N.C Oysters: A Workshop to Chart Future Restoration, Learning from the Past

March 12-13, 2014

Beaufort, NC

Poster Abstracts

GIS Based North Carolina Shellfish Siting Tool

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The North Carolina Shellfish Siting Tool is an interactive decision-support tool for the North Carolina coastline that will assist new or current growers in siting new or expanding shellfish operations by providing a simple tool to assess conditions based on existing datasets. The tool is designed to provide information to help potential shellfish growers determine site feasibility and help them identify potential risks and long-term suitability for particular areas. This project is a data visualization tool providing information on data specifically related to shellfish aquaculture including salinity, bottom type, depth soundings, shellfish growing area classifications, boat access areas, surrounding land cover and current shellfish growing operations.

Testing a Novel Restoration Method to Enhance Oyster Populations in Tidal Creeks

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Oyster-based habitats provide important goods and ecosystem services, including fisheries production, protecting sensitive shores, acting as critical habitat for a wide range of fish and invertebrate species, water clarification and nutrient removal. Tidal creeks along NC's smaller coastal sounds and estuaries receive and filter much of the region's runoff. There is a critical need to restore and enhance tidal creek oyster populations to improve water quality in creeks and adjacent sounds and river estuaries. While subtidal oysters occupy upper reaches of many tidal creeks, where periodic freshening diminishes biological stressors, oyster reefs generally only form in intertidal refugia at the mouths of the creeks where salinities are elevated. In conducting a survey of boring sponges in NC oyster habitats, project oystermen harvested numerous large, often single, oysters largely buried in sandy and muddy sediments in high salinity environments. Partial burial in sediments appears to provide oysters an alternative refuge from biological stressors. In this APNEP-funded project, we are using the little recognized buried growth of oysters to enhance oyster populations in the lower portions of tidal creeks in Carteret County, NC. If successful, this restoration methodology would be readily transferable to tidal creek oyster restorations throughout coastal NC and beyond.

Developing a Comprehensive NC Salinity Database to Improve Ecosystem Management, Habitat Restoration and Human Health

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Salinity is a primary driver of estuarine species distributions, including many foundation species such as oysters, submerged aquatic vegetation, and marsh plants. Spatial and temporal variations in salinity also greatly influence the distribution of higher trophic species (e.g., crustaceans and fishes) and human pathogens. Importantly, sea-level rise over the next century will inject increasing volumes of saltwater into our State's sounds and estuaries, thereby greatly impacting estuarine species and ecosystems. Presently there is no salinity database for North Carolina with sufficiently high spatial and temporal resolution to rigorously examine salinity effects on critical estuarine habitats at multiple spatial and temporal scales [historical (1880s) to present] and for detecting sea-level rise effects on estuarine salinity dynamics. While past and on-going studies provide disparate salinity records for various coastal regions of North Carolina, these data have not been integrated into a single, inclusive platform that connects multiple regions over past, present and future time scales. The objective of this CRFL-funded project is to develop a comprehensive NC salinity database that will support queries and analyses valuable for informing diverse management decisions and better guiding restoration of critical habitats. Here we provide an overview of the status of the discovery phase of this project.

Patch dynamics and the role of edge and interior for southeastern North Carolina oyster reef communities

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A common theme for edge and interior dynamics and edge effects is the necessity to critically evaluate and understand the processes and the impacts edge has on a species, species interactions, organism's dispersal, and community composition. However, the majority of these issues for reefs comprised of the eastern oyster (*Crassostrea virginica*) have never directly been addressed on a large scale. The eastern oyster is an important ecological and economic estuarine organism. Ecologically, oysters are important due to their filtering capacities which can maintain or increase water quality. Oysters are ecosystem engineers because they provide structure and habitat for many sessile and mobile invertebrates, as well as various trophic levels of fish. Despite all of the services oysters provide, populations are declining due to overfishing, eutrophication, disease, disturbances, and deposition of sediments and pollutants. The decline in oyster abundances creates habitat fragmentation within the reefs, thus decreasing the amount of interior habitat on the reef. Even with the ecological and economic importance of this species as few studies have directly addressed oyster reef habitat fragmentation and the influence of the resulting change in edge and interior habitats. The goal of this study was to determine edge and interior dynamics on oyster reefs for oysters, benthic macrofauna and icthyofauna. Specifically, we examined

three different sizes of reefs intertidal oyster reefs patches; reefs with small (2-3 m), medium (5-8 m), and large (>10 m) distances from the edge to the center. This was done for both patch reefs and reefs fringing *Spartina alterniflora* marsh. Densities and size demographics for oysters were sampled one meter away from the edge of the reef, three meters away from the edge for the medium and large reefs, and the center of the reef. Abundances, community composition, and species diversities were sampled at the same distances on the reefs for benthic macrofauna and fish. The benthic macrofauna were sampled via excavating oysters and fish communities were sampled with Breder traps. The role of patch size and the distance from edge to interior elicits a response in oysters, benthic macrofauna, and fish communities.

