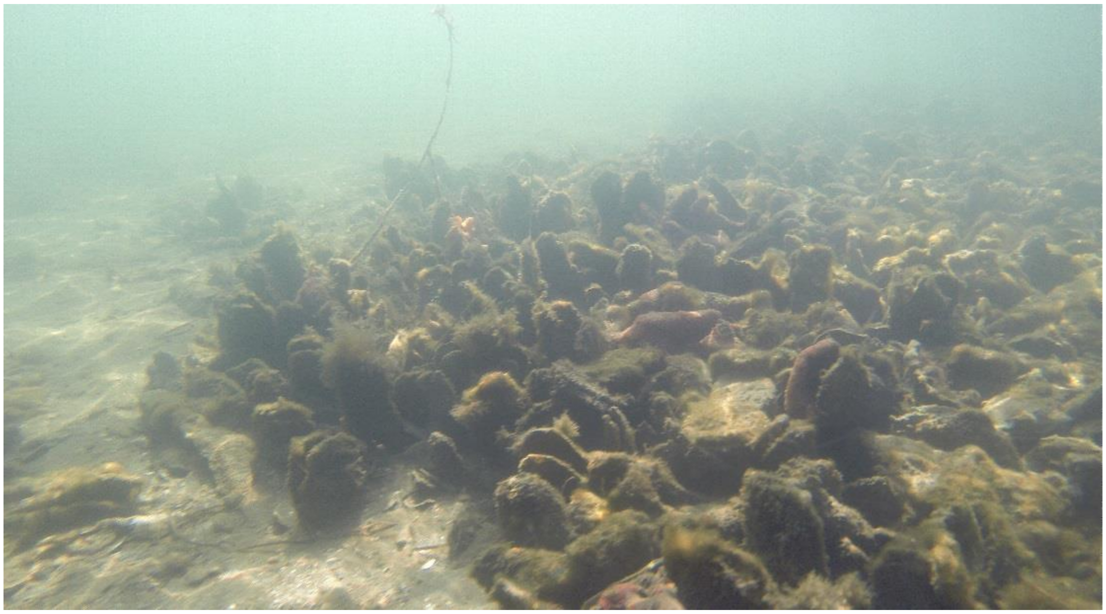
Assessment and Monitoring for the Oyster Reef Restoration Initiative

- Final Report -



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Recipient Program: Rhode Island Department of Environmental Management
Division of Fish and Wildlife, Marine Fisheries
Fort Wetherill Marine Fisheries Laboratory
3 Fort Wetherill Road, Jamestown, RI 02835

Program Contact: Eric Schneider, Principal Marine Fisheries Biologist
Technical Staff: William Helt, Marine Fisheries Specialist
Prepared By: William S. K. Helt and Eric G. Schneider

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Summary

This report summarizes the work conducted by Rhode Island Department of Environmental Management, Division of Fish and Wildlife, Marine Fisheries (DFW) in accordance with the Statement of Work contained within USDA Natural Resource Conservation Service (NRCS) Agreement No. 68-1535-14-08. The purpose of this work was to provide essential eastern oyster (*Crassostrea virginica*) resource assessment and restoration information to support and guide current and future NRCS practices in the coastal lagoons of Rhode Island and in Narragansett Bay. Prior to conducting this work, oyster restoration sites established by the former NRCS Environmental Quality incentives Program (EQIP) Oyster Reef Restoration Initiative (Oyster Initiative), as well as native oyster reefs, had not been adequately monitored. Thus, the Rhode Island Department of Environmental Management, Division of Fish and Wildlife, Marine Fisheries (DFW) lacked basic information, such as the current status and overall effectiveness of these former practices, which was needed to identify the appropriate location for oyster restoration and implement adaptive management strategies aimed at improving the restoration work conducted by the NRCS EQIP Oyster Initiative.

This work aimed to monitor oyster restoration sites established by former NRCS EQIP Oyster Initiative and native oyster reefs to determine the success of previous restoration work, provide guidance for future restoration sites, and develop adaptive management strategies for improving the existing contracted restoration work. The monitoring and assessment conducted as part of this work found that oyster density across these former EQIP restoration sites is highly variable, and typically contained many large oysters with few recent recruits. Oyster density appears to increase with reef height, suggesting that reef design should be revised in future restoration work. Based on the current status of the oyster reefs formerly established by the NRCS EQIP Oyster Initiative, we recommend that future EQIP oyster restoration practices be conducted at the following sites (listed in order of highest current status): Great Salt Pond, Potter Pond, Quonochontaug Pond, Winnapaug Pond, Northern Ninigret Pond, Southern Ninigret Pond, Bissel Cove, and Point Judith Pond. In addition, further research and continued monitoring of current restoration practices are needed to improve adaptive management techniques that will ultimately lead to increased likelihood of successful oyster reef restoration.

Introduction

Oysters are known as “ecosystem engineers” and provide essential habitat services, such as improved water quality, habitat for fish and invertebrates, shoreline stabilization, carbon sequestration, and wave attenuation (Coen et al. 2007, Grabowski and Peterson 2007). It’s suspected that human-induced impacts including degraded water quality, habitat destruction, and overharvest in combination with disease prevalence has reduced eastern oyster (*Crassostrea virginica*) populations to a fraction of historic levels. This decline has led to a limitation in recruitment, where populations can no longer be sustained by a reduced supply of larvae and poor benthic conditions. In an effort to restore oyster populations, and thereby increase the ecosystem services and habitat functions they provide, the Natural Resources Conservation

Service (NRCS) developed the Environmental Quality incentives Program (EQIP) Oyster Reef Restoration Initiative (Oyster Initiative).

Unfortunately, most of the previous oyster restoration work in Rhode Island (RI) has not been adequately monitored and thus, the current status and overall effectiveness of these practices is poorly understood. Although tools exist (e.g., “Oyster Habitat Suitability Model” developed by TNC), RI Department of Environmental Management, Division of Fish and Wildlife, Marine Fisheries (DFW) lacks the basic information regarding the success of previous restoration work that could be used to site future restoration work and develop adaptive management strategies for improving the existing restoration work conducted by the NRCS EQIP Oyster Initiative.

Rationale and Purpose

Through the EQIP program, oyster aquaculturists are partnered with NRCS and DFW to restore aquatic habitats degraded by human activity by planting cultch and seed on shell at designated oyster restoration sites to provide habitat for rare and declining species. This partnership began in 2008 with the first round of oyster restoration work conducted under the NRCS EQIP Oyster Initiative. From 2008 through 2010 an estimated 117 oysters reefs across 8 areas (Figure 1) were created by this program. Unfortunately, these reefs have not been thoroughly monitored and quantified for success since being created.

The purpose of this work was to provide essential eastern oyster (*Crassostrea virginica*) resource assessment and restoration information to support and guide current and future NRCS practices in the coastal lagoons of Rhode Island and in Narragansett Bay. Existing oyster restoration sites and native oyster reefs were monitored to determine the success of previous restoration work, provide guidance for future restoration sites, and develop adaptive management strategies for improving the existing contracted restoration work.

The overarching goal of this work was to collect information that would improve all aspects of oyster restoration efforts through adaptation of techniques and improved decision making with respect to habitat assessment and final site selection. This work focuses on three primary goals: (1) Provide essential oyster resource assessment and restoration information, (2) Contribute to adaptive management plan, and (3) Guide future restoration work in Rhode Island’s coastal waters.

Objectives

In general, this work will provide critical information to improve oyster restoration practices. Specific objectives of this work are:

1) Facilitate the collection of oyster monitoring data as per the recommendations of the Rhode Island Oyster Monitoring Protocol for all essential parameters not including artificial spat collectors.

2) Provide the data collected to NRCS on at least a semi-annual basis to ensure that site selection and adaptive management innovations are incorporated as quickly as possible.

3) Provide quarterly updates and conduct quarterly meetings with NRCS and other stakeholders to discuss any emerging issues of concern.

4) Compile a final report that documents the optimal areas and conditions for future oyster restoration projects, as well as recommendations for improving existing restoration sites.

Expected Accomplishments and Deliverables

Based on these objectives, the following deliverables were identified as part of this work:

1) Complete the "Essential Monitoring" requirements detailed in the Rhode Island Oyster Restoration Minimum Monitoring Metrics (Griffin et al. 2012), except for number 3 (i.e., recruitment monitoring using artificial pat collectors) for the 8 former EQIP sites (e.g., Point Judith Pond, Potter Pond, Ninigret Pond, Quonochontaug Pond, Winnapaug Pond, Bissel Cove in Narraganset Bay, Jenny’s Creek in Narraganset Bay, and Great Salt Pond on Block Island) and 2 native sites (e.g., Winnapaug Pond, Quonochontaug Pond), which were listed in the original Monitoring Budget document.

- Note: we had originally expected that the EQIP sites would be monitored twice, except for Block Island; however, this was later modified to a single monitoring series– see Modifications Section below.

2) Complete Oyster Reef Monitoring for the 4 remaining native sites (Ninigret Pond, Potter Pond, Point Judith Pond, and Bissel Cove in Narraganset Bay), which were listed in the original Monitoring Budget document.

3) Compile data and complete a report that outlines the status of each reef sampled, and rank each reef based on the quality of the habitat and the survivability of the oyster population. The report should outline the areas that will provide the highest likelihood of success for future restoration.

4) Select sites for potential future sanctuaries that will be used for the Rhode Island EQIP Reef Oyster Restoration Initiative.

Modifications

After reviewing the intensity and overall quality of data collected, and considering the time and staffing requirements needed to conduct and complete the initial monitoring of all former EQIP sites and natural sites (once), the DFW and NRCS (Gary. Casabona, PI, NRCS) agreed that a single, robust monitoring of former EQIP and natural sites was sufficient to satisfy the goals and objectives of this work. Thus, the modification to conduct only a single monitoring of the identified former EQIP and natural sites was determined to be an acceptable modification.

