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Eelgrass Functions, Services, and Considerations for Compensatory Mitigation

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Abstract

Coastal-marine eelgrass habitat is a critical resource within New England and throughout the world. Eelgrass habitat provides functions and services including providing structure, biogeochemical cycling, erosion reduction, habitation provision, and water quality improvement. Declines in eelgrass distribution are often due to anthropogenic processes impacting temperature and water quality. Declines in distribution and abundance highlight the importance of protecting the existing eelgrass, improving environmental conditions allowing for ecosystem restoration, and identifying viable in-kind and out-of-kind compensatory mitigation measures. Considering the limited availability of New England sites for in-kind compensatory mitigation, additional approaches for out-of-kind compensatory mitigation should be considered. These include (1) creation of alternative plant or kelp habitat, (2) using a multi-pronged, multi-habitat and structure approach, (3) contributing to the development of water quality improvement initiatives to encourage current eelgrass bed expansion over time, (4) reduce physical impacts to eelgrass habitat, (5) and identifying locations for future eelgrass habitat suitability based on climate predictions and investing to create future compensatory mitigation habitat in these locations.

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Preface

The work reported herein was conducted at the US Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, MS. Funding was provided by the Wetlands Regulatory Assistance Program (WRAP) under Project 2020-ERD-0450-0001, "Developing Effective Compensatory Mitigation Options for Impacts to the Marine Submerged Aquatic Vegetation (SAV), Eelgrass (*Zostera marina*)" Funding Account Code U4388074; AMSCO Code 088893.

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1 Introduction

1.1 Background

Seagrasses are aquatic angiosperms that thrive in marine environments. More than 50 species of seagrass occur worldwide with 13 reported genera (Paramasivam et al. 2015). Seagrass meadows provide critical nursery habitats for many infauna and epifauna species, as well as a wide range of juvenile fishes. These underwater meadows are the base of many food chains and serve as the minimum energy source for charismatic herbivores such as sea turtles, manatees, ducks, and geese (Heck and Valentine 2006). Seagrasses also protect underwater habitats from sediment scouring from continuous wave action and are ranked as one the most efficient carbon dioxide sequestering ecosystems in the marine biosphere (Duarte et al. 2010). The capacity for the underwater ecosystem to uptake carbon and store it under oxygen depleted conditions is remarkable as the sequestered carbon can remain stored for hundreds of years, contributing significantly towards mitigating climate change (Fourqurean et al. 2012; Githaiga et al. 2017).

Zostera marina (eelgrass) is the most widespread plant in temperate coastal waters of the northern hemisphere (Krause-Jensen et al. 2005) with a geographical distribution ranging from Arctic waters (Mcroy 1968; Duarte et al. 2002) to North Carolina (Thayer et al. 1984), as well as the Gulf of California (Meling-Lopez and Ibarra-Obando 1999; Staehr and Borum 2011). Due to its widespread abundance, eelgrass is a major seagrass species that provides the ecosystem benefits previously described. Eelgrass is found in 16 of the 21 coastal states of the US. Along the Atlantic coast, eelgrass is the dominant seagrass species from Maine to North Carolina; and along the Pacific coast from Washington to California (Xu et al. 2020). Eelgrass exhibits optimal productivity between 10^{o}C and 30^{o}C in polyhaline waters with salinities between 20 and 25 parts per thousand (ppt) (Short et al. 2010); thus attributing to its dominance and abundance in the lower intertidal zones into the subtidal zones of coastal waters. Its extensive distribution and sensitivity to pollution make it a potential indicator species for changes in water quality (Kennish and Fertig 2012). Eelgrass is an important foundation species that is a significant contributor to the overall function and productivity of the shallow-coastal water zone (Adams 1976). Presently, the impacts of urbanization, recreation activities, and pollution are degrading eelgrass communities worldwide. These impacts have led to planning efforts to restore eelgrass beds, specifically along the Atlantic coast of the US (Waycott et al. 2009; NOAA Fisheries 2014).

1.2 Objective

This report is intended to identify the current state of knowledge for eelgrass, identify gaps to be addressed in the future restoration planning efforts, and provide examples of potential compensatory mitigation strategies for eelgrass. The review provides eelgrass compensatory mitigation strategies, including in-kind as well as out-of-kind options. Prior to the discussion of mitigation, a synthesis is provided that includes available information regarding the ecological services and functions of eelgrass and identifies water quality parameters that are critical for eelgrass colonization and growth. Site conditions documented in the literature leading to varying levels of success for eelgrass restoration are also outlined.

1.3 Approach

In 2020, a literature search was conducted to gather information on the ecological contributions of eelgrass to an aquatic system, and the specific conditions required for growth and sustainability. The main parameters considered in that search included plant characteristics, growth requirements, factors affecting eelgrass restoration, and restoration techniques. These parameters were selected because they play an important role for eelgrass compensatory mitigation strategies.

2 Eelgrass Characteristics

Eelgrass are perennial seagrasses that primarily maintain their meadows via asexual reproduction but utilize sexual reproduction to produce seeds under conditions of extensive biomass reduction, or colonization of new areas (Plus et al. 2003). Orth et al. (2007) notes the following regarding the reproductive and growth cycles of eelgrass in temperate regions:

- Seed germination can be observed as temperatures drop below 15°C (the fall season in the North Atlantic region).
- Flowering shoots develop during the winter months.
- Anthesis (i.e., flowering) occurs in mid-spring.
- Mature seeds are released mid spring to early summer.
- Peak biomass and shoot density occur at water temperatures around 25°C.
- Shoot production rapidly declines and leaf senescence occurs when water temperatures exceed 25°C (mid-Atlantic and Pacific regions).
- Subsequent shoot production occurs when temperatures drop below 25°C and continues until a dormancy phase is reached when water temperature drops below 10°C (fall through late spring in the North Atlantic region).

However, note that the seasonal timing of eelgrass growth and reproductive cycles varies considerably across populations and depends greatly on temperature gradients. At subtropical latitudes, for example, eelgrass seedlings emerge in late fall and complete their life cycle in mid-spring (Blok et al. 2018). The temperature driven growth sequence of eelgrass is attributed to its lack of phytochromes associated with red and far-red receptors as documented by Olsen et al. (2016). Because phytochromes are vital in the entrainment of the circadian clock and for the perception of the photoperiod (Legris et al. 2019), the lack of these receptors suggest the cycle of eelgrass growth and dormancy is influenced more by temperature than light.

