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Pratt, Martin, & Saila (URI)

Narragansett Bay Estuary Program

STATUS OF THE HARD CLAM (MERCENARIA MERCENARIA) IN THE PROVIDENCE RIVER AND MOUNT HOPE BAY

S.D. Pratt, B.K. Martin, and S.B. Saila
Graduate School of Oceanography
The University of Rhode Island
Narragansett, RI 02882-1197

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FOREWORD

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

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

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

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

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

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INTRODUCTION

The hard clam or quahog, Mercenaria mercenaria, is a resource of major economic importance in Rhode Island. The value of the catch to Rhode Island fishermen was approximately $13 million in 1984 (National Marine Fisheries Service, unpublished). Catch value has increased steadily since 1972 due to increases of nearly four times in both price per pound and in pounds landed. Indications that landings may have leveled off since 1983 makes it important to consider ways to open new areas to the fishery and to assure that exploited stocks are self- sustaining.

Large populations of hard clams are found in the Providence River and in Mount Hope Bay. Both of these areas have been closed to commercial fishing for over forty years, although they were used as a source of transplant stock until 1967. This project was undertaken as an effort to describe the standing stock and condition of hard clams in these areas. This information will have immediate practical use in the management of the fishery if portions of Mount Hope Bay are opened in the near future. While the Providence River will probably not be opened to fishing soon, information on the spatial distribution and population structure of clams can be used as a measure of environmental quality. Both areas are sources of clam larvae and may serve as "breeder sanctuaries" as described by Carter et al. (1983).

The major task of this study was a survey of hard clam distribution and population structure. Techniques of shell aging and possible measures of condition (tissue color and shell shape) were examined to obtain information on present populations and to test the utility of these methods. For each task, historical information on the closed portions of the Bay is reviewed to show long-term trends and to establish the rational for certain tests.

Spatial Distribution and Standing Crop

Quantitative surveys of hard clams have been carried out in the closed portions of Narragansett Bay on three occasions using the same techniques. In 1956 the Providence

River and Mount Hope Bay were surveyed along with much of the upper Bay (Stringer 1959; Campbell, n.d.). The Providence River was surveyed in 1957 (Stringer 1959) and in 1965 (Saila et al. 1967; Canario and Kovach 1965).

In each survey, stations were located on a 274 m (900 foot) grid: 120 in the Providence River from 700 m north of Sabin Point to Conimicut Point, 188 in the Rhode Island portion of Mount Hope Bay, and an unknown number in the Massachusetts 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. Samples collected in 1956 and 1957 were washed on a 12.7 mm screen and clams larger than 15 mm in height were recorded. A 6.35 mm screen was used in 1965. Clam density is given in four size classes for 1956 and 1957 data (Stringer 1959) and contoured in three commercial size categories for 1956 and 1965 data (Campbell, n.d.; Canario and Kovach 1965). The sample density in these surveys is twice that used in the present survey of the Providence River and about six times that used in Mount Hope Bay. The high sample density and the systematic coverage of each area (at depths of less than about 6 meters) made it possible to map clam distribution in detail (Figures 5, 6, 7).

The survey reported on here was much less intensive than the three described. It utilized a dredge rather than a quantitative grab, a chain bag with 50 mm openings rather than a 12.7 mm screen, and fewer stations. Use of a dredge is justified by savings in time and by its ability to integrate small scale patchiness. A study carried out by the Rhode Island DEM (Russell 1972) demonstrated that acceptable estimates of population size can be made with dredge data for single substrate types. The stratified random sampling plan used in the present study was chosen to improve estimates of standing crop and to identify effects of different substrates on clam condition.

A survey of the Massachusetts portion of Mount Hope Bay was made in 1980-1981 using a commercial dredge and a 274 m sample grid (Hickey 1983). The results of that study are directly comparable to those presented here.

Size Distribution

In the portions of Narragansett Bay open to commercial fishing, fishing pressure is the dominant influence on population structure. The absence of fishing in the closed areas sampled in this study provides an opportunity to assess the effects of natural variables and to contrast population structure in areas with different levels of pollution stress. A major problem in the interpretation of size-frequency distributions in these areas is the long period of time over which variables may have affected growth rate and survival.

Size distribution data has been routinely obtained in surveys of hard clams conducted by the Rhode Island Division of Environmental Management in order to estimate the potential yield of different market sizes. The relative abundance of four clam size categories are given for the surveys of the closed portions of the Bay carried out in 1956 and 1957 (Stringer 1959). The relative abundance of three categories are given for the 1965 survey (Canario and Kovach 1965). Diamond (1981) provides the size distribution of clams from south of Sabin Point in the Providence River on three dates in 1977-1978. McDonald and Grimm (1984) give size distributions of clams from five stations in the Providence River sampled in June 1984.

Age and Growth Rate

If the Providence River and Mount Hope Bay were opened to fishing, the potential sustainable yield would be dependent on rates of spat settlement and growth of young clams. Growth rate over long time periods can give an integrated measure of environmental quality in stressed portions of the Bay. As quahog management becomes more sophisticated, it will be valuable to know the effect of population density and harvest strategy on long-term growth rates. Information on growth rate over short periods is needed to determine the effects of temperature, spawning, or quality of suspended food.

The ability to age hard clams would be a valuable asset to studies of accumulation of pollutants over time. It is not clear from the literature whether metals accumulate in hard clams over long time periods. Many metals are internally regulated or vary seasonally with activity and reproductive cycle. Rapid uptake to a stable level has also been frequently observed. In several studies copper was found to decrease with size (Boyden 1977; Larsen 1979; Behrens and Duedall 1981; Cullen 1984). Less is known concerning uptake of hydrocarbons over time. The finding of a non-depuratable hydrocarbon pool in clams from the Providence River (Boehm and Quinn 1977) suggests the absence of active metabolic transfer and the possibility of slow accumulation. If contaminants accumulate over time, determination of the age of transplanted clams from polluted areas would provide a safety factor and improved public acceptance.

Many mollusk species have exterior shell patterns correlated with rate of growth. Hard clams in areas north of Chesapeake Bay develop a groove or "break" in the shell during cessation of growth in the winter (Fritz and Haven 1983). In some clams these exterior lines are clear enough to provide reliable ages. In most cases, however, exterior winter breaks are obscured by shell erosion, additional breaks from other causes, and crowding of breaks at older ages.

Internal microstructure is protected from erosion and can give information on growth for periods as short as one day. Of a large number of publications on shell preparation and interpretation of microstructure , the following papers are particularly useful: Lutz and Rhoads (1980) review mollusc and shell growth patterns in general. Ropes (1984) reviews techniques developed for aging Spisula solidissima and Arctica islandica (surf clam and ocean quahog). Kennish (1980) provides a detailed description of his work with microgrowth analysis of hard clam shells in an area where power plant effluent is a potential problem. Jones (1983) reviews some of the applications of "sclerochronology," particularly the record of environmental change in growth of S. solidissima. Fritz and Haven (1983) made detailed examination of hard clams from long-term experimental growth lots in Chesapeake Bay.

The only study of hard clam shell microstructure in Narragansett Bay have been carried out in support of archaeological studies of Indian middens. Pratt (1984) used relatively crude techniques to examine shells from a 600-1000 year old midden on Potowomut Neck, Warwick, Rhode Island. More than half the shells examined had visible daily growth increments and continuous growth throughout the summer and fall. It was possible to determine the season during which these individuals were harvested.

For some time there has been interest in the potential of shell microstructure analysis at the Marine Fisheries Laboratory of the RI Department of Environmental Management and at the Applied Marine Research Group of the Graduate School of Oceanography. Funding of the hard clam population distribution study has provided an opportunity to obtain equipment for shell preparation and to try to find a technique which will provide adequate data with the minimum expense of time. It is very important to be able to examine enough shells to be able to detect treatment effects despite the natural variation found within populations.

The technique of shell preparation chosen from the literature was epoxy encapsulation, sectioning, and examination of an acetate peel of the whole shell. When there were problems with this technique, thick and thin sections of the hinge plate were examined as an alternative. Because of the time required to install equipment and to develop techniques, it was not possible to process the large number of clams originally projected. For this report selected populations were examined to characterize growth rate in major subareas.

Condition

The quality of different environments for shellfish production can be assessed by growth rate and physiological and histological measures. In this section, two measures are examined which have only been used descriptively in the past: tissue color and shell proportions. Tissue color is an expression of histological and physiological condition, while shell proportion may be related to growth rate and physiological condition.

Tissue Color—Color variation is found within individuals of several commercially important bivalve species. In some cases color is environmentally induced and is used by both consumers and fisheries managers as an indicator of quality or source of shellfish.

Under natural conditions hard clam color ranges from cream to brownish orange. The muscular foot is usually darker than the visceral mass and the aductor muscles are light colored and sometimes pink. Light colored sex products and dark stomach, digestive gland, pericardium, and kidney can be seen through the body wall.

Abnormally dark colored hard clams from the Providence River were observed by Phelps and Barry (1968) and described by Jeffries (1972) and Diamond (1981). Brown colored clams were found in the Quonset/ Davisville area by Brown (1977). Color was one of the variables observed in a recent Bay Project survey (Kern 1986).

Brown (1977) proposed that lipofuscins were the cause of discolored clams. It has been suggested that these are "age pigments" which accumulate at a regular rate in marine crustaceans and squid (Nicol 1987 and references within). It is thus necessary to assess the age effect before color can be considered as an indicator of environmental quality.

Some form of quantification of color is necessary for comparisons over time, between investigations, and to aid the perception of subtle patterns within single studies. Phelps and Barry (1968) made a record of the darkness of hard clams from a variety of environments with black and white photographs and standard lighting. These photographs show that both the foot and visceral mass of Sabin Point clams were very dark. Clams from other parts of the Providence River and upper Narragansett Bay were lighter colored but variable. Clams from Charlestown Pond were uniformly light colored. The Sabin Point clams appeared to be pigmented black rather than merely dark orange (Phelps, EPA Narragansett, personal communication). Color photography would have retained more information in this case, but film dyes are prone to change over time. Thus, color pictures are not practical for interlaboratory comparisons.

In many fields where color specification is necessary, notation has been standardized by use of the Munsell system. This system provides a large number of color combinations based on hue (position in the spectrum), value (lightness, black to white), and chroma (strength, or departure from a neutral of the same value). Cheng and Iancu (1984) described the color of clams from stations in the Providence River and north of Patience Island using Munsell charts. They did not find a marked difference in tissue color along the pollution gradient. Size of clams was measured, but no attempt was made to correlate size and color.

The present survey of hard clams from the Providence River and Mount Hope Bay provided an opportunity to record the color of a large number of measured and weighed individuals. The data were used to test the utility of the color notation technique, to test the hypothesis that Sabin Point clams are unusually colored, and to establish a baseline for future studies.

Shell Proportions. In Narragansett Bay hard clams are found with a range of length/width proportions. The extreme cases are termed "sharps" and "blunts." Sharp clams have shells which come together at a small angle and add new material along the distal border. The edges of blunt clams come together at a large angle and shell growth takes place along facing inner bands. There is a tendency for sharp clams to be found in good condition and to be actively growing. Blunt clams appear to be older and to be more abundant in crowded or stressed conditions. Although clams have a generally similar appearance within different parts of the Bay, both sharp and blunt individuals are found in most areas.

As far as is known, shape has not been studied quantitatively in Narragansett Bay hard clams. Although shell proportion has important implications in analysis of growth rate and productivity, only the response of shape to environmental quality along the Providence River is addressed in this report..

METHODS

Field Sampling

The sample areas were: (1) Providence River north of the closure line from Conimicut Point, Conimicut light house, and Nayatt Point and south of a line from Pawtuxet Neck to Sabin Point, and (2) Mount Hope Bay between Mount Hope Bridge, Bragga Bridge, and Tiverton Bridge, but excluding the Kickamuit River. Tows were limited to depths of more than 9 feet (3.74 m) at low tide outside the dredged channels (Figures 2 and 8). The approximate area of each sediment type (limits in Figure 1) mapped by McMaster (1960) within the potential sampling areas was determined. In each major area 60 tow locations were divided among sediment strata in proportion to the area of the strata. Potential tow locations in each strata were established at intersections of a 0.1 minute grid of longitude and latitude and numbered in sequence. The assigned number of tows was located by choosing random numbers within the range of the number of locations. Sediment strata are given in Figures 2 and 8. Sample locations are shown in Figures 3a and 9a.

Sampling was carried out from the R/V Thomas J. Wright, a 42-foot trawler utility vessel from November 7 to December 5, 1985. Sampling locations were determined by Loran C. At each location a rocking-chair (Fall River style) dredge with a two-inch ring collection bag was towed over a circular course for five minutes. On deck the catch was washed and mud-filled clams identified and removed. Catches of one bushel or less (about 200 clams) were placed in mesh bags. For larger catches, the total number of bushels was recorded, the catch was "coned and quartered" to produce a subsample, the subsample volume was measured, and the subsample bagged. Clams were returned to the Graduate School of Oceanography on the day collected. Selected clams were removed from the samples and depurated for 24 hours in filtered seawater. These clams were labeled, measured, weighed, and frozen for possible studies of size-specific heavy metal load. The remaining clams were frozen immediately in a walk-in blast freezer.

Examination of Whole Clams

Clams were examined a few hundred at a time over a number of months. On removal from the freezer they were washed and placed in numbered cells between low partitions on 3' x 3' plywood sheets. This made it possible to conduct a series of observations on the clams without having to mark the wet and rough outer shell surface. While the clams were still frozen, length and width were recorded to 0.01 mm with an electronic digital caliper. Note that width refers to the dimension across the hinge, the "thickness" of the clam in layman's terms. Total weight was recorded to 1 g with a top loading balance. After two hours of thawing, one shell was removed and foot color was determined by matching with Munsell soil color charts which had been sealed in plastic. Three charts were used (5YR, 7.5YR, 10YR) and comparisons were made under a GE 100 watt "long life" white incandescent bulb. Clam tissue was removed a nd discarded, and the shells were weighed, labeled by pencil on their inner surfaces, and archived for age and growth studies.

Data was entered in a LOTUS 1-2-3 spreadsheet on the same day it was recorded. The LOTUS 1-2-3 program was used for all data entry, sorting, calculation of confidence limits, and outputs of tables and graphs.

Shell Analysis

Shell cutting and polishing equipment was obtained on loan from the EPA Narragansett Laboratory to the Division of Environmental Management. The equipment was installed at the Graduate School of Oceanography and a storage building for shells was obtained.

Intact shell pairs were chosen for examination. If periostracum was well developed, shells were soaked in sodium hypochlorite for one hour and rinsed. The line chosen for sectioning was marked from the umbo to the posterio-ventral edge along the axis of maximum growth (Kennish et al., 1980, Figure 1). This line also cuts through the internal hinge plate.

For the acetate peel technique shells were cut with a 10-inch diamond saw along a line parallel to, and 1 cm posterior of the desired section. Shells were placed cut-side down in rectangular aluminum foil boxes and embedded in epoxy resin (SP Systems, SP105) which had been warmed to decrease viscosity so as to release air bubbles and allow entry into small voids. When cured, the shell and epoxy were cut along the section to be examined.

The section was ground on 12-inch lapidary wheels with 120, 240, 320, and 600 grit adhesive disks lubricated with water. Polishing was done with 6 u Metaldi and 1.0 and 0.3 alumina abrasives on cloth-covered wheels. The polished sections were etched with 1% concentrated HCl for 10-15 seconds, rinsed and dried. The shell surface was flooded with acetone and a 30 x 90 mm slide of 3.17 mm acetate applied. When the acetate was dry, the slide was removed and examined under the microscope with transmitted light. Some epoxy-embedded shells were mounted and made into thin sections as described below.

Sections for hinge plate analysis were cut 2 mm from the desired section without epoxy encapsulation. If the shell was large, the hinge area was trimmed to fit a 27 x 46 mm petrographic slide. Thick sections were ground smooth on 120, 240, 320, and 600 grit disks. Thin sections were mounted on slides with epoxy, cut to 1-2 mm with the saw, and ground and polished to transparency (Clark 1980). Thick sections were examined under a binocular microscope with reflected light, and thin sections were examined with a compound microscope and transmitted light.

Shells were examined from station P 2 and 3 south of Sabin Point, P 32 off Gaspee Point, P 52 north of Conimicut Point, P 43 off Nayatt Point, and from an area sampled by fishermen southwest of Common Fence Point in Mount Hope Bay, and from stations south of Sabin Point sampled in June 1984.

RESULTS AND DISCUSSION

Data

Station numbers, locations, sediment strata and catch per tow for the Providence River and Mount Hope Bay are shown in Tables 1 and 2. Raw data on shell measurements, weights, and tissue color of individual clams are given in Appendix 1. Data in Tables 1 and 2 and Appendix 1 have been entered in the EPA/Bay Project Data System.

Spatial Distribution

Hard clams were recovered from 57 of 60 stations in the Providence River. Catch size is shown by the area of the station location circles in Figure 3b and is contoured in Figure 4. It was necessary to contour this data by hand because of low sample density and the narrow area sampled between shore and dredged channels in some reaches. Closed dashed contours drawn shoreward of the area sampled are suggested by the results of other surveys which extended into shallow water.

The greatest hard clam density was found south of Bullock Cove. High density areas south of Gaspee Point and north of Conimicut Point extended into depths too shallow to sample by dredge. Each of these concentrations coincides with dense patches found in 1956 and 1965 (Canario and Kovach 1965)(Figures 5-7). Small patches found off Pawtuxet Cove, north of Gaspee Point, Occupessatuxet Cove, and west of Bullock Point in earlier studies were not sampled in 1985 because they were in shallow water or in depth strata with limited areas.

Density was low in an area south of Sabin Point where it had previously been high. This change is consistent with reports of mortality (D. Phelps, EPA, Narragansett., personal communication) and physiological abnormalities (Jeffries 1972) in clams from that area. Clam densities were higher at adjacent deeper stations.

The distribution of hard clams recovered from Mount Hope Bay is shown in Figures 9b and 10. The stations in which no clams were found are predominantly in strata. Although dredge clogging was a problem in this strata, the results are consistent with the 1956 survey which also found many "zero" catches. One tow off Touisset yielded more than 500 clams. The concentration off Touisset is on level sandy bottom, but other patches are not associated with specific depths or topographic features. Two patches extend across dredged channels.

Concentrations off Touisset and east of Mount Hope coincide with high-density areas found in 1956 (Figure 11). The shallow area east of Common Fence Point, in which clams were abundant in 1956, was not sampled in 1985; conversely, deep areas in which clams were found in 1985 were not sampled in 1956. Additional high-density areas mapped in 1956 may be too small or in too shallow water to have been sampled in 1985 (Bristol Narrows, Fall River and Tiverton shore).

The three areas of high concentration in Massachusetts waters shown by Hickey (1983)(Figure 12) were in shallow or obstructed areas and were not sampled. The absence of hard clams in deeper areas of Mount Hope Bay is consistent with Hickey's results.

Substrate Effect

The mean and 95% confidence limits of number of clams per tow in different sediment strata in the two study areas are given in Tables 3 and 4. In the Providence River, mean number of clams per tow for each strata was clay/silt-32, sand/silt-102, sand/silt/clay-461, sand-619, and silt/sand-860. The means in clay/silt and sand/silt were significantly lower than the means in the other strata. There were no significant differences within these two strata groups.

There were only two sediment strata types within Mount Hope Bay. These had very similar low mean catches of 12.1 and 14.6 clams/tow with no significant difference between them. Low catches in clay/silt strata are consistent with the results from the Providence River. However, the catch in sand/silt/clay is only 3% of the mean catch in the same strata of the Providence River.

Size Distribution

The length-frequency distribution of all measured clams from the Providence River and Mount Hope Bay are shown in Figure 13. Individuals less than 60 mm long and 35 mm wide can pass through the 2-inch rings of the dredge bag. This is significantly larger than a legal 25.4 mm wide clam. Small clams are sometimes retained in nets clogged by cohesive sediment or large catches.

When all clams are considered, the distribution of size in the Providence River is unimodal with a peak of 72 mm. The largest individuals in the river were 108 mm long. In contrast the size distribution of Mount Hope Bay clams is bimodal with peaks at 68 and 96 mm. The largest clams in Mount Hope Bay were 118 mm long.

Both areas were divided into groups of stations with high and low densities of clams. The density criteria used was different in each case and was chosen to provide equivalent numbers of individuals in each group. In the Providence River the high-density group included 17 stations yielding more than 500 clams/5-minute tow, and the remaining stations made up the low-density group. The size distributions within the two groups were nearly identical (Figure 14).

In Mount Hope Bay the high-density group included 9 stations which yielded over 50 clams/tow, and the low-density group included 20 stations in which at least one clam was caught. The size distributions within these groups were very different. In high-density stations length was distributed unimodally with a peak at 97 mm (Figure 15), and no clam less than 77 mm long was recovered. The low-density stations had a bimodal size distribution with a large peak at 92 mm and a small peak at 68 mm. All of the small clams seen in the total Bay catch came from the low-density group.

