North Cape Shellfish Restoration Program
2006 Annual Report

Rhode Island Department of Environmental Management
National Oceanic and Atmospheric Administration
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Acknowledgements

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2006 *North Cape*
SHELLFISH RESTORATION PROGRAM

Executive Summary

North Cape restoration efforts by State and Federal Trustees continued to move forward in 2006 to address the natural resource injuries resulting from the release of 828,000 gallons of heating oil into Block Island Sound during the 1996 *North Cape* oil spill. Following legal settlement in 2000, the Trustees established a Shellfish Restoration Program to address the loss of 150 million surf clams (*Spisula solidissima*) and another 648,000 other bivalves by implementing projects targeting three species. The multi-year Program, with field operations beginning in 2002, includes enhancing quahog (*Mercenaria mercenaria*) and restoring bay scallop (*Argopecten irradians*) and eastern oyster (*Crassostrea virginica*) populations to Rhode Island waters. The goals of the Shellfish Restoration Program are to restore lost shellfish wet-tissue biomass (due to direct loss and foregone production) and lost ecological services through the restoration and enhancement of bivalve populations.

The 2006 bay scallop project included establishing a bay scallop spawner sanctuary in Quonochontaug Pond, stocked with hatchery-reared broodstock. The recruitment of juvenile bay scallops produced by these broodstock was monitored using artificial 'spat' collectors. In 2006, scallop recruitment monitoring also continued in Ninigret Pond following the successful deployment of spawner sanctuaries there in 2004 and 2005. Scallop spawner sanctuaries have proven to be a cost effective method of enhancing recruitment to the coastal ponds. The spat-fall recorded from the spat bag surveys in 2005 developed into an estimated population of 130,000 broodstock in Ninigret Pond in the summer of 2005. These broodstock, combined with an additional 10,000 in the spawner sanctuary produced substantial mid and late-season spat-falls, resulting in an estimated 190,000 broodstock in Ninigret Pond in 2006. Surveys of Quonochontaug Pond estimated that there were 2,790 naturally occurring broodstock in the pond, plus an additional 20,000 caged sanctuary broodstock in 2006. These broodstock produced a settlement of juveniles that bodes well for the scallop population in 2007. Aspects of the scallop program formed the basis of one NOAA Hollings Fellow research project. A field experiment was conducted in collaboration with the US EPA's Atlantic Ecology Division to examine the habitat utilization of bay scallops in Ninigret Pond. Results indicated that three-dimensional vegetation is not essential for successful recruitment, and will be incorporated into the development of a model of scallop habitat requirements being developed by the US EPA.

The 2006 oyster project included an expanded remote setting of oyster larvae to produce disease-free oyster spat for subsequent nursery grow-out and release to selected sites.

Survivorship and growth of the oysters released in 2003, 2004 and 2005 was also monitored. A total of 1.95 million oysters were produced in 2006 to supplement the approximately 2 million oysters released from 2003 to 2005. The recruitment of newly settled oysters at each of the restoration sites was the basis of a URI Coastal Fellows research project. Spat settlement collectors were deployed to monitor recruitment in the area of the restoration sites, but the most positive measures of recruitment came from the population monitoring.

The quahog project began with retrieval of seed from a successful overwintering, and the harvesting of a bottom grow-out trial. High survival in the bottom grow-out trial suggests that quahog seed can be overwintered in the bottom grow-out arrangement intended for rearing seed for a second year. Additional seeding experiments confirmed the need to grow quahog seed in a protected nursery environment for a second year to avoid the very high mortalities associated with the release of seed less than about 20mm length.

During 2006 a total of 110,600 quahog seed were released into Ninigret and Quonochontaug Ponds. The survival of these seed will be determined from results obtained by sampling the experimental plots in 2007. Preliminary results suggest a higher survival in Quonochontaug Pond than Ninigret Pond, potentially as high as 50%.

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1.0 Introduction

The South County salt ponds have historically provided a valuable bay scallop resource for Rhode Island fisheries. Environmental changes, both natural and anthropogenic, have likely contributed to the significant decline of this native species (Blake and Shumway 2006). The appearance of a previously unrecorded toxic microalga (*Aureococcus anaphaegefferens*) known as 'brown tide' in the mid 1980s caused catastrophic declines throughout southern New England to New York (Tetelbach and Wenczel 1993). Other environmental factors influencing the decline include increased sedimentation at the pond openings reducing tidal exchange, increased pond use for recreational activities causing increased water column turbidity, and increased release of nutrients causing excess algal growth causing decreases in eelgrass and periods of hypoxia (Hinga *et al*. 1991, Short *et al*. 1996). Eelgrass beds, once abundant in the ponds and an important structural component for bay scallop habitat, have largely disappeared due to increasing water temperatures, turbidity, and excess algal growth (Short and Neckles 1998). Lastly, over-fishing may have also played a role in the decline of the bay scallop. There has not been a functional fishery for bay scallops in Rhode Island for more than twenty years.

In fall of 2003, the *North Cape* Shellfish Restoration Program seeded scallops directly into four coastal ponds; Ninigret, Potter, Quonochontaug, and Green Hill Ponds (Figure 1), in an attempt to re-establish an effective breeding population for the 2004 season (Holly *et al*. 2004). In spring 2004, the ponds were surveyed to estimate the total abundance of the scallops remaining. The number of scallops in all ponds was low (Holly *et al*. 2004). Ninigret Pond had the highest number of surviving scallops, estimated to be 9,500, and these were primarily in the western area of the pond. As a result of the low survival of the seeded scallops, the focus of the scallop project was shifted to establishing a caged spawner sanctuary in Ninigret Pond, where broodstock could be placed in mesh cages to be protected from predation to minimize mortality and maximize their reproductive output.

Measures of the relative abundance of scallop spat settling from the larval stage can be used as an indicator of the performance of the spawner sanctuary, or the scallop restoration project overall (Coleman 1988, Tammi *et al.* 1997). The settlement of scallop spat in Ninigret Pond has been monitored using artificial spat collectors or spat bags, collected and replaced regularly throughout the season since 2004. Monitoring the settlement of scallop spat in Quonochontaug Pond began in 2006 as a component of the Quonochontaug Pond scallop restoration project.

Changes to the physical and chemical characteristics of Rhode Island's coastal salt ponds have increasingly become a cause for concern during the last twenty years (Lee and Olsen 1985, Short and Nekles1998). It is possible that these changes have contributed to the very low abundance of natural scallops. During 2003 and 2004, dissolved oxygen concentrations were monitored at a site within Ninigret Pond using a submersible data logger. Results indicated large diurnal fluctuations in oxygen concentrations including periods of very low dissolved oxygen (URI-GSO Coastal Habitat Research website, K. Ford, personal communication). Demonstrating the occurrence of low dissolved oxygen levels highlights this as a potential limitation to sustainable scallop populations. The tolerance of juvenile scallops to prolonged hypoxic conditions was tested in 2005, and juvenile bay scallops were found to be tolerant of hypoxia to 1.4mgl^{-1} dissolved oxygen for up to 96 hours (Hancock *et al*. 2006).

1.1 Bay Scallop Surveys

Introduction

Bay scallops are a short-lived species that generally only survive for two years, one year of growth and a second year in which they reproduce (Sastry 1970). Scallops seeded into Ninigret Pond in fall 2004 were thus no longer directly relevant to the 2006 survey. Conducting the surveys early in the season meant that the newly settled scallops in 2006 were not yet likely to be large enough to be detected by divers. Consequently, the scallops surveyed in 2006 quantified the settlement of juveniles that were recorded during the spat settlement monitoring in 2005. A caged spawner sanctuary had not been implemented in Quonochontaug Pond prior to 2006. Dive surveys conducted in Quonochontaug Pond were completed to develop a baseline estimate of natural abundance, thus providing a reference to determine the contribution of scallops resulting from restoration methods implemented in 2006.

Objective

The objective of the 2006 bay scallop surveys was to determine the abundance and spatial and temporal distributions of scallops entering their second season in Ninigret Pond and Quonochontaug Pond.

Methods

The 2006 scallop dive surveys were conducted as stratified random transect surveys in late May, June and July. The primary level of stratification was by habitat type, as determined using information from previous habitat surveys (Constas *et al*. 1980, Hancock *et al*. 2007, Mapcoast website, pers. obs.) and included sand/gravel bottom type, generally in the shallow water areas (<1.8m mean low water), and silt/mud, typically in the deeper water areas (>1.8m mean low water).

Randomized transect locations were generated using GIS software (MapInfo Professional v. 7.0, Troy, NY) to create a grid over each stratum on a nautical chart (Figure 2). The grid size was 0.1 x 0.1 minutes of latitude and longitude used for both ponds. Each intercept of the grid was numbered, and intercept numbers were randomly selected to define the starting points for each survey transect. Survey transects were laid out in a north-south orientation. GIS software was used to convert each stratum into polygons to gain accurate estimates of area of each stratum and total pond area. Total survey area for each pond was 6,222,373m^2 and 3,071,847m^2 for Ninigret Pond and Quonochontaug Pond, respectively (Table 1). Stratum areas varied in size from 228,160m^2 to 1,748,259m^2 in Ninigret Pond and 295,457m^2 to 1,260,298m^2 in Quonochontaug Pond (Table 1).

All dive transects were 50m long, using lead line to hold them on the bottom and attached to end floats to mark their location at the surface. Each transect was searched by a pair of divers sampling a 1-m wide strip on each side of the transect line, resulting in a 100 m^2 area surveyed per transect. Divers carried a 1m long measuring bar to determine accurately if scallops were within each search area. The mean number of scallops m^{-2} (±SE) was calculated and extrapolated to an estimated abundance per stratum (±SE) using the total area of the stratum.

Results

A total of 80 transects were surveyed in the six strata in Ninigret Pond, a total survey area of 8,000m^2, while a total of 39 transects were completed in Quonochontaug Pond, a total survey area of 3,900m^2 (Table 1). In Ninigret Pond, the total estimate of scallop abundance was 192,269 ±96,504, a 158 % increase over the abundance estimate of the 2005 population. The greatest numbers of scallops were found in the Northern stratum of the Western Basin (88,616 ±34,858), in the Southern stratum of the Western Basin (68,473 ±43,968) and in the Central stratum of the Western Basin (34,379 ±16,877). No scallops were found in any of the other areas of Ninigret Pond, except a single scallop in the Central Basin, which extrapolates to an estimated abundance of 801 scallops and standard error of ±801 (Table 1).

The total estimated scallop abundance in Quonochontaug Pond was 2,790 ±1,644. This is an extrapolation from a total of 4 scallops all found in the Outer Sand stratum of the Eastern Basin.

Habitat monitoring

During the 2006 scallop surveys of Ninigret Pond, habitat characterization was conducted as a student project under the Hollings Fellowship program. The project was to enable collaborative use of the survey data between the *North Cape* Shellfish Restoration Program and the U. S. Environmental Protection Agency's scallop habitat modeling project at the Atlantic Ecology Division. A component of this work was measurement of water salinity, sediment grain size, vegetation cover and predator numbers along each survey transect. Surveys were conducted between May 30 and July 16, 2006. Bottom salinities in the Western Basin ranged between 21‰ and 27‰; in the Central Basin, between 21.5‰ and 31‰; in Fort Neck Pond, between 19‰ and 26‰; and in Foster Cove between 16‰ and 21‰ at the time each transect was surveyed.

Discussion

In 2006 all areas of Ninigret Pond were surveyed. In 2005 only the strata within the Western Basin were surveyed. In 2006 the additional areas surveyed contained few or no scallops. The complete survey conducted in 2006 provides a more robust assessment of broodstock abundance throughout the entire pond and between strata, and this survey also supports the estimates derived from the less extensive survey in 2005.

Quonochontaug Pond was divided into four strata, and the entire pond was surveyed in 2006. These baseline scallop abundance estimates gathered prior to restoration efforts in 2006 will provide the basis for estimating of the change in scallop abundance resulting from the restoration effort. The abundance estimate for scallops in Quonochontaug Pond are derived from a total of 4 scallops observed in the 3,900 m^2 surveyed, making this an estimate with wide error margins (2,790 ±1,644).

1.2 Bay Scallop Spawner Sanctuary

Introduction

Scallop populations have been demonstrated to be limited by a lack of larvae in situations of low broodstock abundance (Peterson *et al.* 1996), making enhancing the supply of larvae a priority for restoration. In 2004, a caged spawner sanctuary was adopted as an alternative approach to the direct seeding of scallops. A spawner sanctuary enhances the supply of larvae to a release site by protecting broodstock from predation, better ensuring that their maximum spawning potential is realized. Broodstock surveys and scallop recruitment monitoring results have revealed the success of this method in providing increased numbers of scallops in Ninigret Pond. Due to the continued success of the spawner sanctuary approach, this method was implemented in Quonochontaug Pond in 2006.

Objectives

The objective of the caged spawner sanctuary project was to enhance the recruitment of bay scallops to Quonochontaug Pond by protecting broodstock in mesh spawner cages.

Methods

Scallop broodstock being installed into spawner sanctuary cages in Quonochontaug Pond, 2006

In 2006, *North Cape* staff deployed and maintained 64 wire cages containing 21,450 adult bay scallops in Quonochontaug Pond. Cages were deployed on June 30, July 6 and July 7 and were monitored periodically until retrieval in November 2006. Cages were approximately 75 x 75cm, made of 5cm (2 inch) plastic-coated wire mesh. Four tiers in each cage held four plastic 13mm (1/2 inch) mesh bags, each containing ~380 mature, hatchery-reared 1+ year class scallops. The scallop spawning sanctuary was located at 41° 20' 10.9"N, 71° 44' 17.4"W in an area with a water depth of ~1.8m at MLW (Figure 3). Site location was based on suitable habitat, estuarine flow dynamics, historical scallop production, and the pattern of boat usage in Quonochontaug Pond. A permit for the equipment was secured from the Rhode Island Coastal Resource Management Council. A service platform was built for deployment and retrieval of the spawning cages. Spawning events were determined by analysis of spat collectors placed in the vicinity of the spawning cages and other locations in the pond (Figure 3).

Results

A total of 21,450 adult bay scallops were held in the cages of the shellfish spawning sanctuary during the potential scallop spawning season. The scallop broodstock were in their second year with percent survivorship expected to be very low beyond the 2006 season. Scallop survival at the end of September 2006 was 8.9% ± 1.7%. Monitoring of spat in the pond indicated an initial spawning in mid July, continuing through to early October.

1.3 Monitoring Recruitment: Bay Scallop Spat Collection

Introduction

The *North Cape* Restoration Program aims to establish self-sustaining populations of bay scallops in Rhode Island's South County salt ponds. To demonstrate the performance of the project, abundance monitoring of mature scallops in the ponds targeted for restoration was done. Monitoring the relative abundance of settling spat provides an alternative independent measure of the success of the larval and post-larval life history stages. This is critical to identifying the life history stage responsible for variations in cohort abundance as the dynamics of the different life history stages is not necessarily coupled (Orensanz *et al.* 2006). Monitoring recruitment also provides the ability to relate the abundance of spat to the abundance of mature scallops the subsequent year. This relationship provides the basis for using settlement measures to predict the abundance of the mature year class, one year in advance.

Objectives

The objectives of this program were to use spat collectors to monitor the relative abundance of scallop spat settling in Ninigret Pond and Quonochontaug Pond, to determine the variation in abundance of spat settling in four study areas, and to document the approximate timing of spawning/settling events.

Methods

Spat collector arrays were deployed at four study sites each in Ninigret Pond and Quonochontaug Pond and monitored between June and November 2006. Deployment locations were selected based on tidal flows and wind patterns to provide information on the distribution of scallop settlement. In Ninigret Pond, Array 1 was located off Hall Point (41° 21.37′N, 71° 40.00′W) in ~1.2 – 1.5m water depth at MLW. Array 2 (West End) was located in the west end of the pond (41° 21.22′N, 71° 41.43′W) in ~ 1.5 – 1.8m water depth. Arrays 3 and 4 were located in the central basin of Ninigret Pond. Array 3 (Aqualease) was located near and aquaculture lease to the north of the central basin (41° 21.98′N, 71° 38.95′W) in 0.9 – 1.5m water depth. Array 4 (Breachway) was near the entrance to the Charlestown Breachway (41° 21.82′N, 71° 38.62′W) in 0.9 – 1.5m water depth. Tidal exchange was most significant at this site, being in close proximity to the pond opening to Block Island Sound.

Spat bag arrays were also moored in Quonochontaug Pond at four sites. Array 1 was in the area of the spawner sanctuary (Spawner Sanctuary) (41° 20.25′N, 71° 44.33′W) in ~ 1.8 – 2.0m water depth. Array 2 was placed in the west end of the pond (West End) (41° 19.95′N, 71° 44.95′W) in ~ 0.6 – 1m water depth. Array 3 was placed west of Bill’s Island (Bill’s Island) (41° 20.53′N, 71° 43.16′W) in ~ 1.2 – 1.8m water depth. Array 4 was placed in the north east corner of the pond (East End) (41° 20.93′N, 71° 42.96′W) in approximately 0.9 – 1.5m water depth (Figure 3).

Single spat lines were deployed to each study site every second week, beginning in June. Each line consisted of six artificial spat collectors (42 x 75cm with 0.75 to 1mm mesh) stuffed with plastic mesh (Netron) and rigged on 3.8m-long floated long-lines (Figure 4). Bags were collected after ~30 days at liberty, and analyzed by rinsing the contents through a 1mm mesh sieve before collecting the scallop spat. Some temporal overlap exists between the collections. Two lines of spat bags were maintained at each site and bags were deployed for approximately 30 days. Bags from alternating lines were collected approximately every two weeks. Functionally, this overlap was less than two weeks, as it generally required several days for the surface of the mesh within each bag to accumulate a 'biofilm' and become attractive as a settlement substrate for the scallop larvae (See Cragg 2006, and Parsons and Robinson 2006). Collections were conducted over a 22-week period to evaluate scallop settlement patterns at the four array sites. Sites were compared by examining the mean number of scallops per bag. The mean number of scallops per bag was converted to settlement indices (SI) to compare spat settlement for each pond, per year. Settlement indices were used to examine spat recruitment potential in relation to available broodstock from year-to-year. SI = Σ mean spat per bag, per site, for the n collections per year

Results

The first spat lines were deployed on June 19, 2006 and June 26, 2006 in Ninigret Pond and Quonochontaug Pond, respectively. The last bags were collected on November 20, 2006 and November 27, 2006, in Ninigret Pond and Quonochontaug Pond respectively. In Ninigret Pond, a total of 175 artificial spat collectors were deployed on eight lines, two at each of the four study sites, yielding a total 213 spat. The highest number of spat was recorded from the Breachway (153 spat) followed by the Aqualease (48 spat) (Table 2).

Scallops collected from Quonochontaug Pond during 2006

The major settlement events in Ninigret Pond occurred sometime between August 8th and September 8th in the central basin of the pond, as indicated by the mean spat per bag values (Table 2). This settlement was not nearly as pronounced in the western arm of the pond. Three smaller settlement events occurred between September 19th and October 26th, primarily in the central basin. Only one scallop was found in the western basin, with seasonal settlement index of 0.2. Hall Point, despite having a low settlement index, 1.8, had a relatively consistent number of spat found on each collection. The central basin (Breachway and Aqualease), primarily demonstrated the greatest number of spat fall. The Breachway and Aqualease demonstrated settlement indices of 25.5 and 7.8, respectively. The seasonal settlement index for the cumulative pond monitoring was 35.3, considerably lower than the settlement index for Ninigret Pond in 2005, which was 137, and resembled the settlement index of 32 in 2004, the first year using the caged spawner method (Figure 5).

A total of 168 artificial spat collectors were retrieved over seven collection periods at each of the four study sites in Quonochontaug Pond, yielding a total of 311 spat. The greatest number of spat was recorded from the west end of the pond (118 spat), followed by Bill's Island (106 spat), the spawner sanctuary (52 spat), and lastly the east end of the pond (35 spat) (Table 2).

