APPENDIX A

Ecosystem Services of Tidal Marshes

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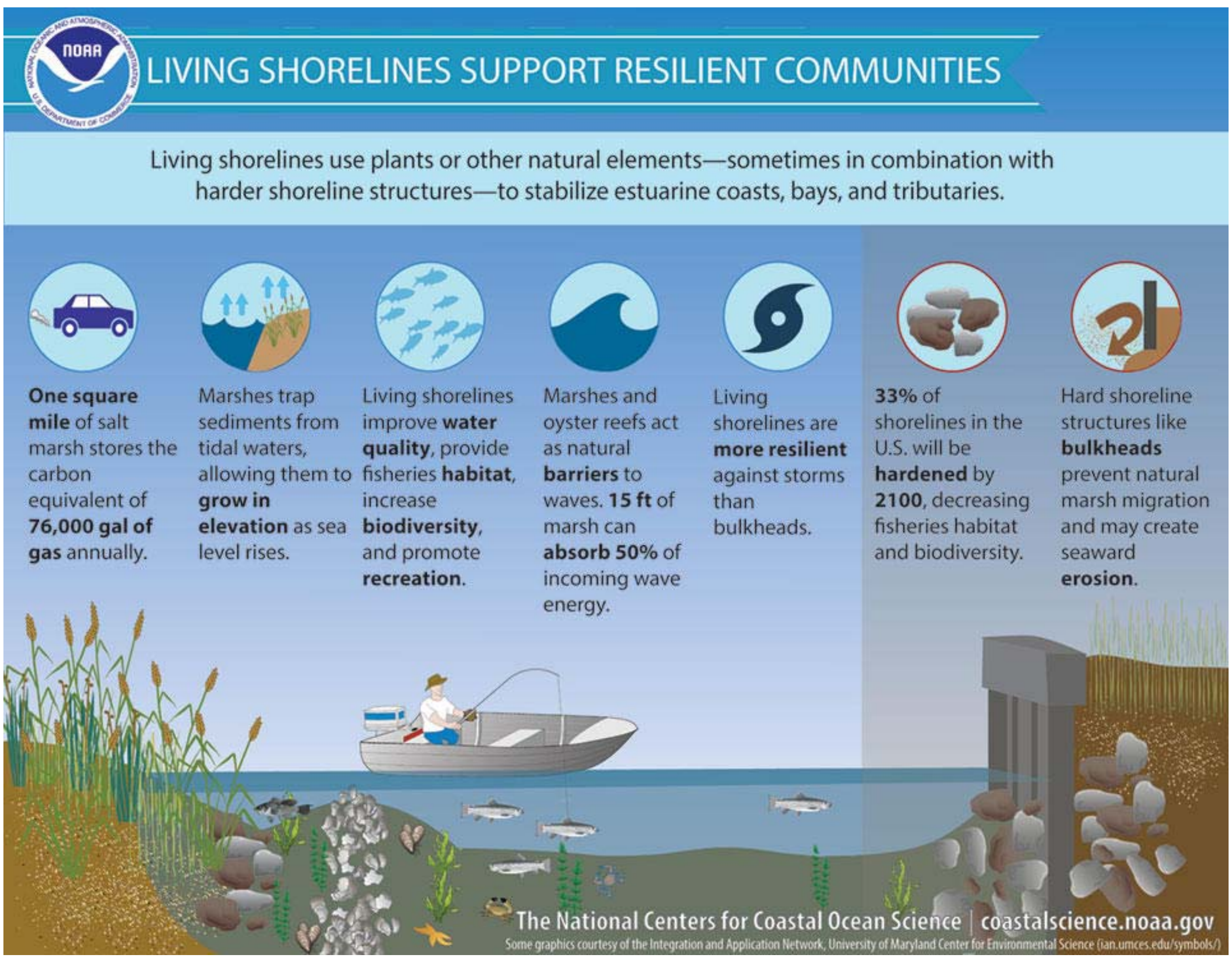
Rationale – Ecosystem Services of Tidal Marshes

Tidal marshes along our coastlines support resilient communities by providing a number of ecosystem services. Ecosystem services have been defined as, "*benefits human populations derive, directly or indirectly, from ecosystem functions*" (Costanza, et al., 1997). These services can be divided into a few different categories which are discussed in greater detail later in this section. Examples include:

- ✓ Tidal marshes seaward of built infrastructure protect those structures by dampening wave energy and resisting erosion of the shoreline, a *regulating* service (see page 4).
- ✓ Marshes increase aesthetic value and provide opportunities for recreation, a *cultural* service (see page 5).
- ✓ Many animals use the marsh for foraging and refuge, leading to greater biodiversity in the local area and providing services such as pollination and nutrient cycling, which are *supporting* services (see page 6).
- ✓ Around the world, marshes provide direct benefits to humans as a source of food, fiber, and fuel; these are *provisioning* services (see page 7).



