1987). It is probable that techniques for discriminating genetic markers, either through DNA or expressed proteins, will allow species-specific identification of bivalve larvae (see Twombly and Goldsmith, this volume).

In summary, the key period of bivalve spawning in Greenwich Bay is during mid-June, as the water temperature reaches 20C. There is no shortage of bivalve larvae in the water during spawning events, so it is unlikely that lack of broodstock hinders quahog recruitment into Greenwich Bay. And finally, distributions of bivalve larvae in Greenwich Bay are not uniform. There is an apparent lack of bivalve larvae in coves with high numbers of large adult quahogs that are the presumed broodstock. The explanation for this discrepancy remains unclear.

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Questions and Answers

Q: (Robert Rheault, Ocean State Aquaculture Association (OSAA))
Your data, along with Najih Lazar's, seem to show an inverse relationship between adult abundance and larval abundance. A number of studies that I have read suggest that adults may be filtering the larvae out of the water. Can you comment on this?

A: (Michael Rice) Yes, that's a possibility. Another possibility might be crowding effects that somehow reduce the fecundity of the animals. Another possibility might be that larvae are killed by certain pollutants in coastal runoff, but the adults are not. There could be a number of explanations.

Q: (Joseph DeAlteris, URI department of fisheries, animal and veterinary science (FAVS)) It seems that you are working in the water column here, and there are a great many studies that have focused on adult populations. I think that a missing part of the puzzle is just how many larvae are actually settling and metamorphosing. There is one researcher at Brown—Steve Gaines—who has used formalin-filled settlement traps to look at crustacean settlement. Has anyone done this with quahogs, to answer the question about how many are actually reaching the bottom?

A: (Rice) Yes, there is a researcher at the University of Connecticut at Avery Point—Robert Whitlatch—who has used settlement traps to look at settlement of a number of invertebrates, including *Mercenaria*.

Q: (DeAlteris) Don't you believe that this type of information is of interest, particularly since there is good evidence that adult quahog abundance is strongly influenced by post-settlement survival? So the question might be: How many settle and how many of those survive?

A: (Rice) You are absolutely right. This is an area of research that deserves much more attention

than it has received. But I caution that these types of studies are difficult—not intractable, just difficult. From the data presented, we can see that there is probably a great deal of mortality in the larval stages. I would not be surprised at all if similar high mortalities are found among fresh post-set animals. We need the data.

Q: (Wayne Durfee, professor emeritus, URI) I was surprised by the data showing less larvae in the coves. Is there a possibility that freshwater runoff killed larvae or outgoing tides swept the larvae into the open bay?

A: (Rice) The freshwater runoff killing the larvae is unlikely. There were no major rainfall events around the data collection periods, and our salinity measurements in the coves were only one or two parts per thousand less than the open bay. The tidal flushing hypothesis may be a possibility. During the next Sea Grant funding cycle, there is a group proposing a major study of the hydrodynamic flow patterns in Greenwich Bay. Their data may be useful for answering this question. But I was particularly struck by the time-series data. Larvae seemed to be consistently lower in numbers in the coves from week to week.

Q: (John Williams, Warwick Cove Marina) Did you take any temperature measurements?

A: (Rice) Yes we did, and our data showed what is already well-known from the literature. Once the water temperature reached about 20 C, the spawning commenced.

Q: (Williams) Was there any temperature disparity between the coves and the open bay?

A: (Rice) Not very much.

A: (Joseph Goncalo) On any given day, the temperatures in the coves did not vary by more than 1 C from the open bay sites. Also, sampling was always done on an incoming tide, so the likelihood of larvae being swept out from the coves is not high.

Q: (Kim Tetrault, FAVS) Dr. Rice, you did a study of quahog recruitment in Greenwich Bay in 1988, right?

A: (Rice) No, it was a study of adult populations and juveniles greater than 5-mm valve length.

Q: (Neal Perry, Rhode Island Divers Association and OSAA) Getting back to Bob Rheault's question. We have an idea how many quahogs are in the coves, and an idea of how much water might be pumped by individuals. Would it be feasible to calculate the amount of water filtered during a tide cycle?

A: (Rice) Yes, we have enough data to make those types of feasibility calculations. I suspect that water filtered by the quahogs will be in the same ballpark as the amount of physical water exchange during a tidal cycle. This is true of the quahog population in the Providence River.

Comment: (Jeffrey Kassner, Town of Brookhaven, N.Y.) I think one of the key factors to remember is that there is a redistribution of quahogs when they are small post-set animals. Storms kick up the top layers of the sediment, and there is good evidence for secondary settlement. Larval abundances may not account for secondary redistribution. The other point I want to make is that larval abundances should be coupled with hydrodynamic models to make predictions as to sources and settlement areas.

A: (Rice) I agree.

Q: (Rod Pierce, shellfish aquaculture student) Do you have time-series data on the larvae?

A: (Rice) No, this is the first time we did this.

Q: (Pierce) So it is likely that the heavy set of littlenecks and top necks is from earlier years?

A: (Rice) Yes. It is very likely that recruitment has been occurring annually in Greenwich Bay since before shellfishermen started shellfishing. If recruitment were not relatively constant, the million-pound-per-year harvests would not be sustainable for as long as they have been. There is evidence for very sporadic quahog recruitment into other areas. (Editor's note: See paper by Steve Malinowski in the *Proceedings of the Second Rhode Island Shellfish Industry Conference.*) What makes Greenwich Bay such a great area for recruitment is a real mystery.

Q: (Pierce) Would you hazard a guess as to the cause of the lack of larvae in the coves?

A: (Rice) No, these are just observations. I don't want to commit to any particular explanation without more data.

Population Genetic Analysis of *Mercenaria mercenaria* in Narragansett Bay: Questions, Techniques, and Proposed Research

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Abstract ■ *Harvests of the northern quahog,* Mercenaria mercenaria, *the most valuable commercial fishery in Narragansett Bay, have declined during the 1990s. The future of this fishery depends critically on development of an effective management strategy. Investigations of the quahog's population genetic structure—and particularly, identification of brood stocks and assessment of the impact of overfishing—play a critical role in the formulation of such policy. Many aspects of the biology of* M. mercenaria *increase the likelihood that established molecular genetic techniques can provide population-specific markers—markers that can be used to identify the origin of new recruits and to quantify loss of genetic variation due to overfishing. We outline the genetic techniques available and briefly describe our plans to use two of these techniques—allozyme electrophoresis and randomly amplified polymorphic DNA (RAPDs)—to investigate the population genetic structure of* M. mercenaria. *Our ultimate goal is to develop a suite of molecular tools that can be used for effective management of a variety of commercially important species in Narragansett Bay.*

Introduction

Many problems in fisheries science center on the genetics of natural populations and on the ability to discriminate among individuals or populations over spatial and temporal scales (Wirgin and Waldman, 1994). Individual growth, survival, and reproductive output depend directly on levels of genetic diversity or heterozygosity, which also determine a population's resilience to environmental change. The degree of genetic differentiation among populations of a species—due to isolation or to selection—indicates the rate at which individuals adapt to local environmental conditions, the amount of inbreeding present (and thus loss of vigor due to inbreeding depression, e.g., Neal, 1935; Mukai, 1964) and the dynamics of recruitment. For example, a species whose recruitment depends on input from only one or a few subpopulations may be more vulnerable than one in which many populations contribute to overall dynamics. An important consequence of genetic differentiation among populations is that individuals or populations can be identified, providing the possibility of identifying brood stocks, and of answering a number of important management questions.

The increasing importance of effective management practices for species of commercial importance has resulted in the widespread use of genetic techniques to understand and to manage exploited species (see Wirgin and Waldman, 1994). These techniques rely on markers that use gene products such as proteins (enzyme electrophoresis) or nuclear and mitochondrial DNA molecules directly (DNA sequencing, restriction fragment length polymorphisms, randomly amplified polymorphic DNA). Although these techniques are routinely used to investigate population dynamics (see Harrison, 1989; Wirgin and Waldman, 1994), they have not as yet been applied to commercially important species in Narragansett Bay.

Mercenaria mercenaria provides the most important commercial fishery in Rhode Island, based on biomass landed, catch value, and the number of fishermen supported (Rice and Grossman-Garber, 1993). Considerable data on abundances, growth rates, and fishing pressures exist for sub-

populations of *M. mercenaria* throughout the Bay (e.g., Campbell, 1959 a,b,c; Canario and Kovach, 1965 a,b; Saila et al., 1967; Sisson, 1977; Rice et al., 1989; Pratt et al., 1992). However, questions concerning patterns of recruitment and the identification of subpopulations contributing new recruits are as yet unanswered (Rice, 1993), despite their importance to the maintenance of harvestable populations.

Our goal is to use molecular genetic techniques to address important basic and applied questions for *M. mercenaria*. In this paper, we first outline questions or issues that lend themselves to genetic analysis. This is followed by a brief review of aspects of the biology of *M. mercenaria* that enhance the potential for producing genetic differences among populations and for identifying specific populations (thereby allowing for the identification of brood stocks or particularly vulnerable populations). Finally, we describe the genetic techniques that can be used to address these questions. Preliminary investigations indicate that two of these techniques will work well with *M. mercenaria* in Narragansett Bay.

Population Structure: Genetics and Practical Applications

M. mercenaria occupies diverse habitats in Narragansett Bay, which divide this species into many subpopulations. Pressing management issues depend directly on this spatial population structure. From the perspective of the entire Bay population, individual subpopulations form the basis for the quahog fishery, and may freely mix (and therefore be genetically uniform), or may effectively be isolated from one another and genetically distinct. The degree of differentiation among subpopulations tells us a great deal about the extent of larval dispersal and exchange, and whether a few or all subpopulations contribute new recruits to areas open for fishing. In addition, each subpopulation may be genetically diverse (heterozygous) or genetically uniform (homozygous).This information is important, as heterozygotes are more vigorous, grow faster (e.g., Zouros et al., 1988; Gaffney et al., 1990; Pogson and Zouros, 1994), survive better, and are more fecund than homozygotes (e.g., Zouros et al., 1980; Koehn and Gaffney, 1984; Koehn et al., 1988). Moreover, genetically diverse populations may be more resistant to environmental changes or disturbance (such as fishing) than are genetically uniform populations (Philipp et al., 1993).

Answers to these issues can form the basis for assessing a number of management questions that gain added importance as evidence of declining populations in Narragansett Bay accumulates (Rice and Grossman-Garber, 1993; contributions to this symposium). Should specific subpopulations (major "brood stocks") be protected from fishing, or their habitats targeted for environmental restoration? Should currently profitable subpopulations continue to be fished heavily? Some studies suggest that overfishing reduces levels of genetic variation (see Smith et al., 1991), and that existing levels of diversity indicate whether a population shows signs of overfishing, can sustain further fishing, or can recover if fishing is suspended. How much additional fishing can be supported by currently exploited subpopulations? How rapidly will harvested subpopulations recover from heavy fishing or overfishing? An understanding of the genetic structure of *M. mercenaria* can also identify individuals (genotypes) that will be best suited for aquacculture programs (Dillon, 1992).

Each of these questions targets the poorly understood aspects of the biology of *M. mercenaria* in Narragansett Bay, and each relies on the ability to identify genotypes and to discriminate genetically between subpopulations of the same species, or between individuals from the same population.

Potential for Genetic Variation in *Mercenaria mercenaria*

Why is *M. mercenaria* a good subject for these questions and for the application of molecular genetic techniques? Aside from its commercial importance in Narragansett Bay, many aspects of its biology increase the likelihood that subpopulations are differentiated to some extent, and that genetic techniques will identify specific genotypes or subpopulations. The habitats occupied by *Mercenaria mercenaria* in Narragansett Bay cover a spectrum of natural environmental conditions (temperature, salinity, turbidity, sediment characteristics),

population sizes, fishing or natural predatio pressures, and pollution levels. These habitats represent divergent selection pressures that may encourage genetic differentiation among subpopulations. For example, sediment or bottom characteristics, the kind and abundance of natural predators, and levels of toxins or pollutants all allow for differential growth and survival rates (reviewed in Rice and Pechenik, 1992). Population density has a large effect on survival of new recruits (Bricelj, 1993; Malinowski, 1993), so that habitats of differing population sizes (or population age or size structure) will have different inputs of new recruits each year. In addition to this spatial variation, major recruitment events in *M. mercenaria* may be sporadic (Malinowski, 1993), adding an important temporal component to long-term population dynamics.

The physics of water movement in the Bay may further encourage isolation among subpopulations. Despite studies showing that larvae can be dispersed by wind or currents throughout estuaries like Narragansett Bay (e.g., Wood and Hargis, 1971; Andrews, 1983), a recent study on the barnacle *Semibalanus balanoides* (Gaines and Bertness, 1992; Bertness and Gaines, 1993) shows genetic differences between subpopulations from Mt. Hope Bay and Little Compton, within Narragansett Bay. The authors claim that flushing rates in Mt. Hope Bay are low enough in some years (years with low rainfall and low freshwater runoff) to effectively isolate its barnacle subpopulation from subpopulations in lower portions of the Bay. These low flushing rates, together with the overall current flow in the Bay (in through the East Passage and out of the Bay through the West Passage) may further prevent free larval exchange, and may encourage isolation among subpopulations.

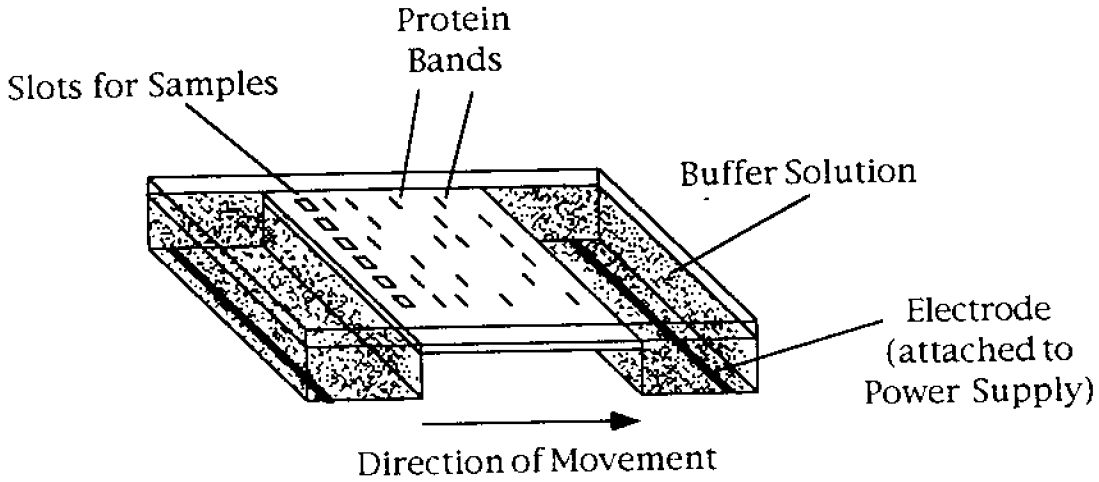
When habitat variation, population size and structure, current patterns, and dispersal abilities are taken together, the resulting potential for genetic divergence among subpopulations of *M. mercenaria* provides a strong rationale for being able to use genetic markers to identify specific populations and to answer the kinds of questions posed here.

Genetic Techniques

Enzyme Electrophoresis: Molecular genetic techniques used in population studies differ in their ease of application, cost, and in the level of genetic resolution produced. Enzyme electrophoresis was the first method used to detect genetic variation in natural populations (Hubby and Lewontin, 1966; Lewontin and Hubby, 1966; Harris, 1969), and studies using this method have revealed large amounts of genetic variation in diverse natural populations (e.g., Clegg and Allard, 1972; Richmond, 1972; Powell, 1975; Levin, 1978; Lewontin, 1978; Nevo, 1978). This technique is based on the idea that one gene codes for one protein (enzymes are most commonly used), and a slight change in a gene (a mutation) will therefore code for a slightly different form of the same enzyme (called an allozyme) that often has a slightly different electrical charge. Differences between two or more allozymes are detectable as proteins that migrate different distances when subjected to an electrical field. The result is a series of bands on a gel matrix (Figure 1), with differing banding patterns representing individuals having different genetic makeups. A wide range of enzymes are detectable by their biochemical reactions and can be analyzed in natural populations. Quantification (or scoring) of the resulting gels allows identification of genotypes in a subpopulation, measurements of the amount of genetic variation present in a single subpopulation, and quantification of differences between subpopulations or populations of the same species.

Although we now know that a single protein is not encoded by a single gene, and that other assumptions underlying the technique are questionable (see discussion in Hartl and Clark, pp. 23–24), allozyme electrophoresis continues to be a relatively cheap, fast, and a powerful way to characterize the genetic structure of many populations, and has been widely used for marine bivalves (reviewed by Hilbish and Koehn, 1985; Koehn and Hilbish, 1987; Zouros and Foltz, 1987; Zouros et al., 1988; see also Dillon, 1991). For example, Koehn and colleagues used allozyme electrophoresis to document genetic variation in *Mytilus edulis* over a small spatial scale

Electrophoresis Setup



Typical Gel Pattern for dimeric enzyme

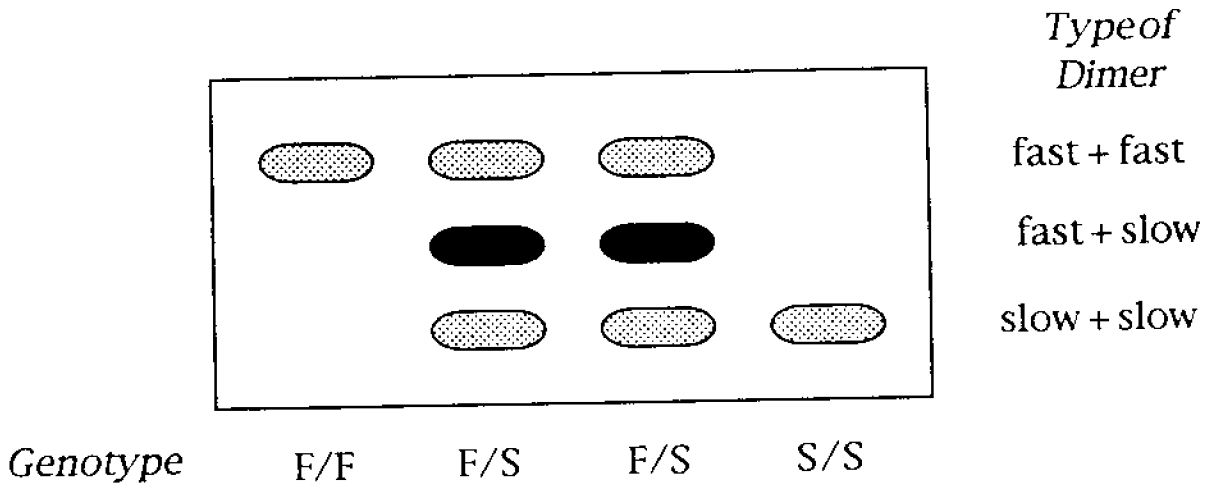


Figure 1.

in Long Island Sound (Koehn et al., 1980). The basis for this variation was post-settlement selection for one allele (or genetic form) of leucine aminopeptidase (Lap-94), which is present in highest frequencies in high-salinity environments. Genotypes carrying this allele suffer high mortality as salinity declines toward inner Long Island Sound.

Although there is still considerable controversy over whether the different enzymes detected by this method are themselves responsible for population attributes of ecological or practical importance (e.g., Pogson and Zouros, 1994; Mitton and Grant, 1984), enzymes clearly are extremely useful markers for distinguishing genetically different populations.

DNA Analysis: More recently, a variety of techniques have been developed that analyze DNA molecules directly, rather than analyzing the expressed products of genes. These are loosely classified as "fingerprinting techniques," because they can yield results that are unique to a single individual. Techniques based on DNA analysis are better able to detect variation in natural populations than allozyme electrophoresis, because they scan the DNA directly, examining both coding and non-coding portions of the genome—the latter of which are known to be more variable (e.g., Kreitman, 1983; Li et al., 1985; Aquadro et al., 1986). The ultimate level of DNA analysis is DNA sequencing, which identifies the order of the four possible bases (A, T, G, or C) along an entire molecule. DNA sequencing has proven extremely valuable in answering many evolutionary questions (see Hartl and Clark, 1989, for a review), but is time-consuming, technically demanding, and costly. Most population-level questions are adequately answered with somewhat lower levels of genetic resolution.