Two major settlement events occurred in Quonochontaug Pond. The first occurred sometime between August 17th and August 30th, with the greatest number of mean spat per bag being found in the western end of the pond (Figure 6). The second occurred between August 30th and September 12th, with the greatest number of mean spat per bag found at Bill's Island. The West End and Bill's Island had similar seasonal settlement indices, 19 and 17, respectively. The Spawner Sanctuary and the East End had seasonal settlement indices of 9 and 6, respectively. The seasonal settlement index for the cumulative monitoring of Quonochontaug Pond in 2006 was 50.

Discussion

Mean spat per bag values provide a measure of recruitment standardized for variation in the number of bags retrieved at each collection, while the number and timing of collections has remained consistent. The settlement index has been calculated for Ninigret Pond (Figure 5) since the caged spawning sanctuary method was incorporated in 2004. Figure 5 provides a whole project scale summary of the restoration in Ninigret Pond over the 3 years through 2006. Caging relatively few broodstock, and thereby maximizing the reproductive output, was successful in establishing a population in Ninigret Pond during 2004 and 2005, however results for 2006 are more complex. In 2004 and 2005, scallop settlement was predominately found in the western basin. In 2006, however, settlement was predominantly in the central basin. The lower than expected settlement in Ninigret Pond in 2006 corresponds to a number of unusual environmental conditions noted during this period. During 2006 a mass mortality of experimental scallops as part of an USEPA project occurred in the central basin and Fort Neck Pond (Chintala and Weisberger, personal communication). This probably resulted from low surface water column salinities associated with an unusually high summer rainfall, and the associated water density stratification leading to low oxygen concentrations in bottom waters. Also, northern bay scallop larvae do not develop in salinities less than 15‰, and development is seriously compromised in salinities of less than 20‰ (Tetelbach and Rhodes 1981). In any areas where stratification caused by a surface layer of low salinity water resulted in a hypoxic layer below the halocline, there would be no refuge for scallop larvae. In areas where mixing was sufficient to mix the surface fresh water, such as the more exposed western basin, there is evidence that the amount of fresh water during 2006 was sufficient to lower the salinity throughout the water column (See scallop surveys, Section 1.1). This would result in conditions tolerable to the more robust adult scallops but not suitable for larval development. Conversely, the pond area less susceptible to low water salinities and more likely incurring water column mixing would be the central basin near the breachway, where mixing with full-salinity Block Island Sound occurs.

The 2006 results suggest that water quality in Ninigret Pond may be marginal for scallop restoration. Based on previous year's results, the approximately 200,000 broodstock in the western basin would be predicted to produce a higher spatfall than was observed in 2006. The highest spatfall would be expected in the western basin, the location of the broodstock, rather than predominantly in the central basin, distant from the location of the broodstock but in the area closest to the breachway, the source of oceanic water. These observations, combined with the 100% mortality of caged scallops in all but the western portion of the western basin (Chintala and Weisberger, personal communication), suggest an environmental basis for the low survival of both larvae and adults. The environmental variables responsible are probably low salinities and hypoxia, promoted by density stratification with the surface fresh water. Bay scallops have been demonstrated to only be sensitive to extended periods of hypoxia **(**VanDam 1954, Voyer 1992, Hancock *et al.* 2005), and the period of hypoxia in Ninigret Pond in 2006 may have been prolonged, resulting in higher scallop mortality.

Settlement of scallop spat in Quonochontaug Pond was strong in 2006, despite the high rainfall (Figure 6). Quonochontaug Pond is characterized by a centrally located, deep breachway, and lower freshwater input from streams. As a result, the pond is less affected by periods of high rainfall. Comparing results from Ninigret and Quonochontaug Pond suggests that water quality is a critical consideration for scallop restoration, and ponds with higher flushing rates may be the best candidates for future work.

II. Oyster Projects

2.0 Introduction

The *North Cape* Restoration Program has focused on creating a supply of breeding adults to areas of suitable habitat. The suitability of the sites for oyster restoration was initially assessed in relation to substrate, hydrodynamics, fishing history, and the presence and abundance of predators and diseases (Holly *et al.* 2004). Once candidate sites were selected, the approach to oyster restoration varies depending on the number of oyster larvae that are likely to be available in the area (Takacs *et al*, 2005). In Rhode Island, populations of native oysters now persist in only a few discrete locations, so at the restoration sites broodstock has been introduced to generate the reproductive output needed to promote recruitment to the populations.

Broodstock for the *North Cape* oyster restoration project has been grown from larvae using the remote setting technique (Jones and Jones 1988, Kennedy 1996), with hatchery-produced larvae being transported to the Coastal Fisheries Laboratory for setting, subsequent nursery growout, and final seeding to restoration sites. This technique has been used in previous years and was again expanded in 2006. Weathered shell cultch was bagged as a substrate for setting larvae. The bags of cultch with newly settled spat were then transferred to trays and placed in a nursery in the lower inter-tidal zone of Pt. Judith Pond for grow-out. Following approximately five months of husbandry in the oyster nursery, the trays were sampled to determine the mean size and number of juveniles. The juvenile oysters were then transported and seeded at the selected release sites, as discussed in the following section. The expanded remote set and nursery phase of the broodstock production relied heavily on the participation of an active and dedicated volunteer group.

Annual monitoring of each restoration site has been undertaken to determine the survival and growth of the seeded stock, and annual monitoring of the presence and level of disease pathogens has provided insight into the potential mortality due to disease. Recruitment to the restoration sites has been inferred from the population structure obtained from annual surveys, and from monitoring recruitment to both natural substrate and settlement collectors placed at each restoration site.

2.1 Oyster Remote Setting

Objective

The objective of the remote set was to provide large numbers of settled oyster spat for placement into a nursery area where they would be grown for a season prior to transfer and release to oyster restoration sites.

Methods

Remote setting of oyster larvae was done using natural weathered shell as a settlement substrate. Shell cultch material for the 2006 remote set was provided by Blount Seafood, Warren, RI. The cultch consisted almost entirely of surf clam shell (*Spisula solidissima*). The shells were broken up to provide shell fragments within a size range of approximately 4.0 to 7.5cm maximum length. A 3.8cm mesh sieve was used to sift out small shell fragments. The cultch was then placed into ~45cm long by 20cm wide tubular polyethylene net bags and sealed at both ends with hog rings. Removing the small fragments of shell provides a shell bag that packs sufficiently loosely to allow water and larvae to access to the interior of the bag during setting, taking advantage of available surface area. Using shell fragments of a medium size range provides settling oyster larvae with the maximum surface area of substrate, and reduces the tendency for large numbers of oysters to settle on any one fragment with a potentially high subsequent mortality due to competition. A total of 1,586 shell bags, each containing approximately 8 to 10 litres of shell

Large setting tank partially stacked with shell bags cultch, were assembled. They were soaked in holding tanks, power-washed, and air dried in preparation for remote setting. Preparation of cultch and shell bags is labor intensive and was made possible by the efforts of numerous volunteers from the *North Cape* volunteer program.

Oyster larvae were purchased from Muscongus Bay Aquaculture Inc., Bremen, ME, transported to the CFL on ice, and introduced into two closed-circulation setting tanks containing cultch bags. This process was repeated for four separate sets at the CFL. The swimming eyed-larvae settled on the cultch within 48-72 hours of being introduced into the tanks. The large setting tank (big tank) was 3.0m x 1.5m x 0.8m, and contained approximately 216 bags arranged on a PVC rack with two levels, each level supporting two layers of shell bags. Dimensions of the second setting tank (small tank) were 3.7m x 1.25m x 0.5m; this tank contained a rack with only one level supporting approximately 160 bags in two layers. Aeration pipes were placed under the racks on the bottom of each tank.

Results

During the 2006 season, four batches of approximately 6.25 million larvae each were set to shell cultch. Upon arrival to the CFL, each batch was divided into two portions; approximately 3,750,000 eyed-larvae were introduced into the large tank, which contained approximately 216 shell bags for each set, and approximately 2,500,000 eyed-larvae were introduced into the small tank, containing approximately 160 shell bags for each set. Actual total number of shell bags in all four sets was 1,586 bags. The number of larvae put into each tank was proportional to each tank's total number of bags as well as its total volume, resulting in a release of approximately 16,500 larvae/shell bag in each tank. The four remote sets took place on June 15, June 27, July 7 and July 17. Larvae were fed a larval shellfish algae diet twice daily, and the tank water was changed daily. Water temperature was maintained at 24°C (Jones and Jones 1988). After being in the tanks for 48 – 72 hours, the larvae settled onto the shell cultch and were ready to be transferred into the intertidal nursery in Pt. Judith Pond along the CFL facility. The abundance and number of settled spat was not determined until later in the season during the nursery grow-out phase due to the substantial time required to assess spat measuring approximately 200µm.

2.2 Oyster Nursery

Objective

The objective of the oyster nursery is to foster spat growth during their first season, while protecting them from predation, thereby increasing the size, condition and subsequent survival rate of the oysters once they are seeded into the restoration sites.

Methods

The 1,586 shell bags containing the newly settled spat were placed in covered plastic trays (0.9m x 0.9m x 10cm). Each tray was lined on the bottom by 6.0mm mesh, and filled with six or seven shell bags. The trays with bags were placed on 61 steel re-bar racks (3m x 0.8m x 0.5m) to minimize bottom predators, and set at or below mean low water at the CFL beachfront nursery. During the grow-out period, the number of shell bags was reduced to four per tray, with the shell bags opened and emptied directly into the trays to reduce overcrowding. The spat in the trays were sampled to obtain estimates of size and abundance of oyster spat prior to release.

Results

In 2006, approximately 1,928,000 oysters were produced on 1,586 bags of shell. Overall survival rate for all four sets was 8% from the eyed-larvae stage to the time of seeding. Set 1 produced an estimated 683,831 oysters with a mean survival of 11%. Set 2 produced 820,293 oysters with a mean survival rate of 13%; set 3 produced 37,152 with a mean survival of 0.6%; set 4 produced 386,684 with a mean survival of 6% (Table 3). 'Overset' of a subsequent spat cohort, on top of the remotely set spat was observed during sampling. This was likely provided by a natural spawning of broodstock in Pt. Judith Pond, primarily oysters lost from the nursery trays during previous years. An attempt was made to differentiate natural spat from remote-set spat when sampling. Natural spat were differentiated by the obviously smaller size, and from when they settled on the shells of larger spat, indicating the natural set occurred after the shell bags were placed in the nursery.

Oyster spat on cultch prior to opening the bags

Size distributions for both tanks in each set are provided in Figure 7. An increased abundance of larger oysters (>20mm) is apparent in sets 3 and 4. The mean length of oysters from sets 1, 2, 3 and 4 from the nursery was 13.6±0.1mm. The mean length of oysters from the *North Cape* upwellers was 24.6±0.6mm and 22.6±0.5mm from the CFL and Camp Fuller upweller locations, respectively. Mean lengths (±SE) of each set by tank and grow-out treatment is shown in Table 4.

Discussion

The four remote sets conducted at the CFL in 2006 successfully provided the *North Cape* Shellfish Restoration Program with nearly two million oyster spat. The anticipated goal for the 2006 season was 1.5 million spat. The overall survival of eyed-larvae to seeding was 8%. This figure is an under-representation of the actual number of oyster spat present on the cultch. Evidence of natural recruitment to the cultch in the nursery was documented during the grow-out season. An effort was made to differentiate natural spat and remote-set spat during sampling; otherwise the inclusion of naturally set spat would have lowered the estimation of length frequency and increased estimates of abundance of spat gained via remote setting.

An increased abundance of larger oysters (>20mm) is apparent in sets 3 and 4. This is likely due to the lower survival rate of oysters to the time of seeding in those sets. The lower abundance of living oysters most likely provided less competition, resulting in increased growth rate for the surviving animals. The low survivorship of set 3 oysters could not be readily attributed to any specific variables that differed from the other sets. It is possible that set 3 was exposed to an unsuspected contaminant or deleterious environmental condition, or was a weaker cohort of larvae.

The efficiency of using floating upweller systems for grow-out can be seen from the comparison of mean size of the same group of oysters grown in the nursery and upweller (Figure 8). The oysters in the upwellers were provided greater access to food due to the high water flow-through in the upwellers, maintained with flow pumps. Better nutrition resulted in larger oysters than those found in the nursery trays at the CFL with natural flow. The increased growth will optimally translate into increased survival, as the oysters enter the first winter with a higher energy reserve. This improved survival comes at the cost associated with increased labor for service and maintenance of the upweller. Oysters in the upweller were cleaned at least twice every three weeks during the season.

2.3 Monitoring of Oyster Release Sites

Objective

The objective of the monitoring project was to estimate the mean size and abundance of the oysters planted at restoration sites in the fall of 2003, 2004, and 2005, and to compare the mean size and abundance information at the time of seeding with information recorded from the 2004 and 2005 monitoring to determine the growth and mortality of the oysters at each site.

Methods

Six oyster restoration sites established in 2003, 2004 and 2005 were sampled using random $1m^2$ quadrats. The release sites were small enough in spatial scale and of sufficient density to make $1m^2$ an effective quadrat size. Site boundaries were reestablished using a handheld Garmin 12 Global Positioning System and by diving to determine the limits of oysters seeded in previous years and adjusting area boundary marks, accordingly. The seeded area boundary was then marked with surface floats. The seeded sites were marked in the same geometric shapes used for seeding, and the dimensions of each were re-measured using a 100m tape, ensuring the area surveyed was accurately calculated. The total abundance (±SE) of oysters within each seeded site was estimated from mean densities sampled, using total area as a basis for extrapolation. All oysters sampled were enumerated and measured to separate cohorts for collecting survival and growth data.

True 'randomization' of the quadrat locations would require creating a grid system and placing quadrats at pre-determined randomly selected locations. This process posed logistical difficulties, which outweighed the potential benefit derived. Instead, boats traveled an approximate grid along the axis of the seeded sites, throwing quadrats to provide a haphazard, unbiased distribution. Each quadrat was marked with a float, and divers or waders returned to the quadrats to collect all oysters within the quadrat for measuring.

Results

Between August 8 and September 7, 2006, dive teams surveyed $288m^2$, using $1m^2$ quadrats, at the six locations where oysters were released in 2003, 2004 and 2005 (Figure 1, Table 5). Smelt Brook Cove had the highest estimate of live oysters (Table 5, Figure 9), however, the abundance estimates for Saugatucket River, Smelt Brooke Cove, and The Cove sites have high standard errors, resulting in no significant difference between these estimates at the $\alpha = 0.05$ level (Figure 9). Smelt Brook Cove and Saugatucket River are the only two sites that were seeded consecutively in 2003, 2004 and 2005. The Cove and Potter Cove sites were seeded in 2003 and 2005. Bissel Channel and the Bissel Cove Deep site had a considerably lower number of live oysters than the other four sites. Bissel Channel was seeded in 2003 and 2004, while the Bissel Cove Deep site was seeded only in 2004.

The size distribution of the first year cohort seeded in 2005 was sufficiently discrete from the second and third year cohorts seeded in 2003 and 2004 to allow for analysis of survival of the first year oysters versus the second and third year releases (Figure 10). Figure 9 clearly demonstrates that the composition of oysters at each site is composed of mainly first year oysters. First year survival of seeded oyster spat historically has been greatest at the Saugatucket River site (Figure 11). First year survival of the 2005 cohort release to the Saugatucket River in 2006 was 18%, followed by The Cove and Smelt Brook Cove sites (12% and 11%, respectively); Potter Cove had the lowest survival rate of first year animals in 2006 (7%). Despite considerable changes in first-year survivorship at each site, year-to-year, the sites have maintained a similar performance ratio in each year relative to each other. The first year survivorship of the 2005 cohort is comparable to the survival of the first year survival of the 2003 cohort. Both cohorts have considerably lower first-year survival than the 2004 cohort (Figure 11).

By 2006, the length distribution of second and third-year cohorts seeded in 2003 and 2004 have overlapped such that distinguishing between the cohorts became difficult (Figure 10). The proportion of oysters surviving to their second and third years is greatest in Bissel Cove Deep and The Cove (97% for both, Figure 12). Bissel Channel and Smelt Brook Cove had the next greatest survival of second and third year animals (57% and 52%, respectively). Potter Cove and the Saugatucket River had considerably lower rates of second and third year survival (25% and 4%, respectively, Figure 12). These results for each site are not consistent with the results from the 2003 cohort surviving from 2004 to 2005. In relation to the second year survival of the 2003 cohort, the Saugatucket River had the greatest survivorship (121%), followed by Bissel Channel (104%), Smelt Brook Cove (73%), The Cove (32%), and Potters Cove (31%) (Figure 12). The length distribution of oysters at the Bissel Channel site appears stepped at 75mm (Figure 13), about the legal harvest size (76mm or 3 inches).

Mean size of oysters after one year of growth (Figure 14) suggests distinct differences between oysters seeded in 2004 versus oysters seeded in 2003 and 2005 in the same area. Surveying months, however, were not consistent year to year. The 2004 cohort was sampled in late June/early July of the following year, while the 2003 and 2005 cohorts were sampled in late August, most likely accounting for the smaller observed size of the 2004 cohort after one year. First year growth can be compared at three sites (Smelt Brook Cove, The Cove, and Potter Cove) that were seeded in 2003 and 2005. No notable difference in first year growth was detected within or between sites for the 2003 and 2005 cohorts. The exceptionally high first year growth witnessed in the Saugatucket River for the 2003 cohort is due to the fact that these oysters were already 1+ year old single oysters seeded at this site in 2003.

Discussion

The first year survival of the 2005 cohort was comparable to the first year survival of the 2003 cohort (Figure 11). The substantially higher survival rates of the 2004 cohort are likely due to environmental variation between seasons as the same genetic stock was used for 2004 and 2005, and related stock was used in 2003. The high 2004 survival of the Saugatucket River site is an artifact of strong recruitment at this site in 2004 (Hancock *et al.* 2005). The similar first year survivals of the 2003 and 2005 cohorts support previous conclusions (Hancock *et al.* 2005) that the survival of the 2004 cohort was high.

The Saugatucket River continues to demonstrate the greatest first year survivorship of seeded oysters. Previous annual reports (Hancock *et al.* 2005 and 2006) comment on the high first-year survival of the 2003 cohort, and considerably higher survivorship of the 2004 cohort in this site, and suggest it is a result of seeding a mixed cohort in 2003 (with larger animals), and a resulting natural recruitment to the site being indistinguishable from the oysters seeded in 2004 (as sampled in 2005). The considerably higher first year survivorship of the 2005 cohort compared to the other four sites emphasizes the high success of first-year animals at the Saugatucket River site. Smelt Brook Cove, The Cove and Potter Cove also produced good survival of juveniles for the first year at liberty. The first-year annual survivorship of oysters has varied considerably within each site, but the relative performance of each site has remained fairly consistent between years. This emphasizes the importance of thorough early planning and site screening, targeting restoration sites to achieve maximum potential from seeded oysters. It also suggests that environmental factors may control oyster seeding success on a year-to-year basis, but that variations in conditions may affect all areas to a similar degree.

