INVENTORY OF NEW JERSEY'S ESTUARINE SHELLFISH RESOURCES: HARD CLAM STOCK ASSESSMENT

NAVESINK AND SHREWSBURY RIVERS (Survey Year 2015)

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Abstract

The New Jersey Marine Fisheries Administration - Bureau of Shellfisheries ("Bureau"), conducted a hard clam [*Mercenaria mercenaria* (Linnaeus 1758)] stock assessment in the Navesink and Shrewsbury Rivers in Monmouth County, New Jersey. One prior comprehensive survey was completed in 1983. The Bureau sampled 62 stations in the Navesink River and 53 stations in the Shrewsbury River using a hydraulic clam dredge and estimated each river's standing stock and relative distribution of hard clams. Work was conducted between September 18, 2015 and October 27, 2015. The survey resampled stations that were sampled during the inaugural survey, as well as five new stations (two stations in the Navesink River and three stations in the Shrewsbury River) to cover areas not previously sampled.

The standing stock of hard clams in the Navesink River for 2015 was estimated at 48.5 million clams. For the purposes of direct comparison, the estimated stock was also calculated using only those stations sampled during both surveys, which yielded an estimate of 48.8 million clams. The higher estimate without the two new stations was due to the extrapolation of a higher density station. The two new stations in 2015 reduced the average densities for those areas and subsequently was a more accurate estimate. The direct comparison of stock estimates demonstrated an approximately 19% increase in the standing stock of the Navesink River since 1983 (40.9 million clams).

The standing stock of hard clams in the Shrewsbury River for 2015 was estimated at 38.6 million clams. For the purposes of direct comparison, the 2015 stock estimate, using only the same stations sampled in 1983, resulted in an estimate of 33.2 million clams. That estimate represented an approximately 12% decrease in the standing stock when compared with the 1983 stock estimate of 37.6 million clams.

Statistical analysis indicated there was no significant change in the mean hard clam abundance at all stations with paired data for the Navesink and Shrewsbury Rivers when comparing stations sampled in 2015 to those same stations sampled in 1983. The observed increase or decrease in the population estimate over time was attributed to changes in the relative distribution of the population. The mean length of hard clams for the Navesink River collected in 2015 was 70.8mm and was a statistically significant increase in length from the mean length of 62.9mm in 1983. The mean length of clams in the Shrewsbury River in 2015 was 74.8mm and was a statistically significant increase from the mean length of 71.2mm in 1983. For the Navesink River, the recruitment index (the percentage of clams sized 30-37mm collected at each station compared with all clams >37mm collected at the same station) was significantly lower in 2015 than in 1983, but no significant difference in recruitment was found for the Shrewsbury River. Analysis showed no significant difference in mortality estimates for either river between 2015 and 1983.

Introduction

The Navesink and Shrewsbury rivers are located in northern Monmouth County, New Jersey (Figure 1). These rivers are the southern-most waterbodies included in the Hudson-Raritan Estuary and are directly connected to the Raritan/Sandy Hook Bay. The Hudson-Raritan Estuary spans the states of New York to the north and New Jersey to the south. The Hudson River and Arthur Kill feed into the estuary from the north, the Raritan River from the west, and the Navesink and Shrewsbury Rivers from the south. For a recent inventory of hard clams in the Raritan/Sandy Hook Bay complex, please see Dacanay (2016).

The first modern comprehensive survey of hard clams in these two rivers was conducted in 1983 by the Bureau as part of its Estuarine Shellfish Research and Inventory Program (McCloy and Joseph 1983). The primary purpose of that survey, as well as the one conducted in 2015, was to determine the standing stock, distribution, and relative abundance (density) of hard clams in the two rivers. The survey completed in 2015 was nearly identical to the surveys performed in 1983, except for the addition of five stations and use of a single tow at each station instead of duplicate tows. Quantitative and qualitative comparisons were made between the surveys where appropriate.

Materials and Methods

Sampling

All field work was conducted in the Navesink and Shrewsbury Rivers, Monmouth County, New Jersey (Figures 1 and 2). A total of 115 stations (Navesink: 62, Shrewsbury: 53) were quantitatively sampled between September 18, 2015 and October 27, 2015. All stations were sampled with a hydraulic clam dredge that was deployed from the research vessel *Zephyrus*, a 42-foot long, Chesapeake dead rise style vessel. The dredge was equipped with a 12" – wide "knife" that cut 4" in to the substrate. The body of the dredge was a stainless-steel cage with bars spaced to retain clams 30mm and larger. Although clams less than 30mm were occasionally obtained, clams less than 30mm were not included in any statistical analyses. Water was jetted through nozzles to either loosen the substrate ahead of the knife or to push sediment to the back of the dredge. The forward nozzles, located above the knife, were opened when towing through harder, sandy substrates to loosen the sediments. The rear nozzles, positioned towards the back of the dredge cage, were opened while towing through softer, muddy substrates, to help prevent the knife from becoming clogged with sediment and to expel sediment through the back of the cage. Occasionally, both sets of nozzles were opened when towing through "sticky" sediments, where the sand/mud substrate needed to be both loosened and expelled.

Water was supplied to the nozzles through a 3" hose attached to a hydraulically powered Berkeley irrigation water pump mounted on the rear deck of the vessel. At 35-40 pounds of pressure per square inch, the pump delivered approximately 300-500 gallons of water per minute. The dredge was deployed and retrieved using a 3/8" stainless steel wire cable attached to the main haul back winch on the vessel. Towing was accomplished using a 3/4" polypropylene graduated line from the dredge to the towing bit.

The 2015 survey closely followed the previously established protocols from the 1983 survey and other recent surveys conducted by the Bureau. McCloy and Joseph (1983) established a grid system that placed stations at approximately ¼ - mile intervals throughout the rivers, making allowances for coastline morphology as necessary. Stations sampled in 2015 were identical to those sampled in 1983 except where it was not feasible due to recent obstructions or changes in bathymetry, in which case the station was relocated as close to the original station as possible. Two additional stations were added to the Navesink River in 2015, and three were added to the Shrewsbury River. The additional stations helped to clarify information on the distribution of stock in areas previously designated as "No Data."

Stations were located using a Garmin GPS 4210 chart plotter. Water quality parameters (salinity, temperature, pH, and dissolved oxygen) were taken in the field at the first and last stations sampled each day using a YSI-Professional Plus multimeter.

Water depth was determined using the Garmin GPS 4210 chart plotter. The towline length was set at a length-to-depth ratio of 4:1, plus an additional 15' of length to account for the distance from the towing bit to the water line. Nozzle selection was determined by probing the substrate prior to towing. In instances where it appeared that the dredge was not fishing properly, nozzles were adjusted and the tow was repeated. At each station, qualitative substrate information was collected. One 100' tow was attempted at each station, although 100' was not always achievable at some stations due to submerged obstructions, high percentages of clay, or subsurface currents. Once the dredge was deployed from the vessel and the tow line became taught, vessel speed was adjusted using a trolling valve.

A graduated distance measuring line with a weight attached to the end was deployed perpendicularly to the vessel and released gradually as the vessel moved forward. Additional length was added to the distance line to account for water depths and the angle of the line to the bottom, to ensure 100' of towing distance at all depths. When the 100' mark was achieved, the dredge was hauled back while the vessel was kept as stationary as possible to avoid sampling additional area.

After the dredge was retrieved, the dredge cage was either washed by dragging it briefly at the surface to expel remaining sediment, or brought on board the vessel immediately if washing was not necessary. The contents of the dredge were deposited on the culling table and sorted. All live hard clams were counted and lengths were measured to the nearest millimeter. Empty, paired hard clam valves, referred to as boxes, were also enumerated and measured to the nearest millimeter.

Horseshoe crabs (*Limulus polyphemus*) and blue crabs (*Callinectes sapidus*) were sexed and measured to the nearest millimeter. Other associated species, including surf clams (*Spisula solidissima*), soft clams (*Mya arenaria*), and blue mussels (*Mytilus edulis*) were noted for presence. Observations of live submerged aquatic vegetation and macroalgae collected in the dredge (if any) were also noted.

Hard Clam Analysis

Only clams sized 30mm and greater were included in the statistical analyses. Although the dredge was not designed to retain clams smaller than 30mm, a fair number of small seed clams were found, and that information is provided in summary form only.

Abundance and Distribution

Hard clam abundance, expressed as number of clams per square foot, was calculated for the catch per tow at each station. All data were adjusted for the dredge's estimated overall mean efficiency of 88.0% (±7.7%) by increasing raw abundances by a factor of 1.137 (100 ÷ 88) (see Celestino 2003a)[1]. For the purpose of understanding relative abundance and distribution of *M. mercenaria*, the following categories were employed: none (0.00 clams/ft^2), occurrence (0.01 - <0.20 clams/ft^2), moderate abundance (0.20 - <0.50 clams/ft^2) and high abundance (≥0.50 clams/ft^2). Each station was assigned a category once the data had been adjusted for dredge efficiency. This category system was employed in previous studies by the Bureau. Figures were produced that illustrated the distribution of the different densities of hard clams throughout the rivers.

For the purpose of estimating the standing stock of hard clams, stations were categorized according to the same classification intervals established in prior surveys: (0.00 clams/ft^2), (0.01 - <0.06 clams/ft^2), (0.06 - <0.12 clams/ft^2), (0.12 - <0.50 clams/ft^2), (0.50 - <1.0 clams/ft^2), (1.0 - <2.0 clams/ft^2) and (≥2.0 clams/ft^2). Adjacent stations of the same density category were grouped together in polygons using ESRI ArcMap v10.3.1. The mean density of clams was calculated for each polygon and multiplied by the area of the polygon to get an estimate of the standing stock for that area. All areas were summed for a total stock estimate in each river.

A standing stock estimate was also calculated excluding stations new to the 2015 survey, allowing for a direct comparison with the stock estimate of 1983.

A t-Test for paired means where $\alpha=0.05$ was conducted on hard clam density data for stations that were sampled in both surveys. The null hypothesis was that there was no difference in densities of clams between the two surveys. In the Navesink River, 58 pairs of stations were analyzed, and 49 pairs of stations were analyzed for the Shrewsbury River.

Population Age/Size Structure

All clams collected that were 30mm and larger were measured for length and graded in to the following commercial size classifications: sublegals (30-37mm), littlenecks (38-55mm) cherrystones (56-76mm) and chowders (>76mm). A composite (sum of all clams measured) length-percent-frequency distribution graph and length-frequency graph were produced, where lengths were combined into three-millimeter groupings (starting at, but not including clams

[1] This study was performed with a different vessel, the *R/V Jennings* (née *Notata*). The same dredge was used in this study and all subsequent sampling events. The Bureau plans to perform an efficiency study with the new vessel as soon as possible. The outcome of the study may require a slight revision of this data.

obtained at 29mm). This three-millimeter bin system was employed in previous estuarine inventories. Length-percent-frequency plots were produced for each river.

A paired t-Test where $\alpha=0.05$ was used to analyze mean clam lengths between 1983 and 2015, where paired data were available (n=57 stations where ≥1 clam was collected in both survey years for Navesink River; n=48 stations for Shrewsbury River). The null hypothesis was there was no change in mean clam lengths between the two surveys.

Recruitment

The percentage of sublegal clams collected at each station was calculated as a measure of recruitment at each station. Sublegal clams (30-37mm) collected represented a single year class and thus were expected to recruit into the fishery at the legal length of 38mm the following year. The recruitment index per station was calculated as

$$\left\{\frac{\text{no. of clams collected between 30 and 37mm at station } i}{\text{total no. of clams collected at station } i}\right\} \text{ x } 100\%$$

If no live clams were collected, recruitment = NA as 0÷0 is undefined. The result from each station was binned and plotted, except those stations where recruitment was undefined.

A paired t-Test for means statistical analysis was performed for paired stations where abundances were ≥0.20 clams/ft^2 in both survey years (n=32 pairs of stations for Navesink River; n=17 pairs for Shrewsbury River). The null hypothesis was that there was no change in recruitment between the two survey years, where $\alpha=0.05$.

Mortality

Natural mortality was calculated for each station using the number of boxes relative to the station's entire sample of boxes and live hard clams.

$$\left\{\frac{\text{no. of boxes at station } i}{\text{no. of boxes at station } i + \text{no. of live clams at station } i}\right\} \text{ x } 100\%$$

The calculation was independent of age, size, or gender of *Mercenaria mercenaria*. If no live clams or boxes were collected, mortality = NA as 0÷(0+0) is undefined. The result from each station was binned and plotted, except those stations where recruitment was undefined.

A paired t-Test for means (n=57 pairs of stations for Navesink River; n=49 pairs for Shrewsbury River) where $\alpha=0.05$ was used to compare mortality indices between the two survey years. The null hypothesis was that there was no difference in mortality percentages between the two surveys.

Submerged Aquatic Vegetation (SAV)

Vascular vegetation was collected in the dredge at one station in the Navesink River, and three stations in the Shrewsbury River. Vegetation was collected in the 1983 survey, but due to small sample sizes, no statistical analysis was performed. A summary of the SAV data collected in both years is provided. Macroalgae was observed and recorded, but the data are not provided in this report.

