North Cape Shellfish Restoration Program
2008 Annual Report

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

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2008 *North Cape*
SHELLFISH RESTORATION PROGRAM

Executive Summary

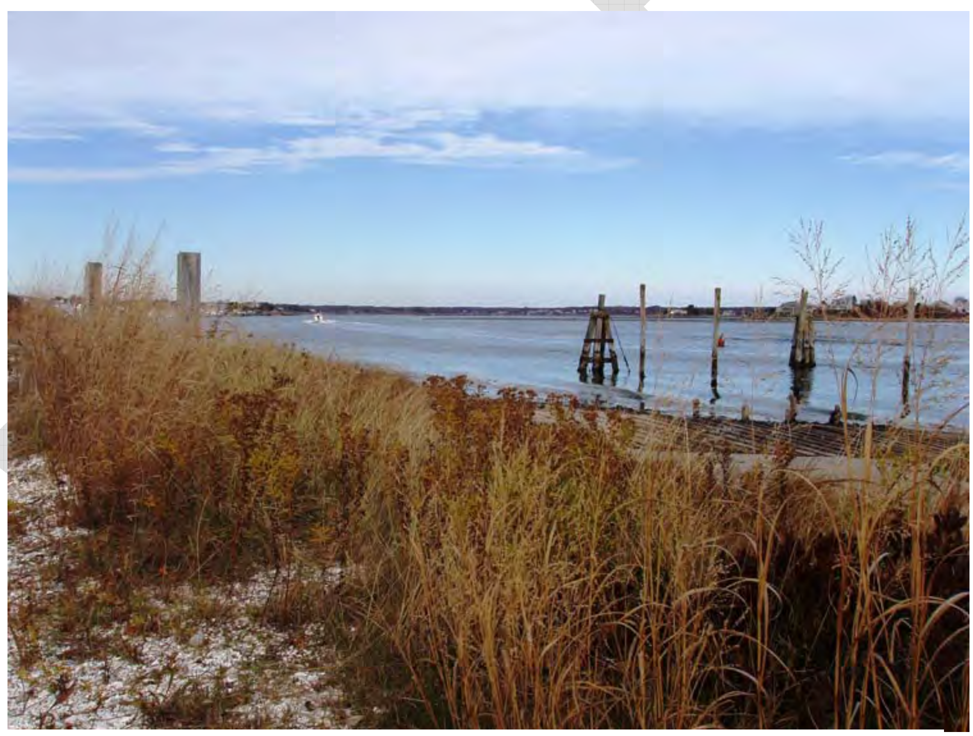
North Cape restoration efforts by State and Federal Trustees continued to move forward in 2008 to address the natural resource injuries resulting from the release of 828,000 gallons of heating oil into Block Island Sound during the 1996 *North Cape* oil spill. Following legal settlement in 2000, the 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. In 2008, the bay scallop project was moved to Point Judith Pond which included establishing a bay scallop caged spawner sanctuary 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 2008 scallop population in the pond. Twenty-thousand five hundred caged scallops were placed inside of a spawner sanctuary in Point Judith pond to increase the spawning biomass. These hatchery scallops, along with the estimated 30,490 resident scallops in Point Judith Pond in 2008, resulted in a modest mid-summer spatfall, which is encouraging for first year restoration efforts. During 2008, scallop recruitment monitoring was also continued in Ninigret Pond following the successful deployment of spawner sanctuaries there in 2004 and 2005. The natural abundance of scallops in Ninigret Pond produced a mid season spat fall in 2007 which yielded a population estimate of just under 300,000 scallops in 2008. A strong July spatfall in 2008 should sustain a healthy population of scallops in Ninigret Pond in 2009. During 2008, scallop recruitment monitoring also continued in Quonochontaug Pond following the successful deployment of spawner sanctuaries there in 2006 and 2007. In Quonochontaug Pond, the limited spatfall that occurred in 2007 translated into a population of just over 5,000 adult scallops in 2008, down from an estimated 11,000 in 2007. Scallop spatfall monitoring in Quonochontaug during 2008 recorded a substantial increase in settlement which could potentially yield a healthy Quonochontaug Pond scallop population in 2009.

The 2008 oyster project included the husbandry of nearly 1.2 million hatchery produced juvenile oysters in a floating upweller system for grow out and subsequent release to

selected restoration sites. To date, over 5.4 million *North Cape* oysters have been seeded into seven restoration sites in Rhode Island salt ponds and Narragansett Bay. In 2008, the survivorship and growth of the oyster cohorts released in 2003, 2004, 2005 and 2006 were monitored. Evidence suggests overall survival at the restoration sites was lower than years past, although it was unable to be determine if the mortality was associated with the youngest cohort, older animals, or combination of both. In 2008, a seeding experiment was conducted to examine the influence of size on survival of seeded oysters.

The gonadal development, spawning and settlement of oysters at two Point Judith Pond *North Cape* restoration sites were the basis of a URI Coastal Fellows research project. Visual examination of oyster gonads, computation of oyster condition indices and sampling of the water column for oyster larvae abundance was conducted continually throughout the spawning season. Spat settlement collectors were deployed to monitor oyster settlement throughout Point Judith Pond. Oyster settlement was not observed despite oyster larvae being found in the water column throughout the spawning season. These results provide *North Cape* and future oyster restoration efforts with valuable information regarding the reproductive and recruitment success of oyster restoration in this geographic area.



Looking North in Point Judith Pond from the Coastal Fisheries Laboratory, Narragansett, Rhode Island.

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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 (Shumway and Parsons 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 global 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 decades.

In fall of 2003, the *North Cape* Shellfish Restoration Program seeded scallops directly into four coastal ponds in an attempt to re-establish an effective breeding population for the 2004 season (Holly *et al*. 2004). In spring of 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 (Figure 1) had the highest number of surviving scallops, estimated to be 9,500. 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 maximizing 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 and Point Judith Pond in 2008, using the same monitoring techniques as in Ninigret Pond.

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.

1.1 Bay Scallop Surveys

Introduction

Bay scallops are a short-lived species that generally survive 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 2008 were not yet likely large enough to be detected by divers. Consequently, the scallops surveyed in 2008 quantified the settlement of juveniles that were recorded during the spat settlement monitoring in 2007. A caged spawner sanctuary was implemented in Point Judith Pond (Figure 1) in 2008; this was the first year of scallop restoration in this pond since direct seeding in 2002. Dive surveys conducted in Point Judith Pond in 2008 were completed to quantify the scallop population that was present in the pond prior to the caged spawner restoration efforts. This baseline population estimate will be used in conjunction with diver survey data, which will be collected in 2009, to determine the efficacy of the spawner sanctuary in Point Judith Pond. Bay scallop surveys were also conducted in both Ninigret and Quonochontaug Ponds (Figure 1) during the summer of 2008 to quantify bay scallop populations in those sites resulting from caged spawner sanctuaries in 2004-2005 and 2006-2007 respectively.

Objective

The objective of the 2008 bay scallop surveys was to determine the abundance and spatial distribution of scallops entering their second season in Ninigret, Quonochontaug, and Point Judith Ponds.

Methods

The 2008 scallop dive surveys were conducted as stratified random transect surveys in 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 (<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 each pond. 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 5,173,124m^2, 3,101,445m^2, and 5,087,347m^2 for Ninigret, Quonochontaug, and Point Judith Ponds, respectively (Table 1). Stratum areas varied in size from 960,400m^2 to 1,748,259m^2 in Ninigret Pond, 1,448,000m^2 to 287,426m^2 in Quonochontaug Pond and 1,088,645 to 384,019 in Point Judith 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 completing observations along a 1m wide strip on each side of the transect line, resulting in a 100 m^2 area surveyed per transect. Divers carried a 1-m 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. A total of 41 transects were completed in Quonochontaug Pond, a total survey area of 4,100m^2. A total of 55 Transects were surveyed in Point Judith Pond, a total survey area of 5,500m^2 (Table 1).

In Ninigret Pond, the total estimated scallop abundance in 2008 was 287,782 ± 90,082, a 454% increase above the abundance estimate of the 2007 population. The greatest numbers of scallops were found in the Northern stratum of the Western Basin (244,846 ± 71,482), followed by the Central stratum of the Western Basin (29,824 ± 11,107) and the Southern stratum of the Western Basin (13,112 ± 7,493). No scallops were found in the Central Basin (Table 1A).

The total estimated scallop abundance in Quonochontaug Pond in 2008 was 5,358 ± 4,162, a 48% decrease below the abundance estimate of the 2007 population. The East Basin Outer Sand stratum had the greatest relative abundance (4,783 ± 3,588). A single scallop was found in the West Basin Outer Sand, which extrapolates to an estimated 575 scallops in that stratum. No scallops were found in either the East or West Central Mud Basins (Table 1B).

The total estimated scallop abundance in Point Judith Pond in 2008 was 30,490 ± 22,839. The greatest number of scallops were found in the Central Basin Sand (14,152 ± 11,820), followed by the Central Basin Grass (8,390 ± 3,980) and the Central Basin Mud (7,948 ± 7,039). No scallops were found in the Northern Basin or Eastern Basin (Table 1C).

Discussion

Despite a large decrease in the relative abundance of scallops in Ninigret Pond in 2007 compared to 2006, the population rebounded over 400% in 2008, to the largest population observed in the pond since restoration began. During 2006, unusually high rainfall was the likely cause of the lower than expected recruitment that was observed in 2006 (Tettelbach *et al.* 1985), thus leading to a lower population in 2007 (See Hancock *et al*. 2007). Despite the reduced population in 2007, spatfall was significant enough that year to produce the 400% population increase in 2008. Our 2008 survey results suggest that the bay scallop restoration efforts in Ninigret Pond has been successful in restoring a bay scallop population which was sufficiently resilient to rebound from a population decline caused by extreme environmental conditions

There is a well understood association between scallops and seagrass (Belding 1910, Thayer and Stuart 1974). Only one scallop has been found in the Central Basin of Ninigret Pond since 2004; despite being the only basin of the pond where seagrass exists. All other scallops observed over five years of survey data were found in the Western Basin of the pond (See Hancock *et al*. 2005; Hancock *et al*. 2006; Hancock *et al*. 2007). The Western Basin of the pond was sub-divided into three general types of habitat; the Northwest Arm which fringes the shallow water along the northern shore and characterized by a sand/rubble habitat, the Southwest Arm characterized by a beach-sand like over-wash which fringes the shallow water along the southern shore, and the Central West Arm, characterized by a deeper water muddy habitat. Scallop abundance in Ninigret Pond was significantly higher in the sand/rubble habitat of the Northwest Arm, followed by the Southwest and Central West Arm, which had relatively comparable abundance year-to-year. Examination of spatial variability of larval settlement suggests this may be partially attributed to hydrodynamic patterns, proximity to broodstock, or a combination of both, since larval settlement is typically greatest in the Western Basin. Larval settlement, however, does not explain the consistently (year to year, since 2004) greater abundance of scallops on the sand/rubble habitat over other habitats in the Western Basin, nor does it explain the lack of scallops found in the Central Basin, where seagrass exists.

The sand/rubble habitat of this pond is typically a shallow water environment, which may be a factor contributing as suitable scallop habitat. Similar results have been found in Massachusetts studies where scallops tended to be located in shallow water at the pond edges, while deeper, muddy areas were essentially devoid of scallops (Chintala *et al*. 2008). The preference for sand/rubble versus the sand over-wash may be explained by the lack of macroalgae on the sand over-wash habitat. While Chintala *et al*. 2008, demonstrated that seagrass alone was a poor predictor of scallop abundance; they did demonstrate vegetation (seagrass and macroalgae combined) was a better predictor. Although the sand/ rubble habitats of our study sites lack considerable seagrass, there is seasonal coverage of macroalgae, which may contribute to increased abundance of scallops over the other habitats.

The observed decrease in naturally occurring scallops in Quonochontaug pond from 2007 to 2008 may be a function of poor recruitment in 2007. The settlement index dropped from 50 in 2006 to 12 in 2007. The low recruitment in 2007 could have been a result of the reduced number of caged broodstock provided (20,000 in 2006; 7,100 in 2007). Secondly, it was known that a large proportion of the caged scallops in 2007 were in their third year of life. It is possible that the health and fecundity of the older animals was lower than expected, therefore providing a lesser reproductive potential than anticipated. Quonochontaug Pond demonstrated similar results to that of Ninigret; with significantly more scallops found in the sandy/rubble Outer Sand habitat than that of the Central Mud habitats. 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 and 2008 surveys were also in this location while a single scallop was found in the Outer Sand stratum of the West Basin during both of these years.

Scallop abundance is consistently greater in the sandy/rubble habitats of both Ninigret and Quonochontaug Pond. While this type of habitat in Ninigret encompasses a large area, in Quonochontaug this habitat is a summation of small areas dotted along the northern shore and pockets surrounding rocky outcroppings in the pond. It is possible that the differences in success between the comparable restoration efforts can be attributed to a smaller area of this suitable habitat in Quonochontaug Pond. The results from the *North Cape* scallop restoration demonstrate that seagrass habitat is not a necessity for successful bay scallop restoration; however this work and other research suggests it may be prudent to consider what habitat does exist, particularly in the shallow water habitats fringing the coastline, and the degree of protection and substrate it will provide to post-settlement juveniles.

In 2008, the *North Cape* Shellfish Restoration Project moved the focus of its bay scallop restoration to Point Judith Pond. Point Judith Pond has historically supported prolific bay scallop populations and fisheries (personal communication, D. Erkan, RIDEM). The population observed in Point Judith Pond in 2008 represent the pre-restoration, naturally occurring scallop population. Survey results in 2008 suggest a small natural population in the pond. This population may be a result of scallop seed maintained in Potters Pond (an adjoining body of water), since 2006. Scallop seed were being held for various scallop restoration programs in Rhode Island.

Habitat varies greatly within Point Judith Pond. The Northern Basin of the pond is primarily characterized by fine muddy silt with little vegetation. The Central Basin of the pond contains the most suitable scallop habitat; characterized primarily by a sandy/rubble substrate with large areas of eelgrass beds and macroalgae. All scallops observed in the diver surveys were located within the Central Basin; but generally found in the sand/rubble habitat rather than amongst the eelgrass.