The following aspects were considered when evaluating this modification:

1) The amount of time and staffing required to conduct the initial monitoring was severely underestimated when this project was scoped. For example, the Monitoring Budget estimated that 71 field days would be required to conduct the two samplings of the EQIP reef sites and one sampling of natural reefs sites. In reality, it took DFW 80 days to complete only one sampling of the EQIP reef sites and natural reef sites; ~13 % greater than anticipated, and budgeted, for the entire monitoring work, including both the first and second monitoring events. The reason for the underestimate of the level of work required is due to the fact that this monitoring had not been previously conducted and thus, there were no previous budget and staffing estimates available to estimate the level of work. Funding was secured in order to offset the extra field days required to complete the first round of EQIP monitoring through the Rhode Island Coastal and Estuary Habitat Restoration Fund administered by the Coastal Resource Management Council.

2) Given the age of the EQIP reefs and considering that these reefs had not been monitored prior to this work, DFW conducted a level of monitoring that was both robust and greater than that required by the Statement of Work for this project. This additional level of monitoring took longer to conduct, but also provided both greater quality of data quality and insight into the status of a given reef and a system as a whole. It was determined that conducting a robust, higher quality single monitoring would be sufficient to satisfy the goals and objectives of this work, and in most cases more effective than conducting two rounds of monitoring at a reduced level of intensity.

Revised Timeline of Work

Summary of work completed through December 31, 2016:

a) Oyster Reef Monitoring
   i) Sampled 117 of 117 EQIP sites in 8 of 8 locations. We grouped multiple reefs into a single reef-unit, where reefs' margins were not discrete.
   ii) Sampled natural reefs in 6 of 6 locations.
b) Collect oysters for disease testing
   i) Collected oysters from former EQIP locations (fall of 2014 and 2015) and sent them to RWU for disease testing
c) Complete disease testing
   i) Received results from 2014 and 2015 disease testing in late February 2015 and 2016, respectively.

Methods

Between 2008 and 2010, 117 EQIP restoration oyster reefs were established across 8 ponds (Figure 1). In some cases, multiple reef sites were sited in close proximity, thus the continuous reef was monitored as such. In addition, some reefs were not found, thus the final number of reefs is less than 117 (Table 2). All found EQIP reefs were monitored as well as native reefs in 6 ponds (Figure 1). EQIP reefs in Ninigret Pond were split to represent two spatially discrete groups, a norther group (N Ninigret Pond) and a southern group (S Ninigret Pond), each representing different habitat settings. Oyster reef monitoring follows the Essential Monitoring requirements of the Rhode Island Oyster Restoration Minimum Monitoring Metrics and Assessment Protocols, not including artificial spat collection (Griffin et al. 2012).

Reef Site Characteristics

To measure water quality, an YSI handheld conductivity meter (YSI-85) placed directly above the reef recorded water temperature (C), salinity (ppt), and dissolved oxygen (mg/L) at the time of oyster sampling (Figures 8 & 9). Quadrats were used to quantify benthic substrate and macroalgal cover using standard cover classes for percent coverage (Carlisle et al. 2004). Location of the reef was recorded on a Garmin GPSMAP 78sc handheld device by referencing the longitude and latitude of the reef's center point. Reef area was estimated by measuring the maximum span of the reef North to South and East to West. Mean reef height was estimated by sampling the height of reef from the bottom within the center of each quadrat sample.

Oyster Sampling

Oysters were sampled by haphazardly placing quadrats on the reef and excavating all contents up to 10cm below the reef surface. Quadrat size ($1m^2$ or $1/4m^2$) was determined based on oyster density and reef size. The number of quadrats sampled per reef was based on the variance in oyster density and general composition of the reef. For example, reefs with homogenous densities of live oysters required fewer quadrats to accurately assess reef composition and status. At minimum, 3 quadrats were sampled per reef, assessing 2-10% of the overall reef area.

In order to quantify oyster density, all live and recently dead oysters (oysters with hinge still intact) were enumerated, while recording new recruits, number of drill holes, and presence of boring sponge. Length of oysters found in the quadrat were measured from the umbo to the edge of the lip to the nearest millimeter. When reasonable, oyster measurements were subsampled, totaling 50 live and 30 dead oysters per quadrat. Other shellfish within the quadrat were measured and enumerated, and abundance of non-shellfish species were roughly estimated.

In order to map and assess natural reefs, we performed a visual inspection for oysters along the shallow subtidal coastline of all ponds monitored. Oysters were considered a reef when found at densities greater than $0.2m^2$. This density threshold allowed us to focus on aggregations of oysters rather than sampling sparse individual recruits. Reefs were then sampled using the same monitoring metrics as the EQIP reefs.

Oyster Disease Testing

From each restoration area 15-30 individual oysters were collected for processing by Dr. Roxanna Smolowitz of the Aquatic Diagnostic Laboratory at Roger Williams University.

Presence and intensity of Dermo (*Perkinsus marinus*), MSX (*Haplosporidium nelsoni*), and SSO (*Haplosporidium costale*) were measured by triplex qPCR. Intensity of disease was quantified using a Mackin Index, in which 0 = no infection, 0.5 very light, 1 = light, 2 = light-moderate, 3 = moderate, 4 = moderate-heavy, and 5 = very heavy (Mackin 1962).

Data Analyses

All field data collected were entered into a relational Access database for quality assurance and long-term data management. The database was then queried for descriptive statistical analyses that were conducted using R- statistical software (R Core Team, 2013). Spatial analyses regarding the location of potential future EQIP work were conducted using ArcGIS (GIS software, ESRI, 2014). Other spatial layers used for future EQIP reef siting were subaqueous soils, The Nature Conservancy's Oyster Habitat Suitability Index, depth contours, and DEM's Shellfish Management Areas and Spawner Sancutaries. In this report, the average density of oysters are presented as the arithmetic mean ± 1 standard error (Mean±SE) per m^2.

Results

Oyster Sampling

Oyster Density

To serve as a baseline metric, s6 ponds were surveyed for naturally occurring oysters. Although individual oysters were occasionally found at previously documented natural reef sites, distinct reefs (i.e., densities greater than $0.2m^2$) were only found in Foster Cove, within Ninigret Pond. Foster Cove contained 5 discreet oyster reefs along the Northern and Eastern shores, with a mean oyster density of 67.6±11.9 m^2.

Oyster density varied across former EQIP sites (Figure 2). EQIP restoration sites with similar density to the natural reefs in Foster Cove are Potter Pond and Winnapaug Pond with mean oyster densities of 58.4±6.7 m^2 and 52.3±3.6 m^2, respectively. Great Salt Pond's mean oyster density was 208.4±36.4 m^2, which is 208% higher than that of the natural reefs in Foster Cove. Quonochontaug Pond contained oysters at a density of 26.1±5.8 m^2. Bissel Cove, N Ninigret Pond, S Ninigret Pond, and Point Judith all exhibited very low oyster densities at 2.7±2.7 m^2, 1.3±0.4 m^2, 3.4±0.8 m^2, and 2.0 m^2, respectively.

Live Oyster Size Distribution

Live oysters sampled on EQIP reefs spanned a range of 8mm to 287mm (Table 3). The mean length sampled across ponds was 97.3mm. The EQIP site with the smallest mean length was Great Salt Pond (63.8mm) and the largest was Winnapaug Pond (140.9mm). The natural reefs in Foster Cove contained a length distribution from 1mm to 83mm with a mean length of 29.9mm.

Dead Oyster Size Distribution

Dead oysters sampled on EQIP reefs spanned a range of 7mm to 287mm (Table 4). The mean length sampled across ponds was 99.8mm. The EQIP site with the smallest mean length was S Ninigret Pond (81.8mm) and the largest was Winnapaug Pond (130.8mm). The natural reefs in Foster Cove contained a length distribution from 7mm to 83mm with a mean length of 54.0mm.

Oyster Recruitment
New recruits are assumed to be any live oysters with a measured length of less that 25mm. The oyster population on natural reefs in Foster Cove is composed of 56±11% recruits (Figure 3). The new recruits in Foster Cove are found at a proportion over 7 times greater than in Great Salt Pond where new recruits compose 6.8% of the oyster population. Proportion of new recruits in the oyster population in Potter Pond and Quonochontaug Pond were 0.3±0.1% and 0.4±0.4% respectively. The standard error for new recruits in Quonochontaug Pond was high, because recruits were only found at one of the reefs sampled. In Bissel Cove, N Ninigret Pond, S Ninigret Pond, Point Judith, and Winnapaug Pond, no new recruits or negligible numbers were recorded.

Oyster density by reef height
Across all ponds, oyster density appears to increase with vertical reef relief (Figure 6). The lowest live oyster density reefs were found at reef heights of 0-5cm 17.0 m^2. Meanwhile, the highest live oyster density reefs were found at reef heights of 20.1 – 25.0cm at 106.7 m^2. On the natural reefs within Foster Cove, oysters were predominantly found on hard substrates such as rock or cobble.

Non-disease mortality

Boring Sponge Presence
Boring sponge was found present on oysters at EQIP reefs in N Ninigret Pond, S Ninigret Pond, Potter Pond, Quonochontaug Pond, and Winnapaug Pond (Figure 7; boring sponge presence was not recorded in Great Salt Pond). Among sites with boring sponge, the mean percentage of oysters with sponge present was 18.9%. The highest prevalence of boring sponge was found in N Ninigret Pond at 28.6% and the lowest when boring sponge was found was Winnapaug Pond 6.3%. Boring sponge presence was not sampled in Great Salt Pond.

Drill Hole Abundance
Drill hole abundance was either absent or present at negligible rates in all ponds sampled. Drill holes were only found on EQIP reefs in Quonochontaug Pond and Potter Pond at a rate of 0.01±0.0 and 0.0009 ±0.0009 (i.e., negligible) drill holes per oyster, respectively. Drill hole abundance was not sampled in Great Salt Pond.

