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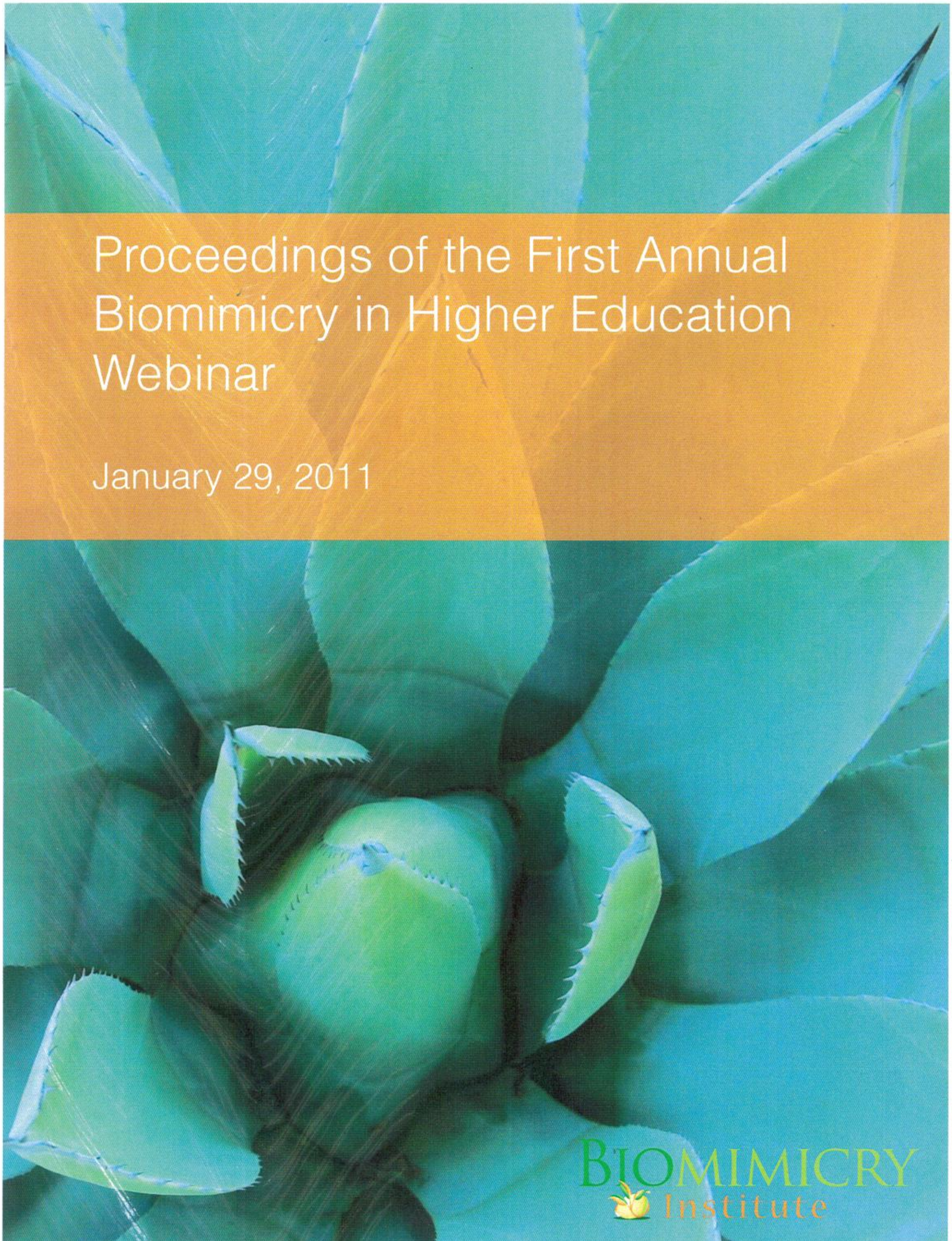

Biomimicry Institute

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Teaching and Learning with Nature Using a Biomimicry-based Approach to Restore Three Keystone Habitats: Salt Marsh, and Eelgrass and Shellfish Beds

