Considering an "Ecofunctional-zoning" Approach to Ecosystem-based Management for Narragansett Bay

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Ecosystem-based management is a multi-faceted, integrated approach that strives to maintain healthy, productive and resilient ecosystems that provide the goods and services required by resident and migrant user populations, including human.[3] Our current understanding of Narragansett Bay in Rhode Island is lacking the systems-level detail that would foster effective management at the system-level scales needed for successful ecosystem-based management. Despite gaps in our understanding of systems-level functions for Narragansett Bay, efforts must be made to move forward, based upon the best available science to manage the whole ecosystem in an integrated, systems-based approach.

We suggest as a starting point for a discussion on how to better model and manage the Narragansett Bay ecosystem—and for other shallow water estuarine systems as well—an "ecofunctional zoning" approach that takes account for the bay's response to, and assimilation of, nutrient inputs. This concept of "ecofunctional zones" provides a beginning by which to array the existing scientific knowledge and make gaps apparent, as well as incorporates restoration, rehabilitation, conservation, and engineering and development practices alongside policy and governance for Narragansett Bay.

Ecofunctional zones in Narragansett Bay arise from the biochemical and ecological gradient of conditions that are observed along a north–south axis of the bay, driven in part by the discharge of rivers and sewage treatment facilities into the Providence and Seekonk Rivers at the northern terminus of the bay.[4] Low freshwater flows and high effluent discharges into the Providence River characterize the head of the estuary, resulting in high primary productivity. Dilution of the heavy nutrient load begins just outside the Providence River, and proceeds south along a gradient which decreases in magnitude with distance south towards the mouth of the bay (Figure 1).

A transitional zone exists from the Providence River south to the northern tip of Prudence Island, with high productivity at the northern end, and decreasing nutrient and productivity levels with distance south.[5] Below this transition zone is an area of much lower nutrient availability, which progressively decreases down bay. In loose terms, Narragansett Bay is comprised of three ecofunctional zones: a nutrient enriched upper

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[3] K.L. McLeod, et. al., Scientific consensus statement on marine ecosystem: Communication Partnership for Science and the Sea (2005), http://compassonline.org/?=EBM.

[4] C. Deacutis, *Evidence of ecological impacts from excess nutrients in upper Narragansett Bay*; C.A. Oviatt, *Impacts of nutrients on Narragansett Bay productivity*; Smayda and Borkman, *Nutrient and plankton dynamics in Narragansett Bay*; Costa-Pierce and Desbonnet, *An "ecofunctional" approach to ecosystem-based management for Narragansett Bay, in* SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21ST CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).

[5] C.A. Oviatt, *Impacts of nutrients on Narragansett Bay productivity, in* SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21ST CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).

bay zone—"Enrichment Ecofunctional Zone"—and a nutrient poorer lower bay zone—"Advection Ecofunctional Zone"— linked by a transitional zone—"Depuration Ecofunctional Zone"—between them.[6]

Defining, understanding and managing ecological functional zones for Narragansett Bay may be a very effective way to understand the response of the bay to changes in nutrient dynamics, climate change, and other forcing functions, whether of natural or anthropogenic origin. Attempting to replicate the functions of these zones in models is of primary importance from an ecosystem-based management perspective. Models based on ecofunctional zones would help ecosystem-based management efforts consider cause-and-effect from a real world perspective of how the bay ecosystem assimilates wastes and responds to other forces of change, both natural and anthropogenic.

Of particular importance in any ecofunctional zoning model is hydrodynamic circulation, which moves nutrients and other materials into, out of, and back and forth within the bay ecosystem, and between ecofunctional zones, whether originating from wind stress or water column density driven forces. Circulation models are critical because they inform ecosystem-based management efforts about system-wide response to perturbations at varying scales. They also allow for "prediction" of changes in bay assimilation functions from changes in nutrient inputs, for instance. Since hydrodynamic circulation is the force driving the movement of water borne constituents between ecofunctional zones, ecosystem-based management schemes need to rely heavily upon these models. There are however, myriad complexities.

Unlike many east coast estuaries, Narragansett Bay is bifurcated into two narrow passages which, because of variations in soil types have undergone differential weathering of the landscape, created the East and West Passages.[7] This geological configuration has a profound influence on the overall circulation characteristics exhibited within Narragansett Bay, between Narragansett Bay and Mount Hope Bay, and within Rhode Island Sound.[8] These profound differences create the need for differential management which must be captured in any ecofunctional zoning utilized in an ecosystem-based management approach for Narragansett Bay.