Oyster Disease Testing

Oyster disease testing of individuals retrieved from EQIP reefs at all 8 locations shows high prevalence of Dermo with varying intensities (Table 5). Dermo was present in all oysters sampled at Potter Pond, Cormorant Cove, Winnapaug Pond, and Bissel Cove. MSX was only present at low level in Southern Ninigret Pond. SSO was present at Quonochontaug Pond, Potter Pond, and Bissel Cove.

Discussion

Oyster Sampling

Oyster Density and Size Distribution

Our results reveal very different oyster densities on EQIP restoration reefs across ponds; however, the lack of monitoring until present limits our ability to determine the influence of a given factor on reef health. Theoretically, oysters on reefs within an area protected from harvest, such as the locations of EQIP reefs sampled, should exhibit a broad size distribution, containing a mixture of new recruits, juveniles, and adults. Overall, all ponds contain reefs with adult oysters, which suggests that habitat conditions are suitable and stable enough to support oyster survival into adulthood. All ponds also contain juvenile oysters, which suggests that recruitment has occurred at some point in recent years. Furthermore, Potter Pond, N Ninigret Pond, and Quonochontaug Pond contain recent recruits. Unless spat have recruited within the year prior to sampling we cannot speculate when recruitment has occurred, because year classes are difficult to identify given the variable growth rate of oysters (Kraeuter et al. 2007). These results emphasize the need for annual reef monitoring.

On the natural reefs in Foster Cove, we found new recruits, as well as one to two-year-old oysters (Figure 4). We speculate that Foster Cove lacks large oysters, because some reefs are subject to harvest, and the reefs in shallow water (less than 2 ft. MLW) may succumb to mortality from freezing and ice scour during the 2014-2015 winter. Despite the presence of new recruits and juvenile oysters on the EQIP reefs, the relative abundances of these young oysters are not at a level that can repopulate and sustain the reef long-term. While oyster length on the EQIP reefs reveal a normal distribution of individuals (Figure 4), a self-sustaining reef should exhibit an even or exponential distribution with a larger representation of new and recent recruits. Given our findings, the EQIP reefs monitored will require maintenance seeding in order to persist.

It appears that oyster density on EQIP restoration reefs appears to positively increase with vertical relief of the reef (Figure 6). These results support findings by Schulte et al. 2009 who attributed the correlation to optimal flow rates at higher relief. Optimal flow rates are said to correspond to healthier physiological condition, which can maximize growth and survival while minimizing disease influence and sedimentation (Lenihan and Peterson 1998, Lenihan 1999).

Recently Dead Oyster Size Distribution

Sampling the length distribution of recently dead oysters is insightful, because it allows us to track their size at mortality. Our results reveal that the modal lengths of recently dead oysters at reefs within each EQIP site ranged between 75mm and 116mm. These results show that most mortality is occurring following the first year of growth, and we speculate that recent mortality is due to disease pressure, which is supported by our results from disease testing, showing that Dermo disease is prevalent across all ponds (Table 5; Encomio et al. 2005).

Ranking Potential Future EQIP Restoration Sites

Based on the current status of the former EQIP reefs, we recommend future EQIP oyster restoration practices be conducted at the following sites, listed in order of highest current status (see also Table 2). Though our confidence in this ranking is reduced by the lack of information pertaining to these reefs until recent monitoring, we suggest these rankings be used until more information is available. Since information regarding disease levels at the time of seeding and over time was not available, as well as the similar prevalence of Dermo disease across reef sites, we did not include disease pressure as a metric in our ranking.

Great Salt Pond

The highest density of oysters (208.4 m^2) was found on the EQIP reef in Great Salt Pond, specifically Cormorant Cove. Furthermore, a large proportion of oysters are less that 50mm and have likely recruited since reef construction. The presence of adult oysters shows that conditions are suitable for oyster survival. Unless the Cormorant Cove sites received undocumented supplemental seeding after the completion of the 2010 EQIP practices, they appear to be self-sustaining and suitable for continued oyster restoration.

Potter Pond

EQIP reefs in Potter Pond support an oyster density (58.4m^2) comparable to densities on natural reefs found in Foster Cove (68.0m^2). The presence of extremely large oysters on these reefs (>250mm) suggests that the oysters on these reefs grow quickly at a desirable density. We observed recruitment, but at low rates. We suggest continued restoration in Potter Pond coupled with maintenance seeding. The effect of reef height and over-seeding of previous reefs on oyster survival should be evaluated as part of future practices.

Quonochontaug Pond

Quonochontaug Pond supports EQIP reefs with an oyster density of 26.1m^2. Though the density appears low, these reefs may have been seeded at a lower density in order to cover a larger area. Oysters on these reefs exhibit a broad length distribution with some recruitment. Over time, many reefs became continuous and were monitored as one large reef. We suggest continued restoration in Quonochontaug Pond coupled with maintenance seeding.

Winnapaug Pond

EQIP reefs in Winnapaug Pond support an oyster density of 52.3m^2, which is comparable to densities found on natural reefs in Foster Cove. Though oysters on these reefs have grown extremely large (>250mm) at reasonable densities, minimal recruitment was observed. The habitat appears to be conducive for oyster growth and survival but not recruitment. If continued restoration occurs in this area, maintenance seeding is recommended.

N Ninigret Pond

Restoration reefs in N Ninigret Pond sustain the lowest density of oysters at 1.3m^2. The length distribution of oysters on these reefs suggests that oysters are capable of surviving in the habitat and have obtained recruits at some point, but not at a rate that is able to sustain these reefs. Many reefs appear to have subsided and been silted over, so future restoration in this area would require creation of reefs with more height can reefs should be carefully sited on firm sediment.

S Ninigret Pond
In S Ninigret Pond, oyster density on reefs was 3.9m^2. The low density coupled with no observed recruitment in recent years suggest that this area may not be suitable for continued restoration. We believe that the relatively higher wave action at this site may be responsible for the low observed oyster density in that the oysters may have been transported off the reef. Currently, restoration reefs created by the Fish Habitat Enhancement Project through DFW and The Nature Conservancy with a reef design intended to dampen the effects of wave action are being monitored. We suggest that the ranking of this area be revised based on the results from the Fish Habitat Enhancement reef monitoring.

Bissel Cove
Restoration reefs in Bissel Cove maintain a low mean oyster density (2.7 m^2) and only 2 of the 8 documented reefs were found. Furthermore, some reefs sited in close proximity became one continuous reef over time. This system likely has the potential for high larval retention and appears to have suitable conditions for oyster survival provided oysters are elevated in the water column. If future work occurs in this area, significant reef height must be achieved in order to account for subsidence.

Point Judith Pond
The EQIP reef within Pt. Judith Pond contained an oyster density of 2.0 m^2. A possible explanation for the low density is that the reef was located in a high flow area, which may have washed oysters away from the reef. We are unable to predict restoration success of future reefs in Pt. Judith based on past restoration, because we only sampled one reef that was exposed to acute circumstances within the pond. We advise future restoration work within this pond occur in more suitable habitats.

<u>Future Work:</u>

Monitoring Needs
Unfortunately, there is not enough information about the implementation processes of these former EQIP reefs to infer how factors influence restoration success across reefs and ponds. We recommend that future EQIP restoration practices maintain detailed records of the overall implementation process including: cultch quantity, seed quantity and mean size, initial reef area, initial reef height, cultching and seeding methods, exact milestone dates, and precise locations. We also recommend that restoration monitoring begin either immediately or the season following reef construction. Initial monitoring of reefs through this project is being performed up to eight years post-construction, which greatly reduces our ability to detail reef succession as well as drivers for success and failure of the reefs. Fortunately, many of these issues have already been addressed by EQIP practitioners. The reef implementation documentation process is now more robust and detailed, and contracts for restoration include an oyster monitoring plan beginning the year following initial implementation as a component of the work.

Currently, the monitoring protocol calls for collecting water quality data at every sampling event. Given that water quality can be dynamic in the coastal ponds where the EQIP restoration reefs are located, we suggest increased water quality sampling frequency. We believe that the most efficient method to achieve this increased frequency is through the implementation of submersible dataloggers. These dataloggers can collect time-series water quality data at desired intervals, which will provide us with a more detailed account of water quality through time at the reefs

Research Needs

Although cultch established by the EQIP program persists and appears suitable, recruitment of new oysters to these EQIP reefs appears to be limited in many ponds, which in turn hinders the long-term success and sustainability of these reefs. The lack of these recent recruits implies there is a bottleneck at a given life history stage of oysters on these reefs. We suggest performing independent experiments in order to begin teasing out possible limitations on recruitment. For example, results from experimental research focusing on the following factors will provide information to improve recruitment and survival of juvenile oysters on restoration reefs: fecundity of restoration oysters, genetic diversity and disease resistance of wild lines of oysters across RI waters, how the composition of a reef community influences the prevalence of disease at the reef level, larval transport and retention within the ponds, the effect of vertical relief on recruitment and survival, and the ability of larvae to recruit onto suitable substrate and survive post settlement.

Considering that some local oyster populations persist in closed waters (i.e. waters in which harvest is prohibited due to water quality impairments), we hypothesize that wild-strain oysters or oysters selected for reef restoration may increase the likelihood of a successful, sustainable restoration project. To address this research need DFW is currently collaborating with Dr. Randall Hughes from Northeastern University to test the effects of oyster genetic identity and diversity on recruitment, growth, survival, and disease prevalence. This research will be conducted in conjunction with current and future EQIP oyster restoration.

Previous research (Schulte et al. 2009), as well as the observed positive relationship between oyster density and reef height (Figure 6) suggest that future work should evaluate the response of reef health to vertical relief (i.e., reef height). To evaluate this factor we designed a split-plot experiment to accompany the EQIP restoration in Ninigret Pond for 2015. In each restoration plot we created three reefs, each reef with a different reef height (i.e., 18”, 24”, and 30”). From this experimental design, we hope to quantify the effects of reef height on reef success through annual monitoring and possibly determine an optimal height for oyster productivity.

