

Summary Report for the Northern Big Bend Region

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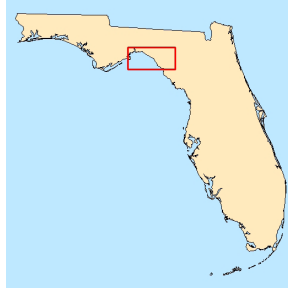


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Summary report for the Northern Big Bend region

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General assessment

The Northern Big Bend region contained 195,145 acres of seagrass in 2015, and acreage increased 2,483 acres (1.3%) since the last mapping effort in 2006 (Table 1, Figure 1). Between 2006 and 2015, total acreage declined in the northern part of the region but increased in the southern part of the region. All areas showed substantial increases in areas of patchy beds (15–28%). Seagrass density is declining throughout the region but is most pronounced near the mouths of the Econfina and Steinhatchee rivers. Seagrass species and macroalgal composition have also changed over the past 10 years due to declines in species diversity and distribution. Manateegrass (*Syringodium filiforme*) is the most common seagrass, and turtlegrass (*Thalassia testudinum*) is second in occurrence. Shoalgrass (*Halodule wrightii*) and stargrass (*Halophila engelmannii*) are less common, and widgeongrass (*Ruppia maritima*) is observed occasionally. Stressors include reduced optical water quality, which has resulted from elevated phytoplankton concentrations and water color in the region. Tropical cyclones and heavy rains cause rivers to discharge large volumes of darkly colored, nutrient-rich water, reducing water clarity and dramatically increasing phytoplankton levels in the coastal region. Turbidity is elevated west of the mouth of the St. Marks River, where discharge from the Ochlockonee River affects coastal waters. Heavy propeller scarring is evident around the mouth of the St. Marks River, near Keaton Beach, and near Steinhatchee but is minimal elsewhere.

Geographic extent

Northern Big Bend extends from the mouth of the Ochlockonee River in the west to the mouth of the Steinhatchee River to the east and south and includes the in-

shore part of Apalachee Bay (Figure 1). The area surveyed during annual summer monitoring extends from shallow areas west of the mouth of the St. Marks River to the mouth of the Steinhatchee River. Several rivers discharge freshwater to the region. The Ochlockonee River is the largest, and freshwater from the river enters Ochlockonee Bay, which opens to Apalachee Bay. The Ochlockonee River is about 216 miles long from its origin in southern Georgia and drains about 2,480 square miles. More information about the Ochlockonee River watershed is available in the Ochlockonee River and Bay Surface Water Improvement and Management (SWIM) Plan (Northwest Florida Water Management Plan 2017a). To the east of the Ochlockonee, the St. Marks River drains about 1,170 square miles, 91% of which is in Florida. Much of the headwaters originates from surface drainage in the eastern Tallahassee area; springs, seeps, and the Wakulla River, a spring-fed river, also contribute to flow in the St. Marks River. The St. Marks and Apalachee Bay SWIM Plan has detailed information on the watershed and land use (Northwest Florida Water Management District 2017b). The Aucilla River empties into Northern Big Bend east of the mouth of the St. Marks River; it is spring-fed, 89 miles long, drains 731 square miles and originates in southern Georgia. The Econfina River drains into coastal waters at the corner of the Big Bend. It is only 40 miles long and originates in the San Pedro Bay Swamp in Madison County. To the south, the Fenholloway River also begins in the San Pedro Bay Swamp and runs 36 miles before reaching the coastline. The river passes through Perry and receives treated effluent from the Georgia-Pacific Foley Cellulose Mill. The location of effluent discharge to the river will soon be moved downstream to about 1.5 miles from the river mouth. The Steinhatchee River begins in Mallo-ry Swamp in Lafayette County and runs 35 miles to its mouth which marks the southern border of the Northern Big Bend region. The Econfina, Fenholloway, and Steinhatchee rivers are characterized by darkly stained waters and together drain 1,859 square miles. More information about these rivers and their watersheds may be found in the Coastal Rivers SWIM Plan (Suwannee River Water Management District 2017). Coastal waters in the region are also influenced by discharge from the Apalachicola River to the northwest and the Suwannee River to the south during high-flow periods. Regional water circulation patterns, often visible in satellite imagery, cause variations in water mass characteristics, from clear waters originating offshore to lower-salinity, dark, and sometimes turbid, waters originating from rivers.

