# *North Cape* Shellfish Restoration Program
# 2007 Annual Report

## Rhode Island Department of Environmental Management
## National Oceanic and Atmospheric Administration
## United States Fish and Wildlife Service

Prepared by: Bryan DeAngelis, Boze Hancock, Michael Kocot, Jim Turek, Najih Lazar

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Acknowledgements

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# 2007 *North Cape*
# SHELLFISH RESTORATION PROGRAM

## Executive Summary

*North Cape* restoration efforts by State and Federal Trustees continued to move forward in 2007 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 shellfish 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.

Caged bay scallop spawner sanctuaries have proven to be a cost effective method of the *North Cape* Program for enhancing recruitment to the coastal ponds. The 2007 bay scallop project included establishing a bay scallop caged spawner sanctuary in Quonochontaug Pond, for a second consecutive year, stocked with hatchery-reared broodstock. The recruitment of juvenile bay scallops produced by these broodstock was monitored using artificial 'spat' collectors, and diver surveys were completed to estimate the 2007 scallop population in the pond. The 2006 Quonochontaug Pond caged spawner sanctuary increased the number of naturally occurring scallops in the pond from an estimated 3,500 in 2006 to over 11,000 in 2007. The addition of another 7,100 caged scallops in the pond in 2007 resulted in a relatively low, but consistent spat fall throughout the 2007 season. During 2007, scallop recruitment monitoring also continued in Ninigret Pond following the successful deployment of spawner sanctuaries there in 2004 and 2005. The success of the caged spawner method produced an estimated 190,000 broodstock in Ninigret Pond in 2006. Despite difficult environmental conditions in 2006, the natural abundance of scallops in Ninigret Pond produced a mid to late season spat fall which yielded a population estimate of 63,000 scallops in Ninigret Pond in 2007. Scallop spat recruitment monitoring recorded a mid season spat fall in 2007 greater than that observed in 2006, which should yield a healthy scallop population in 2008. Scallop abundance and spat recruitment monitoring will be continued in Ninigret and Quonochontaug Ponds in 2008.

To date, over 4.3 million *North Cape* oysters have been seeded into seven restoration sites in Rhode Island salt ponds. In 2007, the survivorship and growth of the oyster

cohorts released in 2003, 2004, 2005 and 2006 were monitored. Due to shell size overlap amongst cohorts, the first year survivorship of oysters seeded in 2006 could only be determined at one location, the closed area of Bissel Channel. Survivorship of that cohort after one year was 21%, which is 6% higher than the cumulative average first-year survivorship of all cohorts seeded at all sites since 2003. Evidence suggests overall survival at the other sites was lower than years past, although we were unable to determine if the mortality was associated with the youngest cohort, older animals, or combination of both.

The *North Cape* quahog pilot stock enhancement project was completed in 2007. In 2006, two experimental areas were established in Ninigret and Quonochontaug Ponds to obtain estimates of growth and survival of quahogs seeded at two stocking densities and three shell-size classes. The objective was to use the results to comment on the likely survival of the broad-scale free planting conducted in 2004 (Hancock *et al*. 2006). The experiment was a replicate of a previous one conducted in Quonochontaug Pond in 2004. The results of our experiments support previously suggested results that lower seeding densities generally result in lower predation and increased survival. Also, survival of seeded quahogs increased with increased seed size, until the quahogs reach a 'size refuge', at which survivorship no longer increases significantly with size. The results of the experiments also suggest that fine-scale habitat differences have a significant impact on quahog seed survival, in addition to seed density and size. Results from 2007 revealed that quahogs seeded in Quonochontaug Pond exhibited much greater survival than those seeded into Ninigret Pond. The 2005 and 2007 annual experiment results applied to previously estimated 2004 broad-scale seeding survival estimates in Quonochontaug Pond suggest that annual survival of quahog broad-cast seeded in 2004 was likely higher than originally estimated in our previous annual reports.

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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 throughout much of its range (Blake and Shumway 2006). For example, 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 bay scallop 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 epiphytic algal growth causing decreases in eelgrass and periods of hypoxia (Hinga *et al*. 1991, Short *et al.* 1996). Eelgrass beds, once abundant in Rhode Island's coastal ponds and an important structural component for bay scallop habitat, have largely disappeared due to increasing water temperatures from gloabal climate change, 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 thirty 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 very low (Holly *et al*. 2004). Ninigret Pond had the highest number of surviving scallops, estimated to be 9,500, and these scallops 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 a lower number of broodstock could be placed in mesh cages to be protected from predation to minimize mortality while 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, and the performance of 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/spat bags, collected and replaced regularly throughout the season since 2004. Monitoring the settlement of scallop spat in Quonochontaug Pond began in 2006 using the same monitoring techniques 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 Nekles 1998). 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). Documenting the occurrence of low dissolved oxygen levels highlights this as a potential limitation to sustainable scallop populations in the coastal ponds and other Rhode Island waters. 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 survive only for two years, one year of growth and a second year in which they reproduce (Sastry 1970). Conducting the surveys early in the season means that newly settled scallops in 2007 were not yet likely to be large enough to be detected by divers. Consequently, the scallops surveyed in 2007 quantified the settlement of juveniles that were first recorded during the spat settlement monitoring in 2006. A caged spawner sanctuary had been implemented in Quonochontaug Pond in 2006. Dive surveys conducted in Quonochontaug Pond in 2007 were completed to quantify scallops that were recorded during the spat settlement monitoring in 2006. This monitoring was used to determine the contribution of scallops resulting from restoration methods implemented in 2006. A caged spawner sanctuary was implemented in Quonochontaug Pond for the second consecutive year in 2007, and spat settlement monitoring continued.

### Objective

The objective of the 2007 bay scallop surveys was to determine the abundance and spatial and temporal distributions of scallops entering their second season in both Ninigret and Quonochontaug Ponds.

## Methods

The 2007 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, URI Mapcoast website) and included sand/gravel bottom type, generally in the shallow water areas ($\leq$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 for each pond (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 habitat areas within each pond. 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 287,426m$^2$ to 1,448,000m$^2$ in Quonochontaug Pond (Table 1).

Diver transects were 50m long, using a bottom lead line attached to end floats to mark their location at the surface. Each transect was searched by a pair of divers competing observations along 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 48 transects were surveyed in four strata in Ninigret Pond, a total survey area of 4,800m$^2$, while a total of 40 transects were completed in Quonochontaug Pond, a total survey area of 4,000m$^2$ (Table 1). In Ninigret Pond, the total estimate of scallop abundance was 63,465 ± 45,715, a 67 % decrease below the abundance estimate of the 2006 population. The greatest numbers of scallops were found in the Southern stratum of the Western Basin (30,595 ± 21,640), followed by the Central stratum of the Western Basin (22,625 ± 17,508) and the Northern stratum of the Western Basin (10,245 ± 6,567). No scallops were found in the Central Basin (Table 1).

The total estimated scallop abundance in Quonochontaug Pond was 11,123 ± 8,309, a 399 % increase over the 2006 abundance estimate of the naturally occurring population. The East Basin Outer Sand stratum had the greatest relative abundance (10,165 ± 7,351). A single scallop was found in the West Basin Outer Sand, which extrapolates to an estimated 958 scallops in that stratum. No scallops were found in either the East or West Central Mud Basins.

## Discussion

In 2006, the *North Cape* Shellfish Restoration Project moved the focus of its bay scallop restoration to Quonochontaug Pond. A caged spawner sanctuary was not used in Ninigret Pond. Therefore, 2007 was the first year in which all scallops observed in Ninigret Pond were offspring of a naturally occurring broodstock. Despite a large decrease in the relative abundance of scallops in Ninigret Pond compared to 2006, the results are encouraging. During 2006, unusually high rainfall was the likely cause of an observed mass mortality of experimental scallops that were part of a USEPA project, as well as the lower than expected recruitment that was observed in 2006 (See *Hancock et al. 2007*). Our 2007 survey results suggest that despite a low recruitment year in 2006, the natural population of scallops in Ninigret Pond is large enough to withstand these poor environmental conditions. Nearly all of the recruitment recorded in 2006 was in the Central Basin of the pond. No scallops were detected in the Central Basin in 2007; all scallops observed were found in the Western Basin of the pond. These results support a four-year trend of data (See *Hancock et al. 2005; Hancock et al. 2006; Hancock et al. 2007*) that suggests the Western Basin of Ninigret Pond is the only basin of the pond that appears to currently support a significant scallop population.

The great increase in scallop abundance in Quonochontaug Pond can be attributed to the caged spawner sanctuary that was implemented in the pond in 2006. During the 2006 surveys, all naturally occurring scallops were found in the Outer Sand stratum of the East Basin. Similarly, the majority of scallops found in the pond during the 2007 surveys were also in this location while a single scallop was found in the Outer Sand stratum of the West Basin. These results emphasize the importance of suitable habitat that must be available for sustaining scallop populations. The majority of the total area of Quonochontaug Pond is characterized by the Central Basins. The Central Basins of Quonochontaug Pond are characterized by barren, wide-open areas, and a fine, muddy silt, with little vegetation. The Outer Sand stratums are characterized by a gravelly, sandy bottoms, healthy vegetation and poriferans. The Outer Sand stratum of the East Basin is mostly located in deeper water (generally > 2.5 m, mean low water (MLW)), whereas much of the Outer Sand stratum in the West Basin is a very shallow (< 0.6 m, MLW) which likely has a high fishing mortality attributed to both bird and recreational fishing pressure, which may account for the decreased abundance in the Western Basin versus the Eastern Basin. The results from two years of scallop monitoring in Quonochontaug Pond suggest that the low percentage of suitable habitat that is free from recreational fishing pressure may be a limiting factor governing the potential for scallop restoration in the pond.

## 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 free broadcasting of seed 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 and again in 2007.

### Objectives

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

### Methods

In 2007, *North Cape* staff deployed and maintained 36 wire cages initially containing 7,100 adult bay scallops in Quonochontaug Pond. Scallops were purchased from two commercial growers, 4,100 and 3,000 scallops, respectively. Cages were deployed on May 22, and June 6 and were monitored periodically until retrieval in November 2007. Cages were approximately 75 x 75cm, made of 5cm (2 inch) plastic-coated wire mesh. Three tiers in each cage held three plastic 13mm (1/2 inch) mesh bags, each containing ~70 mature, hatchery-reared 1+ and 2+ 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 installation was secured from the Rhode Island Coastal Resource Management Council. A service platform was built for simplifying 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 7,100 adult bay scallops were held in the cages of the shellfish spawning sanctuary during the potential scallop spawning season. The majority of scallop broodstock were in their second year with percent survivorship expected to be very low beyond the 2007 season. Some scallops were known to be in their third year, with no survival expected beyond the 2007 season. Monitoring of spat in the pond indicated an initial spawning in early July, continuing through to mid 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 performance 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 are 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 in 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 are 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 in each Ninigret Pond and Quonochontaug Pond and monitored between June through November 2007. 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, 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, MLW. 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, MLW. 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, MLW. Tidal exchange was most significant at the Breachway site, being in close proximity to the pond opening with 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, MLW. 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, MLW. 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, MLW. 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, MLW (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 seed 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 $= \Sigma$ mean spat per bag, per site, for the n collections per year

**Results**

The first spat line was deployed on June 14, 2007 in Ninigret Pond. The last bags were collected on November 15, 2007. In Ninigret Pond, a total of 190 artificial spat collectors were deployed on eight lines, two at each of the four study sites, yielding a total 316 spat. The highest number of spat was recorded from the Hall Point (159 spat) followed by the West End (91 spat), Aqualease (38 spat), and Breachway (28 spat) (Table 2).