Another research need is identifying the appropriate location for restoration sites based on how oyster larvae are transported within the coastal pond system. Research into the circulation patterns of the coastal ponds, with additional modeling work focusing on the transport of oyster larvae, would allow the DFW to identify areas that could be established as restoration sites to provide spawning stock biomass. The goal of the spawning stock would be to produce larvae that would travel to and settle out in suitable habitat for future harvest.

Management Needs

The DFW recognizes that some areas suitable for oyster restoration have likely not been identified and do not have the protections required to conduct EQIP restoration practices (i.e., are not closed to oyster harvest). To establish a new management closure the DFW follows a public process that provides for stakeholder participation and seeks to both maximize the likelihood of a successful restoration practice and minimizing conflicts with existing shellfish harvest. Information such as long-term monitoring data on current and former restoration practices, surveys to capture spatial use patterns in marine waters, in concert with new scientific research will improve the ability of DFW to successfully establish new management closures to support oyster restoration in Narragansett Bay and locations outside of the coastal pond system.

Conclusion

Prior to conducting this work, oyster restoration sites previously established by the NRCS EQIP Oyster Initiative, as well as native oyster reefs, in RI had not been adequately monitored and thus, the current status and overall effectiveness of these practices was poorly understood. As a result, the DFW lacked basic information, such as the current status and overall effectiveness of these former practices, which was needed to identify the appropriate location for oyster restoration and implement adaptive management strategies aimed at improving the restoration work conducted by the NRCS EQIP Oyster Initiative. Though conducting the initial monitoring on these EQIP reefs 8-10 years post construction limits our ability to determine the influence of specific factors on reef success, the monitoring and assessment conducted as part of this work found that oyster density across these EQIP restoration sites is highly variable, typically containing many large oysters with few recent recruits. Oyster density appears to increase with reef height, suggesting that reef design should be revised in future restoration work. Based on the current status of the oyster reefs formerly established by the NRCS EQIP Oyster Initiative, we recommend that future EQIP oyster restoration practices be conducted at the following sites (listed in order of highest current status): Great Salt Pond, Potter Pond, Quonochontaug Pond, Winnapaug Pond, N Ninigret Pond, S Ninigret Pond, Bissel Cove, and Point Judith Pond. In addition, further research and continued monitoring of current restoration practices are needed to improve adaptive management techniques that will ultimately lead to increased likelihood of successful oyster reef restoration.

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Table 1. Timeline of project activities and summary of work completed. Note that the expected completion dates for this project were revised as part of the No-cost Extension Request approved December 2015.

Table 1. Progress Report – Quarter Ending	Expected Completion Date	Status 12/31/16	Status* 3/31/17
1. 1st monitoring 8 EQIP restoration sites	11/31/15	*Completed*	*Completed*
2. Monitoring of 6 native sites	11/31/15	*Completed*	*Completed*
3. Sample collection for disease testing for all 8 EQIP Restoration Sites	1/15/16	*Completed*	*Completed*
4. Analysis of oysters collected for disease testing	2/15/16	*Completed*	*Completed*
5. Compile and analyze data collected to date	12/16/16	*Completed*	*Completed*
6. Provide Preliminary Draft Report	12/28/16	*In progress*	*Completed*
7. 2nd monitoring of 7 Remaining EQIP restoration sites	12/28/16	*Revised***	*Revised***
8. Compile and analyze all available data collected	11/15/16	*In Progress*	*Completed*
9. Complete Report			
i. Prepare Draft Report	12/28/16	*Completed*	*Completed*
ii. Final Report	12/28/16	*In progress*	*Completed*

* No funds from NRCS grant No. 68-1535-14-08 were used for work conducted after 12/31/16.
** Determined that a single monitoring was sufficient thus, 2nd monitoring was not conducted.

Table 2. Table shows the number of EQIP reefs sampled by pond and the restoration priority of each site based on the current status of the former oyster reefs established by the NRCS EQIP Oyster Initiative.

Pond	# of EQIP Reefs	Restoration Rank
Great Salt Pond	1	1
Potter Pond	14	2
Quonochontaug Pond	3	3
Winnapaug Pond	10	4
N Ninigret Pond	28	5
S Ninigret Pond	12	6
Bissel Cove	2	7
Point Judith Pond	1	N/A

Table 3. Table summarizes the lengths of live oysters measured by pond.

Pond	Mean Length (mm)	Minimum Length (mm)	Maximum Length (mm)	Mode Length (mm)
Great Salt	63.83	10	165	84
Potter	120.21	11	287	111
Quonochontaug	85.25	8	210	75
N Ninigret	90.24	22	167	76
S Ninigret	83.64	36	146	75
Winnapaug	140.89	27	264	116
Foster Cove	29.90	1	83	11

Table 4. Table summarizes the lengths of dead oysters measured by pond.

Pond	Mean Length (mm)	Minimum Length (mm)	Maximum Length (mm)	Mode Length (mm)
Potter	115.71	20	287	109
Quonochontaug	82.31	8	210	75
N Ninigret	88.50	22	153	100
S Ninigret	81.80	36	146	75
Winnapaug	130.82	27	264	116
Foster Cove	53.96	7	83	51

Table 5. Table depicts results from 2015 oyster disease testing from EQIP reefs.

Location	Collection Date	No. of Animals	Dermo			MSX		SSO	
			Infected (%)	Weighed Prev.	Weighed Intensity	Infected (%)	Weighed Prev.	Infected (%)	Weighed Prev.
Quonochontaug Pond	10/27/2015	15	93.3	1.83	1.96	0.0	0.0	46.7	0.5
Northern Ninigret Pond	11/2/2015	15	73.3	1.43	1.95	0.0	0.0	0.0	0.0
Southern Ninigret Pond	11/2/2015	15	93.3	1.60	1.71	13.3	0.2	0.0	0.0
Point Judith Pond	11/9/2015	6	83.3	1.67	2.00	0.0	0.0	0.0	0.0
Potter Pond	11/6/2015	15	100	2.43	2.43	0.0	0.0	20.0	0.2
Cormorant Cove	11/22/2015	15	100	1.67	1.67	0.0	0.0	0.0	0.0
Winnapaug Pond	11/23/2015	15	100	1.93	1.93	0.0	0.0	0.0	0.0
Bissel Cove	12/16/2015	10	100	2.40	2.40	0.0	0.0	30.0	0.3

Table 6. Table describing EQIP and natural reefs designated for monitoring.

Site ID	Pond	Oyster Den. (m2)	Latitude	Longitude	Area (m2)	Reef Type
1	Bissel Cove	5.33	41.5459	-71.4291	30.24	EQIP
2	Bissel Cove	0.00	41.5461	-71.4290	135.28	EQIP
3	Foster Cove	59.00	41.3667	-71.6765	N/A	Natural
4	Foster Cove	42.00	41.3660	-71.6743	N/A	Natural
5	Foster Cove	30.00	41.3656	-71.6734	N/A	Natural
6	Foster Cove	77.00	41.3649	-71.6723	N/A	Natural
7	Foster Cove	132.00	41.3650	-71.6761	N/A	Natural
8	Great Salt Pond	208.40	41.1908	-71.5883	N/A	EQIP
9	Northern Ninigret Pond	5.00	41.3535	-71.6932	28.86	EQIP
10	Northern Ninigret Pond	0.00	41.3535	-71.6933	9.20	EQIP
11	Northern Ninigret Pond	0.00	41.3533	-71.6935	7.00	EQIP
12	Northern Ninigret Pond	0.33	41.3531	-71.6934	28.00	EQIP
13	Northern Ninigret Pond	0.33	41.3530	-71.6934	45.51	EQIP
14	Northern Ninigret Pond	3.67	41.3525	-71.6935	96.00	EQIP
15	Northern Ninigret Pond	0.33	41.3536	-71.6933	51.75	EQIP
16	Northern Ninigret Pond	0.33	41.3535	-71.6934	30.60	EQIP
17	Northern Ninigret Pond	1.33	41.3534	-71.6935	17.48	EQIP
18	Northern Ninigret Pond	0.00	41.3534	-71.6935	10.00	EQIP
19	Northern Ninigret Pond	0.00	41.3533	-71.6936	12.00	EQIP
20	Northern Ninigret Pond	0.00	41.3536	-71.6931	55.60	EQIP
21	Northern Ninigret Pond	1.33	41.3527	-71.6937	21.16	EQIP
22	Northern Ninigret Pond	2.33	41.3527	-71.6938	21.16	EQIP
23	Northern Ninigret Pond	0.00	41.3526	-71.6938	20.58	EQIP
24	Northern Ninigret Pond	1.67	41.3524	-71.6939	30.00	EQIP
25	Northern Ninigret Pond	0.00	41.3547	-71.6940	8.36	EQIP
26	Northern Ninigret Pond	3.75	41.3549	-71.6936	45.00	EQIP
27	Northern Ninigret Pond	1.00	41.3544	-71.6936	22.88	EQIP
28	Northern Ninigret Pond	1.00	41.3550	-71.6931	26.40	EQIP
29	Northern Ninigret Pond	3.00	41.3551	-71.6930	31.40	EQIP
30	Northern Ninigret Pond	0.00	41.3547	-71.6937	15.58	EQIP
31	Northern Ninigret Pond	0.00	41.3545	-71.6935	10.23	EQIP
32	Northern Ninigret Pond	0.33	41.3543	-71.6932	14.72	EQIP
33	Northern Ninigret Pond	0.00	41.3543	-71.6932	25.61	EQIP
34	Northern Ninigret Pond	0.00	41.3542	-71.6932	30.36	EQIP
35	Northern Ninigret Pond	0.00	41.3553	-71.6931	31.30	EQIP

Table 6. Table describing EQIP reefs designated for monitoring. (Continued …)