The watersheds of the Northern Big Bend are mostly rural with forests and silviculture common and with

Table 1A. Seagrass acreage in subregions of the Northern Big Bend, 2006, 2015.

Subregion	2006			2015		
	Continuous	Patchy	Total	Continuous	Patchy	Total
St. Marks West	13,683	1,011	14,695	12,560	2,128	14,688
St. Marks East	15,810	2,042	17,853	13,248	4,285	17,533
Aucilla	17,273	923	18,195	12,843	4,593	17,436
Econfina	40,757	415	41,173	29,588	11,268	40,856
Fenholloway	30,208	4,043	34,251	30,111	6,245	36,356
Keaton	49,277	1,630	50,907	41,079	11,457	52,536
Steinhatchee North	14,369	1,220	15,589	11,813	3,927	15,740
Total	181,377	11,284	192,662	151,241	43,904	195,145

Table 1B. Change in seagrass acreage, 2006–2015, in subregions of northern Big Bend, and percentage of beds that were patchy in texture, 2006, 2015.

Subregion	Change, 2006–2015		% patchy	
	Acres	%	2006	2015
St. Marks West	–7	–0.05%	6.9%	14%
St. Marks East	–320	–1.8%	11%	24%
Aucilla	–760	–4.4%	5.1%	26%
Econfina	–316	–0.8%	1.0%	28%
Fenholloway	2,105	5.8%	12%	17%
Keaton	1,630	3.1%	3.2%	22%
Steinhatchee North	151	1.0%	7.8%	25%
Total	2,483	1.3%	5.9%	22%

wetlands along the coastline. The Ochlockonee River drainage includes several communities in Gadsden County (Greensboro, Gretna, Havana, Midway, and Quincy) and Sopchoppy in Wakulla County. The St. Marks River drains Tallahassee, Crawfordville, and the city of St. Marks, and the Fenholloway River travels through the town of Perry. Wetlands and forests (upland and silviculture) cover 36% and 48%, respectively, of the Ochlockonee watershed (Northwest Florida Water Management District 2017a). Wetlands make up 37% and forests cover 50% of the watersheds of the St. Marks River and Apalachee Bay. Watersheds of the other rivers to the south contain 40% wetlands and 45% forests (Suwannee River Water Management District 2017a). Row crops cover <6% of all watersheds, and developed areas are also small in area (6–7% of the watersheds).

Nutrient pollution of river waters is a concern, and some waters are monitored closely for compliance with total maximum daily loads (TMDLs) and numeric nutrient criteria (NNC). The levels of total nitrogen are increasing in the Aucilla and Suwannee rivers, but nitrate concentrations in Wakulla Spring decreased between 1997 and 2017. Inputs from septic tanks, atmospheric deposition, and

farm fertilizers are major sources of nutrients (Florida Department of Environmental Protection 2018). In addition, portions of the Steinhatchee River are listed as impaired for bacteria by the Florida Department of Environmental Protection (FDEP), and the Fenholloway River is listed as impaired for dissolved oxygen, specific conductance, and unionized ammonia (NH_3). See the SWIM plans for more information on nutrients and impairments.

For this report, the Northern Big Bend is divided into seven subregions (Figure 1). St. Marks West extends from the mouth of the St. Marks River west to Ochlockonee Bay. St. Marks East extends from the mouth of the St. Marks River east to about halfway between the mouth of the St. Marks River and the mouth of the Aucilla River. The Aucilla subregion starts at the eastern end of the St. Marks East subregion and extends just southeast of the mouth of the Aucilla River. The Econfina subregion covers coastal waters southeast of the border of the Aucilla subregion, the mouth of the Econfina River, and continues southeast about two-thirds of the distance to the mouth of Fenholloway River. The Fenholloway subregion begins just north of the mouth of the Fenholloway River and continues southeast to the

