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Assessment of Shellfish Populations in the Great Bay Estuary

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ASSESSMENT OF SHELLFISH POPULATIONS IN THE GREAT BAY ESTUARY

A Final Report to

The New Hampshire Estuaries Project

Submitted by

Dr. Richard Langan
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University of New Hampshire

December 31, 1997

This report was funded in part by a grant from the Office of State Planning, New Hampshire Estuaries Project, as authorized by the U.S. Environmental Protection Agency pursuant to Section 320 of the Clean Water Act.

New Hampshire Estuaries Project

EXECUTIVE SUMMARY

Major subtidal oyster beds and selected intertidal clam beds in the Great Bay Estuary were assessed in 1997. The areal cover, density, population structure and condition of oyster beds in Great Bay at Nannie Island and Adams Point and in the Salmon Falls, Piscataqua, Bellamy, and Oyster Rivers determined by SCUBA survey of bed perimeters and condition and a series of random quadrat samples at the beds. A Differential Global Positioning System (DGPS) was used to mark the location of each bed. The positioning data was digitized and entered into the GRANIT Geographic Information System (GIS) and mapped. Comparison of the data to earlier mapping and population studies indicates that some beds (Oyster and Bellamy) have been substantially reduced in area due to sedimentation and that the Nannie Island bed is considerably larger than records from earlier studies indicate. Oyster density was found to be lower than densities reported in the 1980's and early 1990's at all locations with the greatest reduction in numbers observed in the Salmon Falls and Piscataqua River beds. The size distributions of oysters indicates very poor recruitment since 1993 when a major set occurred. Overall, the data indicates a decline in oyster populations in recent years. The reasons for the decline include sedimentation, poor recruitment, mortality due to the oyster parasite *Haplosporidium nelsoni*, the causative agent of the disease MSX, and removal of shell (cultch) by recreational harvesters. Some of these causes are interrelated therefore, resource management strategies should include consideration of these factors in an integrated fashion. Recommendations include continuing a program of disease monitoring, cultivation and shell (cultch) planting at beds that have received heavy sedimentation, and enhancement using disease resistant hatchery reared oyster seed.

Intertidal flats along the western shore of the Salmon Falls River, the southern shore of Dover Point in Little Bay, the eastern shore of Little Bay from Fox Point south to Welch Cove, in the vicinity of Sandy Point and the southern section of Durham Point immediately north of Adams Point were assessed for populations of the softshell clam, *Mya arenaria*.. Estimates of clam density were made by counts of clam siphon holes within a series of randomly placed quadrats while several inches of water covered the flats, as well as counts of clams after excavation of sediments within 1/8 m2 quadrats to a depth of 20 cm. Excavated clams were measured to determine population structure. Results indicate that with the exception of some very small areas of high clam density (most notable at Sandy Point, the southern shore of Dover Point, southern Durham Point and in the Salmon Falls River), clam densities were low in the areas surveyed, despite what appears to be suitable habitat. In some areas, few large clams were found, indicating that predation on smaller size classes may be a factor limiting the number of harvestable clams. The presence of a very firm layer of marine clay, in some areas only a few cm beneath a mud/sand matrix may also hinder the burrowing activities of *Mya*, making them more susceptible to predation. Large numbers of horseshoe crabs as well as evidence of bioturbation (feeding pits) indicate that horseshoe crab predation may be an important factor in limiting clam populations. Recommendations include experimental larval enhancement studies and predator protection to determine if these methods could potentially increase clam populations in the Great Bay Estuary.

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INTRODUCTION

The estuaries of New Hampshire are ideal habitat for a number of molluscan shellfish species. The Great Bay Estuary, including Little Harbor and the Back Bay area, supports populations of the eastern oyster (*Crassostrea virginica*), the European flat or Belon oyster (*Ostrea edulis*), softshelled clam (*Mya arenaria*), the blue mussel (*Mytilus edulis*), the razor clam (*Ensis directus*), and the sea scallop (*Placopecten magellanicus*). Molluscan shellfish in the Great Bay Estuary are of economic importance as they support important recreational fisheries and have tremendous potential as aquaculture species. They are also excellent bioindicators of estuarine condition because they are relatively long lived, and integrate their environment over time. Additionally, because they are filter feeders, they play an important role in nutrient cycling, improving water clarity, and in removing significant quantities of nitrogen and phosphorus from the water column via phytoplankton and organic detritus consumption. Epibenthic shellfish such as mussels, oysters and scallops provide valuable habitat for a rich assemblages of invertebrates and fish while large infaunal bivalves oxygenate soft sediments with their burrowing activities. Oysters are considered by many estuarine ecologists to be a "keystone" species, and oyster beds in temperate estuaries are considered the equivalent of coral reefs in tropical seas. Many studies have shown that species density, diversity and biomass is significantly greater in oyster beds than on equivalent bottom without oysters. Molluscan shellfish play an important role in the ecology and economy of the Great Bay Estuary. Proper management of these important resources requires an understanding of the geographic location of the resource, the population size and structure, areal coverage, and habitat condition. Additionally, knowledge the biotic and abiotic factors that influence shellfish populations must be understood for effective management.

Of the molluscan shellfish species inhabiting the Great Bay Estuary, Eastern oysters and softshell clams have received the most attention due to their popularity with recreational harvesters. Eastern oysters (*Crassostrea virginica*) can be found throughout the estuarine system in scattered clumps and as single oysters, as well as in major concentrations or beds that have been identified in previous studies. A substantial amount of intertidal area has been identified as clam habitat in the estuary (Jackson 1944, Nelson 1982, Banner and Hayes 1996), and they can indeed be found throughout the system. However, most studies report generally low densities with only small pockets where clams are abundant. In the past, both species were exploited commercially, however, population declines due to overharvesting, pollution and sedimentation led to a prohibition of commercial sale and a resident only recreational harvest.

The location and dimension of oyster beds in the Great Bay Estuary is discussed in a number of publications dating back to the late 1940's. Maps of oyster bed locations can be found in Ayer et al (1970) and in Nelson (1982, Fig. 1). More recently, oyster habitat, based on occurrence and suitability modeling has been mapped by the U.S. Fish and Wildlife (Banner and Hayes 1996, Fig. 2). The earliest written description of oyster and clam resources can be found in Jackson's 1944 report entitled <u>A Biological Survey of Great Bay</u>, though earlier historical documents refer to bountiful stocks of shellfish during colonial times. Jackson (1944) gave a general description of the locations of oyster beds, and described a reduction in oyster populations due to siltation and pollution. Though numbers for acreage and density from that period are not reported, it is obvious from Jackson's description that even in the 1940's, much of the oyster habitat in the Great Bay Estuary had already been lost. Ayer et. al. (1970) described the location, acreage and population structure of Great Bay oysters and estimated a standing crop of market sized oysters of 38,000 bushels. This estimate was calculated using the areal coverage of the all beds and density and size frequency of oysters in the Oyster River only, assuming equal density and size structure for all beds, though the number of acres for each bed were not defined. Ayer et. al. (1970) also studied spatfall and growth in various locations and determined that spatfall varied temporally and spatially and that it takes approximately four years for an oyster to reach market size (80 mm). Nelson (1982) estimated the density and standing crop of market sized oysters, and NH Fish and Game conducted additional assessments on selected beds in 1991, 1993 and 1996 (NH Fish and Game 1991, Merrill 1995 and NH F&G unpublished data). There are some discrepancies in the historical data with regard to specific oyster beds. The Adams Point bed, one of the most popular harvest spots in Great Bay, is not included in the 1981 estimate (Nelson 1982), but appears in 1991 and 1993. NH Fish and Game (Nelson 1982) reported a great abundance of oysters in southwest Great Bay, a 90% reduction from 1981 to 1991 (NH Fish and game 1991), and no mention of this bed in 1993 (Merrill 1995). Reduction in areal coverage of some beds is indicated by the data from for the Bellamy and Oyster River beds from 1991 to 1993, with a 67% reduction in the Bellamy and a 19% reduction in the Oyster River (Merril 1995). Jackson (1944) mentioned a significant reduction in the size of Oyster River bed, though precise changes in dimension were not reported. Density data for all sizes of oysters was obtained for the years 1991, 1993, 1995 and 1996 for two beds near Nannie Island and for 1993 and 1996 for Adams Point by personnel from the NH Fish and Game. According to the data, from 1991 to 1996, there has been a 46% reduction in the Nannie Island south bed, a 42% reduction in the Nannie Island/Woodman Point bed and a 69% reduction in the Adams Point bed.

These data suggest a decline in oyster abundance in Great Bay. With the exception of the late 1960's data for the Oyster River (Ayer et. al. 1970), however, estimates were based on a relatively small number of samples and should be considered rough estimates at best. Additionally, the first recorded epizootic of the oyster disease MSX occurred in 1995 (Barber et. al. 1997). This study, in addition to unpublished density data (NH Fish and Game), personal observations and anecdotal information relayed to the Fish and Game by recreational harvesters, indicates that considerable oyster mortalities have occurred over the past few years. For these reasons, a general update on the condition of oyster populations in the estuary was warranted.

Clam populations have received considerably less attention than oyster populations in the Great Bay Estuary, however, a 1989 closure and more recently (1994), the limited conditional opening of clam flats in Hampton Harbor (and therefore limited harvesting opportunities) combined with the tremendous popularity of clams as a recreational species has illuminated the need to explore additional opportunities for clam harvesting.

Jackson (1944) reported acreage of flats in the Great Bay Estuary and stated that clams declined steadily in number between 1900 and 1944, and at that time there was "only a vestige of their former abundance", though no quantitative data is available for that period. Total acreage was reported to be 2,815, though at the time, most of the beds were determined to be "non-productive" due to pollution and siltation.

NH Fish and Game reported the location (Fig. 1) and abundance of clams in Great Bay (Nelson 1982) and again in 1991 (NH Fish and Game 1991). These reports use the same figures reported by Jackson (1944) for acreage and estimate a total standing crop of clams at 10,700 bushels. The U.S. Fish and wildlife (Banner and Hayes 1996) mapped clam habitat based on suitability models, however, the areas of highest habitat value do not intersect with historical occurrence data in many cases. The 1981 Fish and Game assessment (Nelson 1982) reported that though seed clams were abundant at most sites, it appears that few survive since the abundance of larger size classes was low at all sites. Jones and Langan (1996) estimated clam abundance and spatfall on several flats in the Little Harbor area. They found that densities were generally low, despite the presence of suitable habitat, and that recent spatfall was poor.

In general, historical data on clam populations throughout the Great Bay Estuary is insufficient to establish a reliable baseline from which to determine population trends and target effective management strategies. An updated assessment of clam populations and an analysis of the factors affecting them is needed in all areas of the Great Bay Estuary. Though such a comprehensive study was beyond the scope of this project, assessment of clam abundance at selected sites conducted in this study represents an initiation of this task that should continue in subsequent years.

PROJECT GOALS AND OBJECTIVES

The purpose of this project was to provide updated information on the condition of oyster and clam populations in the Great Bay Estuary. Since project funding was modest, the scope was limited to assessments of the major oyster beds that have been identified in previous studies and to clam habitats in the areas of the estuary that are either classified as approved for harvesting or areas where sanitary surveys were underway during the project period. Additional information on clam populations was gathered opportunistically in areas adjacent to major oyster beds, regardless of sanitary classification (eg.Salmon Falls River). A greater emphasis was placed on oysters, since they are the primary recreationally targeted species. Specific objectives were as follows:

Oysters

1. Delineate and accurately map the major oyster beds in the Great Bay Estuary
2. Assess oyster density and determine population structure
3. Determine condition of the beds (eg, amount of settleable substrate, silt cover)
4. Assess change in density, population structure and areal cover over time
5. Identify and discuss factors affecting oyster populations
6. Make management recommendations based on project results

Clams

1. Assess the density and population (size) structure of clams at selected sites in the Great Bay Estuary
2. Identify and discuss factors affecting clam populations
3. Make management recommendations based on project results

METHODS

The general location of major oyster beds in Great Bay, the Oyster, Piscataqua and Bellamy rivers were initially identified from maps that resulted from previous studies. The oyster bed in the Salmon Falls which does not appear on existing maps was located from prior experience with the area. The location and coverage of each oyster bed was determined by first probing and sampling the substrate from a boat a low tide using long handled oyster tongs. SCUBA divers then swam transects in the areas identified and set markers (bottom weights with attached surface buoys) at what was judged to be the perimeters of the bed. Since oyster beds are highly irregular in shape, these markers were placed using "the best professional judgement" of the divers and field personnel as to where concentrations of oysters began and ended. The position of the surface buoys was logged using a hand held DGPS, after which the positioning data was checked against navigational charts before being digitized and entered into the GRANIT GIS database. Maps were then generated using the digital data, and reviewed by project personnel for reconciliation with known occurrence.