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ABSTRACT

Salt marsh, shellfish and eelgrass beds are keystone coastal habitats that provide important ecological services, many of which are frequently overlooked in urban settings. These habitats are endangered locally and globally. Although these habitats coexist together in the coastal environment, restoration efforts often focus on a single species or habitat. We propose to restore these three habitats simultaneously at two pilot sites at the University of Massachusetts. Subsequently we will apply the lessons learned for a re-development project on Pier 5 in the Charlestown Navy Yard on Boston Harbor. A major goal of the project is to develop and apply a biomimicry-based habitat restoration approach that first examines how nature improves water quality and resiliency, stabilizes sediments, and adapts to sea level rise and storm surges within three coastal systems; then applies those functions and techniques within the solution pathway. Our hypothesis is that by using the biomimicry restoration approach coastal habitats will respond and recover better, as well as provide ecological services more effectively and efficiently in the future. As part of the Green Boston Harbor project (GBH) several pilot sites will become the first "living labs" on the campus, allowing students, community members, and researchers to have "hands-on" experiences in these coastal ecosystems. This "hands-on" approach - teaching and learning by doing - will illustrate its value in collecting information for the solutions pathway, synthesizing knowledge of the ecosystems more deeply into the participants and providing the basis for potential new jobs in this and other coastal regions. The biomimicry approach to education will include conducting short-term research and long-term monitoring on the re-established salt marsh, shellfish beds and eelgrass habitats, their associated communities, and related environmental parameters. This project's goal of biomimicry-based habitat restoration fits within GBH's larger mission of learning how to solve our current environmental issue by ensuring that human systems function more like the natural world, as the environment sets the limits of human development and progress.

INTRODUCTION

Boston Harbor (BH) once teemed with shellfish. Colonial records speak of oysters the size of dinner plates (Ingersoll 1881), salt marshes, shellfish and eel grass beds; but citizens of communities surrounding Boston Harbor spent over 350 years transforming their harbor from a pristine near-wilderness to the nation's dirtiest coastal environment. However, over the last 12 years the environmental conditions have begun to improve, largely due to provisions in federal and state clean water legislation (Maciolek et al. 2009; Libby et al. 2007; Libby et al. 2009).

Though the water quality has been improved (Hunt et al. 2009; Taylor 2006), shellfish, salt marsh and eel grass may not return on their own, but may instead require substantial restoration and stock enhancements as well as additional improvements in water quality. As noted in authors Frankic and Greber's earlier work, eelgrass populations were once present throughout the harbor, but have been degraded by development, pollution and disease, with concomitant cascade effects on their ecosystems (Gedan, Silliman and Bertness 2009; Bertness, Ewanchuk and Silliman 2002; Bromberg and Bertness 2005; Orth et al. 2006). Restoration of eelgrass beds here has in general been unsuccessful, possibly due to a lack of water quality (e.g. clarity). The failures may also indicate a need, as discussed here, to restore multiple coastal keystone habitats simultaneously (Wall, Peterson and Gobler 2008; Frankic and Greber 2010; Leschen, Ford and Evans 2010).

Salt marshes are highly productive ecosystems, comparable only to coral reefs. Due to the high productivity and diversity of habitats supported by the salinity, oxygen and inundation changes, salt marshes are able to support complex food webs (AHRTF 2008). We do not know the exact status and acreage of salt marsh habitat that was dredged and filled in Boston Harbor to expand the city. However, according to John and Mildred Teal from Life and Death of a Salt Marsh (Teal and Teal 1969), there was a gain of 2055 acres of dry land made by filling the marshes and lowlands (Taylor 2008). A salt marsh may require more than five hundred years reaching a stable climax community state (Berrill and Berrill 1981). It is much easier to preserve an existing salt marsh than it is to restore or create a new one.

Human perceptions of the value of eelgrass, salt marsh and shellfish vary and often reflect individual interests, concerns, and knowledge, as well as particular historical and ecological moments (Frankic and Greber 2010). As communities face increasingly severe storms and rising tides from both natural variability and anthropogenic climate changes, the ecosystem engineering abilities of these intertidal habitats to stabilize sediments as well as absorb storm energies and water inundation may be more appreciated (Beck et al. 2001; Bos et al.2007).

Dr. Frankic has been working on the idea of strategically placing restoration sites of salt marshes, eelgrass and shellfish beds in a spatial relation to each other to potentially increase their collective water filtration, wave buffering, and sediment stabilization, and provide a greater chance of success for these habitat restoration efforts. How might we do this practically and most successfully? Although it is a huge challenge to restore coastal ecosystems, we do have the knowledge, science and technology to live harmoniously within these systems, following Frankic's premise that "The environment sets the limits for sustainable development and coastal stewardship" (Frankic 1998). This premise is the seed of the Green Boston Harbor project (GBH), the coastal stewardship project at UMass Boston utilizing our new biomimicry-based approach to restoration (www.gbh.umb.edu) (Frankic and Greber 2010; Harding and Margulis 2006). GBH defines a "green urban harbor" to be a harbor that is "managed within environmental limitations, recognizes strength in ecological and human diversities, and supports local and place-specific economic production within a regional and global context." (Frankic and Greber 2010).

