Summary Report for St. Joseph Bay

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Mapping and Monitoring Report No. 3

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General assessment

Seagrasses covered 7,676 acres in St. Joseph Bay in 2015, a loss of 696 acres since 2010 (Table 1). Most of the seagrass (93%) was in continuous beds in the southern bay (Figure 1). Between 2010 and 2015, patchy seagrass beds decreased by 963 acres and continuous beds increased by 267 acres. Turtlegrass (*Thalassia testudinum*) dominates beds in St. Joseph Bay, but manateegrass (*Syringodium filiforme*), shoalgrass (*Halodule wrightii*), and drift red macroalgae occur infrequently. Monitoring data from 2008, 2009, 2011, 2014, and 2016 indicated that the occurrence of turtlegrass was stable but the occurrence of manateegrass and shoalgrass varied among sampling efforts (see Table 3). The density of seagrass beds was highest in 2008 and 2009 and has declined since (see Figure 4). Propeller scarring affects 30% of seagrass beds, and severe scarring occurs in locations in the southern bay (Table 2). Generally excellent optical water quality indicates that factors other than available light are stressing seagrass beds; suggested stressors are grazing by sea urchins and turtles, heavy epiphyte levels on seagrass, which would limit the amount of light that reaches blade tissues, and propeller scarring. In October 2018, Hurricane Michael created a large pass through the St. Joseph Peninsula State Park and leveled the dunes along the west-facing beach. Burial of seagrasses by overwash of sand and changes in water circulation in the bay will change the bay ecosystem and seagrass extent.

Geographic extent

St. Joseph Bay is in Gulf County in the central Panhandle. The bay is bounded on the eastern shoreline by the city of Port St. Joe and St. Joseph Bay State Buffer Preserve lands and on the west by the St. Joseph Peninsula and St. Joseph Peninsula State Park. The total surface area of the bay at mean high water is approximately 42,872 acres (Hemming et al. 2002). The watershed of the bay is small, consisting of lands immediately adjacent to the bay, and the bay does not receive much freshwater inflow (NWFWMD 2017). The bay is listed by the Florida Department of Environmental Protection (FDEP) as an impaired waterbody for bacteria and nutrients. More information about the St. Joseph Bay watershed is available in the St. Andrew Bay Watershed Surface Water Improvement and Management Plan (NWFWMD 2017).

Mapping and monitoring recommendations

- Continue to acquire imagery and map seagrasses every 1–2 years to determine if the trend of declining acreage is continuing.
- Continue the recently resumed spring and fall field monitoring by staff of the Central Panhandle Aquatic Preserves. In 2014, the National Fish and Wildlife Foundation (NFWF) awarded the FDEP a grant to re-establish management of the St. Joseph Bay Aquatic Preserve. In 2015, personnel resumed seagrass monitoring at sites visited by earlier field programs.
- Continue monthly monitoring of chlorophyll-a, turbidity, and water color at 5 locations by the Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute (FWRI) to better evaluate optical water quality in the bay.

1. General Status of Seagrasses in St. Joseph Bay

Status and stressors	Status	Trend	Assessment, causes
Seagrass cover	Red	Declining	8% loss, 2010–2015
Water clarity	Yellow	Stable	Storm runoff a concern, especially since 2012
Natural events	Yellow	Episodic	Storm runoff, urchin grazing, harmful algal blooms
Propeller scarring	Red	Extensive	Severe in southern bay

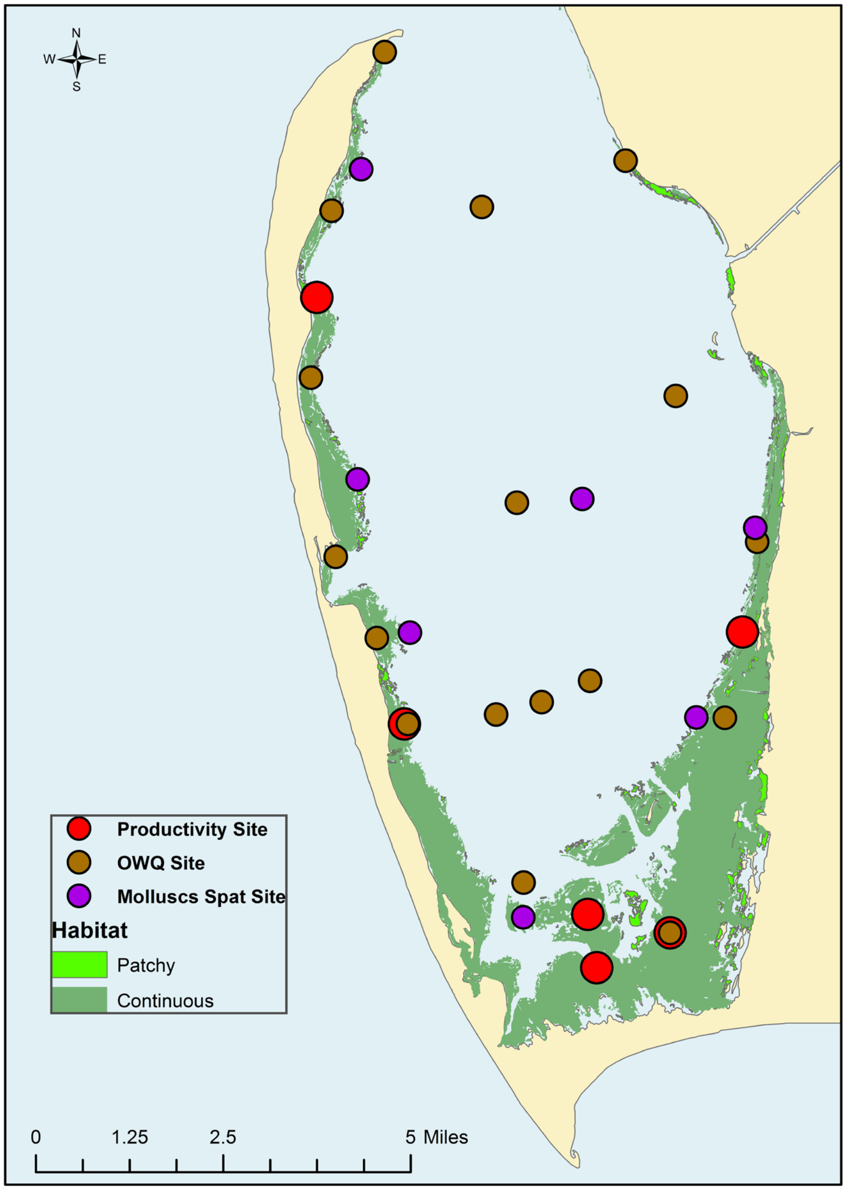

Figure 1. Seagrass cover in St. Joseph Bay in 2015, shown as patchy and continuous beds; locations of sites for sampling water quality by the Dauphin Island Sea Lab in 2016 (brown circles); sites where scientists from FWRI's Molluscan Fisheries team sample water monthly for optical water quality (purple circles); and locations of field measurements of the productivity of turtlegrass in 2016 (red circles).

