North Cape Shellfish Restoration Program
2005 Annual Report

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

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Acknowledgements

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Cover photograph, clockwise from top left. Bay scallops collected during Ninigret Pond surveys, three year-classes of seeded oysters collected from Pt. Judith Pond, and seeded quahogs collected from Quonochontaug Pond.

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2005 *North Cape*
SHELLFISH RESTORATION PROGRAM

Executive Summary

North Cape restoration efforts by State and Federal Trustees continued to move forward in 2005 to address the natural resource injuries resulting from 828,000 gallons of heating oil released into Block Island Sound during the 1996 *North Cape* 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 bivalves by implementing projects targeting three species. The multi-year Program, with field operations beginning in 2002, includes enhancing quahog (*Mercenaria mercenaria*), and restoring bay scallop (*Argopecten irradians*) and eastern oyster (*Crassostrea virginica*) populations to Rhode Island waters. The goals of the Shellfish Restoration Program are to restore lost shellfish wet-tissue biomass (due to direct loss and foregone production), and lost ecological services through the restoration of bivalve populations.

The 2005 bay scallop projects included follow-up monitoring of the abundance of scallops in Ninigret Pond. These scallops represent the survivors from a spat-fall that was recorded in Ninigret Pond in the fall of 2004 and produced by Program-supplied broodstock. A bay scallop spawning sanctuary was also maintained in Ninigret Pond in 2005, and stocked with commercial hatchery-reared broodstock. The recruitment of juvenile bay scallops to this pond was monitored using artificial 'spat' collectors. The scallop spawner sanctuary proved to be a cost-effective method of enhancing recruitment to the pond. The late season spat-fall recorded from the spat bags in 2004 developed into an estimated 132,000 broodstock principally in the western arm of Ninigret Pond during the summer of 2005. These broodstock, combined with an additional 10,000 in the spawner sanctuary produced substantial mid and late-season spat-falls, a result that bodes well for 2006. Aspects of the scallop program formed the basis of one University of Rhode Island's Coastal Fellows research project. A laboratory experiment was conducted in collaboration with the USEPA's Atlantic Ecology Division to test the tolerance of juvenile scallops to low oxygen events reported from Ninigret Pond. Results indicated that juvenile scallops are tolerant of low oxygen levels of a diurnal nature that have been recorded in Ninigret Pond.

The 2005 oyster projects included an expanded remote setting of oyster larvae to produce disease-free oyster spat for subsequent nursery grow-out and release to selected sites. Survivorship and growth of the oysters released in 2003 and 2004 was also monitored. A total of 1.4 million oyster seed were produced in 2005 to supplement the approximately 0.5 million oysters released in each of 2003 and 2004. The growth, survival and disease profile of the 2003 and 2004 oysters formed the basis of a second Coastal Fellows research project. Oysters appeared tolerant of the Dermo parasite at the levels observed in the field, where the most productive sites also showed the highest incidence of disease. Settlement collectors were deployed to monitor recruitment in the area of the restoration

sites, but the most positive measures of recruitment came from the population monitoring through dive surveys.

The 2005 quahog projects included the purchase and grow-out of disease-free commercially-produced quahog seed, and continued nursery grow-out of 2004 quahog seed prior to release into sanctuary areas in two coastal salt ponds. Bottom grow-out of the second year quahogs was compared to quahog growth results from the floating upweller system. The upweller produced much higher survival and slightly better growth, but demanded a higher investment of staff time. Experiments to assess the growth and mortality of quahogs released during 2004, at two different densities and three size classes, were sampled. Results indicate an increasing survival of seeded quahogs up to a size of 16mm to 22mm. Survival was also consistently higher at the lower seeding density of 10 m^{-2}. Overall survival of quahogs seeded in 2004 varied between ponds with 5% survival in Quonochontaug Pond and 33% survival in Ninigret Pond.

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Overview of Program

The 2005 *North Cape* Shellfish Restoration Program consisted of restoration projects targeting three bivalve species: the Bay Scallop, Oyster and Quahog Projects. Each project was designed to be compatible with, and enhance the ongoing restoration efforts for that shellfish species in Rhode Island. The Bay Scallop Projects included survivorship surveys of the pond selected for the caged bay scallop spawner sanctuary in 2004, maintenance of the caged spawner sanctuary in 2005, monitoring the recruitment of bay scallop spat, and the completion of a URI Coastal Fellows project to assess the susceptibility of juvenile scallops to low oxygen events. The Oyster Projects included oyster remote setting, grow-out and planting of oyster seed, monitoring of oyster release sites established in 2003 and 2004, oyster disease surveys and a second URI Coastal Fellows project to assess oyster growth and survival. The Quahog Projects consisted of the second year of grow-out of seed purchased in 2004, monitoring to assess survival and growth of quahog seeded at three different size classes at two different release densities, the purchase and first year of grow-out of a new cohort of quahog seed, and comparing the success of bottom grow-out of second year seed compared to floating upweller grow-out.

I. Bay Scallop Projects

1.0 Introduction

The South County salt ponds have historically provided a valuable bay scallop resource for Rhode Island fisheries. Recent environmental changes in the salt ponds, both natural and anthropogenic, have likely contributed to the significant decline of these native scallop populations. Some of the environmental factors affecting scallop survival include: increased sedimentation at the pond openings reducing tidal exchange, increased pond use for recreational activities causing increased water column turbidity, and increased release of nutrients causing excess algal growth (Hinga *et al.* 1991, Short *et al.* 1996). Eelgrass beds, once abundant in the ponds and an important structural component for bay scallop habitat, have been substantially reduced due to increasing water temperatures, turbidity, and excess epiphytic algal growth (Short and Neckles 1998). Lastly, overfishing and brown tide events 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 20 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), in an attempt to re-establish an effective breeding population for the 2004 season (Hancock *et al.* 2005). In spring 2004, the ponds were surveyed to estimate the total abundance of the surviving scallops. The number of scallops in all ponds was low (Hancock *et al.* 2005). Ninigret Pond had the highest number of surviving scallops, estimated to be 9,300 and these were primarily in the western area of the pond. Diver observations of post release scallops suggested high mortality due to crab predation (Holly *et al.* 2005). As a result of the low survival of the seeded scallops, the focus of the scallop project was shifted to establishing a 'caged spawner sanctuary' in Ninigret Pond, where broodstock could be protected from predation within mesh cages to minimize mortality and maximize their reproductive output.

Measures of the relative abundance of scallop spat settling from the larval stage can be used as an indicator of the success of the spawner sanctuary and the scallop restoration project overall (Coleman 1988, Tammi *et al.* 1997). The settlement of scallop spat in Ninigret Pond has been monitored using artificial spat collectors or spat bags (described in Hancock *et al.* 2005), collected and replaced regularly throughout the season, since 2004.

Changes to the physical and chemical characteristics of Rhode Island's coastal salt ponds have increasingly become a cause for concern during the last 20 years (Lee and Olsen 1985, Short and Nekles1998). It is possible that these environmental 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 (K. Ford pers. comm.). The occurrence of periods of low dissolved oxygen suggests this is a potential limitation to the success of scallop populations.

1.1 Bay Scallop Surveys

Introduction

Bay scallops are a short-lived species that generally only survive for two years, one year of growth and a second year in which they reproduce (Sastry 1970). As a result the scallops seeded into Ninigret Pond in the fall of 2003 would no longer have an appreciable effect on the 2005 survey, and the seeding areas were removed as strata within the survey design. Conducting the surveys early in the season meant that the scallops settling in 2005 would not yet be large enough to be detected by divers. As a result, the 2005 scallop surveys quantified the survival of juveniles recorded from the spat bag monitoring in 2004.

Objectives

The objectives of the 2005 bay scallop surveys were to determine the abundance and spatial distribution of scallops entering their second season in Ninigret Pond.

Methods

The 2005 scallop surveys were conducted as stratified random transect surveys in July and August. Stratification was by habitat type, as determined using information from previous habitat surveys (Constas et al. 1980, Mapcoast website, pers. obs.) and included sand/gravel, generally in the shallower areas (<6ft mean low water), and silt/mud, typically in the deeper areas (>6ft MLW).

Randomized transect locations were generated using GIS software to create a grid over each survey stratum (Figure 1). Each grid intercept was numbered, and intercept numbers were randomly selected to define the starting points for each survey transect. To obtain a random distribution of transect starting points, it was necessary to generate at least 3 times as many potential start points, (grid intercepts) as transects. The grid size was 0.1 x 0.1 minutes of latitude and longitude for all three survey strata in Ninigret Pond. In the western basin of Ninigret Pond where surveys were conducted (41° 22.0' North latitude), the width (E-W) of each 0.1 minute grid was 141.6m and the length (N-S) of each grid was 185.2m. GIS software was used to convert each stratum into polygons and get accurate estimates of the area of each stratum and total pond area. Survey strata varied in size from 228,160 m^2 to 1,748,259 m^2. The total area surveyed was 4,211,724 m^2. Each strata was sampled using 12 randomly selected transects. Survey transects were laid out in a north-south orientation.

Mature scallops found in Ninigret Pond during 2005 scallop surveys

Each transect was 50m long, made of a weighted nylon line anchored at each end, with a buoyed line at each end to mark the transect location at the surface. A pair of divers each searched a 1 m strip on either side of the transect line, resulting in a $100m^2$ area surveyed per transect. Divers carried a 1m measuring bar to determine accurately if scallops were within or outside 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

There were 12 transects surveyed in each of three strata in Ninigret Pond, a total survey area of $3{,}600m^2$. The highest number of scallops was found in Area 1 (Table 1), the northwestern arm of the pond (but excluding Fosters Cove), where the estimated total population was 57,370. The total population estimate for Area 2, the central west arm, was 30,853, and the estimated population for Area 3, the southwestern arm, was 33,620 scallops. The estimated abundance in Ninigret Pond in 2005 was 121,843 scallops (±50,600), resulting in a 1280% increase over the abundance estimate for 2004. The mean size of sampled scallops was 40.9mm (±0.6). Figure 2 depicts the size distribution of scallops found in 2005 Ninigret Pond scallop surveys**.**

Discussion

The 2005 survey did not include the areas of Ninigret Pond other than the western basin, where the bulk of the scallops and settling spat were recorded in 2004. Fort Neck Pond, the central basin of Ninigret Pond and Foster Cove were included in the 2004 survey but no scallops were collected. Consequently, these areas were dropped from the 2005 survey design. The settlement of scallop spat was monitored in the central basin of Ninigret Pond in 2004, and spat were collected, however, their abundance was low compared to the abundance recorded in the western area. Any scallops resulting from the spat fall in these additional areas of Ninigret Pond were not included in the 2005 survey. Thus, the extrapolation of total scallop abundance in Ninigret Pond for 2005 was a minimum estimate.

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), suggesting that enhancing the larval supply is a priority for restoration. Habitat and fishing history assessments conducted in 2003 (Holly *et al.* 2004) identified several regions of Ninigret Pond as suitable candidates for scallop release. These areas were seeded with scallop broodstock in the fall of 2003. Surveys in 2004 revealed low survivorship of the seeded scallops, although Ninigret Pond produced the highest survival of the four ponds seeded in 2003. A caged spawner sanctuary in Ninigret Pond was adopted as an alternative approach to the direct seeding of scallops. A caged 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.

Objective

The objective of the caged spawner sanctuary project was to increase the recruitment of bay scallops to Ninigret Pond by using protective mesh spawner cages to decrease predation rates on the scallop broodstock.

Methods

In 2005, *North Cape* staff deployed and maintained 28 wire mesh cages containing 10,000 adult bay scallops in Ninigret Pond. Cages were deployed on June 10, 2005 and were monitored periodically until retrieval in November. Cages were approximately 75cm x 75cm made of 5cm (2 inch) plastic coated wire mesh. Four tiers in each cage held four plastic mesh 13mm (1/2 inch) bags, each containing ~380 mature, hatchery-reared 1+ year class scallops. The scallop spawning sanctuary was located at Hall Point (41^{o} 21.37'N, 71^{o} 40.00'W) in an area with depth of ~1.5m at MLW (Figure 3). Site location was based on suitable habitat, estuarine flow dynamics, historic scallop production, and boat traffic in Ninigret Pond. A permit for the facility was issued by Rhode Island's Coastal Resources Management Council. A service platform was built for deployment and retrieval of the spawning cages. Spawning events were determined by analysis of four spat collector arrays placed in the vicinity of the spawning cages and three other locations in the pond.

Results

A total of 10,000 adult bay scallops were placed in the cages of the shellfish spawning sanctuary at the start of the potential scallop spawning season. The scallop broodstock were in their second year and not expected to live beyond the 2005 season. The survival rate by the end of August was 48.9% (±3.4%SE). When the cages were removed in December, 4.2% (±0.7%SE) of the broodstock scallops remained alive. Analysis of the spat bags deployed in the area indicated an initial spawning in mid July. Scallop spat were collected continuously between July and November in Ninigret Pond.

1.3 Monitoring Recruitment: Bay Scallop Spat Collection

Introduction

The *North Cape* Scallop Restoration Project aims to establish self-sustaining populations of bay scallops in Rhode Island's South County salt ponds. To demonstrate the performance of the project it is necessary to monitor the abundance of scallops in the ponds targeted for restoration. Monitoring the relative abundance of settling spat provides an indicator of the success of the larval and post-larval life history stages.

Monitoring recruitment also provides the ability to relate the abundance of spat to the abundance of mature scallops the subsequent year. This relationship provides the basis for using settlement measures to predict the abundance of the mature year class one year in advance.

Objectives

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

Methods

Spat collector arrays were deployed at four study sites in Ninigret Pond and monitored between June and November 2005 (Figure 3). Locations were selected to provide information on the spatial distribution of scallop settlement. Array 1 was located off Hall Point in the vicinity of the caged spawner sanctuary (41° 21.37' N, 71° 40.00' W) which housed ~10,000 broodstock. Spat bag array 1 was moored in ~ 1.2 to 1.5m water depth. Array 2 (West End) was located in the west end of the pond (41° 21.22' N, 71° 41.43' W) in ~ 1.2 to 1.5m water depth. This site was in the portion of the pond where the majority of the free broodstock that survived from the 2003 release were located. 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 ~1 to 1.5m water depth. Array 4 (Breachway) was at the entrance to the Charlestown Breachway (41° 21.82' N, 71° 38.62' W) in ~1 to 1.5m depth. Tidal exchange was most significant at this site, being in close proximity to the breachway with Block Island Sound.

Spat lines were deployed at each study site every second week, beginning in June. Each line consisted of 12 artificial spat collectors (42cm x 75cm with 0.75mm to 1mm mesh) stuffed with plastic mesh and rigged on 7.5m long-lines with 2 bags per float (Figure 4). Six bags were removed from each line after 4 weeks soaking (~30 days), and the remaining 6 bags remained for 8 weeks (~60 days soaking). Each bag was analyzed by rinsing the contents through a 1mm mesh sieve and collecting the scallops. With this method settlement was assessed on both the 30 and 60-day soak bags for all weeks except the first two weeks when only 30-day bags were collected, and the last two weeks, when only 60-day bags were collected. Studies were conducted over a 20-week period to evaluate scallop settlement patterns at the four spat monitoring sites.

Spat bag collection from Ninigret Pond

Results

The first spat lines were deployed on June 16, 2005 and the last line was deployed on September 27, 2005. The last 30-day bag was retrieved on October 18, 2005, and the last 60-day bag was collected 4 weeks later on November 15, 2005. A total of 336 artificial spat collectors were deployed on 8 lines at each of the four study sites. Of these, 320 were retrieved and yielded a total of 1,716 spat from all 30 and 60-day collections (Tables 2 and 3). The highest number of spat was recorded from the Breachway site (509 spat) followed by the West End (469) and the Aqualease (449) sites, all with similar total numbers of spat.

The highest total number of spat recorded from the spat bags deployed for approximately 30 days was from the West End site, followed by Hall Point, with the Breachway and Aqualease sites documenting fewer recruits (Table 2). In contrast, the total number of spat recorded from the bags deployed for approximately 60 days was highest at the Breachway and the Aqualease sites, followed by the West End and Hall Point sites (Table 3). Most of the difference was due to a strong, late season spat-fall, which was recorded after the last of the 30-day bags were retrieved on October 18th. The settlement recorded between October the 18th and November 15th was concentrated in the central basin, including the Aqualease and Breachway sites.

There is some temporal overlap between the collections indicated in Table 2. At all sites two lines of spat bags were deployed. For the 30-day collections, bags were deployed for approximately 30 days but alternate lines were collected approximately every 2 weeks. Functionally, this overlap is less than 2 weeks, as it takes several days for the surface of the mesh within each bag to accumulate a 'biofilm' and become attractive as a settlement substrate for scallop larvae (Parsons *et al.* 1993). The overlap between collections of bags that were deployed for 60 days was far more pronounced than for the 30-day collections.

Scallop spat found in spat bag during analysis

Mean spat per bag values provide a measure of recruitment standardized for variation in the number of bags retrieved at each collection. The major settlement events in the western arm of Ninigret Pond occurred between August 11th and 23rd as indicated by the mean spat per bag figures of 57.0 at the West End and 16.0 at Hall Point, on August 23rd (Tables 2 and 3). This early settlement was not nearly as pronounced in the central basin of Ninigret Pond, with mean spat per bag values of 2.2 and 1.8 at the Breachway and Aqualease sites, respectively. A second smaller settlement occurred between September 9th and 27th at all sites, except Hall Point (Table 2). The source of larvae to the pond (broodstock) were concentrated in the west end as free scallops (section 1.1), or at Hall Point in the caged spawner sanctuary (section 1.2), so the distribution of settling scallops recorded in the spat bags gives an indication of the dispersal of larvae throughout the system.

The August and September settlement events are also apparent in sequential size distributions of scallops from the 30-day bags at each site (Figure 5). The sequential size distributions for the 60-day bags allow the late season settlement to be separated from the carry-over effect of a single settlement recorded in multiple subsequent collections. For example, the settlement at Hall Point that was poorly recorded in the August 23rd collection (size class 0.1 - 2.0 mm only) can be traced through the September 9th and 27th collections (Figure 6). The October 18th collectors were deployed on August 23rd and, therefore, do not capture this settlement event. Similarly, the settlement captured in the August 23rd collection from the Breachway is easily traced through to the September 27th collection, where a second settlement event is evident in the recorded smaller size categories. This September settlement recorded is fully represented in the October 18th collection, and there was no subsequent settlement at this site. In contrast, the October settlement at the Aqualease site was not fully represented until November 3rd, and a subsequent settlement is evident in the small size categories recorded for November 15th. The recruitment from the West End is not as discrete, and it is likely that the settlement first recorded in the October 18th plot was augmented by subsequent settlement by November 15th.

The amount of settlement recorded in 2005 far exceeded the level measured in 2004 (Figure 7). The abundance of scallops in Ninigret Pond in 2006 is predicted to be proportionally higher than the estimated 2005 abundance.

1.4 Low oxygen tolerance of juvenile bay scallops

Introduction

In 2002 and 2003, the *North Cape* Shellfish Restoration Program released 2.75 million juvenile bay scallops (*Argopectin irradians*) into five Rhode Island coastal salt ponds. The highest survival rate after one year was just 1.6%. Bay scallops are considered to be sensitive to low dissolved oxygen concentrations (VanDam 1954, Voyer 1992). Stressful diurnal low oxygen levels are considered to be a potential cause of high mortality in the released bay scallops. The adverse effect of low oxygen is potentially exacerbated by the presence of predators if they stimulate an escape response and increase the oxygen demand.

The U. S. Environmental Protection Agency's (USEPA) National Health and Environmental Effects, Atlantic Ecology Division Laboratory houses state-of-the-art oxygen-stripping equipment, designed for experiments where fine control of dissolved oxygen concentrations is required. The *North Cape* Shellfish Restoration Program collaborated with the Scallop Habitat Modelling group at USEPA's Atlantic Ecology Division to investigate the tolerance of juvenile scallops to low dissolved oxygen conditions.

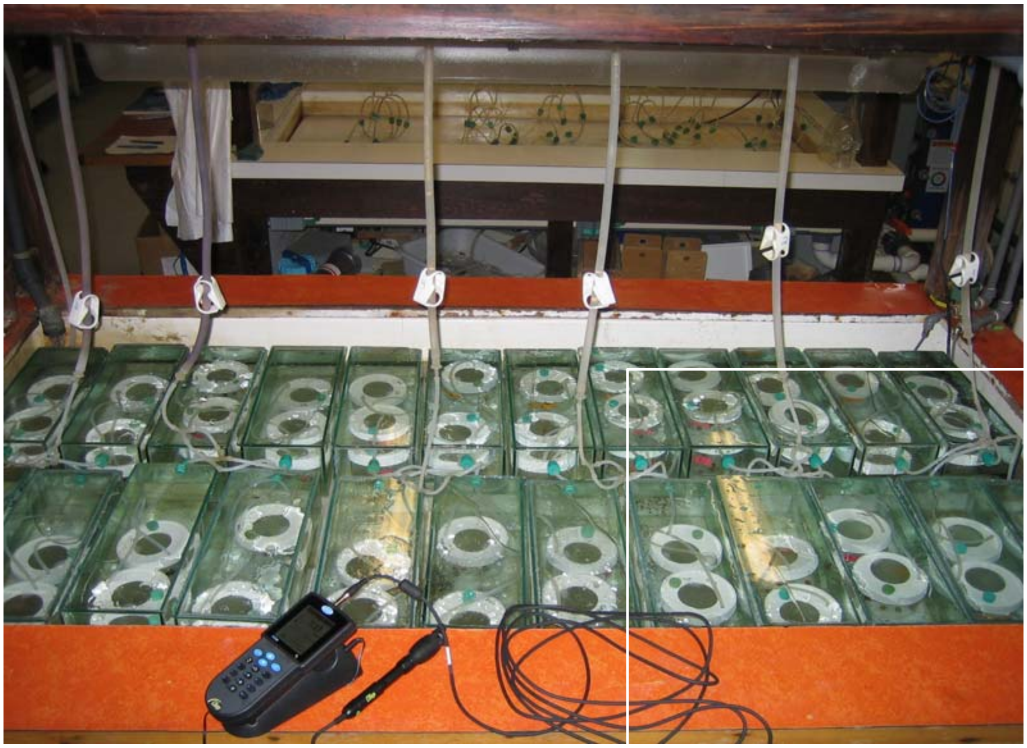
Objectives

The purpose of this study was to determine both the impact of low dissolved oxygen, and the combined impact of low dissolved oxygen coupled with predator stimulus, on juvenile bay scallop mortality rates.