More commonly used techniques for population studies identify fragments of DNA produced by digestion with restriction enzymes that recognize and cut the DNA at specific sequences, generating restriction fragment length polymorphisms, or RFLPs. These will have different lengths when the base sequences at target sites differ, or if insertions or deletions have occurred between them. This approach is most easily used with mitochondrial DNA molecules, which are smaller in size (by several orders of magnitude) than nuclear DNA, and which evolve faster in most organisms (e.g., Avise, 1986; Brown, 1985). Analysis of mitochondrial DNA variation promises considerable advantages over allozyme electrophoresis for studying geographic structure of populations or subpopulations (Harrison 1989), but is primarily maternally inherited, and so leaves out an important component of genetic analysis—namely the participation of the paternal genome. Detailed sequence information about mitochondrial DNA molecules is also required to use this technique to its best advantage.

A second DNA technique that has gained significant popularity in recent years identifies fragments of nuclear DNA of varying length known as randomly amplified polymorphic DNA, or RAPDs, which are generated using specific, short, arbitrary DNA primers in the polymerase chain reaction (PCR). The primers are used to scan the entire DNA molecule and bind to all complementary target sequences, coding or non-coding. When two primers bind in opposite orientation within a critical distance of each other, the intervening DNA is copied by an added DNA polymerase, and the resulting fragments can be detected by electrophoresis, similar to allozymes. Because the arbitrary primers for the PCR reaction are relatively short (around 10 base pairs), mutations in the target DNA of the individual will result in a different number or size of fragments identified, due to alterations in priming sites, or, as with RFLPs, changes in the intervening DNA, yielding individual-specific patterns on gels (Figure 2). Although there still are some problems in interpreting RAPD bands—which may correspond to different sequences of similar lengths, this technique is especially attractive for ecological and population studies (e.g., Chapco et al., 1992; Hadrys et al., 1992), due to the relative ease of setting it up with any organism, using commercially available sets of primers, without knowing any specific characteristics of the organism's DNA; the relative speed and simplicity of performing the assay on many samples at one time; and because of the high degree of variation observed using different primers.

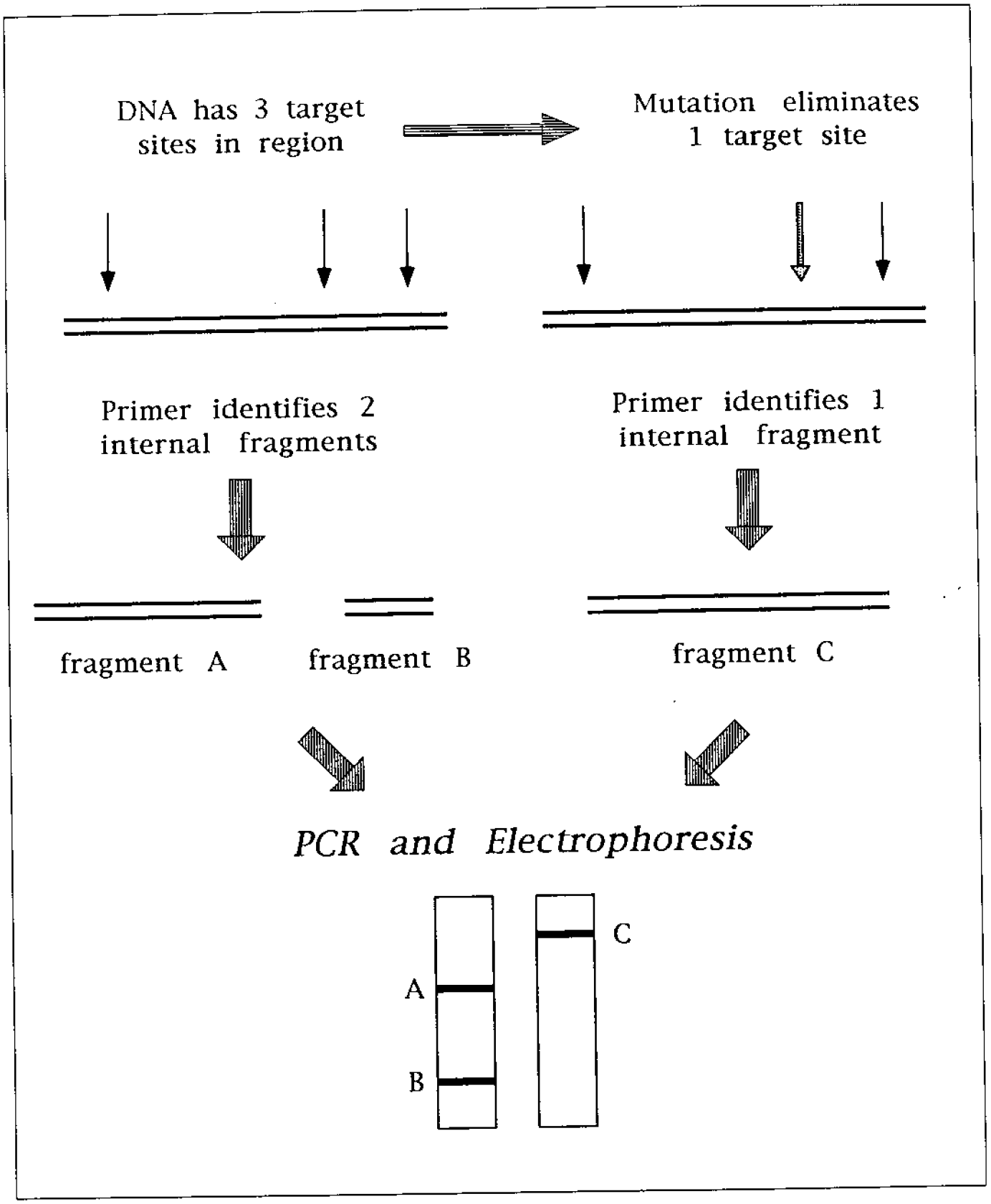

DNA has 3 target sites in region
Mutation eliminates 1 target site
Primer identifies 2 internal fragments
Primer identifies 1 internal fragment
fragment A
fragment B
fragment C
PCR and Electrophoresis
A
B
C

Figure 2.

Proposed Study

We plan to survey individuals from subpopulations distributed throughout Narragansett Bay, using two of the molecular techniques described here: allozyme electrophoresis and RAPDs. The first phase of our study will quantify the level of genetic differentiation among spatially discrete subpopulations, and will analyze the temporal stability of these subpopulations over a two-year period. These data will then be used (Phase II) to address the basic and applied questions raised above.

Allozyme electrophoresis has been used extensively to quantify genetic variation in marine mollusks, and published protocols (Dillon, 1991, 1992) greatly facilitate application of this method to *M. mercenaria*. Dillon reports results for 14 different enzyme systems, using starch gel electrophoresis. In a preliminary study of *M. mercenaria*, using a different protocol (cellulose acetate electrophoresis, Hebert and Beaton, 1989), we identified at least six polymorphic enzymes (phosphoglucoseisomerase, Pgi; phosphoglucose mutase, Pgm; malate dehydrogenase, Mdh; mannose-6-phosphate isomerase, Mpi; glutamate oxaloacetase transaminase, Got; and arginine phosphokinase, Apk) for two subpopulations (Wickford Harbor and Patience Island). We will assay individuals from specified subpopulations of commercial importance, such as Providence River, Mt. Hope Bay, and Greenwich Bay, for these and other polymorphic marker enzymes to measure allele and genotype frequencies over space and time. These data will quantify genetic differentiation among and within subpopulations, and may also provide the means to identify specific subpopulations by revealing localized, rare alleles (Slatkin, 1981, 1985) or distinctive localized allele frequencies.

To obtain a finer resolution of genetic differentiation in *M. mercenaria*, we plan initially to use anonymous nuclear DNA markers identified by the RAPD technique. This will entail screening single random oligonucleotides as primers for PCR, and analyzing the products of these reactions on standard agarose gels to look for ones that generate reproducible, distinctive patterns on sample DNAs. In preliminary studies, we have found that a published protocol for extracting DNA from mollusks (Winnepenninckx, Backeljau, and DeWachter, 1993) gives high yields of *M. mercenaria* DNA. We primed this DNA with four of the several hundred primers available; three yielded amplification products, while the fourth did not. Amplification of DNA extracted from two subpopulations (Pine Hill and Patience Island) showed considerable variation among individuals within each subpopulation, as well as between subpopulations, with both common and unique bands.

Future Prospects

Our preliminary investigations show abundant genetic variation in *M. mercenaria* in Narragansett Bay. A large number of enzymes and DNA primers remain to be tested to find subpopulation-specific markers. Enzyme electrophoresis is relatively easily accomplished and inexpensive, but provides a cruder level of genetic analysis than RAPDs. Analysis of nuclear DNA is more expensive and technically demanding, but provides a level of genetic resolution necessary to identify specific individuals. By using both techniques, we will maximize our ability to identify specific subpopulations (and thus "brood stocks"), to quantify levels of genetic variation (on spatial and temporal scales) throughout the Bay and, eventually, to test many of the questions raised earlier in this paper. Our long-term goal is to develop molecular tools that can be used to address basic and management questions for a variety of commercially important species in Narragansett Bay.

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Questions and Answers

Q: (Kim Tetrault, URI department of fisheries, animal, and veterinary science) From my experience, if you spawn one female and get 400,000 larvae, and treat the animals alike in terms of food, water conditions, etc., the animals will grow at vastly different rates. How do you handle genetic variability among individuals?

A: (Saran Twombly) The process of finding population-specific markers is more tedious than you might think. You may screen a large number of primers before you find one that is specific for populations. Many primers pick up individual variability, but the trick is to find one that "fingerprints" a population. With allozymes, the problem is even more difficult. Allozyme electrophoresis yields allele frequencies. For example, the Greenwich Bay population might be characterized by a high frequency of a specific allele or gene product, whereas quahogs from the West Passage may have a lower frequency of the same allele.

Q: (Walter Blogoslawski, National Marine Fisheries Service, Milford, Conn.) There is a genetic strain used by most quahog culturists called Mercenaria mercenaria notata. *It carries chestnut-colored shell markings, and is used by aquaculturists as an identifying mark for their stock. What kindof differences do you find in a "notata" strain? Or what kind of variation would you expect to find once you have selected for one trait, such as this color morph trait?*

A: (Twombly) The color morph is only one trait. My guess is that you can probably find a great deal of variation in other traits. Along another line, such rare color morphs or "color markers" are valuable in population studies to quantify the amount of gene flow or mixing among discrete subpopulations. In *M. mercenaria*, this color morph could be used, if placed in a specific location or subpopulation, to quantify larval dispersal from specific areas of the Bay.

(Discussion on this topic followed—Dr. Blogoslawski said that the "notata" strain is cultured in Connecticut, and someone from Rhode Island interjected that there are Rhode Island populations of "notata." These strains give us a known genetic and morphological marker to use in our studies.)

Editor's note: For discussion of "notata" frequencies and hatchery genetics, refer to C.M. Humphrey and R.L. Walker. 1982. The occurence of *Mercenaria mercenaria* form "notata" in Georgia and South Carolina: Calculation of phenotypic and genotypic frequencies. *Malacologia* 23: 75-79; and J.J. Manzi, N.H. Hadley, and R.T. Dillon. 1991. Hard clam, *Mercenaria mercenaria*, broodstocks: Growth of selected hatchery stocks and their reciprocal crosses. *Aquaculture* 94: 17-26.

Habitat Enhancement as a Means to Increase the Abundance of the Northern Quahog, *Mercenaria mercenaria*

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Abstract ■ *The northern quahog* (Mercenaria mercenaria) *has historically been a commercially important shellfish species harvested from the coastal waters of the East Coast of the United States. Because of the quahog's economic importance, there has been a longstanding interest in undertaking projects to augment the natural population abundance of this species. Population-based augmentation projects seek to increase the harvestable quahog population by adding more individuals to a habitat, while habitat enhancement–based projects seek to increase the harvestable population by increasing the "suitability" of benthic habitats to support a higher abundance of quahogs. A review of available information suggests that modifying the substrate by the addition of shell may be an effective habitat enhancement project. Habitat enhancement, however, is more than just manipulating habitat, and must occur in the context of comprehensive planning.*

Introduction

Projects to augment the naturally occurring abundance of quahogs in a population are generally popular undertakings because they are seen as an active solution to the "problem" of a low abundance of harvestable shellfish. Shellfish harvesters generally support projects to augment existing quahog populations because they offer the potential of sustained and possibly increased harvests, and, at the same time, provide an attractive alternative to many other management options, such as harvest restrictions. Population augmentation projects typically enjoy the political support needed for funding and regulatory approvals, because they are seen as protecting the viability of the shellfish industry, and because they benefit an important local constituency.

There is a fairly large and diverse number of population augmentation projects that offer at least some theoretical potential to increase the abundance of quahogs on the public beds. Determining which particular project to implement is not, however, an easy task for several reasons: decisions often need to be made without adequate information; there is often an extreme sense of urgency; the alternative projects vary with respect to cost and length of time required to achieve results; logistics may eliminate several potentially viable candidate projects; and some projects may be more acceptable to shellfish harvesters and/or regulatory authorities than others.

The decision first to implement population augmentation, and then the choice of which particular project to implement, is extremely critical. Most important, because the amount of money available for quahog management is generally fixed, the spending of certain funds to implement a population augmentation project often means that alternative management options and other augmentation projects may not be implemented. Additionally, if augmenting quahog populations becomes the cornerstone of a quahog resource management program, it may create a false sense of security, such that the implementation of other measures—which may, in reality, be more effective—is precluded. Thus, making the "wrong" choice can have negative consequences beyond simply not increasing abundance.

Augmentation projects to increase the size of harvestable shellfish populations in general, and

quahog populations in particular, can be divided into two basic strategies: population-based and habitat enhancement–based. The population-based augmentation strategy seeks to increase a harvestable quahog population by adding more individuals to a habitat. The habitat enhancement–based augmentation strategy seeks to manipulate ("improve") habitats so that they will be capable of supporting a higher abundance of quahogs. Habitat enhancement–based projects thus seek to take advantage of a quahog population's existing biotic potential that is "lost," while population-based projects seek to supplement the biotic potential of a quahog population.

Population-based projects, which include the planting of undersized (seed) quahogs, spawner transplants, and relays, have been extensively studied, and have been undertaken in a number of locations, often with considerable success (COSMA, 1985). Habitat enhancement–based projects, even though offering a number of advantages, have received comparatively little attention, and the results of only a few habitat enhancement projects have been reported. This paper will provide a general overview of quahog habitat enhancement as a means to augment quahog populations. It will also review the planting of shell as one example of a potentially effective large-scale habitat enhancement project, and will offer a protocol for undertaking habitat enhancement.

Quahog Habitat Requirements

In order to undertake projects to enhance habitat and thereby increase the abundance of quahogs, the habitat requirements of the quahog must first be identified. Useful information can be obtained from two sources—the distribution of quahog abundance with respect to environmental conditions and the environmental biology of the quahog. By knowing what factors are associated with high quahog abundance, and then what factors are absent from a particular habitat, a habitat enhancement project can be designed.

Although the quahog is widely distributed, the abundance of quahogs varies considerably from one habitat (eelgrass beds, mud bottoms, relict oyster reefs) to another. Thus, within the quahog's geographic range, the different habitats have a different "suitability" with respect to quahogs, and this suitability determines the abundance of quahogs. The objective of habitat enhancement is, therefore, to manipulate habitat characteristics so as to increase the habitat's quahog suitability, and thereby transform a habitat with low suitability and low quahog abundance into one with high suitability and high quahog abundance.

While many factors influence the size of a quahog population, the distribution of the abundance of quahogs is closely related to the distribution of substrate type. Wells (1956) observed in Chincoteague Bay, Md., the highest density of adult quahogs in sand and sand/shell bottom. In Christmas Bay, Texas, the highest abundance of quahogs was in sediment containing shell fragments (Craig and Bright, 1986). In Great South Bay, N.Y., quahogs were distributed throughout the bay, but areas of muddy sediments and of sandy sediments lacking shell had lower abundances of quahogs relative to areas of sandy sediment containing shell (Kassner et al., 1991). In Delaware Bay, quahogs were most common in and near oyster bars, and oystermen considered old, noncultivated oyster beds as productive sites for the harvest of quahogs (Maurer and Watling, 1973). Similar patterns have been reported by Pratt (1953), Walker and Tenore (1984), Saila et al. (1967), and Carriker (1961).

Numerous studies have been undertaken on the environmental biology of the quahog, and many are relevant to the enhancement of quahog habitats. The following observations are particularly noteworthy:

1. Newly set quahogs seek out hard surfaces covered with a thin layer of material into which they burrow and then anchor (Carriker, 1961).

2. In laboratory experiments, quahogs set at higher densities in sand substrates than in mud substrates and appeared to be gregarious (Keck et al., 1974).

3. In flume experiments, quahog settlement appears to be passive, that is, determined by flow conditions and not by larval choice (Batchelet et al., 1992).

4. Shells and gravel offer the quahog refuges from predation (Sponagule and Lawton, 1990).

5. Quahog growth and survival is reduced in the presence of organisms causing bioturbation (Murphy, 1985).

6. Quahog settlement appears to be reduced by the presence of adults and other filter feeders (Maurer, 1983).

Shell Planting as a Habitat Enhancement Option

Based on the distribution of quahog abundance and the environmental biology of quahogs, substrate modification—through the addition of shells to low-quahog-abundance sediments lacking shell—would appear to be an effective approach to habitat enhancement. Several anecdotal reports provide support for this approach. In Long Island Sound, for example, shell (cultch), distributed on the bottom to provide substrate for oysters to set upon, was also associated with increased quahog abundance (Volk, 1986). In the Broadkill River, Del., quahogs were found in an area that had been recently covered with surf clam shells to create oyster habitat (Maurer and Watling, 1973).

There have been three reported pilot-scale projects that added ("planted") shell to bottom sediments in order to increase quahog abundance. In North Carolina, in the early 1970s, Parker (1975) planted scallop shells at a density of .081 cubic meters (m^3) of shell/m^2 of bottom, and found that the average initial recruitment was 10 times greater in the planted shell than in an unshelled control. In 1989 in the Great South Bay, N.Y., 100 m^3 of surf clam shells were planted in two 0.4-hectare (ha) plots located in muddy, low-quahog-abundance areas that lacked shells (Kassner et al., 1991). The planting, however, did not result in increased quahog abundance, because the shell sank into the bottom and the project's scale was deemed to be too small to give meaningful results (Kassner, unpublished). In 1990, 120 tons of clam shell were planted in Barneget Bay, N.J., in six plots, each measuring 20 m by 70 m (Cronin, 1990). Three of the plots were covered with "heavy" shell, and three were covered with "light" shell, while three unshelled plots served as controls. Three years later, the shelled plots had slightly more than five times more recruits than the unshelled control (Clyde MacKenzie, National Marine Fisheries Service, Sandy Hook, N.J., personal communication).

A Recommended Protocol for Habitat Enhancement

Based on the pilot projects and what is known about quahog biology, shell planting as a habitat enhancement project appears to offer considerable utility as a quahog management tool. However, successful habitat enhancement requires more than just manipulating habitat to improve its suitability for quahogs, as the project must also be acceptable to shellfish harvesters and other groups that may be directly or indirectly affected, as well as to fishery managers and environmental regulators. Because even the most technically sound habitat enhancement proposal is likely to be blocked by any opposition that develops, bringing these groups into the decision-making process is critical, and obtaining their support and concurrence is essential.

Therefore, the successful implementation of a habitat enhancement project for the quahog or any other shellfish species requires a comprehensive planning process that integrates biology and ecology, management goals, design constraints, and user- and interest-group concerns. The following sequence of steps is presented as one possible comprehensive planning protocol:

Step 1. A preliminary assessment of existing conditions is undertaken to determine if habitat suitability is limiting the size of the quahog population. If habitat manipulation appears to be viable, then the planning process for a habitat enhancement project can continue. If habitat enhancement does not appear to be viable, then consideration can be given to population-based enhancement strategies.

Step 2. Having identified a specific habitat enhancement project, it is necessary to develop the project's goals, objectives, and scope, in order to provide a basis by which the project can be evaluated. It is also beneficial to establish what level of increase in quahog abundance can reasonably be anticipated from the habitat enhancement project, so as to minimize the dangers of unrealistic and unfufilled expectations. Concurrently, all involved and interested groups are brought into the

planning process, and alternative and potential funding sources contacted.

Step 3. The design of the project is finalized, making sure that locational, budgetary, logistical, engineering, and maintenance considerations have been taken into account. The regulatory approvals and funding commitment are obtained. Consultation with interested groups and involved parties is continued.

Step 4. Once regulatory approvals and funding are secured, and assuming any opposition to the project has been addressed, the implementation of the project is initiated. Considerable oversight must be provided during implementation to ensure that what is actually undertaken matches the project's design.

