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Restoring an oyster reef for mitigation of estuarine water quality

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Restoring An Oyster Reef For Mitigation of Estuarine Water Quality

A Final Report Submitted to

The NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)

Submitted by

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Abstract

This project was designed to test two oyster restoration techniques on a disease-decimated (by the protozoan parasite, *Haplosporidium nelsoni*, or MSX) eastern oyster (*Crassostrea virginica*) reef in New Hampshire, to quantify material uptake by the constructed reefs, and develop a model suitable for use by environmental managers to predict the effects of restored reefs on water quality. Two experimental reef areas were constructed, one using native oysters with associated shell cultch material transferred from a nearby reef and the other using spat from CROSBreed larvae remotely set at Jackson Estuarine Laboratory. CROSBreed is a line of eastern oysters resistant to MSX and Dermo (another major oyster disease caused by the protozoan *Perkinsus marinus*) produced by a consortium of mid-Atlantic universities, and largely funded by NOAA's Oyster Disease Research Program. Construction of both reefs was completed in 2000. Each of the experimental reefs and the adjacent natural (disease-decimated) reef were monitored in October 2000, and May and October of 2001 and 2002. The natural reef remained at low densities (< 50 individuals/m^2) of adult and juvenile oysters for the entire 2.5 yr study period, and consisted of nearly equal numbers of ribbed mussels (*Geukensia demissa*) with smaller numbers of blue mussels (*Mytilus edulis*). The natural reef, the native transplant reef, and the CROSBreed reef averaged approximately 40, 90, and 120 individuals/m^2, respectively, for the period October 2000 – May 2002. All three reefs caught dense sets of spat in summer 2002, increasing total oyster densities to 220, 290, and 450/m^2, respectively, on the natural, native transplant, and CROSBreed reefs in October 2002. Further development of all three reefs, including infection by MSX and other pathogens, will be monitored as part of an ongoing shellfish program.

The potential impacts of the constructed reefs on water quality were estimated by modeling and direct measurements of seston uptake rates. The following model was developed to estimate the percent of the total water column cleared of seston by suspension feeding bivalve mollusks on an hourly basis:

% Water Clearance (seston uptake) = (A x B x C)/(D x E) x 100

where A = mean bivalve density (# ind/m^2), B = mean individual clearance rate (m^3/individual/hr), C= bottom area of reef (m^2), D = cross-sectional area of water column (m^2), and E = mean water flow speed (m/hr).

The intent is to provide a simplified but usefully accurate model that predicts how much of the overlying water column is "processed" by the bivalves. The major simplifying assumption in the model is a completely mixed water column. Mean clearance rates are based on literature values. Tests of the model on several eastern oyster and blue mussel reefs indicated good agreement between model predictions and measured uptake rates.

Keywords: oyster reef, *Crassostrea virginica*, seston uptake, oyster disease, bivalve feeding, CROSBreed

Introduction

Over-harvesting, disease, and pollution in many areas along the US Atlantic and Gulf of Mexico coasts have resulted in long-term declines of populations of the eastern oyster, *Crassostrea virginica* (Kennedy 1989; MacKenzie 1996; Hargis and Haven 1999), including the present study area in New Hampshire (Langan 1997, 2000). Oyster management and restoration programs in most areas focus on one or more of several general techniques (MacKenzie 1999): broodstock enhancement, environmental improvements of the water column and/or substrate, and predator (including pathogens) control. Probably the most widely used technique for restoring oyster reefs has been the placement of shell or other "cultch" material directly onto the reef to provide suitable substrate for natural settlement of spat (Kennedy 1989; O'Beirn et al. 2000). However, its effectiveness depends on a number of factors, including the kind of cultch material used, placement of the cultch, environmental conditions, prevalence of disease, and reproductive output of the native oyster populations. For example, in the Chesapeake Bay region, extensive shell planting programs resulted in substantial increases in oyster production from the 1940s until oyster diseases (MSX and Dermo) became widespread (MacKenzie 1999).

Shell planting programs in the present study area in New Hampshire have been undertaken twice over the past several decades, in the 1960s (Ayer et al. 1970) and 1980s (Nelson 1988). Both programs demonstrated that planted shell was effective in catching oyster spat, but subsequent to these projects the oyster disease MSX affected oyster populations in the entire area (Barber et al. 1997).

"Spat seeding" is a rapidly developing approach to oyster reef restoration that has resulted from the fact that disease has been a major reason for decline of oyster populations in many areas (Supan et al. 1999; also see Ayer et al. 1970). It involves the use of disease-resistant and/or fast-growth broodstock to produce larvae that are remotely set in tanks, held in some kind of "nursery" environment, then broadcast onto the area being restored. This approach has the unique dual potential of providing direct population enhancement as well as introduction of disease-resistance to the local gene pool.

The most widely used disease-resistant stock on the east coast is the CROSBreed (Cooperative Regional Oyster Selective Breeding) line developed for resistance to MSX and Dermo by a consortium of mid-Atlantic institutions and funded by the Oyster Disease Research Program of NOAA/Sea Grant (Leffler 1999). The CROSBreed line was initiated in 1992 using an existing MSX-resistant line from the Haskin Laboratory at Rutgers University. Field tests of CROSBreed spat were started in 1995. Although it is too early for definitive conclusions, studies in several areas have shown promising results. For example, ongoing experiments since 1998 in Virginia indicate that CROSBreed oysters performed as well or better with respect to growth and survival than local controls in all three testing sites: low, medium, and high salinity (Mark Luckenbach, pers. comm.; also see www.mdsg.umd.edu/oysters/disease/breeding, Allen [2000], and Leffler [2002]). Much remains to be learned, however, about the overall efficacy of the CROSBreed line for reef restoration. For example, will its use result in introduction and long-term persistence of disease resistance to local gene pools? Is its use cost-effective?