In contrast, ecosystem disservices, or "*functions of ecosystems that are perceived as negative for human well-being*," may also be introduced when a salt marsh is established in an urbanized setting (Bolund, Hunhammar, 1999; von Döhren, Haase, 2015). While the ecosystem services vastly outweigh the disservices, addressing concerns such as increase in mosquitoes and an increased presence of animals is an important step in garnering support from the local community; this topic is more fully discussed in the section on "Mosquitoes and Other Potential Pests."


Salt marsh, as part of a living shoreline. Photo credit: Dr.DeNo (CC BY-NC-ND 2.0). https://www.flickr.com/photos/denatale/35499552040.

Coastal ecosystems are extremely productive and provide both direct and indirect ecosystem services including coastal protection, erosion control, water purification, maintenance of fisheries, and carbon sequestration (Barbier, et al., 2011). In addition to providing protection from erosion and storm surge, living shorelines can be self-maintaining and have the potential to repair themselves following storm damage (Sutton-Grier, et al., 2015). The minimum value[1] of tidal wetlands is on the order of $16,900/ha to $29,600/ha ranging to a high estimate of $195,700/ha; with storm protection estimated at around $33,000/ha (Barbier, et al., 2011; Costanza, et al., 2008; Gedan, Bertness, 2009; Kocian, et al., 2015; Sutton-Grier, et al., 2015).

Long Island Sound experienced a 31% ± 9% loss of tidal wetlands over the past 130 years, with a net decline in Connecticut of 27% ± 10%, changing from 8,024 ha in the 1880s to 5,895 ha in the 2000s (Basso, et al., 2015). Connecticut marshes exhibited a slight gain in area of 8% ± 2% relative to the 1970s extent of 5,436 ha, marking progress towards wetland restoration. The value of this ecosystem, both locally and globally, drives the need to preserve and restore tidal marshes (Basso, et al., 2018).

[1] All dollar values have been adjusted to US$2017 using the US Bureau of Labor Statistics CPI Inflation Calculator.

Regulating Services

Rip rap or oyster reefs located just offshore of a marsh help to reduce the energy of waves hitting the coastline. Hollow concrete reef balls provide a manmade structure with functions similar to rip rap but designed to act as habitat for local fish and invertebrates. Under the right conditions, reef balls may encourage the establishment of oysters leading to an oyster reef. Photo credit: Reef Balls at Dutch Springs by Neil DeMaster, (CC BY-ND 2.0). https://www.flickr.com/photos/84169650@N07/10544449634.

climate regulation
water regulation
pollution control
detoxification
erosion protection
natural hazard protection

Tidal marshes regulate the impact of storm surges and associated erosion from wind waves along the coast (Gedan, et al., 2011; Shepard, et al., 2012). The physical structure of the grass slows the velocity of water, accounting for ~60% of wave dissipation effects, with the peat (soil) of the marsh absorbing some of the water and further dissipating the wave energy (Möller, et al., 2014). With the addition of an offshore sill of riprap or an oyster reef, the living shorelines are even more effective. During small storm events, a living shoreline may completely absorb and abate the energy of waves and flooding water. During larger events, the marsh may be overtopped by water, but it still provides some reduction of energy and supports built protections located further inland against storm surges (Gittman, et al., 2014; Sutton-Grier, et al., 2015). The width of the living shoreline impacts the level of protection afforded to inland structures and populations. Wind waves may be dissipated by a relatively small expanse of living shoreline. For storm impacts, living shorelines reduce wave action, to some extent, for all storms, while impact on storm surge varies (Möller, et al., 2014; Shepard, et al., 2011). These systems are more effective at handling the storm surge associated with fast moving storms versus slow moving storms, which have time to push water past the barrier provided by the living shoreline (Sheng, et al., 2012; Zhang, et al., 2012).

