Chapter 4. Ecological Resilience Indicators for Seagrass Ecosystems

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Ecosystem Description

Seagrasses are marine angiosperms found in many shallow coastal and oceanic waters around the world. They are widely dispersed, extending from the tropics to the Arctic Circle (Green and Short, 2003). Despite their large geographic extent, seagrasses have low species biodiversity. Globally, there are approximately 60 seagrass species with approximately 10% of the total number of species present in the Northern Gulf of Mexico (NGoM): *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila engelmannii*, *Halophila decipiens* and *Ruppia maritima*. The three most prevalent species (*T. testudinum*, *S. filiforme* and *H. wrightii*) can form monospecific stands or mixed assemblages. The areal extent of seagrass beds in the NGoM (Figure 4.1) comprises nearly half of total seagrass coverage in the United States of America (Green and Short, 2003).

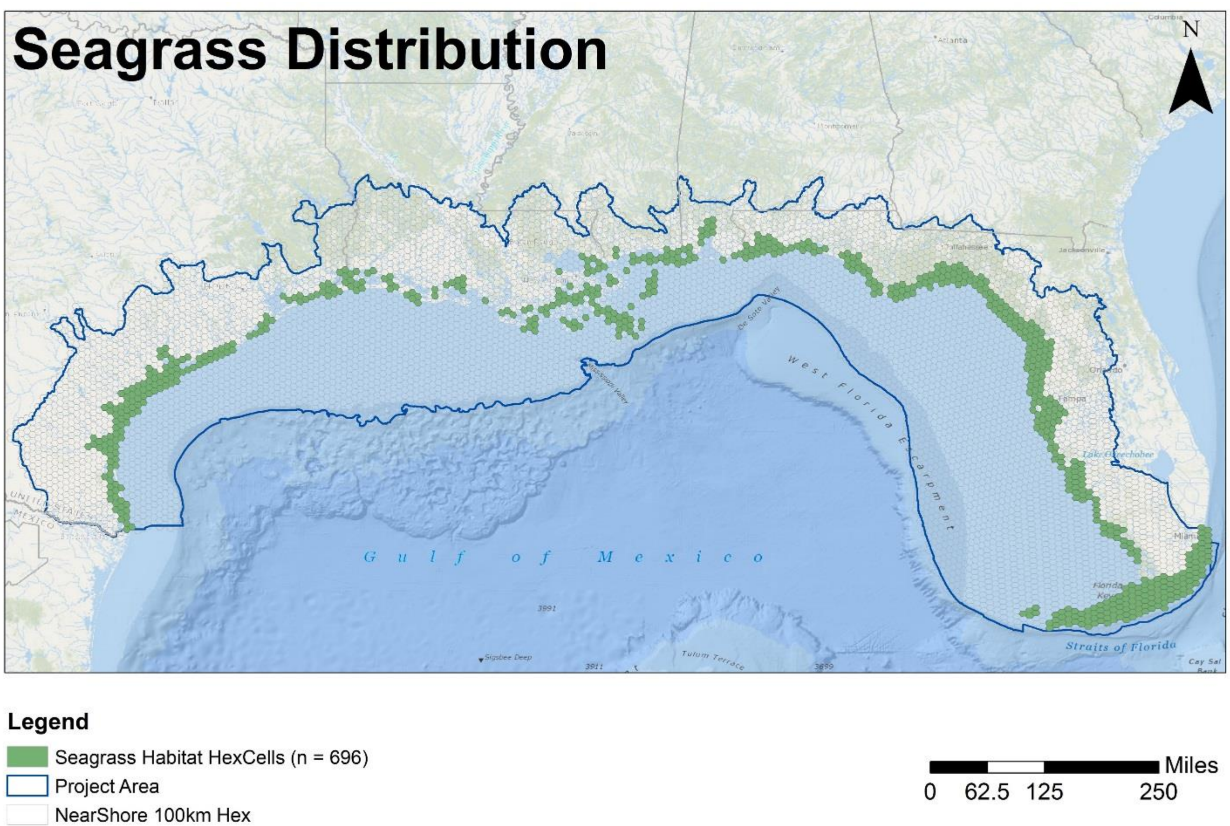


Figure 4.21. *Distribution of seagrass beds in the Northern Gulf of Mexico*

Seagrass growth and productivity are largely controlled by the quantity and quality of light reaching the seagrass bed; therefore, changes in water transparency can alter seagrass abundance and distribution. Light stress is attributed to natural and anthropogenic stressors, often driven by coastal development (Dennison et al., 1993). Additionally, temperature and salinity are important abiotic factors that influence seagrass productivity. Physiological tolerances regulate the abundance and distribution of a given species, resulting in fluctuations in species composition and density. Seagrass response to nutrient addition is rapid, often involving sudden declines in abundance and shifts in species dominance stemming from a cascade of direct and indirect effects including decreased light availability, sediment hypoxia and anoxia, and increased turbidity. Despite unprecedented global declines in seagrass (Orth et al., 2006; Waycott et al., 2009), these ecosystems are resilient and have exhibited recovery when stressors are controlled and disturbances are minimized (Macreadie et al., 2014). Nutrient loadings that are properly managed can reduce their input into coastal zones and allow stressed seagrass populations to rebound (Greening and Janicki, 2006). Therefore, monitoring the parameters that exert control on seagrass productivity, mainly light availability, and seagrass ecosystem structure and function, will allow early detection of habitat degradation.

Coastal bays and watershed land use are tightly connected, and due to this strong coupling, the effects of increased nutrient sources from human activities ultimately impact the structure and function of seagrass habitats. Seagrasses are important indicators of ecosystem health, where changes in abundance and distribution signify environmental perturbation. Seagrasses can respond to natural or human-induced disturbances rapidly over periods of a few weeks to months (Roca et al., 2016). However, response varies by species, where larger, climax species such as *T. testudinum* have a longer response time due to larger belowground carbohydrate reserves. Despite species differences, seagrasses are reliable indicators of deteriorating ecosystem condition because response times are quicker for degradation processes than for recovery.

We developed a conceptual ecological model (CEM) to identify the most important ecological and human processes influencing seagrass ecosystems in the NGoM. We provided a visual diagram (Figure 4.2) in conjunction with this narrative to describe and identify indicators for the Drivers, Major Ecological Factors (MEFs) and Key Ecological Attributes (KEAs) and Key Ecosystem Services (KESs) that control seagrass abundance, distribution, and persistence. There are numerous factors that exert control on seagrass ecosystems; however, we identified the most robust and direct relationships between drivers and ecosystem response and function. The CEM serves as a tool to assist resource managers by connecting physical and biotic parameters and ecosystem structure to major climatic and anthropogenic drivers. The linkages illustrate the overlap between drivers and indicators, which is important when considering driver-stressor-response relationships, as one driver can control several different aspects of seagrass ecosystem response. Since temporal comparisons are important in assessing the direction of condition, several indictors and metrics focus on the degree of change across time. Seagrass ecosystem condition can be assessed using the ecological factors and services derived from our model.

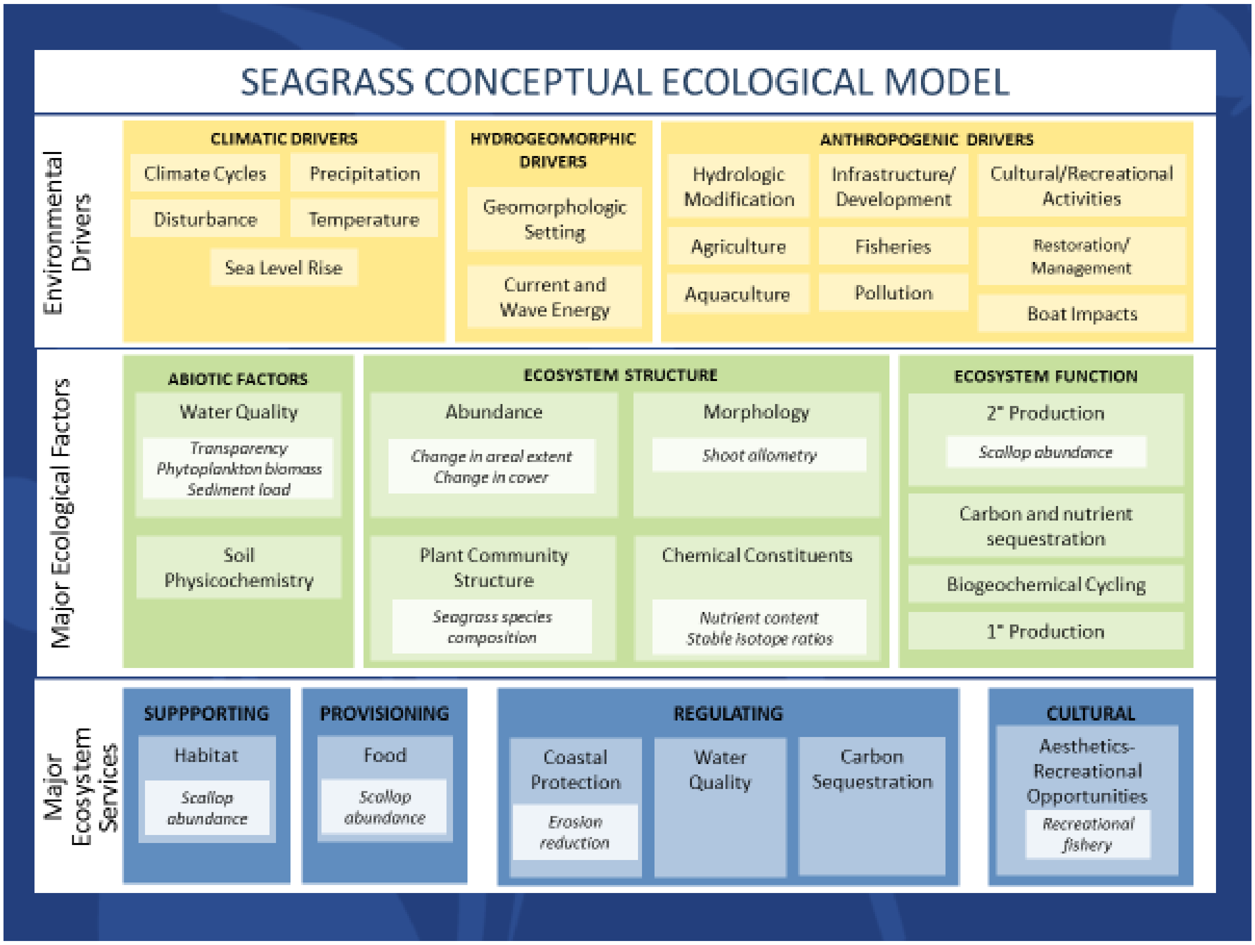


Figure 4.22. *Seagrass Conceptual Ecological Model*

Factors Involved in Ecological Integrity

Abiotic Factors

Water Quality

Seagrasses have specific habitat requirements that control their abundance, distribution, and persistence. As human population densities continue to increase along coastlines worldwide, the transition of wetlands for agricultural, suburban, and urban land use will ensue, leading to enhanced delivery rates of nutrients from non- and point sources (Valiela et al., 1992). Residence time, water depth, and the level of eutrophication can facilitate optimal conditions for micro- and macroalgal dominance. Therefore, shallow embayments and water bodies with long residence times are particularly susceptible to rapid changes in population and land use.

Excessive nutrient conditions are ideal for stimulating and supporting rapid growth of algae, including phytoplankton and more commonly epiphytes and macroalgae. Algae blooms and epiphytes have minimal light requirements (~ 1%) and block sunlight from penetrating to the seagrass canopy (Dennison et al., 1993). Conversely, seagrasses in Texas have been shown to require > 18% surface irradiance (Dunton, 1994), and when surface irradiance falls below 18%, photosynthesis is reduced. Oxygen transport to the rhizosphere (roots and rhizomes) is impaired and belowground tissue respiration will exceed production, resulting in the accumulation of sulfides and ammonium in adjacent sediments, which are toxic to seagrasses at high concentrations (Carlson et al., 1994; Koch and Erskine, 2001; Mateo et al., 2006). Ultimately, lower light penetration to the seagrass canopy results in a decrease in net photosynthesis, reduced seagrass biomass, and an overall decline in seagrass condition.

Developmental pressures including urbanization, maintenance dredging, nutrient and sediment loading from runoff and sewage effluent, and cultural activities such as boating and commercial fishing practices can increase turbidity (Short and Wyllie-Echeverria, 1996). There is generally a concomitant increase in sediment loading and sediment re-suspension with nutrient loading, which reduces light availability. If coupled with algal overgrowth from nutrient enrichment, seagrass decline is exacerbated as carbon reserves are depleted during low-light conditions. Moreover, wind, waves and currents increase erosion and accelerate seagrass loss, which compromises the integrity of the seagrass bed. As seagrass continues to decline, sediments are easily re-suspended and amplify poor water quality conditions.

Although nutrients have been linked to algal overgrowth, mesograzers can directly control epiphyte abundance and ameliorate stress caused by eutrophication (Hughes et al., 2004; Heck and Valentine, 2007). Neckles et al. (1993) found that epiphyte growth stimulated by nitrogen and phosphate enrichment failed to overcome grazing pressure by mesograzers. Greatest negative impacts on seagrass populations were observed when amphipod mesograzers were removed from nutrient enriched *H. wrightii* beds, which increased epiphyte loads and decreased seagrass leaf biomass (Myers and Heck, 2013). Therefore, seagrass beds facing chronic exposure to elevated concentrations of nutrients may lead to declines in seagrass health in the absence of grazers over sustained periods of time.

Soil Physicochemistry

Seagrasses are robust indicators of nutrient availability since they often grow in nutrient-limited environments with clear water. Because seagrasses integrate water column conditions, their tissues reflect the relative availability of the macro-elements nitrogen and phosphorus (Atkinson and Smith, 1982; Duarte, 1990). Although the amount of nutrients in the soil can limit the growth of seagrasses, they can still colonize areas with nutrient limitations. Sediment type varies across the NGoM and can be clastic (terrigenous) or carbonate in origin. Terrigenous sediments from human-induced perturbations (dredging or runoff) can cause water quality issues due to the fine particle size. In terrigenous sediments, nitrogen is typically the limiting nutrient for seagrass growth, whereas phosphorus is usually the limiting element in marine carbonate sediments (Short, 1987). However, some regions can exhibit patterns of both N- and P-limitation despite sediment type. For example, seagrasses collected from the carbonate sediments in Florida Bay reveal both N- and P-limited spatial patterns (Fourqurean et al., 2002) that are a function of increasing P availability with proximity to the NGoM.

Additionally, light availability indirectly influences sulfide toxicity via photosynthesis. More specifically, in anoxic sediments, sulfate-reducing bacteria generate sulfides during the remineralization of nutrients. Remineralization can increase plant growth due to the production of nutrients (ammonium) but can also lead to plant decline through the accumulation of sulfides. Increased productivity, however, allows for the translocation of oxygen to the belowground tissue, thereby oxidizing the sulfides (sulfates) and reducing its toxic effects (Koch et al., 1990; Lee and Dunton, 2000; Koch et al., 2007). Sulfide toxicity can be exacerbated when light availability is reduced due to eutrophication and can result in seagrass decline.

Ecosystem Structure

Abundance

Seagrass abundance responds to natural and human disturbances and is reflected in changes of extent, cover, biomass, and/or density. Abundance measurements are sensitive enough to reflect changes in water quality, thus are widely collected by a variety of monitoring programs. However, seagrass bed response can vary, and there can be a change in biomass or density without a change in areal extent. Additionally, some seagrass parameters are less widely collected because they are destructive and labor intensive (e.g., biomass and density). Therefore, measurements of extent and cover provide a rapid and non-destructive alternative and are frequently collected by monitoring programs (Neckles et al., 2012), specifically in the NGoM.