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 and Quonochontaug Ponds. Due to the continued success of the spawner sanctuary approach, this method was implemented in Point Judith Pond in 2008.

Objectives

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

Methods

In 2008, *North Cape* staff deployed and maintained 64 wire cages initially containing 20,500 adult bay scallops in Point Judith Pond. Scallops were purchased from a local commercial grower in adjacent Potters Pond. Cages were deployed on June 10, and June 11 and were monitored periodically until retrieval in November 2008. 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 ~80 mature, hatchery-reared 1+ and 2+ year class scallops. The scallop spawning sanctuary was located at (41° 24' 27N, 71° 30' 16W) in an area with a water depth of ~1-3m at MLW (Figure 4C). Site location was based on suitable habitat, estuarine flow dynamics, historical scallop production, and the pattern of boat usage in Point Judith Pond. A permit for the equipment installation was secured from the Rhode Island Coastal Resource Management Council.

Empty scallop cage used in spawner sanctuary.

Results

A total of 20,500 adult bay scallops were held in the broodstock cages during the potential scallop spawning season (June-November). The majority of the scallop broodstock were in their second year, product of a late spatfall in 2006.

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 completed. 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, Quonochontaug and Point Judith Ponds; to determine the spatial and temporal variation in abundance of spat settling in four study areas, and to document the approximate timing of spawning/settling events.

Methods

Spat bag arrays were deployed at four study sites in each Ninigret, Quonochontaug and Point Judith Ponds and monitored from June through November 2008. Deployment locations were selected based on tidal flows and wind patterns to provide information on the distribution of scallop settlement. 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 3.8-m long floated long-lines (Figure 3). Bags were collected after ~30 days at liberty, and analyzed by rinsing the contents through a 1-mm 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 (Cragg 2006, 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 = Σ mean spat per bag, per site, for the n collections per year

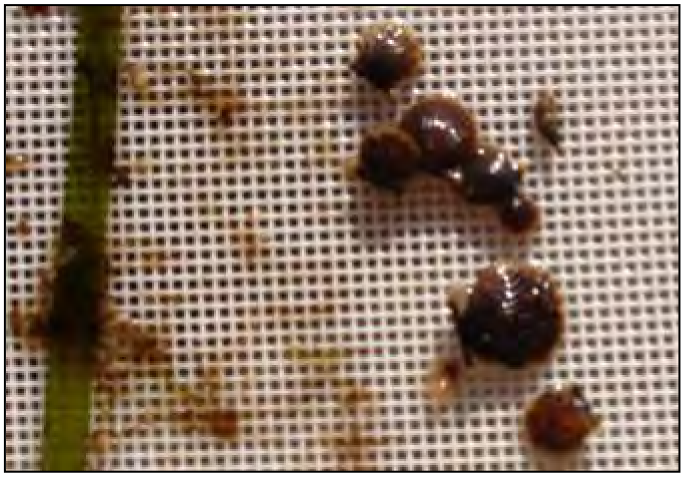
In Ninigret Pond array 1 (Hall Point) was located off Hall Point (41° 21.37′N, 71° 40.00′W) in ~1.2 – 1.5m water depth, MLW. Array 2 (West End) was located in the west end of the pond (41° 21.22′N, 71° 41.43′W) in ~ 1.5 – 1.8m water depth, MLW. Arrays 3 and 4 were located in the central basin of Ninigret Pond. Array 3 (Aqualease) was located near an 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 (Figure 4A).

In Quonochontaug Pond, array 1 (Upper West Basin) was in the middle area of the West Basin (41° 20.25′N, 71° 44.33′W) in ~ 1.8 – 2.0m water depth, MLW. Array 2 (West End) was placed in the far west end of the pond (41° 19.95′N, 71° 44.95′W) in ~ 0.6 – 1m water depth, MLW. Array 3 (Bill's Island) was placed west of Bill's Island (41° 20.53′N, 71° 43.16′W) in ~ 1.2 – 1.8m water depth, MLW. Array 4 (East End) was placed in the north east corner of the pond (41° 20.93′N, 71° 42.96′W) in approximately 0.9 – 1.5m water depth, MLW (Figure 4B).

In Point Judith Pond, array 1 (Smelt Brook Cove) was located in Smelt Brook Cove (41° 24.80′N, 71° 30.48′W) in ~ 1.5m water depth, MLW. Array 2 (spawner sanctuary) was located in the spawner sanctuary (41° 24.45′N, 71° 30.27′W) in ~1.5m water depth, MLW. Array 3 (snug harbor) was located next to Snug Harbor Marina (41° 23.116′N, 71° 31.03′W) in ~1 - 1.5m water depth, MLW. Array 4 (strawberry point) was located to the north of Strawberry Point (41° 23.48′N 71° 30.53′W) in ~1 - 1.5m water depth, MLW (Figure 4C).

Results

In Ninigret Pond, the first spat lines were deployed on June 5, 2008. The last bags were collected on November 7, 2008. In Ninigret Pond, a total of 238 artificial spat collectors were retrieved over 10 collection periods at each of the four study sites, yielding a total of 298 spat. The highest number of spat was recorded from Hall Point (137 spat) followed by the Breachway (66 spat), Aqualease (60 spat), and West End (35 spat) (Table 2A). The major settlement events in Ninigret Pond appeared to have occurred between July 3rd and August 26th in the Western basin of the pond, as indicated by the mean spat per bag values (Table 2A). Three smaller settlement events occurred between August 14th and October 10th, again primarily in the Western Basin. Hall Point, Breachway, and Aqualease were the most consistent sites, with settlement indices of 22.8, 12.5 and 10.0, respectively, while the West End site had only one major settlement event with a settlement index of 5.8 (Table 2A). The seasonal settlement index for the cumulative pond monitoring of Ninigret Pond in 2008 was 51.2, a 8.57% decrease from the cumulative settlement index of 56 in 2007 (Figure 5).



Scallop spat on 1-mm mesh sieve. Collected from artificial spat collector in Quonochontaug pond.

In Quonochontaug Pond, the first spat lines were deployed on June 5, 2008. The last bags were collected on November 7, 2008. A total of 239 artificial spat collectors were retrieved over 10 collection periods at each of the four study sites in Quonochontaug Pond, yielding a total of 981 spat. The highest number of spat was recorded from the Bill's Island site (572 spat), followed by the East End site (151 spat), West End (136 spat), and the Upper West Basin (122 spat) (Table 2B). Relatively substantial settlement events occurred in Quonochontaug Pond throughout the season from July 3rd to September 24th with most of the observed settlement occurring in the Eastern Basin of the pond, as indicated by the mean spat per bag values (Table 2B). An exceptionally large settlement event occurred sometime between the 24th of September and the 10th of October with the highest concentration of spat located at the Bills Island Site (430 spat), followed by the West End (110 spat), Upper West Basin (91 spat) and the East End (70 Spat). This settlement event accounted for 71.5% of the total observed spat fall in Quonochontaug Pond during 2008. Seasonal settlement indices of the four study sites were: Bills Island 95.3, East End 25.2, West End 22.7 and Spawner Sanctuary 20.6 (Table 2B). The seasonal settlement index for the cumulative monitoring of Quonochontaug Pond in 2008 was 163.7, a 1264% increase from the cumulative settlement index of 12 in 2007 (Figure 6).

In Pt. Judith Pond, the first spat lines were deployed on June 12, 2008. The last bags were collected on November 13, 2008. A total of 240 artificial spat collectors were retrieved over 10 collection periods at each of the four study sites in Pt. Judith Pond, yielding a total of 97 spat. The highest number of spat was recorded from the Snug Harbor site (46 spat) followed by Strawberry Point (26 Spat), Spawner Sanctuary (20 spat) and Smelt Brook Cove (5 Spat) (Table 2C). Settlement in Pt. Judith Pond was relatively equal amongst the four sites with the major settlement events occurring between June 23rd and August 6th. Smaller settlement events continued until the middle of October (Figure 7). The seasonal settlement index for the cumulative monitoring of Pt. Judith Pond in 2008 was 16.2.

Discussion

The seasonal settlement index has been calculated in Ninigret Pond 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 5 years through 2008. The cumulative settlement index in Ninigret Pond for 2008 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 translated into an exceptionally healthy scallop population in 2008. Settlement results in 2008 resembled those of previous years, 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 settlement monitoring data suggests recruitment levels in the Western Basin of Ninigret Pond in 2009 should be strong.

Interpretation of the history of cumulative settlement indices in Quonochontaug Pond is more complex. Figure 7 illustrates the project scale summary of restoration over three years. In 2006, the first year implementing the caged spawner sanctuary in the pond, recruitment results were encouraging with a cumulative settlement index of 50. The increased pond population in addition to the caged animals provided in 2007 was expected to produce a greater cumulative settlement index than what was observed in 2007. This low settlement may have resulted in the decreased scallop population in 2008. With a low scallop population in 2008 and restoration efforts removed from Quonochontaug Pond the cumulative settlement index was expected to be proportional. Despite the low available broodstock the cumulative settlement index for Quonochontaug pond in 2008 was 163.7, a 1264% increase from the previous year and the highest that has been observed in any pond of study within the five years of *North Cape* restoration. This may suggest that relatively small numbers of spawning stock may be adequate to supply a recruitment limited restoration site, on a small-basin scale where larval retention is likely. Large fluctuations in scallop settlement not concurrent with scallop population size exemplifies the unclear relationship between stock and recruitment relationships, particularly in exploited invertebrates (Hancock 1973), and emphasizes the inherent fluctuations expected to be witnessed in larval survival (Dickie 1955, Wolff 1988).

Two thousand eight was the first year scallop restoration and spat monitoring was conducted in Pt. Judith Pond. Although scallop settlement in Pt. Judith Pond was low in comparison to the other ponds of study, the results are encouraging. Our data from the other bay scallop restoration projects indicate an important factor to a successful next year population is location of spat settlement and subsequent recruitment into favorable habitat. The strongest recruitment was recorded from Snug Harbor and Strawberry Point which are located in the western portion of the Central Basin. This area contains the best scallop habitat in the pond and is comprised of a sandy/rubble substrate with relatively extensive eelgrass beds and macroalgae. With a healthy population in 2008 and good recruitment to favorable habitat, it is expected Point Judith Pond will exhibit a healthy scallop population in 2009.

II. Oyster Projects

2.0 Introduction

The *North Cape* Restoration Program has focused on creating a supply of breeding adult oysters, *Crasostrea virginica* 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 (See Holly *et al.* 2004, Hancock *et al.* 2005, Hancock *et al.* 2006, Hancock *et al.* 2007). In 2008, a different approach was taken to maximize growth and reduced labor costs. Post settled oysters individually set on micro cultch were purchased from a commercial hatchery and raised in a floating upweller system (FLUPSY). Following approximately five months of husbandry in the upweller, the oysters were sampled to determine the mean size and number of juveniles. The juvenile oysters were then transported and seeded at selected release sites. Annual monitoring of each restoration site has been undertaken since 2004 to determine the survival and growth of the seeded stock.

In 2008, two North Cape restoration sites in Point Judith Pond were evaluated for gonad development, spawning, and recruitment of the eastern oyster. A seeding experiment was also conducted to examine the influence of size on growth and survival of seeded oysters.

2.1 Monitoring of Oyster Release Sites

Objective

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

Methods

From 2003 to 2006, seven oyster restoration sites have been seeded with juvenile oyster. The sites have been monitored annually from 2004 to 2008, using random 1-m^2 quadrats. The release sites were small enough in spatial scale and of sufficient density to allow for effective quadrate sizes of 1m^2. 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 100-m 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 500m 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 2008 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 August 8, 2008 and September 17, 2008 dive teams surveyed a total of $250m^2$ using $1\text{-}m^2$ quadrats, at five restoration sites. A total of seven areas have been seeded one or more times since 2003 (Table 3). The Bissel Channel closed site was estimated to have the greatest number of total oysters (43,652 ± 7,678), followed by Smelt Brook Cove (18,991 ± 2,644), The Cove (12,671 ± 2,928), Potter Cove (10,311 ± 4,697) and Saugatucket River (8,192 ± 1,273) (Table 3).

The Bissel Channel closed site was seeded for the first and only time in 2006, therefore, 2nd year survivorship could be determined from the dive surveys. Overall survivorship of oysters seeded into Bissel Channel closed site since 2006 in 2008 was 10%. Second year survivorship, oysters surviving from 2007 to 2008, was 47%. Mean size of age 2+ animals in Bissel Channel closed was 94.99 ± 0.8mm, representing an annual growth increment of 47.5mm.

In the other four restoration sites, survival from 2007 to 2008 was highest in Smelt Brook Cove (36%), followed by Saugatucket River (25%), The Cove (20%) and Potter Cove (19%) (Table 3). The mean shell length of oysters sampled from these sites, a measurement of all cohorts seeded since 2003 was, 94.58 ± 1.1mm in Smelt Brook Cove, 79.2 ± 1.4mm in the Saugatucket River, 94.1 ± 2.4mm in The Cove, and 93.5 ± 2.5mm in Potter Cove. The frequency of occurrence of older and younger animals can typically be inferred from length frequency relationships of the sites (Figure 8A-E), however, overlap of different cohorts was too great to accurately distinguish between them. This is particularly true in a site such as The Cove (Figure 8D) where a 'tail' of older animals can be witnessed from the size distributions, but individual cohorts are no longer obvious.

Discussion

Example of size overlap of oyster cohorts at restoration sites.

The total numbers of oysters at each restoration site sampled in 2008 have decreased, despite successful seeding efforts in 2003 to 2006. It is unclear if the increased mortality is attributed primarily to first year animals, older animals, or a combination of both. 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. Disease testing in 2008 has shown an increase in prevalence and pathogen loads in all restoration sites (see Disease monitoring 2.2). 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. Traditionally 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 survival rate from 2006-2007 at the Bissel channel closed site was exceptional. The high survival had been attributed to its favorable habitat with regular freshwater input and high flushing rate; this habitat still exists in 2008. Despite high first year survival at Bissel Closed the survival and growth rate of the second year cohort was below average in 2008. This may be attributed to natural mortality, such as predation and disease, as well as fishing pressure. Despite the site being located in an area closed to shellfishing, harvesting pressure is suspected in playing a role in the decline of the survival rate. The northern boundary of the site is situated directly on the closure line and some discrepancy amongst boundary location may exist. Observations from the 2008 dive survey revealed a precipitous drop off of oysters near the northern boundary of the seeding site, or closure line. To mitigate this problem in the future, the 2008 seeding site was moved further west, away from the closure line.