Management and restoration actions and recommendations

- Establish the bay as an area of special concern (ASC) to determine the cause of recent seagrass losses. Possible causes are grazing by high populations of sea urchins and sea turtles observed in summer 2018; propeller scarring, especially in southern portions of the bay; and light attenuation by phytoplankton blooms.
- Assess the effects of watershed development on the quantity and quality of storm runoff.
- Use the boating and angling guide for waters in the region to improve boater education and awareness of seagrass beds and to reduce propeller scarring.
- Continue management of the St. Joseph Bay Aquatic Preserve. Activities funded by the NFWF include implementing a comprehensive management program, updating management plans, establishing an advisory

committee, re-establishing a seagrass monitoring program by building on existing information, and updating local boater's guides.

- Monitor propeller scarring to develop a strategy for reducing impacts. In 2014, the FDEP received a grant as part of the Natural Resources Damage Assessment (NRDA) following the 2010 Deepwater Horizon oil spill for the restoration of propeller scars caused by boat damage to seagrass beds along the Florida Panhandle in the Gulf of Mexico. The goal of this project is to provide early restoration of seagrass habitat that was injured due to the Deepwater Horizon accident and oil spill response, as well as other activities. The recovery program and boater outreach effort are expected to restore approximately 2 acres of propeller-scarred seagrass habitat in three designated Florida Aquatic Preserves, including St. Joseph Bay. This project will also replace and update buoys marking seagrass beds in St. Joseph Bay and develop an outreach program to help boaters navigate shallow areas of the bay.

Summary assessment

In the Florida Panhandle, the status of seagrasses and the potential for recovery of seagrass where beds have been lost are being assessed by the Roadblocks to Seagrass Recovery project of the FWRI (http://myfwc.com/research/habitat/seagrasses/projects/roadblocks/). This project is funded by the NFWF Gulf Environmental Benefit Fund (GEBF). Activities include mapping of seagrasses from the Alabama state line to the mouth of the Suwannee River, field assessments of seagrass cover and species composition, and quantitative evaluation of factors affecting recovery and restoration of seagrasses. These factors are current and historical seagrass extent, optical water quality and light attenuation, sediment quality and toxicity, bathymetry, propeller scarring, and physical stressors such as wind energy. Data and results are part of a seagrass recovery potential (SRP) model that will be served on the Web.

Seagrass beds in St. Joseph Bay are declining in acreage but have a stable species composition. Seagrass cover, which is a measure of density (see Figure 4), appears to be declining slightly based on field monitoring information. Turtlegrass is the dominant seagrass species in the bay; manateegrass and shoalgrass occur at low levels. Macroalgae sporadically occur at high densities and are primarily drift red algae. Propeller scarring affects 30% of seagrass beds, and severe scarring occurs in some locations in the southern bay (Figure 2).

Monthly monitoring of nutrients in the bay has detected increased levels of dissolved nitrogen which may be the cause of increased epiphyte coverage on seagrass blades. St. Joseph Bay is widely known for its recreational fishery of bay scallops (*Argopecten irradians*), and the bay scallop depends on turtlegrass beds as habitat. Annual surveys conducted by FWRI showed that summer abundance of bay scallops was very high in 2010 and 2011 but dropped sharply in 2012 and reached its lowest levels in summer of 2016 (http://myfwc.com/research/saltwater/mollusc/bay-scallops/season/). Low numbers greatly shortened the open harvest season. Abundance increased slightly in 2017, and the bay will be open to recreational harvesting for a short time in late summer-early fall in 2018.

Seagrass mapping assessment

Seagrass acreage in St. Joseph Bay varied between 1992 and 2015, but overall, acreage decreased (Table 1). Between 2010 and 2015, seagrass loss occurred in patchy beds (−963 acres), a loss partly offset by a small gain in continuous seagrass. There are additional sources of

2. Seagrass Status and Potential Stressors in St. Joseph Bay			
Status indicator	**Status**	**Trend**	**Assessment, causes**
Seagrass cover	Red	Decreasing	8% loss, 2010–2015
Seagrass meadow texture	Yellow	Thinning	Grazing; declining water clarity?
Seagrass species composition	Green	Stable	Primarily turtlegrass
Overall seagrass trends	Orange	Declining	Declining water quality, scarring
Seagrass stressor	**Intensity**	**Impact**	**Explanation**
Water clarity	Yellow	Impacted by storms	Storminess since 2012; development in watershed
Nutrients	Yellow	Increasing	
Phytoplankton	Yellow	Increasing?	
Natural events	Yellow	Episodic	Harmful algal blooms, sea urchins, storms
Propeller scarring	Red	Extensive	Severe in southern bay

mapping data: 1) in 2006, hyperspectral imagery was collected over bay waters and interpreted, and 2) in November 2010, multi-spectral imagery was collected by the WorldView II satellite, and imagery was interpreted using supervised software. Both these data sets resulted in lower acreage estimates, 6,672 acres in 2006 and 7,166 acres in 2010. However, the footprints for these two datasets likely differ slightly from that of the data shown in Table 1.

Propeller scarring

Propeller scarring of seagrass beds was quantified using aerial imagery collected in 2013 by the U.S. Department of Agriculture National Agricultural Imagery Program (NAIP). The imagery was overlaid by a grid of cells, each with an area of 1 ha. Inside each cell that covered seagrass, scars were counted, and the cell was given a score (Table 2). Scarring affected 30% of seagrass beds (about 3,660 acres), and 28 cells (270 acres) were heavily scarred. The most heavily scarred locations were in the southeastern bay (Figure 2). See also, the image in Figure 3, showing scarring in the southern bay. In 1992–1993, about half of all seagrass beds (4,840 acres) exhibited propeller scarring (Sargent et al. 1995), and 640 acres were estimated to be moderately or severely scarred. Assessment of hyperspectral imagery acquired in 2006, showed that scarred areas had been reduced to 1,900 acres, but moderately scarred areas had increased by 900 acres.

Monitoring assessment

Several agencies have conducted field monitoring of seagrasses in St. Joseph Bay. The Coastal and Managed Areas (CAMA) program of the FDEP monitored seagrasses twice a year from 2002 through 2008 and then annually in 2009 and 2010. This program resumed in the summer of 2015, and the Central Panhandle Aquatic Preserves (CPAP) continues this effort. FWRI conducted field assessments in late summer/fall in 2008, 2009, 2011, and 2014 using a randomly-selected spatially-distributed sample design. Staff from the Dauphin Island Sea Lab (DISL) assessed seagrasses in June 2016 but sampled only where seagrasses were present.

Seagrass cover data were used to calculate the frequency of occurrence (FO) of each species of seagrass present as well as that of drift red algae (Tables 3A and B). In Table 3A, values from 2008 through 2014 can be compared, but values from 2016 are provided only to show what species were present, because 2016 assessments were made only in seagrass beds. Turtlegrass was the dominant seagrass in all

Table 1. Seagrass acreage in St. Joseph Bay in 1992, 2003, 2010, 2015.