Seagrass presence and distribution may be reduced by human impacts such as eutrophication, land use changes, coastal development, and dredging (see Short and Wyllie-Echeverria, 1996; Erftemeijer and Lewis, 2006). Mapping seagrass beds to determine areal extent allows for a coarse assessment of seagrass distribution across a large geographical area. Seagrass bed delineations from areal extent can be used to assess large-scale gains or losses of seagrass habitat over a long period of time depending on the frequency of sampling (at least five years if not more frequently but ideally no more than 10 years; Krause-Jensen et al., 2004). Because seagrass beds can be highly dynamic and exhibit local or region-specific changes, cover estimates are required to assess the degree of seagrass expansion or retraction. Ultimately, the use of percent cover observations and areal extent in seagrass mapping can detect areas that change in habitat coverage.

Plant Community Structure

Plant species diversity and composition influence ecosystem productivity, nutrient cycling, and resiliency. Seagrass ecosystems in the NGoM are composed of six seagrass species (*Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Ruppia maritima*, *Halophila engelmannii* and *Halophila decipiens* [Florida]), numerous species of macroalgae, and host a suite of microalgal epibionts. Inter- and intraspecific competition arising from physiological differences in nutrient, light, temperature and salinity requirements control species distributional and abundance patterns (Fourqurean et al., 2002). It is well documented that bottom-up processes such as nutrient loading are responsible for an increase in micro- (epiphytes and blooms) and macroalgal (drift algae) growth. This overgrowth of algae can cause shading stress on seagrass beds, thereby reducing their abundance (Herzka and Dunton, 1998). However, top-down processes are also responsible for manipulating epiphyte and seagrass abundance. Mesograzers can alleviate stress induced by eutrophication on seagrasses by controlling epiphyte abundance (Hughes et al., 2004; Heck and Valentine, 2007). Myers and Heck (2013) found an increase in epiphyte loads and decrease in seagrass leaf biomass when mesograzers were removed from nutrient enriched *H. wrightii* beds. Additionally, nutrient loading can enrich plant tissues and stimulate herbivory by increasing the palatability of the seagrass, which can result in biomass decline from preferential overgrazing (Heck et al., 2006).

Shifts in species composition can occur when plants undergo extreme stress events brought on by biological and environmental variability. Typically fast-growing pioneer species, *H. wrightii* and/or *S. filiforme*, are precursors to *T. testudinum* dominance; however, environmental perturbations can alter species composition based on their physiological differences. For example, nutrient enrichment can influence competitive interactions between these predominant seagrass species, where fertilization experiments in Florida Bay resulted in a dominance shift from *T. testudinum* to *H. wrightii* communities (Howard et al., 2016). Additionally, *S. filiforme* beds were replaced by *H. wrightii* in Upper Laguna Madre, Texas during extended periods of drought (salinities > 50; Dunton, *unpublished data*). Ultimately, sudden shifts in dominance and community structure signal an imbalance in the ecosystem.

Morphology

Seagrass growth is an important measure of productivity and can vary spatially and by season, and in response to anthropogenic impacts. Seagrass species in the NGoM can exhibit strong seasonality where seagrass leaf lengths and numbers of leaves per short shoot are at a minimum in winter and maximum in summer. Nutrient and light climates can also influence seagrass morphology; however, seagrass response to changes in nutrients are not uniform and can vary by species (Roca et al., 2016). With a reduction in light availability, seagrasses can exhibit a photoacclimatory response where they initially increase in height or width (Czerny and Dunton, 1995; Longstaff and Dennnison, 1999); however, carbohydrate reserves cannot sustain plant demands and plant size eventually decreases (Gordon et al., 1994). Unlike responses to light, morphological responses to nutrient loading are not as predictable, and some studies have shown that enrichment can result in either increased or decreased plant size (Roca et al., 2016). The duration of nutrient enrichment can also influence seagrass response, where biomass and density increased in short-term enrichment studies and decreased simultaneously when exposed to the long-term effects of nutrient addition (Cabaço et al., 2013). Regardless, seagrass morphologies respond to changes in water quality and can be used to assess condition.

Chemical Constituents

Seagrasses require light and nutrients for plant growth and are reliable indicators of changes in water quality because they respond over time scales of weeks to months (Burke et al., 1996; Vermaat, 2009; van Katwijk et al., 2010; Roca et al., 2016). Although growth and structural responses are useful measures of condition, biochemical responses are faster and better capable of detecting habitat degradation prior to collapse because they are not buffered by the structure of the ecosystem. The chemical constituents of living tissue reflect nutrient composition and availability, as nutrient acquisition by seagrasses consists of an equal contribution from the sediment pore water and water column (Lee and Dunton, 1999). Nutrient content—the proportion of carbon, nitrogen, and phosphorus and stable isotopic composition of the leaves—indicates the availability and source of nutrients, respectively. Under nutrient replete conditions, the availability of nitrogen (N) to phosphorus (P) is reflected in a balanced ratio of 30:1 for seagrasses. Nutrient limitation can be identified when N:P ratios deviate from the seagrass Redfield ratio of 30:1 (Atkinson and Smith, 1983; Duarte 1990; Fourqurean and Zieman, 1992; Fourqurean et al., 2001; Fourqurean and Zieman, 2002; Fourqurean et al., 2005; Fourqurean et al., 2015).

Stable carbon isotopic signatures reflect changes in irradiance due to increased light attenuation. $\delta^{13}C$ values indicate that as light becomes limiting, carbon becomes less limiting, and $\delta^{13}C$ values become more negative (Durako and Hall, 1992). Additionally, benthic macrophytes residing in eutrophic marine ecosystems are documented to exhibit enriched stable nitrogen isotopic ($\delta^{15}N$) signatures (McClelland et al., 1997). Although $\delta^{15}N$ response is not unidirectional and varies based on fractionation, $\delta^{15}N$ signals are commonly used to identify the source of nitrogen. For example, seagrass tissues that have a $\delta^{15}N$ near 0‰ are typically influenced by agricultural runoff. Therefore, we can use stable isotope values to determine if seagrasses are growing under low-light conditions or receiving sewage or agricultural inputs.

Generally, $\delta^{13}C$ and $\delta^{15}N$ are related to shading and nutrient processes, respectively. Coupled with C:N:P ratios, seagrasses can be used to identify nutrient over-enrichment. Chemical constituents can be linked to changes in one, or sometimes a few, stressing agents which makes them efficient and useful in the identification of stressor-response relationships (Roca et al., 2016).

Ecosystem Function

Secondary Production

One important function of seagrass beds is that they support a rich assemblage of vertebrate and invertebrate species. Numerous commercially and recreationally fished species – red drum, sea trout, blue crabs, shrimp, etc. – take refuge in the structurally complex habitat that seagrass canopies provide. Seagrass abundance and species morphology determine habitat preference, which is particularly true for the bay scallop (*Argopecten irradians*). Bay scallops are exclusively found in, or adjacent to, seagrass beds (Eckman, 1987; Ambrose and Irlandi, 1992). Unfortunately, the decline in bay scallops, and their slow recovery, results from human impacts, specifically overharvesting and habitat degradation (Arnold et al., 2008). The removal of suspension-feeding bivalves disrupts the reciprocal positive interactions between seagrasses and bivalves, and can lead to increased water column primary production (Wall et al., 2008). In the presence of bivalves, seagrass productivity significantly increases and there is a reduction in epiphytic load on seagrass leaves as phytoplankton densities are regulated (Peterson and Heck, 2001; Wall et al., 2008). Additionally, seagrasses offer refuge and facilitate bivalve growth and recruitment, thereby enhancing bivalve survivorship (Peterson and Heck, 2001; Wall et al., 2008). Ultimately, declines in bivalve densities can have adverse effects on water quality and alter the development, structure, and organization of seagrass ecosystems.

Natural (hurricanes, droughts, and precipitation) and human (coastal development, sediment loading, eutrophication, and propeller scarring) disturbances can lead to seagrass ecosystem degradation, fragmentation, patchiness, and loss. These processes can reduce biodiversity and lead to bed collapse (Fonseca and Bell, 1998). Moreover, the risk extends to species that rely on these habitats, particularly ones with habitat-specific preferences such as the bay scallop.

Carbon and Nutrient Sequestration

Ammonium and nitrate are the primary nitrogenous forms supplied to seagrass leaves; however, seagrasses prefer to uptake the reduced form of nitrogen, ammonium. This facilitates nitrogen removal via uptake by seagrass tissue. Additionally, seagrasses act as ecosystem engineers by dissipating wave energy and modifying the underwater environment. Seagrass canopies alter the flow of water, which facilitates sediment deposition, thereby enhancing water quality and augmenting carbon sequestration within seagrass soils (McGlathery et al., 2012; Duarte et al., 2013), creating important carbon stocks (Duarte et al., 2005; Duarte et al., 2010; Fourqurean et al., 2012).

Locations with increased canopy complexity facilitate particle trapping and enhance sediment accretion (Gacia et al.. 1999). Studies suggest that increasing seagrass abundance yields greater long-term carbon storage capacity in the sediments (Armitage and Fourqurean. 2015). Furthermore, sediment organic carbon stores are strongly correlated with grain size and proximity to the bed edge, where current attenuation increases fine-sediment deposition and carbon burial within the interior of the bed (Oreska et al., 2017). Therefore, large, contiguous beds may have the capacity to store more sediment organic carbon than small, fragmented patches. However, land use conversion and habitat degradation disrupt the carbon and nutrient cycling within these invaluable ecosystems. Specifically, ecosystem loss may result in re-emission of previously sequestered carbon into the atmosphere and can alter the global carbon pool (Fourqurean et al., 2012; Pendleton et al., 2012; Macreadie et al., 2015).

Biogeochemical Cycling

Coastal sediments consist of a thin oxic layer followed by a deep anoxic layer. Typically, terrigenous soils are rich in organic material and microbial content, which control the relationship between reduction-oxidation zones. Because of the anoxic sediment, the nitrogen pool surrounding the seagrass rhizosphere is primarily composed of reduced nitrogen (Short et al., 1983). Ammonium can originate from the decomposition of organic matter via microbial activity, nitrogen fixation, and/or animal excretions. Nitrogen fixation can occur at the root surface when oxygen leaks and oxidizes ammonium, thereby decreasing the amount of ammonium in the sediment. However, in carbonate systems, phosphorus is readily adsorbed by carbonate sediments and leaves minor concentrations in the interstitial water resulting in plants that are P-limited (Short et al., 1985).

Buried nutrient stores, specifically carbon, are a function of seagrass canopies, as they can trap re-suspended sediments and other organic material. As seagrasses senesce, blades decay and are remineralized by microbes in the sediments. On average, around 24% of seagrass net primary production is exported from seagrass beds, where some of these seagrass-derived nutrients are immediately used by organisms or are remineralized in nearby ecosystems. Seagrass matter may be exported hundreds to thousands of kilometers away and remineralized in the deep ocean (Duarte and Krause-Jensen, 2017).

Primary Production

Seagrasses are one of the most productive ecosystems in the world. As primary producers, seagrasses fix inorganic carbon into organic carbon as biomass via photosynthesis. Since photosynthesis requires carbon dioxide and light, these are the two main drivers of plant growth and biomass.

Primary production relies on resource availability and photosynthetic efficiency. Net primary production considers the balance of energy between aboveground biomass, belowground biomass, reproductive organs and respiring tissues. Since seagrasses have high light requirements (10-25% SI; Duarte, 1991; Dunton, 1994), underwater light availability regulates seagrass productivity. As previously described, cultural impacts increase light stress to seagrasses due to decreased water transparency from coastal development, dredging, river runoff, and sediment loading. Human activities can expose seagrasses to chronic, low-light conditions, which remains the largest threat to seagrass worldwide (Dennison et al., 1993; Orth et al., 2006; Waycott et al., 2009).

Factors Involved in Ecosystem Service Provision

Seagrass beds provide a variety of goods and services for marine biodiversity and people. These ecosystems play multiple functional roles in human well-being, such as filtering of nutrients and sediments, species nursery grounds, fisheries, control of erosion, and protection against floods (Barbier et al., 2011, Unsworth and Cullen-Unsworth, 2014). Although seagrasses are structurally similar, they vary widely in size, productivity, and distribution across the NGoM. Consequently, the ecosystem services that they provide vary across the different seagrass species and ecoregions (Mtwana et al., 2016).

The ecosystem services that seagrasses provide are the consequences of their basic ecological attributes, including physiological functions, such as primary production and nutrient recycling (by which they provide food to consumers and trap carbon and nutrients), and the habitat provided by their physical structures. A complete list of the services provided by seagrasses in the NGoM is provided by Yoskowitz et al. (2010). Below we provide an overview of the most important Key Ecosystem Services that we included in the conceptual ecological model.

Supporting

Habitat

The provision of shelter, feeding, and nursery grounds are vital ecosystem services provided by seagrass beds (Unsworth and Cullen-Unsworth, 2014). A rich assemblage of commercially important vertebrate and invertebrate species is dependent on seagrass beds. Many invertebrate species live on their leaves and many other species live in the refuge offered by the seagrass bed canopies. Therefore, seagrass beds harbor complex food webs and maintain high marine biodiversity through the combined trophic and structural roles they serve. Thus, the abundance of other species varies in relation to the abundance of seagrass beds.

Provisioning

Food

Seagrass ecosystems generate value as habitat for ecologically and economically important species such as scallops, shrimp, crabs, and juvenile fish. Seagrass beds provide physical shelter and nursery habitat to protect these species from predators (Duarte, 2000).

Regulating

Coastal Protection

Coastal protection and erosion control are often listed as important ecosystem services provided by seagrasses, as they can attenuate waves (Koch et al., 2009). Seagrasses act as ecosystem engineers by dissipating wave energy and modifying the underwater environment. Seagrass beds help stabilize the shoreline by reducing the erosion and therefore making the shoreline less vulnerable to other natural hazards (The Nature Conservancy, 2017). The protection benefit of any reef will depend on many factors, such as exposure, intensity and local condition.

Water Quality

Seagrasses improve water quality via nutrient uptake and suspended particle deposition. Their canopies alter the flow of water, which facilitates sediment deposition, thereby enhancing water quality. Seagrass beds not only remove nutrients from the sediments and water column, but also their leaves are colonized by algae (epiphytes), which further remove nutrients from the water column (Cornelisen and Thomas. 2006).

Carbon Sequestration

Coastal wetland ecosystems (i.e., salt marshes, mangroves, and seagrass beds) can store large quantities of carbon in the soil because of high rates of belowground primary production (carbon input) and relatively low rates of decomposition (carbon export). Seagrass beds cover less than 0.2% of the area of the world's oceans but are estimated to sequester roughly 10% of the yearly estimated organic carbon burial in the oceans (Duarte et al., 2005). Seagrass canopies alter the flow of water which facilitates sediment deposition, thereby augmenting carbon sequestration within seagrass soils (McGlathery et al., 2012; Duarte et al., 2013), creating important carbon stocks (Duarte et al., 2005; Duarte et al., 2010; Fourqurean et al., 2012). Increasing seagrass abundance yields greater long-term carbon storage capacity in the sediments (Armitage and Fourqurean, 2015).

Cultural

Aesthetics-Recreational Opportunities

As stated above, seagrasses provide habitat for commercially and recreationally fish species such as spotted sea trout, red drum, and many others.

Indicators, Metrics, and Assessment Points

Using the conceptual model described above, we identified a set of indicators and metrics that we recommend be used for monitoring seagrass ecosystems across the NGoM. Table 4.1 provides a summary of the indicators and metrics proposed for assessing ecological integrity and ecosystem services of seagrass beds organized by the Major Ecological Factor or Service (MEF or MES) and Key Ecological Attribute or Service (KEA or KES) from the conceptual ecological model. Note that indicators were not recommended for several KEAs or KESs. In these cases, we were not able to identify an indicator that was practical to apply based on our evaluation criteria. Below we provide a detailed description of each recommended indicator and metric(s), including rationale for its selection, guidelines on measurement, and a metric rating scale with quantifiable assessment points for each rating.

