Seagrass Restoration in NJ/Mid-Atlantic Coastal Bays: Best Practices and Recommendations

A Report to the Barnegat Bay Partnership Scientific and Technical Advisory Committee

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Chapter 1: Introduction

1.1. Document Goals

This technical resource aims to provide guidance for the restoration and protection of New Jersey seagrass meadows to state and federal agencies, local jurisdictions, nonprofit organizations, and others with an interest in New Jersey seagrass meadows. The goal of this document is to consolidate information about seagrass restoration and relay it using language that non-experts from diverse backgrounds can reference and use for planning seagrass protection and restoration projects. This document explains the steps and considerations for planning and executing projects to protect and restore seagrass in New Jersey including site selection, restoration methods, and post-restoration monitoring techniques that promote resilient seagrass meadows.

Problem Statement

Seagrass meadows are ecologically and economically important coastal habitats present around the world. However, seagrasses have declined globally over the past several decades due to environmental and human-created threats (Orth *et al.* 2006). In New Jersey, 62% of submerged aquatic vegetation was lost over a 25-year period in Little Egg Harbor, mostly eelgrass although widgeon grass also declined (Bologna *et al.* 2000). New Jersey seagrass declines have been attributed to stressors including nutrient enrichment, increased water turbidity, ice scouring, boat scarring, and changing climate conditions (Bologna & Sinnema 2012, Kennish *et al.* 2008). Prioritizing the protection and restoration of seagrass in New Jersey is essential to ensure resilient seagrass meadows and healthy coastal ecosystems in New Jersey in the future. Factors including the high cost and labor intensity of some restoration techniques as well as the economic and cultural importance of recreation in coastal New Jersey may prevent efforts to restore these important habitats. However past projects have been successful in restoring seagrass meadows as well as the ecosystem services that they provide, demonstrating the viability and economic worth of investing in seagrass restoration (Orth *et al.* 2020, Reynolds *et al.* 2016, Bologna & Sinnema 2012). Barriers to success in past seagrass restoration projects include poor site selection (Shafer and Bergstrom 2010, Fonseca *et al.* 1998), timing incompatibility, and environmental and anthropogenic disturbance. Many of these issues could be solved with the availability of comprehensive and accessible information for practitioners regarding all steps of seagrass protection and restoration. Therefore, a practical resource detailing steps and decision-making strategies for the implementation of sustainable restoration and protection techniques for an audience of various levels of expertise is necessary to facilitate the recovery and expansion of seagrass in New Jersey.

1.2. Introduction to Seagrass

What are seagrasses?

Seagrasses, also referred to as submerged aquatic vegetation (SAV), are marine flowering plants present in coastal waters of every continent except Antarctica (Green and Short 2003). One of the world's most productive ecosystems, seagrass meadows have been designated as Essential Fish Habitat by the NMFS (Havel 2018). Seagrasses are composed of aboveground leaves and belowground roots and rhizomes, the proportions of each depending on species and environmental conditions (Collier at al. 2021, Lee *et al.* 2007). Seagrass meadows can grow on scales from small, isolated patches less than a meter wide to dense, continuous meadows covering many acres. Reproduction of seagrasses can occur sexually through seeds or asexually through rhizome elongation. Some seagrass meadows maintain cover throughout the year (perennial), others die back annually and rely on seeds to return each year (annual meadows), and some meadows exhibit strategies that are a mix between annual and perennial (Jarvis *et al.* 2012). The life history strategy of a particular meadow can depend on seagrass species, geographic location, and environmental conditions.

There are 72 seagrass species distributed across 6 global bioregions (Short *et al.* 2007). The distribution of seagrasses is determined by environmental factors including water clarity, salinity, current velocity, nutrients, and temperature. A high light requirement restricts seagrasses to shallow coastal environments where they receive enough light to grow and distribute oxygen throughout the plant (Dennison *et al.* 1993). Salinity determines seagrass location and species composition. Current velocity also shapes seagrass meadow distribution; currents greater than 180 centimeters per second (cm/s) lead to erosion of seagrass beds while velocities less than 0.25 cm/s limits carbon dioxide (CO2) diffusion (de Boer 2007). Seagrasses require relatively little nutrients but increasing nutrients can change species composition or favor other organisms such as phytoplankton and algae (de Bour 2007). Temperature influences seagrass distribution as well, with hot and cold extremes limiting growth, altering reproduction, restricting species ranges, and sometimes leading to mortality (Moore & Jarvis 2008, Orth *et al.* 2006, Green and Short 2003). The global seagrass coverage is estimated to exceed 177,000 km2 (Green and Short 2003). Seagrass distribution, abundance, and density vary seasonally as well as among years due to environmental variability and anthropogenic impacts. Therefore, there can be large-scale changes in seagrass meadow extent from year to year.

Ecosystem services and economic impact

Seagrasses are ecologically and economically important ecosystem engineers that provide a variety of beneficial services. The estimated global economic value of seagrasses and algal beds in 2014 was $28,000 per hectare (ha.) per year (Costanza *et al.* 2014). Seagrasses provide food and habitat for fisheries species and other marine organisms including birds, crabs, manatees, and shellfish (Beck *et al.* 2001; Unsworth *et al.* 2014; Unsworth *et al.* 2019). Seagrass meadows are relatively low-velocity marine environments, making them ideal nursery habitats for many species (McDevitt-Irwin *et al.* 2016). Biodiversity and faunal abundance can be much higher in seagrass meadows compared to adjacent unvegetated areas (Stoner *et al*. 1980; Alsaffar *et al.* 2020, Surugiu *et al.* 2021). Seagrass protects coasts by decreasing the impact of storms through wave attenuation and the prevention of sediment erosion (Fonseca & Cahalan, 1992; Koch *et al.* 2007; Reidenbach & Thomas, 2018). They also store large amounts of carbon in the sediment (Duarte *et al.* 2010; Fourqurean *et al.* 2012; Kennedy *et al.* 2010) and improve water quality conditions by trapping suspended particles (Dennison *et al.* 1993; Moore, 2004). Seagrass leaves and roots serve as a link between the water column and sediment (Marba *et al.* 2010; Moriarty *et al.* 1986). This connection, as well as the high amount of light that seagrasses require in order to distribute sufficient oxygen throughout the plant, make seagrasses very susceptible to environmental change, causing them to be early indicators of changes in environmental health (Dennison *et al.* 1993; Orth *et al.* 2006; Orth *et al.* 2017).

New Jersey seagrasses

Figure 1. A) Eelgrass shoots. B) Widgeon grass shoots. Photo credit: Madison Lytle and Hannah Baker.

New Jersey's estuaries and bays provided ecosystem services estimated to be worth over $5 billion in 2004 (Costanza *et al.* 2006). New Jersey's high-salinity seagrass habitats are composed of two meadow-forming species, eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) (Bologna *et al.* 2000, Loveland *et al.* 1984), occurring in waters with salinity greater than 10ppt (Orth and Moore 1982). Widgeon grass can also grow in freshwater environments, however, freshwater SAV is not discussed in this report. Seagrasses here grow in subtidal water typically <2 meters deep (Kennish *et al.* 2008). New Jersey eelgrass and widgeon grass are most predominant in Barnegat, Manahawkin, and Little Egg Harbor Bays and shallow portions of the Navesink, Shrewsbury, Manasquan, and Metedeconk Rivers (Rutgers 2021 Report). The largest extent of seagrass is in Barnegat Bay, accounting for ~75% of New Jersey's seagrass resource (Lathrop *et* *al.* 2001). In Barnegat Bay, seagrass coverage estimates have ranged from 8,799 ha. in the 1980s to 6083 ha. in the 1990s (Lathrop *et al.* 2001). Within Barnegat Bay, eelgrass is the dominant seagrass south of Toms River and widgeon grass is the dominant seagrass in the central and northern portions of the Barnegat Bay (Barnegat Bay Partnership 2019 report). In Little Egg Harbor, eelgrass was reported to be the dominant species (Bologna *et al.* 2000). Seagrasses globally as well as in New Jersey have declined over the past several decades (Orth *et al.* 2006). An estimated 62% of submerged aquatic vegetation was lost over a 25-year period in Little Egg Harbor, mostly eelgrass, although widgeon grass also declined (Bologna *et al.* 2000). During that time period, a study of a larger area in New Jersey indicated losses of 2000 to 3000 ha. (Lathrop *et al.* 2001). In the Barnegat Bay-Little Egg Harbor Estuary, seagrass biomass in 2006 decreased by 50-88% compared to that of the 2004-2005 period (Kennish *et al.* 2007). Currently, there is a lack of current and sufficient information on the extent and species distribution of seagrasses in New Jersey since most documentation is ≥10 years (Rutgers Report 2021).

Eelgrass

Eelgrass is a robust plant with leaves that are flat, long, and wide (average leaf length 80cm; average leaf width 0.3-1.2cm), with rounded tips (Thayer *et al.* 1984, Larkum *et al.* 2006). Morphological variations in leaf length and width are influenced by light availability (Phillips and Backman 1983, Larkum *et al.* 2006). The below ground material composed of roots and rhizomes, which are responsible for plant stabilization and nutrient uptake, are dark brown in color and robust (mean width = 3.5 mm) (Thayer *et al.* 1984, Duarte 1991, Marbà and Duarte 1998). Eelgrass is a temperate seagrass species distributed in the western Atlantic from Nova Scotia, Canada to its southern range limit in North Carolina, US (Thayer *et al.* 1984). Eelgrass inhabits areas with coarse- to fine-grained sediments (Short *et al.* 2001) in coastal waters with salinities greater than 18 (Moore *et al.* 1996, Short *et al.* 2001). Eelgrass can grow intertidally and up to depths of more than 15m (Murphy *et al.* 2011), dependent on light availability and temperature (Dennison 1987; Duarte 1991). At its northern extent it is primarily light-limited (Thayer *et al.* 1984) while at its southern extent it is limited primarily by thermal stress which begins around 25 °C (Nejrup & Pedersen, 2008; Thayer *et al.* 1984). Exposure to low light conditions and temperatures exceeding the optimal range can be lethal to eelgrass. In the Chesapeake Bay, large eelgrass die-off events were largely attributed to low light and high temperature conditions (Moore & Jarvis 2008, Orth & Moore 1983).

Eelgrass reproduction, growth, and senescence are cued by temperature. Eelgrass in New Jersey is most abundant in the spring through summer, reaching peak biomass in summer (June-July) when water temperatures are relatively low (Kennish *et al.* 2008; Thayer *et al.* 1984). There is a subsequent seasonal decline in eelgrass in the fall (October-November) when water temperatures are greater. Water temperatures above 25 °C inhibit Z. marina growth and cause increased mortality (Hoffle *et al.* 2011; Nejrup & Pedersen, 2008). Eelgrass can reproduce asexually through clonal growth of vegetative shoots or sexually through seed production. Asexual reproduction occurs through rhizome elongation and new vegetative shoot growth from an existing individual plant. Sexual reproduction produces new individuals through pollination that forms seeds. Eelgrass seeds germinate in response to water temperatures cooling to 10 °C (Setchell 1929). Seedlings grow vegetatively at water temperatures from 10-15 °C and when water temperatures reach 15-20 °C they begin to flower and produce seeds (Setchell 1929). In some mid-Atlantic meadows, the seeds are released around early May and the flowering shoots senesce shortly after seed release (Combs *et al.* 2020). Currently there is no available data about when seed release occurs in New Jersey meadows. Once seeds are released some are buried in the sediment, forming a seed bank (Setchell 1929; Phillips *et al.* 1983; Simpson 1990). The eelgrass seed bank is transient, meaning seeds only remain viable for less than one year (Jarvis *et al.* 2014). Some seeds in the sediment seed bank will be lost to factors including predation (Fishman & Orth, 1996), dispersal (Harwell & Orth, 2002a), or decay (Morita *et al.* 2007), while others will germinate in the next growing season in response to temperature cues.

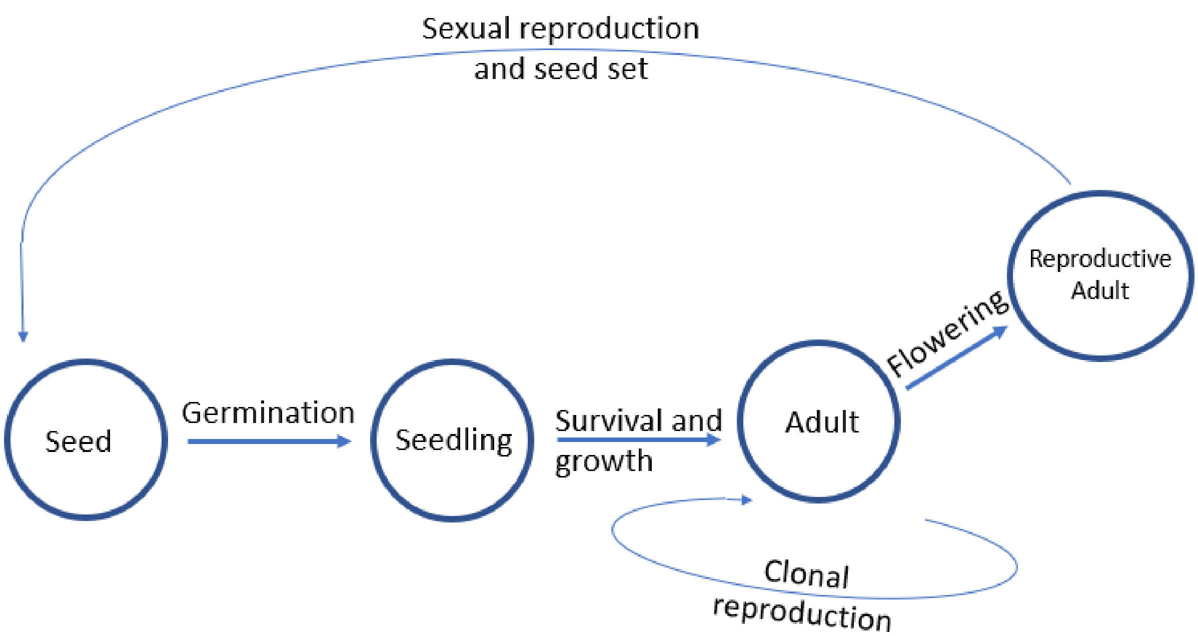

Figure 2. Two reproductive pathways, asexual via vegetative growth, and sexual via flowering and seed formation, for both eelgrass and widgeon grass.