The potential for use of bivalve mollusks in water quality enhancement programs in coastal areas was proposed over 20 years ago (Cloern 1982; Officer et al. 1982), and is largely based on what is known about the feeding process and life habit modes of bivalves. Suspension-feeding bivalves remove phytoplankton and other suspended particulates and, thus, organic forms of N, P, and C as they feed (Newell and Langdon 1996). Hence, they have the potential to affect water quality. Reef-forming species such as oysters have particularly high potential in this respect because they can occur at high densities. In a widely cited paper, Newell (1988) hypothesized that the historical depletion of oyster populations in Chesapeake Bay has been a major factor in water quality degradations and other changes in the Bay. This benefit of oyster reefs has become an important management goal for restoration of shellfish populations (Breitburg et al. 2000). Quantitative modeling of the relationship between various environmental factors, including water quality conditions, and bivalve feeding is an active area of research (e.g. Newell and Shumway 1993; Butman et al. 1994; Fréchette and Bacher 1998; Grant and Bacher 1998; Grant et al. 1998; Newell et al. 2002).

Objectives

The present CICEET project had the dual goal of testing two restoration techniques and modeling the impacts of oysters on water quality. The project was designed to provide new knowledge important to environmental managers concerned with deciding on appropriate oyster restoration techniques, and assessing the potential impacts of the restored reefs on water quality. The following five major project objectives were met during the 3-year study.

1. Characterize the existing hydrodynamic, water quality, and general habitat conditions in the study area.

2. Construct an experimental reef consisting of transplanted native oysters.

3. Construct an experimental reef consisting of spat from remotely set, disease-resistant oyster larvae.

4. Monitor development of the two constructed reefs and changes in the natural disease-decimated reef.

5. Develop a mathematical model of seston uptake and estimate the impacts of the constructed reefs on water quality.

Methods

Environmental conditions at the study site (Fig. 1) were characterized based on existing data and new data collected as part of the present study. Emphasis for the new data was on water flow conditions relevant to modeling seston uptake. Water flow over the constructed reefs was measured as part of the present study during portions of two separate tidal cycles using an acoustic Doppler velocimeter in August 2000. Additional measurements of horizontal flow were made on two other occasions with an electromagnetic current meter. Inspection and measurement by divers provided data on size and shape of the existing natural, disease-decimated reef and the two experimental constructed reefs.