	Seagrass acreage				Change, 2010–2015	
Bed Texture	**1992**	**2003**	**2010**	**2015**	**Acres**	**%**
Continuous	5,306	–	6,906	7,173	267	3.9%
Patchy	3,802	–	1,466	503	−963	−66%
Total	9,108	7,158	8,372	7,676	−696	−8.3%

Table 2. Assessment of propeller scarring of seagrass beds in St. Joseph Bay using imagery acquired by the USDA's National Agricultural Imagery Program in 2013. Imagery was overlaid by a grid, each cell of which had an area of 1 ha. Each grid cell received a scarring score.

Description	Score	Cell count	% of vegetated cells
Vegetated, no scars	0	3,160	64.6%
<5 scars	1	651	13.3%
5–10 scars	2	458	9.4%
11–25 scars	3	265	5.4%
26–50 scars	4	82	1.7%
>50 scars	5	28	0.6%
Uninterpretable	6	248	5.1%
Total vegetated		4,892	
Total scarred		1,484	30.3%

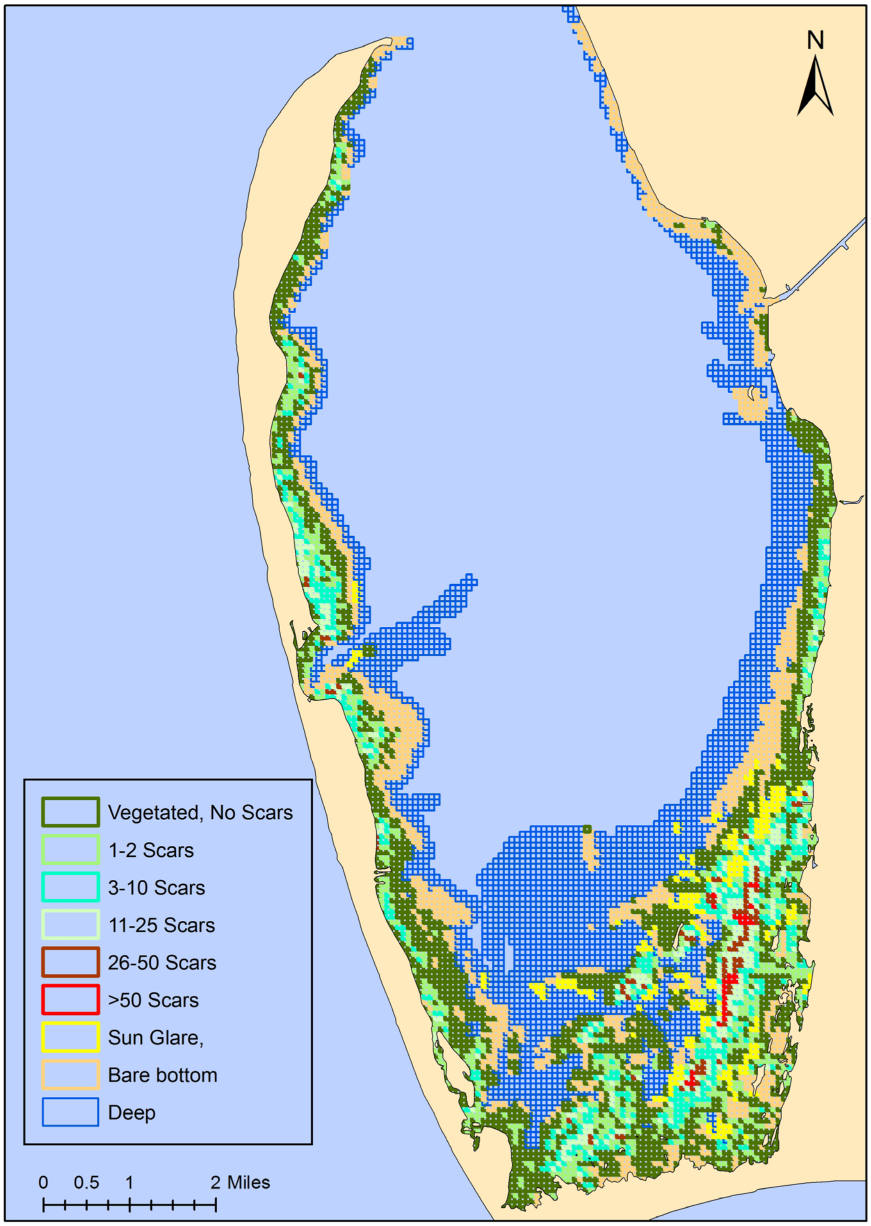

Figure 2. Scoring of 1-ha grid cells for propeller scarring in St. Joseph Bay.

years, occurring most frequently (in 66–71% of quadrats). Shoalgrass, manateegrass, and drift red algae occurred much less frequently than did turtlegrass and were also more variable. The percentage of bare quadrats varied around 30% from 2008 through 2014. The FO calculated from assessments by CPAP staff in 2016 and 2017 also showed that turtlegrass was most common (78% of quadrats) with shoalgrass and manateegrass occurring at much lower frequencies. The frequency of bare sites was much lower in CPAP assessments, and the occurrence of drift red algae was more variable than in data collected by FWRI.

In addition to identifying the seagrass and macroalgal species present in a quadrat, FWRI personnel also estimated the percentage of the quadrat covered by each species; this estimate is called percent cover, and the technique is similar to the Braun-Blanquet method. Mean percent cover of seagrasses and drift red algae decreased substantially in 2011 from levels in 2008 and 2009 (Figure 4), recovered somewhat in 2014, and then declined again in 2016. These data include only quadrats in which a species was present (bare quadrats were omitted). Interestingly, where present, shoalgrass was almost as dense as turtlegrass was in 2008, but its mean cover dropped sharply in 2009 and 2011 and remained considerably lower than that of turtlegrass in 2014 and 2016. Turtlegrass had greatest mean cover of all species in the five years of monitoring.