Growth and relative size is very comparable amongst all restoration sites. Mean shell length of oysters falls between 93.5 and 94.0mm at all sites with the exception of Smelt Brook Cove, where oysters have a mean length of 79.2mm. The smaller size of oysters in

Smelt Brook Cove may be attributed to the consistently higher pathogen loads of *P. marinus* at this site. As previously stated it is known that Dermo infection increases in oysters with age, and thus mortality is higher in older and larger individuals.

2.2 Disease Monitoring

Objective

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

Methods

Samples of eight oysters were taken from three restoration sites seeded; Saugatucket River, Smelt Brook Cove and Bissel Channel, to determine abundance of the *Perkinsus marinus* parasite, the pathogen responsible for the disease Dermo. Samples of eight oysters were taken from the oldest cohort (largest oysters) available at each site. These samples were transported on ice to the University of Rhode Island, Fisheries Animal and Veterinary Science Department. Pathology tests were performed and the results were provided to the *North Cape* Shellfish Restoration Program. 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

Disease testing revealed 100% prevalence of Dermo in all restoration sites tested with varying degrees of pathogen loads. Of those tested, in Saugatucket River, 87.5% ranked moderate-to-heavy while 12.5% ranked heavy. In Smelt Brook Cove 87.5% ranked moderate while 12.5% ranked heavy. Of the oyster tested in Bissel Cove 71% ranked moderate while 29% ranked heavy. A summary of prevelence of *P. marinus* and pathogen loads in the *North Cape* restoration sites from 2005 to 2008 can be viewed in Table 4.

Discussion

The level of Dermo infection generally increases with age, as does the associated percent mortality (Encomio *et al*. 2005). Saugatucket River and Smelt Brook Cove have exhibited moderate to high pathogen loads since 2004. From the decreased survival of year 2+ cohort of oysters at these sites, it appears that with increased age, size and subsequent disease load, Dermo has begun to cause higher mortality. Percentage of Dermo prevalence at Bissel Cove has exhibited a near 90% increase from previous years. The increase in disease prevalence coupled with increased pathogen loads is most likely a contributing factor to the decreased survival of the year 2+ cohort from 2007 to 2008. Disease testing was not conducted in 2008 in The Cove or Potter Cove, although with the increased mortality of oysters at these sites it is likely disease prevalence and pathogen loading has increased as well. The increase in percent prevalence of *Perkinsus marinus* in Bissel Cove may indicate an increase in the prevalence of parasites in the northern sections of Narragansett Bay.

2.3 Upweller Growout

Introduction

In previous years, 2004-2006 broodstock for the *North Cape* oyster restoration project has been raised from larvae using the remote setting technique (Jones and Jones 1988, Kennedy 1996). In 2008 a different approach was taken to maximize growth and reduced labor costs of remote setting. In 2008, post settled oysters individually set on micro cultch were purchased from a commercial hatchery and raised in a floating upweller system (FLUPSY). The efficiency of using a FLUPSY for grow-out was apparent from the comparison of mean size of the same group of oysters grown in the nursery and upweller in 2006 (See Hancock *et al.* 2007). The oysters in upwellers are provided greater access to food due to the high water flow-through, maintained with flow pumps. Better nutrition results 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 their first winter with a higher energy reserve (Beal *et al.* 1995, Taborsky 2003).

Objective

The objective of the upweller growout is to maximize food availability to the juvenile oyster during their first season, thereby maximizing growth, condition, and subsequent survival rate of the oysters once they are seeded into the restoration sites.

Methods

In 2008, approximately 1,000,100 juvenile oysters (estimated by commercial hatchery) singly set on micro cultch, with an average length of 1.5mm, were purchased from Muscongus Bay Aquaculture Inc., Bremen, ME. On June 11th the oysters were delivered to the Coastal Fisheries Laboratory via the U.S. Postal Service fist day air and immediately placed in a FLUPSY located at Camp Fuller in Point Judith Pond, Narragansett, Rhode Island. To insure optimal flow, the oysters were cared for by daily gentle stirring and twice weekly washing out pseudo feces and other debris caught in each bin. Seven complete screenings of the oysters took place throughout the season to partition size classes. Screen sizes were 1-mm, 2-mm, 3-mm, 6.4-mm and 12.7-mm. At the time of screening, the mesh on the bottom of the upweller bins was increased accordingly to maximize water flow and oysters were redistributed to bins of the FLUPSY with appropriate mesh.

In October of 2008, the oysters in the upweller were sampled to obtain estimates of size and abundance prior to release.

Results

The total number of oysters raised in the FLUPSY in Point Judith Pond was estimated to be 1,104,463 ± 33,277. The volume of oysters increased from 530ml with a mean size of 1.5mm when purchased on June 11, 2008, to 2,107 L with a mean size of 27.0 ± 0.3mm on October 25 prior to seeding. Size frequency of all oysters raised in 2008 prior to seeding is provided in Figure 8. The oysters were split into four size classes; extra large, large, medium and small. The small size class comprised 53% of the total (583,649 ± 11,876) with a mean length of 15.4 ± 0.19mm. The medium size class comprised 26% of the total (292,659 ± 9,555) with a mean length of 22.9 ± 0.26mm. The large size class comprised 11% of the total (123,136 ± 4,577) with a mean length of 31.5 ± 0.3mm. The extra large size class comprised 10% of the total (105,019 ± 7,268) with a mean size of 38.2 ± 0.5mm (Table 5).

Four distinct size classes of oysters raised in the FLUPSY. Photo taken approximately two months after oyster were placed in upweller.

Discussion

In 2008, the approach of purchasing singly set juvenile oysters and the use of a FLUPSY as a means of an oyster nursery proved to be an effective and efficient way to maximize growth in a given season. In 2006, the mean length of oysters from four remote sets and subsequent nursery growout in the intertidal zone at the CFL was 13.6 ± 0.1mm, while the mean length of oysters from the same cohort grown out in the *North Cape* upwellers was 24.5 ± 0.6mm. In 2008, the mean length of oysters raised in the upweller was 27.0 ± 0.32mm, larger than the average size of oysters raised in the CFL nursery in previous years. The increased growth of the oysters in the upweller in comparison to the nursery at the CFL is presumably a function of greater food availability. Upwellers are designed to create a constant flow of water past the animals held within, and ultimately maximize the food source available. The increased growth of oysters achieved in the first season will provide them better predator protection and an increased energy reserve which should translate into a higher survival rate during their first winter (Beal *et al.* 1995, Nakaoka 1996, Taborsky 2003)

The process of growing oyster spat using the remote setting technique is very time consuming and labor intensive. In previous years, preparation of shell cultch and aquaria to setting and subsequently creating and maintaining a nursery required at least 7 employees and occupied a large proportion of the season, including multiple volunteer days. *North Cape* staff was reduced to 4 employees in 2008. While labor was still intensive, the approach taken in 2008 of raising single set oysters in an upweller allowed

North Cape staff to effectively reduce labor time and costs while producing seed that will likely contribute to higher first year survival.

There was no apparent mortality while raising oysters in the upweller in 2008. The abundance of oysters purchased from Muscongus Bay Aquaculture Inc. was estimated by the commercial company at just over 1,000,110 individuals with an average size of 1.5mm. The *North Cape* staff estimated the abundance of oysters in the upweller prior to seeding at 1,104,463 ± 33,277 individuals. The discrepancy of over 100,000 oysters can be attributed to sampling error. The observation of no mortality throughout the season, coupled with an increase in abundance of oysters from what was purchased, suggests a survival rate of close to 100%. The high survival rate can be attributed to proper husbandry of the oysters along with favorable environmental conditions throughout the growing season.

2.4 Oyster release

Objective

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

Methods

Oyster seeding in Smelt Brook Cove, November 2008.

Oysters were carried in totes from the upweller to predetermined release sites by boat and truck. Seven 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 were 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 and the boundary of the Bissel channel site was moved approximately 500m north into an area closed to shellfishing. Seeding did not take place in 2007. In 2008 seeding took place in 3 sites; Smelt Brook Cove, Saugatucket River and Bissel Cove Closed. The northern boundary of the Bissel Cove site was moved 10m west in 2008 to create a larger buffer between the shellfishing closure line and the seeding site. This was done in hopes to mitigate the fishing pressure on the restoration site (see Section 2.1).

Prior to seeding, the restoration site was marked using floats to clearly delineate each site. Oysters were distributed evenly throughout the entire area of each site. In 2009, the restoration sites will continue to be monitored to determine long-term survival and growth, as well as bed stability, siltation, predation, and disease prevalence.

Results

In November of 2008, approximately 1.1 million juvenile oysters were seeded amongst three sites. Oysters were seeded into Saugatucket River, South Kingstown on November 25, 2008; Smelt Brook Cove, Pt. Judith Pond, South Kingstown on November 26, 2008 and Bissel Cove, North Kingstown on December 4, 2008. The oysters were broken down into four size classes; extra large, large, medium, and small (Table 5).

Bissel Cove received ~50% of the total oysters (~552,231 ± 16,638), Smelt Brook Cove and Saugatucket River each received 25% of the total oysters (~276,115 ± 8,319). A breakdown of the estimated number of each size class seeded in each site is shown in Table 6.

2.5 Oyster Seeding Experiment

Introduction

To maximize the effectiveness of restoring shellfish populations by introducing broodstock, it is imperative to maximize the survival and success of the introduced stock. Mortality of juvenile shellfish is often dependant on effective predator protection which is frequently a function of size and their associated energy reserve (Beal *et al.* 1995, Nakaoka 1996, Taborsky 2003). In 2008, experimental plots were established in Bissel Cove to obtain estimates of growth and survival of oysters released at four different size classes.

Objective

The objective was to sample the experimental plots on both a short and long term basis to determine the influence of seed size on survival and use this data to comment on suggested size of oysters for free seeding as well as advantages of single seed oysters vs. spat on shell cultch.

Methods

Three replicated experimental plots were established within the closed fishing area of Bissel Cove. Each plot was 2m x 2m and was comprised of four treatments; four size classes seeded at $100m^{-2}$. Each treatment occupied a 1m x 1m area within the experimental plot. The four sizes classes used in the 2008 plots were all separated out of the 2008 cohort of oysters raised in the floating upweller at Camp Fuller. Oysters from the four size classes were selected in early November prior to seeding. The extra large size class had a mean length (± SE) of 38.2 ± 0.5mm, the large size class had a mean length of 31.5 ± 0.3mm, the medium size class had a mean length of 22.9 ± 0.26mm, and the small size class had a mean length of 15.4 ± 0.19mm. Each experimental plot was separated by approximately 15m to minimize the potential to alter predator-searching behavior by having a larger area of high-density prey (Barbeau *et al*. 1998, Clark *et al*. 2000).

The plots were established on December 9, 2008. Short term sampling was attempted on January 6, 2009, but was unsuccessful due to ice cover. Long term sampling will be conducted in the spring of 2009. Each sampling will consist of total count of all live and dead oysters within each plot.

2.6 Monitoring Oyster Gonad Development and Larval Settlement in Point Judith Pond

Introduction

In an effort to restore oyster broodstock populations, over 5.3 million oysters have been seeded by *North Cape* staff and volunteers to six restoration sites in Rhode Island since 2003. Although survivorship of seeded oysters has been successful (Hancock *et al*. 2007), limited recruitment has been observed at the restoration sites.

Traditionally, the North Cape project has monitored oyster settlement immediately at the restoration sites via the use of spat collectors or 'spat condos' (Hancock *et al*. 2006). Although this is a reasonable and widely used method to monitor oyster settlement, it does not provide an indication of sexual development of the animal, larvae that may have been present in the water column which did not survive to settlement, or account for larval transport away from the restoration site. In 2008, two *North Cape* restoration sites in Point Judith Pond were evaluated for gonad development, spawning, and settlement of the eastern oyster. The objectives of the study were to: monitor temporal development of oyster gonads as well as interspecific site variations between the two locations; obtain estimates of veliger stage oyster abundance present in the water column at each site temporally; and monitor oyster spat settlement at each restoration site and throughout the entire salt pond to monitor presence of oyster settlement and examine differences in oyster recruitment on a larger horizontal plane.

Methods

The monitoring was conducted at two *North Cape* oyster restoration sites within Pt. Judith Pond; Smelt Brook Cove and Saugatucket River. The two sites are situated within the same body of water but located 2,500m apart (water distance) and represent two ecologically separate habitats (see Figure 10). The Saugatucket River site is located in the northern terminus of the pond at the confluence of the major freshwater input and is separated from the main body of water by a narrow channel. The Smelt Brook Cove site is located within the main body of the Pond and is more directly influenced by tidal flux than a freshwater source. Larval transport between the two sites is unlikely. The monitoring took place throughout the natural reproductive season of eastern oysters; May through September, and was conducted on a weekly or bi-weekly basis.

Development of gonads
Five oysters were collected from each site on a weekly basis beginning on May 5, 2008 and ending on September 8, 2008. The oysters were shucked and the tissue was dried at 80°C for 48 hours while the shell was air dried for the same time period. Dry shell and dry soft tissue were weighed to the nearest 0.1g. Temporal development of oyster gonads at the two sites was monitored by calculating the condition index, a ratio of dry soft tissue weight as a function of dry shell weight (Walne and Mann 1975).

CI = [Dry tissue wt. (g) x 1000] / Dry shell wt. (g)

Larvae monitoring
Both sites were monitored twice weekly beginning on June 2, 2008 and ending on September 8, 2008. On each sample date 500L of seawater, from the mid-water column in the center of the restoration sites, was sieved through a 53µm plankton net. The contents were stored in 50ml vials and fixed with ethanol for preservation. Samples were examined under a compound microscope and oyster larvae were enumerated using a Sedgwick-rafter cell. Three replicate counts were conducted for each sample and the average number of larvae per sample date was extrapolated to larvae m^{-3}.

URI Coastal Fellow Patrick Shepard collects a water sample to estimate oyster larvae abundance in the water column.