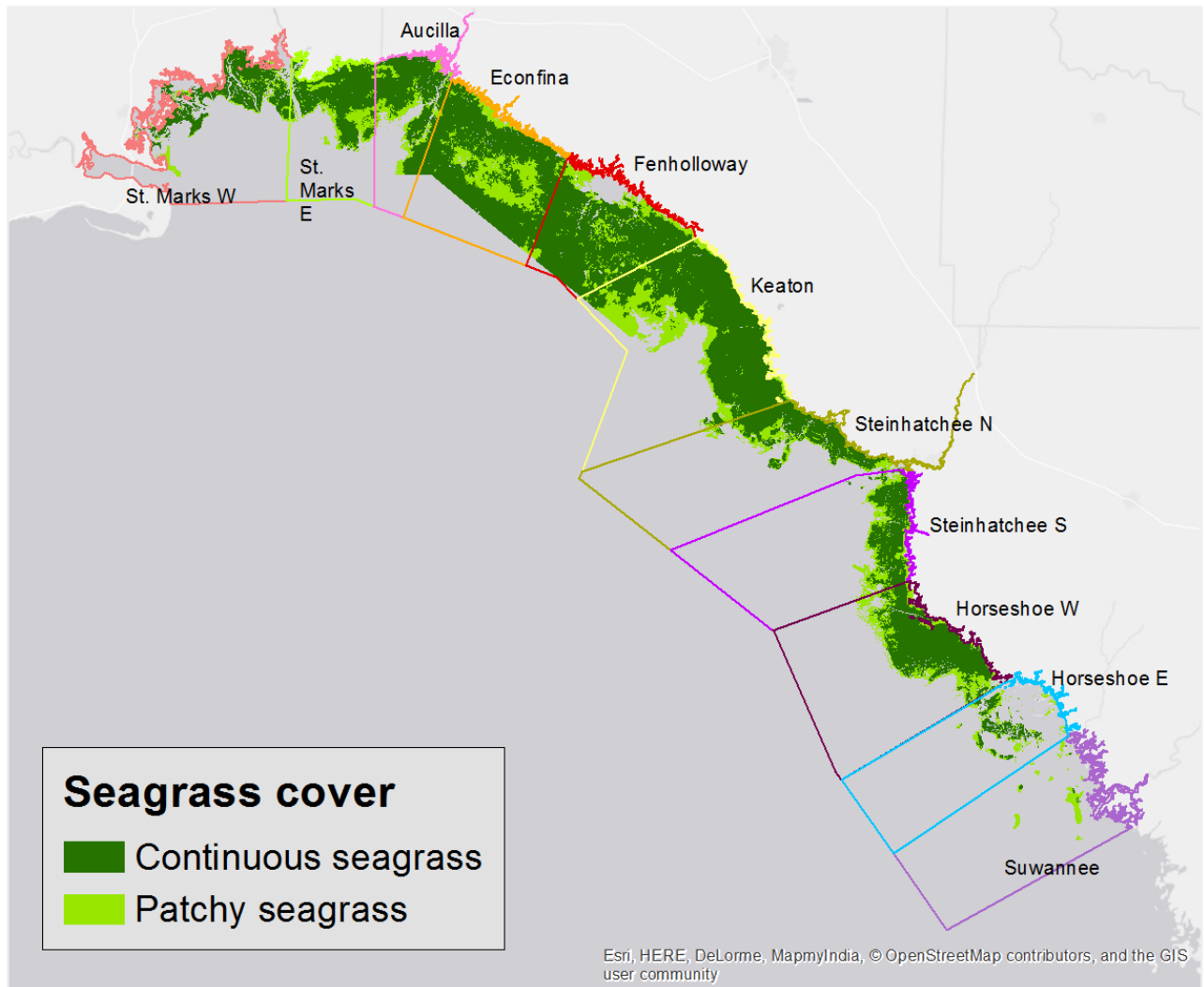


Figure 1. Map of seagrass in the northern Big Bend in 2015.

mouth of Spring Warrior Creek. The Keaton subregion extends from the mouth of Spring Warrior Creek, includes Keaton Beach and Hagen's Cove, and ends about halfway between Hagen's Cove and the mouth of the Steinhatchee River. Steinhatchee North includes the coastal areas from the border of the Keaton subregion to the mouth of the Steinhatchee River.

Mapping and monitoring Recommendations

- Obtain high-resolution imagery and map the region every five years.
- Continue the annual field monitoring program conducted by staff of the Fish and Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission and the FDEP Big Bend Seagrasses Aquatic Preserve.

- Continue to measure the quantity and quality of runoff entering the region.
- Establish a monitoring program near the mouth of the Ochlockonee River.
- Map and monitor seagrasses in water too deep for the use of conventional aerial photography and field methods.

Management and restoration recommendations

- Assess changes in the water volume and nutrient loads in the Ochlockonee, St. Marks, Aucilla, Econfina, Fenholloway, Steinhatchee, and Suwannee rivers and their effects on coastal seagrasses.
- Evaluate the effects of changing regional weather patterns, including increases in summer freshwater runoff, on optical water quality of coastal waters.