Site ID	Pond	Oyster Den. (m2)	Latitude	Longitude	Area (m2)	Reef Type
36	Point Judith	2.00	41.4149	-71.5072	16.20	EQIP
37	Potter Pond	42.67	41.3839	-71.5370	12.29	EQIP
38	Potter Pond	24.00	41.3843	-71.5366	27.50	EQIP
39	Potter Pond	67.33	41.3840	-71.5370	27.50	EQIP
40	Potter Pond	44.80	41.3841	-71.5369	79.05	EQIP
41	Potter Pond	32.00	41.3842	-71.5367	36.00	EQIP
42	Potter Pond	66.67	41.3842	-71.5368	136.88	EQIP
43	Potter Pond	17.33	41.3842	-71.5367	42.30	EQIP
44	Potter Pond	132.00	41.3844	-71.5366	65.90	EQIP
45	Potter Pond	102.67	41.3847	-71.5364	18.87	EQIP
46	Potter Pond	1.33	41.3846	-71.5363	N/A	EQIP
47	Potter Pond	112.00	41.3846	-71.5365	10.23	EQIP
48	Potter Pond	57.33	41.3845	-71.5364	12.88	EQIP
49	Potter Pond	64.00	41.3845	-71.5365	29.97	EQIP
50	Potter Pond	53.33	41.3845	-71.5366	20.90	EQIP
51	Quonochontaug Pond	44.67	41.3468	-71.7102	119.78	EQIP
52	Quonochontaug Pond	10.67	41.3467	-71.7103	153.30	EQIP
53	Quonochontaug Pond	22.97	41.3465	-71.7104	N/A	EQIP
54	Southern Ninigret Pond	0.00	41.3474	-71.6858	48.00	EQIP
55	Southern Ninigret Pond	2.67	41.3472	-71.6861	36.26	EQIP
56	Southern Ninigret Pond	2.33	41.3471	-71.6864	48.99	EQIP
57	Southern Ninigret Pond	5.33	41.3471	-71.6867	57.60	EQIP
58	Southern Ninigret Pond	1.33	41.3470	-71.6874	57.80	EQIP
59	Southern Ninigret Pond	10.00	41.3546	-71.6934	57.85	EQIP
60	Southern Ninigret Pond	0.67	41.3479	-71.6846	78.32	EQIP
61	Southern Ninigret Pond	1.33	41.3476	-71.6847	111.36	EQIP
62	Southern Ninigret Pond	0.00	41.3474	-71.6851	94.55	EQIP
63	Southern Ninigret Pond	0.33	41.3477	-71.6850	60.00	EQIP
64	Southern Ninigret Pond	9.00	41.3475	-71.6852	150.20	EQIP
65	Southern Ninigret Pond	7.00	41.3476	-71.8856	39.68	EQIP
66	Southern Ninigret Pond	10.67	41.3473	-71.6854	96.00	EQIP
67	Winnapaug Pond	48.00	41.3309	-71.7986	38.43	EQIP
68	Winnapaug Pond	25.33	41.3309	-71.7983	32.30	EQIP
69	Winnapaug Pond	57.33	41.3310	-71.7986	37.95	EQIP
70	Winnapaug Pond	53.33	41.3312	-71.7986	62.41	EQIP

Table 6. Table describing EQIP reefs designated for monitoring. (Continued …)

Site ID	Pond	Oyster Den. (m2)	Latitude	Longitude	Area (m2)	Reef Type
71	Winnapaug Pond	54.67	41.3311	-71.7985	53.60	EQIP
72	Winnapaug Pond	49.33	41.3309	-71.7985	54.51	EQIP
73	Winnapaug Pond	49.33	41.3311	-71.7983	41.58	EQIP
74	Winnapaug Pond	54.67	41.3313	-71.7983	38.25	EQIP
75	Winnapaug Pond	64.00	41.3312	-71.7980	72.16	EQIP
76	Winnapaug Pond	66.67	41.3310	-71.7981	45.05	EQIP

Figure 1. Map depicts the general locations of all 117 EQIP reefs [shown in Pink circles] located across 7 sites (e.g., Point Judith Pond, Potter Pond, Ninigret Pond, Quonochontaug Pond, Winnapaug Pond, Bissel Cove in Narraganset Bay, and Great Salt Pond on Block Island) and the 6 systems surveyed for natural reefs [shown as Blue circles] (e.g., Point Judith Pond, Potter Pond, Ninigret Pond, Quonochontaug Pond, Winnapaug Pond, and Bissel Cove in Narraganset Bay). Note that reefs could not be found at Jenny's Creek in Narraganset Bay and, thus this site is excluded from this figure.

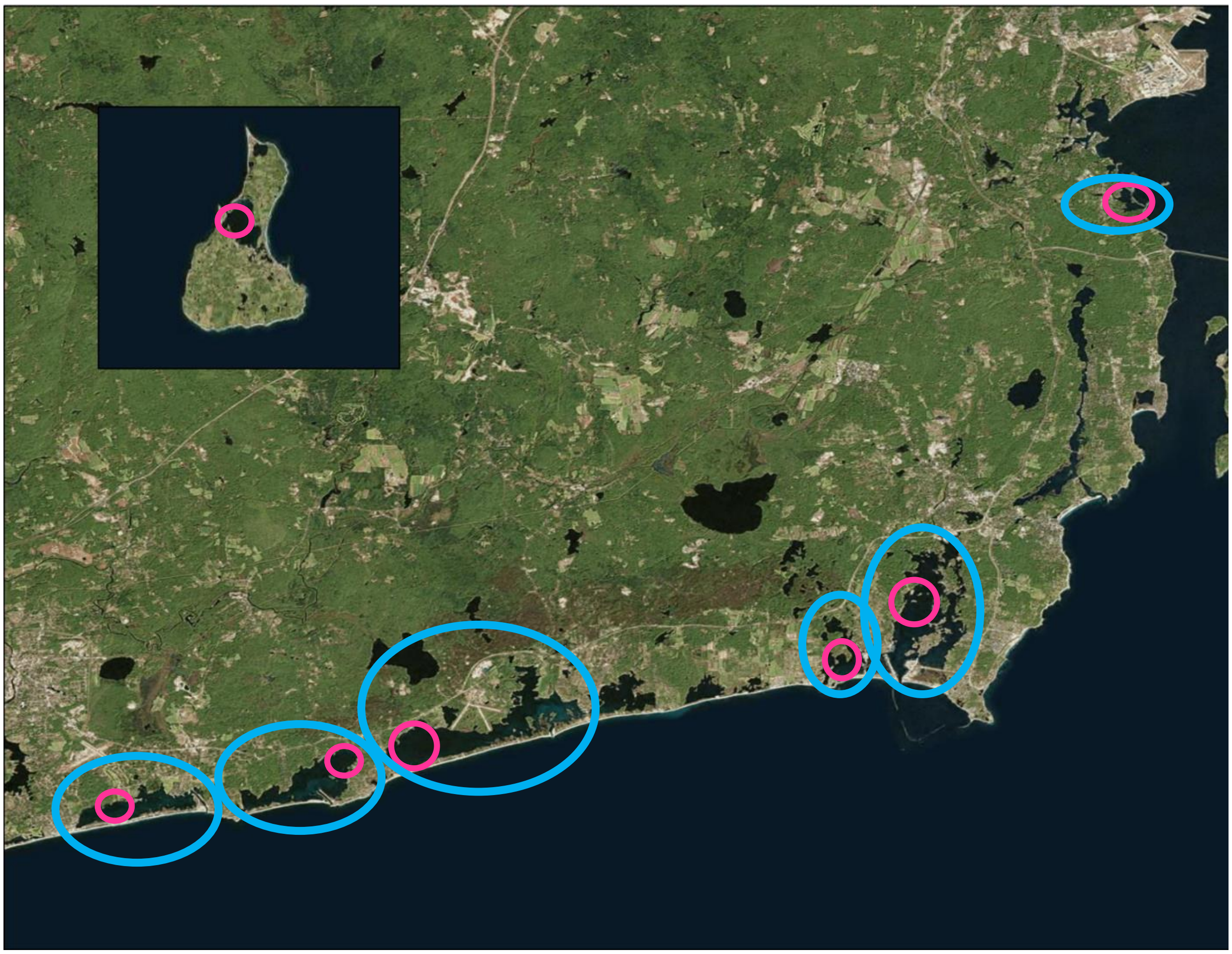

Figure 2. Bar plot shows the estimated mean+SE density of oysters per m^2 on EQIP and natural reefs in the ponds sampled.

