VIRGINIA SALTWATER RECREATIONAL FISHING DEVELOPMENT FUND SUMMARY PROJECT APPLICATION*

NAME AND ADDRESS OF APPLICANT:

Virginia Institute of Marine Science
P.O. Box 1346
Gloucester Point, VA 23062

PROJECT LEADER (name, phone, e-mail):

Rochelle D. Seitz

(804) 684-7698, seitz@vims.edu

PRIORITY AREA OF CONCERN:

Habitat Improvement and Research

PROJECT LOCATION:

Northern Neck, Poquoson, and Lynnhaven Bay

DESCRIPTIVE TITLE OF PROJECT:

Habitat Suitability for Artificial Recreational Fish and Oyster Reefs

PROJECT SUMMARY:

We request funds to monitor environmental factors surrounding recently deployed subtidal artificial reefs that were designed to attract large, structure-dependent fish such as sheepshead and tautog, as well as to allow oyster settlement. We will investigate the effectiveness in placement of various combined artificial fish/oyster reefs in enhancing fish production of structure-associated recreational fish (e.g., sheepshead) by examining the prey food base and predator-prey interactions. Based on knowledge of habitat quality, we hypothesize that where environmental factors are optimal, the prey will develop, and production of large fish and oysters will be enhanced. Sampling of artificial reefs and fish will elucidate density and production.

EXPECTED BENEFITS:

Field sampling of the environmental parameters and resultant epibenthic fauna on recently deployed artificial reefs will give direct evidence of the community of prey for recreational fishery species that develop on these artificial reefs. A comparison of environmental factors will allow a quantitative understanding of ecological conditions beneficial to local recreational fishery species and their food-web interactions. We will document increased production of the ecosystem that stems from optimal deployment of these reefs and a comparison among reefs in three habitats will identify key habitat characteristics that are beneficial for increased production. Further studies could elucidate the performance of such alternative substrates in comparison to traditional reefs and identify key environmental factors that lead to increased recreational fish production.

COSTS:

We are requesting funds for one month of salary for Project Director Seitz, 12 months of support for an hourly technician at VIMS to help with field and lab work (30% fringe for faculty, 7.65% for staff), 45 days of boat time, supply costs (nets, sieves, chemicals, glassware, etc.), and travel funds for trailering boats.

VMRC Funding:	$ 61,076
Recipient Funding:	$ 18,583
Total Costs:	**$ 79,659**

Detailed budget must be included with proposal.

Updated 6/1/05

***This form alone does not constitute a complete application, see application instructions or contact Sonya Davis at 757-247-8155 or sonya.davis@mrc.virginia.gov : Due dates are June 15 (Jul. – Nov. Cycle) and December 15 (Jan. – May Cycle)**

Peterson CH, Kneib RT, Manen CA (2003b) Scaling restoration actions in the marine environment to meet quantitative targets of enhanced ecosystem services. Mar Ecol Prog Ser 264:173–175

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Seitz, RD, Lipcius, RN, Hines, AH, Eggleston DB (2001) Density-dependent predation, habitat type, and the persistence of marine bivalve prey. Ecology 82 (9), 2435-2451

Seitz, RD, Lipcius RN, Stockhausen WT, Delano KA, Seebo MS, Gerdes PD (2003) Potential bottom-up control of blue crab distribution at various spatial scales. Bulletin of Marine Science 72 (2): 471-490

Verner J, Morrison ML, Ralph CJ (1986) Wildlife 2000: modeling habitat relationships of terrestrial vertebrates

6.) **Estimated Cost and Justification**

	months	VMRC	VIMS
Salaries			
Seitz, PI - 1 month	1	6,017	6,017
Technician (BS level) - 12 months	12	26,004	
Fringe, 30% salaries; 7.65% waged		3,794	1,805
Supplies			
Boat fuel, bags, jars, chemicals, labels		5,450	
Travel			
Domestic to field sites @$.58/mile VIMS truck		1,470	
Vessel Rental			
Rental - $125/day x 45 days	45 days	5,625	
Publication and dissemination		500	
Facilities & Administrative Costs		12,215	10,761
(plus an additional $ 10,761 as match)			
Total from VMRC		61,076	18,583

Brief Project Budget Justification

The Project Director Seitz, will oversee and manage the project, sample collection, and data analyses. We are requesting funds for one month of salary ($6,017/mo) for Seitz, with $6,017 match. We include 12 months of support for an hourly technician at VIMS ($2167/mo) to help with field work collecting environmental data, sampling invertebrates on the replicate reef structures, and conducting gut-content and production analyses. We apply the allowable 30% fringe for faculty, 7.65% for hourly staff.