Oyster density and size frequency data was determined by collection of all oysters and shell found within a series of randomly placed 1/8 m^2 quadrats. All live oysters were counted and measured (shell height), and shell and "boxed" oysters (articulated empty shells) were counted. Quantitative density data was not determined for the Salmon Falls and Bellamy Rivers due to sampling difficulties, however, samples were collected using oyster tongs and processed for size frequency data as described above. All oysters were processed and measured in the field and returned to the site of collection.

Clam populations in the selected areas were determined by counts of siphon holes a series of randomly placed 1/8 m^2 quadrats as well as counts of clams after excavation to a depth of 20 cm of all sediments within a minimum of 16 randomly placed 1/8 m^2 quadrats for each survey area. Excavated clams were measured to the nearest mm, and returned to the sediments with the siphon oriented upward. The location of sample sites was marked on enlarged U.S.G.S. maps or navigational charts for the area.

RESULTS AND DISCUSSION

Oyster Beds

The dimensions and locations of the major oyster beds in the Great Bay Estuary surveyed in this study are listed in Table 1 and presented in Figures 3 and 4. Comparison of the data collected for this study to data from previous studies shows a differences in acreage for several oyster beds as well as different configuration for the Nannie Island bed. Total acreage for the major oyster beds in the Great Bay Estuary was estimated by this study to be 66.5 acres as compared to 50.2 acres from previous studies. The majority of this difference was due to the size determination for the Nannie Island bed. NH Fish and Game (Nelson 1982) reported the size of the Nannie Island bed at 18.5 acres while this study determined the bed to be 43.9 acres (Table 3). The configuration of the Nannie Island bed is also quite different than reported by Fish and Game (Nelson 1982, Fig. 1), however, it is similar in shape to what was reported more recently by U.S. Fish and Wildlife (Banner and Hayes 1996, Figure 2). Differences in total acreage determined for the Oyster River Bed between this study (1.8) and the most recent Fish and Game estimate in 1993 (6.0 acres) may be the result of inaccuracy in measurement, however, the condition of the bed and the amount of buried shell found upstream and downstream of the bed, indicates that much of the bed has been lost to sedimentation. A similar case was found with the Bellamy River bed, for which a size reduction was reported 1993 (Merrill 1995). Oyster in the Bellamy survey consist of small clumps of in an otherwise muddy area, and cannot at present be considered a major oyster bed. The size and dimension of beds in the Piscataqua River and Adams Point determined for this study are similar to earlier reports, and the location, and size determination of the Salmon Falls oyster bed (2.5 acres) is the first known documentation. Though not surveyed in detail in this study, an oyster bed located in the vicinity of the railroad bridge that crosses the Squamscott River has been sampled on several occasions for disease diagnostics by the NH Fish and Game. For this study, the location of this bed was marked and mapped on the GRANIT GIS, however, size frequency and density of oysters was not obtained. NH Fish and Game (Nelson 1982) reported a 9.8 acre oyster bed in Great Bay, however, field efforts for this study failed to locate any large concentrations of oysters at the location indicated in that study. Since only soft substrates were found at the location marked on the 1982 map, it is possible that this bed has silted over and is no longer a productive oyster bed.

Oyster density at the beds surveyed in 1997 appears in Table 2. The highest density of oysters was found at the Nannie Island bed, however, this was the case for only a small portion of the total bed located between the island and Woodman Point on the mainland. The density of oysters in the Woodman Point portion of the Nannie Island bed was 158 oysters/ m^2 while south of the Island wher the cover is much greater, oyster density was only $52/m^2$. This difference was noted after the first series of samples were processed, so the areas were resampled to confirm the accuracy of the data. Results from the second round of sampling were very similar to the original data. Size frequency analysis also indicated differences in the two "sub-areas" of the Nannie Island bed, further confirming that there are differences in the oyster populations over a distance of only a few hundred feet. For the purpose of determining the populations and value of oysters at the Nannie Island bed, the bed was separated into Nannie Island-Woodman Point (WP) and Nannie Island- south (S), to reflect differences in density and population structure. The relative size of each sub-area was estimated from the GIS maps and percentage of total areas was applied to earlier data for determination of temporal changes in population.

A relatively high density of oysters was found at the Adams Point bed ($106/m^2$); moderate density at the Oyster River ($60/m^2$); and low density at the Piscataqua River bed ($32/m^2$). As stated earlier, densities were not determined for the Bellamy and Salmon Falls River, however, qualitative information obtained from sampling the areas with oyster tongs indicated that densities were very low, as live oysters were difficult to find despite repeated grab sampling. Change in oyster density over time can be illustrated by comparing the 1997 data for the Nannie Island (WP and S beds) and Adams Point beds to data collected by NH Fish and Game in 1991, 1993, 1995 and 1996. Though there are some year to year irregularities with respect density changes, the general trend for all three locations from 1991 to 1997 is a decline in oyster density at all three locations (Fig. 9). Based on the data available, the percentage decline in oyster density from 1991 to 1997 is 66% for Nannie (WP), 80 % for Nannie Island (S) and 66% at Adams Point from 1993 to 1997. Determination of a larger areal coverage of the Nannie Island bed offsets the reduced density when estimating the total number of oysters, however, even with the larger area, a reduction in total numbers of 35% was calculated. Similar comparisons for the Oyster River, Piscataqua River and Southwest Great Bay indicate declines in oyster density since 1991 of 35%, 73% and 100% respectively. Though historical data is not available for the Salmon Falls River, mortality estimates made in 1995 (Barber et. al. 1997) indicate a 90% reduction in oysters from that bed. The loss of oyster resource is even more dramatic when the reduced area of some of the beds is considered. For example, oyster density in the Oyster River has dropped 35% and approximately 5.6 acres have been lost. The combined reduced density and areal coverage constitutes an net loss of 68%.

The size frequency distribution of the oysters sampled from the beds surveyed is displayed in Figures 5-8. In general, the majority of oysters from all beds were >60mm, indicating poor recruitment for a minimum of three years. A near total absence of smaller individuals was recorded in the Nannie Island (S) bed and in the Piscataqua River. While a small percentage of oysters in the 40-60 mm range was found at some beds, it is possible that these oysters are from the 1993 year class and grew very slowly due to disease related stress. Both slow growth and depressed reproduction are symptomatic of MSX infection.

Bed condition (eg.amount of settleable substrate, amount of silt) varied among the oyster beds surveyed. Beds in the Bellamy River, Oyster River and at Adams Point were heavily silted with a considerable amount of blackened shell, boxed oysters and live oysters, covered with several inches of soft sediment. Beds in the Salmon Falls, Piscataqua and at Nannie Island appeared to be well scoured with ample clean shell for larval settlement.

Despite the reduction in oyster populations at the major beds in the Great Bay Estuary, the current standing crop of harvestable oysters is considerable. The total number of oysters > 80 mm was estimated to be >10,000,000, valued at $3,328,441,based on an ex-vessel market value of $.30 each. (Table 4).

Intertidal Clam Flats

The locations of the intertidal flats surveyed in this study are shown in Figures 2 and 10-14, and clam densities are shown in Table 5. The intertidal flat along the shoreline of Fox Point (Fig. 10) consists of a firm sand/mud/clay mixture that would appear to be ideal clam habitat, however, clam density was lower on this flat (6 clams/m^2) than all others surveyed. The eastern shore of Little Bay (Fig. 11), south of Fox Point had a substrate similar to Fox Point, consisting primarily of a sand/mud/clay mixture. The entire area, including Fox Point, is underlain with marine clay, which in some small places is only a few centimeters below the surficial sediments. Clam density in this area was also quite low (16 clams/m2), and in the areas with shallow surficial sediments clam burrowing appeared to be impeded by the marine clay layer. In addition to a low density of clams in the Fox Point and eastern shore of Little Bay, clams there were very small, and only a few clams > 50 mm were found (Figs. 15 and 16).

The intertidal sediments along the southern shore of Dover Point (Figure 12) consisted primarily of a firm sandy mixture, and clam density was relatively high (57 clams/m2). All size classes were represented, though the greatest number of clams were in the 20-40 mm size class (Fig. 17). The highest density of clams was found on the western shore of Little Bay immediately north of Adams Point (Fig. 2). The sediments ranged from sandy mud to very soft mud, and the majority of clams were found in the slightly firmer areas. All sizes of clams were found and the average density was 64 clams/m2 (Table 5). In the vicinity of Sandy Point in Great Bay (Figure 13), sediments ranged from sandy mud to soft mud, and as was the case with the area north of Adams Point, most clams were found in the firmer sediments. Average clam density was 45 clams/m2, and clams of all sizes were found. Clams in the 60-80 mm size class were most numerous (Fig. 18). Clam density in the Salmon Falls River (Fig. 14) was measured by counting siphon holes within 1/8 m2, however, no clams were excavated so the size frequency of the population was not determined. The intertidal flat in this area is very narrow, and the sediments are a somewhat firm mixture of sand, mud and silt. Clams were less abundant in the immediate vicinity of Three Rivers Point than further upstream toward the Maine-NH bridge. Average clam density was 42 clams/m2 (Table 5).

CONCLUSIONS

Based on the data collected in this study, it appears that oyster populations in the Great Bay Estuary have declined in recent years. A reduction in density and poor recruitment was observed for all major oyster beds, and a reduction areal cover was observed for the Oyster River and Bellamy River Beds. A number of factors appear to be responsible for this decline, including sedimentation (Oyster and Bellamy Rivers, Adams Point), mortalities caused by the oyster disease MSX, poor recruitment (which may very well be related to MSX), and removal of shell (Adams Point). The impact of recreational harvesting on the oyster population is considered minimal, since total annual harvest has been estimated to be approximately 3,000 bushels, or roughly 600,000 individuals, which is a small percentage of the total standing crop. The one negative impact associated with recreational harvesting is the removal of shell. A 1997 survey by NH Fish and Game indicated that nearly 80% of the shell removed from the estuary is not returned. Since the amount of settleable substrate is an important limiting factor for some beds (eg. Adams Point), future recruitment will be impacted if shell is not returned to the bed.

Clam abundance generally low in the intertidal survey areas, and larger clams were very scarce in some of the intertidal flats. A combination of predation, light sets, and in some cases substrate that is too firm (marine clay) or too soft (soupy mud) make conditions less than favorable for settlement and survival of *Mya*.

RECOMMENDATIONS

Oyster management

Despite the decline in oyster populations in recent years, a substantial amount of resource still exists, and the potential for recovery and restoration is high. Of the factors that will determine the future of oyster populations, disease is at present the most important. Since the MSX epizootic that occurred in 1995, diagnostic studies have revealed the persistence of MSX as well as the presence of another oyster pathogen, *Perkinsus marinus*, the causative agent for the oyster disease Dermo. Though no mortalities have been attributed to Dermo, advanced infections were found in Piscataqua River oysters in 1997, so the potential of disease transmission exists. Since both diseases proliferate during extended periods of low salinity and high temperature, there is little that can be done to prevent an epizootic if environmental conditions favorable to the disease organisms occur as they did from 1993-1995. At minimum, an oyster disease monitoring program should be continued. A restriction placed on the movement of oysters from areas of higher disease prevalence (eg. Salmon Falls and Piscataqua River) to other areas of the estuary could help to slow, but would not eliminate disease proliferation. Disease resistant larvae, seed or adult oysters, which are available from Rutgers University, may be used to restore areas that have suffered high disease related mortalities. This can be done either publicly or privately (i.e. commercial aquaculture).