Second and third-year survival of 2003 and 2004 cohorts surviving to 2006 (Figure 12) was highest in The Cove and the Bissel Cove Deep sites, despite the Bissel Cove Deep site having the lowest first-year survivorship for the one year that this site was seeded (2004). The reason for the increased survival at The Cove is not apparent. The Saugatucket River site demonstrated the lowest survival of second and third-year oysters between 2005 and 2006, despite having the highest first-year survival of all cohorts, and an exceptionally high second-year survival of the 2003 cohort to 2005. This dramatic decline in the survival of the older cohorts may be the result of an exceptionally wet summer lowering water salinity at the site below 5ppt (Perry Raso, personal communication) combined with increased incidence of Dermo disease, an endemic disease in Rhode Island (See section 2.5). The level of Dermo infection generally increases with age, as does the associated percent mortality (Encomio et al. 2005). Disease sampling in previous years suggested that the Saugatucket River was supporting substantial pathogen loads. *North Cape* scientists and shellfish pathologists could not explain the apparent contradiction of the high disease load and very high survival of oysters in 2005 (Hancock *et al.* 2006). The accumulated disease load, plus the increased stress from low salinities likely caused the low survival in 2006. The Dermo load at Smelt Brook Cove has also been high (See section 2.5), but the survival of the older cohort at Smelt Brook Cove was similar in 2005 and 2006 (Figure 12) indicating that these oysters have not yet been substantially affected by Dermo. The survival of the older cohort in the Bissel Channel was similar to Smelt Brook Cove in 2006 (approximately 60%), but considerably lower than the survival of oysters from 2005. Heavy fishing pressure in Bissel Channel is the likely cause for the decreased number of oysters (Figure 13).

2.4 Oyster Release

Objective

The objective of the oyster release project is to continue efforts to build the future reproductive capacity of restored oyster populations in Rhode Island waters by relaying juvenile oysters from the nursery at the RIDEM CFL to the restoration sites in Narragansett Bay and South County coastal salt ponds.

Methods

Before oysters were transferred from the nursery to the release areas, they were first tested for diseases including Dermo, MSX, and histological indicators of pathology. The disease-free oysters were carried in trays from the CFL nurseries to the predetermined release sites by boat and truck. Six sites have been seeded since 2003. In 2003, five sites were seeded; Saugatucket River, Smelt Brook Cove, Bissel Channel, The Cove-Portsmouth, and Potter Cove. Four sites had been seeded in 2004; Saugatucket River, Smelt Brook Cove, Bissel Cove Deep site, and Bissel Channel. In 2005, four sites were seeded; Saugatucket River, Smelt Brook Cove, The Cove-Portsmouth, and Potter Cove. In 2006, all of the sites were seeded except for the Bissel Cove Deep site (Table 6).

Prior to seeding the oysters, the restoration site was marked using floats to clearly delineate each site. Because some of the seeding sites were not simple geometric shapes, the area was broken down into smaller sub-areas of easily delineated geometric shape, so the length of the boundaries could be easily measured and the areas seeded accurately determined. The number of oysters released into each geometric section was proportional to the area of that section. Oysters were distributed evenly throughout the entire area. In 2007, the restoration sites will continue to be monitored to determine long-term survival, growth and disease prevalence as well as observation of bed stability, siltation and predation.

Results

In November and December of 2006, approximately 2 million juvenile oysters were seeded in five sites. Oysters were seeded into Smelt Brook Cove in Pt. Judith Pond on November 15 and December 7; Saugatucket River in Pt. Judith Pond on November 21 and December 7; Bissel Channel, North Kingstown on November 28; The Cove, Portsmouth on November 30; and Potter Cove, Prudence Island on December 5th. Overall mean size ±SE of seeded oysters from the CFL nursery was 13.6 ±0.1mm, oysters from the CFL upweller were 24.6 ±0.6 mm , and oysters from the Camp Fuller upweller were 22.6 ±0.5mm. The Saugatucket River received ~29% of the total oysters (~575,600), Bissel Cove received ~23% (~439,400 including all the oysters from the CFL upweller), Smelt Brook Cove received ~22% (~425,600 including all the oysters from the Camp Fuller upweller), Potter Cove received ~15% (288,800), and The Cove received ~11% (~222,400) (Table 6).

2.5 Disease Monitoring

Objective

The objective of the disease monitoring of restoration sites was to monitor the pathogen loads in the seeded populations and to assess the impact of pathogens on the success of each site.

Methods

Samples of 30 oysters were taken from each of five sites seeded; Saugatucket River, Smelt Brook Cove, Bissel Channel, The Cove, and Potter Cove, to determine abundance of the *Perkinsus marinus* parasite, the pathogen responsible for the disease Dermo, and to test for the presence of other molluscan pathogens. Samples of 30 oysters were taken from the oldest cohort (largest oysters) available at each site. These samples were transported on ice to Micro Technologies Inc, Richmond, ME. Pathology tests were performed and the results were provided to the *North Cape* Shellfish Restoration Program prior to seeding. The prevalence of the Dermo disease was rated using a Mackin Index; a scale of 0-5 where 0 is no infection and 5 is a heavy infection.

Results

No pathogens were observed in the nursery stocks tested. Oysters from the 2003 and 2004 cohort at Saugatucket River and Smelt Brook Cove exhibited 100% prevalence of Dermo and were assigned the highest Mackin indices; 5 and 4, respectively, indicating heavy and moderate-to-heavy disease loads. The Cove-Portsmouth tested third highest with 40% of the oysters testing positive and a Mackin Index of 1 (light). Bissel Channel also received a Mackin Index of 1, but only 10% disease prevalence. Potter Cove samples did not exhibit any signs of disease and therefore the site was given an index of 0 (Table 7).

Discussion

The level of Dermo infection generally increases with age, as does the associated percent mortality (Encomio et al. 2005). The Smelt Brook Cove site has exhibited moderate to high pathogen loads since 2004 (Table 7). Continued high survival of this population suggests potential Dermo-resistent animals (Takacs *et al.* 2005), or particularly favorable environmental conditions providing oysters the ability to grow well, despite high disease loads. From the poor survival of second and third-year oysters from 2005 to 2006, it appears that with increased age, size and subsequent disease load, Dermo has begun to cause higher mortality. At the Saugatucket River site, the very low survival of the 2003/2004 cohort (Figure 12) is likely due to Dermo in combination with anomalously low estuarine salinities (see section 2.3). The same cohort at Smelt Brook Cove, the site with the second highest pathogen load, was not incurring high mortalities due to disease. The slight decrease in the percent prevalence of Dermo at The Cove and Potter Cove sites and the decreased Mackin index at Potter Cove site between 2005 and 2006 may indicate a decline in the prevalence of parasites in the northern sections of Narragansett Bay during this period.

2.6 Recruitment Monitoring

Objective

The objective of recruitment monitoring is to document the occurrence of spat settling in the area of the restoration sites, and to obtain relative measures of the size and timing of recruitment events attributed to the oyster restoration project.

Methods

Recruitment of oyster spat in the vicinity of the seeded sites was monitored using two types of spat collectors. Artificial spat collectors were made of five pieces of Hardibacker® ($10cm^2$ x 1.3cm thick), a cellulose and cement mixture, separated by 1cm thick spacers (PVC tubing). The Hardibacker® material and the PVC were strung onto 10mm rope and suspended above a mooring using a sub-surface float. This design was similar to collectors designed by Jay Odell at the Nature Conservancy, Newfields, NH. The collectors were moored using a cinderblock and marked with a surface float. To account for possible preferences in settlement substrate, a second collecting method was deployed to conduct side-by-side comparisons with the Hardibacker collectors. The second collecting method was a 91cm x 91cm tray containing surf clam (*Spisula solidissima)* valves. Four pairs of collectors were put immediately adjacent to each restoration site. Two were placed immediately adjacent to the seeded area and two within a 1km distance, with consideration of the probable pattern of water movement and tidal flow. Five valves were collected from the trays at each collection. Spat collectors were analyzed using a dissecting microscope to identify recruits.

A comparison experiment was performed to compare the attractiveness to oyster larvae of the Hardibacker® plates and the natural shell, during the remote setting to see if the test substrates were suitable for spat collection (See remote setting methods, Section 2.1). In two tests, ten whole surf clam valves (approximately 170mm in length) and ten 100mm squares of the Hardibacker® were suspended in the tank in an alternating line, for the approximately 5-day duration of the remote sets. The number of oyster spat attached to each settlement unit was then counted using a dissecting microscope.

Results

Settlement substrate experiments concluded both test mediums (natural shell and Hardibacker®) are suitable substrate for oyster spat settlement. Oyster larvae in experiment one settled solely on natural shell (n = 56, mean = 5.6). No larvae were observed on the Hardibacker®. In the second experiment, a greater number of oyster larvae settled on the Hardibacker® (n = 24, mean = 2.4), than the natural shell (n = 5, mean = 0.5). No spat were recorded from either spat collecting methods at any of the restoration sites during the deployment period.

Discussion

The two settlement techniques were lab tested prior to being deployed to monitor spat recruitment for the 2006 season. *North Cape* lab results supported previous field tests (J. O'Dell, personal communication) that the Hardibacker® plates and the surf clam shell are suitable methods to monitor spat recruitment. The lack of recorded spatfall during 2006 is consistent with results from the previous year (Hancock et al. 2005). The fecundity of the 2003 and 2004 cohorts at the *North Cape* restoration sites would be expected to increase; however, the settlement at each site remained low compared to a natural oyster bed. Natural settlement has been observed throughout the *North Cape* project, most notably at the CFL nursery in 2005 and 2006, and at the Saugatucket River in 2004. The presence of spat recruiting at the CFL nursery is most likely a result of 'spill-over' broodstock that were lost from trays in previous years combined with any pre-harvest reproduction from two oyster farms in the pond. The lack of evidence of spat fall at other sites may be a result of transport of larvae while still in the water column. Oyster larvae live in the water column for two to three weeks prior to settlement (Kennedy 1996). Our knowledge of specific water movement patterns, spatially and temporally, at each site is limited. It is likely that larvae at the restoration sites are transported from the vicinity before settlement.

Oyster larvae settlement substrate experiments revealed that both settlement substrates (natural shell and Hardibacker®) are suitable for oyster larvae settlement. In the first experiment, the natural shell was the only substrate that yielded any settled oysters, while in the second experiment, the Hardibacker® yielded more oyster larvae than the natural shell. These results indicate that both settlement substrates are suitable for oyster larvae, however, the experiment run produced highly variable results.

III. Quahog Projects

3.0 Introduction

The quahog enhancement project was established in 2002 and was based on the release of hatchery-produced seed, grown out to a suitable size to enhance the breeding population, and ultimately, recruitment of subsequent generations. The grow-out of quahog seed typically requires a two-year period in Southern New England (Appleyard and DeAlteris 2001). This necessitates 'overwintering' the juvenile quahogs for at least one winter prior to seeding At the end of 2005 both the 2005 and the 2004 cohorts were overwintered, as the 2004 cohort were the subjects of a growout experiment. During the over-wintering of 2005-06, quahogs from the *North Cape* upweller were housed in troughs in the shallow sub-tidal waters of Pt. Judith Pond adjacent to the CFL. Quahogs in the bottom grow-out treatments established in 2005 were left in those treatments after sampling in November 2005. In 2006 the over-wintered seed from 2005 was retrieved, sampled, and the grow-out continued in the *North Cape* upweller at Camp Fuller. The quahog bottom grow-out treatments were sampled at retrieval to determine annual performance, and added to the *North Cape* upweller for further grow-out prior to seeding.

All overwintered quahogs were maintained in the upweller to the beginning of August, when a portion of the seed was used to establish growth and mortality experimental plots in both Quonochontaug and Ninigret Ponds. The experimental plots were repeats of a design used in Quonochontaug Pond in 2004-05, and were designed to provide spatial information on mortality and growth within the seeding areas and between ponds, as well as temporal variation between years. The final samples will be taken in August 2007. All remaining quahogs were seeded into Ninigret Pond toward the end of the 2006 growing season. No additional quahogs were purchased for future grow-out in 2006 and beyond. The sampling in 2007 will be the culmination of the *North Cape* quahog enhancement program.

3.1 Overwintering 2005/06

Objectives

To provide an environment for quahog seed that promotes a high survival during the winter period.

Methods

In December 2005 the quahog seed from the upweller were overwintered in troughs one-half filled with sand so that a protective mesh could be attached to cover the quahogs without resting on the surface of the sand. The quahogs were retrieved and sampled in April 2006. The quahogs that had been installed in the bottom grow-out trial remained in those treatments for the winter.

Results


A quahog overwintering trough being prepared

The overwintering survivals were within the predicted range (Table 8). The 2004 cohort had an overall survival of 81.6%. The larger quahogs within this year class survived better, with the 20mm quahogs having a 97.0% survival and the 16mm quahogs a 75.5% survival. This is the expected trend with the faster growing, larger animals, tending to have a larger energy reserve to support them during the dormant winter period, and the early spring period prior to the first algal bloom. The younger 2005 cohort suffered higher overwintering losses with an overall survival of 30.4%. The smaller animals within this cohort, with a mean size of 4.5mm (SE ±0.1mm) suffered the highest losses with 20.4% surviving (Table 8). The larger and more robust quahogs within the cohort, with a mean size of 5.5mm (SE ±0.1mm) had a 47.3% survival.

In contrast to the portion of the 2004 cohort that were removed from the upweller for overwintering, the portion of the same group that were installed in the bottom grow-out treatments generally had high survival rates (Table 9). The lowest survival was among the quahogs in the mesh box treatments at 5,000m^{-2}, with a survival of 75.3% (Table 9). This does no appear to be a simple treatment effect as the overwintering survivals for the box treatments at 10,000m^{-2} and the mesh cover treatments at both densities (5,000m^{-2} and 10,000m^{-2}) were within one standard error of 100% (Table 9).

Discussion

The overwintering procedures in 2003-04 and 2005-06 were successful with overall quahog seed survival rates for the 0+ year class of 55.2% and 30.4%, respectively. The finer mesh used to cover the overwintering trays and high sediment depositions used to cover the overwintering trays in 2004/05 resulted in a low survival of the 2004 cohort (16.1%). The higher overwintering mortality of the 1+ year class compared to the bottom grow-out treatments constitutes an additional expense in the upweller grow-out procedures. It is not known if this mortality would affect quahogs that were seeded to a natural substrate during the fall, as would have been done with this group if they were not part of the growout experiment.

3.2 Quahog Grow-out

Objectives

To compare the survival and mean growth increment for 1+ year class quahogs grown in three different treatments: upweller growout (FLUPSY) with overwintering on the bottom, and bottom growout with two treatments for predator protection, with each treatment housing quahog seed at 2 different densities.

Methods

In July 2005, the approximately 1 year old quahogs from the FLUPSY (FLoating UPweller SYstem) were mixed, sampled to determine abundance and mean length, and divided approximately equally between three grow-out treatments. The grow-out treatments tested were mesh boxes and mesh covers, established on the bottom of Smelt Brook Cove in Point Judith Pond, and the upweller at Camp Fuller, located in Turner Cove, approximately 900 m south of Smelt Brook Cove. A total of 36,225 (± 3,066 SE) quahogs were assigned to the bottom grow-out boxes, 36,400 (± 3,081 SE) to the mesh covers, and 37,914 (± 3,209 SE) were retained in the upweller (See also Hancock *et al.* 2006).

Bottom grow-out bags and covers in situ at Smelt Brook Cove

Boxes were constructed of 3mm (1/8in) black plastic diamond mesh fastened with stainless steel hog rings that measured 0.9m x 0.35m x 0.05m, an area of 0.32m² each. The shape of the box was maintained by fixing six evenly spaced 5cm lengths of PVC pipe vertically within each box. Covers were also made of 3mm black plastic diamond mesh which covered an experimental plot marked directly on the sediment using steel pegs and rope. The experimental plots measured 1.3m x 0.4m, an area of 0.52m² each. The mesh was kept from contacting the sediment by fixing net floats to it. Each mesh cover was weighted down around the entire periphery using heavy scrap chain as a means of excluding predators (See photograph, above). All covers and boxes were situated at a water depth of 1.2m at MLW.

Densities of 5,000 quahogs m^{-2} and 10,000 quahogs m^{-2} were used for each bottom grow-out treatment (Following method by Flimlin et al. 1997). A total of 11 bags of 5,000m^{-2} and 6 bags of 10,000m^{-2} were filled to the specified densities using volume to estimate the appropriate number of quahogs. Each bag was labeled and pegged to the bottom. A total of six covered plots with quahogs spread at a density of 5,000m^{-2} and four covered plots with quahogs spread at a density of 10,000m^{-2} were established.

The bottom grow-out treatments required cleaning once in late 2005. To clean the bags, the steel pegs were removed, the bag turned upside-down and again pegged to the bottom. The mesh of the covered plots was scraped down and brushed free of alga and fouling growth. Upweller bins containing the 1+ year class were removed and the quahogs were washed down approximately once a week.

The bottom grow-out treatments were sampled in October 2005 (Hancock *et al.* 2006) and June 2006. Three bags were sampled from each of the 5,000m^{-2} and 10,000m^{-2} densities. The entire contents of each bag were emptied, the total volume of the quahogs measured, and three 150ml sub-samples were taken. All live quahog within each sample were counted. The maximum shell lengths of the live quahogs from one of the three samples were measured. Quahogs were harvested from the covered plots using a suction sampler. All quahogs from a plot were harvested, the total quahog seed volume measured, and a 200ml sub-sample taken. All live quahogs in the sub-sample were measured. A sample was taken from all six 5,000m^{-2} mesh cover treatments. Quahogs from pairs of the four 10,000m^{-2} mesh cover treatments were combined in one container prior to sampling, mixed, and these two containers were sampled in the same way as the 5,000m^{-2} mesh cover treatments.

The 2004 cohort in the upweller was also sampled by counting three sub-samples and taking maximum shell length of quahogs from one sub-sample. The percent survivals along with standard errors were extrapolated based on total volume. The quahogs that remained in the floating upweller at the end of November were placed into overwintering trays at the CFL nursery location (See Section 3.1). The quahog growth and survival from the upweller treatment were based on measures taken when retrieving the quahogs from the overwintering trays in April, after spending 285 to 289 days in the trays. The bottom grow-out treatments were sampled in early June, after spending 324 to 343 days in the bottom treatment. Growth increments were annualized to minimize the impact of this discrepancy.

Results

Survival of the bottom growout treatments during the winter was not significantly different from 100% for 3 of the 4 treatments (Table 10), the exception being the 5,000m^{-2} mesh box treatment at 75.3% survival. Mortalities in the bottom grow-out treatments were higher during the period from July to November (Table 10), with the overall survival during this period being around 50%, except for the 5,000m^{-2} mesh cover treatment at 38.5% survival. The overall survival among the bottom growout treatments was similar (Figure 15). The survival for the 10,000m^{-2} treatments are within two standard errors ($p>0.05$). The period of higher mortality for each of the 5,000m $^{-2}$ treatments resulted in a slightly lower overall survival for both.

The annualized growth (Figure 15) is higher for the 5,000m $^{-2}$ treatments (7.1mm ±2.6 SE box and 7.3mm ±2.9 SE cover) than the 10,000m^{-2} treatments (5.0mm ±3.3 SE box, 6.1mm ±5.8 SE cover). The annualized growth in the upweller was 12.0mm ±3.6 SE.

The annual expense of each grow-out method is primarily the cost of maintenance as all equipment has a minimum serviceable life of 3 to 5 years. All bottom grow-out treatments combined required twelve staff days to install, sample, clean and harvest. The upweller required two staff days per week from July through November and May through June, a total of 61 staff days with an additional five days for overwintering, a labor commitment of 5.5 times that of the bottom grow-out.

Discussion

Overwintering was very successful in the bottom grow-out treatments, with ~100% survival except for the 5,000m^{-2} mesh box treatment (~75%). The majority of the mortality occurred during the July to November period with survival at ~50% except for the 5,000m^{-2} mesh cover treatment (~39%). The source of this mortality is largely a matter of conjecture. Some small mud crabs were noted within the covered plots but not the mesh boxes, and other predators such as platyhelminths are not excluded by the mesh barrier. The higher mortalities would be predicted for the higher density treatments rather than the 5,000m^{-2} treatments, due to increased competition, but the opposite pattern occurred. Also, the lack of consistency with lower survival occurring in the 5,000m^{-2} mesh cover treatment in summer, and in the 5,000m^{-2} mesh box treatment in winter, suggests a source of mortality that is not a treatment effect. The upweller grow-out of the 1+ year class continued to be highly successful with the mortalities among this group occurring during the overwintering stage (~18%).