The size distribution of Providence River clams from 10 station groups in different sediment strata and in different segments of the sampled area are shown in Figure 16. In the nine upstream groups size distributions were unimodal with a slight increase in modal length downstream. The Nayatt-South samples had length modes at 46, 68, and 80 mm. Conimicut-South samples had a narrow range of size and few individuals smaller than 68 mm.

Many finfish populations show a gradual decrease in density with size and age because mortality rates are similar for all ages. A different pattern is found in species such as the hard clam in which individuals are better able to resist the attack of predators as they become larger. Under natural conditions and in a stable environment, clam populations become dominated by large individuals. Recruitment of juvenile clams into the population of large clams may take place either at a low but constant rate or in a pulse when conditions are optimal. Because most studies have been made on exploited populations, little is known about the fate of large clams or the effect of high density on the growth of adults and recruitment of young.

Although length-frequency data can tell nothing about the rate of recruitment of juvenile clams into harvestable size classes, the presence of small clams would indicate that conditions had been suitable for spat settlement and growth within the past three to four years. Small clams were collected in all of the Providence River station groups other than Conimicut-south. No small clams of comparable size were collected in the Mount Hope Bay dredge stations. The absence of clams in the 60 to 77 mm range in the Mount Hope Bay high-density stations suggests that there has been no recruitment to this size range for a number of years. Sufficient larvae must be present since recruitment takes place in other parts of Mount Hope Bay. Sediments in the high-density areas are relatively sandy which should promote settlement and growth. Competition from adults could be a problem if densities were higher than indicated by rocking chair dredge samples. The density of other competing species and predators could be high in areas that were very productive and undisturbed by man. The potential for settling and growth of hard clams is of concern if Mount Hope Bay is to be opened for fishing.

The two study areas have remained undisturbed long enough to yield an indication of the maximum size achievable in each. Significant numbers of clams from Mount Hope Bay reach lengths of more than 100 mm and some reach 120 mm. This is the maximum size of clams in other parts of Narragansett Bay.

With only a few exceptions, the maximum size of clams from the upper Providence River stations is less than 100 mm. This could have resulted from mortality of all clams followed by repopulation of clams which have not yet reached their maximum size, death of clams larger or older than 100 mm, or environmental limitation on maximum size. Clam ages are needed to verify the first two hypotheses. Unfortunately, after about seven years, slow and irregular growth makes aging very difficult. The fact that growth has slowed is consistent with environmental limitation. Evidence of a population that is not growing in size is found in the similarity of length-frequency distributions in 1977-1978 (Diamond 1981; Figure 16) and 1984 (McDonald and Grimm 1984; Figure 7). No physiological mechanism for age-specific mortality in hard clams is known, nor were any size-specific histopathological abnormalities found in Narragansett Bay clams by Kern (1986). However, changes in size and weight do change burrowing ability, and thus the ability to escape from predators such as starfish.

McDonald and Grimm (1984) calculated von Bertalanffy growth curves for Providence River clams from the first four years growth increments seen on the shell exterior. Although there is uncertainty in their measurement, generated curves yielded a maximum length of only 90-100 mm, indicating long-term sub-optimal growing conditions.

The uniformity of size distribution within high- and low-density stations, and the absence of large clams from any station, suggest that density is not a growth limiting factor. There was also no difference in clam size in different sediment strata and only a slight increase in sizes down river.

A pattern of uniform growth limitation could be produced by a combination of water-borne pollutants and phytoplankton food sources with low nutrition value which grow in response to high nutrient loads. In recent Marine Ecosystems Research Laboratory (MERL) experiments examining the effect of sewage sludge on Mytilus edulis (blue mussel), both variables were identified as responsible for reduced growth and increased mortality (G. Tracey, EPA Narragansett., personal communication). The absence of growth limitation in Mount Hope Bay agrees with evidence that it has better water quality than the Providence River (Rippey and Watkins 1987) and a phytoplankton community similar to mid-Narragansett Bay (Toner 1981; Pratt 1965, and Marine Research, Inc., Brayton Point Investigations Quarterly Progress Report from 1971-1986).

In the past, hard clams have been transplanted from the Providence River for depuration. If growing conditions within the river are suboptimal, transplantation should be carried out while the clams are very small to enable them to grow in better conditions. Early removal and prolonged exposure to clean conditions would provide additional assurance of complete depuration.

Standing Stock

Accurate estimates of standing stock cannot be made from the present survey because of lack of information on dredge efficiency and because small clams were not sampled. At 100% efficiency, the dredge used would harvest 188 m^2 or 0.04653 acres (5-minute tow at 2 knots, dredge 2 feet wide). Unfortunately, the rocking chair dredge samples at less than 100% efficiency and is also subject to variation in efficiency under different conditions. In sandy sediments, the dredge alternatively buries and exposes its digging teeth; consequently, clams are missed over significant portions of the track. In cohesive sediments, the dredge tends to form a plug of mud at its mouth which pushes sediment and clams aside.

Russell (1972) used a dredge to estimate standing crop during commercial harvesting in West Passage. We have used his results to calculate a dredge efficiency of 40-60% with a 95% confidence interval of 17-95% on "highly compacted" sandy sediment. Although all the details of sampling operations were not provided, they are probably very similar to those used in the present survey.

In a survey of Mount Hope Bay, Hickey (1984) used a "mud" dredge which does not have a rocking action. He measured efficiency by recording the density of class left in the dredge track and displaced from the track. He obtained an average efficiency of 15% for representative trials and noted that high towing speeds, hard bottom, heavy bottom cover, and very high clam density all lowered efficiency.

The dredge used in this study had a collection bag made up of 2-inch diameter rings which allow individuals less than 35 mm wide (65-67 mm long) to pass through. This includes most littleneck size clams (25.4 - 38 mm wide). Hickey (1984) avoided complete washing of his dredge catch to retain smaller clams. This procedure identifies the presence of small clams, but cannot give density measures.

Length-frequency distributions of clams show that in the Providence River the modal size class is retained by 2-inch rings, but that there are significant numbers of individuals less than 65-67 mm long which may or may not be retained (Figures 13 and 14). In five quantitative samples obtained by divers at Sabin and Conimicut Points in 1985, approximately 25% of the total catch was small enough to pass through two-inch rings (Pratt, unpublished data). In the high density stations in Mount Hope Bay, all individuals would be retained even with thorough washing.

Because of the uncertainties discussed above, we have presented standing stock (Table 6) and retail value estimates (Table 11) without correction for gear efficiency or loss of small individuals.

Uncorrected densities of hard clams from the Providence River averaged 2.3/m^2 for all substrates and 4.24/m^2 for silty sand. The largest catch was 9/m^2. The uncorrected density on silty sand is 33% of the mean density of clams over 66 mm long recovered from five diver-collected samples on equivalent substrate. Uncorrected densities are also much smaller than the densities of legal-size clams obtained in earlier quantitative surveys, even if loss of small individuals is considered. Average density fro the lower Providence River was 24.5/m^2 in 1956 and 41.2/m^2 in 1965 (Canario and Kovach 1965).

It is necessary to assume a dredge efficiency of 10% or lower to obtain a similar density from the 1985 survey. An alternate explanation to very low-dredge efficiency is a decrease in standing stock. This would be consistent with informal reports of hard clam die-offs around 1970. Although it was difficult to age Providence River clams, it does appear that most of the individuals present are less than 20 years old and that the stock sampled in 1965 is no longer present.

The uncorrected density of hard clams from Mount Hope Bay was only 0.137/m^2. The largest catch was 2.66/m^2. This is much lower than the mean of 2.34/m^2 obtained in 1956 (Campbell, n.d.). The differential between 1956 and uncorrected 1985 densities was about twice as large in Mount Hope Bay as in the Providence River. The uncorrected largest catch was lower than that reported by Hickey (1984) for high density patches (7.7 - 7.8/m^2).

In conclusion it is clear that some form of quantitative samples is required to determine the standing stock in the closed portions of the Bay and to resolve the question of changes since 1956 and 1965.

The value of standing stocks in the study area was calculated by adding the market value of each size category in each sediment strata based on a conservative retail price of $3, $0.6, and $0.3 per pound for littlenecks, cherrystones, and chowder-sized clams (Tables 7 and 8).

The retail value of clams from the lower Providence River (Table 11) averaged $3.7 million without correction for dredge efficiency. While the actual stock size is certainly larger than that measured, this figure has little importance for management, since there is little likelihood of harvest for direct sale in the near future. The most likely use of this stock would be for relay or depuration.

The retail value of the portion of Mount Hope Bay sampled was only about $71 thousand. This is an underestimate of the potential of the area since it is known that exploitable densities of clams exist around the Bay's perimeter.

It is difficult to predict the sustainable yield of the study areas because they have not been harvested in recent years. Length-frequency data shows that recruitment of juveniles is taking place in the Providence River, but not in the sampled parts of Mount Hope Bay. For an area where recruitment is taking place, a 20% annual harvest should be possible (Hickey 1984). The potential of the Providence River to sustain an exploited population is suggested by the doubling of stock size between 1956 and 1965 (Canario and Kovach 1965) while an average harvest of 4.5 - 2% was taking place (Saila et al. 1967).

Age and Growth Rate

The equipment and procedures used for cutting and polishing hard clam shells were adequate to demonstrate the strengths and liabilities of various techniques and the special problems involved in aging slow-growing individuals.

The technique of precutting and mounting in a small volume of epoxy saved time and materials and adequately stabilized shells for grinding and polishing. Unfortunately, the epoxy used was soluble in acetone causing acetate peels to develop voids. Peels also had a tendency to pluck material from the polished shell surface. Daily growth rings could be easily seen in undamaged portions of the peel.

Thin sections examined with transmitted light showed as much detail as peels on the outer surface of shells and more detail than peels on the inner hinge plate. Thick sections examined with reflected light showed hinge pl ate features but in less detail.

The main purpose of shell microstructure examination was to confirm the identification of winter growth breaks by the presence of daily rings of diminishing and increasing width on either side of the break. These daily increments are best seen in the outer shell layer where they are perpendicular to the shell surface. In many of the clams examined, the thin shell deposited in the first year was chemically and mechanically eroded, making it difficult to identify the position of the first winter break.

It was also difficult to determine the age of clams at collection. The majority of clams examined were in a senile stage characterized by narrow growth increments separated by deep breaks, presenting a crenellated appearance in microscopic cross section. These increments are too narrow to be able to identify periods of accelerating and decelerating growth needed to establish that the breaks are annual. In Providence River clams it seems likely that one or more bands are deposited during short favorable periods during the growing season, possibly in spring and fall. In less stressed environments each band may represent a year's growth.

Examination of the hinge plate and adjacent concave portion of the shell (inner angle) was found to be useful in interpreting the growth history of Providence River clams. Confirming daily rings cannot be seen in this part of the shell, but early growth increments are preserved. Width of annual rings in both areas increased until the third or fourth year. These wide bands are marked by diffuse bands that may relate to events during the growing season. Clams in the range of five to eight years old lay down a single well-defined band. Thin bands of varying width laid down by older clams may represent annual or sub-annual growth.

In some individuals shell in the "inner angle" has rough texture. Sections show that this develops over a period of years as subsequent layers develop greater elevation over existing microtopography. In the upper parts of the Providence River, inner angle and hinge plate increments were divided by very thin bands of chalky material which make them stand out clearly. In some cases inner angle layers was separated by voids. It is hypothesized that both conditions represent a loss of shell material during prolonged periods of anoxia and extrapallial fluid acidity.

The general appearance of the exterior shell edge, hinge plate, and inner angle tend to be consistent in similar sized clams from the same location.

Because of difficulties in obtaining reliable measurements of first year growth and age at collection, a limited number of individuals were examined to identify general trends and help to interpret size distribution data. Groups of approximately ten clams were processed from four Providence River stations sampled in 1985 and from a Sabin Point station sampled in 1984. Groups and individuals were also analyzed from the fishermen-collected samples from Mount Hope Bay.

In most cases more than one section was made of each shell. Most sections were examined at least twice. In each examination age was estimated from hinge plate and inner angle and sometimes also the outer shell. Narrow increments deposited in the senile stage were interpreted as sub-annual in many cases giving a minimal age estimate. Age estimates for single individuals made from more than one shell section usually varied by one or two years.

A summary of observations is given in Table 14 listing the mean lengths and apparent ages of groups of similarly sized clams. The population of clams in the Providence River about 70 mm in length were estimated to be about ten years in age with a range of 7-13 years. Most of the clams collected in 1985 had smooth inner shell layers. A few 1985 Sabin Point clams and many 1984 Sabin Point clams had rough inner layers or layers with voids. Virtually all Providence River clams examined were in a stage of very slow shell growth.

An area of high density of relatively small clams was sampled in Mount Hope Bay west of Common Fence Point by fishermen in 1986 (Pratt, unpublished). In this population, size was generally correlated with age: the smallest individual was 52 mm long and 4 years old; the largest 68 mm long and 13 years old. Clams up to 75 mm long and 11 years old had exterior shells without close-spaced breaks, indicating active growth. Clams from 60 mm long and 7 years old to 68 mm long and 13 years old had frequent breaks on the edge of the outer shell. The inner shell layers of these clams were smooth with regular growth increments.

Large clams from deeper water in Mount Hope Bay ranging from 95-121 mm long were impossible to age from the external shell because of the large number of breaks. The inner shell showed wide distinct growth increments for about six years. After 10-20 years growth increments became crowded and indistinct. Narrow increments in Mount Hope Bay clams may be annual because the environment is favorable throughout the growing season. If this is so, many of the large clams examined would be about 30 years old.

It can be concluded that slow and irregular growth in clams retained in dredge samples in both the Providence River and Mount Hope Bay would make analysis of the present rate of growth and productive potential difficult. Clams less than 60 mm are still actively growing, so that small individuals are most useful in determining growth in relationship to environment.

The large clams found in Mount Hope Bay appear to have grown without disturbance for many years. Although Providence River clams have reached an age of reduced growth rate, they are still significantly younger than the large clams in Mount Hope Bay and a reason for the absence of older individuals must be sought.

Kern (1986) found a relatively high level of rough deposits on the internal surfaces of shells from Providence River stations 47 and 49, from Mount Hope Bay station 64, and the Mount View station. He found smooth shells in Greenwich Bay. Kern concluded that the general pattern of abnormalities persisted through both sampling periods, but could be obscured by variation within an area. The present study shows that individual roughness does not change with time so that percentage incidence should not change.

Although Jeffries (1972) lists ridged inner shell as symptomatic of a stress syndrome, shell roughness alone cannot be used to indicate poor growing conditions. Smooth shells collected at Sabin Point may have been the result of dissolution of inner layers during periods of hypoxia. The voids and distinct lamina found in Providence River clams may be a better indicator of stress.

Condition

Tissue Color—Color codes for individual clams are given in Appendix Table 1. The numbers 5, 7.5, and 10 refer to the three color charts used. The basic hues of these charts are half-way between red and yellow, three quarters of the way between red and yellow, and pure yellow. The two numbers in the following column give the value (lighter colors have higher numbers) and chroma (stronger colors have higher numbers). Colors varied from pinkish white (8/2) to strong brown (5/8).

Age-color relationship was examined in a subset of 948 individuals from each stratum of the Providence River. Of these 830 had colors found in the 7.5 YR chart. The size frequency distributions of clams in major 7.5 YR color categories are plotted in Figure

19. This method of data presentation was chosen to provide for future statistical testing. The alternative of plotting the distribution of colors within size classes would be harder to analyze since two color axes would be needed and each axis would have only a small number of steps.

The size distribution of clams in the more frequent color combinations (top graph) show similar means, ranges, and dispersions. The size distributions of clams in less frequently occurring colors (bottom graph) fall within the envelope of the more abundant colors even though these include the darkest and lightest combinations (6/6 and 8/2). The second peak of 6/6 animals represents a single individual and has no statistical significance. This data suggests that, in general, tissue color is not a function of clam size.

When clams in station groups within the Providence River were examined, five of six showed an absence of size separation of color categories. On sandy bottom off Bullock Cove, however, small clams were relatively light in color, possibly reflecting rapid growth under good growing conditions.

The geographic distribution of tissue darkness in all clams (1,492) from the Providence River was examined by calculating the percent of clams from each station in each value category regardless of hue or chroma. These categories can be considered to make up a gray scale such as is used in black and white photography.

Only one individual was found in the medium gray range (category 5, station 10). The darkest gray-scale category 6 with significant numbers of individuals occurs the most frequently in deeper stations off Sabin and Gaspee Points (station groups 2 and 4). Most of the clams examined fell in category 7, and many stations between Gaspee and Conimicut Points had 60-100% of clams in this range. A high proportion of light-colored category 8 clams were found at Nayatt Point. Shallow stations at Gaspee and Sabin Points (groups 1 and 3) contained category 7 and 8 clams, while deep stations (groups 2 and 4) contained darker category 6 and 7 clams.

Color strength categories of station groups showed a pattern similar to that found for gray scale values. Deep, up-river, clams from groups 2 and 4 were more strongly colored than those from shallow stations (groups 1 and 3). The shallow stations are also differentiated by hue. Pink colors (found on the 5YR chart) were seen in 7 of 12 shallow samples but in no deep samples.

It is clear that the population of very dark clams documented at Sabin Point in 1968 (Phelps and Barry) is no longer present. There is no way to say when or at what rate color values became lighter, since no documented or quantified observations were made until 1984. In 1984 Cheng and Iancu (1984) found relatively light-colored animals at Sabin Point and further up-river off Pawtuxet Neck. Kern (1986) found no gradient of tissue colors and reported high relative abundance of dark clams at down-river stations (47, 49), in parts of Mount Hope Bay and off North Kingstown.

The dark clams reported in the 1960s were apparently exposed to very adverse conditions which have improved since. The dark clams found at stations 2 and 4 in this study may still be affected to some extent. Although clams in shallow water at Sabin Point are relatively light colored, the fact that they can be differentiated from down-river populations suggests that they may also be "abnormal." This could be a response to differences between upper and lower river conditions of temperature, salinity, nutritional value of phytoplankton, or pollutant concentration. Other studies have established that there is a steep pollution gradient within the mid to lower Providence River. Monitoring of hard clam condition in this area will give early warning of changes in the position of the gradient.

The effect of freezing on color was not tested. Frozen samples included a wide enough range of colors so that age and substrate effects could be tested without reference to "fresh color." It is likely that color produced by "age pigments" (Nicol 1987) are stable and would be resistant to many physical changes.

The Munsell color notation system proved to be a rapid way to quantify hard clam colors and demonstrated a change in color pattern in the Providence River since 1968. Full utilization of this system will require experience in difficult analysis within 3-dimensional color space.

Shell Proportions—Measurements of shell length, width, and weight and total clam weight are given in Appendix 1. The relationship between shell width and length in the Providence River was chosen for preliminary examination of the response of shape to environment.

Figures 20 and 21 and Table 15 show the average w/l ratio and w/l regression slope of clams from the Providence River station groups (Figure 3). Clams were a little more than one half as wide as long. The station group ratios averaged from 0.525 to 0.542. This represents only a 1 mm difference in width in 70 mm long clams. Significant differences are found between the three southernmost groups which have a high ratio (blunt) and clams from Sabin Point, Gaspee Point, and Conimicut-North (sharp). Nayatt-Mid is significantly different from six out of seven upstream groups. There is no relationship between shape and sediment strata within upstream-downstream segments. The apparent increase in the w/l ratio downstream is the reverse of that which would result from retardation of growth in length by pollution stress. The variation in ratios found in stations 1-9 occurs in populations with similar size distributions.

Width-length regressions were calculated. Slopes, 95% confidence intervals, and correlation coefficients for station groups are given in Table 15 and Figure 23. While both Nayatt-Mid and Nayatt-S clams have high w/l slopes, Nayatt-S clams have a lower y-intercept and w/l ratio than Nayatt-Mid clams. Conimicut-S and N have very different ratios, but the same slopes. Gaspee had a significantly lower slope than Bullock and Nayatt-N, Mid, and S. Nayatt-Mid and S are different from Gaspee, Sabin, Conimicut-N and Conimicut-S. Nayatt-S is also different from Gaspee-deep. Although the pattern of variation of slopes is different than for w/l ratios, the increase of slope downstream is consistent with the general trend of w/l ratios.

It is possible that physiological condition or environmental effects slow the growth in length of older clams. This non-allometric growth would result in an upward curve in untransformed width verses length plots and a poorer fit to a linear regression line. Width and length data points are given for two stations with contrasting parameters in Figure 22. Nayatt-S samples included a large range of clam sizes; nevertheless, there is very little variance in slope, and the correlation coefficient is high ($R^2 = 0.947$). There is no indication of increasing slope with length. Clams from Conimicut-S had a much smaller size range and much more variance in slope ($R^2 = 0.693$). No change in slope with length is indicated; an examination of the residuals plot revealed no evidence of curvature in the data.