- Recommend and implement nutrient management strategies for rivers that will reduce nutrient inputs to coastal seagrass ecosystems.
- Evaluate the effects of seagrass losses, such as changes in species distribution and plant densities, on local scallop populations.
- Begin monitoring seagrass beds near the mouth of the Fenholloway River to evaluate the effects of the relocation of the effluent discharge from the Georgia-Pacific Foley Cellulose Mill, scheduled for 2020, on seagrass acreage, species composition, and health.

Summary assessment

Mapping data obtained from imagery collected in 2006 and 2015 showed that seagrass acreage increased by 1.3% or 2,483 acres (Table 1). While seagrass acreage was stable for the region, subregions in the north (St. Marks West and East, Aucilla, and Econfina) lost seagrass between 2006 and 2015, and subregions in the south, Fenholloway, Keaton, and Steinhatchee North, realized substantial gains. All subregions showed increases in the percentage of beds that were patchy in texture. Overall, 30,117 acres of continuous seagrass beds were lost, and 32,620 acres of patchy seagrass were gained (see Figure 2).

Manateegrass is the most common seagrass in the region, followed by turtlegrass. Shoalgrass and stargrass occur at substantially lower levels than manateegrass and turtlegrass, and widgeongrass is uncommon. Since 2013, the density of seagrass shoots inside beds, seagrass and macroalgal species diversity, and the distribution of seagrass and macroalgal species have declined. Tropical storms Debby and Andrea, in late June 2012 and late June 2013, respectively, and excessive rainfall in July 2013 increased water color and chlorophyll-*a* concentrations in coastal waters in the Northern Big Bend, which remained elevated for months. Resulting reductions in water clarity likely contributed to observed decreases in shoot densities in seagrass beds in 2013 and 2014 and to reductions in the occurrence of seagrass species throughout the region since 2013. While occurrence of manateegrass, shoalgrass, and stargrass has increased since 2015 to nearly the values mea-

sured before 2013, the densities of seagrass shoots of all species have not returned to values observed in 2008–2012. Heavy propeller scarring is evident around the mouth of the St. Marks River, near Keaton Beach, and near the mouth of the Steinhatchee River but is minimal elsewhere.

The general status of seagrasses (Status graphic 1) has improved since the second edition of this chapter, because recent mapping efforts show that total seagrass acreage is stable or increasing slightly. Seagrass thinning has also partly rebounded since losses in 2013 and 2014. A detailed assessment of seagrass status (Status graphic 2) also indicates improving conditions with recovery from poor optical water quality and seagrass thinning in 2014.

Seagrass mapping assessment

Seagrass acreage mapped in 2015 covered 195,145 acres, an increase of 2,483 acres (1.3%) from acreage mapped in 2006 (Table 1A). The Econfina, Fenholloway, and Keaton subregions contained nearly two-thirds of the mapped acreage (129,748 acres). The northern part of the region, St. Marks West through Econfina, lost 1,402 acres between 2006 and 2015, while the southern part of the region gained 3,886 acres over the same period. While the change in acreage across the region was small between mapping efforts, there were much greater changes in the texture of seagrass beds, with all subregions having patchier seagrass in 2015 than in 2006 (Table 1B). Patchy seagrass beds expanded by 32,620 acres and comprised 22% of all beds, while continuous beds contracted by 30,137 acres. The Econfina subregion had the greatest change, with a loss of 11,170 acres of continuous beds and a gain of 10,853 acres of patchy seagrass. The Fenholloway subregion had the smallest loss of continuous seagrass, while gaining 1,630 acres overall between 2006 and 2015. Seagrass losses and changes from continuous to patchy beds occurred both inshore and offshore in the region (Figure 2). Large areas of continuous seagrass in 2006 in the offshore parts of the Econfina and Keaton subregions were patchy in 2015.

These mapping efforts did not extend far enough offshore to capture the deep edge of coastal seagrasses. Furthermore, there are extensive, but sparse, beds of pad-

1. General status of seagrasses in Northern Big Bend

Status and stressors	Status	Trend	Assessment, causes
Seagrass acreage	Green	1.3% increase, 2006–2015	Substantial changes from continuous to patchy beds
Seagrass density	Orange	Thinning in all subregions	Limited recovery from 2014
Water clarity	Yellow	Variable	Better water clarity, 2014–2017
Natural events	Yellow	More frequent storms	Inter-annual climatic variation
Propeller scarring	Yellow	Localized, shallow waters	Ongoing, low impact

dlegrass (*Halophila decipiens*) offshore on the continental shelf that cannot be mapped using conventional aerial photography. These beds probably serve as a bridge for grouper and other important fish and shellfish species as they migrate inshore and offshore.