The morphology of eelgrass is defined by its ribbon-like leaves with rounded tips, bound together in a sheath, that can grow up to 1.2 m long and 2–12 mm wide (or longer and wider depending on environment), with each sheath connected by underground rhizomes that produce root and nodes spaced 1–3.5 cm apart (Murphy et al. 2012). Eelgrass roots anchor the seagrass into the sediment, and take up/in nutrients such as carbon

(C), nitrogen (N), and phosphorus (P) from the substrate (Penhale and Thayer 1980). Eelgrass roots help prevent sediment erosion, while eelgrass blades dampen wave energy. Its linear, grass-like leaf structure allows for the formation of large meadows with high biomass which can stabilize sediment (James 2004). In the North and Mid Atlantic coasts of the eastern US, eelgrass' morphology is distinct, differing considerably from other submerged aquatic vegetation (SAV) found in the coastal areas. Because eelgrass produces roots and shoots with greater biomasses relative to other regional SAV, the increased production translates to higher primary productivity, increased sediment stabilization, and more favorable habitat for vertebrate and invertebrate species (Ballie et al. 2015). A recent report highlighting the success of a unique, large-scale, eelgrass restoration project in the Chesapeake Bay demonstrated an increase in invertebrate and fish biomass supported by the eelgrass habitat, as well as an increase in carbon and nitrogen sequestration over a 20+ year period (Orth et al. 2020).

3 Eelgrass Functions and Services

The functions and services of eelgrass along the North Atlantic coasts of the US are of great economic and ecological significance due to their role in shoreline stabilization, habitation for juvenile fish, and water quality improvement. Plummer et al. (2013) classifies nutrient cycling, primary productivity, seafood nutrition, and habitation provision as the direct or indirect fundamental services that eelgrass provides. Thus, eelgrass is a foundation species in submerged aquatic ecosystems of both the Atlantic and Pacific coasts. In this report, eelgrass functions refer to the ecological roles that are actively carried out by the seagrass, while eelgrass services refer to the benefit that the seagrasses provide resulting from their functions. Moreover, a correlation between eelgrass functions and services has been determined by Short et al. (2000), and further summarized in Table 1. The basic categorized functions of eelgrass that will be discussed in this section include habitat structure, primary production, nutrient cycling, sediment stabilization, and wave attenuation.

Table 1. Relationship between eelgrass functions and services (adapted from Short et al. 2000).

Function Performed	Service Provided
Underwater canopy structure	Habitat, refuge, nursery, settlement, and support of fisheries
Primary production	Food for herbivores and support of fisheries and wildlife
Epibenthic and benthic production	Support of food web and fisheries
Nutrient and contaminant filtration	Improved water quality and support of fisheries
Epiphyte and epifaunal substratum	Support of secondary production and fisheries
Oxygen production	Improved water quality and support of fisheries
Organic production and export	Support of estuarine, offshore food webs, and fisheries
Nutrient regeneration and recycling	Support of primary production and fisheries
Organic matter accumulation	Support of food webs and counter sea level rise
Wave and current energy dampening	Prevents erosion/resuspension and increases sedimentation
Sediment filtration and trapping	Improved water quality, counter sea level rise and support of fisheries
Sediment stabilization	Reduced erosion

The physical structure of eelgrass stands create the habitat and refuge sought by many juvenile fish, shellfish, waterfowl, and other economically important species. The meadow-forming structure of eelgrass is an ideal shelter for forage fish from predators. Eelgrass has been directly correlated to certain species of concern that depend on its meadows. In past years, eelgrass disappearance was reportedly associated with the loss of the eelgrass limpet, brant geese, and shellfish (Hughes et al. 2009).

Not only has eelgrass decline been associated with the loss of fish and invertebrate species, but also other larger animal species. Presently, the decline of New England eelgrass meadows threatens endangered sea turtles that depend on the seagrass for food and/or protection (Waycott et al. 2009). Bertelli and Unsworth (2013) found that abundant seagrass meadows considerably reduce predation of young commercial fish species, resulting in increased feeding and growth rates. Considering that the demand of fish and aquatic invertebrates are projected to increase over time, it is imperative that juvenile fish populations of commercial value are protected. While Bertelli and Unsworth (2013) note that many juvenile fishes are not obligate eelgrass users, the availability of a continuous seagrass meadow will ultimately lead to an increase in the respective fish populations utilizing seagrass beds for nursery habitats.

In the case of the economically import Atlantic cod, Lilley and Unsworth (2014) provide further evidence that eelgrass meadows are significant to Atlantic cod stocks as these species selectively rely on eelgrass meadows for nursery habitat. Although other environmental factors may also contribute to the Atlantic cod decline, the disappearance of eelgrass beds further contributes to the loss of this species. Similarly, the presence of young-of-the-year pollock, Atlantic cod, Atlantic tomcod, white hake, and red hake were all reported to correlate strongly to eelgrass meadows over a five-year evaluation of shallow-water habitats along the coast of Maine (Stevenson et al. 2014); thereby suggesting that the availability of shallow water vegetated habitats may be a limiting factor for juvenile fish less than two years old.

The ecological importance of eelgrass is not limited to its physical ability to provide habitat for sensitive aquatic species, but also includes its trophic complexity that results from several factors. As primary producers, the abundance of decaying eelgrass serves as a food source supporting epifaunal and infaunal communities, while the aboveground shoots support a wide array of epiphytic flora and fauna as the eelgrass blades trap sediments and invertebrate species (Joseph et al. 2013). These infaunal and epifaunal species, which are food for juvenile commercial fish species, are directly supported by eelgrass meadows. Also, waterfowl and sea turtles extensively graze eelgrass meadows, which has been found to play a vital role in maintaining healthy seagrass beds because of biotic dispersal of consumed seeds. Sumoski and Orth (2012) provide strong evidence that eelgrass seeds can pass through the digestive systems of resident and transient vertebrate species and remain viable after excretion; thereby demonstrating the ability of the faunal species to seed isolated areas.