If the high variance of width-length ratios at upstream stations was due to the presence of sharp and blunt clams in the same sample group, the frequency distribution of the ratio would have a wide peak and possibly be bimodal. The distribution of ratios for station groups (Figure 23) does not show such mixtures. Most of the distributions are unimodal and symmetrical except for a tail toward higher ratios (blunt clams). The Gaspee-deep station group, with the lowest number of clams (40), has a narrow asymmetrical distribution and a few clams with very high width/ length ratios (up to 0.67).

It is clear from the preceding analysis that shell shape is not a simple reflection of environmental quality. The average w/l ratio and w/l slope increased downstream in the Providence River. This is not accounted for by the presence of larger clams in downstream samples since shape was not related to size. Shell shape may be related to age rather than size, with older clams of a given length having a greater w/l ratio. If this were so, downstream clams would have to be slower growing than upstream clams, a relationship which is the opposite of what might be expected. The correlation between shape and clam density has not been tested yet. It can be hypothesized that clams will have a low w/l ratio in areas where high density is the result of good growing conditions. Extremely dense populations could have a negative effect on growth.

In the field, shape variation is most noticeable in the angle at which shell edges come together. It may be possible to develop a rapid method of taking this measurement to assess recent growth. In general, the absence of a pattern in w/l ratio in this large sample indicates that it is not a good measure of growing conditions despite the obvious visual differences between "sharps" and "blunts."

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

More of the conclusions listed here relate to the Providence River than to Mount Hope Bay. This is because in the Providence River large numbers of hard clams are found between Sabin Point and Conimicut Point and are of interest as a source for harvest. The presence of these clams also offers the opportunity to examine measures of condition along a gradient of water quality. In Mount Hope Bay stocks are much lower, and there is no clear-cut pollution gradient in the sampled area.

1) In the Providence River, relatively dense concentrations of hard clams are found north of Conimicut Point and between Bullock Point and Nayatt Point. Smaller patches are found off Gaspee Point and in deep water south of Sabin Point. These coincide with concentrations found in 1956 and 1965 surveys. Density was low in a shallow area south of Sabin Point where clams had been abundant previously.
2) In Mount Hope Bay, concentrations of hard clams are found off Touisset and east of Mount Hope as had been found in 1956.
3) The average density and density of concentrations of hard clams from dredge tow data is more than ten times greater in the Providence River than in Mount Hope Bay. In Mount Hope Bay, many stations yielded no clams.
4) In the Providence River, significantly more hard clams are found in sediment strata with a high proportion of sand (sand, silty sand, and sand-silt-clay strata) than are found in more fine grained sandy silt and clayey silt strata.
5) In Mount Hope Bay, clam densities are low in both clayey silt and sand-silt -clay sediments.
6) In the Providence River, hard clam length-frequency distribution is unimodal with a peak at 72 mm (the dividing line between littleneck and cherry stone sizes). A higher proportion of small clams are found in sandy silt and sand-silt-clay than silty sand or

clayey silt. Size frequency distributions are similar in stations with high and low population densities. The average size of clams increases downstream. Few very large individuals are found in the Providence River. The largest clam collected was 108 mm in length.

7) In Mount Hope Bay, hard clam length-frequency distribution is bimodal with a small mode at 68 mm (littleneck size) and a large mode at 96 mm (chowder size). In areas of relatively high abundance, only large clams are found. The largest individual collected was 120 mm long.
8) The presence of small, sublegal size clams in the Providence River indicates that recruitment is taking place there. No small clams were obtained in Mount Hope Bay dredge samples.
9) Providence River hard clams in the most numerous size class (mode 68 mm long) are 10-13 years old and in many cases have stopped growing.
10) Large hard clams from Mount Hope Bay (98-121 mm long) appear to be more than 30 years old.
11) While estimates of standing stocks in the study areas were not made because sampling efficiency was not known, it is clear that harvestable densities are found in the lower Providence River but not in most portions of Mount Hope Bay.
12) In the Providence River, the tissues of hard clams at up-river and at deeper stations are darker than at down-river and shallow stations, but are probably much lighter than the tissues of stressed animals observed 20 years ago. Clams from the lower river have no color abnormalities which could be identified by consumers.

Recommendations

A limited number of recommendations are made here. Hard clam management in Narragansett Bay is discussed in greater detail in another Narragansett Bay Project report (Pratt 1988).

Research should be conducted on: (1) the ability of both closed areas to repopulate themselves following harvest, (2) the reasons for an absence of hard clams in large portions of Mount Hope Bay, and (3) the nutrition status of Providence River clams as an alternative to pollution stress in limiting size of individuals.

The Division of Marine Fisheries should develop or obtain equipment to take quantitative samples of all sizes of hard clams to determine stock density and recruitment success in both open and closed portions of the Bay. The division should continue development of techniques to age shells to be able to determine growth rates in different Bay habitats. Young clams (less than seven years old) should be used to avoid difficulties in interpreting crowded annual rings.

The state should consider utilizing the hard clam stock in the lower Providence River for transplantation. Recent studies of contaminate concentrations should be examined to determine whether an extended period in clean water is required to provide assurance of quality.

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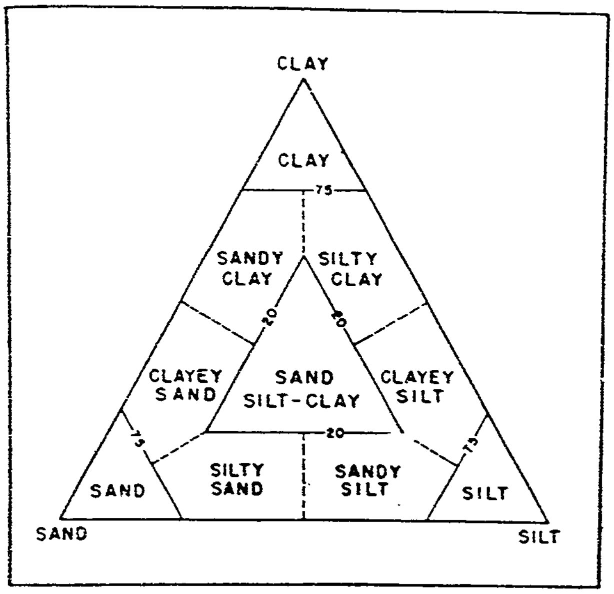
Figure 1. System of textural class limits used by McMaster (1960)(from Shepard 1954). Class limits derived fromthe end-member triangle are given below. Limits are approximate where the described space is a pentagon.



cl/si	clayey silt	50-75% silt, 25-50% clay, 0-20% sand
sd/si	sand silt	50-75 silt, 25-50% sand, 0-20% clay
sd/si/cl	sand-silt-clay	20-40% sand, 20-40% silt, 20-40% clay
si/sd	silty sand	50-75% sand, 25-50% silt, 0-20% clay
sd	sand	75-100% sand, 0-25% silt, 0-25% clay

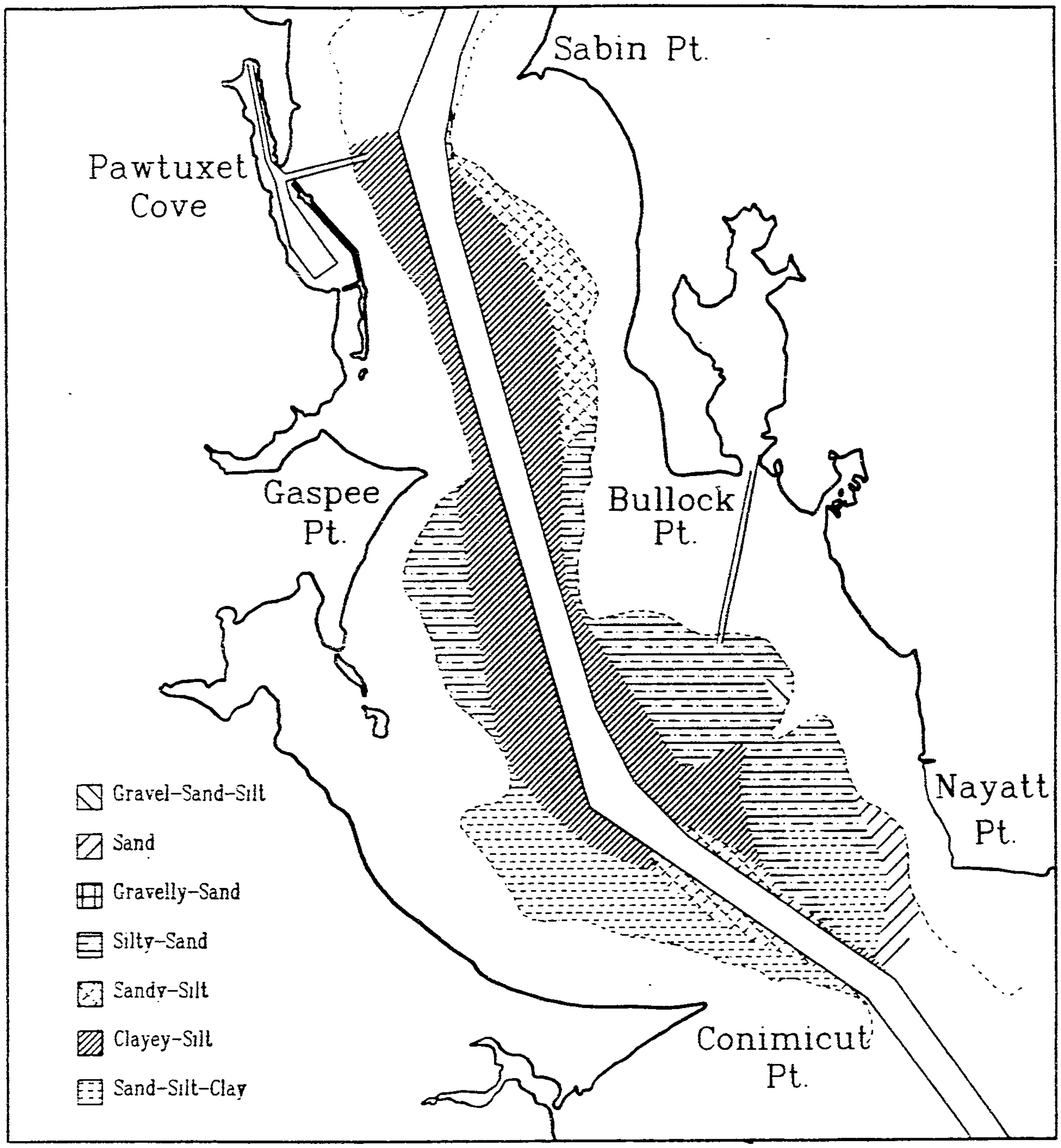


Figure 2. Sediment strata within the area sampled in the Providence River. Sediment type from McMaster 1960. The sampled area is between the 9-foot contour and the dredged channel.

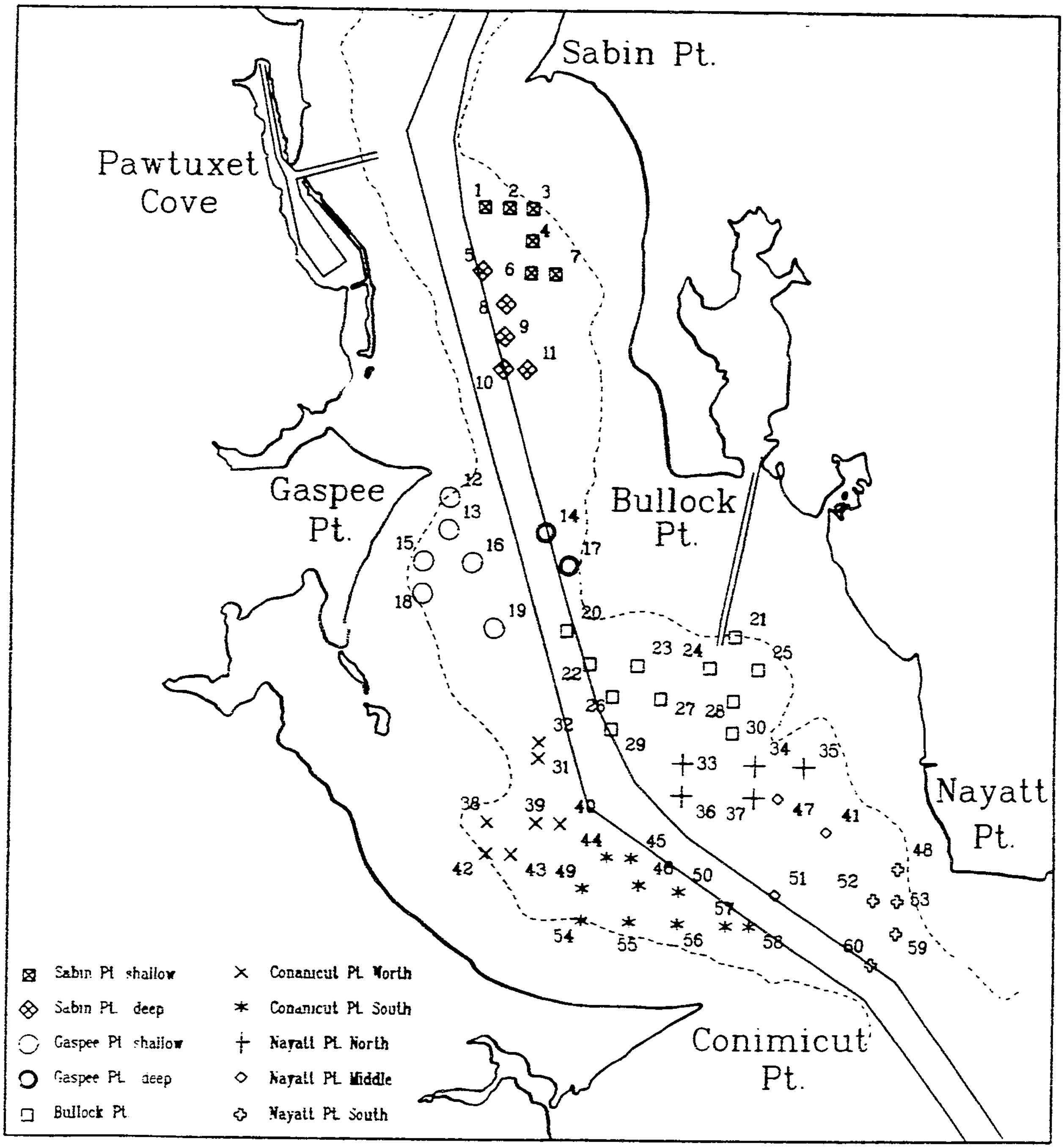


Figure 3a. Sample locations within the Providence River. stations are numbered and placed in groups used in analysis of size and tissue color.

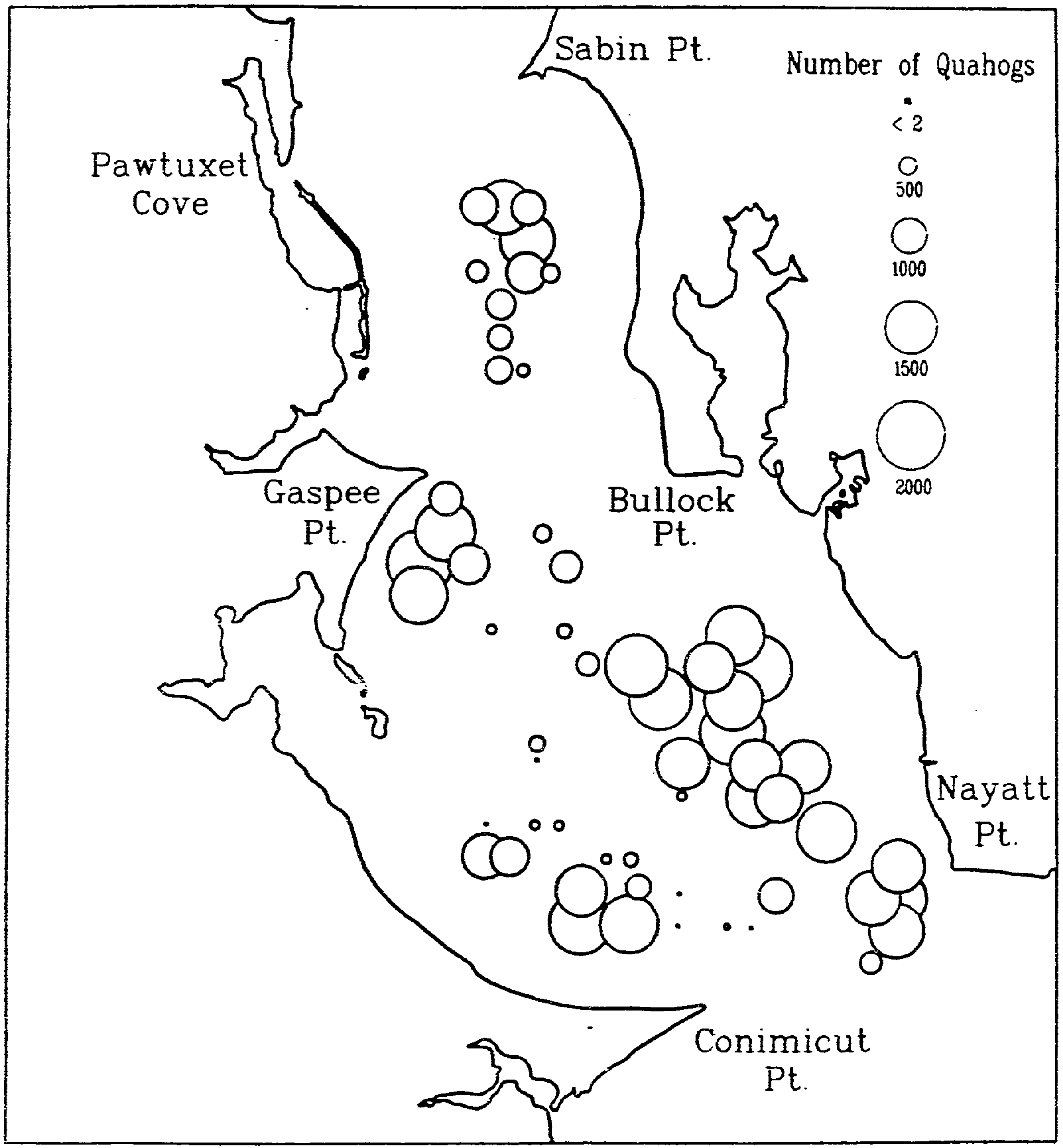


Figure 3b. Catch per tow in the Providence River. The areas of the circles are proportional to the number of hard clams caught in 5-minute tows. Circles representing given catch numbers are shown for comparison.