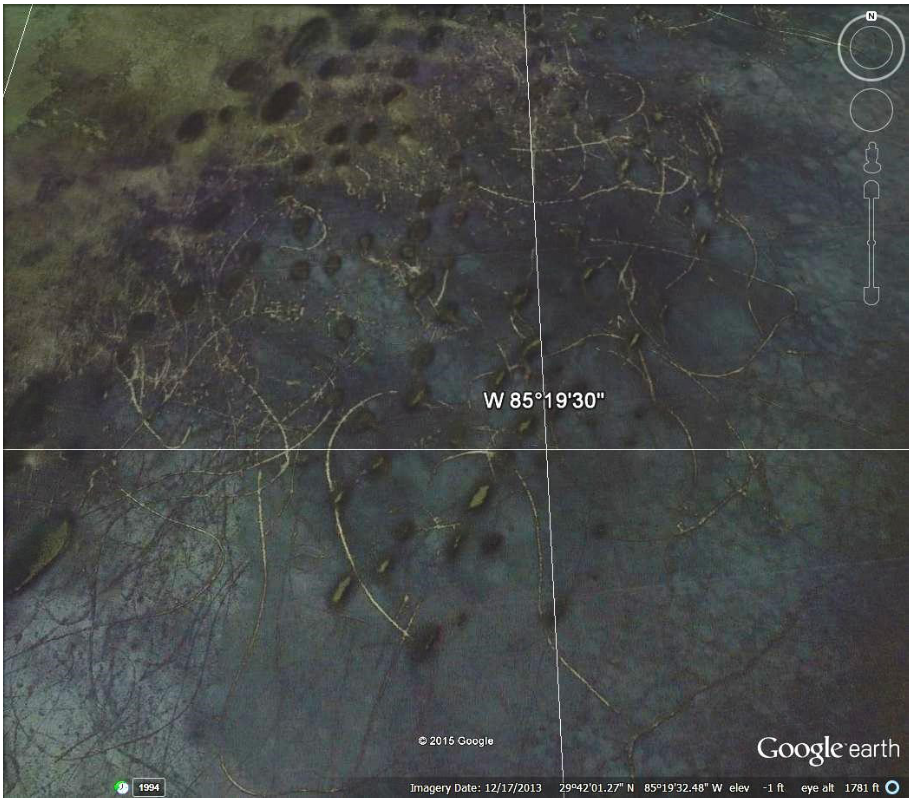

Figure 3. Propeller scarring in the southern region of St. Joseph Bay, from Google Earth, December 2013.

The mean percent cover of drift red algae varied between 8 and 41% but, as for seagrass species, was lowest in 2011.

Productivity of turtlegrass

Field measurements of the productivity of turtlegrass were made in June and August 2016 at six sites (see Figure 1) by scientists from the DISL, using the punch and harvest method developed by Zieman and Zieman (1989). Live biomass ranged from 370 to 1,390 g/m^2 (Table 4). The northwest site (10PSJ04) had the greatest live biomass (an average of 1,322 g/m^2), and the eastern site (10PSJ17) had the least live biomass (an average of 430 g/m^2). Dead biomass ranged from 6 to 33% of live biomass. No consistent differences were observed between sampling months.

A variety of measures of productivity can be reported using the data collected from these experiments. We have chosen to report counts of turtlegrass shoots, 1-sided leaf area index (LAI), and average shoot specific blade growth (SSBG). Shoot counts, reported per m^2, are a common metric for seagrass ecosystems, and counts can vary widely over short distances. Because turtlegrass is a long-lived species, variation in shoot counts over short periods is likely to be less than that from one place to another. In these experiments, scientists conducted measurements at the same site twice, but the locations of the quadrats were by necessity slightly different in each sampling period. Shoot counts were highest at sites 16PSJ23 and 16PSJ24 in the southern bay, ranging from 1,012 to 1,331 shoots/m^2 (Figure 5). Lowest counts were found at the western site 10PSJ09 and at the eastern site 10PSJ17. Only at site 10PSJ17 was there a large, and likely significant, difference in shoot counts between sampling periods.

The 1-sided LAI is a unitless metric calculated by dividing the total blade area in cm^2 covering 1 m^2 of sediment surface by 10,000 (i.e., the number of cm^2 in 1 m^2). The 2-sided LAI (2 × 1-sided LAI) estimates total blade surface area covering 1 m^2 of sediment surface. As might be expected, levels of 1-sided LAI mirrored mean shoot counts at sites in St. Joseph Bay: lowest LAI was observed at 10PSJ17, and greatest LAI at 16PSJ23 and in June at 16PSJ24. The large drop in LAI at site 16PSJ24 between June and August is likely the result of fewer shoots with reduced blade area per shoot.

Shoot-specific blade growth (SSBG) is a measure of the increase in blade area of each punched shoot during the experiment and is reported in cm^2/day. We report means of SSBG because the data provide information on shoot performance at each site; multiplying SSBG by shoot counts estimates productivity in cm^2/m^2/day.

Table 3A. Frequency of occurrence (FO; percent of quadrats having a seagrass species present) of seagrasses and drift red algae in St. Joseph Bay in 2008, 2009, 2011, 2014, 2016. Ten quadrats were evaluated by FWRI at each site in 2008–2014, and DISL assessed five quadrats per site in 2016 and visited only locations in seagrass beds. **3B.** FO of seagrasses in St. Joseph Bay assessed by CPAP in summer and fall 2016 and summer 2017. Four quadrats were assessed at each site.

A.

Year	# quadrats	Turtle-grass	Manatee-grass	Shoal-grass	Drift red algae	Bare
2008	315	70.8	2.56	3.85	10.6	26.3
2009	424	58.7	0.71	7.31	6.13	36.6
2011	420	66.0	6.19	3.33	4.29	30.5
2014	470	68.9	7.23	5.74	12.8	28.9
2016*	120	99.2	28.3	3.33		

*only sites with seagrass were visited

B.

Year	Season	# quadrats	Turtle-grass	Manatee-grass	Shoal-grass	Drift red algae	Bare
2016	Summer	96	78.1	7.3	11.5	30.2	10.4
2016	Fall	96	78.1	3.1	14.6	4.2	9.4
2017	Summer	100	78.0	8.0	17.0	13.0	8.0

Patterns of mean SSBG differed from patterns of shoot counts and 1-sided LAI. Mean SSBG was greatest in June at the southern bay sites 16PSJ23 and 16PSJ24, suggesting that high shoot counts (and plant density) did not reduce blade growth. But mean SSBG was much lower at these two sites in August. The opposite trend was observed at all the other sites: mean SSBG was higher in August than in June. Overall, the range in mean SSBG was low: 0.19–0.76 cm^2/day. These values, though, were the highest measured in productivity experiments carried out in Panhandle estuaries in summer 2016.

Water quality and clarity

As part of the field monitoring program, FWRI and DISL personnel also measured water conditions (salinity, water temperature, pH, dissolved oxygen concentration, water depth, and Secchi depth) as well as the optical water quality (OWQ) parameters chlorophyll-a concentration (an estimate of phytoplankton density), color, turbidity, and depth profiles of ambient light (Table 5). Light attenuation is expressed as an extinction coefficient, k_{par} (m^{-1}), calculated from depth profiles of available light using a spherical sensor, and is an indicator of the light available to seagrasses. Light attenuation is a function of the levels of the other OWQ parameters, and the relative contribution of each component to light attenuation varies with location, season, and year. Mean values of salinity and the OWQ parameters were low and varied little among sampling efforts. These data are remarkably uniform, especially compared with data from other estuaries in the Florida Panhandle. The low values of chlorophyll-a, color, and turbidity resulted in low light attenuation values. St. Joseph Bay is the likely sole estuary in the Panhandle in which light availability does not curtail seagrass growth. This increases the concern that other factors are driving seagrass losses in the bay.