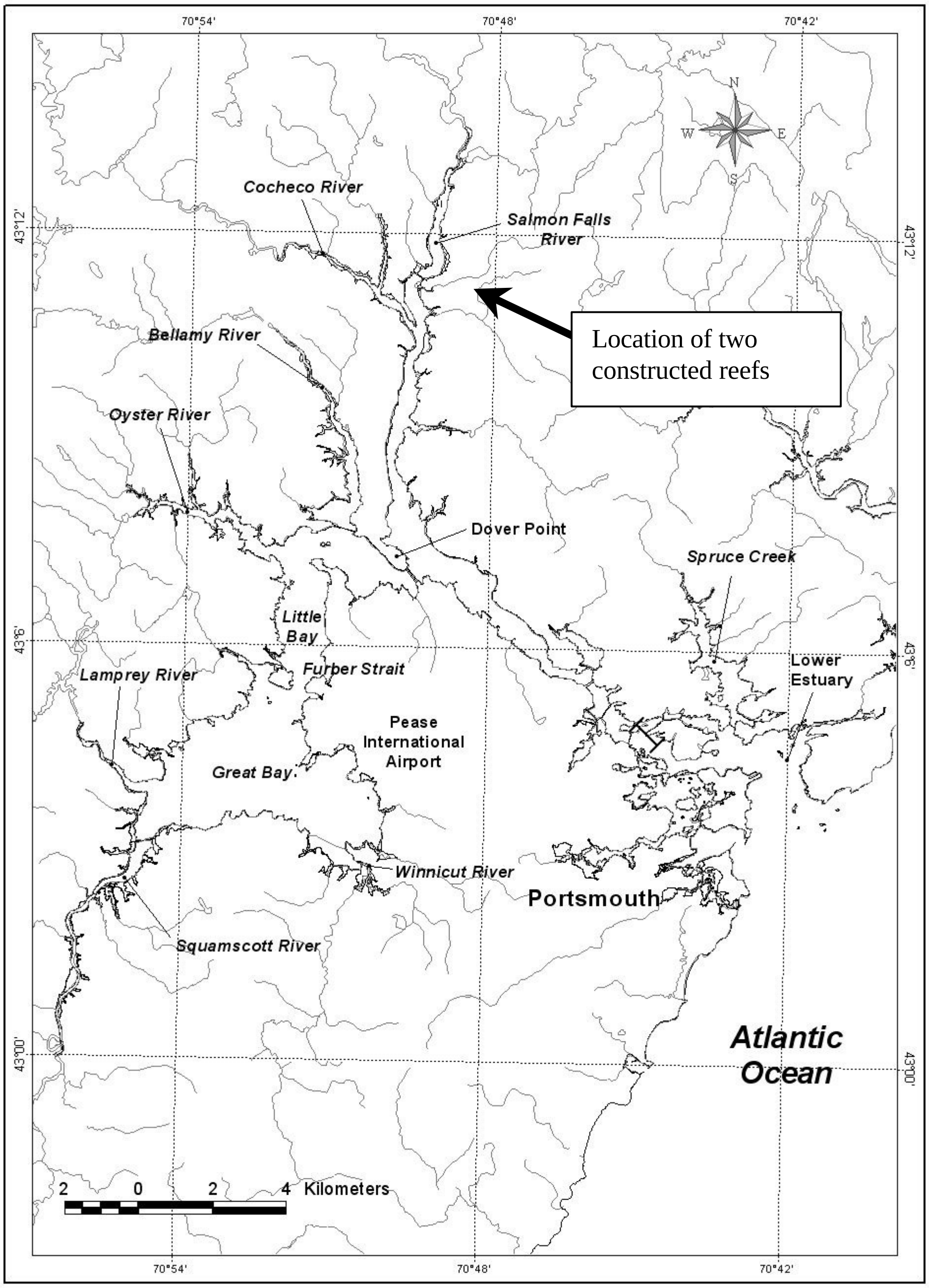

Fig. 1. Study area in Salmon Falls River, New Hampshire.

One experimental reef was constructed with live oysters and associated shell cultch material transplanted from a natural reef located 1 km south of the study site (Fig. 2). Oysters were dredged from the bottom, placed into baskets, and transported immediately to the study site where they were placed onto a culling board and spread by hand into the water covering the reef area as evenly as possible.

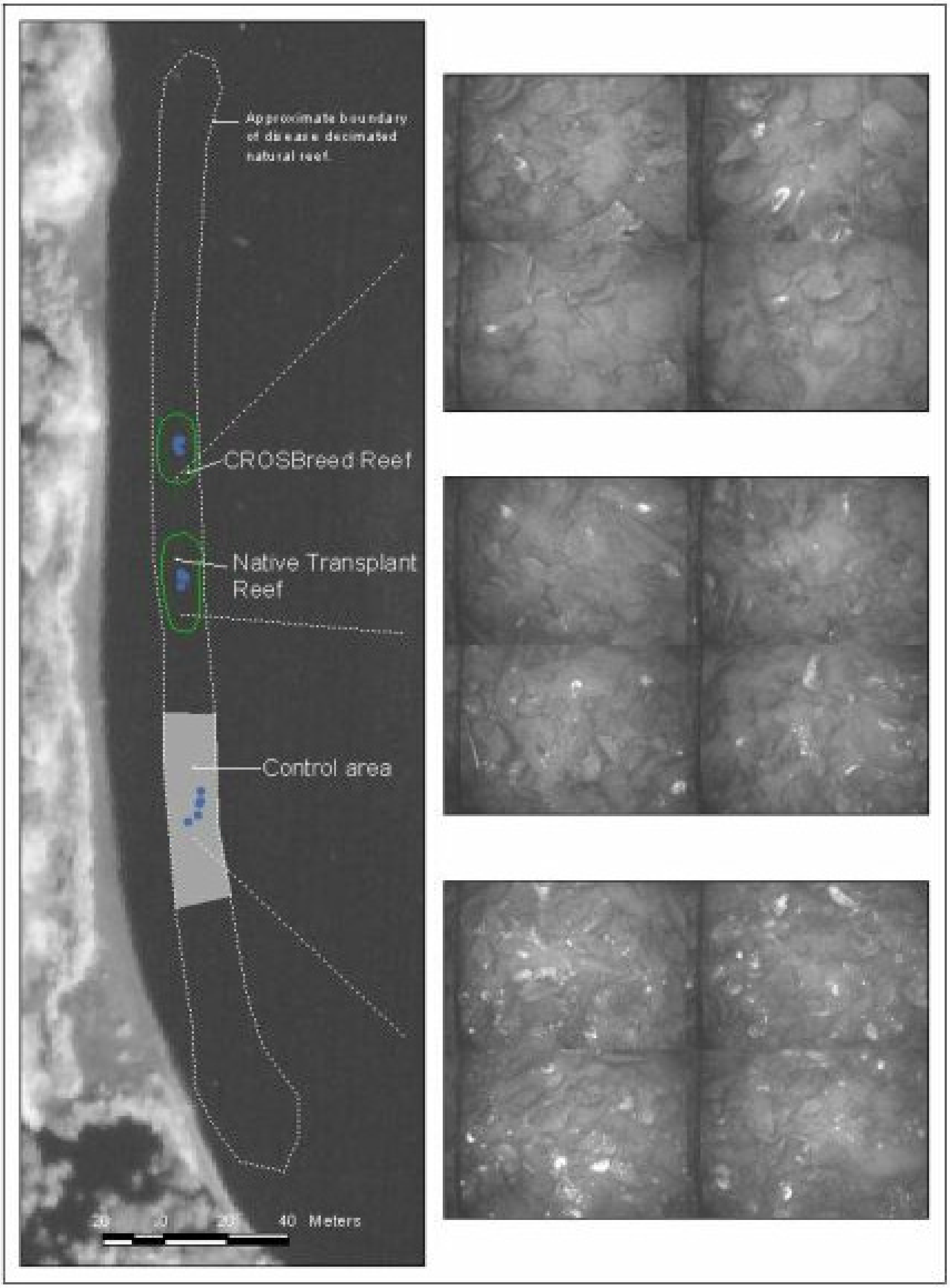

Fig. 2. Approximate dimensions of disease-decimated reef and two constructed reefs within its general area. Four video stills taken from each reef area in November 2001; note sea scallop shells on CROSBreed reef used as cultch for remote setting of larvae. All three reefs have similar low relief (5 to 10 cm) with most oysters occurring as singles or in small clumps.