One of the ecosystem services often attributed to wetlands is their ability to regulate or modulate the hydrologic cycle, reducing the impact of flooding by storing water (Millenium Ecosystem Assessment, 2005). In an urban setting, wetlands have the potential to store or convey surface runoff. In addition to acting as a sponge to excess quantities of water, marshes also act as a filter, removing some of the nutrients and toxins carried in surface runoff before it reaches coastal waters (Craft, 2016b). For coastal marshes, excess water may originate from either storm surge that has overtopped shoreline protections (natural or man-made) to reach inland areas or flooding due to surface runoff and rising river levels. A comprehensive literature review evaluating the impact of salt marshes on floodwater attenuation identified four studies which evaluated the effect of salt marshes on flooding (Shepard, et al., 2011). These four studies consistently noted that natural salt marshes drain floodwater more efficiently than altered salt marshes (As reviewed by Shepard, et al., 2011: Bolduc, Afton, 2004; Brody, et al., 2007; Meeder, 1987; Swenson, Turner, 1987). The marshes absorb water and efficiently move water in a sheet flow towards the ocean (Shepard, et al., 2011). While we cannot identify the capacity of marshes, evidence indicates coastal marshes contribute to the removal of excess water generated during storm events (Craft, 2016b; Millenium Ecosystem Assessment, 2005; Shepard, et al., 2011).

More recently, the ability of salt marshes to sequester carbon dioxide in their sediment for hundreds to thousands of years has resulted in national and international efforts to protect and conserve these 'blue carbon' habitats as a means to reduce atmospheric greenhouse gases and mitigate the impacts of climate change (Executive Office of the President, 2013; Nellemann, et al., 2009). The high productivity of plants found in marsh habitats coupled with the marsh's ability to increase sediment volume over time results in higher carbon storage rates per area in salt marshes than any terrestrial ecosystem, including tropical rainforests (Hopkinson, et al., 2012; McLeod, et al., 2011). Marshes incorporated in living shorelines are typically thin strips along the coast; while thin when compared to larger marshes, these fringing marshes are also efficient at sequestering carbon (Davis, et al., 2015; Fodrie, et al., 2017). The importance of marshes as a 'blue carbon' sink, is matched by their central role in retaining and mediating storage and fluxes of other problem nutrients. Both nitrogen and phosphorous are buried along with carbon as sediment is trapped by plants and sequestered on long timescales during the process of sediment accumulation on the marsh (Craft, 2016d; Tobias, Neubauer, 2009).

Cultural Services

In an urban setting, *green spaces* (parks, urban forests, gardens, yards, vacant lots, campus areas) and *blue spaces* (lakes, ponds, rivers, streams) provide a number of ecosystem services to local residents that are both tangible and intangible. These areas provide a place for people to meet and enjoy the outdoors. Living shorelines in particular provide opportunities for bird watching, fishing, crabbing, kayaking, and general enjoyment of the outdoors. The increase in habitat area for plants and animals is important for increasing biodiversity, but also provides psychological, cultural, and health benefits to local residents (Craft, 2016c; Millenium Ecosystem Assessment, 2005).

spiritual
inspirational
recreation
aesthetics
health
education

Photo credit: Aquatic Restoration by June Marie (CC BY-SA 2.0).
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A recent review of the benefits of restoring natural ecosystems in urban areas cites a number of studies on the benefits of restoring green and blue spaces in urban settings (Elmqvist, et al., 2015). Their review notes that green and blue spaces in urban settings can reduce the urban heat island effect and improve air quality. Elmqvist et al. (2015) reference studies indicating links to reduced mortality, improved recovery from surgeries, reduced stress, improved mental health, and improved perceived and actual general health. From a cultural viewpoint, Elmqvist et al. (2015) cite studies indicating common green and blue spaces enhance social cohesion by providing a neighborhood meeting spot, increasing social trust, and establishing a firm sense of identity or place. These spaces also provide educational opportunities to young people and to people of all ages. Restoration of shorelines benefits both local diversity and human health and enjoyment of the area.