As described below, GBH is testing this biomimicry-based approach to restoration at two pilot "living lab" sites on the UMass Boston campus. The major ecological goals of this complex restoration project include minimizing erosion, mitigating degraded coastal ecosystems in BH, repopulating native shellfish species (oysters, blue mussels, soft shell clams), and restoring connectivity between salt marsh, eelgrass, shellfish habitats, and surrounding waters. Through this process we are developing and applying the biomimicry-based approach for coastal habitat restoration. It includes first "asking and listening to nature" during the restoration of the two "living lab" sites. Biomimicry is used in this first step to help define research questions and to choose research methodologies. The lessons learned in this process will then be applied to design living environments for the restoration of built coastal structures, in our case Pier 5 in nearby Charlestown Navy Yard.

BIOMIMICRY FOR HABITAT RESTORATION: REMEMBERING TO "ASK NATURE"

BACKGROUND

What might benefit efforts to restore these vital coastal ecosystems? The philosophy underlying biomimicry may hold the key: "ask nature" (Benyus 2006). What would nature do to operate these ecosystems effectively? A biomimicry approach to restoration may both assist in restoration efforts directly, as well as bring human activities more in line with natural limits. Biomimicry is based on life's principles. These principles are nonnegotiable and involve creating and supporting conditions conducive to life that are essential not only for life itself, but for any ethical and environmentally sound activity, design or decision (BI 2010). In order to develop and apply biomimicry-based restoration, this project will address how to best: 1. Evolve to survive; 2. Be resource efficient; 3. Adapt to changing conditions and be resilient; 4. Integrate development and growth; 5. Be locally attuned and responsive; and 6. Use life-friendly materials, water-based chemistry and self-assembly (BI 2010) (Table 1).

What will a biomimicry-based restoration look like? How might our practice of education, coastal management and adaptation change if we start from this new culture of belonging to and living within the coastal ecosystems we study? Our own work and the related work of many sustainability and biomimicry practitioners suggest that there are at least three fundamental characteristics necessary for any approach to coastal sciences which effectively support stewardship and adaptive choices respecting life's principles and the ecological needs and limits of the places humans inhabit. These are: I) Ask and listen to nature as life changes, adapts and evolves; II) Acknowledge and integrate the fact that life creates conditions conducive to life; and III) Understand the environment sets the limits for human development and how it does so.

THE PROJECT SITES AT UMASS BOSTON

The University of Massachusetts Boston (UMass Boston) is a coastal campus, on the shores of Dorchester Bay, Boston Harbor (BH). The campus and the harbor at large face some of the same difficulties found in coastal settings globally, including water quality concerns, loss of habitats and biodiversity, and threats from climate change, most notably from sea level rise and increasing storm surges. UMass Boston is thus a perfect urban coastal academic setting in which to establish an outdoor living lab where we can learn how to restore salt marsh, eel grass and shellfish beds together (Fig. 1). Lessons learned here are likely to be transferable to similar coastal communities.

Figure 1. Biomimicry restoration project sites at UMass Boston

The two proposed restoration sites border the campus. Their proximity to the main campus makes them ideal for our university setting, with easy access to both sites for students, faculty, and local community residents.

Site 1 – red square

The project proposes the restoration of the salt marsh, eel grass and shellfish beds on the north side of the Columbia Point peninsula, adjacent to both UMass Boston and the JFK Library. Presently this area between the old waste water pump house and Old Harbor has been experiencing severe erosion including debris topple, slump and subsidence. This area is part of the Harbor-walk, and the effects of erosion present a danger for joggers and bikers. We propose that the Harborwalk at this area (approximately 100 meters long) be supported by a combination of culverts and stone walls with a path passing over the salt marsh and shellfish bed restoration site through appropriate culverts (Fig. 2).