Growth increments were also higher in the upweller group at about twice the growth of the 10,000m^{-2} treatments. The impact of increased competition in the 10,000m^{-2} treatments over the 5,000m^{-2} treatments is apparent in the growth results with the 5,000m^{-2} treatments having consistently higher growth.

The unit labor cost of upweller production could be reduced below a factor of 5.5 times that for bottom grow-out, by increasing the number of quahogs in the upweller. This is possible because deployment time is a component of the overall time required for daily servicing, and this becomes a smaller proportion of the total time with an increase in the number of quahogs maintained.

3.3 Quahog Seeding Experiment

Introduction

In 2004 experimental plots were established in Quonochontaug Pond to obtain estimates of growth and survival of quahogs released at two stocking densities and three shell size classes. The objective was to sample the experimental plots after 12 months and determine the influence of the treatment density and seed size on growth and survival, and to use these results to comment on the likely survival of the broad-scale seeding conducted in 2004 (Hancock *et al.* 2006). The experimental design used in 2004 was repeated in 2006 in Quonochontaug Pond and Ninigret Pond. Sampling these plots at the end of the 2006 growing season provides seasonal growth and mortality information, while sampling at one year would provide annual results. Replicating the experimental design established in 2004 enabled assessment of the spatial and temporal variation in the measured parameters on a number of different scales.

Objective

To comment on the influence of seed size and seeding density on the spatial and temporal variation in survival of seeded quahogs. To assess this relationship by replicating experimental plots established in Quonochontaug Pond in 2004, and in Quonochontaug Pond and Ninigret Pond in 2006. To sample these additional experimental plots at the end of the first growing season at liberty (2006) and at one year (2007), to comment on within pond, between pond, and between year variation in survival of quahogs seeded at 3 different mean sizes and 2 densities.

Methods

Three replicate experimental plots were established within the 2004 quahog seeding area in Quonochontaug Pond (Figure 16) and within the range of areas seeded in Ninigret Pond in 2004 and 2006 (Figure 17). The plots in Quonochontaug Pond were extensions of the areas used in 2004 (Hancock *et al.* 2006). Each experimental plot measured 12m x 8m and was comprised of 6 treatments; three size classes, each seeded at two different densities (Figure 18). Each treatment occupied a 4m x 4m area within the experimental plot. The three size classes used in the 2006 plots were all separated out of the 2004 cohort of notata quahogs. Quahogs from the three size groups were selected in late July from quahogs that went through a 13mm (0.50in) mesh but not through a 6mm (0.25in) mesh (small), those that went through a 19mm (0.75in) mesh but not a 13mm mesh (medium), and those that were too big to sieve through a 19mm mesh (large). Quahogs from each size class were released at two different densities, $10m^{-2}$ and $100m^{-2}$. The experimental plots, containing one replicate of each treatment, were separated by another treatment to account for variations in substrate between parts of the release area, and to minimize the potential to alter predator-searching behavior by having a larger area of high-density prey.

In November 2006, each experimental plot was located and ropes replaced between the steel pegs used as corner markers. The experimental treatments within each plot were sampled using haphazard placement of 1.0m² quadrats. All sediment to a depth of ~30cm was extracted with the use of a suction sampler attached to a 5.5hp motor and water pump and collected in a 5mm mesh bag. The maximum lengths of all quahogs collected were recorded. After collection of data, the sampled quahogs were replaced into the plots from which they came.

Handpiece of a suction sampler with the inlet hose from the water pump (blue), venturi suction pipe (in water), and outlet through a mesh bag.

Results

The mean size of the three size groups at release were 13.1mm, 18.1mm, 22.5mm, for the small, medium and large groups, respectively. Length distribution data, standardized to represent an equal number of quahogs from each size group, indicate some overlap of length distributions between adjoining groups, with clearly distinct modes (Figure 19). The annual survival data collected in 2005 and the seasonal survival data from 2006 consistently indicated an increased survival of quahogs seeded at $10m^{-2}$ over those seeded at $100m^{-2}$ (Figures 20 and 21). It is also evident that survival increased with an increase in the mean size at seeding for the three sizes tested in 2006. The unreplicated 25.9mm group added to the 2004 plots suggests that this increased survival with increased size at seeding may not persist much beyond 22mm. The seasonal survival was also substantially higher in Quonochontaug Pond than Ninigret pond for the period from August to November (Figure 21). The results for Quonochontaug Pond from the 2004 and 2006 experiments do not represent the same period at liberty, and thus are not directly comparable.

Discussion

Results of the seeding experiment support the conclusions that lower seeding densities result in higher survival of juvenile quahog seed. This is thought to be because lower densities do not influence predator behavior by concentrating a predator's search efforts in an area where prey have been introduced at a higher abundance (Peterson *et. al.* 1995). Results demonstrate a significant increase in survival with increased size at seeding. Results also suggest that increased survival derived from larger seeding size may not

Quahog seed sampled from the experimental plots in Ninigret Pond in November 2006. The large quahog is from the 2004 seeding and the remainder was seeded in 2006. The limit of the dark shell corresponds to size reached during bottom grow-out, the pale shell was laid down during upweller grow-out and the bright 'notata' band since seeding.

persist beyond a size of about 22.5mm indicating that by this size, quahog seed have attained a 'size refuge' (Peterson *et. al*. 1995).

Monitoring the success of released seed is a critical component of the stock enhancement process. By monitoring growth and survival, it is possible to assess the impact of the released seed on the resident population, and their potential impact on future generations (Brumbaugh *et al.* 2006). The results of the quahog seeding experiment will be used to estimate the survival trajectory of the broad scale quahog releases into Ninigret and Quonochontaug Ponds.

3.4 2006 Quahog Releases

Introduction

The release of quahogs raised independently of the natural recruitment of juveniles will form part of the restoration of shellfish populations impacted by the oil spill.

Objective

To release quahog seed into pre-determined areas at a density of approximately $10m^{-2}$.

Methods

The boundaries of pre-determined target areas were marked with 50m ropes with floats on risers attached every 10m. With these surface marks in place, 10m x 10m sections could be reasonably visualized from a boat and 1,000 seed quahogs distributed within each.

Quahog seed from three size groups prior to seeding

Results

All broad scale seeding of juvenile quahogs in 2006 was in Ninigret Pond. Three areas were seeded, all extending north from the northern boundary of the area seeded in 2004 (Figure 17). These were in addition to the quahog seed that had been used to make up the experimental plots (Section 3.3). A total of 94,750 quahogs were added to Ninigret Pond in 2006 (Table 11), 38% from the smaller size group of seed (mean length 13.1mm), 38% from the medium size group (mean length 18.1mm), and 24% from the larger size group (mean length 22.5mm). Quonochontaug Pond received 15,840 quahog seed in the 288m^2 area of the experimental plots. A total of 110,600 seed were released in 2006.

Discussion

The survival of the quahog seed released in 2006 will be assessed from sampling of the experimental plots to be conducted in 2007 after 12 months at liberty. Preliminary results indicate a higher survival in Quonochontaug Pond in 2006 (Figure 21).

3.5 Conclusions

The 2006 season was a successful one for the quahog program. The 2005 cohort was grown through the size range that were susceptible to the fouling that caused high mortalities in 2005, and contributed to the seed stock released late in the season. The 2004 cohort suffered relatively low mortalities and contributed to the larger-sized groups seeded. Estimates of the survival of the quahogs seeded in 2006 will be derived from the results of the experimental plots due to be sampled in 2007.

The bottom grow-out trial demonstrated a very low overwinter mortality, with the majority of the mortalities occurring during the summer. This contrasts with the very high survival in the upweller during the summer with most mortalities occurring during the overwintering stage. The lower maintenance cost of the bottom grow-out and low overwinter mortality suggest that establishing bottom grow-out plots late in the first season of growth would be a cost-effective method of grow-out for the second year.

V. Outreach

The *North Cape* Shellfish Restoration Program has continually depended on the participation of the many community volunteers that have contributed their time and effort to help us accomplish the laborious and time-consuming exercises that make up the program, particularly the oyster restoration. In 2006, the project team held eight volunteer days in which community residents donated their Saturdays and Sundays breaking shell and making shell bags for the remote set, as well as sampling oysters set on cultch to determine the average size and abundance of oyster spat prior to seeding. In total, we had 73 community volunteers assist us in 2006, for a total of 334 volunteer hours, with many people being repeat volunteers.

Students from the University of Rhode Island and Middletown High School also participated in various aspects of the project. Students contributed a total of 98 volunteer hours during the year, adding a key work force to the project in many of the time-consuming tasks, including splitting cultch bags containing the newly settled oysters as a means to provide the oyster spat room to grow.

The *North Cape* Project has been extremely fortunate in having many community volunteers participate in the volunteer program on an on-going basis. The consistency and knowledge that repeat volunteers offer has been an extraordinary help to the shellfish restoration work. On May 24, we held an evening meeting to highlight program accomplishments and volunteer participation. That evening, Bob and Gloria Benton, Coral Hines, Knute and Marianne Schmidt, and Fred Matazarro were recognized for their exceptional service and commitment to the *North Cape* Shellfish Restoration Project by RIDEM Director, Dr. Michael Sullivan.

The management of the YMCA Camp Fuller continued their generous support in hosting the *North Cape* upweller for quahog and oyster grow-out, and allowing access for service and maintenance of the upweller.

During the summer of 2006, the *North Cape* project hosted a NOAA Hollings Fellow biology student Samuel Crickenberger who studied the habitat characterization of bay scallops in Ninigret Pond. In addition, two Coastal Fellows from the University of Rhode Island, Nick Larghi and Steve Carpenter worked with the project and developed project materials from the oyster and quahog restoration projects. In December, the students presented posters of results to the URI Coastal Fellows Program.

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Figure 1. Location of the North Cape shellfish restoration sites.

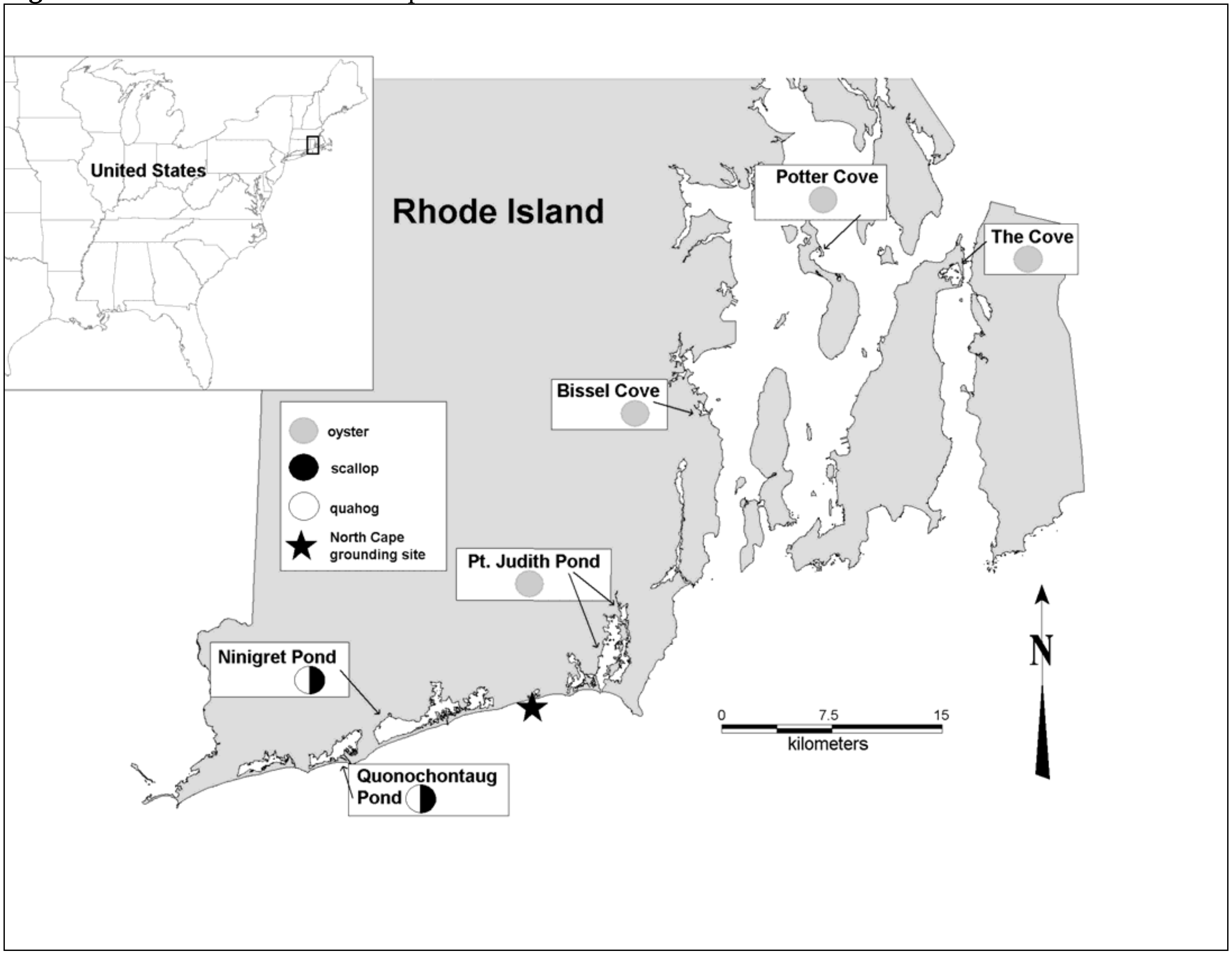
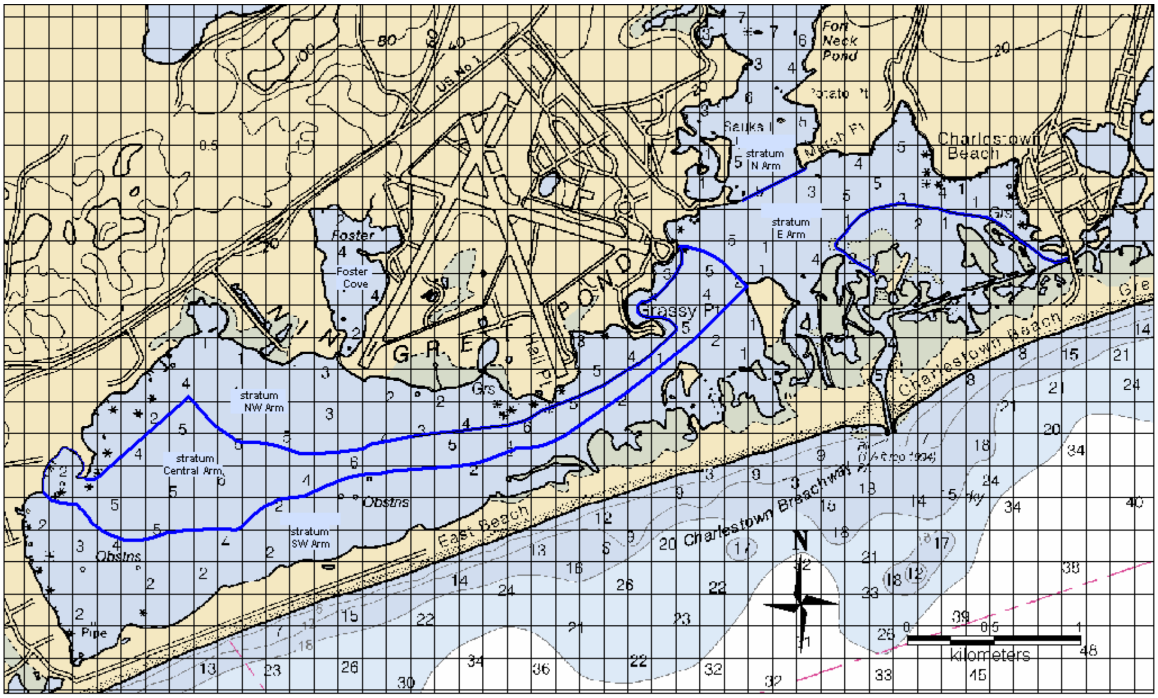


Figure 2. Ninigret Pond (A) and Quonochontaug Pond (B) scallop survey strata.

(A)



(B)

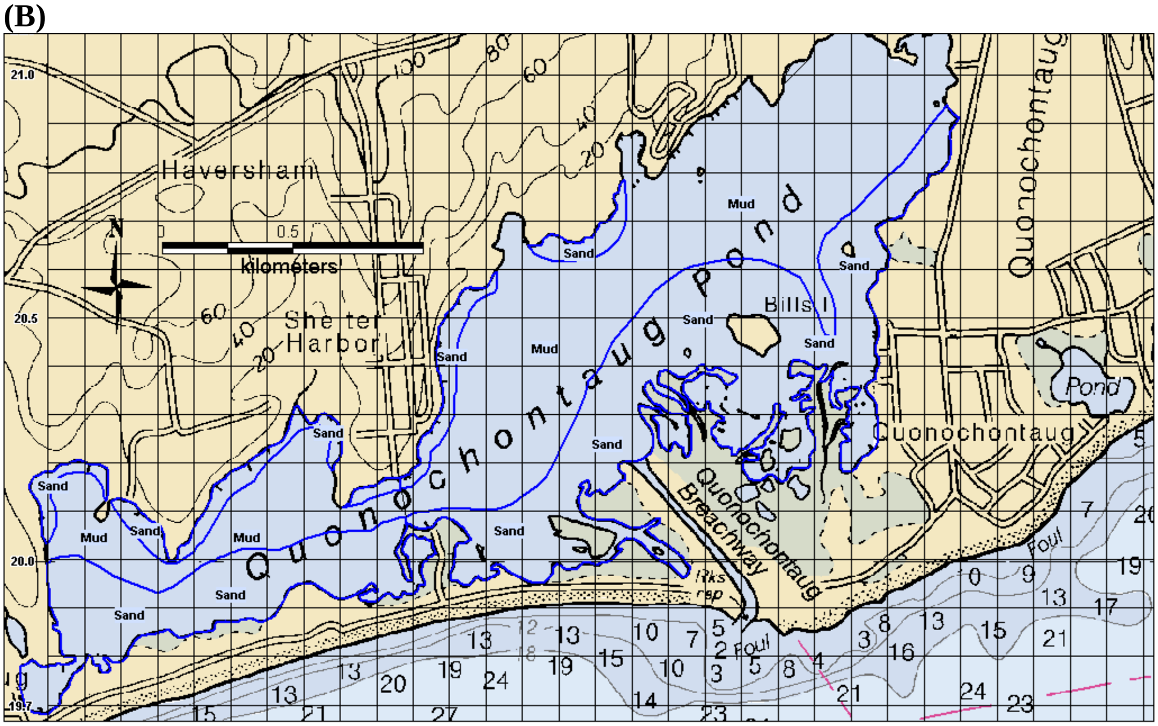


Table 1. Scallop survey distribution and abundance estimates.

