National Park Service
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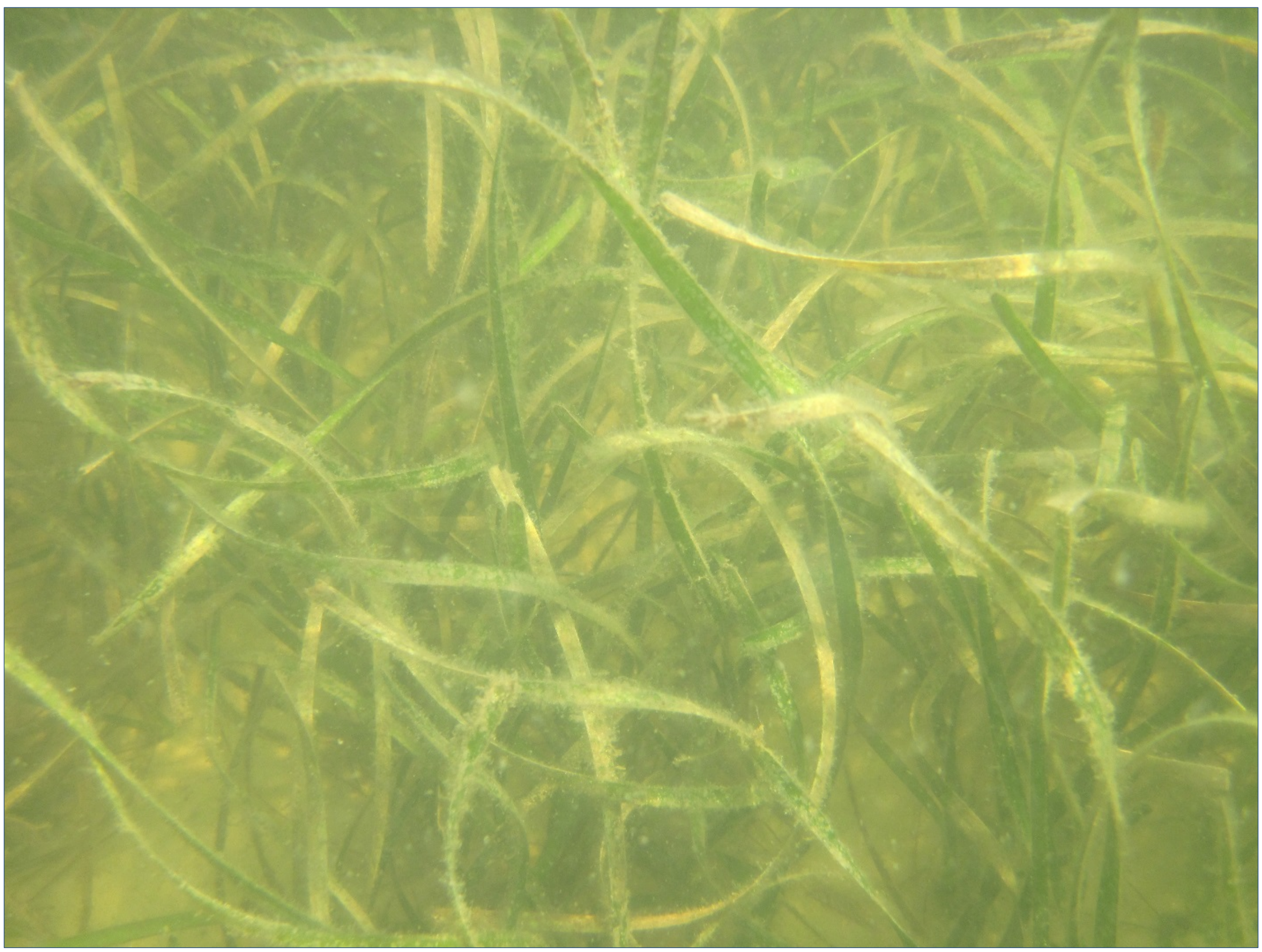
Natural Resource Stewardship and Science

Monitoring Seagrass in National Parks of the Gulf Coast Network

Protocol Narrative

Natural Resource Report NPS/GULN/NRR—2019/1973



ON THE COVER
Turtlegrass, *Thalassia testudinum*, at Gulf Islands National Seashore

Monitoring Seagrass in National Parks of the Gulf Coast Network

Protocol Narrative

Natural Resource Report NPS/GULN/NRR—2019/1973

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Change History

Version numbers will be incremented by a whole number (e.g., version 1.3 to version 2.0) when a change is made that significantly alters project requirements, procedures, continuity of the data, or interpretation of the data. Version numbers will be incremented by decimals (e.g., version 1.6 to version 1.7) when there are minor modifications that do not affect project requirements, procedures, data continuity or data interpretation.

Revision Date	Author	Changes Made	Reason for Change	New Version #

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Executive Summary

The mission of the National Park Service (NPS) is to conserve unimpaired the natural and cultural resources of the national park system for the enjoyment of this and future generations (NPS 1999). To uphold this goal, the NPS has implemented a science-based program to document and monitor important natural resources in over 270 parks, which are organized into 32 Inventory and Monitoring (I&M) networks. Early in program development, each I&M network and their parks worked together to identify a set of high-priority ‘Vital Signs’ that are monitored as indicators of park ecosystem health. During network vital signs selection, Gulf Islands National Seashore (GUIS) and Padre Island National Seashore (PAIS) recognized the need to monitor seagrass meadows, both to serve as indicators of ecological integrity in the park and to contribute to the region-wide seagrass monitoring efforts that began in 1999 (Dunton et al. 2011). To meet this need, the Gulf Coast Network now conducts long-term seagrass monitoring in these two coastal parks, which are located on the northern Gulf of Mexico and contain extensive seagrass meadows of up to five seagrass species.

Seagrass meadows are recognized as key aquatic resources worldwide for their high productivity and ecosystem services (Hemminga and Duarte 2000). They support diverse marine lifeforms, including many commercially important fish and crustaceans; they improve water quality through transpiration of oxygen; and they help stabilize the sea floor against wave action. However, the extent and density of seagrass meadows are declining worldwide due to direct physical disturbance and indirect effects of watershed development resulting in water quality degradation (Orth et al. 2006; Waycott et al. 2009). Waycott et al. (2009) estimated that 29% of the global seagrass habitat has disappeared over the past 100 years. Recognition of these losses has led to a proliferation of seagrass monitoring efforts around the world, with some notable examples of cross-agency and cross-border cooperation (Neckles et al. 2012). Within the Gulf Coast region, effectiveness and scope can be maximized by different federal and state agencies sharing their methods and data region-wide. The Gulf Coast Network has taken this approach by patterning their methods on the Texas statewide seagrass monitoring plan (Dunton et al. 2011).

Seagrass monitoring by the Gulf Coast Network occurs at 170 permanent stations in Texas, Florida and Mississippi, with each station sampled once every three years. There are 64 stations at PAIS, all located within the hypersaline Upper Laguna Madre of South Texas. At GUIS there are 106 stations: 60 are in the lagoons and sounds of west Florida and 46 are in the shallow waters of the Mississippi Sound. When sampling each station, field crews estimate percent cover and measure leaf length of each seagrass species in four 0.5 × 0.5 meter quadrats (1.6 × 1.6 feet). They also collect water quality data on-site. As data are collected and analyzed, the network generates two types of reports (Monitoring Event Reports and Change Analysis Reports) and publishes them, along with the raw data, so that they are available to park staff and the scientific community in a timely manner. These data and reports serve to meet the network’s primary and secondary seagrass monitoring objectives. The primary objective is to monitor changes in seagrass percent cover, community species composition, and leaf length. The secondary objective is to collect ancillary data (physicochemical measurements of the water column) in order to determine relationships between seagrass percent

cover, species composition, and leaf length and the ancillary data. An additional programmatic objective is to participate in regional seagrass monitoring when fiscally and logistically feasible.

The Gulf Coast Network's approach, rationale, and required resources for seagrass monitoring are described in this narrative document. The eight associated Standard Operating Procedures (SOPs) provide detailed instructions on how to collect, manage, analyze and disseminate the project's findings. Results obtained from this monitoring program are expected to fill gaps in the knowledge of seagrass systems in network parks and help expand the collective understanding of regional seagrass conditions.

Acknowledgments

The network thanks Ken Dunton for his major contribution in planning, developing, and helping implement statewide seagrass monitoring in Texas, which is the basis for this protocol. The network also appreciates the work of Hillary Neckles and colleagues in establishing the multi-scale method to monitor seagrasses and providing the statistical analyses that supports the sampling scheme detailed in this protocol. We acknowledge the contribution made by Victoria Congdon et al. (2018) for providing an ecological integrity framework and metric assessments. We also appreciate the work of Kim Jackson and Dottie Byron, the field leaders at University of Texas at Austin Marine Science Institute and the Dauphin Island Sea Lab, respectively, during the pilot years of 2011–2016. This appreciation extends to Sara Wilson and Maddie Kennedy, graduate students of these institutes who spent many hours in the field and lab during the pilot study.

Background

Program History

The National Park Service (NPS) is tasked with managing park resources "unimpaired for the enjoyment of future generations" (NPS 1999), which requires knowledge of both current resource conditions and whether they are changing over time. To meet this information need, the National Park Service initiated a long-term ecological monitoring program known as Vital Signs Monitoring (Fancy et al. 2009). In this context, vital signs are a subset of park organisms and ecosystem processes that are selected to reflect the overall condition and health of park resources, reflect the effects of stressors, or have particular value to park visitors. The NPS Inventory and Monitoring program (I&M) monitors vital signs in over 270 national park units, with the goal of providing broad-based, scientifically-sound information to park management, park stakeholders, other scientists and the public.

Vital signs monitoring is implemented by the National Park Service Inventory and Monitoring Division (IMD) through 32 networks, which are regional groupings of parks that are served by a single network office (Fancy et al. 2009). All I&M network offices follow the same planning and design strategy for monitoring in their parks, which includes a network-wide monitoring plan and a series of peer-reviewed protocols that describe how data are collected, managed, analyzed, and reported for each vital sign (Oakley et al. 2003). Although each network creates their own monitoring protocols, they do so based on a shared suite of program-wide goals for integrated natural resource monitoring. As stated by Fancy et al. (2009), these goals are to:

1) "Determine the status and trends of selected indicators of park ecosystem conditions" for improved decision-making and collaboration.
2) "Provide early warning of abnormal conditions" to allow for timely mitigation and reduced management costs.
3) "Provide data to better understand" dynamic park ecosystems and to serve as reference points.
4) "Provide data to meet certain legal and Congressional mandates."
5) "Provide a means of measuring progress towards performance goals."

The Gulf Coast Network conducts vital signs monitoring in eight National Park units, which includes all of Louisiana and Mississippi and parts of Texas, Florida, Alabama, and Tennessee. From 2002–2006, the network underwent an extensive scoping process that involved network staff, park staff and academic researchers, with the goal of identifying key natural resources and stressors to park ecosystems. The scoping process, relevant resources, and probable stressors are described in the *Gulf Coast Network Vital Signs Monitoring Plan* (Segura et al. 2007). As part of this process, marine submerged aquatic vascular plants, or seagrass, was selected as a top priority for long-term monitoring at Gulf Islands National Seashore (GUIS) and Padre Island National Seashore (PAIS), both of which contain significant marine resources, including seagrass meadows. This protocol narrative details the rationale for monitoring seagrass, sampling strategy, field methods and analysis approaches, which enable network personnel to achieve monitoring objectives identified in this document and in the network monitoring plan (Segura et al. 2007). Note that much of the preceding material describing the overall I&M programmatic history was written by Carlson et al. (2018) and adapted for this protocol.

Rationale for Monitoring Seagrass

The network identified "Marine and Estuarine Submerged Aquatic Vegetation" (SAV), or seagrass, as a vital sign (Segura et al. 2007). The seagrass communities of Padre Island and Gulf Islands National Seashores have been exposed to anthropogenic change, such as alterations to sediment dynamics (shipping channel construction and maintenance) and water quality (changes in salinity and nutrient influx). These changes are made against the background of natural estuarine dynamics and sea level change. Segura et al. (2007) relates GULN vital signs to monitoring objectives and conceptual models. For Marine and Estuarine SAV, the monitoring plan states that determining the extent and community composition/structure of this vital sign and monitoring it over time would help to understand ecosystem effects of multiple stressors (Table 3.3 in Segura et al. 2007).

Estuarine seagrass communities occur at Gulf Islands National Seashore (GUIS) and Padre Island National Seashore (PAIS). Seagrasses are found in all GUIS units, from west to east: the Mississippi Sound of Ship, Horn and Pettit Bois Islands, and portions of the Florida estuaries of Big Lagoon, Santa Rosa and Choctawhatchee Sounds. For simplicity, in this text the terms "seagrass," "seagrass habitat," "seagrass communities," and "seagrass ecosystems" are meant to include all other associated submerged aquatic vascular plants. Five species of seagrasses are found in these National Seashores: shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), widgeon grass (*Ruppia maritima*), turtle grass (*Thalassia testudinum*) and star grass (*Halophila engelmannii*).

Seagrass communities in nearshore coastal ecosystems provide a variety of ecosystem services, including primary production, nutrient cycling, and providing both food and habitat for numerous invertebrate and vertebrate species, including fish and sea turtles. Congdon et al. (2018) developed a conceptual model "to identify the most important ecological and human processes influencing seagrass ecosystems" in the northern Gulf of Mexico (Figure 1). This model illustrates the links between drivers and ecosystem responses, and is used to describe and identify indicators of seagrass abundance, distribution, and persistence. These indicators include abiotic factors such as water quality, and indicators of ecosystem structure such as seagrass abundance, community structure and leaf morphology.

Seagrass meadows are dynamic and can respond to natural or anthropogenic disturbances rapidly, sometimes on the scale of a few weeks or months (Roca et al. 2016). However, response time can vary by species. For example, climax species such as *Thalassia testudinum* have a greater resilience to stress due to their larger belowground biomass. One hundred percent changes in species dominance have been observed at the station-scale from one year to another during pilot data collection (2011–2016) in Texas. Because of the relatively rapid response to deteriorating ecosystem condition, seagrass monitoring is a reliable indicator of changing estuarine condition (Congdon et al. 2018). These plants integrate the conditions present during the growing season, including natural and anthropogenic stressors. In many cases, declines in seagrass condition can occur rapidly but recovery may be much slower and is often linked to changes in water quality (Fourqurean et al. 2003).

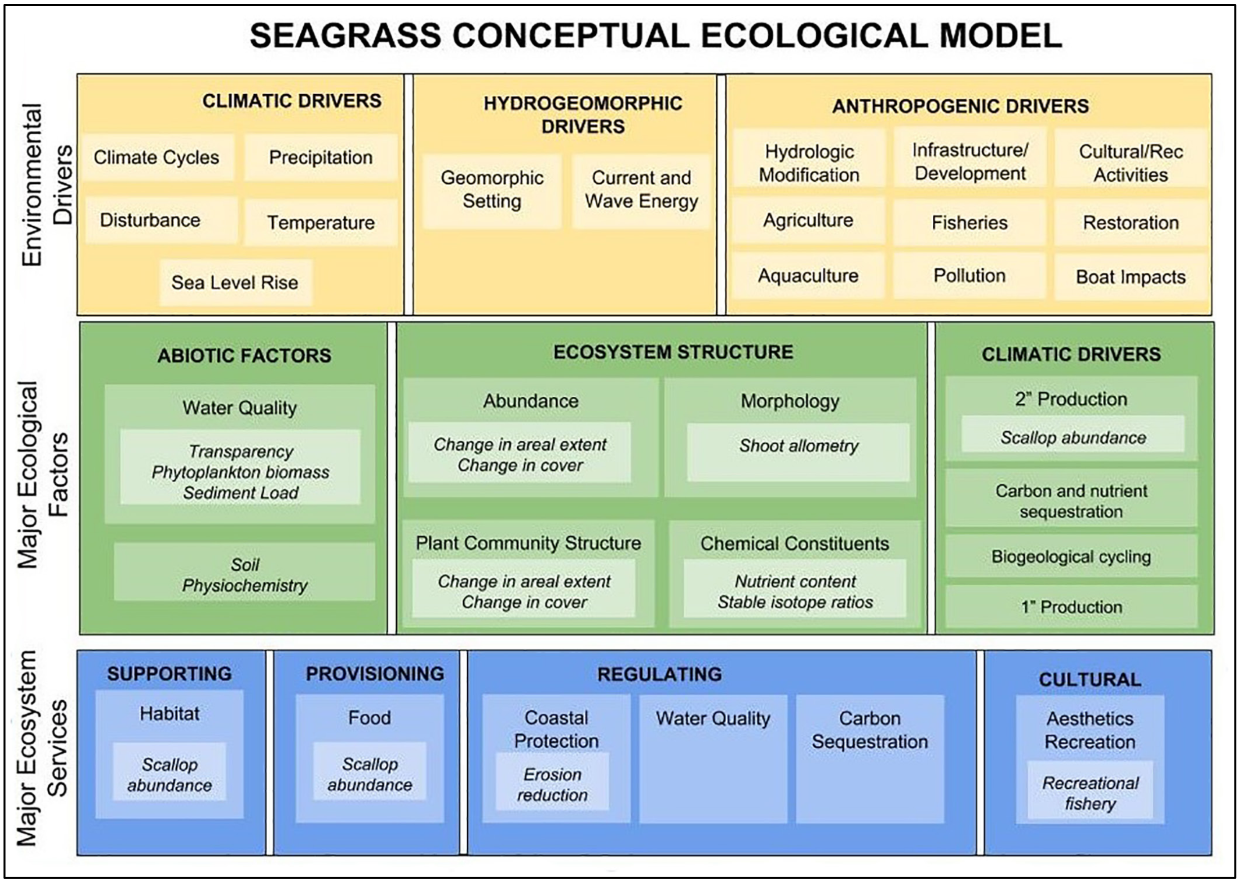

Figure 1. Conceptual model of environmental drivers, ecological factors and major ecosystem services of seagrasses in the northern Gulf of Mexico (Congdon et al. 2018).

Seagrass Protocol

This protocol describes how monitoring data will be collected, managed, and reported for the submerged aquatic vegetation (seagrass) vital sign as described in the approved GULN monitoring plan (Segura et al. 2007). The protocol is based on implementing methods used in the Texas statewide seagrass monitoring program (Dunton et al. 2011). The Texas program is, in large part, an application of the rationale and methods detailed in Kopp and Neckles (2009) and Neckles et al. (2012), establishing a three-tiered monitoring program: Tier 1 is remotely sensed mapping of seagrass extent, Tier 2 is broad scale rapid assessment using repeated visits to fixed stations to collect field indicators of seagrass condition and water quality, and Tier 3 entails detailed subsampling of transects to determine cause of changes to seagrass condition. The metrics used are also linked to the conceptual model (Figure 1) from Congdon et al. 2018 (Table 1).