Eelgrass meadow life history strategies include perennial, annual, or a mixture of the two called mixed-annual (Thayer *et al.* 1984; Jarvis *et al.* 2012). Perennial eelgrass meadows maintain aboveground biomass throughout the year, relying mainly on asexual clonal growth to persist for multiple seasons. In perennial populations, seed production does occur but in low densities and not until a plant's second year of life (Jarvis *et al.* 2012). Annual eelgrass meadows die off seasonally and rely completely on the previous year's seed production in the seed bank to return each year. This life history modality is common where eelgrass inhabits stressful environments prone to extreme temperatures or desiccation, as seeds provide a mechanism for the meadows to return each year when environmental conditions are more favorable. Mixed-annual meadows die back seasonally and reproduce via clonal growth as well as seeds (Jarvis *et al.* 2012). This strategy allows meadows to benefit from both strategies, able to utilize available resources throughout the year and also withstand repeated years of disturbance because plants produce seeds in their first year of life rather than second year (Jarvis *et al.* 2012). Consequently, a mixed-annual life history might allow eelgrass persistence through both short-term and long-term periods of environmental stress (Jarvis *et al.* 2012). A meadow's life history strategy can be determined by quantifying the proportion of plants that are reproductive, determining if plants die back annually or persist year to year, as well as observing the meadow to determine if plants flower in their first year of life.

Widgeon grass

Widgeon grass is a small-bodied, opportunistic seagrass species that grows in brackish or saline waters (Kantrud 1991). It has narrow leaves (average leaf length ≤ 20cm; average leaf width ≤ 1cm) with pointed tips (Short *et al.* 2007; Thayer *et al.* 1984). Its belowground material is narrow and light brown (Kantrud 1991). In the western north Atlantic the species is found from Newfoundland, Canada to Florida, USA (Phillips 1960). Widgeon grass can handle a broad salinity range (freshwater (0) to hypersaline (132); Congdon and McComb 1981) as well as temperature range (0.5 ^{o}C – 35 ^{o}C; Wetzel and Penhale 1983). These broad ranges allow the species to colonize estuarine and riverine habitats where environmental conditions can be highly variable. Widgeon grass will take on different morphologies depending on the environment. In fresher water, it can be found growing as tall canopies up to several feet long that reach the surface, while in marine waters growth is stunted and it does not form canopies as dense (Kantrud 1991). In temperate climates, widgeon grass biomass may peak in the summer. When temperature-stressed, such as in shallower areas, biomass may peak in the fall. In deeper, stable habitat, widgeon grass grows year-round.

In temperate regions such as New Jersey, widgeon grass can reproduce through clonal growth or seed production (Kantrud 1991). Widgeon grass flowering occurs about 5-6 weeks after spring growth begins (Kantrud 1991). Its seeds grow in clusters of 2 to 4 seeds. Although widgeon grass seed germination occurs under a relatively narrow set of environmental conditions, the seeds are able to survive under highly variable conditions and are easily dispersed (Kantrud 1991). The seeds can remain viable in the sediment for up to three years (Kantrud 1991). Widgeon grass can exhibit either perennial or annual life history strategies (Malea *et al.* 2004).

1.3. Threats to seagrasses

Globally, seagrasses are declining at a rate of 110 km2 per year with declines attributed to large-scale changes in weather patterns (e.g. frequency and intensity of storms) and regional changes in water quality, as well as localized events (e.g. sedimentation from coastal development) (Orth *et al.* 2006; Waycott *et al.* 2009). Water quality degradation, specifically due to eutrophication (phytoplankton and macroalgal blooms) and increased sediment loading which reduce water clarity (Burkholder *et al.* 2007; de Boer 2007), has been identified as one of the most significant threats to seagrass distribution, abundance, survival, and expansion (Dennison *et al.* 1993). In New Jersey, seagrasses are threatened by water quality degradation from excessive nutrient and sediment loading, human activity for recreation and development, and the emerging threat of changing climate conditions. An additional threat to eelgrass is a species-specific wasting disease caused by *Labyrinthula zosterae* (Rasmussen 1977). Additionally, lack of knowledge about seagrasses and their importance to coastal ecosystems prevents further protection and restoration of this important resource (Unsworth *et al.* 2019). Loss of seagrass is accompanied by a loss of the ecosystem services that seagrass meadows provide, such as storm buffering and essential fisheries habitat. Seagrass loss also has direct negative impacts on associated faunal abundance and diversity (Hughes *et al.* 2009). Consequently, threats to seagrasses are also threats to the broader coastal ecosystem.

Water quality is one of the biggest threats to New Jersey seagrass. Macroalgae and phytoplankton blooms, as well as sediment loading, decrease water clarity and cause hypoxia (Han & Liu 2014), conditions that can lead to seagrass mortality. In Little Egg Harbor, large accumulations of macroalgae have formed mats that smothered seagrass, decreasing eelgrass biomass and eliminating it from parts of the bay (Bologna *et al.* 2007). After this loss event, Bologna *et al.* (2007) found that although part of the disturbed eelgrass bed had recovered to >80% coverage, most of the disturbed bed had not recovered in four years. Brown tides, or large blooms of certain species of single-celled algae, reduce light availability and have caused seagrass loss as well (Dennison *et al.* 1989). Brown tides may also be responsible for slowing eelgrass recovery following losses caused by other factors (Bologna *et al.* 2007).

Human activity also has a substantial impact on seagrass in New Jersey. Recreational and commercial boat activity can physically harm and uproot seagrass (Orth *et al.* 2017). Boat propellers, anchors, seines, and crab scrapes can physically uproot seagrass, leaving scars in a meadow that take several years to recover (Orth *et al.* 2017). Dredging affects seagrass through the physical upheaval of plants, sediment burial, and increasing water turbidity (Erftemeijer & Lewis 2006). Shoreline development also has a large impact on seagrass. Construction in or near water bodies can lead to pollution and sediment loading which reduce water quality. Achieving a balance between the needs of humans and seagrass meadows will be necessary for maintaining a sustainable seagrass resource moving forward (Unsworth *et al.* 2019).

Climate change is reconfiguring the structure and function of marine ecosystems and under future climate change scenarios these conditions could be exacerbated (Hyndes *et al.* 2022). An increasing frequency of high intensity precipitation events is likely increasing the delivery of sediments and nutrients to estuaries (Paerl *et al.* 2019), potentially causing reductions in light availability. Continued degradation of water quality could influence the distribution and persistence of both eelgrass and widgeon grass. As seagrasses have high light requirements relative to other aquatic plants (Duarte 1991; Lee *et al.* 2007), continued reduction in water clarity could disproportionately affect these seagrasses and limit their distribution, especially deeper portions of seagrass meadows. Increasing water temperature may also negatively impact temperate seagrasses. Warmer waters lead to higher rates of respiration of organic matter within the plants and causes death if the enhanced loss of organic matter is not compensated by higher rates of photosynthesis. Consequently, the negative health impacts of decreasing light availability for photosynthesis are exacerbated as waters become warmer (Zimmerman 2006). Warming may also affect the species composition and seasonal distribution of eelgrass and widgeon grass. With the impending threat of increasing water temperature, maintaining adequate water clarity for sufficient photosynthesis will be critical for maintaining seagrass meadows in New Jersey.

1.4. Ecosystem Goals

Developing and maintaining the integrity and continuity of resilient seagrass meadows is the ultimate goal of this document. A reliable and resilient seagrass system provides a substantial amount of primary production, serves as critically important fisheries and nursery habitat, and stabilizes coastal habitats. The decline or disappearance of seagrass beds can result in a negative cascading effect that impacts not only the seagrass meadows but also the other organisms in the ecosystem and the environmental conditions that seagrasses moderate (Barko *et al.* 1986; de Boer 2007). Consequently, the presence of resilient seagrass meadows is vital to the health of coastal ecosystems. In no particular order of prevalence or importance, the following are strategies for fostering resilient seagrass meadows. Note that restoration and protection goals may vary depending on the project and projects do not necessarily have to meet every goal to achieve a resilient seagrass resource.

Protection

One of the most effective ways to maintain resilient seagrass systems is to protect existing beds from degradation. This could include reducing or prohibiting human (e.g. dredging, boat scars) as well as environmental impacts (e.g. sediment loading, nutrient pollution) to prevent harm or reduce further loss of seagrass. This often takes place through regulation (e.g. specific area closures, Clean Water Act, requiring permits, etc). Protection (pre-disturbance) is often more successful and less expensive than restoration (post-disturbance).

Enhancement

Seagrass ecosystems that are stressed by non-ideal environmental conditions or human interference may benefit from efforts to improve conditions in and around the meadow. This may aid in the natural recovery or growth of the meadow. Prioritizing multiple levels of diversity (i.e. genetic, taxonomic, functional) in the design of protection and restoration plans will enhance the resilience of seagrass ecosystems and increase success of protection and restoration projects (Naeem *et al.* 2012).

Restoration

Restoration is an attempt to assist or speed up the recovery of a degraded ecosystem with the hope that the structure and function of the pre-disturbance system will return (Society for Ecological Restoration International Science & Policy Working Group 2004). It has been demonstrated that seagrass restoration can also restore the ecosystem services that seagrasses provide (Lefcheck *et al.* 2017, Reynolds *et al.* 2016). Restoration can greatly speed up the time that it takes seagrass meadows to recover from disturbance (Reynolds *et al.* 2016). Relative to natural recovery, recovery time assisted by restoration was ten times faster than the estimated time to natural recovery (Reynolds *et al.* 2016). Seagrass restoration methods include broadcasting seeds and transplanting shoots.

Natural recovery

Natural recovery is when seagrass recovery occurs via natural processes without human assistance. We can promote natural recovery by improving environmental conditions that impact seagrasses, supporting their resilience. For example, research recommends the improvement of water quality to support SAV habitat recovery (Zimmerman *et al.* 2015). This may be achieved by reducing nutrient input, introducing filter feeders, or altering sediment composition (Zimmerman *et al.* 2015). Zimmerman *et al.* (2015) noted that good water quality has led to the return of eelgrass populations in portions of the Chesapeake region, and further predicted that continued efforts towards water quality enhancement should facilitate seagrass survival.

Research

The need for further research is one of the major challenges to seagrass conservation (Unsworth *et al.* 2019). A well-developed body of research typically comes from various sources including performing observational studies and experiments, communication and collaboration among researchers, and fostering a research community through meetings, seminars, and outreach events. Research provides a better understanding of the complex physiologies, community structures, and threats to seagrass meadows which are necessary for their protection and restoration (Unsworth *et al.* 2019). Establishing long-term datasets is valuable and can assist in identifying changes or threats and predicting future trends of seagrass meadows. In New Jersey especially, a lack of information on the distribution and region-specific traits (e.g. ranges of tolerance to environmental factors, life history strategies, responses to restoration projects, etc.) is a challenge to successful protection and restoration of seagrass in the area. More research on New Jersey seagrasses and the surrounding ecosystems would provide valuable information to enhance the resilience of seagrass meadows in the state.

Regulatory Mitigation

Regulatory mitigation can be a powerful tool for improving conditions of a seagrass meadow. Regulation can potentially improve water quality and reduce damage from boats, for example. The implementation of regulations also establishes social legitimacy to the issue of seagrass protection and restoration, an important factor considering public perception can affect funding and willingness of the public to contribute to restoration efforts. Additionally, as climate conditions are predicted to change, new policies should take into account projected future distributions of seagrass rather than past distributions (Unsworth *et al.* 2019).

Social - ecological integration

Balancing the needs of "people and planet" is one of the most important factors for seagrass conservation today (Unsworth *et al.* 2019). In addition to providing many environmental benefits, seagrasses benefit humans immensely (Cullen-Unsworth *et al.* 2014), providing economic and recreational services. To achieve a sustainable and resilient seagrass resource, human interests as well as environmental impacts to coastal ecosystems need to be taken into account in future management plans (Unsworth *et al.* 2019). The complexities associated with balancing social dimensions of coastal ecosystems with ecological requirements need to be recognized and integrated into management planning to improve outcomes (Kittinger *et al.* 2014).