We also completed a spatial analysis of existing monitoring efforts for the recommended indicators for seagrass ecosystems. Figure 4.3 provides an overview of the overall density of indicators monitored. Each indicator description also includes a more detailed spatial analysis of the geographic distribution and extent to which the metrics are currently (or recently) monitored in the NGoM, as well as an analysis of the percentage of active (or recently active) monitoring programs that are collecting information on the metric. The spatial analyses are also available in interactive form via the Coastal Resilience Tool (http://maps.coastalresilience.org/gulfmex/) where the source data are also available for download

The proposed list of indicators and metrics are applicable to the entire NGoM. To account for regional variation among ecosystems, we constructed two sets of metric ratings and assessment points for some indicators. This list of indicators and metrics is compatible with indicators proposed in recent synthetic reviews of seagrass ecological indicators (e.g. Marbà et al., 2013 and Roca et al., 2016) and can serve as robust measures of ecosystem integrity.

Table 4.16. *Summary of Seagrass Metrics Based on the Conceptual Ecological Model*

SEAGRASS ECOSYSTEMS			
Function & Services	**Major Ecological Factor or Service**	**Key Ecological Attribute or Service**	**Indicator/*Metric***
Sustaining/ Ecological Integrity	Abiotic Factors	Water Quality	Transparency/*Percent Surface Irradiance*
			Phytoplankton Biomass/*Chlorophyll* a *concentration*
			Sediment Load/*Total Suspended Solids*
		Soil Physicochemistry	--
	Ecosystem Structure	Abundance	Change in Areal Extent/*Areal Extent*
			Change in Cover/*Percent Cover*
		Plant Community Structure	Seagrass Species Composition/*Species Dominance Index*
		Morphology	Shoot Allometry/*Leaf Length*
			Shoot Allometry/*Leaf Width*
		Chemical Constituents	Nutrient Content/*Nutrient Limitation Index*
			Stable Isotope Ratios/$\delta^{13}C$ *and* $\delta^{15}N$
	Ecosystem Function	Secondary Production	Scallop Abundance/*Scallop Density*
		Carbon and Nutrient Sequestration	--
		Biogeochemical Cycling	--
		Primary Production	--
Ecosystem Services	Supporting	Habitat	Scallop Abundance/*Scallop Density*
	Provisioning	Food	Scallop Abundance/*Scallop Density*
	Regulating	Coastal Protection	Erosion Reduction/*Shoreline Change*
		Water Quality	--
		Carbon Sequestration	--
	Cultural	Aesthetics-Recreational Opportunities	Recreational Fishery/*Spotted Seatrout Density* and *Recreational Landings of Spotted Seatrout*

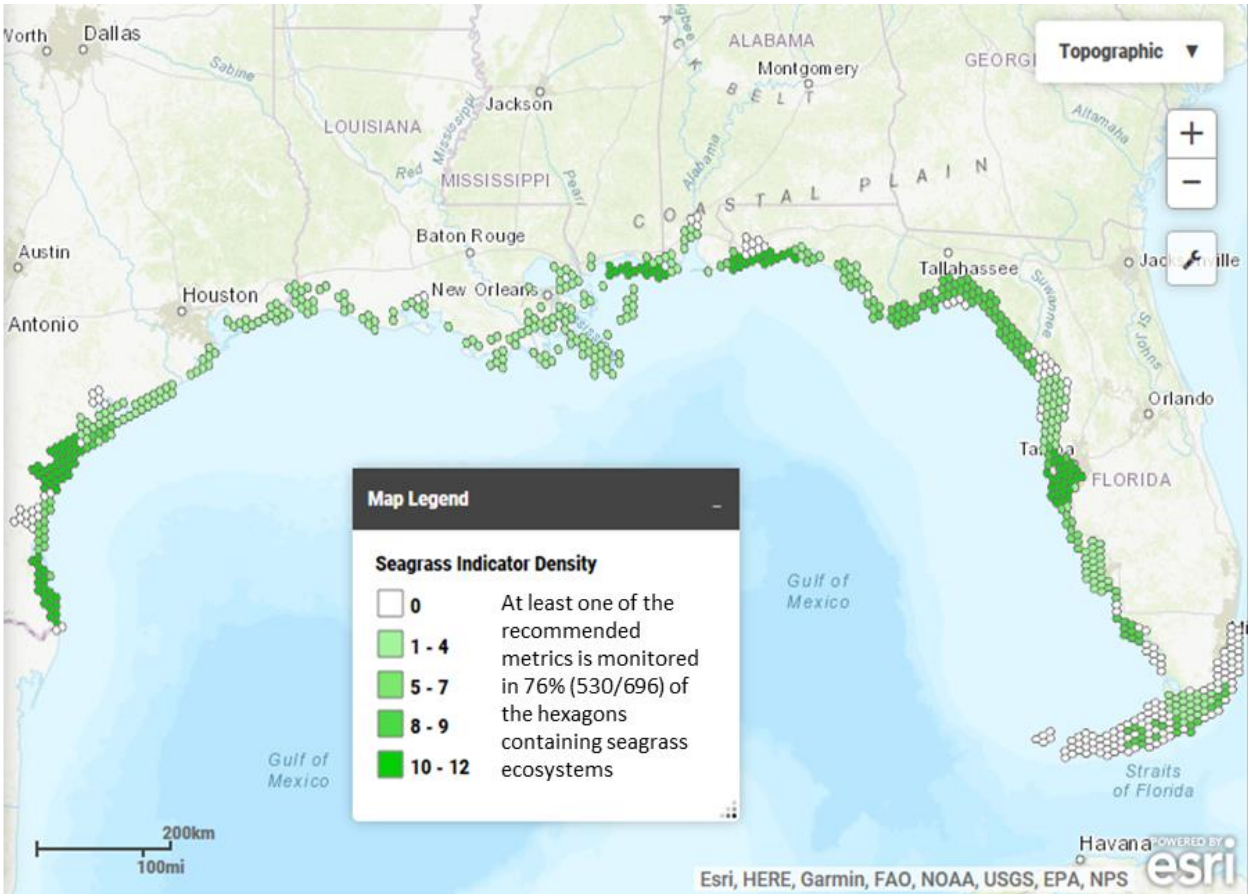


Figure 4.23. *Density of the recommended indicators being collected in seagrass ecosystems in the NGoM. Shaded hexagons indicate the number of the recommended indicators that are collected by monitoring programs in each hexagon.*

Ecological Integrity Indicators

Indicator: Transparency

MEF: Abiotic Factors
KEA: Water Quality
Metric: Percent Surface Irradiance (% SI)

Definition: Percent surface irradiance (% SI) is the percentage of incident light that reaches the canopy and is the minimum amount of light required for seagrass growth. Percent surface irradiance determines the maximum depth limit for seagrass survival and can vary by region and species.

Background: Reductions in underwater light are one of the main factors responsible for global seagrass declines (Dennison et al., 1993; Orth et al., 2006; Waycott et al., 2009). Poor land management practices, altered river flows, increased nutrient loads, and dredging are a few of the stressors that affect underwater light regimes (Ralph et al., 2007). Photosynthesis is required for plant growth, where seagrass productivity, survival, and depth distribution are controlled by underwater irradiance (Dennison et al., 1993). Light requirements are higher for seagrasses compared to other marine flora, where light availability controls the maximum depth at which seagrasses can grow, therefore, excluding them from areas with poor light conditions (Dennison et al., 1993; Abal and Dennison, 1996).

Rationale for Selection of Variable: Seagrass growth and survival are directly related to the quantity and quality of light available for photosynthesis (Dennison et al., 1993). Seagrasses have a high minimal light requirement (10–25% SI; Duarte, 1991) compared to marine phytoplankton (~0.5–1%; Parsons et al., 1984); therefore, light attenuation processes play an important role in controlling seagrass distribution. Additionally, seagrasses found in turbid waters have higher light requirements than those found in clearer waters (Duarte, 2007). Various water column and sediment stressors can decrease the amount of irradiance reaching the benthos and reduce plant photosynthetic efficiency. Decreased photosynthetic activity curtails the translocation of oxygen to belowground tissues and the rhizosphere (Mateo et al., 2006). As a result, belowground tissues undergo anaerobic conditions and deplete carbohydrate reserves, which can lead to declines in seagrass abundance.

Measure: Percentage of incident light reaching the benthos

Tier: 2 (rapid field measurement)

Measurement: Surface or underwater irradiance measurements of photosynthetically active radiation (PAR; ca. 400–700 nm) are collected using LI-COR quantum or spherical sensors. Percent surface irradiance (% SI) available at the seagrass canopy is derived using LI-COR or secchi depth measurements, and is calculated as follows:

$$\%\ \mathrm{SI} = \left(\frac{\mathrm{I_z}}{\mathrm{I_0}}\right) \times 100 \quad \text{(LI-COR)}$$

$$\%\ \mathrm{SI} = \mathrm{e}^{(-\mathrm{k_d z})} \times 100 \quad \text{(Secchi)}$$

where I_z and I_0 are irradiance (µmol photons $m^{-2}sec^{-1}$) at depth (*z*; meters) and just below the water surface, respectively. Percent surface irradiance is determined using the light attenuation coefficient and maximum depth penetration, *z*. Light attenuation is calculated using the transformed Beer-Lambert equation:

$$\mathrm{k_d} = \frac{-\left[\ln\left(\frac{\mathrm{I_z}}{\mathrm{I_0}}\right)\right]}{\mathrm{z}}$$

where k_d is the light attenuation coefficient (m^{-1}) and can be determined using PAR measurements or secchi depths. The secchi depth (meters) is the point in the water column at which the black and white disk can no longer be seen from the surface. Where secchi depths are measured and recorded, the light attenuation coefficient is calculated following Giesen et al. (1990):

$$\mathrm{k_d} = \frac{1.65}{\text{Secchi depth}}$$

Metric Rating and Assessment Points:

Metric Rating	Percent Surface Irradiance (% SI)
Good/Excellent	> 30%
Fair	20–30%
Poor	< 20%

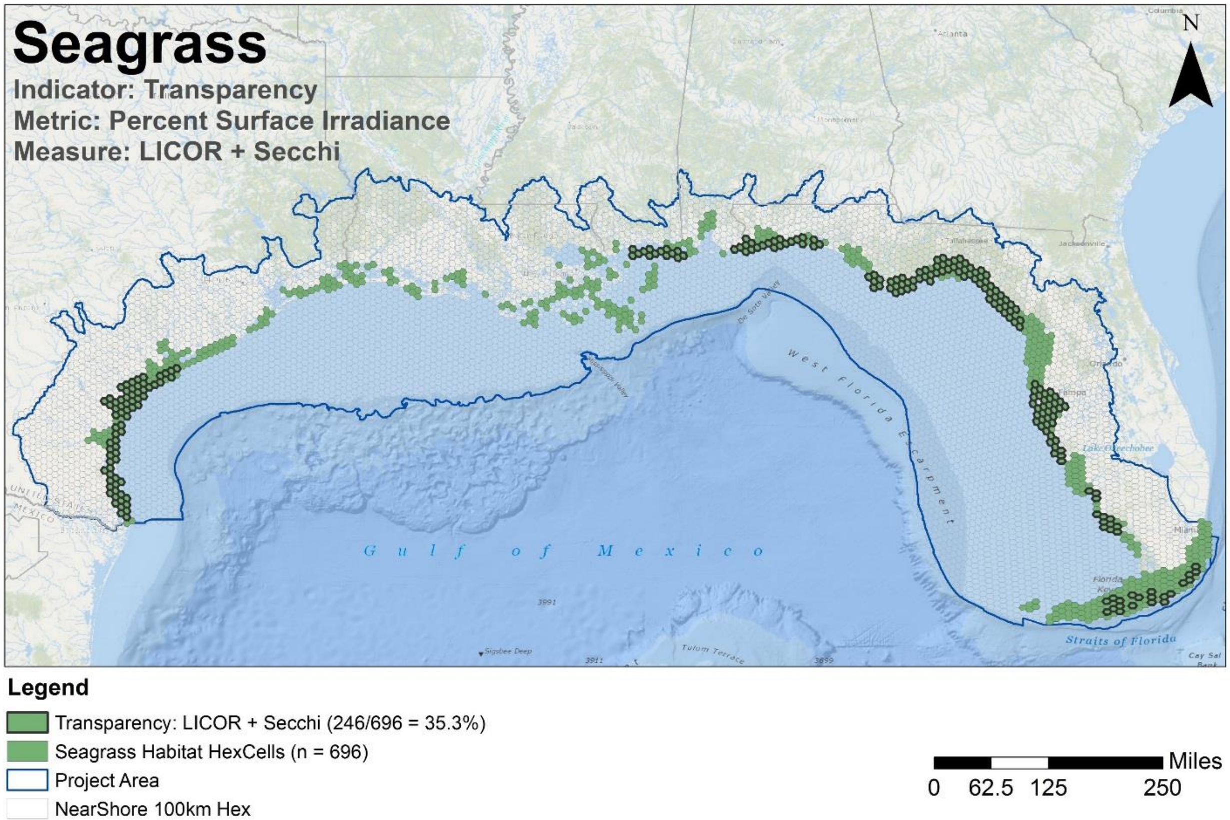
Scaling Rationale: Assessment points were established using natural data ranges observed in the literature. *Halodule wrightii, Syringodium filiforme,* and *Thalassia testudinum* in Indian River Lagoon, Florida, require 33% of SI (Steward et al., 2005), whereas *T. testudinum* in Tampa Bay, Florida, needs 23% SI (Tomasko and Hall, 1999). Dunton (1994) determined that *H. wrightii* requires a minimum of 18% SI in Texas; however, in Florida, surface irradiance for *H. wrightii* was 25–27% SI (Choice et al., 2014). Additionally, irradiance is not as limiting in Florida Bay, where waters are clearer (ranged from 44–70% of SI; Fourqurean et al., 2015) unlike other coastal environments that have greater turbidity.

Analysis of Existing Monitoring Efforts:

Geographic*:* Percent surface irradiance as measured either by Secchi Depth or LI-COR is moderately well collected geographically in the NGoM, with 35% of habitat hexagons containing at least one monitoring site using either method. Monitoring locations for this metric are somewhat well distributed across the NGoM. Collections are missing in Louisiana and parts of Texas.

Programmatic: Data for this metric are collected by 17/38 (49%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Percent Surface Irradiance (measured by either LI-COR or Secchi Depth)	38	17	45%	35%

Indicator: Phytoplankton Biomass

MEF: Abiotic Factors
KEA: Water Quality
Metric: Chlorophyll *a* Concentration (μg L^{-1})

Definition: Chlorophyll *a* concentration is used as a proxy for the biomass of primary producers and is a measure of trophic condition.

Background: Chlorophyll *a* is frequently used as a measure of phytoplankton biomass, as planktonic primary production closely reflects algal biomass. Algal biomass is often associated with eutrophication, where an excess input of nutrients into near-shore waters can fuel algal production (Nixon, 1995; Smith et al., 1999). Light requirements for phytoplankton are minimal (1% SI; Strickland, 1958), allowing them to proliferate under low light conditions. Seagrasses, however, have high light requirements and the decreased light availability due to algal blooms can result in seagrass decline (Cloern, 2001).

Rational for Selection of Variable: Phytoplankton blooms are sensitive to nutrient loading and availability, providing a measure of overall water quality. There is a strong positive correlation between chlorophyll *a* and light attenuation (Dennison et al., 1993; Abal and Dennison, 1996), and this relationship controls seagrass survival and maximum depth distribution.

Measure: Chlorophyll *a* (μg L^{-1})

Tier: 2 (rapid field measurement)

Measurement: Water samples are collected, and a known volume of water sample is filtered onto a glass filter. The filters, with particulates, are stored in a dark vial and are immediately frozen until further processing. Acetone is used to extract chlorophyll *a* from phytoplankton cells and the extract is analyzed on a fluorometer (Strickland and Parsons, 1972).

