SESSION B – IMPROVING THE HEALTH OF COASTAL WATERS

Dr. Hauke Kite-Powell – THE ECONOMICS OF ECOSYSTEM SERVICES FROM OYSTER FARMING

Dr. Austin Humphries - THE ROLE OF OYSTER RESTORATION AND AQUACULTURE IN NUTRIENT CYCLING WITHIN A RHODE ISLAND ESTUARY
Co-Authors: Suzanne Ayvazian, Robinson Fulweiler

Mr. Jefferson Flood - ECONOMICS OF ECOSYSTEM SERVICES FROM OYSTER AQUACULTURE – DELAWARE

Dr. Jonathan Grabowski - RESTORING OYSTER REEFS TO RECOVER ECOSYSTEM SERVICES *(Not included)*

Dr. M. Lisa Kellogg, presented by Mark W. Luckenbach - NITROGEN REMOVAL ASSOCIATED WITH OYSTER REEFS
Co-Authors: Mark W. Luckenbach, Jeffrey C. Cornwell, Michael Owens

Dr. Anamarija Frankic - IMPROVING THE WATER QUALITY AND BIODIVERSITY BY RESTORING OYSTER REEF HABITATS IN WELLFLEET HARBOR, MA, USA

Mr. George Chuckie Green and **Dr. Richard H. York, Jr.** - TOWN/ WAMPANOAG TRIBE OYSTER AQUACULTURE AND RESTORATION OF POPPONESSET BAY, CAPE COD, MA, USA

Mr. Ronald Zweig - CLARIFYING A MEANS TOWARD ESTUARY WATER QUALITY IMPROVEMENT: THE FALMOUTH OYSTER AQUACULTURE DEMONSTRATION, MA, USA

Dr. Brian Howes – MONITORING WATER QUALITY ASSOCIATED WITH OYSTER ACQUACULTURE IN LITTLE POND, FALMOUTH, MA AND ITS' EFFECTIVNESS IN REDUCING AMBIENT NUTRIENT CONCENTRATIONS *(Not included)*

Mr. Richard Karney - STRATEGIES TO RESTORE OYSTER POPULATIONS IN TWO SALT PONDS ON MARTHA'S VINEYARD

Ms. Diane Murphy - OYSTER *Crassostrea virginica* SURVEILLANCE IN SOUTHEASTERN MASSACHUSETTS, USA

Mr. Joshua Reitsma - CAPE COD OYSTERS IN TERMS OF NITROGEN AND NUTRITION
Co-Authors: Abigail Archer and Diane Murphy

Dr. Scott Gallager - AMERICAN OYSTER RESTORATION PLAN IN POPPONESSET BAY, MASSACHUSETTS: TOWARDS A SUSTAINABLE COMMERCIAL FISHERY THROUGH NOVEL APPROACHES TO MAXIMIZING YIELD AND ECOSYSTEM RECOVERY *(Not included)*

ECONOMICS OF ECOSYSTEM SERVICES FROM OYSTER FARMING

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In addition to the immediate market value of the harvested oysters, oyster aquaculture can generate ecosystem service value from the sequestration and removal of excess nutrients and from improvement of water quality. Here we describe an economic framework for estimating the value of these ecosystem services as a function of the scale of the oyster farm and the environmental conditions and human uses of the water body and watershed in which oyster farming takes place. Significant economic value can arise from nutrient removal and bio-filtration by oysters in settings where anthropogenic nutrient loading has let to excessive phytoplankton growth and degraded water quality, it is costly to address the problem upstream (e.g. through installation of centralized sewage systems), and oyster farming is practical and socially accepted at scales that remove substantial fractions of anthropogenic nutrient loading. We review the literature on oyster nutrient sequestration and ecosystem service value to identify biological and economic parameters for the estimation framework, and illustrate the framework with an application to Waquoit Bay, Cape Cod, Massachusetts. We show how the framework can help communities identify an economically optimal scale of oyster aquaculture, taking into account carrying capacity and competing uses such as recreational boating and swimming, and aesthetic considerations.

THE ROLE OF OYSTER RESTORATION AND AQUACULTURE IN NUTRIENT CYCLING WITHIN A RHODE ISLAND ESTUARY

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Coastal ecosystems are increasingly impacted by over-enrichment of nutrients, which has cascading effects for associated organisms. Oyster aquaculture and oyster reef restoration are hypothesized to mitigate excessive nitrogen (N) loads via benthic denitrification. However, this has not been examined in New England, where oyster aquaculture and oyster reef restoration are increasing and nutrient runoff is high. Using 50 L chambers, we conducted benthic experiments to examine benthic metabolism and net N_2 fluxes across the sediment-water interface. In a shallow (~1 m) estuary in southern Rhode Island, we collected samples seasonally in 2014 using the N_2/Ar technique. Preliminary results indicate oyster reef restoration and aquaculture had greater denitrification rates than bare sediment, but the degree to which they were different was highly seasonal. We relate our net N_2 fluxes to differences in site-specific environmental factors, such as sediment oxygen demand, sediment chlorophyll a, dissolved inorganic nutrient availability, and associated benthic organism abundance and diversity. Our results demonstrate that oyster reef restoration and aquaculture can increase denitrification rates, but nutrient processing varies dramatically over small spatial scales.