Step 5. Following implementation, the project is monitored to provide information to determine the project's contribution to the quahog population. Engineering and logistical aspects are evaluated, and consideration given to any input from the shellfish industry. Based on this information, together with a cost-benefit analysis, a decision is made to expand the scale of the project, modify its design, or abandon it entirely.

Discussion

The planting of shell to improve the suitability of quahog habitat appears to have considerable potential as a means to increase the abundance of quahogs. How shell planting brings about an increase in quahog abundance is not readily apparent, and there are several possible mechanisms. In the final analysis, however, the reason why it, or any other enhancement project, is successful is not as important as the fact that it is successful.

For the quahog, shell planting to enhance habitat suitability offers a number of benefits as a management tool. Shell planting should be self-sustaining and long-term, so that future recurring expenditures will be minimized. It can be used to replace or restore habitat that has been degraded, and it can be used as a mitigation measure to compensate for the closure of high-abundance shellfish beds when they do not meet water quality standards.

There are several other positive aspects of using shell to enhance quahog habitats that are worth noting. In some areas, the disposal of shell by shellfish processors is a problem, and using shell to create quahog habitat provides a beneficial use of what would otherwise be a solid waste. Shell is a natural component of sediments, so that the addition of shell would not be expected to have any significant adverse environmental impacts, and shell should not pose a significant obstacle to the harvest of quahogs. Finally, it should be possible to undertake shell planting on a large enough scale to make a meaningful contribution to the quahog harvest.

Habitat enhancement is used for other species of shellfish. Shell planting is a traditional and well-accepted oyster management practice. Habitat enhancement by substrate modification has also been used on the Pacific coast of the United States to enhance the abundance of another clam species, the Manila clam (Thompson and Cooke, 1991). Between 1974 and 1988, nine Washington-state beaches, with a total area of 6 ha, were covered with gravel to depths ranging from 13 to 60 centimeters. Beach graveling was found to increase Manila clam on the order of two to 10 times over ungraveled beaches. According to Toba et al. (1993), most of the productive clam beds are already being cultivated, and any significant increase in clam production will come from the enhancement of less-productive beds.

Given its potential, it is not obvious why the habitat enhancement–based strategy has not received as much interest as the population-based strategy. One possibility is that population-based augmentation directly and visibly adds more shellfish, and is more immediate and tangible than habitat enhancement, which is not as obvious, and more long-term and indirect. A second possibility is that population abundance is perceived as being more limited by the supply of individuals to a habitat than by habitat conditions, making population-based augmentation more philosophically compatible. In the particular case of seed clam planting, this population-based strategy is the beneficiary of the promise of mariculture technology and an extensive mariculture research effort. Finally, it may simply be because habitat enhancement is a nontraditional quahog management activity, and there is an underlying resistance to change.

In conclusion, one cautionary note is in order. Projects that augment the natural quahog population are generally seen as a panacea to the problem of low shellfish abundance, but the basic assumptions have not been adequately evaluated. In particular, population augmentation is premised on the basic, but largely untested, belief that the environment is capable of sustaining a higher level of quahog abundance. However, if the maximum abundance of quahogs is determined by prevailing environmental conditions, it may well be that augmentation projects will only be successful when environmental conditions naturally favor a high quahog abundance and not when natural quahog production fails. Thus, population enhancement may not work when it is most needed.

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Questions and Answers

Comment: (Joseph DeAlteris, URI department of fisheries, animal, and veterinary science) We seem to be putting a lot of faith in habitat enhancement without stepping back to analyze underlying causes. There is evidence of greater recruitment in coarser sediment environments. But, coarser sediment environments are usually associated with higher-energy hydrodynamic conditions. Perhaps there is greater recruitment because the higher-energy hydrographic conditions somehow clean things out or bring more food. An example may be some artificially created oyster reefs in Chesapeake Bay. The oyster industry has created numerous artificial reefs in low-energy hydrographic areas by placing about 5,000 bushels of oyster shells/acre, but in most cases there has been relatively little spatfall of natural oysters. These artificial reefs are generally used for placement of seed oysters from elsewhere for final grow-out.

A: (Jeffrey Kassner) You are absolutely right; however, I wish to point out that we really need to get away from such methods as seed clam planting and relays, which don't work very well. The oyster industry along Long Island Sound has been planting cultch for 150 years, and it does seem to work. What we need to do is refine our ideas about where we put the enhancement projects. It is clear that placing shell on any bottom type and expecting increases in quahog recruitment is rather foolish. I think that time should be spent working on the details, but I think it is an option that we should not overlook.

Q: (name not stated) What are you going to do differently in next year's shelling project?

A: (Kassner) I don't think that shell planting in a very muddy-bottom area is the best way. We're going to look for firmer-bottom areas and we are not going to plant shell only, but a mixture of sand and shell. It is not entirely clear what the role of the shell is. At least in the case of relict oyster reefs, we often find them topographically elevated from the rest of the bottom. Shell in those areas is usually covered by 1 or 2 centimeters of sediment. Perhaps we are looking to "roughen" up the bottom, thereby creating improved hydrodynamic conditions in the near-bottom water.

Q: (name not stated) How do you expect the quahogs to be harvested from the shelled areas?

A: (Kassner) I have found shellfishermen to be incredibly creative when it comes to harvesting shellfish. If we are careful not to plant the shell too thickly, I don't think that the industry will have any problem getting the shellfish out.

Q: (Gerald Carvalho, shellfisherman) Have you done anything with just "cultivated bottom?"

A: (Kassner) I have not. One of Joe DeAlteris' students reported at the last Rhode Island conference (1992) such a study. To my knowledge, projects of this type have not worked very well.

Q: (Gregg Rivara, Cornell Cooperative Extension, N.Y.) Where do you think the larvae go if the shell weren't there? Wash out to the ocean?

A: (Kassner) They probably just die.

Q: (Rivara) Yes, but what if the larvae originate in one area and are destined for settlement in the usual place, but they are intercepted by the new shell. Something of larval stealing!

A: (Kassner) I haven't thought of it that way, but with the great numbers of larvae available it is most likely that they are in such great excess that the "larval stealing" scenario would be pretty unlikely. I don't envision larval supply being a limiting factor. The converse of this is if you increase the geographic extent of the spawning population, you further increase the larval supply.

Trends in U.S. Clam Production and Marketing

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Abstract ■ *Total landings of clams in the United States have risen dramatically since the 1950s, largely due to the increased production of ocean quahogs* (Arctica islandica) *and surf clams* (Spisula solidissima). *Landings of the higher-valued northern quahogs* (Mercenaria mercenaria) *and soft-shell clams* (Mya arenaria) *have decreased significantly in the last decade, due to many factors, including habitat degradation and overfishing. Meanwhile, aquaculture of clams—mainly* M. mercenaria—*in the United States has increased steadily. This paper provides a broad overview of trends in clam production and marketing in the United States, along with insight into consumer perceptions of clam products. Results of two recent surveys examining consumer perceptions of seafood safety and aquaculture suggest that (1) consumers in the Northeast perceive some risk in consuming clams; and (2) they perceive aquacultured clams to be better, safer, or more protected from pollution than wild-harvested clams. The adoption of a more consumer-oriented approach to shellfish marketing that focuses on product quality, packaging, and consumer education will be essential for competing in the domestic and global marketplace.*

Introduction

Total U.S. clam landings have increased dramatically since the 1950s. Much of this is due to large increases in the production of surf clams (*Spisula solidissima*) and ocean quahogs (*Arctica islandica*), which typically are used for processed clam products. Meanwhile, the higher-valued species—soft-shell or steamer clams (*Mya arenaria*), and northern quahogs (*Mercenaria mercenaria*), often known as hard clams or hard-shell clams (terms used interchangeably in this paper)—have seen substantial decreases in landings over the last decade, due to a variety of factors, including disease, overfishing, and habitat degradation. Clam aquaculture, particularly that of quahogs, has experienced some success with a resultant steady increase in production during the past decade.

Increased consumer concerns about seafood safety highlight a need for innovative marketing of clam products and consumer education. This paper provides a brief overview of trends in U.S. clam production, with a focus on the Northeast. Consumer perceptions of seafood safety and aquaculture are discussed, along with results of two recent consumer surveys, and implications for the marketing of clam products.

U.S. Clam Production

Total U.S. clam landings have experienced an erratic, but overall, increase in production over the last 35 years (Figure 1). Much of this increase is due to expanded production of ocean quahogs in response to stringent regulations imposed on the surf clam industry in the late 1970s.

While ocean quahogs and surf clams account for the bulk of clam landings in the United States, soft-shell clams and hard-shell clams are the higher-valued, premium products. Hard-shell and soft-shell clams accounted for an average of 15 percent of the total U.S. landings since 1980. However, these high-value species made up an average of 57 percent of the total value (Figure 2).

Maryland, Massachusetts, and Maine are the leading suppliers of soft-shell clams (steamers). Steamer clam production has declined steadily from a 13.5-million-pound (meat weight) peak in

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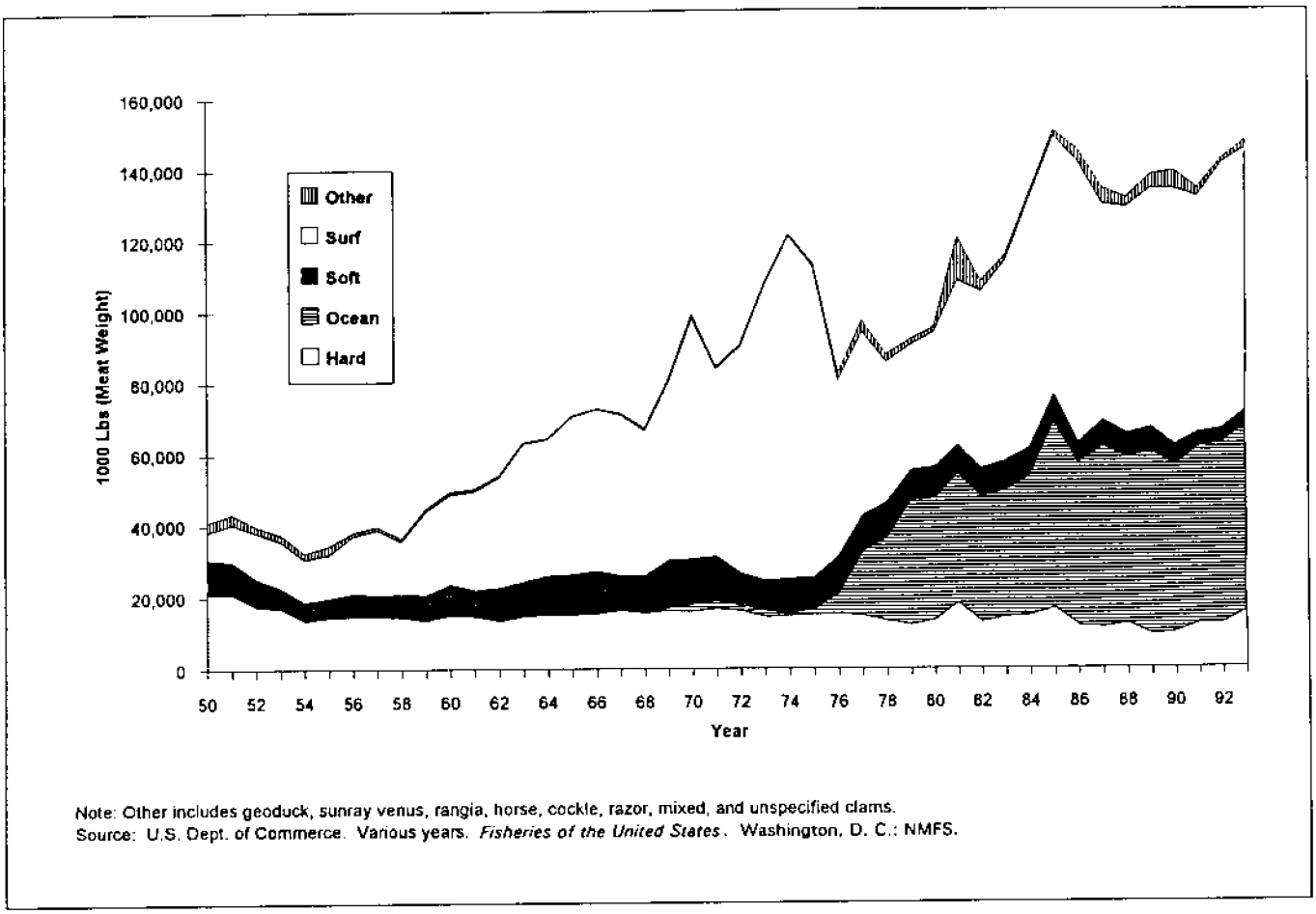


Note: Other includes geoduck, sunray venus, rangia, horse, cockle, razor, mixed, and unspecified clams.
Source: U.S. Dept. of Commerce. Various years. *Fisheries of the United States*. Washington, D. C.: NMFS.

Figure 1. U.S. clam landings 1950–1993.

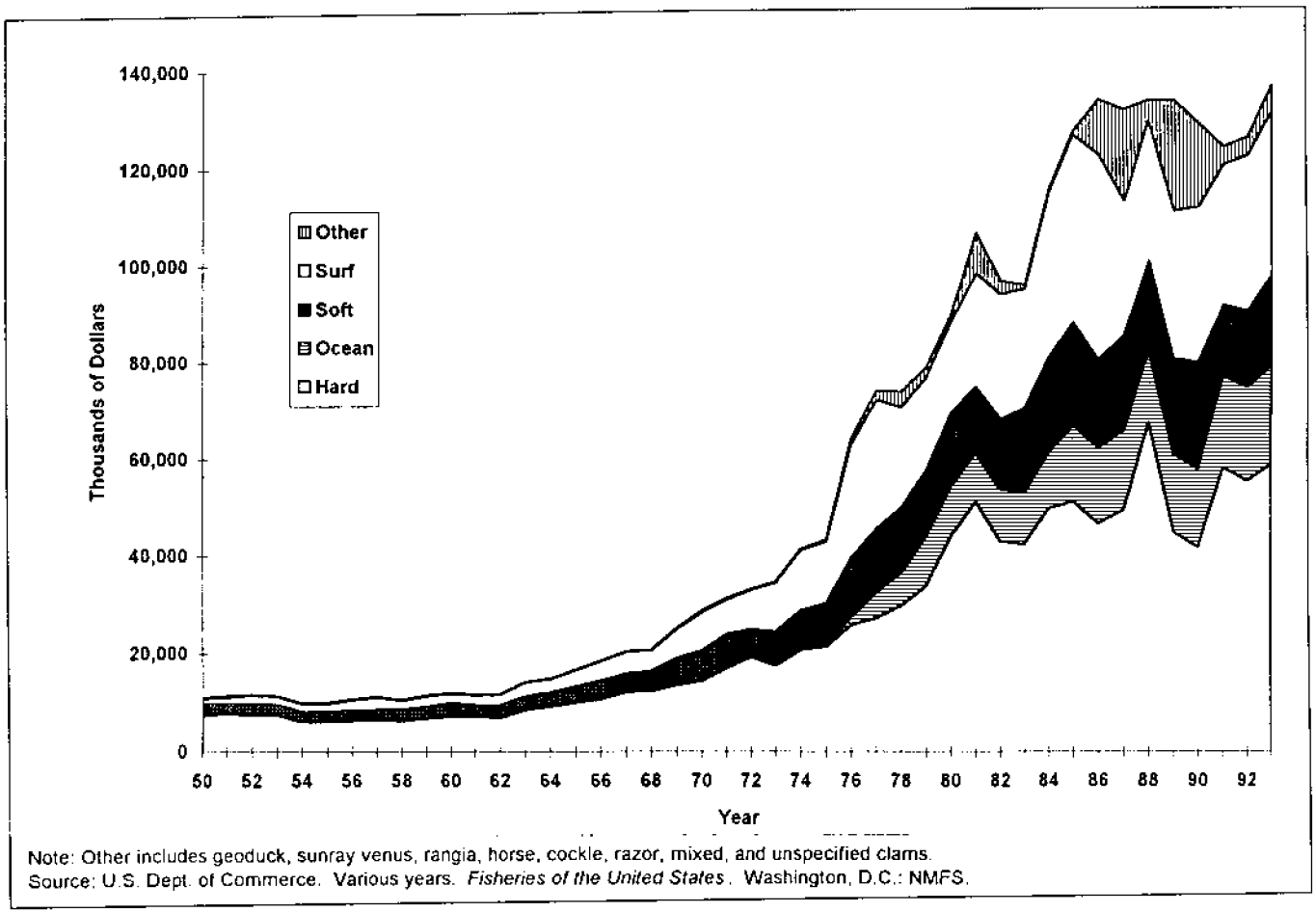
1969 to a low of 3.9 million pounds in 1992 (USDC, various years). Steamer production rebounded slightly in 1993 to 4.5 million pounds.

U.S. Hard Clam Production

Landings of hard clams have historically been concentrated in the Northeast, mainly in New York, Rhode Island, and Massachusetts. However, due to aquaculture, hard clams are now produced all along the East Coast, from Maine to Florida. Since 1980, hard clams have accounted for an average of 10 percent of the total clam landings, but 42 percent of the total value (USDC, various years). In fact, hard-shell clams are the most highly valued species of clams produced in the United States. Since 1980, hard clam landings have exhibited dramatic increases and decreases in annual production. For example, landings in 1981 increased 36 percent, to 18 million pounds, their highest level in almost three decades (USDC, various years). After peaking again in 1985, hard clam landings fell sharply to a low of 9.2 million pounds in 1989. Landings have since slowly increased to 15.6 million pounds, at a value of $59.1 million in 1993 (USDC, various years).

Rhode Island landings of hard clams are down significantly from the high levels exhibited in the early 1980s (Figure 3). The year 1983 saw a peak in production of hard clams in Rhode Island, with landings of 4.3 million pounds at a total dockside value of $10.3 million (National Marine Fisheries Service, Fisheries Statistics Division, personal communication; A. Valliere, personal communication). Landings have since declined to a low of 1.7 million pounds, at a dockside value of $8.2 million. This represents a 59 percent decrease in landings since 1983, with only a 20 percent decline in value.

New York wholesale prices for fresh littlenecks—the highest-value size class of hard clam—have exhibited a general downward trend during the



Note: Other includes geoduck, sunray venus, rangia, horse, cockle, razor, mixed, and unspecified clams.
Source: U.S. Dept. of Commerce. Various years. *Fisheries of the United States*. Washington, D.C.: NMFS.

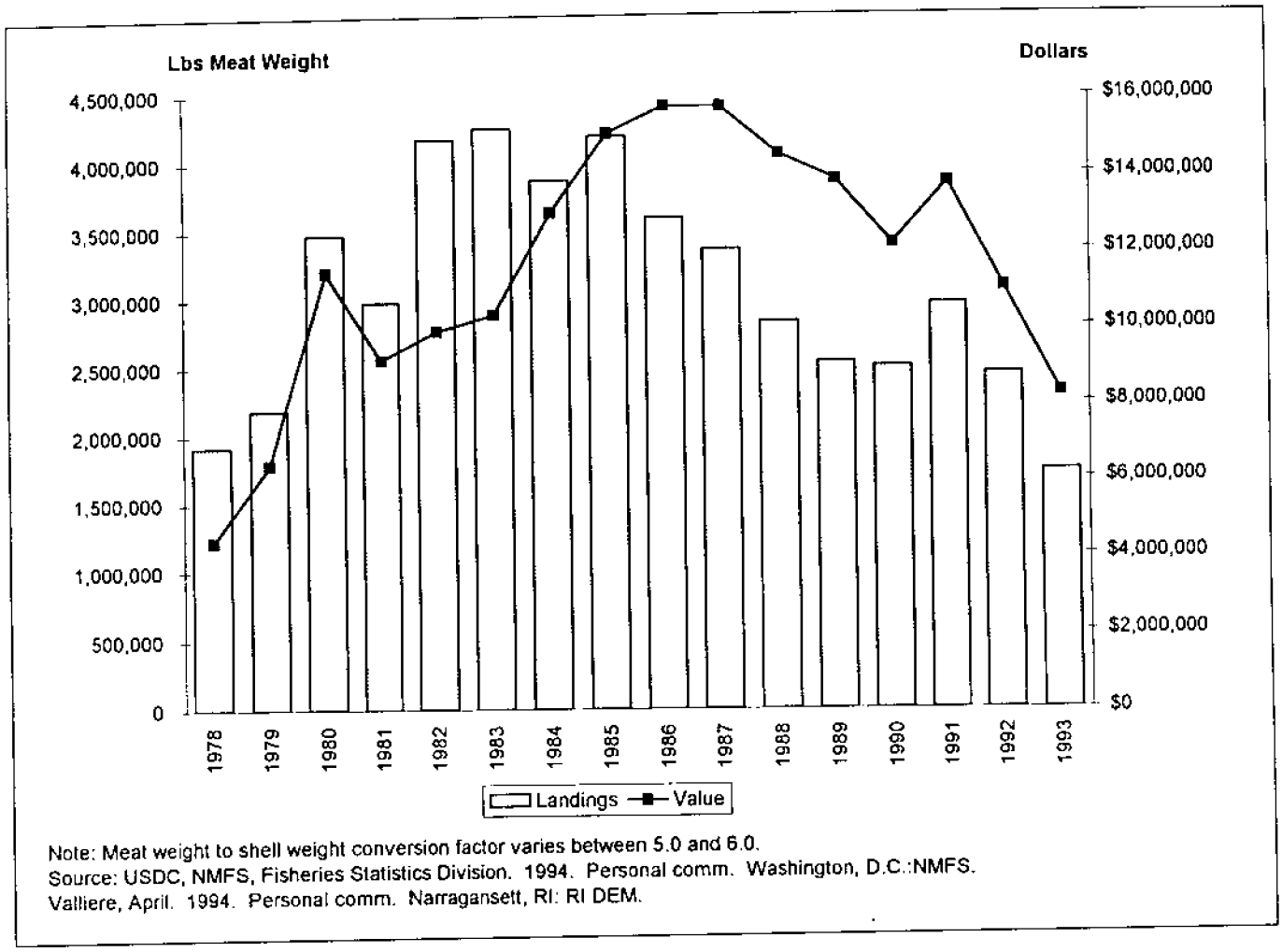
Figure 2. Value of U.S. clam landings 1950–1993

1990s (Figure 4). Monthly average prices during the 1985 to 1993 period ranged from a high of 29 cents/clam in December of 1990 to a low of 14 cents/clam in November of 1992 (Urner Barry, 1985–1993) (per-clam prices were calculated by dividing wholesale prices per bushel by a typical count of 480 littlenecks per bushel).