Supporting Services

biodiversity
soil formation
nutrient cycling
pollination
refugia

In addition to serving as a buffer against storm surges and extreme weather events, salt marshes are one of the most productive ecosystems in the world, and provide critical ecological functions and services (Nixon, Buckley, 2002). Marshes and the structures provided in hybrid living shorelines provide nursery habitat for fish and crabs, as well as other animals less familiar to our dinner plates (Gittman, et al., 2016; Meng, et al., 2004; Nicolas, et al., 2010). Birds and other wildlife use marshes as a year round habitat for food and refuge and these habitats also serve as rest stops for migrating birds (Tinkler, et al., 2009), though neighboring roadways and development can discourage use of the marsh by some birds (Boström, et al., 2011). Pollinators, bees and birds, find both a home and food in the marsh. Marshes are considered focal points for natural resource management for threatened and endangered species, particularly shorebirds, and as essential fish habitat (Balouskus, Targett, 2012; Craft, 2016c; Jordan, et al., 2009). The rich diversity of life supported by salt marshes and the submerged portions of living shorelines is what makes them one of the most productive ecosystems in the world.

The services living shorelines, and marshes in particular, provide to wildlife improves biodiversity, which refers to the variety of life found in Long Island Sound. Maintaining biodiversity makes our ecosystem resilient to change. One aspect of biodiversity is redundancy, having different species capable of filling the same role in the environment. If a sudden change occurs and one species is unable to survive the change, a different species is able to fill their ecological role. Another aspect of biodiversity is genetic diversity, or differences within a species. If certain genetic variants are unable to cope with warming temperatures, having members of the species capable of surviving at higher temperatures ensures the species survives. Maintaining biodiversity is a critical role of natural

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ecosystems (Duarte, 2000; Powell, et al., 2017; Yu, et al., 2017).

Returning urbanized, modified shorelines to a more natural state has the potential to improve ecosystem health and provide enjoyment of the environment to local residents (Basso, et al., 2018). Evidence suggests restored marshes provide similar services for fish, plants, and the critters that live in the soil, with those services increasing as the marsh matures (Havens, et al., 1995; Warren, et al., 2002). Urban shorelines are often lacking the physical habitat complexity which supports the needs of both aquatic and terrestrial animals; installing living shorelines can return this complexity to the urban shoreline and bring a bit of the wild back into the lives of the people living in cities (Munsch, et al., 2017; Verdiell-Cubedo, et al., 2012).

Provisioning Services

food
fiber
fuel

Marshes can provide direct and tangible benefits in terms of fish and shellfish harvest, vegetative foodstuffs for humans and livestock, and a source of wood (Craft, 2016a; Gedan, et al., 2009). While marshes worldwide still provide these services, an urban marsh in Long Island Sound is not likely to be a major provisioning source for the local population

Sea beans or Samphire (*Salicornia* sp.), are a group of common marsh plants harvested for human consumption. Photo credit: Sea beans by dutchbaby, (CC BY-NC-ND 2.0) https://www.flickr.com/photos/godutchbaby/4322888138.

(left) Cattle and sheep graze on marshes worldwide. "Salt marsh lamb" is considered a delicacy in the U.K. Photo credit: Cattle grazing - Sefton Coast, Copyright Natural England/Peter Wakely 1991 (CC BY-NC-ND 2.0) https://www.flickr.com/photos/naturalengland/6120683174.

(Foley, et al., 2005).

Valuation of Living Shorelines

Surveys of coastal homeowners in North Carolina and Alabama reveal the cost and perceived effectiveness of shoreline protection drives decisions regarding installation of a bulkhead, rip-rap, revetment, or living shoreline as coastal protection (Scyphers, et al., 2015; Smith, et al., 2017); people are willing to pay more for a bulkhead because they perceive it as more effective. However, Smith, et al. (2017) and Scyphers, et al. (2015) note that bulkheads were far less effective at preventing erosion than homeowner expectations, were less durable, and required more maintenance than living shorelines or rip-rap. In fact, Hurricane Irene damaged 76% of bulkheads along the coast where the storm came ashore while having no impact on the elevation of tidal marshes in the same areas (Gittman, et al., 2014)

Given the drawbacks and expense of shoreline stabilization, coastal municipalities are increasingly turning to natural, or nature-based, shoreline protection as a cost-effective and multifunctional solution (Sutton-Grier, et al., 2015). Rising sea levels and large storm events such as Superstorm Sandy emphasized the value of salt marsh as both valuable habitat and a means to attenuate waves and buffer uplands from adjacent waters (Bridges, et al., 2016; Smith, et al., 2017). In the aftermath of Superstorm Sandy, federal, state, and local governments as well as non-governmental organizations emphasized increasing coastal resilience – defined as the ability of a coastal community to prepare for, resist, and recover from disturbances such as storms – as part of storm recovery planning. Salt marsh management is increasingly being incorporated into a 'natural infrastructure' approach to coastal resiliency; in terms of sustaining marsh ecosystem services and for protecting adjacent built infrastructure (Gedan, et al., 2011; Sutton-Grier, et al., 2015). Inclusion of living shorelines in the green redesign of urban areas such as Bridgeport, CT and New York City points to the growing recognition of these natural features as important contributors to developing a resilient coastal community (WB unabridged, Yale ARCADIS, 2014; Zhao, et al., 2014).