As earlier stated, the multiple trophic levels supported by eelgrass stands range from avian animals to microscopic algae. At the microscopic level, nitrogen fixation within the eelgrass meadows has been suggested to come from autotrophic or heterotrophic epiphytes (Cole and McGlathery 2012), although heterotrophic N fixation that occurs within the seagrass rhizosphere is also significant (Welsh et al. 2000). Eelgrass meadows are a “hotspot” for N cycling as N_2 fluxes were directly proportional to the amount of N in the water column in the seagrass meadow (Zarnoch et al. 2017). Another geochemical process notable in eelgrass beds is their carbon storage. Eelgrass is noted for its remarkable ability to store large quantities of C in biomass and sediments. Findings from Novak et al. (2020) suggest that high C storage in eelgrass meadows is correlated to shoot density and growth rates. The key benefit of C and N cycling by eelgrass is the transformation of these nutrients into forms that are readily available to other primary producers that further support higher levels of the food web.

Seagrasses, in general, play an important role in sediment stabilization as roots prevent significant displacement of substrate, while the canopy structure controls sediment movement at the sediment-water interface (Potouroglou et al. 2017). Fonseca and Fisher (1986) reports eelgrass meadows stabilize sediment at an intermediate level (relative to other seagrass species), noting the strength of the feedback mechanisms of eelgrass for both the above- and below-ground biomass. These characteristics were found to directly influence water flow, wave energy, and sediment stabilization. Flexible seagrass shoots bend in response to flowing water, thus forming a compact, interwoven structure that reduces the water velocity within the compressed canopy, while simultaneously redirecting water flow over the canopy (Gambi et al. 1990). This reduction in flow-induced shear on the substratum can potentially enhance both sediment stability and carbon accumulation in the substrate (Kenworthy et al. 1982). This physical process dampens wave energy, which is critical in preventing erosion as coastal sediments are stabilized. An additional facet of sediment stabilization by eelgrass is the stabilization of sediment bound nutrients. The immobilization of nutrients and organic matter in the sediment encourages biogeochemical processes including oxygen production, mineralization of organic matter, ammonification, and nitrification-denitrification.

4 Factors Influencing Eelgrass Decline

Natural fluctuations in eelgrass distribution can be observed because of (1) variable growth conditions, (2) seasonal diebacks, and (3) declines during storm events (Olesen and Sand-Jensen 1994). Seasonal diebacks and intense storms are important events that facilitate a limited amount of local erosion as buried detritus may be removed and resuspended into the water column to maintain carbon/nitrogen balance in sediment (Dauby et al. 1995). However, fluctuations in eelgrass distribution due to anthropogenic influences that considerably impact water quality often result in the species' continued decline and significant loss of function. To date, the primary drivers of seagrass decline have been attributed to increasing temperatures, turbidity, nutrient loading, and recreational activities.

In the Mid-Atlantic region of the US, the main factors driving eelgrass decline are chronically reduced water clarity due to degraded water quality and increased water temperatures due to climate change (Lefcheck 2017). In the North Atlantic region, however, average water temperatures are highest in August at 23.3°C (NOAA National Centers for Environmental Information 2022), and are currently not documented as a stress factor for eelgrass in this region. Although climate change is projected to bring about increasing temperatures over time, at present, eelgrass decline in the North Atlantic region is be primarily attributed to decreased water clarity (eutrophication induced), and recreational boating activities (Koch and Beer 1996).

Eelgrass has been in a global state of decline as a result of changing environmental and water quality factors (Short et al. 2011; Wong et al. 2021). Documented declines in the distribution and abundance of eelgrass in the US have been reported as far back as the 1930s when the wasting disease practically eliminated eelgrass in the North Atlantic for 30 years (Short et al. 1987; Graham et al. 2021). Since that time, eelgrass distribution has been tracked at local scales in several areas in the Mid- and North-Atlantic regions. In general, there are several factors that determine the growth and distribution of any seagrass species, including nutrient availability, water clarity, wave energy, water temperature, and tidal amplitude. In the subsequent sections, the following water quality parameters and their relationship to eelgrass will be discussed: temperature, water clarity, salinity, wave action, and nutrients.

4.1 Temperature

In general, vascular plants undergo metabolic fluctuations in response to changing temperatures. At low temperatures, they exhibit constraints on enzymatic activity, membrane fluidity, light, and nutrient uptake. At elevated temperatures, metabolic rates increase considerably, along with nutrient demand (Staehr and Borman 2011). At temperatures above optimal range for seagrass, metabolic activity is significantly reduced or halted as a result of protein denaturation or inactivation (Jensen 2000; Atkin and Tjoelker 2003). The impacts of global climate change have been suggested as a factor adversely affecting the distribution of eelgrass (Marsh et al. 1986). Previous studies have shown that eelgrass demonstrates the ability to acclimate to temperatures between 5°C and 25°C (Nejrup and Pedersen 2008). Despite its ability to acclimate to varying temperatures, substantial reductions in photosynthesis and respiration at elevated temperatures have shown to affect light requirements of the species, ultimately limiting depth distribution (Staehr and Borman 2011; Zimmerman et al. 1989). This hypothesis is consistent with findings reported in studies where eelgrass photosynthesis was decreased dramatically when temperatures exceeded 19°C in Chesapeake Bay (Evans et al. 1986). Hammer et al. (2018) found that oxidative stress occurs when temperatures rise to 30°C, yielding reduced tissue growth, tissue integrity, nitrogen metabolism, and protein synthesis. This study also reported that the current climatic trajectory will continue to increase water temperatures, thereby exacerbating other factors such as nutrient loading and turbidity which could potentially degrade the remaining eelgrass beds along the eastern coast of the US.

Additionally, the presence of eelgrass in the Gulf of California as an annual winter species is determined by the average water temperatures which range between 17°C and 25°C (Meling-Lopez and Ibarra-Obando 1999). In addition to the direct metabolic impacts to eelgrass observed due to temperature variation, Staehr and Borum (2011) suggests that reduced oxygen concentrations in water at high temperatures can cause the oxygen diffusion coefficient to increase, which increases oxygen consumption, and thus reducing eelgrass tolerance to anoxia. Temperature has also been shown to proportionately affect light requirements of eelgrass and decrease photosynthesis when summer temperatures are high (Murray and Wetzel 1987; Moore 2004; Zimmerman et al. 1989). When temperatures are nonoptimal, temperature-dependent conditions result in the reduced biomass production in eelgrass beds. Also, the relationship between temperature and turbidity increases the complexity of addressing eelgrass decline as suspended particles in the water column absorb sunlight, thus increasing local water temperatures. Ultimately, the upper elevation limits of eelgrass growth can be determined by physical factors (wave action, desiccation, etc.), while the lower elevation limits are determined by the period of light intensity above photosynthetic saturation (Dennison 1987). Climate change shifts can also alter the impacts to eelgrass meadows by nutrients and turbidity.