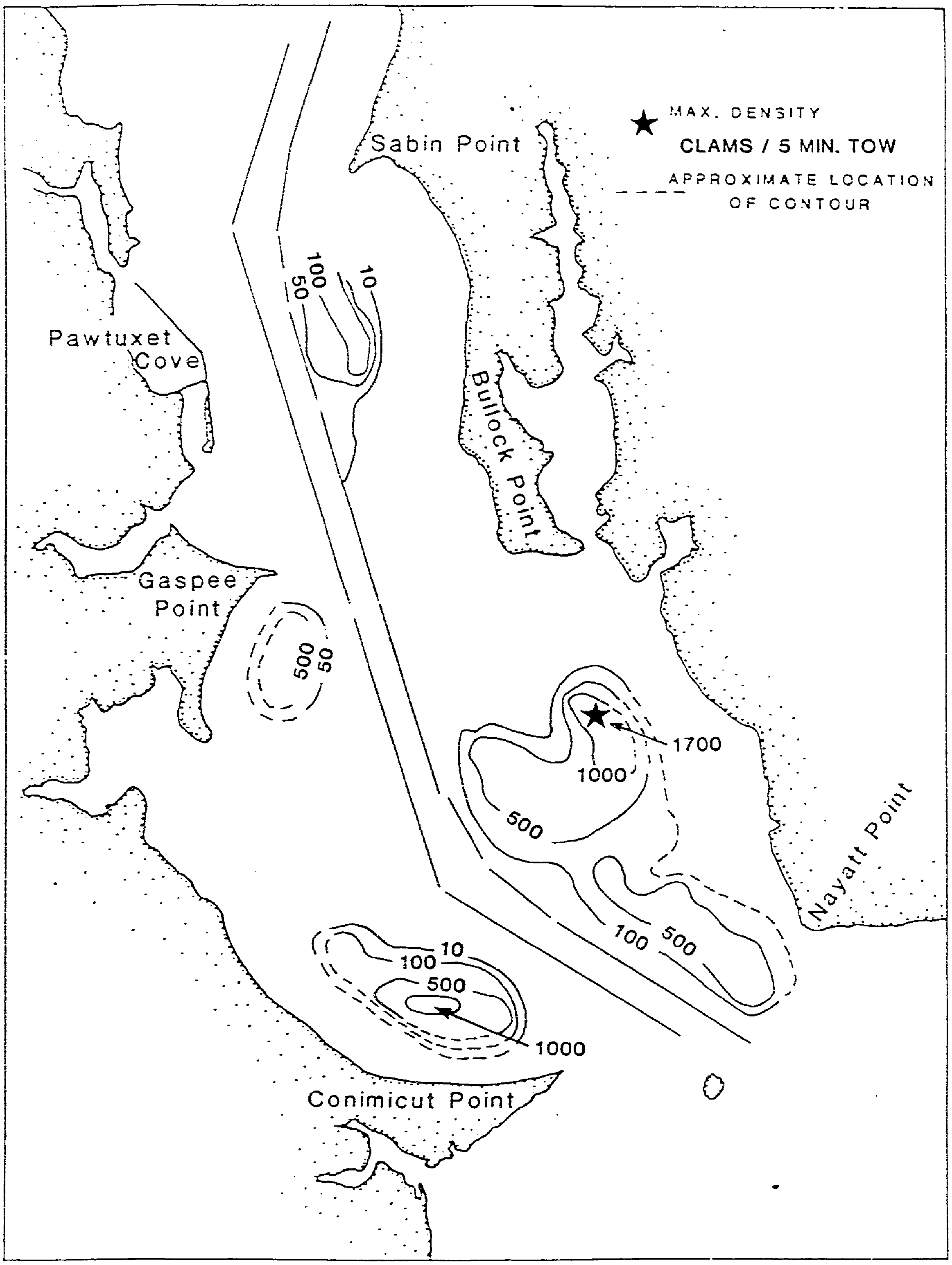


Figure 4. Contoured catch per tow in the Providence River, November-December 1985.

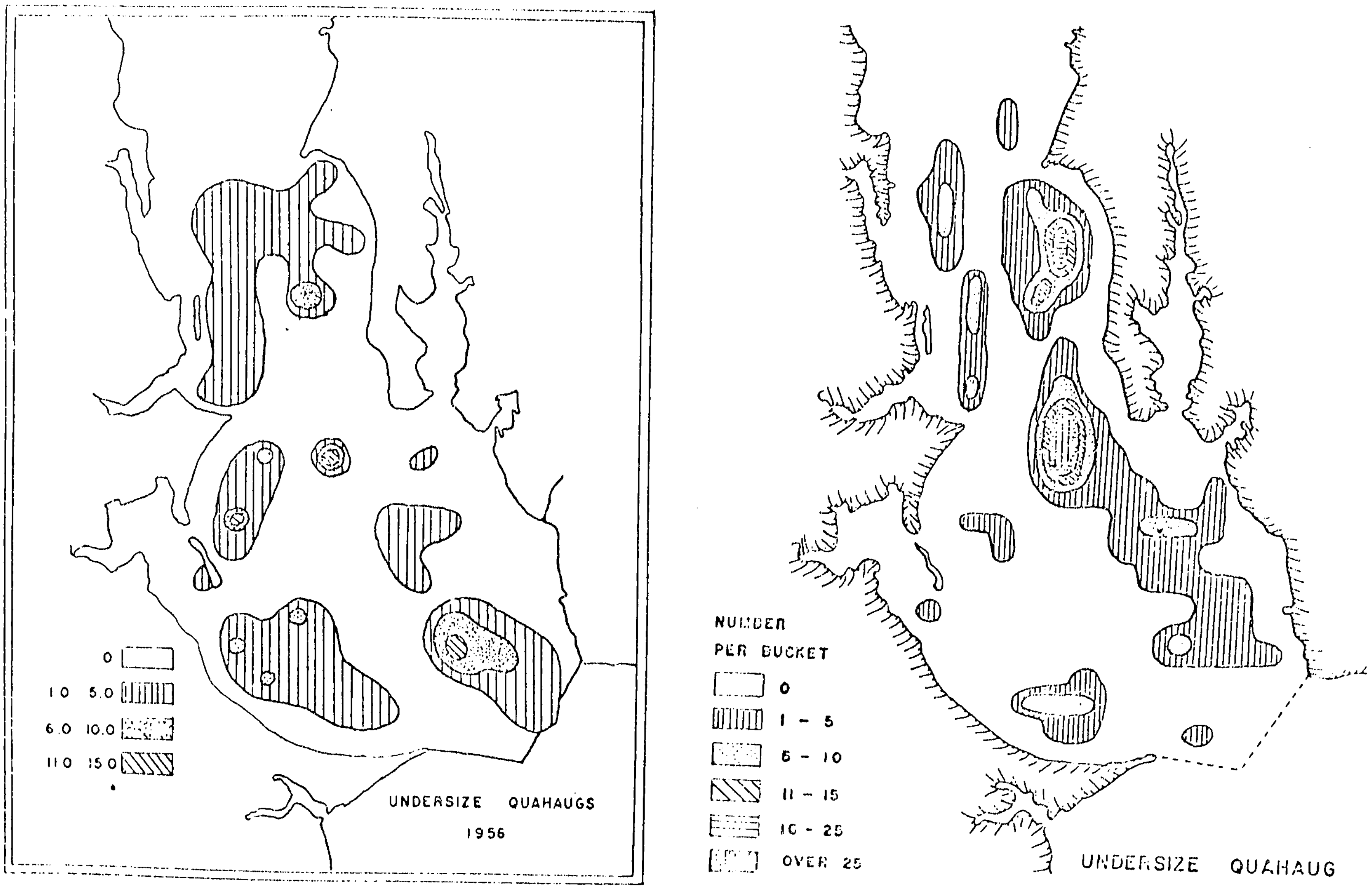


Figure 5. Contoured catch per sample in the Providence River in 1956 and 1965: undersized clams. Size limits are 1956:15-47 mm long, 1965:6-47 mm long. Figure from Canario and Kovach, 1965.

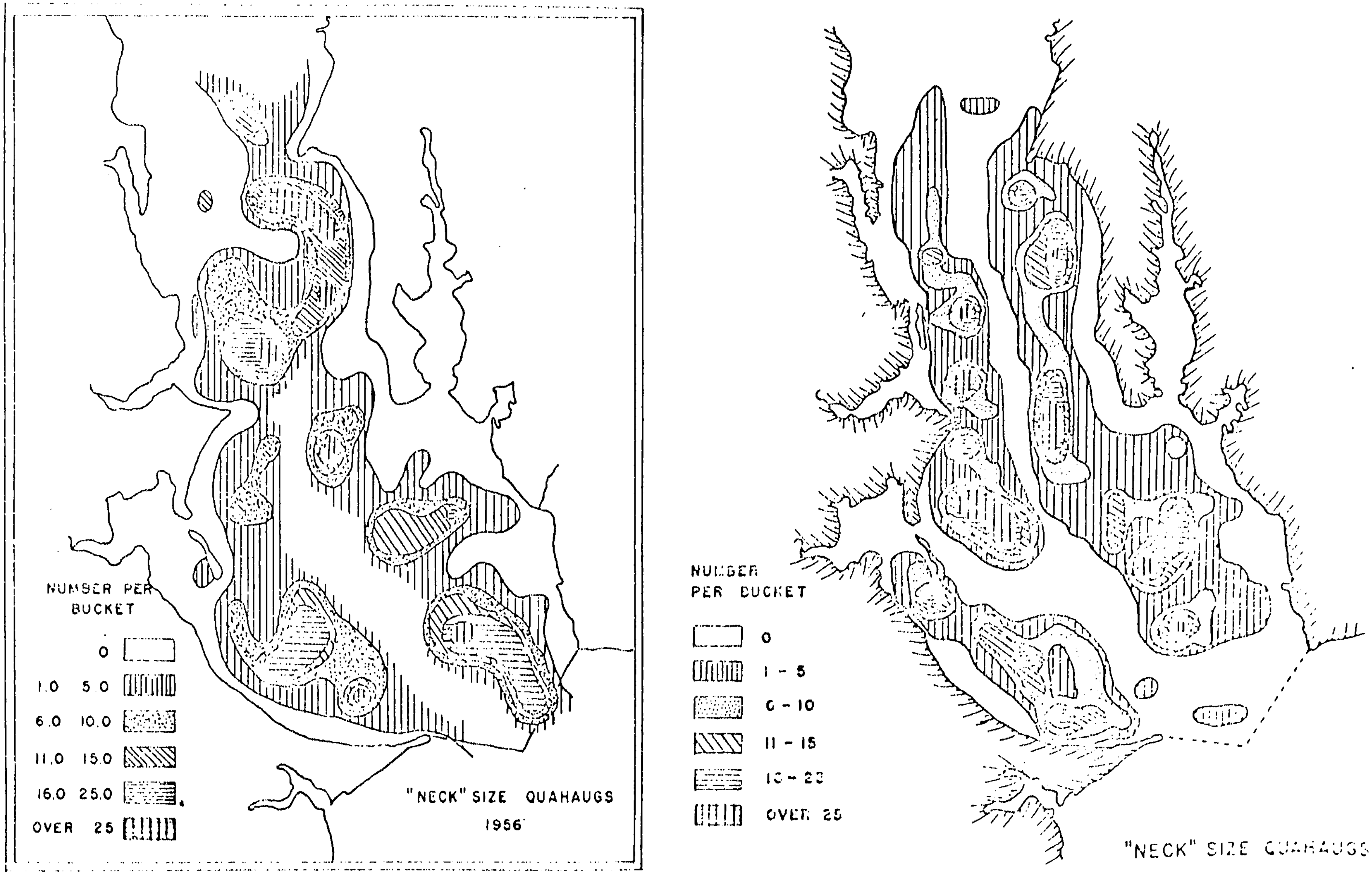


Figure 6. Contoured catch per sample in the Providence River in 1956 and 1965: littleneck-sized clams (48-66 mm long). Figure from Canario and Kovach, 1965.

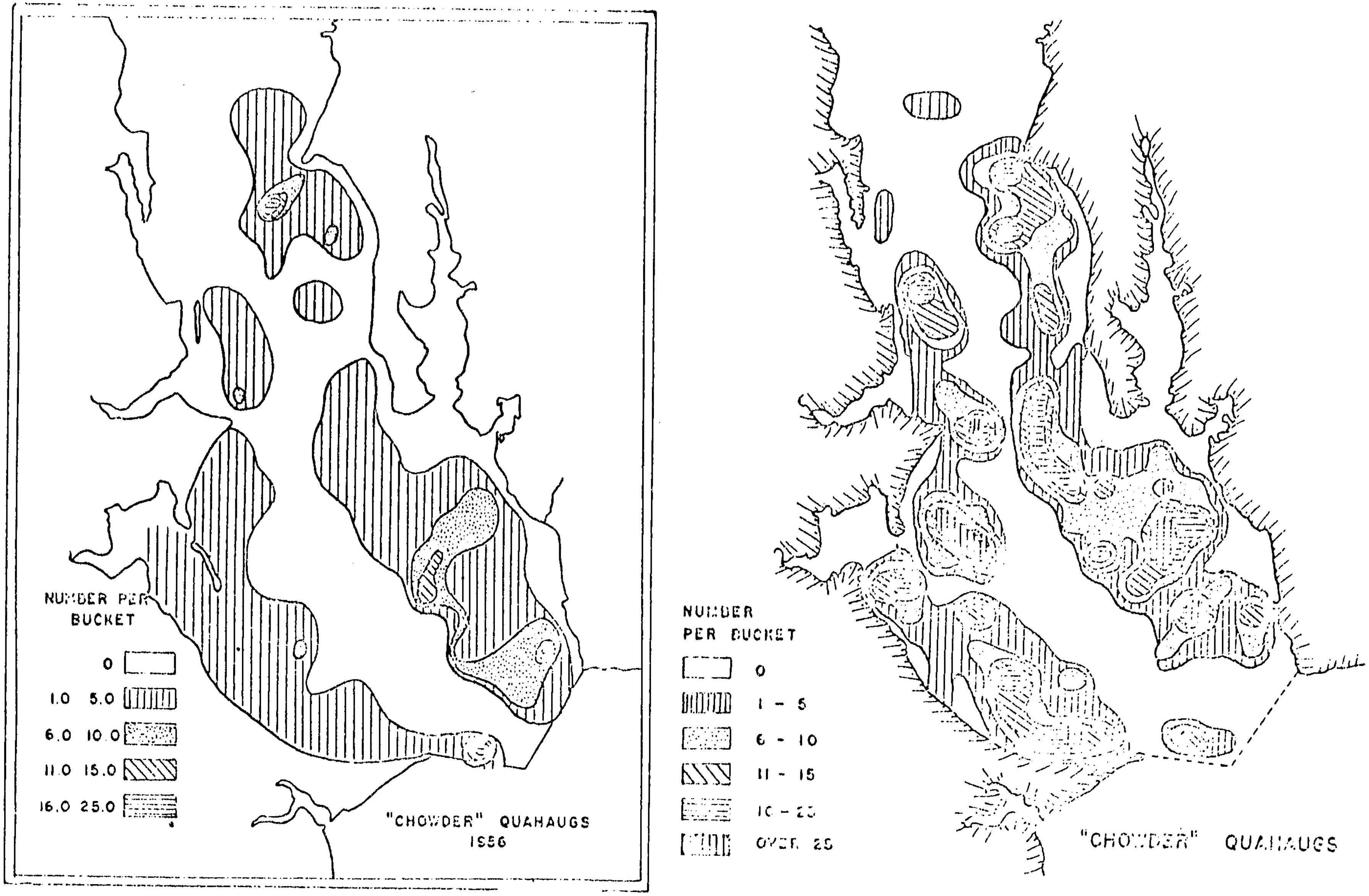


Figure 7. Contoured catch per sample in the Providence River in 1956 and 1965: large clams (> 66 mm long). Figure from Canario and Kovach, 1965.

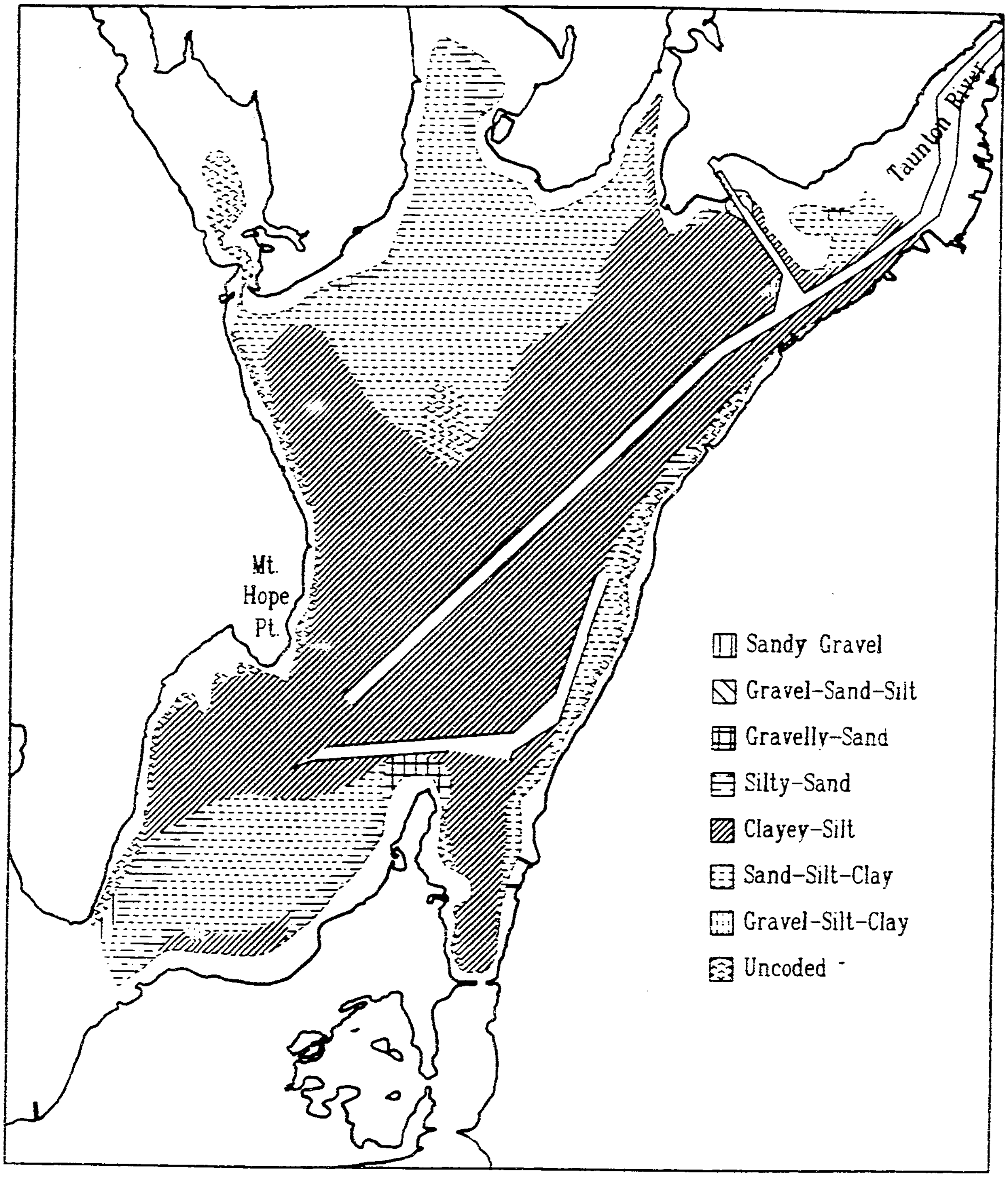


Figure 8. Sediment strata within the area sampled in Mount Hope Bay. Sediment types from McMaster 1960. The sampled area is between the 9-foot contour and the dredged channel.

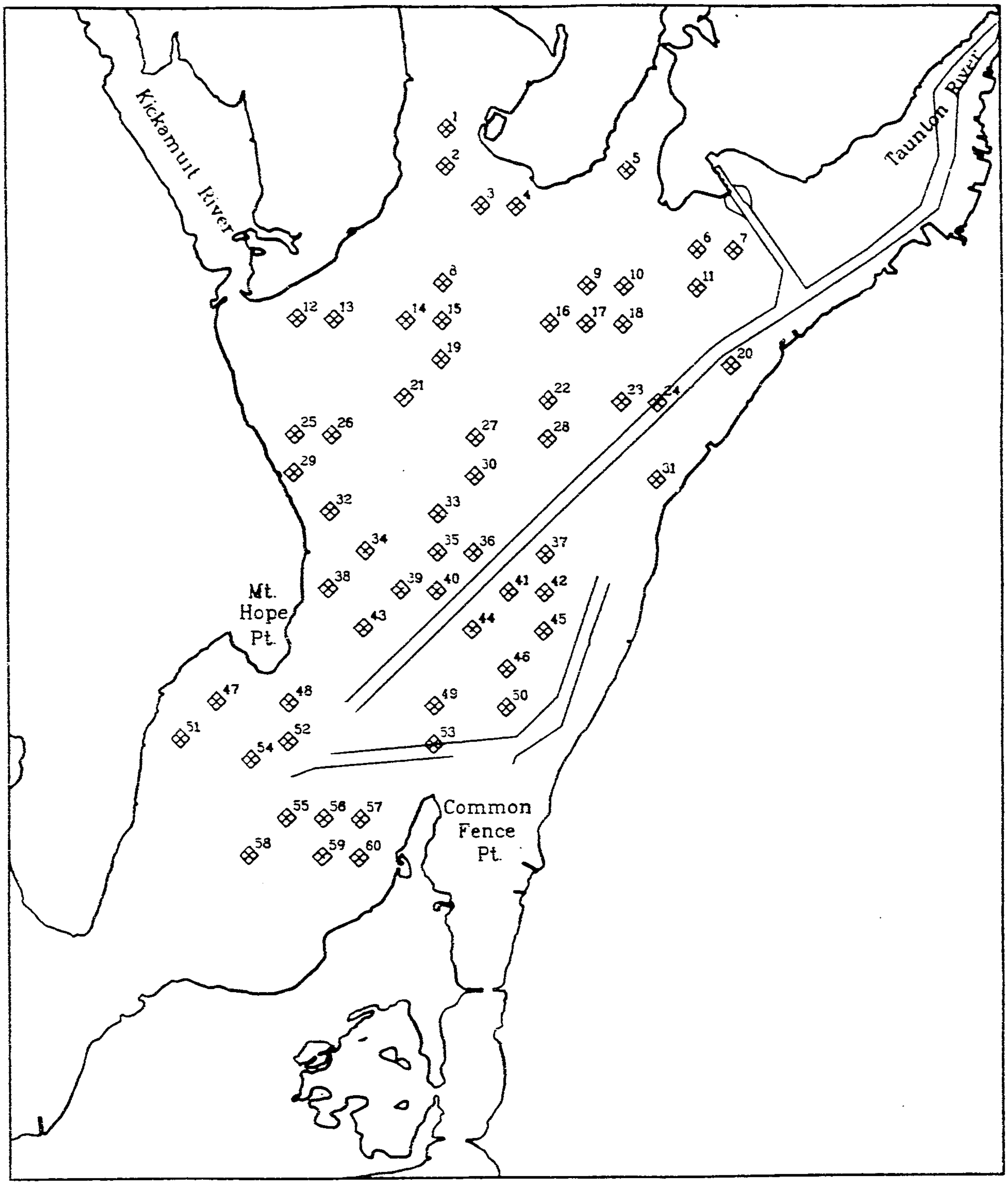


Figure 9a. Sample locations within Mount Hope Bay. Station numbers are shown.