Results

Description of the Study Site

Sediment type in both rivers ranged from hard sand to soft mud, and included cobble, gravel, and shell (Table 5). Tables 1a (Navesink River) and 1b (Shrewsbury River) below summarize the water quality characteristics of each river, respectively.

Table 1a. Water quality measurements for Navesink River, 2015.

			Surface				Bottom			
Station	Date	Raw Depth ft	Temp °C	DO mg/L	Sal ppt	pH	Temp °C	DO mg/L	Sal ppt	pH
NR-15-007	9/18/2015	8	24.4	7.59	28.39	7.44	23.7	5.59	28.87	7.21
NR-15-052	9/18/2015	8	23.1	5.48	26.89	7.05	22.9	4.86	27.58	6.98
NR-15-005	9/28/2015	10	19.5	5.6	29.5	7.5	19.4	5.73	29.59	7.5
NR-15-022	9/28/2015	12	20.5	9.0	29.09	7.41	19.8	8.39	29.37	7.28
NR-15-025	9/29/2015	12	20.3	0.1*	29.83	7.41	20.3	0.01*	29.85	7.38
NR-15-054	10/14/2015	5	17.5	7.49	27.51	7.37	17.5	7.6	27.5	7.28

* Anomalous readings were attributed to a faulty DO probe which was subsequently replaced.

Table 1b. Water quality measurements for Shrewsbury River, 2015.

			Surface				Bottom			
Station	Date	Raw Depth ft	Temp °C	DO mg/L	Sal ppt	pH	Temp °C	DO mg/L	Sal ppt	pH
SR-15-040	10/14/2015	6	18.16	8.23	24.85	7.3	17.9	8.16	26.07	7.2
SR-15-008	10/20/2015	12	11.2	12.97	26.53	7.58	11.2	13.04	26.62	7.52
SR-15-060	10/20/2015	13	10.9	17.2	27.01	7.64	10.9	17.01	27.04	7.5
SR-15-012	10/26/2015	7	12.8	11.71	29.38	7.67	12.8	11.59	29.38	7.62
SR-15-027	10/26/2015	12	13	13.03	29.23	7.64	12.9	13.29	29.27	7.58
SR-15-021	10/27/2015	12	12.7	ND	28.4	7.76	12.7	ND	28.46	7.71
SR-15-044**	10/27/2015	4					12.6	11.63	29.18	7.58

**measurements taken at mid-column due to shallow depths

Hard Clam Abundance and Distribution

The total hard clam resource in the Navesink River and the Shrewsbury River was estimated at 48.5 and 38.6 million clams, respectively (Table 2). When the dredge efficiency factor was not applied to the raw data (to produce a conservative estimate), the stock was estimated at 42.6 million clams for the Navesink River and 33.9 million clams for the Shrewsbury River. Additionally, the stock for each river was calculated using only those stations also sampled in the 1983 survey (to allow for a direct comparison of the data). When calculating the stock using only the same stations that were sampled in 1983, the estimate for the Navesink River was 48.8 million clams, and 33.2 million clams for the Shrewsbury River.

An estimate of the stock based upon commercial size classes is presented in Table 3 and Figure 3.

There was no statistical significant difference in the mean abundance of clams (clams/foot^2) in either the Navesink River or the Shrewsbury River when comparing data from the two survey years of 1983 and 2015. Details of the analysis are provided in Table 4.

A data summary for each station is provided in Table 5.

Figure 4 illustrates the relative abundance and distribution of hard clams sized 30mm and larger for 2015. Figure 5 is a copy of the relative abundance and distribution chart from the 1983 report.

Figure 6 depicts the stations where clams less than 30mm were collected. The dredge was not designed to retain clams less than 30mm, so a failure to collect these small clams should not be interpreted as an absence of smaller clams.

Table 2. Summary of hard clam stock estimates for Navesink and Shrewsbury Rivers.

	Clams	
Survey Year	**Navesink**	**Shrewsbury**
1983	40,931,932	37,634,638
2015	48,455,528	38,594,544
2015 (orig. stations only)	48,818,094 (+19%)	33,202,063 (-12%)

Table 3. Stock estimate based upon commercial size classes.

	Sublegals	**Littlenecks**	**Cherrystones**	**Chowders**
Navesink	2,474,659	7,913,035	21,013,272	17,054,562
Shrewsbury	788,405	3,542,909	13,585,449	20,677,780

Table 4. Summary of abundance analysis

Navesink	**Abund15**	**Abund83**
Mean	0.471	0.526
Variance	0.215	0.500
Observations	59	59
Pearson Corr.	0.227	
Hypothesized Mean Difference	0	
df	58	
t Stat	-0.464	
t Critical two-tail	2.002	
P(T<=t) two-tail	0.645	

Shrewsbury	**Abund15**	**Abund83**
Mean	0.349	0.440
Variance	0.126	0.253
Observations	49	49
Pearson Corr.	0.175	
Hypothesized Mean Difference	0	
df	48	
t Stat	-1.128	
t Critical two-tail	2.011	
P(T<=t) two-tail	0.265	

Population Age/Size Structure

A composite (sum of all clams measured) percent-length-frequency and length-frequency distribution graph were produced for each river (Figures 7 and 8), where lengths were combined into three-millimeter groupings (starting at, but not including clams obtained at 29mm). A summary of the total number of clams collected and measured in each survey year, along with mean lengths, standard deviation, and other measures of central tendency are presented in Table 6. A t-Test for means of paired samples indicated significantly greater mean lengths of clams for both rivers in 2015 when compared with the 1983 data (Table 7).

Table 6. Summary statistics for hard clam lengths[2].

Navesink	**2015**	**1983**
n	2798	4736
Mean	68.8760	61.0251
SD	16.240	17.491
Median	71	62
Mode	71	72

Shrewsbury	**2015**	**1983**
n	1589	3418
Mean	74.6010	71.2712
SD	16.336	16.384
Median	78	74
Mode	84	72

[2] In the 1983 surveys, two dredge tows were taken, increasing the total number of clams measured. In the 2015 survey, as with all surveys beginning in 2000, only one dredge tow was performed.

Table 7. Summary of hard clam lengths analysis[3].

Navesink	**2015**	**1983**
Mean	70.845	62.938
Variance	48.315	82.433
Observations	57	57
Pearson Correlation	0.334	
Hypothesized Mean Difference	0	
df	56	
t Stat	6.344	
t Critical two-tail	2.003	
P(T<=t) two-tail	4.17E-08	

Shrewsbury	**2015**	**1983**
Mean	74.821	71.238
Variance	47.082	70.078
Observations	48	48
Pearson Correlation	0.0133	
Hypothesized Mean Difference	0	
df	47	
t Stat	2.309	
t Critical two-tail	0.025	
P(T<=t) two-tail	0.025	

[3] Minor differences between the means in Tables 7 and 8 is a result of eliminating unpaired stations to perform statistical analysis.

Recruitment

A paired sample t-Test was conducted for stations with abundances of ≥ 0.20 clams/ft^2. Table 8 summarizes the analysis. Statistical comparison in the Navesink River indicated a significant decrease in the average percentage of recruitment in 2015 from 1983. Further, the proportion of stations where sublegal clams were found decreased to 63% of the sampled stations in 2015, compared with 79% of stations sampled in 1983.

For the Shrewsbury River, there was no significant difference in recruitment between 2015 and 1983. However, sublegal clams were found at only 42% of stations sampled in 2015, whereas in 1983 sublegals were found at 52% of the stations sampled. Figure 9 provides the percentage of recruitment (the percentage of sublegal clams found) at each station throughout the rivers. Data from 1983 (Figure 10) are also provided for comparison purposes.

Table 8. Summary of recruitment analyses.

Navesink	**2015**	**1983**
Mean	0.048	0.123
Variance	0.002	0.009
Observations	32	32
Pearson Correlation	-.084	
Hypothesized Mean Difference	0	
df	31	
t Stat	3.903	
t Critical two-tail	2.040	
P(T<=t) two-tail	0.00047	

Shrewsbury	**2015**	**1983**
Mean	0.022	0.050
Variance	0.001	0.002
Observations	17	17
Pearson Correlation	-0.174	
Hypothesized Mean Difference	0	
df	16	
t Stat	-1.915	
t Critical two-tail	2.120	
P(T<=t) two-tail	0.074	

Mortality

Statistical analysis using a paired t-Test for means showed no significant difference in mortality in the Navesink River between 2015 and 1983. The proportion of stations exhibiting mortality in 2015 decreased by 8% from 1983, but in both years natural mortality was observed at nearly every station sampled (90% of stations in 2015; 98% of stations in 1983). In the Shrewsbury River, mortality was not significantly different between 2015 and 1983, but the proportion of stations exhibiting mortality slightly decreased in 2015 to 91% of stations sampled from 94% in 1983. Table 9 summarizes the mortality analysis. Figure 11 plots the binned mortality percentages throughout the rivers in 2015. For comparison purposes, Figure 12 depicts the mortality percentages in 1983.

Table 9. Summary of mortality analysis.

Navesink	**2015**	**1983**
Mean	0.142	0.195
Variance	0.020	0.035
Observations	57	57
Pearson Correlation	0.258	
Hypothesized Mean Difference	0	
df	56	
t Stat	1.946	
t Critical two-tail		
P(T<=t) two-tail	0.057	

Shrewsbury	**2015**	**1983**
Mean	0.228	0.247
Variance	0.024	0.039
Observations	49	49
Pearson Correlation	0.048	
Hypothesized Mean Difference	0	
df	48	
t Stat	-0.539	
t Critical two-tail		
P(T<=t) two-tail	0.593	

Associated Species

At each sampling location, the presence of associated species of interest was noted, but not enumerated, except for blue crabs (*Callinectes sapidus*) and horseshoe crabs (*Limulus polyphemus*), where length and sex were recorded. The data are not presented in this report but are available upon request.

Figure 13 illustrates the relative distribution of other recreationally and commercially valuable shellfish species documented in 2015. These species include Atlantic surf clams (*Spisula solidissima*), Eastern oysters (*Crassostrea virginica*), and soft clams (*Mya arenaria*). A copy of the 1983 associated species chart is provided as Figure 14. The distribution chart for soft clams in 1983 included information supplemental to the dredge survey, including personal communication with local clammers and the authors' experience in those rivers (McCloy and Joseph 1983).

Submerged Aquatic Vegetation (SAV)

Figure 15 depicts the stations where vascular vegetation was retained in the dredge for years 2015 and 1983. Only the species *Ruppia maritima* (wigeon grass) was collected in 2015. The 1983 report documented only *Zostera marina* (eelgrass) in the Shrewsbury River (no SAV was collected at the Navesink River stations in 1983). Since the 1983 report did not include a chart of the SAV data, the data were incorporated into the 2015 chart.

Discussion and Conclusions

The standing stock of hard clams for the Navesink and Shrewsbury Rivers was estimated at a combined total of approximately 87.1 million clams. The estimate for the Navesink River was 19% higher than the inaugural survey in 1983, while the estimate for the Shrewsbury River was 12% lower than in 1983. Statistical analyses comparing the means of abundance in each river over time showed no significant difference between the two years (for either river), which was unexpected given the population fluctuations. The reason for this appearance of discrepancy was likely due to the changes in the population's physical distribution, where fragmentation of the population affected estimates as well as more or less total area occupied by a given density range.

In both rivers, relative abundance increased or decreased in many places, representing an expansion or contraction of the population within suitable habitat. Except in areas not sampled (identified as ND = No Data on the charts), at least one hard clam was collected in all but three stations (two in the Navesink River, where Eastern oysters were collected instead, and one in the Shrewsbury River, known as Blackberry Bay). Thus, while relative densities changed throughout the rivers, most of the river bottom supported the species.

While this report does not provide an exhaustive evaluation of all changes in relative density, some changes are notable. In the upper Navesink River, a large area of moderate density reduced significantly, resulting in a small isolated patch within a low density area. However, upriver of this patch was the westward expansion of a moderate and high density area beginning at Lewis

Point. At the mouth of the river, the area of low density in 1983 was replaced with moderate and high density areas in 2015. Clay Pit Creek and McClees Creek remained low density areas.

In the Shrewsbury River, the overall trend was a decrease of moderate and high density areas, where higher density beds diminished in the shoreline areas and concentrated in the center of the river and the river mouth. The river mouth and moving south along the back side of Sea Bright experienced an expansion of high density areas into ones previously designated as low or moderate density. Conversely, upper Branchport Creek and the upper main stem of the river (the mouths of Parkers Creek and Oceanport Creek) downgraded from a moderate density area to a low density area.

In the 1983 survey, a few areas in both rivers were described as "no data" on the charts. In most areas, this was due to inaccessibility by the research vessel under small, fixed bridges. The same areas were designated as "no data" on the 2015 charts for that reason. However, it is important to understand that "no data" does not necessarily mean shellfish were absent. The Bureau has some older data on shellfish populations in some of the no data areas, demonstrating the species presence and relative abundance. The data are not included in this analysis but the Bureau plans to summarize that information in the future.