U.S. Clam Aquaculture

U.S. aquaculture of clams has seen a steady and large increase in the past decade. Production since 1983 has increased over 150 percent, with a 13 percent increase in 1992 alone (Figure 5) (USDC, 1994b). Supply of farm-raised clams is expected to increase, particularly as some large-scale operations come on-line. In an article in *Seafood Leader* magazine (1993), Atlantic Little Neck Clam Farms of South Carolina indicated a production target of 100 million clams by the year 1995–1996, equal to about one-fifth of current U.S. production. While this production goal may be optimistic, it does underscore the potential of aquaculture to significantly increase supplies of clams in the United States.

Production of farm-raised hard clams in the Northeast was estimated to be about 216,000 bushels at a farm-gate value of $15.6 million (Bush and Anderson, 1993). Connecticut accounts for the bulk of production, with about 57 percent, followed by Massachusetts with 21 percent, New Jersey with 12 percent, and New York with 9 percent. Other states active in hard-shell clam aquaculture include Maine and Delaware. Much of the Connecticut production comes from natural sets of clams that inhabit oyster-bed leases. Hard clam aquaculturists surveyed for the *Northeast Aquaculture Situation and Outlook Report* (Bush and Anderson, 1993) received prices ranging from 14 cents to 25 cents in 1992.



Note: Meat weight to shell weight conversion factor varies between 5.0 and 6.0.
Source: USDC, NMFS, Fisheries Statistics Division. 1994. Personal comm. Washington, D.C.:NMFS.
Valliere, April. 1994. Personal comm. Narragansett, RI: RI DEM.

Figure 3. Rhode Island hard clam landings and harvest value between 1978 and 1993.

Issues in Shellfish Marketing

Shellfish producers in the United States are faced with several challenging issues regarding the marketing of their products, particularly in the area of seafood quality and safety, consumer education, and product packaging. Increased consumer concern for seafood safety, fueled by an intense barrage of media reports assailing the safety of seafood—particularly bivalve mollusks—have had a negative impact on shellfish markets (Brooks, 1993). Studies indicating consumer preference for aquacultured products suggest that aquaculturists may have a marketing advantage over the wild-harvesters. Quality and safety assurance, consumer education, and innovative product packaging will be essential tools for shellfish producers to maintain a competitive edge in the domestic and global marketplace.

Seafood Safety and Consumer Perceptions

Shellfish, particularly filter-feeding mollusks such as clams, mussels, and oysters, have long been associated with the transmission of such health problems as paralytic shellfish poisoning caused by red tide, and hepatitis due to pollution of shellfish beds. In the last few years, there has been a succession of media reports that have questioned the safety of seafood, fueling public pressure for increased seafood inspection in the United States (see Brooks (1993) for a detailed discussion of consumer perceptions of seafood safety and the impact of media reports on the demand for shellfish). However, during the period 1978–1988, seafood—both shellfish and finfish—only accounted for approximately 3.6 percent of all reported cases of food-borne illness (Committee on the Evaluation of the Safety of Fishery Products, 1991). Approxi-

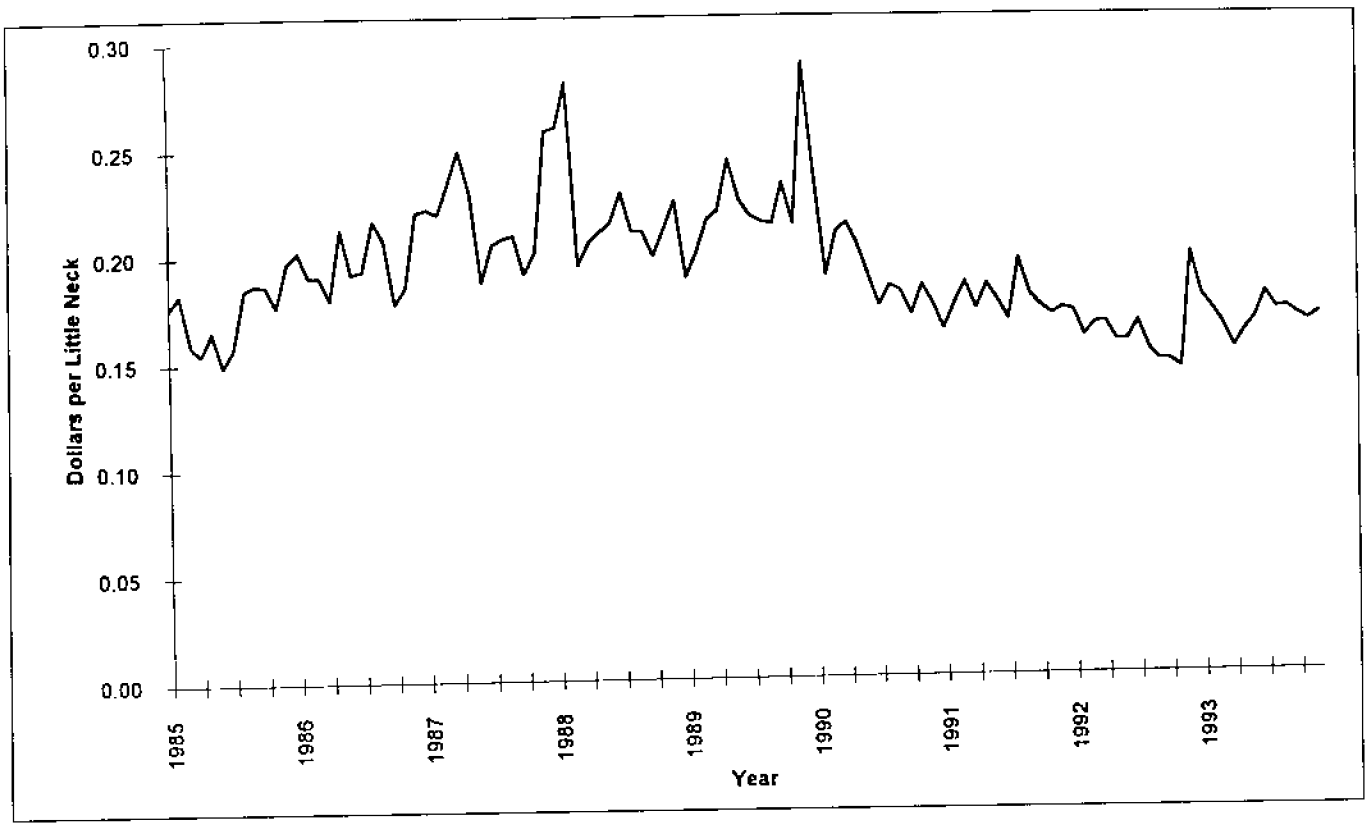


Figure 4. Average monthly wholesale prices for fresh little necks in New York from 1985 to 1993.

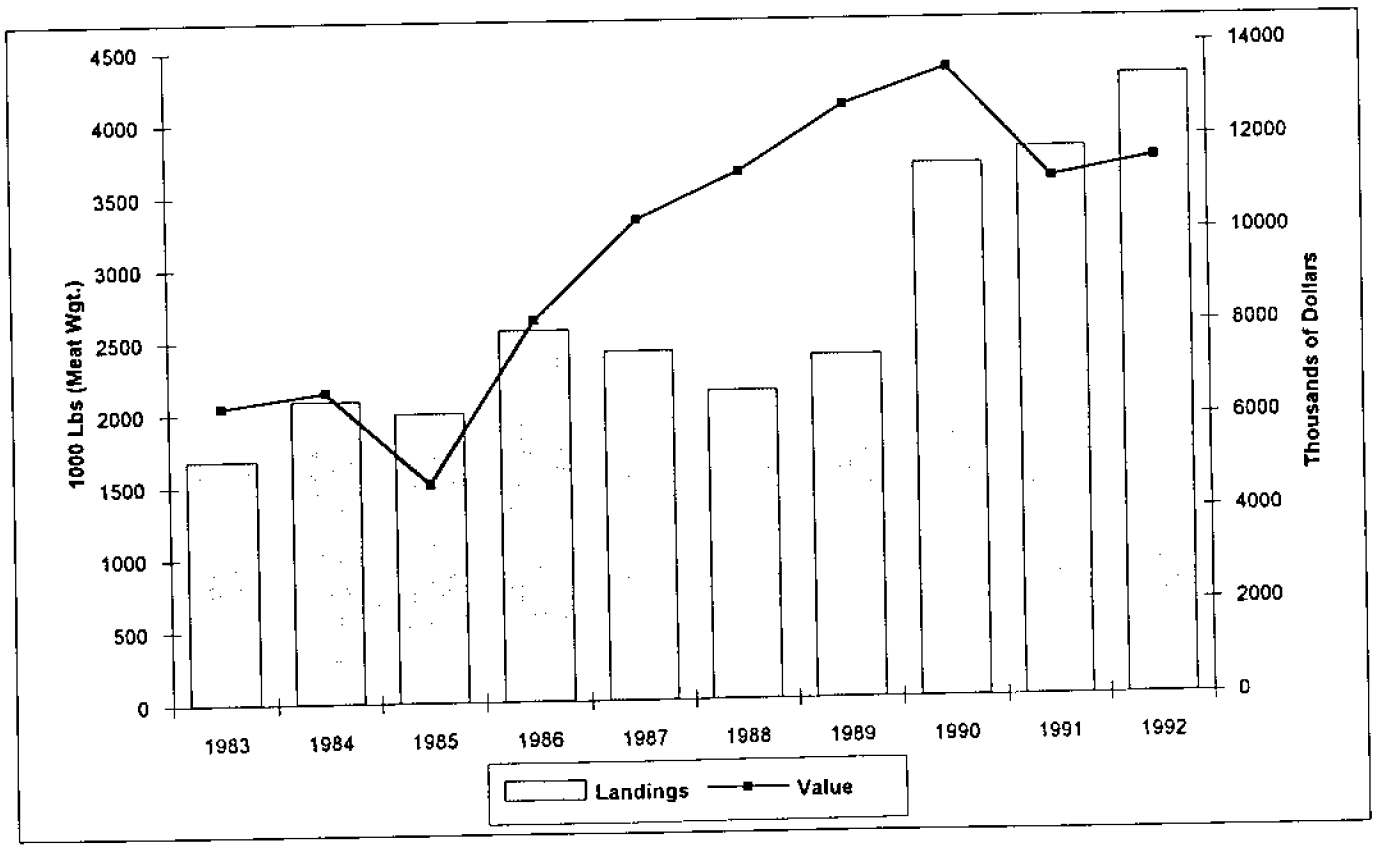


Figure 5. U.S. aquaculture production of clams in landings and harvest value for the period 1983–1992.

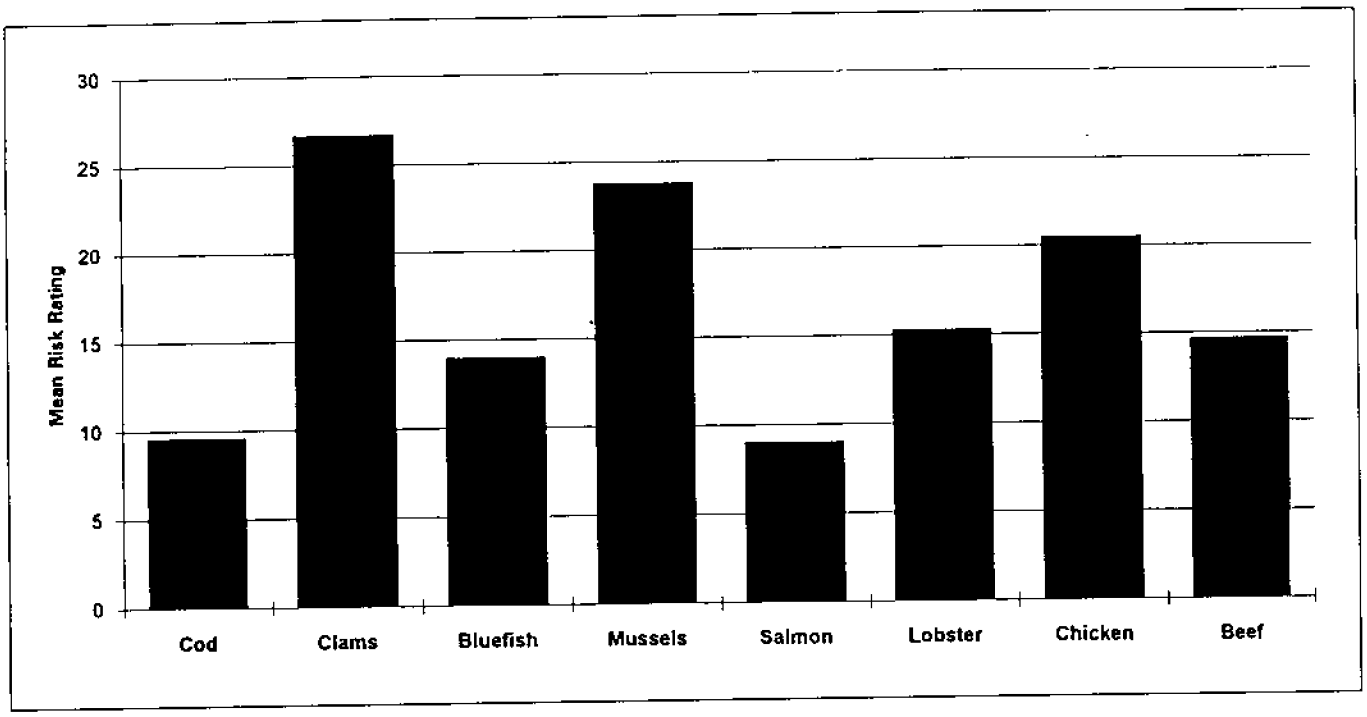


Figure 6. Mean perceived risk on a scale of zero to 100 (zero=no risk, 100=certain chance)

mately 2.3 percent of food-borne illness cases were attributed to shellfish, while 1.2 percent were attributed to finfish. Beef, on the other hand, was responsible for 4 percent of the total number of food-borne illness in the period 1978–1988, followed by turkey with 3.7 percent, pork with 2.7 percent, and chicken with 2.6 percent. If one considers shellfish and finfish separately, the percentage of cases of food-borne illnesses attributed to shellfish and finfish is lower than any other animal meat category.

Despite the relatively low incidence of illness, consumers are nonetheless concerned about the safety of seafood, particularly that of shellfish. Studies by Brooks (1993) and Wessells et al. (1994) underscore the pervasiveness of these concerns among consumers in the Northeast. For example, in a shellfish consumption survey of 1,529 consumers in the Northeast, 52 percent said that they were very doubtful or somewhat doubtful that shellfish contained nothing harmful to one's health (Wessells et al., 1994). Only 5 percent of the respondents were completely confident, and 44 percent were somewhat confident that shellfish contained nothing harmful to one's health. When asked whether all shellfish currently in the marketplace were harvested from government-certified waters, about 35 percent did not know, 22 percent strongly disagreed, and 23 percent somewhat disagreed. Surprisingly, less than 10 percent of the respondents strongly or somewhat agreed that all shellfish in the marketplace were from government-certified waters.

In another survey of 400 consumers in the Northeast, Brooks (1993) asked consumers to rate their chances of getting ill from eating the following foods: cod, clams, bluefish, mussels, lobster, salmon, chicken, and beef. Consumers were asked to rate their chances on a scale of zero to 100, where zero indicated no chance at all and 100 was a certain chance. It is important to note that the relative perceived risk of eating mussels compared to other foods is the key issue here, rather than the absolute level of risk, since the zero-to-100 scale is not appropriate for eliciting realistic risk estimates.

Results from the risk rating are particularly revealing regarding consumer perceptions of risk from eating bivalve mollusks relative to the risk perceived from eating some other foods. Figure 6 illustrates the mean risk ratings of the total sample for all eight foods. Clams and mussels scored higher risk ratings than the other foods, with aver-

age risk ratings of 26.9 and 23.7, respectively. Furthermore, mussels and clams were rated as having a significantly greater health risk (at the 99 percent significance level, based on a two-tailed t-test) than all other seafood. Mussels and clams also scored a higher risk rating than chicken or beef, with finfish (cod, bluefish, and salmon) scoring the lowest perceived risk ratings.

The Brooks (1993) and Wessells et al. (1994) studies underscore the need to educate consumers about the safety of shellfish products and the associated inspection and water quality monitoring programs now in place. Consumers would also benefit from information on safe handling and preparation of shellfish products. Strict quality and safety standards must be maintained if the shellfish industry is to bolster consumer confidence in its products. The net result will be better-informed purchase decisions, as well as a likely increase in the demand for shellfish products.

Consumer Preference for Wild Versus Aquacultured Shellfish

Results from the Brooks (1993) and Wessells et al. (1994) surveys strongly suggest that consumers in the Northeast perceive aquacultured shellfish to be better or safer than wild-caught shellfish. When consumers were asked what they thought was a better mussel, one that was farm-raised or one that was wild, about 42 percent said that they thought farm-raised mussels would be better, while only 5.4 percent preferred wild, 2 percent were indifferent, and 50 percent said that they didn't know (Brooks 1993). Many of the respondents preferring cultivated mussels claimed that cultivated mussels were grown under controlled conditions and in cleaner waters.

Similar results were obtained in the Wessells et al. (1994) survey, in which consumers were asked if farm-raised shellfish were safer than wild-harvested shellfish. Nearly 45 percent of the respondents strongly or somewhat agreed that farm-raised shellfish were safer than wild-harvested, 33 percent did not know, 15 percent were neutral, and less than 5 percent strongly or somewhat disagreed. Nearly 70 percent of the respondents strongly or somewhat agreed that water pollution was more likely to create a problem for wild shellfish than farm-raised shellfish.

Clearly, these results suggest that consumers perceive aquacultured products to be somehow better, safer, or more protected from pollution than wild-harvested product. To the extent that this is true, aquaculturists may be able to use these product attributes to their advantage in promoting cultivated shellfish. Conversely, these results indicate that consumers lack confidence in the safety of wild-harvested shellfish. Again, these results point to a need to educate the consumer about the safety and handling of bivalve shellfish.

Packaging

Hard-shell clams have long been marketed to the consumer without any packaging, brand naming, or information, except that which may be supplied by the retail clerk. In fact, most hard clams are moved through the wholesale market in a commodity-like fashion, in onion bags, often with labels that have nothing to do with the actual shellfish product. With aquaculture production increasing, and a clear need for consumer education about the safety of shellfish products, packaging and point-of-purchase materials will become a key avenue for distinguishing one's product and for educating consumers. Packaging can provide consumers with essential safety, handling, and preparation information, along with a brand name that can build repeat sales.

To the extent that consumers prefer aquacultured or wild-harvested clams, or clams from a particular geographical region, shellfish marketers can use packaging and point-of-purchase materials to convey these product attributes. Shellfish marketing clearly needs to move out of the bulk processing commodity approach, to a more consumer-oriented packaging and information approach.