The GULN seagrass monitoring program will focus on the Tier 2 component (highlighted in Table 1) while continuing to interact with partners to accomplish Tiers 1 and 3 as opportunities arise. Results obtained from this monitoring program will provide park managers with status and changes in seagrasses within their management areas. When combined with data from regional partners using the common methods of Dunton et al. (2011), GULN seagrass data can be used in analyses describing seagrass status and change at estuary and/or coast wide scales.

Table 1. Summary of seagrass metrics modified from Congdon et al. 2018.

Function & Services	Major Ecological Factor or Service	Key Ecological Attribute or Service	Indicator/*Metric*	Tier
Sustaining/ Ecological Integrity	Abiotic Factors	Water Quality	Transparency/*Percent Surface Irradiance*[1]	Tier 2
	Abiotic Factors	Water Quality	Phytoplankton Biomass/*Chlorophyll a Concentration*[1]	Tier 2
	Abiotic Factors	Water Quality	Sediment Load/*Total Suspended Solids*[1]	Tier 2
	Ecosystem Structure	Abundance	Change in Areal Extent/*Areal Extent*	Tier 1
	Ecosystem Structure	Abundance	Change in Cover/*Percent Cover*[1]	Tier 2
	Ecosystem Structure	Plant Community Structure	Seagrass Species Composition/*Species Dominance Index*[1]	Tier 2
	Ecosystem Structure	Morphology	Shoot Allometry/*Leaf Length*[1]	Tier 2
	Ecosystem Structure	Morphology	Shoot Allometry/*Leaf Width*	Tier 3
	Ecosystem Structure	Chemical Constituents	Nutrient Content/*Nutrient Limitation Index*	Tier 3
	Ecosystem Structure	Chemical Constituents	Stable Isotope Rations/ *δ13C and δ15N*	Tier 3
	Ecosystem Function	Secondary Production	Scallop Abundance/*Scallop Density*	Tier 3
Ecosystem Services	Supporting	Habitat	Scallop Abundance/*Scallop Density*	Tier 3
	Provisioning	Food	Scallop Abundance/*Scallop Density*	Tier 3
	Regulating	Coastal Protection	Erosion Reduction/*Shoreline Change*	Tier 3
	Cultural	Aesthetics-Recreational Opportunities	Recreational Fishery/*Spotted Seatrout Density and Recreational Landings of Spotted Seatrout*	Tier 3

[1]The GULN seagrass protocol focuses on the Tier 2 metrics (also highlighted in blue).

Measurable Objectives

The primary objective for monitoring seagrass at Gulf Islands and Padre Island National Seashores is to monitor changes in seagrass percent cover, community species composition, and leaf length. The secondary objective is to collect ancillary data (physicochemical properties of the water column) that can be used to improve understanding of the relationships between seagrass percent cover, species composition, and leaf length and the environmental conditions of the estuary. An additional programmatic objective is to participate in regional seagrass monitoring when fiscally possible.

While numerous studies discuss changes in seagrass cover and species composition, there have been no long-term (greater than 10 year) regular, repeated monitoring efforts using the same method in the northern Gulf of Mexico. This protocol duplicates the monitoring design, rationale and methods of Dunton et al. (2011) for statewide seagrass monitoring in Texas. In cooperation with our partners, a large portion of the seagrass habitats from the US–Mexico border to Destin, Florida will be monitored under a single method. Long term monitoring of seagrass will help inform park staff about both the status of the grass beds within the park and the overall condition of the estuaries. Changes detected through monitoring will inform management decisions and allow the parks to coordinate with State and Federal partners to address broader scale changes that impact park resources. Long term monitoring data sets also provide valuable baseline information that relates to natural disasters, tropical storms, or anthropogenic disasters such as industrial spills. Having a standardized monitoring approach in place not only provides baseline data but provides an impartial approach to evaluate the impacts of such events.

Seagrass Status of Padre Island and Gulf Islands National Seashores

The seagrasses of Gulf Islands and Padre Island National Seashores should be reviewed in context of the estuaries they are located in rather than simply areas managed by the National Park Service. The USGS, in partnership with the USEPA, published *Seagrass Status and Trends in the Northern Gulf of Mexico: 1940–2002* (Handley and DeMay eds 2007). This report presents five state summaries and specific discussions for each of the 14 estuarine systems where seagrasses occur. Each estuary is detailed in chapters that examine current and historic extent of seagrasses, seagrass mapping and monitoring, causes of status change, restoration activities, and general background information. The following information about seagrass status borrows heavily from the USGS report.

Table 2 places the NPS-managed seagrass habitat in spatial context to the entire estuary. Additionally, the total area of potential seagrass habitat (limited only by depth) within NPS-managed property and that of the entire estuary is presented.

Table 2. Areas of estuaries that the network will monitor under this protocol with respect to NPS-managed portions and potential seagrass habitat as limited by water depth.

Estuary	Total Area	Depth-limited area1	NPS managed	Depth-limited NPS managed area1
Choctawhatchee Bay	35,564	13,360	737	539
Santa Rosa Sound	15,347	6,555	6,439	3,968
Big Lagoon	1,464	780	942	465
Mississippi Sound	194,892	50,573	10,511	1,557
Upper Laguna Madre	39,214	38,455	14,990	14,990

[1] Depth limit set at 2 meters.

The Laguna Madre, Texas; Padre Island National Seashore

Pulich and Onuf (2007) state that seagrasses are unevenly distributed along the Texas coast, largely due to variations in precipitation and freshwater discharge, with an increase in seagrasses from the northeast (Galveston Bay) to the southwest (Laguna Madre). The authors state that a consequence of greater precipitation and freshwater discharge is that estuaries are subject to greater freshening and receive heavier sediment loads, resulting in greater turbidity and limited areas of tolerable salinity to allow seagrass proliferation. Pulich and Onuf (2007) cite both natural and human-induced changes to seagrass communities along the Texas coast. The most pronounced natural changes are caused by hurricanes, floods, and droughts. The human effects include (1) nutrient loading causing water quality degradation and light attenuation from phytoplankton blooms, epiphyte growth, or macroalgae accumulation, (2) suspended sediments from dredging or boat traffic, and (3) direct physical disturbance.

Onuf (2007) notes that while the mapped watershed of the hypersaline Laguna Madre is some 15 times larger than the estuary, the watershed is so flat and the precipitation so low that most of the watershed is non-contributing during periods of normal rainfall. There is little inflow of fresh water, thus limiting suspended sediments and nutrients to the estuary (Figure 2). Pulich and Onuf (2007) suggest that this relative isolation from freshwater inflows is the main reason why there is a rich distribution of seagrasses in the Laguna Madre.

The Laguna Madre is divided between the Lower Laguna Madre and the Upper Laguna Madre by a 20-kilometer (12.4 mi) long emergent sand/mud flat. The Upper Laguna Madre is further bounded to the east by Padre Island, to the west by the Texas mainland and to the north by the Kennedy Causeway. Padre Island National Seashore manages 14,990 hectares (57.9 square mi) of the Upper Laguna Madre estuary. Onuf (2007) summarizes the distribution of seagrass in the Upper Laguna Madre over a roughly 35-year period in Figure 3 and Table 3).

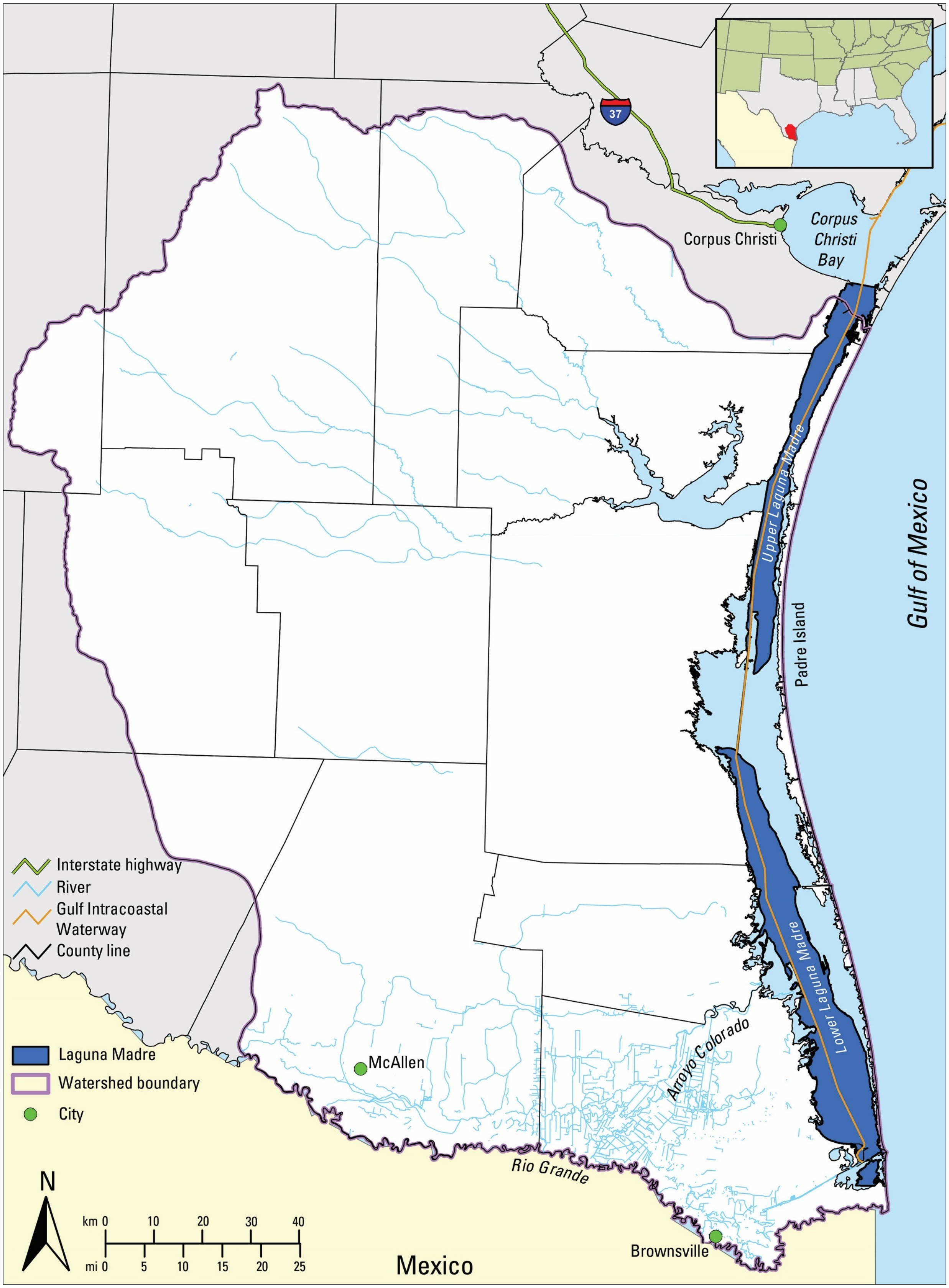

Figure 2. Watershed for the Laguna Madre (Onuf 2007).

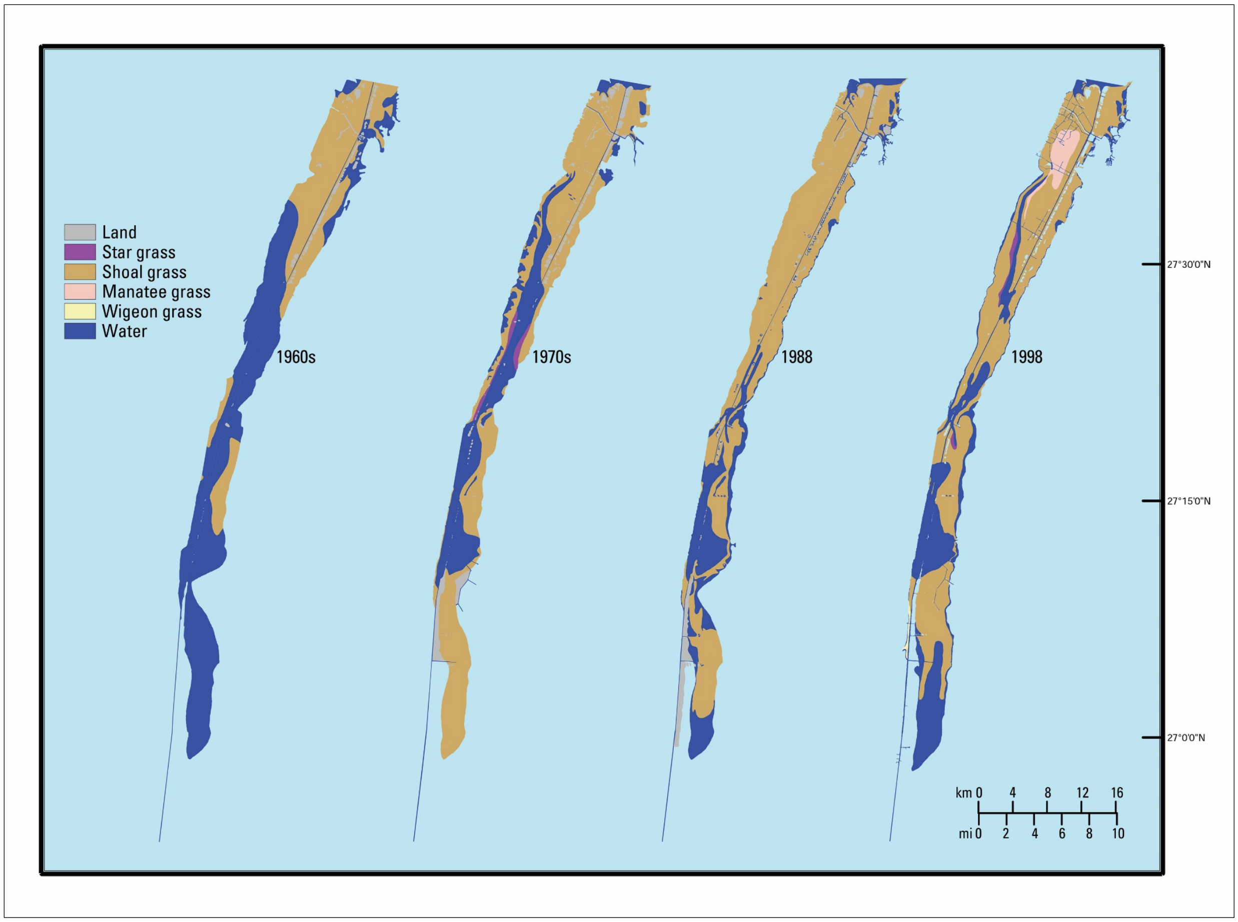

Figure 3. Distribution of seagrass in Upper Laguna Madre, 1960s-1998 (Onuf 2007).

Table 3. Bottom cover (in hectares) of Upper Laguna Madre in different years (Onuf 2007).

Cover Type	Mid-1960s[1]	Mid-1970s[2]	1988[3]	1998
Bare	20,826	10,785	9,893	12,950
Shoal grass (*Halodule wrightii*)	12,321	19,644	22,903	20,553
Manatee grass (*Syringodium filiforme*)	0	0	0	1,452
Star grass (*Halophila engelmannii*)	0	611	0	307
Wigeon grass (*Ruppia maritima*)	0	0	0	132
Total	33,147	31,040	32,796	35,394
Total Vegetated	12,321	20,255	22,903	22,444

1 Areas computed from digitized versions of maps from McMahan (1965–67).

2 Areas computed from digitized versions of maps from Merkord (1978).

3 Areas computed from digitized versions of maps from Quammen and Onuf (1993).

Onuf (2007) provides a comprehensive summary of nearly four decades of seagrass research and monitoring and describes the status of seagrass in the Upper Laguna Madre. However, system-wide trend analyses are not possible as methods were not consistent through time.

Pulich and Onuf (2007) note data limitations and future needs. Primary is the inconsistency in methods used over the years. Issues arise from monitoring scale, both spatial and temporal. Pulich and Onuf (2007) state that remote sensing was inconsistent in quality and periodicity. They also report that resource managers must examine seagrass responses cautiously and on a case-by-case basis to identify environmental stressors causing change because net quantitative change in area for an entire bay seldom yields accurate clues as to causation. Pulich and Onuf (2007) also suggest that species composition is a key parameter for monitoring incipient stress, and such monitoring would require more detailed ground surveys coupled with remote sensing.

Beginning in 2011 the network entered a cooperative agreement with the University of Texas Marine Science Institute (UTMSI) to conduct seagrass monitoring in Padre Island National Seashore's portion of the Upper Laguna Madre as part of the newly established statewide seagrass monitoring program. UTMSI continued annual monitoring through 2017. With the exception of 2013 when only NPS-managed property was sampled, all other years were monitored as part of a partnership with state and federal resource managers and their respective properties along the Texas Coast or estuaries of the Coastal Bend. Wilson (2015) provides analysis of seagrass coverage and composition of the Texas Coast for 2011–2013 monitoring data. Wilson (2015) concludes that significant changes to seagrass percent coverage and species composition are detected from year to year, indicative of the dynamic nature of Texas seagrass meadows in response to changes in salinity and nutrient availability (Wilson 2015).

The Mississippi Sound, Mississippi; Gulf Islands National Seashore

Moncreiff (2007a) provides the summary of seagrass information in Mississippi including the 175,412-hectare (677.3 square mi) Mississippi Sound. This estuary is bound by the mainland coast of Mississippi to the north, the barrier islands of Gulf Islands National Seashore to the south, Mobile Bay to the east and fades into Lake Borgne to the west (Figure 4). The open estuary of Mississippi Sound is fed by eight freshwater inflows, west to east from Lake Borgne to the Pascagoula River. The majority of seagrasses of Mississippi Sound are found in Gulf Islands National Seashore waters on the landward side of the barrier islands (Figure 5; Moncreiff 2007b). The National Park Service manages 10,511 hectares (40.6 square mi) of marine resources in the Mississippi Sound, including 1,557 hectares (6.0 square mi) of potential seagrass habitat, defined as equal to or less than two meters depth.

Unlike the vast seagrass beds of the Laguna Madre, Moncrieff (2007a) reports that estimates in the 1990s indicated that only 3% of the bottom of the Sound supports seagrass, about 800 hectares out of 6,000 hectares (3.0 of 23.2 square mi) of potential habitat (2 meters [6.6 ft] deep). This distribution should be viewed in light of a 1969 survey when seagrass covered over 5,000 hectares (19.3 square mi; Moncrieff 2007a).