Some areas that were not sampled in 1983 were sampled in 2015, including the upper end of Clay Pit Creek in the Navesink River and Blackberry Bay, Little Silver Creek, and Town Neck Creek in the Shrewsbury River.

When comparing other commercially and recreationally valuable bivalve species between the two surveys, it is notable that in 2015, as in 1983, Eastern oysters were collected in a small pocket along the northern bank of the Navesink River just east of the Route 35 bridge connecting Red Bank and Middletown Township. In contrast, soft clams were only collected at one small area in the Shrewsbury River in 2015, being far more abundant and widely distributed in 1983. This trend was also observed in the Raritan/Sandy Hook Bay survey (Dacanay 2016) where soft clams were found in one area compared to a near bay-wide distribution in 1983. Although the cause of the population decline was not investigated as part of this survey, it's speculated that the decline was a product of multiple influences including predation, loss of suitable habitat, and possible changes in the physio-chemical parameters of these waters. Finally, while not documented in 1983, surf clams (*Spisula solidissima*) were collected in the mouths of both rivers, likely a function of larval transport from Raritan/Sandy Hook Bay. The surf clams collected were very small "seed" clams, and due to a preference for colder, deeper waters, it is unlikely the surf clams would survive beyond juvenile life stages.

Hard clam lengths were analyzed and compared in each river across the two survey years. In both rivers, the 2015 population had an average length that was greater than the average length of clams in 1983. These results were also statistically significant. In the Navesink River, the average length of a clam increased by nearly 8mm, while in the Shrewsbury River this increase was approximately 4mm.

The population in the Navesink River was dominated by cherrystone sized clams in both 1983 and 2015, comprising just over 40% of the population in each survey year (Figure 7). Likewise, the

2015 population did not have strong year classes for either sublegal or littleneck clams, a contrast to the 1983 population where the year classes were much more evenly distributed. The low percentage of sublegal clams is indicative of weak recruitment. Recruitment in 2015 was significantly lower than in 1983, and Figures 9 and 10 reflect both the change in percent recruitment at each station over time and the general distribution pattern of sublegal sized clams. Overall, fewer stations contained sublegal clams in 2015 than in 1983, and those stations with sublegal clams in 2015 had fewer sublegal clams than in 1983.

In the Shrewsbury River, the population in 2015 was dominated by chowder clams, in contrast to 1983 where the population was dominated equally by cherrystone and chowder clams (Figure 8). In both survey years, recruitment was low. As with the Navesink River, fewer stations contained sublegal clams in 2015 than in 1983, and those stations at which sublegal clams were found in both years, the 2015 samples showed fewer sublegal clams. The distribution also shifted in 2015, where stations with sublegal clams were concentrated in the central part of the river, having been more dominant in Branchport Creek and along the northeastern side (behind Sea Bright) in 1983. For both rivers, caution should be used in interpreting the recruitment estimates, since the data are reported as percentage of the total catch, not absolute numbers.

For both rivers, there was no statistical difference in mortality between 2015 and 1983. In the Navesink River, box clams were found at 90% of the stations in 2015, and 98% of the stations in 1983. In the Shrewsbury River, box clams were found at 91% of stations in 2015 and 94% of stations in 1983. The majority of box clams in both rivers were cherrystone or chowder sized, and most boxes did not show obvious predation damage (drill holes, chips, etc.).

In 2015, submerged aquatic vegetation (SAV) was collected in the dredge in both the Navesink and Shrewsbury rivers (Figure 15). The species collected in both rivers was widgeon grass, *Ruppia maritima*. In the Navesink River, widgeon grass was collected in the dredge at a station northwest of the Rumson municipal boat ramp. In the Shrewsbury River, it was collected at stations in the general northeastern area/mouth of the river, near two existing bay islands and at one station off the shoreline of Raccoon Island in Monmouth Beach. In contrast, in 1983, SAV was collected only in the Shrewsbury River, and the species was eelgrass, *Zostera marina.* The stations where it was collected in 1983 are in the same general vicinity as where widgeon grass was collected in 2015, although there were no stations where SAV was collected during both surveys.

Acknowledgements

Sincere appreciation is extended to Jeff Normant for vessel operation, instruction and guidance in completing the survey work and analysis. Special thanks are extended to the vessel operator, Bill Maxwell, and to Garrison Grant, Julie McCarthy, Chuck Karr, Stephanie Pazzaglia, Scott Stueber and Nick Lombardi, for field, office, and laboratory assistance. Sincerest appreciation is extended to the Cove Sail Marina and New Jersey State Police in Sea Bright, NJ, for dockage access. This report benefited from the review and comments of Jeff Normant and Jeff Brust.

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Figure 1. Location of the Navesink River and Shrewsbury River, Monmouth County, New Jersey.

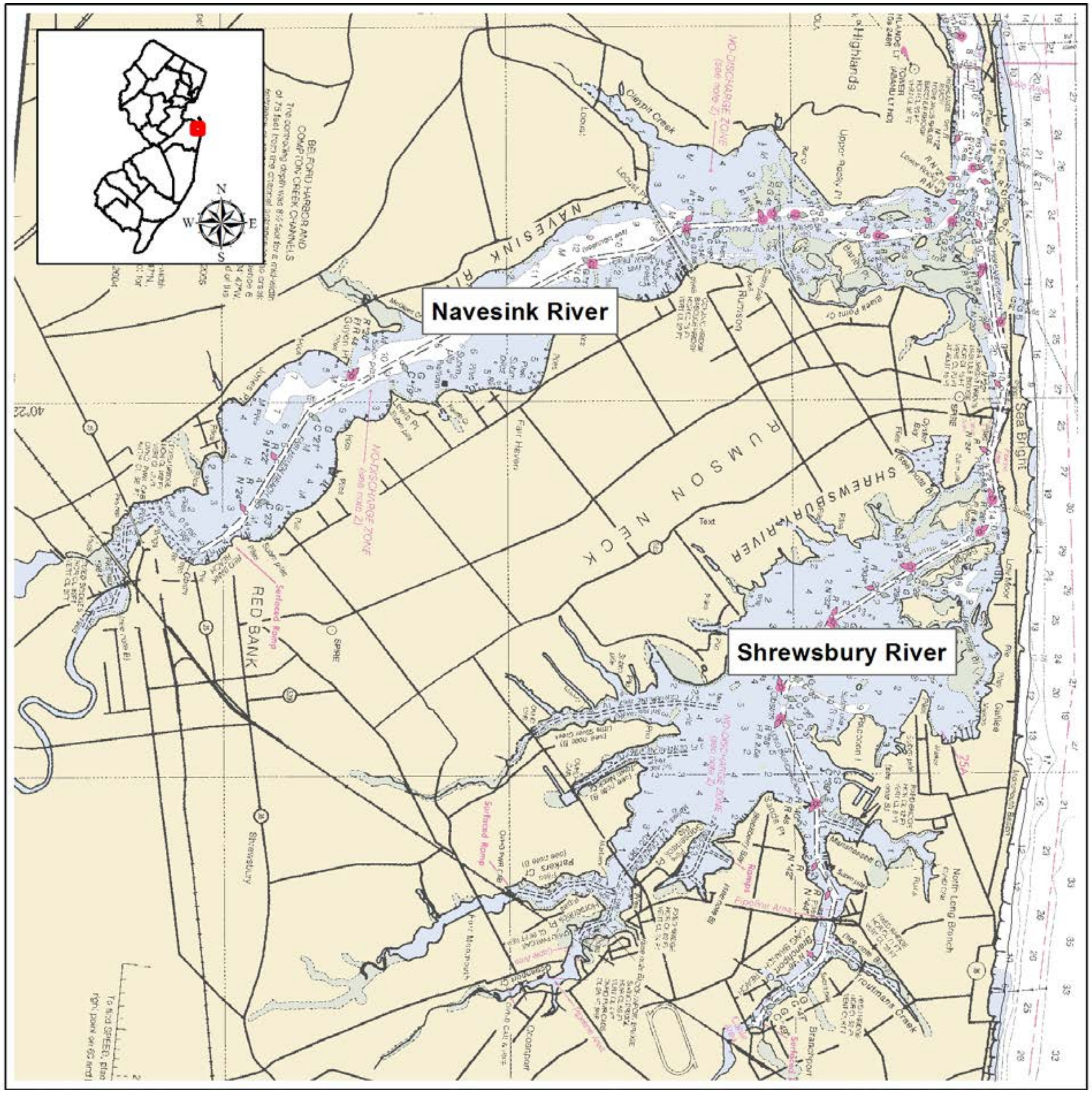


Figure 2. Navesink and Shrewsbury Rivers estuarine inventory sampling locations.

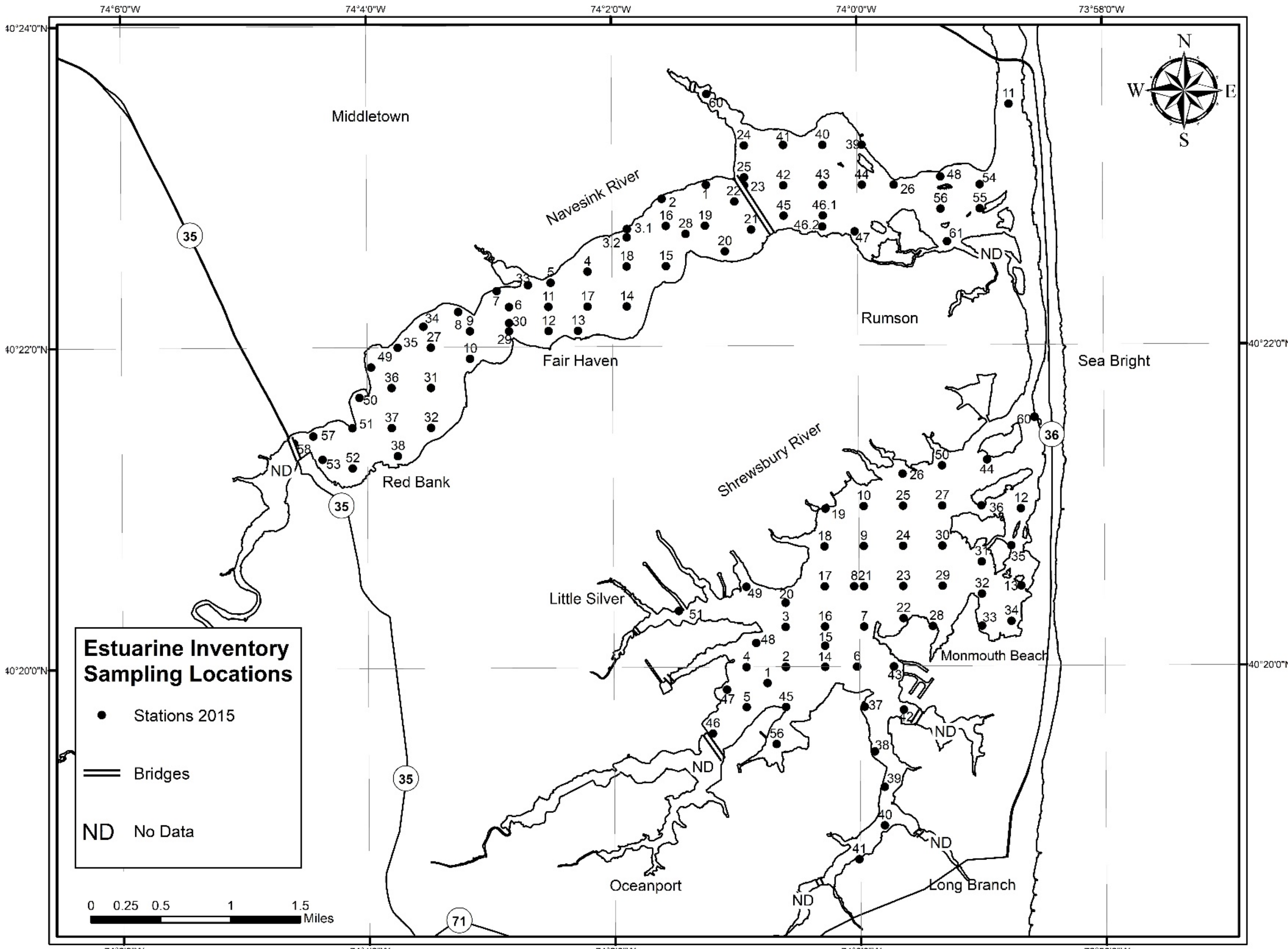


Figure 3. Stock estimate for Navesink and Shrewsbury Rivers, by commercial size class, 2015.