Effects of Hypoxia on Metal Bioavailability and Tissue Damage in Eastern Oysters and Ribbed Mussels

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Estuarine organisms are exposed to multiple stressors including heavy metal pollution and fluctuations in dissolved oxygen, pH and salinity. Habitats characterized by low dissolved oxygen (hypoxia), accompanied by increased PCO2 (hypercapnia) are expanding in coastal habitats worldwide. Hypoxia and metals can induce oxidative stress in aquatic organisms and interactions between these stressors can exacerbate subsequent tissue damage. Copper and manganese are essential metals which can be toxic if bioaccumulated in tissues. These metal ions exist in the environment complexed with organic or inorganic matter, and their bioavailability may be affected by water quality. The goal of our study was to evaluate the effects of hypoxia on tissue metal uptake of two bivalves-Crassostrea virginica, Eastern oysters, and Geukensia demissa, ribbed mussels. Both of these organisms are indicators of habitat quality and help in maintaining ecosystem integrity. We hypothesized that hypercapnic hypoxia increases bioavailability of copper and manganese from estuarine sediments, resulting in increased metal concentrations in hepatopancreas and gill tissues of both bivalves. Tissue metal concentrations were measured using atomic absorption spectrophotometry after exposure to contaminated sediments under different hypoxic conditions. Sediment samples were also analyzed for metal concentrations. Tissue malondialdehyde concentrations were measured using a lipid peroxidation assay to evaluate tissue damage. Exposure to hypercapnic hypoxia affected tissue metal concentrations and led to elevated tissue damage. Determination of the sensitivities of two ecologically important bivalves to hypoxia and bioavailability of metals and evaluating the interactions between these two stressors are critical for predicting impacts on ecosystem health.

Soundscapes and larval settlement: characterizing the stimulus from a larval perspective

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The underwater soundscape is emerging as a potentially rich source of sensory information for larval organisms during settlement and habitat selection, but the relevant scales of spatial and temporal variability of habitat-related sounds remain largely uncharacterized, particularly in shallow-water estuarine habitats. Oyster reef soundscapes are of particular interest because reefs are patchily distributed, productive habitats that harbour many sound-producing organisms (e.g. sciaenid fish, snapping shrimp). To examine the spatiotemporal variability in acoustic characteristics of these estuarine habitats, we used short-term stationary and drifting hydrophone-recording surveys at sub-tidal oyster reserves and soft-bottoms throughout Pamlico Sound, NC, and conducted a year-long recording time-series at a single reef site. Data show that reefs consistently produce distinct acoustic spectra and generally higher sound levels compared to adjacent soft-bottom habitats, that reef sound characteristics are highly localized to the habitats and that reef sound has daily, lunar and seasonal patterns. This study indicates that the scales of temporal and spatial variation in the estuarine soundscape are relevant to larval settlement, and provides the acoustic data needed to develop a conceptual model of how habitat-related sound could function as a settlement cue for planktonic larvae of obligate reef-dwellers.

Potential "spill-in" of oyster larvae to marine reserves

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Understanding meta-population dynamics is key to effectively guiding conservation and restoration strategies of focal species. Large-scale restoration of eastern oysters (*Crassostrea virginica*) in Pamlico Sound (PS), North Carolina indicates that this metapopulation, located within a network of no-take reserves, is strongly dependent upon larval subsidies from fished areas outside the network. To begin to identify larval sources in fished areas (natural reefs vs cultch planted sites) that facilitate metapopulation persistence within reserves, we quantified potential larval contribution of three oyster habitats (natural, cultch-planted, and marine reserve) to the larval pool. Estimates of potential larval output were made for # oysters per m^2, as well as sound-wide larval output based on total footprint coverage of each habitat type. Differences in size structure and density between habitat types were striking - natural reefs resembled isolated oyster shell hash with no vertical relief, whereas cultch sites, although variable, tended to have relatively high shell cover. Both cultch and natural reefs contained few legal sized (>75mm shell length) oysters, whereas marine reserves exhibited high density and frequency of legal oysters. Potential larval output per m^2 varied significantly according to habitat type,