Figure 4. Watershed for Mississippi Sound (Moncreiff 2007b).

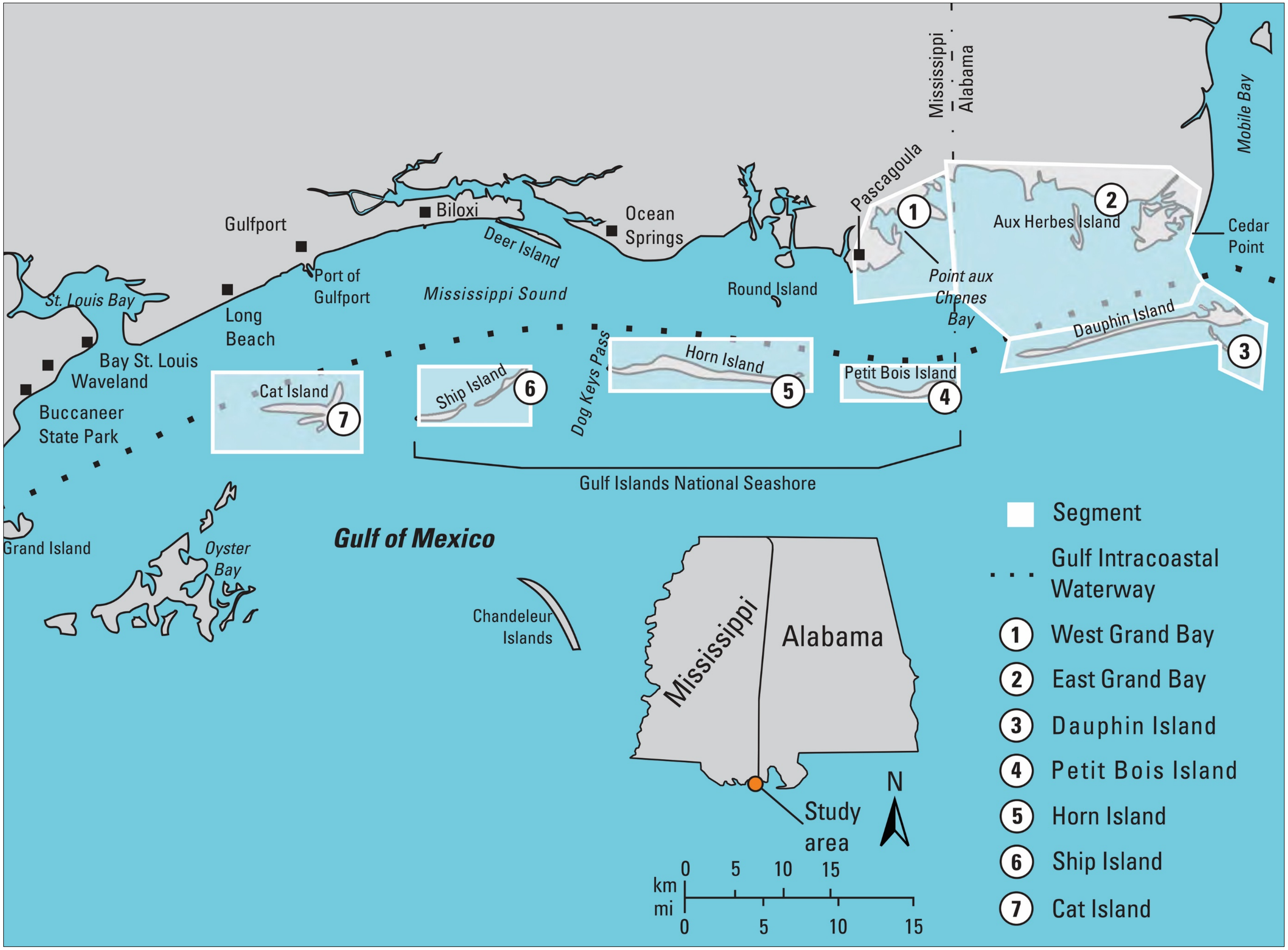

Figure 5. The Mississippi Sound (Moncrieff 2007b).

Moncreiff (2007b) summarizes the state of knowledge of seagrasses in Mississippi Sound, particularly those associated with Gulf Islands National Seashores barrier islands. West to east they are: West Ship, East Ship, Horn, and Petit Bois Islands. Moncreiff (2007b) states that seagrasses began to diminish in the late 1960s to early 1970s. This may be the result of the cumulative effects of human activity in the coastal marine environment, including land use change in the eight watersheds draining into the Sound and coastal development.

Moncrieff (2007b) had similar limitations as Onuf (2007) in performing trend analysis, and cites lack of method consistency. For example, the 1992 and 1999 surveys were based on aerial photographic interpretation, while the 1969 survey was based on an estuarine inventory that included seagrass habitat that was lost by the time of later surveys. Normalized for habitat loss, overall decline in seagrass appears to be the accumulative effect of both natural and human activities in the coastal marine environment (Moncrieff 2007b). This includes depressed salinity from flooding rains and physical disturbances, including habitat loss, from tropical storms. Habitat loss or decline in quality from disruption of long-shore movement of sand by shipping canals are also blamed (Moncrieff 2007b).

Pham (2017) examined the historical change in seagrasses in the Mississippi and Chandeleur Sounds from 1940 through 2011 and reported that three seagrass species (*Halophila engelmannii, Syringodium filiforme,* and *Thalassia testudinum*) disappeared from the Mississippi Sound during the 1970s. Vegetated seagrass areas of the Mississippi Sound barrier islands (exclusive of Cat Island) experienced a 63% decline from 1940–2008, with most loss occurring between 1940 through the mid-1970s (Pham 2017). These observations are illustrated in Figure 6.

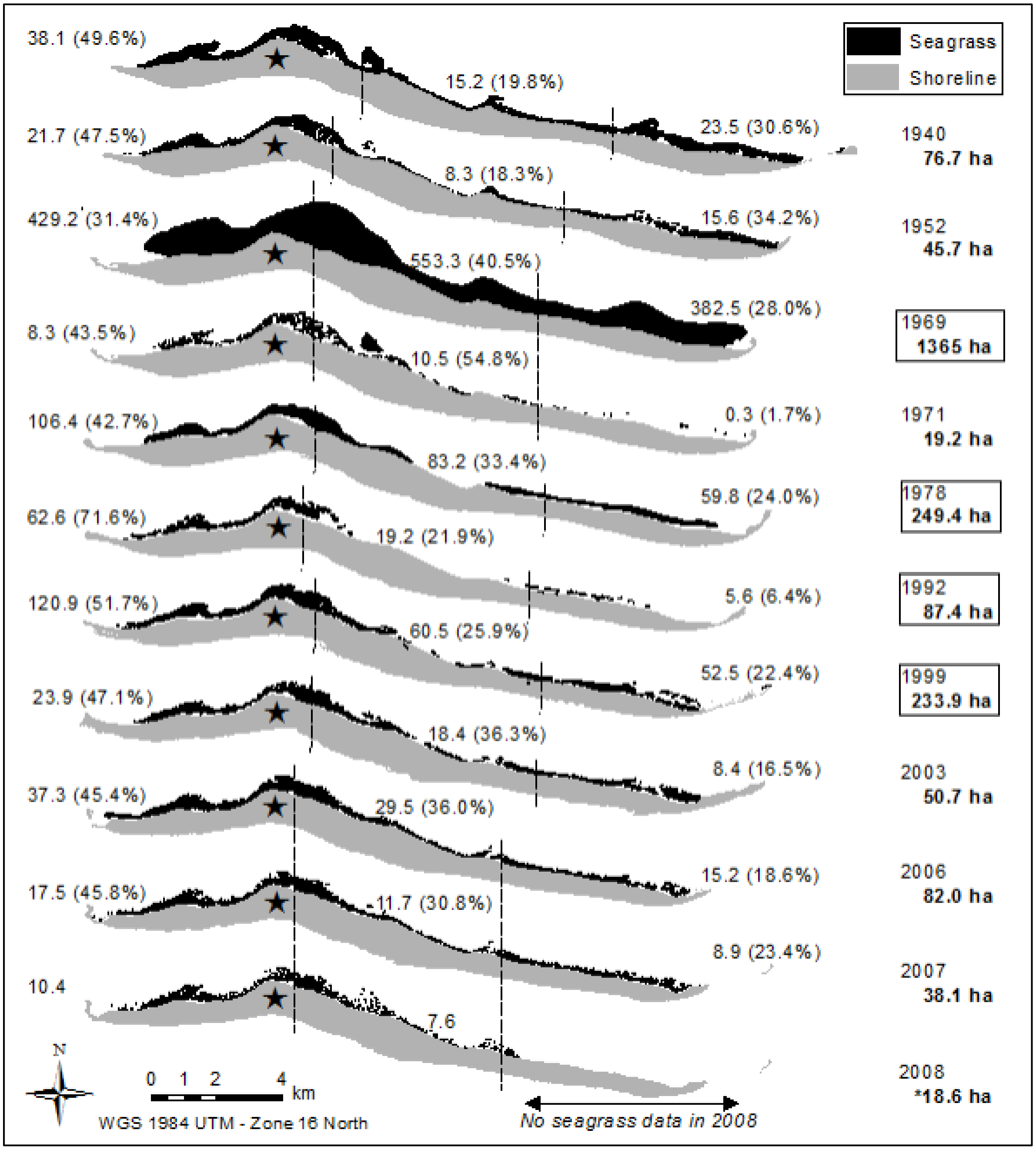

Figure 6. Time series maps showing changes in island size and seagrass coverage of Horn Island between 1940 and 2011 from Pham (2017).

The Big Lagoon and the Santa Rosa Sound, Florida; Gulf Islands National Seashore

Florida has nine Gulf estuaries positioned along a coast that stretches 1,000 kilometers (621.4 mi) from the Alabama state line to the Dry Tortugas (Carlson and Madley 2007). Gulf Islands National Seashore manages portions of estuaries in Pensacola Bay (Big Lagoon and Santa Rosa Sound) and Choctawhatchee Bay on the Panhandle of west Florida.

Schwenning et al. (2007) provides detail on Pensacola Bay, which includes the portions managed by Gulf Islands National Seashore (Big Lagoon and Santa Rosa Sound), and reports that the Pensacola Bay system has experienced point and nonpoint pollution, direct habitat destruction and cumulative impacts of development in its watershed. These impacts have combined to degrade the health and productivity of the bay system (Schwenning et al. 2007).

The Pensacola Bay system covers 51,000 hectares (197 square mi) bounded by 885 kilometers (550 mi) of coastline, and contains about 373 square kilometers (144 square mi) of open water fed by a 18,000 square kilometer (7,000 square mi) watershed (Figure 7; Schwenning et al. 2007). Gulf Islands National Seashore manages portions of estuaries in Big Lagoon and Santa Rosa Sound (Figure 8). Big Lagoon is a link connecting Perdido Bay on the Alabama-Florida state line to Santa Rosa sound to the east. It is bound to the south by the Seashore's Perdido Key and to the north by Big Lagoon State Park, residential development, and the Pensacola Navy Air Station. Santa Rosa Sound is also a link, in this case connecting Pensacola Bay on the west and Choctawhatchee Bay on the east. The seashore manages portions of the Sound from the northwestern edge of Santa Rosa Island eastward to Pensacola Beach, the area subjacent to the Naval Live Oaks Unit, and along the northern shore of Santa Rosa Island between Pensacola Beach and Navarre Beach communities. The National Park Service manages 942 hectares (3.6 square mi) of the Big Lagoon and 3,605 hectares (12.9 square mi) of the Santa Rosa Sound.

Figure 7. Watershed for the Pensacola Bay system (Schwenning et al. 2007).

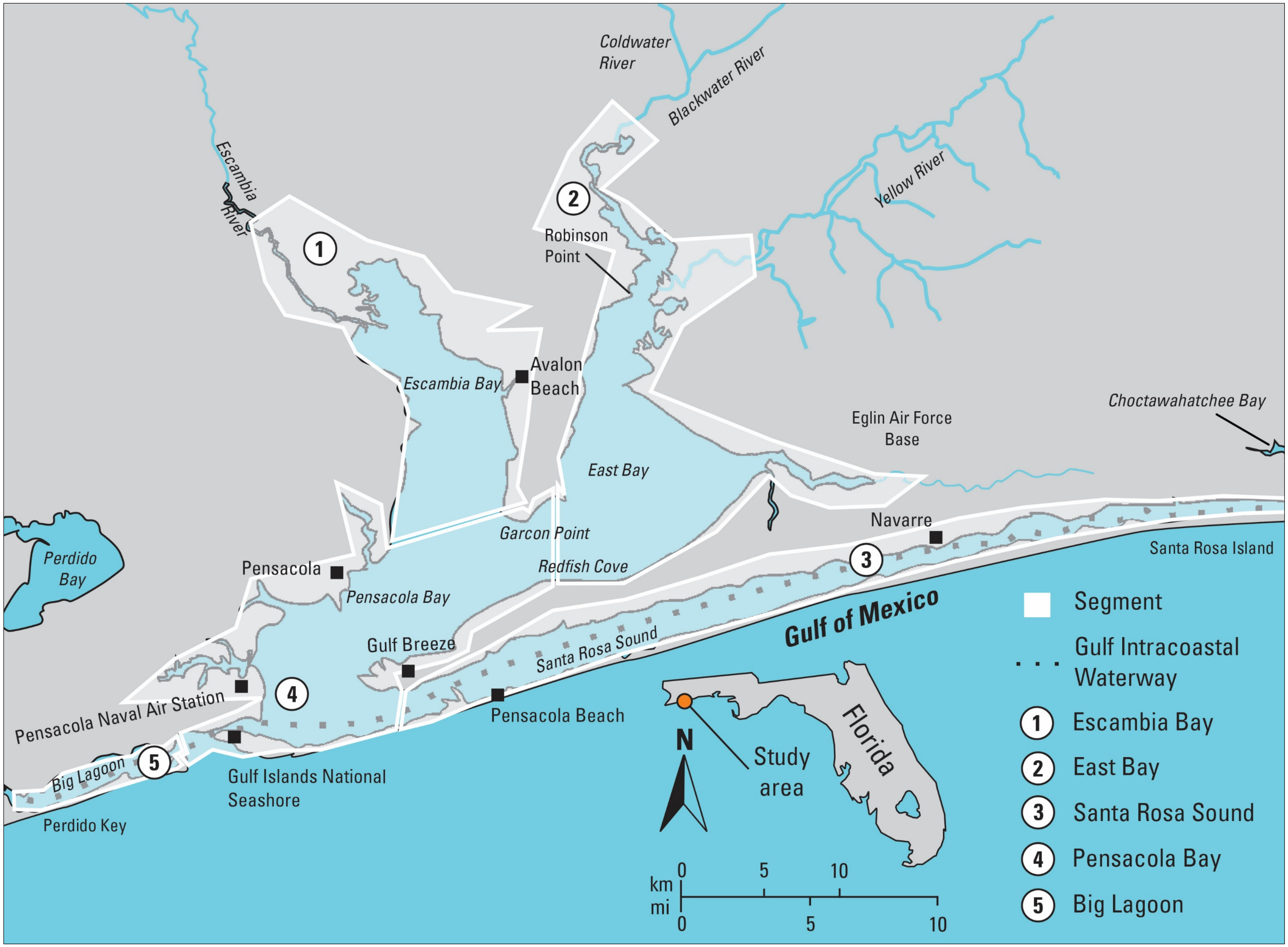

Figure 8. Pensacola Bay (Schwenning et al. 2007).

Changes in seagrass coverage in the Pensacola Bay system are plotted over three surveys from 1960, 1980, and 1992 (Table 4). All estuaries, except Escambia Bay, had a reduction of seagrass coverage. Big Lagoon lost approximately 20% of its seagrass area, and Santa Rosa Sound's decreased to less than half its size between 1960 and 1992. It should be noted that seagrass mapping methods were not consistent among the surveys highlighted in Schwenning at al. (2007). Schwenning et al. (2007) points to human activities including sewage and industrial discharge, dredge and fill, beachfront alteration, and watershed land use change to explain the decline in seagrass coverage.

Table 4. Seagrass coverage as hectares (acres) in the Pensacola Bay system (Schwenning et al. 2007).

Year	Escambia Bay	East Bay	Pensacola Bay	Big Lagoon	Santa Rosa Sound
1960	105 (259)	476 (1,175)	372 (918)	271 (670)	2,634 (6,508)
1980	24 (60)	99 (245)	55 (137)	236 (582)	1,489 (3,680)
1992	178 (441)	165 (408)	114 (282)	218 (538)	1,140 (2,816)

Schwenning et al. (2007) calls for a long-term monitoring program that relies on remote sensing to map coverage at large, supported by biotic and abiotic monitoring. Such monitoring would include measures of shoot length, species composition, density, epiphyte load and water quality measurements including nutrients and light attenuation.

The Choctawhatchee Bay, Florida; Gulf Islands National Seashore

The 334 square kilometer (129 square mi) Choctawhatchee Bay connects to Santa Rosa Sound at its western end and receives freshwater inflow from the 14,000 square kilometer (5,405 square mi) Choctawhatchee River (Figure 9). Choctawhatchee Bay is divided into Western (west of Highway 293 Mid-Bay Bridge), Middle (between Highway 293 Mid-Bay Bridge and Highway 331 Bridge) and Eastern (east of Highway 331 Bridge) portions (Figure 10). Gulf Islands National Seashore manages 782 hectares (3.1 square mi) of the southwestern portion of Choctawhatchee Bay adjacent to Santa Rosa (Okaloosa) Island near Fort Walton Beach.

Ruth and Handley (2007) describe seagrass beds of Choctawhatchee Bay as supporting diverse populations of fish and invertebrates, including many recreational and commercially important species. The western portion of the Bay is generally more saline and has a longer history of human development than other portions (Ruth and Handley 2007). There is very limited information on seagrass distribution through time in Choctawhatchee Bay. Most of continuous seagrass beds are found within the national seashore according to a USGS photointerpretation survey in 1992 (Ruth and Handley 2007). There is not enough information to state if a change in seagrass coverage has occurred in Choctawhatchee Bay. Ruth and Handley (2007) calls for a seagrass monitoring program that would map and determine the condition of submerged vegetation and that would identify trends and potential threats.