4.2 Water clarity

Eelgrass is regarded as a useful indicator of water quality because water clarity regulates its colonization towards deeper waters (Krause-Jensen et al. 2005). Oriented in the subtidal zone of coastal habitats, the elevation and depth of eelgrass beds are determined by low tide level and light penetration. Orth et al. (2010) suggest that a key factor in eelgrass decline is light attenuation caused by high turbidity. Results from a long-term water quality monitoring effort in the York River estuary showed that the magnitude of eelgrass recovery was inversely proportioned to turbidity. Moore et al. (2012) cited reduced light availability related to anthropogenic inputs of nutrients and sediments as a principal factor responsible for eelgrass decline. The response of eelgrass distribution to light availability suggests that water clarity imposes an ultimate limit on the seagrass's biomass and production (Short 2012). This notion is supported by Lee et al. (2007), as light availability is stated as the major factor controlling eelgrass growth along with nutrients and temperature. Sand-Jensen and Borum (1983) correlated eelgrass distribution in the Mid-Atlantic region with water clarity illustrating that turbid bays without appreciable wave energy consisted of eelgrass from the low intertidal zone to 2 m, and at 1–2 m to 4.5 m in wave-swept coasts with clear water. In general, seagrasses require relatively high light levels in order to thrive. However, Moore et al. (1997) reports that seagrasses are generally acclimated to relatively short (hours), pulsed high turbidity events, while turbidity events lasting several days or more (e.g., shoreline erosion, excessive sediment laden runoff, or phytoplankton bloom) can cause seagrass to undergo stress.

4.3 Salinity

Salinity is also a key factor determining the distribution of eelgrass. In a 1984 US Fish and Wildlife Service (FWS) report, Thayer et al.

recommended that eelgrass be classified as a euryhaline species based on early research that reported eelgrass to be tolerant to a wide range of salinities from nearly freshwater to full strength seawater. No optimal salinity was determined at that time. In recent years, Salo et al. (2014) evaluated the salinity tolerance of eelgrass from two regions to determine the effect of varying salinities on each and found that eelgrass from both origins were able to successfully adapt to high salinities (approximately 20 ppt), but the eelgrass that originated from the higher salinity environment displayed significant reductions in plant production as well as higher incidences of mortality with low salinities. It can be concluded that extended exposure to freshwater brought on by intense weather events could adversely affect eelgrass meadows depending on their existing adaptability to low salinities. Sola et al. (2020) found that storm and precipitation events increase salinity fluctuations in estuarine and inshore areas and that hypo salinity stress associated with climate change may threaten associated populations. Thayer et al. (1984) explains that eelgrass beds exhibit higher productivity in areas where salinity levels are in the mid to high range.

4.4 Wave energy

The role of seagrasses to function as a breakwater to dampen wave energy has been well established in previous literature. However, in some studies there has been documentation of the influence of wave energy on eelgrass landscape. Kenworthy and Fonseca (1977) reported the morphology of eelgrass to exhibit considerable plasticity in growth in response to physical energy of the environment and nutrient content of sediments. This evaluation of eelgrass beds in their natural ecosystems revealed that plants growing in shallow, wave-swept bottoms tended to have short narrow leaves, grow in high densities, and produce dense root and rhizome clusters; whereas plants growing in deeper water have longer, broader leaves, grow in lower densities, and produce less root and rhizome material. Although eelgrass can reportedly tolerate current velocities of 120–150 cm/sec (Fonseca et al. 1983), the seagrass' response to wave energy is seasonally variable. Kopp (1999) showed that strength of eelgrass shoots is most vulnerable and exhibits the highest breakage in September when the plants begin to senesce.

4.5 Nutrients

Nutrient availability for eelgrass is variable and highly dependent on the geomorphological features of the area in which the seagrass bed is located. In eelgrass meadows positioned in subtidal zones where wave energy is high, nutrient concentrations in both the sediment and overlying waters are generally limiting (Whippelhauser 1996). Eelgrass has the ability to uptake nutrients through both roots and leaves to sustain maximum productivity. Pellikaana and Nienhuis (1988) investigated the importance of eelgrass in the release and storage of nutrients and reported that P uptake by roots was significant if P in the interstitial water is higher than in the overlying water. The study also concluded that considerable amounts of ammonium (NH_4), the major source of N for eelgrass, is absorbed through eelgrass leaves from the water columns, unless limiting, in which case NH_4 is absorbed through the root-rhizome system. In many cases, nutrients N and P are in great abundance rather than limiting. Short et al. (1995) explains that excess nutrient loading reduces eelgrass growth and bed structure considerably as a shift in plant dominance from eelgrass to phytoplankton, epiphytic algae, and macroalgae occurs. The eutrophic effects from high nutrient loading encourages algal growth which causes significant shading of the seagrass beds as the floating algae reduces light availability for the plants. A case study review conducted by Short et al. (1996) reported significant declines in eelgrass distribution that were linked to groundwater discharge as a source of nutrient enrichment. The point source of the nutrient discharge was identified as home septic systems. Results from this evaluation showed an inverse, linear correlation between eelgrass abundance and housing density through the 1960s, 70s, 80s, and 90s.

4.6 Physical disturbances

Factors adversely affecting eelgrass health and distribution include shoreline construction that alters the absorption of wave energy, oil spills that directly affect plant health, herbicides that damage eelgrass, boat mooring as propellers and anchors damages and uproot the plants, and shellfish harvesting that can damage and remove the plants. Further, a review by Erftemeijer and Lewis (2006) documents seagrass losses on the order of 21,023 ha due to dredge activities, although the fraction of seagrass that was specifically eelgrass was not reported.