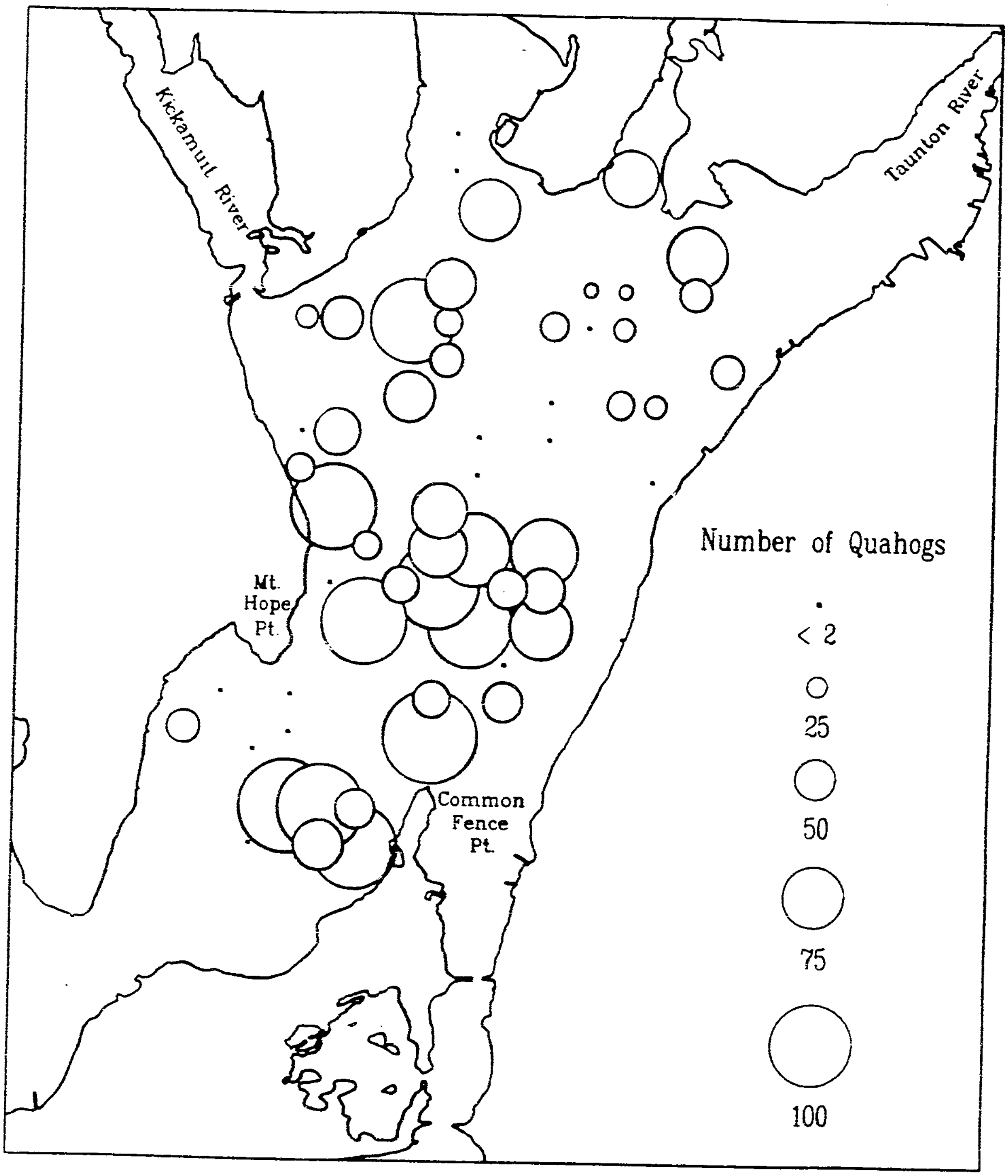


Figure 9b. Catch per tow in Mount Hope Bay. The areas of the circles are proportional to the number of clams caught in 5-minute tows. Circles representing given catch numbers are shown for comparison.

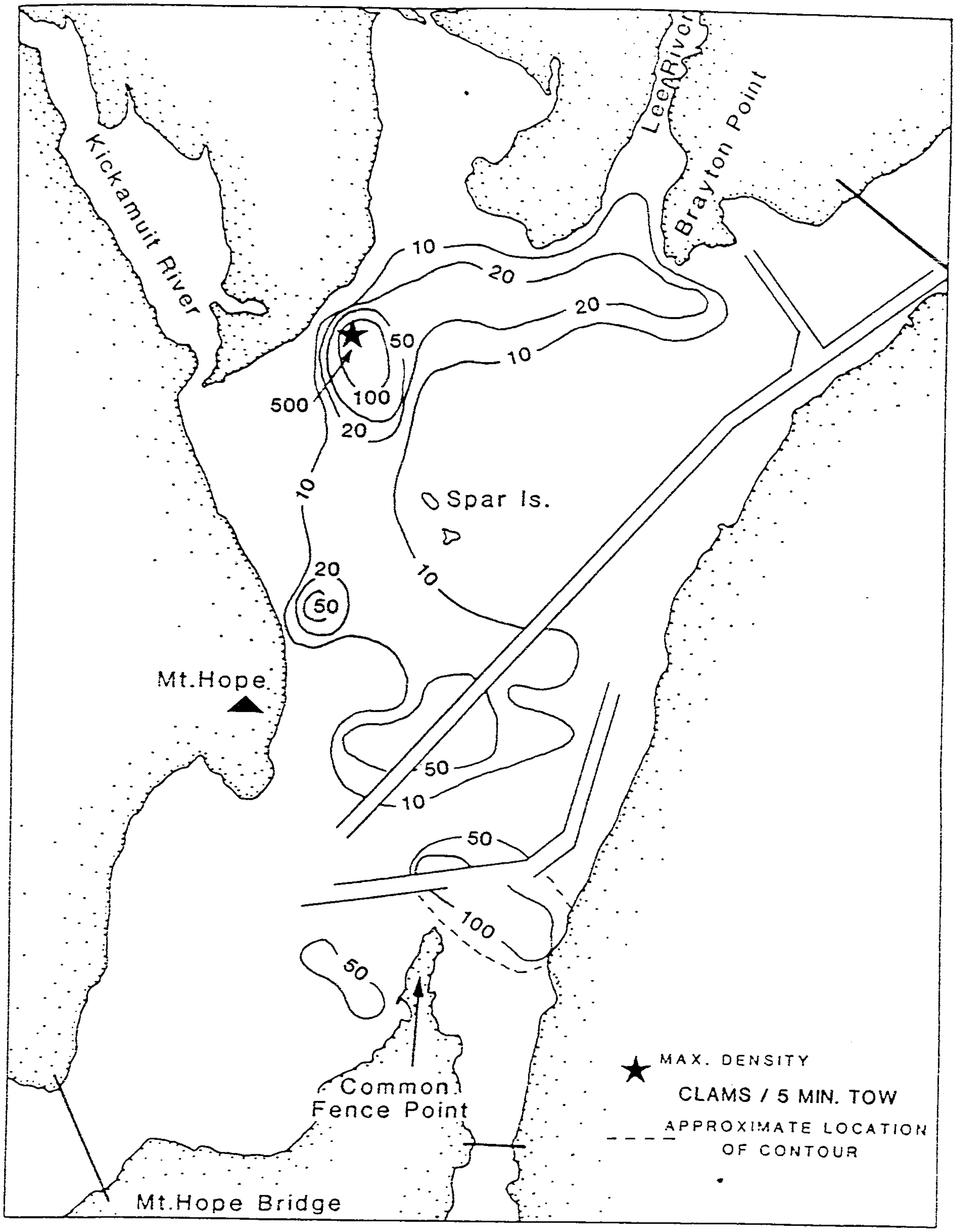


Figure 10. Contoured catch per tow in Mount Hope Bay, November-December , 1985

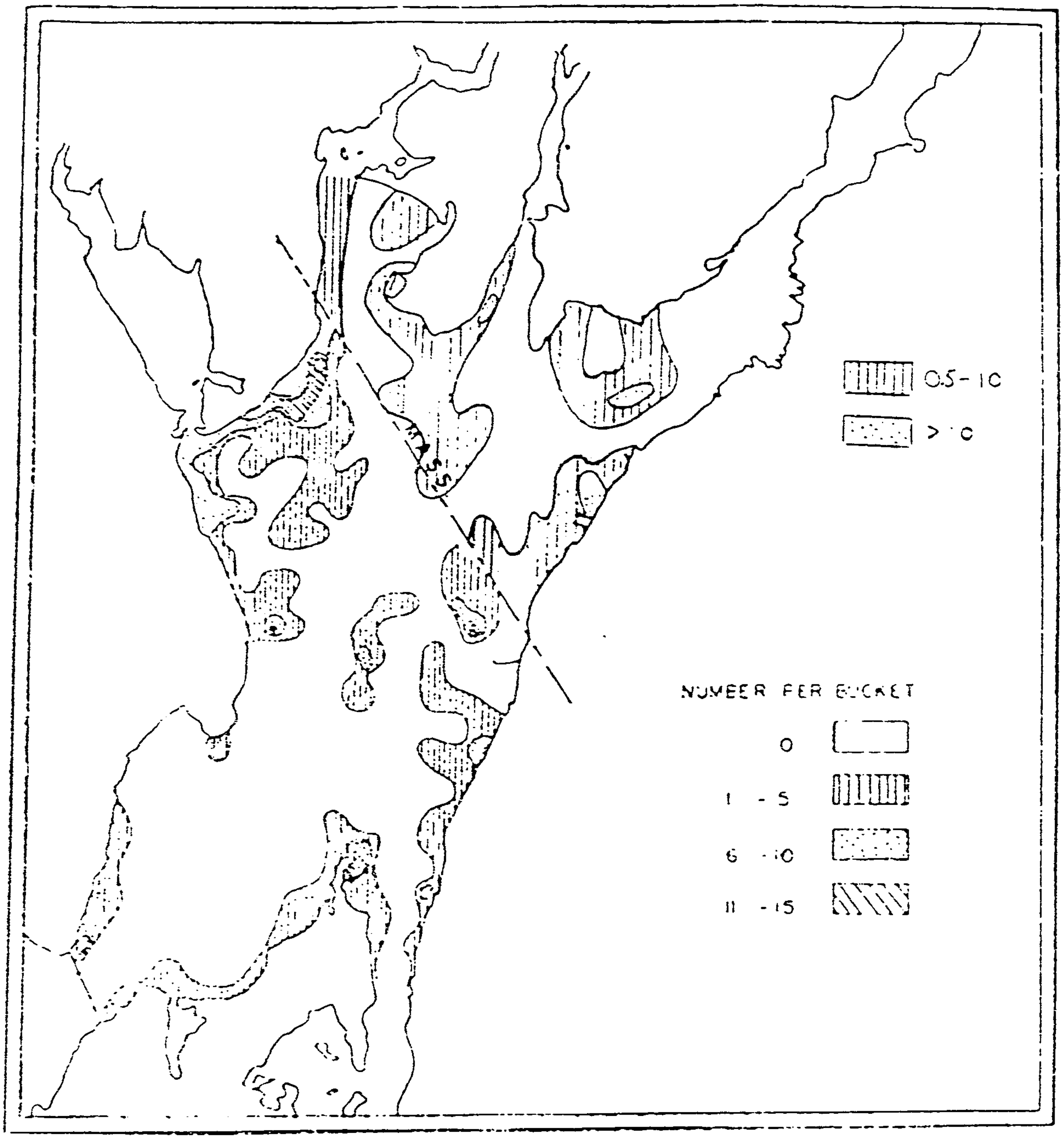


Figure 11. Contoured catch per sample in Mount Hope Bay in 1956. Numbers are individuals over 15 mm long collected by a 0.464 m^2 sampler. Distribution in Rhode Island from Campbell (n.d.). Distribution in Massachusetts from Stringer (1959). Note difference in ranges mapped in each state.

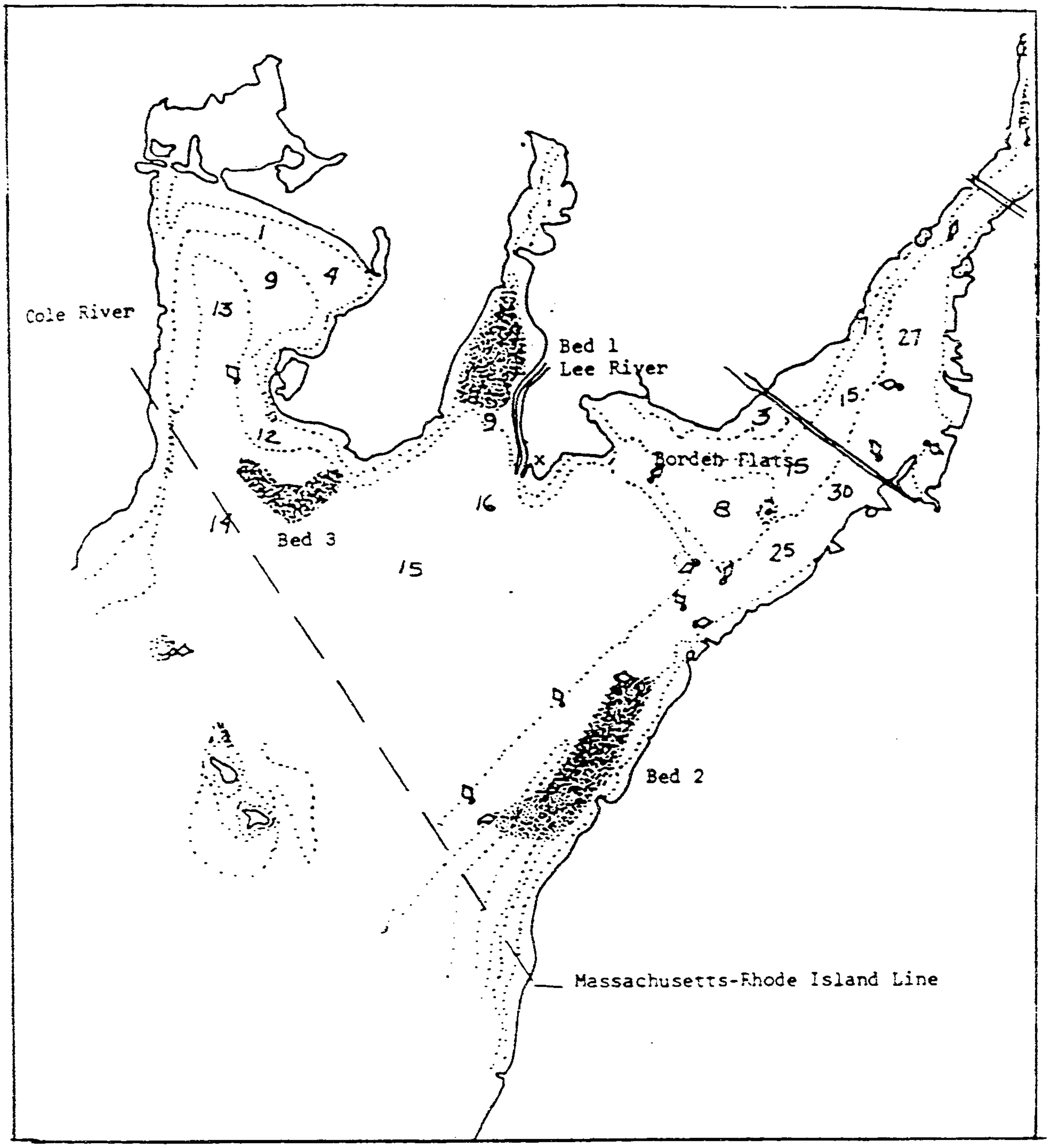


Figure 12. Areas of high clam density in the Massachusetts portion of Mount Hope Bay in 1980 (Hickey, 1984, Figure 3B). Densities in the beds shown averaged 7.2/m^2.

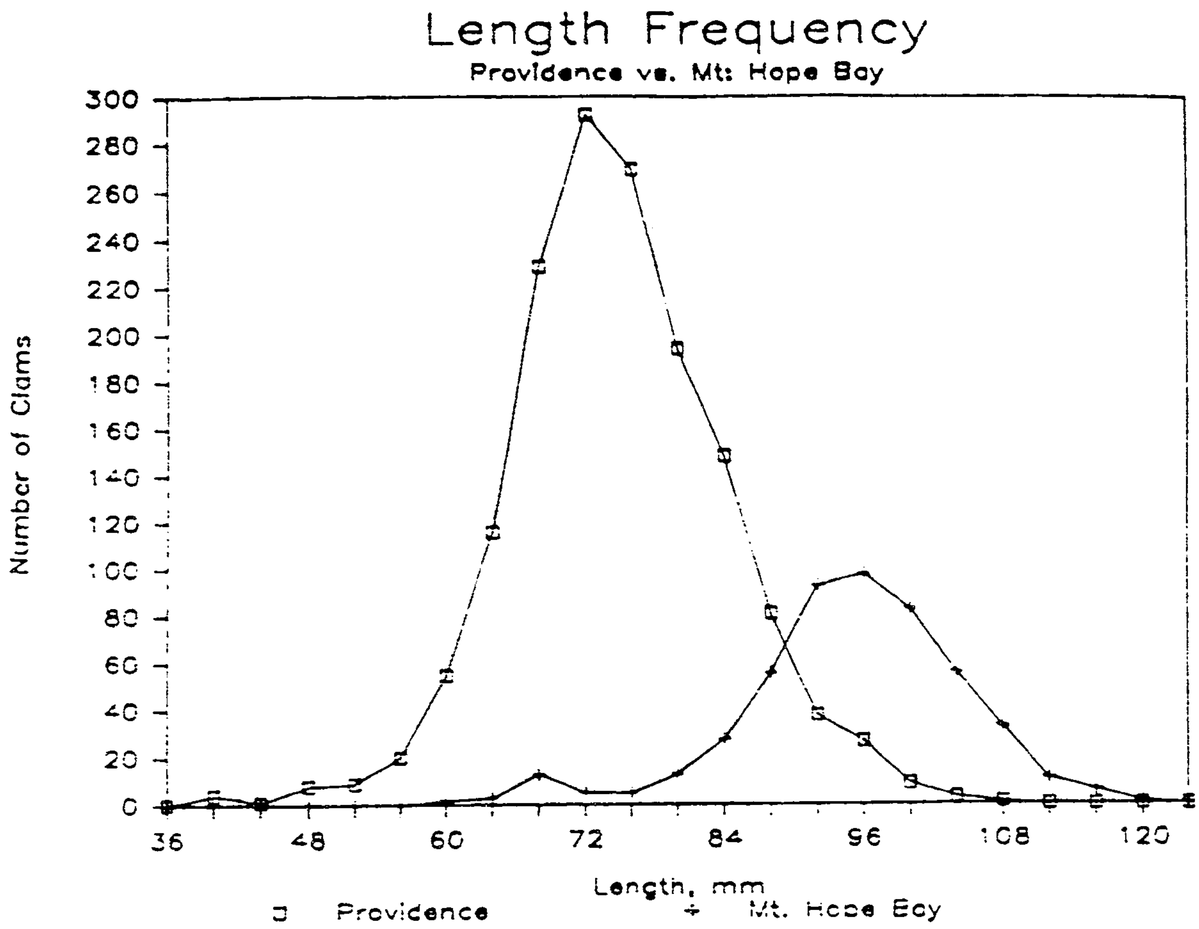


Figure 13. Length-frequency distribution of clams in the Providence River and Mount Hope Bay collected November 1985.