Methods

The research was completed in two experiments using the USEPA's dissolved oxygen (DO) system to control the oxygen concentration of seawater in replicate experimental chambers. In the first experiment, six oxygen concentrations were tested with 8 replicate chambers of 500 ml capacity per treatment. Each replicate contained 10 scallops between 10mm and 20mm shell length. The experiment was run for 96 hours with dissolved oxygen concentrations tested twice daily, with both Winkler titration (Strickland and Parsons 1977) and a DO meter. Mortalities and scallop behaviour were also recorded twice daily.

For the second experiment, six chambers were used for each oxygen concentration treatment. Each replicate contained 10 scallops and was tested as in experiment 1. One sea star (Asterias forbesi) of 25 to 35 mm diameter was added to each of the 4 chambers, while predators were not added to the remaining 2 chambers, to serve as controls. In the second experiment, the cause of mortality was assessed either directly during the twice-daily observations or by the presence or absence of soft tissue in the shell if active predation was not observed.



Experiment 1. Six separate lines each containing sea water with a different DO concentration, each delivered water directly to eight experimental

Each chamber (500ml) had an individual tube delivering water.
Ten scallops were placed in each chamber.

Results

In the first experiment, testing the effect of oxygen concentration alone, only the lowest DO concentration (0.7 mg l^{-1}) produced high mortality rates. The other concentrations resulted in lower mortalities (Figure 8).

As in Experiment 1, the second experiment showed highest mortality rates in the lowest DO concentration (Figure 9). The combined effects of low oxygen and the presence of predators increased mortalities above the control levels at all oxygen concentrations

(Figure 10). At lower oxygen concentrations, mortality rates increased with the combined effect of predators and low oxygen. There was a declining trend in treatment mortalities to 2.1 mg l^{-1} (Figure 10) as the activity of the sea star predators was depressed by decreasing oxygen concentrations. Below 2.1 mg l^{-1}, bay scallop mortalities increased rapidly. As DO concentration further decreased, there was a decrease in scallop predator-mortality and increased non-predation mortality (Figure 11).

Sea star preying on a juvenile scallop in the laboratory experiment

Discussion

These controlled laboratory experiments aimed to determine the low dissolved oxygen tolerance of juvenile bay scallops, and to also assess the influence of predator presence on scallop mortality in low oxygen conditions. The lowest DO concentration showed the most distinct results, indicating that scallops can reasonably tolerate DO concentrations for brief time periods (two days) unless they fall below 2.1 mg l^{-1}. Below this threshold, scallop mortality is much more likely, and changes in behaviour are noticeable. Results indicate that predator presence is likely to increase mortalities when combined with low oxygen concentrations. Predation decreases with decreasing DO because sea stars become less active at lower concentrations, but at low concentrations, mortalities were higher in the presence of a predator than without the increased oxygen demand created by the escape response from a predator stimulus. DO concentrations of less than 2.1 mg l^{-1} have been recorded from Ninigret Pond (K. Ford pers. comm.), over several hours, during the pre-dawn low oxygen period of the diurnal DO cycle. Comparing these results with oxygen data collected from the RI coastal salt ponds, it is unlikely that diurnal low oxygen events in the ponds persist for long enough to cause a major impact on scallop populations in the pond habitats.

II. Oyster Projects

2.0 Introduction

The suitability of an area for oyster restoration is influenced by factors such as the substrate, hydrodynamics, fishing effort, and the presence and abundance of predators and diseases. These factors were carefully considered prior to selecting the restoration sites to be used by the *North Cape* Shellfish Restoration Program (Holly *et al.* 2004). Once candidate sites are selected, the approach to oyster restoration varies depending on the number of oyster larvae that are likely to be produced in the area to be restored, and the suitability of the habitat at the restoration site (Takacs *et al*. 2005). If sufficient broodstock to supply larvae are available around the restoration area, then restoration efforts tend to involve preparing suitable substrate to promote settlement. In Rhode Island, there are so few native oysters in the vicinity of the restoration sites that the broodstock must be supplied to generate the reproductive output to sustain recruitment to the population. A variety of candidate sites were available for restoration, and those with the most suitable existing substrate for settlement were chosen. Consequently much of the effort of the *North Cape* Shellfish Restoration Program has been directed toward introducing broodstock.

In 2005, the *North Cape* Shellfish Restoration Program sought to expand the use of "remote setting" as the first step in producing broodstock, a technique that has proven effective in the past (Jones and Jones 1988, Hancock *et al.* 2005, Kennedy 1996). Remote setting produces newly settled oysters from swimming eyed-larvae by securing eyed larvae from a commercial hatchery to the field location, then promoting the settling of the larvae to shell material, or cultch. The *North Cape* oyster project used bagged, weathered clam shell cultch as a substrate for setting larvae. The bags of cultch with newly settled spat were then carefully transferred to plastic trays with covers and placed in a nursery suspended on racks in the lower inter-tidal/sub-tidal zone for grow-out. Following approximately five months of husbandry in the oyster nursery, juvenile oysters were transported to selected locations and placed on the bottom to become broodstock and supply the larvae for subsequent recruitment.

Monitoring the success of the seeded oysters is a central component in understanding the dynamics of the restored population. It is also important to understand the factors that may impact the survival of the seeded oysters. These factors include the disease load endemic in the restoration site and the abundance and type of predators at each site.

The initial success of the potential restoration project can be gauged from the recruitment of spat produced by the broodstock supplied to each site. Monitoring spat fall can be achieved by sampling with spat collectors or by monitoring evidence of recruitment in the area of the restoration site.

Six locations where oysters were released in 2003 and 2004 were assessed using dive surveys in 2005. Site-specific information was collected to determine survival and growth rates of oysters seeded at each location. Samples were collected at each seeded site, as well as from two proposed future seeding sites, to monitor disease prevalence.

2.1 Oyster Remote Setting

Objective

The objective of the remote set is to provide large numbers of settled oyster spat, which can then be transferred into oyster nurseries for further grow-out and eventual transfer to oyster restoration sites.

Methods

Shell cultch material for the 2005 remote set was provided by Blount Seafood, Warren, RI and Fairtide Shellfish, New Bedford, MA. The shell cultch consisted almost entirely of surf clam (*Spisula solidissima*) shells. The weathered shells were broken up to provide shell fragments within a uniform size range of about 4 to 7cm. A 38mm (1.5in.) mesh sieve was used to sift out small shell fragments that decrease the void space between fragments. The cultch was placed into tubular polyethylene net bags and sealed at both ends with hog rings. Using shell cultch without the small size fragments promotes water flow through the bags and does not promote large numbers of oysters setting on the outer fragments, and thus a potentially high subsequent mortality due to competition. It provides a shell bag that packs sufficiently loosely to allow water, and the entrained larvae, access to the inside of the bag during setting. A total of 1,130 shell bags, each containing approximately 8 to 10 litres of shell cultch gross volume, were assembled. Bags went through three cycles where they were soaked in holding tanks, power-washed to remove biological debris, and air-dried in preparation for remote setting.

Shell bags containing cultch and oyster spat

Eyed oyster larvae were purchased from Muscongus Bay Aquaculture Inc., Bremen, ME, and transported to the Rhode Island Department of Environmental Management (RIDEM) Coastal Fisheries Lab (CFL), Jerusalem, RI on ice, and introduced into two closed-circulation setting tanks containing cultch bags. This process was repeated for three separate remote sets at the CFL. The swimming eyed-larvae settled onto the cultch within 48-72 hours of being introduced into the tanks using previously developed methods (Castagna et al. 1996). The larger setting tank was 3.0m x 1.5m x 0.8m, and contained 216 bags arranged on a PVC rack with two levels, and each level supporting two layers of shell bags. Dimensions of the smaller setting tank were 3.7m x 1.25m x 0.5m. This tank contained a rack with only one level supporting a total of 162 bags in two layers. Aeration pipes were placed under the racks on the bottom of each tank to provide circulation and aeration.

Results

During the 2005 season, 3 batches of approximately 6 million larvae each were set to shell cultch. Upon arrival to the CFL, each batch was divided into two portions and approximately 3,400,000 eyed-larvae were introduced into the large tank, which contained 216 shell bags, and approximately 2,600,000 eyed-larvae were introduced into the small tank, containing 162 shell bags. The number of larvae put into each tank was proportional to each tank's total number of bags as well as its total volume, resulting in approximately 15,950 larvae/shell bag in the large tank and 16,000 larvae/shell bag in the small tank. The first remote set for 2005 took place on June 27, the second on July 11, and the third and final set on July 27. Larvae were fed a larval shellfish algae (Reed Mariculture, Campbell, CA) twice daily, the water changed daily, and water temperature was maintained at 24 ºC (Jones and Jones 1988). After being in the tanks for 48-72 hours, the spat settled onto the shell cultch and were ready to be transferred into the nursery in Pt. Judith Salt Pond, adjoining the CFL property. The number of settled spat was not determined until after the nursery grow-out phase due to the time that would be required to assess the abundance of spat measuring approximately 200µm.

CFL's tanks filled with cultch bags used for settlement of the eyed-oyster larvae.

2.2 Oyster Nursery

Objective

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

Methods

The 1,130 shell bags containing the eyed-larvae were placed in plastic trays (90cm x 90cm x 10cm). Each tray was lined on the bottom by 6mm mesh, and filled with six or seven shell bags. The bags were placed on 61 rebar racks (3m x 75cm x 45cm) at approximately the mean low water level at the CFL beachfront. During the grow-out period, the number of shell bags was reduced to 4 per tray as oyster spat grew and expanded in volume. At this time, the shell bags were opened and emptied directly into the trays to reduce over-crowding. During this process, the bags were also sampled to obtain a size distribution, the number of spat/shell fragment, and estimate abundance.

Floating Upweller Systems (FLUPSY's), or upwellers, are the industry preferred method of increasing oyster growth by increasing water flow and nutrient availability. A total of 44 shell bags containing spat were transferred from the remote setting tanks at the CFL to an upweller, located at Camp Fuller, in upper Pt. Judith Pond; 16 bags from the large tank of set 1, 12 bags from the small tank of set 1, and 16 bags from the large tank of set 2. The oysters in the upweller were cleaned weekly during the grow-out season to remove pseudofeces sediment and fouling.

Upweller bins filled with oyster spat from remote sets 1 and 2

To sample the nursery and obtain a size distribution and abundance estimates three trays from each tank, for each of the three sets, were selected from the nursery at random. From each of these eighteen trays, three bags were opened, the total volume of the contents was measured, and a sub-sample was taken. Each oyster in the sample from the first bag was measured to the nearest 0.1mm using Vernier calipers. Spat in the samples from the remaining two bags per tray were counted. Mean spat per bag (±SE) was calculated for each tank per set and extrapolated based on the total number of bags. Oysters grown in the upwellers were separated by tank and set number. The total volume from each tank per set was measured and three sub-samples taken. Again, oysters from one sub-sample were measured and the remaining two samples counted. Abundance estimates were extrapolated based on volume.

Results

In 2005, approximately 1,378,073 oysters were produced on 1,130 bags of shell. Set 1 produced 701,737 oysters with a mean survival of 11.7% from the eyed- larvae stage to the time of seeding. Set 2 produced 279,058 oysters with a mean survival rate of 4.7%; set 3 produced 397,278 oysters with a mean survival of 6.6% (Table 4). Size distributions for both tanks in each set are provided in Figure 12.

Floating upweller affixed to dock behind oyster nursery trays at the CFL.

The mean length of the oysters from sets 1 and 2 in the CFL nursery was 13.3mm. The mean length of the oysters in the upweller (comprised of spat settled in the tanks from sets 1 and 2 only) was 30.4mm (Figure 12). The oysters in the upwellers were provided greater access to food due to the high water flow through the upwellers, maintained by flow pumps. The upweller at Camp Fuller is located in an area of higher primary productivity than at the CFL which likely added to the improved growth of these oysters. Better nutrition resulted in longer, deeper, and rounder oysters than those found in the nursery at the CFL (Figure 13).

Discussion

The three remote sets conducted at the CFL in 2005 were highly successful with a 7.7% survival from eyed larvae to seeding. The sets were augmented by recruitment to the cultch in the nursery area after removal from the tanks, likely due to larger oysters in the nursery area remaining from past efforts of this Program (See discussion, below).

The 1,130 bags of cultch were the maximum number that could be accommodated in the nursery area, with the equipment available in 2005. To further increase the output of oysters, additional trays, racks, and extending the nursery area, would need to be arranged.

The size distribution plots for some sets show an abundance of oysters in the 1.0 - 5.0mm range (Figure 12). This was caused by a natural spawning event in the nursery at the CFL. Some small spat were observed to have settled on the shells of larger spat, indicating that a second set occurred after the shell bags were placed in the nursery. It is likely that oysters that had been lost from trays during the 3 previous years of the nursery operation produced the larvae settling in the nursery area, or possibly augmented by larvae from 2 oyster farms approximately 2 miles away. The spat are most evident in the size distribution plot from the small tank, set 2, as these bags contained the lowest numbers of remote set oysters. This recruitment, produced by accidental release of restoration oysters, is also evident in other length frequency plots, and acts to increase the number of oysters but lower the mean length of the cohort.

The efficiency of using floating upweller systems for grow-out can be seen from the comparison of mean size of the same group of oysters grown in the nursery and upweller (Figure 13). The increased growth is likely to translate into increased survival, as the oysters enter the first winter with a healthier energy reserve, and subsequently a potentially increased fecundity. This improved performance comes at the cost associated with increased service and maintenance. Oysters in the upweller require cleaning at least twice every three weeks during the season to remove biofouling and the buildup of foreign material and waste products.

2.3 Monitoring of Oyster Release Sites

Objectives

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

Methods

The six *North Cape* oyster restoration sites established in 2003 and 2004 were sampled using $1m^2$ quadrats. Using $1m^2$ quadrats was an effective strategy because of the small spatial scale and oyster density at the sites. Site boundaries were re-established using a hand held GPS and by diving to determine the extent of oyster coverage. Tethered floats were positioned on the periphery of the area to provide visual reference. The seeded sites were marked out in the same geometric shapes used for seeding, and the dimensions of each were re-measured using a 100m tape allowing the areas surveyed to be accurately calculated. Using these areas, the mean density of oysters sampled ($1m^2$ quadrats) was extrapolated to get an estimate of the total abundance (±SE) within each seeded site. All oysters sampled were measured to separate cohorts and to collect growth data. Quadrats were deployed from boats which traveled an approximate grid within the seeded sites, throwing quadrats to provide a haphazard distribution. Each quadrat was marked with a tethered float and divers or waders returned to the quadrats to collect all oysters for measuring.

Results

Between June and July 2005, dive teams using 1m² quadrats, surveyed 287m² at the six locations where oysters were released in 2003 and 2004 (Table 5). The Saugatucket River had the most live oysters; almost triple that of Smelt Brook Cove, and almost 4 times that of the channel at Bissel Cove: the two other sites that were seeded in both 2003 and 2004. The restoration site with the lowest number of live oysters was the deep site at Bissel Cove, the only restoration area that was found to contain oyster drills (*Urosalpinx cineria*), a voracious predator of oysters. The lower density in the channel at Bissel Cove may also reflect the fact that much of the area seeded was in an area open to shellfishing. The Bissel Cove channel location was selected to take advantage of the preferable substrate beyond the boundary of the closed fishing area, but the frequent turning of the substrate during quahog digging may have affected the survival of the released oysters.

The size distribution of the various cohorts sampled at each site was sufficiently discrete to allow visual separation of the cohorts with a high level of certainty (Figure 14). This allows analysis of survival and growth of the 2003 and 2004 cohorts independently.

An estimated total of 544,240 oyster spat were seeded in 2003. The abundance estimate in 2004 for all five 2003 restoration sites was 57,322, a 10.5% first year survival rate (Figure 15). The overall survival rate during the first year for the 2004 cohort, when measured in 2005, was 23.1%. The Saugatucket River had the highest first year survival rate for both the 2003 and 2004 cohorts. Potter Cove also showed a comparatively high first year survival of the 2003 cohort, but was not seeded in 2004. The first year survival of the 2004 cohort was uniformly higher then the survival of the 2003 cohort. The channel at Bissel Cove had the lowest first year survival of all sites seeded in 2003 and the second lowest survival among sites seeded in 2004. The deep site at Bissel Cove had the lowest first year survival for the 2004 cohort and was not been seeded in 2003.

Overall, the second year survival rate for the 2003 cohort was 64.2%. The lowest second year survival sites in the series were Potter Cove with 31% and The Cove-Portsmouth (The Cove) with 32% survival. The highest second year survival was the Saugatucket River at 121%. The channel at Bissel Cove showed a second year survival of 104%, while Smelt Brook Cove showed a 73% survival rate for the second season (Figure 16).

First year annual growth increments were higher in 2003 for all sites containing the 2003 and 2004 cohorts (Figure 17). Second year growth for the 2003 cohort was highest in Smelt Brook Cove with a mean growth increment of 29.9mm. The Saugatucket River site had the smallest growth increment at 8.2mm for the second year. The growth increment at Potter Cove was 18.9mm, the channel at Bissel Cove had an increment of 25.6mm, and The Cove had a mean growth of 16.4mm during the second year (Figure 18).

Discussion

Survival of seeded oysters is expected to be lowest in the first year after release. During this period there will inevitably be an incidental mortality due to seed oysters landing in a position on the substrate that is not favorable after seeding, Higher vulnerability to predators, and greater competition (White and Wilson 1996). There are a number possible of reasons for the substantially higher survival of the 2004 cohort than the 2003 cohort during their first year. Reasons may include environmental differences, such as the warmer winter in 2004/2005 than in 2003/2004. The conditions in the nursery may also have provided a more robust oyster in 2004 than in 2003. The cohorts were also of different genetic stock, the 2003 cohort being from a hatchery strain selected by the Aquaculture Research Corporation (ARC) in Barnstable, MA, while the 2004 cohort is from a 'Flowers' genetic line developed from many generations by Muscongus Bay Oyster Company in Bremen, ME.

It is apparent that the Saugatucket river site has the highest survival of the six sites seeded (Figure 15). It should be noted that the high first year survival of the 2003 seed at the Saugatucket River was due to the source of the oysters. These were singly grown oysters that settled in 2002 and were donated to the project by Moonstone Oysters Inc. in Pt. Judith, RI, early in the 2003 season at a mean size of 33.1mm. The very high survival of the 2004 cohort is likely due to recruits at this site being indistinguishable from the 2004 seed, and being included in the survey results. This recruitment would likely have been produced by the larger/older seed at this site. The larger and older oysters seeded in 2003 should have spawned in 2004. A settlement of these larvae in the restoration area would dramatically increase the apparent survival recorded in 2005 as seen in Figure 15. Smelt Brook Cove, Bissel Cove channel, and Potter Cove also produced good survival over the first year.

Examples of 2005, 2004, and 2003 oyster seed collected from the Saugatucket River restoration site in 2005.

The Saugatucket River, Smelt Brook Cove, and Bissel Cove channel also showed the highest second year survival (Figure 16). The survival values over 100% for the Saugatucket River and Bissel Cove channel sites indicate a high survival, probably approaching 100%, within the inevitably high sampling error associated with environmental experiments conducted at this scale. The error estimates have not been included in the survival plots because the compounding uncertainties make these difficult to interpret. Typical sampling errors (SE) for the estimates of total abundance used to derive the percentage survival are in the order of 26% (mean percentage error from Table 5.).

Atlantic oyster drills (*Urosalpinx cinerea*) are a highly effective predator of oysters (Kennedy 1996). The observation of drills actively preying on oysters at the Bissel Cove deep site, along with the lowest first year survival, suggests that the restoration efforts be discontinued at this site. The Bissel Cove deep site was the only one where oyster drills have been observed during the *North Cape* Project.

The comparison of first year growth (Figure 17) gives the opposite trend to the first year survival (Figure 15) with the 2003 cohort displaying a comparatively higher mean growth increment, but lower survival. This contradiction is not easily reconciled with an environmental explanation, and may support the explanation that varying genetic stocks have different growth and survival rates in the Rhode Island environment. The first year growth at the Saugatucket site was very high in the 2003 cohort but lowest in the 2004 cohort. Smelt Brook Cove and Bissel Channel have had consistently high growth for first and second year cohorts. The slow growth of the second year oysters at the Saugatucket River is consistent with this group being older and providing a substantial reproductive output in 2004.

2.4 Oyster Release

Objective

The objective of the oyster release project is to re-establish oyster populations in Rhode Island waters by relaying juvenile oysters from a nursery at the RIDEM CFL into designated release areas in Narragansett Bay and the South County coastal salt ponds.