5 Recolonization Following Dredge Activity

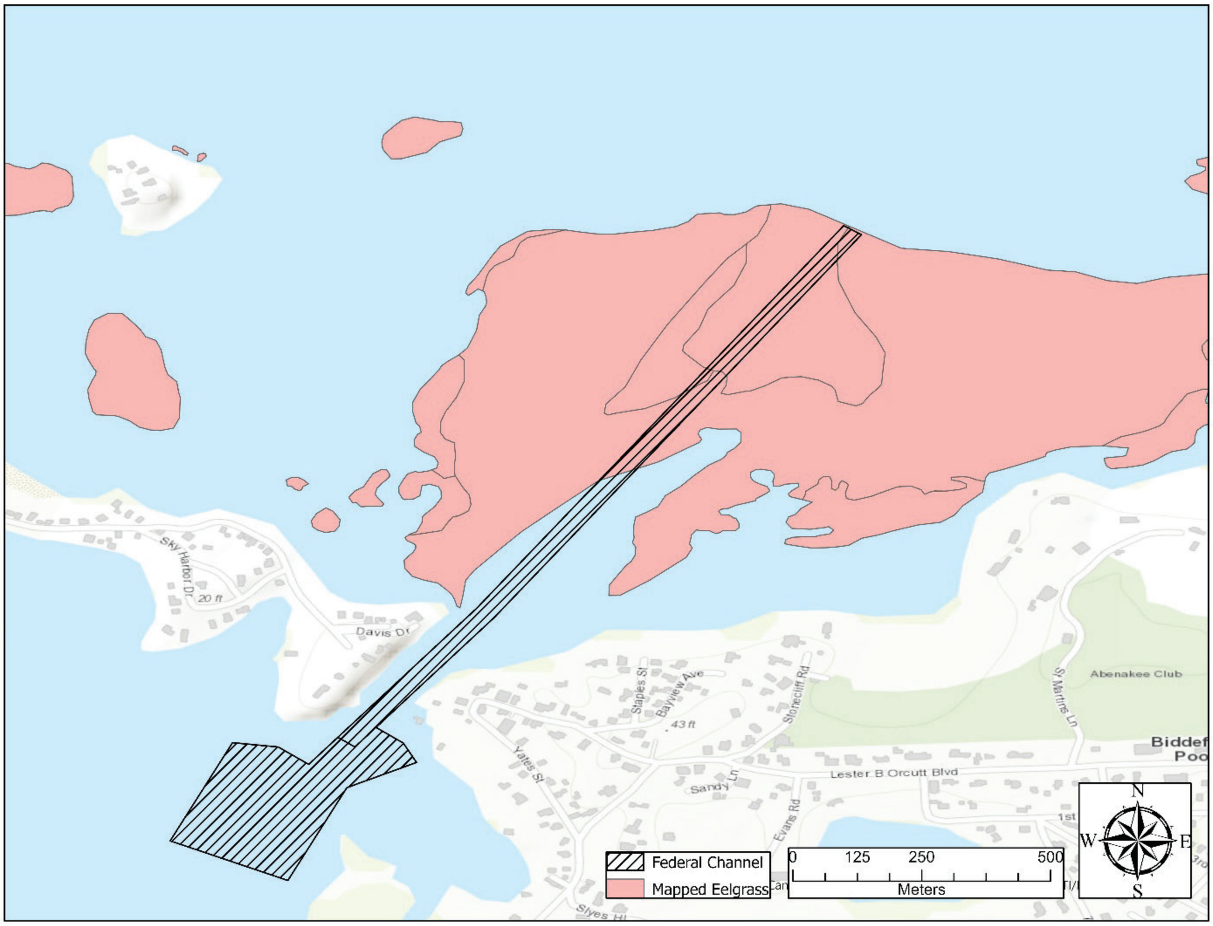
Seagrasses live in dynamic areas which are subject to acute and/or gradual change (Fonseca 1996). Seagrasses have evolved to reestablish after acute burial caused storm events, such as hurricanes, if the environment remains suitable for growth (Michot et al. 2002; Heck and Byron 2006; Carter et al. 2011).

As previously described, most declines in eelgrass distribution have been linked to eutrophication by anthropogenic sources (Jorgensen and Bekkby 2013; Koch and Orth 2003; Orth et al. 1976). Recovery of eelgrass beds within dredged channels has been documented within the US Army Corps of Engineers (USACE) New England District (NAE); one long-term example is Wood Island Channel (Figure 1). In 1990, a 610 m x 30 m section of the Wood Island Harbor and Pool at Biddeford Federal navigation channel was dredged by USACE Civil Works through an eelgrass bed. The channel was dredged down to 3 m below mean-low-low-water (USACE NAE 2020). Channel surveys in 2016 and 2020 documented the presence of eelgrass within the navigation channel, with some areas of the channel having 100% eelgrass coverage in 2016 (USACE NAE 2016, 2020). Wood Island channel was dredged again in the winter of 2020/2021 with an estimated 1.2 hectares of eelgrass being mechanically removed (USACE NAE 2020). Preliminary findings from a summer 2021 survey suggest eelgrass was already reestablishing along the slope of the channel.*

According to the national channel framework index, some NAE navigation channels are maintained as shallow as 1.2 m which is within growth depths of NE eelgrass. Recovery of eelgrass beds within NAE dredged navigation channels does occur and as of the writing of this report, NAE is writing a document describing eelgrass recovery at various dredging projects.

* Todd Randall, NAE District, pers. comm., July 2021

Figure 1. Spatial overlap of “The Wood Island” federal navigation channel and eelgrass meadow coverage within New England District. The Mapped Eelgrass layer was downloaded from the https://Northeastoceandata.org website and based on a 2002 survey. Dredging occurred in 1990, and eelgrass was verified within the channel in August 2020. The channel was again dredged in the winter of 2020/2021.



6 Compensatory Mitigation Options

6.1 Restoration and in-kind compensatory mitigation initiatives

Downward trends in eelgrass distribution and abundance in many parts of the coastal region along the northeastern US and eastern Canada underscore the importance of protecting the existing eelgrass and improving environmental conditions allowing for ecosystem restoration and recovery. Given that eelgrass is an integral component to nearshore ecosystems and the benefits eelgrass habitats provide, the preservation (e.g., maintenance of existing habitat), restoration, and compensatory mitigation efforts in areas that did not historically have these habitats (but can support eelgrass habitat under current conditions) are important. In-kind compensatory mitigation of eelgrass, in which the goal is to create, restore, or enhance eelgrass beds to offset permitted impacts, follows the same general methodology as restoration efforts in terms of transplanting. These methods are described in more detail below.