The second experimental reef was constructed using spat from CROSBreed broodstock, a disease-resistant line of oysters commercially available (see above). CROSBreed larvae were remotely set in tanks onto eastern oyster and sea scallop (*Placopecten magellanicus*) shell cultch (Fig. 3). The spat were allowed to grow for several months in the intertidal zone, then transferred to the study site for construction (as described above for native transplants) of the second experimental reef in October 2000 (Fig. 4).

Fig. 3. Remote setting tank at Jackson Estuarine Laboratory, University of New Hampshire. Bags of sea scallop shells used in one remote setting of CROSBreed larvae.

Fig. 4. Three-month old CROSBreed spat on sea scallop and oyster shells.

The two constructed reefs and the adjacent disease-decimated natural reef were monitored in spring and fall each of the 2.5 years of the study. Oyster density and size were determined based on quadrat samples obtained by divers. During the fall only, disease (MSX, Dermo, other parasites) prevalence was determined using standard techniques by Haskin Shellfish Laboratory, Rutgers University.

The potential impact of the constructed reefs on water quality was estimated based on their potential for clearing the water column of suspended particles (seston). A simplified, spreadsheet-based model that predicts "percent seston uptake" was developed and tested at multiple sites during the final year of the study. To test the model, two identical new seston sampling devices with *in situ* fluorometers were designed and constructed. A total of five oyster reefs and two blue mussel reefs were tested.

The general methods followed in all tests included sampling upstream and downstream of each reef concurrently (or with a time lag coinciding with the time required for water to traverse the sampling area) at 10 to 20-min intervals for up to 5 hr for *in situ* fluorescence and/or seston (chlorophyll *a*, particulate organic matter, and total suspended solids) from a fixed height 10 cm above the bottom and in some cases at a second height near the water surface (Fig. 5). Water depth and mid-depth water flow speed also were measured. Replicate 0.125 m^2 quadrats were sampled on each reef, and mean density and size of live bivalves were determined.

Fig. 5. Measuring seston uptake by oyster reef (see text for details).

Results

<u>Site characterization</u>

The two experimental reefs were constructed on an existing, disease-decimated reef in the Salmon Falls River, one of the major tributaries to the Great Bay Estuary (Fig. 1). This area is not approved for shellfish harvesting, though it could someday be opened to harvesting if environmental conditions improve. Previous studies (1993-1996) documented eutrophic conditions in this reach of the river with a 3-yr mean chlorophyll a concentration of 18 µg/L and some samples exceeding 100 µg/L (Jones and Langan 1996). Inorganic nutrient concentrations were also high relative to other areas of the Estuary. Effluent from three secondary sewage treatment plants and a variety of nonpoint pollution sources enter upstream of the study area. Salinity concentrations can drop to near-zero during periods of high runoff, and may approach full-strength seawater during low-flow conditions at high tide. Typically, salinity averages 15 to 20 psu over a tidal cycle. The river in the vicinity of the study area is about 400 m wide and consists of a wide (300+ m) intertidal flat on the eastern side with a narrow subtidal channel to the west. The average MLW depth in the channel is about 2 m. A once-productive oyster reef covered a 15 x 650 m area along the western channel of the River (Fig. 2). This reef experienced an MSX epizootic in 1995 that killed about 90% of the oysters (Barber et al. 1997).

Maximum free-stream flow speed measured over the constructed reefs was 32 cm/s. Most vertical profiles had the expected shape, indicating roughness elements approximately corresponding to the height (10 cm; see below) of the constructed reefs relative to the surrounding bottom (Fig. 6). The vertical component of some profiles was substantial, indicating the potential for vertical transport of seston to the oyster reef.

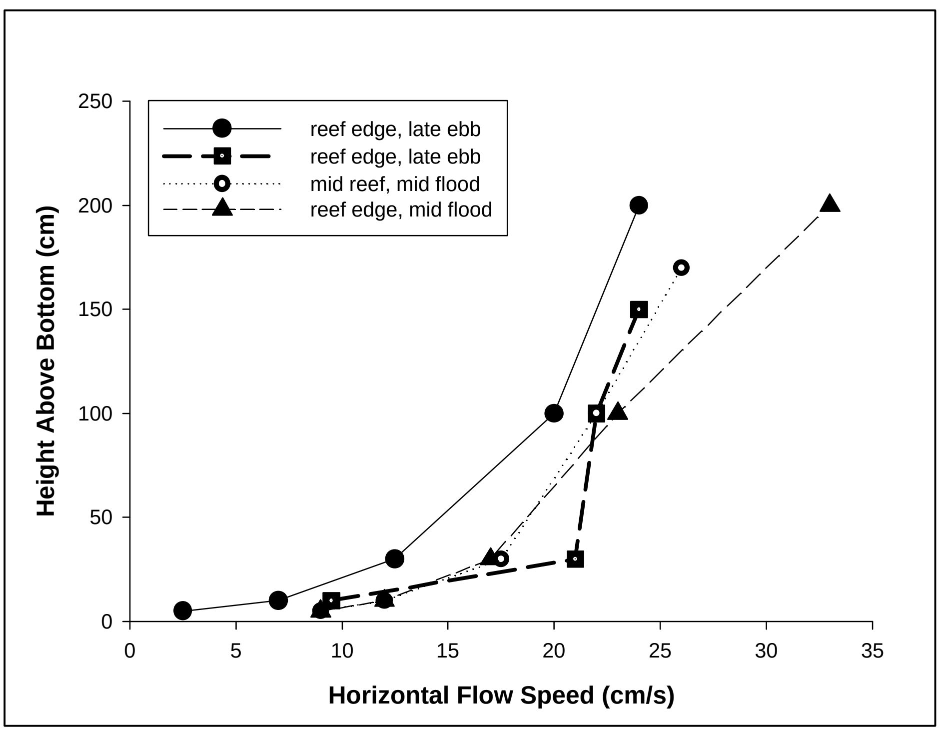

Fig. 6. Typical vertical profiles of horizontal flow speeds over constructed reefs in Salmon Falls River; note minimal flows within 10 cm of the bed.