Methods

Before oysters were transferred from the nursery grow-out to release sites, they were tested for diseases including Dermo, MSX, and histological indications of pathology. Oysters were then relayed in trays from the CFL nurseries to the predetermined release sites by truck and boat. Sites seeded in 2005 were The Cove – Portsmouth, Potter Cove on Prudence Island, Smelt Brook Cove and the Saugatucket River in Pt. Judith Pond. These release sites had been seeded in 2003 and the Pt. Judith Pond sites had been seeded in 2004. Prior to seeding the oysters, each restoration site was marked using tethered floats to clearly delineate each site. Because some of the seeding sites were comprised of multiple geometric configurations, the area was broken down into smaller sub-areas, so the length of the boundaries could be easily measured and the area seeded accurately determined. The number of oysters released into each sub-area was proportional to the area of that section. Oysters were distributed evenly throughout the entire area. In 2006, 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 and December of 2005, approximately 1.4 million juvenile oysters were seeded in four locations in Rhode Island coastal waters. Oysters with an overall mean size of 12.7mm were seeded into The Cove in Portsmouth on November 17, the mouth of the Saugatucket River in Pt. Judith Pond on November 29, Potter Cove off Prudence Island on December 1, and Smelt Brook Cove in Pt. Judith Pond on December 8 and 15. The Cove received ~361,200 oysters, Potter Cove received ~370,900 oysters, the Saugatucket River received ~272,800 oysters, and Smelt Brook Cove received ~373,000 oysters (Table 6).

Oyster spat being seeded into The Cove on November 17, 2005.

2.5 Disease Monitoring

Objective

The objective of the disease monitoring of restoration sites was to document the pathogen loads supported by the seeded populations, to assess the impact of pathogens on the success of each site. Disease monitoring of the release sites and wild stocks was completed to help develop strategies for future oyster releases through the *North Cape* restoration program.

Methods

Samples of 25 oysters were taken from each of the five sites seeded in 2003 to determine abundance of the *Perkinsus marinus* Parasite, the pathogen responsible for the disease Dermo, and to test for the presence of other molluscan pathogens. These samples were transported on ice to Micro Technologies, Inc. in Richmond, ME. Histological examination and standardized pathology tests for known pathogens were performed and the results were provided to the *North Cape* Program prior to releasing any oysters.

Oysters were also sampled from natural populations in three sites in Narragansett Bay; the Potowamut River in Greenwich Bay, Sheffield Cove near Jamestown, and an additional site in The Cove. These sites were investigated as possible future restoration areas. Approximately 25 oysters were taken from these sites and transported on ice to Dr. Marta Gomez-Chiari at the University of Rhode Island, for histological examination and testing for known pathogens.

Results

All testing done in 2005 was performed on oysters seeded in 2003. Both Smelt Brook Cove and the Saugatucket River showed 100% incidence of Dermo infection, although the average amount of hypnospores per gram of wet weight was lower in the oysters from Smelt Brook Cove. 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 heavy infection (Brousseau 1996). The oysters tested from Saugatucket were assigned a Mackin Index of 4, a moderate to heavy prevalence of infection. The oysters sampled from Smelt Brook Cove were assigned a Mackin Index of 3, a moderate prevalence of infection. Of the remaining three seeded sites, the channel at Bissel Cove tested lowest for disease prevalence at 11% with a Mackin Index of 1. Although The Cove and Potter Cove also both scored a Mackin Index of 1, the amount of oysters infected with Dermo was found to be 24% at Potter Cove and 60% at The Cove (Table 7).

Disease tests done on natural oyster populations in the alternative sites in Narragansett Bay were also rated on a Mackin Index with a percent prevalence of Dermo. Sheffield Cove had the highest disease presence at 100% and the highest Mackin Index at 4. The disease presence at the Potowamut River was 84% with a Mackin Index of 2, while the natural population of oysters at The Cove had a 76% prevalence and a Mackin Index of 3 (Table 8).

Discussion

The results of the disease survey of the restoration sites indicate that the Saugatucket River and Smelt Brook Cove sites are supporting a substantial pathogen load. These are also the sites with the highest oyster survival. This apparent contradiction is of interest to the shellfish pathologists as well as the *North Cape* Program. Possible explanations include the oysters being from a Dermo-tolerant strain (Takacs *et al.* 2005), or that environmental conditions at theses two sites provides oysters with sufficient resources (food supply and water exchange) to survive and grow, as well as support a high parasite load.

Dermo is now an endemic disease in Rhode Island. The level of infection generally increases with age, as does the associated percentage mortality (Encomio *et al.* 2005). The samples from the "wild stocks" in The Cove and the Potowamut River were large, older oysters, so the levels of Dermo detected indicate a lower prevalence at these sites than the Mackin Index alone would suggest. The oysters from Sheffield Cove were smaller and younger, yet still heavily infected with Dermo. This suggests a high disease load consistent with the remnants of a native population that had recently collapsed due to the disease. This is consistent with anecdotal reports of the population at this site over the last decade.

2.6 Recruitment Monitoring

Objective

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

Methods

Spawning within seeded sites was monitored using artificial spat collectors designed by Jay Odell at the Nature Conservancy, Newfields, NH. The spat collectors were made of 5 pieces of Hardibacker® a cellulose and cement mixture ($100cm^2$ x 12mm thick), separated by 1cm thick spacers (slices of PVC tubing). The Hardibacker® material and the PVC were strung onto 10mm. rope and suspended above a mooring using a sub-surface float. The collectors were moored using a cinderblock and marked with a surface float. Spat collectors were located close to each restoration site on the north and south sides. Two more collectors were placed up to one kilometer from the site in different directions. Spat collectors were retrieved periodically throughout the summer and fall of 2005 and analyzed using a dissecting microscope to identify recruits.

Results

Only 7 spat were recorded from the spat collectors in 2005. These came from several sites, but do not represent a measure of recruitment that is sufficient to allow conclusions regarding relative abundance of the timing of settlement.

Discussion

Settlement plates as spat collectors have been made from a variety of materials and designs. The Hardibacker® material has been field tested and proved to be successful in Maine (O'Dell pers. comm.). During 2005 there were very few spat recorded from the four spat collector locations monitored at each restoration site. The results suggest that there were few larvae settling in these areas and there was no general widespread recruitment in the area of the restoration sites. This is perhaps not surprising, as the reproductive output from each site would be relatively low compared to a natural bed, given the young age and the low number of the broodstock compared to all but the most depauperate natural oyster beds.

The low settlement count on the spat collectors does not necessarily reflect a low settlement overall. Oyster larvae live in the water column for two to three weeks prior to settlement (Kennedy 1996), so there is ample opportunity for larvae to have been transported from the restoration sites during this time. The fact that new recruits were detected from survival monitoring in the Saugatucket site in 2004, and not from the use of settlement plates in 2005, suggests that any recruits from the 2005 season may have been transported away from this site prior to settlement in 2005. Also, numerous studies have eluded to the 'non-random' dispersal of larvae (Vecchione 1987, Jacobsen *et al.* 1990) or 'swarming' behavior (Pritchard 1953), making spat collectors a less precise measure in situations of low overall larval abundance.

III. Quahog Projects

3.0 Introduction

The quahog restoration project strategy established in 2002 was to release hatchery-produced seed, grown out to a suitable size. This grow-out typically requires a two-year period in Southern New England. In 2005, the seed over-wintered from 2004 was retrieved and continued to grow to release size. An additional cohort of seed was obtained from Roger Williams University in Bristol RI, at approximately 1 mm shell length, for the first season of grow-out. This 2005 cohort will be ready for release in the fall of 2006. Identifying the optimal size and density to release seed quahog is crucial to quahog stock enhancement. Information on the influence of size and seeding density was obtained from sampling three discrete experimental plots established in 2004. In previous years, the *North Cape* Shellfish Restoration Program used floating upwellers to grow quahogs for their second year, a logistically demanding and labor-intensive exercise. During 2005, bottom grow-out methods were used to compare the percent survival and growth increment of quahogs in the upweller to those in different bottom grow-out treatments. As the majority of the 1+ year class quahogs were already in the sediment for the bottom grow-out experiment, these animals remained in the sites over wintered, to be sampled in spring of 2006, while the remaining 1+ year class from the upweller were overwintered in trays.

3.1 Quahog Seeding Experiment - Quonochontaug Pond 2005

Objective

The objective of the quahog seeding experiment was to assess seeding density and shell size on quahog growth and survival.

Methods

Three replicate experimental plots were established within the 2004 Quonochontaug Pond quahog seeding area (Figure 19). These plots were located along the east-west axis of the seeding site and delineated so that no quahogs from any subsequent broad-scale seeding would be released into the experimental plots. Each experimental plot measured 12m x 8m and was comprised of 6 treatments: three size classes, each seeded at two different densities. Each treatment occupied a 4m x 4m area within the experimental plot configuration (Figure 20). The three size classes were all separated out of the 2003 cohort, a group of notata quahogs, which were spawned from Rhode Island broodstock. There were also two treatments that were not replicated which were established along the western side of one of the plots, these consisted of a fourth and largest size class, taken from a group of Rhode Island “whites” that had been spawned in 2002. Quahogs from the four size groups had been separated during the final stage of upweller grow-out during 2004. These size classes selected were from quahogs that went through a 13mm (0.50in) mesh but not through a 6mm (0.25in) mesh (the 6mm group); those that went through a 19mm (0.75in) mesh but not a 13mm mesh (the 13mm group); those that were too large to sieve through a 19mm mesh (the 19mm group); and quahogs from the 2002 cohort, which were the largest, referred to as 2+ year class whites. The mean size of these groups at release were 12.6 mm, 16.7 mm, 21.8 mm, and 25.9 mm for the 6mm, 13mm, 19mm, and 2 + year class, 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 to account for variations in substrate type within the release area, and to minimize the potential to alter predator-searching behavior by having one large area of high-density prey.

In September 2005, each experimental plot was located using GPS to locate the steel pegs used as corner markers. The three replicate plots were then roped off on the substrate surface, to accurately delineate the treatment area. The experimental treatments within each plot were sampled using haphazard placement of three replicate $0.25m^2$ quadrats. All sediment to a depth of ~30cm was extracted with a suction sampler attached to a 5.5hp motor and water pump and passed through a 5mm mesh bag to collect the coarse fraction and quahogs. The maximum shell length of each quahog was measured and recorded. Following the collection of data, the sampled quahogs were placed back into the plots from which they came.

Suction sampler and pump

The data were analyzed as a blocked 2 x 3 orthogonal ANOVA in SAS. The dependent variable was the survival measured by each of the three replicate quadrats sampled per treatment. Each experimental plot represented a design block with six treatments three size classes seeded at two densities.

Results

Results indicate higher survival of quahogs seeded at $10m^{-2}$ than those seeded at $100m^{-2}$ (Figure 21). Plots seeded at $10m^{-2}$ had a maximum survival of 40%. The average survival of all four size classes seeded at $10m^{-2}$ was 25.5%. Plots seeded at $100m^{-2}$ had a maximum survival of 30%. The average survival of all four size classes seeded at $100m^{-2}$ was 13.25%.

There was considerable variation in the survival for each treatment when compared between plots (Table 9 and Figure 21). Of the total variation explained by the model 16% was attributed to these between plot variations, indicating the influence of fine scale variation in habitat on survival. After accounting for the between plot variation there was a highly significant increase in survival with increased size at seeding (Table 9). The largest of the four groups (19mm and 2 year+ whites) had the highest percent survival, 40% each at the $10m^{-2}$ seeding density. The survival of the 19mm and 2 + year class whites was also higher, compared to the smaller classes at a density of 100 m^2, with 30% and 17% survival, respectively (Figures 21). There was a higher, though not significant, survival of quahog seeded at the lower density ($10m^{-2}$) for all size classes.

Discussion

Results of the seeding experiment support the conclusions that lower seeding densities result in higher survival. This is thought to be because lower densities are less likely to influence predator behavior by concentrating the predators' search efforts in areas where prey are available at a higher abundance (Peterson *et. al.* 1995). Results also demonstrated a significant increase in survival with increased size at seeding. Results suggest that increased survival derived from larger seeding size may not persist beyond a size between 16.7mm and 21.8mm indicating that by this size, about 20mm, quahog seed have attained a 'size refuge' from predation (Peterson *et. al*. 1995).

3.2 Monitoring of 2004 Quahog Releases

Introduction

Monitoring the success of released seed is a critical component of the stock enhancement process. By monitoring growth and survival, it is possible to assess the impact of the released seed on the resident population, and their potential impact on future generations (Brumbaugh *et al.* 2006).

Objective

The objective of the monitoring program was to estimate the growth and survival of the quahog seed released into regulated shellfish spawner sanctuaries closed to shellfishing within both Ninigret and Quonochontaug Ponds.

Methods

Monitoring of previously released quahog seed in Ninigret and Quonochontaug Ponds was done by sampling $1m^2$ quadrats haphazardly placed within a one hectare section of the seeded area. The one hectare section sampled in Ninigret Pond was chosen as it had been seeded with approximately equal numbers of large (mean size 21.8mm) and small (mean size12.6mm) quahogs in a controlled manner in 2004. The size class of the seed released into specific areas of the spawner sanctuary in Quonochontaug Pond was not recorded, so the seeding history of the area sampled was unknown. Seeded areas were identified using GPS (Hancock *et al.* 2005), and the corners of each area were marked with floats. Divers removed the sediment within each quadrat to a depth of ~ 30cm with the use of a suction sampler powered by a 5.5hp motor and pump, with sediment passing through a 5mm mesh bag to retain the coarse fractions. The maximum lengths of all quahogs collected were recorded. Mean densities (±SE) were calculated and percent survivals were determined based on the seeding density of $10m^{-2}$ as seeded in 2004.

Results

In Ninigret Pond, twenty-five quadrats were sampled from the selected one hectare area of the spawner sanctuary between November and December 2005. This sampling produced a total of eighty-nine quahogs that were identified by size and notata strain markings to be quahogs that were seeded in 2004. This gives a mean density of seeded quahogs in the entire sanctuary of 3.28 quahogs m^{-2}, a 32.8% survival. It is estimated that there were 104,546 (± 28,301 SE) seeded quahog in the sanctuary based upon the 318,737 quahog released in 2004 (Table 11). The mean length of the seeded quahogs sampled in Ninigret Pond was 41mm (± 0.58 SE), a growth increment of 27.2mm for the thirteen months at liberty.

In Quonochontaug Pond the sanctuary sampling was completed in October, with 24 quadrats sampled and a total of 11 quahogs found. The mean density of seeded quahog remaining in the sanctuary was estimated to be 0.46 quahogs m^{-2}, a survival of 4.6%. It is estimated that there were 14,492 (± 7,116 SE) seeded quahog remaining in the Quonochontaug sanctuary based upon the 316,194 quahog released in 2004 (Table 10). In Quonochontaug Pond, the mean length of quahogs sampled was 40mm, a growth increment of 26.2mm for thirteen months at liberty (Table 10).

Discussion

There was a marked contrast in the average survival between the sanctuaries in Quonochontaug Pond versus Ninigret Pond. Both ponds were seeded at 10 quahogs m^{-2}, with a similar number of quahogs released, 316,194 in Quonochontaug Pond and 318,737 into Ninigret Pond. The mean survival in Ninigret Pond (32.8%) was over six times higher than in Quonochontaug Pond. It should be noted that the exact areas seeded with the different sized quahogs were not recorded during seeding in Quonochontaug Pond. It has been demonstrated that the survival was positively correlated with seed size (section 3.1), so the accuracy of the survival estimate is dependant on the random distribution of quadrats among areas seeded with different size classes. As this cannot be verified for Quonochontaug Pond, the survival estimate should be considered as a preliminary guide. The samples from Ninigret Pond were taken from an area seeded with equal numbers of large and small seed and should provide a representative measure of the overall survival of the range of sizes seeded The experimental plots will be replicated in future years in both ponds, to more accurately determine survival. Anecdotal information from diver observations suggests that the difference may, in part, be due to the relatively high abundance of lady crabs (*Ovalipes ocellatus)* in Quonochontaug Pond. During set-up and monitoring of the seeding experiment in Quonochontaug Pond, many lady crabs were noticed in the area, which was not the case in Ninigret Pond.

The difference in survival was not reflected in growth, with the average growth increment being very similar in the quahogs sampled from each pond. It should be noted that the mean growth increment from the release monitoring will be an overestimate of actual growth, as it has been clearly demonstrated that the survival, and therefore the chance of recapture, was much higher for those quahogs with a larger size at seeding. Because of this differential survival, the mean size of all quahogs seeded is likely to be lower than the mean size at seeding would have been for the actual quahogs recaptured.

3.3 Nursery Grow-out 2005

3.3.1 2005 Cohort

Objective

The objective was to secure small seed for grow-out in a floating upweller at Camp Fuller, located in Pt. Judith Pond, South Kingstown, RI.

Methods

A batch of two million seed quahog, at a minimum length of 1mm, was purchased from Roger Williams University in 2005. On June 20, 350,000 seed were placed in an upweller approximately half way up Pt. Judith Pond from the entrance (Camp Fuller). These were combined with 1.65 million seed purchased on July 15 and allowed to grow for the duration of the season. The quahog seed were cared for twice weekly by washing out pseudo-feces and other debris caught in each bin. A screening of the quahog seed was done in August to partition size classes At that time the mesh on the bottom of the bins was increased to maximize water flow. At the end of November, the end of the grow-out season, the quahogs were prepared for overwintering in large fiberglass troughs (2.5m L x 0.2m W x 0.28m H). The troughs were covered with 3mm (1/8in) mesh. These troughs were used in place of the Aqua Trays® used in past years to

Upweller maintenance at Camp Fuller in Pt. Judith Pond increase water flow and to minimize smothering caused by sedimentation, as noticed upon retrieval of the 2004 cohort from overwintering.

Results

Of the two million quahog purchased in July, 294,069 (± 31,607 SE) were placed into overwintering troughs in December, a 14.7 % (± 1.6% SE) survival for the 2005 grow-out season. This relatively lower survival compared to the 2004 season (22.9%) was attributed primarily by fouling and smothering of the juvenile quahog by sea grapes, (*Molgula* sp.), and a brown filamentous alga, both of which persisted throughout the summer season. Despite the persistent fouling, the mean growth increment of the cohort was 3.9mm in the six months.

3.3.2 2004 Cohort

Objectives

The first objective was the further grow-out of the 2004 cohort to a suitable size for seeding. The second objective was to compare efficiency of grow-out using different methods including a floating upweller and two different bottom grow-out treatments stocked at two different densities.

Methods

In May 2005, quahogs from the 2004 cohort were retrieved from overwintering and placed in the upweller located at Camp Fuller, Pt. Judith Pond. At this time the quahogs were sampled to determine the mean number per unit volume for estimating abundance, and quahog shell lengths were recorded.

In July 2005, the 1+ year class quahogs were mixed, sampled to determine abundance and mean length, and divided approximately equally between three grow-out treatments. The grow-out treatments tested were mesh boxes and mesh covers, established on the bottom of Smelt Brook Cove in Pt. Judith Pond, and the upweller at Camp Fuller, located in Turner Cove, approximately 900 m south of Smelt Brook Cove. A total of 36,225 (± 3,066 SE) quahogs were assigned to the bottom grow-out boxes, 36,400 (± 3,081 SE) to the mesh covers, and

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

37,914 (± 3,209 SE) were retained in the upweller.

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

Densities of 5000 quahogs m^{-2} and 10,000 quahogs m^{-2} were used for each bottom grow-out treatment (Flimlin et al. 1997). A total of 11 bags of 5,000m^{-2} and 6 bags of 10,000m^{-2} were filled to the specified densities using volume to estimate the appropriate number of quahogs. Each bag was labeled and secured to the bottom with 25mm bent re-bar pegs. A total of six covered plots with quahogs spread at a density of 5,000m^{-2} and four covered plots with quahogs spread at a density of 10,000m^{-2} were established.

The bottom grow-out treatments were cleaned as required during the grow-out season. To clean the bags, the steel pegs were removed, each bag turned upside-down and then re-pegged to the bottom. The mesh of the covered plots was scraped down and brushed free of alga and fouling growth. Cleaning was necessary only once during the season. Upweller bins containing the 1+ year class were removed, and the quahogs were washed down approximately once a week.

The bottom grow-out treatments were sampled in October. Three bags were sampled from each of the 5,000m^{-2} and 10,000m^{-2} densities. The entire contents of each bag were emptied, the total volume of the quahogs measured, and three 150ml sub-samples were taken. All live quahogs within each sample were counted. The maximum shell length of each live quahog from one sample was measured and recorded. The contents, including sub-samples, were returned to the bags and re-secured to the bottom for the winter of 2005/2006. Three covered plots of each of the two densities were also sampled. A diver removed the covers one at a time and took three haphazard sub-samples within each covered plot, each consisting of the entire contents of a 25cm X 25cm quadrat dug to a depth of 15cm. The quahogs were sieved out and the lengths and number recorded. Quahogs were replaced under their respective covers, which were re-secured for over-wintering. Abundances and percent survival for each of the bottom grow-out treatments at the 5,000m^{-2} and 10,000m^{-2} densities, along with standard errors, were calculated.

The 2004 cohort in the upweller was also sampled by counting three sub-samples and taking maximum shell length of quahogs from one sub-sample. The percent survival along with standard errors was extrapolated based on total volume. The quahogs that remained in the floating upweller at the end of December were then placed into overwintering trays in the CFL nursery.