Figure 2. Old Harbor – Site #1 (map by Mike Riccio)

Site 2 – blue square

Savin Hill Cove, in Dorchester, MA is located between the Vietnam Memorial, the Savin Hill Yacht Club and UMass Boston. Savin Hill Cove has been accumulating sediment and debris, compromising the marsh's capacity to function properly. The majority of the coastline surrounding Savin Hill Cove has been fortified with granite riprap and seawalls (Fig. 3). There is a small remnant of a salt marsh, making it one of the few remaining "natural" sections of the coast in Savin Hill Cove and the surrounding area. Restoring this marsh would protect against floods and erosion, enhance water quality, and provide habitat for many species. In addition, the goal is to improve the conditions of the mad flat by restocking shellfish beds, and eel grass beds in a deeper water layers. This would prevent additional loss of marshland, enhance flood and erosion control, and improve water quality. Due to the interconnectedness of coastal and marine systems, the importance of this project extends beyond the bounds of Old Harbor and Savin Hill Cove into the larger encompassing area of Boston Harbor – an area NOAA has designated as an Essential Fish Habitat (EFH). At least 24 species of fish rely on the habitat provided by

Boston Harbor during one or more life stages. Species and habitats will benefit from the improved water quality, reduced disruption of sediments, and restored marsh habitat generated by this project.

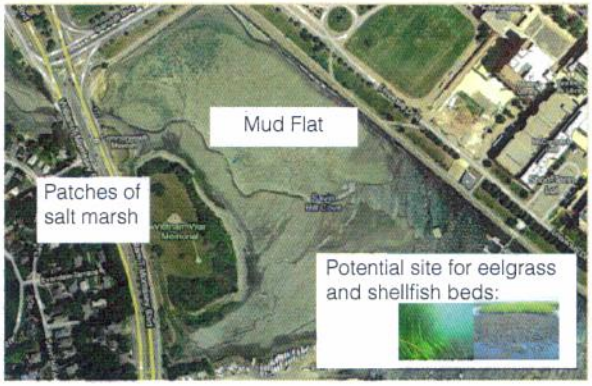

Figure 3. Savin Hill Cove - Site #2 (Google Earth image)

Some of the research questions to be addressed will be ones traditionally found within the field of restoration. These questions will include: Would health, function and ecosystem services be increased if eelgrass beds are placed in the vicinity of salt marshes, and vice versa? If so, what is the optimal spatial relationship for restoration? Would functionality and health be further increased if shellfish beds are restored at the same time? Can habitat health be attributed to connectivity? If so, what specific parameters should be monitored? Does this approach provide a better holistic educational knowledge and ecoliteracy to participants? How to effectively measure and evaluate participants' educational progress?

Most importantly, we will also seek to know how best to "ask and listen to nature" in the context of coastal restoration. We will note, as restoration progresses, how coastal life locally adapts and evolves to changing and challenging conditions – altered pH, temperatures, or more severe incoming storms. What do we, as students, educators, engineers, researchers and conservationists need to change in our approach to restoration in order to become locally attuned and responsive? How does our knowledge of nature change how we carry out our daily activities to blend them more imperceptibly into the local coastal cycles? How do we come to 'dwell' within nature again, to re-member ourselves as part of nature (Davidson-Hunt and Berkes 2003)? We expect our work will begin to answer these questions.

BIOMIMICRY-BASED HABITAT RESTORATION: APPLYING DESIGN LESSONS FROM NATURE

Understanding of a coastal ecosystem's "function, health and resilience" is an imperative for successful applications of adaptive coastal ecosystem restoration based on biomimicry. Learning by doing in the living labs described above, we will be able to apply design lessons from nature onto human built structures, such as Pier 5 (Fig. 4-5), a former working pier located in the nearby Charlestown Navy Yard Park in Boston Harbor.

Our harbors consist mainly of hard structures but the natural disasters like hurricane Katrina have proved that we should include coastal "soft and living structures' in order to protect our urban areas and restore coastal resiliency, environmental quality, as well as human health. Softening these built coastal structures with 'floating skirts' of salt marshes, eelgrasses and shellfish would improve water quality, and biodiversity, while protecting shorelines from erosion, storms and sea level rise. Harborwalks, piers, ripraps and hardened shorelines would add these floating soft structures as green buffers that move with tides, recycling energy and water through