In past years, multiple approaches have been taken to restore and re-establish seagrass habitat. The primary objective in these efforts is to return the system to its previous or reference state, resembling its original habitat in both structure and function. Neckles et al. (2009) reports that the most important determinants of eelgrass restoration success are location, light availability, sediment composition, and bathymetry, as well as regional factors such as shoreline configuration and landscape position. It is important to note that the restoration of eelgrass depends largely on efforts to improve water quality (see Chapter 4). Emphasizing water quality improvement prior to or as a component of restoration efforts is likely to increase success rates. For example, reduction in nutrient pollution because of wastewater and stormwater system upgrades in the Massachusetts Bay area correlated with increased eelgrass health (Massachusetts Bays National Estuary Program 2015) and natural recovery and successful transplanting in Boston Harbor after a relocation of the City of Boston's sewage outfall has been observed.*

Eelgrass restoration can be performed via transplantation of viable seeds or mature plants collected from healthy eelgrass beds. Successful

* Dr. Phil Colarusso, Marine Biologist, US Environmental Protection Agency, pers. Comm., March 2022 meetings.

transplantation methods include seeding, stapling individual shoots or clumps of shoots to a stake or frame structure (Davis and Short 1997), and tying plants to a temporary frame such as the Transplanting Eelgrass Remotely with Frame Systems (TERFS™) method (Leschen et al. 2009; Granger et al. 2002; Orth et al. 1994; Short et al. 2002a). These methods can be used in combination within the same site.

The development of seagrass nurseries can benefit and streamline the restoration process. Nurseries, in which seagrass species are grown in optimal conditions in large tanks, provide a transplantation source outside of existing regional seagrass beds. Not only does this reduce the need for transplanting from existing meadows, it can provide cost and logistical efficiencies. In Florida, there are ongoing efforts to develop seagrass nurseries in multiple locations to maintain sustainable nursery stocks (Galoustian 2022).

To maximize efficiency and minimize cost, level of effort, and environmental impact on the donor site, planting bare roots or individual shoots is a recommended approach in lower density donor eelgrass beds (Evans and Leschen 2010; Davis and Short 1997; Leschen et al. 2009). The bare root method employs divers or snorkelers to manually harvest plants two to three nodes (3–5 cm) down the rhizome (Evans and Leschen 2010). An example collection rate is approximately 200 shoots per hour, per diver (Short et al. 2002a). In cases where eelgrass will be harvested from extensive, high-density beds, the clump method of using a garden trowel to harvest clumps of five to ten plants is recommended. Restoration manuals such as Short et al. (2002a) and Leschen et al. (2009) provide detailed methodology. In addition to bare root and clump methods, frame methods such as TERFS™ can be used when minimizing dive time is a priority because they require fewer people for deployment. The TERFS™ method was developed by Short et al. (2002a) and consists of attaching clumps of eelgrass to a wire frame with biodegradable paper, then burying the frame so the plants can root in the transplant site.

The Massachusetts Division of Marine Fisheries guidelines (Evans and Leschen 2010) recommend planting using ¼ m^2 plots with plant densities of 200 shoots/m^2 and planted plots arranged in a checkerboard pattern (Orth et al. 2019). Plants must be maintained in water prior to transplantation to prevent desiccation and should be transplanted within 72 hr of harvesting. In New England, transplanting is often planned for spring to optimize growth conditions. The seasonal timing of transplantation is important with preference for transplantation in the spring, followed by fall and summer. Success is dependent on various factors including competition with algae and impacts from invertebrates (Evans and Leschen 2010). Despite successes, seagrass restoration survival rates are often less than 50%. Van Katwijk et al. (2016) evaluated 1,786 restoration trials and estimated seagrass restoration trial survival rates of 37% overall and 42% survival for large restoration efforts (>100,000 shoots/seeds planted) after 22 months. Although these levels of survival may seem low, it is important to note that natural SAV recovery (i.e., without transplantation) levels of 40% would be considered highly significant/successful (Fonseca 2011).

One of the biggest contributors to successful SAV restoration lies in the site selection process. Eelgrass site selection models such as those described by Short et al. (2002b) and Short and Burdick (2005), which formulate a preliminary transplant suitability index (PTSI) and transplant suitability index (TSI), and the USDA Subaqueous Soil Interpretation (Stolt et al. 2017) approach for restoration suitability are helpful tools to identify appropriate sites. Sites of appropriate size (acreage) to meet project goals that (1) have similar depths to nearby natural eelgrass habitat, (2) may be anthropogenically disturbed but do not experience chronic natural disturbance, and (3) have both similar water quality characteristic to lost habitat and similar characteristic to successful restoration sites are needed for project success (Fonseca 2011; Fonseca et al. 1998). For any eelgrass mitigation project, monitoring and adaptive management is a critical investment. Due to all the inhibitors of successful restoration, a project specific monitoring and adaptation plan can help improve project outcomes.

Even in cases in which site conditions are not acceptable, some techniques can improve site conditions to make them suitable for seagrass restoration. For example, in Florida, successful planting has occurred when areas with organically rich sediments were excavated and subsequently replaced with clean sand prior to planting (Bourque and Fourqurean 2014). Excavation is useful when it allows for improved sediment conditions, but removal of surface substrate can also be detrimental to seagrass growth when it impacts nearby habitat or degrades sediment conditions. Other ways to improve site conditions include raising the level of the seafloor to a suitable depth to optimize light, or developing wave protection structures to allow seagrass to thrive behind (leeward of) the protection measures.

6.2 Other mitigation alternatives

The 2008 Compensatory Mitigation for Losses of Aquatic Resources Rule (Mitigation Rule) which establishes compensatory mitigation standards for unavoidable impacts to Waters of the US, acknowledges that, while in-kind mitigation is preferred to out-of-kind mitigation, there are situations wherein on-site mitigation is not environmentally preferred or practical. In those cases, the Mitigation Rule states that requiring off-site mitigation to compensate for habitat functions could be an appropriate alternative if the district engineer has determined through "the watershed approach described in the rule (see § 332.3(c) [§ 230.93(c)]) that out of kind mitigation will better serve the aquatic needs of the watershed" (Compensatory Mitigation 2008). The rule further states that in cases in which the in-kind "compensatory mitigation opportunities are not practicable, are unlikely to compensate for the permitted impacts or will be incompatible with the proposed project, and an alternative, practicable off-site and/or out-of-kind mitigation opportunity is identified that has a greater likelihood of offsetting the permitted impacts or is environmentally preferable to on-site or in-kind mitigation, the district engineer should require that this alternative compensatory mitigation be provided" (Compensatory Mitigation 2008). In coastal areas, an ecoregion approach, allowed for by the Mitigation Rule, might also be appropriate.