Results

In December 2004, 1+ year quahogs were placed onto sediment in Aqua Trays® at the CFL. The trays were lined with fine "landscaping" mesh inside 3mm plastic diamond mesh, as in previous years. Quahogs were retrieved from the overwintering trays between April and May 2005, and placed into upweller bins. The survival of the overwintered quahogs was 16.1%. This is an estimated figure because it is not cost effective to accurately determine the number alive in the smallest size fraction at the end of the first year of growth, which may lead to an overestimate of overwintered quahogs at the end of the first season. There was also a substantial 2004/2005 overwintering mortality due to sediment deposited on the overwintering trays. When retrieving quahogs from the overwintering trays, it was evident that substantial amounts of sediment had settled out of the water column during winter and had built up on the lids of the overwintering trays. The quahogs beneath this sediment layer died.

In the bottom grow-out experiment, bags containing quahogs at 5,000m^{-2} had a 57.7% survival rate and a growth increment of 5.4mm for the five-month duration of the grow-out experiment (Figure 22, Table 11). This was the highest percent survival of the bottom grow-out treatments. The bags containing quahog at 10,000m^{-2} exhibited a slightly lower percent survival at 52.1%, and a growth increment of 4.1mm. The covered plots had a lower percent survival than the bag treatments with 38.5% survival for the 5,000m^{-2} and 47.2% survival for the 10,000m^{-2} treatments. The growth increments of these treatments were 5.9mm for the 5,000m^{-2} covers and 4.8mm for the 10,000m^{-2} covers. In comparison to the bottom grow-out treatments, the upweller produced a substantially higher 98.9% survival and a 6.9mm growth increment (Figures 22, 23 and Table 11).

Discussion

The poor overwintering results related to sediment buildup on the lids of the overwintering trays led to a redesign of the overwintering facilities for expected use in 2005/2006. The new overwintering "troughs" are deeper than the Aqua Trays® used in years past, and kept the 3mm mesh well above the sediment surface.

It is clear that the upweller is a much more efficient method of growing 1+ year class quahogs than the bottom grow-out systems tested, with better growth and near 100% survival as opposed to less than 60% for the best result from the bottom grow-out treatments. The labor associated with the two methods of grow-out, floating upweller and bottom grow-out, also varies greatly. It is more costly to maintain the grow-out in the upweller due to the weekly cleaning in the peak growing period, June – September, as opposed to the single cleaning that was required for the bottom grow-out treatments during this same period. In this case the upweller was the preferred grow-out method due to the combination of nearly twice the survival and growth rates.

3.4 Conclusions

Throughout the 2005 season, the fieldwork of the *North Cape* staff produced many valuable results. It was determined that the optimal size and density for seeding quahog in an area of high predator pressure in Rhode Island is greater than approximately 20mm (17mm - 22mm), seeded at a density of $10m^{-2}$. Quahogs were also maintained for seeding in 2006 and enhancements were made in overwintering procedures to increase survival during critical winter months. At the end of the 2005 season, there were approximately 286,200 quahogs from the 0+ year class and 37,500 from the 1+ year class in the over-wintering facilities at the CFL. There were also approximately 35,700 quahogs overwintered in bottom grow-out treatments in Smelt Brook Cove. A total of 359,400 quahogs were overwintered. The survival of seeded quahogs was different in the two previously seeded spawner sanctuaries, 32.8% in Ninigret Pond and 4.6% in Quonochontaug Pond. Approximately 33% survival in Ninigret Pond is a very encouraging result. The figure for Quonochontaug may not be representative for the quahog seeded as the samples were taken from areas with an unknown distribution of initial seed size. The difference in pond survival is also possibly due in part to differences in predator profiles in each pond. The upweller grow-out of the 0+ year class in 2005 resulted in a relatively low survival due to many difficulties associated with heavy fouling among the small seed soon after being introduced to the upweller. Alternatives for future restoration seasons include purchasing fewer quahogs at a larger size of 4–6mm for upweller and bottom grow-out, or purchasing larger quahog, if commercially available, at a size of 17–22mm that are an appropriate size for seeding directly into restoration sites.

IV. Outreach

During 2005 the *North Cape* Shellfish Restoration Program continued to seek and advance volunteer participation as an integral component of the shellfish projects and provide community outreach. Throughout 2005, the program benefited from the assistance of numerous volunteers. There were two Saturday events where volunteers from the community donated their time and effort to make bags of shell cultch, a laborious and time-consuming exercise essential for the oyster remote setting. There were an additional four days scheduled for sampling oysters set on the shell culch prior to seeding, to determine the average size of oyster spat and calculate the total abundance of oysters in the nursery. In total, 220 hours were donated by community volunteers. Students from URI and Middletown High School also participated in various aspects of the project. Ten students from URI's BIO 101 class sampled oysters in the nursery contributing approximately 55 hours to the project. The high school students from Middletown were a key work force in splitting the culch bags containing the newly settled oysters as a means to provide the oyster spat room to grow. These students contributed approximately 88 hours to the project.

Volunteers bagging shell cultch at the Coastal Fisheries Lab in preparation for the remote setting of oyster larvae

In addition to the groups of volunteers that participated in the project, the *North Cape* Shellfish Restoration Program benefited from having a long-term volunteer work experience student. Coral Hines, a senior at North Kingstown High School, assisted the program approximately three to five hours per day, four days a week, between September 9, 2005 and December 30, 2005, for a total of 192 hours. In all, a total of 555 volunteer hours were contributed to this program in 2005.

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

In addition to the community volunteer program, the *North Cape* Shellfish Restoration Program generated a range of media reports to inform the public on the progress of the projects. The *North Cape* Shellfish Restoration Program posted two press releases during 2005. The first was a description of the program and an invitation to a presentation night. The information night was held at the Cross Mills Public Library in Charlestown on April 26, 2005 with a slide show and a presentation of a Certificate of Appreciation to Mr. Prentis Stout on behalf of Camp Fuller, in appreciation of their continued support. Additional notices advertising the volunteer events were posted in local newspapers during the season, and flyers announcing the events were put up around the area. A twopage description of the project and photos of volunteers and staff sampling the oyster nursery was published in the *Narragansett Times*, a local newspaper, in September.

A second press release announced the oyster seeding in Potter Cove, Prudence Island. The seeding was well attended by the press with support from the State research vessels TJ Wright and John H. Chafee provided by the Rhode Island Department of Environmental Management. Descriptions of the project and photographs of the staff seeding oysters in Potter Cove were published in the *Providence Journal, New York Times*, and the *Washington Post.* WJAR Channel 10 news also ran a featured television broadcast on the *North Cape* Shellfish Restoration Program and the community volunteer program in September. A second feature article on the oyster seeding in Potters Cove was released in early December. National Public Radio's WGBH in Boston also ran a broadcast segment on the oyster seeding on several news programs prior to the seeding event.

During the summer of 2004, two Coastal Fellows from The University of Rhode Island (URI) worked with the *North Cape* Shellfish Restoration Program and developed project material from the scallop restoration project. In December 2004, the students presented technical posters of the results at the URI Coastal Fellows Program summit. In March of 2005 the posters were presented at the Twenty-fifth Annual Milford Aquaculture seminar. The abstracts were published in the Journal of Shellfish Research (Griffin *et al.* 2005, Biancani *et al.* 2005).

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Figure 1. Ninigret Pond scallop survey strata.

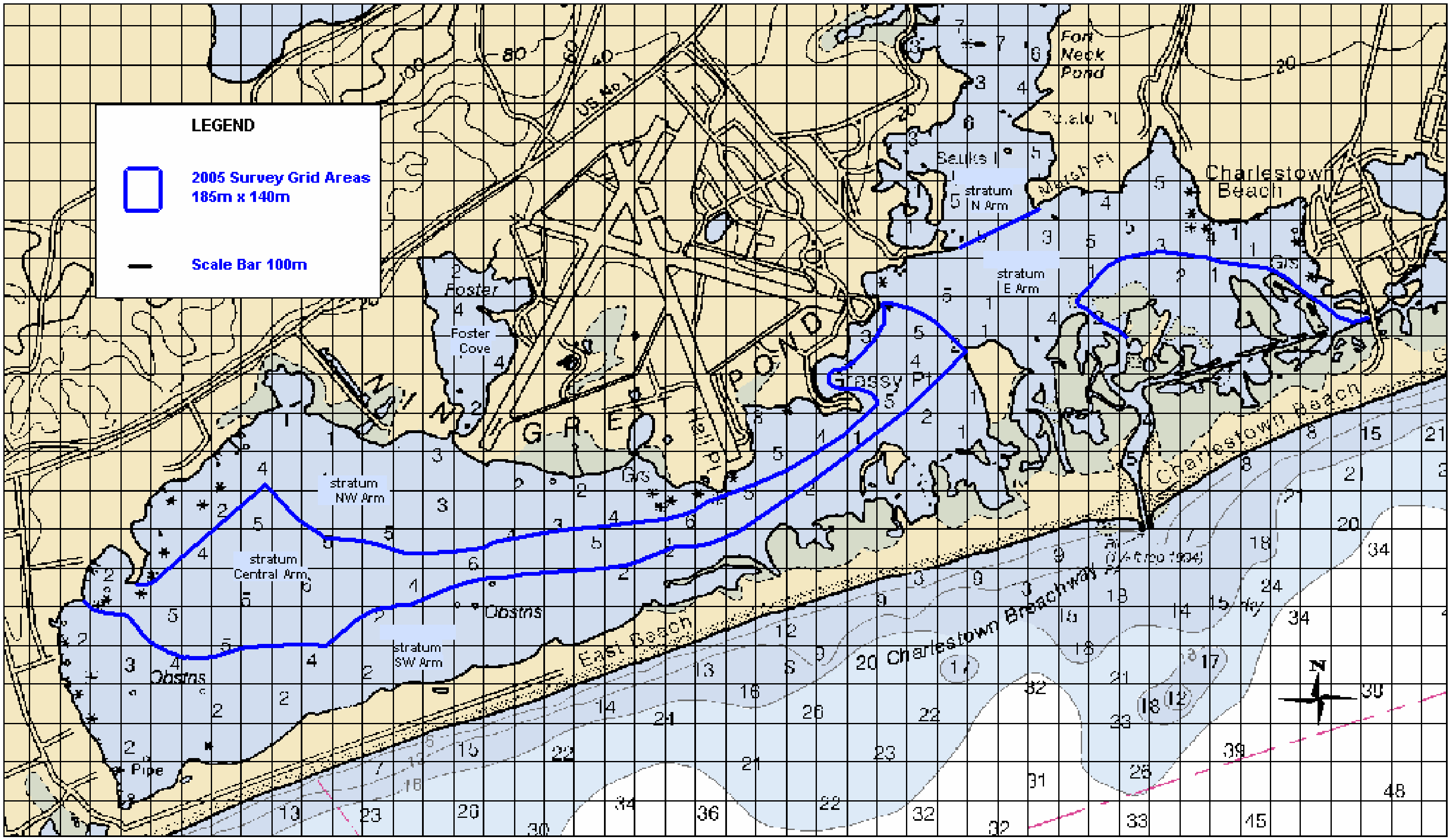


Table 1. Estimates of distribution and abundance of scallops in Ninigret Pond, 2005.

Strata	Area Surveyed (m^2)	Number of Scallops Found	Mean Scallops/m^2	SE	Area of Stratum (m2)	No. Scallops/ Stratum	SE
North West Arm	1,200	56	0.047	0.020	1,229,351	57,370	24,926
Central West Arm	1,200	30	0.025	0.007	1,234,114	30,853	8,660
South West Arm	1,200	25	0.019	0.010	1,7138,259	33,620	17,048
Total	3,600	111			4,211,724	121,843	50,634

Figure 2. Length distribution of scallops found in Ninigret scallop surveys conducted between August 8 and August 25, 2005.

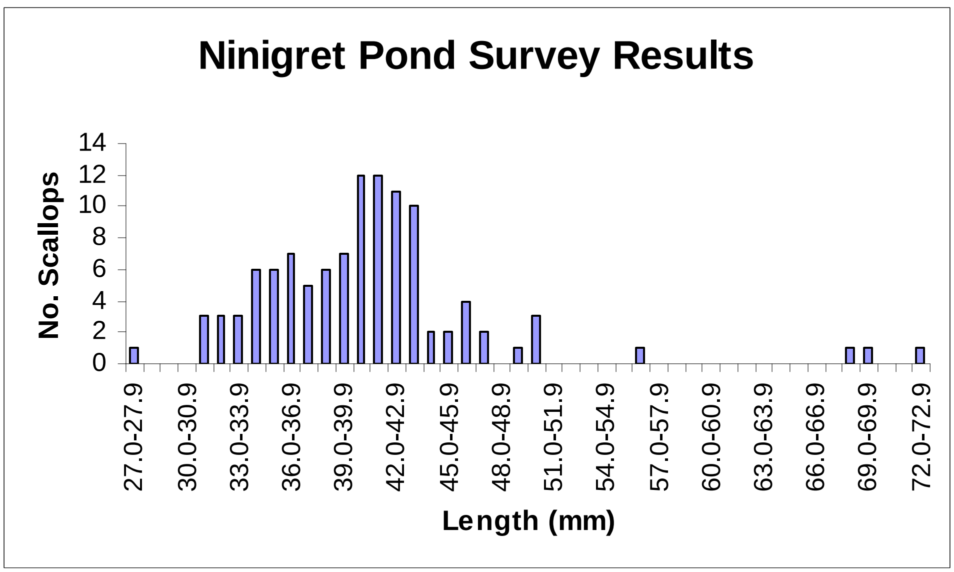


Figure 3. Location of spat line arrays (▲) and spawner sanctuary (■) in Ninigret Pond.

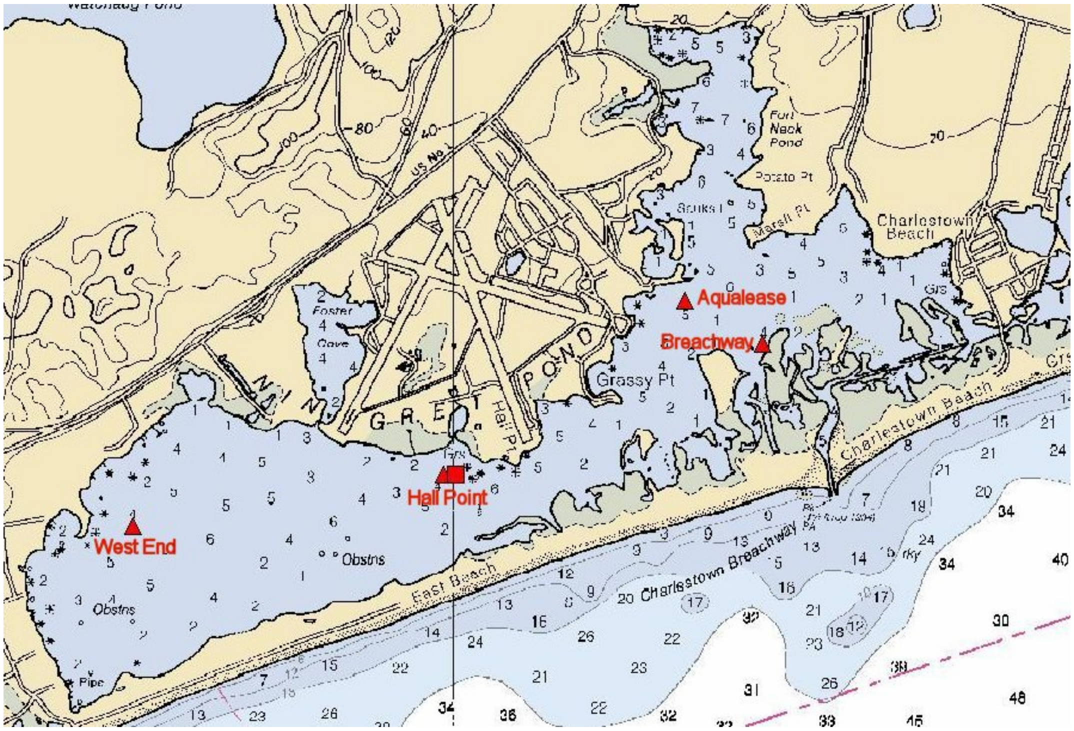


Figure 4. Schematic diagram of a spat bag array.

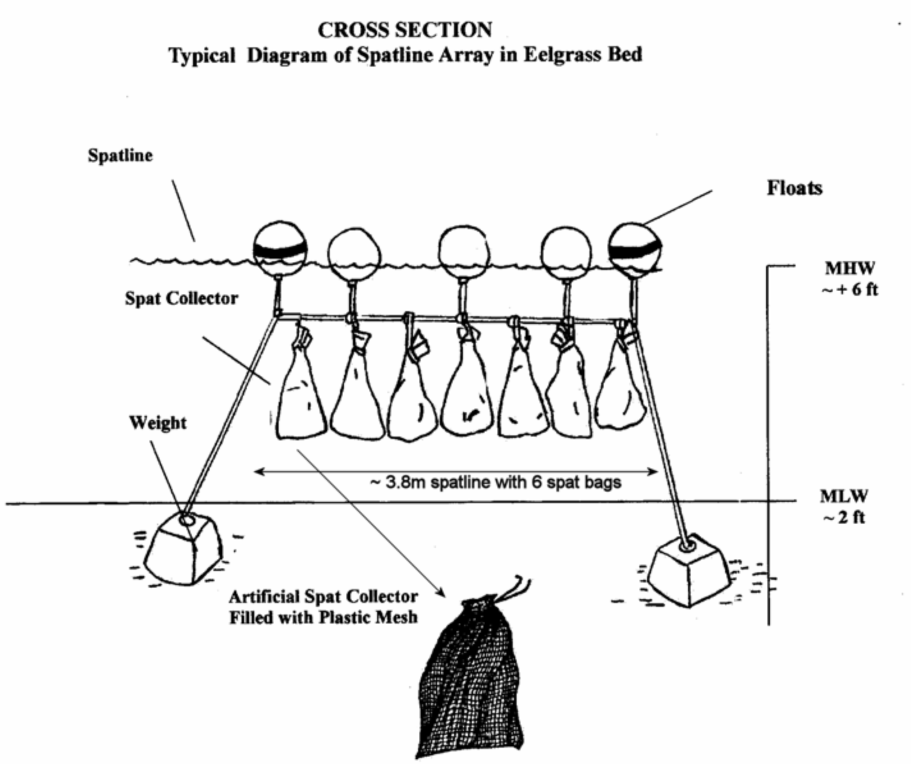


Table 2. Scallop spat collected from 'spat bags' deployed in Ninigret Pond for approximately 30 days, with mean spat per bag and mean size ± SE.

Date Collected	13-Jul	26-Jul	11-Aug	23-Aug	9-Sep	27-Sep	18-Oct	Total
Days at Liberty	27	27	29	28	29	35	21	
Scheduled Liberty	30	30	30	30	30	30	30	30 day
West End								
No. Bags	6	6	6	3	6	6	6	39
No. Scallops	0	0	1	171	0	47	0	219
Mean Scallops/Bag	0 ±0.0	0 ±0.0	0.2 ±0.2	57.0 ±13.9	0 ±0.0	7.8 ±3.4	0 ±0.0	
Mean Size (mm)	0 ±0.0	0 ±0.0	5.3 ±5.2	2.0 ±0.0	0 ±0.0	2.4 ±0.1	0 ±0.0	
Hall Point								
No. Bags	6	6	6	6	6	6	6	42
No. Scallops	0	0	6	97	0	0	0	103
Mean Scallops/Bag	0 ±0.0	0 ±0.0	1.0 ±0.4	16.2 ±3.4	0 ±0.0	0 ±0.0	0 ±0.0	
Mean Size (mm)	0 ±0.0	0 ±0.0	3.1 ±0.5	2.4 ±0.1	0 ±0.0	0 ±0.0	0 ±0.0	
Breachway								
No. Bags	6	6	6	6	6	6	6	42
No. Scallops	0	0	13	6	0	35	0	54
Mean Scallops/Bag	0 ±0.0	0 ±0.0	2.2 ±0.9	1.0 ±0.4	0 ±0.0	5.8 ±0.6	0 ±0.0	
Mean Size (mm)	0 ±0.0	0 ±0.0	4.2 ±0.3	3.3 ±0.7	0 ±0.0	4.6 ±0.2	0 ±0.0	
Aqualease								
No. Bags	6	6	6	6	6	6	6	42
No. Scallops	0	0	6	11	2	20	0	39
Mean Scallops/Bag	0 ±0.0	0 ±0.0	1.0 ±0.5	1.8 ±0.8	0.3 ±0.2	3.3 ±0.7	0 ±0.0	
Mean Size (mm)	0 ±0.0	0 ±0.0	4.6 ±0.4	2.5 ±0.3	2.7 ±0.7	3.5 ±0.4	0 ±0.0	

Table 3. Scallop spat collected from spat bags deployed in Ninigret Pond for approximately 60 days, with mean spat per bag and mean size ± SE.