Metric Rating and Assessment Points:

Metric Rating	Chlorophyll *a* Concentration (μg L^{-1}) for Clastic Sediments
Good/Excellent	0–10.0 μg L^{-1}
Fair	10.0–25.0 μg L^{-1}
Poor	> 25.0 μg L^{-1}

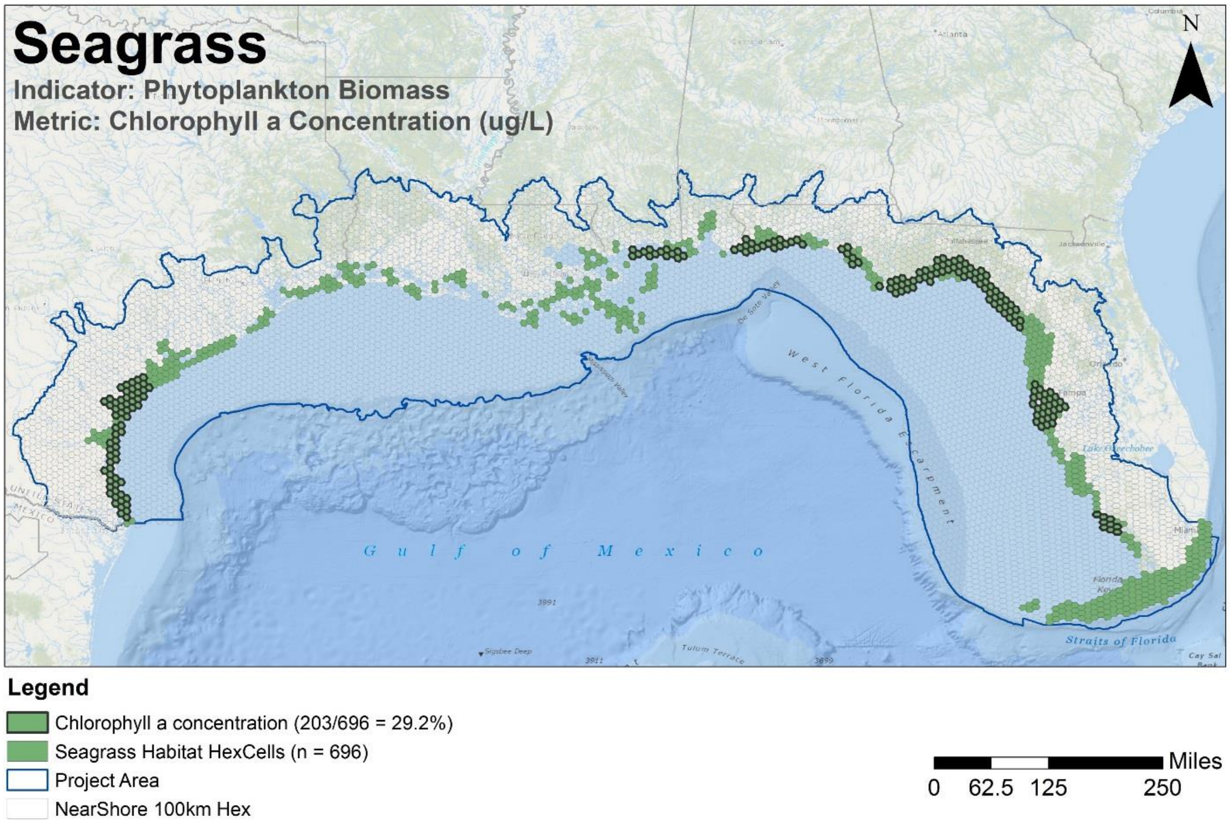
Scaling Rationale: Metric ratings and assessment points are partitioned by sediment type (clastic or carbonate) because the range of chlorophyll *a* concentration is generally higher in siliceous environments that support seagrasses. Assessment points for carbonate sediments follow those prescribed by Boyer et al. (2009), and for clastic sediments, historical datasets (chlorophyll *a* ranges) were used, because Texas waters are generally more turbid (Onuf, 1994; 1996). Additionally, Dennison et al. (1993) found that sites with persistent or fluctuating seagrass beds at depths of 1m or greater occurred when median chlorophyll concentrations were < 15 μg L^{-1}.

Analysis of Existing Monitoring Efforts:

Geographic*:* Chlorophyll *a* concentration is moderately well collected geographically in the NGoM, with 29% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are somewhat well distributed across the NGoM, but measures are missing in Louisiana, parts of Texas, and the Florida Keys.

<u>Programmatic:</u> Data for this metric are collected by 12/38 (32%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Chlorophyll *a* Concentration	38	12	32%	29%
• Spatial footprint unavailable for one monitoring program. Percent of hexagons containing monitoring sites may be an underestimate.				

Indicator: Sediment Load

MEF: Abiotic Factors
KEA: Water Quality
Metric: Total Suspended Solids (TSS; mg L^{-1})

Definition: The concentration of organic and inorganic particles suspended in the water column. Elevated levels of total suspended solids (TSS) can impair water quality by increasing light attenuation.

Background: TSS and light attenuation are tightly coupled, where high concentrations of TSS reduce water transparency (Dennison et al., 1993). Concomitant increases in TSS and light attenuation decrease the light available for photosynthesis, which can deplete carbohydrate reserves when respiration exceeds photosynthesis. In adjacent watersheds, human activities including coastal engineering, boating, and dredging (Onuf, 1994) decrease light availability by increasing sedimentation. Shallow bays may also naturally exhibit greater TSS concentrations driven by wind events (Onuf, 1996).

Rational for Selection of Variable: Seagrasses grow in shallow, near-shore coastal waters, receiving sediment inputs from nearby watersheds. Due to their proximity to these inputs, combined with their hydrologic setting, seagrasses are extremely sensitive to increased sedimentation and decreased water quality resulting in seagrass loss (Orth et al., 2006). Denuded locations often have high turbidity associated with increased sediment loading and re-suspension. These locations are subject to further seagrass loss and bed degradation when coupled with wind-driven wave and current erosion.

Measure: Total suspended solids (TSS; mg L^{-1})

Tier: 2 (rapid field measurement)

Measurement: Measure gravimetrically following the EPA Method 106.2. A well-mixed water sample is filtered through a glass fiber filter to capture the particulate matter. The analyte is dried overnight, cooled in a desiccator, and weighed. Total suspended solids are calculated as:

$$\mathrm{TSS\ (mg\ L^{-1})} = 1000 \times (\mathrm{A} - \mathrm{B}) \times \left(\frac{1000}{\mathrm{C}}\right)$$

where A = weight of filter + analyte (mg), B = weight of filter (mg), and C = volume of sample water filtered (mL).

Metric Rating and Assessment Points:

Metric Rating	Total Suspended Solids (TSS) (mg L^{-1})
Good/Excellent	< 15 mg L^{-1}
Fair	15–25 mg L^{-1}
Poor	> 25 mg L^{-1}

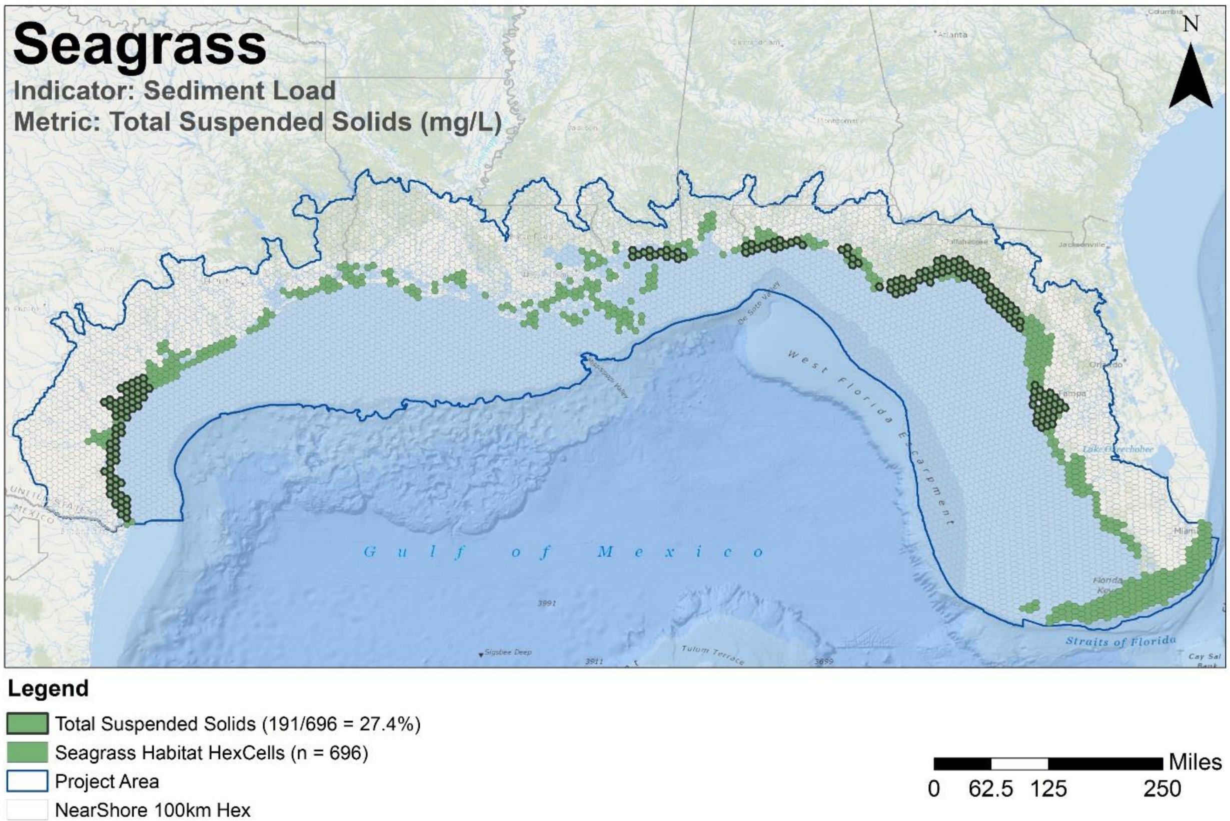
Scaling Rationale: Assessment points and ratings were developed using the median reported value of 15 mg L^{-1} by Dennison et al. (1993) for Chesapeake Bay. They found that sites consisting of persistent or variable seagrass beds occurred in locations that exhibited TSS near this value. These findings are in agreement with historical datasets for the Texas coast and Florida Bay, where values < 15 mg L^{-1} are considered good/excellent conditions.

Analysis of Existing Monitoring Efforts:

Geographic*:* Total suspended solids are moderately well collected geographically in the NGoM, with 27% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric occur in all states but Louisiana, with gaps in parts of Texas and Florida south of Tampa Bay, including the Keys.

Programmatic: Data for this metric are collected by only 3/38 (6%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Total Suspended Solids	38	12	32%	27%

- Very large spatial footprints for two monitoring programs made assessment of sampling sites uncertain, and they were omitted from the map.
- For two monitoring programs there is some uncertainty whether the metrics measured were the same, so they were omitted from the map.
- Percent of hexagons containing monitoring sites may be an underestimate.

Indicator: Change in Areal Extent

MEF: Ecosystem Structure
KEA: Abundance
Metric: Areal Extent (% change yr^{-1})

Definition: The change in seagrass extent (square kilometers or hectares) over time. This is a coarse resolution of seagrass distribution and provides information over very large spatial and long temporal scales.

Background: Areal extent measurements are typically acquired using airborne or satellite remote sensing methods, where imagery is obtained every five years or so. Areal extent is useful for monitoring programs, as it quantifies seagrass distribution over large geographic areas. Despite coarse resolution, seagrass areal extent is sensitive to anthropogenic stressors and can be used to detect change (Latimer and Rego, 2010).

Rational for Selection of Variable: The areal extent of seagrass beds in the NGoM rivals the known distribution of all countries, with the exception of Australia and Indonesia (Green and Short, 2003). To identify major status and trends such as bed expansion, retraction, and patchiness, two main levels of resolution are acquired. Low-resolution, remotely sensed imagery captures broad-scale changes in seagrass distribution, and high-resolution photo imagery can identify changes in edge dynamics (Dunton et al., 2011). Changes observed in the maximum depth distribution, as revealed from areal extent, are integrative and can reveal light and water quality issues. As imagery is collected every five to 10 years, changes and/or patterns in seagrass distribution can be identified at a spatiotemporal scale.

Measure: Areal extent m^2 or hectares

Tier: 1 (remotely sensed)

Measurement: Large-scale assessments characterizing seagrass distribution are acquired by remote sensing using 1:24,000 scale true color imagery. For finer resolution under Tiers 2 and 3, high-resolution imagery (1:96,000) should be attained (Dunton et al., 2011). Ideally, benthic ecosystem and mapping should include both resolution scales and occur at a minimum every two to five years to detect the percent of change over time.

Metric Rating and Assessment Points:

Metric Rating	Areal Extent (% change yr^{-1})
Good/Excellent	0–25% increase
Fair	< 25% decrease
Poor	> 25% decrease

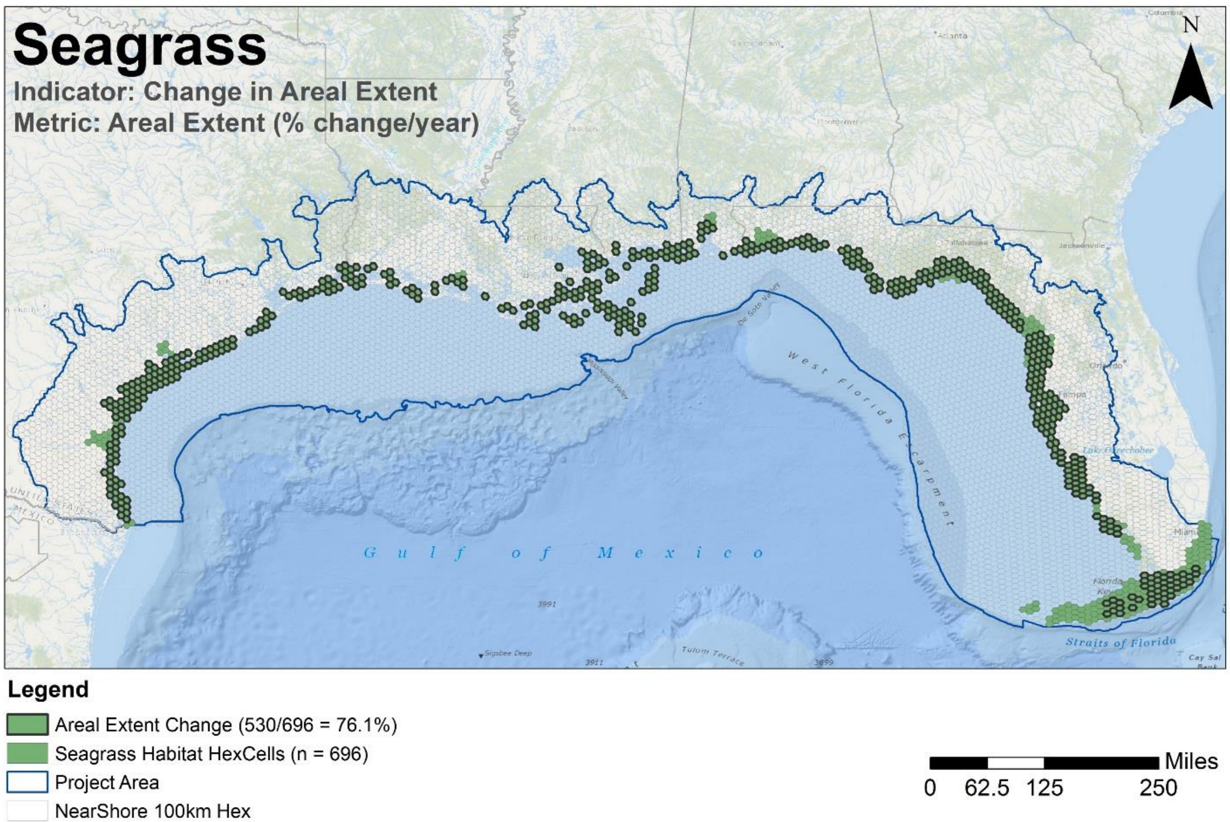
Scaling Rationale: Because areal extent covers a large geographical region, it is not species-specific and assesses change on a bed level. Assessment points were developed using the concept of the Braun-Blanquet cover-abundance scale (BBCA; Braun-Blanquet, 1972), which is commonly used to survey seagrass abundance. The difference between two consecutive scores is equivalent to 25% and is the minimal detectable change in the BBCA scale.