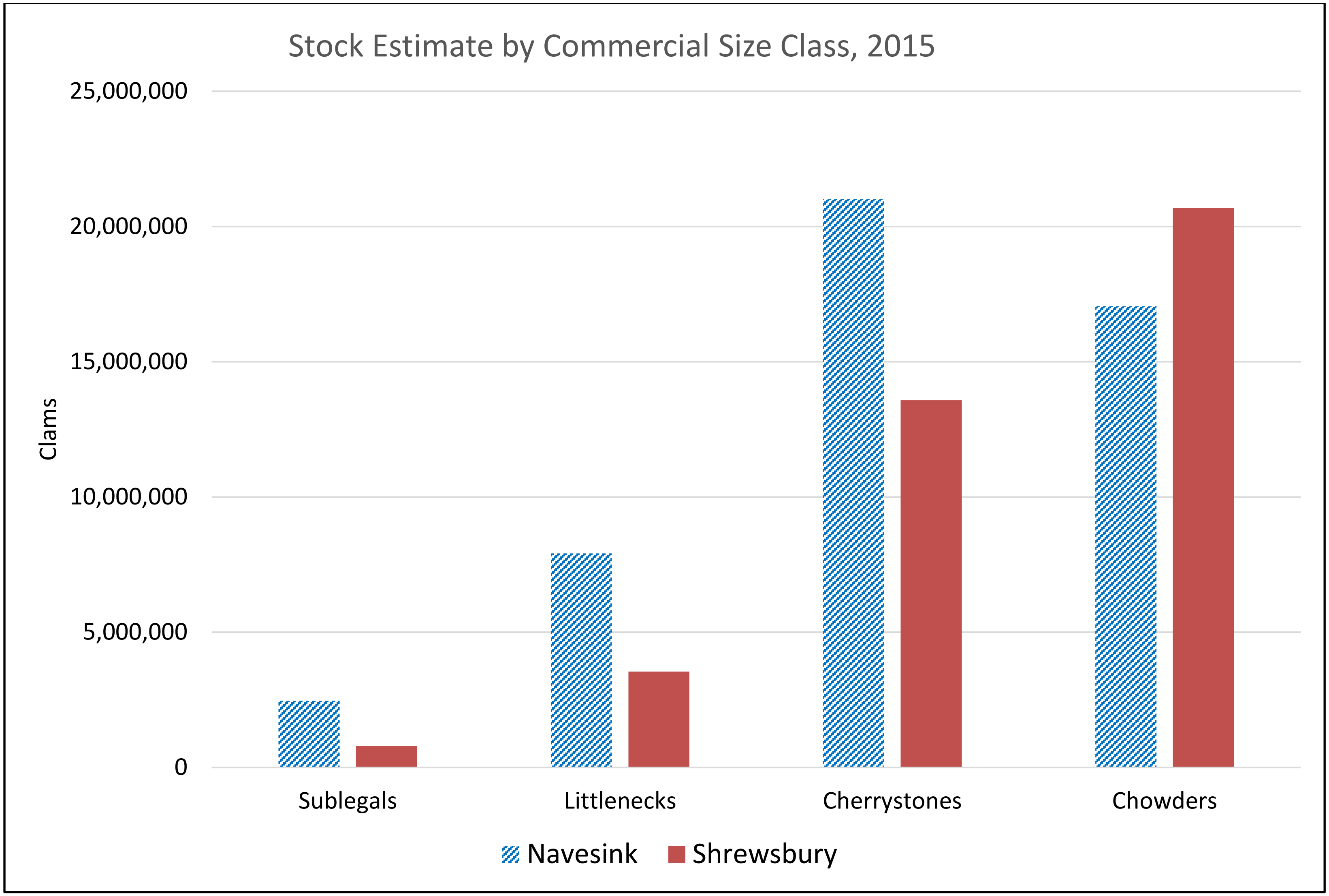


Table 5. Data summary for Navesink and Shrewsbury Rivers, 2015.

Station	Latitude	Longitude	Bottom Type	Abundance$_{adj.}$ (clams/ft^2)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
NR-15-001	40.38342	-74.0205	sticky mud	0.33	79.97	0.00	3.45	27.59	68.97	21.62
NR-15-002	40.38198	-74.0265	mud	0.52	77.72	0.00	0.00	47.83	52.17	16.36
NR-15-003.1	40.37887	-74.0313	sand/mud/shell	0.09	77.00	0.00	14.29	28.57	57.14	0.00
NR-15-003.2	40.378	-74.0313	sand/mud/shell	0.43	73.34	5.26	7.89	36.84	50.00	24.00
NR-15-004	40.37447	-74.0366	mud/shell	0.91	63.20	8.75	26.25	38.75	26.25	1.23
NR-15-005	40.37333	-74.0417	mud, small shell	0.47	78.98	0.00	2.44	39.02	58.54	26.79
NR-15-006	40.37083	-74.0473	mud	0.56	65.41	6.12	14.29	57.14	22.45	10.91
NR-15-007	40.3725	-74.049	mud	0.26	68.74	4.35	13.04	56.52	26.09	14.81
NR-15-008	40.37035	-74.0543	mud, shell	0.20	78.67	0.00	0.00	38.89	61.11	5.26
NR-15-009	40.36833	-74.0527	mud, shell	0.82	62.10	2.78	33.33	48.61	15.28	6.49
NR-15-010	40.36548	-74.0527	mud	0.28	76.04	0.00	4.00	48.00	48.00	10.71
NR-15-011	40.37083	-74.042	mud	0.43	74.87	0.00	5.26	44.74	50.00	9.52
NR-15-012	40.36832	-74.042	mud	0.36	72.53	0.00	15.63	34.38	50.00	15.79
NR-15-013	40.36833	-74.038	mud	0.36	68.88	6.25	18.75	34.38	40.63	15.79
NR-15-014	40.37083	-74.0313	mud	0.27	75.00	0.00	4.17	41.67	54.17	11.11
NR-15-015	40.375	-74.026	mud	0.36	76.59	0.00	3.13	50.00	46.88	8.57
NR-15-016	40.37917	-74.026	mud, shell	1.09	65.19	7.29	26.04	37.50	29.17	4.00
NR-15-017	40.37083	-74.0367	mud	0.36	73.19	0.00	15.63	40.63	43.75	13.51
NR-15-018	40.37498	-74.0313	mud	0.60	69.04	1.89	20.75	45.28	32.08	11.67
NR-15-019	40.37917	-74.0207	mud, shell	0.76	70.29	3.03	16.67	39.39	40.91	8.22
NR-15-020	40.3765	-74.018	mud	0.78	70.87	2.90	14.49	46.38	36.23	15.85

Station	Latitude	Longitude	Bottom Type	Abundance$_{adj}$. (clams/ft^2)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
NR-15-021	40.37875	-74.0144	sand, mud, sticky	0.32	71.89	14.29	3.57	32.14	50.00	12.50
NR-15-022	40.38167	-74.0167	sand	0.51	64.91	10.45	18.50	44.26	26.79	5.86
NR-15-023	40.38333	-74.0153	mud, shell	0.80	62.89	14.29	18.57	38.57	28.57	2.78
NR-15-024	40.38748	-74.0153	mud, soft, sulfurous	0.01	72.00	0.00	0.00	100.00	0.00	75.00
NR-15-025	40.38417	-74.0153	peat, mud, shell	0.45	70.08	5.00	20.00	35.00	40.00	0.00
NR-15-026	40.38333	-73.995	sand, shell, gravel	1.75	63.66	7.14	15.58	59.09	18.18	3.14
NR-15-027	40.36667	-74.058	mud	0.26	77.48	0.00	4.35	39.13	56.52	4.17
NR-15-028	40.37833	-74.0233	sand, shell	0.50	51.64	22.73	34.09	40.91	2.27	8.33
NR-15-029	40.36832	-74.0473	mud	0.40	75.74	0.00	2.86	48.57	48.57	7.89
NR-15-030	40.36917	-74.0473	mud, soft clam shell	1.31	67.63	0.87	13.91	63.48	21.74	6.50
NR-15-031	40.36248	-74.058	mud	0.13	70.73	0.00	9.09	72.73	18.18	8.33
NR-15-032	40.35833	-74.058	mud	0.08	73.00	0.00	0.00	57.14	42.86	46.15
NR-15-033	40.3731	-74.0448	mud	0.16	87.00	0.00	0.00	21.43	78.57	17.65
NR-15-034	40.36883	-74.059	mud	0.17	73.20	0.00	0.00	73.33	26.67	0.00
NR-15-035	40.36667	-74.0625	mud	0.11	79.20	0.00	0.00	50.00	50.00	33.33
NR-15-036	40.36248	-74.0633	mud	0.23	68.50	5.00	15.00	45.00	35.00	13.04
NR-15-037	40.35833	-74.0633	mud, shell	0.13	78.73	9.09	0.00	27.27	63.64	21.43

Station	Latitude	Longitude	Bottom Type	Abundance_adj. (clams/ft^2)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
NR-15-038	40.35542	-74.0625	mud, sticky, shell	0.07	83.17	0.00	0.00	33.33	66.67	33.33
NR-15-039	40.3875	-73.9993	sand, hard, woody debris, rocks	1.71	69.73	5.74	17.21	36.89	40.16	10.29
NR-15-040	40.3875	-74.0047	sticky mud, sand, shell	0.19	71.12	5.88	11.76	47.06	35.29	5.56
NR-15-041	40.3875	-74.01	sand,mud,sticky,shell	0.35	67.95	6.57	19.40	33.19	40.84	4.74
NR-15-042	40.38332	-74.01	sand, hard, shell	0.69	75.21	6.56	9.84	24.59	59.02	7.58
NR-15-043	40.38333	-74.0047	sand, shell, gravel	2.43	70.86	1.87	7.01	55.61	35.51	3.17
NR-15-044	40.38333	-73.9993	sand	0.23	63.75	5.00	20.00	55.00	20.00	42.86
NR-15-045	40.38017	-74.01	sand, shell	1.71	73.13	0.68	15.54	33.78	50.00	12.79
NR-15-046.1	40.38017	-74.0047	sand, mud, shell	1.60	60.82	11.35	28.37	38.30	21.99	9.62
NR-15-046.2	40.37902	-74.0047	sand	0.43	60.47	13.16	31.58	28.95	26.32	0.00
NR-15-047	40.3785	-74.0003	sand, shell	0.41	77.89	0.00	0.00	42.86	57.14	12.12
NR-15-048	40.38415	-73.9887	sand, shell	1.80	75.44	2.53	7.59	37.97	51.90	11.73
NR-15-049	40.36463	-74.0661	mud, shell	0.10	74.67	0.00	0.00	55.56	44.44	40.00
NR-15-050	40.36148	-74.0677	mud	0.02	74.50	0.00	0.00	50.00	50.00	50.00
NR-15-051	40.35833	-74.0687	mud, sand, hard, sticky, shell	0.19	61.47	11.76	17.65	41.18	29.41	10.53
NR-15-052	40.35417	-74.0687	mud	0.03	68.33	33.33	0.00	0.00	66.67	25.00

Station	Latitude	Longitude	Bottom Type	Abundance_adj. (clams/ft^2)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
NR-15-053	40.35507	-74.0727	mud, oyster, soft clam, macoma shell	0.03	54.33	33.33	0.00	66.67	0.00	0.00
NR-15-054	40.38333	-73.9833	sand, gravel	0.78	51.46	13.04	49.28	36.23	1.45	2.82
NR-15-055	40.38083	-73.9833	sand, shell	0.77	62.44	5.88	35.29	47.06	11.76	10.53
NR-15-056	40.38082	-73.9887	sand, gravel	0.42	69.89	0.00	16.22	45.95	37.84	0.00
NR-15-057	40.3575	-74.074	shell, mud, sand, oyster shell	0.00	n/a	n/a	n/a	n/a	n/a	n/a
NR-15-058	40.35675	-74.0766	mud, oyster shell	0.00	n/a	n/a	n/a	n/a	n/a	n/a
NR-15-060	40.39283	-74.0204	mud, woody debris, detritus	0.01	88.00	0.00	0.00	0.00	100.00	0.00
NR-15-061	40.37743	-73.9878	sand/mud sticky,shell	0.22	73.05	5.26	5.26	47.37	42.11	9.52

Begin Shrewsbury River

Station	Latitude	Longitude	Bottom Type	Abundance$_{adj.}$ (clams/ft^2)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
SR-15-001	40.33167	-74.0125	mud, oyster shell	0.50	71.41	2.27	27.27	15.91	54.55	13.73
SR-15-002	40.33333	-74.01	mud	0.30	77.58	0.00	3.85	30.77	65.38	35.00
SR-15-003	40.33748	-74.01	mud,shell	0.51	77.62	4.44	11.11	20.00	64.44	23.73
SR-15-004	40.33333	-74.0153	mud, oyster shell	0.06	76.20	0.00	0.00	60.00	40.00	58.33
SR-15-005	40.32917	-74.0153	mud	0.11	76.50	0.00	10.00	40.00	50.00	9.09
SR-15-006	40.33332	-74.0003	mud	0.55	73.79	4.26	12.77	34.04	48.94	23.81
SR-15-007	40.33748	-73.9993	hard sand	0.93	77.42	3.23	0.00	38.71	58.06	21.95
SR-15-008	40.34167	-74.0007	mud, detritus	0.84	69.31	5.19	26.57	24.35	43.89	9.14
SR-15-009	40.34583	-73.9993	sticky mud, sand	0.40	81.17	0.00	2.86	20.00	77.14	20.45
SR-15-010	40.34998	-73.9993	sticky sand, mud	0.11	83.31	0.00	3.57	19.05	77.38	18.25
SR-15-011	40.39167	-73.9793	rock, sand, smooth cobble	0.06	87.40	0.00	0.00	20.00	80.00	0.00
SR-15-012	40.34967	-73.978	sand,mud,shell	1.03	79.09	1.11	1.11	32.22	65.56	9.90
SR-15-013	40.34165	-73.978	sand,peat,detritus,woody debris	1.42	74.64	0.80	13.60	32.00	53.60	18.83
SR-15-014	40.33332	-74.0047	sand	0.85	60.12	9.33	41.33	17.33	32.00	23.47
SR-15-015	40.3355	-74.0047	sand, shell	0.16	79.15	7.69	0.00	23.08	69.23	6.67