Date Collected	**11-Aug**	**23-Aug**	**9-Sep**	**27-Sep**	**18-Oct**	**3-Nov**	**15-Nov**	**Total**
Days at Liberty	56	55	58	73	56	55	49	
Scheduled Liberty	60	60	60	60	60	60	60	60 day
West End								
No. Bags	6	6	5	1	6	6	6	36
No. Scallops	0	10	4	57	18	67	94	250
Mean Scallops/Bag	0 ±0.0	1.7 ±0.7	0.8 ±0.4	57.0 ±0.0	3.0 ±0.8	11.2 ±1.9	15.7 ±4.2	
Mean Size (mm)	0 ±0.0	1.3 ±0.4	6.6 ±0.8	6.2 ±0.1	3.2 ±0.2	6.8 ±0.4	3.9 ±0.1	
Hall Point								
No. Bags	6	6	6	6	6	6	6	42
No. Scallops	0	3	33	62	13	28	47	186
Mean Scallops/Bag	0 ±0.0	0.5 ±0.4	5.5 ±1.2	10.3 ±2.3	2.2 ±0.7	4.7 ±0.7	7.8 ±1.1	
Mean Size (mm)	0 ±0.0	1.7 ±0.2	5.0 ±0.6	9.2 ±0.5	2.5 ±0.2	5.1 ±0.2	5.4 ±0.2	
Breachway								
No. Bags	6	6	6	6	6	6	6	42
No. Scallops	0	49	49	106	96	127	28	455
Mean Scallops/Bag	0 ±0.0	8.2 ±0.9	8.2 ±0.8	17.7 ±1.2	16.0 ±2.4	21.2 ±1.1	4.7 ±0.8	
Mean Size (mm)	0 ±0.0	7.8 ±0.4	17.6 ±0.9	16.1 ±1.0	8.6 ±0.3	10.6 ±0.6	9.0 ±0.6	
Aqualease								
No. Bags	6	6	5	3	4	6	5	35
No. Scallops	0	6	17	16	35	282	54	410
Mean Scallops/Bag	0 ±0.0	1.0 ±0.4	3.4 ±0.8	5.3 ±0.9	8.8 ±1.4	47.0 ±10.1	10.8 ±2.0	
Mean Size (mm)	0 ±0.0	7.2 ±1.7	15.8 ±1.7	17.0 ±1.9	6.2 ±0.6	5.5 ±0.1	6.8 ±0.4	

Figure 5. Sequential size distributions of all scallop spat collected in the 30-day spat bag collections from Ninigret Pond during 2005.

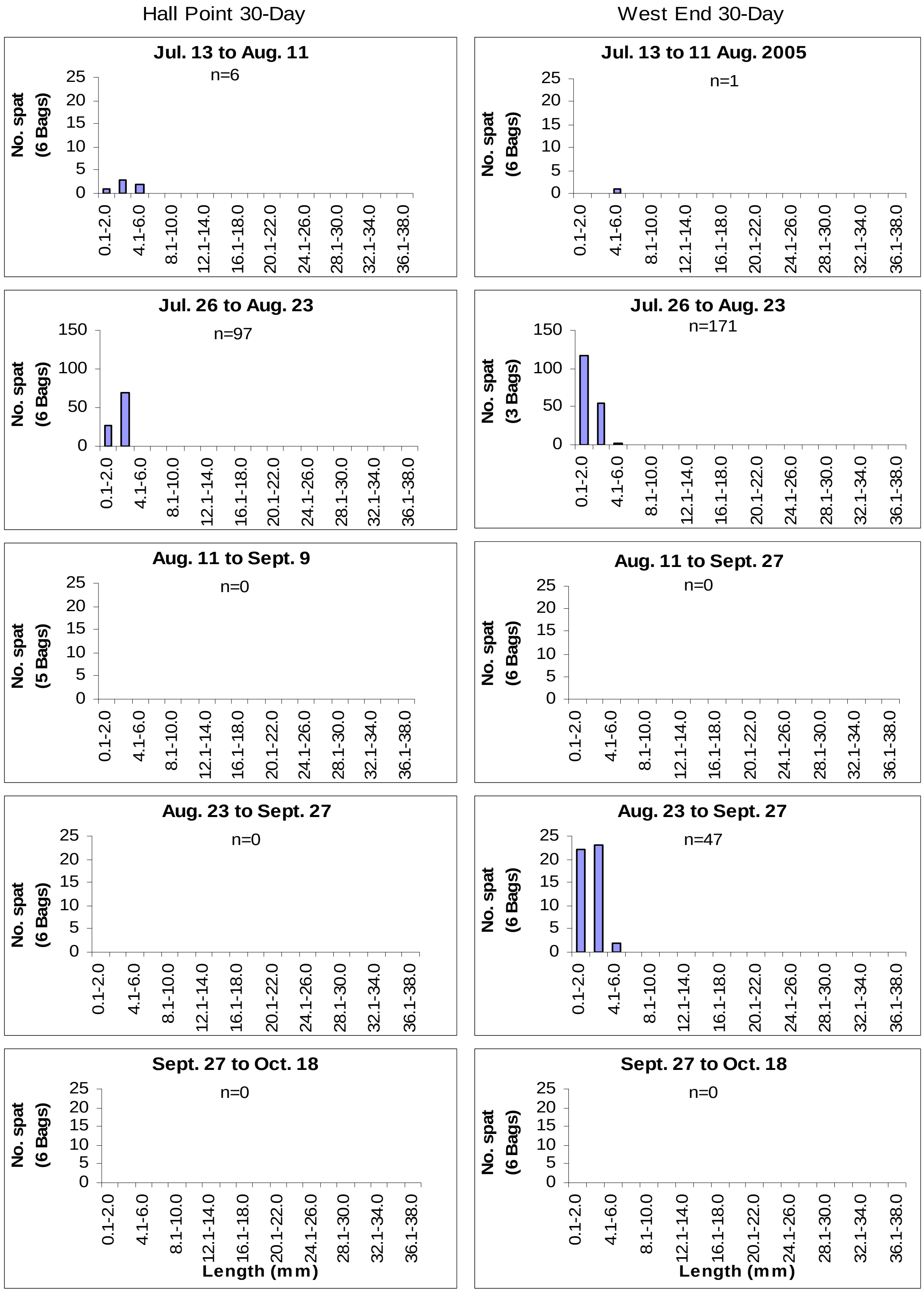


Figure 5. (continued).

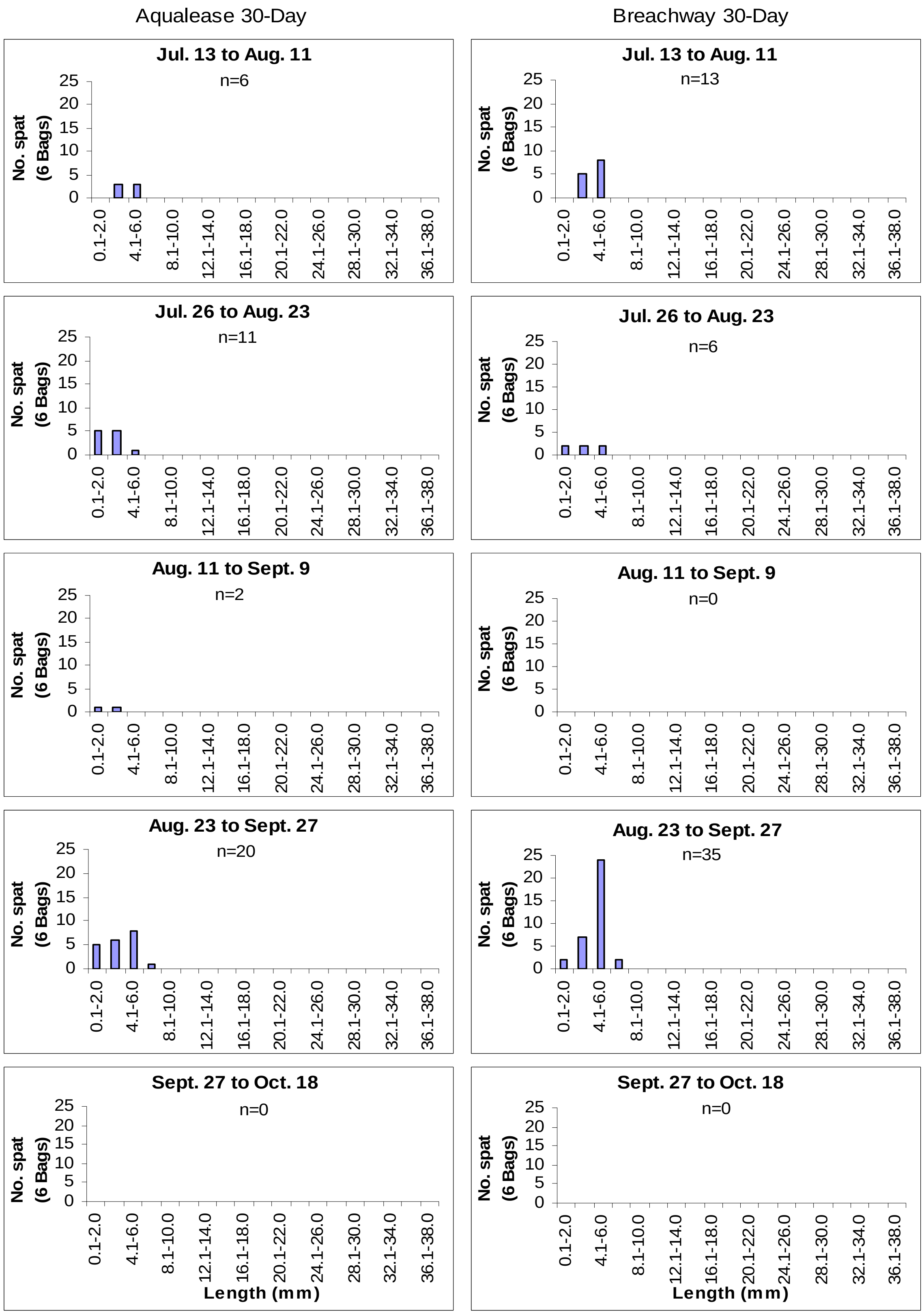


Figure 6. Sequential size distribution of all scallop spat collected in the 60-day spat bag collections from Ninigret Pond during 2005.

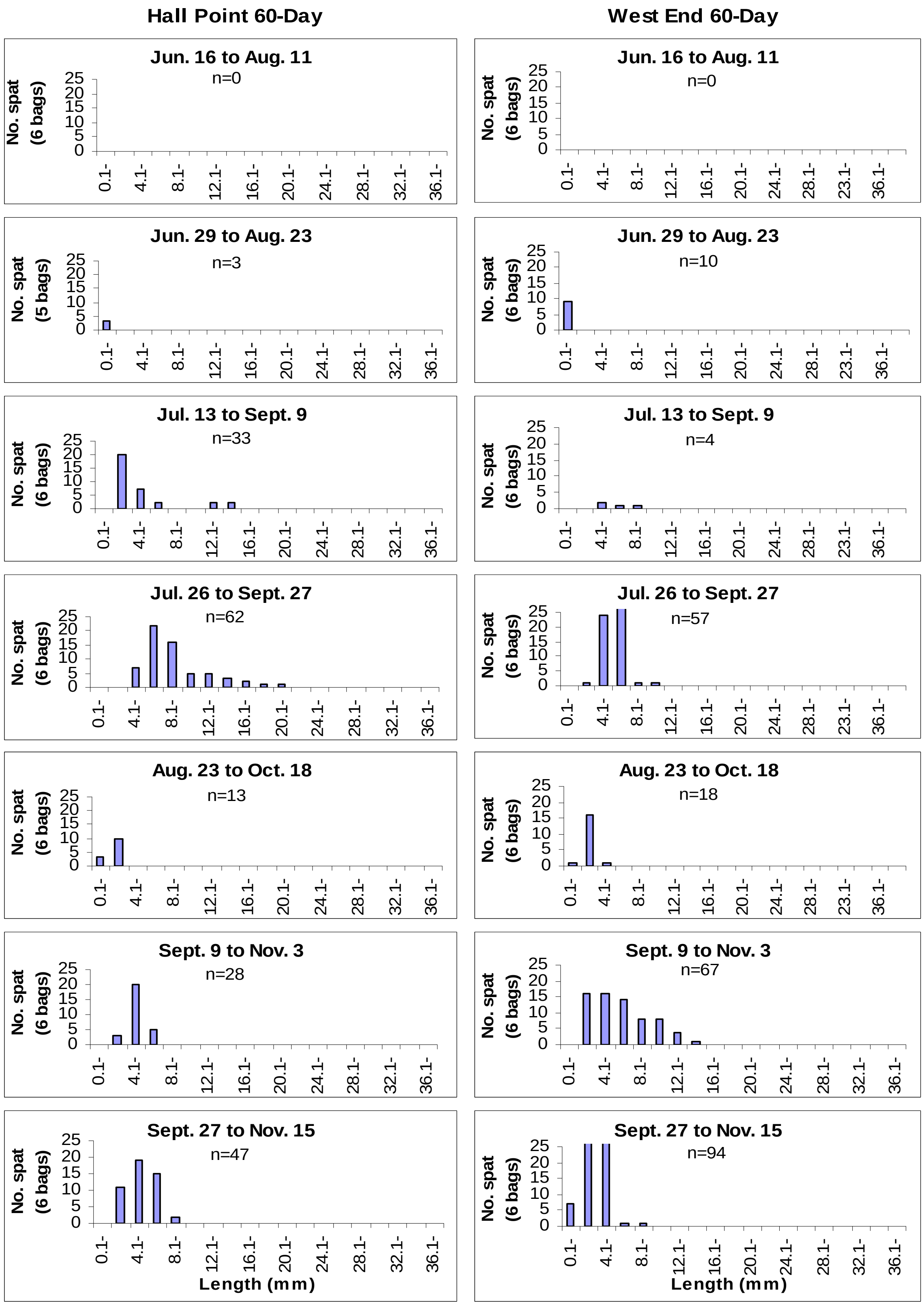


Figure 6. (continued).

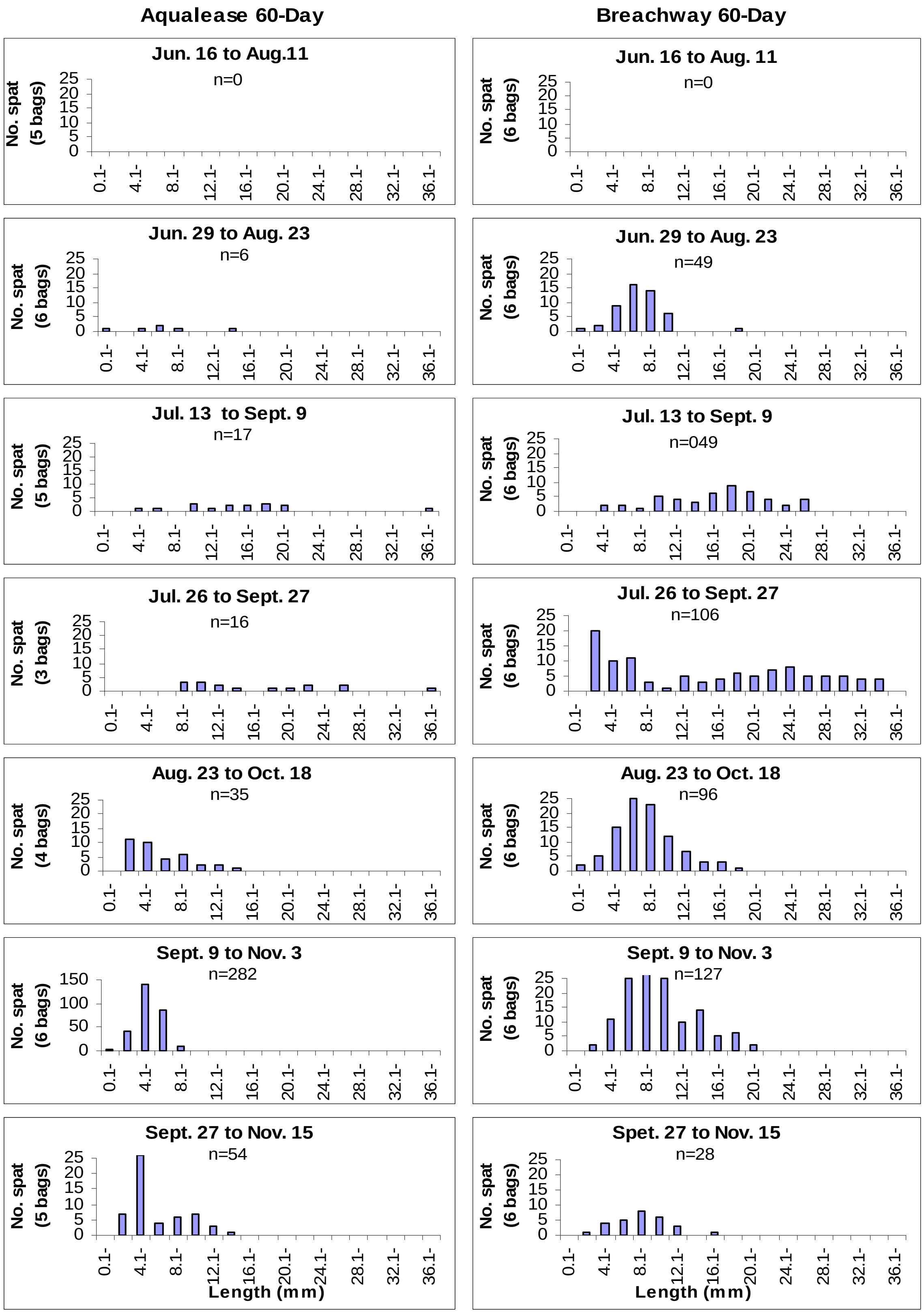
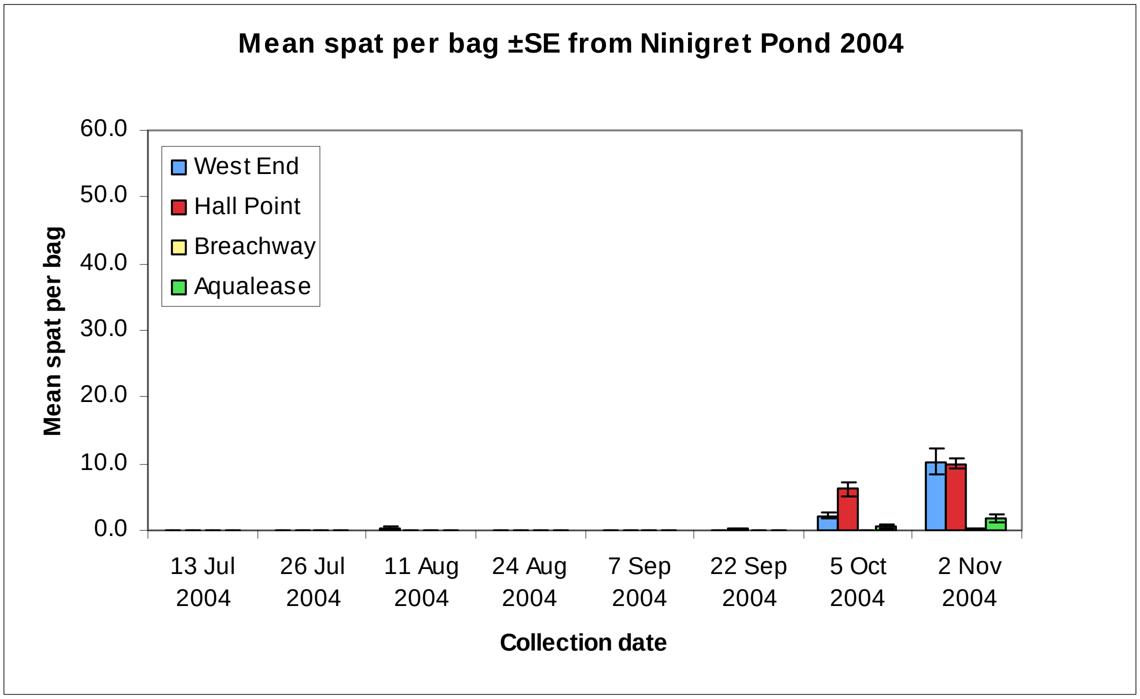


Figure 7. Comparison of the mean number of spat found per bag ±SE, in spat collectors at each of 4 Ninigret Pond sites for the 2004 and 2005 scallop settlement surveys.



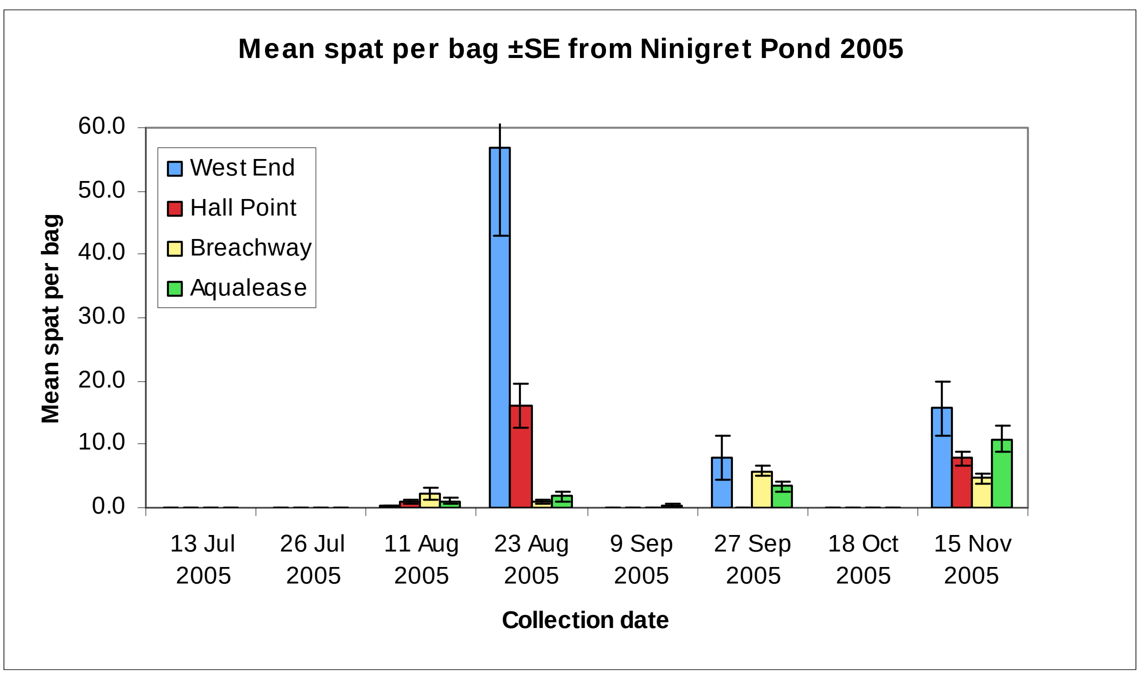


Figure 8. Experiment 1 results showing cumulative percent scallop mortality for all dissolved oxygen concentrations ±SE over 96 hours.