The major settlement events in Ninigret Pond appeared to have occurred sometime between August 7$^{th}$ and August 30$^{th}$ in the Western Basin of the pond, as indicated by the mean spat per bag values (Table 2). This settlement was not nearly as pronounced in the Central Basin of the pond. Four smaller settlement events occurred between August 20$^{th}$ and October 31$^{st}$, primarily in the Central Basin. Although the West End site had the second highest settlement index (18.2), spat were only found on one collection throughout the season, and therefore, was the least consistent site. Hall Point, Aqualease, and Breachway were the most consistent sites, with settlement indices of 26.5, 6.9, and 4.7, respectively (Table 2). The seasonal settlement index for the cumulative pond monitoring was 56, an increase compared to the settlement index 35.3 in 2006 (Figure 5).

The first spat lines were deployed on June 12, 2007 in Quonochontaug Pond. The last bags were collected on November 6, 2007. A total of 192 artificial spat collectors were retrieved over eight collection periods at each of the four study sites in Quonochontaug Pond, yielding a total of 42 spat. The highest number of spat was recorded from the Bill's Island site (18 spat), followed by the Spawner Sanctuary and East End sites (10 spat), and lastly the West End site (4 spat) (Table 2).

The settlement events that occurred in Quonochontaug Pond throughout the season were relatively small, with most of the observed settlement occurring in the beginning of the season, between July 12th and August 24th. During this period, the settlement was mainly observed at the Spawner Sanctuary, Bills' Island and the East End, with settlement indices being relatively even (Figure 6). A larger settlement event occurred sometime between September 6th and October 6th at the East End site, but the settlement index for that event was only 5.6. The seasonal settlement index for the cumulative monitoring of Quonochontaug Pond in 2007 was 12, considerably lower than the cumulative settlement index in 2006 of 50 (Figure 6).

## Discussion

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 4 years through 2007. The cumulative settlement index in Ninigret Pond for 2007 provides encouraging results. Despite unusual environmental conditions in 2006 (See section 1.1) that resulted in lower than usual recruitment in 2006 and reduced broodstock levels in 2007, the recruitment observed in 2007 suggests the potential for a healthy scallop population in 2008. Recruitment results in 2007 resembled those of 2004 and 2005, with most of the settlement occurring in the Western Basin of the Pond. The history of the *North Cape* scallop restoration in Ninigret Pond suggests the Western Basin of the Pond is the most suitable for supporting scallop populations. Interpretation of the available data suggests broodstock levels in the Western Basin of Ninigret Pond in 2008 should be strong.

Interpretation of the history of cumulative settlement indices in Quonochontaug Pond is more complex. Figure 6 illustrates the project scale summary of restoration over the two years through 2007. In 2006, the first year implementing the caged spawner sanctuary in the pond, recruitment results were positive, with a cumulative settlement index of 50. The increased broodstock and the positive recruitment results in 2006 resulted in nearly a 400% increase in the pond scallop population in 2007, above the estimate of naturally occurring scallops before restoration began. The increased pond population, plus the caged animals provided in 2007, was expected to produce a greater cumulative settlement index than what was observed.

The lower than expected recruitment observed in 2007 could have been a result of the reduced number of caged broodstock provided. Due to complications obtaining the broodstock from two commercial growers, the total number of scallops that were available to place in the caged sanctuary was reduced. Secondly, it was known that a large proportion of the caged scallops were already in their third year of life. It's possible that the health and reproductive potential of the older animals was lower than expected, therefore reducing the ultimate number of caged broodstock even further.

# II. Oyster Projects

## 2.0 Introduction

The *North Cape* Restoration Program has focused on creating a supply of breeding adult oysters 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 have 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. 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.

## 2.1 Monitoring of Oyster Release Sites

### Objective

The objective of the monitoring project was to estimate survivorship of individual cohorts, mean size and abundance of oysters planted at restoration sites in the fall of 2003, 2004, 2005, and 2006.

### Methods

Five oyster restoration sites established in 2003, 2004, 2005 and 2006 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 120 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.

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.

In 2006, the boundaries of one of the restoration sites, Bissel Channel (Figure 1), was moved approximately 500 m north into an area closed to shellfishing. Because 2006 was the first time this area was seeded, it was possible to determine survivorship and growth of that cohort from the 2007 survey. In the other four sites sampled, it was not possible to enumerate separate cohorts by size, and therefore, analyze survival and growth information of newly seeded and older cohorts.

**Results**

Between October 29, 2007 and November 14, 2007 dive teams surveyed $125m^2$ using $1m^2$ quadrats, at five locations. One of these locations (Bissel Channel closed area) was seeded for the first time in 2006. The other four areas had been seeded once or more prior to 2006 (see Table 3). A total of seven areas have been seeded one or more times since 2003. The Bissel Channel closed site was estimated to have the greatest number of total oysters (92,184 $\pm$ 15,435), followed by The Cove (63,288 $\pm$ 20,068), Potter Cove (54,647 $\pm$ 10,271), Smelt Brook Cove (52,174 $\pm$ 5,604), and Saugatucket River (33,014 $\pm$ 5,734) (Table 3).

The Bissel Channel closed site was seeded for the first time in 2006, therefore, first year survivorship could be determined from the dive surveys. Survivorship of oysters seeded into Bissel Channel closed site was 21%, which is 6% greater than the average first year survivorship of all sites seeded since 2003. Mean size of age 1+ animals in Bissel Channel closed was 76.7 $\pm$ 0.8 mm, representing an annual growth increment of 66.3 mm. The average first year annual shell length growth increment for all oysters seeded from 2003 – 2005 was 31.9 mm.

The mean shell length of oysters sampled from the other four sites, a measurement of all cohorts seeded since 2003 (see Table 3) was 66.1 $\pm$ 1.1 in Smelt Brook Cove, 58.2 $\pm$ 0.6 in the Saugatucket River, 74.7 $\pm$ 1.3 in The Cove, and 81.0 $\pm$ 1.1 in Potter Cove. The frequency of occurrence of older and younger animals can typically be inferred from length frequency relationships of the sites (Fig 7a-e), however, overlap of different cohorts was too great to accurately distinguish between them. This is particularly true in a site such as Smelt Brook Cove (Fig 7b) where a ‘tail’ of older animals can be witnessed from the size distributions, but individual cohorts are no longer obvious.

**Discussion**

The total numbers of oysters at each restoration site sampled in 2007 have decreased, despite successful seeding efforts in 2006. Historical data from surveys conducted at each restoration site from 2004 – 2006 indicate that first year survivorship averages 15.5% for all the restoration sites, and second year + survivorship averages approximately 75% (*North Cape* unpublished data). Using these survival rates to predict the total number of oysters that should have been observed in 2007, it’s clear that our survival rates for oysters from 2006 – 2007 was less than average survival, compared to past years. It is unclear if the increased mortality is attributed primarily to first year animals, older animals, or a combination. The *North Cape* project has been monitoring the pathogen loads of Dermo (*Perkinsus marinus*) in the seeded restoration sites since 2004 (see Hancock *et al. 2007*). Those studies have shown a 100% prevalence of disease at Smelt Brook Cove and Saugatucket River, moderate pathogen loads at The Cove and Potter Cove and low levels at Bissel Channel. It is known that the level of Dermo infection increases with age, as does the associated percent mortality (Encomio et al. 2005). It is possible that the older animals seeded into the *North Cape* restoration sites are beginning to succumb to an accumulation of Dermo that they can no longer withstand. Traditionally, however, survival rates at the restoration sites have been high, and therefore future monitoring of both newly seeded and older cohorts needs to continue to better understand the demographics of each site

The first year cohort in the Bissel Channel closed site had exceptional survival and growth. This site has a regular freshwater input, and high rate of flushing, which may contribute to the site’s apparent suitability for rapid oyster growth and survival. However, historical evidence from previous surveys show that survivorship and growth can have wide variation from site to site and year to year, and therefore, this degree of survivorship of first year animals can not be assumed at the other restoration sites.

# 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 (See Hancock *et al. 2005;* Hancock *et al. 2006;* Hancock *et al. 2007*).

In 2006, growth and mortality experimental plots were established in Quonochontaug and Ninigret Ponds. The experimental plots were repeats of a design used in Quonochontaug Pond in 2004-2005, 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 where taken in 2007. Results from the two seeding experiments are used to comment on likely survivorship of broad-scale seeding performed in 2004 and 2006.

## 3.1 Quahog Seeding Experiment

### Introduction

Experimental plots were established in Ninigret and Quonochontaug Ponds in 2006 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 a few months at liberty, and again at 12 months, and determine the influence of the treatment density and seed size on growth and survival, and to use these results to relate to the likely survival of the broad-scale seeding conducted in 2004 (Hancock *et al.* 2006) and in Ninigret Pond in 2006. The experimental design used in 2004 in Quonochontaug Pond (See Hancock *et al. 2006*) was repeated in 2006 in both ponds.

### Objective

The objective of this work was 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, experimental plots established in Quonochontaug Pond in 2004 were replicated in Quonochontaug Pond and Ninigret Pond in 2006. Experimental plots were sampled 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 variations in survival of quahogs seeded at three different mean shell sizes and two stocking densities.

### Methods

Three replicate experimental plots were established within the 2004 quahog broad-scale seeding area in Quonochontaug Pond (Figure 8) and within the range of areas seeded in Ninigret Pond in 2004 and 2006 (Figure 9). The plots in Quonochontaug Pond were extensions of the plots used in 2004 (Hancock *et al.* 2006), each new plot being placed immediately adjacent to the 2004 plots. Each experimental plot measured 12m x 8m and was comprised of 6 treatments; three size classes, each seeded at two different densities (Figure 10). 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 through a 13mm mesh (medium), and those that were too big to sieve through a 19mm mesh (large). These size groups were sampled again prior to seeding in September of 2006, and were determined to have a mean size of 14.6 mm, 20.8 mm, and 25.7 mm, respectively. 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.

Experimental plots were sampled in November 2006 (See Hancock *et al. 2007* for detailed seasonal results) and again in August (Ninigret Pond) and October (Quonnochontaug Pond) of 2007, to allow for comparisons of survival after approximately one year of liberty. In 2007, only one of three experimental plots was able to be sampled in Ninigret Pond, due to difficulties in sampling and project time constraints.

During sampling, 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 $1.0m^2$ quadrats. All sediment to a depth of ~30cm was sampled 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.

Each experimental plot represented a design block with six treatments, three size classes seeded at two densities. General Linear Models (GLM) were used to test for statistically significant differences ($\alpha = 0.05$) in survivorship of quahog with respect to three predictive factors; plot, size and density. When significant differences were noted, multiple comparison procedures were used within each independent variable to determine which means were significantly different from which others. The method used to discriminate among the means was the Fisher's least significant difference (LSD) procedure.