We request 45 days of boat time on a VIMS vessel (large privateer) for sampling of all three reef locations and fish collection for diet analysis (3 work weeks for each of 3 months in summer). This vessel costs $125/day x 45 days (= $5625) plus fuel and mobilization fee of $20 for 45 days ($900) (listed in supplies).

Supply costs including nets for sampling fish on reef structures ($700), sieves, formalin preservation chemicals, glassware, and forceps ($1,100), suction sampling bags and other field sampling supplies ($500) totaling $3,800. Supplies also include vessel fuel: 45 boat days @ $50 fuel per day ($2250) plus $900 in mobilization fees.

Travel includes trucks for trailering boats from the VIMS main campus to field sites on the Lynnhaven Bay at 41 miles away ($0.58 per mile x 2 ways= $47/day) for 15 days ($705), Poquoson at 15 miles away ($0.58 per mile x 2 ways = $18/day) x 15 days = ($270), and Northern Neck (leave from Deltaville at 28 miles away ($0.58 x 2 trips = $33/day) for 15 days = ($495). This totals $1,470 for travel. In addition, we request $500 in all years for publication and dissemination costs including journal page charges and public relations printing/artwork support. Indirect costs limited to 25% for funds provided by Marine Recreational Fishing Advisory Board. Institutional approved rate is 45%. The remaining costs are contributed as part of the VIMS match for this project. The total funds requested from the Marine Recreational Fishing Advisory Board are $61,076, with $18,583 in match, totaling $79,659 for the project.

Proposal Submission to

Virginia Marine Resources Commission

By

THE VIRGINIA INSTITUTE OF MARINE SCIENCE
COLLEGE OF WILLIAM AND MARY

Habitat Suitability for Artificial Recreational Fish and Oyster Reefs

Rochelle D. Seitz
Principal Investigator

Romuald N. Lipcius
Co-Principal Investigator

J. Emmett Duffy
Chair, Biological Sciences

Jane A. Lopez
Director, Sponsored Programs

Roger Mann
Director for Research and Advisory Services

December 17, 2007

Habitat Suitability for Artificial Recreational Fish and Oyster Reefs

P.I.: R.D. Seitz

1.) **Need**

A. Introduction

Habitats vary in physical and biological attributes that can influence their ability to support various species. Habitat Suitability Indexes (HSIs) are numerical indexes that demonstrate the capacity of a given habitat to support selected species. They are influential management tools and have been used for many years by natural resource managers (Cole and LeFebvre 1989). Species-habitat relationships are important in determining the HSIs, and positive correlations of environmental factors with elevated species abundances can indicate increased habitat suitability; however, these models do not prove cause and effect relationships (Brooks 1997). HSI model results represent the interactions of the habitat characteristics with abundance of species. A value of the habitat suitability (between 0 [not suitable] to 1 [optimal]) can aid in understanding species-habitat relationships and can lead to educated decision making (Verner et al. 1986) with regard to locating artificial reefs in optimal habitats. Various ecological factors affect the abundance and density of species within a habitat and these factors can be predictive of habitat suitability. For example, recent analyses of benthic data from the Chesapeake Bay show that dissolved oxygen is a strong predictor of benthic community density (Fig. 1), suggesting that optimal habitats can be predicted by oxygen conditions. We propose to examine environmental factors that affect reef success with the goal of predicting where to place future reefs to optimize fish production.

Artificial reefs can enhance the production of recreationally important fish by providing habitat for structure-dependent fish (Seaman 2000) and by increasing prey availability for resident and transient fish that forage on the reefs (Peterson et al. 2003a). The empirical means of estimating fish production on artificial reefs has been developed and used successfully to demonstrate enhanced production of fish with artificial reefs (Peterson et al. 2003a). There are various ways by which fish production is increased by artificial reefs. For example, if there is a bottleneck for survival of early life history stages of fish, then providing additional habitat (e.g., artificial fish reefs) is projected to cause increased recruitment of the species. Moreover, artificial reefs may provide additional food resources, via the reef-associated invertebrate prey, that may enhance growth of fish species associated with the reef (i.e., bottom-up control), or reefs can enhance fish survival by providing refuges from predation (Hixon 1998; Peterson et al. 2003a, b). If recruitment is limited by habitat area, additional reef habitat can result in increased fish production by improving habitat area, or by augmenting growth currently limited by reef refuges and associated prey (Peterson et al. 2003a). Given these strong arguments in support of enhanced fish production with artificial reefs, it is typically recognized that such reefs can benefit recreational anglers who fish on artificial reefs.