Economic valuation of ecosystem services is a useful tool for comparing the benefits gained versus cost of installation of flood protections; putting a dollar amount on an ecosystem service allows us to express the value in terms we can all understand. A recent review of the impact of natural and built infrastructure, as well as hybrids of the two approaches, states: *"Based on our synthesis, we determined that, where data are available, the resilience and protective benefits provided by coastal ecosystems against waves, floods and storm surge is very valuable."* (Sutton-Grier, et al., 2015) This statement is followed by economic valuations and case studies defining "very valuable" and supporting the overall conclusions of the authors. For example, an estimated $23.2 billion per year in storm protection is provided by coastal wetlands in the U.S. with a loss of 1 ha of wetlands corresponding to an increase of $33,000 in storm damages (Costanza, et al., 2008; Sutton-Grier, et al., 2015).

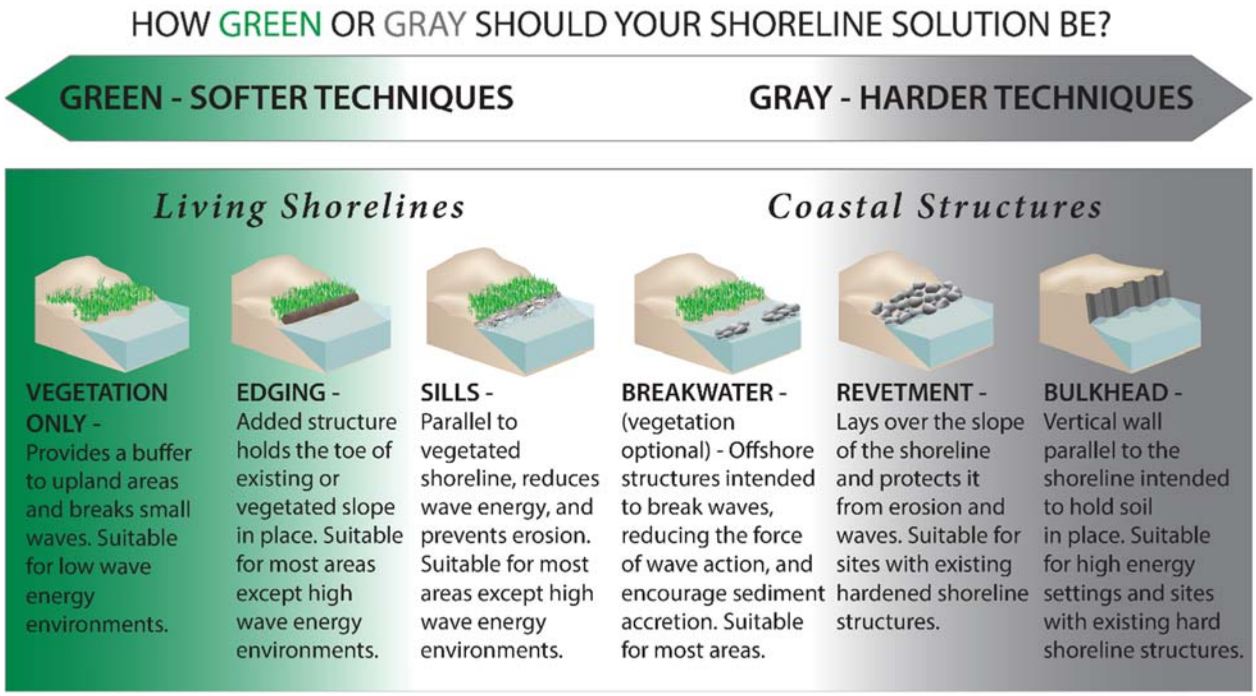

Image credit: NOAA, https://www.habitatblueprint.noaa.gov/living-shorelines/.

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