## Results

In 2007, mean annual survival rates for all quahog seeded into experimental plots was greater in Quonochontaug Pond (25%) than Ninigret Pond (8%). Results indicate that survival was higher with the lower density. In Ninigret Pond, survival rates for the small, medium and large size classes, at a density of $10m^{-2}$ were 16.7%, 23.3%, 33.3% versus 2.0%, 1.3%, 15.7% at $100m^{-2}$. In Quonochontaug Pond survival rates for the same size classes at $10m^{-2}$ were 21.1%, 45.6%, 43.3% versus 2.7%, 13.4, 55.3% at $100m^{-2}$ (Table 4). This trend of increasing survival at the lower density for each pond can be seen in Figure 11a and b. Figure 11 also demonstrates an increased survival with increasing shell size sampled from both ponds.

In Ninigret Pond, only one of the three experimental plots was able to be sampled in 2007 to retrieve annual results, therefore, direct comparisons of seasonal versus annual results becomes more complicated. A GLM conducted on the 2006 seasonal results revealed that plot had a significant impact on quahog survival (p-value < 0.001), indicating the influence of fine scale variation in habitat on survival. When fitting a GLM to the 2007 annual survey data from the single sampled plot, relating quahog survival to two predictive factors (size and density), the p-value that describes the model is greater than

0.05 (p-value = 0.11), indicating there is not a statistically significant relationship between quahog survival and the two independent variables that the 95% confidence level. Additional complexities are seen in Table 4, which compares seasonal survival rates to annual survival rates. Results indicate that often survivorship of quahog within a specific size class and density actually increased after one year, compared to surveys conducted after only a few months. Length-frequency distributions of quahogs surveyed did not indicate the presence of a large number of new recruits into the area (n = 2).

In 2006, a total of 94,753 quahogs were seeded into Ninigret Pond (See Hancock *et al. 2007*). If the annual survival rates from the 2007 survey are applied to the number seeded, a total survival rate of 22.2% is estimated in Ninigret Pond, yielding an estimated 21,009 quahog remaining. Because plot location was determined to influence quahog survivorship, however, this figure of survival can be used only as a guide, since only one plot was sampled.

Seasonal and annual results are more consistent in Quonochontaug Pond. Table 4 illustrates the decreased survival of quahog within a specific size class and density after one year at liberty, compared to a few months at liberty. Independent variables effecting survivorship of quahog seasonally and annually remained consistent as well. Quahog survival varied significantly between experimental plots (p-value < 0.001 both seasonally and annually), indicating the influence of fine scale variation in habitat on survival. After accounting for the between-plot variation, there were significant increases in survival with increased seed size (p-values < 0.001, both seasonally and annually), and decreased densities (p-values = 0.01, both seasonally and annually) (Fig. 11a, Tables 5 and 6).

Yearly comparisons of Quonochontaug Pond quahog data can be achieved by examination of experimental results in 2005 versus 2007. Since statistical tests have suggested that fine scale variations significantly effect quahog survival, survival between years has been analyzed by plot (A, B, C). In 2007, survival of plots A and C were significantly greater than in 2005. In plot B, survival was greater in 2005, but there was not a significant difference (Figure 12).

Length-frequency distributions of quahog sampled from the experimental plots in Quonochontaug Pond suggest an increased number of new recruits into the seeded area in 2007 (n = 256)(Figure 13). Mean density of quahog recruits $m^{-2 \cdot plot}$ was 3.1, 4.0, and 7.2 for the western, middle and central plot, respectively. Survival of experimental areas was calculated using only the seeded animals (See Figure 13), not new recruits, so these animals do not contribute to an increased survivorship.

In 2004, 316,194 quahogs were broadcast seeded in Quonochontaug Pond at $10m^{-2}$. Survival was estimated around 4 – 5% (~17,000 animals) (See Hancock *et al. 2006*), however, survival estimates were unreliable because the exact areas seeded with different sized quahogs were not recorded during the seeding. Applying the results of the two experiments performed in Quonochontaug Pond in 2004/2005 and 2006/2007 provides a more accurate estimate of the annual survivorship from the 2004 seeding. Figure 14 compares the experimental survival rates of similar size classes used in each of the two experiments. Survivorship of similar-sized quahog, although slightly greater in 2007, was not significantly different within size ranges in 2005 versus 2007. Applying the 2004/2005 and 2006/2007 annual results to the broad-scale seeding numbers in 2004 results in an estimated annual survival of 12 – 15%, depending on which years results are used. The number of quahogs ranges from 38,181 ± 21,280 to 48,398 ± 18,169 depending on which years results are used.

**Discussion**

The annual survival data collected in 2007 support the conclusions made in previous experimental plot surveys (See Hancock *et al. 2007*) that survival is significantly increased at lower seeding densities. 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, Hancock *et al*. 2007). The annual survey results also support previous conclusions that survival significantly increases with increasing seed size. Results also suggest this may not persist beyond a size of about 22.5 mm, indicating a 'size refuge' has been attained (Peterson *et al*. 1995, Hancock *et al*. 2007). Variation in survival was also dependent on the location of the test plot. Test plots were no further than about 100 m apart; however, results from the first seeding experiment (See Hancock *et al. 2006*) and second seeding experiment indicate that fine-scale habitat variations significantly impact quahog survival. These fine scale differences in survival of quahog within a few hundred meters of each other may be a result fine scale differences in sediment type and density, hydrology, or predator concentrations.

Due to the fact that plot location plays a significant role on quahog survival, it is difficult to summarize quahog seeding results in Ninigret Pond. During 2004, quahogs were broadcast seeded in both Quonochontaug and Ninigret Pond. The independent survey results from that seeding suggested Ninigret Pond had a significantly greater survival rate than Quonochontaug Pond (See Hancock *et al. 2006*), however, survey results in Quonochontaug Pond were only a preliminary guide, since the seeding location of different size classes was not recorded, and therefore the accuracy of the results were dependent on the random distribution of the quadrats (See Hancock *et al. 2006*). The seasonal results recorded in November 2006 (See Hancock *et al. 2007*), as well as the annual results from the 2007 survey indicate that the survival success in Quonochontaug was considerably greater than Ninigret Pond. Unfortunately, because only a single plot was sampled in Ninigret Pond, it is difficult to make direct comparisons, or to use the 2007 Ninigret Pond survey data as anything other than a single-time outcome.

Results from Quonochontaug Pond are more consistent. Within pond comparisons suggested that plot location, seeding size, and density played similar roles as predictive factors both seasonally and annually. Year to year comparisons were made by comparing the two experiments that were performed in the pond in 2004/2005 and 2006/2007. Quahog survival was significantly greater in two of the three plot locations in the later experiment.

Comparisons of annual survivorship demonstrated that similarly sized animals seeded at $10m^{-2}$ in 2004 versus 2006 had very similar annual survivorships, although slightly higher in the later experiment. These results can be applied to the quahogs that were broadcast seeded in 2004. Although our results show variation in survival due to fine-scale habitat differences, and year to year, the consistency of the results allows them to act as a better predictor of survival. When either of the two experimental annual results are applied to the 2004 data, the annual survivorship has a three fold increase, compared to the original estimates.

It is interesting to note the increased recruitment observed in Quonochontaug Pond in 2007, which has not been observed before in this pond or Ninigret Pond. The majority of the recruitment was observed in plot C, the eastern most plot of the quahog sanctuary.

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

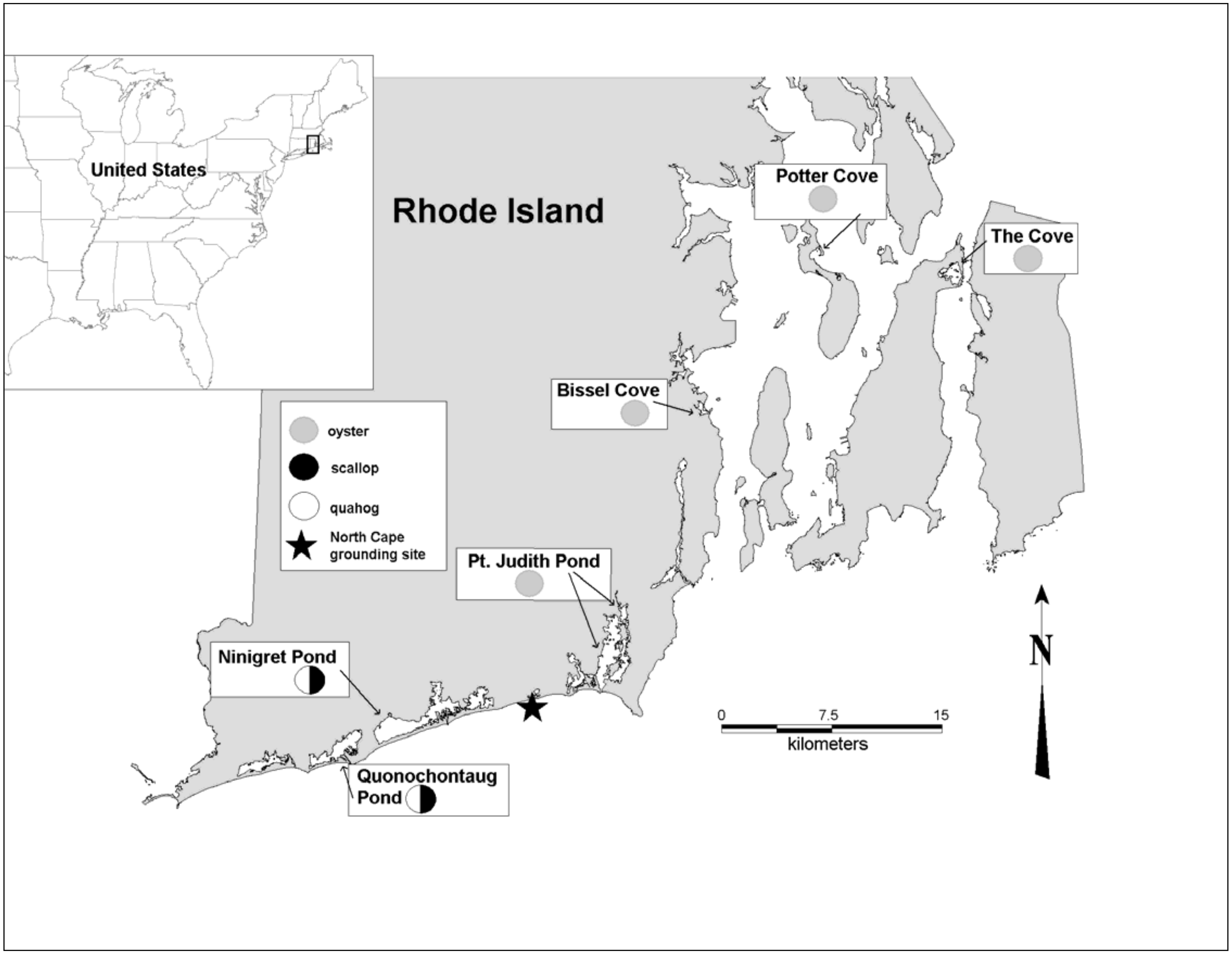
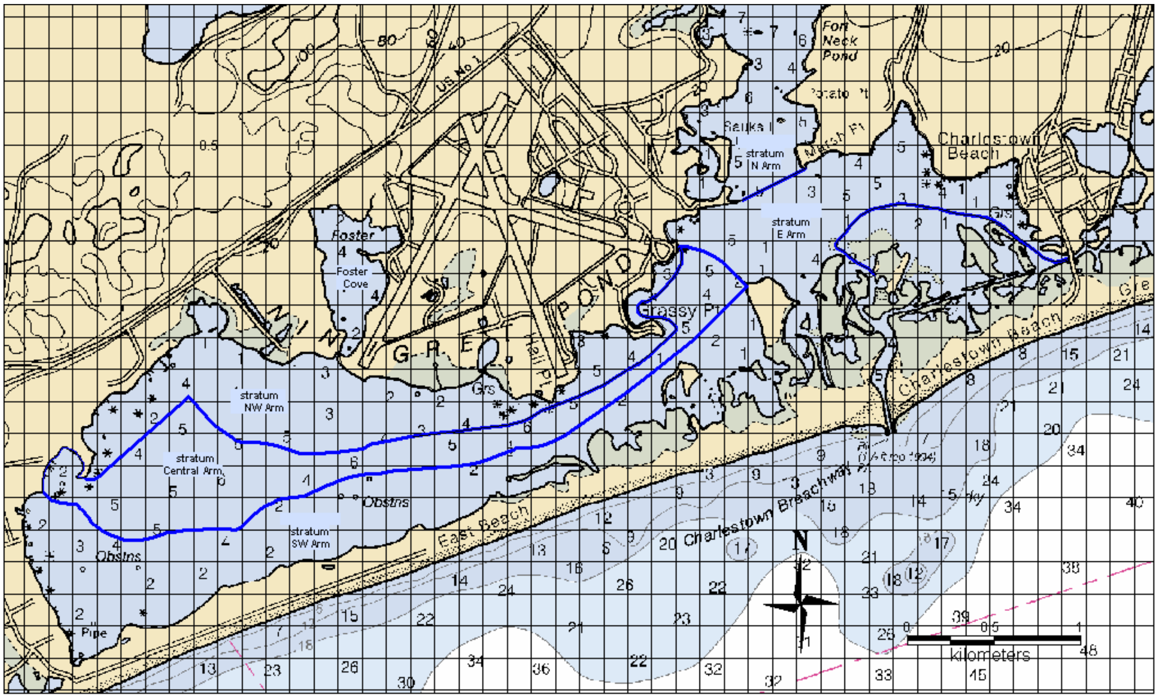