Settlement monitoring
Settlement of oyster spat in Pt. Judith Pond was monitored using artificial spat collectors positioned spatially throughout the pond (Figure 10). The collectors were made using ADPI ½ inch mesh pouches containing surf clam valves (*Spisula solidissima*). Each pouch measured approximately 46cm x 30cm x 10cm and was moored using a cinderblock and marked with a surface float (Figure 11). The surface float also acted as buoyancy to suspend the spat collector in mid water column. Collectors were rotated every three weeks and examined under a dissecting microscope for larval settlement.

Results

The condition index (CI) remained very consistent between the two study sites. The average CI increased throughout the summer, with a general season peak from July 7th to

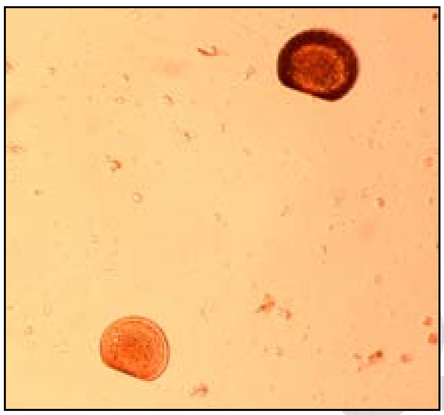
August 12th (Figure 12). The CI in Saugatucket River ranged from 11.5 to 71.9 and had a season average of 38.2. The CI in Smelt Brook Cove ranged from 9.59 to 59.5 and had a season average of 29.9.

Oyster larvae abundance remained very consistent between the two study sites with a general season peak between July 1st and July 30th (Figure 13). Larval abundance in Saugatucket River fluctuated from 0.0 to 1,350 larvae m^3 per sample date, and had a season average of 89.8 larvae m^3. Larval abundance in Smelt Brook Cove fluctuated from 0.0 to 8,575 larvae m^3 per sample date, and had a season average of 527.5 larvae m^3.

Settlement was not observed on any spat collectors in Point Judith Pond throughout the season.

Discussion

Condition Index of a bivalve is a numerical representation of the quality (i.e. ‘fatness’) of its soft tissue. Quantitative methods of determining the CI of bivalves has been conducted as far back as the early 1900’s, and many different formulas have been suggested over the years. Generally, the standard accepted gravimetric formula used by researchers today to obtain CI is a function of dry soft tissue weight to internal shell capacity (Crosby and Gale 1990). Due to problems in data collection and technique, it was not possible to utilize this method to obtain CI estimates of collected oysters. Instead, a formula suggested by Walne and Mann (1975) was used. Considering the formula was calculated to perform inter-pond comparisons of temporal gonad development, the use of an older, less accepted formula does not pose a problem.



Planktonic oyster larvae under 40x magnification. ~65µm

Both restoration sites exhibited very similar patterns of gonadal development, larval production, and spat settlement, despite being discretely separate restoration sites which are subject to varying environmental conditions. As expected, condition index and larval production peaked in mid July. This most likely reflects the oyster’s reaction to seasonal environmental factors, such as increased water temperature (Dame 1972).

The *North Cape* oysters in the restorations sites are reproducing and exhibiting normal gonadal development. Results from the three aspects of this study suggests the cause of the observed limited recruitment may exist somewhere between planktonic stage larvae and settlement. Larvae observed in the water column but not observed as settled spat may be a result of a number of different factors including predation, disease, increased siltation or inadequate available substrate, or larval transport greater than the study area (Dickie 1955, Hancock 1973, Wolf 1988). Juvenile Oyster Disease (JOD) has been documented in Point Judith Pond (Pers. Comm. Marta Gomez-Chiarri URI FAVS). JOD can cause significant mortality in oyster larvae and may represent one explanation for the observed larval abundance in the water column without observed settlement. The larvae samples collected are currently being tested by Dr. Gomez-Chiarri to determine if JOD is present. The *North Cape* project hopes to collect samples again in 2009 to monitor available oyster larvae abundance at the restoration sites and presence of JOD.

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

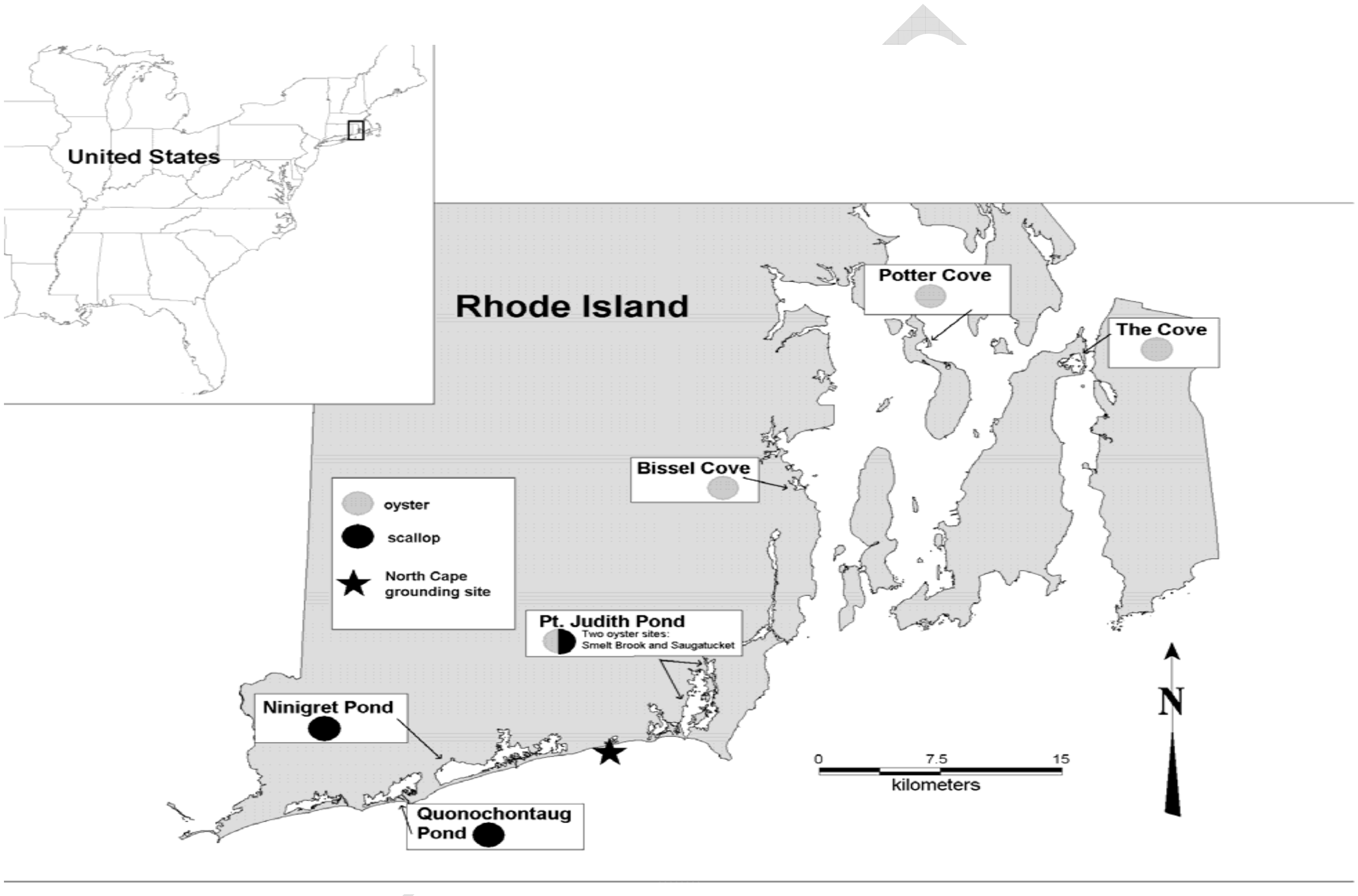
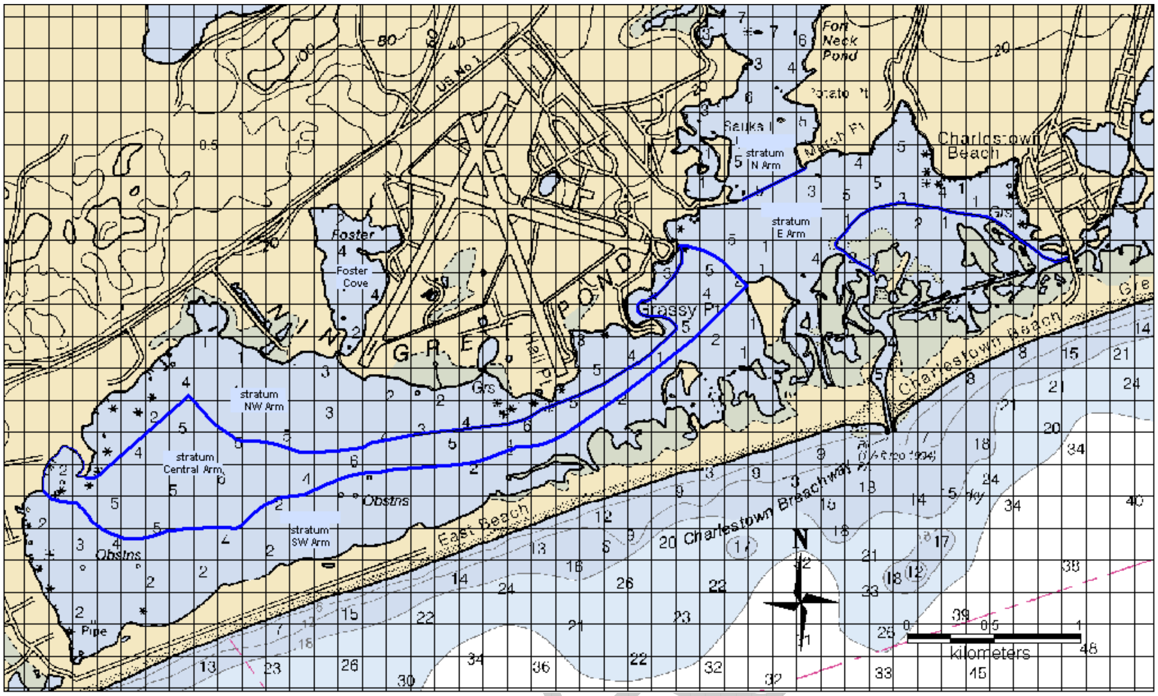
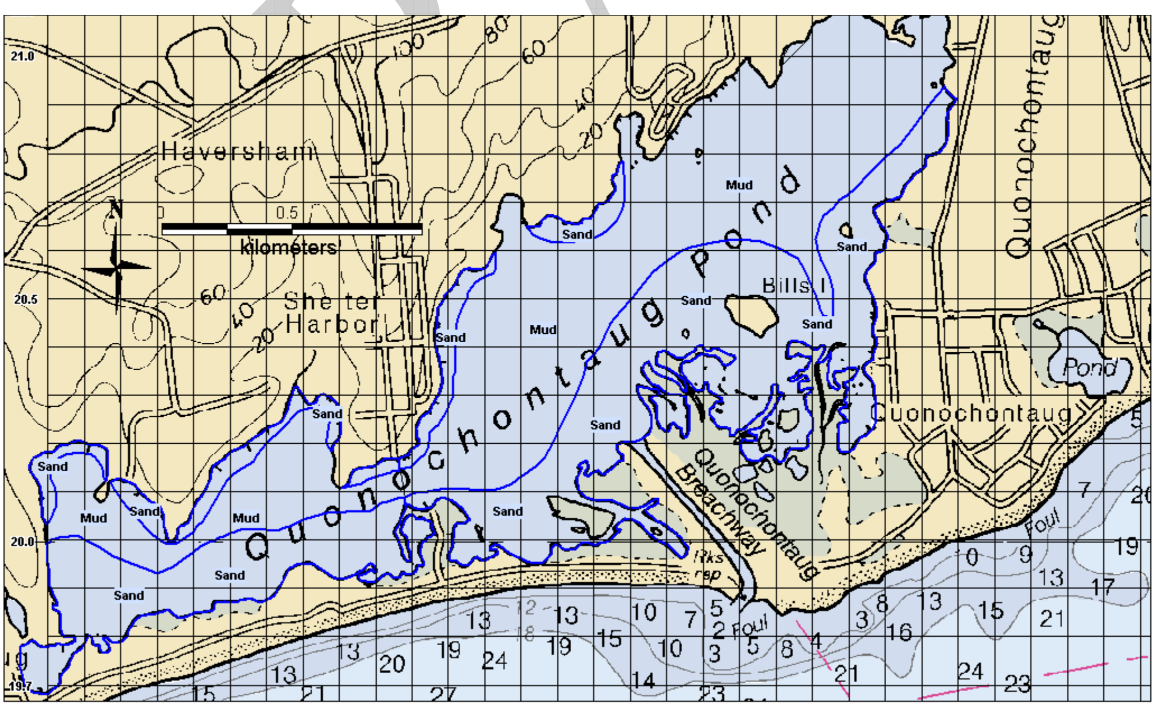


Figure 2. Scallop survey strata, Ninigret Pond (A), Quonochontaug Pond (B), and Point Judith Pond (C).