Several management options exist for oyster beds that have received heavy sedimentation. In areas such as the Oyster and Bellamy Rivers and Adams Point, cultivation using a toothed harrow or an open bag oyster dredge towed behind a boat prior to the spawning season would bring buried shell to the sediment surface and provide additional substrate for larval settlement. Oyster, clam or scallop shell, aged on shore for a year or more, is the ideal settlement substrate, and quantities of shell could be applied to some of the areas of heavy sedimentation prior to larval settlement. At minimum, recreational harvesters should be strongly encouraged to return their shell to the areas from which they were harvested. Techniques used in commercial oyster culture, including remote setting of hatchery reared larvae, deployment of artificial spat collectors, and suspension culture of nursery stock, may all be used to restore natural oyster populations. In summary, management recommendations include:

1. Continue periodic assessment of oyster populations (including density, age structure, areal cover, and spatfall)
2. Continue oyster disease monitoring (four locations, twice per year in August and October)
3. Consider using hatchery reared, disease resistant larvae, seed or adult oysters to restore areas decimated by disease (either public or private aquaculture)

4. Cultivate areas where sedimentation has occurred and/or plant clean, aged shell prior to the larval settlement period
5. Encourage recreational harvesters to return shell to the harvest areas or to designated shell collection areas (e.g. adjacent to boat ramps). The shell can be allowed to age prior to planting on the oyster grounds
6. Identify areas favorable for larval settlement and deploy natural or artificial spat collectors.
7. Use hatchery reared larvae (disease resistant) for remote setting on natural and artificial cultch to supplement natural recruitment
8. Following 7 and 8, continue with suspension nursery culture to enhance juvenile survival prior to bottom planting

Clam Management

Though light spatfall, predation, and unsuitable habitat have been mentioned as possible factors limiting clam populations in the Great Bay Estuary, these factors should be considered speculative at best. Some relatively low cost experimental studies can be used to determine if these factors are indeed limiting clam productivity and if clam populations in the estuary can be enhanced. Management recommendations include:

1. Determine of areas of suitable clam habitat based on sediment texture, temperature, salinity, water flow, etc.
2. Conduct natural seed enhancement studies by planting brush, or using snow fencing or dome tents
3. Conduct predator exclusion studies using plastic mesh

These studies can be done on a small scale and at low cost to determine if any are viable options for enhancing clam populations

LITERATURE CITED

Ayer, W.C., B.C. Smith and R.D. Acheson. 1970. An investigation of the possibility of seed oyster production in Great Bay, New Hampshire. NH Fish and Game Dept. 1970.

Banner, A. and G. Hayes. 1996. Important Habitats of Coastal New Hampshire. U.S. Fish and Wildlife Gulf of Maine Project. November 1996.

Barber, B.J., R. Langan and T. Howell. 1997. *Haplosporidium nelsoni* (MSX) Epizootic in the Piscataqua River Estuary (Maine/New Hampshire, U.S.A.) J. Parisitol., 83(1) 1997 p. 148-150.

Jackson, C.F. 1944. A biological Survey of Great Bay, New Hampshire. No. 1: Physical and biological features of Great Bay and Present Status of its Marine Resources. Marine Fisheries Commission, Durham, NH. 61 pp.

Jones, S.H. and R. Langan. 1996. Assessment of clam resources and sanitary quality of the shellfish growing waters in Witch Creek, Seavey Creek and Little Harbor. Final Report. NH Office of State Planning/Coastal Program, Concord, NH. 57 pp.

Merrill, S. 1995. Governor's Nomination to the National Estuary Program. March 7, 1995.

Nelson, J.I. 1982. Great Bay Estuary Monitoring Survey, 1981-1982. NH Fish and Game in coopperation with the NH Office of State Planning. November 1982

New Hampshire Fish and Game Department (NHF&G). 1991. Coastal shellfish and water quality. Progress report. New Hampshire Fish and Game Department, Concord, NH. 22 pp.

Table 1. Dimensions of oyster beds in the Great Bay Estuary as determined by field GPS surveys, 1997.

Oyster Bed	Square Meters	Acres
Nannie Island (WP & S)	177,863	43.9
Piscataqua River (NH & ME)	51,735	12.8
Adams Point	16,101	4.0
Salmon Falls River (NH)	10,116	2.5
Oyster River	7,403	1.8
Squamscott River	7,024	1.7
Bellamy River	6,272	1.5

Table 2. Density, standing crop, and dollar value of market-size oysters for the major oyster beds in the Great Bay Estuary, 1997

Oyster Bed	Density (#/sq. meter)	# of Oysters >80 mm/sq. meter	Bed Area (sq. meters)	Total # of Oysters >80 mm	$$$ Value @ $.30 each
Nannie Island (S)	52	50	151,184	7,547,105	$2,264,132
Nannie Island (WP)	158	63	26,679	1,686,113	$505,834
Piscataqua River (NH & ME)	32	20	51,753	1,035,060	$310,518
Adams Point	106	38	16,101	611,838	$183,551
Oyster River	60	29	7,403	214,687	$64,406
					$3,328,441

Table 3. Temporal change in oyster bed size (acres) in the Great Bay Estuary, 1970-1997.

Oyster Bed	1970	1981/82	1991	1993	1997
Nannie Island (WP)	•	•	•	•	37.3
		18.5	18.5	18.5	
Nannie Island (S)	•	•	•	•	6.6
Adams Point	•	•	•	5.1	4.0
Oyster River	7.4	7.4	7.4	6.0	1.8
Bellamy River	•	3.1	3.1	1.0	1.5
Piscataqua River	•	12.3	12.3	12.3	12.8
Salmon Falls River	•	•	•	•	2.5
Southwest Great Bay	•	9.8	9.8	•	•
Squamscott River	•	•	•	•	1.7
TOTAL	50*	51.1	51.1	42.9	68.2

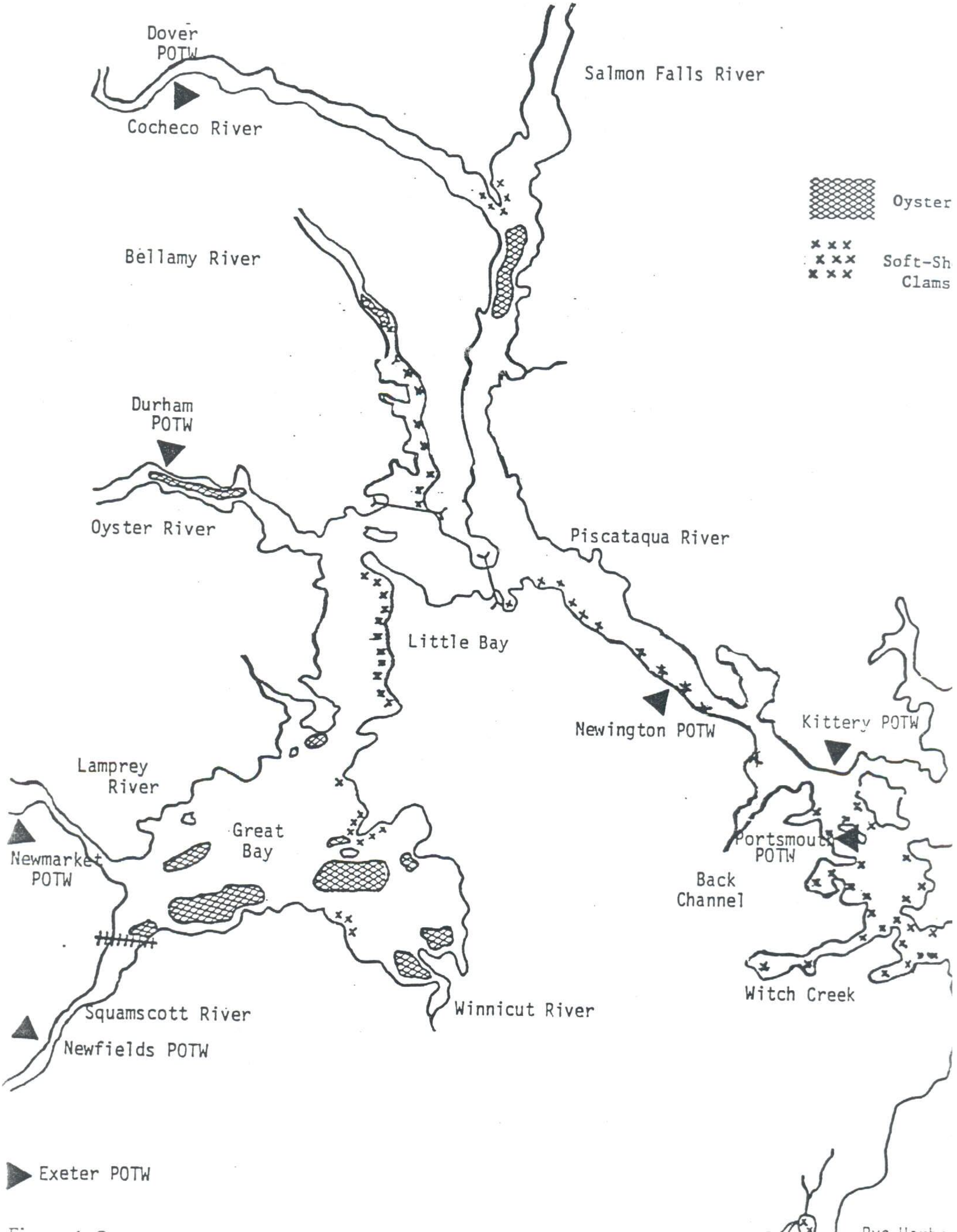
* Ayer et al., 1970

Table 4. Temporal change in oyster bed density (#/sq. meter) in the Great Bay Estuary, 1980-1997.

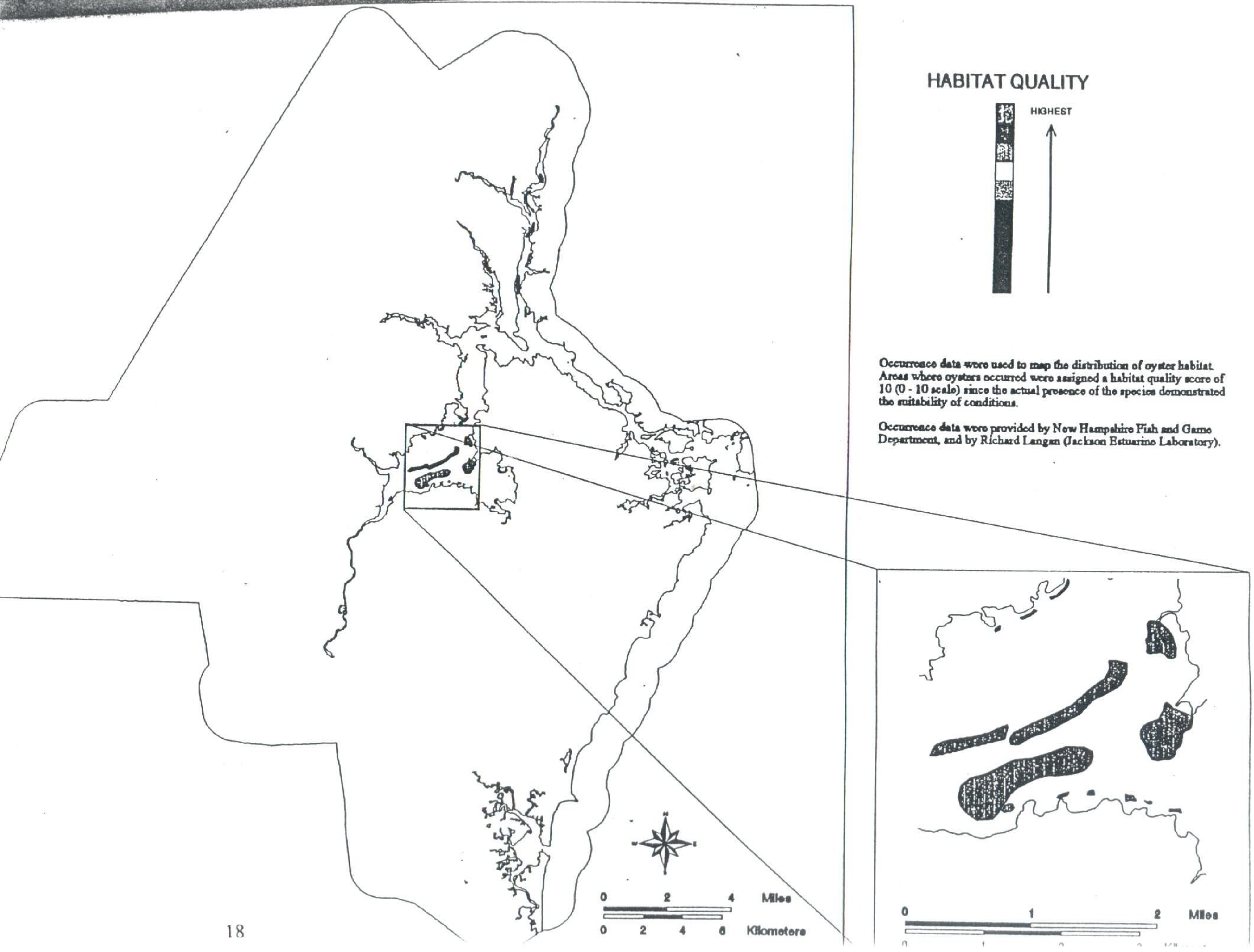
Oyster Bed	1980/81	1981/82	1991	1993	1995	1996	1997
Nannie Island	327.5	155	•	•	•	•	•
Nannie Island (WP)	•	•	400	132	256	232	158
Nannie Island (S)	•	•	400	252	80	216	52
Adams Point	•	•	•	310	•	98	106
Oyster River	217.2	91.3	•	•	•	•	60
Bellamy River	127.4	78.3	•	•	•	•	•
Piscataqua River	84	117.6	•	•	•	•	32
Salmon Falls River	•	•	•	•	•	•	•
Southwest Great Bay	222.4	202.6	•	•	•	•	•

Table 5. Clam density at intertidal flats surveyed in the Great Bay Estuary in 1997.