with lowest output at natural reefs and highest at reserves. Accounting for total habitat footprint coverage and the two orders of magnitude greater spatial coverage of natural reefs to cultch and reserve, larval output from natural reefs was significantly higher than cultch planted reefs, but commensurate with the potential output of reserves. These results highlight the role that fished areas might play in providing larval subsidies to networks of reserves.

Sanctuary site selection: a decision support tool for oyster restoration

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The global decline of native oyster populations and resulting negative impacts to fishery harvests and ecosystem services provided by oyster reefs has fueled large-scale oyster restoration throughout the world. Restoration strategies range from planting shell-material, to hatchery-based stock enhancement, to construction of 3-dimensional artificial reefs protected from harvest (i.e., sanctuaries). The efficacy of sanctuaries is dependent on site selection, whereby sanctuaries are sited in areas that are biologically and economically optimal. In this study, we applied a GIS-based hierarchical optimization approach for site selection of oyster sanctuaries in Pamlico Sound, NC. We (1) created a grid of 5,987 km^2 cells covering Pamlico Sound, assembled 17 biologically- and socioeconomically-based GIS layers relevant to oysters and artificial reef construction, (2) conducted hydrodynamic and particle tracking simulations to develop oyster larval dispersal GIS layers, (3) partitioned layers into "inclusion/exclusion" and "threshold" categories, (4) developed scoring and weighting criteria for threshold layers based on input from an expert panel, and (5) calculated the suitability value for each cell across all threshold layers on a scale of 0 (least suitable) to 1 (most suitable). Based on exclusion layers (e.g., bathymetry and substrate type), 39% of Pamlico Sound was unsuitable for oyster sanctuaries. Of the remaining cells, the max suitability score was 0.79; modal suitability was ~0.35. Optimal sites for oyster sanctuaries were typically clustered in the southwestern and northern portions of Pamlico Sound. These results suggest that the GIS-based hierarchical approach to site selection was effective at (1) narrowing a vast water body to a manageable number of sites for further empirical ground-truthing, (2) identifying restoration "hot spots" where optimal sites were clustered, and (3) integrating biological and socioeconomic considerations in a decision support tool for oyster restoration.

The influence of landscape setting and duration of inundation on oyster reef growth

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Physicochemical boundaries and optimal conditions characterizing the response of coastal foundation species to sea-level rise must be defined to accurately predict sustainability. Using 15-year-old experimental oyster reefs in Middle Marsh, Back Sound, we examine the effects of varying inundation levels and landscape settings on vertical reef growth and oyster density, two proxies of productivity that determine the ability of reefs to maintain their position relative to sea level. These reefs were constructed adjacent to sandflat and saltmarsh habitats over a subtidal-to-intertidal depth gradient. Reefs surrounded by sandflats are defined by a strong parabolic growth pattern in relation to duration of aerial exposure. We find an abrupt switch from reef accretion to reef deterioration occurring at a critical exposure duration of 10%, an optimal reef growth zone (30-40% exposure) defined by the highest vertical accretion rates (~ 2 cm yr^{-1}), and a growth ceiling near mean sea level (~55% exposure) where exposure stress becomes too high to support additional vertical growth. We also discover a landscape-specific response in reef growth as reefs adjacent to saltmarshes exhibit a negative relationship between vertical accretion and aerial exposure. Considering impacts from rising sea level and associated changes to tidal regimes, we present a model that predicts sandflat reef productivity for any inundation condition. Based on our model and future predictions of accelerating sea-level rise, shallow, sandflat reefs will subsist in the euhaline waters of North Carolina, while oyster reefs below the critical exposure depth will perish.