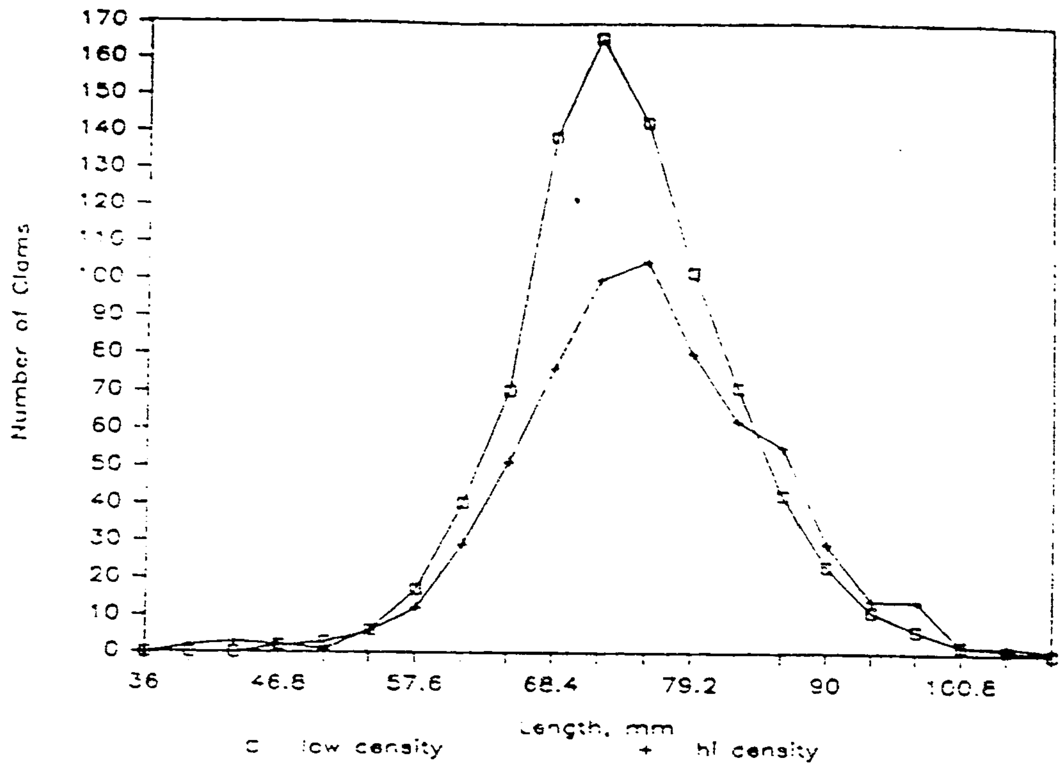


Figure 14. Length-frequency distribution of clams in high- and low-density samples collected in the Providence River November 1985 (high density > 500/tow).

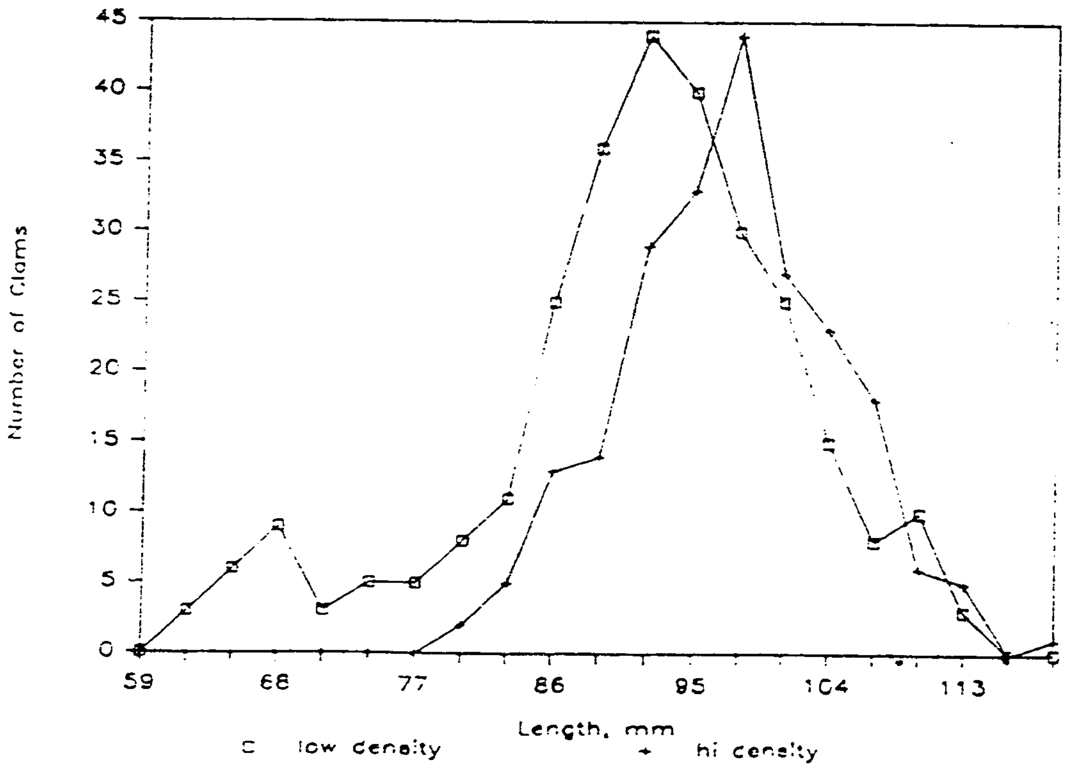


Figure 15. Length-frequency distribution of clams in high- and low-density samples from Mount Hope Bay collected November-December 1985 (high density > 50/tow).

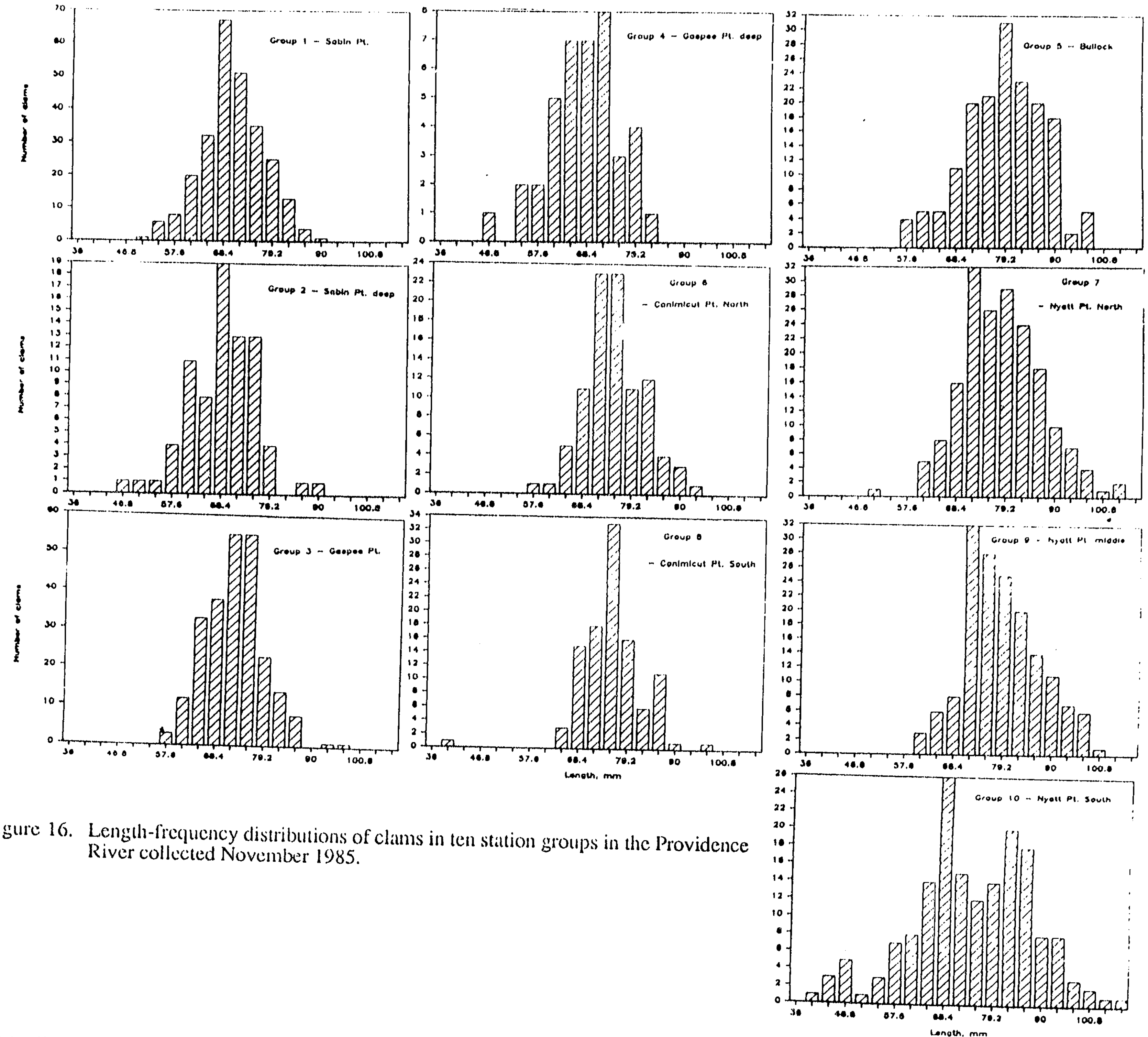


Figure 16. Length-frequency distributions of clams in ten station groups in the Providence River collected November 1985.

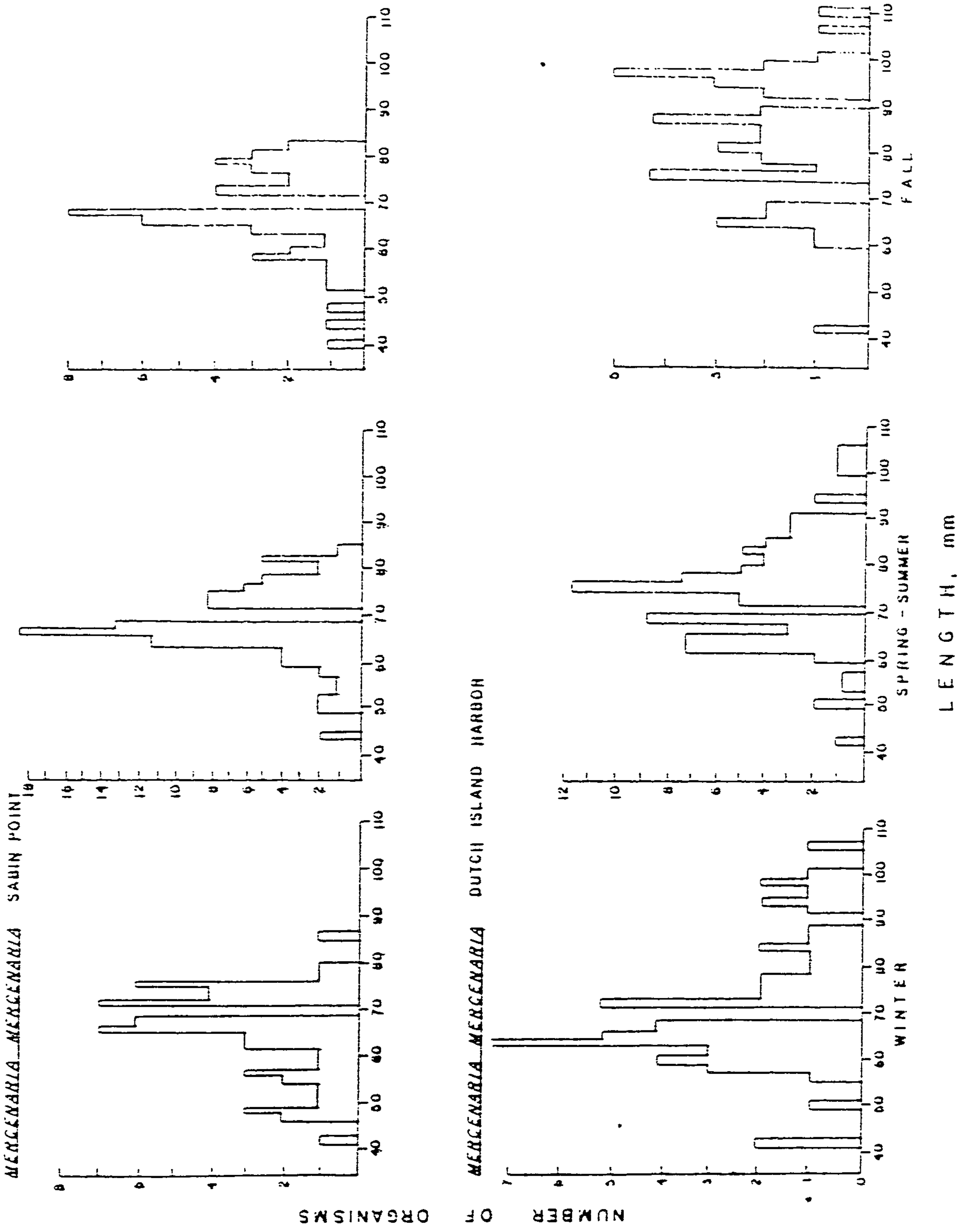


Figure 17. Seasonal length-frequency distributions of clams from Sabin Point and Dutch Island Harbor, 1977-78 (Diamond, 1981, Figure 3).

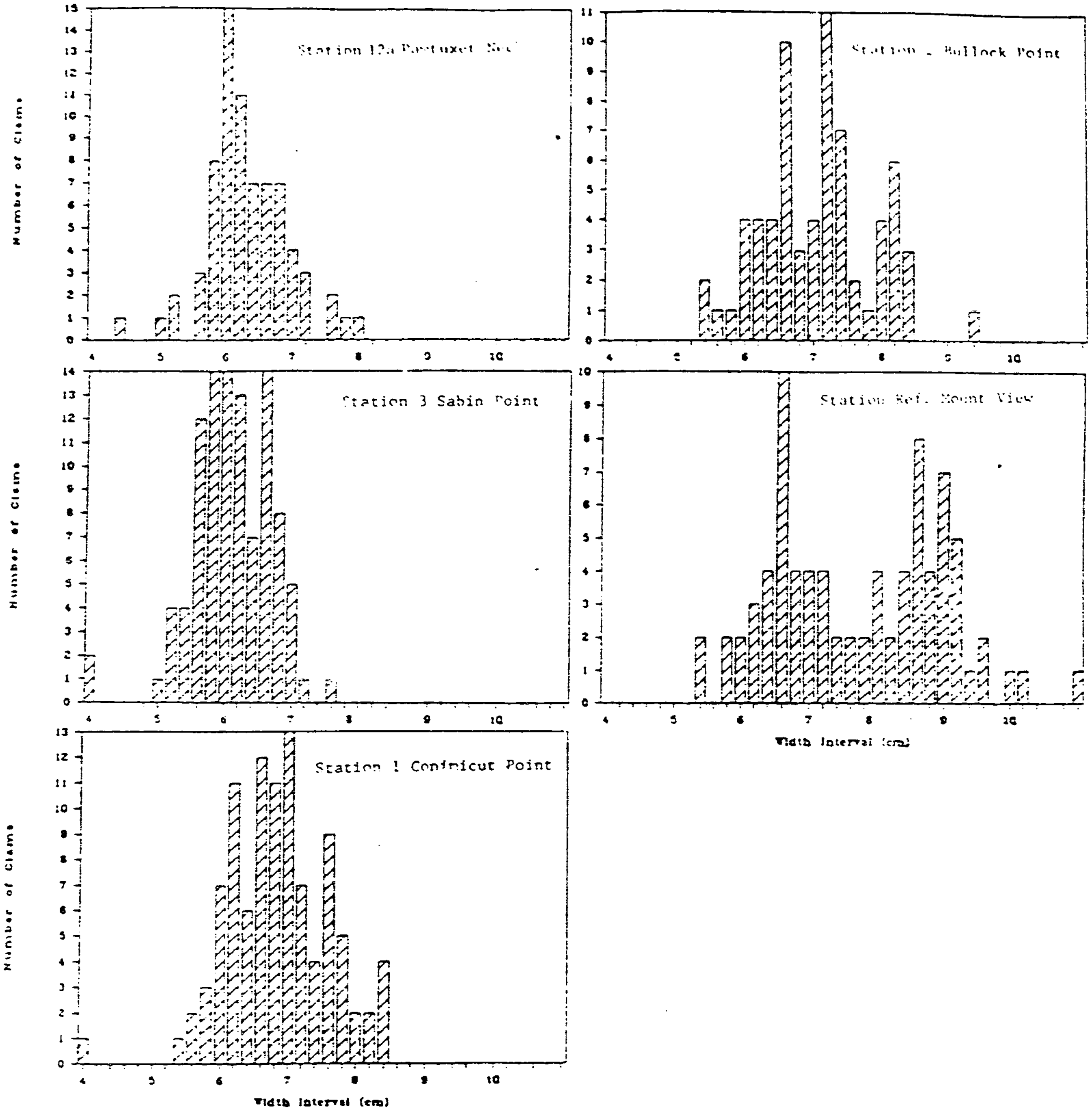
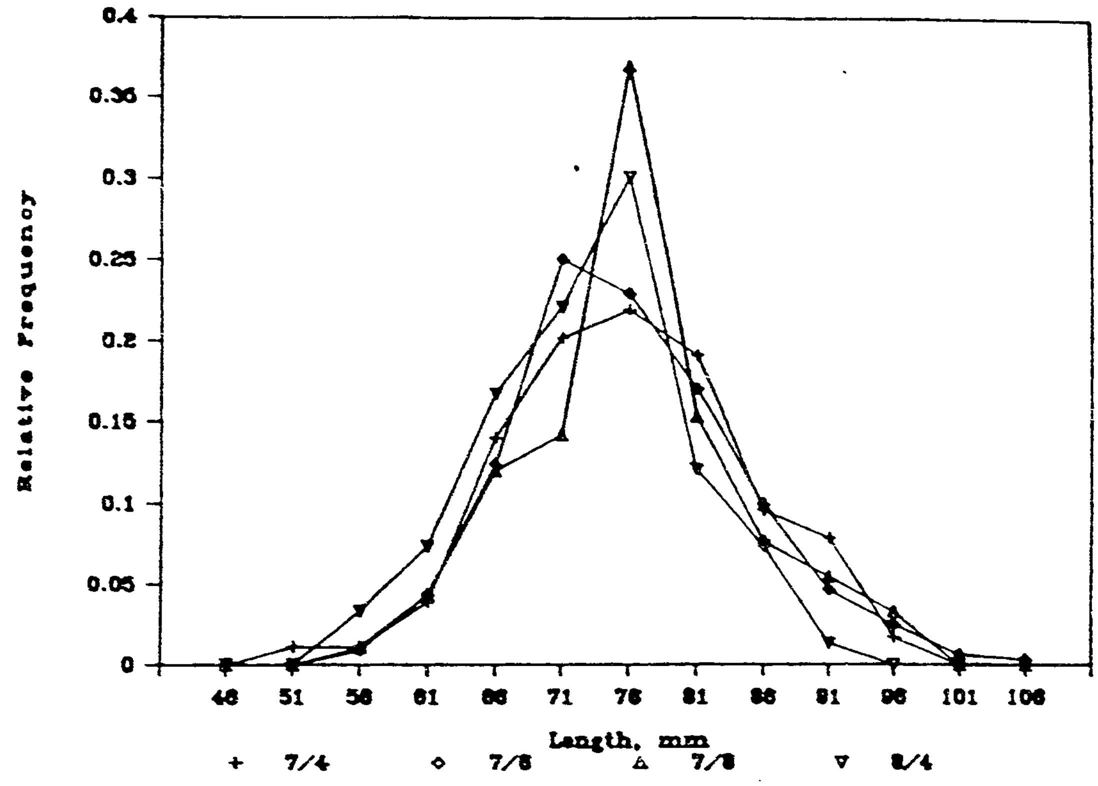


Figure 18. Height-frequency distribution of clams from the Providence River and West Passage collected July 1984 (McDonald and Grimm, 1984). Size intervals must be multiplied by approximately 1.2 for comparison with preceding figures.