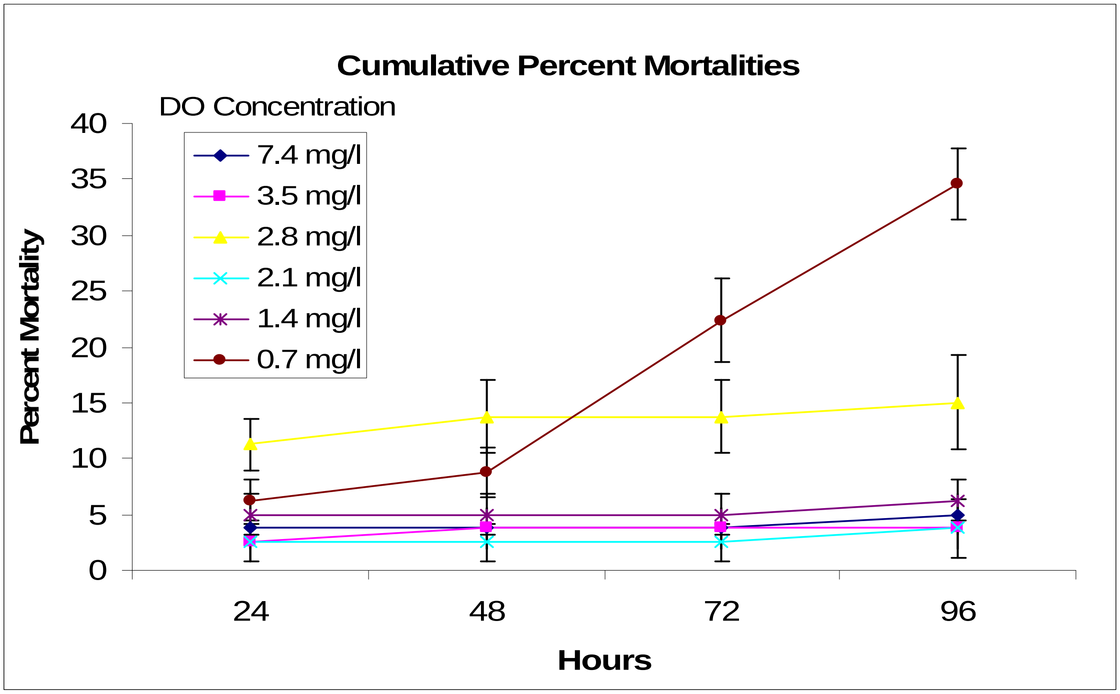


Figure 9. Experiment 2 results showing cumulative percent scallop mortality for all dissolved oxygen concentrations ±SE over 96 hours.

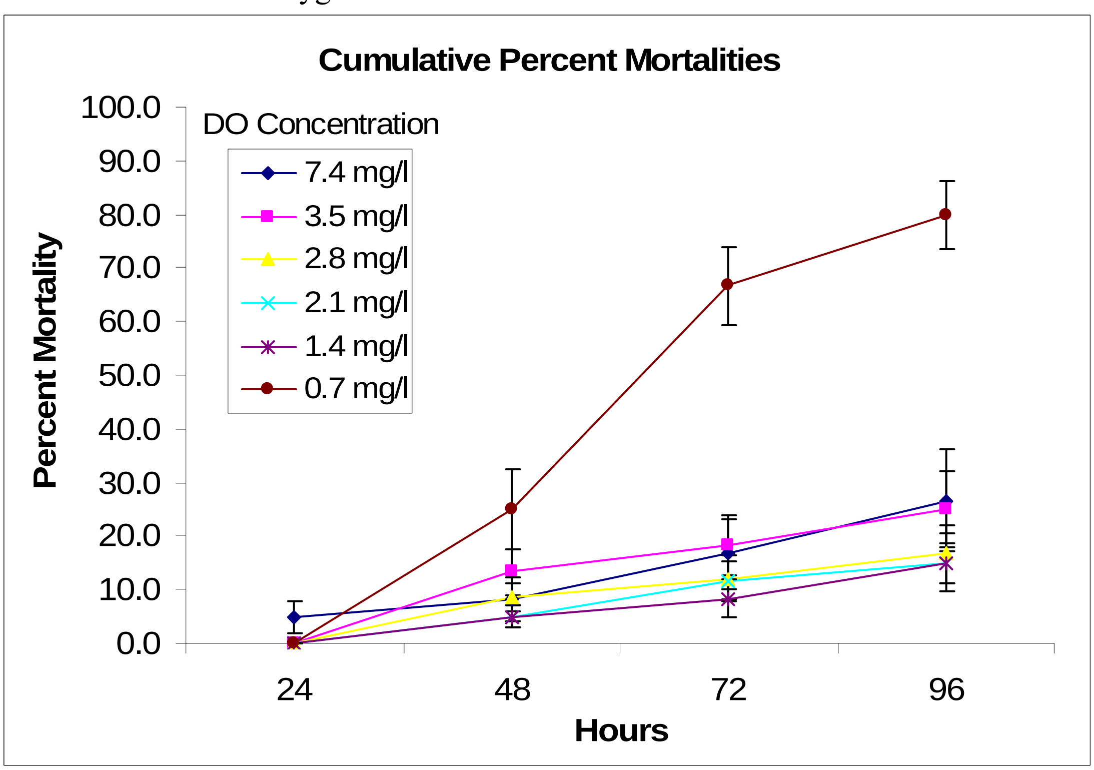


Figure 10. Comparison of treatments in experiment 2 with starfish versus controls for total cumulative percent scallop mortalities ±SE after 96 hours.

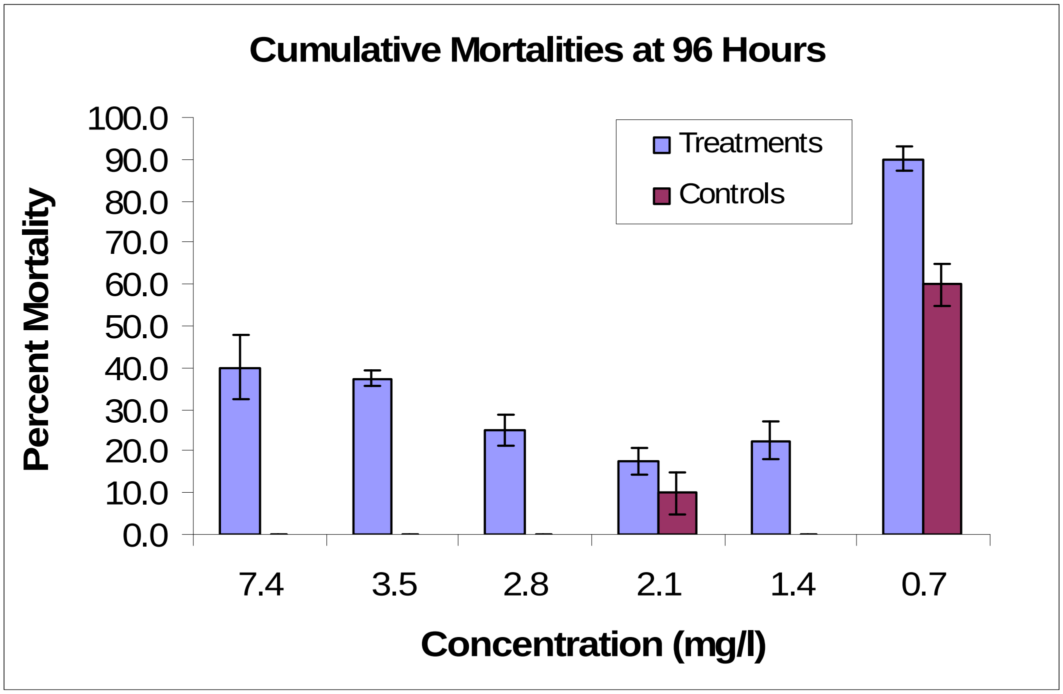


Figure 11. Total cumulative percent scallop mortality in experiment 2, after 96 hours, comparing predation to non-predation mortalities in experimental chambers containing starfish.

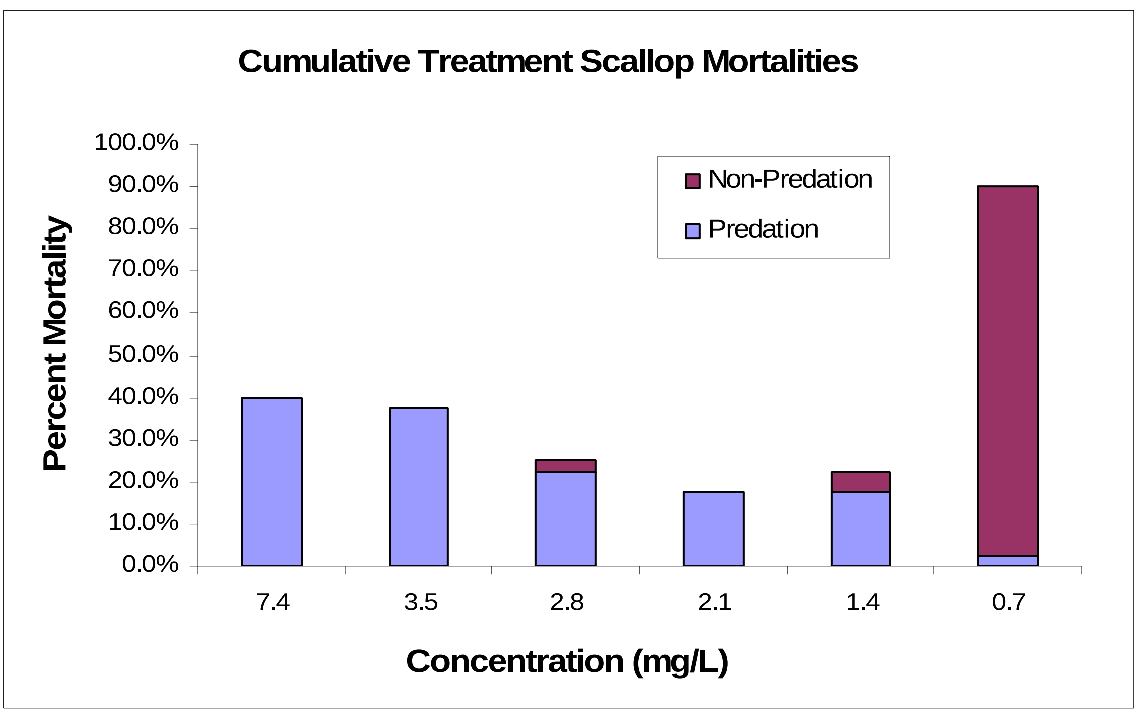


Table 4. Abundance, ±SE and survival of oysters on cultch sampled from both the nursery and floating upweller prior to seeding in 2005.

Sampling Date	Tank	Mean spat/bag (at seeding)	SE spat/bag	No. spat/set	SE spat/set	% Survival
Set 1						
30-Aug-05	Large	1,862	252	402,264	54,252	12
24-Sep-05	Small	1,849	353	299,473	57,251	12
Set 2						
10-Sep-05	Large	932	167	200,434	35,959	6
10-Sep-05	Small	485	188	78,624	30,510	3
Set 3						
10-Oct-05	Large	1,108	187	238,275	40,098	7
10-Oct-05	Small	982	109	159,003	17,577	6

Figure 12. Size distribution of remote set oysters from both the floating upweller and nursery area.

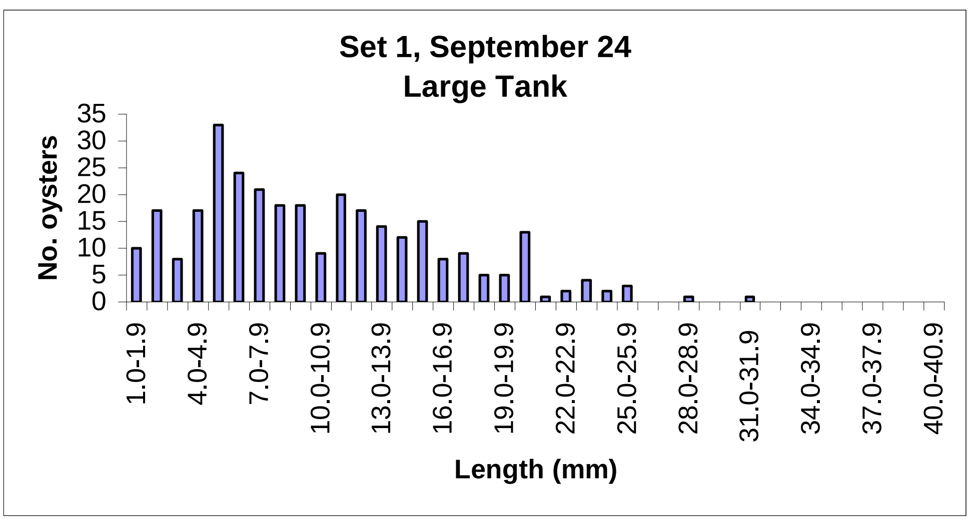
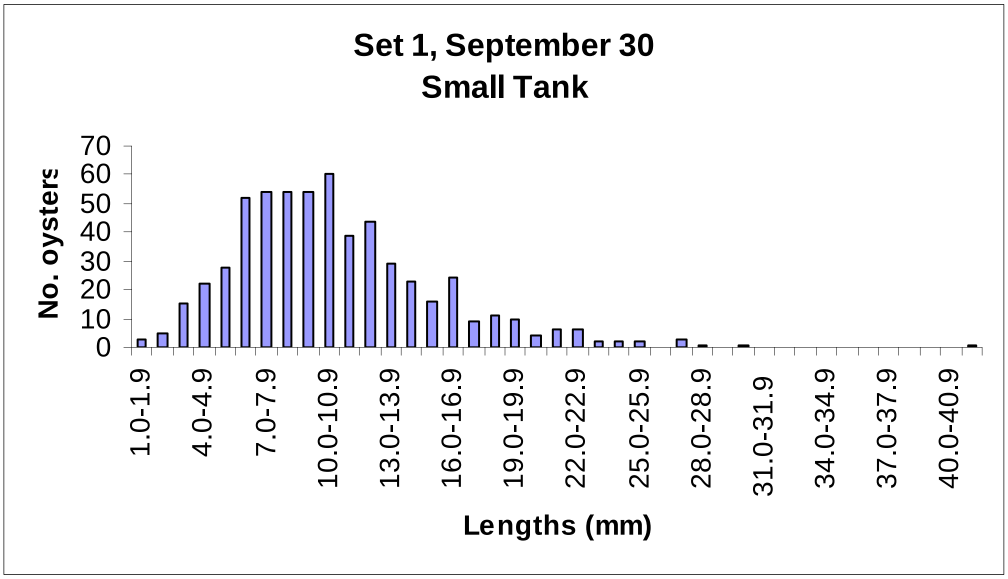


Figure 12. continued.



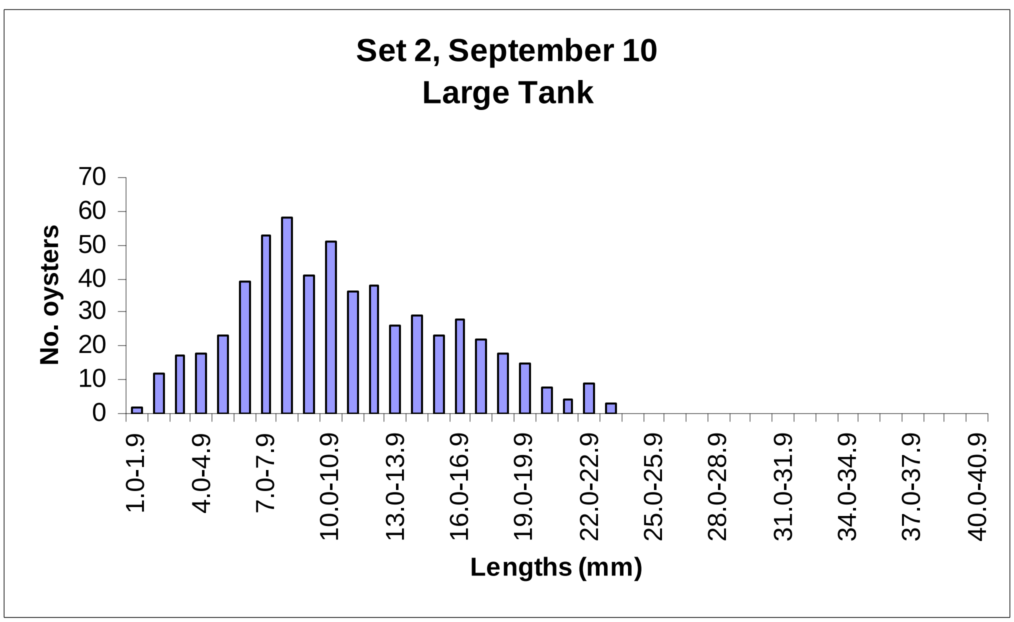
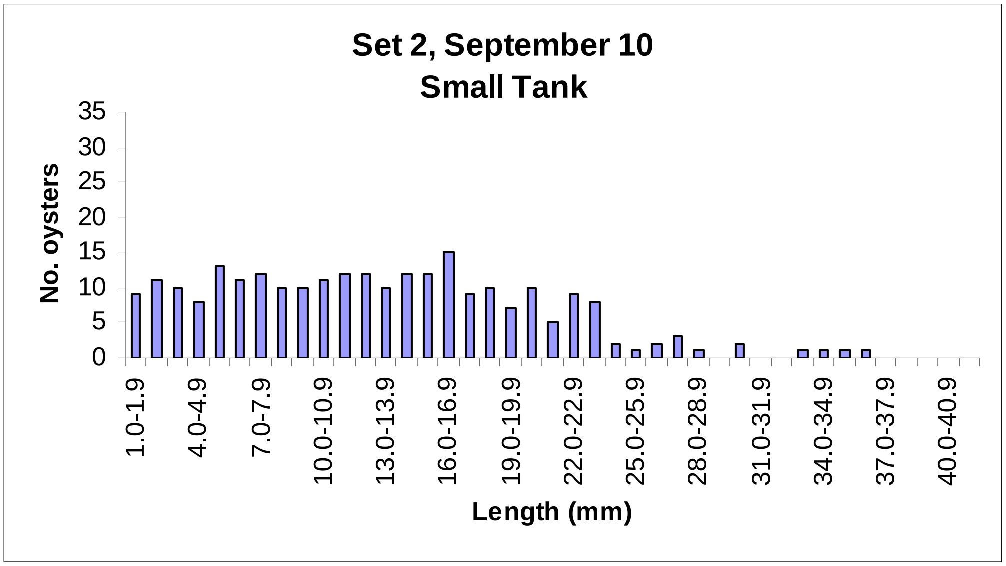


Figure 12. continued.



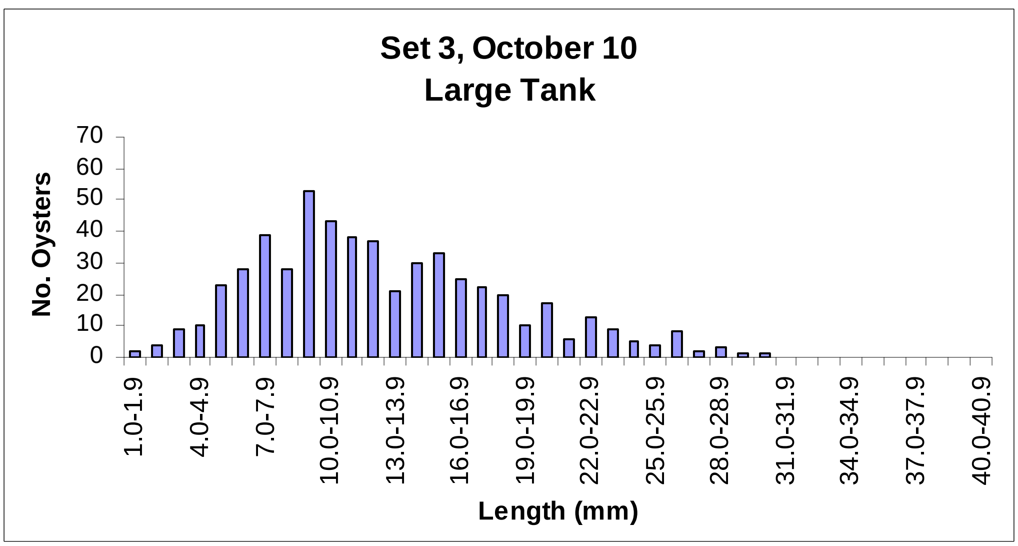
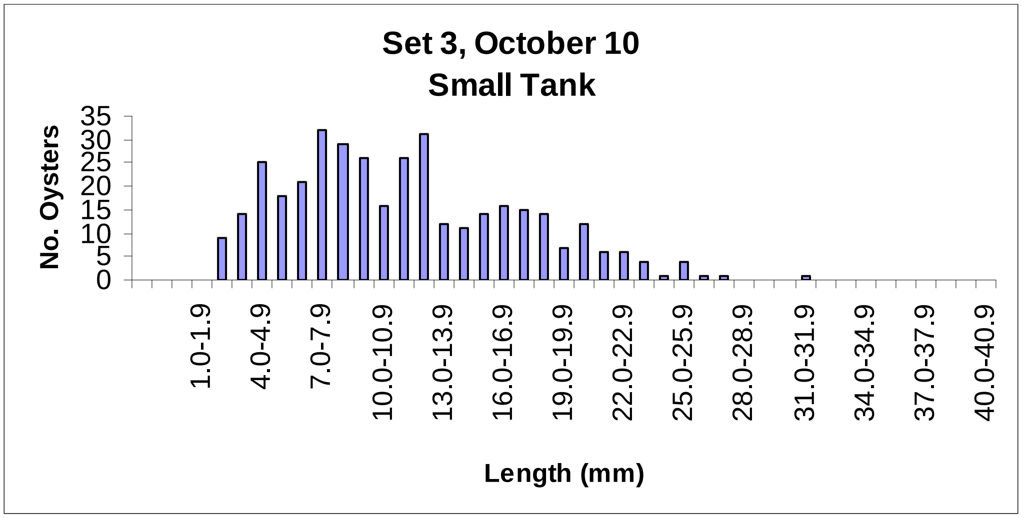


Figure 12. continued.