Bottom-up control of production has been demonstrated in several fisheries species. A combination of predation (i.e., top-down factors) and food limitation (i.e., bottom-up factors) likely influences species distributions in marine, freshwater, and terrestrial habitats, depending on aspects of the local food web (Posey et al., 1995; Menge et al., 1996). At broad spatial scales, bottom-up or physical factors may be more important than top-down factors (Power, 1992; Menge et al., 1997; Seitz and Lipcius, 2001). For instance, a recent study provided evidence for bottom-up control of an upper level omnivore (i.e., the blue crab) by its primary prey (i.e., the Baltic clam) (Fig. 2). Similarly, we expect that abundance of fish on artificial reefs will be directly related to the abundance of their prey.

Oyster restoration has achieved mixed results, with successful reefs in some locations but not others, and on some settlement substrates but not others. Recent evidence suggests that concrete reef structures support not only oysters (Lipcius and Burke 2006), but also many invertebrates that serve as prey for fish predators (e.g., mud crabs, marine worms)(Seitz et al. manuscript in preparation). Such concrete reefs are likely to enhance the productivity of recreationally valuable fish in the area, yet such reefs have not been examined in Virginia waters as artificial fish reefs where recreational fishing is prominent. Recent VMRC funding to establish fish and oyster reefs in the Northern Neck, Poquoson, and the Lynnhaven River system benefits multiple user groups, namely saltwater fishers and those concerned with oyster restoration, and can serve as a model system for establishing such artificial fish/oyster reefs throughout Virginia waters. The productivity of these recently deployed reefs has not yet been quantified since they have been recently established, and the influence of environmental factors on productivity has not yet been determined.

We request funds to monitor environmental factors that influence the production of subtidal artificial fish reefs and determine invertebrate and fish production over time in these newly established reefs in various locations. The reefs attract large, structure-dependent fish, such as sheepshead and tautog, and also promote oyster settlement and survival. Specifically, we will investigate the effectiveness of artificial fish/oyster reefs in enhancing local production of structure-associated recreational fish in three different locations that vary in environmental characteristics. We will accomplish this by examining environmental factors, the prey food base that develops on recently deployed reefs, and predator-prey interactions through direct sampling of the reef invertebrates and fish gut-content analyses. Prey of these recreational fishery species have been identified (Chesapeake Bay Fisheries Ecosystem Plan). We expect that at reefs where environmental factors are suitable, fish have adequate prey, and fish feed upon intermediate predators of juvenile oysters (e.g., mud crabs), both the production of fish and oysters will be enhanced. Sampling of artificial reefs and fish diets, combined with mathematical HSI modeling, will allow quantification of habitat suitability and will elucidate how this relates to reef production. Ultimately, we will be able to determine which environmental factors promote prey and recreationally important fish. We will then integrate our findings with those of the complementary project by Lipcius on sentinel reefs, fish production and oyster survival, and provide recommendations on the optimal reef locations to increase recreational fish production on new reefs.

Based on knowledge of food-web interactions (Chesapeake Bay Fisheries Ecosystem Plan), we hypothesize that on artificial reefs in quality habitats where fish have abundant prey and the benthic community provides high production value, the fish will have increased productivity. Moreover, where fish feed upon intermediate predators of juvenile oysters (such as mud crabs), oysters will survive and thrive. Field sampling of the epibenthic fauna on recently deployed artificial reefs will give direct evidence of the community of prey for fished species that develop over time on these artificial reefs. Reefs were deployed using previous VMRC funding and we request renewed funding to follow development of the reef communities at quarterly intervals over time. Evaluation of benthic production using removable "inserts" will allow quantification of food resources necessary for high fish production. We also aim for a quantitative understanding of ecological conditions that are beneficial to local recreational fishery species. Our studies will help evaluate the performance of some existing reefs (e.g., VMRC tetrahedron and pipe reefs in the Northern Neck) in relation to habitat characteristics. Ultimately, our evaluation of environmental conditions necessary for successful reef production could lead to a rapid assessment of habitats suitable for future reef deployment.