Construction of experimental oyster reefs

Two experimental reefs were constructed. One consisted of transplanted native oysters with associated shell material, and the other of remotely set, disease-resistant spat. To construct the first reef, a total of two hundred and thirty (230) bushels of native oyster shells were transplanted over two days, 17 May and 24 May 2000. All shells were dredged from a natural reef in the Piscataqua River about 1 km south of the study site, and deposited in a 10 x 30 m area (Fig. 2). Measurements made by divers in several areas of the newly constructed reef showed shell material extending between 5 and 10 cm height above the surrounding bottom. This material was mostly empty oyster shells but also consisted of an estimated 3 to 5% live oysters as well as ribbed mussels (*Geukensia demissa*) and blue mussels (*Mytilus edulis*), which can occur in substantial numbers naturally on oyster reefs in the area.

The disease-resistant reef was constructed using spat from oysters produced by the Cooperative Regional Oyster Selective Breeding (CROSBreed) program funded by NOAA/Sea Grant through its Oyster Disease Research Program (Leffler 1999). The CROSBreed line was developed for resistance to MSX and Dermo by a consortium of mid-Atlantic institutions using an existing disease-resistant line from the Haskin Shellfish Laboratory at Rutgers University. CROSBreed oysters are not fully resistant to disease, but they have demonstrated tolerance levels that exceed natural populations in areas where tested. The present project is part of an ongoing national effort to assess the utility of CROSBreed oysters for reef restoration programs.

Two separate batches of larvae were set in early June and a third in August 2000. All larvae were purchased from Middle Peninsula Aquaculture Company, Virginia. The three sets, involving a total of 5 million larvae, resulted in 85,000 spat. Approximately 35,000 spat survived the nursery growth period and were transplanted onto the experimental reef in a 10 x 20 m area 20 m north of the native transplant reef in October 2000 (Fig. 2). Measurements made by divers after construction was completed indicated that the CROSBreed reef extended on average about 5 cm above the surrounding bottom.

Reef development

Development of the two constructed reefs and population dynamics of bivalve populations (eastern oyster, ribbed mussel, blue mussel) on the natural disease-decimated reef were monitored on five different occasions since reef construction in spring-summer 2000 (Fig. 7). Initially, total oyster densities averaged 123 individuals/m^2 on the native transplant reef and 75 individuals/m^2 on the CROSBreed reef. These densities were from 4 to 6-fold the densities on the adjacent disease-decimated natural reef. At 12 months post-construction for the native transplant reef (May 2001), oyster densities had declined to about half their initial densities. In contrast, oyster survival on the CROSBreed reef at 7 mo post-construction (May 2001) remained at about 100%. There were nearly equal numbers of spat and juveniles/adults on the transplant reef. In contrast, the CROSBreed reef consisted almost totally of spat, as expected.

To date, results of disease testing are only available for 2001. At that time, the CROSBreed oysters showed relatively low incidences of MSX and Dermo infection (Table 1). In contrast, native transplants had high levels of infection for both pathogens. Other parasites were at low levels in both groups.