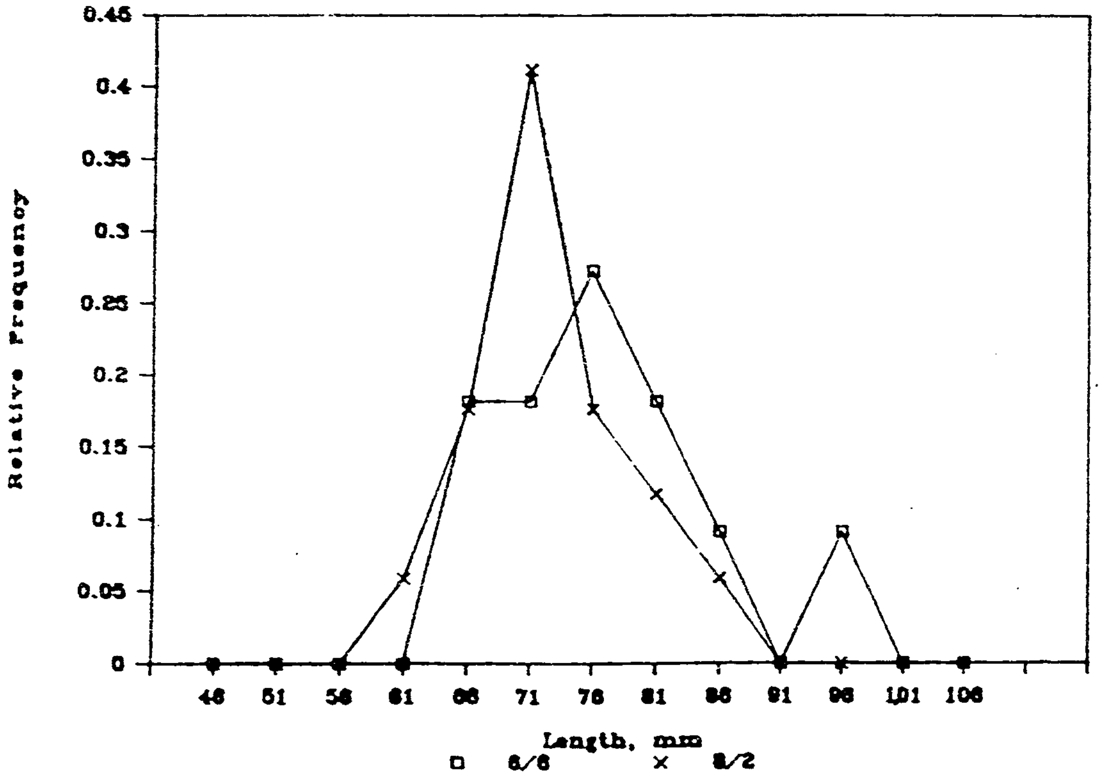


Figure 19. Frequency-distribution of Providence River clam lengths within six color categories. Colors are from the 7.5YR chart and range from pinkish white (8/2) to reddish yellow (6/6). The extreme colors are shown in the lower graph.

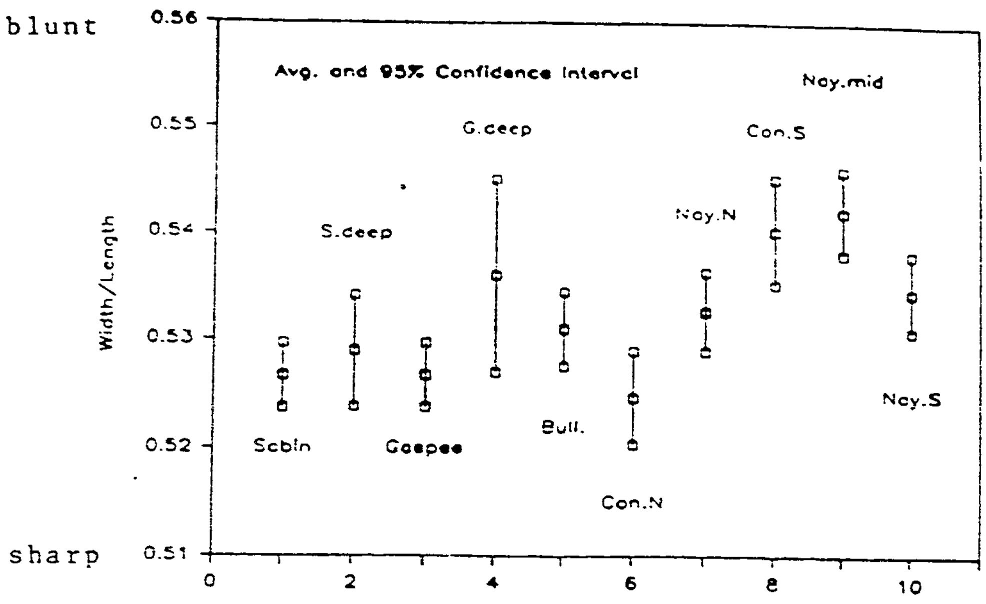


Figure 20. Ratio of width to length in clams from Providence River station groups

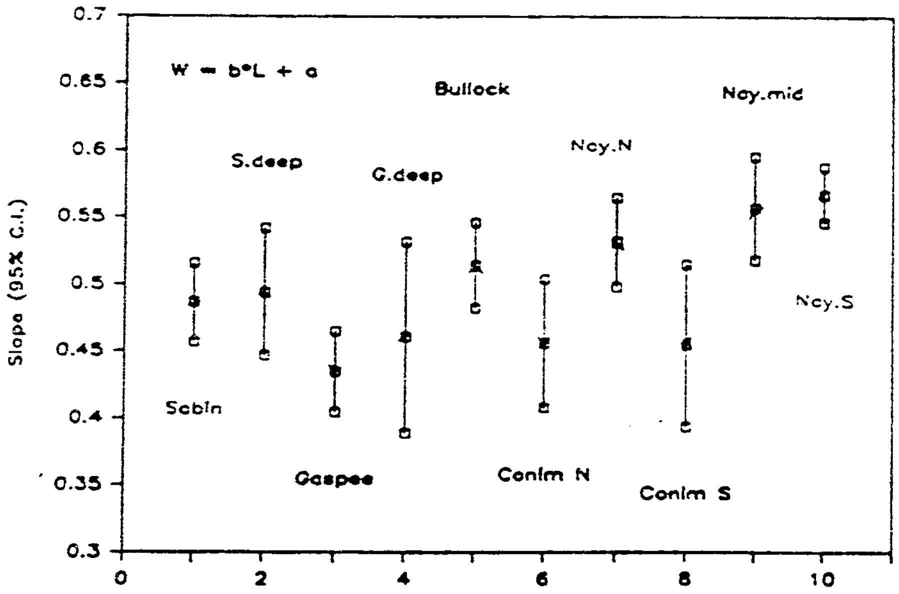


Figure 21. Slope of the width-length regression of clams from Providence River station groups

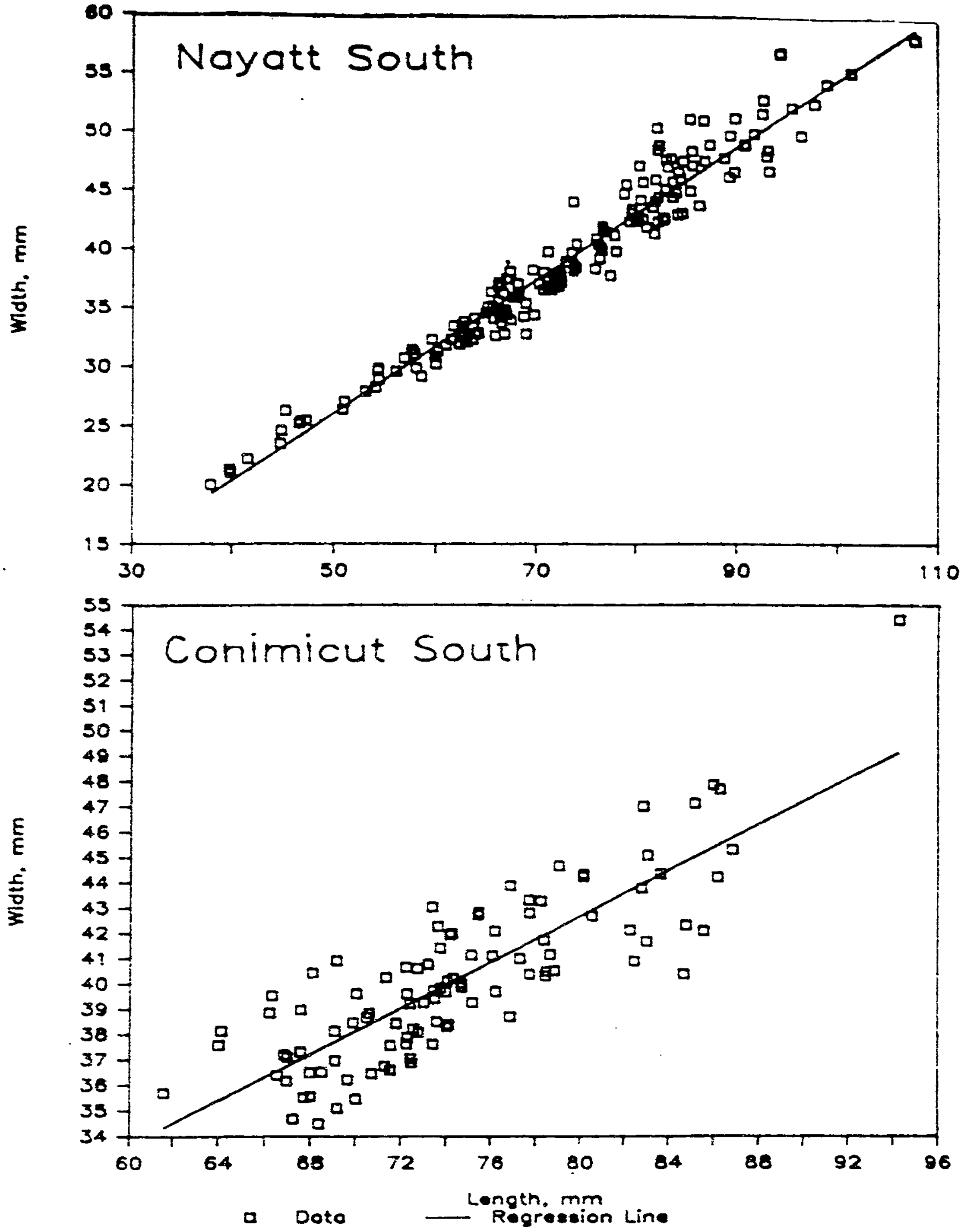


Figure 22. Regression of length and width of clams from two Providence River station groups

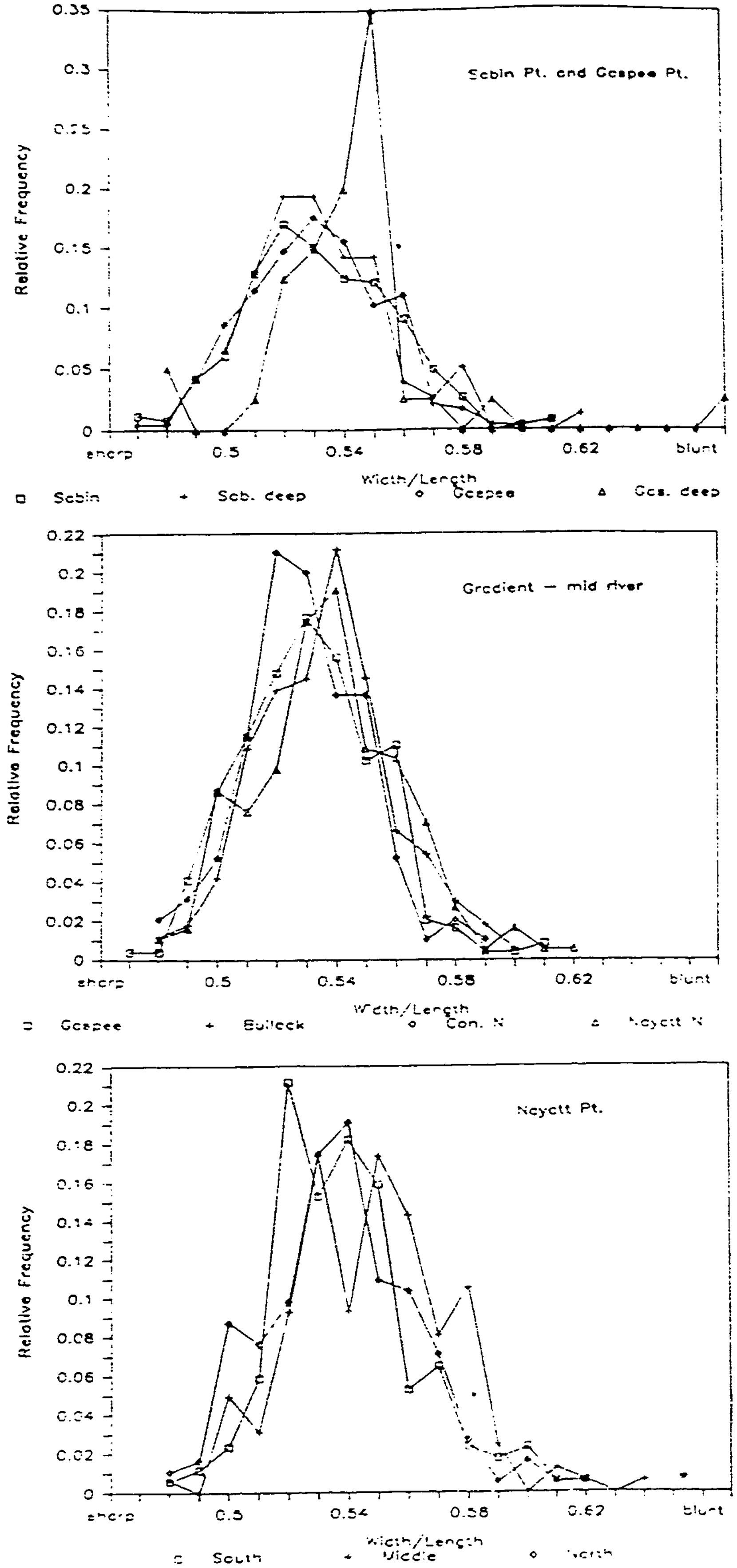


Figure 23. Relative frequency of width-length ratio classes in clams from Providence River station groups. Groups from north, mid, and south segments of the river are graphed together.

Table 1 - Location, substrate, and catch for Providence River stations divided into groups by location and substrate type

Station List for Providence River Groups

Station	Latitude	Longitude	Strata	Clams per tow
1. Sabin Pt. shallow				
1	41o 45.5'	71o 22.4'	sd/si	66
2	41o 45.5'	71o 22.3'	sd/si	480
3	41o 45.5'	71o 22.2'	sd/si	50
4	41o 45.4'	71o 22.2'	sd/si	544
6	41o 45.3'	71o 22.2'	sd/si	98
7	41o 45.3'	71o 22.1'	sd/si	8
2. Sabin Pt. deep				
5	41o 45.3'	71o 22.4'	cl/si	11
8	41o 45.2'	71o 22.3'	cl/si	28
9	41o 45.1'	71o 22.3'	cl/si	16
10	41o 45.0'	71o 22.3'	cl/si	20
11	41o 45.0'	71o 22.2'	cl/si	4
3. Gaspee Pt. shallow				
12	41o 44.6'	71o 22.5'	si/sd	43
13	41o 44.5'	71o 22.5'	si/sd	912
15	41o 44.4'	71o 22.6'	si/sd	1730
16	41o 44.4'	71o 22.4'	si/sd	94
18	41o 44.3'	71o 22.6'	si/sd	688
19	41o 44.2'	71o 22.3'	cl/si	3
4. Gaspee Pt. deep				
14	41o 44.5'	71o 22.1'	cl/si	7
17	41o 44.4'	71o 22.0'	cl/si	35
5. Bullock Pt.				
20	41o 44.2'	71o 22.0'	cl/si	5
21	41o 44.2'	71o 21.3'	si/sd	896
22	41o 44.1'	71o 21.9'	cl/si	14
23	41o 44.1'	71o 21.7'	si/sd	1150
24	41o 44.1'	71o 21.4'	si/sd	313
25	41o 44.1'	71o 21.2'	si/sd	2180
26	41o 44.0'	71o 21.8'	cl/si	no data
27	41o 44.0'	71o 21.6'	si/sd	1250
28	41o 44.0'	71o 21.3'	si/sd	920
29	41o 43.9'	71o 21.8'	cl/si	no data
30	41o 43.9'	71o 21.3'	si/sd	1810
6. Conimicut Pt. North				
31	41o 43.8'	71o 22.1'	cl/si	1
32	41o 43.85'	71o 22.1'	cl/si	6
38	41o 43.6'	71o 22.3'	sd/si/cl	1
39	41o 43.6'	71o 22.1'	sd/si/cl	3
40	41o 43.6'	71o 22.0'	cl/si	3
42	41o 43.5'	71o 22.3'	sd/si/cl	172
43	41o 43.5'	71o 22.2'	sd/si/cl	78

Table 1 (cont'd)

7. Nayatt Pt. North				
33	41o 43.8'	71o 21.5'	cl/si	384
34	41o 43.8'	71o 21.2'	si/sd	376
35	41o 43.8'	71o 21.0'	si/sd	440
36	41o 43.7'	71o 21.5'	cl/si	3
37	41o 43.7'	71o 21.2'	si/sd	740
8. Conimicut Pt. South				
44	41o 43.5'	71o 21.8'	cl/si	3
45	41o 43.5'	71o 21.7'	cl/si	5
46	41o 43.42'	71o 21.67'	sd/si	16
49	41o 43.4'	71o 21.9'	sd/si/cl	352
50	41o 43.4'	71o 21.5'	sd/si	0
54	41o 43.3'	71o 21.9'	sd/si/cl	1310
55	41o 43.3'	71o 21.7'	sd/si/cl	750
56	41o 43.3'	71o 21.5'	sd/si	0
57	41o 43.3'	71o 21.3'	sd/si	2
58	41o 43.3'	71o 21.2'	sd/si	0
9. Nayatt Pt. middle				
41	41o 43.6'	71o 20.9'	sd/si/cl	896
47	41o 43.7'	71o 21.1'	si/sd	228
51	41o 43.4'	71o 21.1'	sd/si	53
10. Nayatt Pt. South				
48	41o 43.5'	71o 20.6'	sd	438
52	41o 43.4'	71o 20.7'	sd/si/cl	536
53	41o 43.4'	71o 20.6'	sd	800
59	41o 43.3'	71o 20.6'	sd/si/cl	520
60	41o 43.2'	71o 20.7'	sd/si	12

Table 2 - Location, substrate, and catch for Mount Hope Bay stations

Mt. Hope Bay clam tows November-December 1985

Station	Latitude	Longitude	Strata	Clams per tow
1	41o 42.8'	71o 13.25'	sd/si/cl	0
2	41o 42.6'	71o 13.25'	sd/si/cl	1
3	41o 42.4'	71o 13.00'	sd/si/cl	20
4	41o 42.4'	71o 12.75'	sd/si/cl	no data
5	41o 42.6'	71o 12.00'	sd/si/cl	16
6	41o 42.2'	71o 11.50'	cl/si	20
7	41o 42.2'	71o 11.25'	cl/si	no data
8	41o 42.0'	71o 13.25'	sd/si/cl	12
9	41o 42.0'	71o 12.25'	sd/si/cl	2
10	41o 42.0'	71o 12.00'	cl/si	2
11	41o 42.0'	71o 11.50'	cl/si	5
12	41o 41.8'	71o 14.25'	sd/si/cl	3
13	41o 41.8'	71o 14.00'	sd/si/cl	8
14	41o 41.8'	71o 13.50'	sd/si/cl	62
15	41o 41.8'	71o 13.25'	sd/si/cl	4
16	41o 41.8'	71o 12.50'	sd/si/cl	4
17	41o 41.8'	71o 12.25'	cl/si	1
18	41o 41.8'	71o 12.00'	cl/si	3
19	41o 41.6'	71o 13.25'	sd/si/cl	5
20	41o 41.6'	71o 11.25'	cl/si	5
21	41o 41.4'	71o 13.50'	sd/si/cl	12
22	41o 41.4'	71o 12.50'	cl/si	1
23	41o 41.4'	71o 12.00'	cl/si	4
24	41o 41.4'	71o 11.75'	cl/si	3
25	41o 41.2'	71o 14.25'	cl/si	1
26	41o 41.2'	71o 14.00'	cl/si	10
27	41o 41.2'	71o 13.00'	sd/si/cl	0
28	41o 41.2'	71o 12.50'	cl/si	0
29	41o 41.0'	71o 14.25'	cl/si	4
30	41o 41.0'	71o 13.00'	cl/si	0
31	41o 41.0'	71o 11.75'	cl/si	0
32	41o 40.8'	71o 14.00'	cl/si	68
33	41o 40.8'	71o 13.25'	cl/si	15
34	41o 40.6'	71o 13.75'	cl/si	4
35	41o 40.6'	71o 13.25'	cl/si	17
36	41o 40.6'	71o 13.00'	cl/si	37
37	41o 40.6'	71o 12.50'	cl/si	28
38	41o 40.4'	71o 14.00'	cl/si	0
39	41o 40.4'	71o 13.50'	cl/si	6
40	41o 40.4'	71o 13.25'	cl/si	66
41	41o 40.4'	71o 12.75'	cl/si	7
42	41o 40.4'	71o 12.50'	cl/si	9
43	41o 40.2'	71o 13.75'	cl/si	66
44	41o 40.2'	71o 13.00'	cl/si	64
45	41o 40.2'	71o 12.50'	cl/si	22
46	41o 40.0'	71o 12.75'	cl/si	0
47	41o 39.8'	71o 14.75'	cl/si	0
48	41o 39.8'	71o 14.25'	cl/si	0
49	41o 39.8'	71o 13.25'	cl/si	6
50	41o 39.8'	71o 12.75'	cl/si	7