In a collaborative effort, staff from the FWRI Molluscan Fisheries team have sampled surface water monthly at 5 locations in St. Joseph Bay since March 2010 and transported these samples to St. Petersburg for the analysis of turbidity and filtered water color. Before 2014, transportation delays precluded the analysis of chlorophyll-a, but since 2014, chlorophyll-a concentrations have also been measured monthly. We averaged the data by season for years 2014–2017 (Figure 6). Mean chlorophyll-a was <5 μg/l except in fall 2015, when the bay experienced an intense red tide. Mean color was low during most seasons and years, reflecting the lack of freshwater runoff to the bay. In summer and fall 2017, color values were elevated

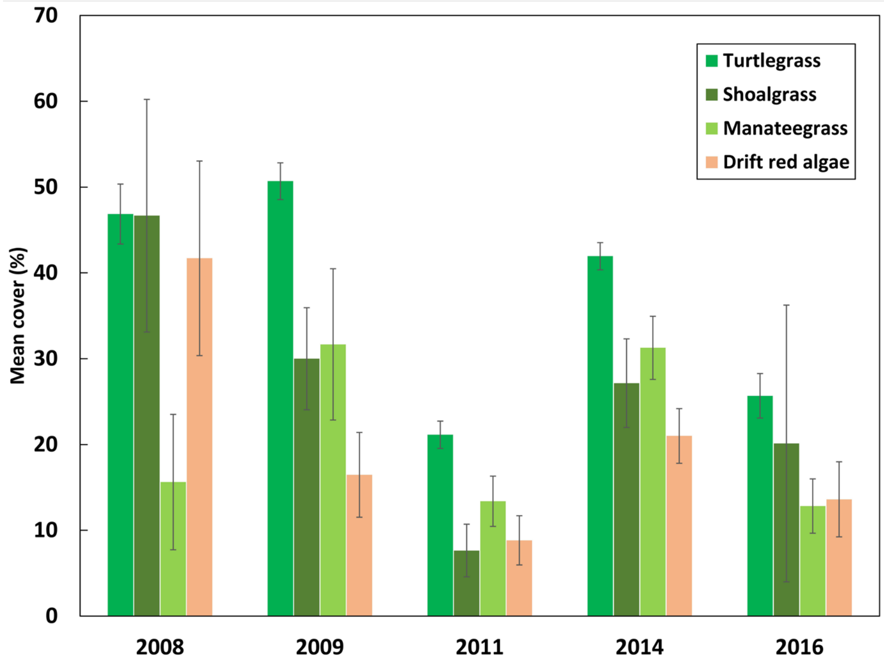

Figure 4. Mean (±2 standard error) percentage cover of seagrasses and drift red algae in quadrats in St. Joseph Bay in 2008, 2009, 2011, 2014, 2016. Means are based only on those quadrats in which a species was present; therefore, a different number of quadrats was used to calculate each mean.

in southern parts of the bay during a bloom of the toxic diatom *Pseudo-nitzschia*. It is not known why color was elevated.

Watershed management

The Northwest Florida Water Management District (NWFWMD), http://nwfwater.com/, through the Surface Water Improvement and Management (SWIM) program, provides a framework for resource management, protection, and restoration using a watershed approach. For the purposes of the SWIM program, the land area surrounding St. Joseph Bay is considered part of the St. Andrew Bay watershed. An updated SWIM plan for the St. Andrew Bay watershed was released in fall 2017: https://www.nwfwater.com/Water-Resources/Surface-Water-Improvement-and-Management/St.-Andrew-Bay. The plan describes the watershed's physical characteristics and natural resources, provides an assessment of current conditions, and identifies priority challenges affecting watershed resources and functions. Priority projects are:

- Stormwater planning and retrofit
- Septic tank abatement
- Advanced onsite treatment systems
- Agriculture and silviculture best management practices
- Basinwide sedimentation abatement
- Riparian buffer zones
- Aquatic, hydrologic, and wetland restoration
- Estuarine habitat restoration
- Strategic land conservation
- Watershed stewardship initiative
- Subbasin restoration plans
- Wastewater treatment and management improvements
- Analytical program support
- Comprehensive monitoring program

District staff continue to help local governments with cooperative stormwater retrofit projects. Implementation of these projects will provide substantial benefits to the public, including improved estuarine water quality and aquatic habitats, and protection from floods.

Mapping methods, data, and imagery

In fall of 2015, the NAIP collected imagery for Panhandle estuaries as part of a collaborative arrangement with FWRI. The imagery was photo-interpreted for benthic habitats by Dewberry Inc. (Tampa). The Florida Land Use, Cover, and Forms Classification System (FLUCCS; Florida Department of Transportation 1999) was used to classify bottom features as continuous sea-

Table 4. Biomass of live and dead turtlegrass, above and below the sediment surface, at productivity sites in St. Joseph Bay in June and August 2016.

Location	Month	Fraction	Biomass (g/m^2)					
			Live			Dead		
			Mean	Std. dev.	N	Mean	Std. dev.	N
Northwest 10PSJ04	June	Above	432	223	3	310	148	3
		Below	822	282	3	62.9	36.4	3
		Total	**1,254**			**373**		
	August	Above	666	165	4	292	90.6	4
		Below	724	317	4	8.00	7.78	2
		Total	**1,390**			**300**		
West 10PSJ09	June	Above	367	184	4	115	85.5	4
		Below	96.3	48.6	4			
		Total	**464**			**115**		
	August	Above	401	136	4	252	109	4
		Below	661	107	4	48.3	35.9	4
		Total	**1,062**			**300**		
South 10PSJ13	June	Above	243	67.5	4	46.8	35.2	4
		Below	128	21.0	4	24.1	15.3	4
		Total	**371**			**70.9**		
	August	Above	472	39.9	4	57.1	29.2	4
		Below	248	65.8	4	10.8	7.04	3
		Total	**720**			**67.9**		
South 16PSJ23	June	Above	551	154	4	86.3	45.6	4
		Below	488	123	4	29.0	16.0	4
		Total	**1,039**			**115**		
	August	Above	414	150	4	29.0	20.6	4
		Below	311	172	4	80.8	117	4
		Total	**725**			**110**		
South 16PSJ24	June	Above	671	61.0	4	60.9	33.5	4
		Below	388	118	4	12.6	8.18	4
		Total	**1,059**			**73.5**		
	August	Above	292	123	4	109	103	4
		Below	221	75.2	4	61.1	57.1	4
		Total	**513**			**170**		
East 10PSJ17	June	Above	438	116	4	50.4	35.5	4
		Below	51.9	32.9	4	2.50	2.48	2
		Total	**490**			**52.9**		
	August	Above	292	106	4	53.7	27.2	4
		Below	78.0	31.6	4	3.75	2.12	2
		Total	**370**			**57.4**		