We intend to address the following major elements: (1) assessment of environmental factors at four replicate locations at three different sites (Northern Neck, Poquoson, Lynnhaven); (2) quantification of the production value of the prey community for recreational species on artificial oyster reefs; and (3) monitoring of fish predators' diet choice on artificial reefs; (4) Utilization of Habitat Suitability Indexes (HSIs) to relate fish and invertebrate production to habitat characteristics.

B. Artificial reef substrates

Various artificial reefs may enhance fish production by (1) providing shelter or (2) providing food (prey) for associated fish, however, some reefs may be able to provide both of those aspects. Environmental factors may influence habitat quality and thus will affect reef performance. This study aims to determining which environmental factors contribute most to the production of recreational fish and invertebrates on artificial reef structures.

Often, artificial reefs serve a dual purpose, either as alternative fish or bivalve habitat or as an outlet for excess materials produced by industry (e.g., pelletized coal ash). For example, of the 11 artificial reefs that exist along the Italian Adriatic coast (Bombace et al. 2000), seven serve as the best European examples of reefs that have provided successful commercial harvests, and which are used both by fishers and by aquaculturists (Jensen 2002). In Europe, the one artificial reef was used for experimental work on suspended shellfish culture (mussels and oysters). On this oyster reef, species richness, species diversity, and fish abundance increased after reef deployment (Fabi and Fiorentini 1997), particularly for reef-dwelling nekto-benthic species (e.g., Sparids and Sciaenids). Three years after deployment, the increase in average catch weight for these species was 10–42 times the initial values. The reefs also had higher catch rates of reef-dwelling fish in comparison with unprotected areas, and seemed to be ‘‘buffered’’ against significant reduction compared to stocks in areas without reefs (Fabi and Fiorentini 1993). Thus, alternative reef structures can provide the stability and complexity of natural reefs via development of adequate prey resources that can lead to higher abundance, biomass, and diversity of many species.

In Chesapeake Bay, a subtidal modular reef structure deployed in 2000 was successful in enhancing oyster and mussel densities as well as recreational fish species. In a recent report, population structure, density, abundance, and biomass of Eastern oyster and hooked mussel, *Ischadium recurvum*, was quantified on this reef. After the reef had been deployed for 4 ½ years, in May 2005, the reef had been colonized heavily by oysters and mussels, which recruited and survived at densities of 28 to 168 per m^2 of reef surface area for oysters and of 14 to 2,177 per m^2 for mussels (Lipcius and Burke 2006). Additionally, the reef supported various additional prey resources such as mud crabs, polychaete worms, and small mollusks. Moreover, this reef supported sheepshead, tautog, striped bass, croaker and other recreational fish (diver observations). This 3-D modular reef structure apparently was in a suitable habitat and provided an architecture that is conducive for settlement, growth and survival of oysters and other prey for finfish. Therefore, such modular structures should be considered as viable alternative reef structures when they are placed in suitable habitats. Given the documented success of modular reef structures, we aim to test the performance of this type of artificial reef for recreational fish and oysters.

In the past year, using VMRC funding, we deployed replicate concrete modular reefs (Fig. 3) in the Northern Neck, Poquoson, and Lynnhaven Bay. In addition, we conducted a detailed examination of environmental factors at the existing Northern Neck reef site (Fig. 4), as well as an assessment of infaunal benthos in the general area of reef deployment, and we have similar information for other sites. Previously at the Northern Neck site, VMRC had established two different reef types, tetrahedrons and pipes, located at slightly different locations (Fig. 5), and the two reefs differ in their effectiveness as fish reefs. Our analyses show that tetrahedron reefs had a ratio of live to dead oysters of approximately 1:1, whereas the pipe reefs had a ratio of 3:1 live to dead, suggesting that the pipe reefs are performing better. Anglers and M. Meier (personal communication) have confirmed that the pipe reefs are more productive for fish in the area. Comparing our environmental data with biological oyster and fish data, we can see that oxygen conditions are adequate (above 2 mg/L) at both reef sites (Fig. 4 bottom left panel, including VMRC reef polygon in green dots), but excessive organic carbon (TOC) (Fig. 4 bottom right panel) at the tetrahedron site may be indicative of poor water quality or poor hydrodynamic flushing of the habitat. Incidentally, the abundance of infaunal benthos nearby the tetrahedrons (mean of 19.4 $\pm$ 2.2 SE individuals/sample) was much higher than that away from tetrahedrons (mean of 10.5 $\pm$ 1.8 SE individuals/sample). This abundance nearby the tetrahedrons was possibly in response to favorable oxygen conditions, or increased TOC, which is beneficial to deposit-feeding polychaetes and bivalves. Additional studies examining production on our recently deployed modular reefs throughout the artificial-reef polygon will allow a direct comparison of environmental factors and reef production; because the prey community is just developing, we will need additional funding to follow the reef establishment, with sampling every three months for one year.