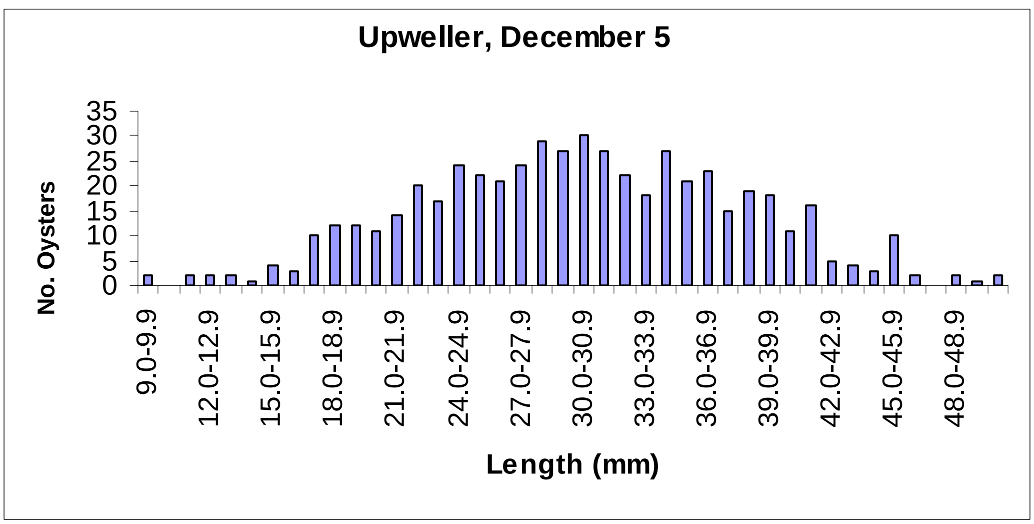


Figure 13. A comparison of the length distributions of the oysters in the CFL nursery to those grown in the upweller at Camp Fuller.

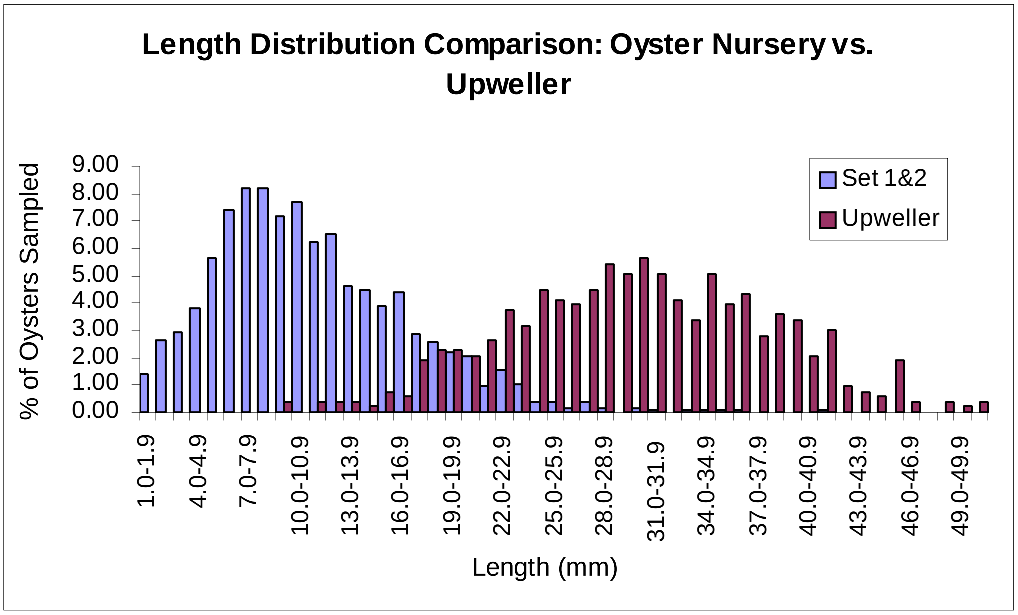
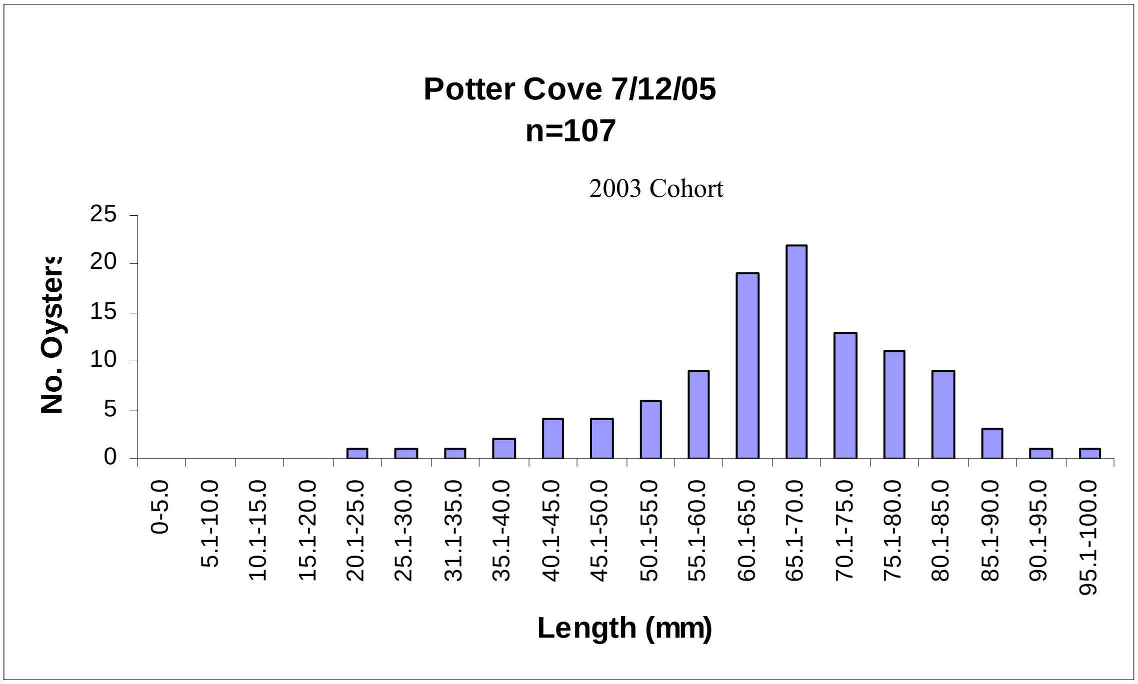


Table 5. Oyster abundance estimates from restoration sites seeded in 2003 and 2004.

Site	No. Quadrats	Total No. Alive	Mean Alive (m^{-2})	SE	Seeded Area (m^2)	Estimated Total Live	SE
Smelt Brook Cove	48	511	10.65	2.12	2,016	21,470	4,274
Saugatucket River	44	1,990	45.23	10.18	2,048	92,625	20,849
Bissel Cove Deep	48	53	1.10	0.46	5,047	5,552	2,322
Bissel Channel	48	582	12.13	3.79	1,784	21,640	6,761
The Cove	49	61	1.24	0.27	3,317	4,113	896
Potter Cove	50	107	2.14	0.45	3,324	7,113	1,492

Figure 14. Size distribution of remote set oysters planted in 2003 and 2004 that were sampled in 2005.



Potter Cove was only seeded in 2003.

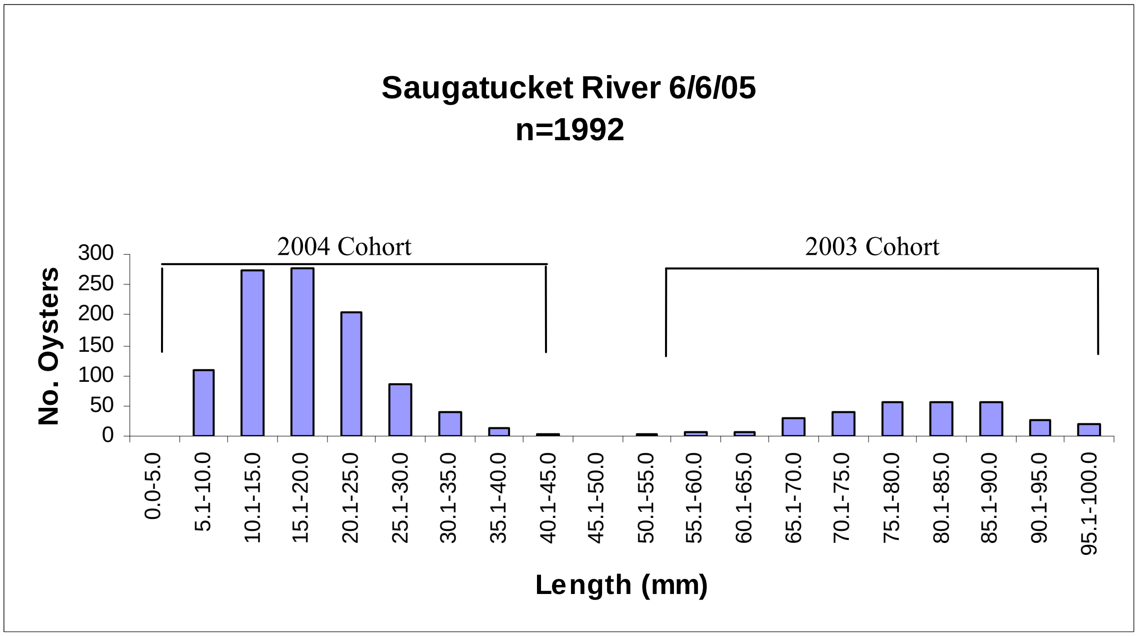
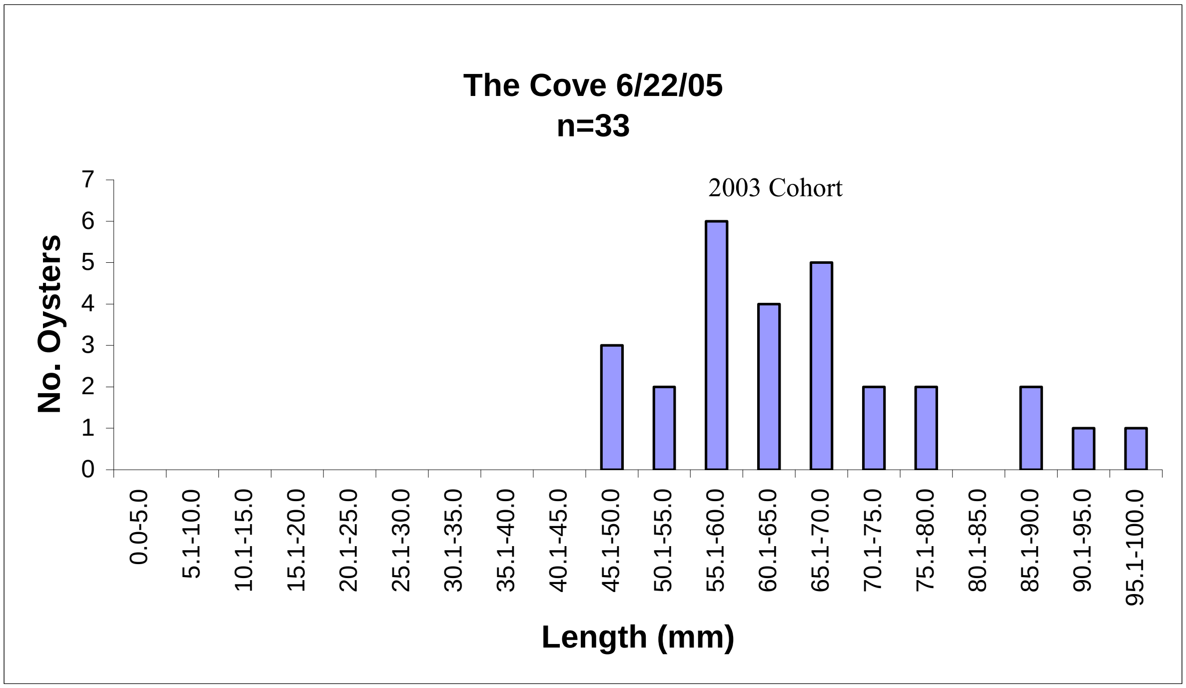
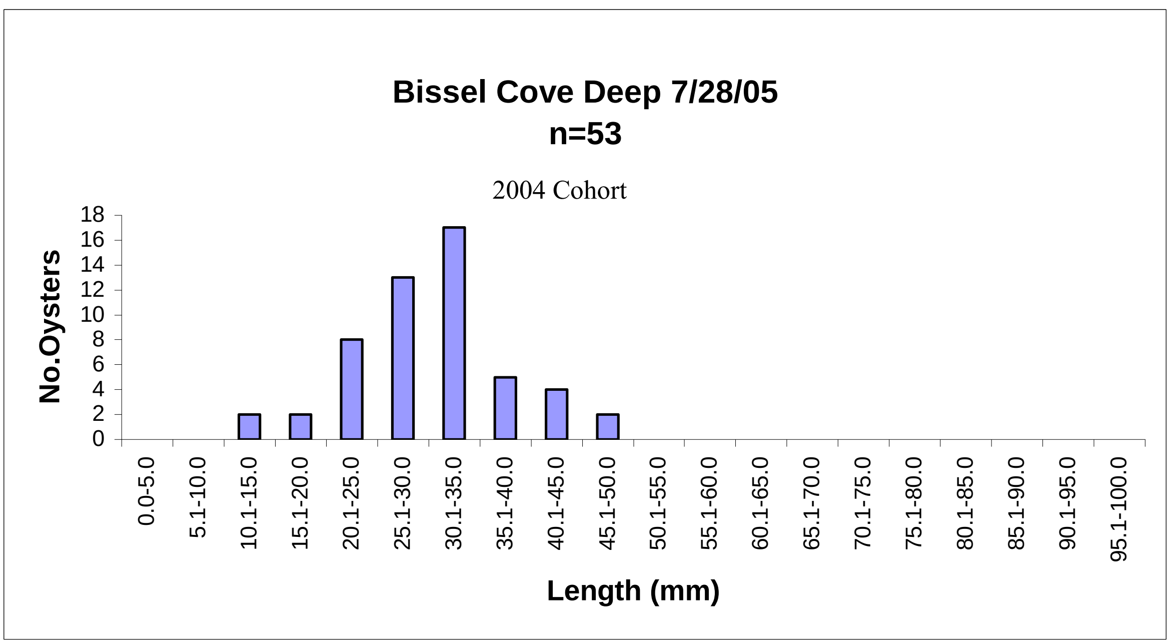


Figure 14. continued.

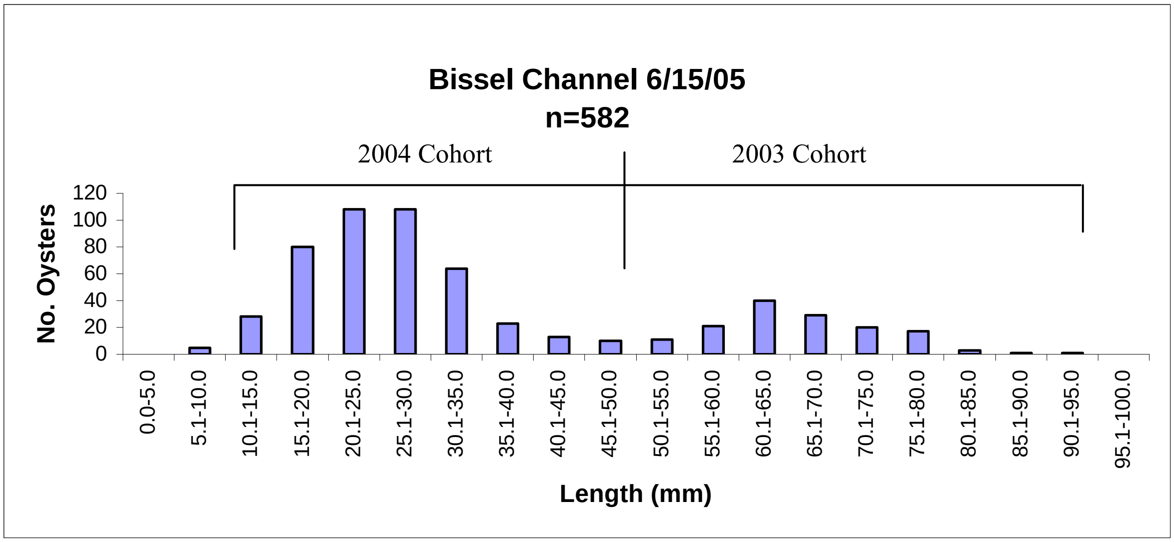


The Cove were only seeded in 2003.



The deep site at Bissel Cove was only seeded in 2004.

Figure 14. continued.



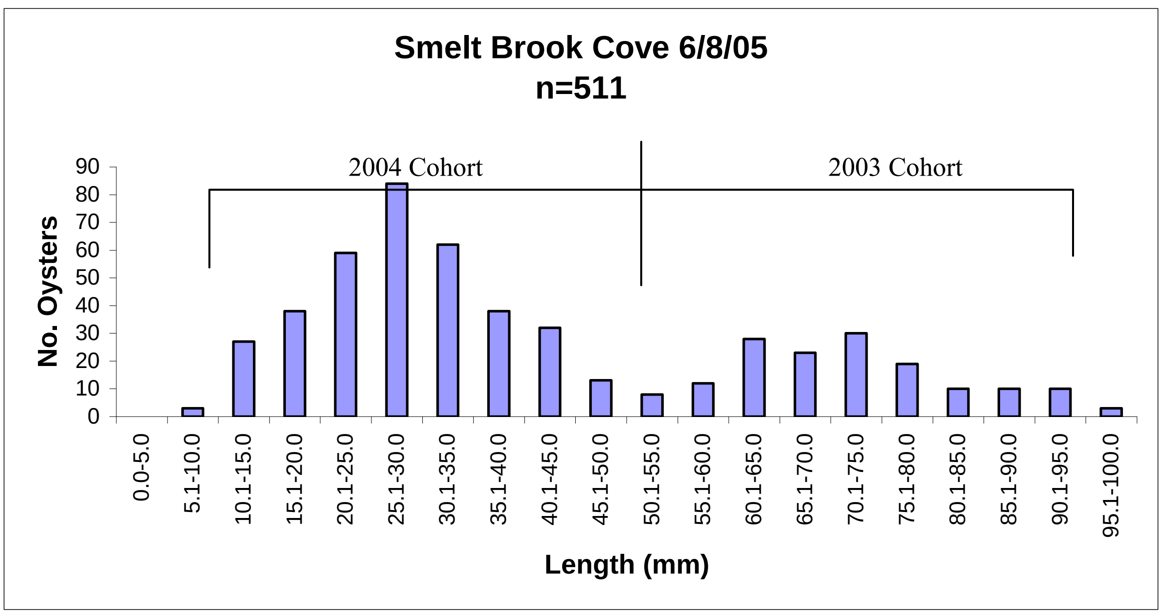
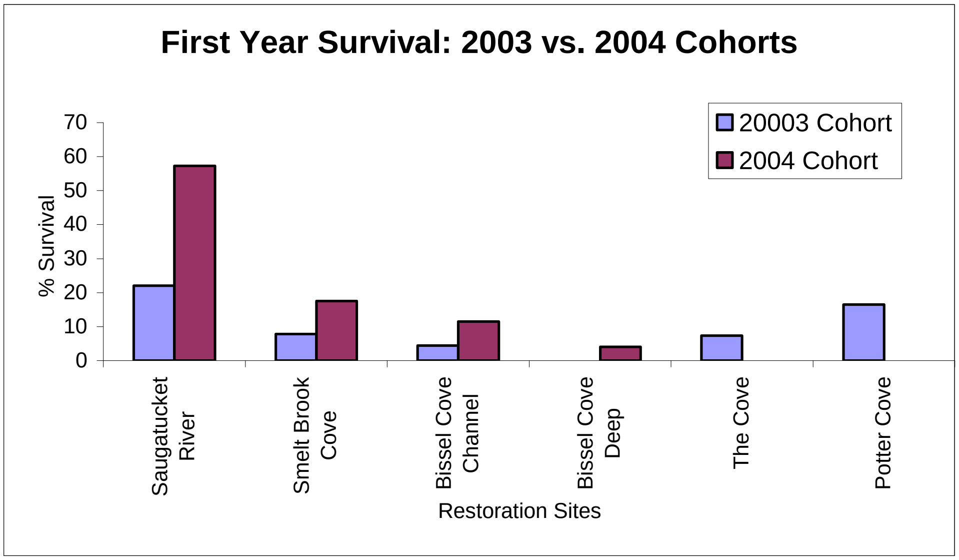


Figure 15. Survival of the 2003 and 2004 oyster cohorts for each restoration site.