A. Ninigret Pond

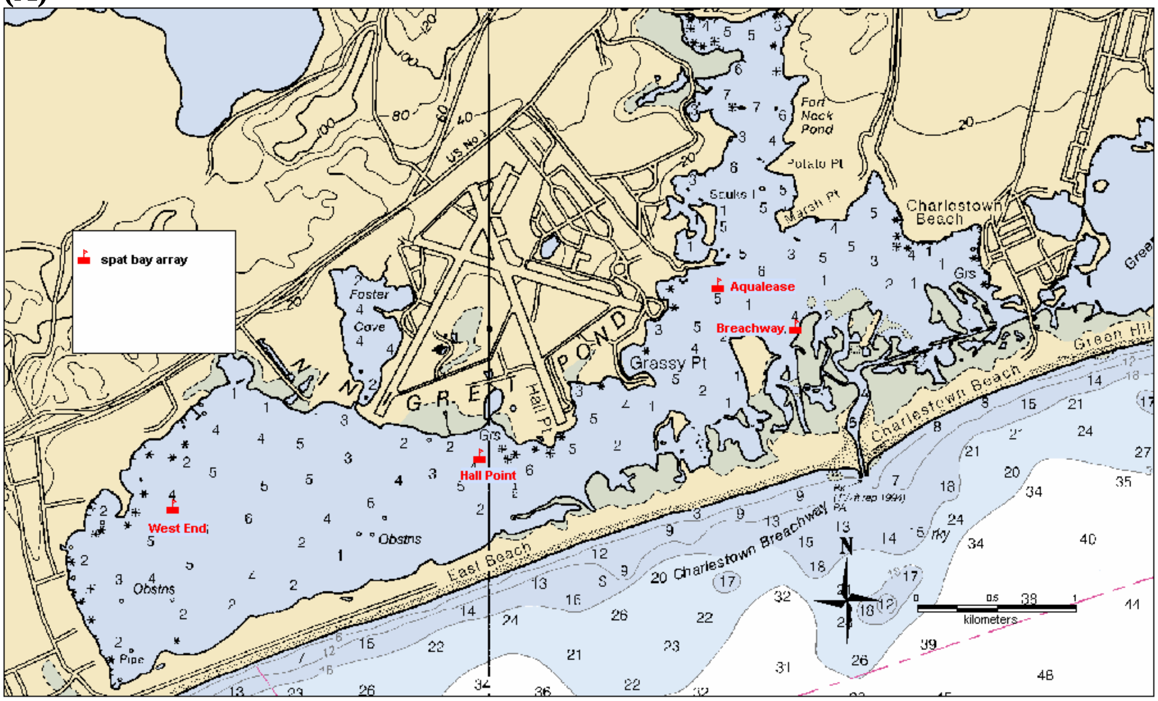
Strata	Area Surveyed (m^2)	No. of Scallops Found	Mean Scallops m^{-2}	SE	Area of Stratum (m^2)	No. Scallops per Stratum	SE
North West Arm	2,400	173	0.072	0.028	1,229,351	88,616	34,858
Central West Arm	1,400	39	0.028	0.014	1,234,114	34,379	16,877
South West Arm	1,200	47	0.039	0.025	1,748,259	68,473	43,968
Central Basin	1,200	1	0.001	0.001	961,400	801	801
Fort Neck Pond	1,200	0	0.000	0.000	821,089	0	0
Foster Cove	600	0	0.000	0.000	228,160	0	0
Total	8,000	260			6,222,373	192,269	96,504

B. Quonochontaug Pond

Strata	Area Surveyed (m^2)	No. of Scallops Found	Mean Scallops m^{-2}	SE	Area of Stratum (m^2)	No. Scallops per Stratum	SE
East Basin Central Mud	1,600	0	0	0	1,448,000	0	0
East Basin Outer Sand	1,200	4	0	0	837,099	2,790	1,644
West Basin Central Mud	300	0	0	0	528,920	0	0
West Basin Outer Sand	800	0	0	0	287,426	0	0
Total	3,900	4	0	0	3,101,445	2,790	1,644

Figure 3. Location of spat bag arrays in Ninigret (A) and Quonochontaug (B) Ponds, including the location of the caged spawner sanctuary in Quonochontaug Pond.

(A)



(B)

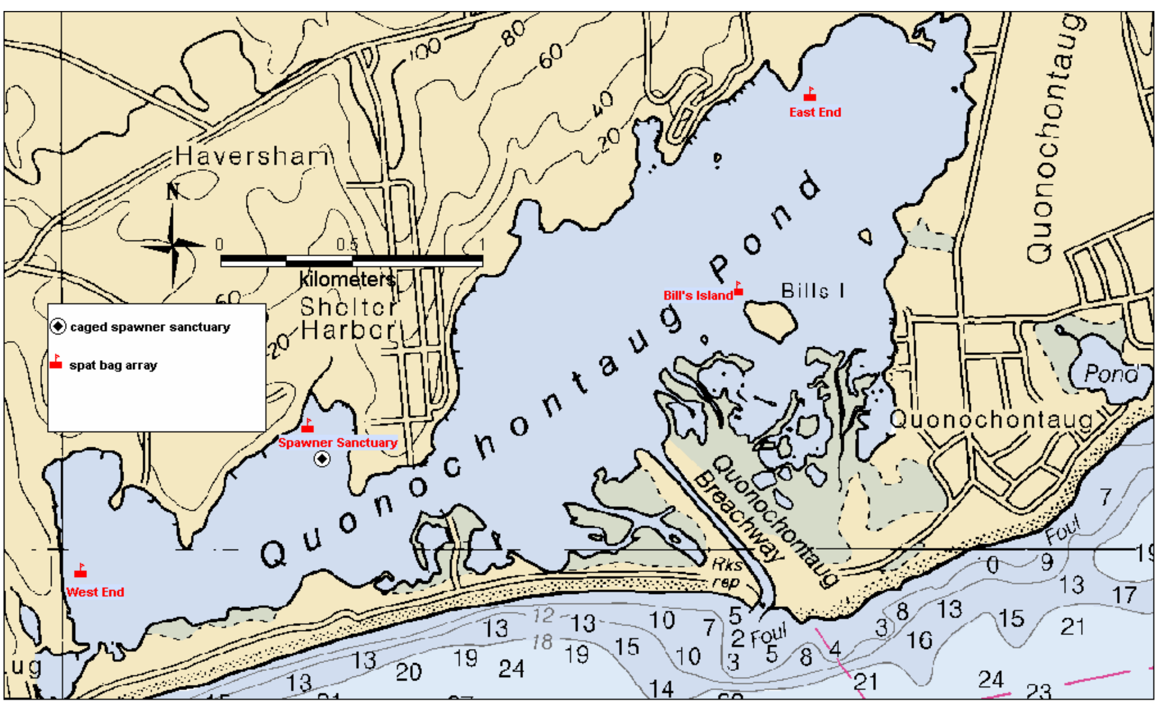


Figure 4. Schematic diagram of spat bag array.

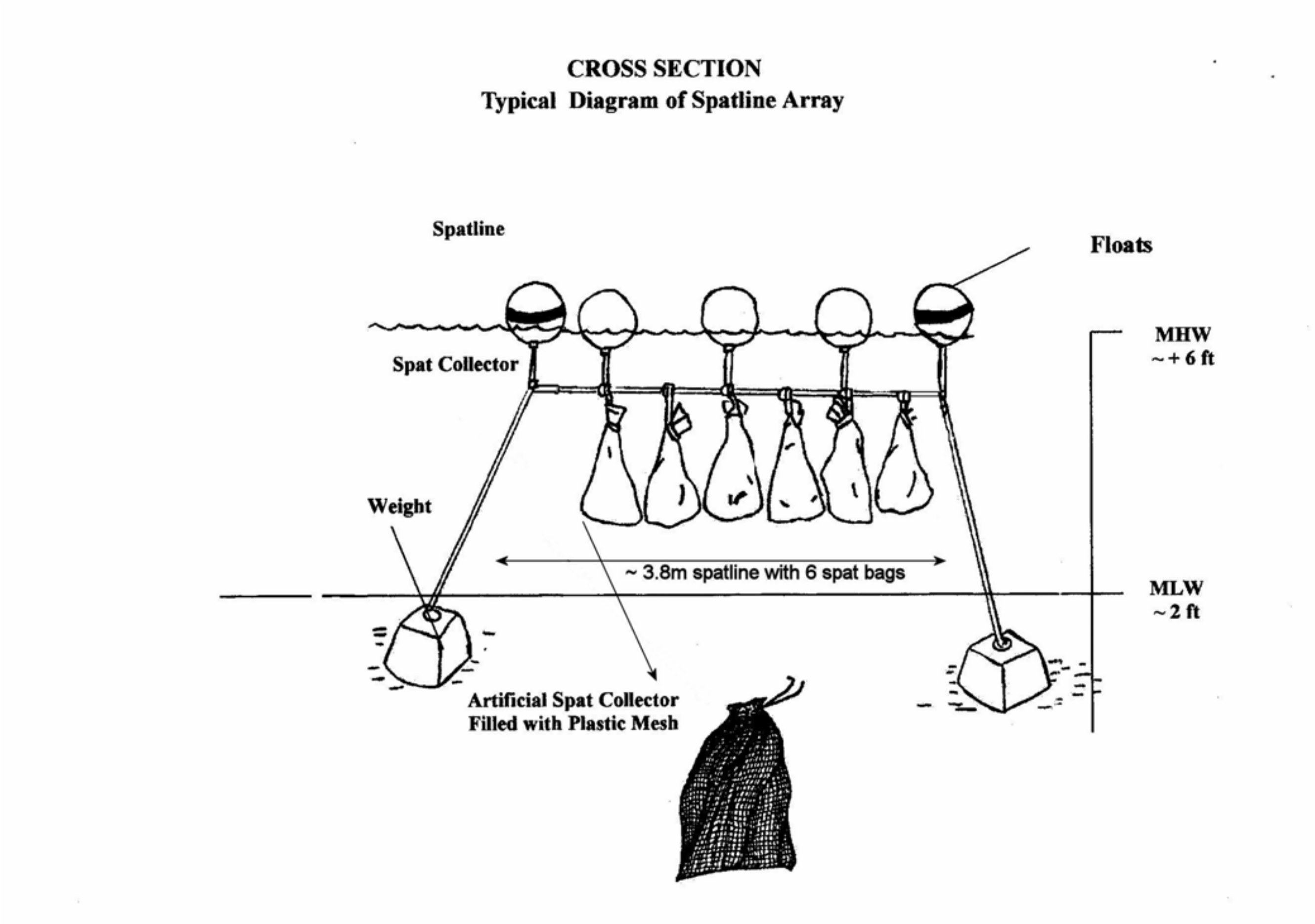


Table 2. Scallop spat collected from spat bags deployed in Ninigret Pond (A) and Quonochontaug Ponds (B).

A. Ninigret Pond.

Date Deployed	19-Jun	11-Jul	26-Jul	8-Aug	23-Aug	8-Sep	19-Sep	4-Oct		Settlement
Date Collected	**26-Jul**	**8-Aug**	**23-Aug**	**8-Sep**	**19-Sep**	**4-Oct**	**26-Oct**	**17-Nov**	**Total**	**Index**
Scheduled Liberty	30	30	30	30	30	30	30	30		
Days at Liberty	37	28	28	31	27	26	37	44		
West End										
No. Bags	6	6	6	6	6	6	6	6	48	
No. Scallops	0	0	0	0	0	0	1	0	1	
Mean Scallops/Bag	0	0	0	0	0	0	0.2	0		0.2
Mean Size (mm)	0	0	0	0	0	0	1.4	0		
Breachway										
No. Bags	6	6	6	6	6	6	6	6	42	
No. Scallops	0	2	10	128	8	3	2	0	153	
Mean Scallops/Bag	0	0.3	1.7	21.3	1.3	0.5	0.3	0		25.5
Mean Size (mm)	0	2.8	5.7	2.2	3.4	1.8	2.0	0		
Aqualease										
No. Bags	6	6	6	6	6	6	7	6	43	
No. Scallops	0	0	1	32	5	3	7	0	48	
Mean Scallops/Bag	0	0	0.2	5.3	0.8	0.5	1.0	0		7.8
Mean Size (mm)	0	0	3.3	3.3	3.6	1.4	5.2	0		
Hall Point										
No. Bags	6	6	6	6	6	6	6	6	42	
No. Scallops	0	2	2	1	1	0	5	0	11	
Mean Scallops/Bag	0	0.3	0.3	0.2	0.2	0	0.8	0		1.8
Mean Size (mm)	0	2	2.7	3.5	1.5	0	1.5	0		
								Total bags	175	35.3
								Total spat	213	

B. Quonochontaug Pond.

Date Deployed	21-Jul	31-Jul	17-Aug	30-Aug	12-Sep	26-Sep	12-Oct			Settlement
Date Collected	**17-Aug**	**30-Aug**	**12-Sep**	**26-Sep**	**12-Oct**	**30-Oct**	**16-Nov**		**Total**	**Index**
Scheduled Liberty	30	30	30	30	30	30	30			
Days at Liberty	27	30	26	27	30	34	35			
West End										
No. Bags	6	6	6	6	6	6	6		42	
No. Scallops	5	79	24	6	0	4	0		118	
Mean Scallops/Bag	0.8	13.2	4.0	1.0	0.0	0.7	0			19.0
Mean Size (mm)	2.2	2.6	1.7	3.8	0	1.5	0			
Spawner Sanctuary										
No. Bags	6	6	6	6	6	6	6		42	
No. Scallops	5	24	19	3	1	0	0		52	
Mean Scallops/Bag	0.8	4.0	3.2	0.5	0.2	0.0	0			8.5
Mean Size (mm)	3.0	2.7	2.0	2.2	1.6	0	0			
Bill's Island										
No. Bags	6	6	6	6	6	6	6		42	
No. Scallops	2	11	78	11	2	2	0		106	
Mean Scallops/Bag	0.3	1.8	13.0	1.8	0.3	0.3	0			17.0
Mean Size (mm)	4.3	2.5	2.5	2.3	1.9	1.5	0			
East End										
No. Bags	6	6	6	6	6	6	6		42	
No. Scallops	1	15	14	4	0	1	0		35	
Mean Scallops/Bag	0.2	2.5	2.3	0.7	0	0.2	0			5.7
Mean Size (mm)	2.8	2.9	2.0	2.4	0	1.4	0			
								Total bags	168	50.2
								Total spat	311	

Figure 5. Comparison of the total number of spat found at each of the four sites in Ninigret Pond and the seasonal settlement indices of each pond from 2004 to 2006, with respect to estimated total number of broodstock each year.

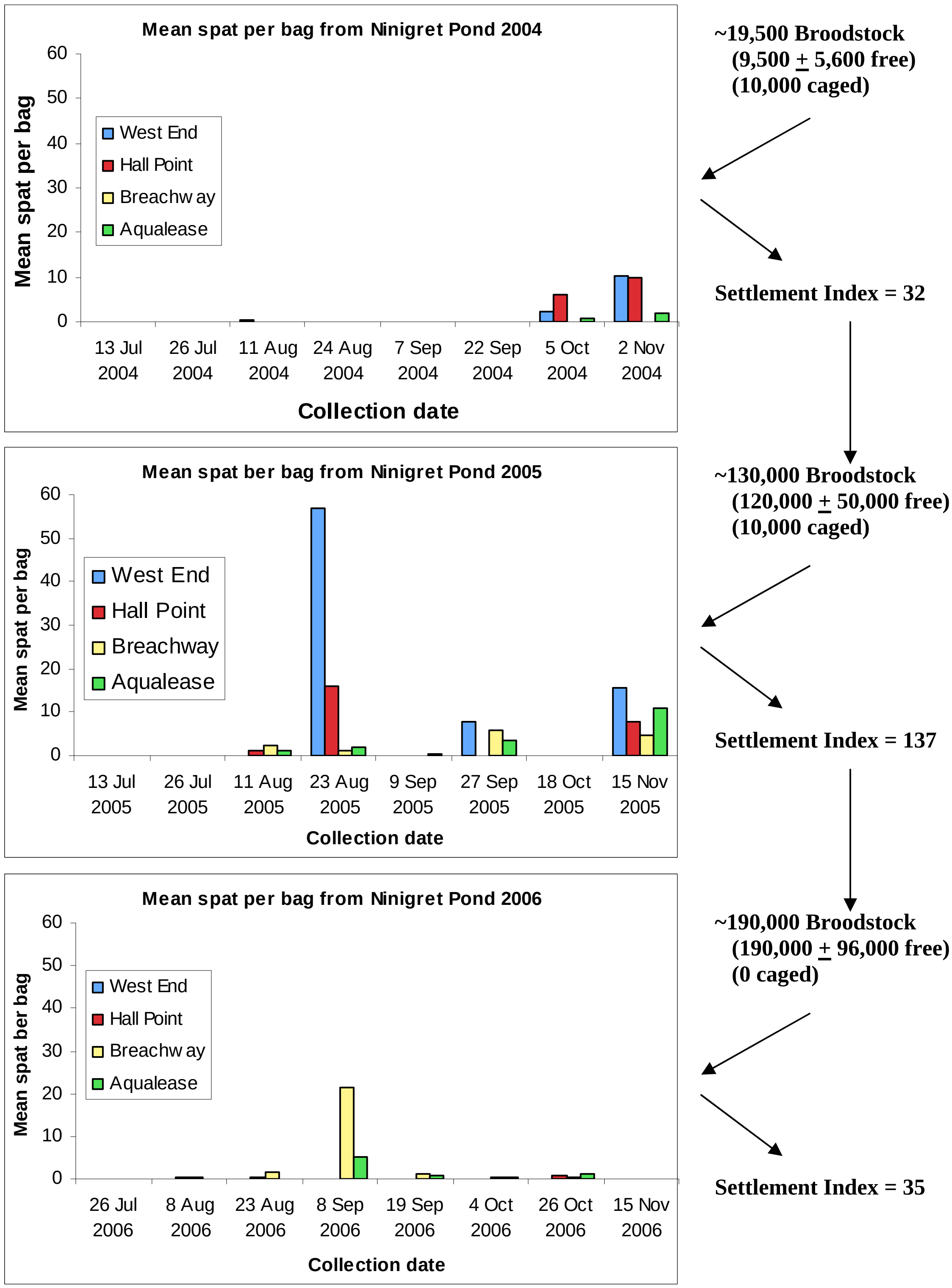


Figure 6. Comparison of the total number of spat found at each of the four Quonochontaug Pond sites.

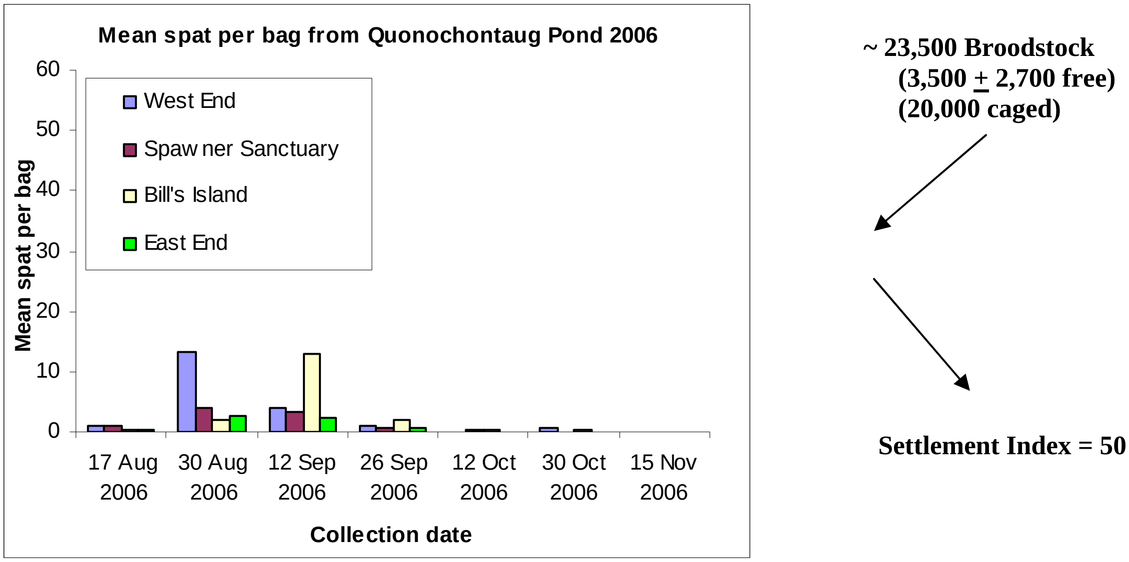
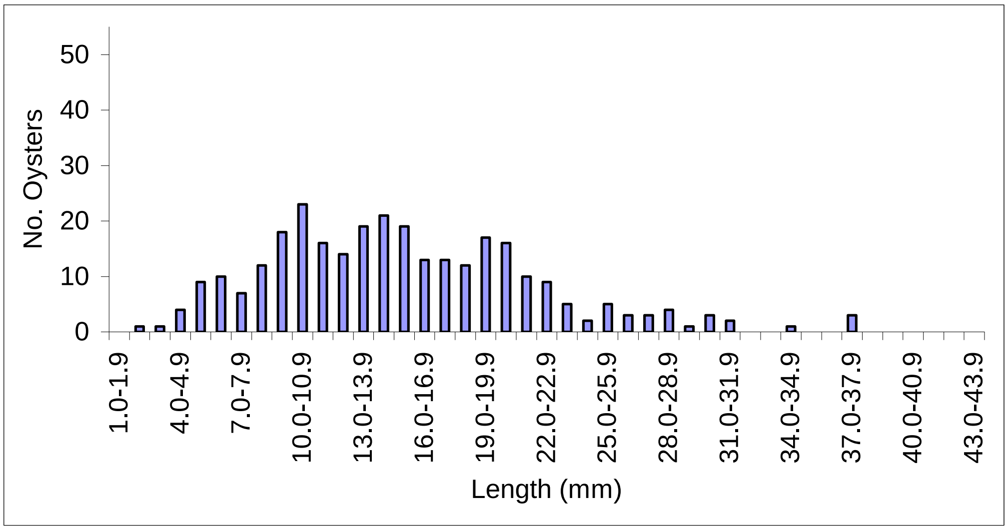


Table 3. Number of spat produced and percent survival of eyed-larvae remotely set in tanks surviving to time of seeding.