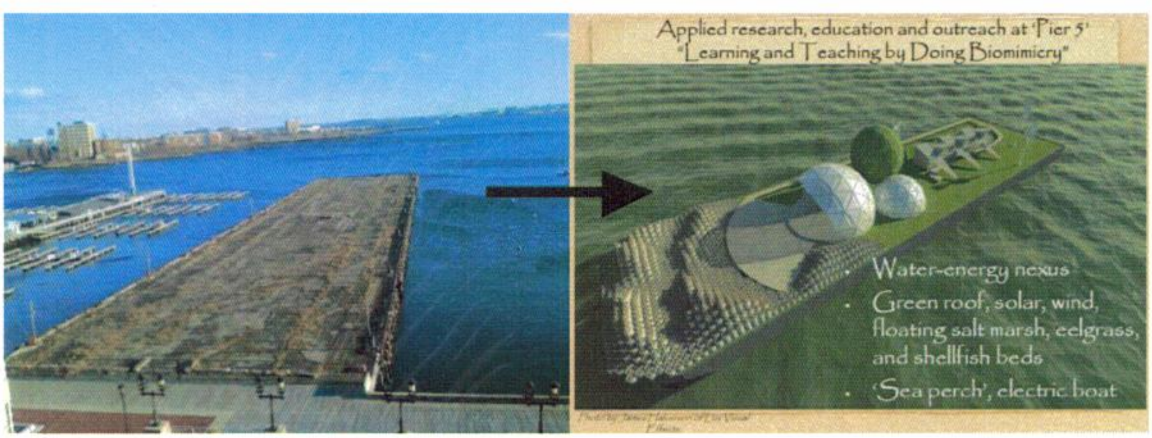

Figure 4. a) Pier 5 in Boston Harbor *b) Waterpod, J. Halverson, Lux Visual Effects*

photosynthesis, filter feeding, decomposition, bioturbation and sediment accretion.

A biomimicry-based approach to habitat restoration will seek to ensure these floating structures are built in such a way that is conducive to life and based on biomimicry's six core life principles:

I) Does the new structure have the capacity to evolve to survive?

The goal for biomimicry restoration projects is for the restored or new communities to become self-sustaining. As described above, Pier 5 will biomimic the three keystone coastal habitats with the attachment of floating salt marsh, eel grass and shellfish beds from the pier. These three layers will occupy three different depths in the water column as they would be found in their natural settings: salt marsh on the surface (higher intertidal area), shellfish in the mid water depth, and eelgrass just below the shellfish layer but not on the bottom itself due to issues with the transparency and quality of BH water. Although this testing site will not significantly change the water quality, we do expect that this approach will sustain itself in-situ and set an example for self-sustainability on a local level. We also hope that a more synergistic community will evolve naturally among the three habitats, providing ecosystem services, such as water filtration, food and habitat for other species.

Human systems evolve along with ecological ones. For example, due to exacerbated affects from global climate change and sea level rise, coastal ecosystems that provide storm protection and nutrient removal may also benefit the community economically (Costanza and Farley 2007; Lindahl et al. 2005; Gren, Lindahl and Lindqvist 2009). Therefore, the salt marsh, eelgrass and shellfish beds may also serve as 'engineers' for sustainable socio-economic communities by providing ecosystem services and zooremediation (Gudimov 2002).

II) Is it resource efficient?

The planned restoration at Pier 5 has a multi-functional design that uses a water-energy nexus process – working with the natural linkages between water and energy systems - between the structures on the Pier and in the water. The research, educational and outreach lab envisioned for the Pier will have a green roof that will provide insulate value, solar electrical and thermal energy while at the same time filter storm water before it reaches the floating salt marsh, shellfish and eel grass beds. This last is particularly critical as adequate water quality and quantity are the most important factors supporting coastal habitats' health, function and biodiversity.

III) How does it adapt changing conditions and model resilience?

Resiliency of habitats and ecosystems is often attributed to their interconnectedness and interdependence, as living things adapt and evolve locally without waste of energy or materials (Wilson 2008). Resiliency of the planned Pier 5 ecosystem has both these intrinsic ecosystem aspects, as well as extensions to its surrounding human communities. Pier 5 can easily adopt and respond to changing conditions, such as storm, inundation and sea level rise. Floating habitats will continue to maintain their integrity by self-renewal and growth. In addition, learning from the ways that interconnectivity strengthens the resiliency of coastal ecosystems may also encourage human communities to adopt more sustainable behaviors, to recognize their interdependence on each other, and to value human as well as biological diversity (Meadows, Meadows and Randers 1992; Hawken, Lovins and Lovins 2004).

IV) Are development and growth integrated?