Clam Flat	Density (#/sq. meter)
Little Bay/Southwestern Durham Pt.	64
Dover Point/Boston Harbor	57
Sandy Point	45
Salmon Falls	42
Little Bay (eastern shore)	16
Fox Point	6



Dover
POTW
Salmon Falls River
Cocheco River
Oyster
Soft-Sh
Clams
Bellamy River
Durham
POTW
Oyster River
Piscataqua River
Little Bay
Newington POTW
Kittery POTW
Lamprey
River
Great
Bay
Newmarket
POTW
Portsmouth
POTW
Back
Channel
Squamscott River
Winnicut River
Witch Creek
Newfields POTW
Exeter POTW



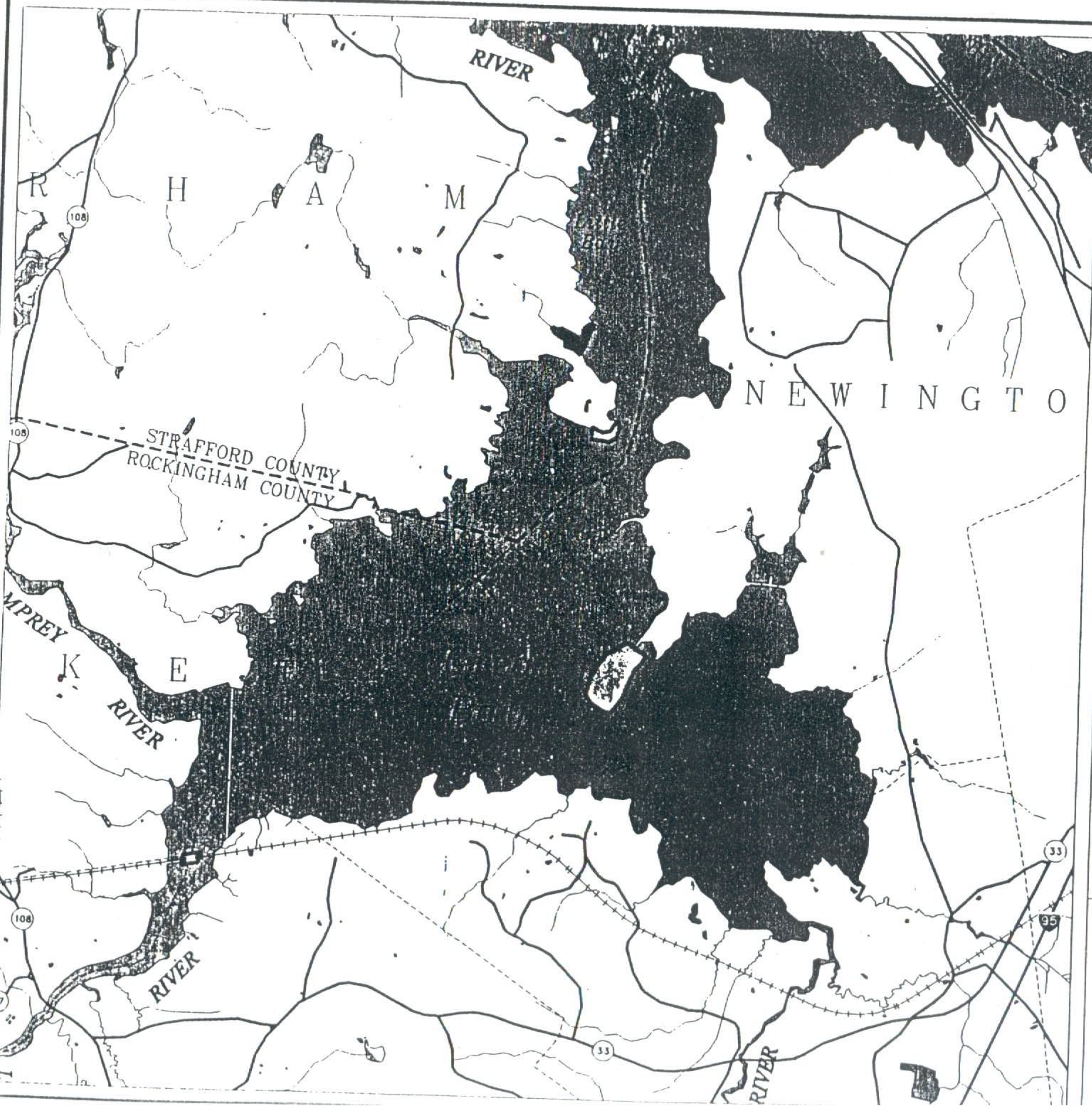
Occurrence data were used to map the distribution of oyster habitat. Areas where oysters occurred were assigned a habitat quality score of 10 (0 - 10 scale) since the actual presence of the species demonstrated the suitability of conditions.

Occurrence data were provided by New Hampshire Fish and Game Department, and by Richard Langan (Jackson Estuarine Laboratory).

NH Estuaries Project Shellfish Assessments

Location of the Adam's Point Clam Flat and Oyster Beds in Great Bay and the Squamscott River

figure 3



Legend:
- Oyster bed
- Clam flat
- Surface water
- River or stream
- Class 1 or 2 road
- Railroad
- State boundary
- County boundary
- Town boundary

Data Sources:

Oyster bed and clam flat locations were provided to NH GRANIT in digital form, September, 1997.

Town boundaries, surface water, roads, and railroads were derived from the US Geological Survey Digital Line Graphs (DLG's), 1:24,000/1:25,000, as archived in the NH GRANIT database.

N

SCALE 1:55,000

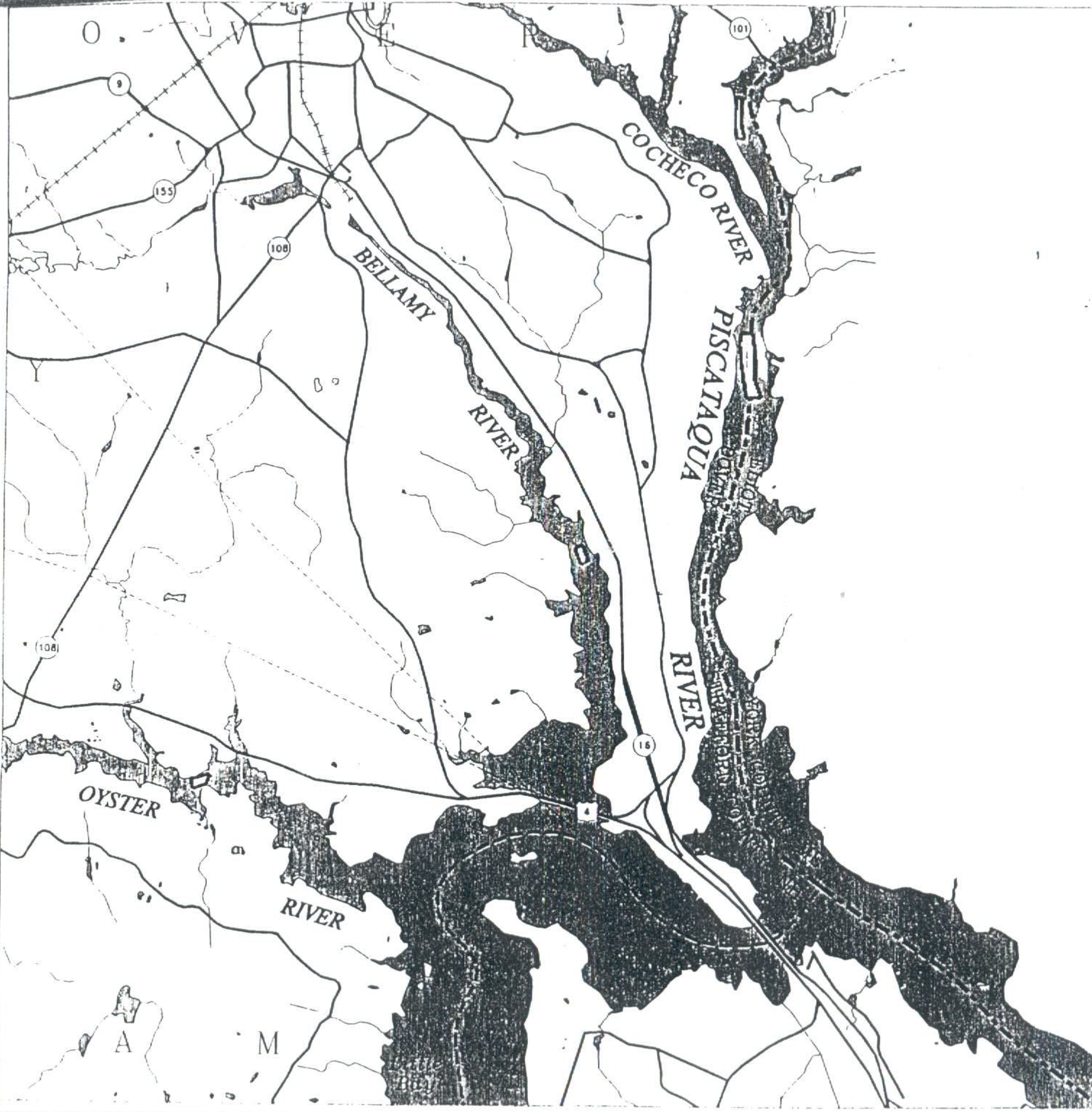
.5 .25 0 .5 MILES

Data registered to NH State Plane coordinates, 1983 datum

This map was produced for the NH Estuaries Project - NH Office of State Planning, as part of the National Estuaries Program, established under Section 320 of the Federal Water Quality Act of 1987.

Map by: Complex Systems Research Center
Institute for the Study of Earth, Oceans and Space
University of New Hampshire
December, 1997

New Hampshire Estuaries Project



NH Estuaries Project Shellfish Assessments

Location of Oyster Beds in the Oyster, Bellamy and Piscataqua Rivers

figure 4

- Oyster bed
- Clam flat
- Surface water
- River or stream
- Class 1 or 2 road
- Railroad
- State boundary
- County boundary
- Town boundary

Data Sources:

Oyster bed and clam flat locations were provided to NH GRANIT in digital form, September, 1997.

Town boundaries, surface water, roads, and railroads were derived from the US Geological Survey Digital Line Graphs (DLG's), 1:24,000/1:25,000, as archived in the NH GRANIT database.

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SCALE 1:55,000

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Map by: *Complex Systems Research Center*
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Figure 5. Size-frequency distributions of oysters at Nannie Island, Woodman Point (WP) and South (S), 1997.