**Figure 2**. Ninigret Pond (A) and Quonochontaug Pond (B) scallop survey strata.

**(A)**




**(B)**

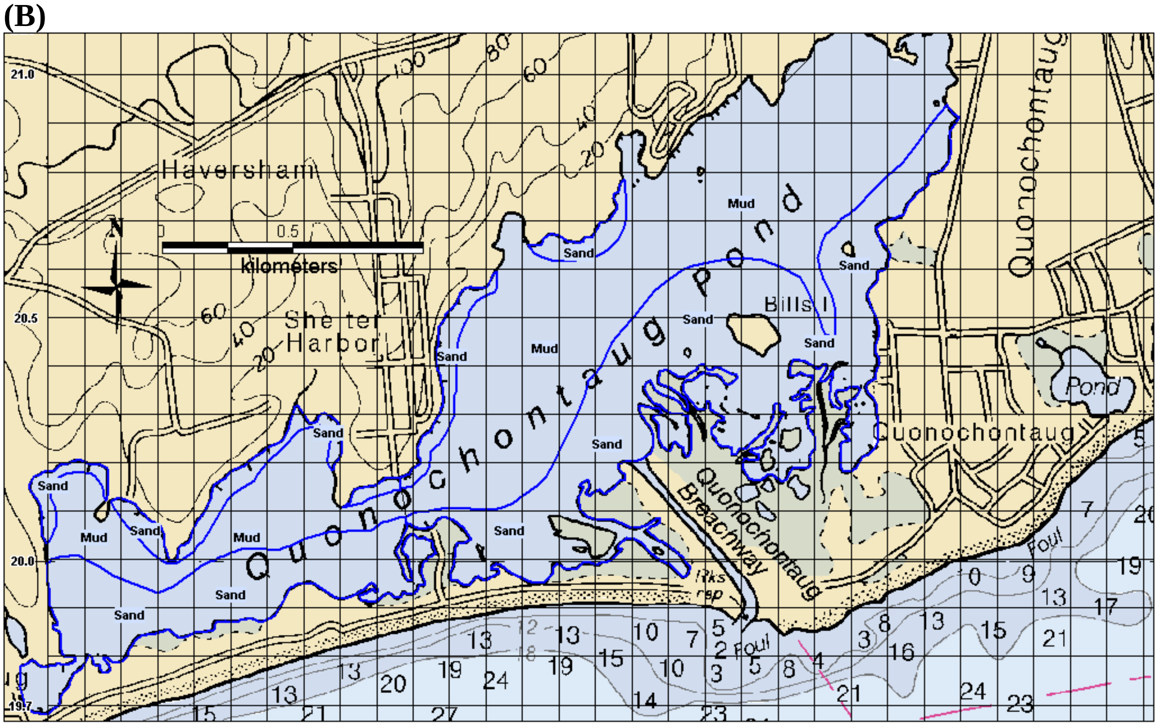


**Table 1.** Scallop survey distribution and abundance estimates.

**A. Ninigret Pond**

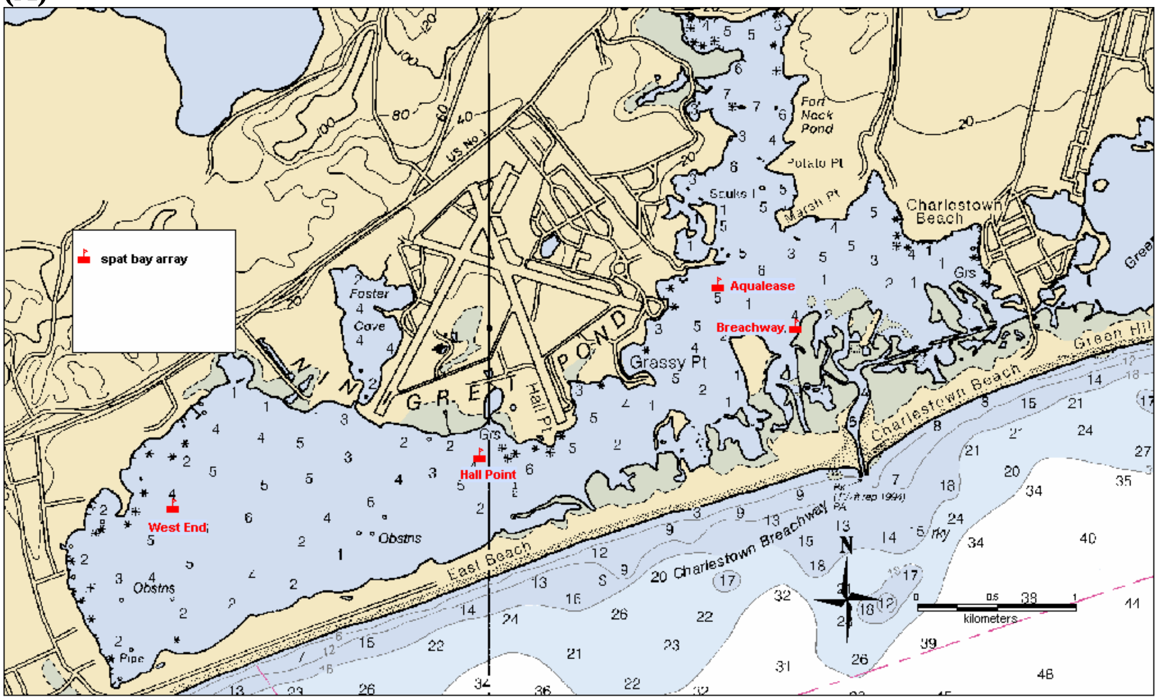
| Strata | Area Surveyed ($m^2$) | No. of Scallops Found | Mean Scallops $m^{-2}$ | SE | Area of Stratum ($m^2$) | No. Scallops/ Stratum | SE |
|---|---|---|---|---|---|---|---|
| North West Arm | 1,200 | 10 | 0.008 | 0.005 | 1,229,351 | 10,245 | 6,567 |
| Central West Arm | 1,200 | 22 | 0.018 | 0.014 | 1,234,114 | 22,625 | 17,508 |
| South West Arm | 1,200 | 21 | 0.018 | 0.012 | 1,748,259 | 30,595 | 21,640 |
| Central Basin | 1,200 | 0 | 0.000 | 0.000 | 961,400 | 0 | 0 |
| Total | 4,800 | 53 | | | 5,173,124 | 63,465 | 45,715 |

**B. Quonochontaug Pond**

| Strata | Area Surveyed ($m^2$) | No. of Scallops Found | Mean Scallops $m^{-2}$ | SE | Area of Stratum (m2) | No. Scallops/ Stratum | SE |
|---|---|---|---|---|---|---|---|
| East Basin Central Mud | 1,600 | 0 | 0.000 | 0.000 | 1,448,000 | 0 | 0 |
| East Basin Outer Sand | 1,400 | 17 | 0.012 | 0.009 | 837,099 | 10,165 | 7,351 |
| West Basin Central Mud | 700 | 0 | 0.000 | 0 | 528,920 | 0 | 0 |
| West Basin Outer Sand | 300 | 1 | 0.003 | 0.003 | 287,426 | 958 | 958 |
| Total | 4,000 | 18 | | | 3,101,445 | 11,123 | 8,309 |