Conclusion

While total U.S. clam production has increased dramatically since the 1950s, production of high-valued hard-shell and soft-shell clams has, more recently, decreased. Rhode Island hard clam producers have experienced a dramatic decline in hard clam production since the mid-1980s. In addition,

New York wholesale prices for fresh littlenecks have been on a downward trend. Consumer seafood safety concerns exacerbate this already-difficult situation.

Continued increases in aquaculture production will ease the shortages in wild production, while at the same time bringing new competition to producers of wild clam product. This is particularly significant, as recent research suggests that consumers in the Northeast perceive aquacultured clams to be better, safer, or more protected from pollution than wild-harvested product. All of the above factors indicate a very clear need for increased consumer education about the safety of clam products. Packaging and point-of-purchase materials can be very effective in educating consumers about the positive attributes of a product, while brand naming can build consumer loyalty and stimulate repeat purchases. The adoption of a more consumer-oriented approach to shellfish marketing, as opposed to the traditional one of commodity sales, will be essential for competing in the domestic and global marketplace of the 21st century.

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Questions and Answers

Q: (Arthur Ganz, Rhode Island Department of Environmental Management, Division of Fish, Wildlife, and Estuarine Resources) Do you think that labels stating the exact location of harvest from Narragansett Bay would be useful? Could someone who works on the water know where each and every quahog in his catch came from?

A: (Priscilla Brooks) I don't think that it is so much a particular area in the Bay, but if they are from Rhode Island, New York, Florida, and so forth.

Comment: (Ganz) But that level of identification is a requirement already.

A: (Brooks) It is required on the onion bag, not at the consumer level...fish markets or restaurants.

Comment: (Neal Perry, Rhode Island Shellfish Divers Association and Ocean State Aquaculture Association) For most aquacultured shellfish, you know exactly where they come from. Moonstone oysters, Cotuit oyster, Blue Points, and others are well labeled. It goes to good marketing.

Comment: (Gerald Carvalho, shellfisherman) Marketing is of prime importance. In this state, the quahog industry submitted a bill to the legislature to identify all shellfish, whether fresh or previously frozen, and its state and country of origin. The bill failed. During the debates, some of the representatives argued, "Who cares where it comes from?" Well, the consumer cares, and the people care. The strongest lobby against us was the supermarkets. They just did not want to reveal their sources.

A. (Brooks) The irony is that the supermarkets have the most to gain by having informed customers.

Comment. (Ed Agin, Rhode Island Shellfishermen's Association) The Narragansett Bay quahog is the best-tasting, and is renowned all over the world. When someone buys a Rhode Island quahog, they assume that it is from Narragansett Bay. All too often, this is just not so. If one goes into the back of many shellfish dealers, whatever clams are around—whether they are from Florida or wherever, are comingled with Rhode Island clams and shipped out. This is not right. This practice can severely hurt the reputation of our product.

A. (Brooks) Don't the tagging requirements take care of that?

Comment. (Agin) Only as far as the wholesalers, after that you don't know what you have.

Comment. (Kenneth Smith, Rhode Island Department of Health) That's a pretty strong statement you are making there.

Comment. (Agin) It's pretty strong because it's true.

Comment. (Smith) Can you prove that?

Comment. (Agin) Yes, I can.

Comment. (Smith) Let's talk afterwards.

Comment. (Agin) This has been a problem since there have been sales of Narragansett Bay quahogs. When we pointed this out to Kenneth Kovach of the Department of Health, his reply was that he knew, but there was nothing that could be done about it.

Comment. (Smith) That is a wrong statement.

Comment. (Agin) It's true.

Comment. (Smith) John Mullen and I are the Department of Health representatives here.

Comment. (Agin) You did not make the statement. Kenny Kovach did.

Comment. (Smith) There is a big difference between a Florida clam and a Rhode Island clam. There must be something very wrong if people can't see the difference.

Comment. (Agin) The colors are different, we all know that, but the consumers do not.

Comment. (Smith) If you were a restaurant owner, why would you want to spend 20 cents for a Rhode Island clam, when you could get a Florida clam for a dime? Restaurant owners usually protect the bottom line.

A. (Brooks) By this discussion, this is obviously an interesting area. Consumer labeling and marketing can help with this.

Lessons from Aquaculture Development in Coastal Fishing Communities in Latin America and Asia

■

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Abstract ■ *This paper examines use conflicts associated with aquaculture development in Latin America and Asia, as well as attempts to deal with these problems. Since most conflicts examined occur at the community level, it seemed obvious that community involvement in conflict avoidance and resolution should be stimulated at the early stages of aquaculture development, to avoid polarization that would be difficult, if not impossible, to resolve at later stages in the implementation process. It is suggested that the most efficient means for community participation in the process would be through the use of fish farmer organizations and appropriate government agencies involved in comanagement of resources associated with aquaculture development.*

Introduction

This paper reviews use conflicts associated with the operation of aquacultural systems in fishing communities in Southeast Asia and Latin America. Conflicts examined include those among different user groups, such as aquaculturists versus capture fishermen, mangrove swamp hunter and gatherers, agriculturists, industry, and tourism developers. Incompatibilities and potential for dispute between various aquacultural practices are also reviewed. The relationship between various types of conflicts and other socioeconomic and cultural variables are examined in terms of implications for the development and spread of aquaculture in other regions.

Aquaculture Conflicts With Capture Fisheries

Improvement of any area originally exploited as an open-access or common-property resource results in conflict when it is perceived as interfering with fishermen and others who normally exploit the natural region (Pollnac, 1982). The primary reason for this is that the displacement can have a negative impact on the employment of fishermen, and there is a real potential for conflict if they cannot take part in the new aquaculture activities (Kapetsky, 1981). An important example can be found in the Philippines, where, as a result of the development of fish pens for culturing milkfish in Laguna de Bay, open-water fishing area was reduced, as well as access to the capture fishery. Fishermen straying too close to the pens were intimidated by armed guards, and some killings were reported. Fishermen's incomes were drastically reduced (Davies, 1988). This conflict involved some 15,000 poor fisherfolk families versus a "few hundred rich fish pen operators." Influential investors were able to circumvent laws regulating maximum pond size by "putting up interlocking corporations actually controlled by the same people"(Lacanilao, 1987).

In Ecuador, access to traditional fishing areas in the mangrove areas was similarly inhibited (Merschrod, 1989). At times close to pond harvesting, armed guards reportedly would not let fishermen operate anywhere near pond enclosures (Epler, 1992), despite the fact that fish and shellfish from the mangrove traditionally make up an important part of local diets (Whitten, 1974). In the Philippines, the response to the fishermen-versus-fish-farmer conflicts in Laguna de Bay was the establishment of a presidential commission by the new government, which proposed a reduction to 10,000 hectares (ha) of fish pens, and the phasing out of

private ownership, with remaining fish ponds to be operated by fishermen's cooperatives (Davies, 1988). I noticed a great reduction in the area of fish pens when flying over Laguna de Bay in recent years, but do not know if this is due to enforcement of the law, as some have suggested, or to fish morbidity resulting from excessively dense stocking.

Another potential source of conflict is the impact of extensive seed and/or feed collection from the wild on resources traditionally exploited by capture fishermen. For example, in the Philippines, capture of milkfish fry had larvae of the valuable shrimp fry *Penaeus monodon* as bycatch, which was discarded (Kapetsky, 1981). Epler (1992) reports that in Ecuador, larvae of many other aquatic organisms are captured with the postlarval shrimp, and that techniques for separating the shrimp larvae kill the other organisms. How this affects the natural stocks is unknown according to Kapetsky (1981). Some fishermen believe that the practice will deplete natural stocks, hence, they oppose fish culture (Ceylon Department of Fisheries, 1972). In some cases, the fishermen's perceptions of reduced catches appear to be justified. For example, Meltzoff and LiPuma (1986) report that the indiscriminate harvesting of aquaculturally undesirable, as well as desirable, shrimp postlarvae has contributed to the decline of a species that is the basis of the trawl fishery. Additionally, Drewes (1986) reports negative impacts on brackish-water and inshore fisheries resources resulting from harvesting fish for feed for pen-cultured species in Thailand. Finally, high pond-stocking densities can lead to pressure on shrimp populations exploited by capture fishermen because of increased pressure on postlarval shrimp (Bailey, 1989).

In some areas, fishermen claim that poisons used by pond operators hurt their fishing operations (Hopkins and McCoy, 1976). These perceptions are frequently based on fact. It has often been noted that the chemicals and excessive nutrient loads released by fish ponds also have a negative effect on original production (Barg, 1992). These effluents have the potential for polluting the nursery and breeding grounds of many terrestrial and aquatic fauna, ultimately having a negative impact on fishermen's catch (Saclauso, 1989). This can go both ways, however. In the Upper Kapuas, Kalimantan, Indonesia, fish and other aquatic organisms are frequently held in cages before marketing. In some cases, some species are held until they reach optimal marketing size. More intensive cage-culturing is also being introduced to this area. While I was there in 1990, there were complaints that use of poison for fish-capturing purposes by fishermen upstream was killing caged fish.

Sometimes aquaculture activity requires clearing of mangroves, which could have a negative impact on some fisheries. For example, in one area of Ecuador (Caraquez Estuary), a crab fishery was destroyed by the removal of mangroves that accompanies the massive construction of shrimp ponds (Epler, 1992). In Bunche, Ecuador, shrimp mariculture activities have cleared mangroves to the extent that collectors of mollusks and crabs have to travel farther from the village to harvest these organisms (Pollnac et al., 1994). This increases costs in both time involved in the activity, and in money required to hire or buy a boat to travel to new, more distant areas.

Clearing of mangroves can result in conflicts with the capture fishery, even in cases where the fishing activity takes place outside the mangrove area. It is well known that mangrove forests contribute organic matter utilized by other aquatic organisms (Field and Dartnall, 1987), and the destruction of mangroves for aquaculture could lead to loss of organic detritus important to fish communities that are harvested by capture fishermen (Kahn and Karim, 1978).

Understanding the potential for these types of conflict is essential for the fish farmer, because they could have negative impacts on the introduction and sustainability of aquaculture activities. In many areas, the capture fishermen can be considered as vested interests who will oppose and potentially impede the development of aquaculture activities. For example, fishermen in an aquaculture project area in southern India opposed a project because they thought it would deprive them of their fishing grounds and provide nothing in return. Some claimed negative impacts on catches. Opposition by vested interests was such that someone actually poisoned the shrimp being cultured (Drewes and Rajappan, 1987).

Aquaculture Conflicts With Agriculture

Both aquaculture and agriculture depend on the use of water; hence, there are potential use-right conflicts. Additionally, since the use of water for one purpose in one area can affect its quality in another area, there is potential for conflict over uses that impair the quality of water for different users. For example, Mukhopadhyay et al. (1989) indicate that many high-yielding rice varieties require pesticides toxic to fish. This presents a real potential for conflict in areas where water from paddy rice culture can reach fish ponds. Runoff from other types of agricultural practices can also impact downstream aquaculture.

Aquaculture practices can also contaminate water used for agriculture and animal husbandry. For example, fish pens in Laguna de Bay contributed to a decline in water quality, which had negative effects on duck production in the 1980s (Lacanilao, 1987). Additionally, extension of brackish-water channels for shrimp ponds increased salinization of rice fields in some areas of Central Java (Hannig, 1988). This decreased rice yields, resulting in further stimulus to change over from rice to shrimp production. The salinization of rice-producing areas has also been reported for other regions in Southeast Asia (New, 1991). The problem cited by Hannig (1988), however, is that poor peasants will not have the opportunity to operate the ponds themselves, because their paddy fields are too small to be operated efficiently as shrimp ponds; hence, they will probably sell out to local elites and seek other employment. Whether or not this will result in an improvement in the quality of life of these peasants depends on occupational alternatives available.

The clearing of mangroves for mariculture can also influence the quality of water available for agriculture. In some areas of northwest Java, near Jakarta, mangroves have been cleared to the edge of the sea. This has resulted in changes in stream flow and siltation, altering coastal sedimentation. Changes in stream flow have reduced drainage of low-lying land and increased salt intrusion, resulting in problems for agriculture. Removal of the mangrove buffer has also increased coastal erosion (Koesoebiono et al., 1982).

Cage culture in streams or canals has also been identified as a potential problem in agricultural areas. Fish cages apparently appeared in West Java during the 1940s. Originally used to hold fish before sale, it was noticed that fish gained weight in the cages. A practice of keeping the fish in fully enclosed, floating cages evolved from this system in the early 1960s. This practice spread rapidly, and nearly filled the watercourses in Bogor and Bandung by the end of the decade. The cages, however, impeded water flows needed to irrigate paddy fields. Additionally, cages blocked the flow of materials during heavy rains, and resulted in flooding; hence, regulations were developed to prohibit floating cages in public waters. This had negative impacts on fish supplies and on producer incomes. The producers adapted, however, and in the 1970s, an "in-bottom, dugout bamboo fish cage" was introduced that did not impede water flow if daily cleared of debris (Costa-Pierce and Effendi, 1988).

Ponds can also be sited in areas where they have the potential to limit traditional access to garden plots. Epler (1992) report that in some regions of Ecuador, wealthy outsiders have established shrimp ponds in areas between coastal communities and garden plots, which are located on the hills backing the communities. This has led to conflict between farmers who wish to have ready access to their plots, and guards protecting the barbed wire–enclosed shrimp ponds.

Finally, some forms of mariculture may also be disadvantageous to agricultural workers. Agricultural workers use the land for gainful employment, and changes in land use can conflict with their needs. Labor requirements for shrimp culture are significantly less than for paddy rice culture in some regions. For example, introduction of shrimp mariculture on lands originally used for paddy rice has resulted in increased unemployment in Bangladesh (Rahman et al., 1985).

Aquaculture Conflicts With Other Uses

We now turn to potential conflicts between aquaculture and other activities such as industry, navigation, forestry, freshwater supplies, and tourism. Turning first to navigation, Lacanilao (1987) indicates that in Laguna de Bay, fish pens obstruct-

ed navigation channels. Additionally, fish pens restricted water circulation, stimulating growth of water hyacinth, which further restricted navigation. Others have also indicated that fish cages and pens can lead to conflict when they restrict navigation in previously open waters (Pullin, 1989; Secretan and Nash, 1989; Weeks, 1988; Smith and Peterson, 1982).

Reforestation projects can also result in use-right conflicts with aquaculture. For example, in the 1970s, Indonesia's Directorate General of Forestry instituted policies of reforesting cleared lands deemed public lands, much of which was mangrove forest that had been converted to fish ponds. This resulted in conflicts between the government and local people claiming traditional use rights for aquaculture (Koesoebiono et al., 1982). Further, in the early 1980s, the replanting of mangroves in brackish-water aquaculture sites in West Java restricted the area available for fish and shrimp culture operations (Muluk, 1985).

Forestry conservation programs can also conflict with certain types of aquaculture. For example, as a means of preserving mangrove swamp area, the Philippine government encouraged intensification of brackish-water fish culture (Juliano and Chan, 1978). Intensification, however, can lead to conflicts with other types of aquaculture, as well as social stratification, as discussed elsewhere in this paper. Sometimes this use-right conflict between forestry and aquaculture can lead to jurisdictional conflicts between government agencies. Jara (1987) has reported this for the Philippines. There, fisheries administrators claimed that all swamplands are suitable for aquaculture and should be under their administration. Forestry disputed this claim, saying that conversion to fish ponds should be discouraged.

Aquaculture practices can also conflict with forestry use rights with respect to consumption of wood products. Fish pens and cages consume large quantities of wood, possibly resulting in deforestation. For example, it has been reported that construction of shrimp ponds contributed to deforestation in Bangladesh (Bashirullah, 1989). Related to this, in 1989, a Bureau of Fisheries and Aquatic Resources official in Manila told me that the price of bamboo in the Philippines increased drastically due to the demands of fish pen operations.

Industry can conflict with aquaculture with respect to use rights of both land and water. Hannig (1988) presents an interesting case where governmental development objectives, including both aquaculture and industry, resulted in conflicts. In order to increase foreign exchange earnings, the government of Indonesia supported many programs to increase production from brackish-water shrimp culture. At the same time, to achieve self-sufficiency with respect to manufactured goods and increased export of the same (hence increasing availability of foreign exchange), areas around several urban centers were declared industrial development zones by presidential decree. The problem was that many of these areas also supported brackish-water aquaculture. Subsequent industrialization of these areas in the late 1970s created pollution that resulted in harvest losses and loss of pond fertility.

Construction of brackish-water ponds in coastal areas with freshwater shortages may also result in problems. While traveling in Ecuador in 1985 to prepare a capture fishery research proposal, I visited a community located on a relatively arid stretch of coastline where local residents were holding meetings to try to block development of shrimp ponds in "communal lands." They feared that the ponds would contaminate their valuable freshwater supply. Pullin (1989) has noted this potential, and adds that pesticides, herbicides, and drugs used in intensive fish farming, as well as the potential for intensive ponds to become reservoirs for infection, can add to this pollution of water supplies.

Use of water for aquaculture can also impact its availability for other purposes, and vice versa. For example, it is reported that on Negros Island in the Philippines, extraction of water for aquaculture sometimes has a negative impact on water available for domestic consumption (Saclauso, 1989), and that the damming of rivers for reservoirs in Singapore in the 1960s resulted in the decline of many prawn ponds (Sien, 1979).

Tourism and recreation compete with aquaculture for both coastal and inland waters in many

areas in both Latin America and Southeast Asia. For example, tourism interests in Prapat, on Lake Toba in North Sumatra, Indonesia, objected to cage culture, and stimulated legislation that effectively blocked fish farming in areas traditionally used for recreation (Pollnac, 1992). In Ecuador, Epler (1992) reports that postlarval shrimp collectors' activities interfere with sunbathing and swimming on tourist beaches. Additionally, he reports that shrimp-pond construction has been blamed for both beach erosion and pollution in another tourist area. Finally, tourism has been identified as a factor restricting the expansion of aquaculture in the Caribbean (Bacon et al., 1991).

Aquaculturalists are also faced with conservationists who object to almost any type of development around resources that are perceived to be endangered. Epler (1990) has suggested that the massive killing of birds to protect shrimp from predation in Ecuador could have a negative impact on species diversity. Fears have been voiced by many environmentally concerned individuals that the mangrove destruction that frequently accompanies brackish-water aquaculture will negatively impact species diversity.

Conflicts in Use Rights Between Fish Farmers

We have seen examples of how aquaculture can conflict with some nonaquaculture activities. It is important to note that different types of aquaculture can conflict with one another. For example, Rice and Suprihatin (1989) note that intensive shrimp ponds are often developed inland from, and higher than, traditional and semi-intensive ponds. The wastewater discharged from the intensive ponds flows into the intake canals of other ponds, adversely affecting production. This is already a problem in some areas of Indonesia. This has an adverse equity effect, because owners of the semi-intensive and traditional fish ponds already have below-average per capita incomes. Related to this is the observation by Saclauso (1989) that widespread instances of disease in shrimp farming have been attributed to "excessive organic overloading"(also see Lin, 1989). Implications for other types of fish farmers using the same water should be obvious. Chemical pollution of downstream fish-farm operations is also a potential problem (Saclauso, 1989; Barg, 1992). For example, fish pond effluents have been reported to have a negative impact on oyster farming in the Philippines (Samonte, 1992).

Finally, and most obviously, crowding can also result in conflict between users. When cage culture was introduced in some newly created reservoirs in Indonesia, many producers crowded areas close to road access, creating a potential for localized pollution, which would negatively affect production (Zerner, 1992). Cage culture of tilapia in lakes in the Philippines has also had problems with overcrowding, which has had several cycles through withdrawal of marginal producers, increasing profits, overcrowding again, withdrawal, and so on (Smith and Pullin, 1984).

Aquaculture and Social Stratification

As was probably obvious from the foregoing, introduction of aquaculture frequently pits the small guy against the big guy. In most cases, the big guy wins, and this frequently results in an even larger income differential between the small guys and big guys. Social scientists refer to this phenomenon as social stratification, and numerous authors have commented on the relationship between certain aquaculture development policies and increases in social stratification (e.g., Bailey, 1989; Molnar and Duncan, 1989; Hannig, 1988; Weeks, 1988; Pollnac, 1991, 1982; Pollnac and Weeks, 1992; Angell, 1993). This is a use-right conflict. Who has rights to the area: the big fish farmer and/or industrialist, or the poor, displaced fishermen, fish farmers, small farm operators, agricultural laborers, and/or other small-scale producers who traditionally used the area to gain their livelihoods? This is an ideological question that will not be answered in this context. The issue is raised in order to point out that the cost and benefits of the various answers to this question should be weighed by decision-makers involved in aquacultural development.