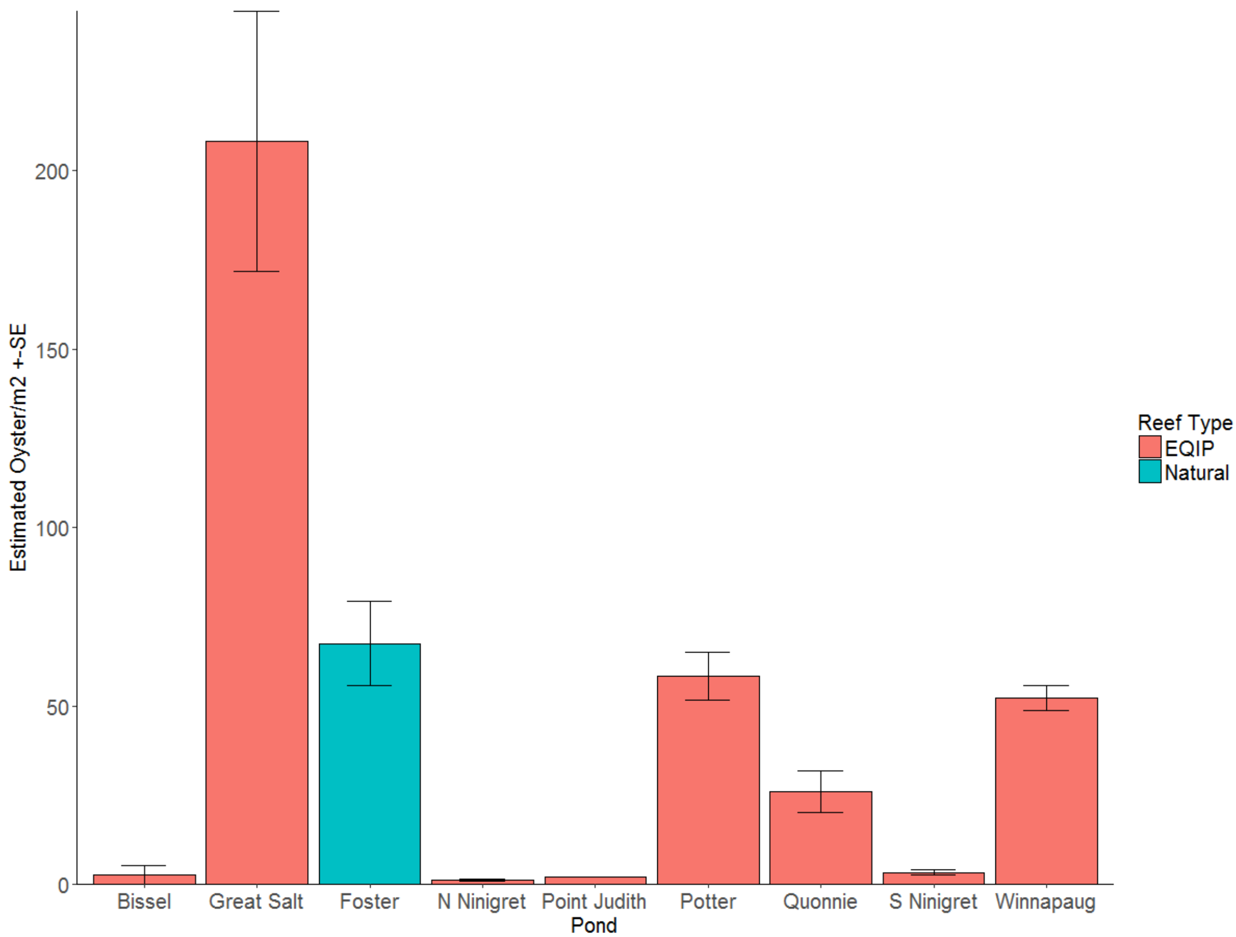

Figure 3. Bar plot shows the estimated proportion of live oyster population that is composed of recruits on EQIP and natural reefs by ponds sampled. N Ninigret Pond, S Ninigret Pond, Winnapaug Pond, Bissel Cove, and Point Judith were omitted from the barplot, because they contained no new recruits.

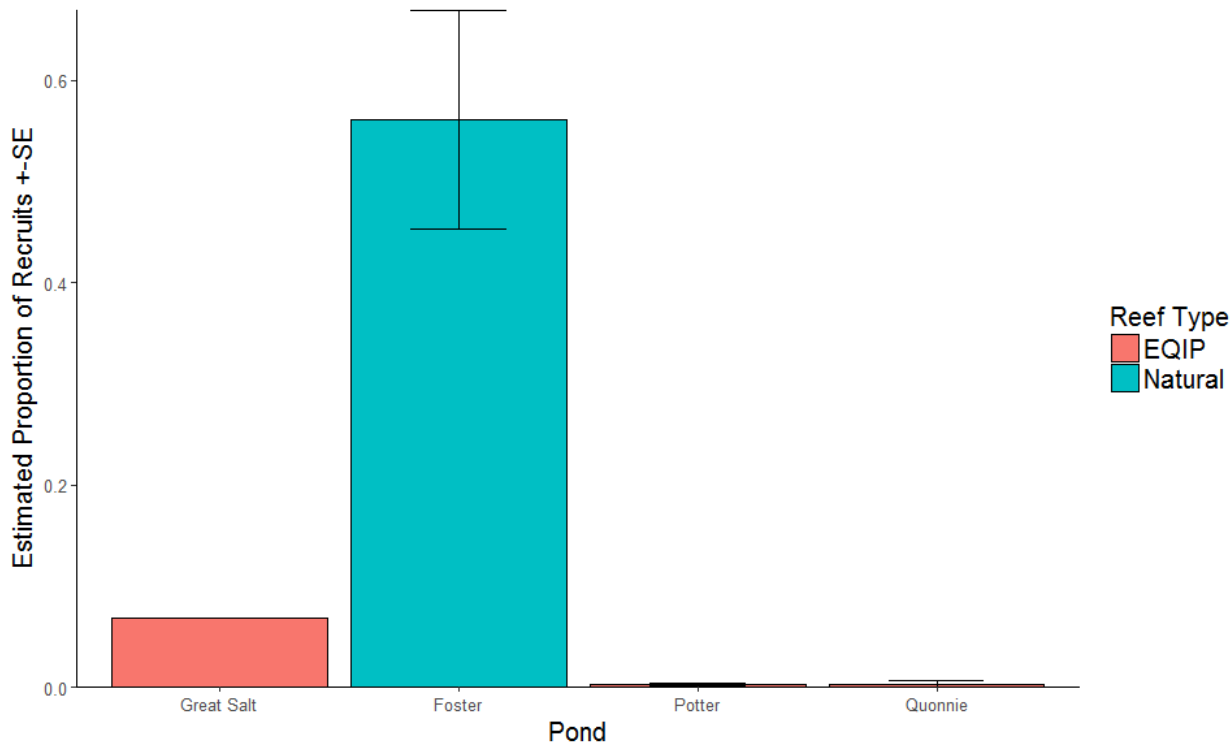

Figure 4. Histograms show the length frequency distribution of live oysters sampled by pond in 10mm bins. The size distribution of oysters on EQIP reefs in Bissel Cove and Point Judith were not plotted due to small sample size. Histograms with grey bars represent EQIP reefs while the histogram with yellow bars represents natural reefs.

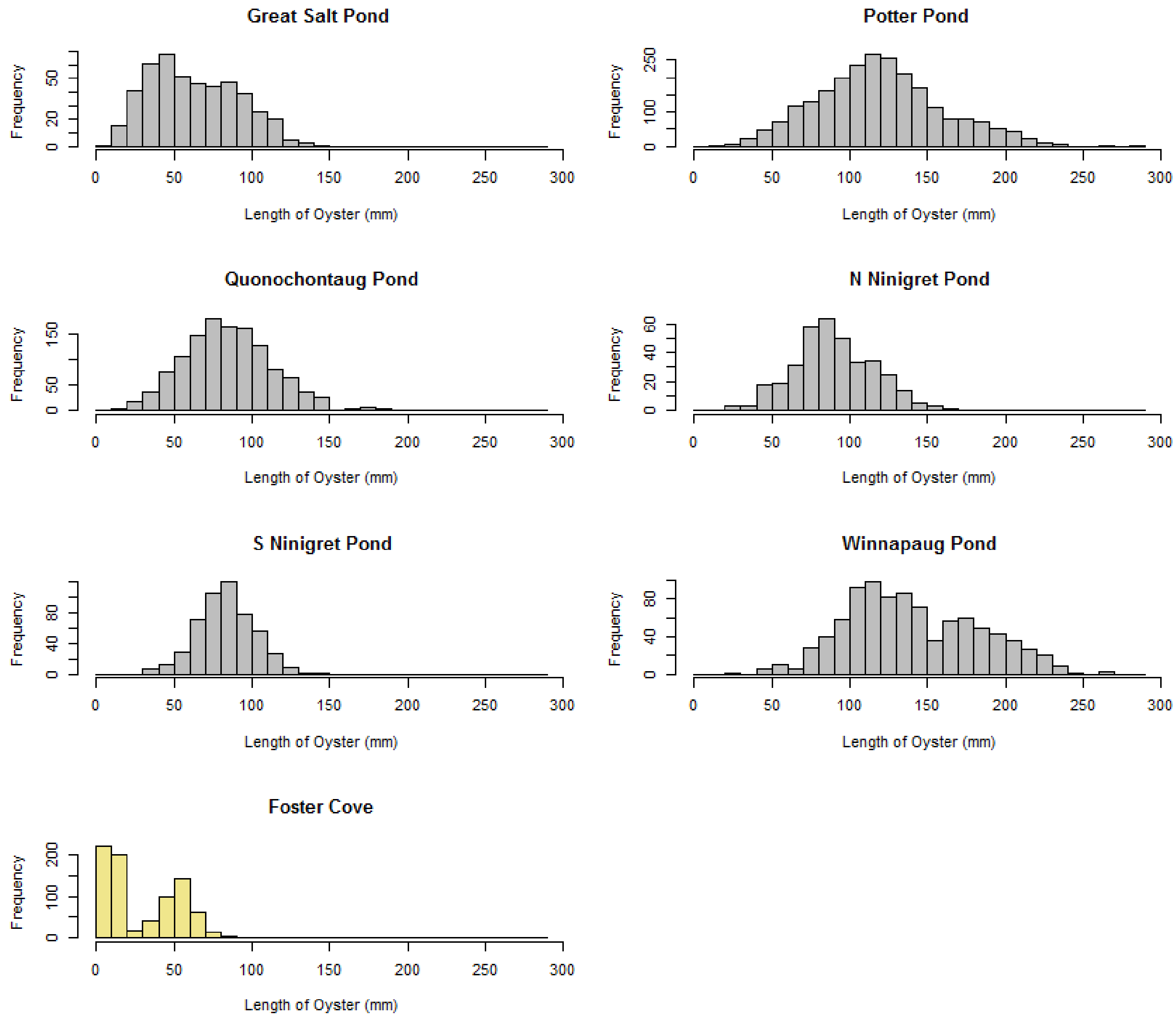

Figure 5. Histograms show the length frequency distribution of dead oysters sampled by pond in 10mm bins. The size distribution of oysters on EQIP reefs in Bissel Cove and Point Judith were not plotted due to small sample size, while dead oysters in Great Salt Pond are not plotted because they were not measured. Histograms with grey bars represent EQIP reefs while the histogram with yellow bars represents natural reefs.