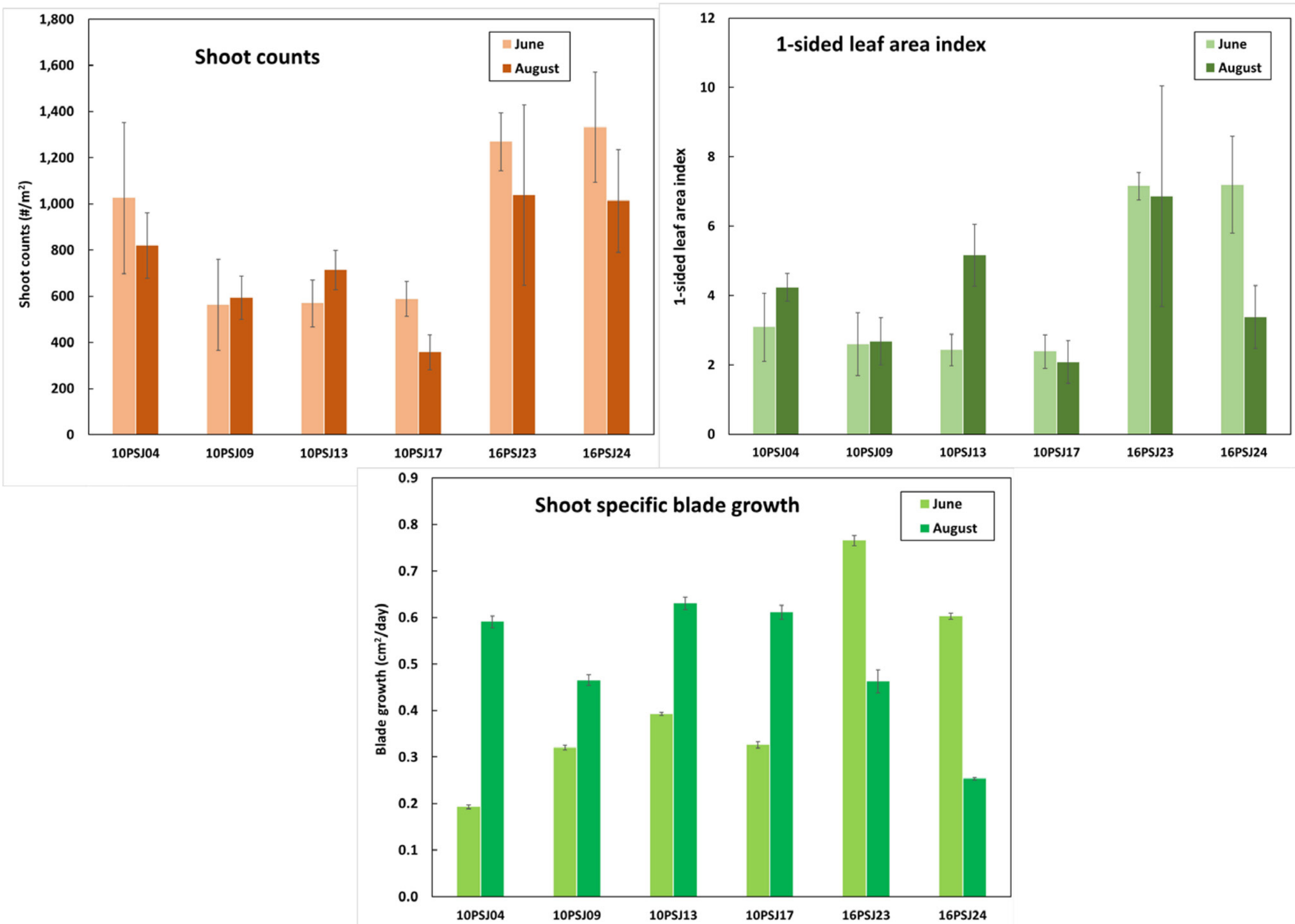

Figure 5. Mean (± 2 standard error) shoot counts (#/m^2), 1-sided leaf area index (LAI), and shoot-specific blade growth (cm^2/day) of turtlegrass at sites in St. Joseph Bay in June and August 2016.

grass, patchy seagrass, oyster bed, bare intertidal, shallow bare bottom, or deep bare bottom. Bottom features were delineated by polygonal shapefiles, with a minimum mapping unit of 0.1 ha.

High-resolution (1 m), four-band aerial imagery was collected for the entire northern Gulf coast in October 2010, and photo-interpretation was completed by PhotoScience Inc. (St. Petersburg). The FLUCCS (Florida Department of Transportation 1999) was used to classify bottom features. Mapping data for 2003 were derived from the interpretation of color infrared photography. These images were mapped at 1:12,000 scale as hard copies rectified to U.S. Geological Survey (USGS) digital orthophoto quarter-quadrangle base maps and were digitized at the USGS National Wetlands Research Center (NWRC). The seagrass beds were classified according to a USGS NWRC-derived classification scheme based on the Coastwatch Change Analysis Project Coastal Land Cover Classification system of the National Oceanic and Atmospheric Administration (NOAA).

In 1992, seagrass distribution along the Gulf coast of Florida from Anclote Key to the Alabama–Florida line was interpreted from natural color photographs (1: 24,000 scale). The joint NWRC/NOAA seagrass mapping protocol was used, and the abundance of seagrasses in St. Joseph Bay was estimated at 9,740 acres. Sargent et al. (1995) used the 1992 and 1993 aerial photography of St. Joseph Bay to estimate the total area of seagrass beds and the area damaged by propeller scarring.

Other sources of imagery and mapping data include hyperspectral imagery collected in 2006. In the fall of 2006, a hyperspectral spectroradiometer with high resolution was used to acquire imagery of the bay. A Florida Coastal Zone Management (CZM) grant provided funds for processing of imagery data to determine area, abundance, and productivity of seagrass meadows, as well as shallow-water (<2 m) bathymetry. These features were quantified and mapped using a combination of algorithms and models. Seagrass beds were distinguished from surrounding sand and optically deep water (bottom not visible in images) by their reflectance characteristics in the near infrared. Bathymetry data and modeled water-column optical proper-

Table 5. Means of salinity and optical water quality parameters chlorophyll-a, color, turbidity, total suspended solids (TSS) and spherical k_{par} in St. Joseph Bay during sampling seasons in 2008, 2009, 2011, 2014, and 2016. The number of replicates ranged from 19 to 32.

Year	Salinity (psu)	Chlorophyll-a (µg/l)	Color (pcu)	Turbidity (ntu)	TSS (mg/l)	Spherical k_{par} (m^{-1})
2008	35.4	2.67	6.23	0.87	3.16	0.389
2009	34.2	4.43	8.73	1.19	3.68	0.514
2011	33.9	4.30	9.42	1.99	7.08	0.586
2014	31.9	1.72	5.28	1.07	2.15	0.377
2016	31.5	4.03	6.52	0.94	2.32	0.390

ties were then used to estimate the absolute reflectance of seagrass. Statistical relationships between reflectance, leaf area index, and biomass were then used to calculate total seagrass productivity. The area of seagrass in the bay was estimated to be 27 km^2, or 6,672 acres, which is 17% of the area of the bay and considerably less than the mapping estimates from 1992–1993.