Aquaculture is capital-intensive. Davies (1988) reports that in the late 1960s, pen culture of milkfish was introduced to Laguna de Bay, and by 1983, fish pens increased to cover over

one-third of the bay's area. Since no credit was extended to poor fishermen who originally fished the bay, only rich individuals and corporations could afford to construct fish pens. Although regulations existed to control sizes of fish pens (5 ha for individuals and 50 ha for corporations), in 1983 about one-half exceeded the limits, with the largest being 1,200 ha. As noted above, poor fishermen had reduced access and incomes, resulting in a greater disparity in wealth between them and the fish pen operators. It is important to note, however, that successful attempts have been, and are being, made to develop less capital-intensive forms of aquaculture, so as to reduce the potential for social stratification (Newkirk, 1993; Pollnac, 1992; Yaakob et al., 1994).

Such impacts on social stratification are recent phenomena. Similar changes in social structure accompanied introduction of oyster cultivation with state-sanctioned limited access rights in the Dutch oyster beds in the 19th century (Van Ginkel, 1988). Development and change is desirable, but we must be aware that the use rights of some may be denied in the process of change, resulting in increased social stratification and the potential for inter-class conflict. This must be accounted for in weighing the costs and benefits of such changes.

Dealing With Aquaculture Use-Right Conflicts

We have reviewed a number of situations wherein incompatibilities were found to exist between aquaculture systems and other uses of the same or linked environments. The question now is: What can we do to ameliorate these conflicts? It is not an easy question to answer. Since one of the basic functions of government is conflict resolution, we should examine governmental approaches to allocation of resources.

All governmental approaches are based on some type of legislation, with the assumption that the laws enacted will be enforced. An examination of a series of regional surveys of the aquaculture sector, commissioned by the United Nations Food and Agriculture Organization (FAO), however, indicates there are great differences between various regions in terms of aquaculture-related legislation (FAO, 1989). While it appears that many countries have legislation dealing with aquaculture, we have to ask why some of the conflicts reviewed occurred in these same countries. Is the legislation inadequate, or are there other problems? A few examples might begin to answer some of these questions.

First, it has been noted that a factor that contributes to the destruction of mangroves, with little or no concern for traditional users is the perception of the resource as a form of "commons" in many countries (Saenger, 1987). Bailey (1989) indicates that in most countries, the state has established claim over coastal resources, providing a legal basis for allocating access to these resources. The poor who traditionally depended on this resource frequently lose access—their "traditional rights" are either unknown or ignored by the larger society (Skladany and Harris, 1993). Governments frequently do not recognize traditional use rights and claim "authority to grant long-term leases to those who have the financial means to develop significant aquaculture and other enterprises"(Bailey, 1989). Such legislation can result in increases in social stratification.

Conflicts at the water/land interface, where aquaculture is frequently sited, are often the result of the fact that in many countries there is no single agency that has jurisdiction over both land and marine areas. For example, in Indonesia, the Ministry of Forestry manages the mangroves, the Directorate General of Fisheries manages the lagoon and offshore fisheries, and the State Ministry of Population and Environment deals with water quality standards (White and Martosubroto, 1989). This has resulted in different agencies assigning use rights to the same property to different individuals, resulting in conflicting claims of ownership. For example, in one area of South Java, Indonesia, the same land was claimed by local inhabitants, the State Forestry Authority, and the Nusa Kambangan Prison Authority. The residents' claim was based on traditional law (*hukum adat*), which states that the one who first clears, occupies, or settles on a piece of land is entitled to it. The forest authority claimed that the tidal forests were essential to the ecosystem, and hence a part of the forest reserves. The Prison Authority claimed

the land on the basis that it was formed from landsliding along the shore of its property (Sujastani, 1989).

Multiple-agency jurisdiction can also result in lease seekers taking advantage of the resultant ambiguity to seek loopholes that could contradict the original intent of legislation. For example, it is reported that in Ecuador, individuals could circumvent laws restricting construction of shrimp farms in mangrove areas by claiming that the area in question is upland (inland from the high tide mark), and obtain their lease from the Ecuadorian Institute for Agrarian Reform, rather than the Merchant Marine and Coastal Directorate for Fisheries, which had more strict inspection procedures. In part, this could be done because the line dividing the bay and beach zone from the upland zone had not been adequately mapped (Perez and Robadue, 1989).

Procedures such as licensing, which would limit access and reduce potential for overcrowding, have been slow to develop, and sometimes result in inequities that could lead to conflict. In one small lake in the Philippines, a system for transferable use rights for shoreline areas developed (Smith and Pullin, 1984). The rights were sold on the open market. The authors classify this as "expropriation of public property by private individuals."

Other types of legislation can also have unintended negative effects on social stratification. Ecuadorian fisheries law in the 1980s provided incentives, such as tax and tariff exceptions, which were meant to encourage large, vertically integrated enterprises, thought to be better for national development (Perez and Robadue, 1989). Hence, the big investor, who already had an advantage over the small investor, gained even more advantages from the legislation, resulting in an ever-widening gap between the rich and the poor. Similar legislation and policies can be found in other parts of the developing world (Bailey, 1989; Skaladany and Harris, 1993).

Often, the legislation is incomplete. For example, in what was probably an attempt to avoid conflicts between agriculture and aquaculture in Ecuador, the Ministry of Agriculture must certify that land is unfit for agriculture before a shrimp farm operating permit can be obtained from the General Directorate for Fisheries. The minimum distance allowed between a shrimp farm and agriculture land was 500 meters (Perez and Robadue, 1989). Nevertheless, conflict still arose where ponds blocked access to agricultural land further inland. The legislation, while helpful, did not address this problem. This observation is, of course, based on hindsight, but indicates that legislation must adapt to new potential for conflict as it develops.

Finally, even well-designed legislation cannot be effective if there are problems in administration and enforcement. For example, although Ecuadorian legislation required that leases be obtained for operating shrimp farms in the zone between the lowest and highest tide marks, aerial photographs of the Guayas Gulf taken in the late 1980s indicated that there were as many as 60 farms illegally occupying the area (Perez and Robadue, 1989). The number of illegal farms elsewhere along the coastline is unknown. According to Perez and Robadue (1989), some sources indicate that most shrimp farms failed to acquire one or more of the required permits. Much of this illegal activity could have been the result of inadequate numbers of personnel in the various agencies responsible for administering leases, monitoring development, and enforcement of regulations. Shortages of personnel and equipment to adequately administer and enforce legislation plague many developing countries.

What can we do to address these problems? It is clear that most of the conflicts identified occur on the community level. Therefore, it seems to make sense that some sort of community involvement in the early stages of aquaculture development should be directed at identifying potential conflicts and techniques for their resolution before the different interests become so polarized that conflict resolution becomes difficult, if not impossible. Deshpande et al., (1986) and Korten (1986) agree with this assessment, arguing that the best technique for managing locally available resources is to use local community participation.

How can this best be accomplished? To begin, it is assumed that there is sufficient justification for the claim that people's participation, when appropriately used, can improve the management of

issues associated with aquaculture development (McGoodwin, 1990). This being the case, how can such participation be implemented? There are numerous, obvious reasons that local organizations, rather than individuals, can efficiently function to facilitate people's participation in aquaculture management. One is the difficulty of determining an appropriate time and place to convene a potentially large, heterogeneous group of individuals with interest in aquaculture. By appropriate, it is meant a time suitable to the work hours of fish farmers and other interested parties, and a location convenient to all. Second is the onerous, and sometimes impossible task of achieving agreement in a large group. The larger the group, the more people who will want to have input, and the greater the chances for conflicts to arise that will inhibit the decision-making process.

A third argument for the use of local organizations for management of issues associated with aquaculture development is the fact that those who usually participate effectively in public forums directed at achieving people's participation are frequently not representative of the masses of people who will be impacted by proposed changes. Effective participants are often the relatively well-educated, wealthy elite who either have, or plan to have, some interest in the resource. Those less wealthy and less educated frequently have difficulty finding time to participate, and when they do, their lower level of education reduces the effectiveness of their input. It is assumed that the person or panel representing members of the local organization at management meetings would be able to overcome these limitations.

Fourth, it is obvious that an individual participant is more vulnerable to pressure than an individual supported by, and delegated authority by, an organization. Pressures applied to the individual can range from the obviously illegal, such as threats of bodily injury, to the marginally legal—for instance, finding "cause" to have the individual separated from present employment—to the legal—a wealthy vested interest instigating a costly, time-consuming lawsuit against the individual petitioner. Most private individuals could afford neither the time nor the expense to defend themselves against this type of legal action. Such "legal" maneuvers have occurred frequently enough in the United States that they are referred to by an acronym—SLAPP (strategic lawsuit against public participation). Organizations would be less vulnerable to such threats.

It is thus relatively simple to establish that there are numerous reasons to advocate use of organizations to facilitate people's participation in aquaculture management. The next question involves the type of involvement in aquaculture management. If we eliminate the polar extremes (for example, dictatorial management by government and self-management), most researchers dealing with this issue make the distinction between consultative management and cooperative comanagement (e.g., McGoodwin, 1990). Consultative management would involve establishment of government entities that would consult with fish farmers' organizations before and during the preparation of management plans directed at conflict avoidance. The content, style, and frequency of consultation will, of course, vary from system to system. Comanagement is succinctly defined by Pinkerton (1992) as "...power-sharing in the exercise of resource management between a government agency and a community or organization of stakeholders." The realization of this concept also includes several variables, such as content, structure, and most important, degree of power sharing. For example, a precise description of any system of comanagement must evaluate the degree of rights and responsibilities of both the government and the fish farmer organization with respect to information generation, rule-making, surveillance, and enforcement.

There are many advantages to using a system of comanagement for dealing with potential conflicts in aquaculture. With respect to comanagement of capture fisheries, Pinkerton (1989) points out some of the advantages of comanagement, such as promotion of conservation and enhancement of fish stocks, improvement of the quality of data necessary for management, development of more equitable allocation techniques, promotion of community economic development, and reduction of conflict between different user groups, as well as

between users and the government. All of the foregoing can be applied to aquaculture management problems. Comanagement can also lead to decentralization of decision-making, which is necessary when diversity, such as the diversity of resources used in aquaculture, characterizes a resource in need of management. It also helps when the resources are spread over a large area, and when government personnel with expertise for management are in short supply.

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Questions and Answers

Q: (name not stated) You mentioned fish ponds upstream dumping their effluents and affecting ponds downstream. Were these ponds culturing different species?

A: (Richard Pollnac) For the most part, they are culturing the same species. However, in most of the low-lying areas of Indonesia, there is a predominance of traditional "extensive" fish culture ponds. These types of ponds rely on low stocking densities and low inputs of feeds and chemicals. Once the profitability of aquaculture was established, corporations started "intensive" ponds in upstream areas. These rely heavily on high stocking densities and on chemicals, such as pesticides and fertilizers, with the effluents often dumped indiscriminately in the waterways.

Q: (name not stated) What I wanted to know is why lowland farmers would not see this as a bonus: free drugs and fertilizers coming downstream?

A: (Pollnac) This pollution of waters by upstream farmers is a common complaint by lowland aquafarmers. Michael, can you elaborate on this?

A: (Michael Rice, URI department of fisheries, animal, and veterinary science) Yes. The classic example was the proliferation of shrimp hatcheries in Southeast Asia during the early to mid-1980s. The technology for shrimp hatcheries spread quite rapidly to the point that there were shrimp hatcheries practically on every street corner. The problem was that each hatchery tried to outdo the next by trying to stock higher and higher densities. To do this, they had to use higher and higher amounts of antibiotics to keep the disease organisms at bay. Because of the indiscriminate use of the drugs, antibiotic-resistant strains of bacteria developed within a few years, multiplied, and invaded the water systems of all the hatcheries downstream. This wiped out the entire industry. So, one of the main functions of regulatory agencies is to assure best management practices so that the entire industry is not wiped out by basic greed.

Comment: (Robert Rheault, Ocean State Aquaculture Association) One of the functions of our trade association, the OSAA, is to spread the good news about some of the positive aspects of aquaculture for Rhode Island. Fortunately, here in Rhode Island there are many governmental regulations that address most of the concerns that were raised, from navigation, monopolistic, ownership, poisons, and chemicals. All of these things are regulated in our current system. Hopefully, with vigorous enforcement, we can develop an industry that will have minimal conflicts with the other "exploiters of the marine resources."

Transient-Gear Shellfish Aquaculture as a Means to Overcome Multiple-Use Conflicts in Rhode Island Coastal Waters

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Abstract ■ *Transient-gear aquaculture is a method of growing shellfish that is designed to minimize multiple-use conflicts and avoid the need for a conventional fixed lease. The concept and methods are described, and a brief economic model based on four years of data is presented. The benefits and disadvantages of the method are discussed in relation to more traditional shellfish culture techniques. Key differences are in quality of product, labor, expenditures for gear, and economic return.*

Introduction

For the past three years, Spatco, Ltd. has been testing a novel method of oyster aquaculture that we call "transient-gear aquaculture." The method involves placing hatchery-reared shellfish in cages resembling lobster pots on the pond bottom. The cages are marked by buoys and hauled every few weeks for cleaning and tending. The primary reason we became interested in this approach was to avoid conflicts with other user groups, principally the commercial shellfishermen and boaters. The buoyed "oyster pots" pose no more of a threat to navigation or shellfishing than do lobster pots or eel pots. Since the gear is transient and periodically relocated, even the wild shellfish resource directly underneath the "oyster pots" becomes accessible to the wild-harvest digger periodically. In short, this method of aquaculture no more requires the exclusivity of a lease than does lobster fishing with traditional traps.

In New England, one of the primary obstacles to the growth of aquaculture is resistance to the leasing or privatization of public waters. Since transient gear does not require exclusive use of one area for more than a short period of time, it should not require a conventional exclusive-use lease. If transient-gear aquaculture can be proven as an economical method of rearing shellfish while not requiring leased beds, it is conceivable that many areas closed to aquaculture because of resistance to leasing will become open to productive shellfish aquaculture. As wild harvests decline and per capita seafood consumption continues to rise, aquaculture must make up the difference. The United States currently imports 60 percent of its seafood, exacerbating a multibillion-dollar trade deficit. We can either continue to increase our imports of seafood from other countries that have developed their aquaculture potential, or we can cultivate new approaches, allowing us to develop our own natural resources to their full production potential.

Regulation

To date, no state or federal authorities have developed regulations to permit transient gear aquaculture, but pending applications by my firm, Spatco, Ltd., in Narragansett, R.I., are likely to force regulators to examine the issue. Officials from the Rhode Island Department of Environmental Management (DEM) are on record as stating that they

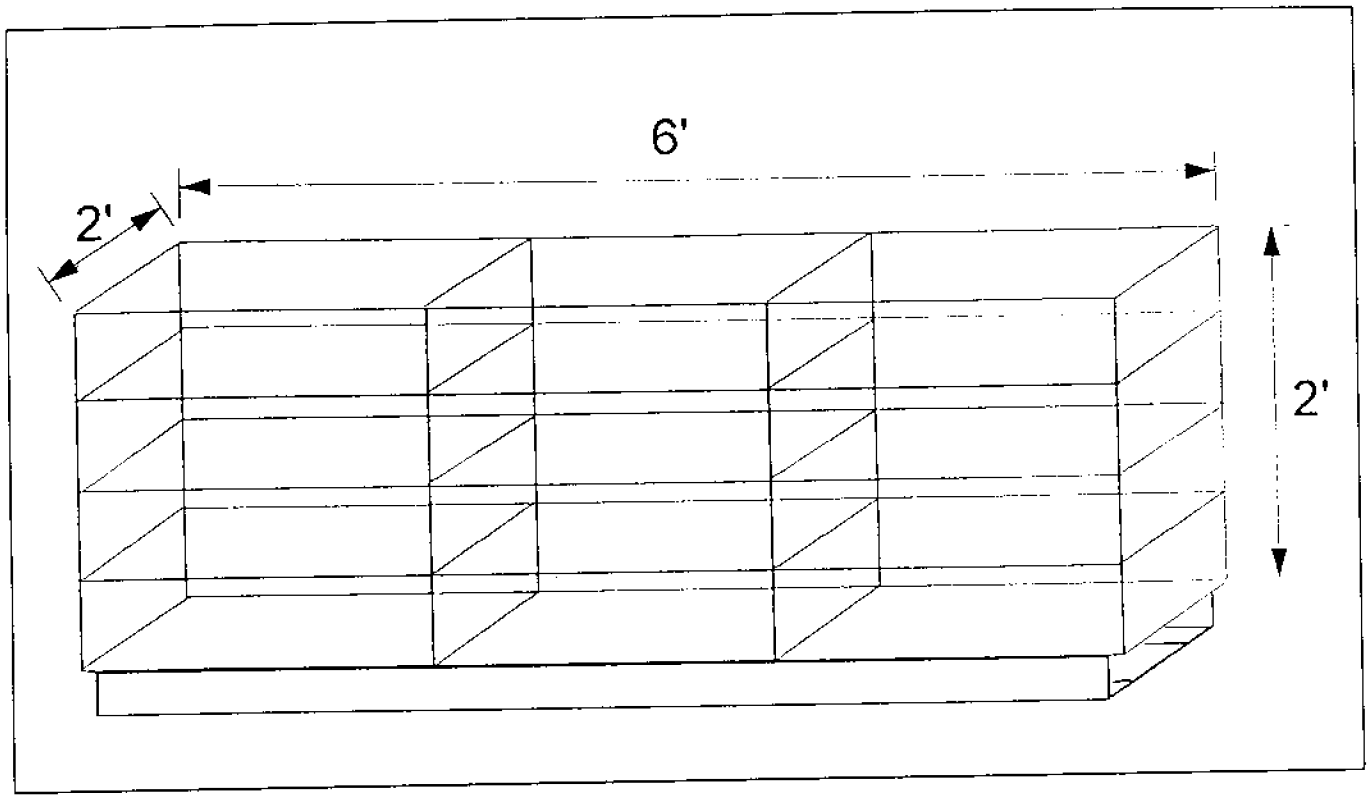

Figure 1. Schematic drawing showing the dimensions of an oyster pot. Each oyster pot has 12 shelves to accommodate plastic mesh shellfish bags. Typically, the oyster pots rest on the estuary bottom and are marked by a small buoy.

prefer the transient gear approach to conventional fixed leases as a way to avoid conflicts with the wild-harvest fishermen. DEM has agreed to develop appropriate regulations in a timely fashion if Spatco'sexperimental transient-gear aquaculture permit is approved by the Coastal Resources Management Council (CRMC). Similarly, the U.S. Army Corps of Engineers (COE) is aware of this permit application and may have to make some adjustments in their regulatory policies if this approach is permitted.

Since there is little difference between an oyster pot and a lobster pot, the regulations regarding their placement should be similar. Both growers and lobstermen must exercise the same common sense in placing their gear, avoiding the main navigational channels, areas where towed dredges would foul their gear, and shallow waters where their pots might be crushed by boats. In fact, since the investment in each pot is greater for a grower, the motivation to keep the gear out of harm's way is greater.

One regulatory approach being examined by DEM would allow the grower to operate within a "permitted area," but unless the applicant is given sufficient space to move his gear around to accommodate the wild-harvest fishermen, the advantages of the technique are lost. Other regulations would be essentially the same as for lobster fishing. In Rhode Island, lobstermen purchase commercial fishing licenses, attach identification tags to their pots, paint and brand their buoys, and place their pots wherever they think they will catch the most lobsters. Periodically, the pots are hauled and placed in a new location. The same regulations should apply for transient-gear aquaculture.

The only real difference between lobster pots and oyster pots is that the former qualifies as a "fish attracting device," and the latter (while it does attract many fish and crustaceans) is designed primarily to hold and grow shellfish. From a regulatory point of view, this is a very important distinction to the COE. Fish attracting devices—pots, traps, and weirs—are covered under Nation-

wide Permit Number 4, giving individual states control over regulation of fishing gear. Aquaculture gear is not covered under Nationwide Permit Number 4, so it requires individual permits from the COE. This policy may change once the technique has been demonstrated, as it is unlikely that the COE is going to want loran coordinates for a few hundred pots that move around every month.

Methods

Fundamentally, this approach is no different from many rack-and-bag shellfish aquaculture techniques that have been developed (Imai, 1977). The only difference is that instead of placing the bags on fixed racks in the intertidal zone, the bags are held in buoyed cages that are mobile. This allows the grower to operate in deeper waters and to grow more shellfish in the same area by stacking in the vertical dimension. It also obligates the grower to haul the gear from a boat, rather than tending it while standing on the shore.