Analysis of Existing Monitoring Efforts:

Geographic*:* Areal extent is very well collected geographically in the NGoM, with 76% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are very evenly distributed across the NGoM.

Programmatic: Data for this metric are collected by 33/38 (87%) programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Areal Extent	38	33	87%	76%

Indicator: Change in Cover

MEF: Ecosystem Structure
KEA: Abundance
Metric: Percent Cover (% change year^{-1})

Definition: Percent cover describes the fraction of the sea floor that is obscured by vegetation within a predetermined area. The change in percent cover of each seagrass species (*Thalassia testudinum*, *Halodule wrightii*, *Syringodium filiforme*, *Halophila engelmannii*, *Halophila decipiens* and *Ruppia maritima*) in the NGoM is determined on an annual basis typically during peak leaf-on conditions.

Background: Global declines in seagrass cover stemming from human alteration of the coastal environment are well documented (Orth et al., 2006; Waycott et al., 2009). Seagrasses in the NGoM comprise nearly 50% of total US seagrass extent (Green and Short, 2003). Measures of plant abundance, such as percent cover, are useful in assessing ecosystem condition, as changes in cover signify natural and anthropogenic perturbations (Lewis et al., 1985; Quammen and Onuf, 1993; Fourqurean et al., 2001; Short et al., 2006a).

Rational for Selection of Variable: Percent cover is an efficient and cost-effective measure of seagrass condition and is sensitive enough to detect spatial and temporal changes in seagrass abundance (Neckles et al., 2012). Numerous monitoring programs and agencies routinely collect percent cover (e.g., Texas Seagrass Monitoring Program, South Florida Fisheries Habitat Assessment Program, Florida Keys National Marine Sanctuary Seagrass Monitoring Project, National Park Service, and Dauphin Island Sea Lab Seagrass Monitoring) because it is relatively inexpensive, robust, and highly replicable (Fourqurean et al., 2001; Neckles et al., 2012).

Measure: Percent cover (estimated)

Tier: 2 (rapid field measurement)

Measurement: Seagrass sampling is conducted at permanent stations annually, usually in midsummer during the time of peak biomass (Krause-Jensen et al., 2004; Neckles et al., 2012). Seagrass percent cover by species is visually estimated (0 to 100%) by vertical observation using a framed quadrat. Cover should be standardized according to the photographic reference manual published in Short et al. (2006b). It is recommended that observers are trained and familiarized with these percent cover standards to minimize bias (Krause-Jensen et al., 2004). Cover measurements may also be determined using a visual assessment technique developed by Braun-Blanquet (1972), where seagrass cover is categorized into abundance classes and scored as: 5 = > 75 %; 4 = 51–75 %; 3 = 26–50 %; 2 = 6–25%; 1 = ≤ 5%; 0 = 0% (modified from Fourqurean et al., 2001; Neckles et al., 2012). Although data from these methods are reported differently, cover estimates following the methods of Short et al. (2006b) are comparable and can be converted into modified cover classes of the BBCA scale. Alternatively, Braun-Blanquet (BB) scores can be converted to percent cover values (van der Maarel, 2007). First, the raw BB scores are converted to ordinal transfer values (OTV) of 1–9 using a “combined transformation,” which is a combination of a cover scale in angular transformation with a weighting based on abundance (van der Maarel, 1979). Then, the OTV is converted to percent cover values using the following equation:

$$\ln C = (OTV - 2)/a$$

In this equation, *C* = cover %, OTV = 1–9 Ordinal Transfer Value, and *a* = factor weighting the cover values (1.380 or 1.415). Additionally, if percent cover or BBCA measurements are not collected, the frequency of seagrass occurrence can also be applied by determining the proportion of binary presence/absence responses.

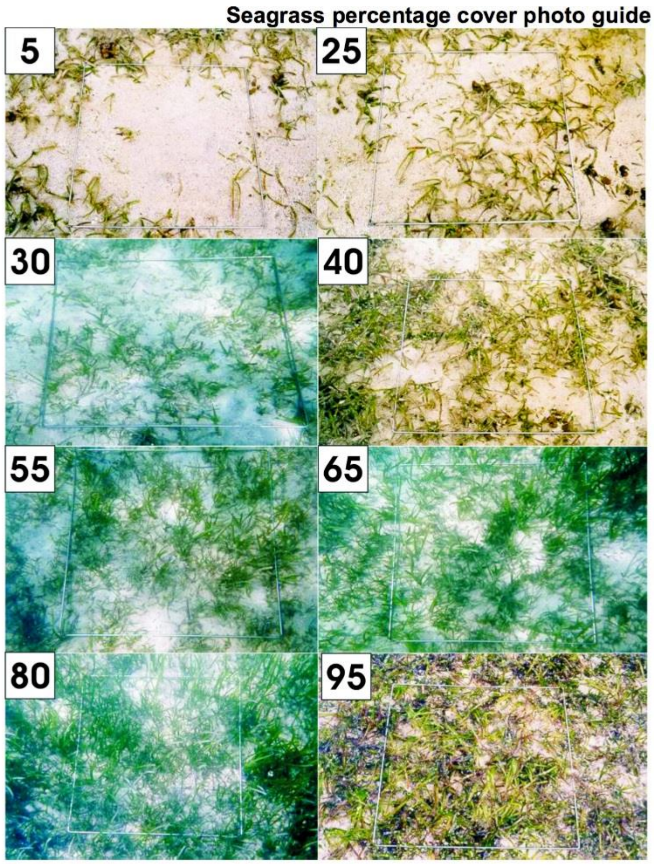


Figure 4.24. *Seagrass Cover Reference Manual published in Short et al., 2006b.*

Metric Ratings and Assessment Points:

Metric Rating	Percent Cover Greater than 50% (% change yr^{-1})
Good/Excellent	0–25% increase
Fair	< 25% decrease
Poor	> 25% decrease

Metric Rating	Percent Cover Less than 50% (% change yr^{-1})
Good	< 10% decrease
Poor	> 10% decrease

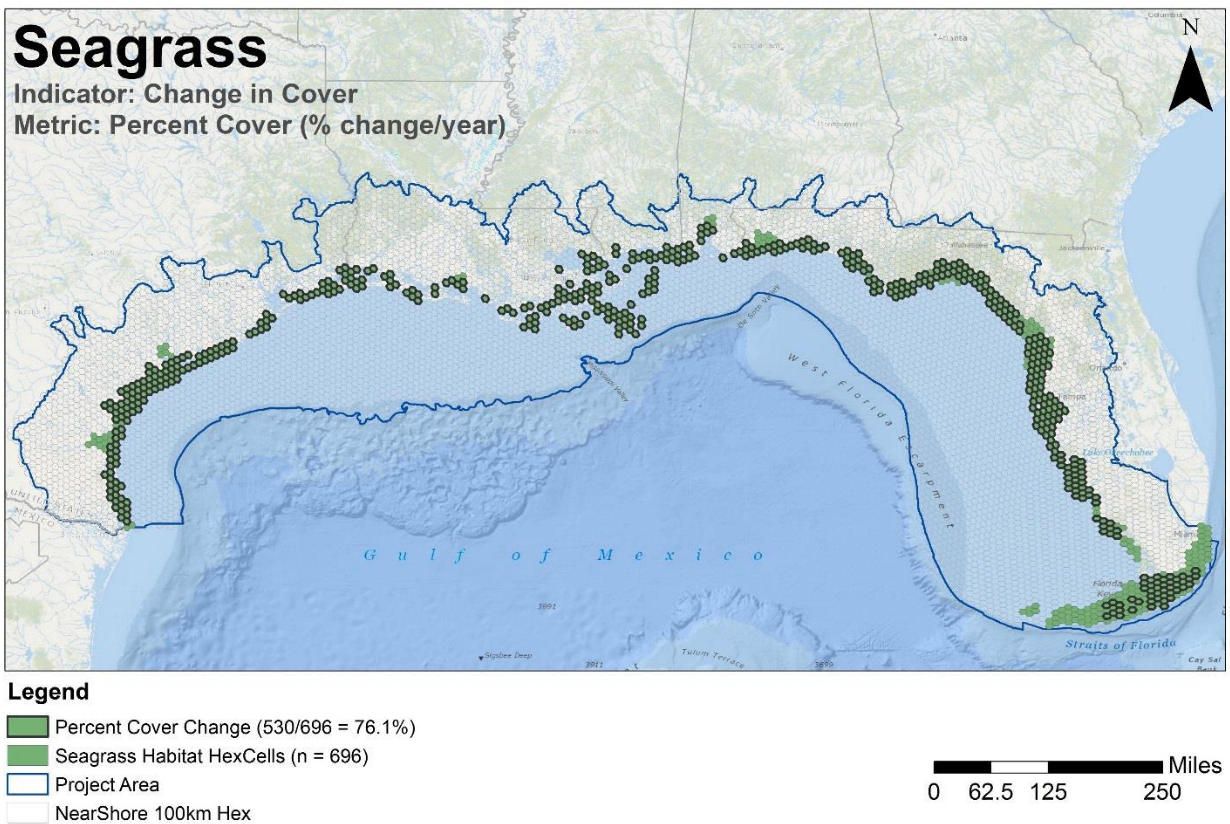
Scaling Rationale: Changes in percent cover are assessed at the basin/bay scale (or the scale of inference) across time and identified at the species level. Assessment points for percent cover are separated into two categories, as some regions are naturally composed of sparser seagrass beds. For example, Fourqurean et al. (2003) found that the probability of a station composed of sparse beds of *T. testudinum* (< 25% cover) in Florida Bay was greater than 50%. This is not unusual for east Florida Bay, as this region is consistently documented with sparse seagrass cover (Zieman et al., 1989; Durako, 1994; Hall et al., 1999). The assessment points for greater than 50% cover were determined using the minimal detectable change of a BBCA; however, assessment points for less than 50% cover were set lower due to sparseness.

Analysis of Existing Monitoring Efforts:

Geographic*:* Percent cover is very well collected geographically in the NGoM, with 76% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are very evenly distributed across the NGoM, with multiple locations in all states.

Programmatic: Data for this metric are collected by 32/38 (84%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Percent Cover	38	32	84%	76%
• Very large spatial footprints for two monitoring programs made assessment of sampling sites uncertain, and they were omitted from the map.				

Indicator: Seagrass Species Composition

MEF: Ecosystem Structure
KEA: Plant Community Structure
Metric: Species Dominance Index (Ratio Change yr^{-1})

Definition: The Species Dominance Index (SDI) provides a measure of diversity by evaluating the degree to which a seagrass species dominates a certain area.

Background: Species diversity is important because community structure and composition influence ecosystem productivity (Lavery et al., 2013). Shifts in species composition can occur when plants undergo extreme stress events brought on by environmental variability. For example, long-term fertilization experiments conducted in Florida Bay illustrate the influence of nutrient additions on seagrass communities. Excremental waste produced by roosting birds was responsible for shifts in species dominance between *T. testudinum* and *H. wrightii* (Howard et al., 2016). Several regions in both Texas and Florida Bay are composed of either *T. testudinum* or *H. wrightii* monocultures; therefore, the index incorporates the concept of a target species, which is the highest species in succession that a bay/basin can support. Target species are identified in order of succession and can vary by region: *H. wrightii*, *S. filiforme* or *T. testudinum*.

Rational for Selection of Variable: Diversity is important for ecosystem resilience, and dense monocultures are susceptible to mass mortality if the conditions present themselves. A suite of environmental conditions control seagrass abundance, distribution, and composition, where interspecific differences in physiology dictate spatial distribution. The SDI (adapted from Madden et al., 2009) provides flexibility for regions that experience extreme environmental conditions, which are inherently low in diversity.

Measure: Species percent cover-abundance

Tier: 2 (rapid field measurement)

Measurement: Species abundances are determined using the Braun-Blanquet cover-abundance scale or percent cover observations following the methods supplied for the metric (percent cover). The Relative Species Composition of the dominant species (RSC_{DOM}) at the site is determined by dividing the mean abundance (D) of the dominant species (D_{DOM}) by the summed mean abundances as follows:

$$RSC_{DOM} = \frac{D_{DOM}}{D_{HD} + D_{HE} + D_{RM} + D_{Target} + D_{DOM}} \qquad \text{(Florida)}$$

$$RSC_{DOM} = \frac{D_{DOM}}{D_{HE} + D_{RM} + D_{Target} + D_{DOM}} \qquad \text{(Texas)}$$

where *Halophila decipiens* (D_{HD}), *Halophila engelmannii* (D_{HE}), *Ruppia maritima* (D_{RM}) and D_{Target}. The targeted species (D_{Target}) is the highest species in succession that the area can support, which is one of the following: *Halodule wrightii*, *Syringodium filiforme* or *Thalassia testudinum*. The relative species composition of the dominant species is then applied to the following equation to determine SDI:

$$\text{Species Dominance Index (SDI)} = 1.25 \times (1 - \text{RSC}_{\text{DOM}}) \qquad \text{(Florida)}$$

$$\text{Species Dominance Index (SDI)} = 1.3 \times (1 - \text{RSC}_{\text{DOM}}) \qquad \text{(Texas)}$$

where index values are on a 0–1 scale. Values closer to 0 indicate dominance by a single species and mixed compositions exhibit values near 1.

Metric Rating and Assessment Points:

Metric Rating	Species Dominance Index (ratio change yr^{-1})
Good/Excellent	No change or increase
Fair	< 0.25 decrease
Poor	> 0.25 decrease

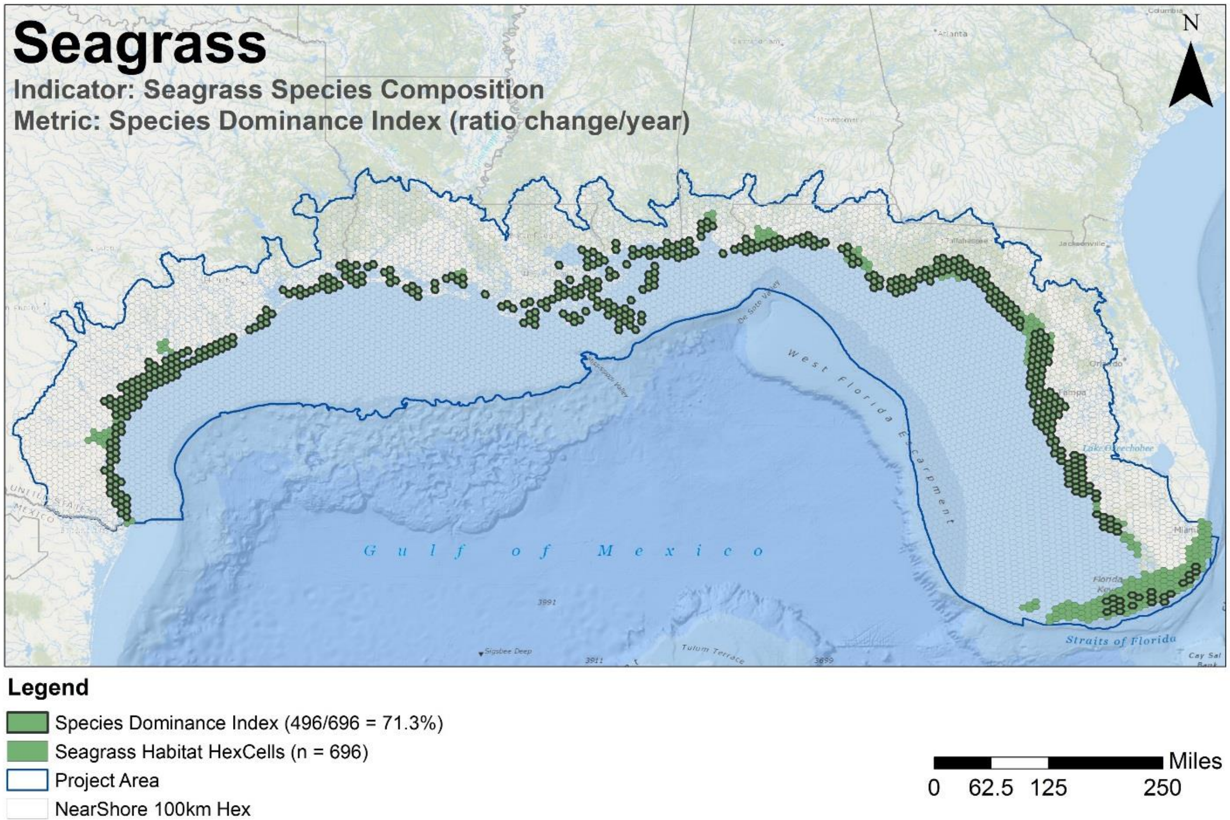
Scaling Rationale: Seagrass communities that remain relatively stable or approach greater diversity are rated as good/excellent. Changes greater than 0.25 in the Species Dominance Index are equivalent to the loss of one species, assuming all four/five species are equally represented, ultimately reducing diversity. These ranges are consistent with the upper and lower metric bounds established by Madden et al. (2009).