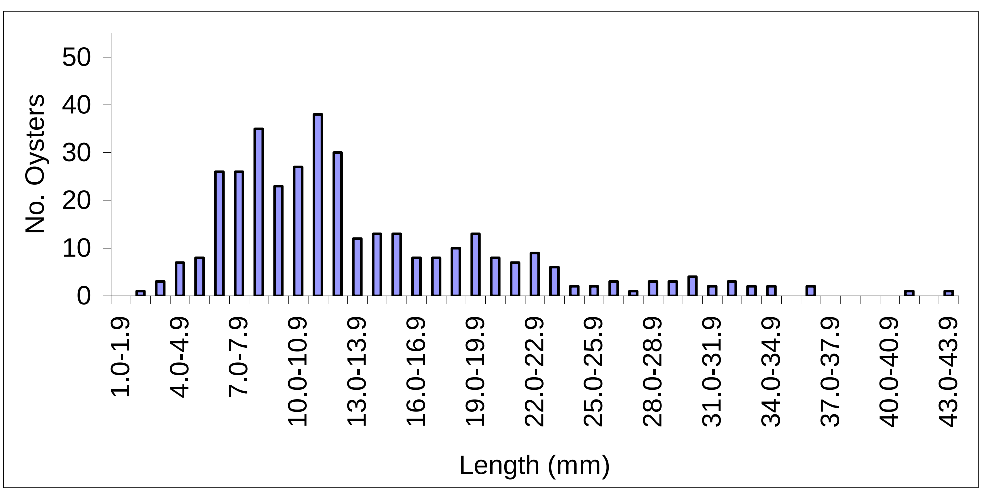
Set	Number of Spat Produced	Percent Survival from Larvae to Seeding
set 1	683,831	11
set 2	820,293	13
set 3	37,152	1
set 4	386,684	6
Total	1,927,960	8

Figure 7 (A – J). Size distribution of oysters from each remote set (big and small tank) at the end of the nursery grow-out raised in both the nursery and in the upwellers.

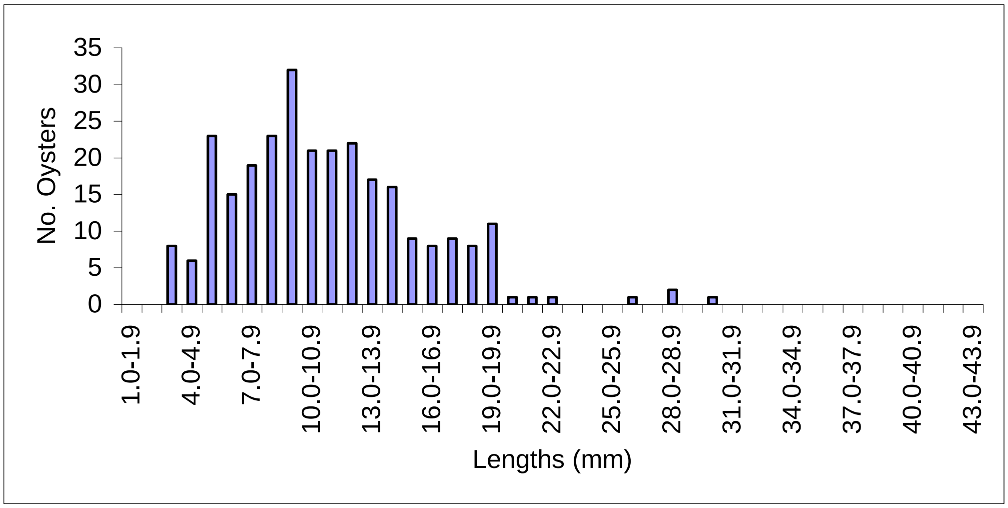
A. Set 1, big tank.



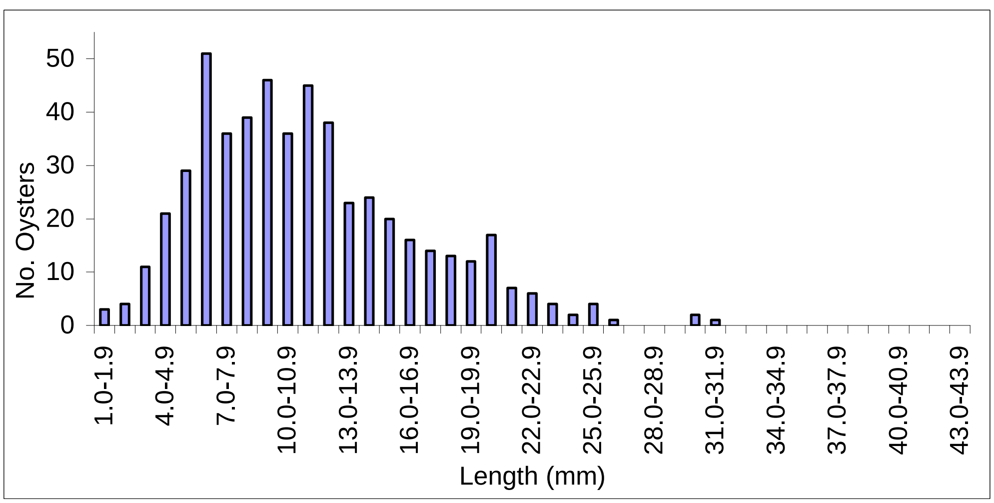
B. Set 1, small tank.



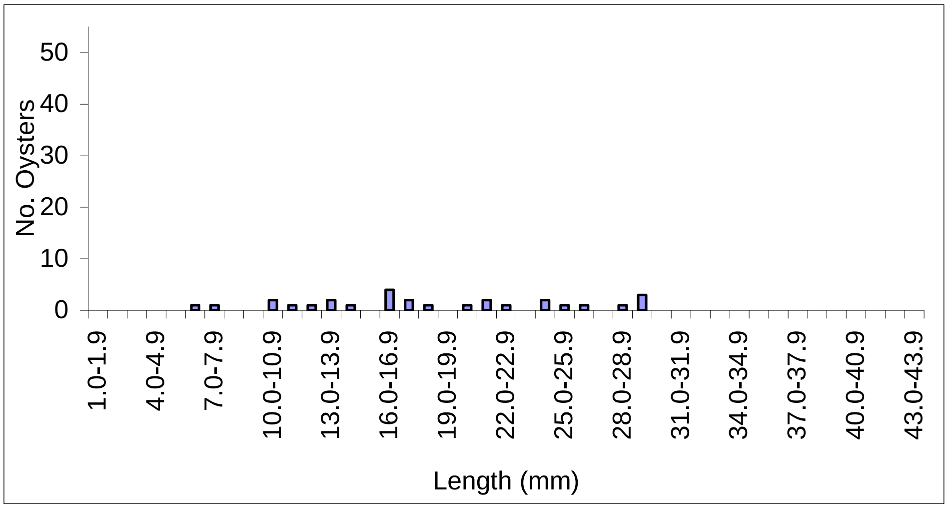
C. Set 2, big tank.



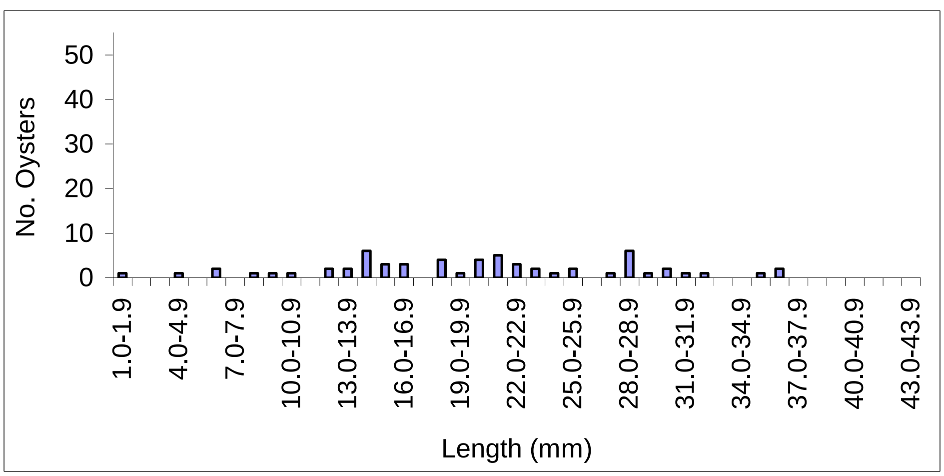
D. Set 2, small tank.



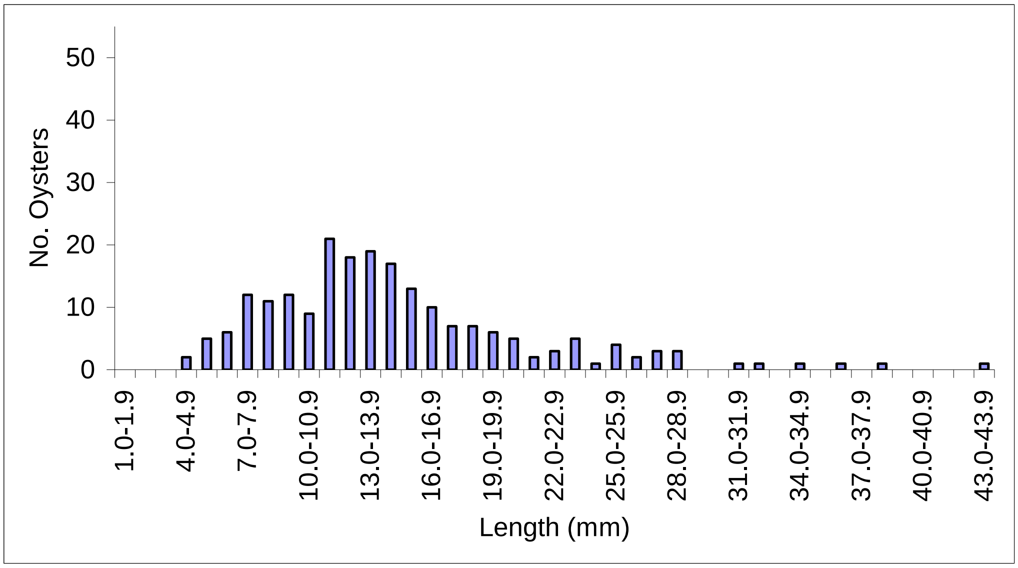
E. Set 3, big tank.



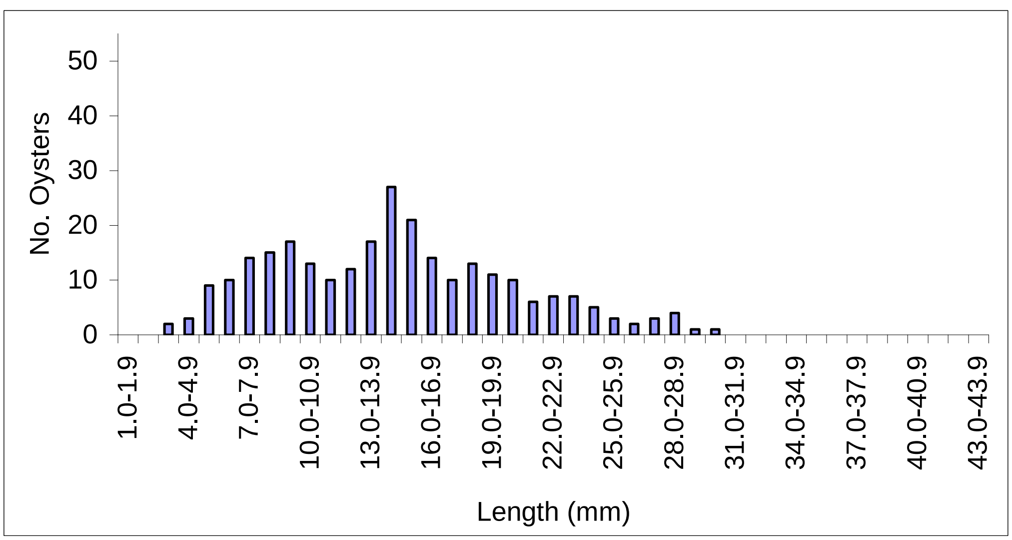
F. Set 3, small tank.



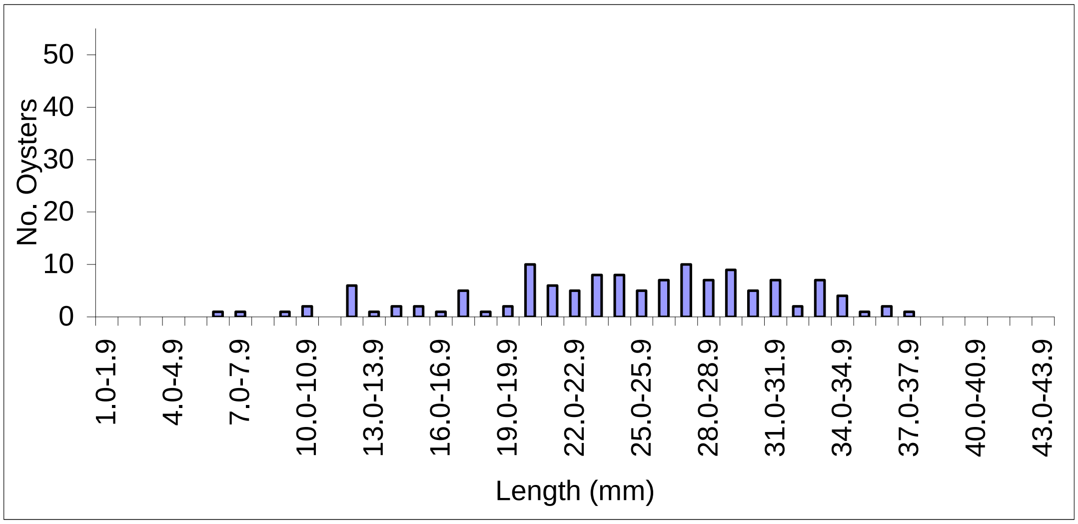
G. Set 4, big tank.



H. Set 4, small tank.



I. CFL upweller (sets 2 big tank, 3 small tank, 3 big tank, 4 small tank, 4 big tank).



J. Camp Fuller upweller (sets 1 big tank, 1 small tank, 2 big tank).

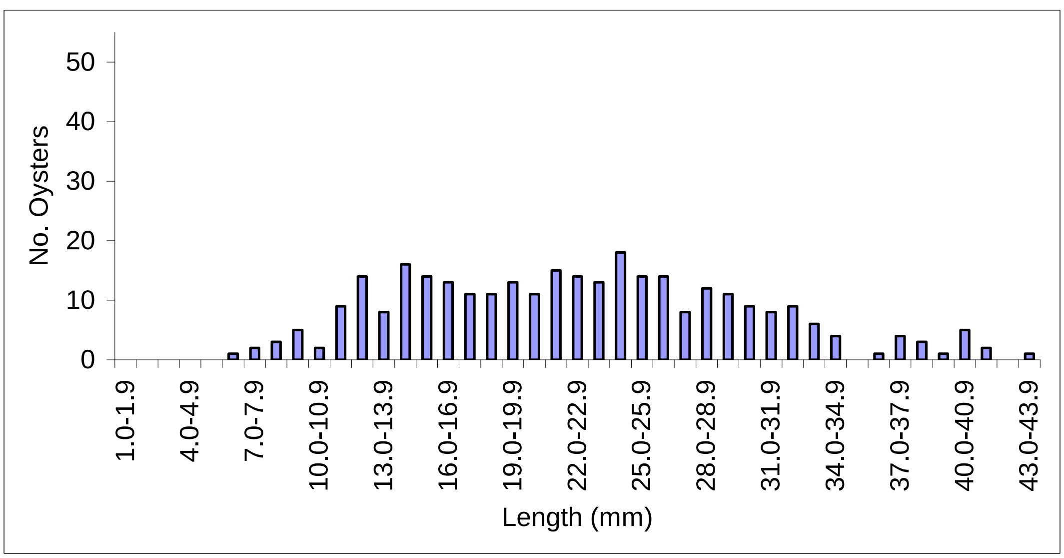


Table 4. Mean size (± standard error) of oysters prior to seeding from each remote set (big, B and small, S tanks) and grow-out treatment.

Nursery	Set	Size	± SE
	1B	15.4	0.4
	1S	13.6	0.4
	2B	11.2	0.3
	2S	11.4	0.2
	3B	18.6	1.3
	3S	19.9	1.0
	4B	14.5	0.5
	4S	17.1	0.4
CFL upweller	2B	25.7	0.7
	3B	30.9	1.7
	3S	25.2	1.2
	4B and 4S	21.4	1.3
Camp Fuller upweller	1B	26.5	0.9
	1S	18.6	0.6
	2B	25.5	0.8

Figure 8. Size distribution of oysters that were grown in the CFL upweller plotted with those grown in the CFL nursery. All oysters were from the second set, in the big tank.

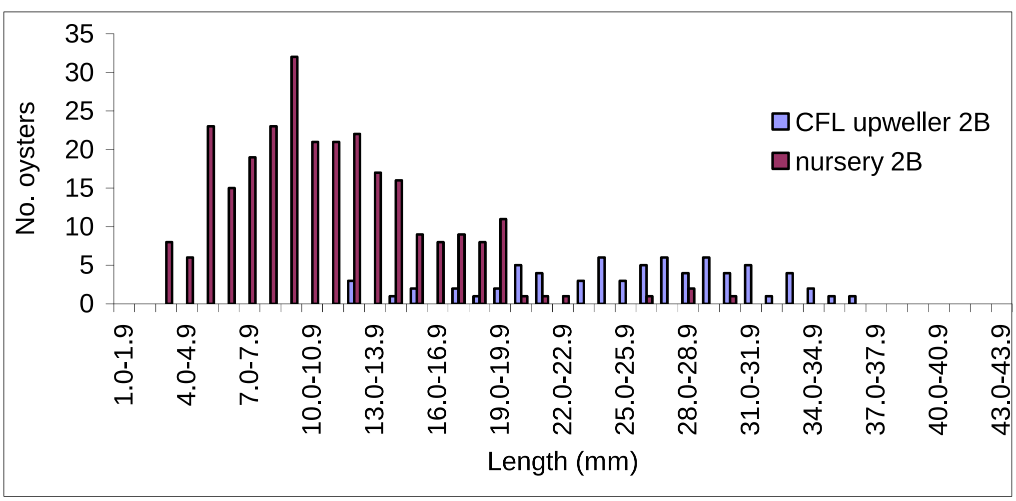


Table 5. Results of 2006 surveys of oyster restoration sites seeded in 2003, 2004 and 2005.