Chapter 2: Restoration Policy and Regulations

There are a number of policies and regulations at the federal and state levels that apply to submerged aquatic vegetation habitats. While many of these policies and regulations are directed at preventing or minimizing disturbance to SAV, several relate to restoration and mitigation and may impact site selection, choice of restoration methodologies, or post-restoration monitoring. Early discussions with the NJ Department of Environmental Protection Division of Fish and Wildlife's Bureau of Marine Habitat and Shellfisheries regarding potential restoration projects is key to understanding how these rules may affect your project choices.

2.1. Federal Policies

Seagrass habitats are designated as Essential Fish Habitats by the National Marine Fisheries Service (NMFS) (Orth *et al.* 2002). Federal regulations providing protection for seagrass habitat include Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act (Orth *et al.* 2002 and references therein). The U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) are required to review any federal permit applications that may impact seagrass habitat. Federal agencies are required by the National Environmental Policy Act (NEPA) and the Fish and Wildlife Coordination Act to consult on potential environmental impacts of federal projects (Orth *et al.* 2002).

In 1997, the Atlantic States Marine Fisheries Commission's (ASMFC) Habitat Committee developed a policy to communicate the need for conservation of coastal SAV resources and highlight state and Commission-based activities for implementation of a coastal SAV conservation and enhancement program (Havel and ASMFC Habitat Committee, 2018). In 2017, the Habitat Committee re-evaluated its recommendations and importance, and determined that the policy is still relevant. Since 1997, the Habitat Committee has left the goals largely unchanged, with a primary goal to preserve, conserve, and restore SAV where possible and to prevent any further losses in individual states by encouraging six key components: (1) assessment of historical, current, and potential distribution and abundance of SAV, (2) protection of existing SAV, (3) SAV restoration and enhancement, (4) public education and involvement, (5) research, and (6) implementation (Havel and ASMFC Habitat Committee, 2018). The background information, policies, and recommended actions have been updated based on emerging issues and new information released over the last 20 years.

Under SAV restoration, the policy discusses that restoration programs should include the establishment of habitat quality necessary for SAV prior to restoration, that methods should incorporate best protocols, and goals should consider potential and historical SAV spatial footprints. It also notes that state ASMFC members should encourage regional or state restoration goals for SAV, identify reasons for losses and needs for habitat improvement prior to restoration, consider areas currently suitable for SAV restoration for protection and future or immediate use in projects, and implement transplanting and planting protocols (Havel and ASMFC Habitat Committee, 2018).

2.2 New Jersey Specific Regulations

The New Jersey Department of Environmental Protection (NJDEP) has several rules in place that protect seagrass by reducing and preventing harmful environmental conditions or otherwise protecting coastal habitats (included as part of Title 7 of the New Jersey Administrative Code). These statutes promote healthier environmental conditions, thereby improving conditions for seagrass.

Coastal Zone Management Rules, N.J.A.C. 7:7

Within the state of New Jersey, the Coastal Zone Management Act Rules (CZM) at N.J.A.C. 7:7 set forth the rules of the NJDEP regarding the use and development of coastal resources. The rules are used in reviewing coastal permit applications under the Coastal Area Facility Review Act, N.J.S.A. 13:19-1 et seq., the Wetlands Act of 1997, N.J.S.A. 13:9A-1 et seq., and the Waterfront Development Law, N.J.S.A. 12:5-3. These rules are also used in the review of water quality certificates subject to Section 401 of the Federal Clean Water Act, 33 U.S.C. § 1341, and Federal consistency determinations under Section 307 of the Federal Coastal Zone Management Act, 16 U.S.C. §1456.

Regulations for Proposed Habitat Creation, Restoration, Enhancement or Living Shorelines in SAV Habitat under N.J.A.C. 7:7-6.24

This General Permit authorizes habitat improvement or living shoreline projects that may occur in SAV habitat, or that are SAV habitat creation, restoration, or enhancement. The rule requires that the total combined area of all special areas onsite (such as SAV, shellfish habitat, coastal wetlands, shallows, etc.) shall not decrease because of the project, but the Department may authorize the decrease of any special area and conversion into another where the Department determines that such habitat conversion is environmentally beneficial. Mitigation for the habitat conversion is not required.

The General Permit identifies criteria for written sponsorship of the proposed project from a Federal or State agency, a conservation program under a government agency purview, a college or university, or another substantially similar organization or plan. This criterion is designed to encourage and facilitate early coordination and an increased likelihood of project success. Early engagement with Federal and State permitting agencies is also strongly encouraged to reduce potential resource or area use conflicts. For example, it would be unwise to begin an SAV restoration project in an area heavily used by summer boaters. Further, early engagement allows for potential project adjustments to reduce impacts to SAV and possibly encourage SAV growth where the main project objective is shoreline stabilization or wetland habitat creation (in other words, not SAV-centric).

If a proposed project does not meet the requirements for the General Permit (such as being more complex, proposing to alter existing habitats substantially, or does not have a sponsored endorsement by programs described in the General Permit) a Waterfront Development Individual Permit is needed.

2.3 Current New Jersey Policy Regarding Restoration

Understanding current policy regarding mitigation and restoration first comes with understanding the difference between the two. While the terms are often used interchangeably, typically ***mitigation*** refers to activities which are carried out to compensate for the permanent loss or disturbance of SAV and is legally required for a permitted impact. ***Restoration*** is not associated with a legal requirement, but often funded by grants, to purposefully contribute to the growth and re-establishment of a targeted seagrass species.

Currently, the policy is informal and there are no regulations regarding SAV restoration excepting the receipt of a permit as described above. At this time, the NJDEP Division of Fish and Wildlife's Bureau of Marine Habitat and Shellfisheries are in the beginning stages of drafting targets to create and fund a restoration program, establish new policies and regulations, and provide guidance for SAV. It is anticipated that such efforts will be underway in the next 2-5 years.

NJDEP mitigation requirements for permitted SAV impacts is described in 7:7-17.10. When mitigation is required in order to compensate for impacts to SAV, the Department shall authorize any regulated activities required to undertake and complete the mitigation through (1) an authorization under a general permit, (2) an individual permit, (3) approval of a mitigation proposal submitted to comply with a condition of an authorization under a general permit or an individual permit, or (4) an enforcement document.

Chapter 3: Site Selection

3.1. Introduction to Site Selection

Site selection is one of the most important elements for facilitating successful seagrass restoration (Fonseca 2011). Poor site selection has often been the reason for failure in past seagrass restoration projects. Factors that can cause a restoration project to fail, including physical disturbances, transplant incompatibility, and biological disturbances, can be mitigated by selecting a suitable site for the specific species and restoration goals of the project. Proper research and monitoring of potential restoration and donor sites before beginning a project will help to increase the probability of successful restoration of seagrasses and their associated ecosystem services in New Jersey. Practical sites to target are sites that currently lack vegetation but have suitable habitat conditions for seagrass to grow (Golden *et al.* 2010). Limiting factors associated with targeting appropriate sites are accessibility, environmental stressors, and aligning environmental conditions with species tolerance ranges for optimal growth and survival. Site accessibility should not surpass the priority of habitat suitability for the desired restoration species.

This chapter describes the steps involved in selecting a suitable site for a seagrass restoration project. Keeping local laws and regulations in mind, the next step in the site selection process is to collect information about key environmental, ecological, and human-impact parameters of your potential restoration sites. In this chapter we identify these key parameters and discuss how each impacts seagrass growth and survival. We also suggest snap-shot and long-term methods for measuring each parameter. Ideal, species-specific ranges for seagrass growth and survival in New Jersey for each site-selection parameter are provided as well. Parameters are categorized into environmental, ecological, and anthropogenic (human) impacts and are **not** listed in any order of importance.

3.2. Steps for site selection

1. Consider fundamental questions:
    - Has seagrass grown in this location before?
    - Is the site accessible for the people who will be involved in the project? Consider ease of access, safety, and cost of travel to and from the site.
    - Is the site similar to the site from which donor plants or seeds will be harvested?
2. Measure/determine environmental and biological parameters (see Chp. 3, sections III and IV).
3. Measure/determine anthropogenic influences. (see Chp. 3, section V).
4. Determine whether or not stressor mitigation is necessary; implement mitigation strategies if necessary (see Chapter 3, section VI).

The first step in considering a potential site for seagrass restoration is to consider these fundamental criteria:

- **Has seagrass grown in this location before or does seagrass grow nearby?**
    - Much of the data on seagrass distribution in New Jersey pre-dates 2010. Below are resources that may assist in determining seagrass extent prior to 2010. This information may be helpful for identifying potential sites but field validation should be done to determine if any seagrass currently grows nearby, due to the age of the dataset.
        - Rutgers University's Center for Remote Sensing and Spatial Analysis (CRSSA) provides an expansive database of coastal SAV mapping from the 1960's through 2009 (https://crssa.rutgers.edu/projects/sav/).
        - The NJDEP's Division of Land Resource Protection provides historical maps of SAV in 31 New Jersey coastal bays (https://www.nj.gov/dep/landuse/sav.html). The maps include 1979 maps produced by Earth Satellite Corporation, maps from 1983-present day produced as part of the "Inventory of New Jersey's Estuarine Shellfish Resources" authorized by the Bureau of Shellfisheries – Marine Resources Administration, and supplemental maps produced ny New Jersey Fish and Wildlife.
        - The US Environmental Protection Agency provides GIS mapping relating to an SAV survey in the Delaware River. This mapping can be found by visiting the link: https://epa.maps.arcgis.com/apps/webappviewer/index.html?id=92d4319f2ab6743d3a9947c737b27d3fe
- **Is the site accessible for the people who will be involved in the project? Consider ease of access, safety, and cost of travel to and from the site.**
- **Is the site similar to the site from which donor plants or seeds will be harvested?** (May need to measure environmental parameters to determine the answer to this question.)

If the answer to any of these questions is no, then it is best to select a different site. Once you have selected a site that meets all of the fundamental criteria, the next step is to measure environmental and ecological parameters at the site to ensure that it is suitable for seagrass growth, reproduction, and survival. Human impact at the site also has the potential to affect seagrass and should be considered as well. It is also important to ensure that the environmental conditions of a site are compatible with the ideal ranges of the seagrass species chosen to be restored at the site (Table 1). Once you have determined that a potential site meets the fundamental criteria and its environmental, ecological, and human-impact parameters are suitable for seagrass growth and expansion, you can begin planning your restoration methods (Chapter 4).

3.3. Environmental parameters

When restoring seagrass, it is necessary to select sites with favorable habitat conditions for the specific seagrass species (in New Jersey, either eelgrass or widgeon grass) that your project intends to restore to optimize long-term success of the seagrass. We have identified important environmental parameters for seagrass growth and expansion that should be determined prior to beginning a restoration project. These parameters can be determined either by obtaining already existing data or by measuring them in the field. The impact that each parameter has on seagrass depends on seagrass species and site characteristics. Often, parameters have interacting impacts on seagrass distribution and growth, so it is important to determine which parameters are the main drivers of seagrass growth and survival for each potential restoration site.

Measurements for Chl-a, TSS, nutrients, depth, salinity, and hydrodynamic conditions should be collected multiple times during the growing season for the target seagrass species (November to May for eelgrass and year-round for widgeon grass). Compare the median of your measurements to the recommendations for each parameter. Monthly measurements should be sufficient but twice a month is best since it will be more likely to capture the range of values caused by variations in tide, temperature, weather, etc. Sediment organic content can be measured one or two times in the summer when sulfide concentrations are highest since it does not change much over time. Temperature is best measured continuously in order to capture the full range of temperatures to which a site is exposed.

We provide suggestions for snap-shot and long-term methods for measuring each parameter. Snap-shot methodologies can be good indicators of current environmental conditions, take less time to obtain than long-term measurements, and are typically less costly. However, short-term measurements may not be representative of a parameter on seasonal to interannual time scales. Alternatively, long-term methodologies provide data that is more representative of what a site experiences on seasonal to interannual scales. This is important because seagrass habitats are continually changing. In many regions globally, seagrass meadows undergo substantial seasonal changes in abundance, extent, and species composition. For example, seagrass abundance and species composition observed at a site in the spring may be vastly different from the abundance and composition of the same site in the fall (Thayer *et al.* 1984). Seagrass distribution and composition also vary over the course of years as physical, environmental, and biological conditions change. Therefore, long-term measurements of important parameters for seagrass growth and survival can be beneficial when determining if a site will be suitable for seagrass for a long time into the future. However, long-term data takes time to collect and is not always available when considering a site for seagrass restoration. One must consider the available resources and timeframe of the planned project when determining whether to use snap-shot or long-term methods for measuring parameters for restoration site selection.

The recommended parameter values below are based on a combination of New Jersey-specific values as well as those recommended for nearby mid-Atlantic regions such as the Chesapeake Bay (Jasinski et al. 2021) if no research has been done on optimal values for New Jersey seagrass. If it is determined that a parameter at a potential site does not fall within the recommended range, that does not necessarily mean that the site should be dismissed as a viable location for seagrass restoration. No site is ever perfect, but efforts should be made to select a site with conditions likely to support seagrass growth and expansion. In this case of a potential site at which one parameter does not meet ideal ranges for the target seagrass species, further analysis should be completed to determine how strong of a driver that particular parameter is on seagrass growth and survival at the site being considered.