Station	Latitude	Longitude	Bottom Type	Abundance_adj. (clams/ft²)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
SR-15-016	40.3375	-74.0047	fine soft sand, mud, hard	0.19	78.76	1.85	5.56	29.10	63.49	31.70
SR-15-017	40.34167	-74.0047	mud,shell,sand, oyster shell	0.52	79.22	4.35	2.17	28.26	65.22	30.30
SR-15-018	40.34582	-74.0047	mud	0.32	75.36	7.14	3.57	25.00	64.29	44.00
SR-15-019	40.34973	-74.0045	sand	0.06	78.00	0.00	20.00	0.00	80.00	16.67
SR-15-020	40.33998	-74.01	hard fine sand, mud +shell	0.17	59.60	5.26	15.79	47.37	31.58	16.67
SR-15-021	40.34167	-73.9993	mud, sand	0.22	69.16	5.26	15.79	47.37	31.58	52.50
SR-15-022	40.33832	-73.994	hard sand	0.06	73.00	0.00	20.00	20.00	60.00	0.00
SR-15-023	40.34167	-73.994	sand, shell	0.33	75.68	7.14	7.14	28.57	57.14	14.71
SR-15-024	40.34583	-73.994	sand,shell	0.50	79.18	0.00	2.27	29.55	68.18	33.33
SR-15-025	40.35	-73.994	sand,shell	0.16	80.15	0.00	0.00	46.15	53.85	17.65
SR-15-026	40.35333	-73.994	fine sand	0.07	78.60	0.00	0.00	60.00	40.00	0.00
SR-15-027	40.35	-73.9887	sand, woody debris	0.22	65.87	11.11	30.56	18.33	40.00	5.88
SR-15-028	40.3375	-73.99	hard sand	0.09	80.25	0.00	0.00	37.50	62.50	38.46
SR-15-029	40.34167	-73.9887	mud	0.06	73.70	0.00	10.00	50.00	40.00	7.14
SR-15-030	40.34583	-73.9887	sand,shell	0.25	69.09	0.00	18.18	45.45	36.36	12.00
SR-15-031	40.34417	-73.9833	sand, shell	0.08	62.14	0.00	28.57	71.43	0.00	12.50

Station	Latitude	Longitude	Bottom Type	Abundance_adj. (clams/ft^2)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
SR-15-032	40.34083	-73.9833	sand, mud, clay,shell	1.01	72.71	1.12	11.24	44.94	42.70	11.00
SR-15-033	40.3375	-73.9833	sand, mud, clay,shell	0.09	90.88	0.00	0.00	0.00	100.00	33.33
SR-15-034	40.33798	-73.9793	sand,mud,soft clay	0.15	79.57	0.00	0.00	45.83	54.17	0.00
SR-15-035	40.34583	-73.9793	sand,shell,peat	1.02	78.26	0.00	3.37	40.45	56.18	13.46
SR-15-036	40.35	-73.9833	sand,shell	1.18	79.57	0.00	1.98	38.61	59.41	7.14
SR-15-037	40.32917	-73.9993	mud, some shell	0.05	62.50	25.00	25.00	25.00	25.00	42.86
SR-15-038	40.3245	-73.998	mud, shell	0.45	80.50	2.50	0.00	32.50	65.00	39.39
SR-15-039	40.32083	-73.9967	mud, shell	0.20	81.83	0.00	0.00	38.89	61.11	30.77
SR-15-040	40.31683	-73.9967	mud, woody debris, shell	0.03	80.33	0.00	0.00	33.33	66.67	70.00
SR-15-041	40.31333	-74.0002	mud, shell	0.15	72.23	7.69	7.69	30.77	53.85	23.53
SR-15-042	40.32883	-73.994	mud, shell	0.06	83.40	0.00	0.00	40.00	60.00	28.57
SR-15-043	40.33333	-73.9953	sticky mud, clay	0.03	64.88	0.00	12.50	62.50	25.00	53.75
SR-15-044	40.35476	-73.9825	sand,shell	0.49	78.12	0.00	4.76	40.48	54.76	15.69
SR-15-045	40.32917	-74.01	sand,shell,clay	0.18	74.00	6.25	12.50	12.50	68.75	20.00
SR-15-046	40.32645	-74.02	sand,shell	0.05	57.25	0.00	50.00	25.00	25.00	20.00
SR-15-047	40.331	-74.018	sand	0.10	77.22	0.00	0.00	44.44	55.56	10.00

Station	Latitude	Longitude	Bottom Type	Abundance$_{adj}$. (clams/ft^2)	Mean Length (mm)	Percent Sublegals	Percent Littlenecks	Percent Cherrystones	Percent Chowders	Percent Mortality
SR-15-048	40.33583	-74.014	mud,shell	0.05	70.25	0.00	25.00	25.00	50.00	33.33
SR-15-049	40.34167	-74.0153	mud, oyster shell	0.06	74.00	20.00	0.00	0.00	80.00	16.67
SR-15-050	40.35417	-73.9887	sand, shell,woody debris	0.68	79.07	0.00	2.44	39.02	58.54	23.64
SR-15-051	40.3392	-74.0245	mud, oyster shell	0.06	78.60	0.00	20.00	20.00	60.00	44.44
SR-15-056	40.32533	-74.0113	mud	0.00	n/a	n/a	n/a	n/a	n/a	n/a
SR-15-060	40.35915	-73.9761	n/a	1.82	73.09	0.00	8.70	52.17	39.13	59.32

Figure 4. Relative abundance and distribution of hard clams in the Navesink and Shrewsbury Rivers, 2015.

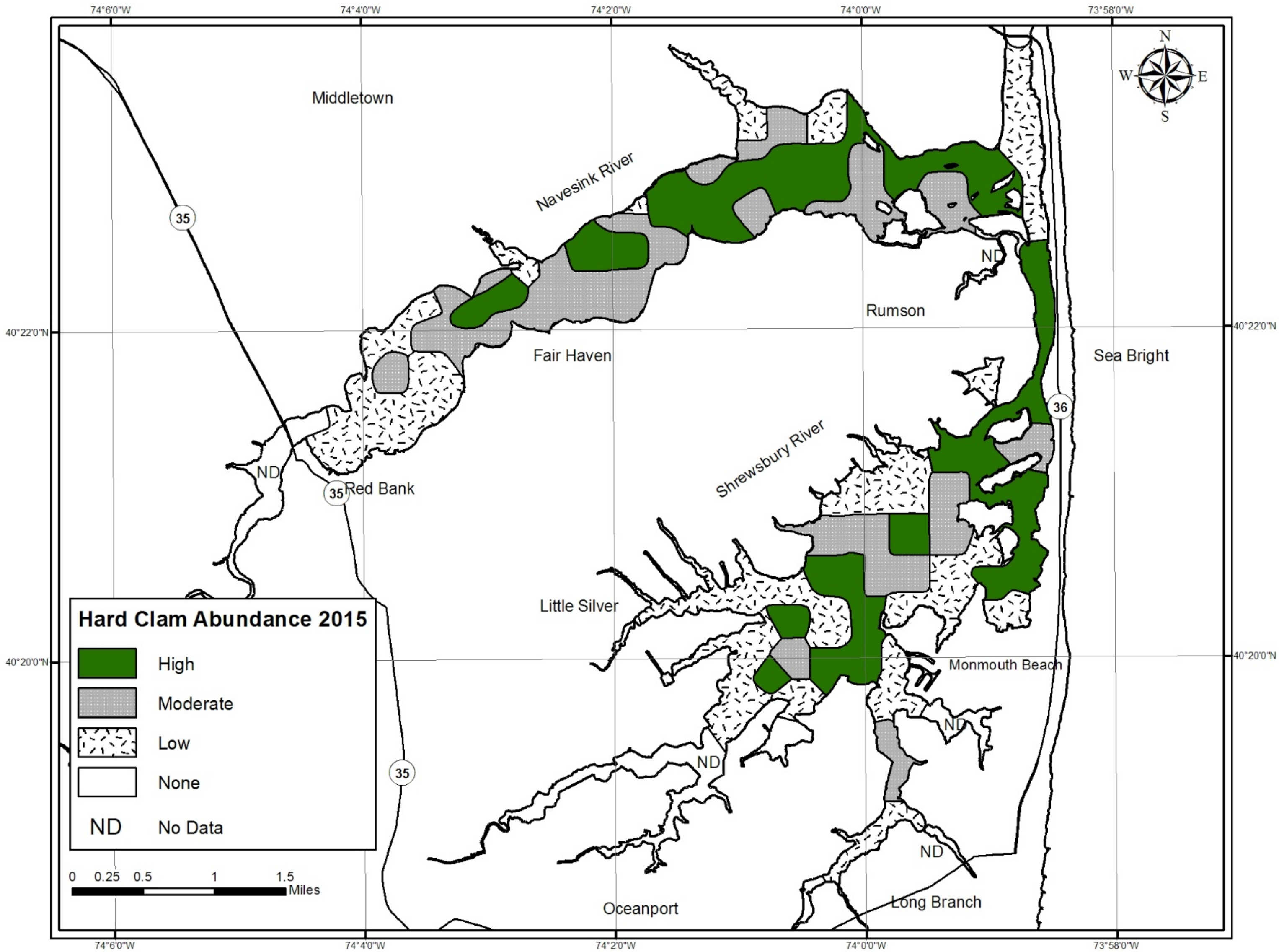


Figure 5. Copy of hard clam distribution chart from McCloy and Joseph 1983 final report.

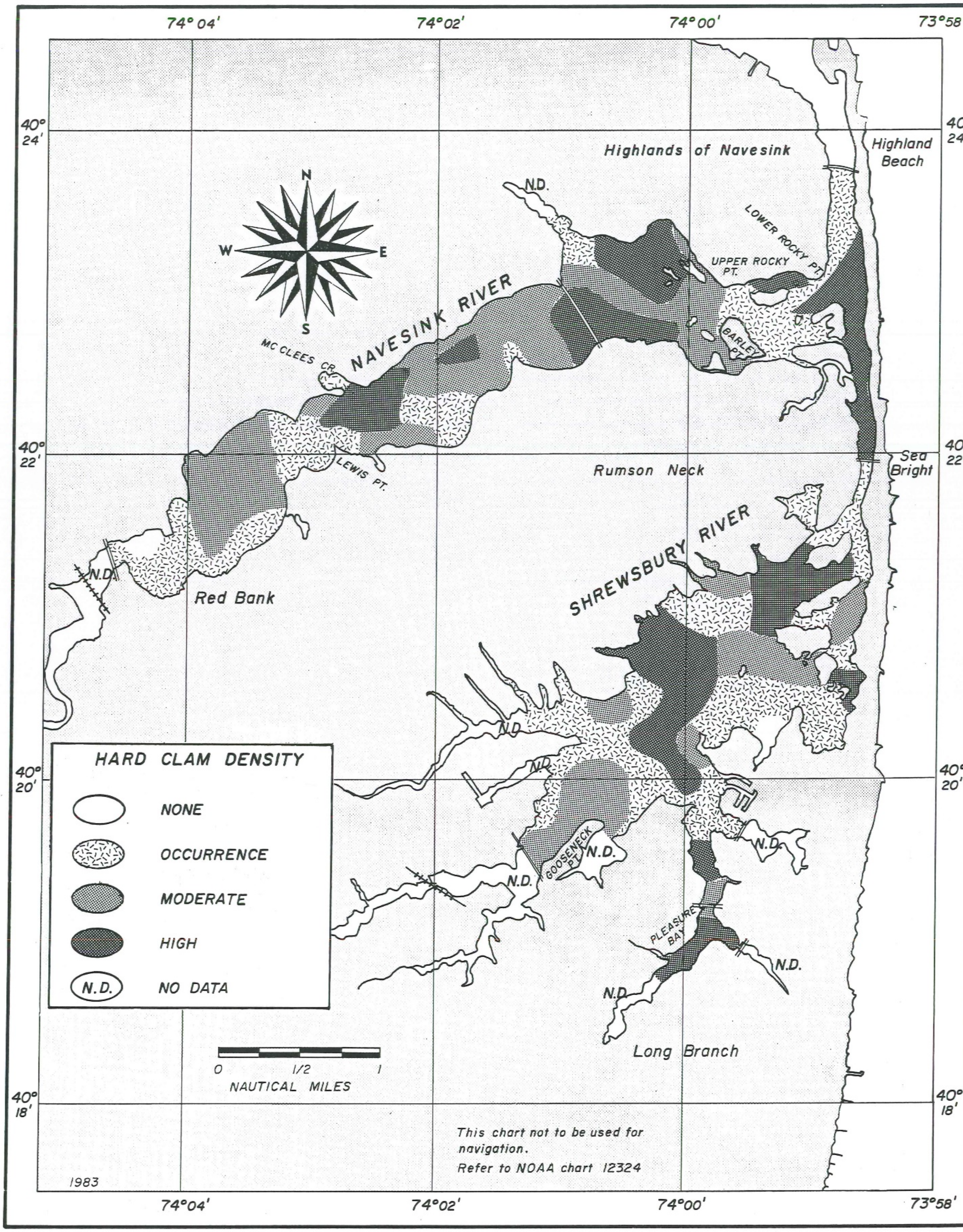


Figure 6. Stations where hard clams less than 30mm were collected in the dredge, 2015.