Site	No. Quadrats	Total No. Alive	Mean No. Alive (m^{-2})	SE	Seeded Area (m^2)	Estimated Total Live	SE
Smelt Brook Cove	50	1,434	28.7	3.5	2,016	57,819	7,056
Saugatucket River	49	1,146	23.4	2.6	2,048	47,898	5,325
Bissel Cove Deep[1]	50	50	1.0	0.5	5,047	5,047	2,524
Bissel Channel[2]	50	333	6.7	1.9	1,784	11,881	3,390
The Cove[3]	49	683	13.9	3.4	3,317	46,235	11,278
Potter Cove[3]	50	420	8.4	1.4	3,324	27,922	4,654

[1]Bissel Cove Deep was seeded in 2004.
[2]Bissel Channel was seeded in 2003 and 2004.
[3]The Cove and Potter Cove were seeded in 2003 and 2005.

Figure 9. Total number of oysters, number of first year oysters (seeded in 2005) and number of second and third year oysters (seeded in 2003 and/or 2004), (±standard error) at each restoration site.

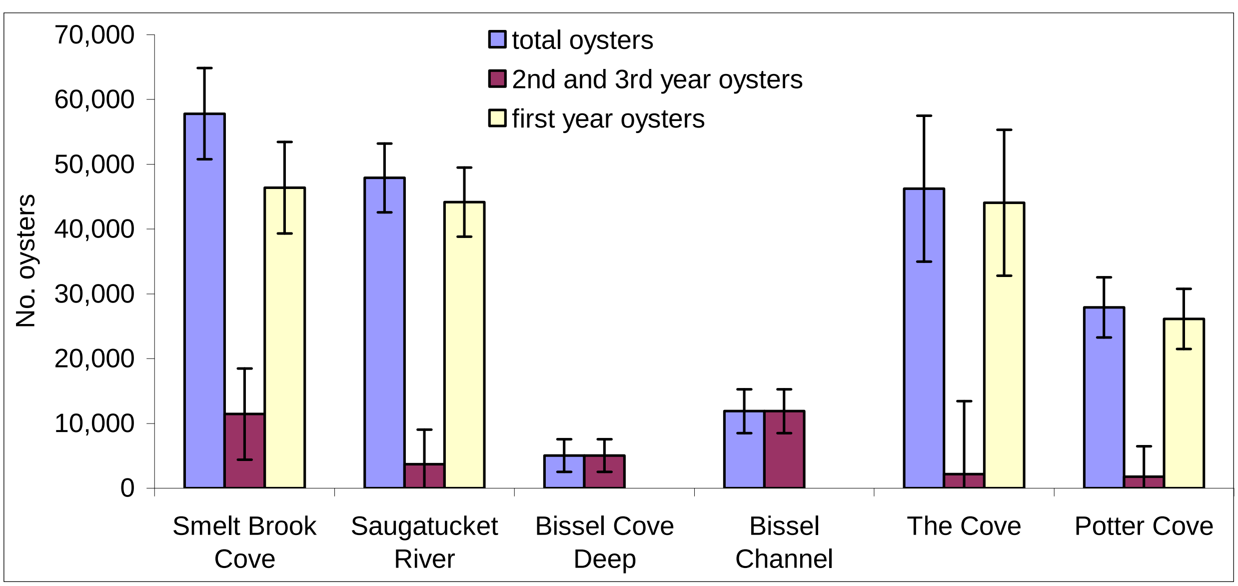


Figure 10. Example of the size distribution of oysters that survived their first year, versus second and third year oysters. Overlap in the second and third years becomes too great to discern different cohorts.

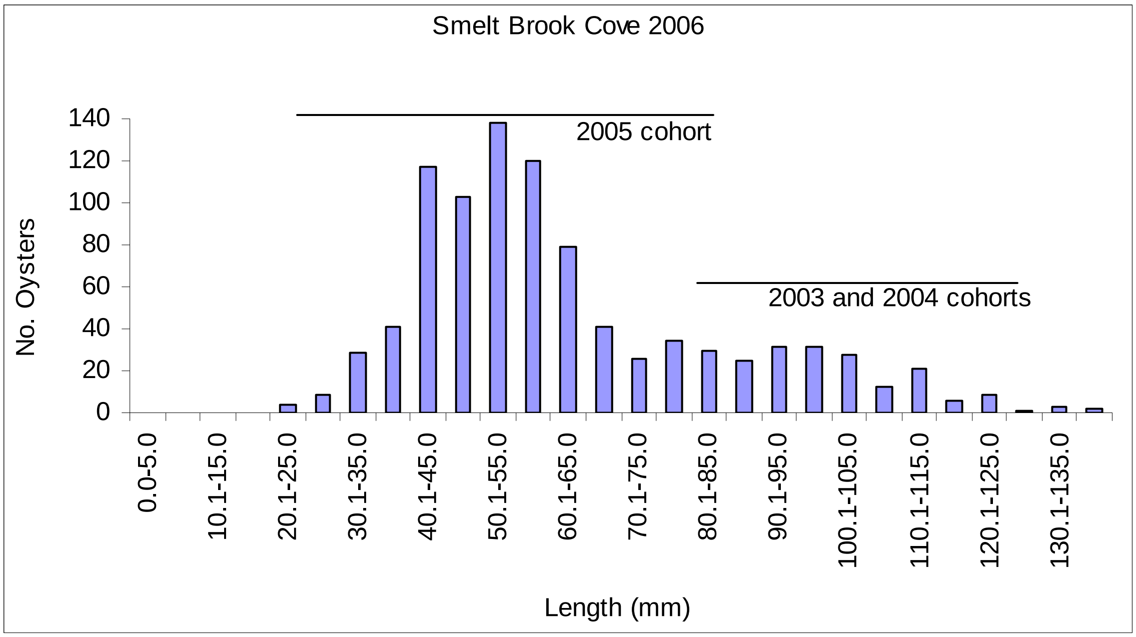


Figure 1. Survival of seeded oysters during their first year.

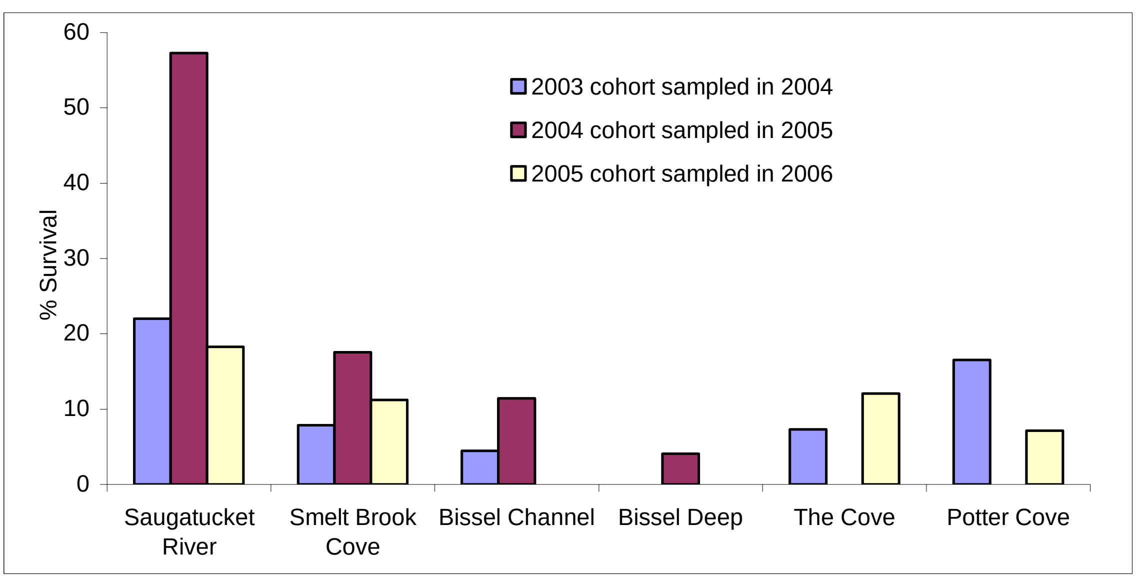


Figure 2. Survival of seeded oysters to their second and third years.

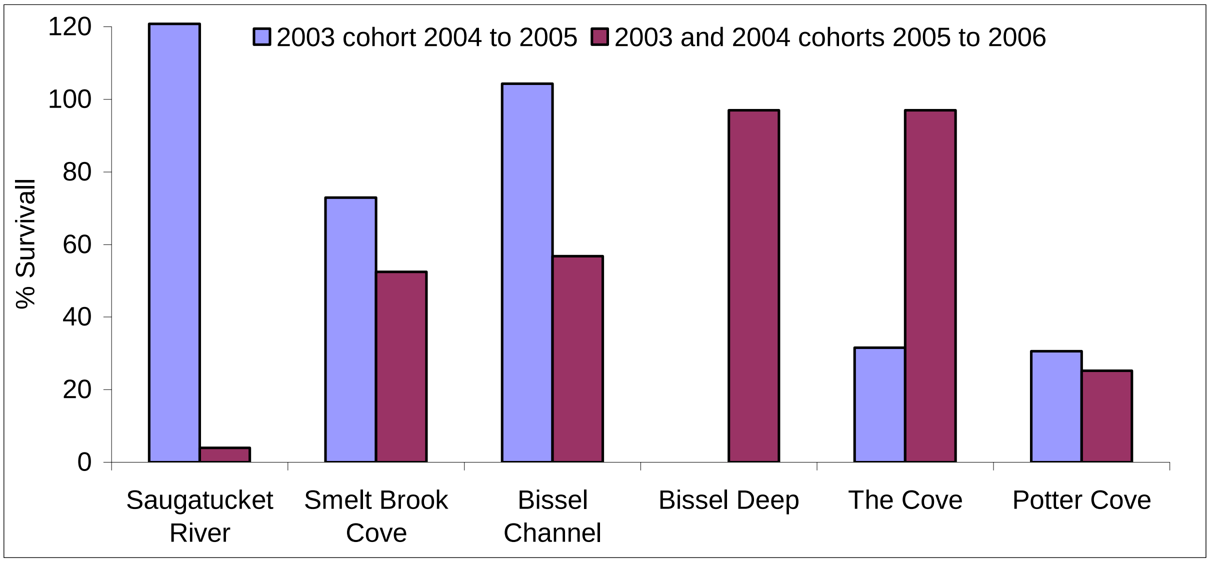


Figure 3. Size distribution of oysters at Bissel Cove in August 2006 showing a step down in abundance at the minimum legal size of approximately 75mm.

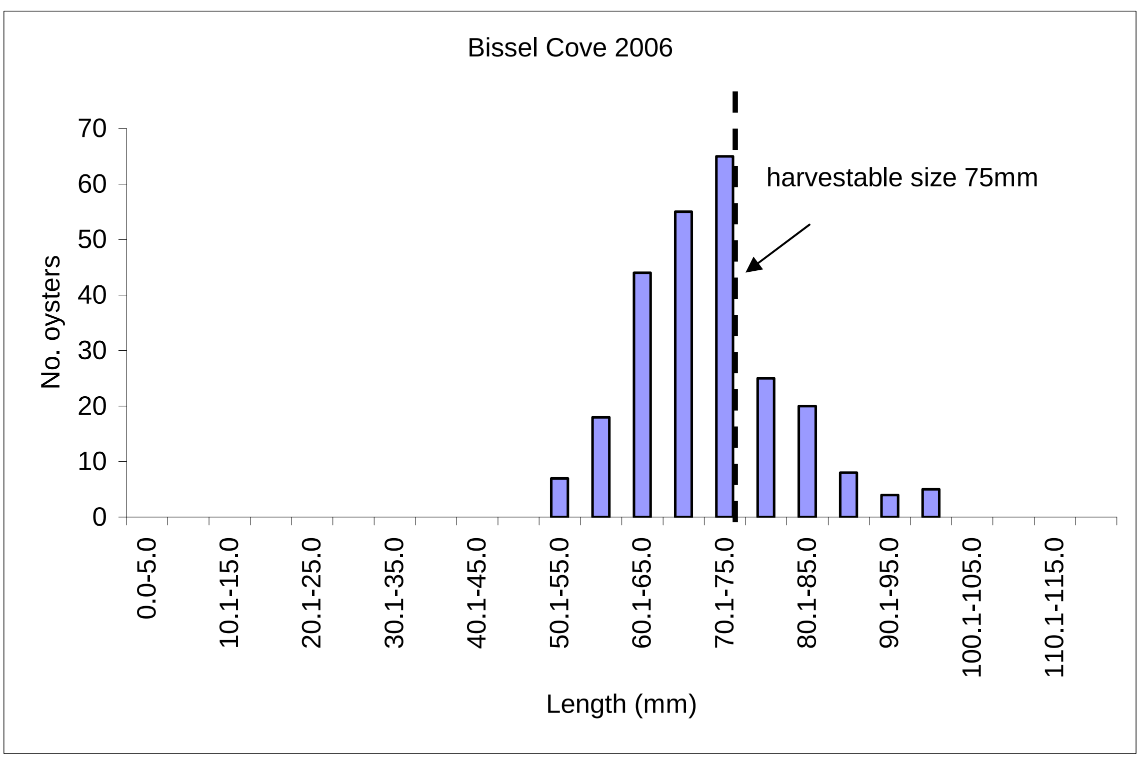


Figure 4. Mean length of oysters (±standard error) at each site after their first year of growth.

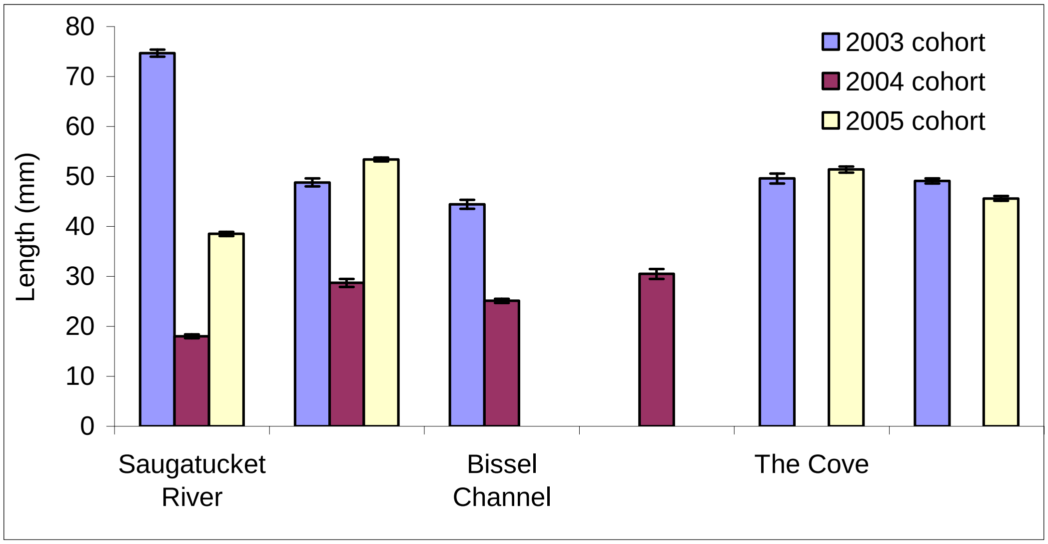


Table 6. Total number of oysters seeded at each restoration site from 2003 to 2006.

Site	2003	2004	2005	2006	Total
Saugatucket	48,700	137,400	272,800	575,642	1,034,542
Smelt Brook	114,400	86,900	372,900	425,600	999,800
Bissel Channel	112,400	137,400		439,362	689,162
Bissel Deep		137,400			137,400
The Cove	96,600		361,200	222,389	680,189
Potter Cove	140,800		370,900	288,389	800,089
Total	512,900	499,100	1,377,800	1,951,382	4,341,182

Table 7. Results of oyster disease testing at five restoration sites from 2004 to 2006.

Year	Site	n	Mean size (mm)	% prevalence	Mackin index
2004	Saugatucket River	25	81	68	2
	Smelt Brook Cove	25	59	86	3
	Bissel Channel	25	52	0	0
	The Cove	25	59	13	1
	Potter Cove	25	50	14	1
2005	Saugatucket River	25	86	100	4
	Smelt Brook Cove	25	96	100	3
	Bissel Channel	25	76	11	1
	The Cove	25	92	60	1
	Potter Cove	25	88	24	1
2006	Saugatucket River	25	87	100	5
	Smelt Brook Cove	25	102	100	4
	Bissel Channel	25	71	10	1
	The Cove	25	100	40	1
	Potter Cove	25	105	0	0

Table 8. Overwintering success for the 2004 and 2005 cohorts transferred from the upweller to overwintering trays between December 2005 and April 2006.

		Dec. 05	**April 06**	**% Survival**
04 cohort Large	Number	10,677	10,357	97.0
	SE	323	510	4.8
	Mean size	19.6	20.3	
	SE	0.2	0.2	
04 cohort Medium	Number	26,811	20,232	75.5
	SE	1353	842	3.1
	Mean size	13.6	13.8	
	SE	0.2	0.3	
04 cohort total	Number	37,488	30,589	81.6
	SE	343	1352	3.6
05 cohort Large	Number	109,667	51,887	47.3
	SE	6,934	3,572	3.3
	Mean size	5.5	5.4	
	SE	0.1	0.1	
05 cohort Small	Number	184,402	37,540	20.4
	SE	24,674	1,110	0.6
	Mean size	4.5	4.7	
	SE	0.1	0.1	
05 cohort total	Number	294,069	89,427	30.4
	SE	31607	4681	1.6

Table 9. Overwintering survival of the 1+ year class quahogs from the 2004 cohort, maintained in the bottom grow-out treatments between November 2005 and early June 2006.

Treatment	Sample	Number in Nov 05	SE	Number of survivors	SE	Survival (%)	SE (%)
5,000m^{-2} Boxes	1	909	37	657	13	72.3	1.4
	2	909		760	15	83.6	1.6
	3	891		624	12	70.0	1.3
	Total # boxes	11					
	Total # quahogs	9,997	407	7,484	451	75.3	4.2
10,000m^{-2} Boxes	1	1,641	85	1,456	118	88.7	7.2
	2	1,641		1,782	122	108.6	7.4
	3	1,641		1,740	111	106.0	6.7
	Total # boxes	6					
	Total # quahogs	9,847	512	9,956	614	101.1	6.2
5,000m^{-2} Covers	1	1,000	146	819	117	81.9	11.7
	2	785		770	63	98.1	8.0
	3	1,000		1,276	99	127.6	9.9
	4	937		908	67	96.8	7.2
	5	1,000		945	101	94.5	10.1
	6	1,089		1,089	99	85.2	7.7
	Total # covers	6					
	Total # quahogs	6,001	876	5,807	545	97.3	6.6
10,000m^{-2} Covers	1 and 2	4,773	67	4,340	1,356	90.9	28.4
	3 and 4	4,907		5,551	1,068	113.1	21.8
	Total # covers	4					
	Total # quahogs	9,814	268	9,891	2,424	102.0	11.1

Table 10. Comparative survival figures for the 5 treatments of growout for the 1+ year class quahogs of the 2004 cohort, between July 2005 and June 2006.

Treatment		July 05-Nov. 05	Nov. 05-June 06	July 05-June 06
Mesh Box 5,000/m²	Survival %	57.7	75.3	43.2
	SE %	3.2	4.2	2.6
Mesh Box 10,000/m²	Survival %	52.1	101.1	52.7
	SE %	2.7	6.2	3.3
Mesh Cover 5,000/m²	Survival %	38.5	97.3	37.2
	SE %	5.6	6.6	2.9
Mesh Cover 10,000/m²	Survival %	47.2	102.0	47.6
	SE %	1.3	11.1	5.8
Upweller and Overwinter trays	Survival %	98.9	81.6	80.7
	SE %	4.4	3.6	3.6

Bottom grow-out treatments were sampled in early June 2006, overwintering trays were sampled in April 2006.