ECONOMICS OF ECOSYSTEM SERVICES FROM OYSTER AQUACULTURE

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Disease and overfishing have led to a dramatic decline in populations and harvests of the eastern oyster *Crassostrea virginica* in Delaware and other states along the Atlantic Coast. However, in addition to consumption values, stable oyster populations can provide many ecosystem services, including water filtration and habitat for aquatic life. Consequently, recent policies in Delaware have sought to reestablish and grow the oyster aquaculture industry. A key challenge to acheiveing efficient levels of industry growth and water quality improvements is that current market prices do not account for the ecosystem services oysters provide. We explore the implications of payments for ecosystem services (PES) in the context of oyster aquaculture. Specifically, we construct a bioeconomic model, based on the Faustmann model used in forestry economics, and simulate industry behavior and water-quality outcomes under various PES schemes including payments tied to oyster biomass extraction, oyster biomass in the water, and nitrogen removal directly. Although payments that are directly tied to nitrogen removal are the most efficient, practical implementation of this scheme is the most difficult. We conclude with a discussion of the economic and political potential for PES in the oyster aquaculture industry, including an assessment of current regulatory frameworks targeting nutrient reduction.

NITROGEN REMOVAL ASSOCIATED WITH OYSTER REEFS

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Both oyster reef restoration and oyster aquaculture have been proposed as means of mitigating eutrophication in estuarine waters. In Chesapeake Bay, interest in their capacity to remove nitrogen has increased in recent years due to mandated water quality improvements that include setting total maximum daily loads (TMDLs) for nitrogen and other pollutants of primary concern and the development of nutrient trading programs which include in-water mitigation. Use of oysters to offset TMDL requirements will depend on their net nitrogen removal capacity and their location relative to nitrogen inputs. The three primary ways in which oysters can remove nitrogen are 1) assimilation into the tissue and shell of oysters and associated organisms, 2) long-term burial of biodeposits, and 3) conversion of particulate and dissolved nitrogen to nitrogen gas via microbially mediated nitrification-denitrification (Fig. 1). Thus, net nitrogen removal will be the sum of assimilation, burial and denitrification. Theoretical considerations suggest that these processes should scale as a partial function of oyster biomass density (Fig. 2). We will present results from recent and ongoing research on how nitrogen conversion processes are affected by oyster reefs and suspended oyster aquaculture, how these effects scale with oyster biomass density, and other factors that may affect measured rates.

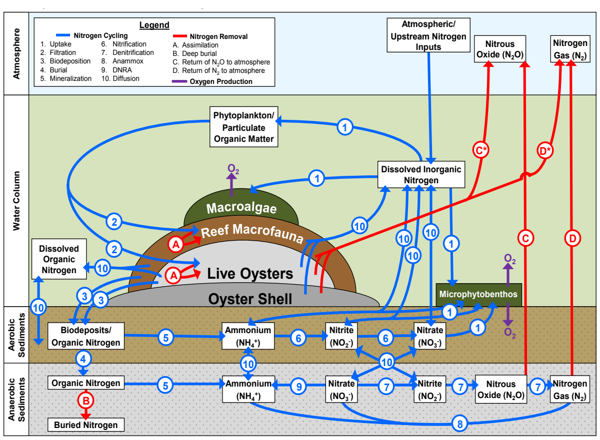

Figure 1. Primary nitrogen cycling and nitrogen removal pathways for an in the euphotic zone. (from Kellogg et al. 2013).

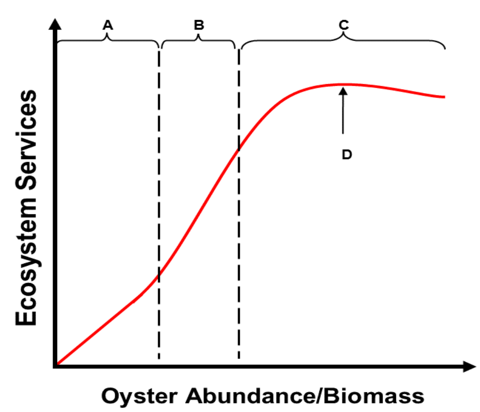

Figure 2. Hypothetical relationship between oyster abundance or biomass and ecosystem services provided by a reef.