CAMA personnel secured another CZM grant to acquire high-resolution satellite imagery of St. Joseph Bay's submerged features in October 2010 by tasking the multispectral sensor on Digital Globe's WorldView-2 (WV2) satellite. This system was chosen for 1) its cost effectiveness for imaging large areas at high spatial resolution; 2) its 8-wavelength spectral resolution; and 3) its ability

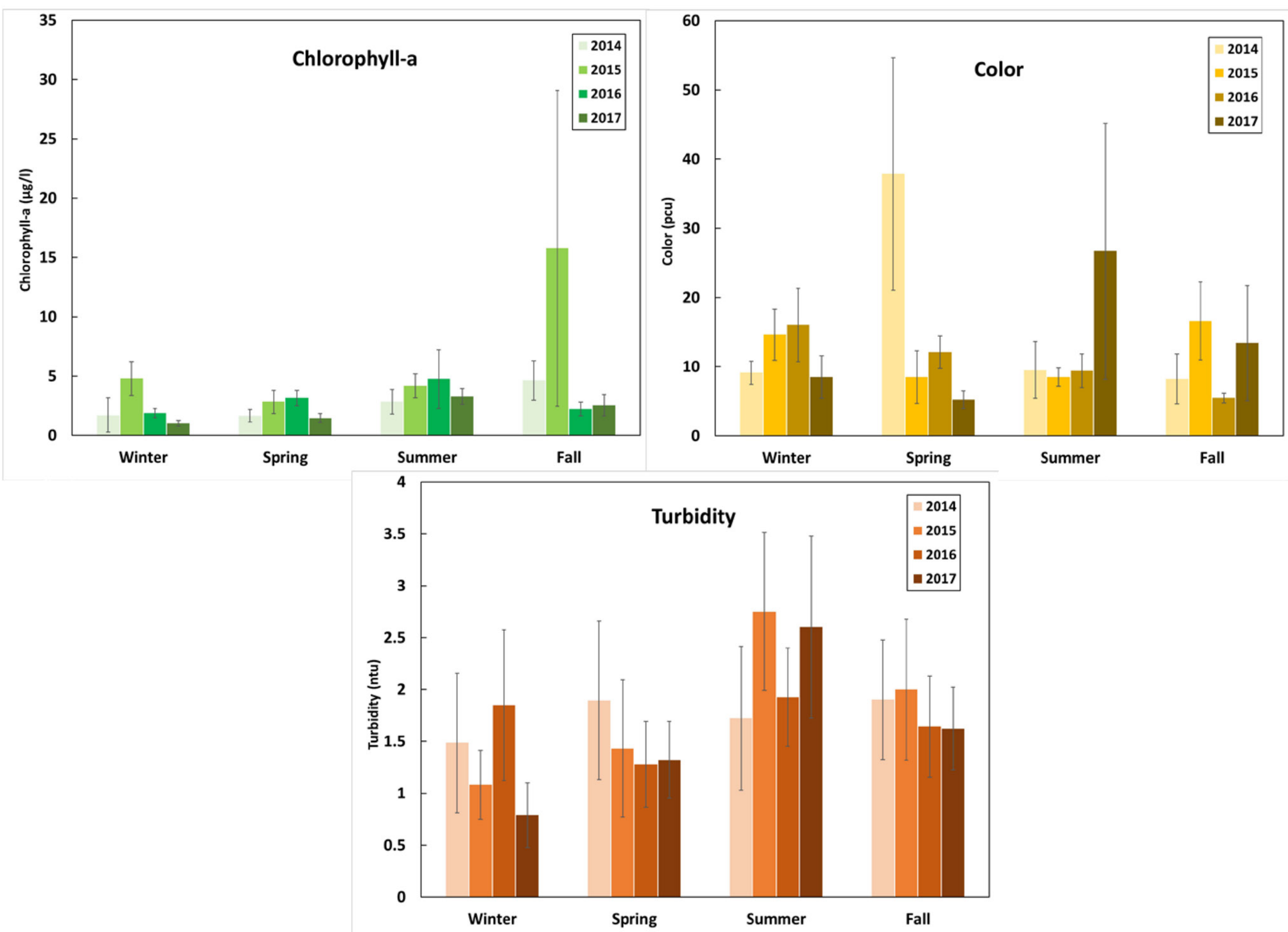

Figure 6. Mean (±2 standard error) seasonal chlorophyll-a concentration, color, and turbidity in St. Joseph Bay in 2014, 2015, 2016, and 2017.

to acquire imagery when even sun glint is present. Area, abundance, and productivity of seagrass meadows, as well as shallow-water bathymetry (<2 m), were quantified and mapped across the bay using a combination of algorithms and models.

Propeller scarring assessment

As part of the Roadblocks to Seagrass Recovery project, scientists at FWRI assessed the extent and severity of propeller scarring of seagrass beds in St. Joseph Bay using imagery acquired in 2013 by the NAIP. ArcMap was used to overlay water areas <4 m deep with a grid constructed of square cells 100 m on a side, thus covering 1 ha each. For each cell that was over seagrass, scars were counted, and the cell was scored in the following manner:

Description	Score
Vegetated, no scars	0
<5 scars	1
5–10 scars	2
11–25 scars	3
26–50 scars	4
>50 scars	5
Doughnut-shaped beds	7
Unreadable, vegetated	10

The number of cells having each score was summed and compared with the total number of vegetated cells to calculate the percentage for each scarring score and overall scarring percentage. In addition, maps were created showing the distribution of scarring intensity, and these maps constitute a layer of the Seagrass Recovery Potential model of the Roadblocks project.

Monitoring methods and data

Seagrasses were monitored in St. Joseph Bay each year from 2002 through 2010 by FDEP CAMA personnel. Seagrass and macroalgal cover were estimated by species in four quadrats at each of 25 sites throughout the bay. Other data collected included canopy height, epiphyte coverage and type, sediment type, animals observed in quadrats, and depth; underwater photographs or video were also taken. Additional samples included biomass cores (taken occasionally) and seagrass blades, collected for quantitative estimates of epiphyte loads. Water quality measurements included dissolved oxygen concentration, temperature, salinity, pH, turbidity, Secchi depth, and light attenuation.