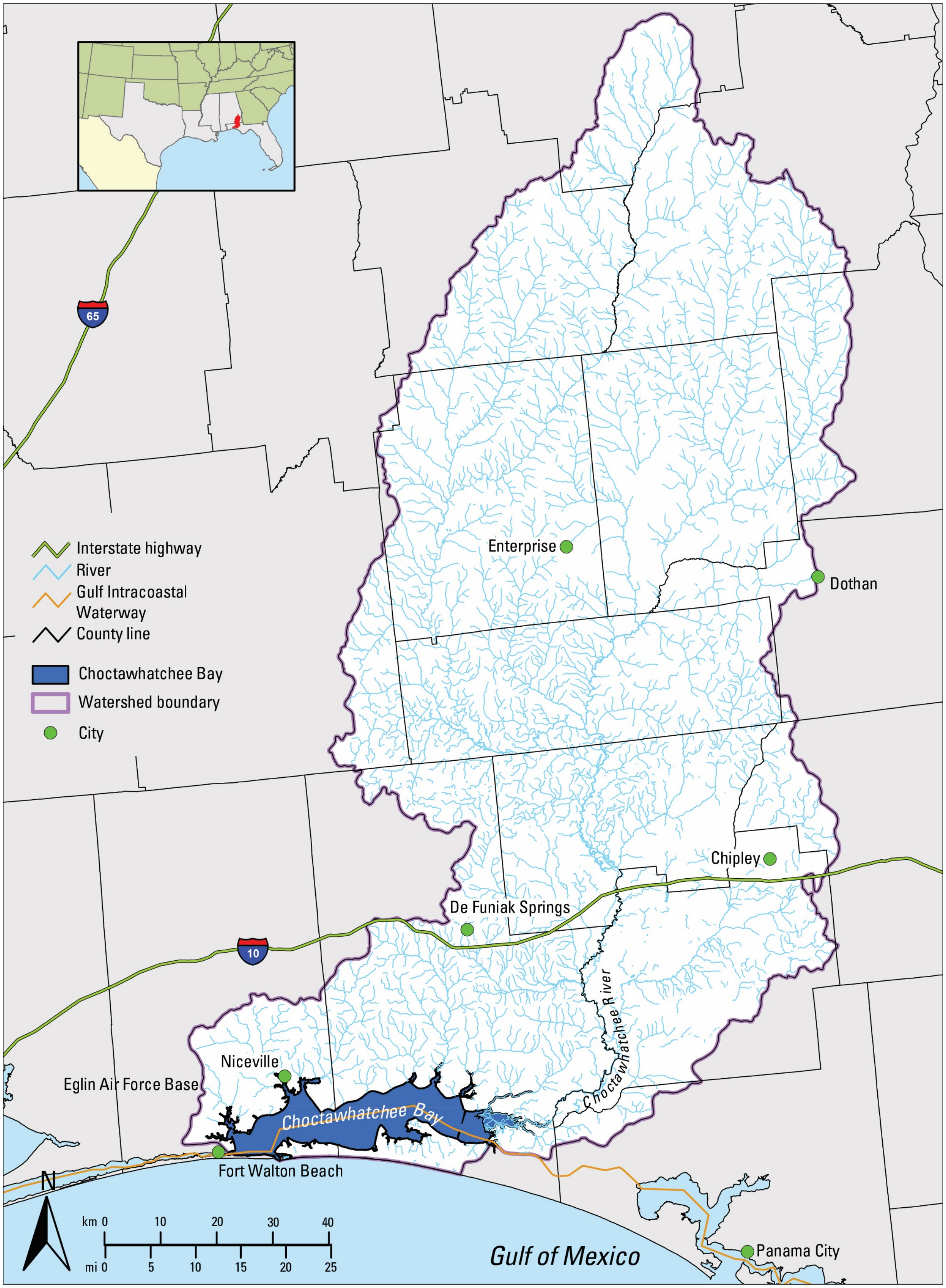

Figure 9. Watershed for Choctawhatchee Bay (Ruth and Handley 2007).

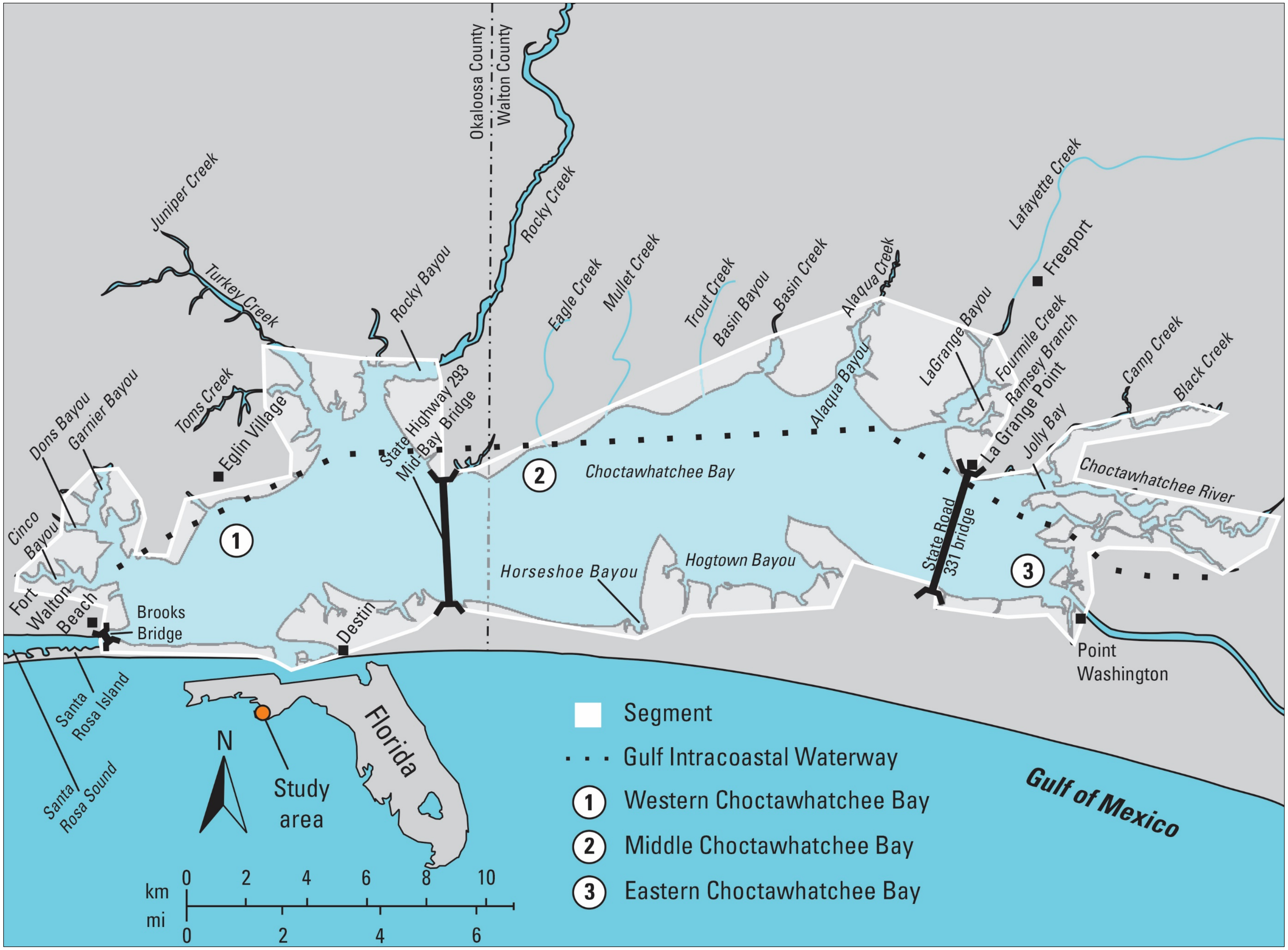

Figure 10. Choctawhatchee Bay system (Ruth and Handley 2007).

In 2011 the Gulf Coast Network entered a cooperative agreement with the Dauphin Island Sea Lab (DISL) to conduct seagrass monitoring in Gulf Islands National Seashore's portions of the Mississippi and Santa Rosa Sounds, and Perdido and Choctawhatchee Bays, following the same design and procedures as that implemented under the statewide plan in Texas (Dunton 2011). The Dauphin Island Sea Lab continued annual monitoring through 2016.

Sample Design and Monitoring Schedule

This protocol will use the same sample design and procedures that are being used in the Texas state-wide seagrass monitoring program implemented by a variety of Texas partners: National Oceanic and Atmospheric Administration (Mission-Aransas National Estuarine Research Reserve), Coastal Bend Bays and Estuaries Program, the Texas Coastal Management Program and the Texas General Land Office. This design is based on selecting permanent monitoring sites that are resampled through time. The sites are randomly chosen within individual hexagons from a tessellated grid that overlays seagrass habitat as described in Neckles et al. 2012. By using the same methods and schedule, GULN data will be directly comparable to estuary-wide or coast-wide sampling by partners who have also adapted Dunton et al. (2011).

The benefit of regional consistency outweighs the potential benefits of alternative designs. Continuing to work within efforts that are implemented on a broader statewide or Gulf-wide scale is very important to ensure that the NPS data can be viewed in a broader context. For example, the network participated in a Gulf-wide Seagrass Needs and Assessment Workshop in October 2017. The workshop was hosted by USGS at the EPA Gulf Breeze Laboratory in Gulf Breeze, Florida as part of the restoration and assessment resulting from the 2010 Deepwater Horizon oil spill. The workshop brought together experts in seagrass research, monitoring, and assessment with the goal of moving toward a more standardized approach to long term monitoring of seagrass in the Gulf of Mexico. The group reached a consensus regarding the use of a tiered approach, with Dunton et al. (2011) held up as an example of how this could be implemented. The team is currently refining which parameters should be used in the implementation of each tier. The GULN protocol already fits into that general framework and should be consistent with the final recommendations that are developed by the workgroup.

The GULN seagrass monitoring protocol uses a probability survey design that was developed by the EPA Environmental Monitoring and Assessment Program (EMAP) in the early 1990s and first applied to the estuaries in Louisianan and Virginian provinces (Kopp and Neckles 2009). It has since been adopted by the EPA National Coastal Assessment (NCA) and became the Tier 2 component of Neckles et al. (2012). Kopp and Neckles (2009) used a grid of tessellated hexagons with a randomly-chosen geospatial coordinate that denotes each cell's permanent station and that produces a set of spatially balanced stations. Because this sampling protocol follows the EPA protocol for the NCA program, the condition of NPS estuaries can be evaluated within the context of other estuaries in the region, and data from park estuaries can contribute toward overall regional condition assessments.

Site Selection

Site selection followed the procedures of Neckles et al. (2012) who used a restricted random sampling design (Elzinga et al. 2001) to select permanent sampling stations within cells of a tessellated hexagonal net. Restrictions were based on light (bathymetry of 2 meters or less), park boundary (at least a portion of the hexagon must be within park boundaries) and not on land (only the submerged portion of the cell was used for selection). The samplers navigate to permanent stations (within 10 meters [33 feet]) and take a series of seagrass measurements from the boat and at four systematically placed quadrats (see Field Methods, below).

Site selection at Padre Island National Seashore (n=64) was established by the University of Texas Marine Science Institute as part of a Texas coast-wide monitoring effort (Dunton 2011). One point was randomly selected within each hexagon of a tessellated 750 m hexagonal grid that was overlain on seagrass areas of the Upper Laguna Madre (Figure 11). This approach ensured that the sampling effort was distributed across the landscape. Some criteria were required to ensure that points were located in seagrass areas and that no sampling area was favored over others (Volstad et al. 1995). This was accomplished by using baseline maps of seagrass cover. The selection of stations was restricted to areas less than 2 meters (6.6 feet) in depth. Figures 12a, 12b, and 12c show the sample frame for the sites at Padre Island NS. The sample point within any hexagon that has any area within the park boundary is included in the sample frame, even if the point is outside of the park boundary. Detailed locations of sampling sites are provided in GULN SOP SEA03 *Site Selection—Version 1.0* (Meiman et al. 2019).

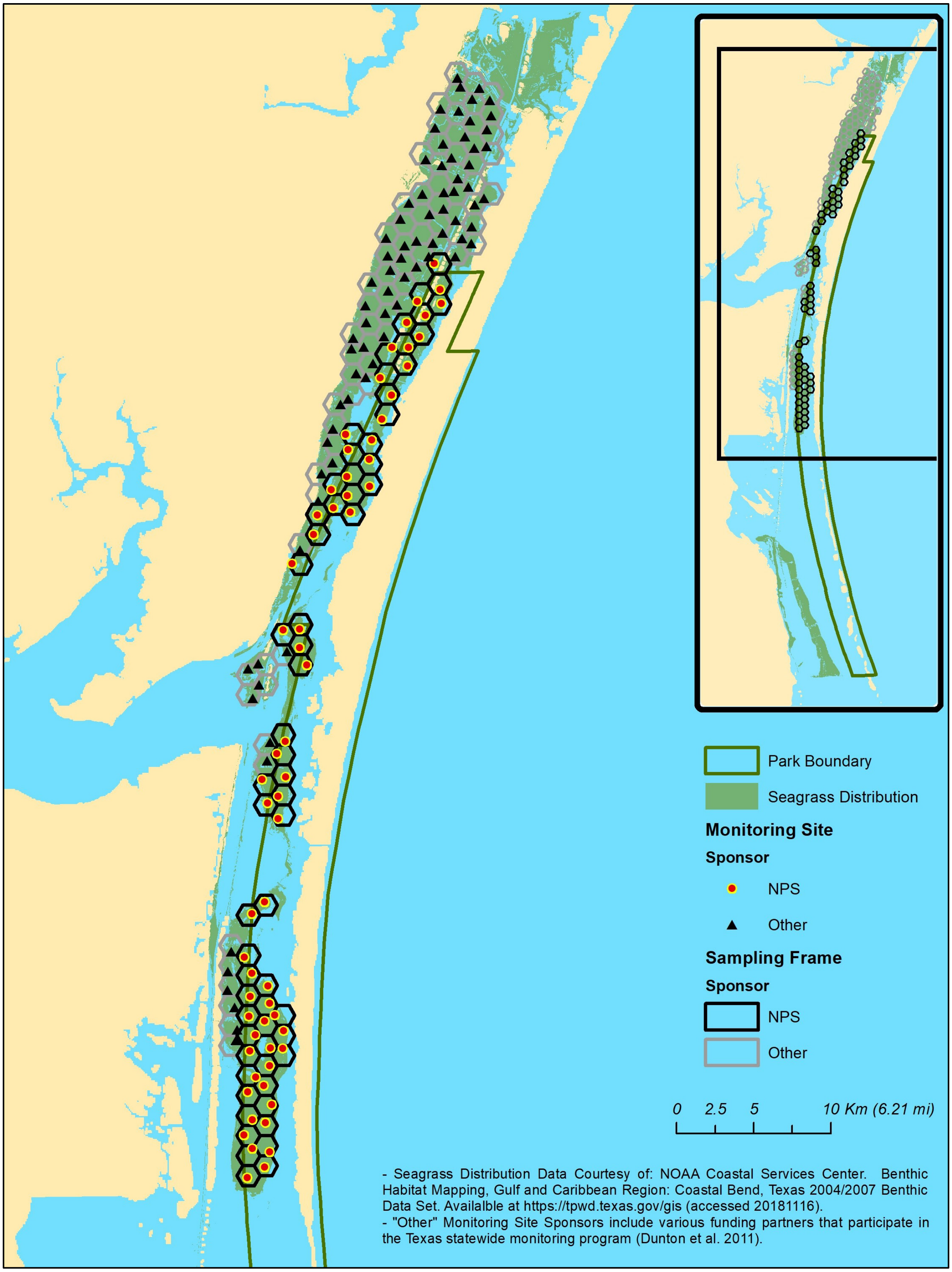

Figure 11. Site selection in the Texas seagrass monitoring program in the Upper Laguna Madre.

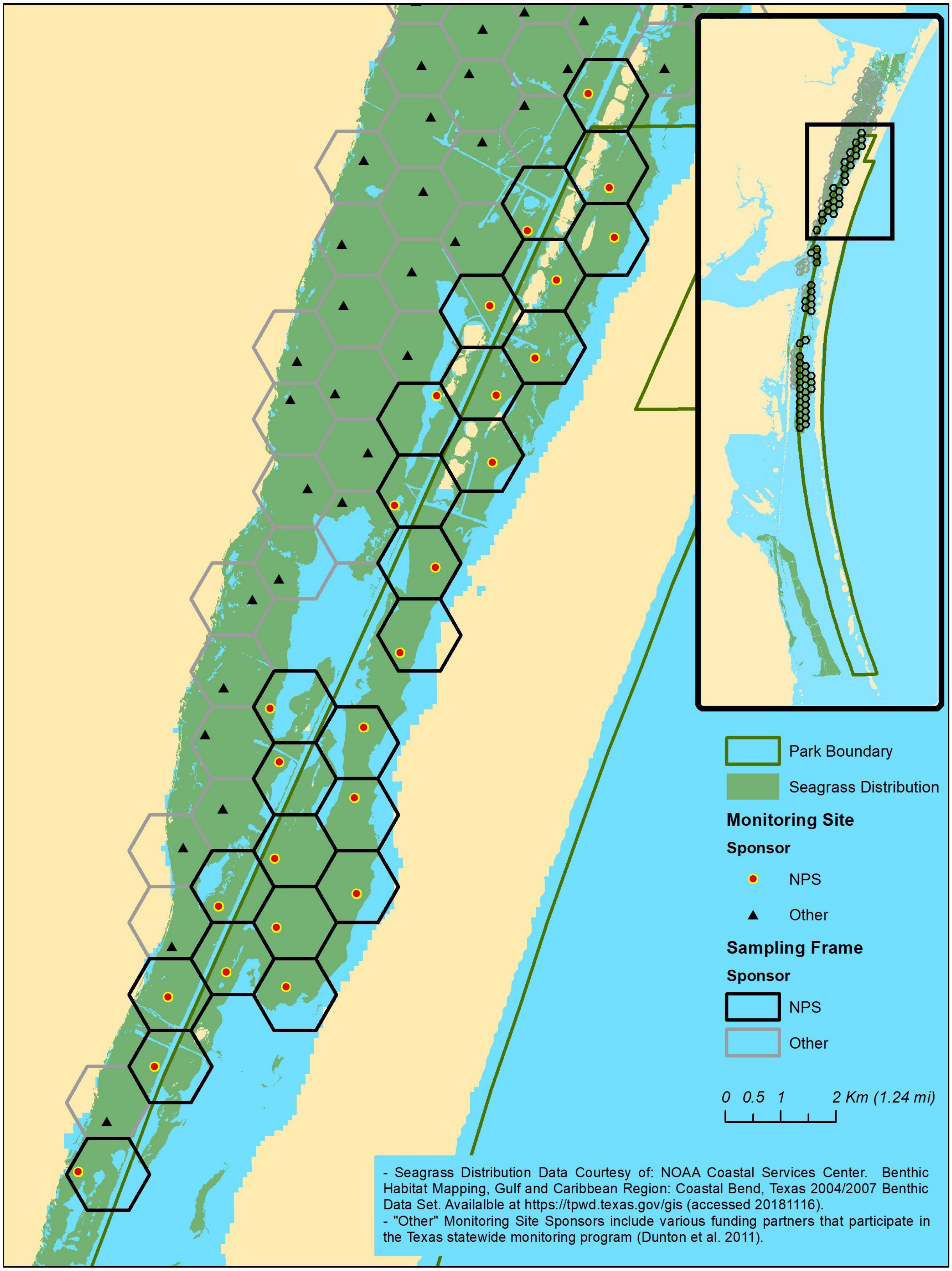

Figure 12a. Detail of the northern portion of NPS managed estuary at PAIS with tessellated hexagonal grid (750 meter edge), depth-limited potential habitat (2 meter) and monitoring sites.