**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)**

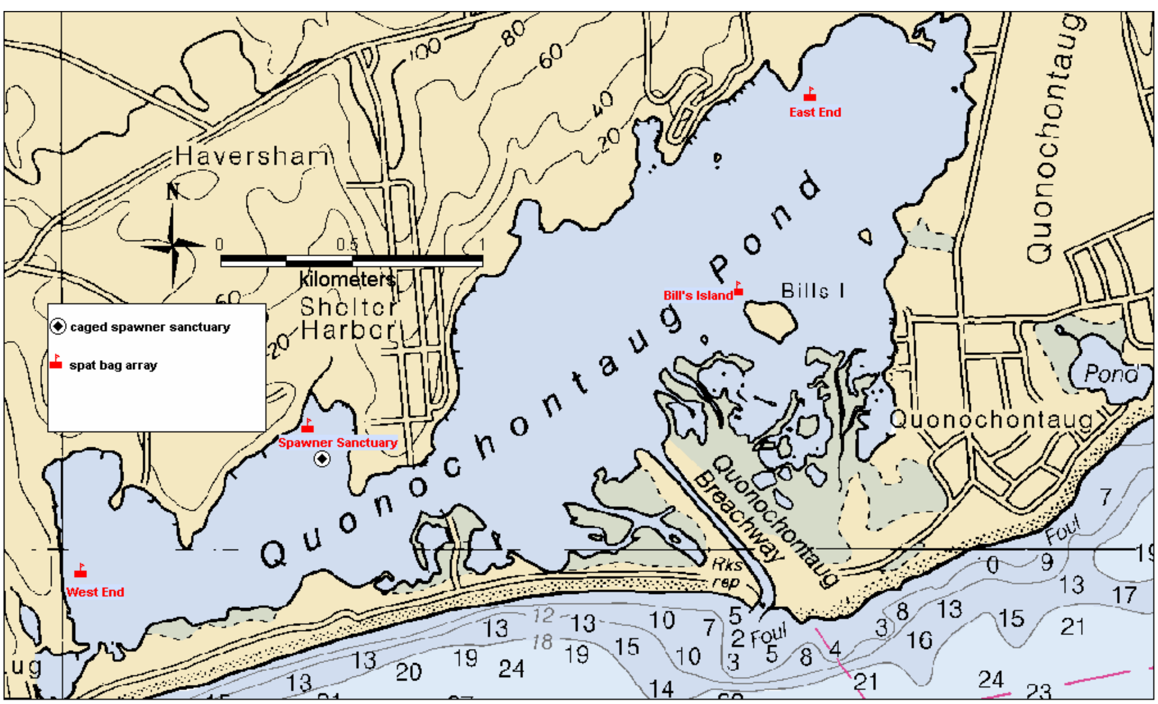


**Figure 4**. Schematic diagram of spat bag array.

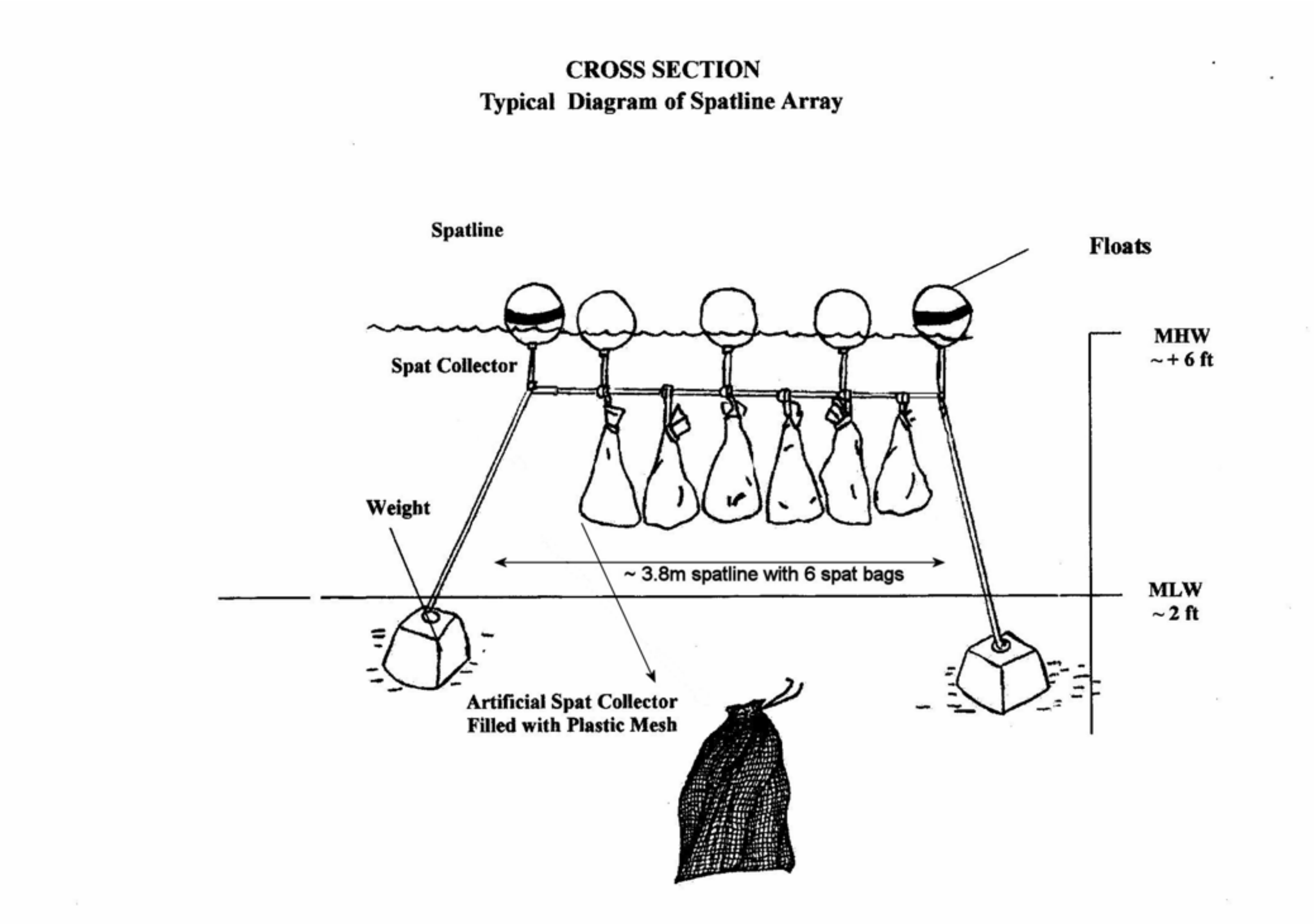


**Table 2.** Scallop spat collected from spat bags deployed in Ninigret Pond (A) and Quonochontaug Pond (B)

## A. Ninigret Pond

| **Date Deployed** | **14-Jun** | **12-Jul** | **7-Aug** | **20-Aug** | **30-Aug** | **11-Sep** | **27-Sep** | **17-Oct** | | **Settlement** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Date Collected** | **19-Jul** | **10-Aug** | **30-Aug** | **11-Sep** | **27-Sep** | **11-Oct** | **31-Oct** | **15-Nov** | **Total** | **Index** |
| **Scheduled Liberty** | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | | |
| **Days at Liberty** | 35 | 29 | 23 | 22 | 28 | 30 | 30 | 29 | | |
| **West End** | | | | | | | | | | |
| No. Bags | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 47 | |
| No. Scallops | 0 | 0 | 91 | 0 | 0 | 0 | 0 | 0 | 91 | |
| Mean Scallops/Bag | 0 | 0 | 18.2 | 0 | 0 | 0 | 0 | 0 | | 18.2 |
| Mean Size (mm) | 0 | 0 | 1.5 | 0 | 0 | 0 | 0 | 0 | | |
| **Hall Point** | | | | | | | | | | |
| No. Bags | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 48 | |
| No. Scallops | 0 | 1 | 151 | 3 | 0 | 3 | 1 | 0 | 159 | |
| Mean Scallops/Bag | 0 | 0.2 | 25.2 | 0.5 | 0 | 0.5 | 0.2 | 0 | | 26.5 |
| Mean Size (mm) | 0 | 4.9 | 1.5 | 2.9 | 0 | 3.6 | 1.6 | 0 | | |
| **Breachway** | | | | | | | | | | |
| No. Bags | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 48 | |
| No. Scallops | 0 | 15 | 7 | 0 | 3 | 3 | 0 | 0 | 28 | |
| Mean Scallops/Bag | 0 | 2.5 | 1.2 | 0 | 0.5 | 0.5 | 0 | 0 | | 4.7 |
| Mean Size (mm) | 0 | 2.4 | 1.4 | 0 | 1.7 | 2.2 | 0 | 0 | | |
| **Aqualease** | | | | | | | | | | |
| No. Bags | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 47 | |
| No. Scallops | 0 | 6 | 17 | 0 | 8 | 6 | 1 | 0 | 38 | |
| Mean Scallops/Bag | 0 | 1 | 3.4 | 0 | 1.3 | 1 | 0.2 | 0 | | 6.9 |
| Mean Size (mm) | 0 | 4.6 | 1.9 | 0 | 1.8 | 2.6 | 2.5 | 0 | | |
| | | | | | | | | Total bags | 190 | 56 |
| | | | | | | | | Total spat | 316 | |

## B. Quonochontaug Pond

| Date Deployed | 12-Jun | 6-Jul | 27-Jul | 9-Aug | 24-Aug | 6-Sep | 19-Sep | 11-Oct | | Settlement |
|---|---|---|---|---|---|---|---|---|---|---|
| **Date Collected** | **12-Jul** | **1-Aug** | **24-Aug** | **6-Sep** | **19-Sep** | **6-Oct** | **23-Oct** | **6-Nov** | **Total** | **Index** |
| **Scheduled Liberty** | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | | |
| **Days at Liberty** | 30 | 26 | 28 | 28 | 26 | 30 | 34 | 26 | | |
| **West End** | | | | | | | | | | |
| No. Bags | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 48 | |
| No. Scallops | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 4 | |
| Mean Scallops/Bag | 0 | 0 | 0.2 | 0 | 0 | 0.5 | 0 | 0 | | 0.7 |
| Mean Size (mm) | 0 | 0 | 3.6 | 0 | 0 | 2 | 0 | 0 | | |
| **Spawner Sanctuary** | | | | | | | | | | |
| No. Bags | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 48 | |
| No. Scallops | 5 | 2 | 2 | 0 | 0 | 0 | 1 | 0 | 10 | |
| Mean Scallops/Bag | 0.8 | 0.3 | 0.3 | 0 | 0 | 0 | 0.2 | 0 | | 1.6 |
| Mean Size (mm) | 3.7 | 4.1 | 3.3 | 0 | 0 | 0 | 1.7 | 0 | | |
| **Bill's Island** | | | | | | | | | | |
| No. Bags | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 48 | |
| No. Scallops | 3 | 4 | 11 | 0 | 0 | 0 | 0 | 0 | 18 | |
| Mean Scallops/Bag | 0.5 | 0.7 | 1.8 | 0 | 0 | 0 | 0 | 0 | | 3.0 |
| Mean Size (mm) | 3.4 | 3.8 | 4.7 | 0 | 0 | 0 | 0 | 0 | | |
| **East End** | | | | | | | | | | |
| No. Bags | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 48 | |
| No. Scallops | 2 | 5 | 0 | 1 | 0 | 1 | 1 | 0 | 10 | |
| Mean Scallops/Bag | 0.3 | 0.8 | 0 | 0.2 | 0 | 5.6 | 0.2 | 0 | | 7.1 |
| Mean Size (mm) | 3.7 | 4.6 | 0 | 1.9 | 0 | 5.6 | 1.4 | 0 | | |
| | | | | | | | | Total bags | 192 | 12 |
| | | | | | | | | Total spat | 42 | |

**Figure 5**. Comparison of the total number of scallop spat found at each of the four sites in Ninigret Pond and the seasonal settlement indices of each pond from 2004 to 2007, with respect to estimated total number of broodstock each year.