IMPROVING THE WATER QUALITY AND BIODIVERSITY BY RESTORING OYSTER REEF HABITATS IN WELLFLEET HARBOR, MA, USA

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Wellfleet Harbor is a designated Area of Critical Environmental Concern presently supporting the oyster aquaculture industry producing 6 million oysters per year. In 1877, this amount of oysters was harvested in just one day by three schooners. Our historic data assessment and GIS analysis showed that, since late 1800s, this Harbor has lost approximately 90% of oyster population, 65% of salt marsh and 95% of eel grass beds. Until recently, these three coastal keystone habitats have been thriving globally for 350 million years, providing ecological services in shoreline protection, supporting water quality, biodiversity, fisheries and coastal resiliency. In 2011 our research team established a two-acre oyster reef restoration site between Duck and Mayo creeks in Wellfleet Harbor. Research monitoring data and analyses show an increase in biodiversity and oyster population by 90%, establishing 5.8 million oysters in three years that provided a 70% nitrogen sink, improving the water quality in this area. Our pilot project is based on cultch, placing 300 tons of shells at the site to provide a suitable substrate for spat settlements of naturally spawning oysters *Crassostrea virginica*. This is the first experimental no-take shellfish sanctuary supported by local communities, the shellfish constable and Division of Marine Fisheries to evaluate the environmental benefits with a particular focus on water quality. Our interdisciplinary project has won three prestigious awards: the Mass Recycle Municipal Innovation, 2013 Engineering Excellence Silver Award by the American Council of Engineering Companies, and 2014 National Award for Public Service.

MASHPEE TOWN/WAMPANOAG TRIBE OYSTER AQUACULTURE AND RESTORATION OF POPPONESSET BAY, CAPE COD, MA, USA

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The Town Mashpee, MA started an oyster aquaculture project in 2004 in the eutrophic Mashpee River that has restored the oyster fishery lost in the 1980s due to oyster disease, and improved water quality by filtering out algae from blooms caused by anthropogenic nitrogen loading. The Mashpee Wampanoag Tribe's commercial oyster farm contributes to the oyster fishery through recruitment from spawning, and improvement of water quality by the filter-feeding of their oysters. Disease-free, hatchery produced oyster seed is grown in trays on bottom in the river. Annual harvests up to 520,000 oysters removed up to 260 kilograms of nitrogen per year based on analysis of those oysters. This is about 5% of the 5000 kg nitrogen annual reduction needed to meet Total Maximum Daily Load of nitrogen limits, and water quality restoration requirements of the US Clean Water Act as specified in Massachusetts DEP/Estuaries Project technical reports. Water quality improvement is monitored with deployed sondes and water sampling. Anoxic conditions caused by algae blooms resulting in the mass mortality of fish and crabs before oysters were re-established have not occurred since. Dissolved oxygen levels remained above 2 mg/l in 2014. The plan is to increase seeding for annual harvest of 500 metric tons live weight oysters removing 2500 kg nitrogen. Another 2500 kg of nitrogen excreted by the oysters could be eliminated by denitrification, deposition and burial for potential total restoration of water quality. Collaboration to create oyster reefs for fisheries/water quality restoration in adjacent Shoestring Bay is also planned.

Clarifying a Means toward Estuary Water Quality Improvement: The Falmouth Oyster Aquaculture Demonstration

By Ronald Zweig[1], Roy Martinsen[2], Brian Howes[3], David Schlezinger[3], Anastasia Karplus[4]

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Estuary water quality across Cape Cod has become seriously degraded particularly due to nitrogen pollution from intensive coastal development and land management practices. This environmental issue continues to worsen in terms of ecosystem function. To remedy the problem through traditional means – sewer development – carries with it enormous economic costs to affected communities. As a result, coastal towns are exploring the use of less costly, non-traditional options such as shellfish aquaculture.

In 2013, Falmouth, Massachusetts initiated a three-year oyster (*Crassostrea virginica*) aquaculture demonstration project in cooperation with the state's Department of Environmental Protection and its Division of Marine Fisheries. The objective is to assess oyster aquaculture's effectiveness with nitrogen removal, including nitrogen assimilated into oyster growth and removal via associated enhanced benthic microbial denitrification and particulate deposition. The intent is to assist the DEP in establishing a nitrogen reduction credit rate for such aquaculture toward meeting water quality targets.