Table 1. Summary of ideal environmental parameters for eelgrass and widgeon grass growth and survival.

Parameter	**Snap-shot measurement methods**	**Long-term measurement methods**	**Eelgrass**	**Widgeon grass**
Water depth	-Pole with depth markings -boat depth finder	Tidal measurements available through NOAA	Up to 2 m, depending on water clarity	Up to 2 m, depending on sediment grain size
Light (water clarity– percent light through water (PLW))	-Secchi disk -LiCOR sensor -Chl-a & TSS	Continuous light sensors	>22%	>22%
Water Temperature	thermometer	Continuous temperature sensor	19ºC-22ºC	23ºC-28ºC
Salinity	-Refractometer, -salinity probe -real-time data	Continuous sensors	>18 ppt	≥ 5 ppt
TSS	Collect water samples	Long-term datasets	< 15 mg/L	< 15 mg/L
Chl-a	Collect water samples	NJDEP DWM&S Continuous Data Monitoring Program	< 15 ug/L	< 15 ug/L

Current Velocity	-measure time it takes an object to float a fixed distance	Wave sensor or online resources	>10 and <30 cm/s	>10 and <30 cm/s
Dissolved organic nitrogen	Sediment analysis	Multiple measurements over time	0.15 mg/L	0.15 mg/L
Dissolved organic phosphorus	Sediment analysis	Multiple measurements over time	<0.01 mg/L	<0.01 mg/L
Grain Size	-qualitative measurements	Multiple measurements over time	Fine sediment (mud) to sand	Fine sediment (mud) to sand
Silt and clay	-qualitative measurements -sediment analysis	Multiple measurements over time	<20%	<20%
Organic Matter	-qualitative measurements -sediment analysis	Multiple measurements over time	<5%	<5%

Salinity

Salinity is a very important parameter to measure. It will determine which seagrass species can grow at a potential restoration site. While widgeon grass can grow in brackish as well as marine environments, eelgrass requires water with salinities of >18 ppt.

Snap-shot measurement:

1) Refractometer. Collect a water sample from approximately 0.3 m below the surface. Rinse a dropper with sample water three times and then rinse the refractometer with the water sample. Drop some of the water sample onto the refractometer, hold it up to the light to read it, and record salinity as parts per thousand (o/oo).

2) Salinity probe. This is an instrument that can provide an instantaneous measure of salinity at a site. Place the probe at least 0.5m below the water surface and record the measurement from the display.

3) Real-time salinity data for New Jersey is available through the NJDEP DWM&S Continuous Data Monitoring Program (https://www.nj.gov/dep/bmw/data.html). Keep in mind the proximity of the data station to the potential restoration site.

Long-term measurement:

1) Continuous sensors. There are sondes that can be deployed over long periods of time to collect continuous data on multiple parameters, including salinity. These are somewhat expensive but may be useful to monitor salinity, as well as other parameters that impact seagrass growth, over longer time scales.

2) Online resources. Datasets of water quality data, including salinity, are available through the NJDEP DWM&S Continuous Data Monitoring Program (https://www.nj.gov/dep/bmw/data.html). Keep in mind the proximity of the data station to the site of interest. Data can be analyzed to evaluate trends over time.

Light

Water clarity is a measure of how far down light can penetrate through the water column and it determines the amount of light that reaches seagrass. Good water clarity is essential for seagrass growth and survival. Light availability is influenced by the amounts of phytoplankton and suspended solid material in the water column as well as turbidity. High amounts of phytoplankton, suspended solids, or both can decrease water clarity and reduce the amount of light reaching seagrass, potentially decreasing seagrass growth and survival. The amount of phytoplankton in the water column can be estimated by measuring chlorophyll-a (Chl-a), a pigment produced in photosynthesis. Suspended solids (SS) include algae, detritus, and inorganic matter such as sediment and can also be measured relatively easily. The quantity of phytoplankton and suspended solids can fluctuate with seasons, climatic events (ie. hurricanes or episodic heavy rainfall), and land use practices (runoff). It is best to select sites within the recommended ranges for Chl-a and TSS (see Table 1). Seeking non-turbid areas will also maximize the probability of seagrass success.

Snap-shot measurement:

1) Secchi disk. This is the least expensive method of measuring water clarity. A secchi disk is a black and white disk attached to a line with depth measurements. To measure secchi depth, lower the disk into the water and record the depth at which the black and white features on the disc are no longer distinguishable. Ideal secchi depth for seagrass growth is when the secchi disk can be seen at the bottom of the water. However, secchi depth can be influenced by tidal height, sun availability at the time of data collection, and weather-related turbidity. Therefore, it is best to determine median (rather than mean, because median is not as influenced by extreme observations caused by storms, for instance) secchi depth over the course of a growing season.

2) LiCOR sensor. This sensor provides an instantaneous measure of light. The user can sample light levels at various depths in the water column. Since this is a snapshot data point, measurements at multiple times would need to be taken to understand how light availability changes throughout the tidal cycle, seasonally, or inter-annually.

3) Measure chlorophyll-a (Chl-a) and total suspended solids (TSS). Water samples should be collected at the site in a location where sediment has not been stirred up by human or boat activity in the last several minutes and from at least 0.5 m below the water surface. Samples should then be processed using a filtration system. Methods for this technique are outlined by Fisher Scientifc (https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/scientific/technical-documents/white-papers/apha-total-suspended-solids-procedure-white-paper.pdf). These methods require access to equipment including a vacuum filtration device, combustion oven, and spectrofluorometer so you may consider partnering with an analytical laboratory. Alternatively, real-time Chl-a and turbidity data are available through the NJDEP DWM&S Continuous Data Monitoring Program (https://www.nj.gov/dep/bmw/data.html). Keep in mind the proximity of the data station to the site of interest.

Long-term measurement:

1) Light data loggers. These are sensors deployed and left at the site to continuously record surface irradiance data at set time intervals (ie. 15 minutes) determined by the user. This provides information on the amount of light that reaches the benthos during various tidal stages and can be used to assess light availability and how it fluctuates over long periods of time (week, months, seasons, or years). Light sensors are costly but provide accurate information on the amount of light reaching the sea floor.

2) Online resources. Datasets on water quality data including Chl-a, algal blooms, turbidity, and nutrients, are available through the NJDEP DWM&S Continuous Data Monitoring Program (https://www.nj.gov/dep/bmw/data.html). Keep in mind the proximity of the data station to the site of interest. Data can be analyzed to evaluate trends over time.

Water Depth

A seagrass restoration site should be shallow enough for seagrass to receive adequate light but deep enough that seagrass will not be exposed to desiccation at low tide. It is also important to consider that water depth varies depending on the tidal stage. In general, the ideal water depth for seagrass is where water is ≤ 1m deep at mean low water (MLW) but not so shallow the seagrass will be exposed during the lowest tides. MLW can be determined by measuring water depth at a site. It is recommended to determine a potential site's tidal range (depth at low tide to depth at high tide) before selecting a site for restoration. NOAA provides tide data that may be useful for determining tidal range at your site (https://tidesandcurrents.noaa.gov/ports.html).

Snap-Shot measurement:

1) Pole with depth markings. Set a pole with depth markings on the bottom of the water and record the depth marking on the pole at the water surface. Note the tidal stage at the time of recording.

2) Boat depth finder. Many boats contain instruments that provide depth measurements. To use your boat's depth finder to estimate water depth, determine how far below the water surface your boat's instrument is attached to the boat and add that length to the depth provided by the boat's depth finder. Note the tidal stage at the time of recording.

Long-term measurement:

1) Approximate tidal ranges for a site or similar nearby location maybe be available in the National Oceanic and Atmospheric Administration (NOAA) Tides and Currents database (https://tidesandcurrents.noaa.gov/tide_predictions.html?gid=1406). The tidal range can be determined from the water level chart. If a water level station is located nearby (within a kilometer), you can estimate the long-term average low-water depth at your site. Measure the snap-shot depth at your site using the pole or depth finder methods described above and note the time when you do so. Then, download the nearby station data. Calculate the difference between your site's depth and the water level station depth at the time of your measurement. Then, use that difference to calculate the depth of your site. Take the average of all of the adjusted low tide water level measurements for your desired period of time to calculate approximate mean low water (MLW) for your potential site. You may also want to determine the lowest tide that your site is likely to have and whether or not seagrass will be exposed at that tidal level.

Water temperature

Water temperature is one of the most important parameters driving seagrass distribution and survival. Water temperature at a site can vary seasonally and annually and is also influenced by site-specific characteristics such as tidal regimen and water depth. Seagrasses have species-specific temperature ranges that are necessary to maintain plant function. Therefore, it is important for water temperatures at restoration sites to be within ideal ranges for the desired restoration species. Temperature is an especially important parameter to consider when selecting a site for eelgrass restoration. Eelgrass becomes thermally stressed when temperatures reach 25 °C (77 °F) and dieback occurs when temperatures exceed 30 °C (86 °F). Obtaining continuous temperature data is ideal for a potential eelgrass restoration site so that the data captures the frequency and duration of temperatures that may stress eelgrass. It is also recommended to closely examine water clarity measurements in conjunction with temperature data for eelgrass restoration. Research suggests that eelgrass may be more likely to survive elevated temperatures if water clarity is very high. Widgeon grass has a larger range of temperatures that it can tolerate, growing best in temperatures between 10 – 30 °C but up to 38 °C (Kantrud 1991).

Snap-shot measurement:

1) Thermometer. Place the thermometer at least 0.5 m beneath the surface of the water, wait for the probe to stabilize (~1min), and record your temperature reading and the depth at which it was measured.

Long-term measurement:

1) Temperature sensors collect measurements at user-programmed fixed intervals for longer periods of time. Sensors such as the HOBO Pendant or similar products are easy-to-use, relatively inexpensive options that can be used to measure temperature over weeks, months, or longer. They are typically easy to deploy. For instance, to deploy a HOBO, simply secure it with a zip-tie to a fixed object such as a piling, PVC pole, or concrete block at least 0.5 m below the water surface. Be sure to deploy it in a location where you can find it again later. You may want to attach a small buoy to the object to which the HOBO is attached. This type of continuous temperature monitoring is recommended if conducting eelgrass restoration.

Sediment characteristics

Sediments are commonly classified into 3 broad categories based on grain size: sand, silt, and clay. Seagrasses have a species-specific response to sediment grain size because of differing root characteristics. There is a relatively wide range in sediment grain size measured in seagrass beds and grain size does not appear to be a major parameter limiting SAV growth. Widgeon grass and eelgrass can be found growing in sandy as well as fine, muddy sediment. However, there is evidence that eelgrass seeds germinate better in fine sediment compared to coarse sediment (Jarvis *et al.* 2014). Seagrass in meso- and polyhaline environments tend to do very well when sediment is composed of <20% sand/silt.

Organic content is the amount of biological material in sediment. Sources of organic material include decomposed plant and animal material, fauna byproducts, or microorganisms such as bacteria. The amount of organic matter in bottom sediments plays an important role in seagrass growth and survival. Sediment with > 5% organic content typically cannot support seagrass growth due to high sulfide concentration (Jasinski *et al*. 2021). Consequently, areas characterized by this type of sediment should be considered with caution. When selecting a restoration site, you might want to conduct a small test study or partner with a lab that can analyze the composition of the sediment to determine whether or not the sediment at the potential site is suitable for seagrass growth. A rule of thumb for assessing sulfide concentration at a potential site without laboratory analysis is that sediment characterized by fine-grained, black mud with a distinctive rotten-egg smell indicates high sulfide concentrations and should not be used as a seagrass restoration site.

Snap-Shot measurement:

1) Grain size. Assess sediment grain size using personal observation. Sediment that has a sandy texture has a large grain size. Fine sediment appears muddy.

2) Organics: Examine the sediment texture, color, and smell. Lighter colored, large grained sediment likely has a lower % organic matter. Fine-grained, black sediment that appears muddy likely has a higher % organic matter. Obtaining a more precise measurement of sediment organic content, requires technical lab equipment. If a technical analysis is required, consider partnering/contracting a local university or analytical lab to process the samples.

Long-term measurement:

1) Sediment characteristics do not change very quickly over time. The best way to obtain a long-term measurement is by taking snap-shot measurements periodically over a long period of time.