Analysis of Existing Monitoring Efforts:

<u>Geographic</u>*:* Species dominance is very well collected geographically in the NGoM, with 71% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are very evenly distributed across the NGoM, with multiple monitoring sites in each state.

<u>Programmatic:</u> Data for this metric are collected by 30/38 (79%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Species Dominance Index	38	30	79%	71%

- Very large spatial footprints for one monitoring program made assessment of sampling sites uncertain, and it was omitted from the map.
- For one monitoring program, there is some uncertainty whether the metrics measured were the same, so it was omitted from the map.
- Percent of hexagons containing monitoring sites may be an underestimate.

Indicator: Shoot Allometry

MEF: Ecosystem Structure
KEA: Morphology
Metric: Leaf Length (% change yr^{-1})

Definition: Leaf length is determined by measuring the distal blade, extending from the meristem to the blade tip. Shoot length characterizes the canopy structure (canopy height) and responds to environmental changes by increasing or decreasing over time.

Background: Blade length, which determines canopy height, is sensitive enough to illustrate changes in water quality; however, seagrasses may exhibit different structural responses to the same stressor. The degree of these effects can vary by species in their response time to alterations in temperature, light, and nutrient climates (Gordon et al., 1994; Longstaff and Dennison, 1999; Lee and Dunton, 2000). Generally, low light availability results in decreased leaf length (Dunton, 1994; Gordon et al., 1994), where environmental shading caused declines in *T. testudinum* leaf measurements in Tampa Bay, Florida (Hall et al., 1999). Photoacclimatory responses such as leaf elongation can initially occur as a way to capture more light (Czerny and Dunton, 1995; Longstaff and Dennison, 1999); however, plant growth is not sustained during prolonged periods of exposure and growth decreases. Additionally, Lee and Dunton (2000) performed nutrient enrichment treatments in *T. testudinum* beds in Laguna Madre, Texas and showed that shoot length increased in fertilized plots, which is consistent with findings from Powell et al. (1989) in Florida Bay, Florida.

Rational for Selection of Variable: Changes in leaf length over time suggest that changes in water quality or chemistry are occurring. Blade length generally decreases under light limitation and increases with nutrient enrichment.

Measure: Shoot leaf length (% change yr^{-1})

Tier: 2 (rapid field measurement)

Measurement: Shoot leaf length is determined by measuring the photosynthetic tissue of aboveground biomass only. If quantifying in situ, shoots and blades are stretched to their maximum height, excluding the tallest 20% of leaves, providing an estimate for 80% of the canopy (Short et al., 2003). Shoots collected in biomass samples or quadrats can be processed for leaf length by measuring the longest leaves of randomly selected shoots. The quantity selected to subsample should provide a close representation of the mean, which can then be multiplied by 80% to obtain a comparable representation (Short et al., 2003). Shoot length must be compared during the same season across years due to temperature related growth differences (Dunton, 1994).

Metric Rating and Assessment Points:

Metric Rating	Leaf Length (% change yr^{-1})
Good/Excellent	< 10%
Fair	10–25%
Poor	> 25%

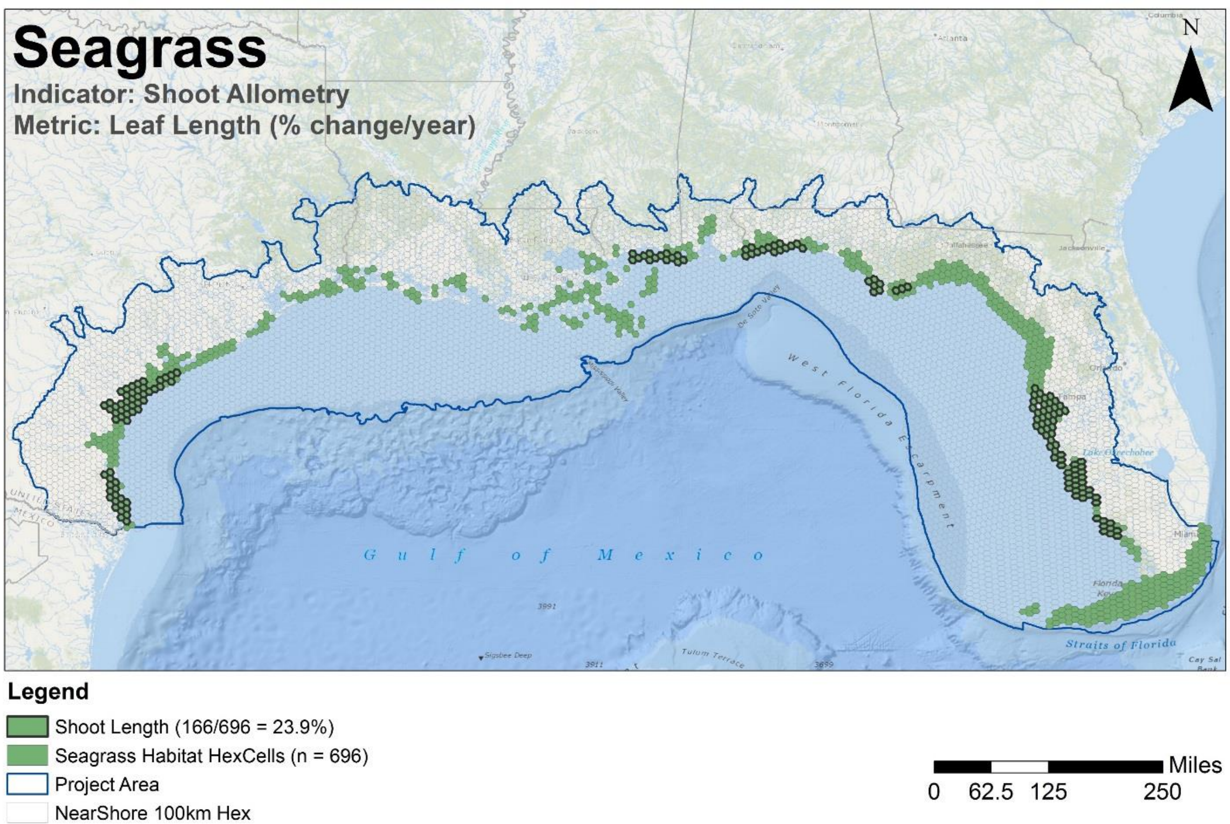
Scaling Rationale: Because morphological plasticity in response to changes in environmental conditions is variable by species (Ralph et al., 2007), the assessment points were derived from the net growth or reduction in shoot length. These ratings were developed using historical datasets for the Texas coast and Florida Bay. Shoot leaf length provides an estimate of canopy height at the bed level and can be scaled up to the basin/bay level for all NGoM seagrass species.

Analysis of Existing Monitoring Efforts:

Geographic*:* Leaf length is less well collected geographically in the NGoM, with 24% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are patchily distributed across the NGoM, with no collection sites in Alabama, Louisiana, parts of Texas, or the Big Bend of Florida.

Programmatic: Data for this metric are collected by 13/38 (34%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Leaf Length	38	13	34%	24%

Indicator: Shoot Allometry

MEF: Ecosystem Structure
KEA: Morphology
Metric: Leaf Width (% change yr^{-1})

Definition: Seagrass leaves that exhibit a change in width (narrowing or widening) over time imply changes in light or nutrient regimes.

Background: As integrators of water quality, changes in seagrass shoot characteristics indicate important alterations in nutrient or light availability in the environment. Reductions in irradiance result in decreased plant size (Gordon et al., 1994; Lee and Dunton, 1997), where blades of *T. testudinum* narrowed in response to low light conditions (Hall et al., 1991; Dunton, 1994). Conversely, leaf width increased in *T. testudinum* when exposed to nutrient enrichment (Powell et al., 1989).

Rational for Selection of Variable: Seagrass blade width responds to various environmental stressors on the scale of weeks to months depending on species size (Roca et al., 2016). When light is limiting, *T. testudinum* blade width decreases (Dunton, 1994); therefore, reductions in leaf width signify changes in water quality and indicate possible impairment. Additionally, an increase in blade width may indicate a shift in nutrient availability. Powell et al. (1989) and Lee and Dunton (2000) found that N enrichment resulted in increased blade width.

Measure: Shoot leaf width (mm)

Tier: 3 (intensive field measurement)

Measurement: Shoots collected in biomass samples or extracted from a quadrat are processed for leaf width by measuring a number of randomly selected shoots, where the width of the leaf is measured to the nearest millimeter. Samples must be obtained during maximum production (summer; Dunton, 1994) to eliminate the effect of growth associated with the normal growing season. Synchronous sampling will allow a temporal comparison of width measurements. The change in blade width is only applicable to *T. testudinum*, as the other seagrass species in the NGoM are generally too narrow to measure (Powell et al., 1989).

Metric Rating and Assessment Points:

Metric Rating	Leaf Width (% change yr^{-1})
Good/Excellent	< 10%
Fair	10–25%
Poor	> 25%

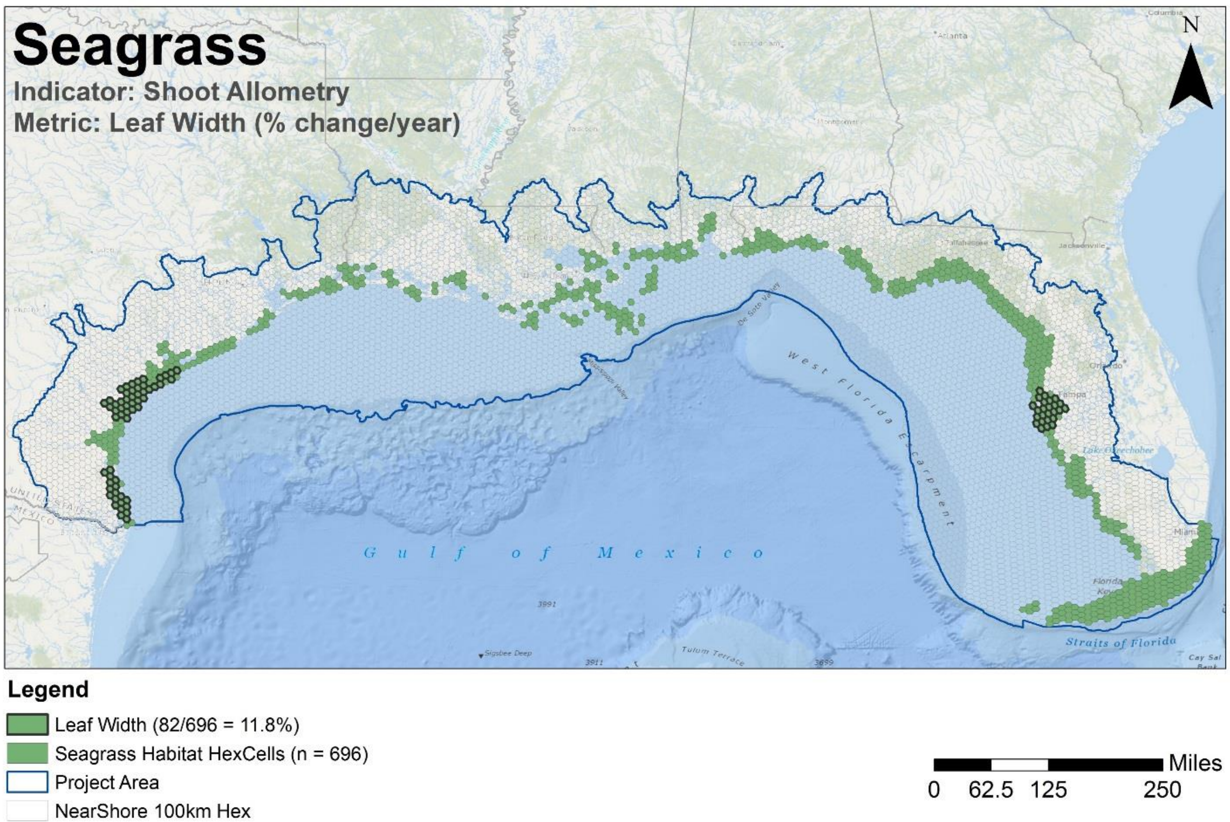
Scaling Rationale: Assessment points were derived using measurements from historical datasets for Florida Bay and the Texas coast. Lee and Dunton (2000) found that *T. testudinum* leaf widths from fertilized plots significantly increased (> 25%) relative to control plots during the summer. Additionally, there was no difference between experimental and control plots when the change in leaf width was < 10%. Findings from this study, in conjunction with historical datasets, helped formulate the metric ratings and assessment points for leaf width.

Analysis of Existing Monitoring Efforts:

<u>Geographic</u>*:* Leaf width is less well collected geographically in the NGoM, with 12% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are found only in Southern Texas and the Tampa Bay area of Florida.

<u>Programmatic:</u> Data for this metric are collected by only 3/38 (8%) of programs representing collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Leaf Width	38	3	8%	12%

Indicator: Nutrient Content

MEF: Ecosystem Structure
KEA: Chemical Constituents
Metric: Nutrient Limitation Index

Definition: The Nutrient Limitation Index (NLI) is used to determine whether a plant, representative of a location, is nutrient limited. Positive or negative index values indicate N or P limitation, respectively (Campbell and Fourqurean, 2009). Additionally, an index value further from the "Seagrass Redfield Ratio (SRR)," referred to as a high index, indicates greater nutrient limitation.

Background: The elemental composition (carbon, nitrogen and phosphorus) of plant tissue is used to assess the condition and availability of nutrients for seagrass communities (Duarte, 1990). Redfield (1958) showed that the relative composition of C, N, and P of marine suspended particulate organic matter (phytoplankton) was 106:16:1 ("Redfield ratio"). The SRR, identified by Atkinson and Smith (1983) and Duarte (1990) was calculated ca. 30:1. Although marine environments are generally N-limited, certain areas may also exhibit P limitation. Seagrass beds can be exposed to spatial gradients in N or P availability, which is characteristic of Florida Bay (Fourqurean et al., 2005). Therefore, the index is particularly useful in determining if a sub-basin or region is N- or P-limited.

Rational for Selection of Variable: Seagrasses effectively integrate water column conditions into their tissues, and the proportion of nitrogen to phosphorus is used as a measure of environmental condition (Duarte, 1990). The nutrient composition of seagrass tissue relates to nutrient availability in the environment. It is well known that nutrient-sufficient seagrasses have a N:P ratio of 30:1 (Atkinson and Smith, 1983; Duarte, 1990); therefore, the degree of deviation from the Nutrient Limitation Index points to the extent and type of nutrient limitation.

Measure: Carbon, Nitrogen, Phosphorus content

Tier: 3 (intensive field measurement)

Measurement: Intact seagrass shoots are harvested, placed on ice, and returned to the laboratory for further processing. Leaves are gently scraped and rinsed in DI/milli-Q water to remove algal and faunal epiphytes. Cleaned seagrass tissues are dried to a constant weight at 60°C and homogenized by grinding to a fine powder using a mortar and pestle. Carbon and nitrogen content are determined using a CHN elemental analyzer (Fourqurean et al., 2005; Dunton et al., 2011). Phosphorus content is determined using a general method that involves oxidation and acid hydrolysis extraction and is analyzed by colorimetric analysis following the methods of Solórzano and Sharp (1980). Elemental ratios (C:N:P) are calculated on a mole:mole basis, where N:P is inserted into the following equation to derive NLI:

$$\text{Nutrient Limitation Index (NLI)} = 30 - \text{N:P}$$

High values indicate a greater degree of nutrient limitation, and negative or positive values imply phosphorus or nitrogen limitation, respectively.