Table 2 (cont'd)

51	41o 39.6'	71o 15.00'	cl/si	5
52	41o 39.6'	71o 14.25'	cl/si	0
53	41o 39.6'	71o 13.25'	cl/si	100
54	41o 39.5'	71o 14.50'	cl/si	1
55	41o 39.2'	71o 14.25'	sd/si/cl	100
56	41o 39.2'	71o 14.00'	sd/si/cl	70
57	41o 39.2'	71o 13.75'	sd/si/cl	7
58	41o 39.0'	71o 14.50'	sd/si/cl	0
59	41o 39.0'	71o 14.00'	sd/si/cl	12
60	41o 39.0'	71o 13.75'	sd/si/cl	66

Table 3 - Hard clam density in various substrate types

Providence River

cl/si		si/sd		sd/si		sd/si/cl		sd	
-A-	-B-	-A-	-B-	-A-	-B-	-A-	-B-	-A-	-B-
5	11	12	43	1	66	38	1	48	438
8	28	13	912	2	480	39	3	53	800
9	16	15	1730	3	50	41	896		
10	20	16	94	4	544	42	172		
11	4	18	688	6	98	43	78		
14	7	21	896	7	8	49	352		
17	35	23	1150	46	16	52	536		
19	3	24	313	50	0	54	1310		
20	5	25	2180	51	53	55	750		
22	14	27	1250	56	0	59	520		
26		28	920	57	2				
29		30	1810	58	0				
31	1	34	376	60	12				
32	6	35	440						
33	384	37	740						
36	3	47	228						
40	3								
44	3								
45	5								
n	17		16		13		10		2
avg.	32.24		860.6		102.2		461.8		619.0
std.	88.44		615.1		177.6		408.2		181.0
95%lo	-10.7		553.1		3.70		203.6		363.0
95%hi	75.13		1168		200.8		720.0		875.0

-A-: Station
-B-: Clams per Tow
95%lo: Lower bound of approximate 95% confidence interval
95%hi: Upper bound of approximate 95% confidence interval
Note: no data for stations 26 and 29

Summary of Significant Differences in Mean Clams per Tow

cl/si,sd/si < sd/si/cl,sd,si/sd

Table 4 - Hard clam density in various substrate types

Mt. Hope Bay

cl/si		sd/si/cl	
-A-	-B-	-A-	-B-
6	20	1	0
7		2	1
10	2	3	20
11	5	4	
17	1	5	16
18	3	8	12
20	5	9	2
22	1	12	3
23	4	13	8
24	3	14	62
25	1	15	4
26	10	16	4
28	0	19	5
29	4	21	12
30	0	27	0
31	0	55	100
32	68	56	70
33	15	57	7
34	4	58	0
35	17	59	12
36	37	60	66
37	28		
38	0		
39	6		
40	66		
41	7		
42	9		
43	66		
44	64		
45	22		
46	0		
47	0		
48	0		
49	6		
50	7		
51	5		
52	0		
53	100		
54	1		

	cl/si	sd/si/cl
n	38	20
avg.	15.45	20.20
std.	24.29	28.47
95%lo	7.57	7.47
95%hi	23.33	32.93

-A-: Station
-B-: Clams per Tow
95%lo: Lower bound of approximate 95% confidence interval
95%hi: Upper bound of approximate 95% confidence interval
Note: no data for stations 4 and 7

Summary of Significant Differences in Mean Clams per Tow

no significant difference between cl/si and sd/si/cl

Table 5 - Hard clams per tow for various substrate types

Providence River

	clams/tow				
	clay/silt				
	sublegal	neck	cherry	chowder	total
avg	0.13	24.86	7.25	0.00	32.24
95%lo	0.00	22.58	4.97	0.00	27.55
95%hi	0.29	27.14	9.53	0.00	36.96
	silty/sand				
avg	1.44	296.77	406.23	156.19	860.62
95%lo	0.00	195.55	348.47	72.94	616.96
95%hi	4.20	397.99	463.98	239.43	1105.61
	sand/silt/clay				
avg	3.87	164.61	257.17	36.15	461.80
95%lo	0.00	93.00	182.35	2.04	277.39
95%hi	9.68	236.22	331.99	70.26	648.15
	sandy/silt				
avg	2.04	51.99	43.48	4.71	102.23
95%lo	0.00	34.42	24.40	0.00	58.82
95%hi	5.92	69.57	62.56	10.67	148.72
	sand	(only one station)			
avg	26.34	223.89	184.38	184.38	619.00

Mt. Hope Bay

	clams/tow				
	clay/silt				
avg	0.00	0.29	2.57	12.59	15.45
95%lo	0.00	0.00	0.93	10.74	11.68
95%hi	0.00	0.85	4.20	14.44	19.49
	sand/silt/clay				
avg	0.00	3.12	2.49	14.58	20.20
95%lo	0.00	0.00	0.44	10.71	11.15
95%hi	0.00	6.26	4.55	18.45	29.26

95%lo, 95%hi: Approximate 95% confidence limits

Table 6 - Hard clams per square meter
for various substrate types

Providence River

	clams/m^2				
	clay/silt				
	sublegal	neck	cherry	chowder	total
avg	6.65E-04	1.32E-01	3.85E-02	0.00E+00	1.71E-01
95%lo	0.00E+00	1.20E-01	2.64E-02	0.00E+00	1.46E-01
95%hi	1.55E-03	1.44E-01	5.06E-02	0.00E+00	1.96E-01
	silty/sand				
avg	7.64E-03	1.58E+00	2.16E+00	8.30E-01	4.57E+00
95%lo	0.00E+00	1.04E+00	1.85E+00	3.87E-01	3.28E+00
95%hi	2.23E-02	2.11E+00	2.46E+00	1.27E+00	5.87E+00
	sand/silt/clay				
avg	2.05E-02	8.74E-01	1.37E+00	1.92E-01	2.45E+00
95%lo	0.00E+00	4.94E-01	9.69E-01	1.08E-02	1.47E+00
95%hi	5.14E-02	1.25E+00	1.76E+00	3.73E-01	3.44E+00
	sandy/silt				
avg	1.09E-02	2.76E-01	2.31E-01	2.50E-02	5.43E-01
95%lo	0.00E+00	1.83E-01	1.30E-01	0.00E+00	3.12E-01
95%hi	3.15E-02	3.69E-01	3.32E-01	5.67E-02	7.90E-01
	sand	(only one station)			
avg	1.40E-01	1.19E+00	9.79E-01	9.79E-01	3.29E+00

Mt. Hope Bay

	clams/m^2				
	clay/silt				
avg	0.00E+00	1.52E-03	1.36E-02	6.69E-02	8.20E-02
95%lo	0.00E+00	0.00E+00	4.96E-03	5.71E-02	6.20E-02
95%hi	0.00E+00	4.50E-03	2.23E-02	7.67E-02	1.04E-01
	sand/silt/clay				
avg	0.00E+00	1.66E-02	1.32E-02	7.74E-02	1.07E-01
95%lo	0.00E+00	0.00E+00	2.32E-03	5.69E-02	5.92E-02
95%hi	0.00E+00	3.33E-02	2.42E-02	9.80E-02	1.55E-01

95%lo, 95%hi: Approximate 95% confidence limits

Table 6.1 - Hard clams per acre
for various substrate types

Providence River

	clams/ac				
	clay/silt				
	sublegal	neck	cherry	chowder	total
avg	2.69E+00	5.34E+02	1.56E+02	0.00E+00	6.93E+02
95%lo	0.00E+00	4.85E+02	1.07E+02	0.00E+00	5.92E+02
95%hi	6.28E+00	5.83E+02	2.05E+02	0.00E+00	7.94E+02
	silty/sand				
avg	3.09E+01	6.38E+03	8.73E+03	3.36E+03	1.85E+04
95%lo	0.00E+00	4.20E+03	7.49E+03	1.57E+03	1.33E+04
95%hi	9.04E+01	8.55E+03	9.97E+03	5.15E+03	2.38E+04
	sand/silt/clay				
avg	8.31E+01	3.54E+03	5.53E+03	7.77E+02	9.93E+03
95%lo	0.00E+00	2.00E+03	3.92E+03	4.37E+01	5.96E+03
95%hi	2.08E+02	5.08E+03	7.14E+03	1.51E+03	1.39E+04
	sandy/silt				
avg	4.39E+01	1.12E+03	9.35E+02	1.01E+02	2.20E+03
95%lo	0.00E+00	7.40E+02	5.25E+02	0.00E+00	1.26E+03
95%hi	1.27E+02	1.50E+03	1.34E+03	2.29E+02	3.20E+03
	sand	(only one station)			
avg	5.66E+02	4.81E+03	3.96E+03	3.96E+03	1.33E+04

Mt. Hope Bay

	clams/ac				
	clay/silt				
avg	0.00E+00	6.15E+00	5.52E+01	2.71E+02	3.32E+02
95%lo	0.00E+00	0.00E+00	2.01E+01	2.31E+02	2.51E+02
95%hi	0.00E+00	1.82E+01	9.03E+01	3.10E+02	4.19E+02
	sand/silt/clay				
avg	0.00E+00	6.72E+01	5.36E+01	3.13E+02	4.34E+02
95%lo	0.00E+00	0.00E+00	9.37E+00	2.30E+02	2.40E+02
95%hi	0.00E+00	1.35E+02	9.78E+01	3.97E+02	6.29E+02

95%lo, 95%hi: Approximate 95% confidence limits

Table 7 - Percentage of different size classes in various substrates

Providence River

	sublegal	neck	cherry	chowder
clay/silt				
n = 17				
avg	0.39	77.12	22.49	0.00
std	1.07	14.60	14.56	0.00
95%lo	-0.13	70.04	15.43	0.00
95%hi	0.91	84.21	29.55	0.00
silty/sand				
n = 13				
avg	0.17	34.48	47.20	18.15
std	0.58	21.20	12.10	17.44
95%lo	-0.15	22.72	40.49	8.48
95%hi	0.49	46.24	53.91	27.82
sand/silt/clay				
n = 9				
avg	0.84	35.65	55.69	7.83
std	1.89	23.26	24.30	11.08
95%lo	-0.42	20.14	39.49	0.44
95%hi	2.10	51.15	71.89	15.21
sandy/silt				
n = 13				
avg	0.17	34.48	47.20	18.15
std	0.58	21.20	12.10	17.44
95%lo	-0.15	22.72	40.49	8.48
95%hi	0.49	46.24	53.91	27.82
sand				
n = 1				
avg	4.26	36.17	29.79	29.79

Size Class	Max. Width, mm
sublegal	25.4
littleneck	38.0
cherrystone	45.0
chowder	>45.0

n refers to number of stations with size data

95%lo,95%hi: approximate 95% confidence limits

Table 8 - Percentage of different size classes in various substrates

Mt. Hope Bay

	sublegal	neck	cherry	chowder
clay/silt				
n = 27				
avg	0.00	1.85	16.62	81.53
std	0.00	9.44	27.48	31.11
95%lo	0.00	-1.78	6.04	69.56
95%hi	0.00	5.49	27.19	93.50
sand/silt/clay				
n = 15				
avg	0.00	15.47	12.35	72.18
std	0.00	30.09	19.73	37.08
95%lo	0.00	-0.07	2.16	53.04
95%hi	0.00	31.00	22.54	91.33

Size Class	Max. Width, mm
sublegal	25.4
littleneck	38.0
cherrystone	45.0
chowder	>45.0

n refers to number of stations with size data

95%lo,95%hi: approximate 95% confidence limits

Table 9 - Percentage of different size classes in individual stations

Providence River

Station	sublegal	neck	cherry	chowder
1	0.00	48.48	51.52	0.00
2	0.00	71.67	26.67	1.67
3	0.00	52.00	48.00	0.00
4	0.00	90.77	9.23	0.00
5	0.00	80.00	20.00	0.00
6	0.00	75.00	25.00	0.00
7	0.00	75.00	25.00	0.00
8	3.57	75.00	21.43	0.00
9	0.00	93.75	6.25	0.00
10	0.00	68.42	31.58	0.00
11	0.00	75.00	25.00	0.00
12	0.00	74.42	25.58	0.00
13	0.00	63.16	36.84	0.00
14	0.00	71.43	28.57	0.00
15	0.00	55.56	40.74	3.70
16	0.00	59.57	40.43	0.00
17	3.03	72.73	24.24	0.00
18	0.00	44.19	55.81	0.00
19	0.00	100.00	0.00	0.00
20	0.00	80.00	20.00	0.00
21	0.00	10.26	69.23	20.51
22	0.00	84.62	15.38	0.00
23	0.00	25.71	51.43	22.86
24	no data			
25	0.00	22.58	67.74	9.68
26	no data			
27	no data			
28	0.00	14.29	45.24	40.48
29	no data			
30	no data			
31	0.00	100.00	0.00	0.00
32	0.00	66.67	33.33	0.00
33	0.00	43.48	56.52	0.00
34	2.17	17.39	47.83	32.61
35	0.00	27.78	53.70	18.52
36	0.00	66.67	33.33	0.00
37	0.00	22.86	45.71	31.43
38	0.00	0.00	100.00	0.00
39	0.00	33.33	66.67	0.00
40	0.00	66.67	33.33	0.00
41	0.00	26.42	62.26	11.32
42	0.00	66.67	33.33	0.00
43	0.00	38.46	53.85	7.69
44	0.00	66.67	33.33	0.00
45	0.00	100.00	0.00	0.00
46	0.00	18.75	68.75	12.50
47	0.00	10.53	33.33	56.14
48	no data			
49	0.00	27.27	65.91	6.82
50	0 clams			

Table 9 (cont'd)

51	0.00	26.92	71.15	1.92
52	1.54	26.15	35.38	36.92
53	4.26	36.17	29.79	29.79
54	0.00	20.51	71.79	7.69
55	no data			
56	0 clams			
57	0.00	0.00	100.00	0.00
58	0 clams			
59	6.00	82.00	12.00	0.00
60	20.00	50.00	0.00	30.00

Size Class	Max. Width, mm
sublegal	25.4
littleneck	38.0
cherrystone	45.0
chowder	>45.0

no data: no size data for station
0 clams: no clams caught at station

Table 10 - Percentage of different size classes in individual stations

Mt. Hope Bay Station	sublegal	neck	cherry	chowder
1	0 clams			
2	0.00	100.00	0.00	0.00
3	0.00	73.68	21.05	5.26
4	no data			
5	0.00	33.33	20.00	46.67
6	no data			
7	no data			
8	0.00	0.00	0.00	100.00
9	0.00	0.00	0.00	100.00
10	0.00	0.00	0.00	100.00
11	0.00	0.00	40.00	60.00
12	0.00	0.00	66.67	33.33
13	0.00	25.00	50.00	25.00
14	0.00	0.00	16.13	83.87
15	0.00	0.00	0.00	100.00
16	0.00	0.00	0.00	100.00
17	0.00	0.00	0.00	100.00
18	0.00	0.00	0.00	100.00
19	0.00	0.00	0.00	100.00
20	0.00	0.00	100.00	0.00
21	0.00	0.00	8.33	91.67
22	0.00	0.00	100.00	0.00
23	0.00	0.00	0.00	100.00
24	0.00	50.00	50.00	0.00
25	0.00	0.00	0.00	100.00
26	0.00	0.00	10.00	90.00
27	0 clams			
28	0 clams			
29	0.00	0.00	25.00	75.00
30	0 clams			
31	0 clams			
32	0.00	0.00	0.00	100.00
33	0.00	0.00	0.00	100.00
34	0.00	0.00	0.00	100.00
35	0.00	0.00	17.65	82.35
36	0.00	0.00	21.62	78.38
37	0.00	0.00	38.46	61.54
38	0 clams			
39	0.00	0.00	0.00	100.00
40	0.00	0.00	21.21	78.79
41	0.00	0.00	0.00	100.00
42	0.00	0.00	11.11	88.89
43	0.00	0.00	0.00	100.00
44	0.00	0.00	0.00	100.00
45	0.00	0.00	13.64	86.36
46	0 clams			
47	0 clams			
48	0 clams			
49	0.00	0.00	0.00	100.00
50	0 clams			

Table 10 (cont'd)

51	0.00	0.00	0.00	100.00
53	no data			
54	0.00	0.00	0.00	100.00
55	no data			
56	0.00	0.00	3.03	96.97
57	0.00	0.00	0.00	100.00
58	0 clams			
59	no data			
60	0.00	0.00	0.00	100.00

Size Class	Max. Width, mm
sublegal	25.4
littleneck	38.0
cherrystone	45.0
chowder	>45.0

no data: no size data for station
0 clams: no clams caught at station

Table 11 - Value of the hard clam in various substrates

Providence River		Total Value
	avg	$3,775,983
	95%lo	$2,165,193
	95%hi	$5,411,389

	$/tow	$/acre	Total Value
clay/silt			
346 acres			
avg	$11.80	$254	$87,756
95%lo	$0.00	$0	$0
95%hi	$25.92	$557	$192,735
silty/sand			
410 acres			
avg	$228.24	$4,906	$2,011,321
95%lo	$124.49	$2,676	$1,097,015
95%hi	$331.99	$7,136	$2,925,626
sand/silt/clay			
250 acres			
avg	$125.60	$2,700	$674,880
95%lo	$51.74	$1,112	$278,027
95%hi	$199.45	$4,287	$1,071,732
sandy/silt			
218 acres			
avg	$45.22	$972	$211,877
95%lo	$0.00	$0	$0
95%hi	$92.02	$1,978	$431,146
sand (only 1 station)			
159 acres			
avg	$231.21	$4,969	$790,150

95%lo, 95%hi: limits of approximate 95% confidence interval.
0.046526 acres/tow based on 2kt. tow speed, 5 min. tow, and 2 ft. effective dredge width.
Area calculated for waters deeper than 9 ft. at MLW.

Note: Value is based on standing stock estimates that are not adjusted for dredge efficiency. Thus, these dollar values may be considered conservative estimates of the value of the resource.

Table 12 - Value of the hard clam in varicus substrates

Mt. Hope Bay		Total Value
	avg	$73,041
	95%lo	$32,128
	95%hi	$113,954

	$/tow	$/acre	Total Value
clay/silt			
775 acres			
avg	$2.52	$54	$42,035
95%lo	$1.20	$26	$19,966
95%hi	$3.85	$83	$64,105
sand/silt/clay			
412 acres			
avg	$3.50	$75	$31,006
95%lo	$1.37	$30	$12,163
95%hi	$5.63	$121	$49,849

95%lo, 95%hi: limits of approximate 95% confidence interval.
0.046526 acres/tow based on 2kt. tow speed, 5 min. tow, and 2 ft. effective dredge width.
Area calculated for waters deeper than 9 ft. at MLW.

Note: Value is based on standing stock estimates that are not adjusted for dredge efficiency. Thus, these dollar values may be considered conservative estimates of the value of the resource.

Table 13 - Value of the hard clam in various substrates in dollars per square meter

Providence River

	neck	cherry	chowder	total
	$/m^2			
clay/silt				
avg	$0.049	$0.014	$0.000	$0.063
95%lo	$0.000	$0.000	$0.000	$0.000
95%hi	$0.101	$0.037	$0.000	$0.138
silty/sand				
avg	$0.720	$0.391	$0.101	$1.212
95%lo	$0.307	$0.197	$0.051	$0.554
95%hi	$1.134	$0.585	$0.151	$1.870
sand/silt/clay				
avg	$0.412	$0.218	$0.038	$0.667
95%lo	$0.160	$0.030	$0.003	$0.192
95%hi	$0.663	$0.406	$0.073	$1.142
sandy/silt				
avg	$0.217	$0.023	$0.001	$0.240
95%lo	$0.000	$0.005	$0.000	$0.005
95%hi	$0.451	$0.041	$0.002	$0.494
sand (only one station)				
avg	$0.816	$0.224	$0.188	$1.228

Mt. Hope Bay

	neck	cherry	chowder	total
	$/m^2			
clay/silt				
avg	$0.000	$0.002	$0.012	$0.013
95%lo	$0.000	$0.000	$0.005	$0.005
95%hi	$0.000	$0.003	$0.018	$0.021
sand/silt/clay				
avg	$0.003	$0.002	$0.013	$0.019
95%lo	$0.000	$0.000	$0.003	$0.003
95%hi	$0.008	$0.003	$0.024	$0.035

95%lo,95%hi: approximate 95% confidence limits

Note: Value is based on standing stock estimates that are not adjusted for dredge efficiency. Thus, these dollar values may be considered conservative estimates of the value of the resource.