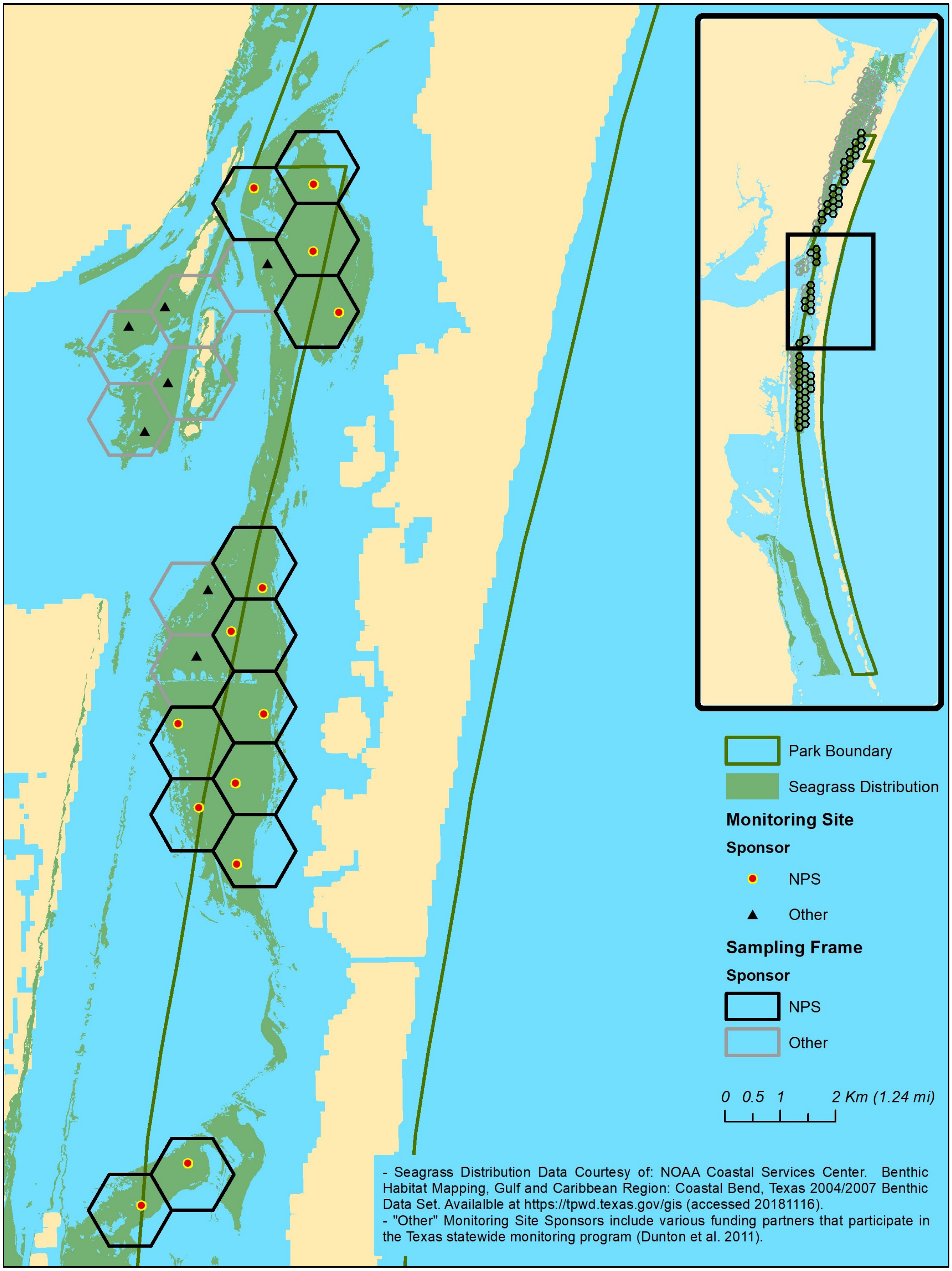

Figure 12b. Detail of the central portion of NPS managed estuary at PAIS with tessellated hexagonal grid (750 meter edge), depth-limited potential habitat (2 meter) and monitoring sites.

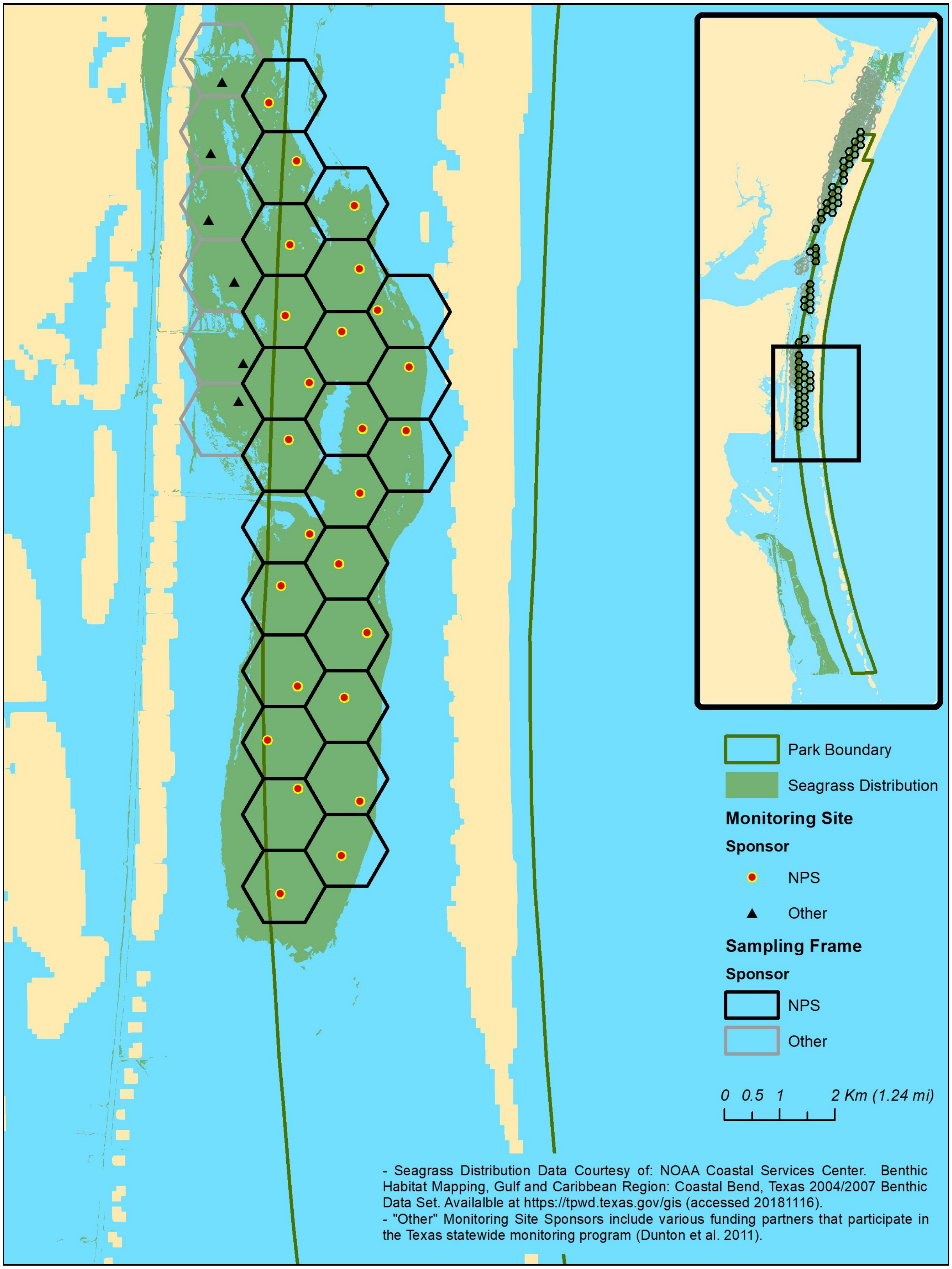

Figure 12c. Detail of the southern portion of NPS managed estuary at PAIS with tessellated hexagonal grid (750 meter edge), depth-limited potential habitat (2 meter) and monitoring sites.

Site selection at Gulf Islands NS was done through a cooperative agreement with the Dauphin Island Sea Lab (DISL) and used the same 750-meter sized hexagonal grid used for the selection of the sites in Texas. However, there were no recent maps of seagrass cover so the sample area was restricted to only those areas located in less than 2 meters (6.6 ft) of water. Based on professional judgment and experience (Ken Heck, personal communication) this was determined to be a valid representation of potential seagrass areas. Unlike Padre Island National Seashore, where NPS sites are embedded in a statewide sampling frame, all sites at Gulf Islands NS are located within park boundaries. The original site selection used a combination of sites using the methods described in Neckles et al. (2012) and pre-existing (legacy) sites to establish sites for the pilot study from 2011 to 2016. If one of the DISL legacy sites was located within a selected hexagon, that location was selected. While these historic data are valuable, there was concern that mixing two site selection methods could introduce bias. Consequently, the decision has been made to have all sites in this protocol selected by the same method. All pre-existing legacy DISL sites have been removed from the sample frame and replaced with a new random point within those hexagons. The result is that all permanent sites (n=106) have been randomly selected from each hexagon and are consistent with the site selection method used at Padre Island National Seashore in Texas (Dunton 2011; Figures 13a–13h). Detailed locations of sampling sites are provided in SOP SEA03. Site selection and pilot data collection at Ship Island were completed prior to the beginning of construction of the Mississippi Coastal Improvements Program (USACE 2019). Part of this project involves the reconnection of East and West Ship Islands that were separated in 1969 during hurricane Camille (Figure 13a). Although construction has begun, and the two islands are now formally re-joined to form Ship Island, the newly created area of potential seagrass habitat has not yet been defined. Part of the MsCIP project includes monitoring and adaptive management of impacted resources, including seagrass mapping and implementation of Tier 2 monitoring. The network will re-evaluate and potentially incorporate additional sampling locations after project construction is complete and new bathymetry and seagrass maps are available.

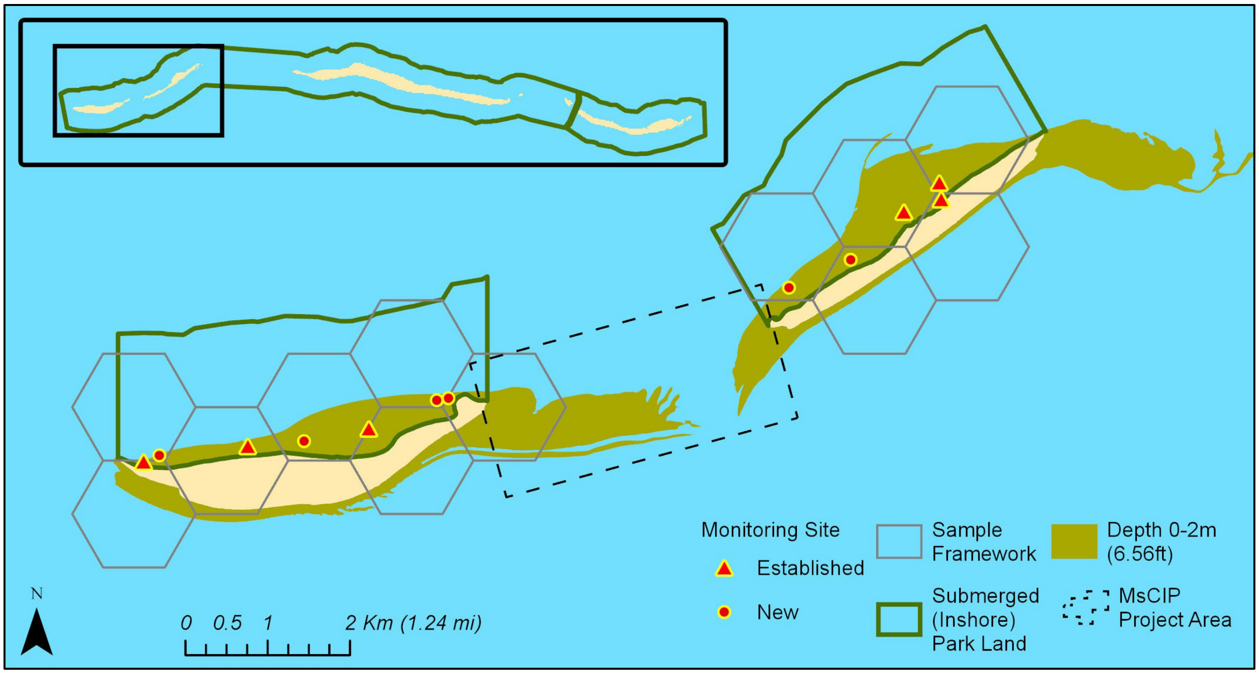

Figure 13a. Gulf Islands National Seashore boundary at Ship Island of the Mississippi Sound with hexagon net and seagrass monitoring stations.

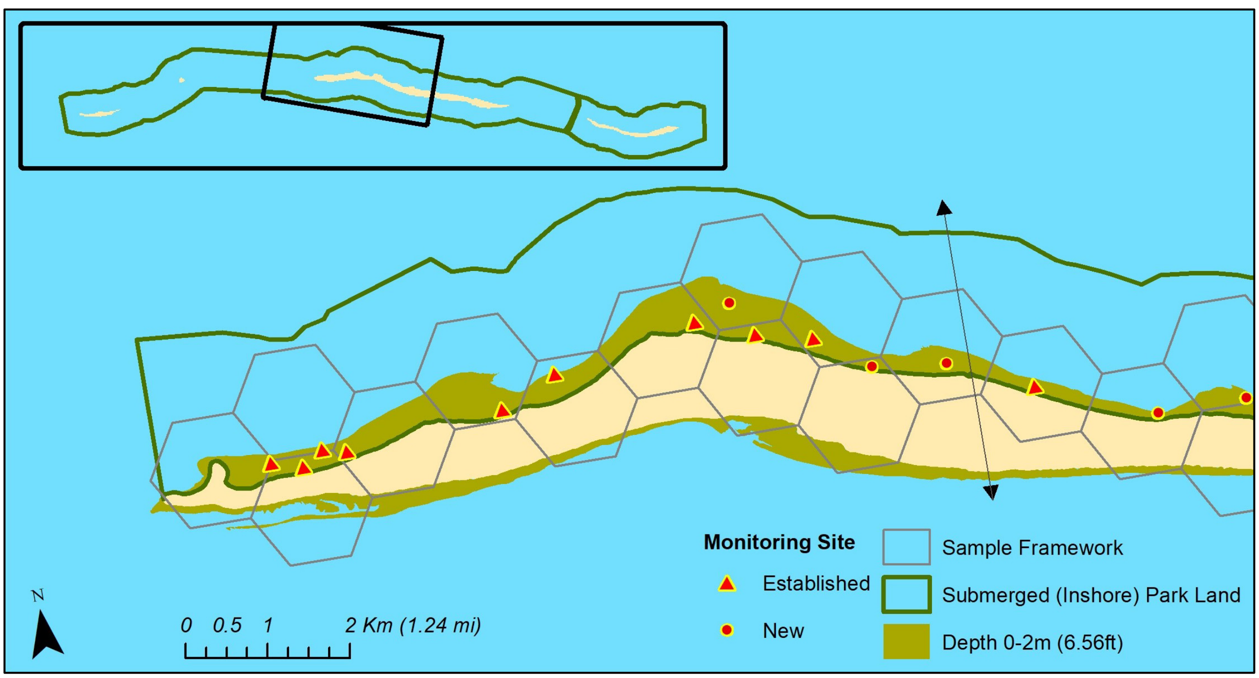

Figure 13b. Gulf Islands National Seashore boundary at the western portion of Horn Island of the Mississippi Sound with hexagon net and seagrass monitoring stations. The double-headed arrow is shown in both Figure 13b and Figure 13c as a shared point-of-reference for the two figures.

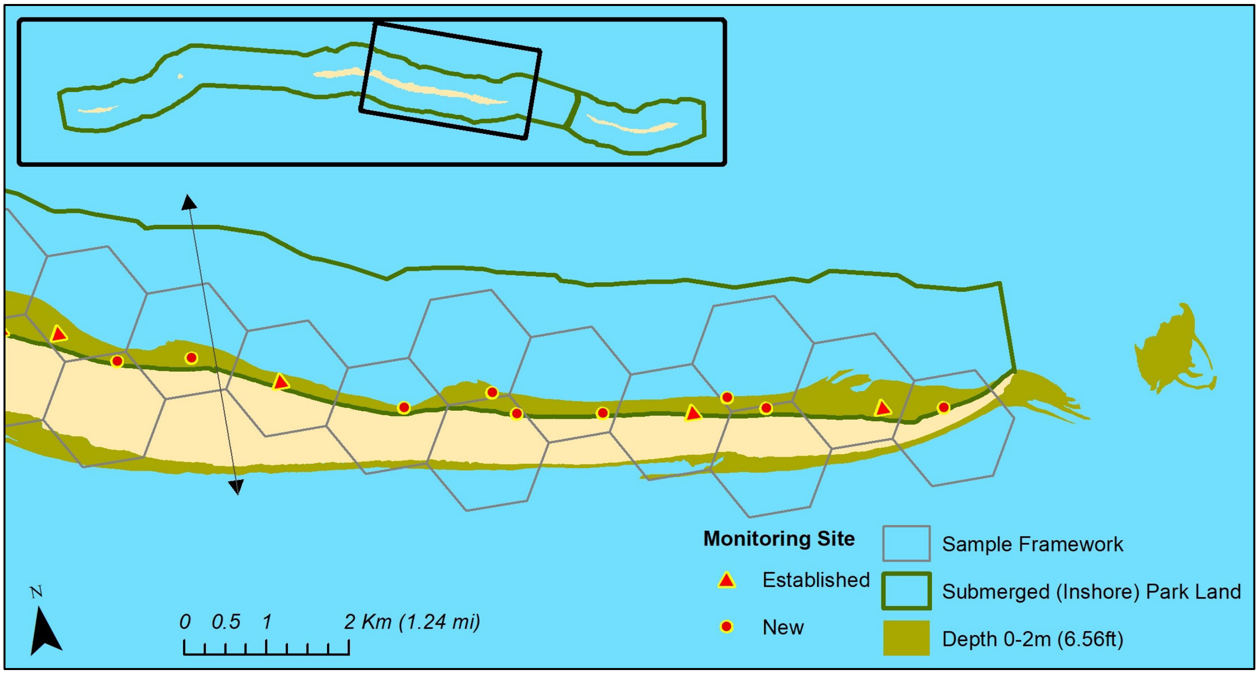

Figure 13c. Gulf Islands National Seashore boundary at the eastern portion of Horn Island of the Mississippi Sound with hexagon net and seagrass monitoring stations. The double-headed arrow is shown in both Figure 13b and Figure 13c as a shared point-of-reference for the two figures.