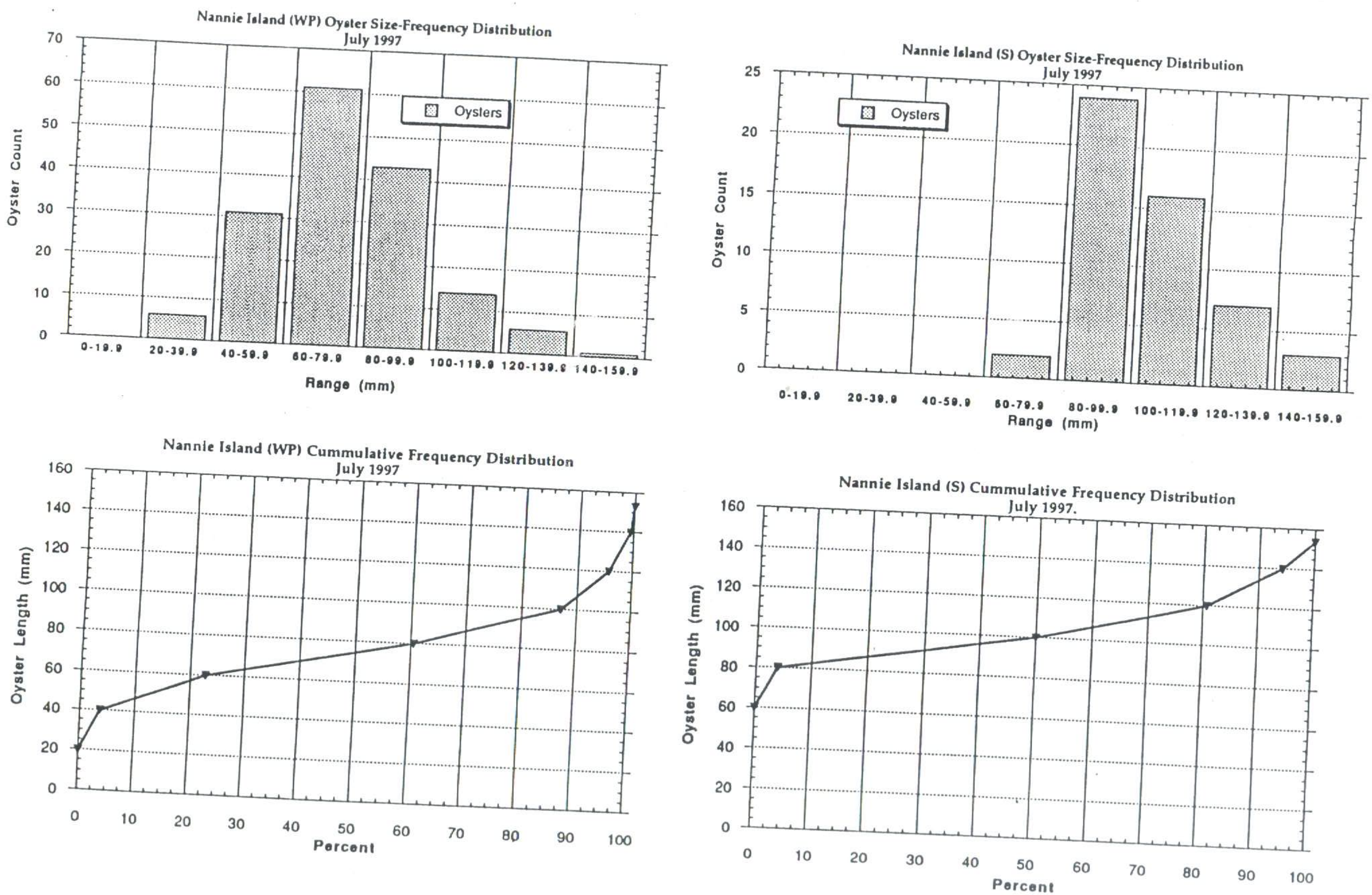


Figure 6. Size-frequency distributions of oysters in the Oyster and Piscataqua Rivers, 1997.

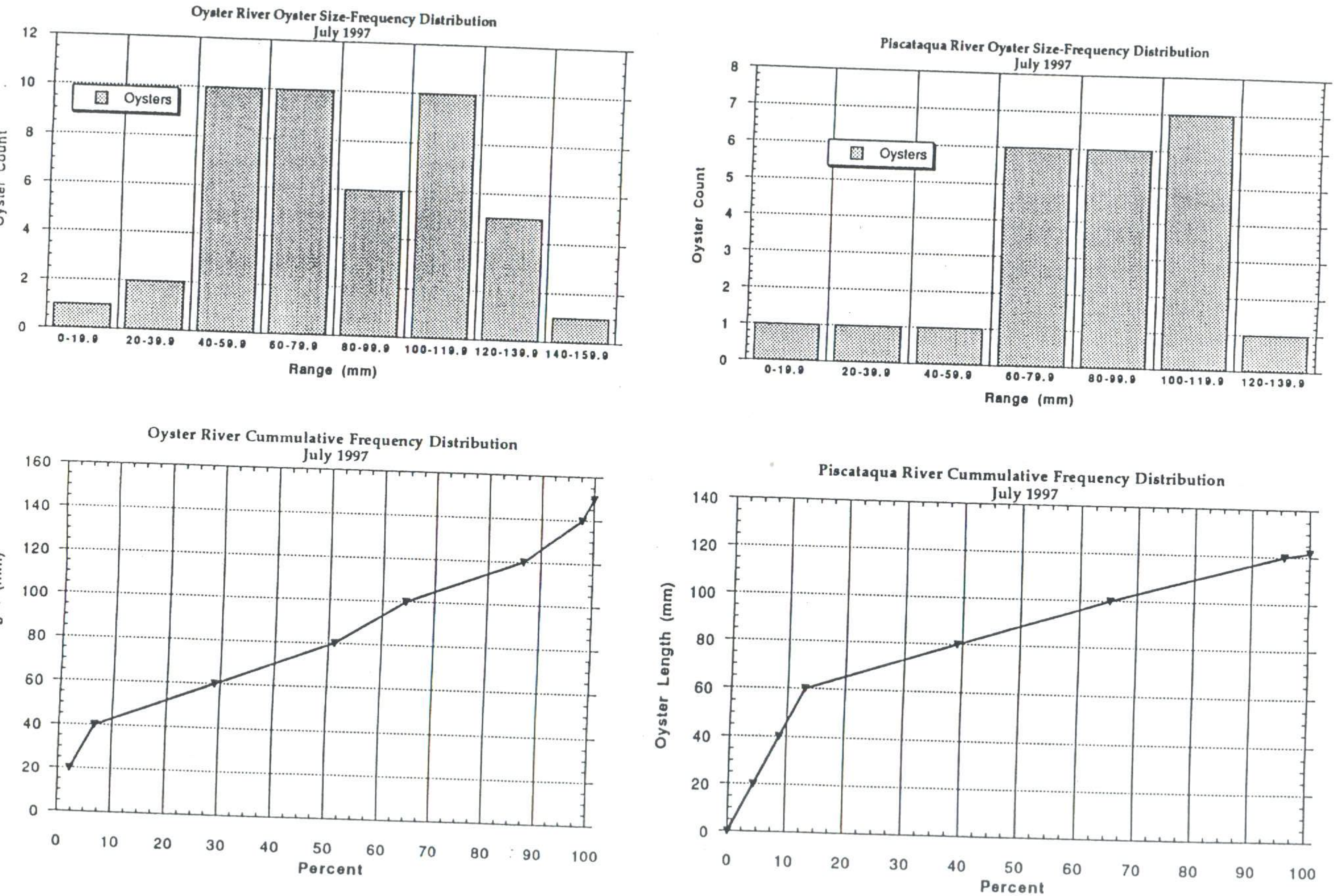


Figure 7. Size-frequency distributions of oysters in the Bellamy River and Adams Point, 1997.

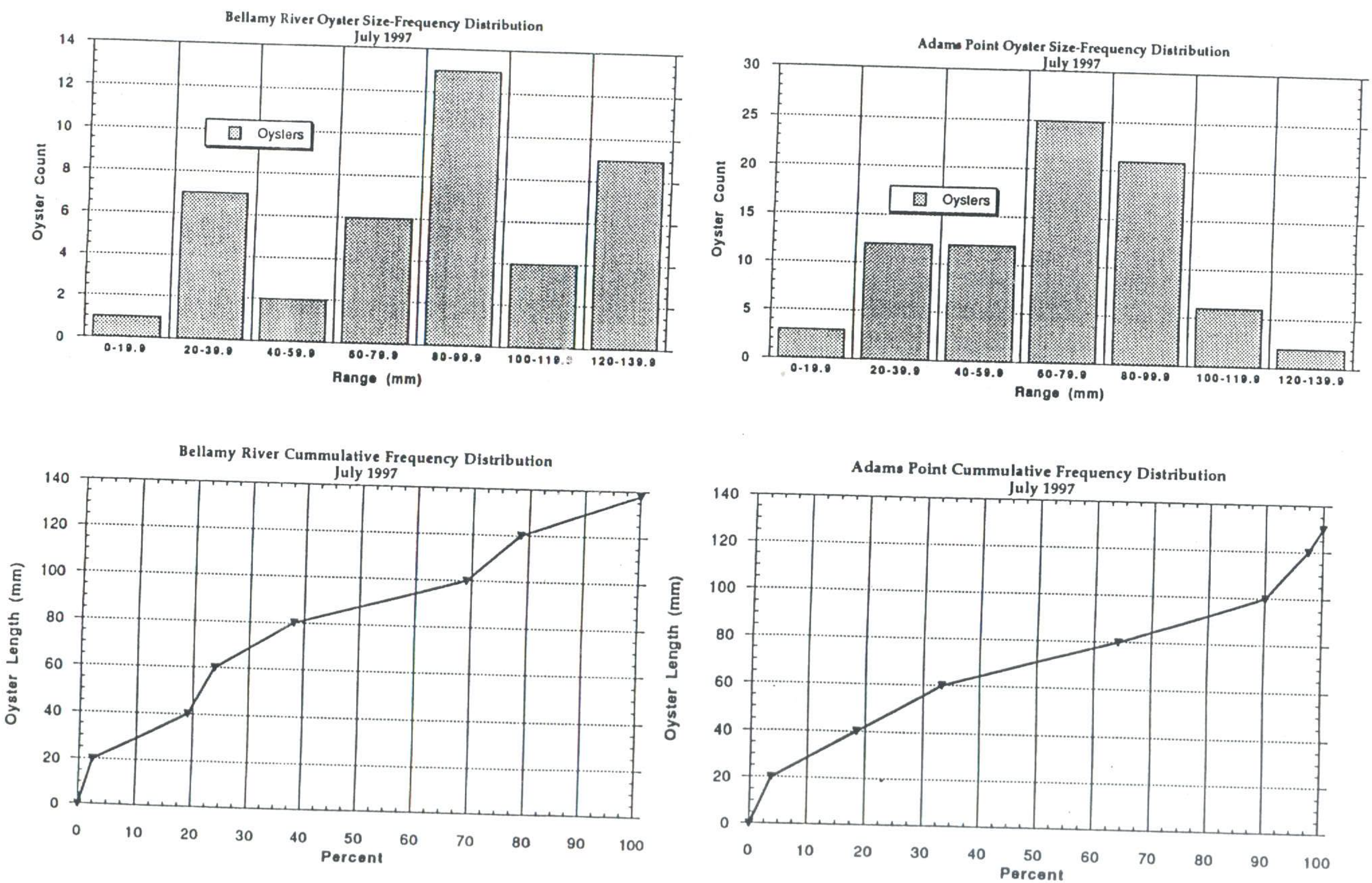


Figure 8. Size-frequency distribution of oysters in the Salmon Falls River, 1997.