This project falls under the categories of both habitat improvement and research. The artificial reefs are designed to improve habitat for recreational fish species, and the accompanying research will identify the environmental conditions necessary for increased benthic and fish production and thus determine the factors necessary for successful reef deployment in the future.

2.) **Objectives**

A) Quantify environmental factors at three different reef-deployment locations.

B) Identify prey species and production on artificial reefs in three locations.

C) Determine predator-prey interactions through gut-content analysis of structure-dependent reef fish.

D) Use habitat suitability indexes to relate fish and invertebrate production to habitat characteristics.

3.) **Expected Results or Benefits**

Virginia's recreational fishermen can benefit from deployment of our experimental reefs (deployed during previous funding period) but the success of these reefs will be determined in subsequent months. In this new phase of the project, we can demonstrate development of the reef-dependent community and relate success at different location to variations in environmental factors. Traditionally, artificial reefs have been deployed but quantitative evaluation of conditions leading to success or failure has not occurred. Fishermen will benefit in subsequent years because this study will determine the optimal reef location for prey settlement and resultant high carrying capacity based on evaluation of environmental conditions and prey resources on various reefs. The use of an experimental approach with replicates throughout the habitat in three different locations will allow determination of the optimal habitat for future artificial reefs. For example, in previous studies on the benefits of artificial reefs, three years after deployment, the increase in average catch weight for certain fish species was 10–42 times the initial values. Some reefs performed better than others and environmental conditions may have played a role in these differences.

4.) **Approach**

A) Experimental Design

In conjunction with a companion study from our previous VMRC funding, 3-4 replicates of modular concrete reefs were deployed at each of three locations (Northern Neck, Poquoson, Lynnhaven)(Fig. 3).

B. Field sampling – environmental conditions

Prior to reef deployment, environmental variables such as temperature, salinity, dissolved oxygen, sedimentary carbon and nitrogen, and sediment grain size (often indicative of water-column turbulence), were quantified. A detailed mapping of these factors (in Arcmap GIS) can lead to a better understanding of habitat quality (for example, Fig. 4). HSI models examining the response of the biological reef community will suggest optimal conditions for future placement of reefs.

C. Field sampling – invertebrates

Before deployment of reefs, we sampled the infaunal invertebrates in the bare sediment in the reef footprint and surrounding area to establish a baseline productivity value for each site and relate initial benthic production to environmental factors. After reefs have been established since fall of 2007, in spring of 2008, we will use a concrete insert of approximately 0.25 m x 0.25 m area within each replicate reef location to evaluate development of the invertebrate prey community. The insert will be removed, and all fauna will be scraped into a mesh bag (1-mm mesh). All invertebrates retained on the screen will be identified to the lowest possible taxonomic level (usually species), measured, and frozen for biomass estimates. To obtain ash free dry weight (AFDW), invertebrates will be dried to a constant weight (~48 h) at 60°C, and ashed at 550°C for 4 h to obtain ash weight. Through collection of invertebrates at multiple sampling times (spring, summer, fall) we can estimate annual production (g AFDW m^{-2} yr^{-1}) by use of the increment summation method (Downing and Rigler 1984) on the basis of AFDWs quantified. In the companion Lipcius proposal, fish production will be quantified with a combination of an underwater video system, direct diver observations, and selective capture of fish with circular nets used previously by us to sample artificial shelters in other locations. Subsequently, we will statistically compare the abundance of fish prey at the three reef locations, and determine which environmental variables lead to optimal prey for recreationally important fish species and highest fish production.

D. Predator-Prey interactions – gut contents

We intend to work with the recreational fishers at the Northern Neck, Poquoson and Lynnhaven bay (with help from the Lynnhaven now community group) to collect stomachs from fish that they have collected. We also intend to collect fish from the artificial reefs with hook and line and sampling nets. Fish will be frozen immediately upon capture and stomachs will be removed either in the field or in the laboratory and immersed in preservative. The gut-processing protocol is as follows: (1) contents of each stomach are emptied and each prey item is identified to the lowest possible taxonomic level (usually species); (2) after identification, each prey item is counted, weighed and measured. We will then calculate diet indices such as %Weight, %Number, %Frequency, and %IRI (index of relative importance).