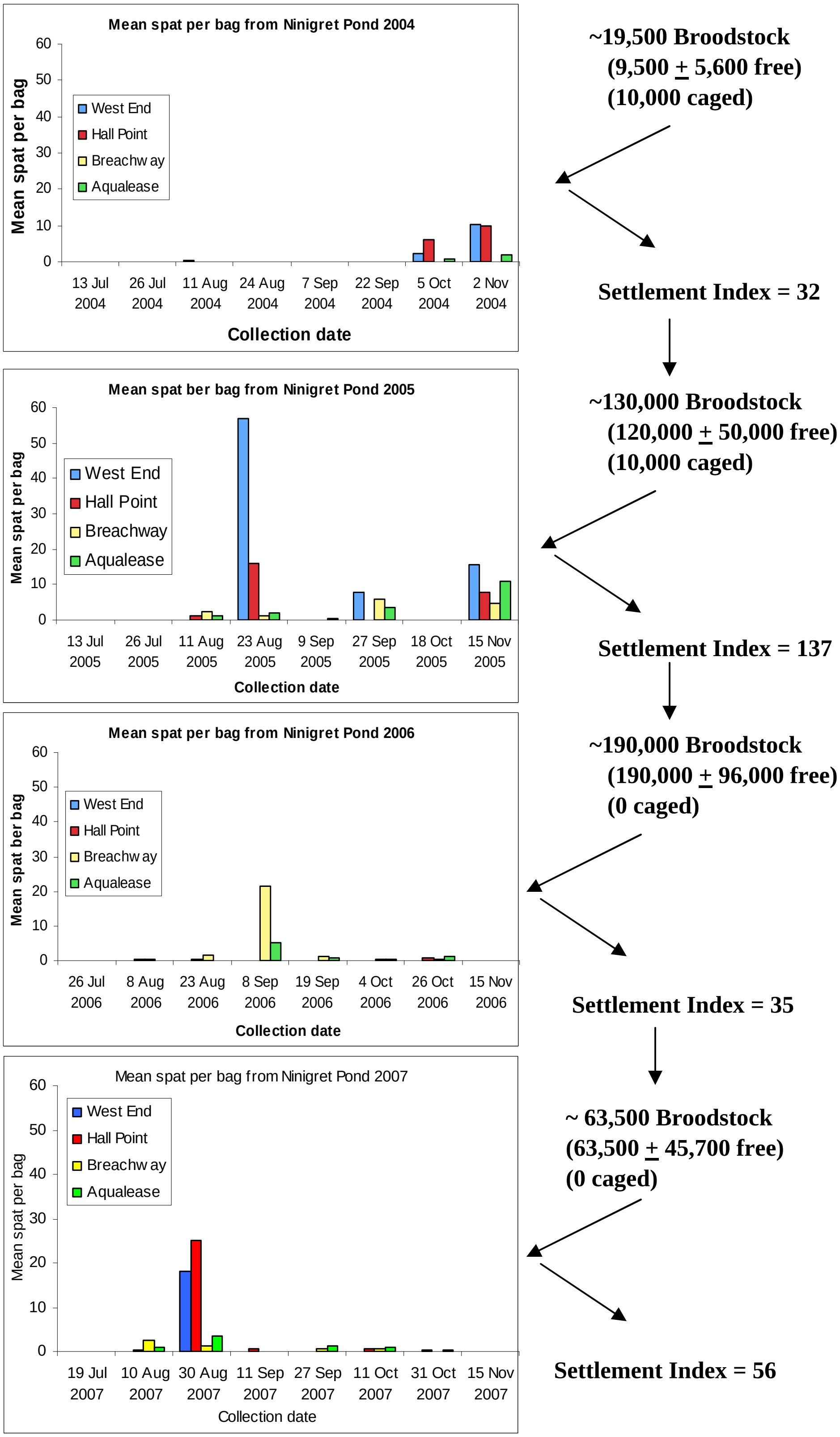


**Figure 6**. Comparison of the total number of scallop spat found at each of the four Quonochontaug Pond sites.

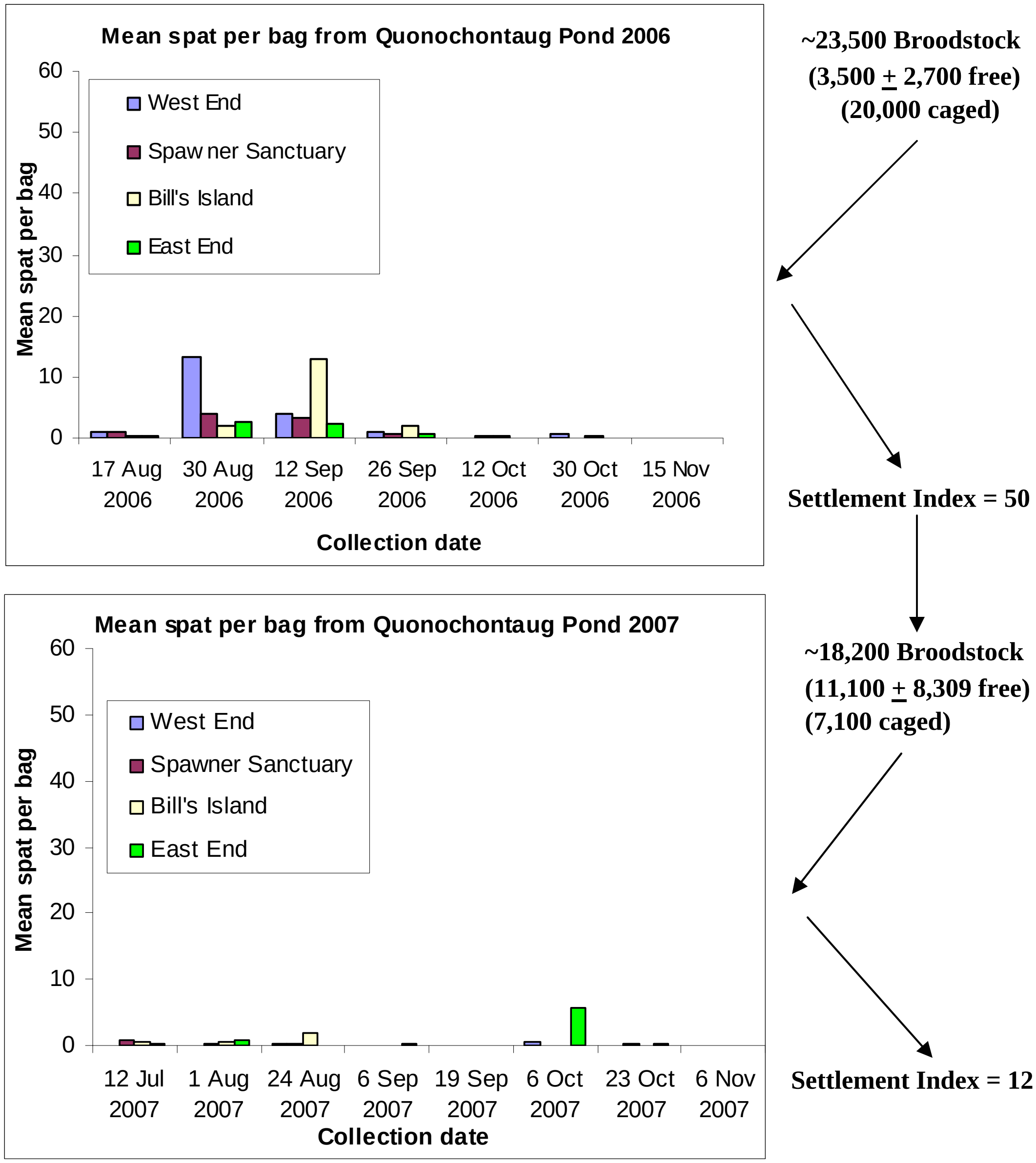


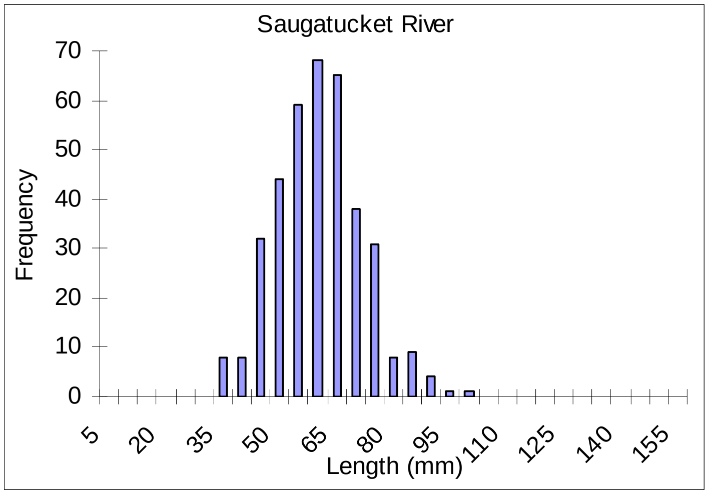
**Table 3.** Results of 2007 surveys of oyster planting sites seeded in 2003, 2004, 2005 and 2006.

| Site | Number Quadrats | Number Alive | Mean Number Alive ($m^{-2}$) | SE | Seeded Area ($m^2$) | Estimated Total Live | SE |
|---|---|---|---|---|---|---|---|
| Saugatucket | 25 | 403 | 16.12 | 2.8 | 2048 | 33,014 | 5,734 |
| Smelt Brook | 25 | 647 | 25.88 | 2.78 | 2016 | 52,174 | 5,604 |
| Bissel Channel | | | | | | | |
| Bissel Channel (closed) | 25 | 869 | 34.76 | 5.82 | 2652 | 92,184 | 15,435 |
| Bissel Deep | | | | | | | |
| The Cove | 25 | 477 | 19.08 | 6.05 | 3317 | 63,288 | 20,068 |
| Potter | 25 | 411 | 16.44 | 3.09 | 3324 | 54,647 | 10,271 |

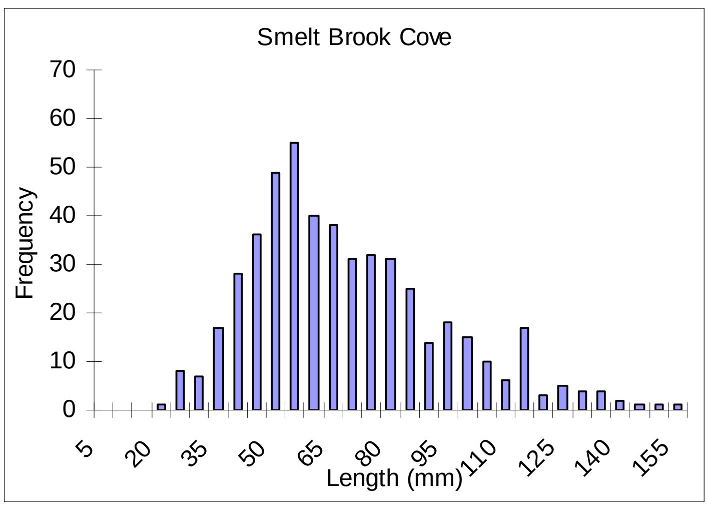
[1]Bissel Cove Deep was seeded in 2004.
[2]Bissel Channel was seeded in 2003 and 2004.
[3]The Cove and Potter Cove were seeded in 2003 and 2005.
[4]Bissel Channel (closed to fishing) was seeded in 2006.

**Figure 7a-e.** Size distribution of total oysters seeded in five planting sites from 2003 – 2006 (See Table 3 for years each site was seeded).