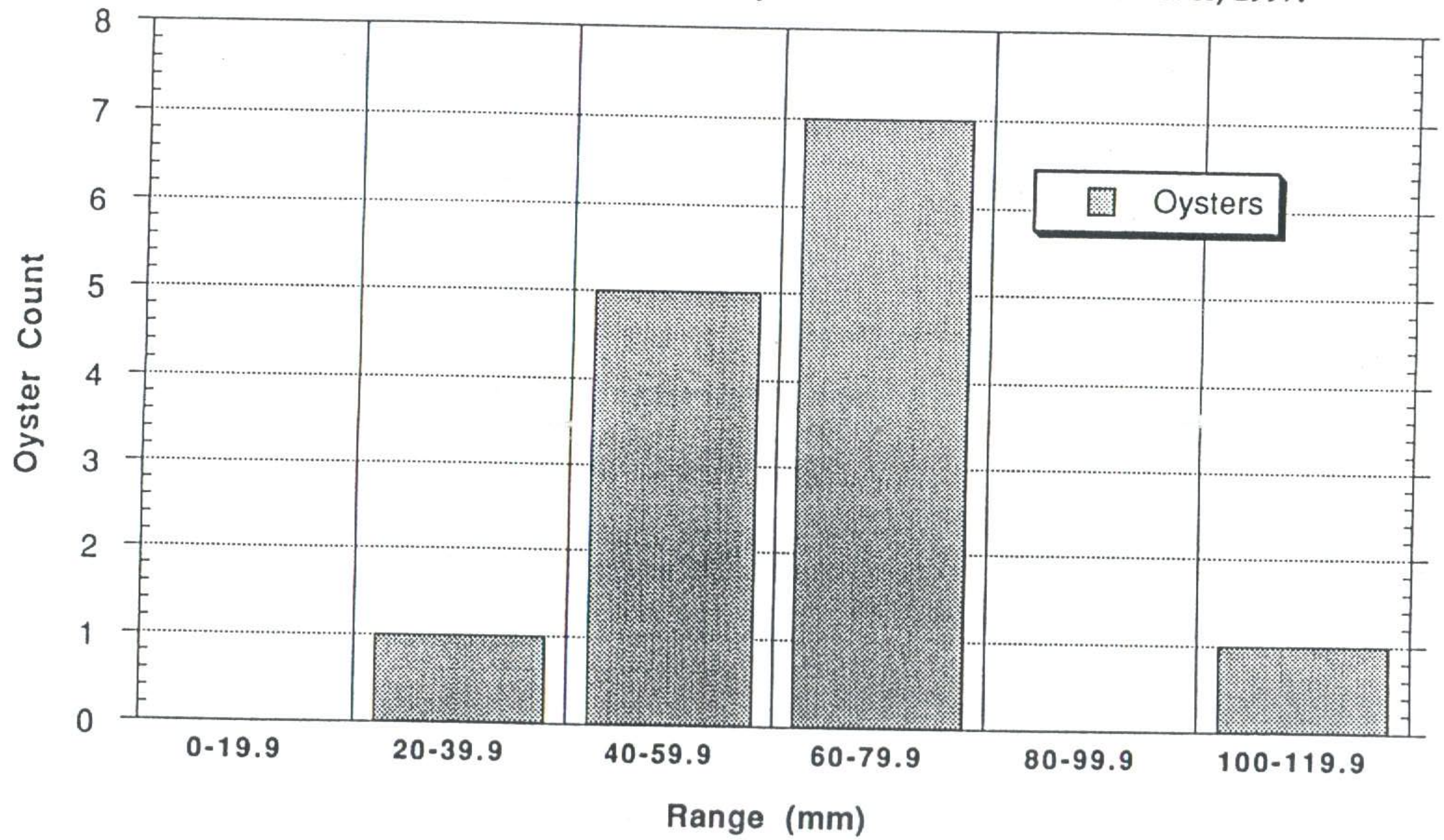


Figure 9. Temporal change in oyster density at Nannie Island and Adams Point, 1991-1997.

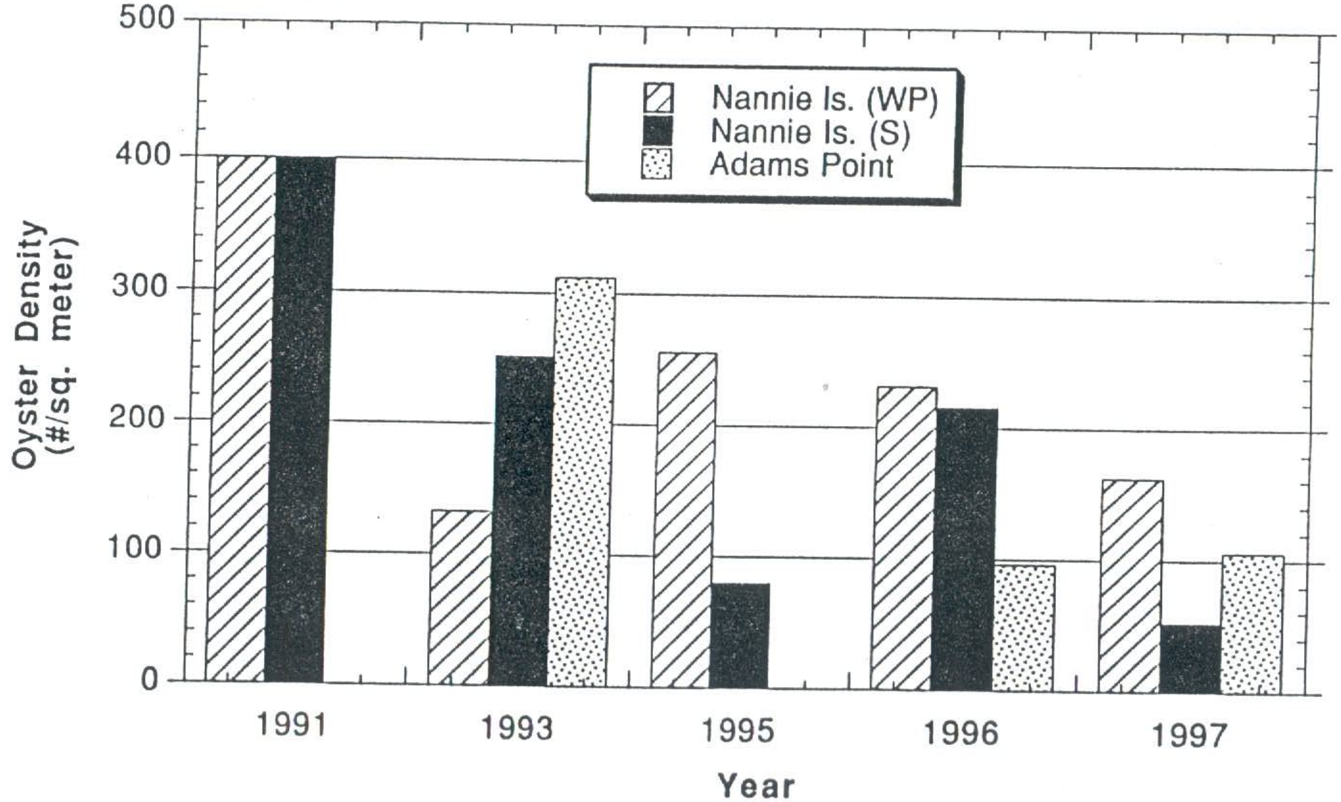
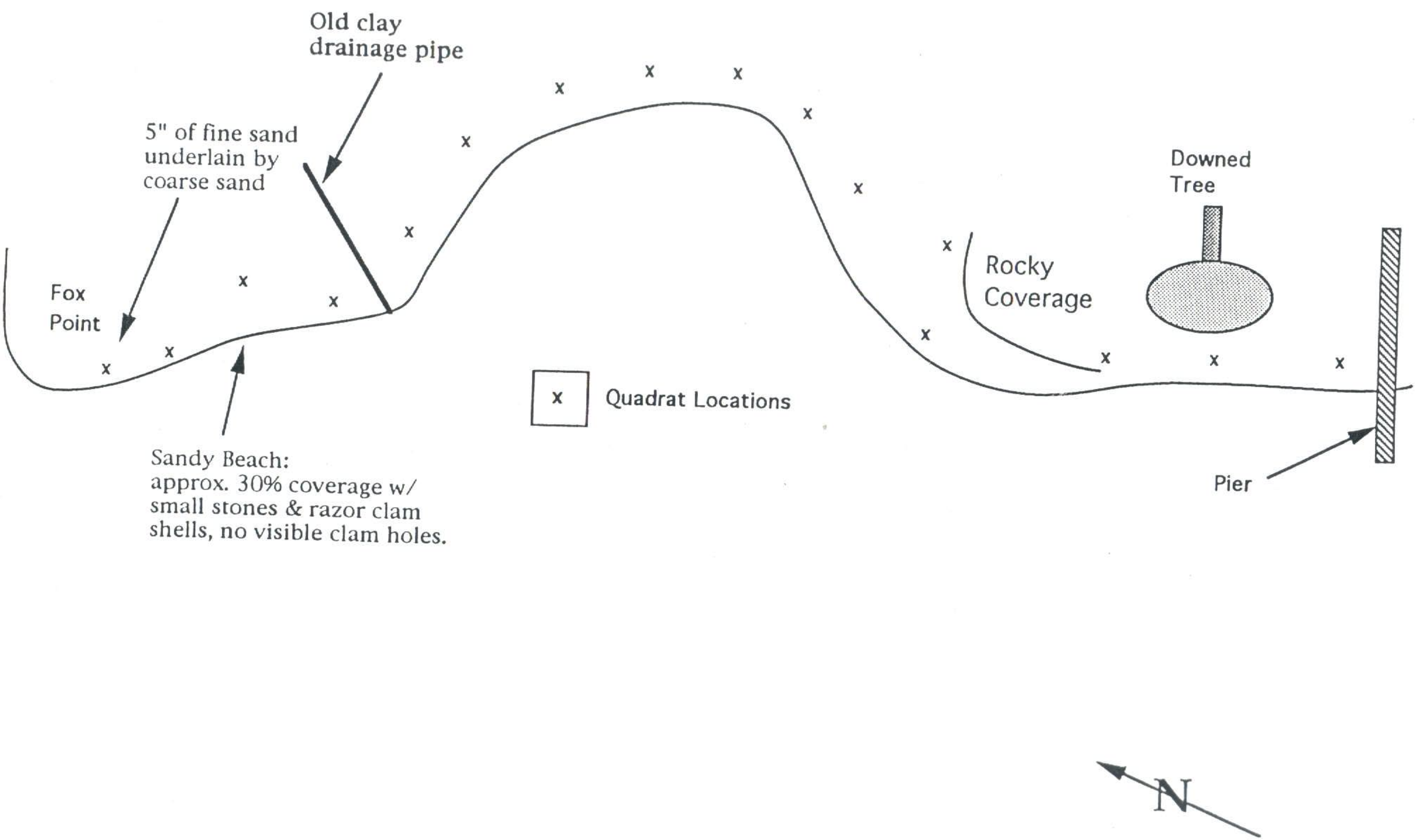


Figure 10. Location of clam survey area for the Fox Point shoreline.



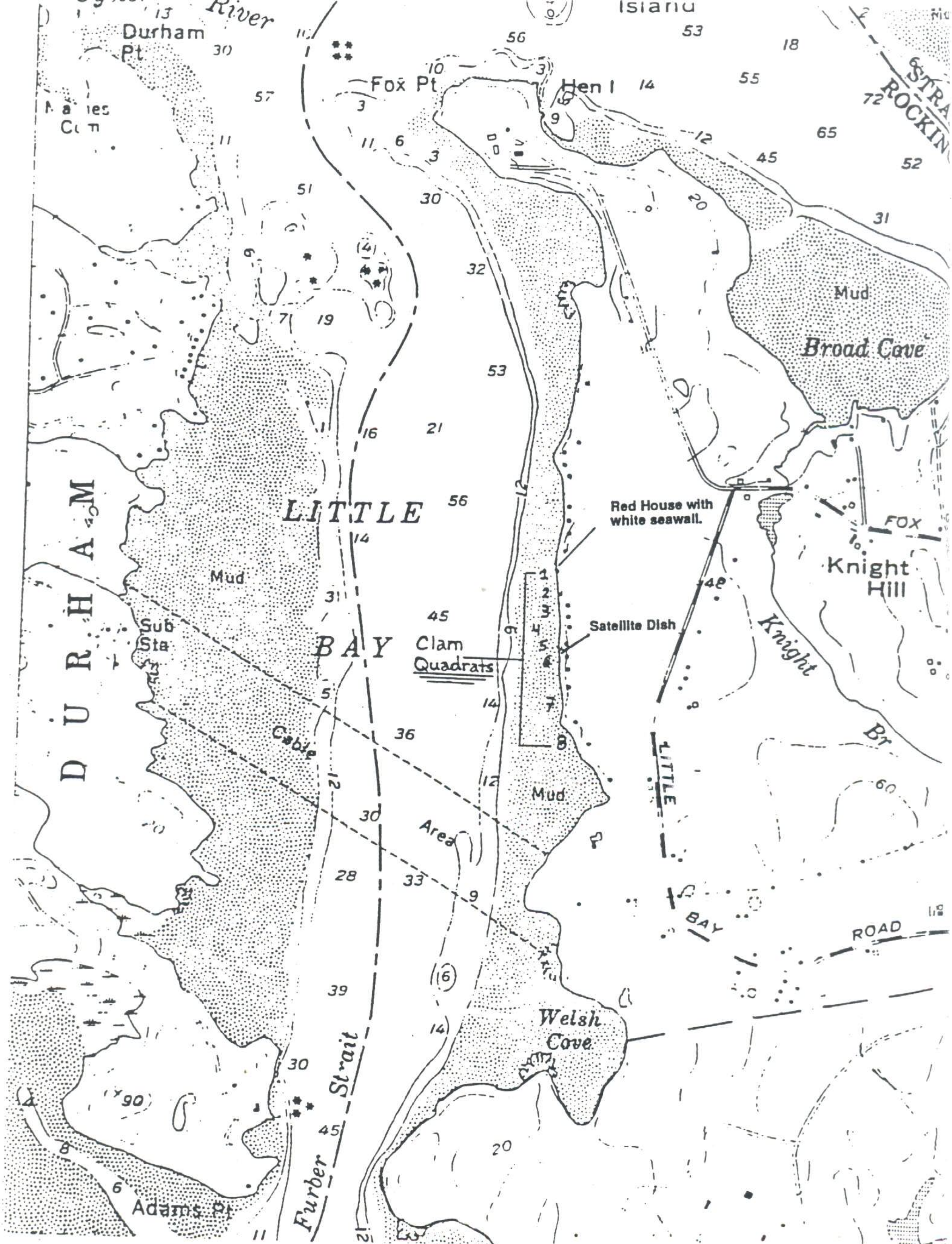


Figure 11. Location of clam survey area for the Little Bay (eastern) shoreline.