Figure 5. Percent survival of 1+ year class quahogs grown in five treatments for the experimental period, with a corresponding growth increment annualized to 365 days.

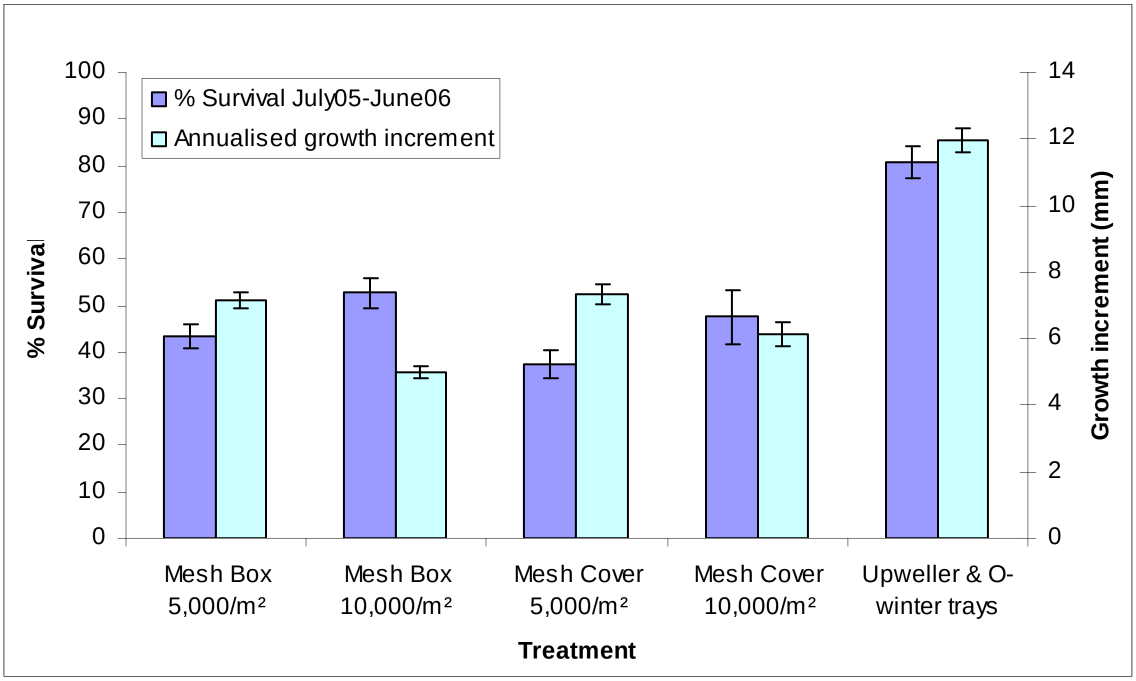


Figure 6. Experimental plots established in 2006 with sites seeded in 2004 in Quonochontaug Pond.

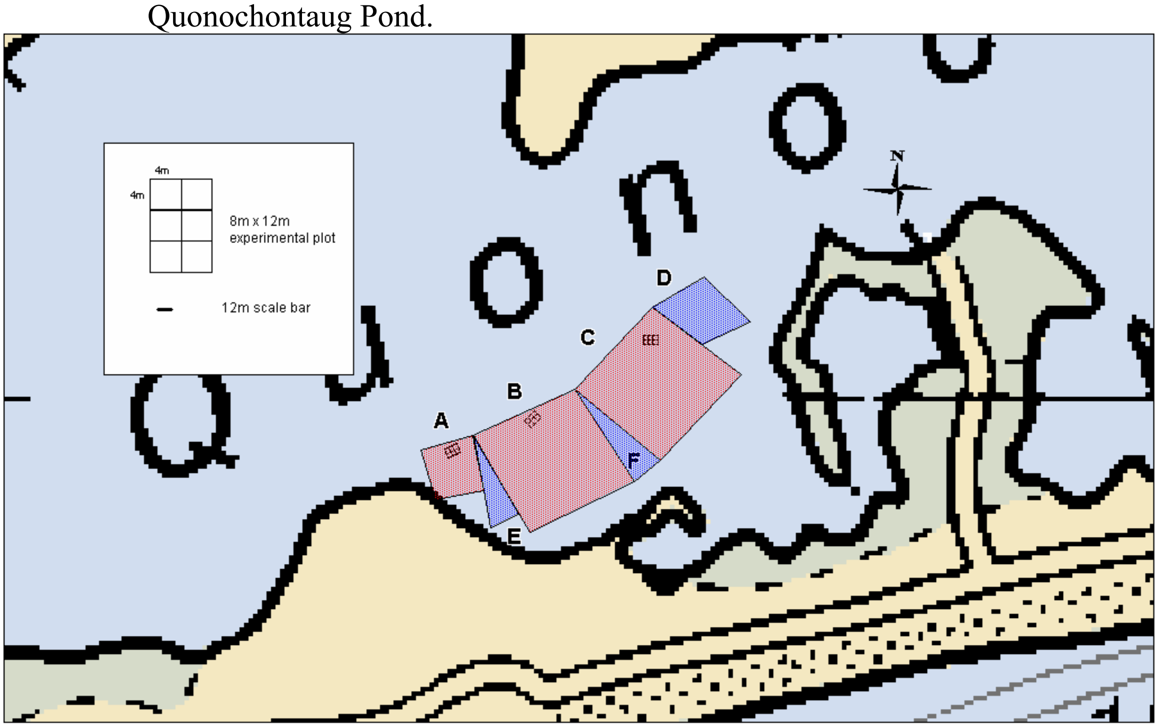


Figure 7. Experimental plots established in 2006 with sites seeded in 2004 (large rectangle) and 2006 (three smaller polygons) in Ninigret Pond.

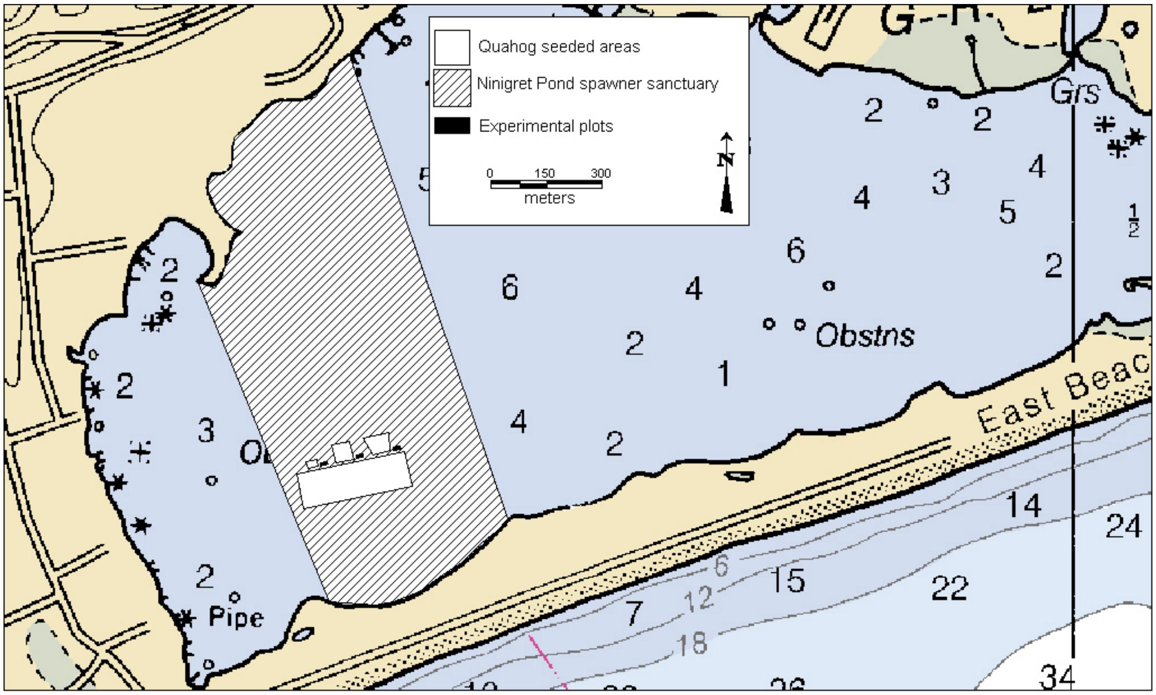


Figure 8. Schematic diagram of 1 of the 3 experimental plots per pond, established in Quonochontaug Pond in 2004 and 2006 and in Ninigret Pond in 2006.

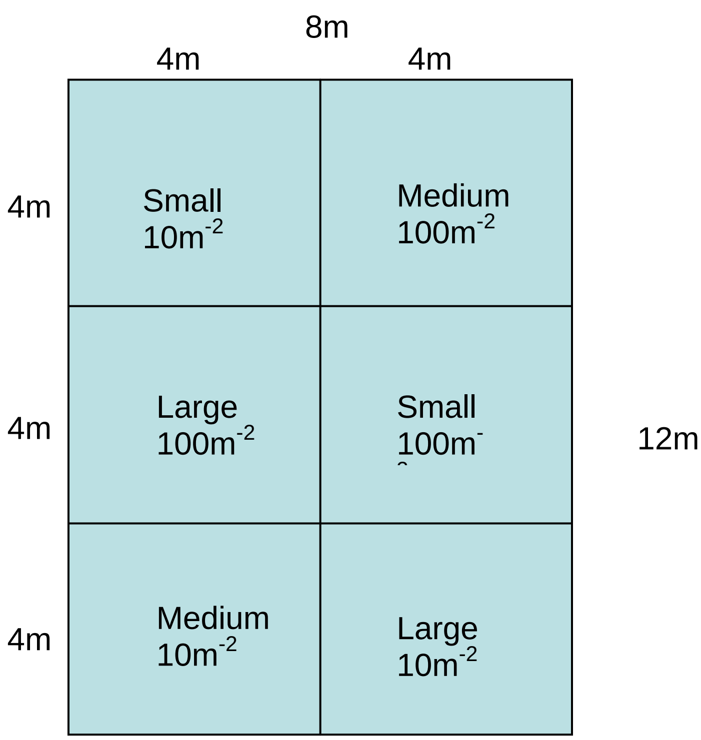


Figure 9. Size distribution of quahogs in each of the three size categories used in the experimental plots in 2006.

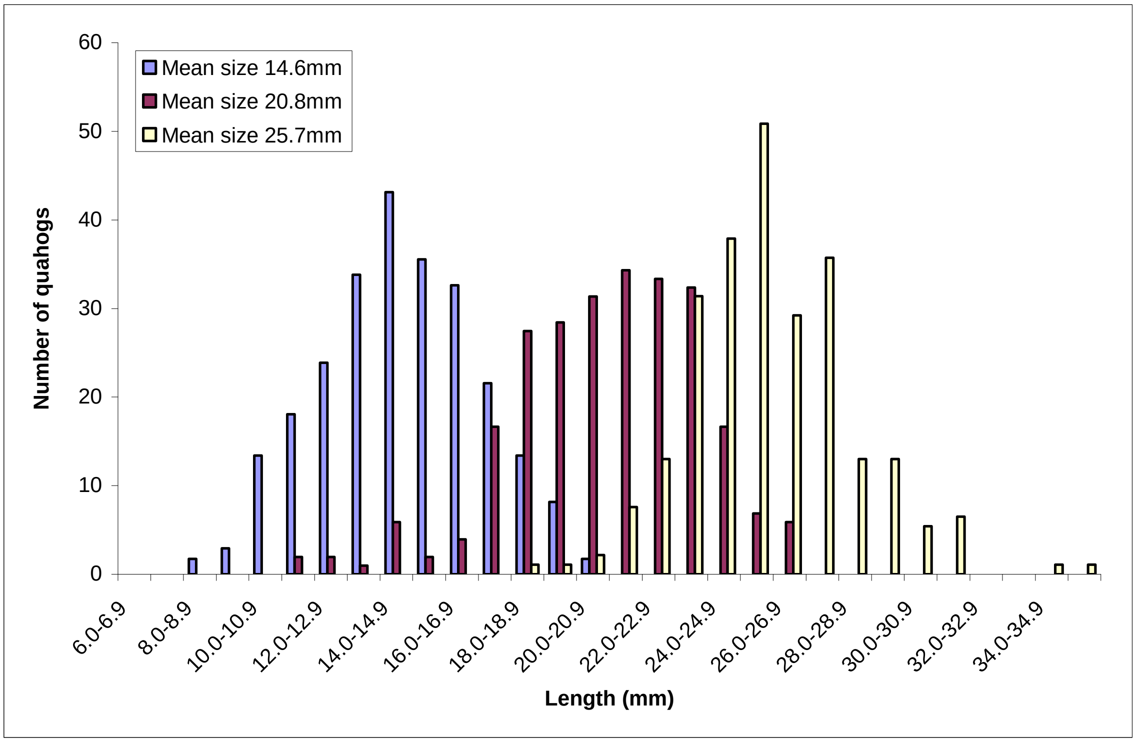
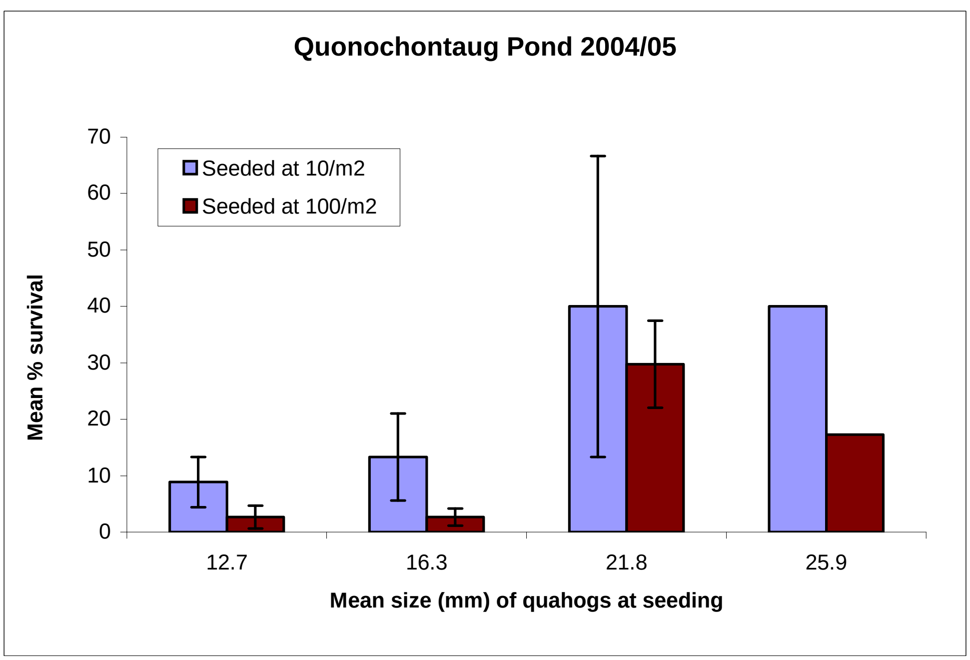


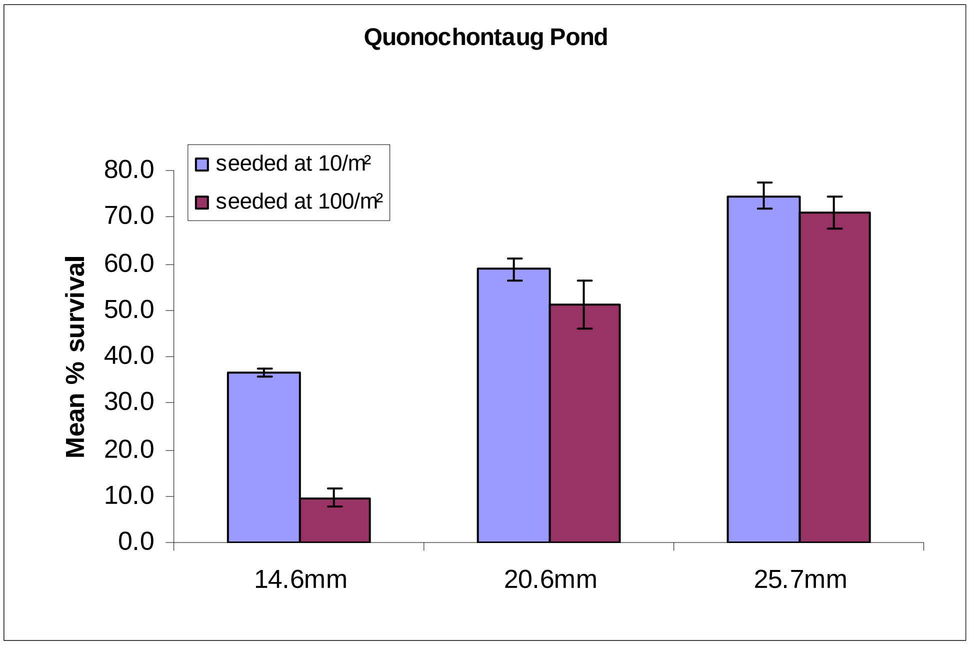
Figure 20. Annual mean percent survival of quahogs from four different size classes, seeded at 10/m² and 100/m² in three replicate experimental plots in Quonochontaug Pond in 2004.



No percent standard errors were calculated for the 25.9mm size as this treatment was not replicated.

Figure 10. Mean percent survival of quahogs from three different size classes, seeded at $10/m^2$ and $100/m^2$ in three replicate experimental plots in both Quonochontaug Pond (A) and Ninigret Pond (B).

A.



B.

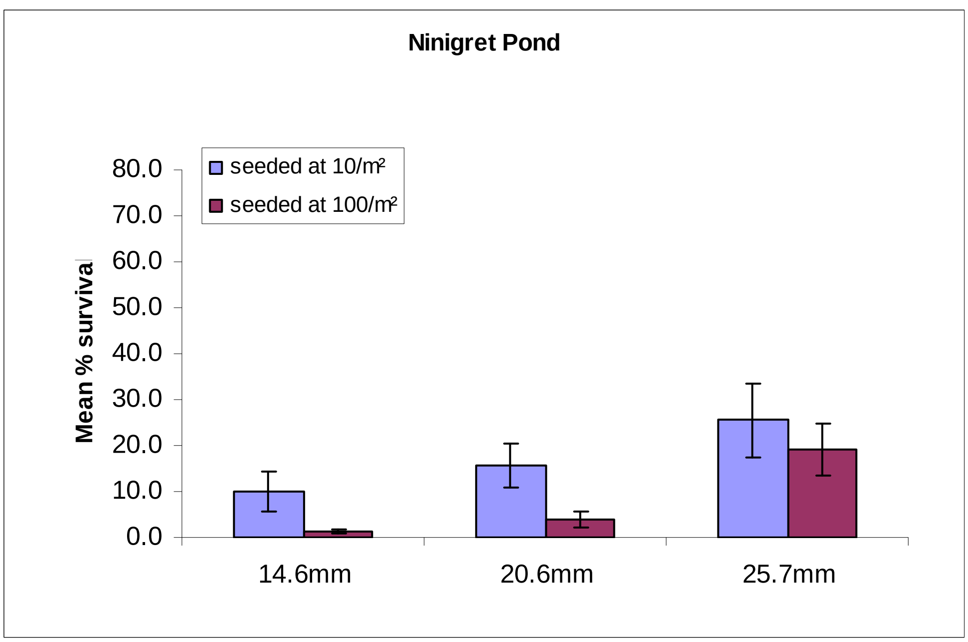


Table 11. Number of quahog in each size group seeded in shellfish sanctuaries in Quonochontaug Pond and Ninigret Pond in 2006.

	Size group	Ninigret	Quonochontaug	Total
Experimental plots	Each size group	5,280	5,280	
	Total	**15,840**	**15,840**	**31,680**
Broad-scale seeding	Small	31,044	0	
	Medium	30,556	0	
	Large	17,313	0	
	Total	**78,913**	**0**	**78,913**
Total	Small	36,324	5,280	
	Medium	35,836	5,280	
	Large	22,593	5,280	
Grand total		**94,753**	**15,840**	**110,593**