Interwoven with circulation is vertical mixing, which is very complex and very difficult to model. Due to the complex vertical structure of Narragansett Bay—well stratified in the Providence River, partially stratified to well-mixed in the mid bay, and

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[6] Smayda and Borkman, Nutrient and plankton dynamics in Narragansett Bay; COSTA-PIERCE AND DESBONNET, An "ecofunctional" approach to ecosystem-based management for Narragansett Bay, in SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21ST CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).
[7] Jon Boothroyd and Peter August, *Geologic and contemporary landscapes of the Narragansett Bay ecosystem*, *in* SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21ST CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).
[8] M.L. Spaulding and J.C. Swanson, *Circulation and transport dynamics in Narragansett Bay*; C. Chen, et. al., *Critical issues for modeling of Narragansett Bay and Mount Hope Bay*; and C.R. Kincaid, et al., *The dynamics of water exchange between Narragansett Bay and Rhode Island Sound*, *in* SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21ST CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).

well-mixed in the lower bay—circulation models for this bay need to capture multiple vertical layers at both horizontal and vertical scales. This presents a major challenge to modelers, and more field data is needed to validate models that incorporate turbulent mixing. More circulation modeling research needs to be done to link more directly to ecosystem functions, and more realistically portray assimilation behavior of the ecofunctional zones.

Of great importance to ecosystem-based management efforts is climate change, which is now considered a major external forcing function with broad implications for altering the ecology of not only the Narragansett Bay ecosystem, but for coastal estuaries at a global scale. Climate change induced temperature shifts are predicted to raise Rhode Island air temperatures by 6°C in the near future, which will cause Narragansett Bay to thermally approximate coastal ecosystems now typical of South Carolina.[9] Ecosystem-based management efforts must consider and incorporate the looming realities of changing climate; the reality is that we should be managing for future, climatically altered conditions. Broad scale change will have significant impacts upon the ecofunctional zones of Narragansett Bay, which then impacts overall bay ecology and biology.

Small scale increases in surface water temperature can significantly impact shallow water systems such as Narragansett Bay—plankton, infauna, macroalgae, eelgrass, and fish populations. For example, the 1°C warming currently observed for Narragansett Bay has been implicated in an observed shift in magnitude and timing of the annual lower bay winter–spring diatom bloom. The warming trend has also been implicated as a causative agent in suppressing winter blooms, which are considered critical to the bay ecosystem because winter recycling fuels summer production. Oviatt considers this to be a fundamental shift in the ecological "bedrock" of the Narragansett Bay ecosystem.[10] In this same regard, Fulweiler et al. find shifts in grazing and/or increased cloudiness have caused a 40% decrease in primary production in Narragansett Bay over the past three decades.[11] These authors found that the sediments of Narragansett Bay, during summer months, have switched from their traditional role as nitrogen sinks to being a source of nitrogen, with the equivalent of as much as 60% of the annual, direct sewage derived nitrogen input to the bay being released into the water column. How this may affect Narragansett Bay food web dynamics, and hence bay ecofunctional zones, is not clear. The massive influx of nitrogen from the system certainly has implications for the ecology of Rhode Island Sound. Such ecosystem level shifts are not trivial, and will certainly challenge ecosystem-based management endeavors; the ability to model such change would expand ecosystem-based management capacity.

Sullivan et al. find further climate-induced ecosystem level change in Narragansett Bay, documenting an increase in abundance of a ctenophore, *Mnemiopsis*

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[9] US GLOBAL CHANGE RESEARCH PROGRAM (USGCRP), THE NEW ENGLAND REGIONAL ASSESSMENT OF THE POTENTIAL CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE (2006), http://www.necci.sr.unh.edu/assessment.html.
[10] C.A. Oviatt, *Impacts of nutrients on Narragansett Bay productivity*, *in* SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21ST CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).
[11] R.W. Fulweiler, et. al., *Reversal of the net dinitrogen gas flux in coastal marine sediments*, NATURE 448, 180–182 (2007).

leidyi, which has extended its range as well as its seasonal cycle in Narragansett Bay.[12] This shift in ctenophore abundance has reduced population densities of bay zooplankton dramatically during summer months, resulting in an almost complete lack of copepods.

Changing climate brings more than increasing temperatures, however; Pilson provides evidence that precipitation to Narragansett Bay has increased as much as 30% since 1900.[13] This additional precipitation could increase the rate at which nutrients are moved out of the Providence River and into Narragansett Bay proper, and given recent findings of nutrient export from bay sediments, increased flushing could have significant impact upon the adjacent Rhode Island Sound ecosystem. Such changes would need to be considered and incorporated into ecofunctional approaches to ecosystem-based management since modification to flushing regimes would influence assimilation and transport within and between ecofunctional zones.

Climate change is impacting biological, chemical and physical attributes and functions of Narragansett Bay. Each individual change has a “ripple effect” that imparts further change in other ecosystem attributes and functions. Ecosystem-based management must capture the changing climate over Narragansett Bay and incorporate it into predictive scenarios and modeling efforts to better comprehend possible future conditions. Ecofunctional zones need to be incorporated into modeling efforts as these zones form the basis for bay assimilatory capabilities.