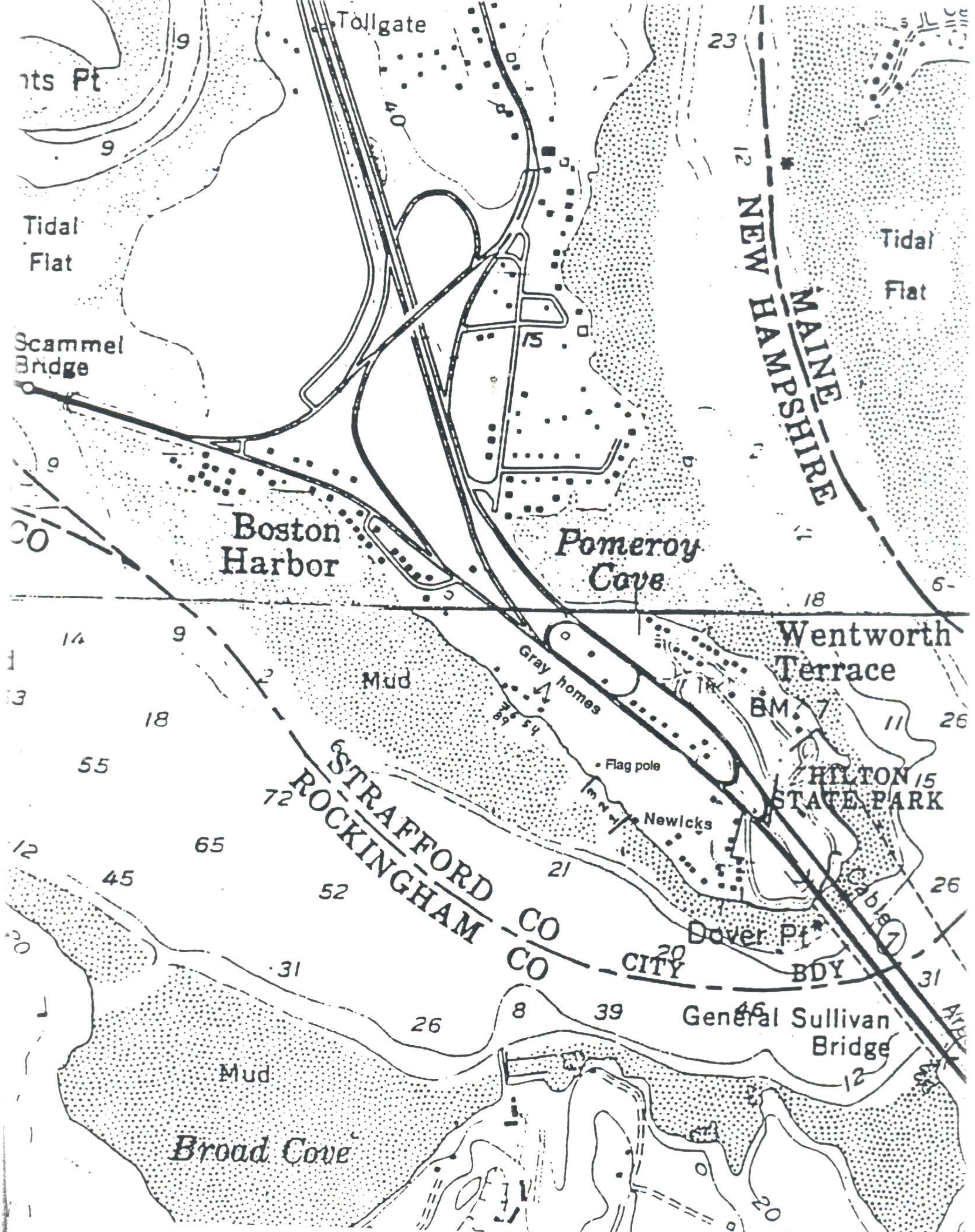


Figure 12. Location of clam

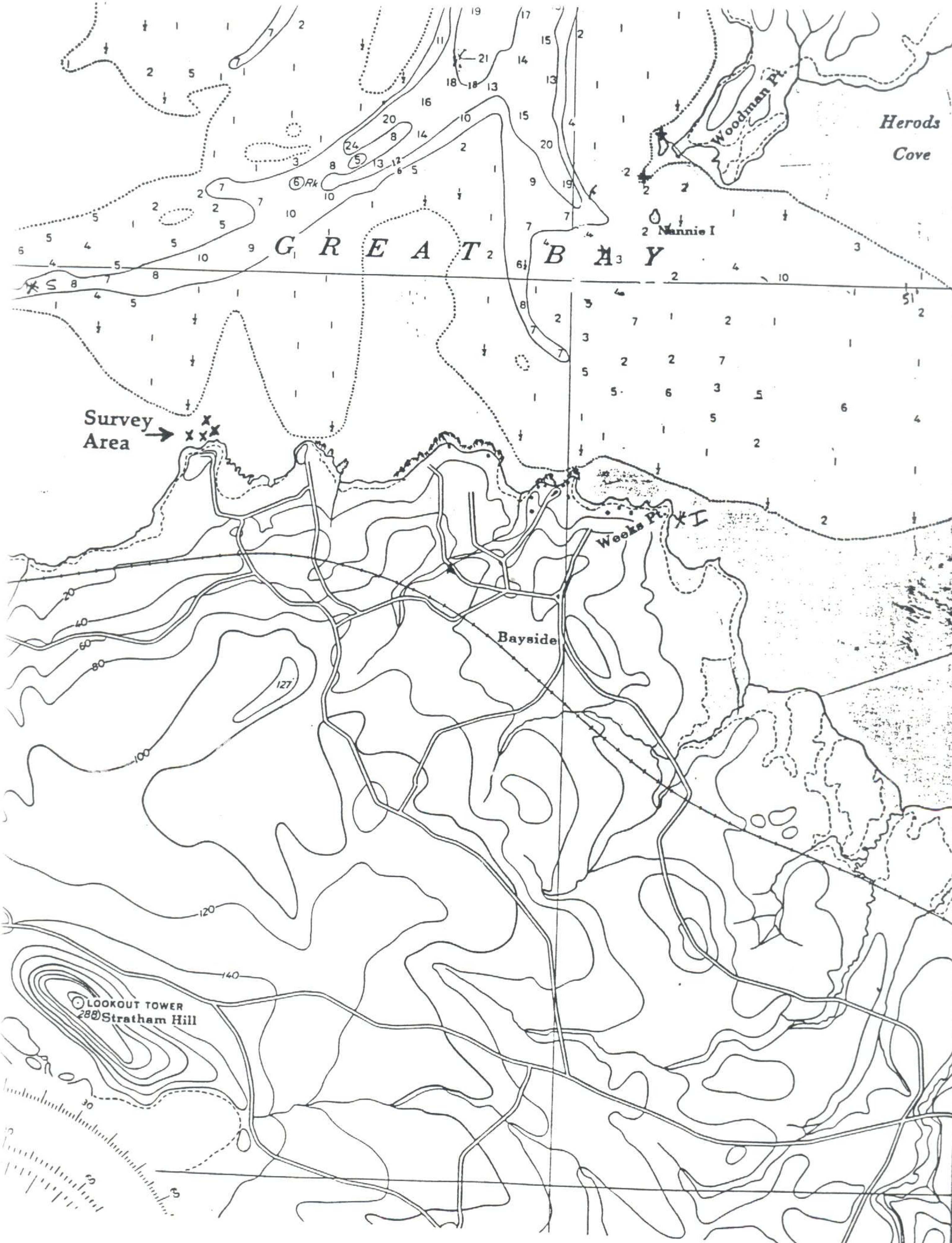
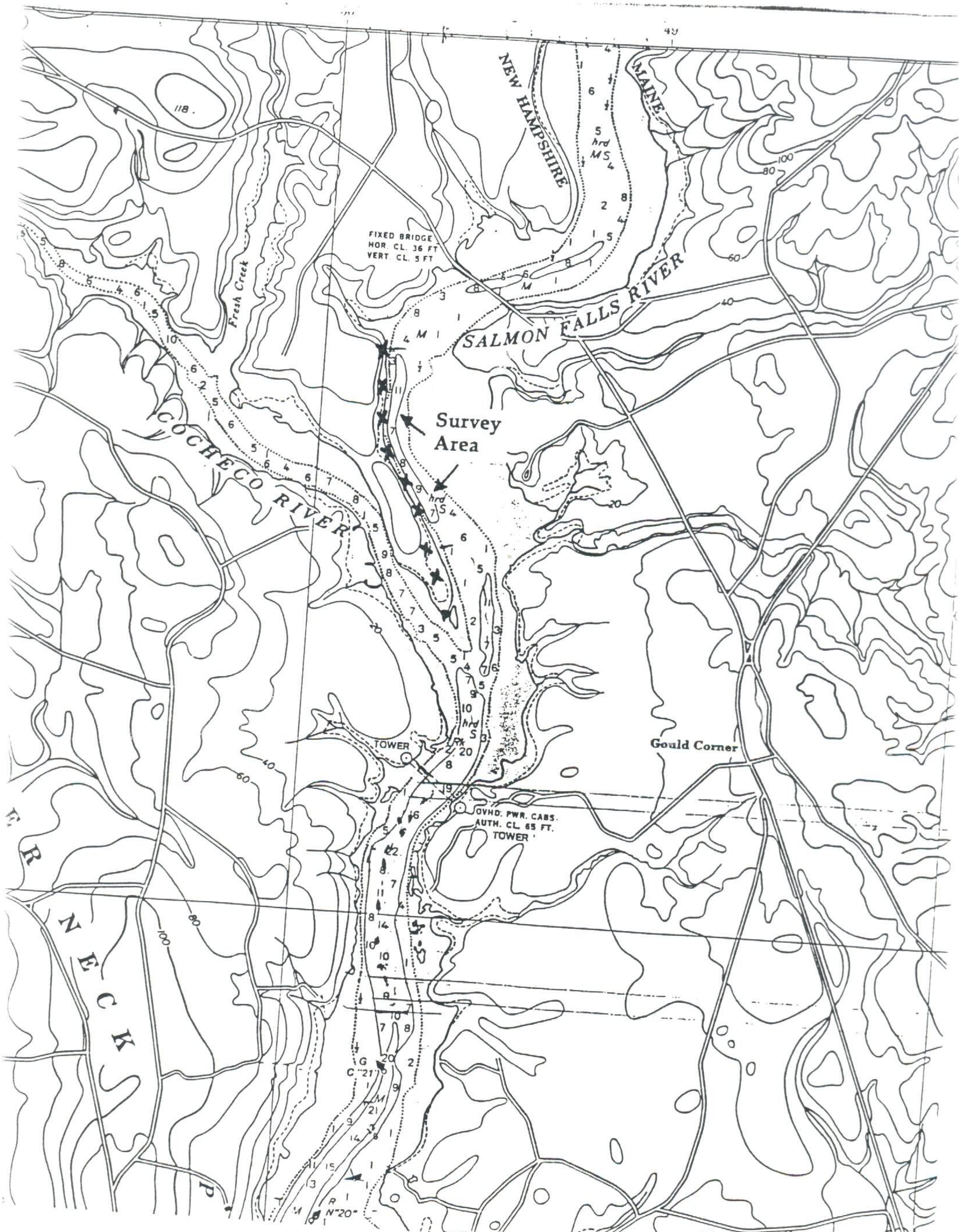


Figure 13. Location of the Sandy Point



NEW HAMPSHIRE
MAINE
FIXED BRIDGE
HOR. CL. 36 FT
VERT. CL. 5 FT
Fresh Creek
SALMON FALLS RIVER
COCHECO RIVER
Survey Area
TOWER
OVHD. PWR. CABS.
AUTH. CL. 65 FT.
TOWER
Gould Corner
NECK

Figure 15. Clam size-frequency distribution for the Fox Point shoreline transect, July 1997.