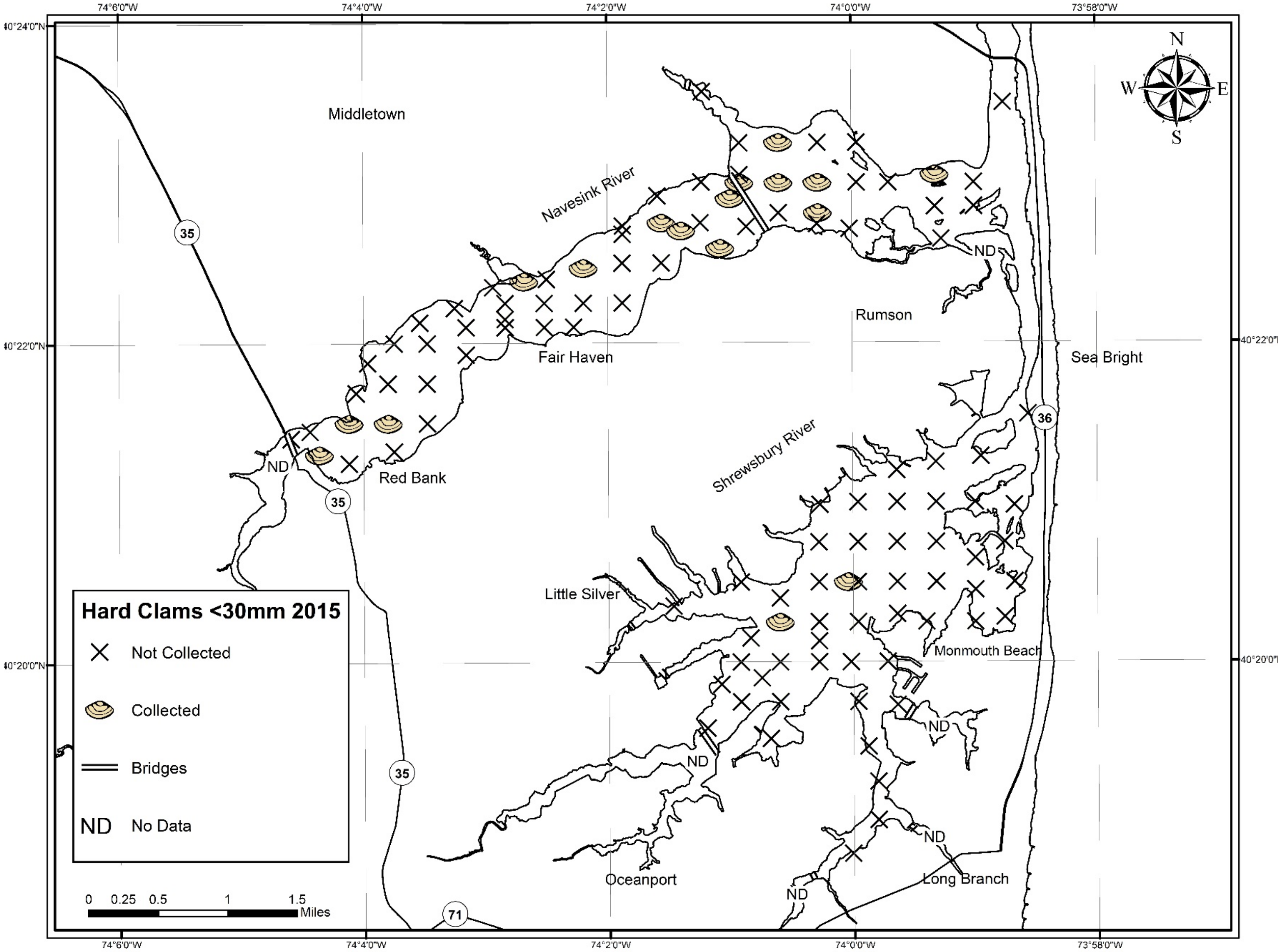
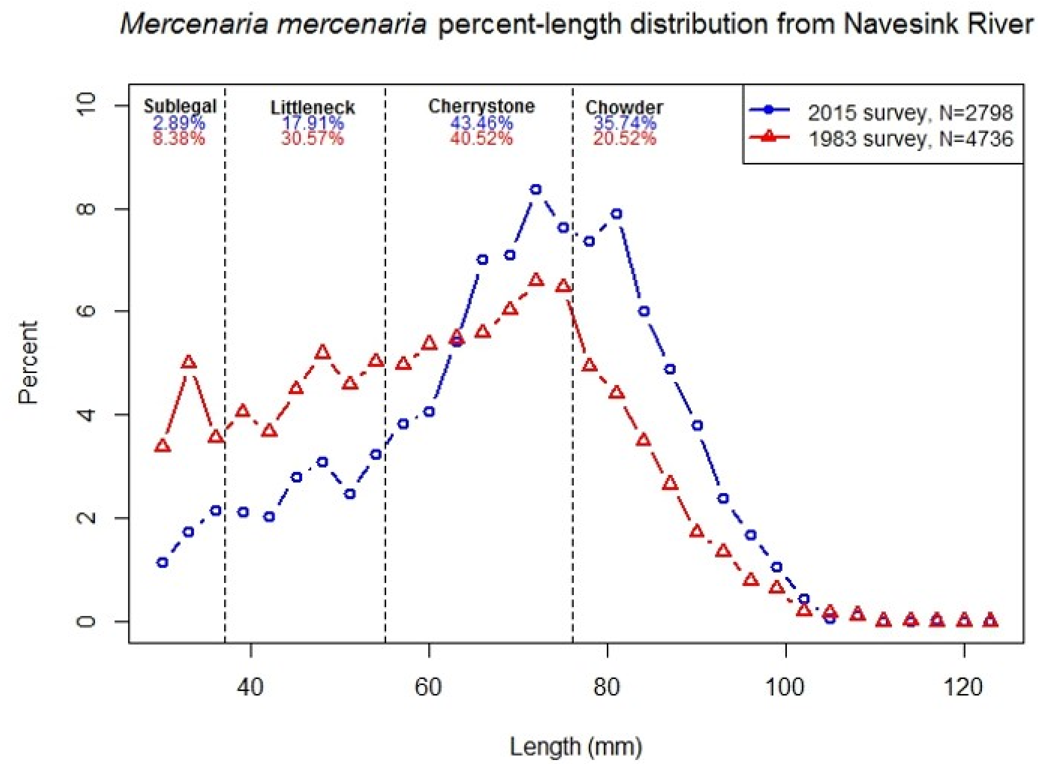


Figure 7. Hard clam percent-length-frequency and length-frequency in the Navesink River, 1983 and 2015.



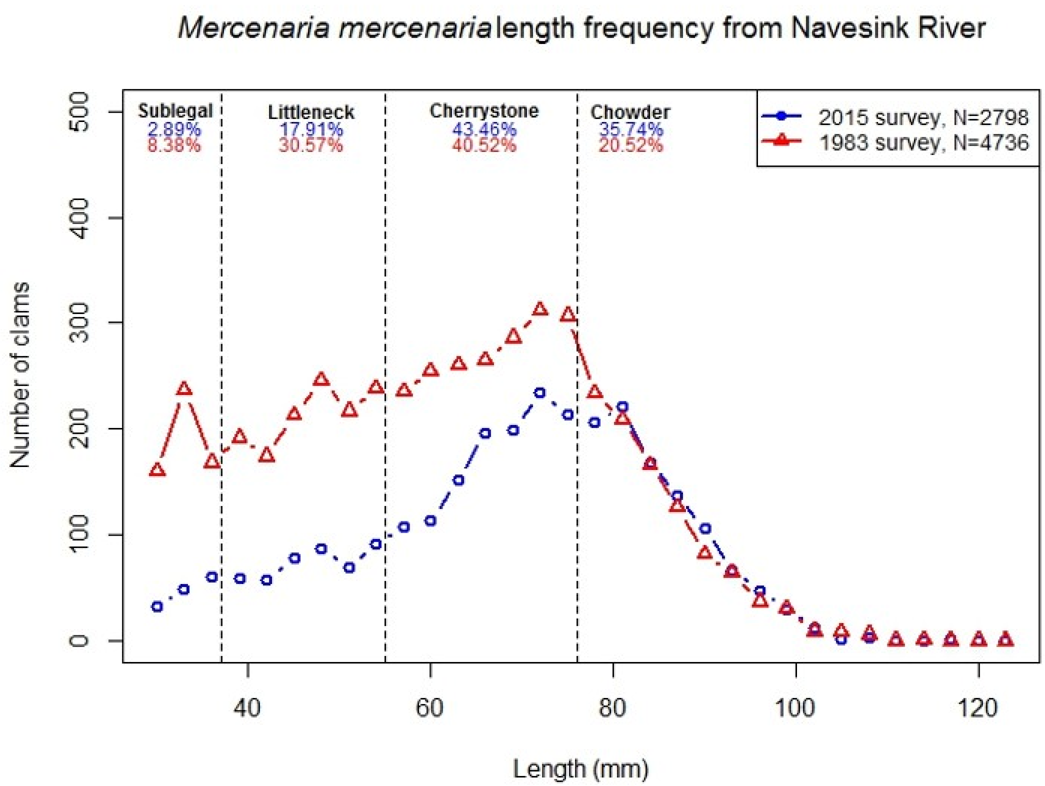
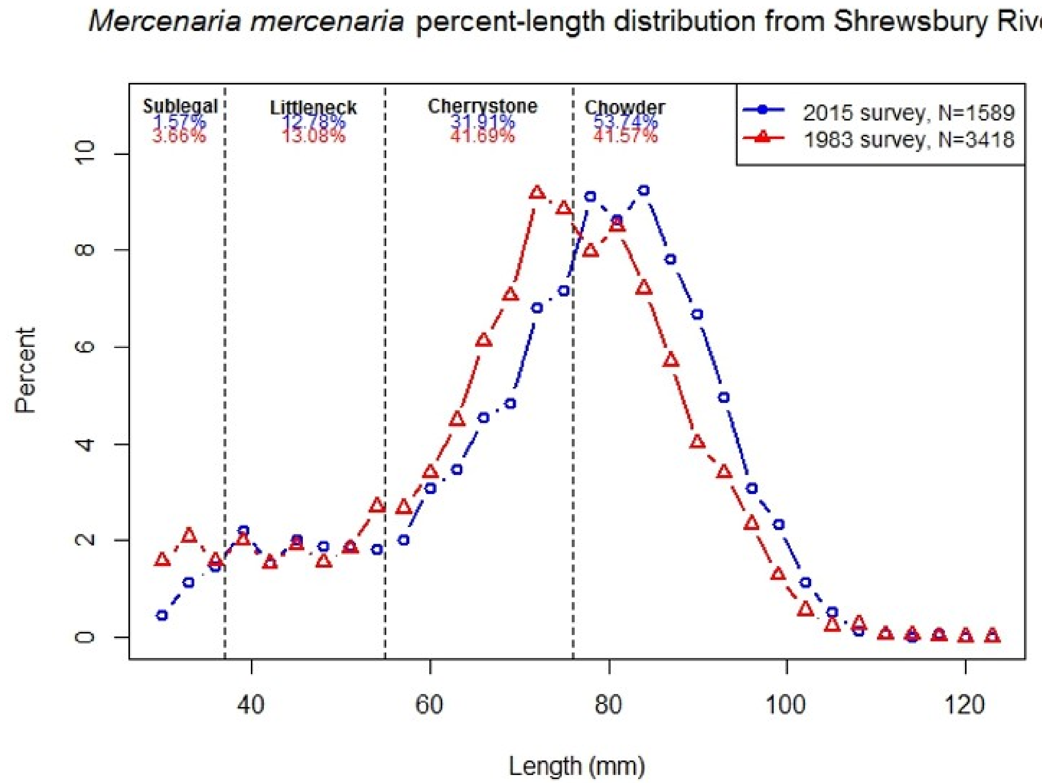


Figure 8. Hard clam percent-length-frequency and length-frequency in the Shrewsbury River, 1983 and 2015.