Metric Rating and Assessment Points:

Metric Rating	Nutrient Limitation Index
Good/Excellent	0 to ±1
Fair	± 1 to 2.5
Poor	> ± 2.5

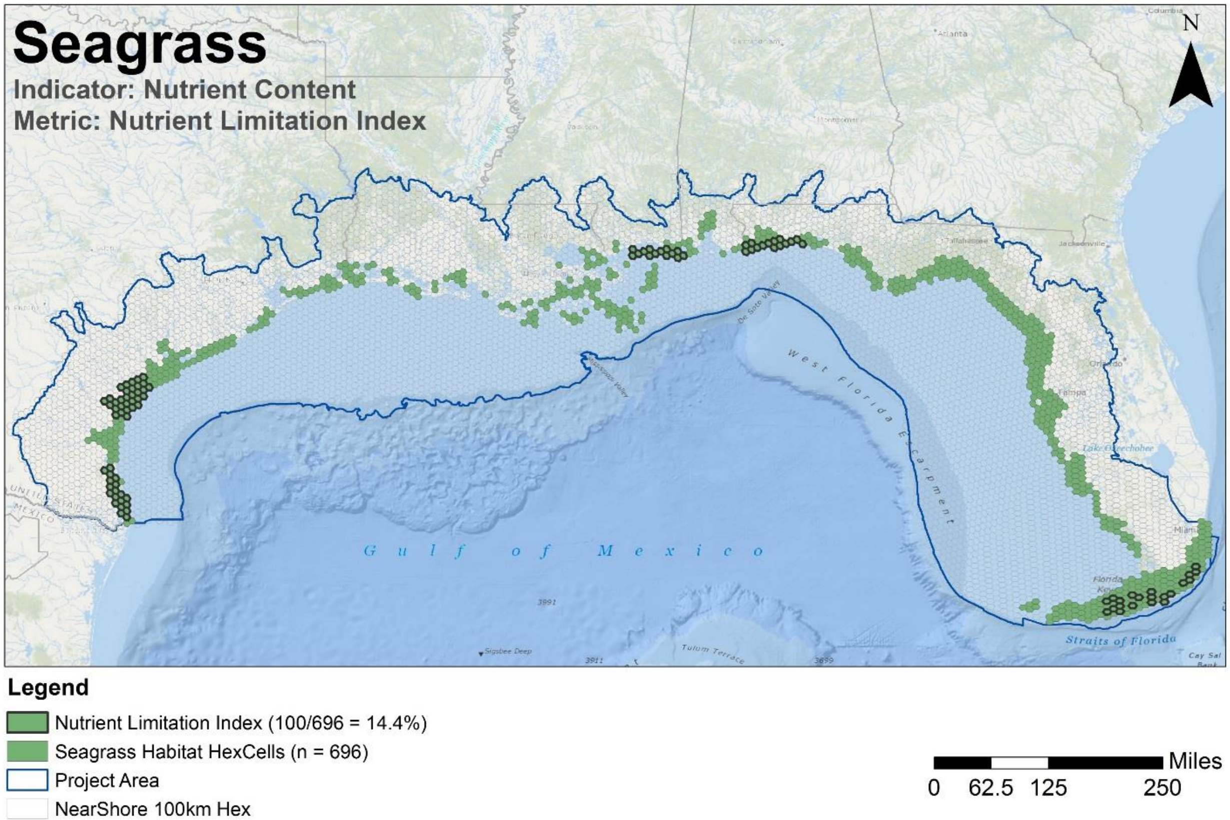
Scaling Rationale: Tissue N:P ratios approaching an SRR of 30:1 indicate nutrient balance (Atkinson and Smith, 1983; Duarte, 1990). Armitage et al. (2005) found that an N:P ratio of 31:1 for *T. testudinum* was not affected by N or P enrichment, suggesting a balance with N and P supply (Atkinson and Smith, 1983). This finding provided a baseline for the metric rating good/excellent. The remaining assessment points were developed using seasonal ranges that occur naturally in seagrass elemental stoichiometry in Florida Bay (Fourqurean et al., 2005). The source of nutrient limitation can be determined in combination with isotope ratios.

Analysis of Existing Monitoring Efforts:

<u>Geographic</u>*:* Data required to calculate the Nutrient Limitation Index are less well collected geographically in the NGoM, with 14% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are found in Southern Texas, Mississippi, Northern Florida, and the Florida Keys.

<u>Programmatic:</u> Data for this metric are collected by only 4/38 (11%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Nutrient Limitation Index	38	4	11%	14%
• Spatial footprint unavailable for one monitoring program. Percent of hexagons containing monitoring sites may be an underestimate.				

Indicator: Stable Isotope Ratios

MEF: Ecosystem Structure
KEA: Chemical Constituents
Metric: $\delta^{13}C$, $\delta^{15}N$ (‰ change yr^{-1})

Definition: Carbon and nitrogen isotopic ratios ($\delta^{13}C$, $\delta^{15}N$) are measured using the ratio of ^{13}C to ^{12}C and ^{15}N to ^{14}N, respectively.

Background: Stable isotope content is used to identify nutrient sources and processing in ecosystems (Dawson et al., 2002). The carbon isotopic signature ($\delta^{13}C$) is controlled by carbon source, irradiance, and temperature (Durako and Hall, 1992; Grice et al., 1996) and reflects the discrimination against ^{13}C during photosynthesis relative to ^{12}C (Durako and Hall, 1992). Optical water quality conditions are important in determining seagrass distribution and growth, where changes to light regimes result in large-scale seagrass loss (Dennison et al., 1993). Grice et al. (1996) demonstrated that seagrass species exposed to full sunlight exhibited less negative values. Thus, $\delta^{13}C$ signatures can be used to assess changes in environmental light and water quality conditions. The nitrogen isotopic signature ($\delta^{15}N$) provides information regarding the source of dissolved inorganic nitrogen. Enriched $\delta^{15}N$ signatures in benthic macrophytes have been linked to eutrophic marine ecosystems (McClelland et al., 1997). Sewage inputs and groundwater are isotopically heavy and are distinguished from other DIN influences by assessing the degree of fractionation from microbial processing in N cycling processes (i.e., denitrification, nitrification, and nitrogen fixation; Dawson et al., 2002). Additionally, artificial fertilizers have a $\delta^{15}N$ of near 0‰.

Rationale for Selection of Variable: Although seagrass $\delta^{13}C$ values exhibit a wide range of values and variation (McMillan et al., 1980; Hemminga and Mateo, 1996), their natural signatures can be used to reconstruct the environmental conditions that impact seagrass dynamics. Thus, $\delta^{13}C$ and $\delta^{15}N$ analyses of seagrass leaf tissue can provide important information about nutrient sources and processing in seagrass ecosystems.

Measure: Isotope ratios δ (‰)

Tier: 3 (intensive field measurement)

Measurement: Intact seagrass shoots are collected, placed on ice, and returned to the laboratory for further processing. Leaves are gently scraped and rinsed in DI/milli-Q water to remove algal and faunal epiphytes. Cleaned seagrass tissues are dried to a constant weight at 60°C and homogenized by grinding to a fine powder. Tissue samples are analyzed for carbon and nitrogen isotopic values ($\delta^{13}C$ and $\delta^{15}N$, respectively) using an Isotope-ratio Mass Spectrometer. Isotopic ratios (R) are reported in the standard delta notation:

$$\delta\ (‰) = \left[\left(R_{sample}/R_{standard}\right)\right] \times 1000$$

Metric Rating and Assessment Points:

Metric Rating	$\delta^{13}C$ and $\delta^{15}N$ (‰ change yr^{-1})
Good/Excellent	< 0.5‰
Fair	0.5 to 1.0‰
Poor	> 1.0‰

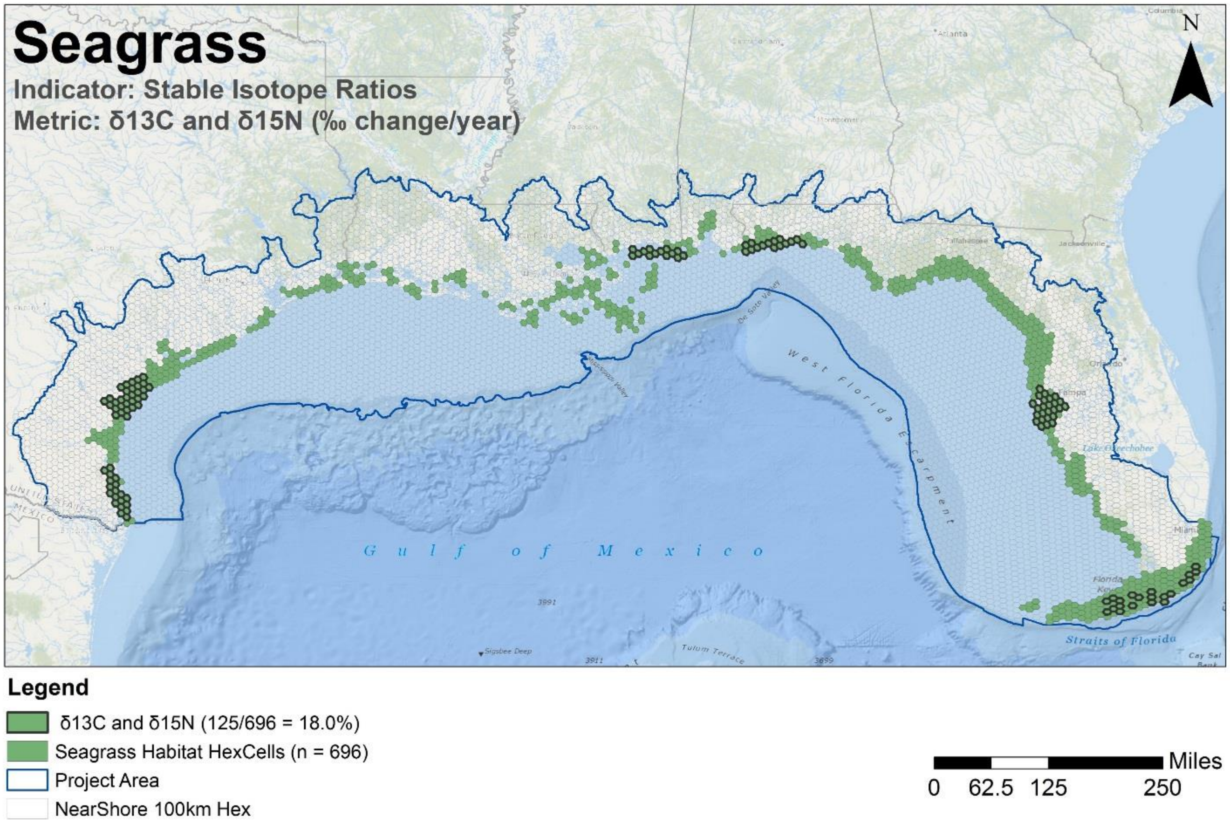
Scaling Rationale: The sinusoidal relationship, with amplitude of 0.5‰, between $\delta^{13}C$ and $\delta^{15}N$, and season were used to develop assessment points (Fourqurean et al., 2005). The amplitude was doubled to provide the seasonal range, values normally observed, and was set as the maximum boundary between a fair and poor rating. Therefore, values that fall outside the seasonal range indicate the influence of a nutrient source. It is strongly recommended that sampling occur during the same season for temporal continuity. Direct comparisons of $\delta^{13}C$ and $\delta^{15}N$ patterns can also reflect seasonal variation, where values peak in summer (Fourqurean et al., 2005) and can be easily misinterpreted. The type of limitation can be determined in combination with elemental ratios.

Analysis of Existing Monitoring Efforts:

Geographic*:* $\delta^{13}C$, $\delta^{15}N$ change is less well collected geographically in the NGoM, with 18% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric are patchily distributed across the NGoM. There are no monitoring sites in Alabama or Louisiana, and monitoring sites are patchily distributed in the other states.

Programmatic: Data for this metric are collected by 5/38 (13%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
$\delta^{13}C$, $\delta^{15}N$	38	5	13%	18%
• Spatial footprint unavailable for one monitoring program. Percent of hexagons containing monitoring sites may be an underestimate.				

Indicator: Scallop Abundance

MEF: Ecosystem Function
KEA: Secondary Production
Metric: Scallop Density (individuals m^{-2})

Definition: The abundance of bay scallops (*Argopecten irradians*) per unit area.

Background: Scallop abundances have decreased significantly, most likely due to overharvesting, recruitment failure, and habitat degradation (Arnold et al., 2008). Bay scallops almost always co-occur with seagrasses (Eckman, 1987; Ambrose and Irlandi, 1992) and scallops appear to actively select seagrass habitat over non-vegetated habitat (Bologna and Heck, 1999). Greenawalt et al. (2004) point out the importance of seagrass habitats, where higher abundances of scallops were found in *T. testudinum* and *S. filiforme* beds, and mixed seagrass assemblages. Additionally, their findings suggest that *S. filiforme* provides a more suitable habitat for scallop recruitment, growth, and preferential settlement of larger scallops.

Rationale for Selection of Variable: The immobility of bay scallops makes this species a useful indicator of habitat quality, as they depend on the presence and refuge of seagrass structure.

Measure: Scallop density (individuals m^{-2})

Tier: 3 (intensive field measurement)

Measurement: In Florida, adult populations are surveyed following the methods of Arnold et al. (2008). Weighted transects, typically 300 m in length, are deployed in seagrass beds at randomly selected stations beginning early summer (June). Two SCUBA divers, with one diver on each side, quantify the number of scallops within 1 m of the transect line. The areas of these surveys are 600 m^2, but scallop density should be reported as the number of individuals m^{-2}. In Texas, scallops are collected using bag seines and trawls in grids stratified by depth depending on the type of fishing gear. Scallops hauled in by seines or trawls are quantified as described in Martinez-Andrade et al. (2005).

Metric Rating and Assessment Points:

Metric Rating	Scallop Density (individuals m^{-2})
Good/Excellent	> 0.4 individuals m^{-2}
Fair	0.01–0.04 individuals m^{-2}
Poor	< 0.01 individuals m^{-2}

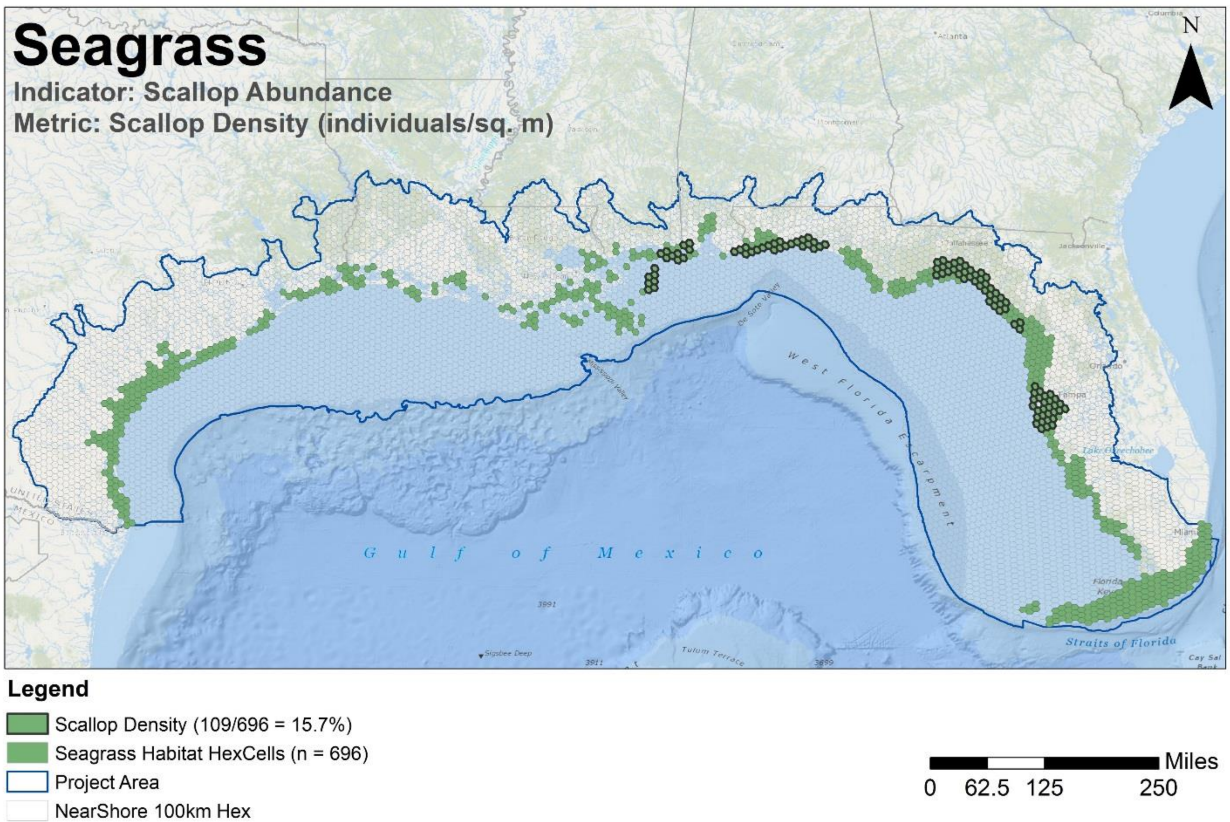
Scaling Rationale: Assessment points were set low and in accordance with the Florida Fish and Wildlife Conservation Commission due to declines in scallop populations. The metric ratings and assessment points translate to collapsed populations when < 5 individuals/600m^2 and healthy scallop populations when > 25 individuals/600m^2 (Leverone et al., 2010).