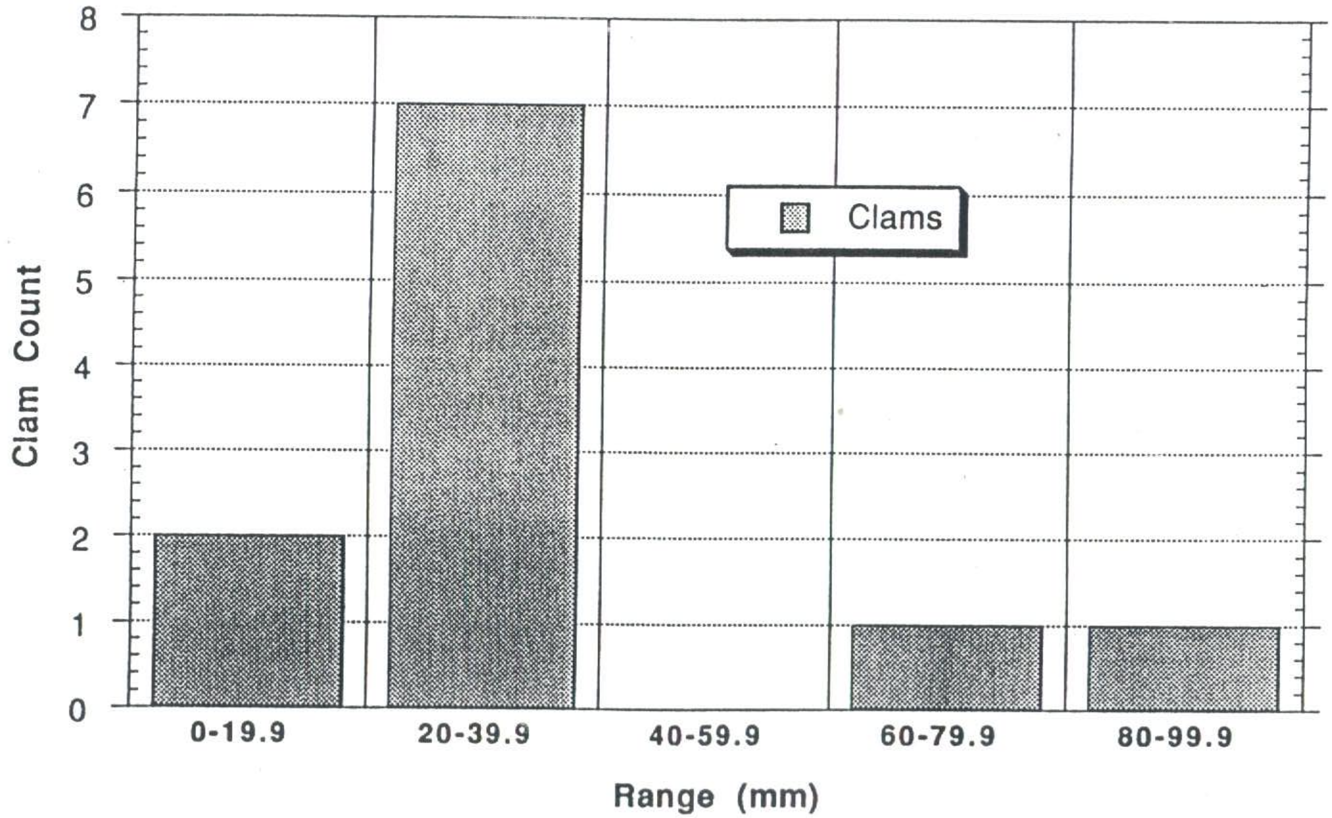


Figure 16. Clam size-frequency distribution for the Little Bay (eastern shore) transect, July 1997.

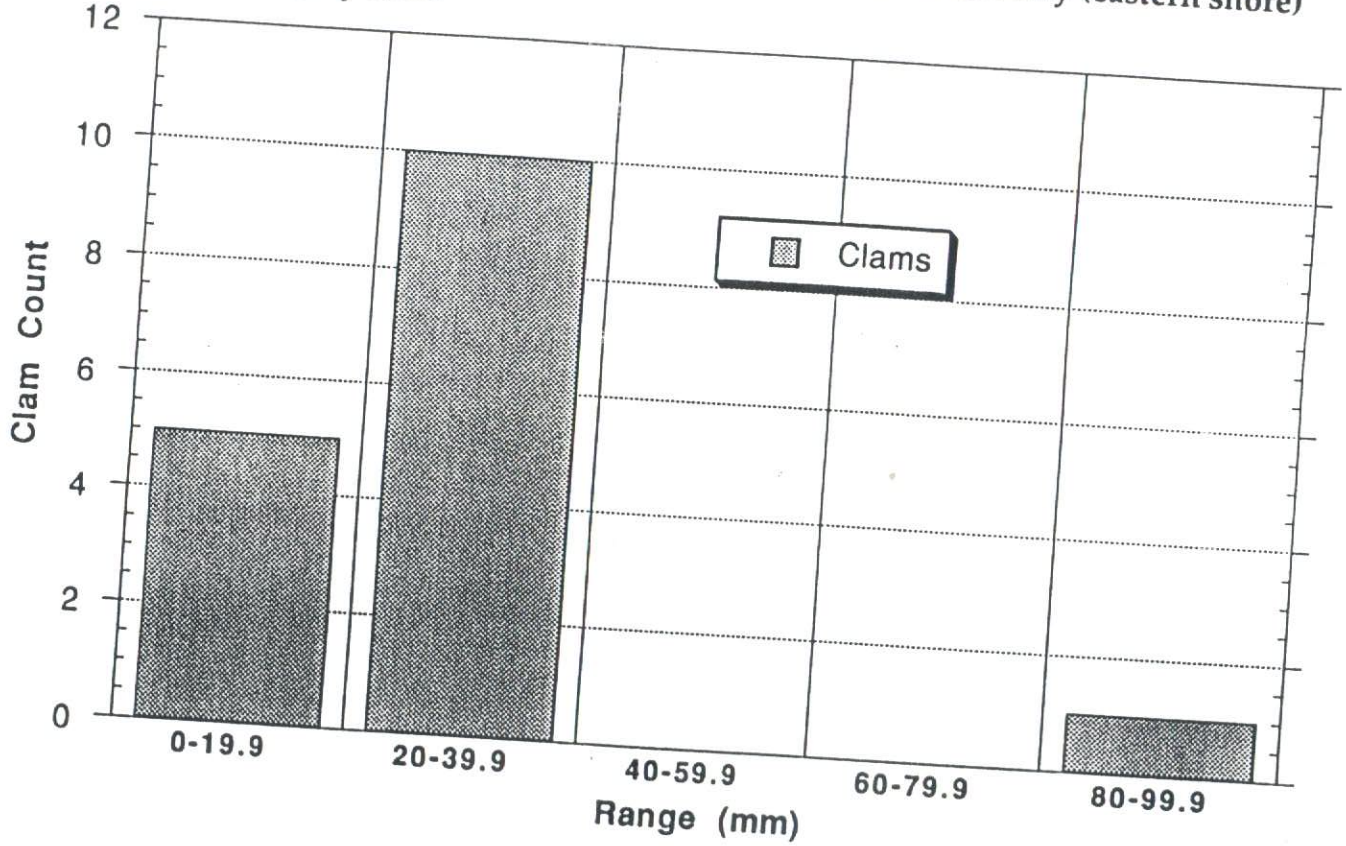


Figure 17. Clam size-frequency distribution for the Dover Point to Boston Harbor transect, August 1997.

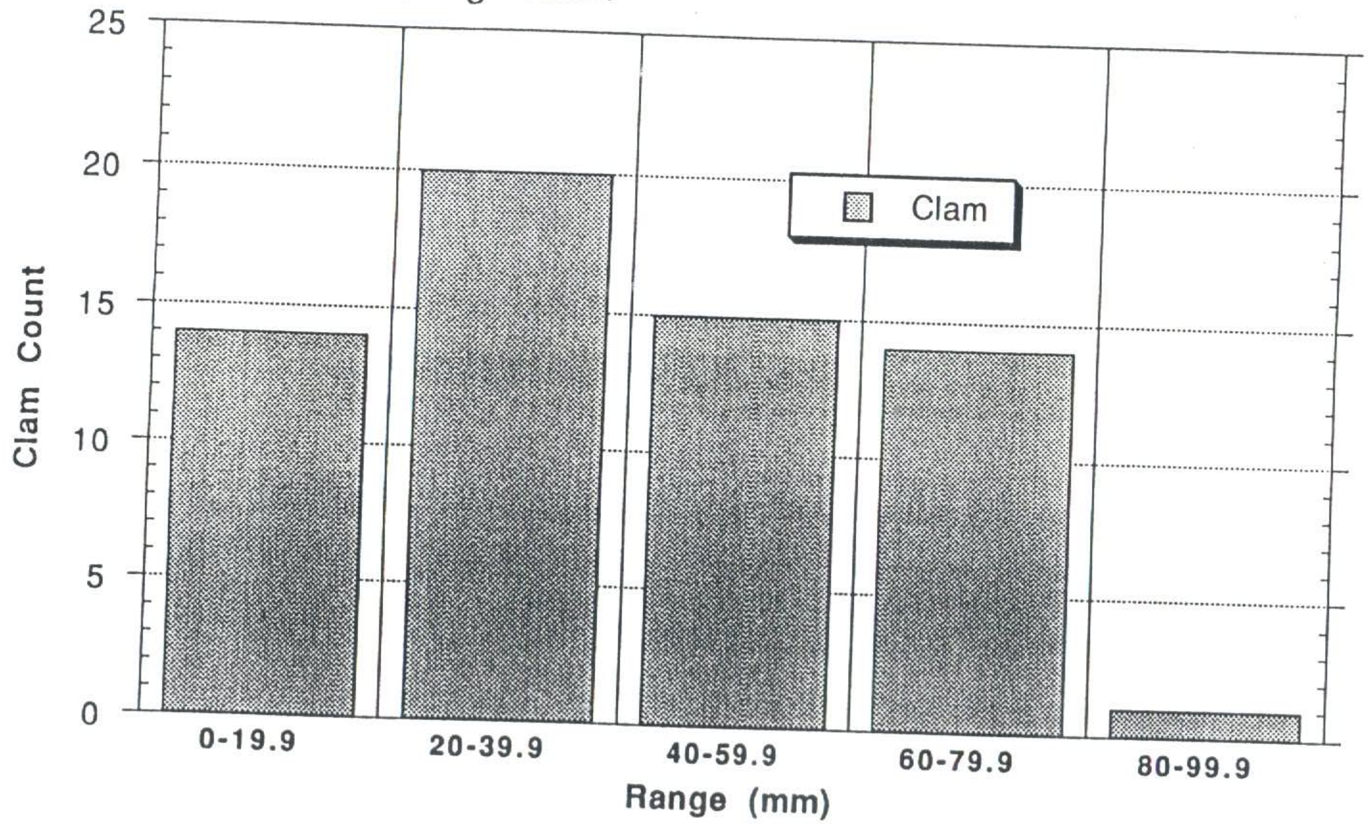


Figure 18. Clam size-frequency distribution for Sandy Point, July 1997.