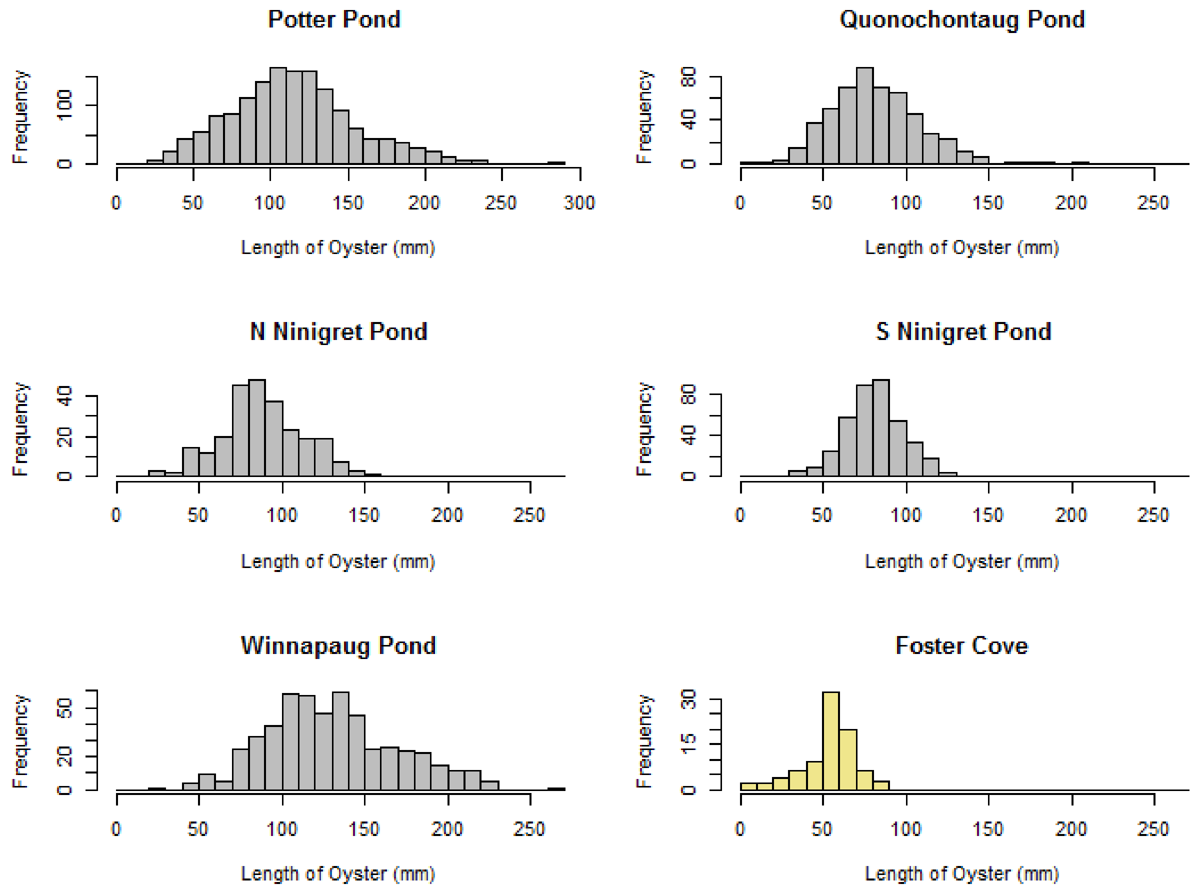

Figure 6. Plot shows oyster density as a function of vertical reef relief aggregated into 5cm bins.

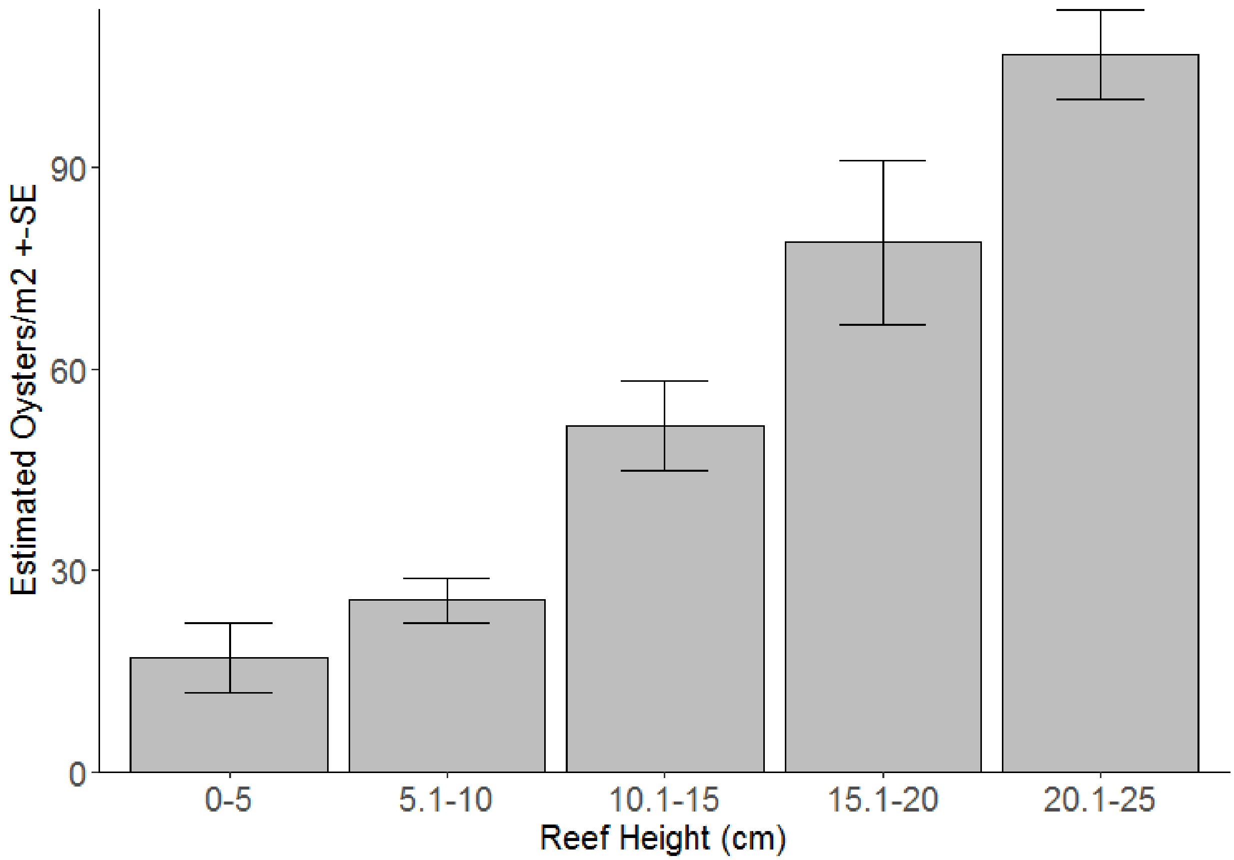

Figure 7. Bar plot shows the proportion of boring sponge presence in oysters by pond. EQIP oysters from Great Salt Pond were omitted, because boring sponge presence was not sampled. EQIP oysters from Bissel Cove and Point Judith were omitted, because the sample size was too low. Foster Cove was omitted, because there was no observed boring sponge presence.

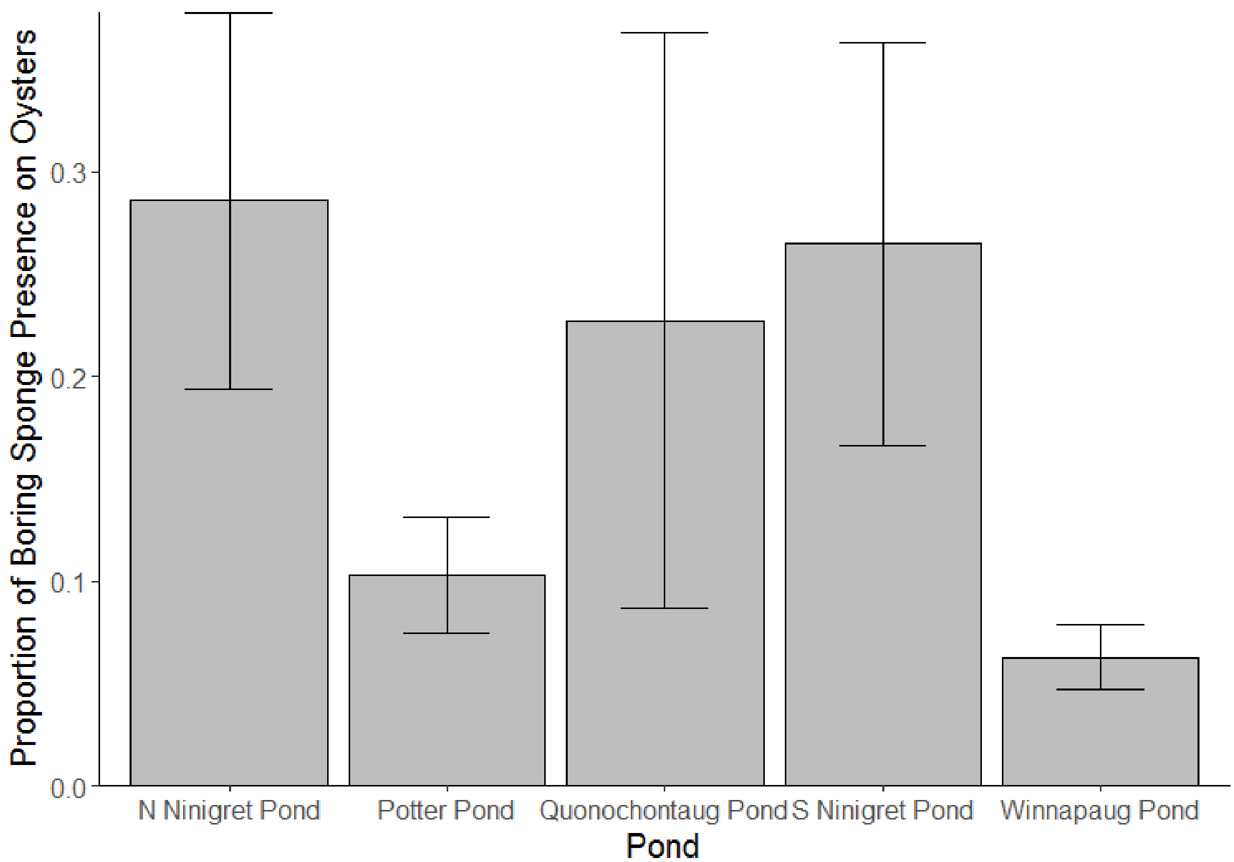

Figure 8. Boxplot depicting salinity during oyster monitoring across ponds.