A. Ninigret Pond



B. Quonochontaug Pond



C. Point Judith Pond

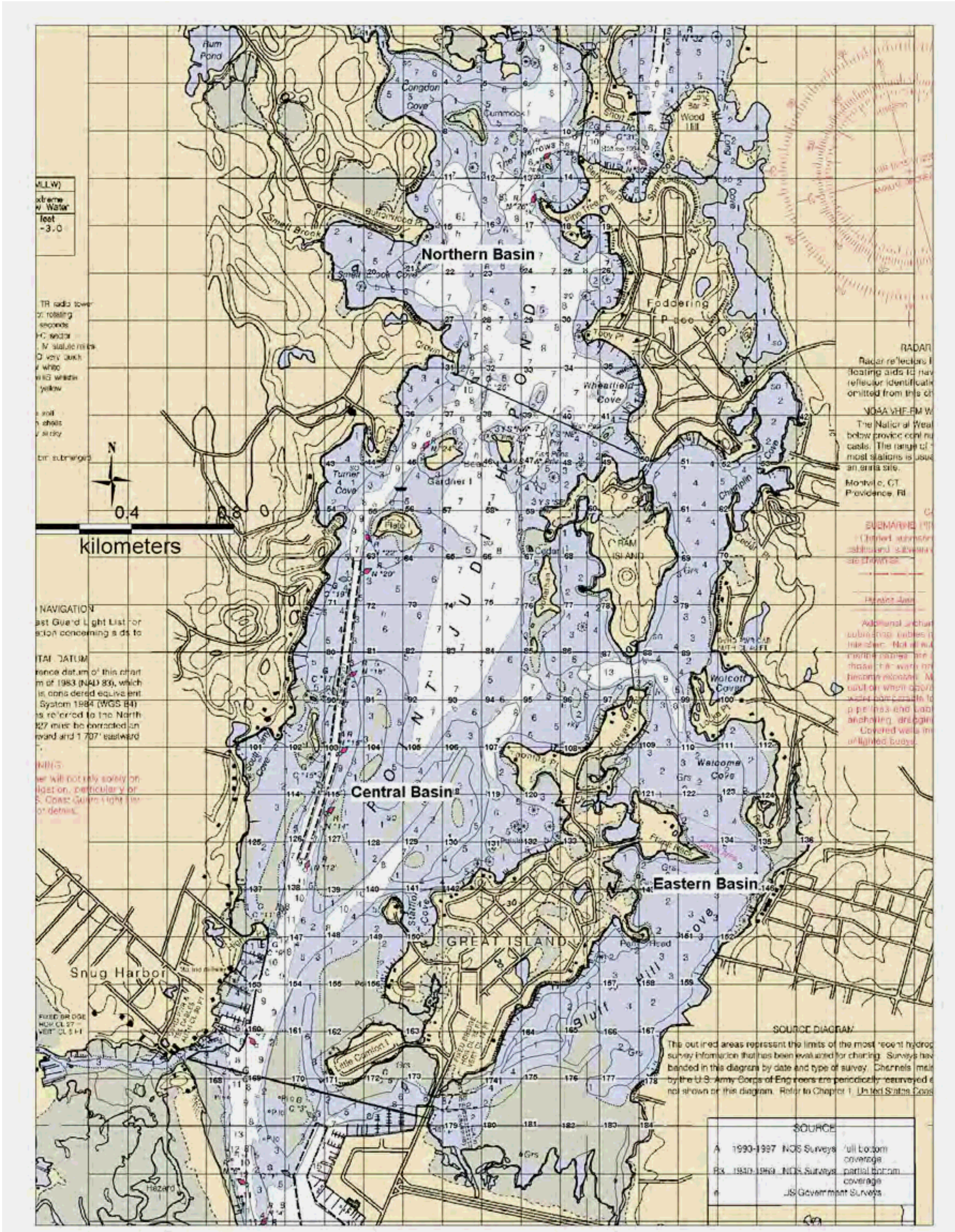


Table 1. Scallop survey distribution and abundance estimates, Ninigret Pond (A), Quonochontaug Pond (B), and Point Judith Pond (C) in 2008.

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	239	0.199	0.058	1,229,351	244,846	71,482
Central West Arm	1,200	29	0.024	0.009	1,234,114	29,824	11,107
South West Arm	1,200	9	0.008	0.004	1,748,259	13,112	7,493
Central Basin	1,200	0	0.000	0.000	961,400	0	0
Total	4,800	277			5,173,124	287,782	90,082

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	1,700	0	0.000	0.000	1,448,000	0	0
East Basin Outer Sand	1,400	8	0.006	0.004	837,099	4,783	3,588
West Basin Central Mud	500	0	0.000	0.000	528,920	0	0
West Basin Outer Sand	500	1	0.002	0.002	287,426	575	575
Total	4,100	9	0.002	0.000	3,101,445	5,358	4,162

C. Point Judith Pond

Strata	Area Surveyed (m^2)	No. of Scallops Found	Mean Scallops (m2)	SE	Area of Stratum (m2)	No. Scallops/ Stratum	SE
Northern Basin Mud	800	0	0.000	0.000	712,400	0	0
Northern Basin Sand	400	0	0.000	0.000	384,019	0	0
Central Basin Mud	1,200	9	0.008	0.007	1,059,681	7,948	7,039
Central Basin Sand	1,000	13	0.013	0.011	1,088,645	14,152	11,820
Central Basin Grass	500	10	0.020	0.009	419,500	8,390	3,980
Eastern Basin Mud	1,000	0	0.000	0.000	880,508	0	0
Eastern Basin Sand	600	0	0.000	0.000	542,594	0	0
Total	5,500	32			5,087,347	30,490	22,839

Figure 3. Schematic diagram of spat bag array.

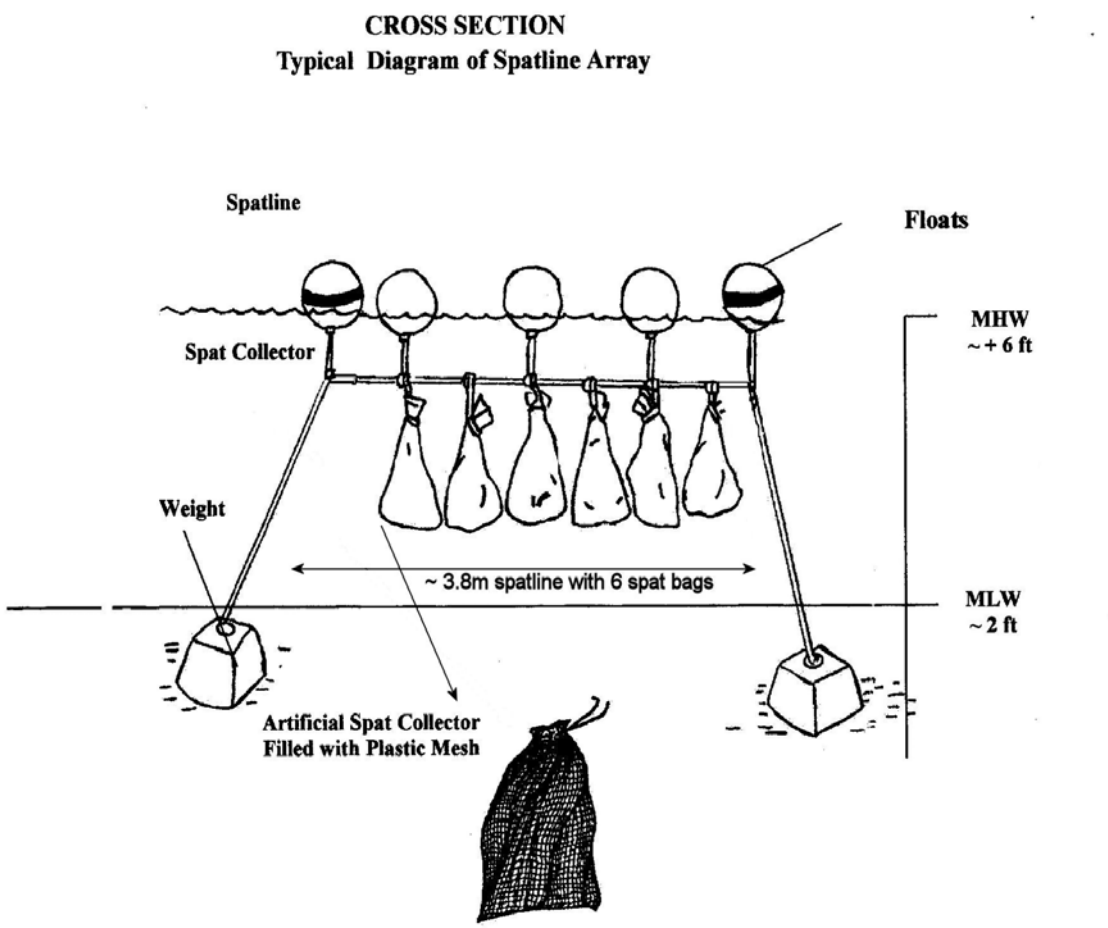
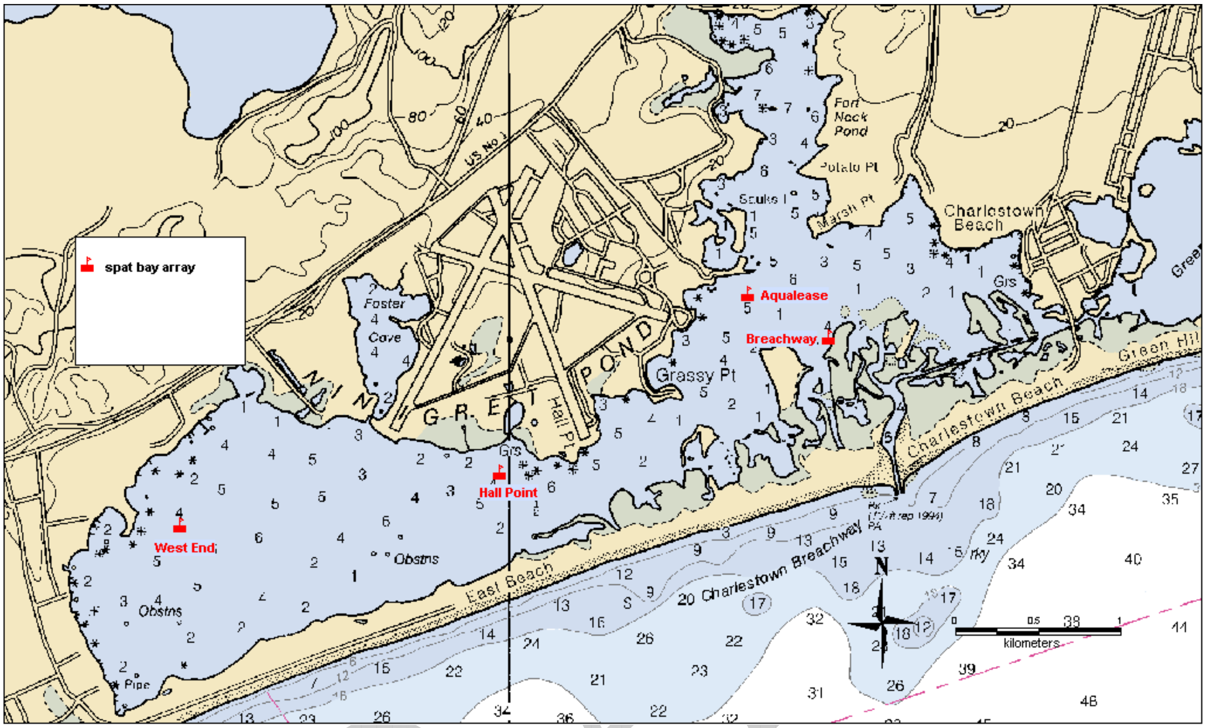
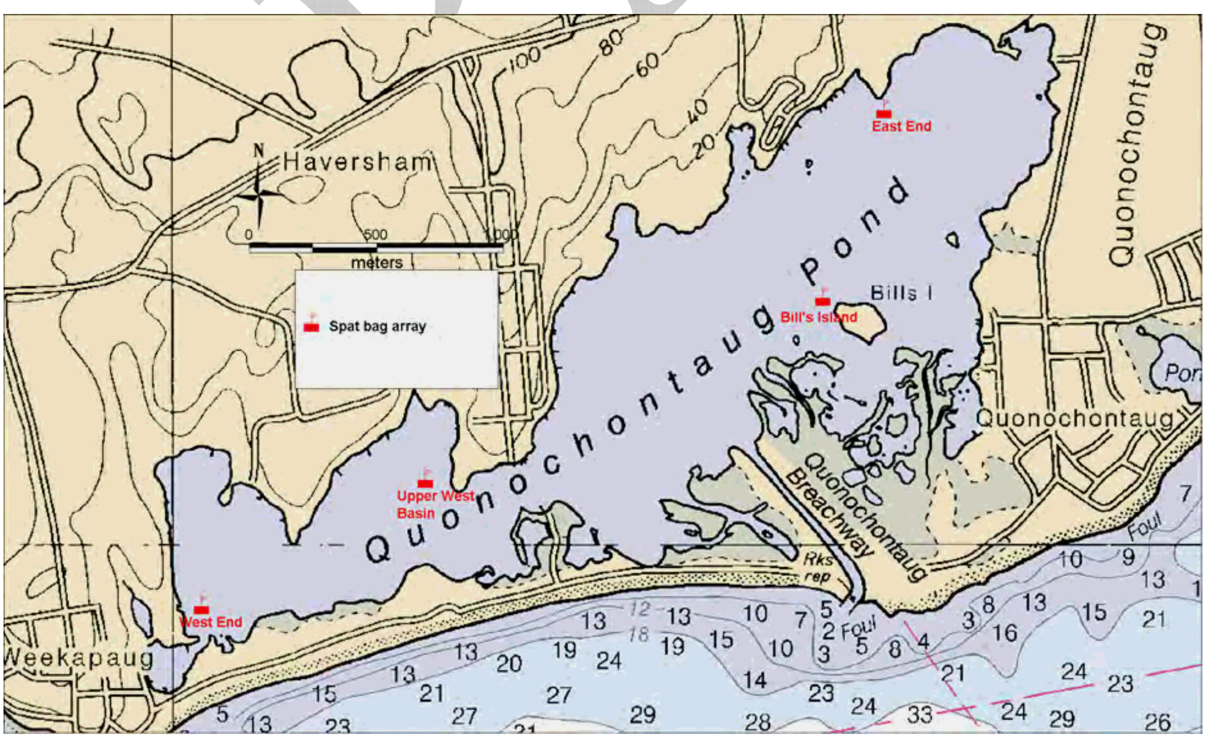


Figure 4. Location of spat bag arrays in Ninigret Pond (A), Quonochontaug Pond (B), and Point Judith Pond (C) in 2008.