Spectacle and Potter Coves were only seeded in 2003, and the deep site at Bissel Cove was only seeded in 2004

Figure 16. Percentage survival of the 2003 oyster cohort in the second year (2004-2005) at each restoration site seeded in 2003.

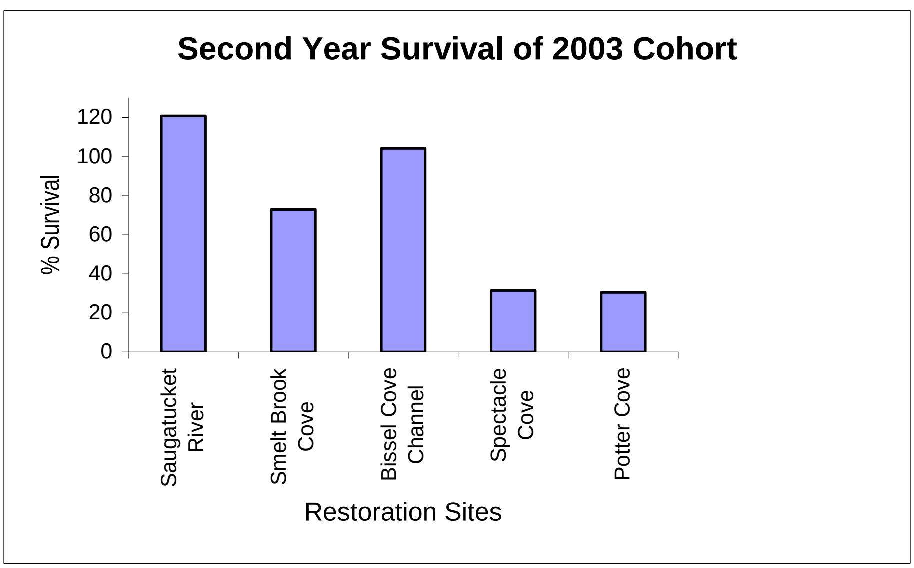


Figure 17. Comparison of the first year of growth for the 2004 and 2003 cohorts for each seeded site. (Note: Spectacle and Potter Cove were only seeded in 2003, the deep site at Bissel Cove was only seeded in 2004).

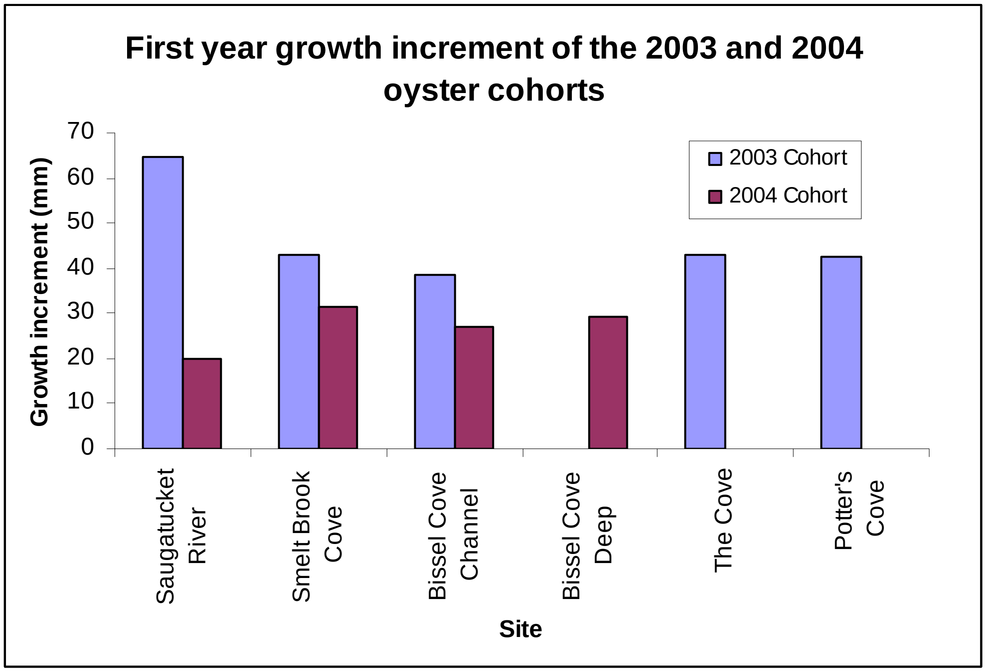


Figure 18. Growth increment of 2003 cohort from surveys conducted in August 2004 and July 2005.

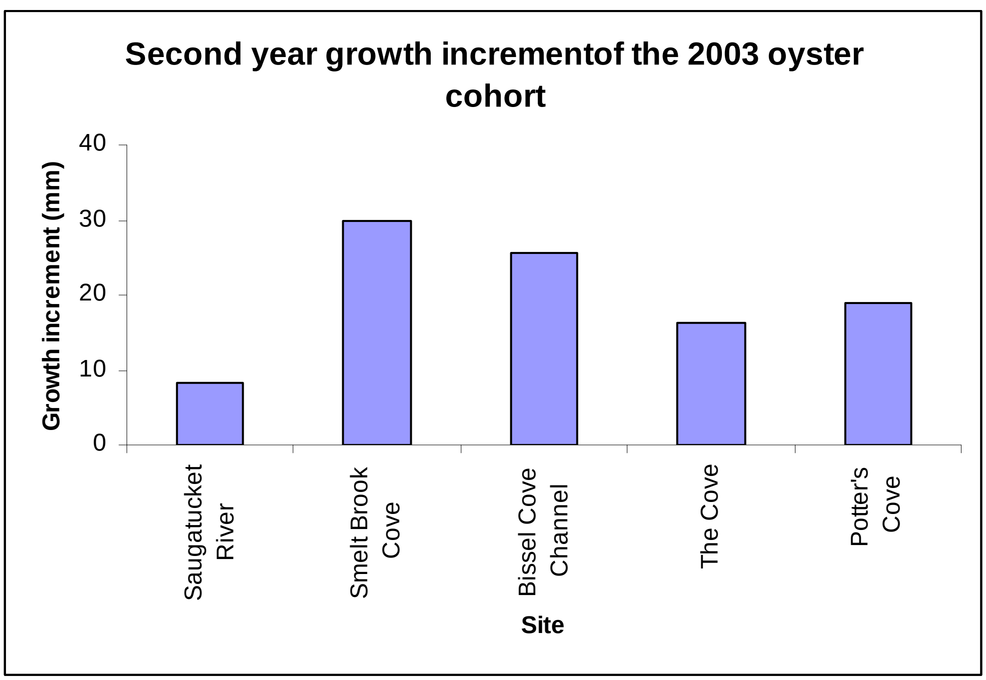


Table 6. Origin and number of oyster spat released in four restoration sites in 2005.

	Tank	No. Bags	No. Spat/Bag	No. Spat
Saugatucket River				
Set 1	Large	48	1,862	89,392
	Small	26	1,849	48,064
Set 2	Large	49	932	45,680
	Small	24	485	1,1648
Set 3	Large	50	1,108	55,413
	Small	23	982	22,575
Total		220		272,771
Smelt Brook Cove				
Set 1	Large	62	1,862	115,465
	Small	30	1,849	55,458
Set 2	Large	74	932	68,987
	Small	30	485	14,560
Set 3	Large	75	1,108	83,119
	Small	36	982	35,334
Total		307		372,922
The Cove				
Set 1	Large	52	1,862	96,841
	Small	52	1,849	96,127
Set 2	Large	49	932	45,680
	Small	46	485	22,325
Set 3	Large	47	1,108	52,088
	Small	49	982	48,094
Total		295		361,156
Potter Cove				
Set 1	Large	56	1,862	104,291
	Small	48	1,849	88,733
Set 2	Large	54	932	50,342
	Small	52	485	25,237
Set 3	Large	48	1,108	53,196
	Small	50	982	49,075
Total		308		370,874

Table 7. Results from disease tests for Dermo at the 2003 seeded restoration sites.

Site	Disease Prevalence (%)	Mackin Index Rating
Saugatucket River	100	4
Smelt Brook Cove	100	3
Bissel Cove Channel	11	1
The Cove	60	1
Potter Cove	24	1

Disease prevalence was measured using a Mackin Index, composed of a scale of 0-5 where 5 is heavy infection and 0 is no infection present.

Table 8. Results from disease tests for Dermo in the alternative sites selected for possible future seeding. Disease prevalence was measured using a Mackin Index composed of a scale of 0-5 where 5 is heavy infection and 0 is no infection present.

Site	Disease Prevalence (%)	Mackin Index Rating
Sheffield Cove	100	4
Potowamut River	84	2
The Cove	76	3

Disease prevalence was measured using a Mackin Index, composed of a scale of 0-5 where 5 is heavy infection and 0 is no infection present.

Figure 19 Chart of experimental and seeded sites in Quonochontaug Pond.

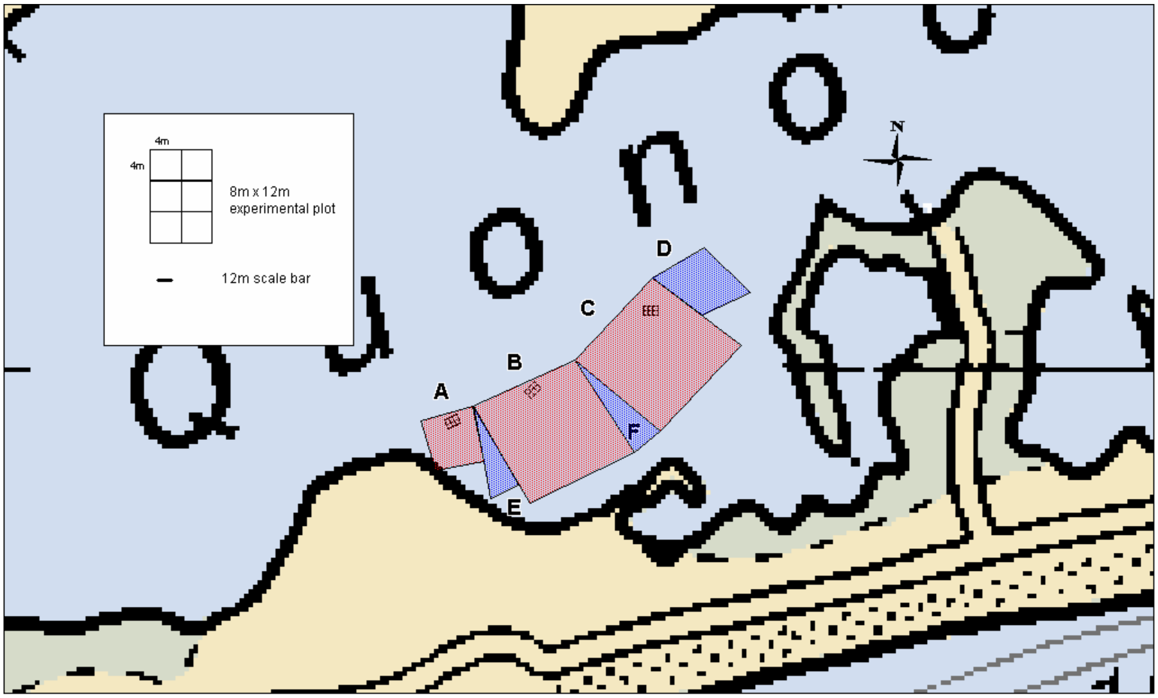


Figure 20. Schematic diagram of the design of 1 of the 3 experimental plots used to investigate growth and mortality of released quahog seed in Quonochontaug Pond.

	4m	4m	
4m	6mm quahog 10 m^{-2}	13mm quahog 100 m^{-2}	4m
4m	19mm quahog 100 m^{-2}	6mm quahog 100 m^{-2}	4m
4m	13mm quahog 10 m^{-2}	19mm quahog 10 m^{-2}	4m

Figure 21. Mean percent survival of quahogs for four different size classes, seeded at 10/m² and 100/m² in three replicate experimental plots in Quonochontaug Pond. Numbers indicate the mean percent survival for each treatment. No percent standard errors were calculated for the 25.9mm size as this treatment was not replicated.

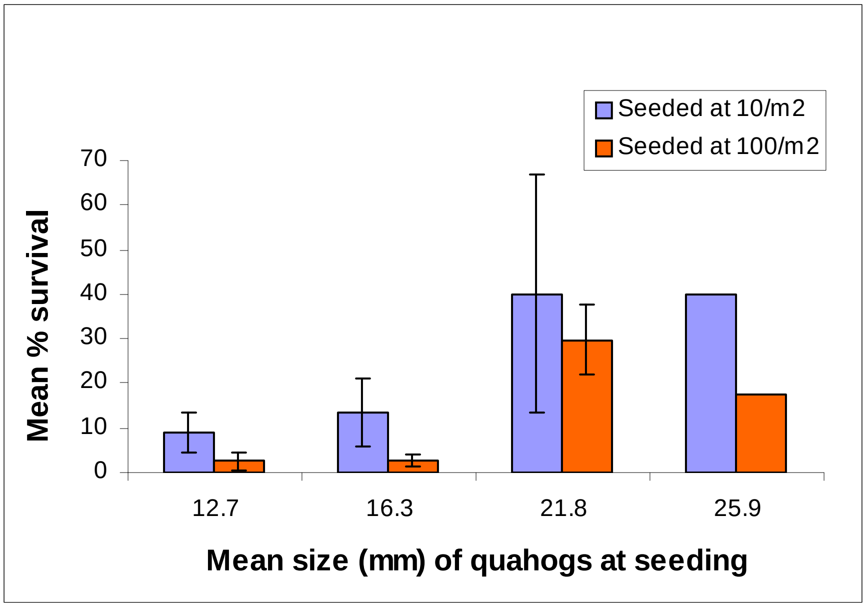


Table 9. ANOVA of annual quahog survival in Quonochontaug Pond between September 2004 and September 2005, from three separate blocks seeded with three sizes of seed each at $10m^{-2}$ and $100m^{-2}$.

Source	df	Mean square	*F*-ratio	p
Block	2	2094.222	3.65	0.034
Size	2	4726.222	8.24	< 0.001
Density	1	1102.519	1.92	0.172
Size * Density	2	26.963	0.05	0.954

Table 10. Growth, survival and abundance of quahog seeded in shellfish sanctuaries in Quonochontaug and Ninigret Ponds.

Site	Quonochontaug Pond	Ninigret Pond
No. quahogs seeded	316,194	318,737
No quadrats sampled	24	25
Mean density (m^{-2})	0.46	3.28
SE	0.23	0.89
Mean % survival	5.42	32.8
SE	2.3	8.9
Estimated abundance	17,127	104,546
SE	7,366	28,301
Mean length (mm)	40	41
Growth increment (mm)	26.2	27.2
Months at liberty	12	13

Figure 22. Comparison of percent survival of 1+ year-class quahogs from two bottom growout treatments and a floating upweller.

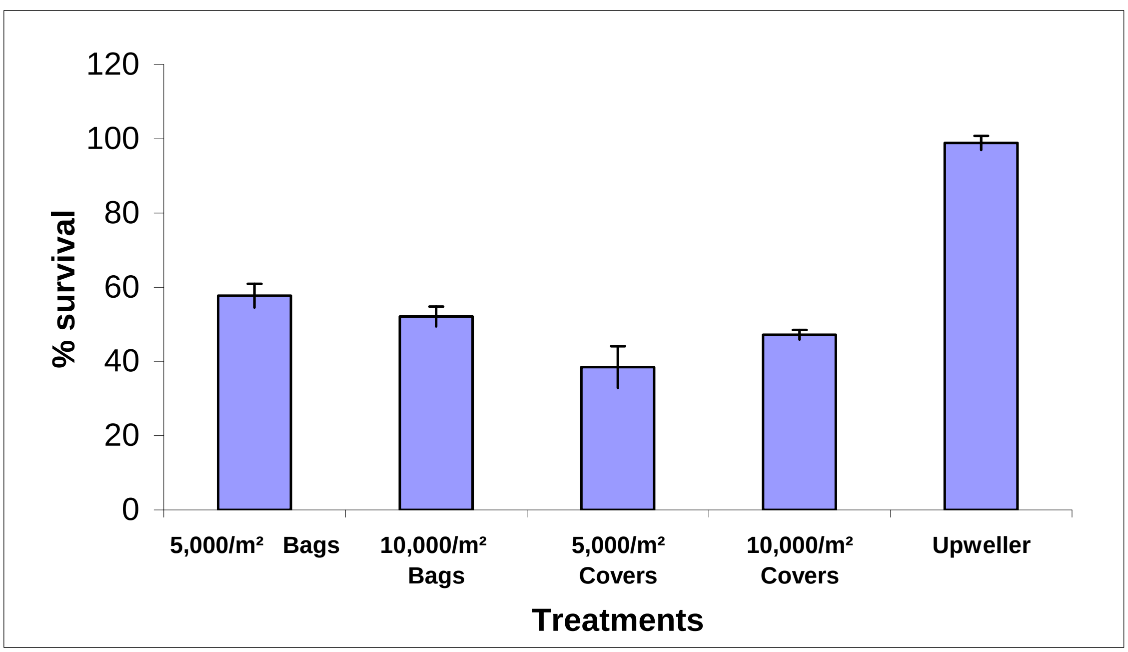


Figure 23. Mean growth increments for quahogs from two bottom growout treatments and a floating upweller in Point Judith Pond, ±SE (at recapture).

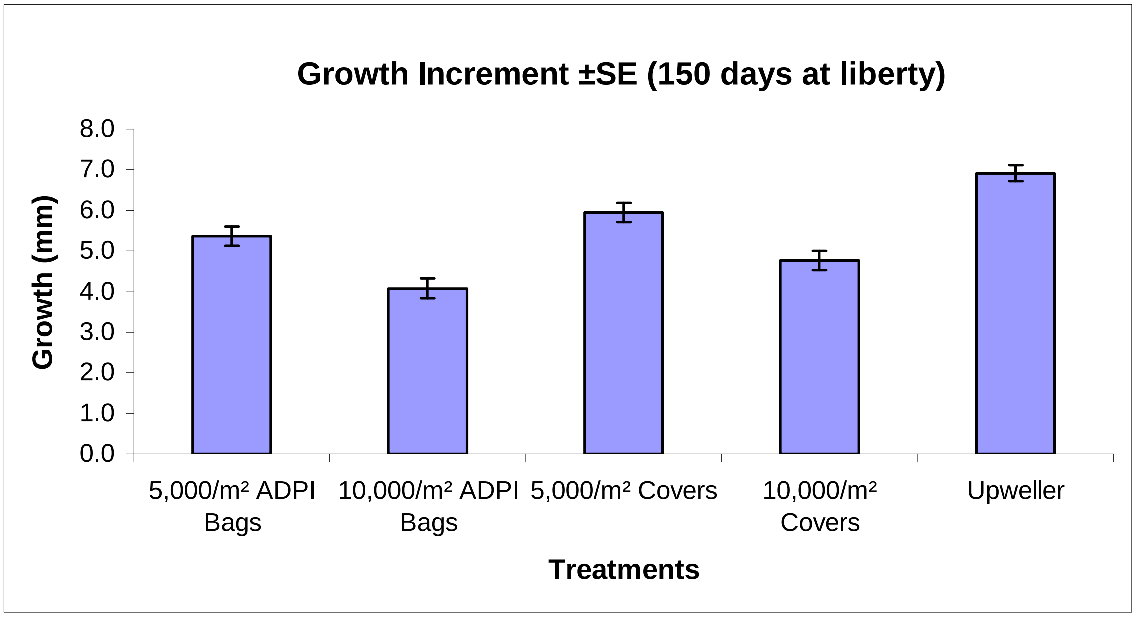


Table 11. Abundance and percent survival ±SE of quahogs from three replicates of each bottom growout treatment, and from the Camp Fuller floating upweller.

Treatment	Replicate Sampled	Initial # (July 05)	SE	# of survivors (Nov. 05)	SE	Mean % Survival	SE (%)
5,000 Bag	1	1,575	134	856	34	54.3	2.2
	2			891	48	56.6	3.1
	3			980	23	62.2	1.5
	Total # bags	11					
	Total # quahogs	17,325	1,471	9,997	407	57.7	2.3
10,000/Bag	1	3,150	267	1,764	57	56.0	1.8
	2			1,683	75	53.4	2.4
	3			1,477	55	46.9	1.7
	Total # bags	6					
	Total # quahogs	18,900	1,605	9,847	512	52.1	2.7
5,000/m² Covers	1	2,600	220	1,279	290	49.2	11.2
	2			937	82	36.1	3.2
	3			785	123	30.2	4.7
	Total # covers	6					
	Total # quahogs	15,600	1,319	6,001	876	38.5	5.6
10,000/m² Covers	1	5,200	440	2,382	336	45.8	6.5
	2			2,391	320	46.0	6.1
	3			2,588	202	49.8	3.9
	Total # covers	4					
	Total # quahogs	20,800	1,759	9,814	268	47.2	1.3
Upweller (Small)				10,677	323		
Upweller (Large)				26,811	1,353		
	Total # quahogs	37,914	3,209	37,488	1,676	98.9	4.4

SE per bag = SE calculated from the 3 sub samples taken from each bag
SE for the estimate of the total No. of quahogs remaining for each treatment = SE of the abundance estimates for the 3 replicates sampled