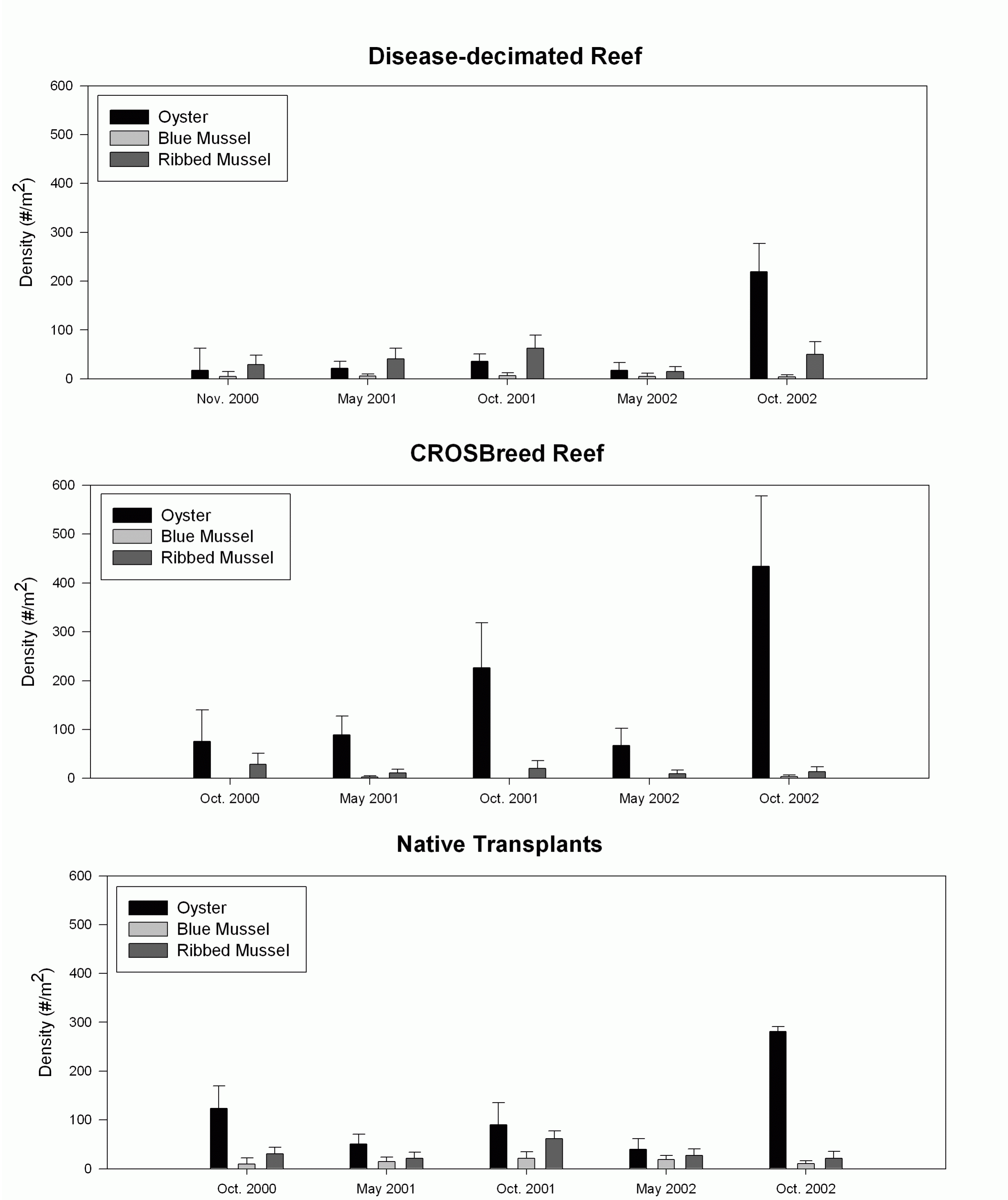

Fig. 7. Mean densities (with 95% CI) of all size classes of three bivalve species on natural disease-decimated reef and two constructed reefs. CROSBreed reef was constructed in October 2000. Native transplant reef was constructed in May 2000. Increased densities in October 2002 reflected dense spat sets on all three reef areas.

Table 1. Percent infection by MSX, Dermo, and other parasites on CROSBreed and native transplant constructed reefs in Salmon Falls River.

Site	Collected	Disease	Stock	% Infected	% Advanced
Salmon Falls River	10/18/2001	MSX	CROSBreed	5%	5%
Salmon Falls River	10/18/2001	MSX	NH Native	43%	10%
Salmon Falls River	10/18/2001	Dermo	CROSBreed	12%	0%
Salmon Falls River	10/18/2001	Dermo	NH Native	60%	12%

				Trematodes	Ciliated Xenoma	Chlamydia	Gonad Papovirus
Salmon Falls River	10/18/2001	Other	CROSBreed	0%	0%	0%	0%
Salmon Falls River	10/18/2001	Other	NH Native	5%	0%	0%	5%

Mathematical model of seston uptake

This objective was the major task of the final reporting period, and emphasis was placed on testing of a new spreadsheet-based uptake model. The model predicts the percent of the total water column cleared of seston by suspension feeding bivalve mollusks on an hourly basis:

% Water Clearance (seston uptake) = (A x B x C)/(D x E) x 100

where A = mean bivalve density (# ind/m^2), B = mean individual clearance rate (m^3/individual/hr), C = bottom area of reef (m^2), D = cross-sectional area of water column (m^2), and E = mean water flow speed (m/hr).

The model is designed for use in predicting the impacts of suspension-feeding bivalves generally on water quality, by estimation of the percent of the overlying water column that is cleared of seston as they feed. A major departure of this model from existing models is that the rate units are hourly. Hence, short-term changes in seston concentration, current speed, and other factors are only considered as they contribute to the longer-term average. The intent is to provide managers with a model that can be used to quantitatively estimate the relationship between restored shellfish reefs (or other populations of bivalves such as aquaculture farms) and water quality by predicting how much of the overlying water column is "processed" by the bivalves. The major simplifying assumption for the model is a completely mixed water column. Mean clearance rates are based on literature values.

Model predictions (Table 2) as well as preliminary field tests on the constructed reefs indicated that mean seston uptake rates would be negligible under most ambient tidal stage and flow conditions. This was in large part due to the relatively deep water in the reef area. Hence, additional reefs were chosen to test the model. During 2001 and 2002, the model was tested on five oyster reefs and two blue mussel reefs (Table 2). For five trials, model predictions and actual seston uptake measured by *in situ* fluorescence averaged 23.0% and 19.5%, respectively. In three trials, model predictions and actual seston uptake measured by changes in chlorophyll *a* concentrations averaged 23.0% and 11.2%, respectively. A scatterplot of these data suggests a linear relationship between predicted and measured uptake rates (Fig. 8). Although the correlation (r^2 = 0.53) between the data was non-significant, the overall trend indicates considerable potential for further development of the model.

Table 2. Summary of seston uptake studies involving eastern oyster and blue mussel. Clearance rates based on literature values. All zero (0) values indicate non-significant (P > 0.05) t-test comparing means of upstream and downstream seston measurements; non-zero percentages for seston uptake given when P < 0.05. Numbers in parentheses following each seston uptake mean indicate number of 5-min sampling intervals characterized by *in situ* fluorometry and number of samples taken for seston analyses.