A. Ninigret pond



B. Quonochontaug Pond



C. Point Judith Pond

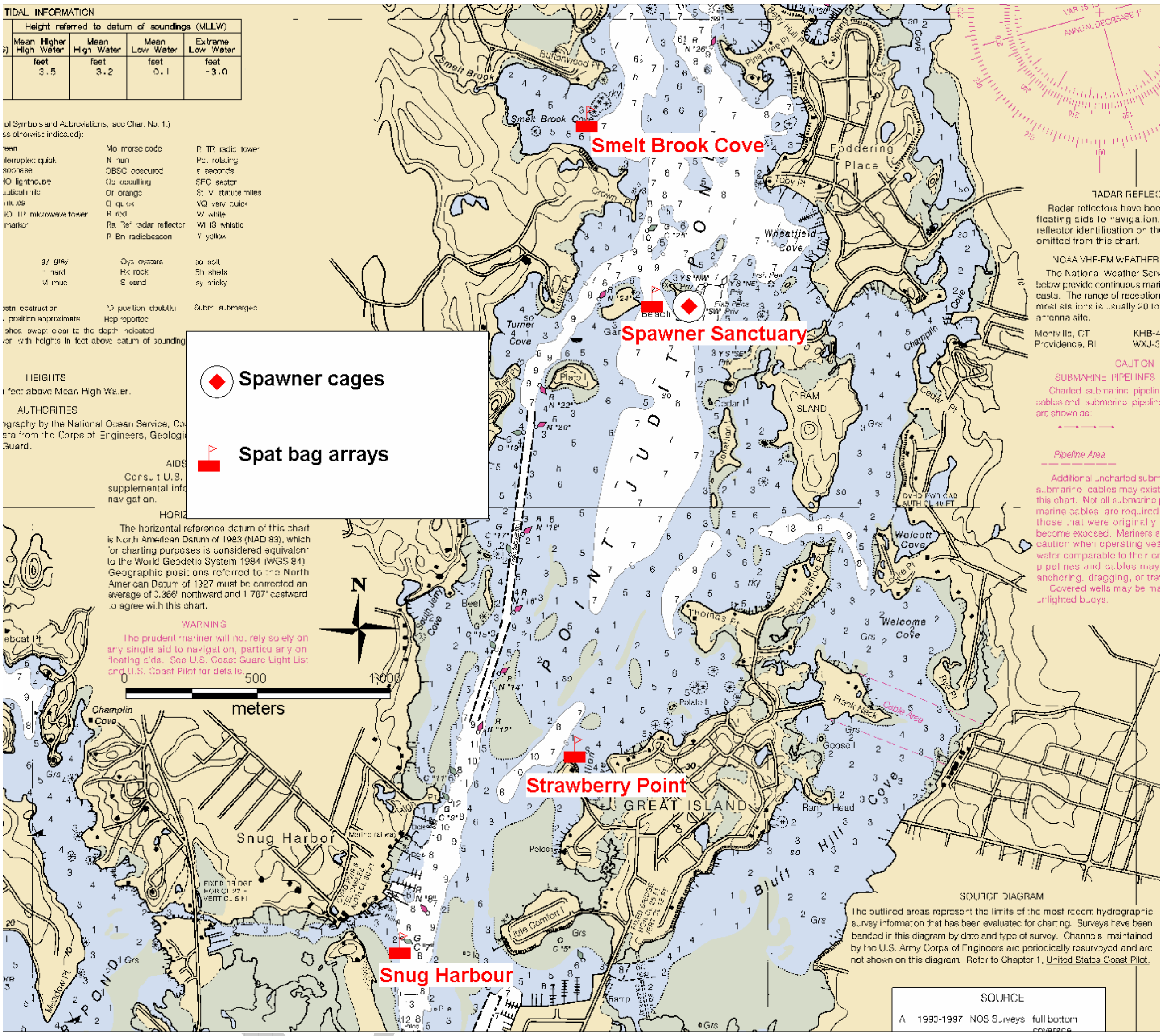


Table 2. Scallop spat collected from spat bags deployed in Ninigret Pond (A), Quonochontaug Pond (B), and Point Judith Pond (C) in 2008.

A. Ninigret Pond

Date Deployed	5-Jun-08	17-Jun-08	3-Jul-08	17-Jul-08	1-Aug-08	14-Aug-08	26-Aug-08	11-Sep-08	24-Sep-08	10-Nov-08		Settlement
Date Collected	**3-Jul-08**	**17-Jul-08**	**1-Aug-08**	**14-Aug-08**	**26-Aug-08**	**11-Sep-08**	**24-Sep-08**	**10-Oct-08**	**24-Oct-08**	**7-Nov-08**	**Total**	**Index**
Scheduled Liberty	30	30	30	30	30	30	30	30	30	30		
Days at Liberty	28	30	29	28	25	28	30	29	31	29		
West End												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	0	1	32	2	0	0	0	0	0	35	
Mean Scallops/Bag	0.0	0.0	0.2	5.3	0.3	0.0	0.0	0.0	0.0	0.0		5.8
Mean Size (mm)	0.0	0.0	3.4	2.4	3.9	0.0	0.0	0.0	0.0	0.0		
Breachway												
No. Bags	6	6	5	6	6	6	6	6	6	6	59	
No. Scallops	0	8	45	9	1	0	1	2	0	0	66	
Mean Scallops/Bag	0.0	1.3	9.0	1.5	0.2	0.0	0.2	0.3	0.0	0.0		12.5
Mean Size (mm)	0.0	1.8	3.1	4.0	5.9	0.0	3.3	2.5	0.0	0.0		
Aqualease												
No. Bags	5	6	6	6	6	6	6	6	6	6	59	
No. Scallops	0	0	38	4	11	1	1	5	0	0	60	
Mean Scallops/Bag	0.0	0.0	6.3	0.7	1.8	0.2	0.2	0.8	0.0	0.0		10.0
Mean Size (mm)	0.0	0.0	4.4	4.0	3.8	5.7	3.7	2.6	0.0	0.0		
Hall Point												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	0	0	77	55	1	4	0	0	0	137	
Mean Scallops/Bag	0.0	0.0	0.0	12.8	9.2	0.2	0.7	0.0	0.0	0.0		22.8
Mean Size (mm)	0.0	0.0	0.0	2.2	3.4	4.4	2.3	0.0	0.0	0.0		
								Total bags			238	51.2
								Total spat			298	

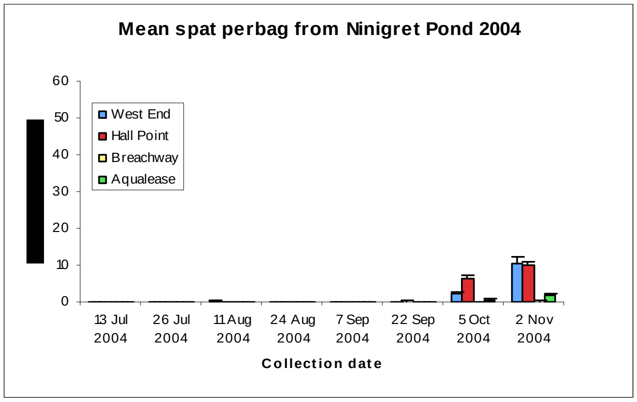
B. Quonochontaug Pond

Date Deployed	5-Jun-08	17-Jun-08	3-Jul-08	17-Jul-08	1-Aug-08	14-Aug-08	26-Aug	11-Sep-08	24-Sep-08	10-Oct-08		Settlement
Date Collected	3-Jul-08	17-Jul-08	1-Aug-08	14-Aug-08	26-Aug-08	11-Sep-08	24-Sep	10-Oct-08	24-Oct-08	7-Nov-08	Total	Index
Scheduled Liberty	30	30	30	30	30	30	30	30	30	30		
Days at Liberty	28	30	29	28	25	28	30	29	31	29		
West End												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	0	5	4	5	4	6	110	2	0	136	
Mean Scallops/Bag	0.0	0.0	0.8	0.7	0.8	0.7	1.0	18.3	0.3	0.0		22.7
Mean Size (mm)	0.0	0.0	5.8	3.4	3.5	3.9	3.8	2.1	2.7	0.0		
Upper West Basin												
No. Bags	6	6	6	6	6	5	6	6	6	6	59	
No. Scallops	0	0	1	12	8	7	0	91	3	0	122	
Mean Scallops/Bag	0.0	0.0	0.2	2.0	1.3	1.4	0.0	15.2	0.5	0.0		20.6
Mean Size (mm)	0.0	0.0	1.5	4.6	3.3	2.7	0.0	2.2	1.5	0.0		
Bills Island												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	0	41	7	11	64	12	430	7	0	572	
Mean Scallops/Bag	0.0	0.0	6.8	1.2	1.8	10.7	2.0	71.7	1.2	0.0		95.3
Mean Size (mm)	0.0	0.0	3.1	5.8	2.1	3.8	4.2	2.3	3.0	0.0		
East End												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	0	12	4	8	52	3	70	2	0	151	
Mean Scallops/Bag	0.0	0.0	2.0	0.7	1.3	8.7	0.5	11.7	0.3	0.0		25.2
Mean Size (mm)	0.0	0.0	4.1	5.7	2.7	3.5	1.7	2.2	1.3	0.0		
								Total bags			239	163.7
								Total spat			981	

C. Point Judith Pond

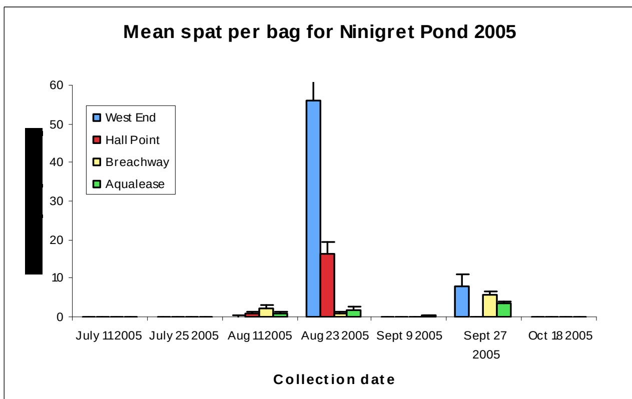
Date Deployed	12-Jun-08	23-Jun-08	10-Jul-08	24-Jul-08	6-Aug-08	22-Aug	4-Sep	18-Sep	2-Oct	16-Oct		Settlement
Date Collected	**10-Jul-08**	**24-Jul-08**	**6-Aug-08**	**22-Aug-08**	**4-Sep-08**	**18-Sep**	**2-Oct**	**16-Oct**	**29-Oct**	**13-Nov**	**Total**	**Index**
Scheduled Liberty	30	30	30	30	30	30	30	30	30	30		
Days at Liberty	28	31	27	29	29	28	30	28	27	29		
Snug Harbor												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	20	23	1	0	0	0	2	0	0	46	
Mean Scallops/Bag	0.0	3.3	3.8	0.2	0.0	0.0	0.0	0.3	0.0	0.0		7.7
Mean Size (mm)	0.0	2.2	3.4	2.8	0.0	0.0	0.0	1.9	0.0	0.0		
Strawberry Point												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	4	9	3	2	2	2	4	0	0	26	
Mean Scallops/Bag	0.0	0.7	1.5	0.5	0.3	0.3	0.3	0.7	0.0	0.0		4.3
Mean Size (mm)	0.0	3.4	2.7	4.3	2.1	3.9	2.0	2.1	0.0	0.0		
Spawner Sanctuary												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	0	17	2	0	0	0	1	0	0	20	
Mean Scallops/Bag	0.0	0.0	2.8	0.3	0.0	0.0	0.0	0.2	0.0	0.0		3.3
Mean Size (mm)	0.0	0.0	2.5	4.4	0.0	0.0	0.0	1.7	0.0	0.0		
Smelt Brook Cove												
No. Bags	6	6	6	6	6	6	6	6	6	6	60	
No. Scallops	0	0	3	1	0	1	0	0	0	0	5	
Mean Scallops/Bag	0.0	0.0	0.5	0.2	0.0	0.2	0.0	0.0	0.0	0.0		0.8
Mean Size (mm)	0.0	0.0	4.1	4.3	0.0	1.5	0.0	0.0	0.0	0.0		
								Total bags			240	16.2
								Total spat			97	

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 from 2004 to 2008, with respect to estimated total number of broodstock each year.



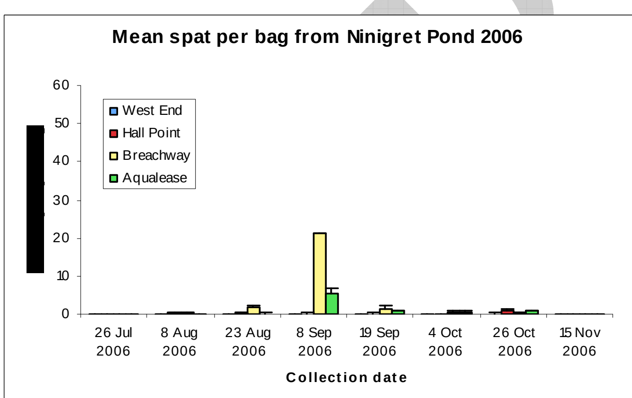
~ 19,500 Broodstock
(9,500 ± 5,600 free)
(10,000 caged)

Settlement Index = 32



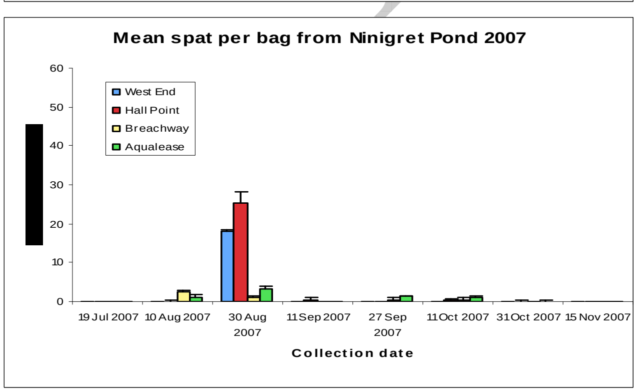
~130,000 Broodstock
(120,000 ± 50,000)
(10,000 caged)

Settlement Index = 137



~190,000 Broodstock
(190,000 ± 96,000 free)
(0 caged)