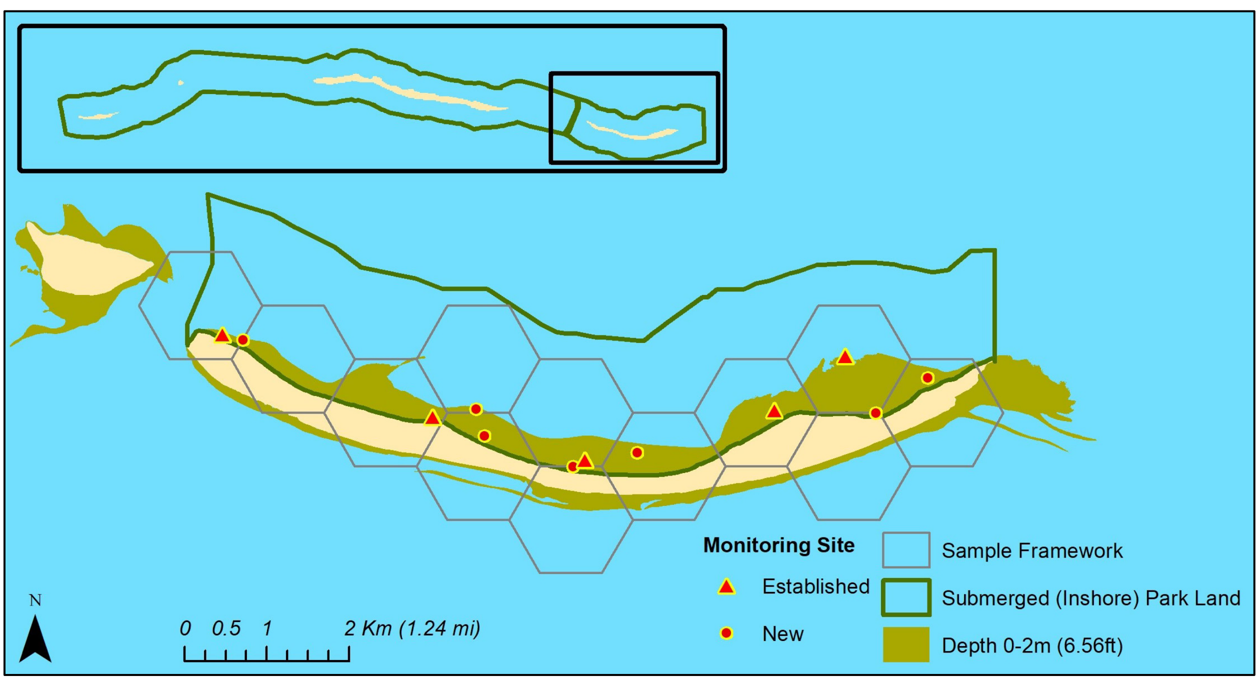

Figure 13d. Gulf Islands National Seashore boundary at Petit Bois Island of the Mississippi Sound with hexagon net and seagrass monitoring stations.

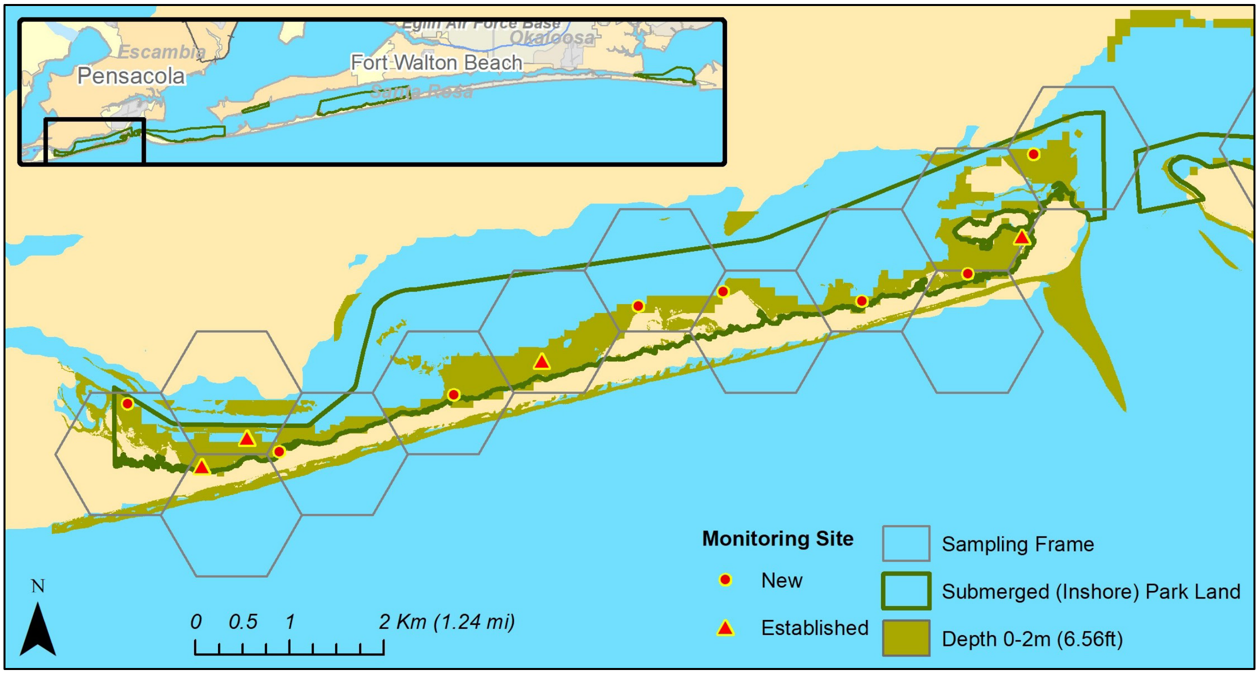

Figure 13e. Gulf Islands National Seashore boundary at eastern end of Perdido Key with hexagon net in Big Lagoon and seagrass monitoring stations.

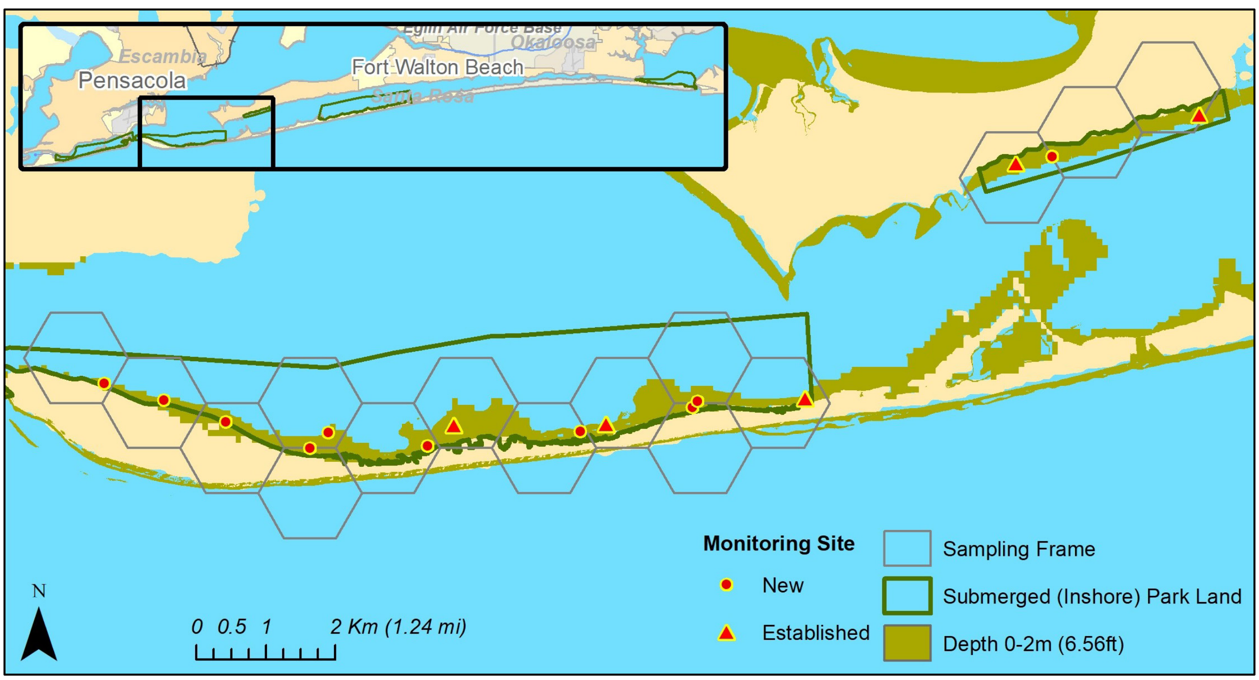

Figure 13f. Gulf Islands National Seashore boundary in Santa Rosa Sound near Fort Pickens and Naval Live Oaks with hexagon net and seagrass monitoring stations.

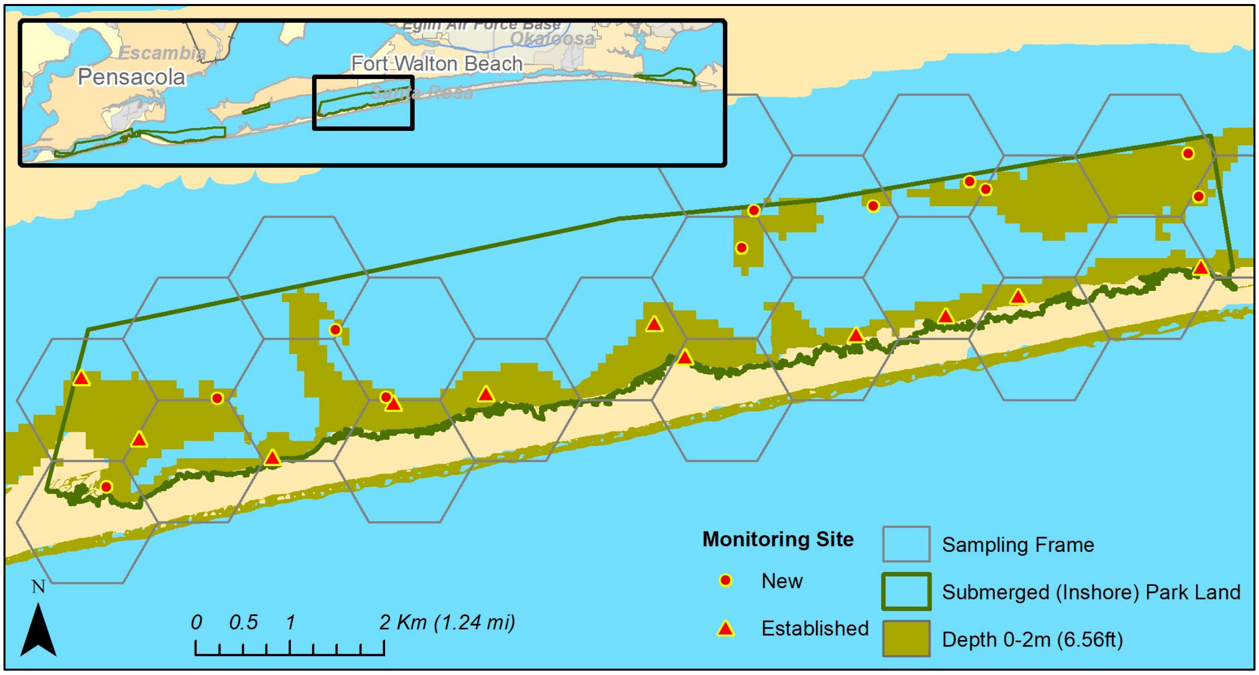

Figure 13g. Gulf Islands National Seashore boundary in Santa Rosa Sound between Pensacola Beach and Navarre with hexagon net and seagrass monitoring stations.

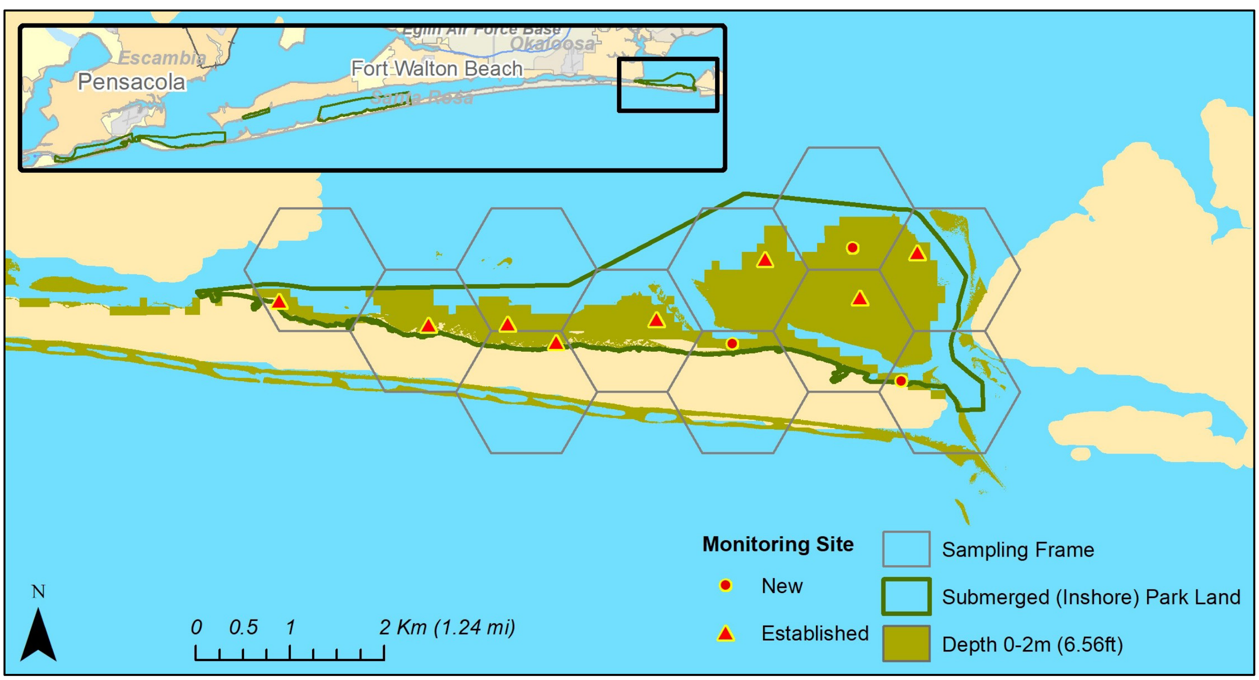

Figure 13h. Gulf Islands National Seashore boundary in Choctawhatchee Bay near Okaloosa Island with hexagon net and seagrass monitoring stations.

Monitoring Schedule

All sampling is performed during or shortly following peak seagrass biomass, during the months of August and September. In the northern Gulf of Mexico this occurs in mid to late summer. The network will conduct sampling at all locations every three years, or more often as funding allows participation in coordinated estuary-wide sampling efforts by partners. Sampling is expected to begin in 2021. The network may advance or delay the first round to be coincidental with the U.S Army Corps of Engineers and the Texas seagrass monitoring using the common method. The network will conduct the field, lab, and data entry and initial data QA/QC portions of this protocol through a cooperative agreement or contract. While paired sampling on a larger scale is preferred, Gulf Coast network will proceed as a stand-alone effort within the park boundaries if no other efforts are ongoing.

Levels of Change and Statistical Targets

The primary objectives for this protocol are to monitor changes in seagrass percent cover, community composition (measured as a dominance index) and canopy height (measured as leaf length). Due to the dynamic nature of seagrasses and their rapid response to changes in water quality, analyses will initially be focused on detecting change between sampling events, not long-term trends. Given this approach, the valuable questions for designing and interpreting the study then become (1) whether the current design is appropriate for detecting significant temporal changes in seagrass metrics and ancillary data (i.e., reflecting more than just year-to-year or site-to-site noise caused by random, non-directional processes); and (2) whether any of the significant changes observed in seagrass metrics or water quality are meaningful indicators of ecosystem change. For the first question, a formal analysis of power to detect change, including ancillary data, will be conducted after two or three sampling events under the new, final design (beginning 2020 onward). We will explore the use of simulations based on various scenarios of changes in seagrass distribution, patchiness, and dynamism. For the second question of whether significant differences are biologically meaningful, the GULN approach relies on the work of Congdon et al. (2018), which uses primary literature to establish biologically relevant thresholds for change in several key seagrass metrics. See SOP SEA07 *Data Analysis and Reporting—Version 1.0* (Carlson and Meiman 2019) and Appendix S07.A for a fuller description and justification of the threshold values.

In addition to having the power to detect change, a successful protocol must also achieve high precision of one-time estimates, to ensure that managers are provided meaningful information. The network has set statistical targets for precision based on 95% confidence intervals around unit-level averages (PAIS, GUIS-MS and GUIS-FL) for percent cover, leaf length, and dominance index. These are ± 5 units (%) of percent cover, ± 3 centimeters for leaf length, and 0.1 units of dominance index.

Field Methods

Field Schedule and Preparations

Field sampling will occur during the peak seagrass biomass months of August and September. Prior to sampling all personnel will be trained according to SOP SEA02 *Training—Version 1.0* (Meiman 2019a). Seashores will be notified at least three months prior to an upcoming monitoring event through the permitting process. The network will be in direct communication with each seashore in the weeks before monitoring to set a range of days for monitoring activities. Additional communications will be made a day prior to monitoring. The cooperator or contractor will be responsible for all materials associated with the field effort.