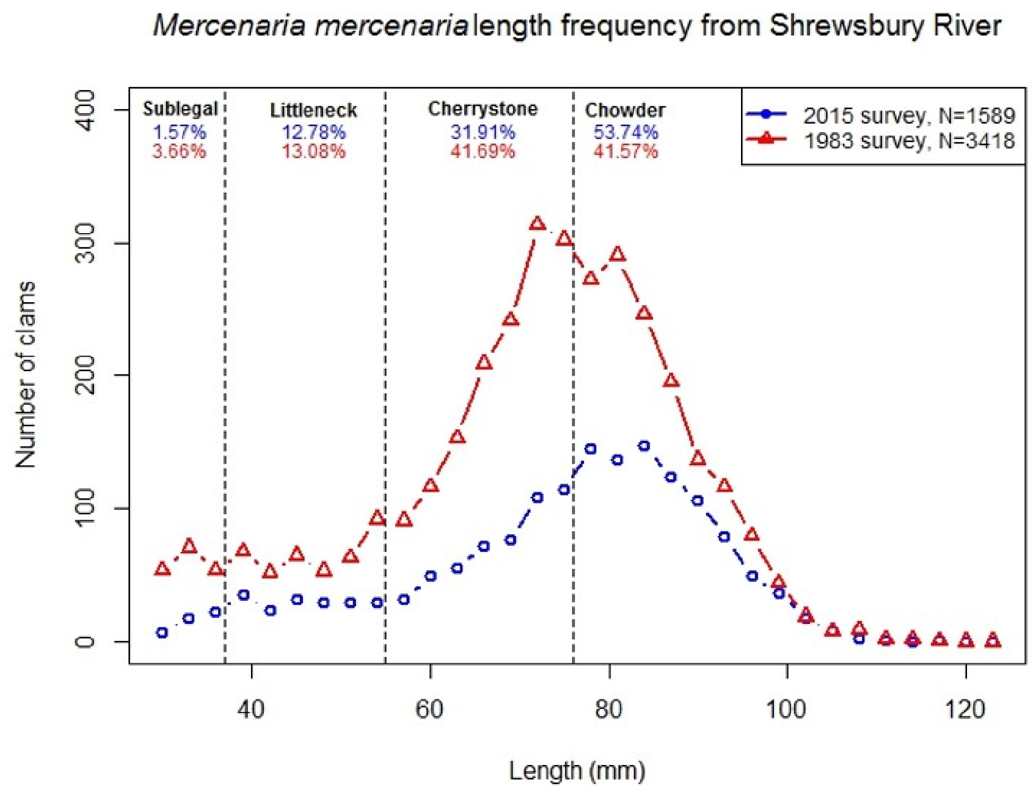


Figure 9. Estimates of percent recruitment of hard clams at each station in 2015.

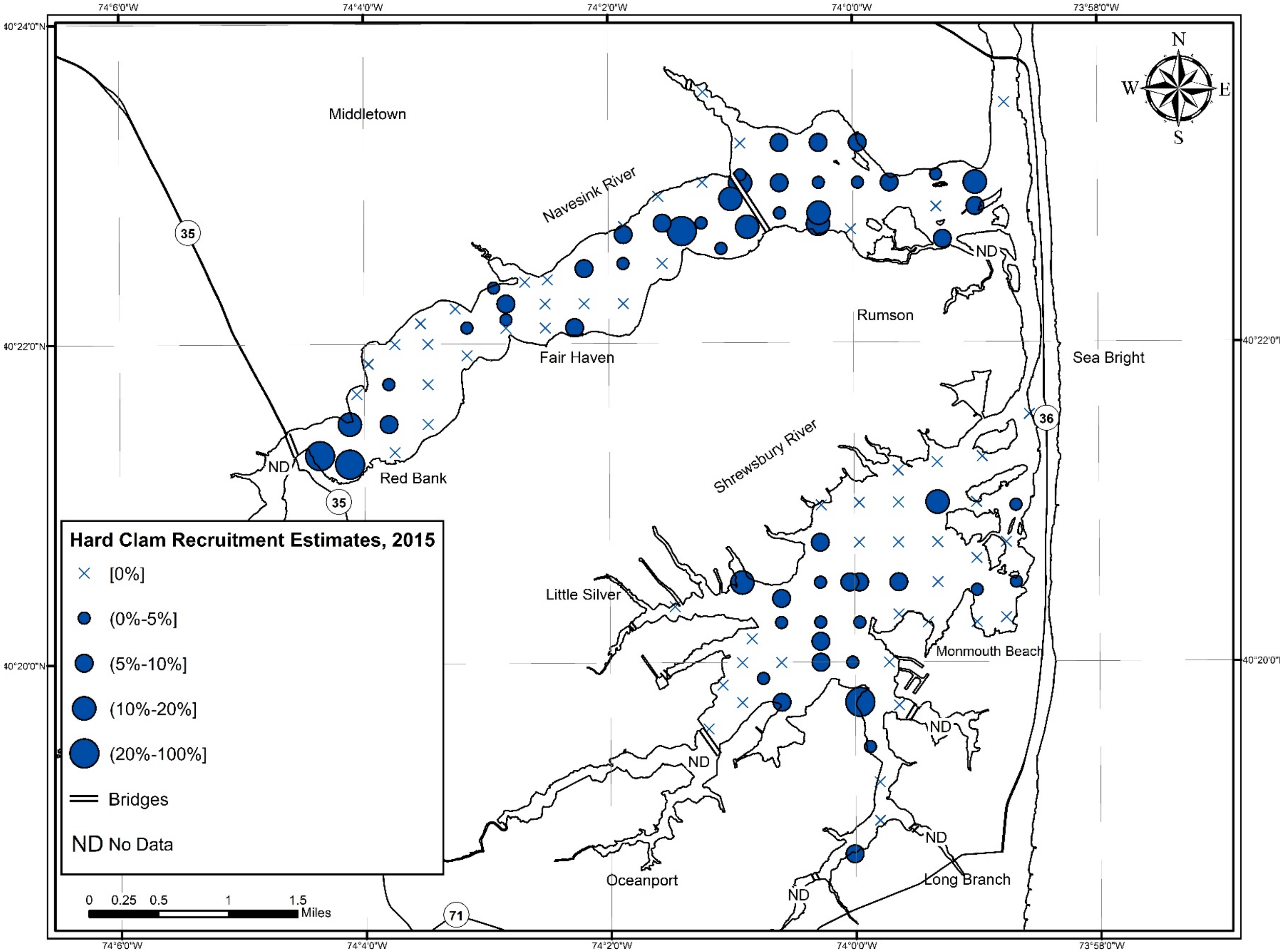


Figure 10. Estimates of percent recruitment of hard clams at each station in 1983.

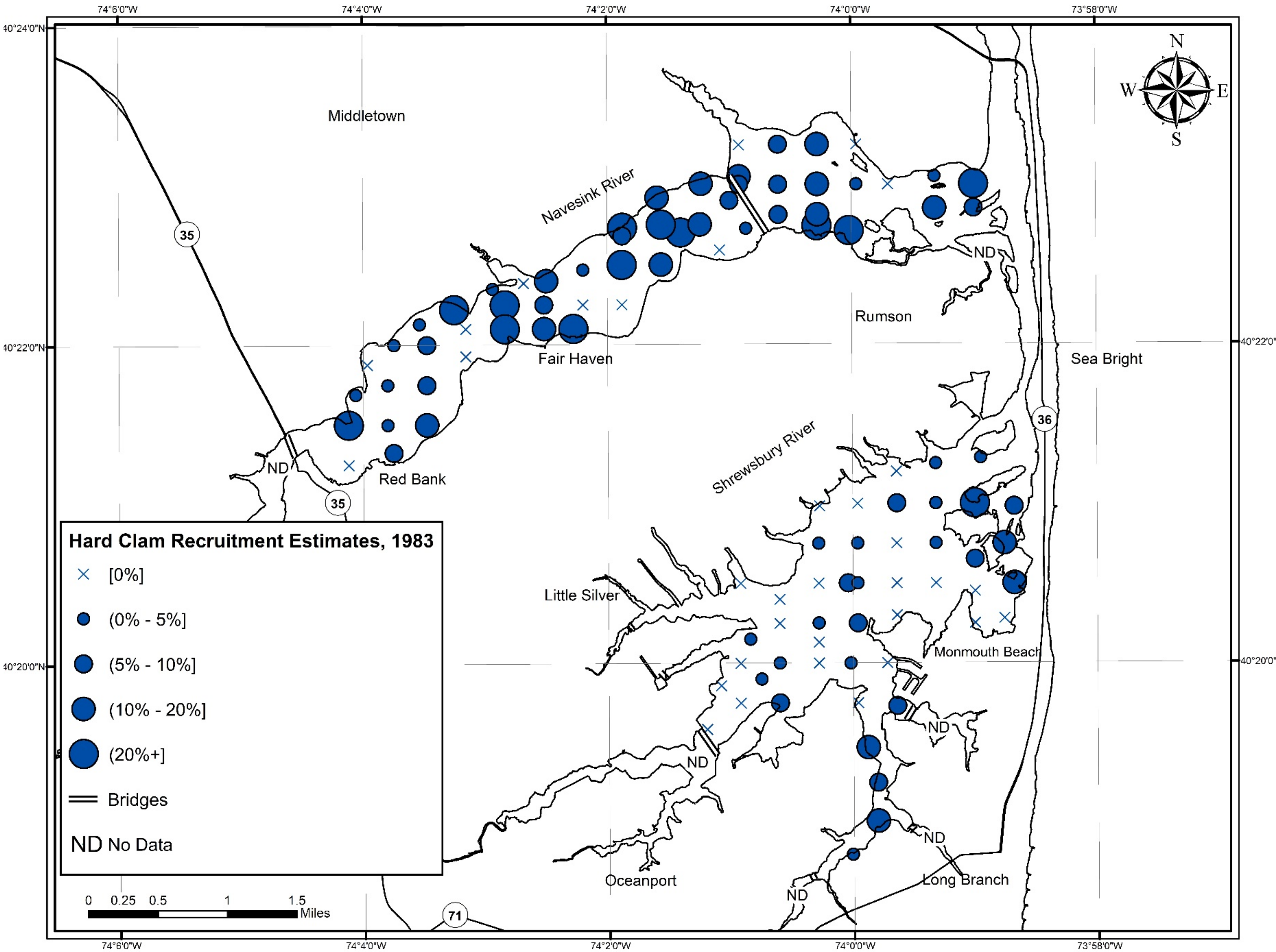


Figure 11. Estimates of percent natural mortality of hard clams at each station in 2015.

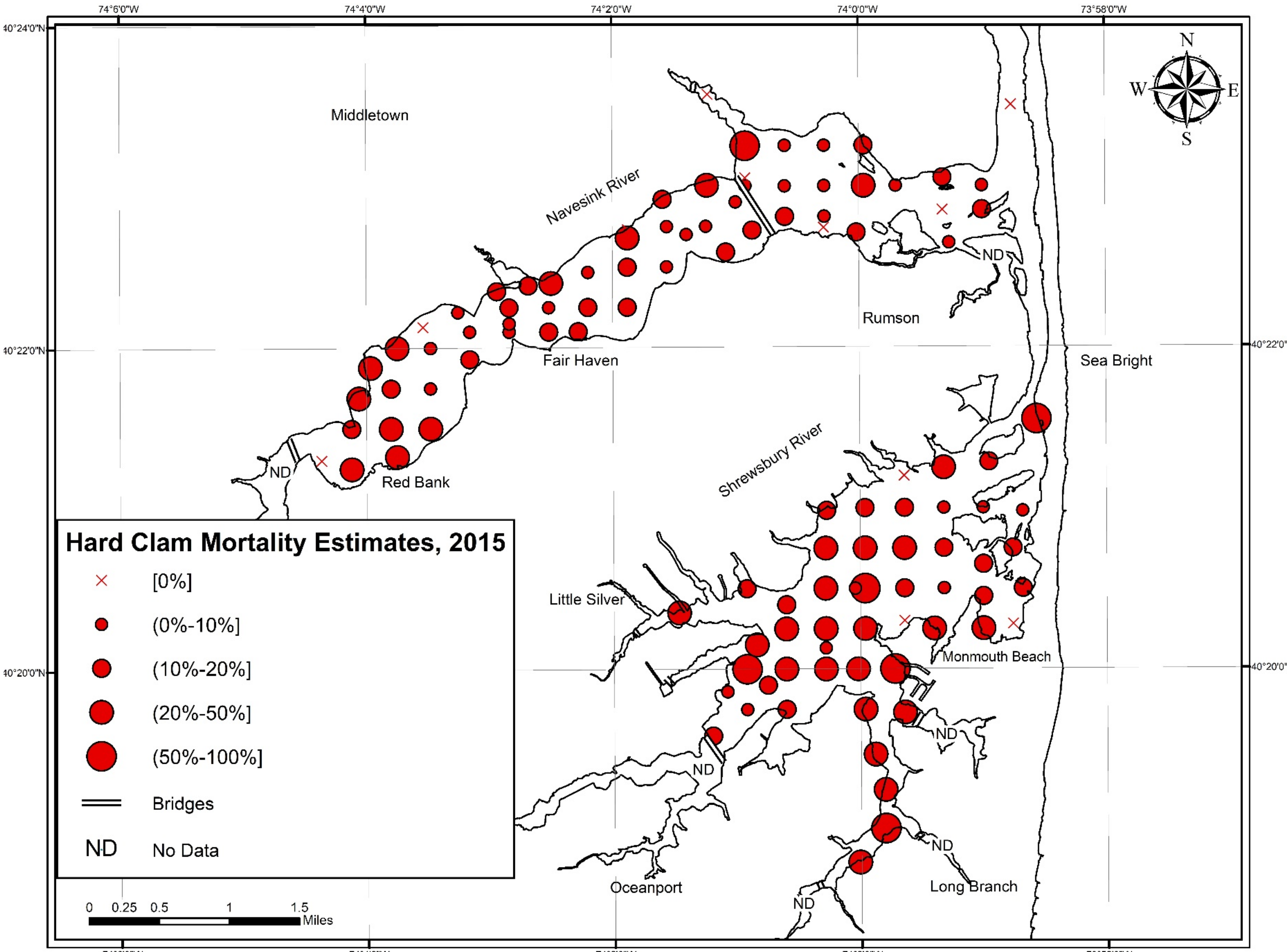


Figure 12. Estimates of percent natural mortality of hard clams at each station in 1983.