Hydrodynamics – Currents and Waves

Hydrodynamic forces such as tidal currents and wind-driven waves can influence where seagrasses can grow as well as meadow architecture (Risandi *et al.* 2023; Fonseca and Bell 1998). Water movement is essential in seagrass habitat because stagnant or low-flow environments may limit the availability of carbon and nutrient molecules for uptake. However, high current velocity or wave energy can prevent plants from becoming established in constantly shifting sediments, damage existing plants, or erode beds. When wave exposure is high, seagrass may only be able to colonize deeper areas where light transmission is greatly diminished, limiting the area for seagrass colonization. High current velocity or wave energy may also affect other site characteristics such as sediment grain size and the frequency of sediment resuspension, leading to reduced water clarity. Hydrodynamics also influence meadow architecture, including the size and spatial patchiness of seagrass beds (Fonseca *et al*. 1998; Robbins and Bell 2000; Hovel *et al*. 2002). Conversely, due to the wave attenuating function of seagrass, seagrass presence influences meadow hydrodynamics. For example, a site where seagrass is absent has increased opportunity for greater wave action and intensity than a similar site where seagrass is present (Donatelli *et al.* 2019). The increased hydrodynamic stressors can result in an array of negative cascading effects such as low seedling establishment, uprooting of plants, and sediment resuspension, all of which might decrease seagrass extent at the site and lead to even more potential for increased hydrodynamic activity. Therefore, establishing the presence of seagrass at a site with higher than desired hydrodynamic activity could mitigate some hydrodynamic stressors as well as restore the functionality of seagrass beds (e.g. protect salt marshes against wind-wave attack, shortens the periods of flood, etc.). However, a site where currents or wave action are high is usually not suitable for seagrass restoration. Signs that a site has too much wave action include white caps and waves breaking on the shoreline or a heavily eroded shoreline. Current velocities of seagrass meadows are typically 3 to 10 cm s-1 and currents stronger than 30 cm s-1 are unlikely to support healthy seagrass populations.

Snap-shot measurement:

1) Qualitative observations. Observe currents and waves. If currents or waves seem strong, consider selecting a different site.

2) Current speed can be estimated by measuring the time it takes a floating object to travel a fixed distance. First measure the distance between two people that are standing oriented parallel to the current direction. The person up-current should release a floating object when a stopwatch is started. The stopwatch should be stopped when the floating object reaches the down-current person. Current speed is equal to the distance traveled (meters) divided by the time it took the object to travel across that distance (seconds). Repeat this measure several times to measure current speed at different points in the tidal stage and cycle, as well as varying wind conditions.

Long-term measurement:

1) Use a wave sensor. The equipment necessary to measure waves and current velocity is costly. However, it is the only method to obtain exact measurements of these parameters over longer periods of time.

Impacts of Climate Change

Climate change is also an important factor to consider when choosing a restoration site. Water temperatures in New Jersey have increased over the past several decades and are projected to continue increasing. Increased water temperatures can lead to additional changes in the marine environment. For example, rising water temperatures have been linked to increases in the frequency and extent of algae blooms and eutrophication in New Jersey (Kennish 2011), events which lead to reduced water quality. This could decrease the amount of light that reaches seagrass. The frequency and intensity of hurricanes in the Atlantic are also projected to continue increasing. These changing conditions should be taken into consideration when selecting sites and methods for seagrass restoration.

3.4. Ecological Parameters

Connectivity and Genetic Diversity

Genetic diversity is important for successful restoration of seagrass. A genetically diverse meadow is more likely to be robust and resilient to a variety of disturbances due to the variety of traits in the population (Duffy 2006, Procaccini et al. 2007, Massa *et al.* 2013, Evans *et al.* 2017), increasing the probability of long-term survival. The ability of seagrass species to persist and thrive in unfavorable environmental conditions depends heavily on their genetic adaptability

(Ehlers *et al.* 2008, Salo and Gustafsson 2016). It has been experimentally shown that genetic diversity in eelgrass could help the plants to cope better with high summer temperatures (Ehlers *et al.* 2008).

Selecting a restoration site that is in close proximity to other seagrass meadows will increase the likelihood of pollination from outside meadows, a source that increases genetic diversity. Genetic exchange between nearby meadows is dependent on current patterns and is restricted by distance, the magnitude of which is species-specific. For eelgrass, dispersal distances of seeds and pollen are relatively short ($\leq$ 10 m) since they are negatively buoyant and sink upon release (Kendrick *et al.* 2012). Information about the maximum dispersal potential for widgeon grass seeds and pollen is unknown.

Genetic analysis requires specialized laboratory equipment and analysis. If genetic information is desired, consider a literature search for the location that is being considered for restoration. Alternatively, consider partnering with a research institution or university to complete a genetic study of your potential restoration site.

Nutrients and Eutrophication

Seagrasses require different kinds of nutrients, with nitrogen (N) and phosphorous (P) the most essential for plant growth. Nutrient requirements of seagrasses are lower than other aquatic organisms such as macroalgae and phytoplankton, giving seagrass an advantage in nutrient-poor environments. Seagrasses take up nutrients from both the water column (through leaf blades) and interstitial sediment pore water (through roots) (Lee and Dunton 1999). However, the main nutrients for seagrass growth are much more concentrated in sediment pore water than they are in the water column. Therefore, sediment porewater is the main source of nutrients for seagrass growth (Lee and Dunton 1999).

Seagrass response to nutrient availability varies depending on the nutrient, seagrass species, and other environmental characteristics (Leoni *et al.* 2008). Sediment nutrient enrichment, especially in oligotrophic environments, frequently results in enhanced shoot density, biomass, productivity, and shoot size of seagrass, clearly indicating that its growth is nutrient-limited (Udy and Dennison, 1997). Although seagrasses require nutrients to grow, it is also possible for nutrient concentrations to be too high. High nutrient concentrations can cause algal blooms and eutrophication. This is harmful to seagrasses because it reduces the light that can reach the seagrass and it can also reduce water column oxygen concentrations, creating hypoxic or anoxic conditions (Kim *et al*. 2015). Eutrophication is considered one of the most important drivers underlying the loss of seagrasses worldwide (Burkholder *et al.* 2007). In New Jersey, macroalgal accumulations can significantly reduce eelgrass biomass through smothering (Bologna, Wilbur, and Able 2001). Additionally, multiple studies have shown that brown-tide blooms significantly reduce light availability to eelgrass, possibly diminishing eelgrass distribution in the mid-1980s in Long Island, New York

(Dennison, Marshall, and Wigand, 1989). The Barnegat Bay-Little Egg Harbor Estuary is shallow, poorly flushed, and bordered by highly developed areas, which makes it particularly susceptible to high concentrations of nutrients. (Kennish *et al.* 2011). Areas where algae blooms and eutrophication are frequent issues should be avoided as restoration sites.

Snap-shot measurement:

1) Nutrient data is available through the NJDEP DWM&S Continuous Data Monitoring Program (https://www.nj.gov/dep/bmw/data.html). Keep in mind the proximity of the data station to the site of interest.

2) Consider partnering with an analytical laboratory if nutrient analysis is necessary.

Long-term measurement:

1) Nutrient sensors can be used to take long-term measurements of nutrients.

Macroalgae and epiphytes

Macroalgae are larger forms of algae that can be found loosely attached to sediments, seagrass, other substrates, or floating in the water column. They can be found in small quantities or large mats. Epiphytes are organisms that attach to plant leaves. Epiphytes can be algae, bacteria, or animals (e.g. hydrozoans, byrozoans, amphipods). Both macroalgae and epiphytes can cover seagrass shoots and reduce the amount of light that the plants can obtain. Higher biomasses of epiphytes and macroalgae can also result in larger quantities of detritus and organic matter settling on the seafloor. It is best to avoid sites with large quantities of macroalgae and epiphytes for restoration sites if possible. However, these may not be a large stressor to seagrass depending on other environmental characteristics.

Predation

Seagrass habitats are essential fish habitat, supporting economically and recreationally important fisheries species as well as many other organisms. Consequently, there are many associated fauna of seagrass ecosystems. Predation of seagrass may be a factor to consider when selecting a restoration site. Herbivores such as turtles, dugongs, and some fish species rely on seagrass as a food source. Predation by fishes is easily detected by visually inspecting shoots for bite marks. There is also some evidence that herbivores including birds and turtles can facilitate seagrass seed dispersal from feeding on seeds in one location and excreting them in another. There doesn't seem to be any one restoration method that reduces predation (Summerson and Peterson 1984; Marion and Orth 2010). However, predation on seagrass might not be a large concern in New Jersey.

Disease

Eelgrass wasting disease (caused by the protist *Labyrinthula zosterae*), is a disease that caused largescale, global declines in eeglrass in the 1930s. An estimated 90% of eelgrass in the Atlantic was lost due to the wasting disease (Muehlstein 1989). Eelgrass wasting disease is stimulated by moderate salinities under which eelgrass is stressed. It is thought that the elimination of eelgrass in the southern part of New Jersey is due to the wasting disease outbreak of the 1930s. Restoring seagrass in that region would increase seagrass spatial coverage in New Jersey greatly. Restoration managers should be aware of the disease and monitor restoration sites for any signs.

3.5. Anthropogenic Parameters

Humans interact with the marine environment in many different ways. Human activity can cause physical, chemical, and ecological impacts on seagrasses and the surrounding marine environment. Human impacts that should be considered when assessing the suitability of a site for seagrass restoration are described below.

Physical impacts of human activity

1) Boating. Areas with moderate to high boat traffic highly disturb seagrass populations because boating can cause direct and or indirect damage to seagrass meadows by increasing waves, polluting waters, and causing scars from propellers or anchors. These scars in seagrass meadows take a long time to heal. They are susceptible to erosion which can create a feedback loop that causes even more erosion.

3) Dredging. Dredging has a similar impact on seagrass meadows to boating. Dredging greatly disturbs sediment and benthic plants and animals in an area. It can decrease water quality as well due to disturbing the sediment and increasing turbidity.

4) Armored/hardened shorelines. Armored/hardedned shorelines are shorelines consisting of manmade structures made of concrete, steel, or riprap borders of stone or boulders such as seawalls, jetties, and bulkheads. Hardened shorelines can alter hydrodynamics, sediment erosion and deposition, and habitat connectivity, causing habitat loss and decreasing biodiversity and ecosystem function (Dugan et al. 2011). There is evidence that seagrass percent cover, species diversity, and species evenness can be significantly reduced in seagrass beds located near hardened shorelines (Landry and Golden 2018). Therefore, proximity of seagrass restoration sites to armored/hardened shorelines may decrease the likelihood of long-term success of the seagrass. Proximity to hardened shorelines should not automatically rule a potential restoration site out, but should be taken into consideration when selecting a site.

Human impacts on water quality

1) Pollution. Pollution from runoff or direct input into the ocean may affect a potential restoration site. Pesticides and herbicides may be dissolved in water or attached to particles washed downstream. Some of the chemicals used to control terrestrial pests are also toxic to aquatic plants and animals. Other types of pollution include excess nutrients from farming or industry. Excess nutrients have the potential to cause algae blooms and eutrophication. It is worth it to do research into the potential level of pollution at a

restoration site. Pollution levels may be obvious due to their effects on an ecosystem, but you may also be able to test for pollutants.

3.6. Stressor Mitigation Strategies

Some parameters may be able to be improved or their impacts on restoration projects may be able to be mitigated through several strategies. The restoration manager must decide if mitigation strategies are a worthwhile endeavor for resources rather than finding a more suitable site to use for restoration.

Water quality improvement

Impacts of water quality, light availability, and depth have interactive effects on seagrass. Improvement of water quality will increase the depth and quantity of light available for seagrass to grow. Efforts to improve water quality have to be taken on a bay-wide or state-level scale. Water quality improvements can be made through regulations that reduce impacts of land use practices that lead to increased sedimentation or nutrient/pollution inputs. Small scale strategies that might aid in improvement of water quality can be the protection and planting of submerged aquatic vegetation, oyster reefs, and marshes. However, for these practices to work the environment must be able to support the growth of these species.

Temperature

If temperature at a site is above the recommended range, it may still be possible to use the site for restoration. If the site has good water quality and water clarity is high, it may be possible to restore seagrass at deeper water depths where temperatures are lower. Additionally, other species of submerged aquatic vegetation or benthic organisms may be planted at the site in conjunction with the target restoration species in order to provide shade for the target species. However, this may also reduce light for the target species.

Protected areas and Policy changes

It may be possible to protect a site through regulation due to its ecological, cultural, or commercial value. Protection is typically not limited to seagrasses themselves, but rather the boundaries of a designated area. This means that the entire ecosystem at the site will be protected, ultimately improving conditions for seagrass growth and expansion. A previously unprotected site that becomes protected from human activity or pollution may begin to have less physical disturbance (from boats, waves, etc.) and improved water quality conditions. This may allow the site to become suitable for seagrass restoration. Planners could benefit from acquiring information on community structure, social equity, or institutional capacity to facilitate acceptable management alternatives that favor both stakeholders and ecological goals (Kittinger *et al.* 2014). Kittinger *et al.* (2014) provides examples in which social data was incorporated into management planning and tables (1&2) that offer detailed step-by-step approaches to achieve these goals.

Community investment

Community investment in seagrass restoration can be a valuable strategy for improving the conditions at a potential restoration site. This may attract citizen scientists who can perform routine monitoring tasks such as water quality, temperature, salinity, etc. to assist in monitoring environmental conditions at the site. A potential way to inform the community of potential restoration projects and ongoing monitoring is placing QR codes in high-traffic areas where interested people might be, such as a boat ramp near a potential restoration site. Community investment is also an excellent way to increase the likelihood that policy to protect seagrass meadows will be put into place.

Test plots

If mitigation strategies have been implemented and environmental conditions have improved, test plots can be used to conduct small-scale tests of your restoration strategy at the potential restoration site. Place multiple test plots in areas of the potential restoration that represent various depths and conditions. Monitor test-plots for at least one growing season. The results will help determine if the site is suitable for seagrass growth and expansion.