Each of the three habitats provides many ecosystem benefits: starting from an initial bottom-up mix of grasses and shellfish, over time these habitats are expected to self-organize to develop complex food webs (Heck et al. 2008) and serve as nurseries for fish and invertebrates (Heck, Hays and Orth 2003). The floating habitats are nested within the water column and have a natural carrying capacity, with clear physical limits; and as they are modular, this design could be adapted to restore other hard coastal structures. Development and growth is integrated and interdependent within each habitat as well as between them: salt marshes, eel grass and shellfish beds enhance opportunities for migration and complex trophic interactions and therefore support conditions conducive to life (Beck et al. 2001).

V) How is it locally attuned and responsive?

In order to restore an area including built structures in a way which is locally attuned and responsive, the likely "natural" ecological functions of the area will need to be determined and compared to the current functions of the existing built structures along with potential counterproductive effects of said structures. Pier 5 in BH suggests the restoration of the three key coastal habitats we have described in order to achieve a more responsive, locally attuned design and site.

What would successful locally attuned restoration look like in this coastal area? Eelgrass beds, salt marshes and shellfish beds buffer wave action and may help to protect the coast from storm surge and sea level rise (Gambi, Nowell and Jumars. 1990; Taylor

Figure 5. Floating salt marsh in Baltimore, MD

2008). Additionally, these important coastal keystone habitats filter nutrients (Evrard et al. 2005), stabilize sediment (Bos et al. 2007) and filter small particles from the water column (Sokoloff 2009). They also serve as sediment traps (sediment accretion), stabilizing coastal areas and minimizing erosion, and improving the water quality in situ. We hypothesize that the design for Pier 5, if replicated throughout urban harbors, would offer similar ecosystem services and integrate its surrounding environment through cyclic and trophic processes. Locally responsive restoration also means asking and listening to local human communities, many of whose members, particularly long-term residents, may know the area well, be attuned to its needs, and have culturally evolved solutions to living well and harmoniously with that ecosystem and each other.

VI) Does it use life-friendly materials, water based chemistry and self-assembly?

This principle requires that structures built on or attached to the pier use local, natural untreated materials, such as granite, sustainable and recycled wood, that are not harmful to water and life. The chemical processes are water based, natural and recyclable. For example, asphalt and concrete can be replaced by "green cement" developed by Dr. Brent Constantz (www.Calera.com).

CONCLUSION

Biomimicry utilizes the study of natural organisms and systems, and the subsequent application of these natural "technologies" to human systems and designs following life's principles: a wind turbine with blade edges scalloped like humpback whales fins; a self-cleaning building covering mimicking the way water rolls off a lotus leaf; an apartment building cooled by structures reminiscent of tunnels in termite mounds. The principles behind natural systems are "abstracted" in order to apply them to human design challenges.

In this study, we have outlined a development and application of biomimicry-based restoration, starting from an understanding that "the environment sets the limits" – that the ecological needs and health of the harbor sustain human activities. The biomimicry principles obtained for purposes of restoration are applied to two pilot restoration sites at UMass Boston, aiding both in the selection of research questions and in the choice of research methods. At Pier 5 learned lessons from the restoration of damaged sites are applied to the design of built human structure. In this study, we have conceived new shellfish habitats, as well as 'islands' of constructed coastal habitats to minimize the effects of storm surges, inundations, and erosion. Myriad other such solutions are likely, drawing on nature's wisdom that has adapted and evolved coastal ecosystems for millions of years despite changes in sea level, water temperatures, pH, nutrients or carbon dioxide. These solutions would provide cost-effective storm-water management, as well as revitalize the harbor's biodiversity, health and resiliency.

The biomimicry-based approach to restoration involves both restoring particular coastal habitats, and in addition, restoring or altering our own human activities within and surrounding these areas to "biomimic" the coastal environment that sustains us. Biomimicry in this latter sense stresses the relationship to a place in situ over the development of specific designs or technologies. In addition, by using a biomimicry approach in an academic setting, it will be possible to practically apply and integrate green education with green jobs and the evolving green economy.

Listening to and biomimicking the complex coastal processes at damaged, healing, as well as at healthy sites helps individuals and communities to re-member how to be part of that nature, thus restoring our cultural relationships with the coast and each other - as we help restore ecological systems. In addition to physical,