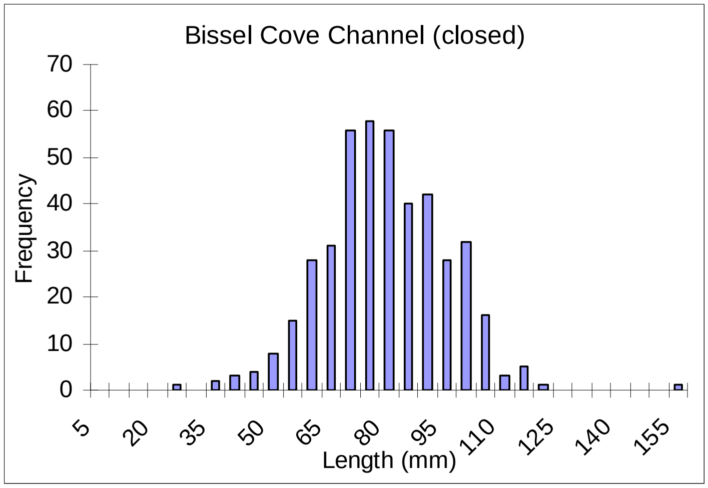
**a.**




**b.**

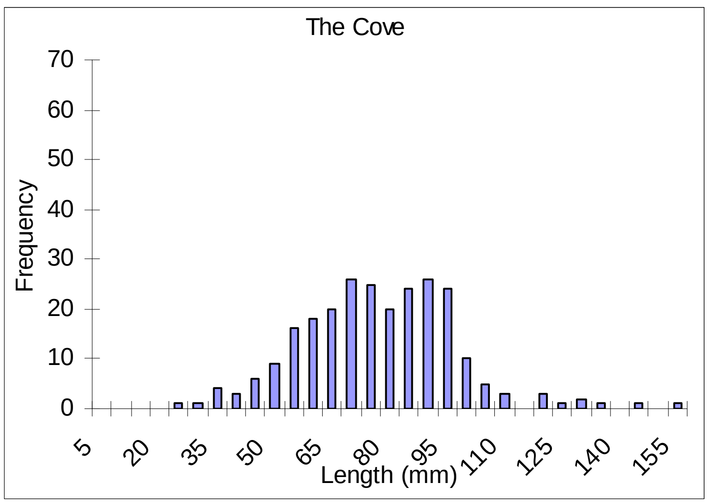


**c.**



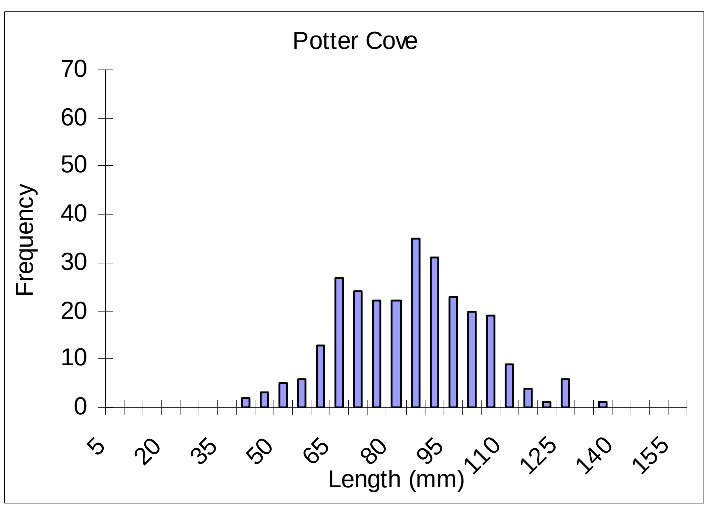
Bissel Cove Channel (closed)
Frequency
70
60
50
40
30
20
10
0
5
20
35
50
65
80
95
110
125
140
155
Length (mm)


**d.**



The Cove
Frequency
70
60
50
40
30
20
10
0
5
20
35
50
65
80
95
110
125
140
155
Length (mm)


**e.**



Potter Cove
Frequency
70
60
50
40
30
20
10
0
5
20
35
50
65
80
95
110
125
140
155
Length (mm)

**Figure 8.** Experimental plots established in 2006 with sites seeded in 2004 in Quonochontaug Pond.

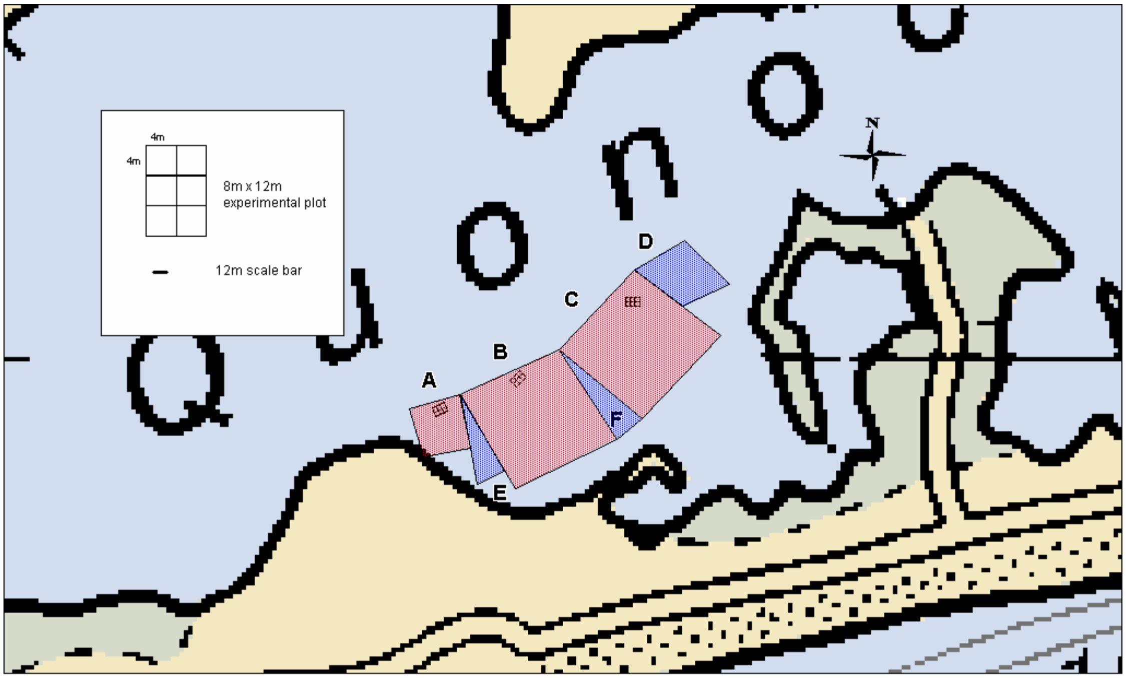



**Figure 9.** Experimental plots established in 2006 with sites seeded in 2004 (large rectangle) and 2006 (three smaller polygons) in Ninigret Pond.

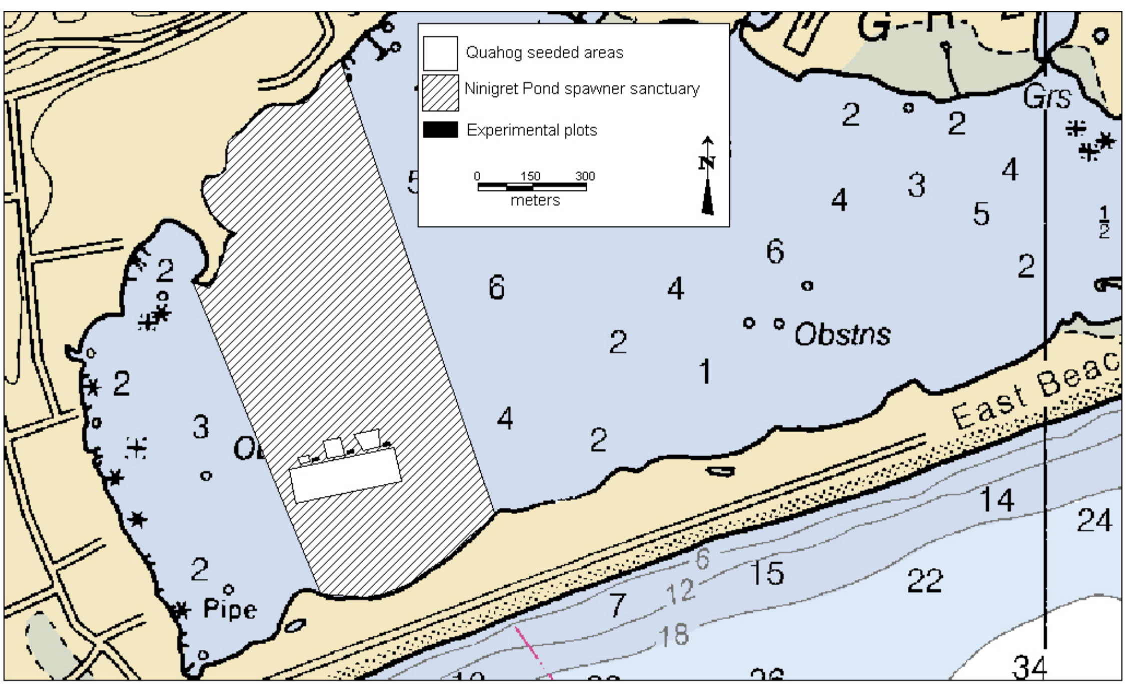


**Figure 10**. Schematic diagram of 1 of the 3 experimental plots per pond, established in Quonochontaug Pond in 2004 and 2006 and in Ninigret Pond in 2006.