Chapter 4: Restoration Methods

4.1. Introduction to Restoration Methods

When deciding which restoration methods to use, consider the ultimate goals of the restoration project, availability of resources such as money and personnel, and timeline to execute the project. If the restoration project is mandated through regulation, there may be established protocol to follow (see Chapter 2). Before selecting a restoration method for a site, information about the past state of the site as well as current environmental conditions should have been collected. Project targets can be used to keep a group aligned with their restoration goals and track progress. A well-developed timeline can be useful in planning when resources will be acquired, how they will be allocated, and identifying benchmark goals. Keep in mind that funding may limit access to resources (plant source and personal) which will influence the selected restoration method and spatial extent. There are a variety of factors that influence costs of restoration per unit area and contribute to the total project costs, including harvest and restoration method, planting density, and equipment to access sites to collect plants or conduct restoration. Access to suitable donor sites may also be a limiting factor for restoration. It is likely that one or more resources necessary to complete the project will be a limiting factor and will determine which restoration method should be chosen.

4.2. Species selection

For the best probability of successful seagrass restoration, it is important to match restoration site conditions with the requirements of the seagrass species that will be restored at the site. Seagrass meadows can be composed of a single species or multiple species. In New Jersey, a main parameter that will determine which of the two native seagrass species to use at a particular restoration site is salinity. Widgeon grass can grow in a larger range of salinities than eelgrass, which requires more saline conditions (see Table 1 for recommended values). The two species also colonize new areas in different ways. Eelgrass is a successional, canopy-forming species while widgeon grass is a cosmopolitan species that grows in many different conditions.

Other factors to consider when choosing a species for restoration are morphological characteristics and life history. Eelgrass has thicker, longer leaves and thicker rhizomes than widgeon grass. This difference in morphological features leads to differences in ecosystem services provided by meadows of each species, such as wave attenuation and habitat for other organisms (Nordlund *et al.* 2016). If the restoration goals of a restoration project are to increase available habitat for a particular fish species that is found more in eelgrass meadows, for example, this might be an important thing to consider. Additionally, species life history is an important consideration because it determines the timing of reproduction as well as the extent of seagrass cover.

Mixed species meadow

Some seagrass meadows are composed of more than one seagrass species. Many seagrass meadows consist of only one seagrass species in temperate areas (Bjork *et al.* 2008), but there might be benefits of two or more species growing in the same area. It is thought that mixed-species meadows might help provide stability to a seagrass meadow. For example, in locations where eelgrass dies back annually due to stressful summer water temperatures, the presence of widgeon grass during that time might help maintain some of the ecosystem services that seagrass meadows provide. However, it is also possible that mixed-species meadows could have negative impacts on seagrass seedling success due to competition for space, nutrients, and light (Fourqurean *et al.* 1995, Orth 1977). The overall impact of a mixed-species meadow seems to be site-specific.

4.3. Collecting source material

Selecting a donor site

The ideal donor site is highly productive, resilient, and adjacent to other seagrass meadows to increase the likelihood of genetic diversity. It is recommended to retrieve material from more than a single bed to optimize success or if resilient meadows are unavailable. A resilient donor meadow is one that has been present and densely populated (70%-100% density) for at least 5 years. This ensures that the site is likely able to withstand removal of some of its shoots or seeds. It is best to collect source material from nearby the restoration site so that the material is adapted to similar conditions. However, it may be impossible to retrieve source material locally if there are no resilient meadows in the area. In this case, importing source material from further away is recommended. Do not collect source material from a different water body than the one in which the restoration site is located (try to stay within the same bay, tributary, etc).

Seeds vs. mature plant transplants

Seeding is the recommended method over transplants in many cases. Compared to transplants, seeding may decrease overall environmental impact as well as the time and economic cost of the project. Seeding is much less labor-intensive than transplanting. Seeds can be harvested by hand and in large quantities, a simple method requiring little equipment or effort. Additionally, meadows restored using seeds are much more likely to be genetically diverse and, therefore, more resilient (Reynolds *et al*. 2012a and 2012b). Seed harvest and dispersal is also much less disruptive to the donor site than transplants. However, factors such as seed predation and the ability of seedlings to survive at the restoration site compared to mature plants should be taken into consideration when deciding between seeding or transplanting.

Although seeding has many advantages relative to transplants, there are some advantages of using mature plants to restore seagrass. Mature plants may be able to withstand stressors and disturbances that seeds/seedlings cannot. Transplants of fast-growing species could help facilitate the growth of slower growing species. Also, the window of time in which mature plants can be harvested for transplantation is not as restrictive as it is for harvesting seeds. However, disadvantages of using transplants versus seeds include high labor requirements and greater damage to the donor meadow due to the invasive nature of the harvest. This disturbance can lead to negative impacts on other species that live or feed in the donor meadow including fish, birds, and benthic organisms. To alleviate such impacts, transplants should be harvested from multiple donor sites with quick recovery rates to reduce the impact that the harvest has on any one donor meadow. Long-term survival rates of transplants are typically low (Tanner and Parham 2010), likely due to weak and unestablished root systems (Alistock *et al.* 2010). The transplantation method can also lead to low genetic diversity when shoots are harvested from small areas. Unless specific circumstances require transplants rather than seeds, seeds are likely a better source to use for restoration.

Table 2. Summary of methods for harvesting donor material for seagrass restoration.

Harvesting Method	**Equipment**	**Labor intensity**	**Max. storage time**	**Window of time to harvest in NJ**	**Disturbance to donor meadow**	**Practicality**
Mechanical seed harvest	Mechanical harvester	low	Several months	<2 weeks in the spring (start monitoring in April)	low	Highly efficient for dense, reproductive eelgrass meadows
Manual seed harvest	Mesh bags, tank with flow-through seawater	high	Several months	<2 weeks in the spring (start monitoring in April)	low	Can be used to harvest seeds from any type of meadow
Transplant harvest (all methods)	PVC core, shovel	high	<1 week	~2 months from July to August	high	May be useful if missed window to collect seeds or if seedlings can't survive at site

Seed Harvesting

Timing of seed harvest

Seeds must be collected during the species-specific period in which the plant's reproductive shoots have developed mature seeds but the seeds have not yet separated from the shoot. For eelgrass, this is a short window of just a couple of weeks. However, the exact timing of seed release in New Jersey is undocumented, so it is suggested to start monitoring the donor site every 1 or 2 weeks in April, to ensure that the window is not missed. The window to collect widgeon grass seeds in New Jersey is about two months long from July to August. The site should be monitored for at least several weeks before these time periods to ensure that the seed collection window is not missed. It is time for seed collection when you collect a few test reproductive shoots from several different areas in the donor meadow and most have mature seeds.

Seed harvest

When choosing donor sites for seed collection, you must first ensure that the donor site produces seeds. To determine this, the donor site must be examined during the window of time when reproductive shoots produce seeds. Alternatively, there may be data already available on which meadows in the area produce seeds. Make sure to choose sites that are not too far away from the restoration site. This will increase the likelihood that the donor seeds are adapted to survive in the local conditions of the restoration site. It is also important to think about creating as much genetic diversity among the donor seeds as possible to ensure that the restored seagrass meadow is robust and resilient. Collecting seeds from a variety of sites, or from areas at least 20 m apart within one meadow, is the best way to increase genetic diversity. This also prevents excessive harvest of seeds from any one donor site. Do not collect seeds from a different water body than the one in which the restoration site is located (try to stay within the same bay, tributary, etc).

Figure 3. A) Eelgrass reproductive shoot. B) Eelgrass spathe with immature seeds. Photo credit: Hannah Baker.

Figure 4. A) Immature eelgrass seeds. B) Mature eelgrass seeds. Photo credit: Madison Lytle.

Identifying seeds

Eelgrass seeds grow in spathes on branching reproductive shoots. Immature eelgrass seeds are light green and grow in an alternating pattern. As they mature, eelgrass seeds become dark in color and grow in more of a straight line. Widgeon grass seeds grow in bunches of 4 or 5 seeds at the ends of branching reproductive shoots close to the water surface.

Methods for harvesting seeds include:

Manual seed collection. Harvesting seeds manually involves collecting mature reproductive shoots by hand and harvesting the seeds once they are released from the flowering shoots (Orth *et al.* 2008). To collect a reproductive shoot simply break off the shoot that contains seeds. Reproductive shoots can be collected in mesh bags and placed in buckets of seawater for transport. An advantage of manual seed collection is that it typically has low impact on the donor meadow (Marion and Orth 2010). However, it is labor-intensive. To isolate eelgrass seeds from the reproductive shoots, place the shoots in a tank with flow-through seawater. As the seeds continue to mature, they will fall from the shoots and sink to the bottom of the tank while the shoot material will continue to float. This may take several weeks.

Mechanical seed collection. There are various designs of mechanical seed planters available that have completed successful seed harvest with minimal impact to the donor meadow, including commercial harvesters and other custom designs (Marion and Orth 2010). The harvesters are typically pulled by a boat and composed of a cutting bar that cuts the vegetation which is then either pumped into a container or caught by a net. It is an efficient strategy that could be useful if the donor meadow is a large, high-density eelgrass meadow with high densities of reproductive shoots. Disadvantages include getting caught on obstacles on the seafloor and requiring specialized equipment.

Seed Storage

Seeds can remain in storage for longer than mature plants. They may be released in the growing season following harvesting to allow for field germination, or they may remain in storage longer to allow for seedling development and subsequent planting (Tanner and Parham 2010).

Eelgrass

Harvested eelgrass reproductive material should be stored in an aerated tank with flow-through seawater kept below 25 ºC (77 ºF) and a drain in the bottom. To reduce anoxic water, tanks should be stirred daily. To prevent desiccation, place coated wire mesh on top of the floating material to submerge it. If the tank is outdoors it should be shaded to reduce temperatures. Once the reproductive shoots have begun to release seeds (typically after a few weeks), there are several methods to separate the seeds from the remaining reproductive material and will depend on the tank set-up. Remove large pieces of vegetation first. One method to collect the seeds is to stir the tank to facilitate mature seeds sinking to the bottom of the tank where the drain is (Marion and Orth 2010). Seeds can be collected by draining the tank onto a 1-mm mesh screen or another method suited to the specific tank setup. Sieve the collected seeds to remove small sediment particles and pieces of organic matter. It is recommended to store harvested seeds in an aerated tank with recirculating, high salinity water and cool temperatures (<20 ºC/68 ºF) through the summer and broadcast them in the growing season in the fall (Marion and Orth 2010). Seeds should not create a layer thicker than 3-4cm to avoid anoxic conditions. Seeds should be dispersed no later than the growing season following harvest because eelgrass seeds do not remain viable longer than one year. Maintaining the seeds in storage over the summer and dispersing them in the fall decreases loss of seeds due to predation, decay, or other factors.

Widgeon grass

Widgeon grass seeds can be isolated following the same procedure used for eelgrass seeds. For storage, widgeon grass seeds do not need to be aerated and can be kept in food-grade polypropylene containers with lids that have 1-inch holes. To allow for venting and gas exchange, a sponge stopper should be placed in the hole. Containers should be kept at 4 ºC (39.2 ºF). To prevent premature germination, seeds can be stored submerged in water with a salinity of 30 ppt. However, high-salinity storage may decrease germination rates if the salinity at the restoration site is also high.

Transplant harvesting

Timing of transplant harvest

New Jersey is located between the northern and southern west-Atlantic populations of eelgrass, which have different preferred transplant seasons. There is evidence that the timing of restoration activities for New Jersey is best aligned with mid-Atlantic eelgrass populations such as the Chesapeake Bay, where eelgrass transplants yield the most success in the fall, rather than the more northern eelgrass populations. Bologna and Sinnema (2006) reported high initial success and flowering by transplanting eelgrass in the fall in New Jersey. However, they reported low survival and no growth for widgeon grass transplanted in the fall. Transplanting widgeon grass in the early spring might result in better survival and growth for this area (Bird *et al.* 1994). Mature plants to be used for restoration are typically harvested and then transported directly to the restoration site rather than held offsite.

Shovel method. A shovel is used to dig whole plants, including roots and rhizomes, out of the sediment. Using a sieve, rinse away the surrounding sediment and store the plants in salt water until they are ready to transplant into sediment at the restoration site. Biodegradable bamboo staples can be used to keep transplanted material in place.

Plug method. Using a 10-15 cm diameter PVC tube with enough depth to collect seagrass roots (Fonseca *et al.* 1998), place the tube over the desired seagrass and manually collect all desired aboveground plant material inside of the tube. Push down on the tube to insert into the sediment, making sure to push far enough down to capture all of the belowground material (roots and rhizomes) of the plants being harvested. Place a plug or cap on the top of the PVC tube to create suction, then wiggle and pull up on the PVC tube to pull it out of the sediment and harvest the plant material. Once the tube is released from the sediment, quickly place a hand or cap on the bottom of the tube to capture the plant material for transport. Alternative storage methods include placing the plants and sediment into peat pots before transport or stabilizing with mesh fabric. The harvested material can be placed into coolers for transport to the restoration site.

Commercial Sources

An alternative to sourcing donor seeds or plants to use for restoration yourself is purchasing from commercial sources. This may help reduce time and labor costs during the collection period and will eliminate the need for scouting out a suitable donor meadow. However, it is imperative to avoid buying seeds or plants sourced outside of the bay or water body in which the restoration will be conducted. Unfortunately, at this time, no local seed sources are available.