We have designed our oyster pots with four shelves to hold 12 mesh bags, four high by three wide. This design is a modification of enclosures previously designed for nursery culture of shellfish seed under floating docks in marinas (Rheault and Rice, 1989). The pots are constructed of vinyl-coated galvanized wire identical to that used in lobster pots. We use a 5-centimeter (cm) mesh, 10-gauge wire (Aquamesh, Riverdale Mills, Northbridge, Mass.) to construct a cage that is 183 cm wide by 61 cm deep by 61 cm high, with shelves to hold the bags 15 cm apart vertically. The pots are fitted with 10-cm high metal or wood skids to keep the bottom of the cage out of the mud (Figure 1). The mesh bags are made of plastic (Vexar, Internet, Minneapolis, Minn.) 61 cm by 61 cm by 5 cm deep. The open end of the bag is closed with a slit piece of 1.9-cm-diameter (3/4 in) PVC pipe. Different mesh sizes are used at various stages of growth: 3 millimeters (mm), 6 mm, and 12 mm.

To facilitate management, we place our pots in trawls of 10, spaced 3 m or more apart along the trawl line with buoys at each end. Management of the oysters involves removal of fouling organisms, restocking the bags, and harvesting the oysters. Most of the labor is devoted to keeping the gear clear of the various fouling organisms that settle on the cages or on the bags, inhibiting the flow of water to the shellfish, and competing for food. In dense assemblages, shellfish growth is food-limited, as their feeding will rapidly deplete the food available unless currents are swift enough to replenish the food (Frechette and Bourget, 1985). Shellfish growth is maximized under conditions of high seston flux—food-rich seawater and moderate or high current speed (Muschenheim, 1987; Grizzle and Lutz, 1989). The cages and bags are rapidly colonized by algae, tunicates, ascidians, sponges, polychaetes, barnacles, and even oysters. Removal of these fouling organisms is accomplished by jetting the gear with a 3,000-psi pressure washer driven by an 11-horsepower gasoline-powered engine. Growth of the fouling organisms varies seasonally with factors such as temperature, light, and depth. During the summer, we find it necessary to clean individual oyster pots every four to six weeks.

The second most labor-intensive aspect of bag culture involves restocking the bags to maintain a proper density for optimal growth. Typically, at this time, the shellfish are also passed through a sieve to separate them by size. Within a given bag, it is desirable to minimize variability in size, because the larger shellfish will filter most of the water available, further slowing the growth among the smaller animals. Shellfish have inherently high variability in growth rates, and should be sieved periodically for ease of management and maximal growth. It is usually desirable to use the largest mesh size possible that will effectively retain the shellfish, since the larger mesh size material has a greater percentage of open area, permitting better flow of water to the shellfish.

Restocking the bags is necessary to accommodate the geometric increase in volume resulting from the growth of the shellfish. Our experience in Rhode Island is that 200 milliliters (mL) of 1-mm seed in May will grow to 500 liters (L) in July, and about 10,000 L by the end of the growing season (Figure 2). We attempt to stock each bag so that the shellfish form a layer no more than one animal deep. Juvenile shellfish can be stocked at great densities in terms of numbers per bag; however,

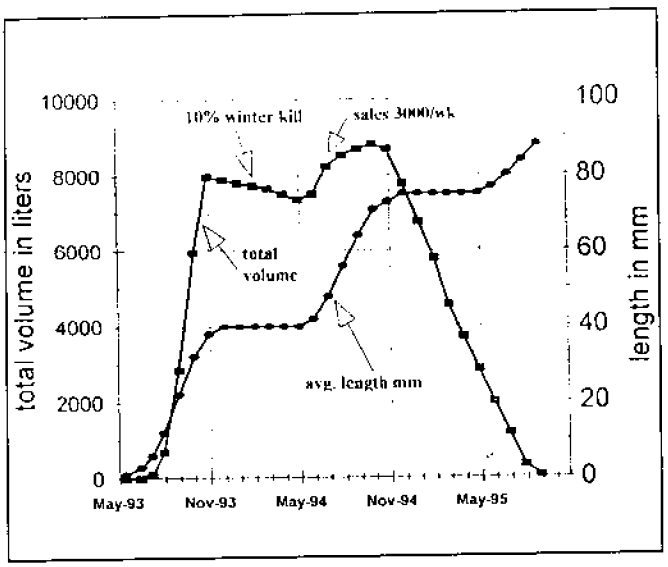

Figure 2. Typical oyster growth during a two-year cycle in oyster pots. Oysters reach market size of about 65-mm shell height in about two growth seasons. Once oysters reach market size, total volume of the oyster pots is limited by the weekly sales of product.

juveniles are stocked at much lower volumes per bag than adults (Table 1). At each location, optimal stocking densities must be determined experimentally, as this figure varies with temperature, current speed, and food concentration.

When sieving and restocking the bags, a considerable amount of time may be spent breaking apart clumps of oysters that have grown together. This is imperative if one is targeting the high-end half-shell market. Clumps of oysters, sold for their meats alone, are worth about one-quarter what they would bring as singles. We also take this opportunity to dip the oysters in a saturated brine solution. This eliminates the parasites *Polydora websteri*—a polychaete that causes mud blisters—and boring sponges (*Cliona* spp.), as well as controlling barnacles and oyster overset (Debrosse and Allen, 1993; Loosanoff, 1957).

When shellfish are cultured at commercial densities, growth is almost invariably food-limited (Wildish and Kristmanson, 1985; Buss and Jackson, 1981). Locations with high seston flux can sustain good growth rates at higher stocking densities than comparable sites with less current or phytoplankton. Optimal stocking density can be defined in terms of maximizing growth, minimizing gear and labor, or some combination of the two. Lower stocking densities will always result in faster growth, but at some point, additional thinning becomes uneconomical, because the gear and labor costs increase as the number of individuals per bag declines. Seasonal variations in growth rate or market demand may also dictate that densities should be varied. In our location, we have found that for good growth, 6-mm oysters in 3-mm mesh bags should be stocked at 1.5 L/bag, whereas 40-mm oysters in 12-mm mesh bags can be stocked at 6 L/bag or more (Table 1).

Optimal stocking densities will vary with the organism in culture as well. The bay scallop, *Argopecten irradians*, filters far more water than a similar-sized oyster (Palmer, 1980). To achieve economically optimal growth with scallops, we use initial stocking densities that are one-third those that we use for oysters.

Production Model

We present here a model that incorporates four years of data utilizing transient gear to grow oysters and scallops. This model can be used as a general guide to estimate start-up gear costs and to generate estimates of expenses and income. Actual production using this system will vary greatly from location to location depending on temperature, current speed, phytoplankton concentration, and the source of the seed.

Mortality

In the four years that Spatco has been working with bag culture, we have run the gamut of possible mortalities from negligible to total losses. Two crops have been victims of Unidentified Juvenile Oyster Mortality (Bricelj et al., 1992; Farley and Lewis, 1993; Davis and Barber, 1994), and one crop was wiped out by an undescribed pathogen. Since it is impossible to predict losses to disease, this model has been constructed to assume realistic mortality due to breakage and handling of 1 to 2 percent per month and winter kill of 10 percent.

Date	Thousands of oysters	Average % mortality	Total liters	Total # of pots	Monthly sales (pcs)	Monthly revenue	
15-MAY-93	200	2.0%	0	0	0	$0	
15-JUN-93	196	2.0%	3	0	0	$0	
07-JUL-93	192	1.0%	120	0	0	$0	
30-JUL-93	190	1.0%	695	29	0	$0	
30-AUG-93	188	1.0%	2,842	79	0	$0	
30-SEPT-93	186	1.0%	5,940	99	0	$0	
30-OCT-93	185	1.0%	7,960	111	0	$0	
30-NOV-93	183	1.0%	7,800	111	0	$0	
30-DEC-93	181	1.0%	7,801	111	0	$0	
28-JAN-94	179	1.0%	7,723	111	0	$0	ANNUAL
30-FEB-94	177	2.0%	7,646	111	0	$0	REVENUE
30-MAR-94	174	4.0%	7,493	111	0	$0	@.40/EA
30-APR-94	370	2.0%	7,344	102	0	$0	$0
30-MAY-94	365	1.0%	7,493	104	0	$0	
30-JUN-94	359	1.0%	8,359	114	0	$0	
30-JUL-94	347	1.0%	9,225	142	8,000	$3,200	
30-AUG-94	334	1.0%	11,541	180	10,000	$4,000	
30-SEPT-94	319	1.0%	14,760	222	12,000	$4,800	
30-OCT-94	303	1.0%	16,651	231	12,000	$4,800	
30-NOV-94	288	1.0%	15,648	217	12,000	$4,800	
30-DEC-94	273	1.0%	14,568	202	12,000	$4,800	
28-JAN-95	259	1.0%	13,500	187	12,000	$4,800	
30-FEB-95	244	2.0%	12,225	170	12,000	$4,800	
30-MAR-95	228	2.0%	11,204	156	12,000	$4,800	
30-APR-95	412	1.0%	10,196	142	12,000	$4,800	$45,600
30-MAY-95	394	1.5%	9,274	129	12,000	$4,800	
30-JUN-95	376	1.0%	9,422	129	12,000	$4,800	
30-JUL-95	352	1.0%	9,444	145	20,000	$8,000	
30-AUG-95	335	1.0%	11,387	178	14,000	$5,600	
30-SEPT-95	319	1.0%	14,362	216	12,000	$4,800	
30-OCT-95	303	1.0%	16,217	225	12,000	$4,800	
30-NOV-95	288	1.0%	15,214	211	12,000	$4,800	
30-DEC-95	273	1.0%	14,139	196	12,000	$4,800	
30-JAN-96	259	1.0%	13,075	182	12,000	$4,800	
28-FEB-96	244	1.0%	12,225	170	12,000	$4,800	
30-MAR-96	228	1.5%	11,204	156	12,000	$4,800	
30-APR-96	212	1.5%	10,195	142	12,000	$4,800	$61,600

Table 1. An economic model for oyster production using a transient-gear aquaculture system. Estimates of mortality, growth, and sales are estimated from data collected in the 1990 to 1994 growing seasons in Point Judith Pond, Narragansett, R.I. For optimum growth, oysters are held to a maximum biovolume of 6 L/bag. See text for details of gear and discussion of model assumptions.

Growth

Based on an annual crop planting of 200,000 1-mm seed in May, the model projects that the average oyster will grow to 40 mm in the first season, while the entire crop will grow to a total volume of 8,000 L (Figure 3), held in 1,300 bags in 110 of our 2-m pots. Growth drops to zero when temperatures drop below 10C. (November to May). Oysters begin to reach market size by the middle of their second growing season and are picked out and sold year-round at a rate of 3,000 oysters per week. Cumulative mortality over the 25-month period for one crop is 25 percent. By the end of the third summer, the first crop has been harvested, the second crop is just reaching market size, and the third crop is averaging 35 mm long (Table 1).

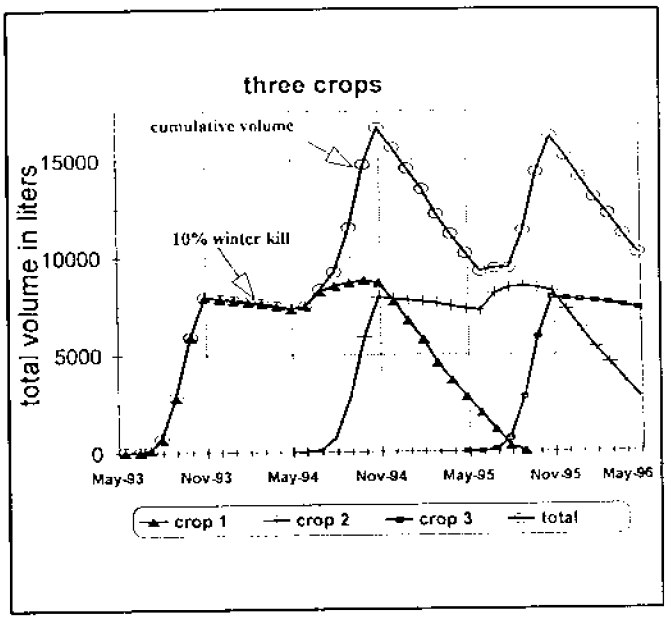

Figure 3. A multi-year production model showing the disposition of three crop years. Cumulative volume totals determine the number of oyster pots to be deployed at any time.

Economics

Depending on how the product is marketed, one can expect to receive 20 to 55 cents apiece. This model projects sales of 150,000 oysters and gross revenues of $30,000 to $82,000 per year. To maintain an annual crop planting of 200,000 requires a maximum of 220 of the 2-m pots at roughly $110 per pot, representing an expenditure of $24,000 for pots and bags alone.

Labor costs are highly variable regionally, and will also vary with the season and the fouling rate at each site. Aquaculture is labor-intensive and many man-hours are devoted to grow-out, cleaning, sorting, marketing, sales, deliveries, maintenance, and constructing new gear. During the peak of summer, we employ four people full-time, but during the winter months, labor is limited to 20 person-hours per week for harvesting, shipping, and maintenance.

Depending on the source and size of seed purchased, seed costs will vary tremendously. Oyster seed cost will triple if 10-mm seed are purchased instead of 2-mm seed; however, seed costs tend to be a minor expense in the overall budget. Seed costs for this model are $1,500 per year. Seasonal availability of larger-sized seed may also change the projections of this model. Other variable costs include a boat, permits, insurance, testing, legal fees, and expendables, such as gas, ice, and salt. We estimate our profit margin (in the absence of disease-related mortality) to be around 20 percent, but we foresee several areas where automation, economies of scale, and aggressive marketing should improve this margin. Substantial savings could be realized by a fisherman who already has a boat and much of the equipment needed for this work.

Risk Factors

In our location, oysters take two to three years to reach market size. During this period, the entire crop is susceptible to disease-related mortalities, such as Unidentified Juvenile Oyster Mortality, MSX, or Dermo (Perkins, 1993). Each of these diseases has, at one time, ravaged American oyster populations and has the potential to kill a large percentage of the crop. The shellfish also can be lost to storm damage and theft; however, the motivation to steal from a grower is slight, because at any given time, 90 percent of the stock is typically of sub-legal size. We have also attempted to minimize theft by making the pots large enough to deter lifting by the casual boater. Each of our 2-m pots can weigh up to 400 pounds when fully loaded and fouled.

Species

We have used this method to culture northern quahogs, *Mercenaria mercenaria;* bay scallops, *Argopecten irradians;* American oysters, *Crassostrea virginica;* and European flat oysters, *Ostrea edulis.* Bag culture works well for bay scallops if the seeds are made available early enough in the season. There is an emerging market for whole bay scallops, live and in-shell, at 5 to 8 cm for 15 to 25 cents each. This size can be achieved in four to five months at proper stocking densities. Unfortunately, bay scallops cultured at commercial densities will suffer very high winter mortalities (50 to 95 percent) if they do not make it to market size in their first season. In spring and summer, the adductor tissue glycogen levels are low, making them less palatable (Barber and Blake, 1981). We have found that this system is inappropriate for quahog culture. The labor and gear costs are too high for an animal that takes two to three years to reach market size and brings only 15 to 20 cents each. Clams will also suffer high winter mortalities unless they are permitted to bury themselves in the sediment. *Ostrea edulis* is attractive because of its fast growth and high market price, but has a short shelf life, is vulnerable to low winter temperatures, and may be considered an undesirable exotic species in some states.

Advantages

The primary advantage of this approach is that it allows growers flexibility in the placement of their gear, so that user conflicts can be minimized. Gear can also be moved to take advantage of seasonal blooms, to avoid red tides, or to minimize winter kill. Since the product is all contained in bags, there are no losses to predators. Oysters grown off-bottom reach market size in two to three years—a full year faster than those cultured on the bottom. Bags also afford growers easy access to the shellfish for sorting and inspection, giving the grower greater control over the quality and uniformity of the product, and facilitating harvest. Quality, single oysters for the half-shell trade bring a high price premium over wild-harvest product. Cultured shellfish are exempt from many of the regulations, such as seasonal harvest restrictions, designed to protect the wild resource. Most states permit shellfish to be sold year-round, and several have relaxed their minimum size regulations for cultured shellfish.

Disadvantages

Transient-gear aquaculture also has disadvantages, when compared to other more extensive methods of shellfish aquaculture. The method is extremely gear- and labor-intensive. During the peak of summer, our company employs four people full-time, and labor costs can reach $1,000 a week. This is a very expensive method of culturing shellfish, justified only by the quality of the product and the ability to avoid user conflicts.

Benefits

- Shellfish are filter feeders, and will improve water quality and clarity by filtering the water. The shellfish in each of our cages will clear an estimated 70 to 300 m^3 day. These "biological filters" are highly efficient at removing phytoplankton from the water column, incorporating nitrogen and phosphorus into oyster tissue, thereby improving sunlight penetration and slowing eutrophication (Officer et al., 1982).
- Cultured shellfish will spawn and release millions of larvae to the wild-harvest fishery. For every oyster in culture, an estimated 1 million eggs are released each year. Of these, a minute fraction will survive to be recruited into the wild-harvest fishery, but we estimate conservatively that 300,000 oysters should bring $50,000 to the wild harvest each year.
- The oyster pots provide an excellent refuge and foraging site for a myriad of juvenile fish. The cages become small portable artificial reefs, enhancing the juvenile survival of many commercially important fish species.

Conclusion

Transient-gear aquaculture is a novel approach designed primarily to resolve multiple-use conflicts currently hampering the expansion of shellfish aquaculture in the Northeast. Our work has demonstrated that the method works well in rich

coastal salt ponds, where oysters can reach market size in two to three years. It remains to be proven whether or not this approach is viable in deeper waters. Since there is insufficient space in the salt ponds for the technique to have any real economic significance in terms of regional production, future studies are aimed at measuring growth rates in deeper, colder, more oligotrophic waters. It is likely that growth rates will be slower, meaning that gear will be tied up for longer periods, making labor and gear costs per oyster proportionately higher. It is equally plausible that fouling growth will be less of a problem in deeper waters. The question remains whether or not this technique can be economically viable outside of the salt pond environment.

Transient-gear aquaculture has the potential to alleviate traditional user conflicts, while allowing aquaculture to develop without the need for conventional, exclusionary, fixed leases. If the aquaculturist can operate without a conventional lease, then the potential exists for aquaculture to proliferate in areas where leasing is not a viable option. Landings of the wild-harvest shellfishery in Rhode Island are down about 60 percent from five years ago. If Rhode Island wants to maintain its position as a major shellfish producer, it must start to look to aquaculture to fill the void.

The technique also has great potential as a supplementary income source for wild-harvest fishermen without significantly altering their way of life, since the technique requires a minimal capital investment for gear, and uses the traditional tools and skills of the waterman. An investment of $15,000 in gear can be sufficient to raise 100,000 oysters per year, potentially worth over $40,000 if marketed properly. Many fishermen already have the skills and equipment necessary to get started in transient-gear aquaculture.

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Questions and Answers

Q: (Gerald Carvalho, shellfisherman) If you are permitted to set out the mobile gear like lobster pots, what assurance is there that we would not be completely overrun once other people discover the method?

A: (Robert Rheault) This is a common question about aquaculture, "What if everybody wants to do it?" I don't know if everybody would want to do it. You have to get out there and work very hard.

Comment: (Carvalho) If there is money in it, then everybody will want to do it.

A: (Rheault) Okay, but you are predicting that this is going to happen in the absence of any regulations. Let me inform you that the aquaculture industry in this state is regulated more heavily than any other industry, short of nuclear waste disposal. We have more regulators getting their finger in the pie than you can imagine. If you wanted to get into the business, I would be happy to bring you up to speed on how many regulations you have to comply with. They will have regulations as to the growth of this industry. I guarantee it.

Comment: (Carvalho) To push the lobster pot analogy further, consider the lobster fishery when lobsters are abundant. You can practically walk from buoy to buoy from Quonset to Jamestown. Likewise, if people see money in aquaculture, they will get into it, and there will be problems when that much bottom is tied up.

A: (Rheault) Pave the Bay! Pave the Bay! It's the devil's work! Every time we have change in our society, there is someone out there calling foul. I seriously believe that there is a great opportunity to develop aquaculture with a minimum of conflicts.

Comment: (Robert DiSanto, Rhode Island Shellfishermen's Association) One of the things that I learned while shellfishing is that lobsters and shellfish are in different areas. It may be preferred salinity, or food availability, or something else. As a shellfisherman, I rarely encounter lobster pots. I don't believe that I will be able to say the same thing for oyster pots. If transient gear is not on top of quahog beds, then there is probably no problem. But as an aquaculturist, you probably want the best water quality possible. There is only a limited amount of SA (high-quality marine waters) in Rhode Island, and that is where the conflict arises.

A: (Rheault) So, you have to get the quahogs under my cages this month? You cannot wait until the cage is moved?

A: (DiSanto) It's not a matter of getting quahogs this month or next month. It is a matter of being able to fish where we have been fishing for years.