Eastern oyster (*Crassostrea virginica*)

	Model Parameters						Seston Uptake (% difference up- and downstream)				
Location	Mean Bivalve Density (# /m^2)	Mean Bivalve Size (mm)	Clear. Rate (L/hr)	Mean Flow Length (m)	Mean Flow Speed (cm/s)	Water Depth (m)	Model Predictions	*In situ* Fluor.	Chl. *a*	Total Seston	Organic Seston
NH reef (SFR)	125	50.0	4.5	70	8.5	3.80	2.2	-	-	-	-
FL reef 1	61	33.3	3.3	12	11.8	0.31	**1.8**	**12.0**(7)	-	-	-
FL reef 2	122	52.2	5.2	20	4.0	0.19	**46.4**	**38.7**(4)	-	-	-
FL reef 3	76	48.8	4.9	45	5.3	0.45	**19.5**	**11.5**(8)	17.2	0	0
FL reef 4	134	45.0	4.5	17	8.0	0.17	**20.9**	**27.1**(5)	-	-	-

Blue mussel (*Mytilus edulis*)

	Model Parameters						Seston Uptake (% difference up- and down-stream)				
Location	Mean Bivalve Density (# /m^2)	Mean Bivalve Size (mm)	Clear. Rate (L/hr)	Mean Flow Length (m)	Mean Flow Speed (cm/s)	Water Depth (m)	Model Predictions	*In situ* Fluor.	Chl. *a*	Total Seston	Organic Seston
NH reef 1(OSMP)	292	47.0	4.7	12	15.0	1.00	**2.5**	-	0	0	0
NH reef 2(Albacore)	440	45.0	4.5	63	19.5	0.37	**47.0**	**27.8**(4)	16.3	-	-
						Mean:	**23.0**	**19.5**			

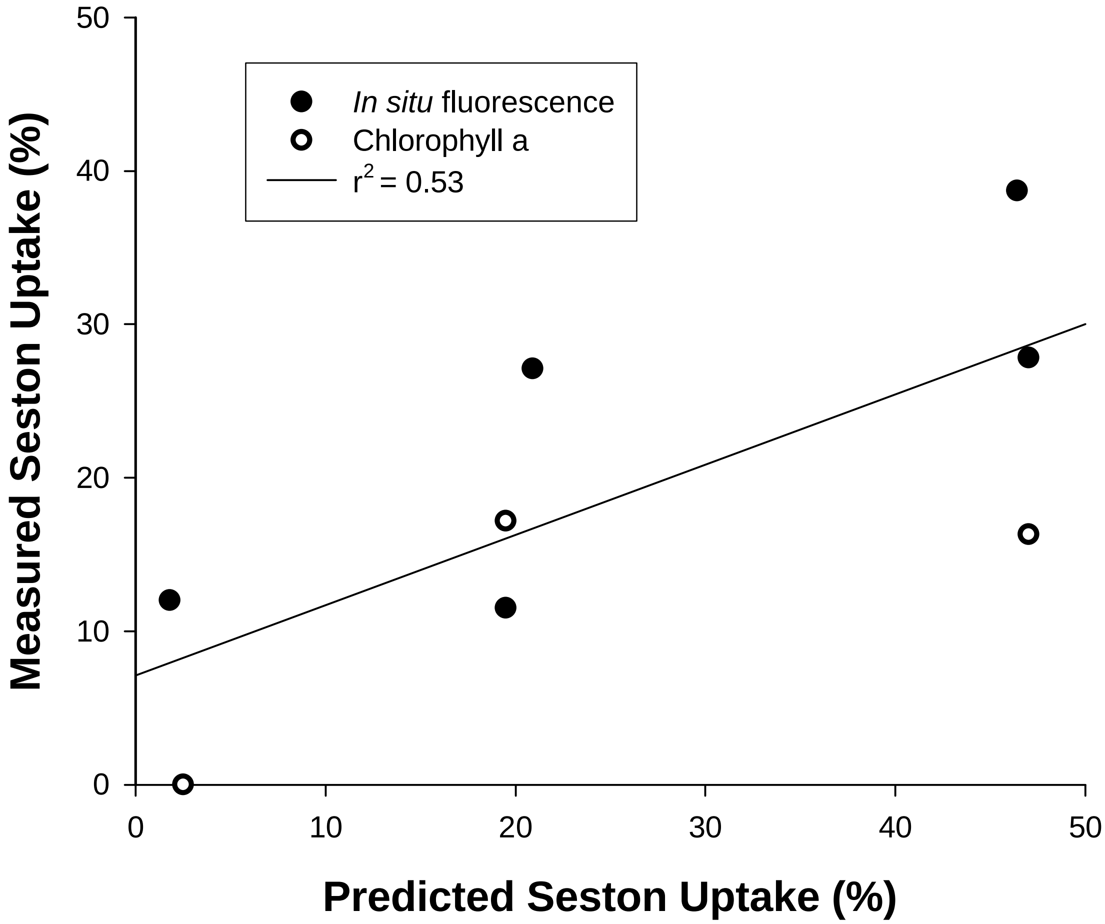

Fig. 8. Model predictions of seston uptake compared to measured (*in situ* fluorometry and laboratory chlorophyll measurements from pumped water samples) uptake as percent of water column cleared of seston.