4.4. Implementing restoration methods

There are several possible methods for restoring seagrass to a site, varying in terms of labor intensity, cost, and personnel requirements. Keep in mind a project's available resources when selecting a restoration method. Other factors that should inform the decision include specific site characteristics (terrain, sediment type, size of area, etc.) and availability of equipment.

Table 3. Summary of restoration methods and associated equipment, labor, cost, and success rate.

Method	**Equipment**	**Labor Required**	**Benefits**	**Associated risks/ disadvantages**
Seed broadcasting	Sand (optional)	low	Low labor and equipment needs	Predation, seed displacement, requires storage and processing of source material
Manual seed planting	Pipette or sealant gun, gel/sediment paste	high	Reduces pre-burial risks for seeds	Injecting at incorrect depth, requires storage and processing of source material
Mechanical seed planting	Specialized mechanical planter	low	Efficient for large areas, uniform dispersal	Difficulty maneuvering, machine clogging
Buoy method (seeds)	Mesh bags, buoys, anchor, line	low	No storing or processing seed and reproductive material	Predation, seed displacement
Manual planting (transplants)	Shovel, bamboo staples (optional)	high	Doesn't require much equipment, straightforward	Labor intensive

Tortilla method (transplants)	Burlap fabric	high	Might secure shoots better than sediment alone	Labor intensive
Machine planting (transplants)	Specialized mechanical planter	low	Less manual labor, possibly less time to plant	Larger site disturbance than other methods, difficulty maneuvering, machine clogging

Seeds

Manual seed broadcast

Broadcasting seeds into the water by hand at a designated restoration site is one method for executing seagrass restoration using seeds. Mixing seeds with sand may help distribute the seeds more evenly. This method can also be done by a diver in deeper water. McGlathery *et al.* (2012) performed a dense broadcasting of seeds in the mid-Atlantic over a relatively uniform distribution of plots in the first year of restoration (e.g. 100,000 seeds per 0.4 hectares). After the first year they recommend concentrating broadcasting efforts in sites with observed succession. For eelgrass, broadcasting by hand may be the best method of seed broadcast due to timing of seed dispersal. Golden *et al.* (2010) found manual broadcasting in the fall yielded greater success than broadcasting via seed buoys in the spring. Risks associated with seed broadcasting are displacement of seeds before being buried in the sediment and susceptibility to clumping. Broadcasting during periods of minimal wave action could reduce this risk. Broadcasting could also result in clusters of seeds in one location, which can be detrimental because high density clusters of seedlings may have higher mortality rates due to competition (Marion and Orth 2010), although McGlathery *et al.* (2012) did not observe this. Predation before being buried is another possible source of seed loss to consider for this method.

Buoy method

The buoy method is another way to broadcast seeds for restoration (see Figure 5). Reproductive shoots from the donor site are collected in mesh bags attached to buoys and fixed in place in the restoration site. The buoys are left in place until the reproductive shoots have released their seeds. An advantage of this method is that it does not require facilities, equipment, or labor for storing and processing reproductive material and seeds. Disadvantages of this method include potentially less time and labor available for harvesting seeds because of the need to transport the reproductive shoots and construct and deploy buoys in a timely manner (Marion and Orth 2010). This method is also vulnerable to disruption by weather because of the shortened timeline to complete the restoration method. Labor and monetary costs are also incurred by the need to retrieve buoys after broadcasting. As this method requires implementation shortly after reproductive shoots are collected so that seeds have not yet separated from the reproductive shoots, this method would not be suitable for broadcasting seeds at any other times of the year.

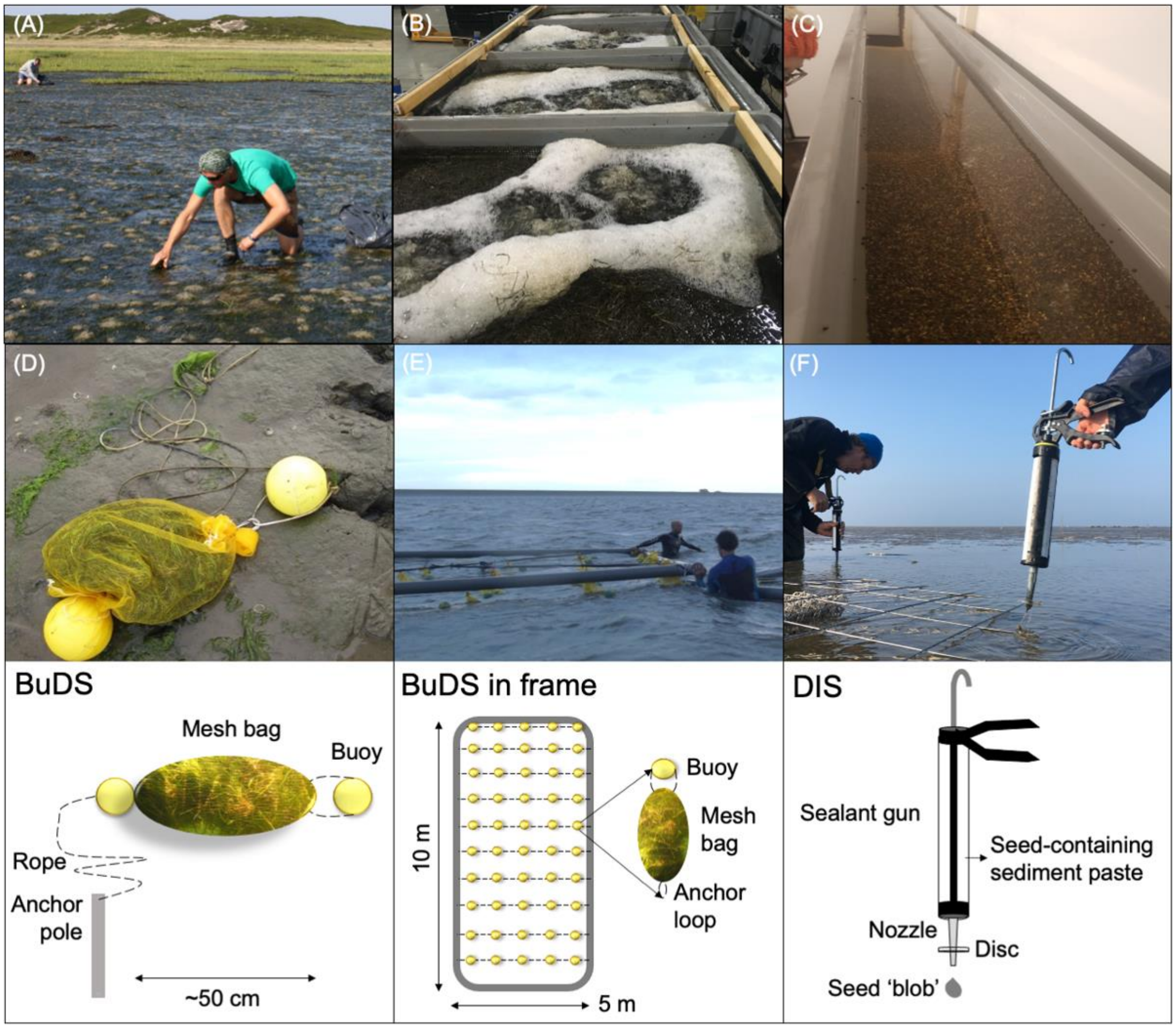

Figure 5. Summary of methods used by Govers *et al.* 2022 for harvesting, broadcasting, and manually planting seeds for restoration. (A) Harvesting reproductive shoots, (B) Harvested reproductive shoots in aerated seawater tubs until seeds have separated, (C) seeds in storage, (D) a buoy used for broadcasting seeds, (E) Buoy Deployed Seeding in frame (BuDS-in-frame) and bird's eye view (illustration), (F) Dispenser Injection Seeding (DIS) on the intertidal mudflats in spring (photo, illustration). Figure credit: Govers *et al.* 2022.

Manual seed planting

Manual seed planting involves planting seeds at a restoration site by hand. Seeds should be planted at fixed intervals along a transect or in fixed-size plots to avoid dense clustering of seeds which may lead to seedling mortality (Marion and Orth 2010). To plant the seeds, use a hand pipette or sealant gun to inject the seeds into the sediment (Gamble *et al.* 2021, Govers *et al.* 2022). Orth *et al.* (2009) recommends creating seed-gel matrix by mixing seeds into Knox gelatin because it is easily soluble in seawater, the gelatin provides a source of organic material for microbial metabolism and could stimulate seed germination by lowering the oxygen levels in the sediment, and the gel might help stabilize the sediment. Others have used sediment paste created by harvesting mud (24 μm median grain size, 15% organic matter) from a donor meadow and sieving it over 1mm mesh to remove benthic organisms and large particles (Govers *et al.* 2022). The recommended depth to plant eelgrass seeds is about 2 cm into the sediment. A plastic disc can be added to the pipette or sealant gun being used to mark the correct depth to inject the seeds.

Seed planting is advantageous because it has the potential to enhance seedling establishment by reducing the risk of seed displacement or predation before the seeds are buried in sediment, which is a risk associated with seed broadcasting. Some studies have observed greater effectiveness of seed planting methods compared to broadcast methods because planting deposits seeds at specific and optimal depths (Marion and Orth 2010). Harwell and Orth (2002a) utilized the manual planting method over an 11-year study, which resulted in a successful establishment and rapid expansion of eelgrass beyond the initial seed plots. Disadvantages associated with manual seed planting operations include the high manual labor requirement and risks of systematic error (e.g. planting at inaccurate depths and densities).

Mechanical seed planting

Seeds can be planted mechanically using specially designed equipment. Mechanical seed planters have rapidly and successfully planted extensive areas (50 to 100 hectares) in a relatively inexpensive way. Another advantage is the spatial evenness of where the seeds are planted due to the standardized method. Disadvantages of using mechanical seed planters are similar to those of mechanical harvesters. The efficiency of mechanical planters can be hindered by submerged obstacles, internal blockage of the apparatus, and difficulties maneuvering along the terrain. Additionally, studies indicate that planting seeds mechanically exhibited little to no significant difference compared to manual planting or broadcasting seeds in terms of seedling establishment (Marion and Orth 2010). It is up to the restoration manager's discretion to determine whether mechanical or manual seed planting is more efficient and effective at the specific restoration site.

Transplants

Transplant timing in NJ

In New Jersey, the ideal time for transplantation has not been studied very extensively. Bologna and Sinnema *et al.* (2012) had success transplanting eelgrass in the fall (Sept.-Nov.) and widgeon grass in May-June.

Manual planting

To transplant a shoot collected from the donor site to the restoration site, the simplest method is to dig a small hole in the sediment, place the bare roots and rhizomes of the shoot into the hole, and cover the hole and belowground material back up with sediment. This is the “bare root” method. The “plug” method is similar except that instead of single shoots, the donor shoots were collected as cores (using PVC or another method) containing multiple shoots and the surrounding sediment. In this case, a larger hole should be dug to accommodate the entire core. Using cores of seagrass may be preferable over individual shoots because cores leave rhizomes intact. Shoots or cores could also be placed in peat pots prior to planting. Another method of transplanting whole plants (not cores) is to place the roots and rhizome of the plant on the sediment surface and secure them there with biodegradable bamboo staples (Davis and Short 1997). All of these manual planting methods are labor-intensive but require little equipment.

Tortilla method

The tortilla method of transplantation involves using a tortilla-sized piece of burlap fabric to secure seagrass shoots (Pickerell *et al.* 2012). The shoots should be woven into the outer edges of the burlap and then the burlap should be covered in sediment to anchor it down. This method allows the shoots to grow outwards and expand.

Mechanical planting

Similar to machine harvesters and seed planters, mature plants can be transplanted by machine planters. This method has similar advantages and drawbacks to those of seed planters.

Chapter 5: Post-Restoration Monitoring

5.1. Defining restoration success

There is no one best metric to define success of a restoration project. However, several metrics can provide insight into how a restored seagrass meadow is doing and where the future of the meadow is headed. Defining short- and long-term goals helps restoration practitioners measure the success of the effort and allows evaluation of restoration methods so that they can be improved in the future. Possible short- or long-term goals may be related to improving environmental conditions, meadow species composition, meadow structural diversity, or ecosystem function. In most cases, it is best if goals are specific and measurable (e.g. increased biomass, presence of eelgrass, decreased turbidity, greater wave attenuation, etc.). Short-term goals should be stepping stones to the long-term goals of seagrass restoration at the site (e.g. short-term goal might be increased eelgrass shoot density and the long-term goal might be increased fish abundance at the site). Short-term goals should be accomplishable in 1-3 years while long-term goals should be more about the continuous future of the meadow. McGlathery *et al.* (2012) provides a diagram of the expected changes in some of the structural and functional characteristics of seagrass beds as they develop overtime which may be useful when defining short- and long-term goals for a restoration project.