Comment: (Rheault) Remember that over one-third of the Bay was leased.

Comment: (DiSanto) Not anymore. It is now a case of your cages. It is no longer my bottom until you move your cages. Without the cages, it is everybody's Narragansett Bay. With the cages, it's your bottom.

Comment: (Rheault) Just like the lobster pots.

Comment: (DiSanto) But there is no conflict, because the lobster cages are not on the clam grounds.

Q: (Ed Agin, Rhode Island Shellfishermen's Association) What about the case of areas being better to fish during certain times of the year? If the cages are in an area that is best fished in summer rather than winter, then we have to wait for a less-than-optimum time to go there.

A: (Rheault) There is no reason why the cages cannot be placed in winter areas when you want to fish the summer areas, and vice versa. This technique is designed with that very type of conflict in mind. It is mobile gear, it can be moved. We are not hampered by the constraints of a fixed lease.

Q: (Agin) What about the importation of shellfish diseases along with your seed purchases? Introduced diseases could be devastating to our industry.

A: (Rheault) Three years ago, there was a 50 percent incidence of MSX in the Taunton River. So, disease is here. Luckily, the diseases are not presently in my oysters (knock on wood). All the seed that I import from hatcheries outside this state must be inspected by a certified shellfish pathologist, and an inspection certificate presented to officials from the DEM Division of Fish, Wildlife, and Estuarine Resources. This is one of the operational regulations that I must comply with, and strongly support. I can assure you that I am the last person who would like to bring in MSX or any other disease into this state.

Q: (Agin) Could importation of inbred shellfish into Rhode Island weaken our wild stocks?

A: (Rheault) Not really. The typical hatchery practice is to collect 30 or 40 of the fastest-growing animals you can find. Then, they spawn all of these animals simultaneously so that there is plenty of genetic exchange to maintain heterozygosity. In a couple of cases, such as hatcheries for Japanese oysters, *Crassostrea gigas*, in the Pacific Northwest, there were theoretical parentages of only nine oysters. In this case, yes, these oysters were severely restricted genetically. Heterogeneity of East Coast quahog and oyster stocks have been checked (by methods outlined by Saran Twombly), and there is a great deal of genetic variability. Hatchery owners have made very conscious efforts to introduce "wild" genes into their broodstock, along with their fast-growing and selected color traits. (Editor's note: See Manzi et al. 1991. *Aquaculture* 94:17-26.)

Comment: (Joseph DeAlteris, URI department of fisheries, animal, and veterinary science) I wish to offer the suggestion that, if appropriate, bodies of water in the state could be zoned for certain activities. I know of a case in the James River in Virginia where several users of the waterway avoid conflict by this aquatic zoning.

Comment: (Neal Perry, Rhode Island Shellfish Divers Association and Ocean State Aquaculture Association) DEM introduced this concept as a "permitted use area" with number of traps being restricted.

A: (Rheault) We have been discussing all of these possibilities with the CRMC. If CRMC decides that permitted areas is the way to go, DEM will come out with appropriate regulations very quickly.

Status of Rhode Island Shellfisheries: Transcript of a Panel Discussion

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DeAlteris: I noted a couple things from the presentations that we can use as the basis for discussion in this wrap-up session. The first question might be the health of the fishermen and the fishery, status of the resource, the role of public resource enhancement, and finally, the role of private-sector aquaculture. By covering these four topics, I believe we can cover most of what was discussed today, and try to reach a consensus about each of them. The first of these topics is the health of the fishermen and the fishery in terms of economics and landings. Priscilla Brooks had some data from the National Marine Fisheries Service in Washington. Presumably, Washington has the same data that the state is giving them, or at least that is my understanding of how things work. Is it a general consensus that landings are declining?

Agin: Yes.

Ganz: Yes.

DeAlteris: In the last decade, are we down 50 percent? 33 percent? 25 percent?

Agin: I'd say about 50 percent.

DeAlteris: Art, what do the data indicate?

Ganz: We have gone from a high value of about $65 million in 1986–87 to the present value of slightly less than $30 million. These figures include economic multipliers.

Brooks: Which multiplier is used?

Ganz: This is a multiplier of four times the actual dockside shellfish value.

DeAlteris: What about the landings?

Ganz: The high was in 1985, with about 27 million pounds (shell-on), and the 1993 landings were about 11 million pounds (Editor's note: About a 60 percent decrease in landings). Additionally, we have gone from having about 44 percent of the U.S. quahog landings in 1986 down to about 25 percent of the market presently. This loss has been mainly due to aquaculture production in the southern states, and loss of Greenwich Bay production during that time period.

DeAlteris: What can you say about the numbers of fishermen during that time period?

Ganz: During the mid-1980s, when the Upper Narragansett Bay was opened, we had about 3,700 licenses. Right now, we have about 900 licenses (both multipurpose and shellfish licenses). Of that, about 200 to 300 are actually out on the Bay on a regular basis.

DeAlteris: So we're looking at about 25 percent of licensees as actually participating?

Ganz: Yes.

DeAlteris: So from my quick figuring, effort is down about 75 percent and landings are down about 50 percent, so catch per unit effort (CPUE) is not down all that much.

Neal Perry, audience: There seems to have been a much greater number of fishermen in the past, particularly during well-publicized openings. So, as things stand now, catches are down, numbers of fishermen are down further, but earnings are way down, because of lower prices, even though CPUE is higher.

Ganz: I do not know if it is an accident, but there are more divers today than there were even a few years ago. The divers catch more quahogs, and this may be reflected in the CPUE figures.

DeAlteris: So to summarize, landings are down, value is way down, and CPUE to the individual fishermen may not be down substantially. Is this reasonable?

Ganz: Yes, but the cost of living and the costs of fishing have gone up.

DeAlteris: So the profitability of the fishery is going down, but the resource is not in particularly poor shape?

Peter Canis, audience: It seems to take more time and effort to get enough quahogs to get the same amount of money.

DeAlteris: Do we all agree with this?

Gerald Carvalho, audience: That seems like a reasonable assessment.

DeAlteris: This is not accounted for in traditional ways of describing catch and effort.

Ganz: Fishermen often set a certain financial goal for the day, and they will fish until the goal is met. The actual number of quahogs is somewhat irrelevant.

Agin: The men working out there are working pretty hard to reach the goal. This is not a good situation. By working so hard for so long, they are just "breaking down." I think that this is happening in a large way to the young guys out there. They are pushing themselves to extinction. They are not so much getting other jobs because they cannot afford to be out there, but because they are having health problems.

Unidentified audience member: Back in the 1950s when I was teaching school, I could make more shellfishing in 10 weeks during the summer than I did all year teaching. Today, I can bring in as much shellfish as then, but I can hardly make any money on it.

Gerald Carvalho: Most fishermen, whether digger or diver, should be working on a time frame. They know that their capacity is limited to

so many hours per day. Afterwards, they should break off and go home—that is the limitation. If you push too much beyond the time frame, you "break down" or "burn out," and it does not pay. So everybody should be aware of their limitations.

DeAlteris: Let's talk about the next topic, health of the resource. We can agree that CPUE is about the same or a little higher, but we have heard some scary things today about a shortage of seed quahogs out there. What is the general feeling about that? Let's rehash that for a couple of minutes.

Unidentified audience member: I have switched much of my effort to cherrystones and chowders, because there are plenty out there and few are targeting them. I need to pull in a lot more of them, because they are not worth very much, but it works for me.

Rheault: I agree that the lack of small seed is disturbing. That does not bode well for the future.

Gerald Carvalho, audience: I do not know the overall health of the resource, but I know of a lot of areas with plenty of seed. There are cases where we have harvested areas very intensely, swore that there was no seed, and then left the area alone. Upon returning a couple of years later, we would marvel at the number of littlenecks present. Over the last several years, I think we have witnessed the harvest of the annual production and all of the surplus stocks that had built up over the years by way of our inefficiency. With the great influx in the 1980s, we were able to put a tremendous effort into the harvest of shellfish. This brought areas down to the point that we are just relying upon annual production. In some areas, you would get a shot in June and another in August, and sell your catch and not have a single chowder or cherrystone in the lot. This means we're relying only on the natural annual production. It's amazing that you can swear that you rake an area clean, then come back and get a phenomenal number of littlenecks. Before condemning Narragansett Bay's natural productivity, I would like to see hard data that say that this, in fact, is true. If we are relying on annual productivity, the Bay will continue to support shellfisheries, but a lesser number of people.

Neal Perry, audience: To really get the data, you have to sample shellfish in a quantitative way with grabs and the like. It is difficult to sample many of the smaller shellfish on the surface because they "blow away" with the slightest disturbance.

DeAlteris: So, the seed you see on the bottom are right at the surface, with no penetration of the bottom?

Neal Perry, audience: That is correct. One wave of the hand and they are all flying.

Wayne Durfee, audience: My recollection is that Greenwich Bay was closed for a couple of years. How are the stocks there?

Ganz: They have just taken 750,000 pounds out of Greenwich Bay in seven days. Two hours a day for seven days. The rebound potential for Greenwich Bay is astounding. We have used the Greenwich Bay study as a prototype for the study of other areas in Narragansett Bay. Hopefully by this time next year, we will have a report on the status of stocks in many key shellfishing areas. The report presented by Najih this morning reports on the Greenwich Bay area that was rebounding. The areas being studied now are "real world" shellfishing areas that were not closed.

DeAlteris: The work you are doing is with a dredge with a 1-inch bar spacing?

Ganz: Yes. But what we would like to do—time and money permitting—is to subsample by taking everything.

DeAlteris: What is the role of public resource enhancement? There have been three approaches: direct seeding, habitat enhancement (as presented earlier), and habitat manipulation (which we reported two years ago; it did not work very well).

Neal Perry, audience: There is not much hope in direct seeding. Placing unprotected hatchery seed out into the environment is expensive, and there are massive losses to predators (much of comments inaudible). Transplants are a viable way of making more product available.

Rheault: Congressman Reed, along with Congressman Studds from Massachusetts, has a bill in the U.S. House of Representatives that has transplant money in it. The bill is in the National Marine Aquaculture Enhancement Act. Since we are on transplants, one thing we might examine is that in other states, particularly New York, the relay is privatized. If you privatize, the profit motive allows for the transfer of much more shellfish. New York does about a $10 million business on the relay, I believe.

Gregg Rivara, Cornell Cooperative Extension, audience: That's about $12.7 million last year, and it's very heavily regulated.

Rheault: You also have less of an impact on the pricing structure because you don't flood the market all at once. Mike Rice has done some studies that suggest that about 70 percent of Rhode Island quahogs are in uncertified waters. There is something like $90 million worth of product in the Providence River alone. There is potential for lots of jobs and plenty of revenue.

DeAlteris: Mike, how do those guys handle polluted-water clams coming out of the James River in Virginia?

Michael Osterling, Virginia Institute of Marine Science, audience: Right now, most of our relay uses cages on the bottom. The cages are 4 feet by 4 feet by 1 foot, and anywhere from 2,000 to 3,000 clams are put into them for 15 days.

DeAlteris: And they are pretty much handled by the traditional clam buyers?

Osterling: The harvesters are the same harvesters that work the clean waters, except that during the summertime they work the polluted waters. The only difference is that the buyers put the clams in waters leased from the state. The buyers purchase the clams from the watermen, and move about 25 million clams a year.

DeAlteris: How much does this represent in terms of the total production?

Osterling: It is about 50 percent of the wild harvest.

Ganz: Don't you clean out the broodstock when you are doing that?

Osterling: No, I don't think so.

Agin: This may be a concern in Narragansett Bay.

Rheault: But if you take only 10 percent of the Providence River quahogs, that's $9 million a year. It's a pretty good return.

Osterling: There is some concern for that now, and Virginia is considering broodstock sanctuaries.

Rice: I think that we need to keep in mind the tremendous fecundity of quahogs. A 50 percent reduction in larval supply would have much less impact on recruitment of littlenecks than just a few percent reduction in post-set juvenile survival. I refer people to an excellent paper by Malinowski and Whitlatch discussing this. (Editor's note: S. Malinowski and R.B. Whitlatch. 1988. A theoretical evaluation of shellfish resource management. *Journal of Shellfish Research* 7:95–100.)

Ganz: We need a good study of the quahogs in the Providence River and the Upper Bay, not one of these "patch jobs" that we've seen over the last 40 years, but carried out with the same quality as the Greenwich Bay study that Najih just presented. This is in the hopper with high priority.

Gerald Carvalho, audience: I think that we need a study that explores shellfish management schemes in other states, to tell us what has been successful, whether it be privatization or enhancing the public resources. I think that we can solve many of our problems by just finding out what works elsewhere. I cannot see how we can produce a plan effectively without a lot of headaches unless we do this.

DeAlteris: Let's move on to the potential role for aquaculture in Rhode Island.

Wayne Durfee, audience: I heard some mention of studies of practices in other states, and I was wondering if this could be a function of the Northeast Regional Aquaculture Center.

Ganz: We have plenty of information of this sort. Mike Rice has collected quite a bit of information. This is not a totally unknown quantity. Yes, we can learn from other states, but that is not the whole story. The situations that we deal with here in Rhode Island are pretty unique. We have some pretty unique governmental structures, starting with our constitution, and we have some very unique problems, including a host of user conflicts—as Dr. Pollnac put it, "conflicts among different exploiters of the resources." We need to try to find out how to work effectively in the system that we are given. These concepts of "free and common fishery," regulation by the state and not by towns, among others, will shape the forms of aquaculture that will develop here.

Unidentified audience member: Rhode Island has historically been conflict-ridden. Tongers strongly opposed the introduction of the bullrake.

Ganz: Have you ever heard of a Yankee that likes change?

Unidentified audience member: I think Art is correct. We can learn from Virginia, but the political systems are too different for direct adoption of their methods.

Ganz: Last night Mike Osterling gave a talk at the Ocean State Aquaculture Association meeting about aquaculture development in Virginia. His opening remark was, "We do this in Virginia, but to try it in Rhode Island..." He just shook his head.

Gerald Carvalho, audience: We have certain things that make us unique, but it does not make change impossible. We can even learn from failures in other states as well as the successes.

Rheault: There are some examples of projects in nearby states that do work. There is a $50-million oyster industry that developed in only the last five years in Connecticut. There are 190 clam growers working in Massachusetts, and 14 million pounds of salmon are cultured in Maine annually. There is no biological reason why these things cannot be done here. At one time, we had 150 million bushels of oysters per year cultured in Narragansett Bay.

Unidentified audience member: Did shell planting by the old oystermen increase the production of quahogs?

Rheault: There are no hard data, but anecdotal evidence suggests that there were very good sets in some of the planted shell.

Griffith: Ever since Mike introduced me as a distinguished guest this morning, I have been wondering and worrying about whether or not I was going to be able to say anything, because after observing this all day, it is clear that we are in an area where fools rush in. Anyway, overlying all of this is a crisis that I think you are aware of at the very least from what you read in the papers. This is the collapse of the groundfish fishery. The Office of Strategic Planning is now undertaking a study to assess the impacts of the collapse of the groundfishery. We started back in March, and we quickly realized that we cannot look at these fisheries in isolation. With the recommendations last week to completely close the Georges Bank fisheries, it is clear that we will have a greater number of displaced fishermen, and in a shorter period of time than we ever planned on. Last March, we were not too concerned about direct impacts of Amendment 5 on Rhode Island fisheries, but we were concerned about the indirect effects of fishing effort moving off Georges Bank onto so-called underutilized species. We are waiting to see what the Fisheries Management Council does about the Georges Bank closure advisory. We have a project underway that to date does not involve you folks. I have talked to many of you as individuals and as representatives of various industry groups. What we intend to do is offer an open invitation to all of the interests to hear what we have done to date. One of the interest areas is exploring the potential and the obstacles of finfish and shellfish aquaculture in Rhode Island. Another opportu-

nity area being developed is the looking at new markets for Rhode Island seafood products. There are several other potential opportunity areas. I would be happy to put anybody here on my mailing list if you are not already on it.

Rheault: The Ocean State Aquaculture Association has requested of the Governor's Office that we develop a strategic plan for aquaculture in this state. It is difficult to develop aquaculture if we don't know where we want to be in five years, and we don't know how to get there. We did not get much of a response from the governor, but Congressman Reed has placed an item in a House aquaculture bill's budget to fund strategic plans in states that do not already have them. There is a DEM proposal that has just been put forth, asking for funds from the National Marine Fisheries Service to fund a strategic plan. It is an important first step that this state needs to take, and I am looking forward to working with many of you on the plan.

DeAlteris: It's getting close to the time to quit. Does anybody wish to make any closing comments?

Gerald Carvalho, audience: There are two things I wish to mention for the record. I would like to see the establishment of a corps of administrative fish inspectors under the Division of Fish, Wildlife, and Estuarine Resources. These inspectors could check fish and shellfish houses for compliance of laws, gaining knowledge for enforcement purposes, and secondly to collect biological data on amounts of product and so forth. The administrative inspectors can do things that the police cannot, such as enter shellfish houses for inspection purposes, but they cannot arrest people. We need fishery inspectors as much as we need enforcement. We really need to know just what is going from our harvesters, through our wholesalers, and to our markets.

The second recommendation is for the state to begin some marketing program. This year we take $90 worth of count-necks in a Texas onion bag and are now putting them in unlabeled bags. It would be nice to see—mandated by law—a Rhode Island bag container that says "Rhode Island Shellfish." There are no marketing requirements for shellfish beyond the simple Health Department requirements.

DeAlteris: Does the quahog industry ever work with the Rhode Island Seafood Council?

Carvalho: Yes, but not successfully. They tried to the best of their ability, and we tried to the best of our ability, but it needs to go beyond that. It needs to be legislation that says that by such-and-such a time, certain marketing efforts will be put in place.

Brooks: Are members of the industry willing to pay for a marketing program based on landings?

Carvalho: I think that details of that sort could be worked out through legislation. It is in the state's best interest to market the product. This is because the product does not really belong to the harvesters or wholesalers. The harvesters are, in fact, paid for the service of harvesting Rhode Island's resource, and the state uses the wholesaler to market it. Since the resource is the property of the Sovereign—the people of Rhode Island—I do not see any other way but to look at state financing of marketing.

Agin: I have one comment. Last week a couple of my colleagues and I met with Congressman Reed. We discussed money put in the aquaculture bill for transplant/relay and management programs over a three-year period. But we need to develop a scheme for self-funding after three years. Part of this was a tax on bags, raising shellfish license fees, and others. I really think that we need to focus on managing our own transplant program before spending any money on advertising.

Carvalho: Let me make it very simple. We do not identify the package that we sell our shellfish in. That is a simple, simple step. Last year they were Texas onions, this year they are California oranges. At some point we need to say that it is a Rhode Island clam right on the package.

Agin: At the Reed meeting, the marketer present was Warren Finn. He told Congressman Reed that he had more problems than it was worth 25 years ago when he tried to introduce it, so he stopped doing it.

Neal Perry, audience: American Mussel Harvesters and Blue Gold mussels don't seem to have any problems with labeled bags.

Carvalho: We have the best hard-shell clam anywhere in the world. I challenge anybody to prove me wrong.

Brooks: But it is amazing, you don't see anybody advertising Rhode Island quahogs.

Carvalho: That's why I'd like to see it mandated by law.

Brooks: You can have it mandated by law, but you must have all of the harvesters behind it. You just can't have the government tell you how to market your product.

Griffith: I think Priscilla made a good point. You are not going to get it solved if you ask government to resolve your differences. If you want some money from the government, I think that you must resolve your internecine warfare and then come up with a program. Only then will the government put up some money. One thing we have learned is that there is not enough money in government to serve each and every special interest. That is certainly true at the state level, and if you just turn on the evening news, it is becoming increasingly true of the federal government as well.

Carvalho: The difference is that this is not something that takes money, it makes money for the state.

Griffith: If it is in the best interest of the state, it is in your best interest to get together amicably with all of the sectors of the industry and, without infighting, produce a coherent plan.

DeAlteris: For the last comment, let's hear from an out-of-stater.

Michael Osterling, audience: In Virginia, we have a very healthy hard clam aquaculture industry. The clams are marketed as Virginia cultured clams and command a premium price. They want to distinguish their product from your product. They are marketed in bags produced specifically for each company. On the bags are the name of the company, the product—"cultured littleneck clams," and the place of origin. There is brand-name identification. Virginia has a state marketing board, a marine product board, and a Department of Agriculture office of consumer services that are supported by license fees. These groups work to actively promote Virginia seafood.

DeAlteris: I might add, as a former Virginia waterman, that they do a hell of a good job. You can see the effect of their work as they target individual products. You can really notice increased prices benefiting the fishermen.

With that I thank you for coming.