Parameters

Parameters measured in the field are consistent with those collected in the Texas statewide monitoring program (Dunton et al. 2011). Field measurements include seagrass species composition, percent cover, and leaf length, as well as a series of abiotic measurements of water quality and light attenuation. The network will take replicate seagrass shoots from each species present from each quarter-quad; leaf length will be measured on board the boat as per Dunton et al. (2011) and described in SOP SEA04 *Field Measurements—Version 1.0* (Meiman 2019b). The network also maintains several continuous water quality monitoring stations in and around the parks (for details, see Meiman 2017a, b and https://www.nps.gov/im/guln/water-quality.htm) and has access to several more that are operated by federal or state agencies. These data may be used to help interpret changes in focal variables.

Field Methods

Field methods of this protocol are from Dunton et al. (2011) and are detailed in SOP SEA04 *Field Measurements—Version 1.0* (Meiman 2019b). Table 5 describes the data collected, data collection frequency, analytical approaches, and associated protocol objectives. Dunton et al. (2011) gives the following sequence performed at each permanent station:

1. Collect all measurements and samples using a crew of two from a shallow-draft vessel.
2. Navigate to pre-selected stations with a GPS accuracy of 4 meters (13.1 ft) or better. Stations are defined as the area within a 10-meter (32.8-ft) radius of the GPS location.
3. Collect physicochemical measurements with a data sonde prior to deployment of any benthic sampling equipment.
4. Calculate water transparency from simultaneous measurements of photosynthetically active radiation (PAR) at the surface and at a measured depth using spherical quantum sensors and the Beer-Lambert equation for calculation of the diffuse attenuation coefficient (kd).
5. Retrieve four replicate samples per station (for indicators listed in Table 5) from each of the four corners of the boat (forward-starboard, aft-starboard, aft-port, forward-port). Previous work has shown that the use of four samples was sufficient to avoid within-station bias in percent cover estimates (Neckles et al. 2012).

6. Visually estimate percent cover within 0.25-m2 (2.7-ft2) quadrats subdivided into 100 gridded squares using monofilament line. Estimates are made via direct observation through the water. If water transparency is extremely poor (Secchi depth less than 1 meter [3.3 ft]), make direct in situ measurements of the bottom with a mask and snorkel.
7. Measure five replicate grass shoots from each species present from each quadrat to establish leaf length.

Table 5. Data collected, area sampled, sampling method, sampling frequency, and associated protocol objectives [PAR=photosynthetically active radiation, TSS=Total Suspended Solids, Chl-a=Chlorophyll *a*].

Description	Area Sampled	Frequency	Method	Data Collected	Monitoring Objectives
Species percent cover	Four locations at each fixed station (random point within a hexagonal cell)	Triennial	Visual quadrat	Percent cover per species	Change over time in percent cover for each species and across all species, and change in community composition.
Leaf length	Five leaves per species at four locations at each fixed station	Triennial	Meter stick	Average shoot length per species within quadrat	Change over time in leaf length by species
Water column Physico-chemical	Fixed station	Triennial	*In situ* measure-ments	Temperature, salinity, dissolved oxygen, Secchi depth, total depth, PAR (to calculate water transparency), pH, Chl-*a*, TSS	Ancillary data to help explain changes in seagrass metrics

Dunton et al. (2011) states that other monitoring programs using this method have demonstrated that such an approach, when all sampling stations are considered together within a regional system, results in greater than 99% probability that the bias in overall estimates will not interfere with detection of change over time.

Field Data Quality Standards

Field data collected under this protocol are both human observations and direct sensor measurements (Table 6). Data quality begins with proper training (SOP SEA02 *Training—Version 1.0* [Meiman 2019a]) and calibration of instruments (SOP SEA04 *Field Measurements—Version 1.0* [Meiman 2019b]). Field data quality expectations are met by adherence to data quality standards.

Table 6. Field Data Quality Standards [cm—centimeter; SU—standard unit; DO—dissolved oxygen; mg/L—milligrams per liter; µg/L—micrograms per liter; rep—repetition].

Parameter	Units	Method	Sensitivity	Expected Range
Depth	cm	Graduated staff	1 cm	1–200 cm
pH	SU	Sensor	0.2 SU	7–9 SU
DO	mg/L	Sensor	0.5 mg/L	2–14 mg/L
Salinity	NA	Sensor	0.1	5–36 FL, MS 5–80 TX
Water Temp	°C	Sensor	0.1 °C	25–40 °C
Secchi Depth	cm	Secchi Disc	1 cm	10–200 cm
Chlorophyll-A	µg/L	Sensor	0.1 µg/L	0–20 µg/L
Percent cover for each seagrass species, averaged over four 0.5 x 0.5 quadrats per station	%	Direct observation	1%[a]	0–100%
Leaf length for each species, averaged over 5 representative individuals per quadrat	cm	Meter stick	0.1 cm	2–40 (*Thalassia testudinum* and *Syringodium filiforme*), 2–30 (*Halodule wrightii* and *Ruppia maritima*), 2–10 (*Halophila engelmannii*) cm

[a] One shoot is the smallest quantity that can be detected by an observer, and will be assigned a percent cover of 1%.

Prior to the day of sampling, 10% of the sites will be randomly selected as QA/QC sites. All measurements will be duplicated at each QA/QC site. The network will use TCEQ (2003) as a guide for field physicochemical measurements. Stabilization criteria for field measurements are based on instrument precision from manufacturer's guidelines. TCEQ (2003) states that criteria for stabilized field readings are defined operationally based upon values of a set of three or more sequential measurements once the instrument is stable. A median value of the three consecutive stable readings is recorded. A QA/QC value is obtained in the same fashion. For example, if a pH sensor with a resolution of ± 0.1 unit, once stable, gives a median reading of 7.4 the result is considered to actually be between 7.3 and 7.5 units. The QA/QC sample must overlap this span, or a maximum of between 7.6 and 7.2 units to account for instrument resolution. All Gulf Coast Network QA/QC measurements must overlap the resolution of the stabilization criteria of the primary sample. If the measurements do not meet this standard the source of error will be identified and mitigated. Biotic measurements will be duplicated by a different trained observer. Each quadrat will be resampled for species identification and percent cover by species prior to repositioning of a quadrat. The second observer will also collect duplicate samples for shoot length measurement. If species identifications do not agree 100% of the time and if percent cover and leaf length are not within 10% the source of error will be mitigated.

Permitting and Compliance

The network will work with the cooperator or contractor to ensure that all appropriate permits are submitted to the seashores at least three months prior to fieldwork. The network will coordinate field operations with the contractor or cooperator and the seashores.

Data Management

Overview of Data Management Workflow for the Gulf Coast Network

An increasing demand for detailed, high-quality data and information about natural resources and ecosystem functions requires a team working together to steward data and information assets. Knowledgeable individuals from scientific, administrative, and technological disciplines must work in concert throughout the data management cycle. This collaboration ensures that data are collected using appropriate methods, and that resulting data sets, reports, and other derived products are well managed, credible, representative and available for current and future needs. As such, data stewardship responsibilities apply to all personnel who handle, view, or report data. Within the Gulf Coast Network, all personnel play key roles in information management. The overall strategy for the network is described in the *Gulf Coast Network Data Management Plan* (Granger 2007). The plan also contains appended guidance documents on various information management topics.

The GULN seagrass monitoring protocol relies on both the cooperator or contractor and the National Park Service to deliver accurate data to the seashores and the public. Tabular data are recorded in the field and lab by cooperators or contractors who perform 100% verification prior to delivery to the network (see Figure 14 for the data flow used by the network). The network uploads these data into NPStoret, which has entry filters established that restrict all data from being entered beyond expected ranges detailed in Table 6. In addition, stations within each estuary comprise an analysis group in NPStoret where expected species are defined. Data that are not compliant with expected ranges or species are flagged and the database will not allow entry to proceed without review by the data manager. Additional validation of the data imported is performed by the protocol lead by plotting and summarizing data as appropriate, as well as generating range and average values to help identify any outliers. Once data are entered in NPStoret the network performs a 10% verification and submits the database to the Water Resources Division for national dissemination via U.S. EPA STORET. Detailed instructions for each step in the data flow process are in SOP SEA06 *Data Management—Version 1.0* (Granger and Meiman 2019).

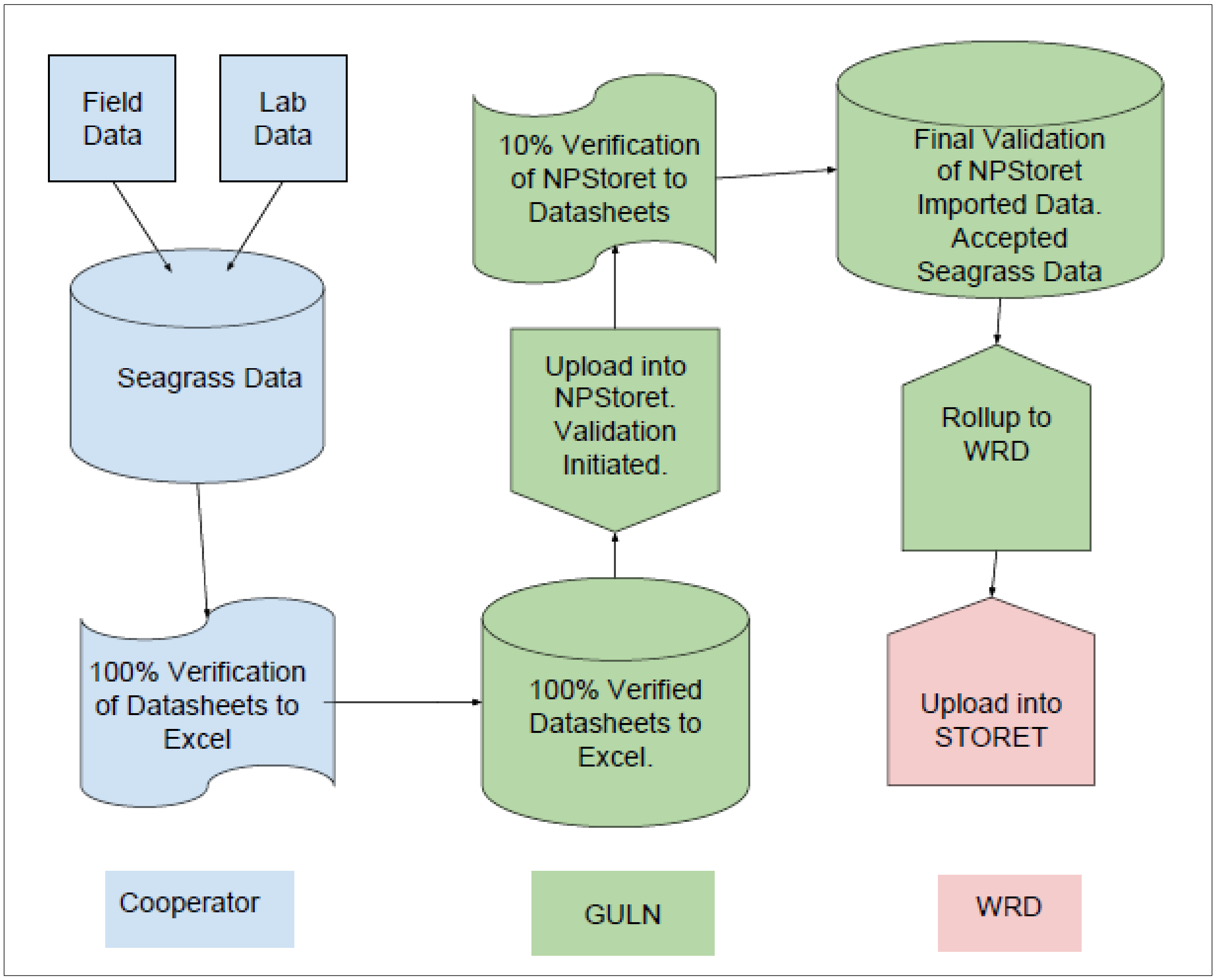

Figure 14. Seagrass data work flow diagram

The specific steps in the data management workflow are:

- **Data acquisition**—Data are collected by the observer on paper datasheets, in accordance with instructions in SOPs SEA04 *Field Measurements—Version 1.0* (Meiman 2019b) and SEA05 *Laboratory analysis—Version 1.0* (Meiman 2019c). The final products from this step are paper datasheets.
- **Data entry**—The cooperator or contractor enters all field and lab data into an Excel spreadsheet. The final product from this step is an Excel spreadsheet of all field and lab data (see SOP SEA06).
- **100% verification of spreadsheet**—The cooperator or contractor performs a 100% verification of the spreadsheet against original paper datasheets. The final product from this step is a 100% verified spreadsheet (see SOP SEA06).
- **Data submittal to the GULN**—The cooperator or contractor scans the paper field and lab datasheets and submits original field sheets to the GULN for archiving. The 100% verified spreadsheet is sent to the network for additional processing (see SOP SEA06).

- **Data upload into NPStoret**—The network uploads the spreadsheet into NPStoret on its server. The final product of this step is the initially validated data in NPStoret on the GULN server (see SOP SEA06).
- **10% verification of NPStoret data to datasheets**—The network uses the NPStoret random selection function and identify 10% of the station visits for comparison to parent field and lab datasheets.
- **Validation of NPStoret database**—The protocol lead plots and summarizes data as appropriate, and generates range and average values to help identify outliers. The final product of this step is an approved database (see SOP SEA06).
- **WRD roll up**—After data are certified by the network they are sent to the Water Resources Division (WRD) to be uploaded to NPStoret on the WRD server and to the EPA STORET database. The final product of this step is publicly available seagrass data (see SOP SEA06).

Protected Data

Currently, none of the species monitored in this protocol are rare, threatened, endangered, or of commercial value. Because maps of seagrass extent are publicly available, and none of the monitoring locations are permanently marked, the network does not currently classify any seagrass data as protected information. However, this is conditional and dependent on coordination with park staff and approval from each superintendent.

Data Archiving

After the digital products are processed and approved (field sheets/reports) or accepted/certified (datasets), the data manager archives them on the local server and prepares for posting them to Integrated Resource Management Applications (IRMA). IRMA is the NPS clearinghouse for natural resource data and metadata. The types of products that are posted on IRMA for this project include Microsoft Excel exports of annual data sets from the NPStoret GULN seagrass database, scanned field sheets and final reports.

Products on IRMA can be shared with the public or restricted to NPS only or to specific NPS employees. Public access is granted to final, approved reports or to datasets that are accepted or certified. Restricted access on IRMA may be used for provisional products (NPS only) or protected information (specific NPS employees). The GULN data manager has created a GULN Seagrass Monitoring Project that houses all products uploaded to IRMA. Refer to the IRMA website for upload and product linking instructions.

The original paper field sheets are filed by project and year in filing cabinets located at the GULN office. Details on data archiving are provided in SOP SEA06.

Procedure for Revising the Protocol

Over time, revisions to both the protocol narrative and SOPs are expected. Careful documentation of changes to the protocol and a library of previous protocol versions are essential for maintaining consistency in data collection and for appropriate treatment of the data during data summary and analysis.

The steps for changing the protocol (either the protocol narrative or the SOPs) are outlined in SOP SEA08 *Protocol Revisions—Version 1.0* (Meiman 2019d). The protocol narrative and each SOP contain a revision log to fill out each time the narrative or an SOP is revised. In this log, GULN staff briefly document when and why the change was made and assign a new version number. Revised protocol narratives must also be assigned a new report number by the National I&M Program Publication Manager. The new version of the SOP or protocol narrative must then be posted to the IRMA Data Store as well as archived in the appropriate GULN vital signs protocol folder on the GULN network drive.

Data Analysis and Reporting

The Gulf Coast Network analyzes or summarizes data and produces reports for their seagrass monitoring project on two time scales: once per monitoring event and once every three events. The report types are called Monitoring Event Reports and Change Analysis Reports, respectively, and they are described in detail in SOP SEA07 *Data Analysis and Reporting—Version 1.0* (Carlson and Meiman 2019). The Monitoring Event Reports are designed to provide parks with a rapid and easy-to-interpret summary of results, with one report for Padre Island National Seashore (PAIS), one for the Mississippi Unit of Gulf Islands National Seashore (GUIS) and one for the Florida Unit of GUIS. Change Analysis Reports are more in-depth and cover the full time-series of relevant data collection, with one such report produced for each park (PAIS and GUIS).

All analyses and reports for this protocol are structured around the network's seagrass monitoring objectives—to monitor change in seagrass beds and collect ancillary data to test for associations with seagrass metrics over time. To put monitoring results into perspective, the network relies on the wealth of published seagrass research, including the Seagrass Conceptual Model of Congdon et al. (2018; Figure 1) with its list of indicator metrics (Table 1) and associated resource quality thresholds (listed in full in Appendix S07.A of SOP SEA07). Both the Monitoring Event Reports and Change Analysis Reports use the thresholds from Congdon et al. (2018) for interpretation of results, and for the former report type, they are one of the central elements of the report. The Gulf-wide model and thresholds from Congdon et al. (2018) are new and are expected to be refined and improved over time, based on feedback and data from practitioners throughout the Gulf Coast Region, including the Gulf Coast Network. The network remains in contact with the Congdon et al. working group to participate in these developments and will adopt refinements as they become available. Over time, we anticipate that our understanding of the system will improve to the point that we will be able to identify metrics and thresholds that will be directly relevant for alerting parks and partners about the need for management action.

Monitoring Event Reports, Maps, and the Ecological Integrity Scorecard

The Monitoring Event Reports summarize the data collected during a given sample event in three ways. First, there is a table of summary statistics at the park or unit level, depicting the average values and variability (standard deviation or confidence intervals) of all focal variables in the protocol (e.g., Table 7). This includes three seagrass metrics from the protocol objectives—percent cover, community composition, and leaf length per species—as well as metrics recorded as ancillary data (e.g., phytoplankton biomass, water transparency, sediment load, salinity, dissolved oxygen, pH, and water temperature). Second, there are maps showing the spatial pattern of data or change in all relevant variables (e.g., Figure 15). Third, there is an Ecological Integrity Scorecard (e.g., Table 8), which uses calculated variables and thresholds as short-term indicators of seagrass ecosystem quality and integrity. The variables used in the scorecard include measures of change (current versus previous event) in percent cover, community composition, and leaf length, as well as current values for phytoplankton biomass, water transparency and sediment load. To determine whether a sampling event's results reflect good, fair, or poor resource condition, the change metrics or unit-wide means are compared to literature-based thresholds from Congdon et al. (2018). The scorecard provides a snapshot of resource condition and recent changes in an easy-to-read format; the summary table provides the actual summarized measures for that event alone, and the maps provide a spatial view and insights into whether changes are localized, patchy or wide-spread.

Table 7. Example of the main summary table of seagrass metrics and ancillary data for a given sampling event. Presented here are pilot results from 63 stations at PAIS in 2015; on final products, bootstrapped confidence intervals will be used where assumptions of normality are not met, such as for percent cover data. Additional measures or illustrations of variability could be added, such as small histogram plots or the data range.