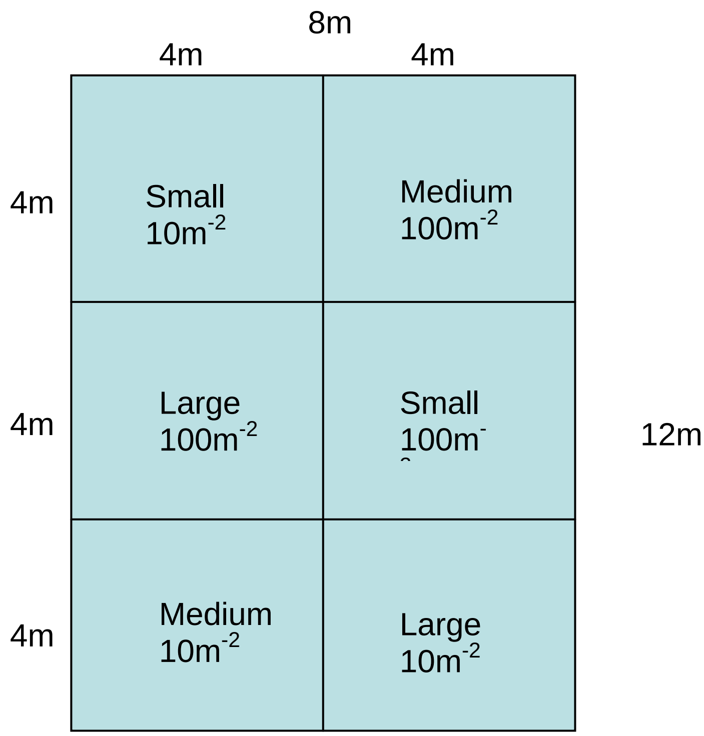
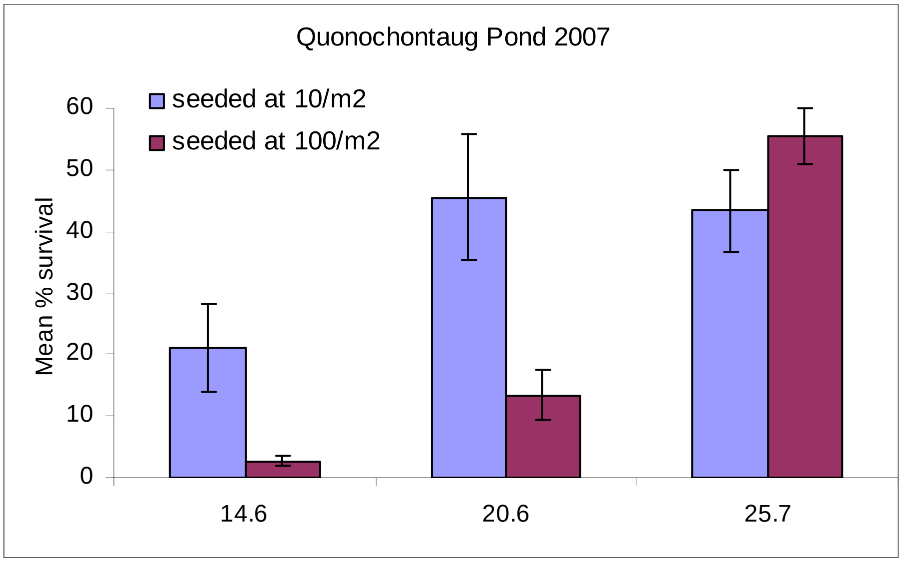


**Table 4.** Mean percent survival results of three different size classes of quahogs, seeded at two varying densities. 2006 results represent seasonal survival rates (approximately 1-2 months after seeding) while 2007 results represent annual survival rates.

| | | Seeded at $10m^{-2}$ | | | | Seeded at $100m^{-2}$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006 (seasonal results) | | 2007 (annual results) | | 2006 (seasonal results) | | 2007 (annual results) | |
| | Seed mean size | % Survival | SE | % Survival | SE | % Survival | SE | % Survival | SE |
| **Quonochontaug** | 14.6mm | 36.7 | 0.8 | 21.1 | 7.2 | 9.7 | 2.1 | 2.7 | 0.8 |
| | 20.6mm | 58.9 | 2.4 | 45.6 | 10.2 | 51.2 | 5.0 | 13.4 | 3.9 |
| | 25.7mm | 74.4 | 2.8 | 43.3 | 6.7 | 71.0 | 3.4 | 55.3 | 4.5 |
| **Ninigret** | 14.6mm | 10.0 | 4.4 | 16.7 | 3.3 | 1.3 | 0.6 | 2 | 0.6 |
| | 20.6mm | 15.6 | 4.7 | 33.3 | 19 | 4.0 | 1.9 | 1.3 | 0.3 |
| | 25.7mm | 25.6 | 8.0 | 23.3 | 6.7 | 19.0 | 5.6 | 15.7 | 1.2 |

**Figure 11a,b.** Mean annual percent survival of quahogs from three different size classes, seeded at $10m^{-2}$ and $100m^{-2}$ in experimental plots in Quonochontaug Pond (A) and Ninigret Pond (B).

**A.**




**B.**

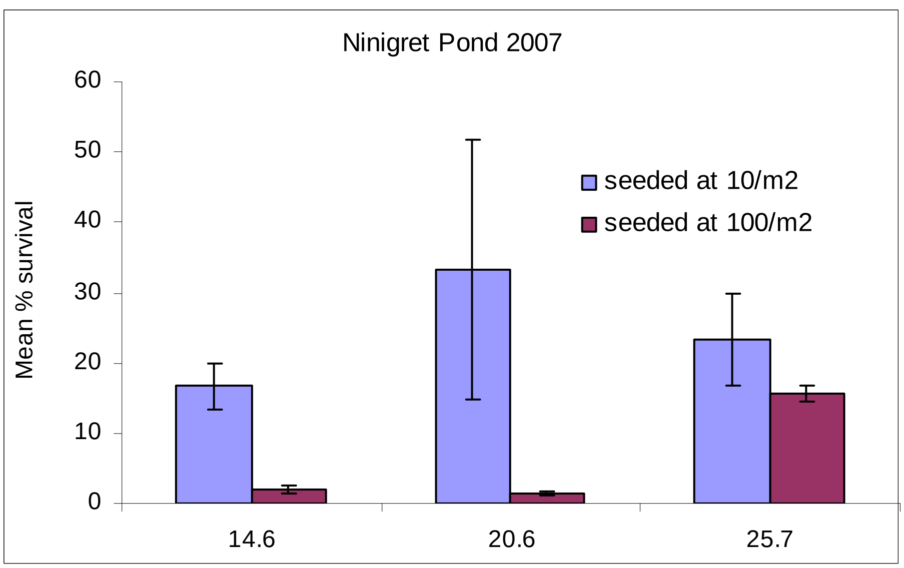


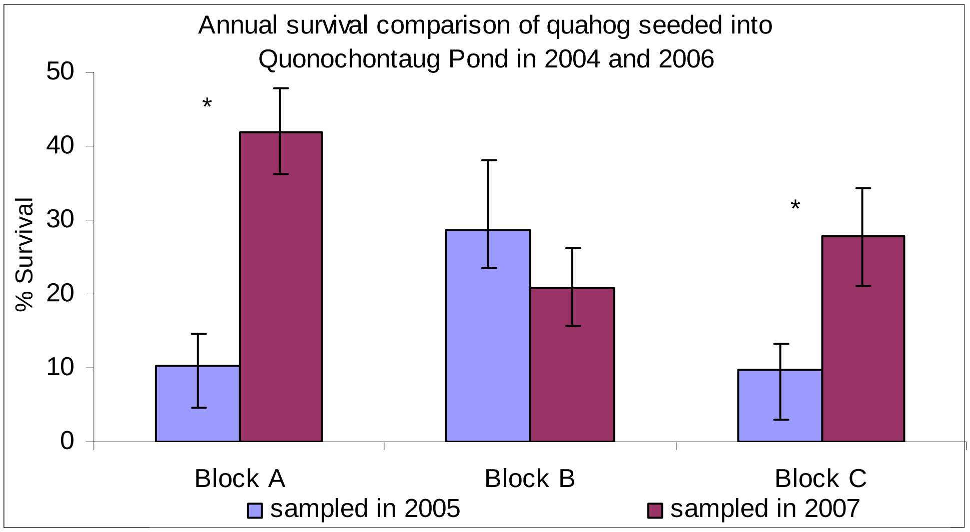
**Table 5.** ANOVA of seasonal quahog survival in Quonochontaug Pond between August 2006 and November 2006, from three separate plots seeded with three sizes of seed, each at $10m^{-2}$ and $100m^{-2}$.

| Source | df | Mean Square | F-ratio | p-value |
|---|---|---|---|---|
| Model | 7 | 4077.9 | 12.02 | 0.00 |
| Plots | 2 | 1119.1 | 3.3 | 0.05 |
| Size | 2 | 11354.3 | 33.5 | 0.00 |
| Density | 1 | 2178.7 | 6.4 | 0.01 |
| Size*Density | 2 | 709.9 | 2.1 | 0.12 |

**Table 6**. ANOVA of annual quahog survival in Quonochontaug Pond between August 2006 and October 2007, from three separate plots seeded with three sizes of seed, each at $10m^{-2}$ and $100^{-2}$.

| Source | df | Mean Square | F-ratio | p-value |
|---|---|---|---|---|
| Model | 7 | 3368.3 | 12.1 | 0.00 |
| Plots | 2 | 2062.7 | 7.4 | 0.00 |
| Size | 2 | 6316.8 | 22.7 | 0.00 |
| Density | 1 | 2229.8 | 8.0 | 0.01 |
| Size*Density | 2 | 2294.6 | 8.2 | 0.00 |

**Figure 12**. Annual percent survival (+ SE) comparisons of quahog seeded into Quonochontaug Pond in 2004, sampled in 2005 and seeded in 2006, sampled in 2007.




*** represents significant differences between overall plot survival (p-value < 0.05).**

**Figure 13.** Size distribution of quahog sampled in Quonochontaug Pond experimental plots, seeded at three different size classes in August of 2006 and sampled October 2007.

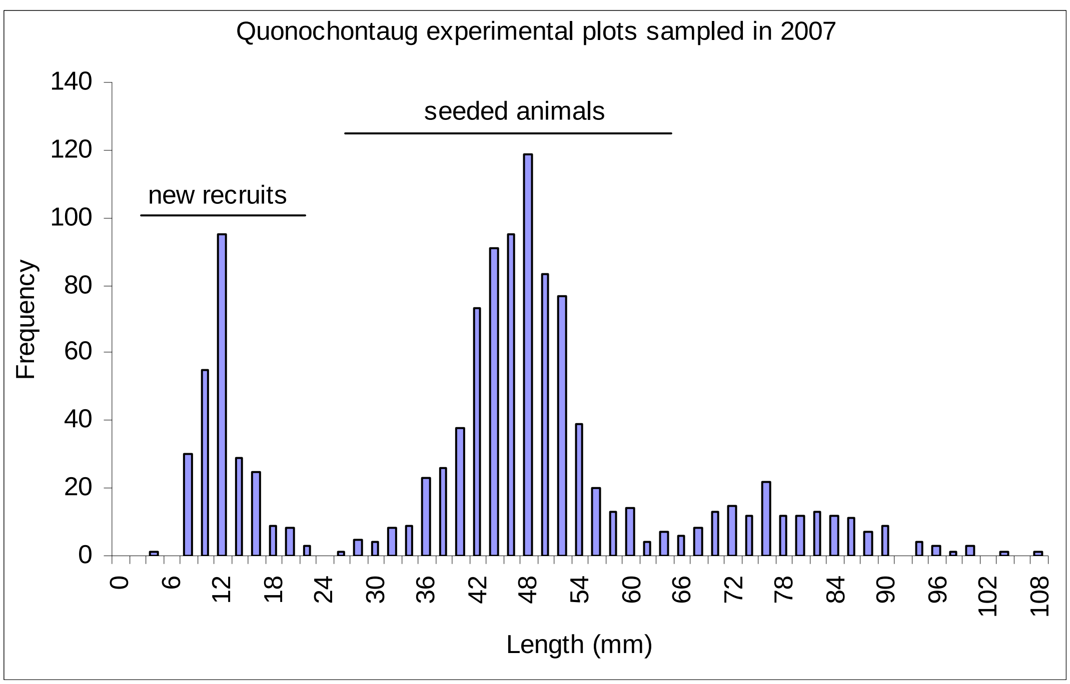


**Figure 14.** Annual percent survival of similar size classes of quahog seeded into experimental plots at $10m^{-2}$ in 2004 and 2006.