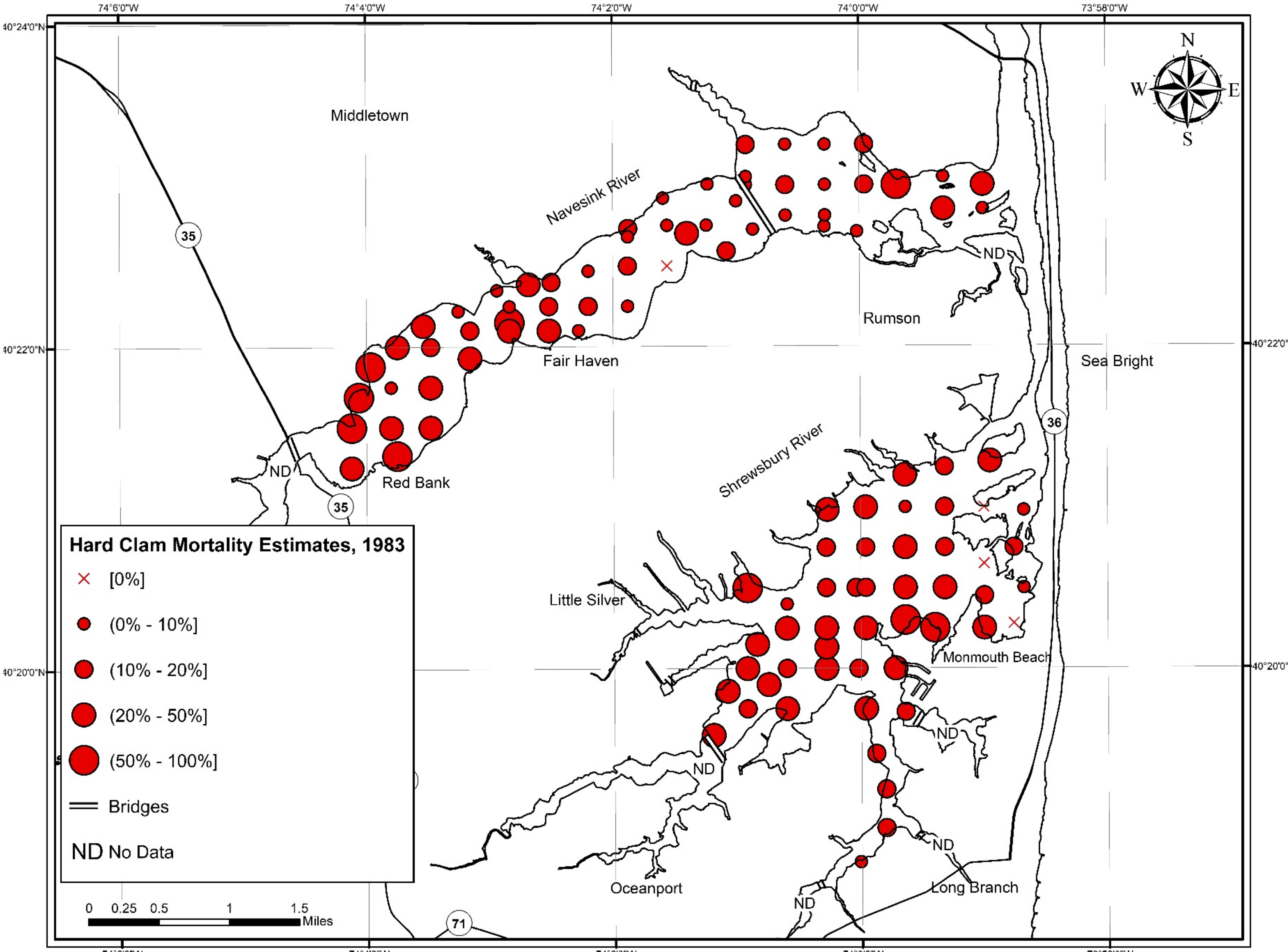


Figure 13. Distribution of other recreationally and commercially valuble bivalve species, 2015.

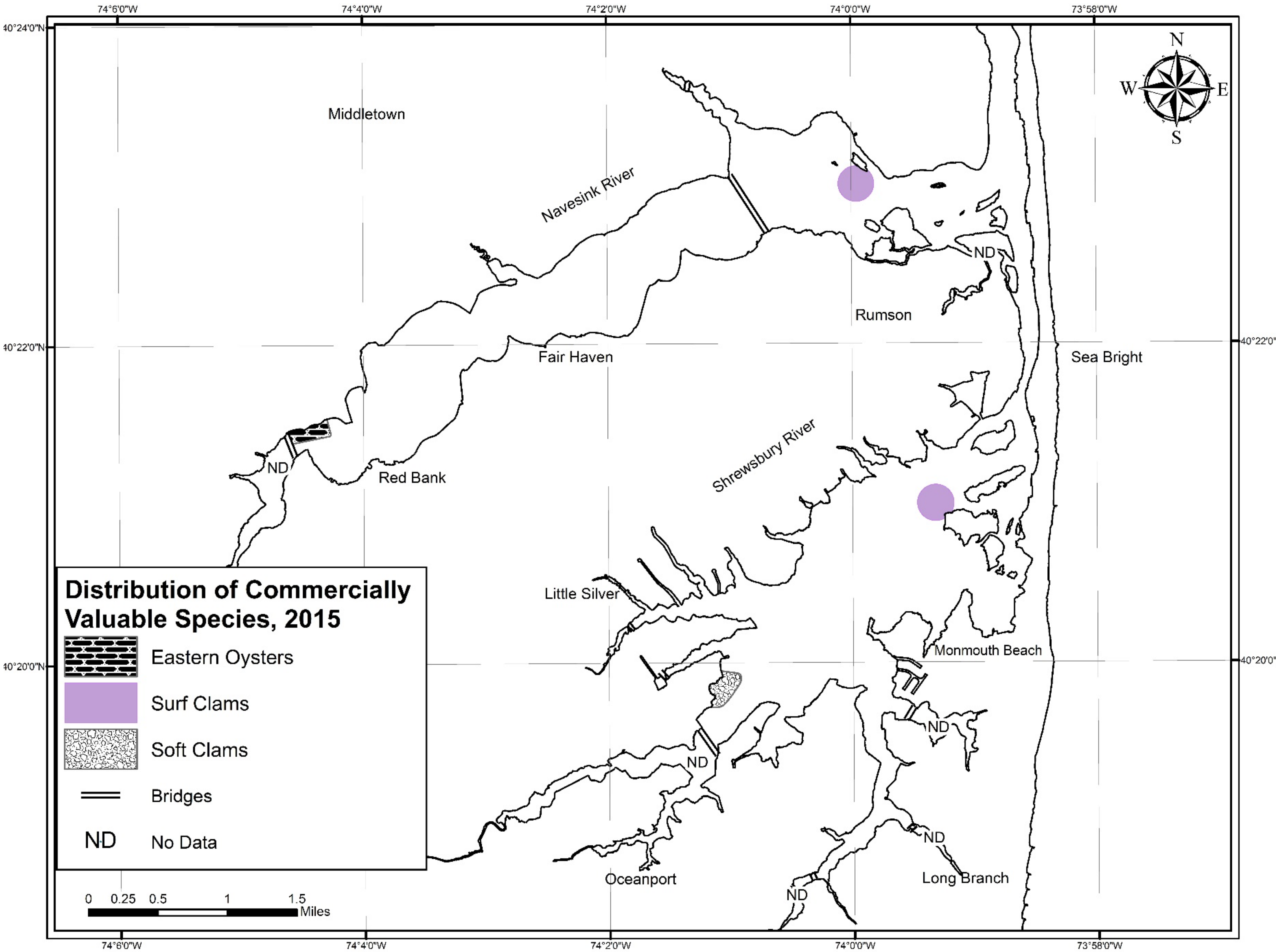


Figure 14. Copy of other recreationally and commercially valuable bivalve species distribution chart from the McCloy and Joseph 1983 report.

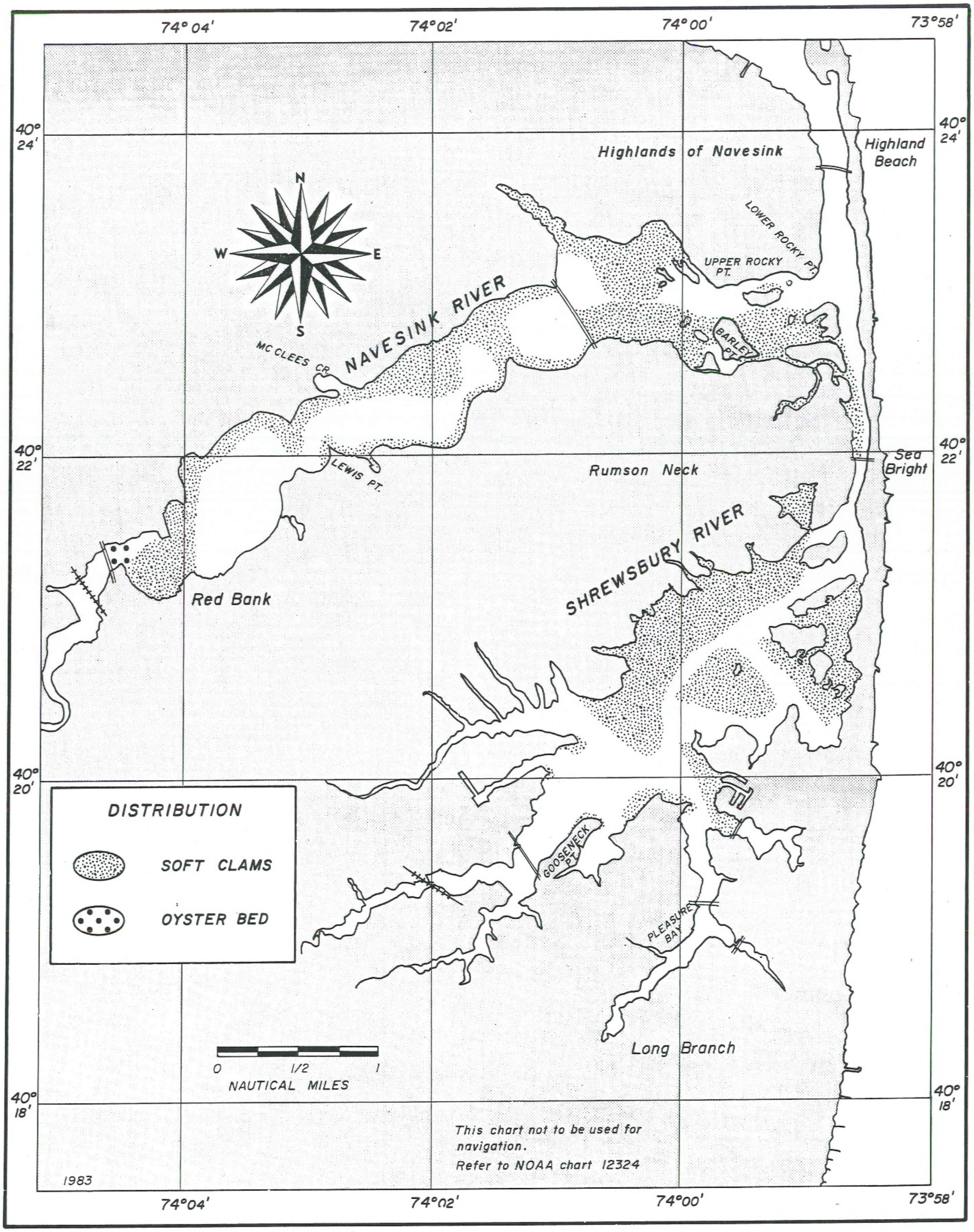


Figure 15. Stations where submerged aquatic vegetation was collected in the dredge during the 1983 and 2015 surveys. No SAV was collected in 2015 where it had previously been collected in 1983.