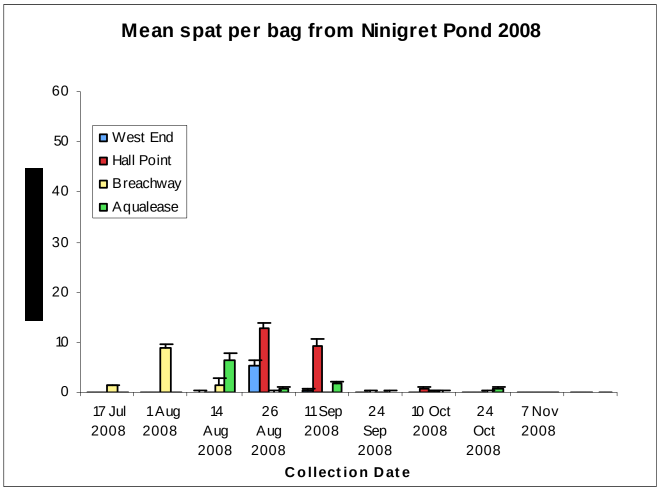
Settlement Index = 35



~63,000 Broodstock
(63,000 ± 45,700 free)
(0 caged)

Settlement Index = 56

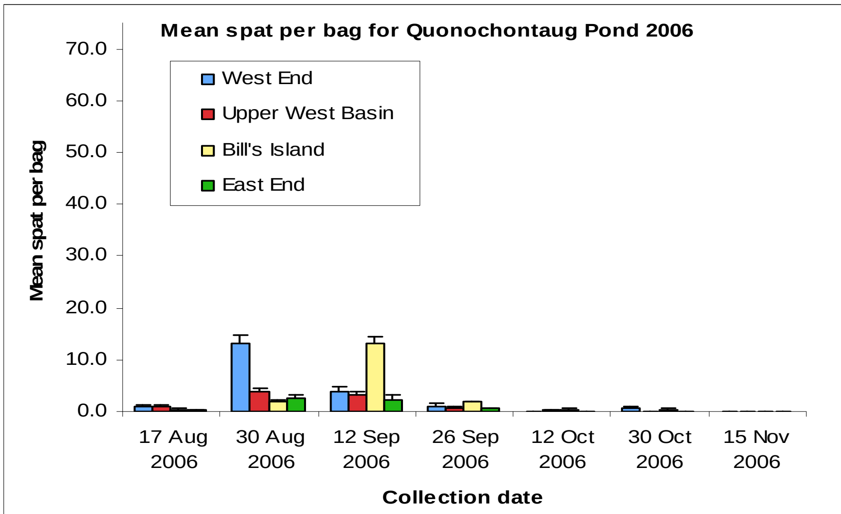
Figure 5. Continued



~288,000 Broodstock
(~288,000 ± 90,082 free)
(0 caged)

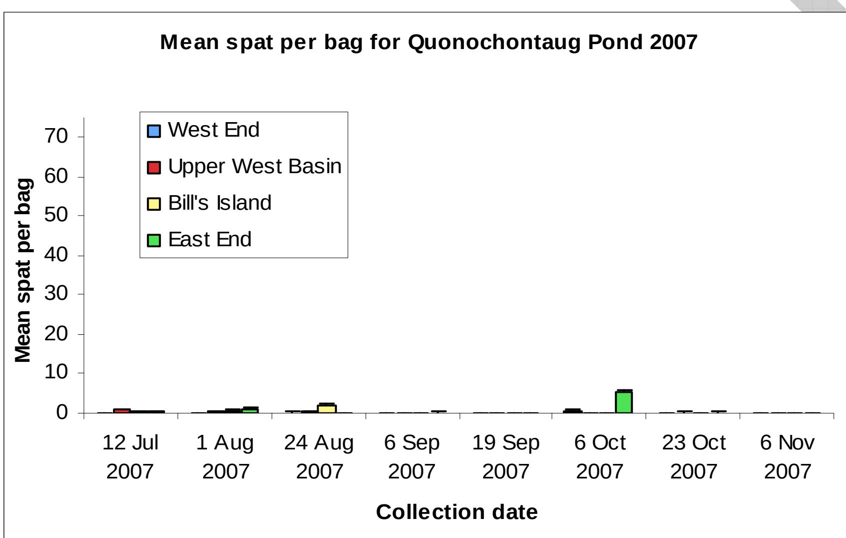
Settlement Index = 51.2

Figure 6. Comparison of the total number of scallop spat found at each of the four sites in Quonochontaug Pond and the seasonal settlement indices from 2004 to 2008, with respect to estimated total number of broodstock each year.



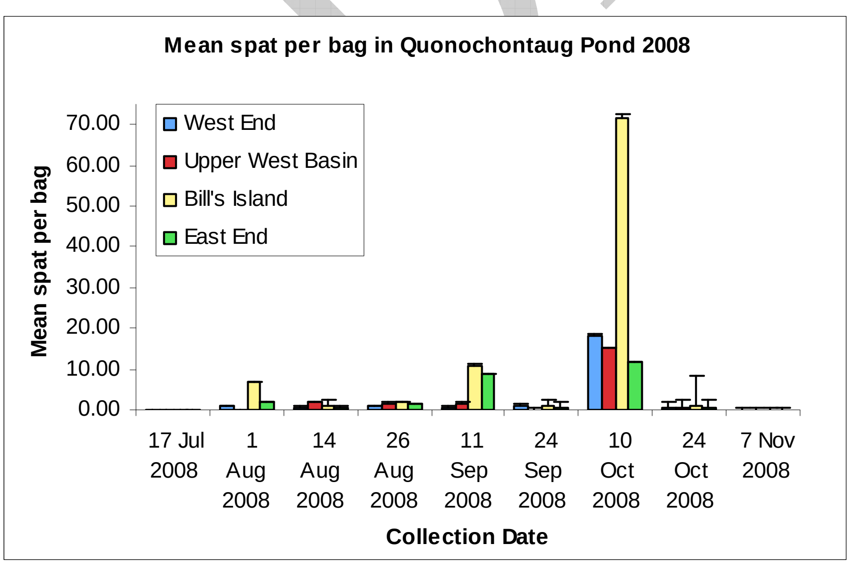
~ 23,500 Broodstock
(3,500 ± 2,700 free)
(20,000 caged)

Settlement Index = 50



~ 18,200 Broodstock
(11,100 ± 8,309 free)
(7,100 ± caged)

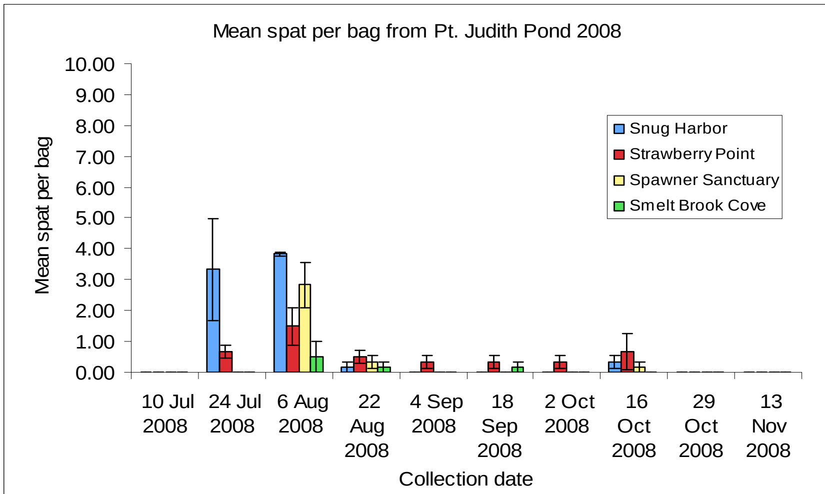
Settlement Index = 12



~ 5,358 ± 4,162 Broodstock
(5,358 ± 4,162 free)
(0 caged)

Settlement Index = 162.7

Figure 7. Total number of scallop spat found at each of the four sites in Point Judith Pond in 2008 and the seasonal settlement index with respect to estimated total number of broodstock.



~ 50,600 Broodstock (~30,490 ± 22,839 free) (20,100 caged)

Settlement Index = 16.2

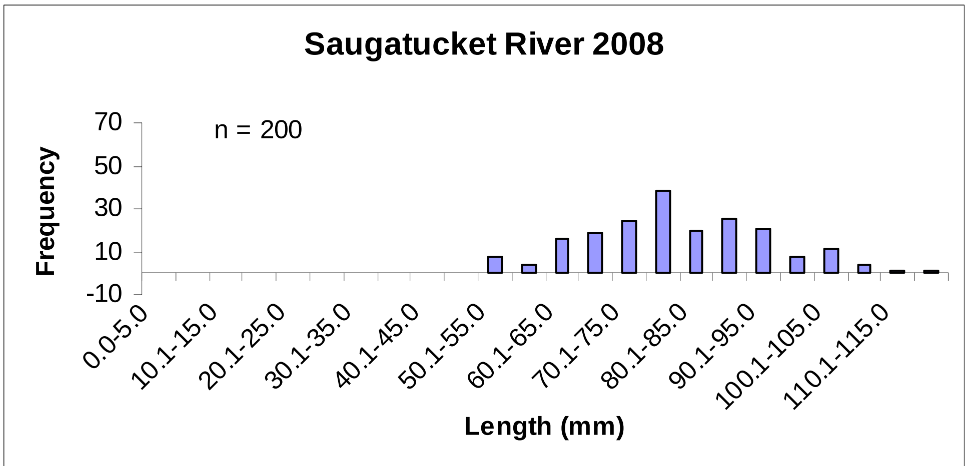
Table 3. Results of 2008 surveys of oyster planting sites seeded in 2003, 2004, 2005 and 2006.

Site	No. Quadrats	Total No. Alive surveyed	Mean No. Alive (m2)	SE	Seeded Area (m2)	Estimated Total Live	SE	% survival 2007-2008
Saugatucket	50	200	4.00	0.62	2,048	8,192	1,273	25
Smelt Brook	50	471	9.42	1.31	2,016	18,991	2,644	36
Bissel ch. (closed)	50	823	16.46	2.90	2,652	43,652	7,678	47
The Cove	50	191	3.82	0.88	3,317	12,671	2,928	20
Potter	50	152	3.10	1.41	3,324	10,311	4,697	19

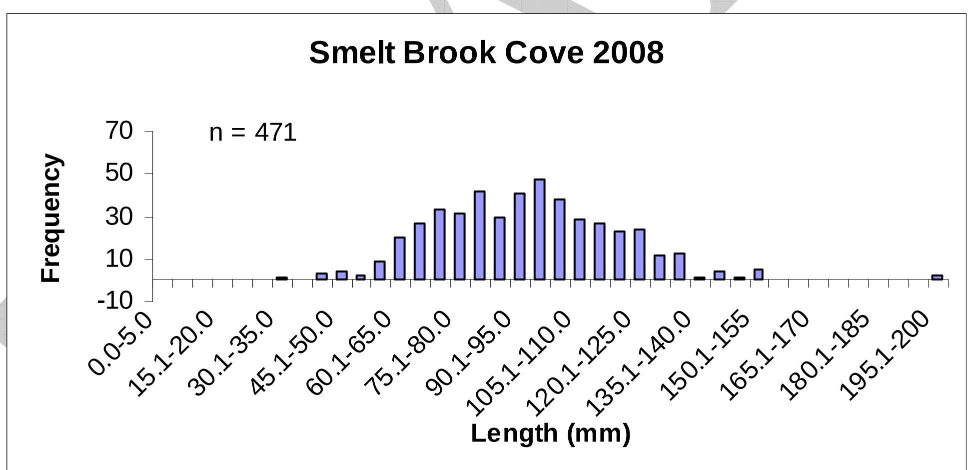
[1]Bissel Cove Deep was seeded in 2004.
[2]Bissel Channel was seeded in 2003 and 2004.
[3]The Cove and Potter Cove were seeded in 2003, 2005 and 2006.
[4]Bissel Channel (closed to fishing) was seeded in 2006.
[5]Smelt Brook Cove and Saugatucket River were seeded in 2003, 2004, 2005, and 2006.

Figure 8A-E. Size distribution of total oysters seeded in five planting sites from 2003-2006. (See Table 3 for years each site was seeded)

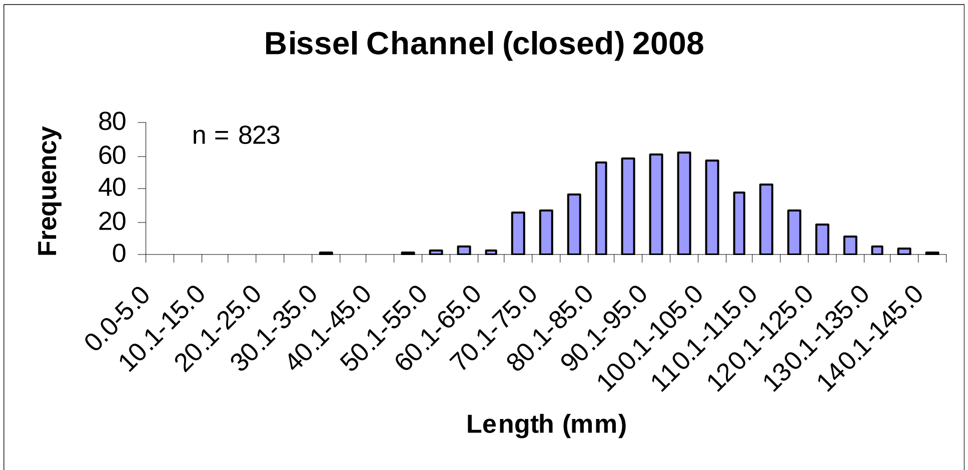
A.



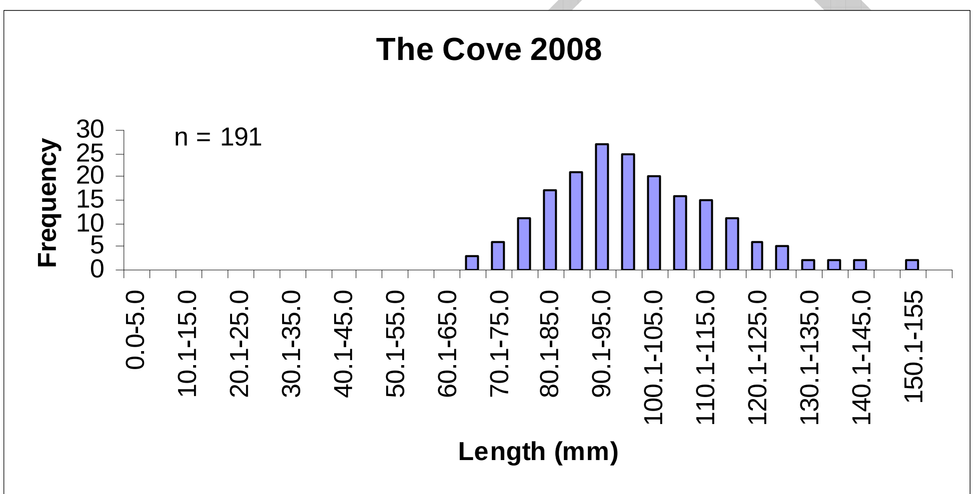
B.