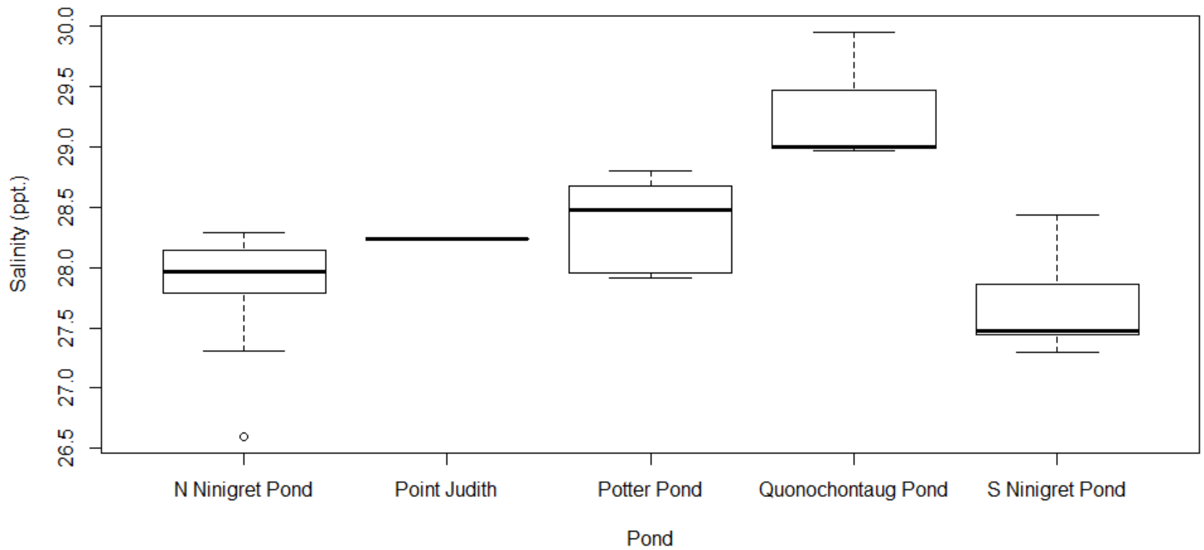

Figure 9. Boxplot depicting Dissolved Oxygen during oyster monitoring across ponds.

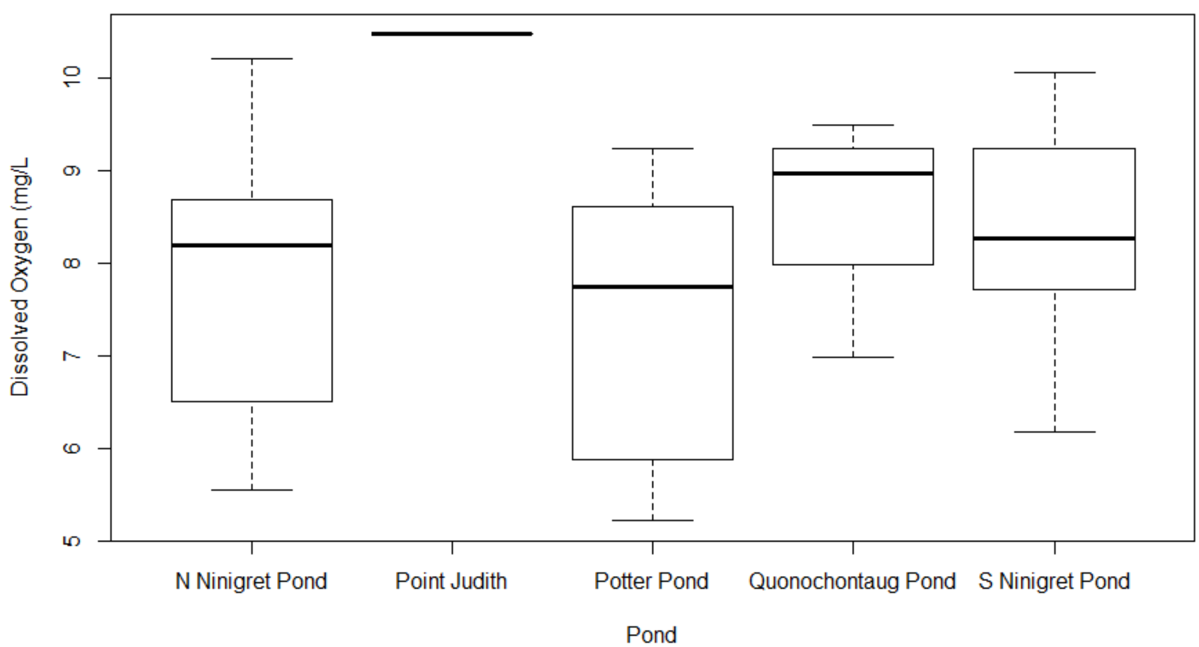

Figure 10. Map depicting proposed EQIP restoration plots in the Eastern Shellfish Spawner Sanctuary of Quonochontaug Pond.

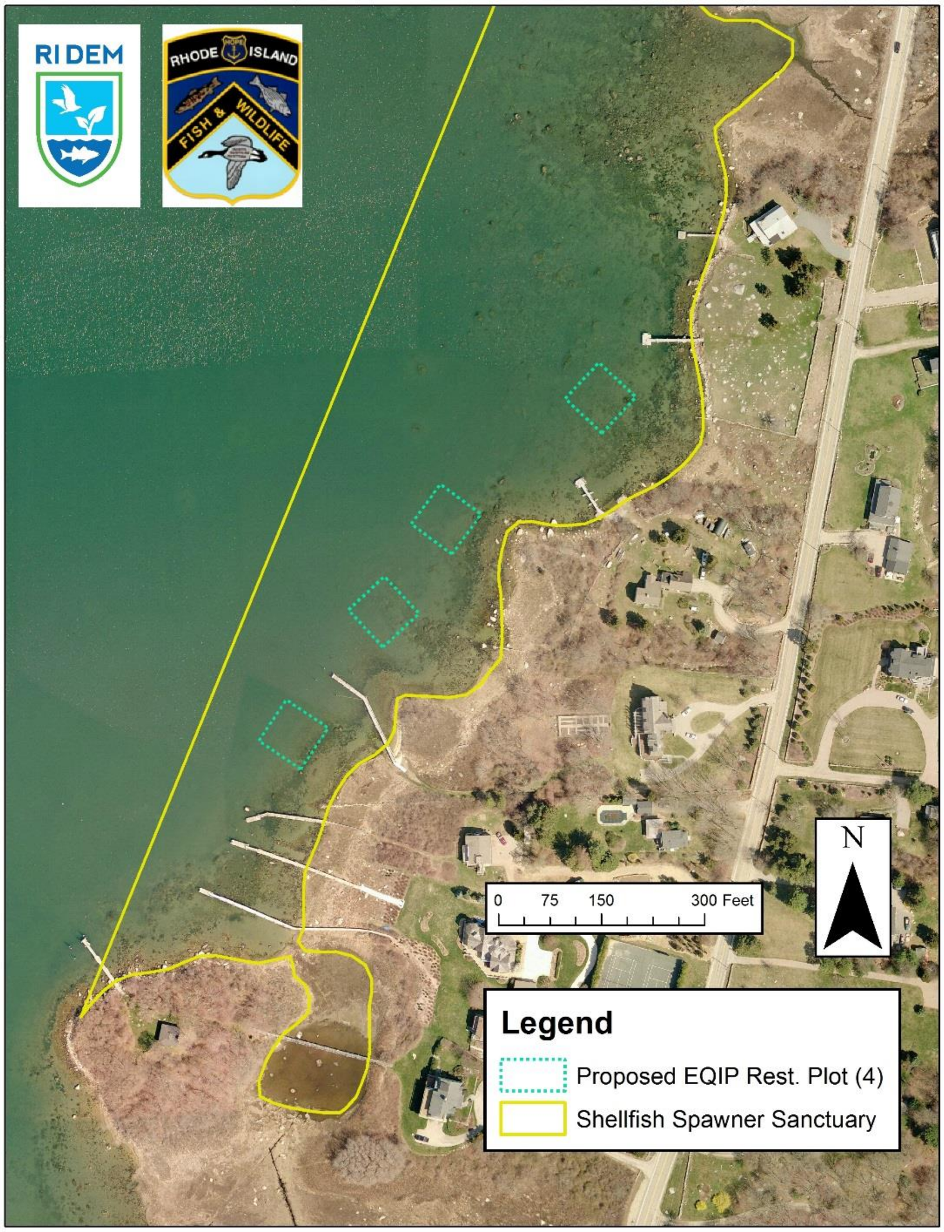

Figure 11. Map depicting potential future EQIP restoration plots within the Shellfish Spawner Sanctuary of Potter Pond.