As managers embrace the concept of ecofunctional zoning, ecological engineering concepts should be an integral part of ecosystem-based management schemes.[14] Shellfish aquaculture, for instance, in the area along the southern terminus of the “Enrichment Ecofunctional Zone,” could remove nitrogen for direct export from the bay ecosystem while creating both jobs and business opportunities. The “Advective Ecofunctional Zone” could be ecologically engineered with eelgrass to create positive feedback loops that lead towards improved water quality in the lower bay. Olsen suggests that using sophisticated ecological engineering concepts can set the stage for developing and applying a more sophisticated governance system.[15] An ecofunctional zoning approach integrated with ecological engineering actions can provide a robust, stable platform for decision-making and research, while maintaining the flexibility to allow for adaptive, ecosystem-based management that can more actively respond to changing climate and other perturbations to the ecosystem. Further dialog on ecosystem-based management for Narragansett Bay, with consideration of the ecofunctional zoning concept, should occur. Marine resources management must be increasingly proactive in the face of rapidly changing climate; an ecofunctional zoning approach to ecosystem-based management advances that direction.

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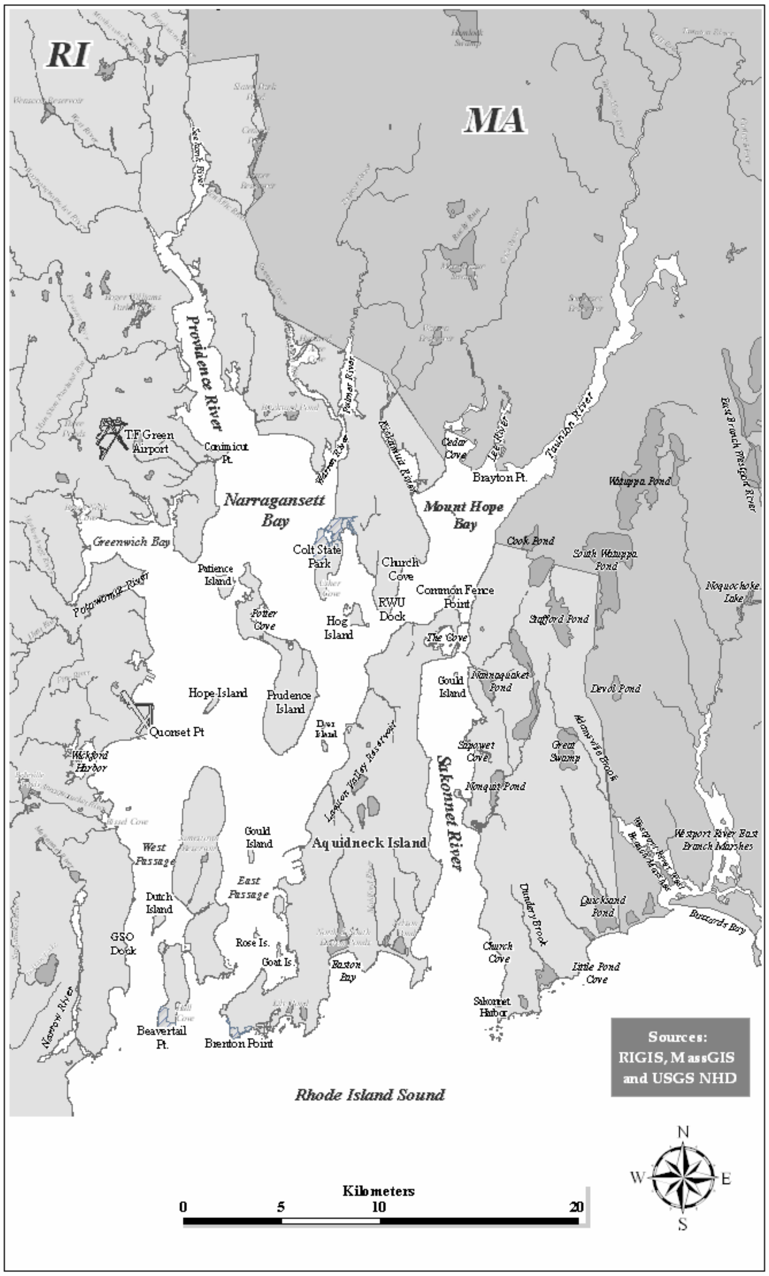
[12] B.K. Sullivan, et. al., *Narragansett Bay ctenophore-zooplankton-phytoplankton dynamics in a changing climate, in* SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21[ST] CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).

[13] M.E.Q. Pilson, *Narragansett Bay amidst a globally changing climate, in* SCIENCE FOR ECOSYSTEM-BASED MANAGEMENT: NARRAGANSETT BAY IN THE 21[ST] CENTURY (Alan Desbonnet and B.A. Costa-Pierce, eds.) (forthcoming 2007).

[14] W.J. MITSCH AND S.E. JORGENSEN, ECOLOGICAL ENGINEERING AND ECOSYSTEM RESTORATION (2004).

[15] S.B. Olsen, *Framework and indicators for assessing progress in integrated coastal management initiatives*, OCEAN AND COASTAL MANAGEMENT 46:347–361 (2003).

Figure 1: Narragansett Bay and its watershed.[16]



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16 Map by Eivy Monroy, University of Rhode Island's Coastal Resources Center (2006).