<table>
<tr><th></th><th></th><th colspan="3">Biomimicry Application:</th></tr>
<tr><th>Biomimicry Life's Principles</th><th>Keystone coastal habitats</th><th>Research Activities at Sites 1 & 2</th><th>Design & Restoration Activities at Pier 5</th><th>Human Systems (e.g., Green Harbors)</th></tr>
<tr><td>Evolve to survive: interdependent, fostering community-based relationship</td><td rowspan="6">Salt Marsh
Eelgrass
Shellfish</td><td>Assessing relationships between habitats and evolving adaptations</td><td>Established floating habitats of three interconnected coastal communities.</td><td>Teaching and learning by working in a "living lab" at an educational facility</td></tr>
<tr><td>Be resource efficient: low energy multi-functional processes, recycling, fit form to function</td><td>Trophic exchange, water-energy recycling,</td><td>In situ water-energy nexus, self-recyclable and self-sustainable cyclic positive feedback loops;</td><td>Water-Energy Nexus</td></tr>
<tr><td>Resilient—adapting to changing conditions;</td><td>Assessing diversity, function, self-renewal and health of each habitat;</td><td>Floating coastal habitats retain resiliency in the face of sea level rise, storm surge, water quality, etc.</td><td rowspan="2">Green Holistic Education for Green Jobs and Green Sustainable Economy</td></tr>
<tr><td>Integrate development and growth: self-organize</td><td>Habitats carrying capacity and sustainability; nested relationship in ecosystems</td><td>Floating coastal habitats are nested within clear physical space and limits.</td></tr>
<tr><td>Be locally attuned and responsive: cyclic processes and feedback loops</td><td>In situ water-energy nexus, self-recyclable and self-sustainable cyclic positive feedback loops</td><td>Biomimicking ecosystems and functions that would likely exist if the built structures were not there.</td><td rowspan="2">Greening Coastal Urban Areas (e.g., Green Boston Harbor)</td></tr>
<tr><td>Live using only life-friendly chemistry (water-based chemistry and self-assembly)</td><td>Water quality and quantity conditions</td><td>Use of local, natural untreated materials, such as granite, sustainable and recycled wood for build structures.</td></tr>
</table>

Table 1. Biomimicry for multi-habitat restoration and application

chemical and biological methods required in the habitat restoration process, the biomimicry here requires only the simplest of technologies: a willingness to be present to the site, to observe, sense, and listen; to watch the tide come in and cover the shellfish beds and salt marsh, except for a few waving tips of grass.

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REFERENCES

AHRTF. *Charting the Course: A Blueprint for the Future of Aquatic Habitat Restoration in Massachusetts.*: Aquatic Habitat Restoration Task Force (AHRTF), 2008. Print.

Beck, M. W., et al. "The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates." *Bioscience* 51: 8 (2001): 633-41. Print.

Benyus, J.(2006) *Innovation Inspired by Nature.* New York: Perennial, Feb-March.

Berrill, M., and D. Berrill.(1981) *A Sierra Club Naturalist's Guide: The North Atlantic Coast.* San Francisco: Sierra Club Books.

Bertness, MD, PJ Ewanchuk, and BR Silliman. "Anthropogenic Modification of New England Salt Marsh Landscapes." *Proceedings of the National Academy of Sciences* 99: 3 (2002): 1395. Print.

BI. "Biomimicry Educators' Training Workshop." Inverness Valey Inn, CA: Biomimicry Institute (BI), 2010. Print.

Bos, AR, et al. "Ecosystem Engineering by Annual Intertidal Seagrass Beds: Sediment Accretion and Modification." *Estuarine, Coastal and Shelf Science* 74: 1-2 (2007): 344-48. Print.

Bromberg, KD, and MD Bertness. "Reconstructing New England Salt Marsh Losses Using Historical Maps." *Estuaries and Coasts* 28: 6 (2005): 823-32. Print.

Costanza, R., and J. Farley. "Ecological Economics of Coastal Disasters: Introduction to the Special Issue." *Ecological Economics* 63: 2-3 (2007): 249-53. Print.

Davidson-Hunt, I. J., and F. Berkes. (2003)."Nature and Society through the Lens of Resilience: Toward a Human-in-Ecosystem Perspective." in *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change.* Ed. F, Berkes, J. Golding, C. Folke. Cambridge, UK: Cambridge University Press.

Evrard, V., et al. "Nutrient Dynamics of Seagrass Ecosystems: Evidence for the Importance of Particulate Organic Matter and Root Systems." *Marine Ecology Progress Series* 295: (2005): 49-55. Print.

Frankic, A. "A Framework for Planning Sustainable Development in Coastal Regions: An Island Pilot Project in Croatia." Virginia Institute of Marine Science; College of William and Mary, (1998). Print.

Frankic, A, and L. Greber. "A Holistic Science Approach to Living within Coastal Ecosystems in Boston Harbor and Beyond." *The International Journal of Environmental, Cultural, Economic, and Social Sustainability* In press.:(2010). Print.