5.2. Monitoring

To determine if short- and long-term goals have been met, restoration sites should be monitored following restoration. Both site (environmental, ecological, and anthropogenic parameters) as well as seagrass metrics should be measured as part of post-restoration monitoring efforts in order to determine the health of the overall ecosystem (Bjork *et al.* 2008). Post-restoration monitoring can also help determine if further restoration efforts or intervention at the site are required to meet the established goals. The metrics that should be monitored depend on the specific restoration methods used, major drivers at the restoration site, and goals of the project. For example, if seeds were used as the source material for restoration then the change in seagrass cover at the site over time should be monitored. If mature plants were used as source material and GPS points were recorded where the plants were transplanted, you can return to each point and quantify plant growth (shoot density and length, etc.) and survival. If after monitoring it is determined that short-term goals are not being met, additional restoration efforts or intervention may be necessary to meet long-term goals. Monitoring should be standardized to facilitate comparisons across projects. There are several metrics and methods (listed in no particular order) discussed in this chapter that will be useful for most post-restoration monitoring of seagrass.

The timeframe in which monitoring should occur will vary depending on restoration goals and restoration methods used. For most metrics, monitoring 1-2 times per month initially is enough, and then every several months for the first several years to ensure that the meadow is growing and no further intervention is necessary. For seed source restoration, it is recommended to perform monitoring during and following the germination period to quantify seedling establishment. For transplants, monitoring should occur about 1-2 months after planting and then again about 3-6 months after initial monitoring (Golden *et al.* 2010).

Methods for monitoring seagrass

Seagrass cores

Seagrass cores can be collected to obtain metrics such as biomass, shoot density, and shoot length. This is the same method used to collect transplant plugs (see Chp. 4). To collect seagrass cores, hover a PVC pipe close to the sediment over a desired patch of seagrass. Collect all blades of the desired plants inside of the PVC so as not to cut the blades. Push or hammer down the PVC pipe far enough to capture the belowground material of the seagrass. Inadequate depth will result in not retrieving the roots and rhizomes. Place a plug or cap on the exposed end of the pipe to create suction and then wiggle the PVC from side to side to loosen it from the sediment. Pulling the pipe straight up will result in a loss of the sample. Pull the core up at an angle and then place a cap or hand on the bottom of the pipe to capture the sample inside. It is easiest to sieve the core to remove sediment in the field, but this can be done later in a laboratory if necessary. Containers for transport can vary but some options include a mesh bag, plastic bag, or plastic tub. Seagrass cores should be kept in a cooler for transport. Cores can be stored in a refrigerator or freezer.

Biomass

To quantify biomass, in a laboratory separate individual shoots and then separate the components of seagrass into the following categories to assist in the data collection of this method: species, above- and below-ground material, and reproductive shoots. Place each category component in its own pre-weighed aluminum foil packet. To dry the samples, place the aluminum boats in a drying oven. Once dry, the foil packets should be weighed three times to obtain the final biomass weight to ensure that the true dry weight has been reached. Subtract the weight of the foil packet from the total to obtain the biomass weight.

Shoot density

To quantify shoot density, separate all of the shoots in a seagrass core by species and count the number of shoots of each.

Collecting seagrass cores provides information about the belowground as well as the aboveground components of seagrass at the restoration site. It is important to monitor both components and not just aboveground material because belowground material performs vital functions, including anchoring the plant to the sediment and uptaking nutrients. However, although this method is advantageous because it reflects components of the whole plant, it is invasive to the restoration site and may not be ideal for low-density areas (Bjork *et al.* 2008).

Transect
A transect is a path along which one records measurements at fixed points. The orientation of the transect will depend on the environmental gradient that is desired to be monitored. The transect should be stationary during data collection. Transects can be constructed using a waterproof, open-real tape measurer. Start at one end of the transect and walk/swim a set distance (will depend on the site) in the direction of the desired transect orientation. PVC pipes can be placed along the transect to mark it and can be left for future use. Metrics that can be measured along a transect to monitor seagrass include seagrass cover, seagrass species present, and extent of epiphytes and macroalgae. Seagrass cores can also be taken along a transect. Common analyses of transect data include determining species richness and evenness by calculating Shannon's Index, biodiversity by calculating Simpson's Index, and comparing the similarity of two populations by calculating Sorenson's Coefficient. Proper analysis of transect data will describe a given ecosystem without needing to measure its entirety.

Quadrat
Quadrats are frames of a known dimension used for sampling environmental and biological parameters of a large area without sampling the entire site. The most common type of quadrat is a square made out of PVC pipe. The dimensions of the quadrat can vary, however 0.5 x 0.5 m is a common size. Sometimes a quadrat will contain internal quadrats designated by thin wire or string and data will be collected at the points where the wires cross. To sample a site using a quadrat, quadrats can be haphazardly placed or placed at randomly generated points throughout the site. They can also be used at fixed distances along a transect. While collecting data, the quadrat must not move to avoid a skew in the results. Data such as species composition, seagrass cover, shoot density, and extent of epiphytes and macroaglae can be collected with this method.

Seagrass cover
Seagrass cover can be measured either by transect or by random point checks within the restoration area. If using the transect method, at least two transects per restoration area should be surveyed. Place a quadrat (0.5 x 0.5 m) at fixed intervals along the quadrat and at each point estimate the percent cover of seagrass within the quadrat. The Braun-Blanquet method might be useful for estimating percent cover (Braun-Blanquet 1932). To use the random point method, map the perimeter of the restoration area and generate random points within the area. Using a GPS to navigate to the points, use the quadrat to estimate percent cover at each point. This method is minimally invasive to the restoration site and is a useful metric if seeds were used as the source material for restoration.

Drone technology can also be used to measure the spatial extent of seagrass at a site. A drone is a remotely controlled, unmanned aircraft and for conservationists it is primarily used for aerial photography. If using drones for this purpose, the following are environmental factors that must be considered for the timing of the photography: consistency of when the photographs are taken (e.g. annually, during peak biomass season), specified tidal stages, sun angle (e.g. between 20 and 40°), cloud cover, turbidity range, and wind (e.g. <10 knots) (Orth *et al*. 2012). This is a useful method to monitor seagrass cover at a site in a short period of time and with minimal manual labor (Orth *et al.* 2012, Bjork *et al.* 2008). However, drone technology is very expensive and requires a specialist to execute this method. This type of data may already be available through government or other organizations that conduct aerial surveys.

Productivity

To determine productivity of above-ground biomass, the plastochrone interval (i.e. time interval between appearance of successive leaves) (Short and Duarte 2001) can be measured. To measure this interval, leaves can be marked to create a reference point and then measured after a set amount of time to determine the amount that the leaf grew. In the field, puncture the plant at a fixed height above the bottom of the shoot with a syringe-type needle. Leave the plant in the field. After a given period of time, for example 10 to 15 days, retrieve the shoot samples using a seagrass core. Return to a lab and separate the shoots into old growth (above the scar) and new growth (below the scar, excluding the shealth bundle and including new shoots). Place each component in its own pre-weighed aluminum foil boat. To dry the samples, place them in a drying oven. Once dry, the foil packets should be weighed three times to obtain the final weight to ensure that the true dry weight has been reached. Subtract the weight of the foil packet from the total to obtain the weight for productivity.

Environmental metrics

The same metrics that were monitored for site selection can be monitored post-restoration. Environmental monitoring should take place 1-2 times per month post-restoration and then every several months afterwards. In the growing season following restoration, monitoring should occur more frequently, at least once per month. For several years post-restoration, monitoring should take place at least twice during the seagrass growing season to ensure that the ecosystem is healthy and suitable for seagrass growth and expansion. Additional environmental metrics that can be monitored include:

Epiphyte coverage

Epiphytes grow on seagrass and may impact seagrass growth by reducing light availability. Quantifying epiphytes can be a useful measure of seagrass health. The best method of quantifying epiphytes is to visually assess the extent of epiphyte coverage on seagrass leaves.

Fauna diversity

Measuring the diversity of the other organisms in a seagrass meadow can be a useful measure of the health of the overall site as well as a measure of the seagrass ecosystem service of providing habitat. Surveys can be done to sample fish, birds, and benthic organisms in the seagrass meadow and determine whether the abundance and diversity of the species changes over time as seagrass continues to grow at the site. Refer to literature for the desired species to determine how to conduct surveys of these organisms.

Additional resources

SeagrassNet | http://www.seagrassnet.org/about/

SeagrassNet is a worldwide ecological monitoring tool that aims to preserve seagrass ecosystems by increasing scientific knowledge and public awareness. This tool offers helpful resources (e.g. monitoring manuals, sampling protocols, and instructions for submitting data) to the scientists and managers who investigate and document the status of seagrass and their threats.

SeagrassSpotter | https://seagrassspotter.org/

SeagrassSpotter is used as a global tool to help easily locate seagrasses by region, species, or with the use of the virtual dichotomous key. Additional information to educate and advocate for seagrasses is also provided.

SeagrassWatch | https://www.seagrasswatch.org/

This is a global network whose mission is to protect nearshore seagrass ecosystems by raising awareness about their conditions and help prevent any further significant areas and species from being lost. There is a strong, scientific foundation to SeagrassWatch with an emphasis on consistent data collection, recording, and reporting. Registering with SeagrassWatch allows individuals to receive different levels of training, access resources (e.g. manuals, field guides, datasheets, literature) and monitoring strategies based on the type and location of seagrass meadows, and submit collected data for analysis. The collaboration between SeagrassWatch's participants (i.e. researchers, coastal communities, and data users) aids their efforts to protect the integrity of seagrass meadows along the coasts.

5.3. Coordination and Outreach

Coordination

Restoration managers should coordinate with relevant state and federal agencies about restoration projects that are being done. Many coastal states have agencies that are already doing some form of seagrass habitat monitoring and/or restoration. In New Jersey, this is the Bureau of Marine Habitat and Shellfish. Collaboration and data sharing could benefit both parties involved, potentially saving time, money, and labor. Academic institutions may also be able to assist with monitoring and restoration activities. Coordinating among all of the relevant parties will also prevent interference in ongoing studies or restoration that may already be taking place.

Outreach

Additionally, restoration managers should try to implement outreach programs associated with restoration projects whenever possible to increase community involvement. The goal of outreach programs related to seagrass restoration is to raise awareness of the importance of seagrass systems as well as the need to protect and restore them. Additionally, outreach programs should aim to promote practices that support the resilience of coastal ecosystems. Examples of behaviors that outreach programs can target include boating practices that disturb seagrass meadows, polluting the waterways, and the introduction of invasive species. Outreach can take place in different forms, including distributing informational pamphlets, community science, and holding in-person events.

Community science

Community science programs can integrate public outreach and scientific data collection across geographical scales to engage communities in marine conservation (Jones *et al.* 2018). Creating opportunities for individuals to participate in monitoring or restoration efforts can be a great way to increase engagement with the public as well as reduce the need for additional personnel to complete a project (Pickerell *et al.* 2005). Community science outreach programs typically have low budget requirements and may financially benefit a project by reducing costs for labor (Jones *et al.* 2018).

An example of community science in seagrass restoration is the smartphone application and website "Seagrass Spotter," a database where community scientists can upload geo-tagged photographs that are useful for seagrass monitoring. Submissions provided an array of data including abundance, environmental conditions, species, phenology, and associated fauna (Jones *et al.* 2018). Some sites were accessible by low tide and required minimal swimming to access. With an ultimate goal of stimulating appreciation for marine environments, this community science program was noted to be a successful way to reconnect growing coastal populations with nature and more specifically seagrass ecosystems (Jones *et al.* 2018).

Local feedback

Introducing social-ecological assessments into management plans allows for decision-makers to make informed choices about priorities, trade-offs, and evaluate management alternatives based on public opinion (Kittinger *et al.* 2014). Surveys can actively educate, create, and demonstrate approaches that foster more investment from the public in their local environment and projects to improve it. The frequency of the evaluation is to be decided by managers and could be based on local conditions or duration of projects. Resource constraints that are associated with public evaluations are personnel, time, and funding. The table below is an example of a social-ecological assessment that could be distributed to the public and which may be used as a template:

Questions

1. Were you informed of the project before it began? a. If so, how were you informed?
2. Do you enjoy living near the Barnegat Bay? a. Why? b. Why not?
3. How often do you visit the Barnegat Bay?
4. Were you involved in the recent restoration project? a. If so, how were you involved?
5. Were you updated on the progress during the restoration?
6. In general, what do you think is the primary goal of any seagrass restoration (not just the ones in the Barnegat Bay)?
7. How do you think the recently restored seagrass will affect your property value?
8. Did this restoration live up to your expectations?

"Glamourize" seagrass

Finally, managers attempting to increase public engagement in protecting seagrass and the surrounding environments should attempt to market seagrass as a glamorous topic. Rather than using extrinsic motivation (promising a reward or punishment), which doesn't typically create lasting motivation, glamorizing seagrass will foster intrinsic motivation (motivation by enjoyment or interest in something), which is more likely to create a long-term relationship between the local community and progression of the management plan. An example of a method to glamorize seagrass is providing a visual comparison of a person's backyard with and without seagrass systems present. A visual representation of a local area without seagrasses may encompass flooded streets and sunken houses, clouded water, "choking" shellfish and minimum aquatic life, and boating scars. On the other hand, the backyard with seagrasses present will be dry and local waterways will be clear and populated by a variety of fish. It is important to make a connection between the health of seagrass ecosystems and the audience's lifestyle. Using phrases such as "Your own backyard" can increase intrinsic motivation. Outreach should reach various levels of expertise including all ages and levels of familiarity with seagrass ecosystems.

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