Discussion

This project initiated two experimental, constructed oyster reefs using different methods: transplanting of native oysters, and seeding using spat from remotely set CROSBreed larvae. It also resulted in development of a new, simplified, spreadsheet-based mathematical model for predicting seston uptake rates by populations of suspension-feeding bivalve mollusks. The model was initially intended mainly for use by environmental managers to estimate the potential impact of restored shellfish reefs on water quality but interest has also been shown by bivalve shellfish farmers to estimate optimum stocking densities (see Technology Transfer section below).

Assessment of the effectiveness of oyster reef restoration methods requires research of longer duration than the present study, which was intended to inititiate reef development and provide a preliminary assessment. Data collected thus far indicate the CROSBreed reef is doing well and has the potential to develop into a self-sustaining reef (Fig. 7). Mortalities and disease infection levels have been low and the oysters have shown good growth rates. The CROSBreed reef also caught a dense spat set in summer 2002. These findings are similar to studies in other areas (Leffler 1999, 2002). However, it should be noted that research on reefs constructed using CROSBreed spat has only been conducted since the mid 1990s, and most studies have been restricted to mid-Atlantic estuaries (Leffler 1999; Sorabella et al. 2002). The present project is the only New England trial. Much remains to be learned about the effectiveness of CROSBreed spat as a restoration technique and such knowledge can only come from long-term studies (see below).

In comparison, the native transplant technique does not appear to be as effective a method for restoring reefs in the present study area. Densities of juvenile and adult oysters on the constructed reef remained greater than on the natural reef after 2.5 yr of development but only about half the densities of oysters on the CROSBreed reef, even though the two reefs started at similar densities (Fig. 7). There also was substantial mortality within 1 year of reef construction, compared to negligible mortality on the CROSBreed reef. Although the native transplant reef caught a good spat set in summer 2002, spat densities were only about half those on the nearby CROSBreed reef.

This technique is typically used as a way to concentrate broodstock in an area in order to increase natural set and thereby "jump start" the constructed reef to become self sustaining (Leffler 1999; Mann 2002; Sherwood 2002). In some cases, the aim is also to establish broodstock sanctuary reefs capable of providing spat for reefs in other areas. The present study should be considered preliminary because it only involved one reef. Although the results thus far (after 2.5yr of reef development) have not been encouraging, the constructed reef will be monitored as part of an anticipated long-term program.

A long-term monitoring program has been proposed (NOAA, Hatch funds) to continue to monitor all three reefs from the present study. If funded, this program will complement the ongoing monitoring by NH Fish & Game Department that concentrates on other reefs in the Great Bay/Piscataqua River estuarine system. With respect to reef restoration techniques, the intent is to provide information needed by environmental managers seeking to restore New Hampshire's oyster populations (NHEP 2002). At this time, spat seeding from remotely set CROSBreed larvae shows promise as a technique that may be appropriate in some areas.

The second major component of the present study was development of a mathematical model capable of predicting the impact of restored reefs on water quality and also being useful to environmental managers. In the past decade, oyster reef restoration efforts in many areas have been explicitly directed towards enhancing the ecological functions of reefs (Breitburg et al. 2000; Mann 2000). One of these functions is the ability to filter substantial volumes of water as the oysters feed and thereby enhance water quality by removing suspended particulates (Newell 1988; Dame 1999). A simplified, spreadsheet-based model was developed and tested on five oyster reefs and two blue mussel reefs. Results thus far have been promising. The model has shown reasonably good agreement with measured uptake rates (Fig. 8; Table 2), but more testing is needed.

The major simplifying assumption of a well-mixed water column (see above) probably limits use of the model to reefs in relatively shallow waters. Oyster reefs on the east coast north of Virginia are found only subtidally (Bahr and Lanier 1981). Many of these reefs, however, are in the shallow subtidal zone where ambient tidal flows coupled with bottom roughness provided by the reef itself may result in a mixed water column much of the time. In mid-Atlantic and southeastern estuaries where most reefs are in the intertidal zone, the assumption of a well-mixed water column may also be the case.

Hence, it seems reasonable to conclude that the model may have wide application for east coast oyster reefs.

Technology Transfer and Management Application

Technology transfer has occurred with respect to three audiences: coastal managers, scientists, and shellfish farmers. Communication with the first two groups was accomplished by presentations at the National Shellfisheries Association annual meeting in 2002, and by informal communications. Contact has also been made with a clam farmer in Virginia and extension agents in Florida who work with clam farmers there.

As already discussed, conclusions regarding the effectiveness of the two restoration methods will require longer-term studies, which are in progress. Although the present study was only experimental in scale, the two constructed reefs represent the first shellfish restoration project in New Hampshire that will contribute to planning goals of 20 acres of restored reefs by 2010. Results from the present study will also be considered as additional restoration projects are developed.

Clam farmers became interested in the seston uptake model and field testing protocol as a way to estimate seeding densities. This was an unexpected but potentially very important result. To date, one collaborative research proposal (NOAA, Small Business Innovation Research) has been submitted and others are anticipated.

Scientific and Academic Achievement

The following presentations were made at the National Shellfisheries Association annual meeting in March 2002 and both were published as abstracts.

Grizzle, R., J. Greene, and M. Luckenbach. 2002. A simplified seston uptake model for bivalves: preliminary field trials. *Journal of Shellfish Research* 21:422 (abstract)

Grizzle, R., J. Greene, S. Jones, M. Luckenbach, and R. Mann. 2002. An oyster (*Crassostrea virginica*) reef restoration experiment in New Hampshire involving CROSBreed stock and native transplants. *Journal of Shellfish Research* 21:430 (abstract)

Acknowledgments

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