Gambi, M., A. Nowell, and P. Jumars. "Flume Observations on Flow Dynamics in Zostera Marina (Eelgrass) Beds." *Marine Ecology Progress Series* 61: 1 (1990): 159-69. Print.

Gedan, KB, BR Silliman, and MD Bertness. "Centuries of Human-Driven Change in Salt Marsh Ecosystems." *Annual Review of Marine Science* 1: (2009): 117-41. Print.

Gren, I. M., O. Lindahl, and M. Lindqvist. "Values of Mussel Farming for Combating Eutrophication: An Application to the Baltic Sea." *Ecological Engineering* 35: 5 (2009): 935-45. Print.

Gudimov, A. V. "Zooremediation, a New Biotechnology Solution for Shoreline Protection and Cleanup." *Arctic and Marine Oil Spills* 1: (2002): 401-12. Print.

Harding, S., and L. Margulis.(2006) *Animate Earth: Science, Intuition and Gaia.* White River Jct, VT: Chelsea Green.

Hawken, P., A. Lovins, and L. H. Lovins.(2004) *Natural Capitalism.* Routledge.

Heck, K. L., G. Hays, and R.J. Orth. "Critical Evaluation of the Nursery Role Hypothesis for Seagrass Meadows." *Marine Ecology Progress Series* 253: (2003): 123-36. Print.

Heck, KL, et al. "Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers." *Ecosystems* 11: 7 (2008): 1198-210. Print.

Hunt, C. D., et al. "Phytoplankton Patterns in Massachusetts Bay—1992–2007." *Estuaries and coasts* 33: 2 (2009): 1-23. Print.

Ingersoll, E.(1881) *The Oyster Industry.* Washington, D.C.: Bureau of Fisheries, Govt. Print. Off.

Leschen, A. S., K. H. Ford, and N. T. Evans. "Successful Eelgrass (Zostera Marina) Restoration in a Formerly Eutrophic Estuary (Boston Harbor) Supports the Use of a Multifaceted Watershed Approach to Mitigating Eelgrass Loss." *Estuaries and Coasts* 33: 6 (2010): 1-15. Print.

Libby, P. S., et al. *Water Column Monitoring in Massachusetts Bay*: 1992-2006. Boston, MA: Massachusetts Water Resources Authority, (2007). Print.

---. *Water Column Monitoring in Massachusetts Bay* 1992-2007: Focus on 2007 Results. Boston, MA: Massachusetts Water Resources Authority. (2009). Print.

Lindahl, O., et al. "Improving Marine Water Quality by Mussel Farming: A Profitable Solution for Swedish Society." *AMBIO* 34: 2 (2005): 131-38. Print.

Maciolek, N. J., et al. *Outfall Benthic Monitoring Report: 2008.* Boston, MA: Massachusetts Water Resources Authority. (2009). Print.

Meadows, D. H., D. L. Meadows, and J. Randers.(1992) *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future.* Chelsea Green Publishing Company.

Orth, RJ, et al. "A Global Crisis for Seagrass Ecosystems." *Bioscience* 56: 12 (2006): 987-96. Print.

Sokoloff, P. D. "Estuarine Water Column Filtration by Zostera Marina L. (Eelgrass) and Crassostrea Virginica (Eastern Oyster)." University of New Hampshire, 2009. Print.

Taylor, D. I. *5 Years after Transfer of Deer Island Flows Offshore: An Update of Water-Quality Improvements in Boston Harbor.* Boston, MA: Massachusetts Water Resources Authority, 2006. Print.

Taylor , P.H. *Salt Marshes in the Gulf of Maine: Human Impacts, Habitat Restoration, and Long-Term Change Analysis*: Gulf of Maine Council on the Marine Environment. (2008) Print.

Teal, J, and M. Teal.(1969) Life and Death of the Salt Marsh. Boston, MA: Atlantic Monthly Press.

Wall, C. C., B. J. Peterson, and C. J. Gobler. "Facilitation of Seagrass Zostera Marina Productivity by Suspension-Feeding Bivalves." Inter-Research, Nordbuente 23 Oldendorf/Luhe 21385 Germany. (2008). 165-74. Vol. 357. Print.
Wilson, E.O. (2008)." Foreword" Sustaining Life: How Human Health Depends on Biodiversity. Ed. Eric Chivian, Aaron Bernstein. Cambridge: Oxford University Press. Print.