5.) **Location**:

The Northern Neck reef system has been used by VMRC and the location of existing artificial reefs are well-known. The Poquoson site also has VMRC reefs made from "materials of opportunity". The Lynnhaven River System, on the southern shore of Chesapeake Bay, is a well-studied system where data on water quality and hydrodynamics are readily available and which supports a large recreational fishery for multiple species. Moreover, Lynnhaven has been chosen as an oyster restoration zone because it has supported oyster populations in recent years and had a history of regular spat settlement and significant private oyster production. We know that this system experiences predictable, high settlement of oyster larvae and is thus a prime location for field experiments that require natural oyster settlement.

Field sampling of the epibenthic fauna on these artificial reefs will give direct evidence of the community of prey for recreational fishery species that develop on reefs. A comparison of various reef locations will allow a quantitative understanding of ecological conditions beneficial to local recreational fishery species and their food-web interactions. We will document food-web interactions leading to increased ecosystem production on and around these reefs, and a comparison among three locations will identify key habitat characteristics that are beneficial for increased production. These studies will elucidate the performance of artificial reefs in various environmental conditions and will allow us to maximize prey availability and increase recreational fish production in future reef deployments.

As noted in the companion Lipcius proposal, this project will be a collaboration among several entities and personnel, and we are leverage various sources of funding to decrease the cost to VMRC and the state:

VIMS— R. Seitz will coordinate the project and interact with R. Lipcius on creating habitat maps for placement of Lipcius's new artificial reefs. A.L. Hernandez, an M.S. student, will aid in coordination of the habitat suitability modeling effort and use a portion of the information for thesis research. A substantial portion of the graduate student costs is covered by other grants.

VMRC—Seitz and Lipcius are working closely with M. Meier and J. Travelstead in the Fisheries Division to determine how our data can aid in knowledge regarding success of existing and future fish reefs, and we have ensured that the reefs are in agreement with the goals and needs of the artificial reef program at VMRC. M. Meier has already used our environmental maps to aid in locating new "materials of opportunity" for artificial reefs. In addition, we will follow through on the formal permit process of the Habitat Division, as we have done recently for the shoreline reefs deployed in 2006 and 2007.

ACoE—D. Schulte and C. Seltzer of the Norfolk District are actively engaged in the project and have funded a portion of the pilot studies for this proposal. In addition, the ACoE may be able to provide further funding for reef monitoring, offsetting the cost to VMRC and the state.

CBF—T. Leggett and C. Everett of the foundation's Virginia office are collaborating and covering some of the external costs of the project.

Lynnhaven Now—This private-citizen group is facilitating interactions with homeowners and oyster lease holders and is providing an avenue of external private funding for the project.

City of Virginia Beach—The city is providing a boat slip at the city marina, and they will fund some of the expenses of the project.

CCA—We will work closely with representatives of CCA (communications have been established with T. Powers) to ensure that the recreational angler community is fully aware of the project and aids in the data collection. We have already gained support from some of the local anglers, but we want to communicate with the broader community through CCA and the "Lynnhaven Now" community group.

NOAA—The Chesapeake Bay Office has funded some of the pilot studies conducted with the Rappahannock River artificial reefs and is funding pilot studies in the Lynnhaven River system.

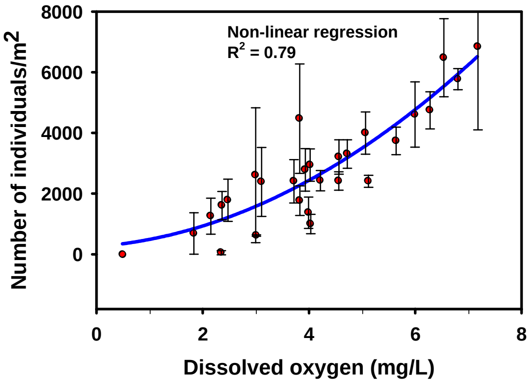

Figure 1. Relationship of benthic infaunal density to dissolved oxygen from Chespeake Bay Program benthic monitoring data from 1996-2004 (Seitz et al., ms in prep).