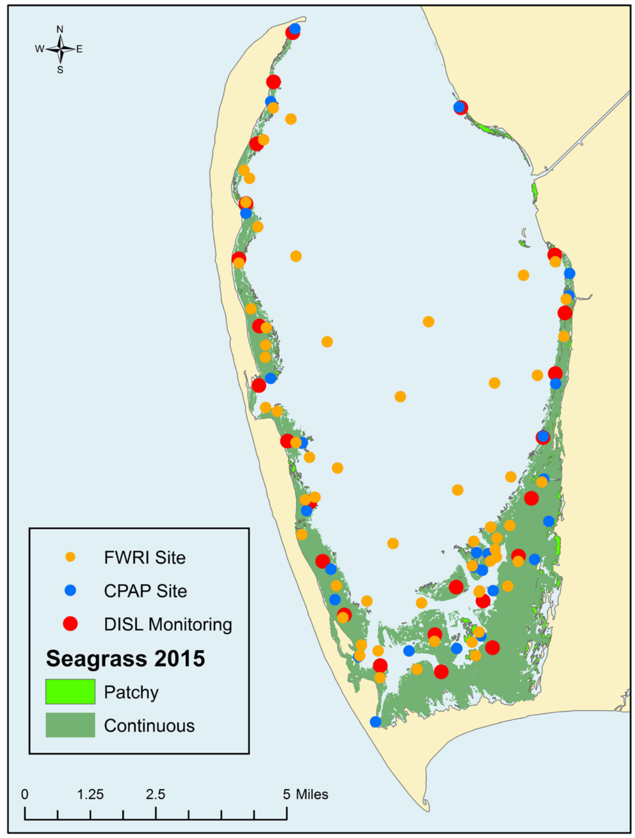

Figure 7. Distribution of patchy and continuous seagrass and locations of sites monitored by FWRI, CPAP, and DISL in St. Joseph Bay.

Other agencies monitor seagrasses in St. Joseph Bay (Figure 7). FWRI included St. Joseph Bay in its summer monitoring program in 2008, 2009, 2011, and 2014. Forty to 60 spatially distributed, randomly-located sites were chosen using a design developed by the U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program (EPA EMAP). Using ArcMap, a spatial layer composed of a hexagonal grid was superimposed over the area where water depth was <3 m; the grids to be sampled and the location of a site within each grid were chosen randomly. The design ensured full spatial coverage of the potential seagrass habitat, but the randomized selection of a point within each delineated hexagon permitted the use of parametric statistics. At each sampling site, seagrass and macroalgal cover was estimated in ten 0.25-m^2 quadrats using a modification of the Braun-Blanquet technique. The presence and numbers of scallops and sea urchins in each quadrat were also recorded. In addition to the seagrass field assessment, personnel measured standard field water quality parameters of salinity, water temperature, water depth, Secchi depth, pH, and dissolved oxygen concentration, as well as the OWQ parameters light attenuation, chlorophyll-a concentration, turbidity, total suspended solids, and water color.

Beginning in May 2015, personnel from the Central Panhandle Aquatic Preserves of the FDEP resumed monitoring of seagrass beds at 27 locations in St. Joseph Bay (Figure 7). Since that time, field monitoring has been done twice a year, in late spring/early summer and in fall. At each site, 4 quadrats are assessed for cover of seagrasses and macroalgae using the Braun-Blanquet technique; in addition, scientists measure the length and width of a subset of turtlegrass blades, determine the water depth, and count scallops and sea urchins. Dissolved oxygen concentration, pH, salinity, water temperature, and Secchi depth are measured at each site.

In June 2016, scientists from DISL conducted field monitoring at 24 sites, all in seagrass beds. Seagrass cover was estimated at 5 quadrats per site.

Productivity of turtlegrass

Field measurements of the productivity of turtlegrass were carried out at six locations in St. Joseph Bay by scientists from DISL once in June 2016 and once in August 2016 (see Figure 1). At each location, 4 quadrats, 20 cm on a side (0.04 m^2), were anchored into a turtlegrass bed within 1 m of each other using 6-inch sod staples. Each shoot of turtlegrass in a quadrat was punched just above the end of the short shoot at the basal meristem with a 20-gauge hypodermic needle, after Zieman and Zieman (1989). Because each blade adds new tissue at the basal meristem below the punch mark, this mark provides a point from which growth of the blade can be measured. After about 10 days, all the seagrass material, both above and below the sediment surface in each quadrat, was carefully harvested, chilled, and taken to the laboratory for processing.

In the laboratory, punched turtlegrass shoots were separated from the rest of the seagrass material, and the length, width, and punch translocation distance were measured for each blade in each shoot, with as many as 20 punched shoots assessed for each quadrat. The location of the punch hole in the oldest blade was used as reference position to measure extension of the remaining younger blades. Remaining seagrass tissues were separated into blade, short shoot, roots and rhizomes fractions and into live or dead fractions. Blades and short shoots were designated as above-sediment and roots and rhizomes as below-sediment. Biomass was gently rinsed with tap water and dried for 5–7 days at 50°C and then weighed. The total number of shoots, both live and dead, of each species of seagrass in each quadrat was also recorded, as was the presence of macroalgae.

Optical water quality measurements

Measurements of optical water quality parameters—chlorophyll-a, color, turbidity, total suspended solids (TSS), and light attenuation—have been part of the field assessments of seagrasses in the SIMM program since 2004. The amount of sunlight reaching the bottom is often critical to the survival of seagrass communities. The attenuation of light in the water column results from reflection, diffraction, and absorption of light by the water itself and absorption by particles and colored dissolved organic matter (CDOM). The effects of the quantity and character of particles in the water are determined by the measurement of chlorophyll-a as an estimate of phytoplankton density, by measurement of TSS as a gravimetric estimate of the number of particles in the water, and by the measurement of turbidity which estimates light scattering by particles as well as the quantity of particles present. The color of the water column can be measured by light absorption of a filtered water sample at 440 nm (color) or, for CDOM, by light absorption over 300–600 nm.

Chlorophyll-a concentrations were determined by filtering triplicate 60-ml aliquots of surface water through 25-mm-diameter GFF glass fiber filters in the field. Each filter was stored in a microcentrifuge vial and immediately frozen in liquid nitrogen. In the laboratory, filters were transferred to an ultra-low-temperature freezer and held at −60°C until analysis. To measure the amount of chlorophyll-a, pigments on the filters were extracted in 10 ml of methanol in the dark for 40 hours at 4°C. On the day of analysis, methanol extracts were centrifuged at 3,500 rpm for 20 minutes to remove filter fibers from the extract. Fluorescence of each extract was measured using a Turner Designs model 10-AU-005 fluorometer following the methods of Welshmeyer (1994). Calibration of the fluorometer used fresh spinach extracts and the trichromatic equations of the Environmental Protection Agency (EPA) method 446.0 (Arar 1997).

Water samples for the measurement of color, turbidity, and TSS were collected by triple-rinsing each sample bottle with site water and then filling each bottle nearly full. Samples were kept on ice or refrigerated until analysis. To measure color, water was filtered through a 0.22-μm membrane filter. Light absorbance at 440 nm of the filtered sample was determined using a 10-cm cell path in a Hitachi U-2900 spectrophotometer after Kirk (1976) and Gallegos et al. (1990). Absorbance of certified color standards was used to estimate color in platinum cobalt units (pcu). Turbidity was measured nephelometrically on a Hach 2100Q turbidimeter using calibrated standards following method 214 A of the *Standard Methods for the Examination of Water and Wastewater* (1985), and units were nephelometric turbidity units (ntu). TSS was measured gravimetrically following method 2540 D of *Standard Methods* (1985) by filtering water samples through combusted, tared GFC glass fiber filters. Filters were then dried at 50°C for at least five days and then re-weighed using a 5-place Mettler balance.

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