Analysis of Existing Monitoring Efforts:

<u>Geographic</u>*:* Scallop density is less well collected geographically in the NGoM, with 16% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric only occur in Mississippi and Florida.

<u>Programmatic:</u> Data for this metric are collected by 6/38 (16%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Scallop Density	38	6	16%	16%
• Spatial footprint unavailable for one monitoring program. Percent of hexagons containing monitoring sites may be an underestimate.				

Ecosystem Service Indicators

Indicator: Scallop Abundance

MES: Supporting and Provisioning
KES: Habitat and Food
Metric: Scallop Density (individuals m^{-2})

Definition: The abundance of bay scallops (*Argopecten irradians*) per unit area.

Background: Scallop abundances have decreased significantly most likely due to overharvesting, recruitment failure, and habitat degradation (Arnold et al., 2008). Bay scallops almost always co-occur with seagrasses (Eckman, 1987; Ambrose and Irlandi, 1992) and scallops appear to actively select seagrass habitat over non-vegetated habitat (Bologna and Heck, 1999). Greenawalt et al. (2004) point out the importance of seagrass habitats, where higher abundances of scallops were found in *T. testudinum* and *S. filiforme* beds, and mixed seagrass assemblages. Additionally, their findings suggest that *S. filiforme* provides a more suitable habitat for scallop recruitment, growth, and preferential settlement of larger scallops.

From 2014–2016, nearly 4300 pounds of scallops were harvested from Florida's west coast (https://www.st.nmfs.noaa.gov/pls/webpls/MF_ANNUAL_LANDINGS.RESULTS). No data are available for other NGoM States. Given bay scallops specificity to and dependence on the seagrass environment, their presence and density is instructive as an integrative ecological indicator of habitat and potential for food provision.

Rationale for Selection of Variable: The immobility of bay scallops makes this species a useful indicator of habitat quality as they depend on the presence and refuge of seagrass structure.

Measure: Scallop density (individuals m^{-2})

Tier: 3 (intensive field measurement)

Measurement: In Florida, adult populations are surveyed following the methods of Arnold et al. (2008). Weighted transects, typically 300 m in length, are deployed in seagrass beds at randomly selected stations beginning early summer (June). Two SCUBA divers, with one diver on each side, quantify the number of scallops within 1 m of the transect line. The areas of these surveys are 600 m^2, but scallop density should be reported as the number of individuals m^{-2}. In Texas, scallops are collected using bag seines and trawls in grids stratified by depth depending on the type of fishing gear. Scallops hauled in by seines or trawls are quantified as described in Martinez-Andrade et al. (2005).

Metric Rating and Assessment Points:

Metric Rating	Scallop Density (individuals m^{-2})
Good/Excellent	> 0.4 individuals m^{-2}
Fair	0.01–0.04 individuals m^{-2}
Poor	< 0.01 individuals m^{-2}

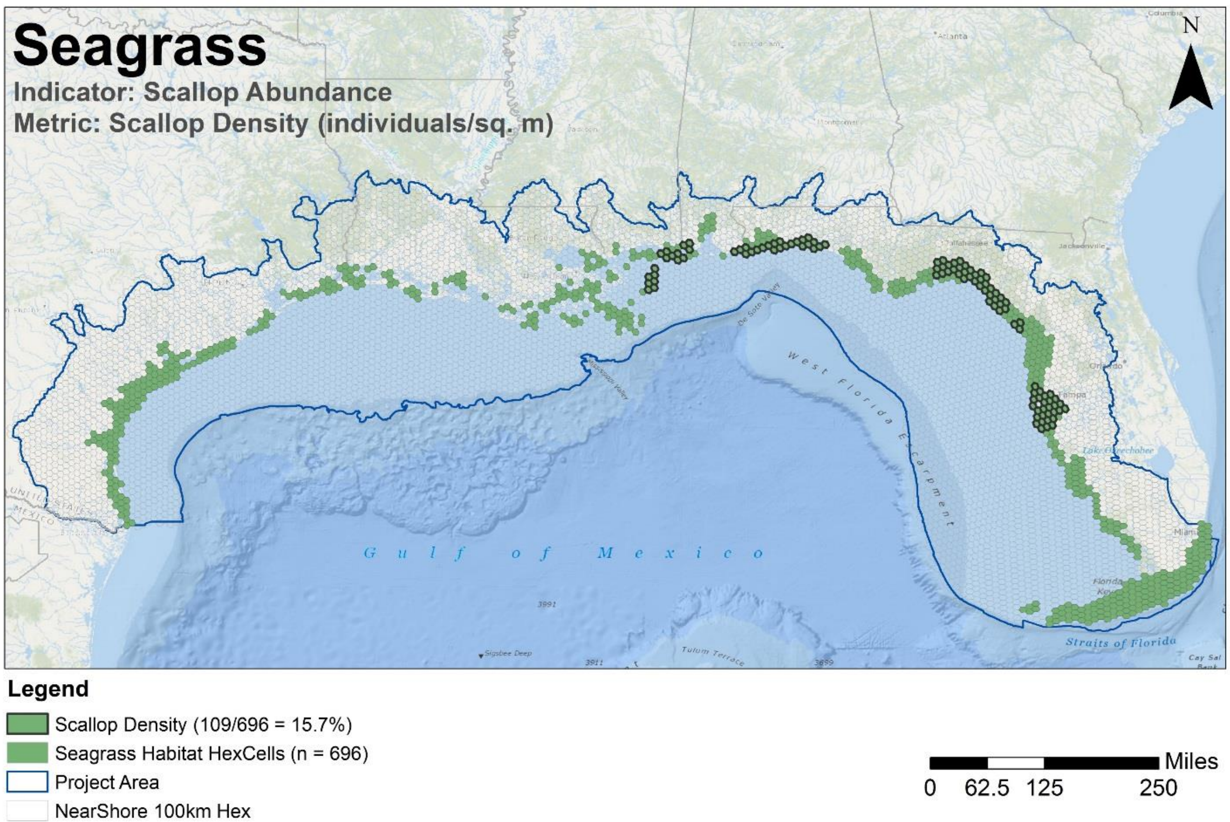
Scaling Rationale: Assessment points were set low and in accordance with the Florida Fish and Wildlife Conservation Commission due to declines in scallop populations. The metric ratings and assessment points translate to collapsed populations when < 5 individuals/600m^2 and healthy scallop populations when > 25 individuals/600m^2 (Leverone et al., 2010).

Analysis of Existing Monitoring Efforts:

Geographic*:* Scallop density is less well collected geographically in the NGoM, with 16% of habitat hexagons containing at least one monitoring site. Monitoring locations for this metric only occur in Mississippi and Florida.

Programmatic: Data for this metric are collected by 6/38 (16%) of programs collecting relevant seagrass bed data in the NGoM.

A list of the seagrass monitoring programs included on the map and table below is provided in Appendix IV.



Metric	Total Relevant Seagrass Monitoring Programs	Number of Programs Monitoring the Indicator	Percentage of Programs Monitoring the Indicator	Percent of Ecosystem Hexagons that Contain Monitoring Sites for the Indicator
Scallop Density	38	6	16%	16%
• Spatial footprint unavailable for one monitoring program. Percent of hexagons containing monitoring sites may be an underestimate.				

Indicator: Erosion Reduction

MES: Regulating
KES: Coastal Protection
Metric: Shoreline Change

Definition: The statistically significant gain or loss in shoreline positions.

Background: Seagrasses provide ecosystem benefits that reduce coastal risks and build resilience, such as coastal erosion and wave energy reduction (Larkum et al., 2006). Their protection capacity is provided by the vertical structure that helps slow currents down, attenuate waves, and increase deposition of and reduce resuspension of sediments. The most favorable protection scenarios might be provided by large, long-living and slow-growing seagrass species, with biomass being largely independent of seasonal fluctuations, and with the maximum standing biomass reached under the highest hydrodynamic forcings.

Ondiviela et al. (2014) found incident energy flux, density, standing biomass, and plant stiffness to be the main physical and biological factors influencing the efficiency of the protection provided by seagrasses.

Site level production statistics are not readily available for most sites.

Rationale for Selection of Variable: Shoreline stabilization constitutes an important measure of the risk reduction benefits provided by seagrass. Seagrass vegetation absorbs wave energy that otherwise would put at risk people, property, or landscapes (The Nature Conservancy, 2017).

Measure: Shoreline change in meters per year across permanent transects, and length of affected shoreline

Tier: 3 (intensive field measurement)

Measurement: Measurements should be performed on the shoreline of the area adjacent to the seagrass, and at a control site with similar current and wave conditions in the region. For a complete description of the methods see The Nature Conservancy (2017).

Metric Rating and Assessment Points:

Metric Rating	Shoreline Change
Good–Excellent	No change, gain (accretion)
Poor	Loss (erosion)

Scaling Rationale: Thresholds for indicator values constitute no-change or positive (accretion) and negative (erosion) changes in shoreline areas adjacent to the seagrass.

Analysis of Existing Monitoring Efforts:

No programs in the monitoring program inventory specifically noted collection of shoreline change associated with seagrass.

Indicator: Recreational Fishery

MES: Cultural
KES: Aesthetics-Recreational Opportunities
Metric 1: Spotted Seatrout Density
Metric 2: Recreational Landings of Spotted Seatrout

Metric 1: Spotted Seatrout Density

Definition: Number of individuals of spotted seatrout (*Cynoscion nebulosus*) per unit area.

Background: Spotted seatrout *(Cynoscion nebulosus*), also known as speckled trout**,** constitutes the largest recreational fishery in the NGoM region, with 36 million fish caught in 2006 (66% in Louisiana; NMFS, 2007). They are euryhaline fish with a large range of salinity tolerance (0.2–75 parts per thousand). Although adult spotted seatrout are typically associated with seagrass habitats in the warmer months and deeper areas within the estuaries during colder periods, habitat utilization varies by geographic location within the NGoM based on the habitat types available and life history stage. Spotted seatrout constitute one of the most important recreational and commercial components to the total NGoM fin-fishery (VanderKooy, 2001). These fish are caught almost exclusively within state waters jurisdiction due to their close association with coastal seagrass habitats. Spotted seatrout have been declared gamefish in Texas and Alabama, and only limited commercial fishery exists in Louisiana, Mississippi, and Florida (VanderKooy, 2001).

Rationale for Selection of Variable: Spotted seatrout density measurements allow for the assessment of population resource utilization at a specific site and provide an indication of the potential for a site to contribute to recreational fishing. This metric is best used to assess ecosystem service of a specific site.

Measure: Number individuals m^{-1}

Tier: 3 (intensive field measurement)

Measurement: Field collected organisms should be identified and enumerated by age/size class. Conduct annual field measures during warmer months, post-spawning, when populations are expected to be the highest. Data should be presented on individuals/m^2.

Metric Rating and Assessment Points:

Metric Rating	Spotted Seatrout Density (or significant change in age/size class distribution)
Good	Increasing/stable
Poor	Decreasing

Scaling Rationale: Specific expected densities at given sites are not available to establish assessment points. Decreases in spotted seatrout density would indicate a decrease in a site's capacity to provide fish for recreational fisheries. Changes in age/size class distribution (e.g., a decline in juveniles over time) may also indicate potential for declining contribution to recreational fisheries.

Analysis of Existing Monitoring Efforts:

No programs in the monitoring program inventory specifically noted collection of spotted seatrout data, so no geographic or programmatic statistics were calculated for this indicator.

Metric 2: Recreational Landings of Spotted Seatrout

Definition: Annual recreationally landed weight of spotted seatrout (*C. nebulosus*). Fishing can be conducted using different gear types as defined and allowed by state regulations.

Background: Spotted seatrout (*C. nebulosus*), also known as speckled trout**,** is a common estuarine fish found along the entire NGoM coast. The spotted seatrout is a euryhaline fish with a large range of salinity tolerance (0.2–75 ppt). Although adult spotted seatrout are typically associated with seagrass habitats in the warmer months and deeper areas open water areas within the estuaries during colder periods, habitat utilization varies by geographic location within the NGoM based on the habitat types available and life history stage. Spotted seatrout constitute one of the most important recreational and commercial components of the total NGoM fin-fishery (VanderKooy, 2001). The spotted seatrout is caught almost exclusively within state waters jurisdiction, due to its close association with seagrass habitats. Spotted seatrout have been declared gamefish in Texas and Alabama, and only limited commercial fisheries exist in Louisiana, Mississippi, and Florida (VanderKooy, 2001). Spotted seatrout constitutes the largest recreational fishery in the NGoM region, with 36 million fish caught in 2006 (66% in Louisiana; NMFS. 2007).

Rationale for Selection of Variable: Recreational fishery landing statistics for spotted seatrout provide a direct measure of ecosystem service. Current statistics are available annually at the state level. The recreational fishery landing statistic metric is best used to assess the potential contribution of seagrass to recreational fisheries at the state level on an annual basis. Because this metric has application at a broad spatial scale (state-level), it can be used to assess other spotted seatrout habitats, such as seagrasses.

Measure: Total spotted seatrout weight caught per year in metric tons

Tier: 3 (intensive field measurement)

Measurement: Assess the total weight of spotted seatrout annually using recreational fishery statistics reported by the National Marine Fishery Service. Data for this database is gathered by the Marine Recreational Information Program (MRIP) and can be accessed at https://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/queries/index.

Metric Rating and Assessment Points:

Metric Rating	Total Spotted Seatrout Weight (tons)				
	NGoM	Louisiana	Mississippi	Alabama	Florida (west coast)
Good	> 6,568 t	> 4,970 t	> 401 t	> 309 t	> 1,130 t
Fair	5,508–6,568 t	3,812–4,970 t	251–401 t	228–309 t	1,075–1,130 t
Poor	< 5,508 t	< 3,812 t	< 251 t	< 228 t	< 1,075 t

Scaling Rationale: The assessment scale is based on the average weight (metric tons) of total spotted seatrout caught during 1995–2015 in state waters in the NGoM (MRIP). The range between the second and third quartile of commercial landing statistics, reported by the NMFS (https://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/queries/index), was used to define the medium rating level. Data for Texas is not available in the MRIP database.

Analysis of Existing Monitoring Efforts:

No programs in the monitoring program inventory specifically noted collection of spotted seatrout data, so no geographic or programmatic statistics were calculated for this indicator.

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