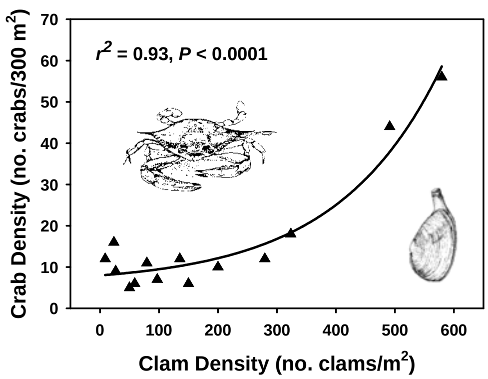

Figure 2. Crab density versus clam density for multiple sites in York River (Seitz et al. 2003).

Figure 3. Example of concrete modular reef recently deployed in Northern Neck, Poquoson, and Lynnhaven (6- foot tall person for scale).

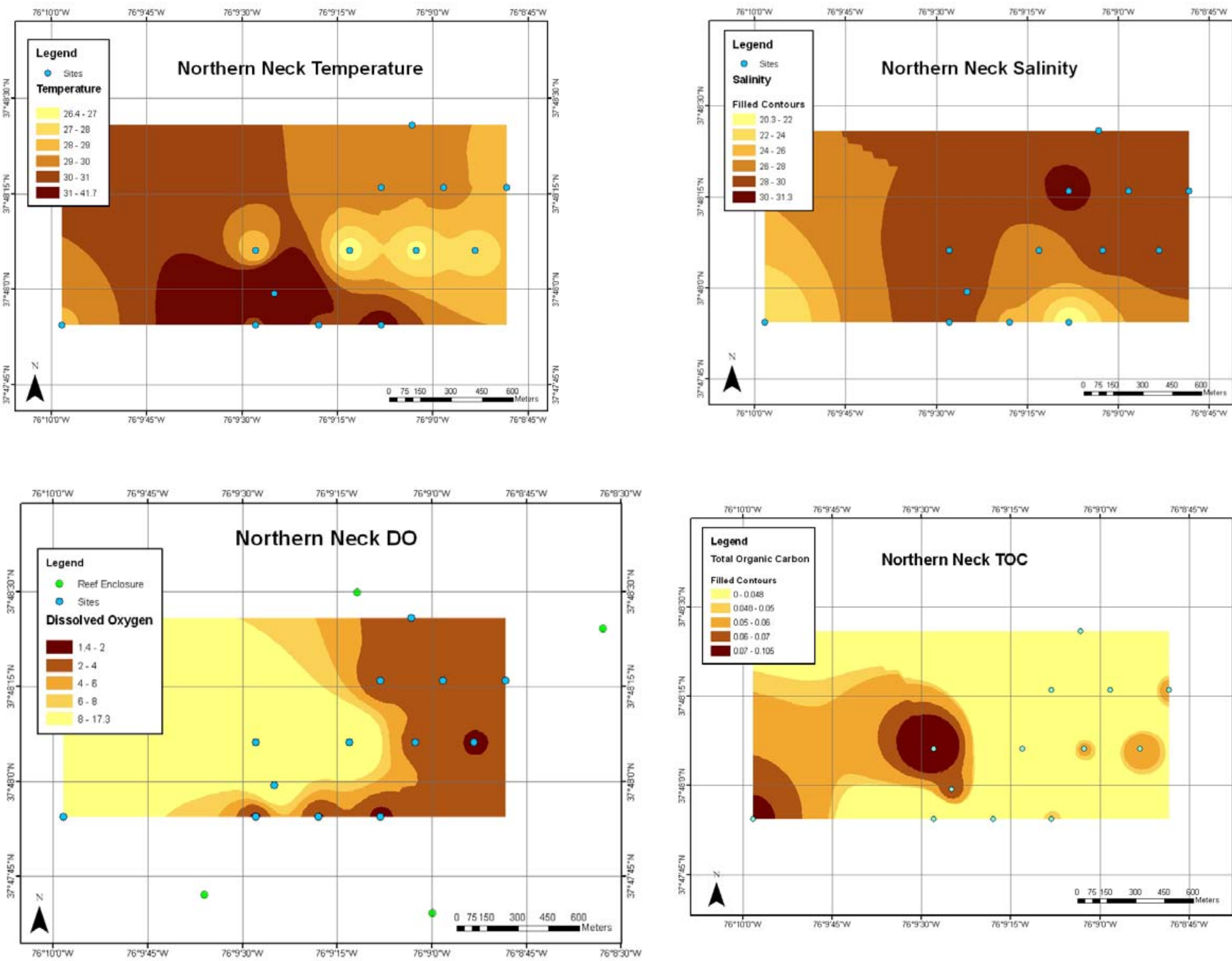

Figure 4. Environmental factors at Northern Neck reef site interpolated from point measurements at sites marked with blue circles including (a) temperature, (b) salinity, (c) dissolved oxygen (this map displays green markers at corners of the VMRC reef polygon, (d) total organic carbon (TOC).