Variable	Average or calculated variable	Standard Deviation	Sample size (# of stations with data)
Seagrass Percent Cover, All Species Combined	61.0	39.6	63
Percent Cover *Halodule wrightii* (in 86% of sites)	60.5	40.0	63
Percent Cover *Ruppia maritima* (in 11% of sites)	0.6	2.2	63
Seagrass Species Composition, Measured as Species Dominance Index (**0 is monodominant, 1 is evenly is mixed compositions**)	0.011	–	–
Canopy Height *Halodule wrightii*	15.9	8.0	54
Canopy Height *Ruppia maritima*	11.0	8.8	7
Water Temperature (° Celsius)	30.9	1.59	63
Salinity	43.9	6.79	60
Dissolved oxygen	5.60	1.82	63
Secchi depth/total depth	0.61/0.70	0.34/0.40	63/63
pH	8.18	0.37	63

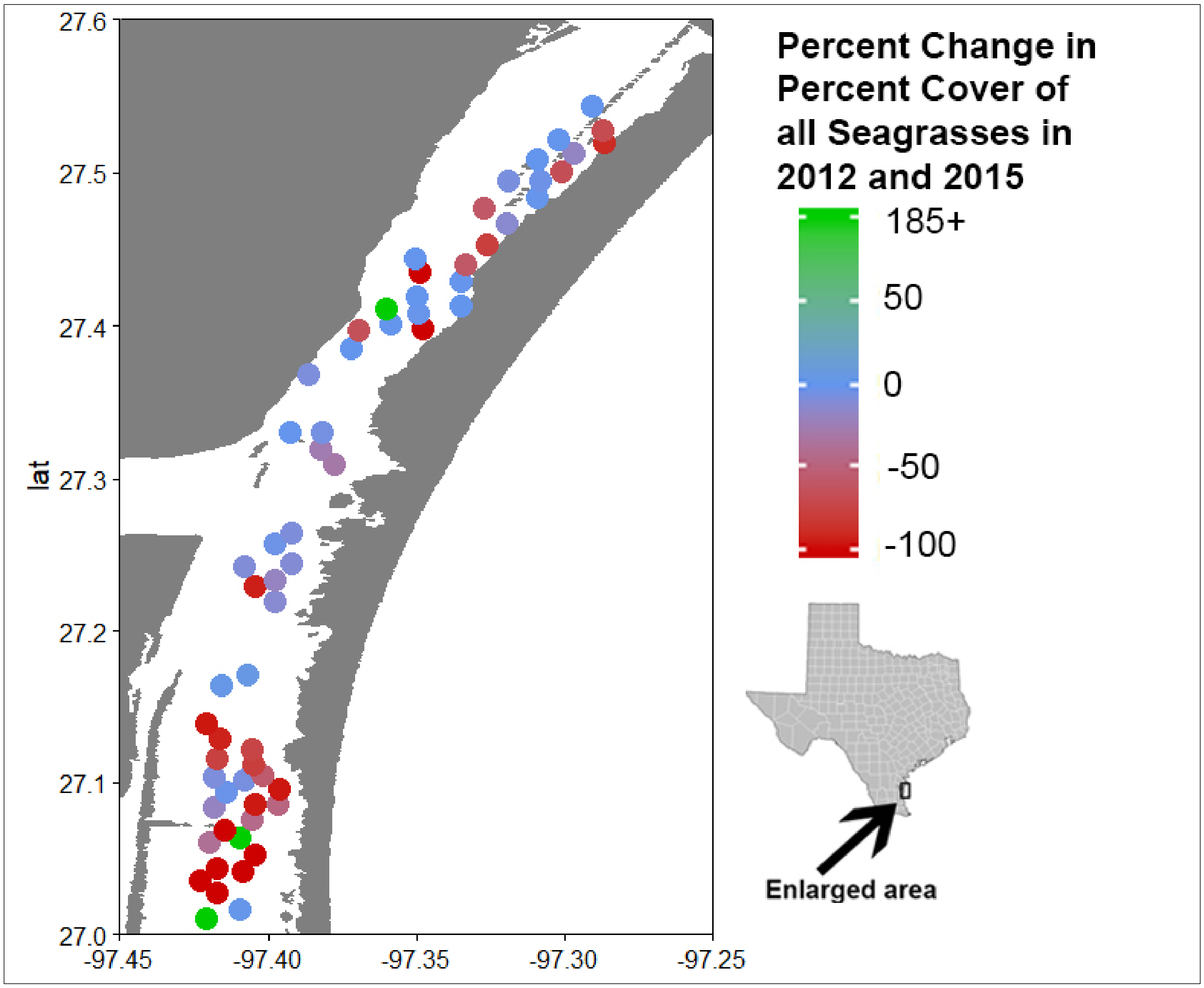

Figure 15. Map of the Laguna Madre at Padre Island National Seashore, showing the location of 63 sampling stations and their percent change in seagrass cover between 2012 and 2015.

Table 8. Example of Ecological Integrity Scorecard for Event-Level Seagrass Monitoring Reports. The thresholds for each variable are from Congdon et al. (2018), and the interval between measurements is three years. For both Seagrass Percent Cover and Shoot Allometry, the variable is percent change, calculated as [($variable_{time1}$ – $variable_{time0}$) / $variable_{time0}$]. Seagrass Percent Cover is calculated for all species combined, and plots that started dense (≥ 50% cover, as in this example) have different thresholds than plots that started sparse (< 50% cover). For sparse plots, Good is ≥ -10% and Poor is < -10%. For Seagrass Species Composition, change is measured as a difference (Species Dominance $Index_{time1}$ – Species Dominance $Index_{time0}$). This example table is based on pilot data from 63 stations in Padre Island NS, measured in both 2012 and 2015. *The initial height measurement was based on data from only one plot, and the second was from only seven plots, so these results should be viewed with caution.

Variable	Thresholds	Good	Fair	Poor
Seagrass Percent Cover	Good is ≥ 0% Fair is < 0% to -25% Poor is < -25%	–	–	-32.6% (Poor)[3]
Seagrass Species Composition	Good is ≥ 0, Fair is < 0 to -0.25, Poor is < -0.25	–	-0.028 (Fair)[2]	–
Shoot Allometry (leaf length), for *Halodule wrightii*	Good is < 10% Fair is 10% to 25% Poor is > 25	–	-16.6% (Fair)[2]	–
Shoot Allometry (leaf length) for *Ruppia maritima*	Good is < 10% Fair is 10% to 25% Poor is > 25	–	–	156.3%* (Poor)[3]
Phytoplankton Biomass	Good is < 10 Fair is 10 to 25 Poor is > 25	3.9 µg/L Chlorophyll a (Good)[1]	–	–
Water Transparency	Good is > 30% Fair is 30% to 20% Poor is < 20%	66% Surface Irradiance (Good)[1]	–	–
Sediment Load as Total Suspended Solids	Good is < 15 Fair is 15 to 25 Poor is > 25	–	23.1 mg/L (Fair)[2]	–

[1] Good ecological integrity (also with a green background).

[2] Fair ecological integrity (also with a yellow background).

[3] Poor ecological integrity (also with a red background).

Seagrass Change Analysis Reports

The Seagrass Change Analysis Reports are in-depth data summary reports for each park, which are provided to park staff, collaborators and the public through distribution on the IRMA portal. The contents of these reports are described in greater detail in SOP SEA07. Although the network has developed a range of reporting products and analyses, they maintain some flexibility in their approach to future reports, to consider and account for new findings in seagrass research as well as explore newly available analytical approaches.

A general overview of these reports is that Seagrass Change Analysis Reports provide a comprehensive statement on the condition of seagrass communities in GULN parks, first by considering new findings from the past three events in isolation and then by analyzing all data going back to the start of the monitoring effort. A primary objective is to examine temporal and spatial patterns in seagrass metrics using the longest-term dataset available for each park, and then test for correlations with ancillary data to help interpret these patterns and determine if they may be indicative of declining ecosystem health. If major changes are detected across several events, this report tests for and discusses potential drivers, including environmental or human-caused stressors.

There are three focal seagrass metrics for the Change Analysis Reports: seagrass percent cover, seagrass community composition, and leaf length. These variables are measured and analyzed on a per-station basis and are not combined into derived variables for this report type, in contrast to their use in the Ecological Integrity Scorecard. The Change Analysis Reports also consider and report on the full range of ancillary data types: phytoplankton biomass, water transparency, sediment load, salinity, pH, water temperature, and dissolved oxygen. Weather-related metrics may also be included, such as rainfall during the previous growing season or year, air temperature and hurricane tracks. The former four water quality variables are measured in-situ during data collection, but when possible, the network will draw from continuously collected data to understand how these variables have changed over the preceding growing season(s).

Approach to Visualization and Change Analyses for Seagrass Data

The Gulf Coast Network uses both graphical visualizations and statistical analyses to reveal and interpret patterns of change in seagrass metrics over time. An initial step is to plot the full time-series for each of the three focal seagrass metrics and then overlay ancillary data on those plots to visually explore fluctuations in water quality and other covariates in relation to changes in seagrass metrics. After or coincident with data visualization, the network uses linear mixed models to test for significant change in seagrass metrics among years and to test for significant associations between seagrass metrics and ancillary data. The three primary seagrass metrics are analyzed separately (percent cover, community composition as dominance index, and leaf length), with additional analyses of percent cover by species, excluding rare species with insufficient data to detect change. Random effects and repeated measures on sampling stations are included to reduce unexplained variability. In situations where analyses are intended to allow for extrapolation over the entire sampling frame, the network adds design weights into the model, which adjust for the percent of each station's grid cell that is sampleable for seagrass (e.g., Starcevich et al. 2018).

To help unravel the relationships between ancillary data and seagrass metrics, the network includes in their linear mixed models all relevant ancillary data as fixed-effect covariates. When doing so, it may be appropriate to use model selection procedures to select a best-supported model for each response variable, based on Akaike Information Criteria (AIC; Burnham and Anderson 2002) or comparable criteria (see SOP SEA07 for more details). The most suitable statistical methods for these tasks should be re-evaluated at the time of analysis, given the field's rapid rate of development.

As of this protocols' writing, the bbmle package is appropriate for performing mixed effects models and obtaining AIC scores (or scores from related criteria) for comparison among candidate models (Bolker and R Development Core Team 2014), as is the lme4 package (Bates et al. 2015). In these mixed models, year is another fixed (categorical) effect, to test for significant differences among events. When statistical differences are found, patterns of change are compared to the thresholds provided by Congdon et al. (2018), as well as other information from the literature, to determine if they are likely to have biological relevance.

Unscheduled Reporting

In addition to these two prescribed reporting formats, the network is also able to report to parks, stakeholders and the public on an unscheduled basis. One type of unscheduled report is the resource brief, which consists of a one- to two-page summary that provides the park with a quick and readily accessible overview of a GULN project. These summaries report on resource status, monitoring progress, salient observed events, and related matters of general interest. Resource briefs are produced and updated on an unscheduled basis, with the intent to provide readers a timely first look at the subject. Another type of unscheduled report comes in the form of peer-reviewed publications and presentations. Publishing monitoring results in scientific journals or giving presentations at scientific meetings allows the network to reach the scientific community in a way that internal NPS reports cannot. Peer-reviewed publications may serve the purpose of promoting investigation by members of the scientific community, either independently or in cooperation with the network. Ultimately, publication in peer-reviewed publications and the collaboration that ensues should foster a greater understanding of ecosystem components and processes.

Personnel Requirements, Training, and Safety

Roles and Responsibilities

The *Protocol Lead*, typically a designated Gulf Coast Network staff member, coordinates the seagrass monitoring program. This duty includes working with park resource managers for necessary permissions, obtaining and sharing updates on park conditions and potential issues for fieldwork, and establishing support from park staff if needed during the monitoring effort. The seagrass protocol lead is also responsible for advertising and recruiting contractors and cooperators that have the skill and experience level needed to implement this protocol. The protocol lead remains in contact with contractors and cooperators as necessary during and after each field season and participates in data collection at both parks. All fieldwork is completed by a contractor or cooperator, and the protocol lead also completes the post-field validation step on all datasheets, signs them, and then provides them to the GULN data manager. After datasets are entered into the database and have become accepted or certified, the protocol lead completes or ensures the completion of all data analyses and reports.

The *Principal Investigator* (cooperator or contractor) is responsible for planning and logistics, and direction of all non-NPS staff in the execution of this protocol and associated SOPs. The Principal Investigator will work with the Gulf Coast Network to make sure all necessary permits are submitted and activities coordinated with the seashore. The principal investigator is responsible for providing all equipment and material needed to do this work, all personnel training and institutional safety requirements, and compliance with NPS procedures and policies regarding safety for contractors and cooperators (SOP SEA01 *Safety—Version 1.0* [Meiman 2019e]) and SEA02 *Training*.

The *Field Chief* works for the *Principal Investigator* and directs protocol and associated SOP execution on the water and in the lab. The field chief is also responsible for all cooperator or contractor data management (see SOP SEA06 *Data Management*). The field chief assures that technicians are properly performing tasks.

The *Technicians* are trained in all field and lab SOPs and make most of the field and lab measurements. Technicians also may enter and verify data with the field chief.

The GULN *Data Manager* and protocol lead are responsible for data certification as described in SOP SEA06 *Data Management*. Tasks include uploading cooperator or contractor data into NPStoret and performing a 10% verification before rolling up data to WRD for upload into EPA STORET.

The GULN *Quantitative Ecologist* is responsible for assisting the protocol lead in performing data analysis and reporting as described in SOP SEA07 *Data Analysis and Reporting*.

Rules and regulations applicable to the performance of these tasks shall be observed, with particular note to individual park policies.

Field Personnel Qualifications

All cooperators or contractors conducting the Gulf Coast Network Seagrass Monitoring Protocol must be experienced in species identification and conducting monitoring or research of seagrass in the northern Gulf of Mexico. They must have experience conducting all the tasks described, and must be capable of navigating to the sites and spending long days working in the estuaries and bays where seagrasses are being monitored.

Training Procedures

As noted above, contracted data collectors must already possess a high degree of skill in seagrass identification and experience collecting seagrass data to participate in monitoring for the Gulf Coast Network. See SOP SEA02 *Training* for more specifics about ensuring that all field staff are trained in the field methods.

Operational Requirements

Contracts and Agreements

Contracts or agreements must be approved and in place six months before sampling is scheduled to begin. Because of the close coordination with network staff, a cooperative agreement with organizations affiliated with the Gulf Coast Cooperative Ecosystems Studies Unit (CESU) is preferred. For initiating these types of agreements, the latest guidance should be solicited from the Gulf Coast Network CESU coordinator.

All pilot data collection was completed through cooperative agreements with organizations affiliated with the Gulf Coast CESU. The network's hydrologist participated in field sampling for two to four days at each park, participated in the cooperator's safety training, field data collection training, and assisting in collecting the data. This maintains a close collaboration with the sampling team and aids in ensuring consistent methods are applied. The Gulf Coast Network program manager serves as the Agreements Technical Representative (ATR) and is responsible for maintaining the agreements. The time commitment for completing cooperative agreements and contracts can range widely, from approximately two to three days up to two weeks annually, depending on the funding instrument used. Cooperative agreements and contract documents are stored on the network server at: U:\Program_Files\Project_Manager\Contracts and Agreements\Active Contracts and Agreements.

Budget Considerations

Anticipated budget for implementation of this protocol is based on the actual costs of implementation of this protocol through cooperative agreements at Gulf Islands NS (Table 9) and Padre Island NS (Table 10) during the pilot implementation phase. In addition to the cost of contracting out the data collection, the network incurs costs associated with contract management, field personnel to spend time in the field with the cooperators, data management, data QA/QA and reporting (Table 11). Note that there are no costs assigned to "startup" expenses for equipment purchase or site establishment since the cooperators are expected to provide all the needed sampling equipment and sites are not permanently marked.

Table 9. Estimated triennial operating cost (based on FY2016 dollars) for the GULN Seagrass Protocol at Gulf Islands National Seashore.

Category	Expense	Costs (FY 2016)	Notes
Personnel (cooperator or contractor)	Principal Investigator	$10,300	Salary and benefits (37%)
	Field chief	$6,000	Salary and benefits (47%)
	Field technicians	$4,600	Salary and benefits (15%)
	Total Personnel Costs	**$20,900**	–
Equipment & Supplies	Boat use and fuel	$2,800	–
	Vehicle use and fuel	$800	–

Table 9 (continued). Estimated triennial operating cost (based on FY2016 dollars) for the GULN Seagrass Protocol at Gulf Islands National Seashore.

Category	Expense	Costs (FY 2016)	Notes
Equipment & Supplies (continued)	Field Supplies	$1,500	–
	Total Equipment Costs	**$5,100**	–
Travel	Mississippi	$1,500	5 days/nights
	Florida	$1,200	4 days/nights
	Total Travel Costs	**$2,700**	
Indirect costs	–	**$5,000**	CESU indirect cost overhead (17.5%)
Total Triennial Protocol Cost	–	**$33,700**	–

Table 10. Estimated triennial operating cost (based on FY2016 dollars) for the GULN Seagrass Protocol at Padre Island National Seashore.

Category	Expense	Costs (FY 2016)	Notes
Personnel (cooperator or contractor)	Principal Investigator	$0	In kind
	Field chief	$12,300	Salary and benefits (27%)
	Field technicians	$11,900	Salary and benefits (28%)
	Total Personnel Costs	**$24,200**	–
Equipment & Supplies	Boat use and fuel	$1,600	–
	Vehicle use and fuel	$400	–
	Field Supplies	$2,000	–
	Total Equipment Costs	**$4,000**	–
Travel	Mississippi	$750	–
	Total Travel Costs	$750	–
Indirect costs	–	**$5,100**	**CESU indirect cost overhead (17.5%)**
Total Triennial Protocol Cost	–	**$34,050**	–

Table 11. Estimated triennial operating cost (based on FY2017 dollars) for GULN personnel during implementation of the GULN Seagrass Monitoring protocol.

Type	No. of Days	Cost per Day	Total Cost	Notes
Program Manager (GS13)	3	$548	$1,644	ATR for cooperative agreements.
GULN Protocol Lead (GS12/10)	15	$503	$7,545	3 days in the field at each park, contract coordination, data management, and data reporting.
GULN Data Manager (GS11/8)	3	$409	$1,227	Data management, data verification, data upload.
GULN Network Ecologist (GS12/2)	2	$391	$782	Assist in data analysis and reporting.
Total Triennial Personnel Costs	–	–	**$11,198**	**–**

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