In terms of eelgrass habitat, restoration efforts and in-kind replacement via compensatory mitigation for unavoidable impacts permitted by USACE Regulatory are only feasible when there are locations for transplanting that offer suitable habitat and environmental conditions. These conditions are not always achievable or possible, and lead to the need to consider effective, alternative compensatory mitigation options, or out-of-kind alternatives, which replace the functions and services of eelgrass. As stated in the California Eelgrass Mitigation Policy and Implementation Guide,

> Any proposal for out-of-kind mitigation should demonstrate that the proposed mitigation will compensate for the loss of eelgrass habitat function within the ecosystem. Out-of-kind mitigation that generates services similar to eelgrass habitat or improves conditions for establishment of eelgrass should

> be considered first (NOAA Fisheries West Coast Region 2014).

In other words, although out-of-kind mitigation is not preferred, when it is considered, the first criterion is that the out-of-kind mitigation provides similar ecological services to eelgrass habitat.

Using a combination of literature searches and a data request to the USACE Regulatory Community of Practice, some state mitigation guidelines (e.g., California, Massachusetts) and project specific mitigation plans were identified, but most did not describe examples of out-of-kind approaches. The small sample of alternative approaches identified will be described below. This section concludes with a discussion of additional options that address the replacement of eelgrass functions and services.

One out-of-kind eelgrass mitigation example was the Convair Lagoon eelgrass mitigation project conducted by MBC Aquatic Sciences in San Diego, CA.* Although part of the compensatory mitigation effort for this project consisted of in-kind restoration of the existing eelgrass bed, there was not enough viable planting area to mitigate the required acreage. Through negotiations with the FWS, an alternate approach focused on restoring and enhancing habitat of the California least tern was acceptable as compensation for 0.5 acre of eelgrass. A second part of the compensatory mitigation effort involved negotiations with National Marine Fisheries Services, California Department of Fish and Wildlife, and FWS to mitigate for an additional one acre of eelgrass by developing a 10-acre kelp restoration project across two sites. This effort provides a good example of a case in which out-of-kind mitigation resulted in two different actions, with each alternative restoration (nesting habitat and kelp) providing a suite of services and functions similar to eelgrass.

A case in the Port of Bellingham, WA, also used out-of-kind mitigation to create eelgrass as compensatory mitigation for loss of mudflat habitat to provide juvenile fish habitat and enhance primary, secondary, and tertiary productivity (Salo et al. 1988). While this example is not describing compensatory mitigation for unavoidable impacts to eelgrass, it is a

* https://www.mbcaquatic.com/project/convair-lagoon-eelgrass-and-kelp-restoration-2

successful out-of-kind mitigation that considers eelgrass functions and services in context to other, noneelgrass special aquatic sites.

Another example in Washington focuses on developing mitigation credits through interagency agreements. In the Fidalgo Bay Eelgrass Mitigation Project, the Port of Anacortes (Port) negotiated with the Washington Department of Fish and Wildlife (WDFW) to develop off-site mitigation plans. In addition, the Port and the WDFW established guidelines and a vehicle for mitigation credits for the eelgrass project (Elsner 2008). This agreement was the first flexible agreement of its kind in the state of Washington. The Port entered into a new type of sublease agreement with the City of Anacortes and the Washington Department of Natural Resources for use of the proposed eelgrass site for 30 yr, to allow for future mitigation “credit” for development actions (Elsner 2008). When the lease has expired, the site goes back to state ownership with the improved habitat becoming a publicly owned site. The eelgrass habitat site was constructed in 2006 through beneficial placement of clean, silty sand dredged material followed by eelgrass transplantation in 2007. The site was designed to be six acres in size but was closer to 4.5 acres due to sediment settlement following placement (Grette 2013). The project objective was to replace the acreage of eelgrass habitat at a rate of 1.5:1 and the performance standard was to provide approximately 140,000 shoots at the site within ten years of transplantation (Grette 2012). A 10 yr monitoring effort was implemented to determine whether the project was on track to meet objectives and/or to identify when additional transplants would be needed. A monitoring report in year four (2012) indicated the eelgrass in the site was healthy and thriving with approximately 97,000 shoots present (i.e., 69% of the 10 yr performance objective met; Grette 2012). Subsequent monitoring reports were not publicly available.

Through development of a programmatic umbrella mitigation banking agreement in 2012 (finalized in 2017), the Port of Los Angeles, CA, has included wetland habitat, eelgrass habitat, inner and outer harbor marine habitats, and artificial reefs under the agreement, with both in-kind and out-of-kind opportunities for compensatory mitigation (Prickett et al. 2013). Habitat equivalences and relative credit ratios were established by the prospectus, and it seems that habitat footprints within the Port are being holistically viewed as dynamic, with the expectation that they may change over time (Prickett et al. 2013). This is an interesting systematic approach that may have utility when considering compensatory mitigation options in other US marine ecosystems.

In addition to the examples described above, which represent solutions to the challenge of compensatory eelgrass mitigation across the nation, alternative approaches could focus on the functions and services that will be impacted with eelgrass loss. Eelgrass functions can be summarized into the following categories: providing habitat structure, primary production, nutrient cycling, sediment stabilization, and wave attenuation (Table 1). Alternative approaches to compensatory mitigation should provide these functions and their associated services. The following describes five potential options that should be considered individually or as combined approaches for out-of-kind eelgrass mitigation:

- Restore or create alternative plant habitat.
- Use a multipronged mitigation approach (e.g., multiple habitats, structural components, etc.).
- Address drivers of decline (e.g., water quality).
- Reduce physical impacts.
- Identify future areas of habitat suitability.

Many eelgrass functions can be provided by other vegetated habitat. Through restoration or creation of alternative plant habitat capable of establishing and recolonizing areas of impact under current water quality conditions, a different suite of aquatic plants could also provide similar functions and services. For example, alternate plant habitat such as tidal wetland habitat would also have sediment stabilization, wave attenuation, carbon and nutrient uptake functionality, and serve as habitat for fish and invertebrates. Careful consideration of plant alternatives and species-specific capacities for each function would be needed to determine the ratio of new plants to use in comparison to eelgrass to account for the mitigation of functional loss.