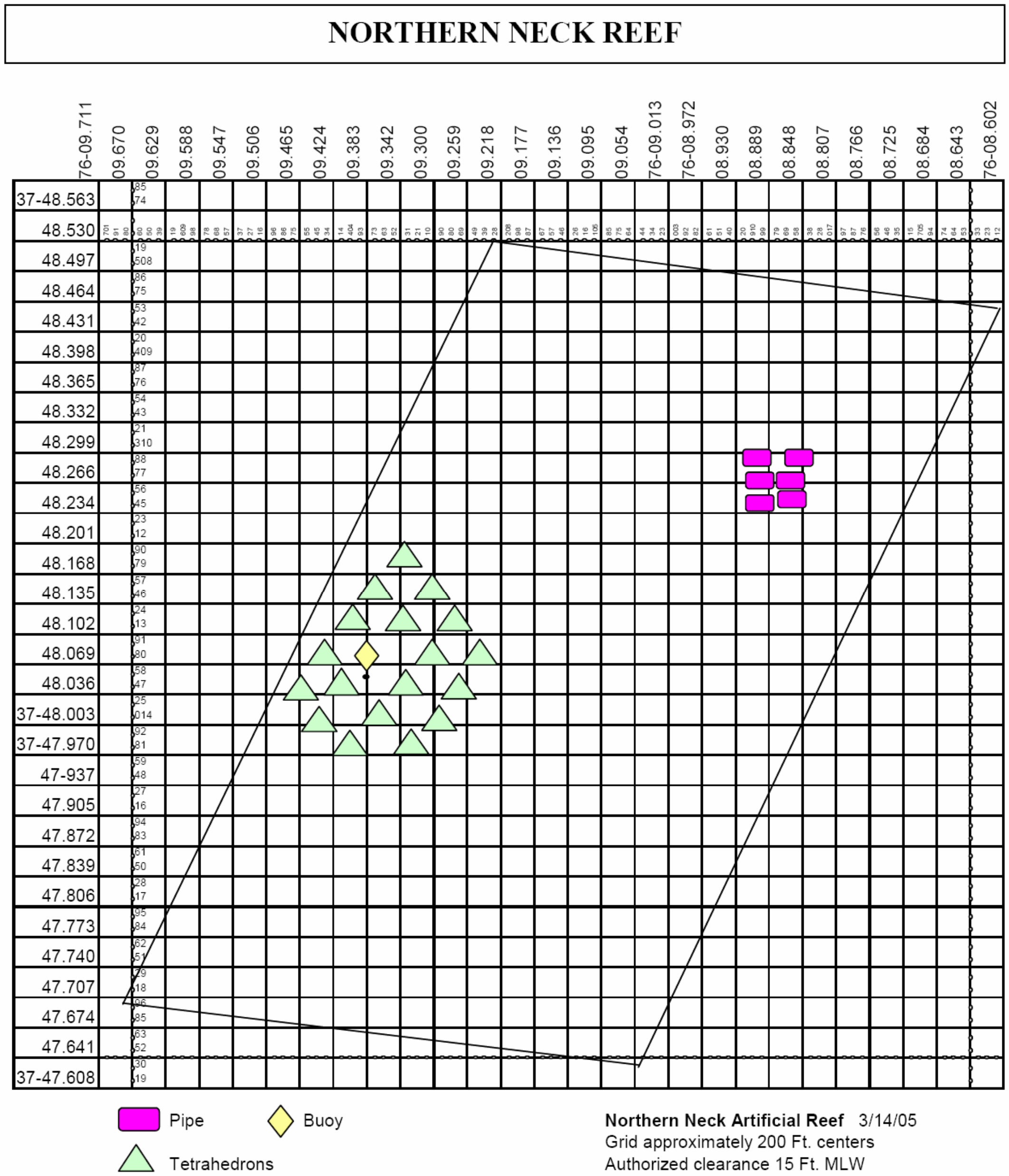

Figure 5. Northern Neck Artificial Reef grid with placement of tetrahedron (triangles) and pipe (rounded rectangles) reef structures.

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