The project is being implemented in a 0.8 hectare area (4.4%) of Little Pond, an estuary covering 18 hectares. In 2013, 1.25 million oysters were grown from about 0.5 cm to 4.5 cm diameter in floating mesh culture bags with a similar follow-on trial in 2014 using 1.5 million oysters. It is supported by a robust water quality monitoring and sediment analysis program. The results from the 2013 and 2014 trials show a beneficial impact upon water quality as well as increased particulate deposition and definitive enhanced denitrification within and near to the culture area.

Details of the findings will be presented.

STRATEGIES TO RESTORE OYSTER POPULATIONS IN TWO SALT PONDS ON MARTHA'S VINEYARD

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The wild oysters on Martha's Vineyard occur as relatively isolated populations in brackish salt ponds along the island's southern coast. In 1996 Edgartown Great Pond oysters were first diagnosed with the oyster disease Dermo. Despite regular, sometimes heavy, natural sets, the majority of the oysters recruited in the pond succumbed to Dermo. By the early 2000's, the pond's oyster population was slowly recovering despite the continued presence of Dermo. Suspicions that the unique breeding isolation of the pond's oysters under constant selection pressure was resulting in a Dermo tolerant oyster strain were supported by a study in which hatchery-spawned offspring of survivor oysters from Edgartown Great Pond survived 17-19% better than a non-resistant control group. Oysters in Tisbury Great Pond first tested positive for Dermo in 1999, and by the summer of 2001, an estimated 95% of the oysters in the pond perished. Similar to what occurred in Edgartown, a remnant population survived and the number of oysters slowly increased. Beginning in 2008, efforts to increase the numbers of oysters in Edgartown and Tisbury Great Pond were expanded utilizing wild oyster broodstock with suggested tolerance to Dermo disease. In 2011, both these populations showed significant divergence from a local control population, using microsatellite markers linked to disease resistance. The multifaceted program utilizes a number of both established and new experimental management methods to help repopulate the ponds. At present, despite the continued presence of Dermo, both ponds support healthy populations of oysters.

OYSTER *Crassostrea virginica* SURVEILLANCE IN SOUTHEASTERN MASSACHUSETTS, USA

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Several monitoring studies have been conducted in southeastern Massachusetts by Woods Hole Sea Grant and Cape Cod Cooperative Extension. These activities were initiated in direct response to a growing aquaculture industry, oyster farming in particular. Individual shellfish farmers as well as local municipalities expressed the need for specific information on oysters to inform their business and management decisions. Three surveillance studies will be discussed in this talk. 1) Site selection is integral to successful oyster restoration, propagation and private culture. A low-cost method of quantifying oyster habitat was developed which allows direct statistical comparisons of sites based on field deployment of oyster seed. For twelve consecutive years (2003 – 2014), seed were deployed at known, standard sizes for 60 days in replicate fashion, allowing a comparison of relative growth and survival among sites. Sites were chosen for their proximity to zones of significant aquaculture activity. 2) A shellfish disease monitoring program was initiated in 2001 in response to growing concerns over diseases reported by the aquaculture industry. The program was intended to establish baseline data for disease in the region, tracking prevalence and intensity and increase knowledge of specific diseases. 3) Increased reports of Vibrio-related human illnesses prompted federal and state regulators to implement control measures to reduce Vibrio risks from raw oyster consumption during warmer seasons. To help provide additional information for management decisions, specific studies of Vibrio levels in the local environment were undertaken.

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Cape Cod Oysters In Terms of Nitrogen and Nutrition

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Abstract

The propagation of filter feeding bivalves represents a unique opportunity to potentially alleviate a growing eutrophication problem and also generate economic activity. Recognizing the importance of locally derived information, legal sized oysters (*Crassostrea virginica*) and for comparison quahogs (*Mercenaria mercenaria*) from various Cape Cod area sources were recently tested for nitrogen content stored in tissues which would represent a net removal from a water body if harvested. These results suggest a harvestable oyster averages 0.69% nitrogen by total dry weight (0.28gN per 84mm oyster), which is slightly higher than a littleneck quahog averaging 0.67% nitrogen by total dry weight (0.22gN per 56mm quahog). These values did vary by season (spring less than fall) and to a lesser extent by location or grow out method, though the biggest driver of difference in N content among similarly sized shellfish cohorts was the mass of shell or meat tissue contained. Nitrogen isotope data indicate shellfish from certain water bodies in the region are incorporating significant amounts of nitrogen from anthropogenic sources. In addition, realizing the occasional misconception oysters are being used to clear contaminants rather than nutrients, local oysters were also screened for potential contaminants and nutritional profile in relation to four other local shellfish species. Cape Cod oysters harvested from approved waters were confirmed as a clean and unique source of nutrition with potential for use in nitrogen removal strategies.