A practical example that successfully went through the permitting process in California was described in the Convair Lagoon. In that case, kelp habitat was used to mitigate for eelgrass habitat. New England kelps and kelp habitat could also be used to mitigate for eelgrass function. Seaweeds can mitigate for nutrient assimilation (Hoekstra et al. 2010) and habitat structure (and loss) (Waycott et al. 2009). In addition, with increased interest in kelp and oyster aquaculture, a recent study found that New

England coasts are among the top 20 sites across the globe with the greatest opportunity for restorative aquaculture (Theuerkauf et al. 2019). While aquaculture efforts would not replace habitat (as the intent is to harvest the species of interest), the identification of New England as a favorable region for kelp growth is promising for potential kelp restoration efforts as well. This could provide additional opportunity for kelp restoration and out-of-kind compensatory mitigation efforts within the New England region.

In any particular project, it may be difficult to compensate for the full suite of eelgrass functions. In these cases, a multi-pronged mitigation approach that incorporates multiple habitats and structural components for wave attenuation, fisheries critical habitat, primary productivity, and nutrient cycling, as well as habitat structure and stabilization may be appropriate. For example, an approach using both plant habitats as well as oyster or mussel reefs could improve water quality and provide habitat. Novel methods, such as those described by Carus et al. (2021), in which artificial seagrass is used in situ to provide positive feedbacks for subsequent natural seagrass growth, may also be a component incorporated into multi-pronged mitigation approaches, but may require further testing.

A different approach to compensatory mitigation would be to address drivers of eelgrass habitat decline in order to increase the habitat footprint. As highlighted in the discussion on eelgrass decline, increased water temperatures and decreased water clarity are the two main factors responsible for eelgrass decline. Although it may be out of the scope of the USACE Regulatory authorities, developing a water quality improvement initiative focused on nutrients and turbidity to encourage current eelgrass bed expansion over time could potentially be completed in conjunction with a compensatory mitigation plan ensuring water quality inputs allow for favorable eelgrass conditions on site.

A complementary approach to improving water quality would be to reduce physical impacts to eelgrass habitat. This could include creative solutions including redesign or reorganization of mooring field locations so deep draft vessels are not moored over eelgrass habitat, establishment of no-anchor zones in eelgrass habitat, and installation of conservation moorings. These types of strategies have been successfully implemented to protect eelgrass habitat in Martha's Vineyard, MA, and Port Townsend, WA, (Hamacek 2016a; Hamacek 2016b; Dowd 2021; Jefferson County Marine Resources Committee 2010).

Finally, as temperature is also a driver of eelgrass habitat decline, understanding the extent of predicted regional temperature change could inform a useful mitigation approach. Using climate fluctuation and warming predictions, areas suitable for eelgrass in future years could be identified. Depending on the size and locations of these future potential eelgrass habitats, they could be targeted as focus areas for future compensatory mitigation actions.

7 Conclusions

Eelgrass habitat is a critical resource within New England and throughout the US. They provide significant value through shoreline stabilization, providing structure, nutrient and chemical cycling (functions), erosion reduction, habitation provision, carbon sequestration, and water quality improvement (services), as well as natural aesthetic and intrinsic values.

Declines in eelgrass distribution are often due to anthropogenic processes that impact temperature and water quality. Although there were substantial declines in eelgrass habitats due to dredge activity (Erftmeijer and Lewis 2006), many practices that contributed to these losses are no longer used during maintenance dredging activities. While there are few documented examples in which eelgrass recovery has followed dredging activity in New England, the Wood Island Channel is showing promising eelgrass recovery.

Declines in eelgrass distribution and abundance highlight the importance of protecting the existing eelgrass, improving environmental conditions to allow for ecosystem restoration, and identifying viable in-kind and out-of-kind compensatory mitigation measures when necessary. Successful in-kind eelgrass compensatory mitigation will rely heavily on-site selection as site location, history, light availability, sediment composition, depth, and shoreline configuration are all very important for habitat establishment. Water quality and disturbance regime at the in-kind mitigation site is critical as well, since chronic disturbance, especially those disturbances that reduce water quality, will not allow eelgrass to thrive. In addition to transplanting, clear and realistic performance criteria, monitoring and adaptive management will all contribute to successful in-kind compensatory mitigation.

While not as common as in-kind compensatory mitigation for eelgrass, there are viable projects outside of New England that can serve as templates for out-of-kind approaches. These include mitigating through development of native New England kelp habitat, development of eelgrass habitat for mitigation credits, and development of a programmatic umbrella mitigation banking agreement. Considering both the limited availability of New England sites for in-kind mitigation as well as eelgrass habitat functions and services, additional approaches for out-of-kind compensatory mitigation should be considered in addition to assessments of the availability on in-kind mitigation sites within the region. These include (1a) creation of alternative plant habitat, (1b) creation of kelp habitat (as based on California example provided), (2) utilization of a multi-pronged approach that incorporates multiple habitats and structural components, (3) contributing to the development of a water quality improvement initiative focused on nutrients and turbidity to encourage current eelgrass bed expansion over time, and (4) identifying suitable locations for future eelgrass habitat based on climate and warming predictions and investing to create future habitat for compensatory mitigation in these locations.

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Abbreviations

EL	Environmental Laboratory
ERDC	US Army Engineer Research and Development Center
FWS	Fish and Wildlife Service
NAE	New England District
PTSI	Preliminary transplant suitability index
SAV	Submerged aquatic vegetation
TERFS™	Transplanting Eelgrass Remotely with Frame Systems
TSI	Transplant suitability index
USACE	US Army Corps of Engineers
WDFW	Washington Department of Fish & Wildlife
WRAP	Wetlands Regulatory Assistance Program

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14. ABSTRACT

Coastal-marine eelgrass habitat is a critical resource within New England and throughout the world. Eelgrass habitat provides functions and services including providing structure, biogeochemical cycling, erosion reduction, habitation provision, and water quality improvement. Declines in eelgrass distribution are often due to anthropogenic processes impacting temperature and water quality. Declines in distribution and abundance highlight the importance of protecting the existing eelgrass, improving environmental conditions allowing for ecosystem restoration, and identifying viable in-kind and out-of-kind compensatory mitigation measures. Considering the limited availability of New England sites for in-kind compensatory mitigation, additional approaches for out-of-kind compensatory mitigation should be considered. These include (1) creation of alternative plant or kelp habitat, (2) using a multi-pronged, multi-habitat and structure approach, (3) contributing to the development of water quality improvement initiatives to encourage current eelgrass bed expansion over time, (4) reduce physical impacts to eelgrass habitat, (5) and identifying locations for future eelgrass habitat suitability based on climate predictions and investing to create future compensatory mitigation habitat in these locations.

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