Cellular Biomarker Assays for Assessing Oyster Health and Sustainability

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Oysters are important estuarine organisms, both environmentally and economically, and serve as habitat engineers. Commercial fishing, anthropogenic effects and disease have caused declines in the stocks and viability of oysters over the last hundred years. Efforts to restore the oyster populations by constructing artificial reefs as sanctuary sites to increase the overall stock of oysters, and rebuild reef systems are important to many other species as well. For this study Eastern oysters, *Crassostrea virginica*, were collected from various sites off the NC coast, both sanctuary and natural oyster reefs established by university and natural resource management agencies. The goal of this study was to compare cellular biomarker assays to assess stress levels using lysosomal destabilization. Oysters were sampled during 2010, 2012, and 2013 The results indicated continued cellular stress in some sites, especially at the Hatteras sites, suggesting exposure to some type of environmental toxins or physiological stressor. Moreover, we have established that the lysosomal responses are also tightly linked to gamete viability and reproductive success. These types of data are essential for assessing sublethal responses to environmental conditions that threaten oyster populations, and can also be used to inform the potential success of environmental management strategies in a timely manner.

Testing Salinity-Based Predictions of Oyster Shell Cultch Planting Success

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The NC Division of Marine Fisheries has for many decades worked to enhance and rehabilitate oyster habitat throughout state waters by "planting" oyster shell and marl (= cultch) to create new oyster habitat. One over-arching goal of the cultch planting program is "…to provide additional fishing opportunities for both commercial and recreational fishermen." Given financial constraints and the need to prioritize section activities, DMF's Resource Enhancement Section has sought to measure cultch planting success mainly through annual "quick-look" surveys of oyster spat density on a limited number of sites within different water bodies. These data show great spatial and temporal variability; however, there is a general decrease in spat counts with increasing plant site age, and these counts often do not reflect subsequent abundance patterns of post-juvenile/adult oysters. The objectives of our FRG project are (1) identify oyster cultch planting site that are failing to perform as expected; (2) examine boring sponges as a cause of cultch plant site failure; (3) use an evolving coast-wide salinity database, underpinned by data from the Shellfish Sanitation Program, to predict cultch plant success from area salinity characteristics; and (4) use project data to help DMF optimize oyster yields from cultch planting efforts.

Five Years Later: Adaptive Management Recommendations and Lessons Learned from a Non-Profit's Application of a Volunteer Based Oyster Reef Restoration Monitoring Program.

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Oysters along the Atlantic and Gulf coasts of North America are recognized as key components of the coastal ecosystem, providing habitat for transient and resident fauna, affecting particulate concentrations in overlying waters, reducing wave energy along sensitive shorelines and influencing local biogeochemical cycling. Increasingly oyster reefs are being evaluated for their roles in global climate change and sea level rise due to their carbon sequestration and shoreline buffering capabilities. As oyster populations have declined along the Atlantic coast, efforts to restore oyster reefs for their ecosystem function(s) have increased. However, the lack of long-term monitoring using standardized methodologies that target both population and ecosystem functions has been an impediment to assessing the success of many restoration projects. In 2004, participants at a Sea Grant sponsored workshop proposed a set of sampling criteria and methodologies to provide standardized population and ecosystem measures for assessing the success of oyster restoration projects. The NC Coastal Federation has taken a subset of those recommended methodologies and adapted them for the scale and scope feasible with a volunteer based monitoring program. The monitoring program has focused on

a series of created reefs of varying ages along the central and southeast North Carolina coast. This presentation will describe the components and implementation of the monitoring program and lessons learned over the past five years. In addition, a summary and evaluation of the monitoring data gained from the program will be provided. Adaptive management recommendations for oyster habitat restoration developed from the program will also be described.

North Carolina's Comprehensive Approach to Oyster Restoration and Protection: A Model Plan For Action 2003-2008

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In 2003, the North Carolina Coast al Federation, working with a diverse group of stakeholders, published the *Oyster Restoration and Protection Plan for North Carolina: A Blueprint For Action*. This plan identified several strategic restoration and protection initiatives, and prioritized those requiring immediate action.Recognizing the Eastern Oyster's role as a keystone species in the estuarine environment, in 2005 the North Carolina legislature supported several key initiatives to protect and restore the native oyster (*Crassostrea virginica*) including: oyster shell recycling, developing regional oyster hatcheries, establishing sanctuaries, identifying and mediating pollution sources, and other watershed based projects. Through the collaborative efforts of federal and state agencies, conservation NGOs, researchers, oyster growers and harvesters, educators and the public, these strategic restoration and protection initiatives are being successfully implemented. Others can use North Carolina's recent accomplishments as a model plan for action. This comprehensive and collaborative approach is valuable to others interested in regional restoration initiatives. This poster will focus on the some of the progress made from 2003-2008 on key initiatives, project partners and lessons learned.