C.


Bissel Channel (closed) 2008
n = 823
Frequency
0
20
40
60
80
0.0-5.0
10.1-15.0
20.1-25.0
30.1-35.0
40.1-45.0
50.1-55.0
60.1-65.0
70.1-75.0
80.1-85.0
90.1-95.0
100.1-105.0
110.1-115.0
120.1-125.0
130.1-135.0
140.1-145.0
Length (mm)

D.


The Cove 2008
n = 191
Frequency
0
5
10
15
20
25
30
0.0-5.0
10.1-15.0
20.1-25.0
30.1-35.0
40.1-45.0
50.1-55.0
60.1-65.0
70.1-75.0
80.1-85.0
90.1-95.0
100.1-105.0
110.1-115.0
120.1-125.0
130.1-135.0
140.1-145.0
150.1-155
Length (mm)

E.

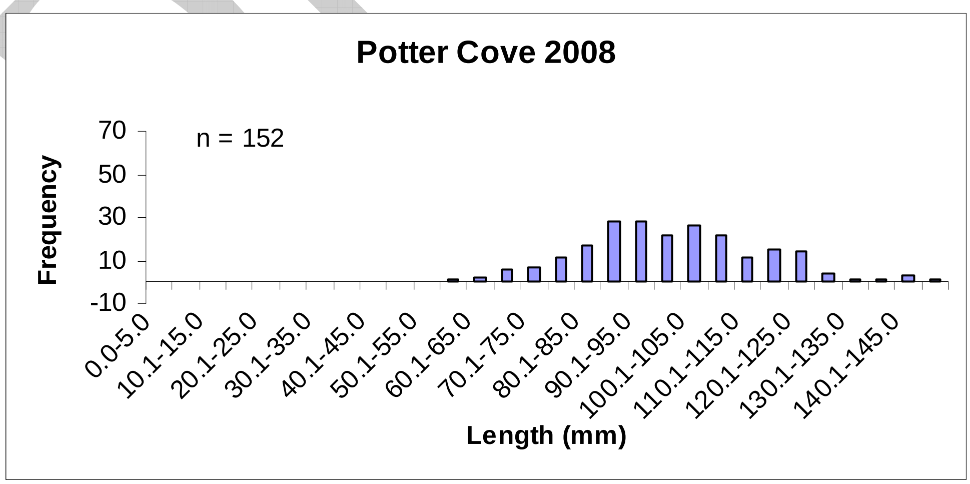

Potter Cove 2008
n = 152
Frequency
-10
10
30
50
70
0.0-5.0
10.1-15.0
20.1-25.0
30.1-35.0
40.1-45.0
50.1-55.0
60.1-65.0
70.1-75.0
80.1-85.0
90.1-95.0
100.1-105.0
110.1-115.0
120.1-125.0
130.1-135.0
140.1-145.0
Length (mm)

Figure 9. Length frequency of sampled oysters from the 2008 cohort raised in the floating upweller system. 250 individuals sampled from each size class. N = 1000.

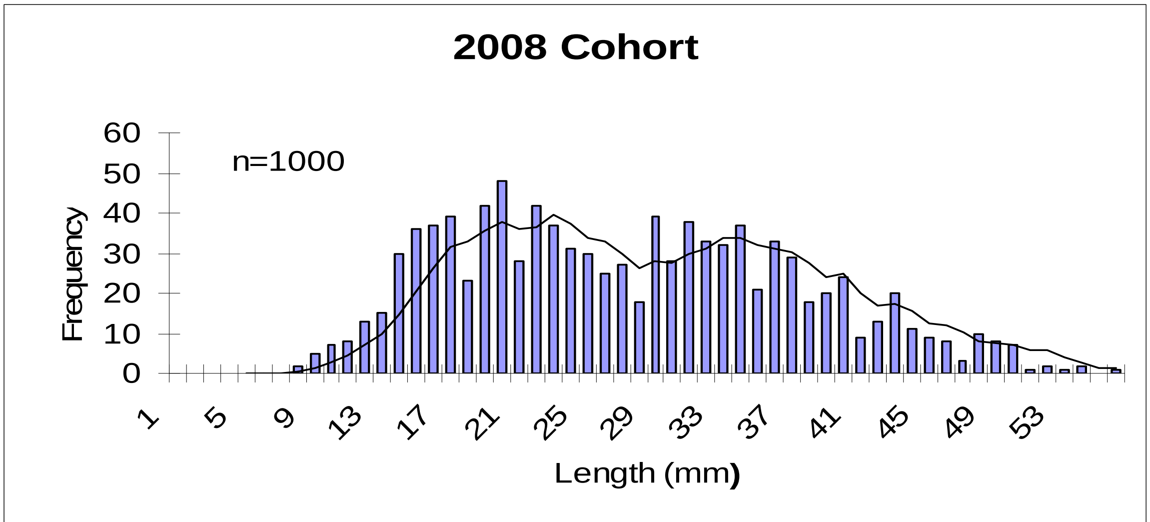


Table 4. Summary of the percent prevalence of *Perkinsus marinus* at each oyster restoration site from 2004 to 2008.

	2004		2005		2006		2007		2008	
Site	% prevalence	Makin index	% prevalence	Makin index	% prevalence	Makin index	% prevalence	makin index	% prevalence	makin index
Saugatucket	68	2	100	4	100	5	100	2	100	4
Smelt Brook	86	3	100	3	100	4	92	2	100	3
Bissel ch.	0	0	11	1	10	1	NA	NA	NA	NA
Bissel ch. closed	NA	NA	NA	NA	NA	NA	79	1	100	3
The Cove	13	1	60	1	40	1	100	2	NA	NA
Potter	14	1	24	1	0	0	92	1	NA	NA

Table 5. Mean Length of size classes and estimated total number of oysters prior to seeding, from 2008 cohort raised in floating upweller system.

Size Class	Length (mm)	SE	Estimated number	SE	% of total
Extra Large	38.23	0.49	105,019	7,268	10
Large	31.51	0.33	123,136	4,577	11
Medium	22.97	0.26	292,659	9,555	26
Small	15.43	0.19	583,649	11,876	53
Total			1,104,463	33,277	100

Table 6. Estimated number of oysters seeded at each restoration site in 2008.

	Extra Large	SE	Large	SE	Medium	SE	Small	SE	Total	SE
Saugatucket	26,254	1,817	30,784	1,144	73,164	2,389	145,912	2,969	276,114	8,319
Smelt Brook	26,254	1,817	30,784	1,144	73,164	2,389	145,912	2,969	276,114	8,319
Bissel ch. closed	52,509	3,634	61,568	2,289	146,329	4,778	291,824	5,938	552,230	16,639
Total	105,017	7,268	123,136	4,577	292,657	9,555	583,648	11,876	1,104,458	33,277

Figure 10. Locations of oyster restoration sites and oyster spat collectors in Pt. Judith Pond in 2008.

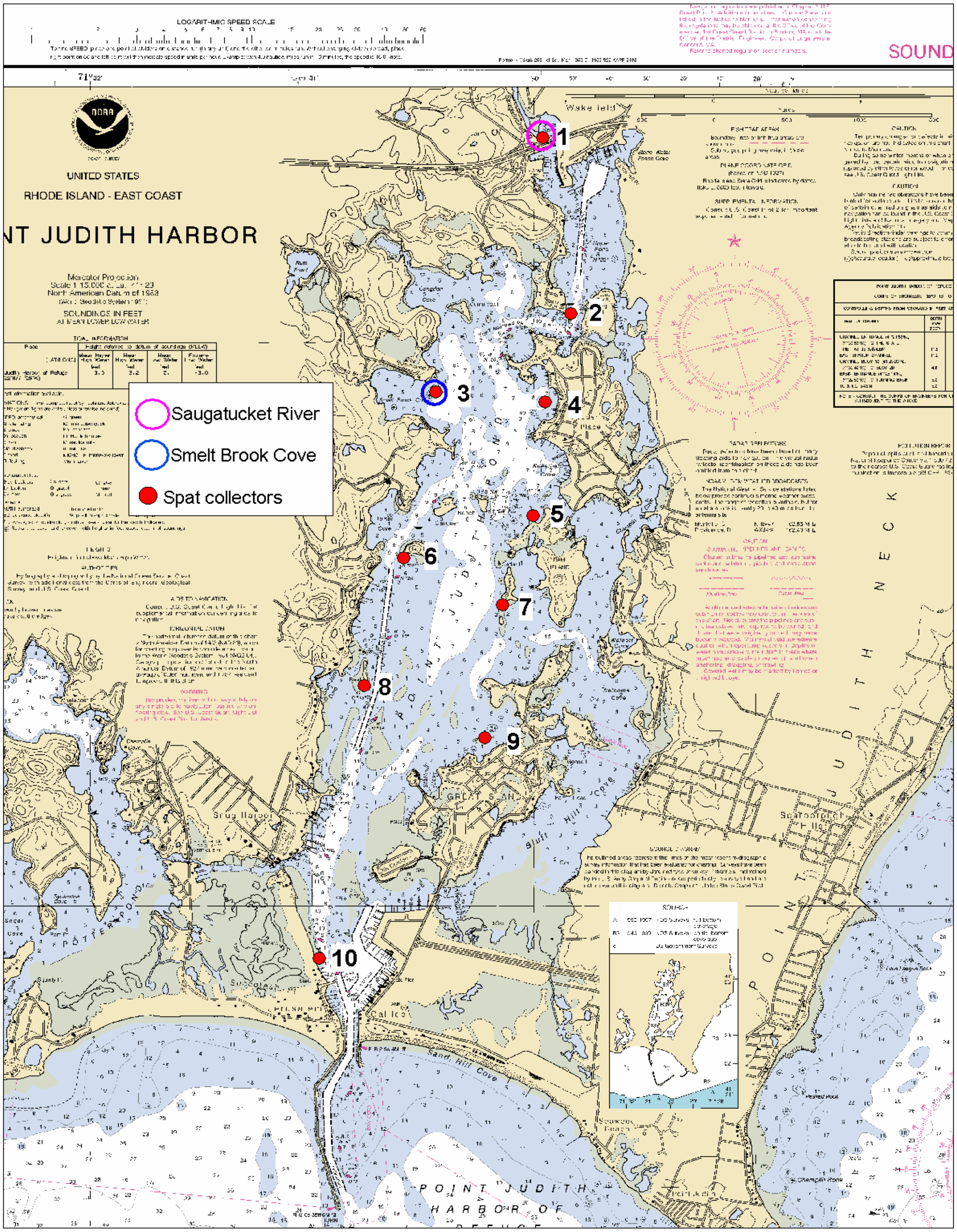


Figure 11. Artificial oyster spat collector used in 2008.

Surface float

ADPI mesh bag filled with surf clam valves. Bag suspended in mid water column.

Cinder block used as mooring.

Figure 12. Average condition index in Smelt Brook Cove and Saugatucket River in 2008. Five samples taken per date at each site. N = 150.

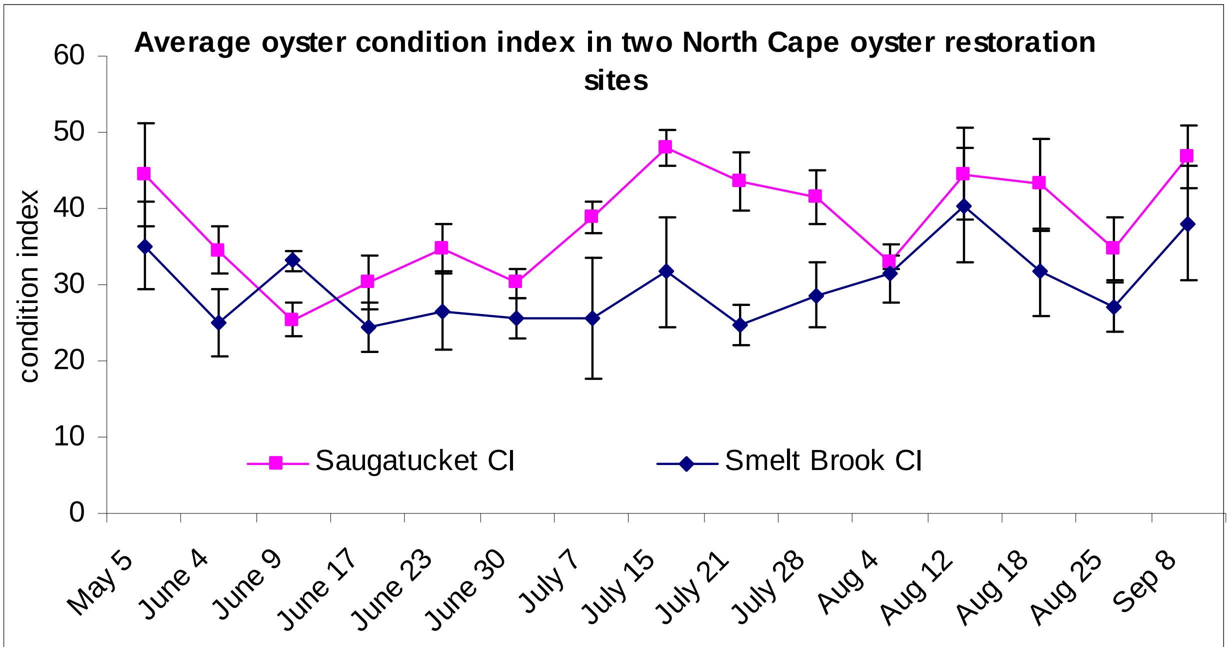


Figure 13. Oyster larvae abundance in Smelt Brook Cove and Saugatucket River in 2008. Larval abundance computed on a logarithmic scale.