Seagrass monitoring assessment

Two agencies, FWRI and the FDEP Big Bend Seagrasses Aquatic Preserve, conduct annual field monitoring of seagrasses using somewhat different methods. FWRI staff and collaborators conduct field monitoring of seagrass beds each summer, using a spatially-distributed, randomly located network of sites located in water shallow enough to support seagrass (<4 m); this program began in 2002. Site selection was not based on whether seagrasses were present or absent, so some sites were bare of vegetation when the project began. The number of sites monitored has ranged from 96 to more than 170, but since 2010, more than 130 sites (usually with 10 quadrats per site) in the Northern Big Bend have been evaluated each year (Figure 3). Staff members from the Big Bend Seagrasses Aquatic Preserve monitor seagrasses once a year in the summer at three locations in the Northern Big Bend: east of the mouth of the St. Marks River, just offshore of Keaton Beach, and near and south of the mouth of the Steinhatchee River (Figure 3).

Data from the FWRI monitoring program show that manatee grass is the most common seagrass in the Northern Big Bend and that turtle grass is second in occurrence (Table 2). These two species also frequently occur in the same bed. The frequency of occurrence (FO) of manatee grass decreased sharply in 2014, to 43% from a high of 63% in 2013, following a long period of poor optical water quality that began in late June 2013. Since 2014 the FO of manatee grass has rebounded almost to levels observed in 2013. The FO of shoal grass also dropped between 2013

and 2014 by nearly 50% and has not completely recovered. The percentage of bare quadrats increased by more than 50% between 2013 and 2014 but has since decreased almost to the percentage observed in 2013. The decrease in the FO of shoal grass and the increase in the percentage of bare quadrats show significant trends between 2002 and 2018. The frequency of occurrence of turtle grass has been fairly stable, ranging from 36% to 47%. The FO of stargrass is lower than that of manatee grass and turtle grass and dropped sharply to 3–4% in 2013 and 2014. Since 2014, the FO of stargrass has rebounded to 17–20%. A similar rebound was observed in 2006, following poor water quality after the hurricanes in 2005. Widgeongrass and the green alga *Caulerpa prolifera* have low and variable FO in the Northern Big Bend.

In June 2018, manatee grass was the most common seagrass in all subregions except Steinhatchee North (Figure 4). In Figure 4, subregions are arranged from northwest to southeast along the x-axis. Turtle grass occurred most frequently in the Steinhatchee North subregion and was second in occurrence in all other subregions except Econfinia. All five species of seagrass were found everywhere except in the Aucilla and Steinhatchee North subregions. Stargrass was present in >30% of quadrats in Econfinia, a value much greater than observed elsewhere. The percentage of bare quadrats varied between 6% and 40% in the region. The low percentage of bare quadrats in Econfinia is a substantial improvement over conditions in 2014 when 34% of quadrats were bare. Before 2014 the Econfinia subregion had diverse and abundant seagrass beds and was considered a pristine area of the Big Bend. In 2014, however, the percentage of bare quadrats in the Econfinia subregion increased by an order of magnitude over 2013, from 3.3% to 34%. The Econfinia subregion has recovered from the poor water quality in 2013 and 2014, but the FOs of turtle grass and manatee grass have

2. Seagrass status and potential stressors in northern Big Bend			
Status indicator	Status	Trend	Assessment, causes
Seagrass acreage	Green	1.3% increase, 2006–2015	Increases in southern subregions
Seagrass meadow texture	Orange	Thinning	Reduced water clarity
Seagrass species composition	Yellow	Local changes	
Overall seagrass trends	Yellow	Thinning	
Seagrass stressor	Intensity	Impact	Explanation
Water clarity	Yellow	Recently improving	River runoff, phytoplankton blooms
Nutrients	Yellow	Likely increasing	Storm-driven river runoff
Phytoplankton	Yellow	Increasing	
Natural events	Orange	Significant impacts	Tropical cyclones
Propeller scarring	Yellow	Localized	St. Marks, Keaton Beach, Steinhatchee

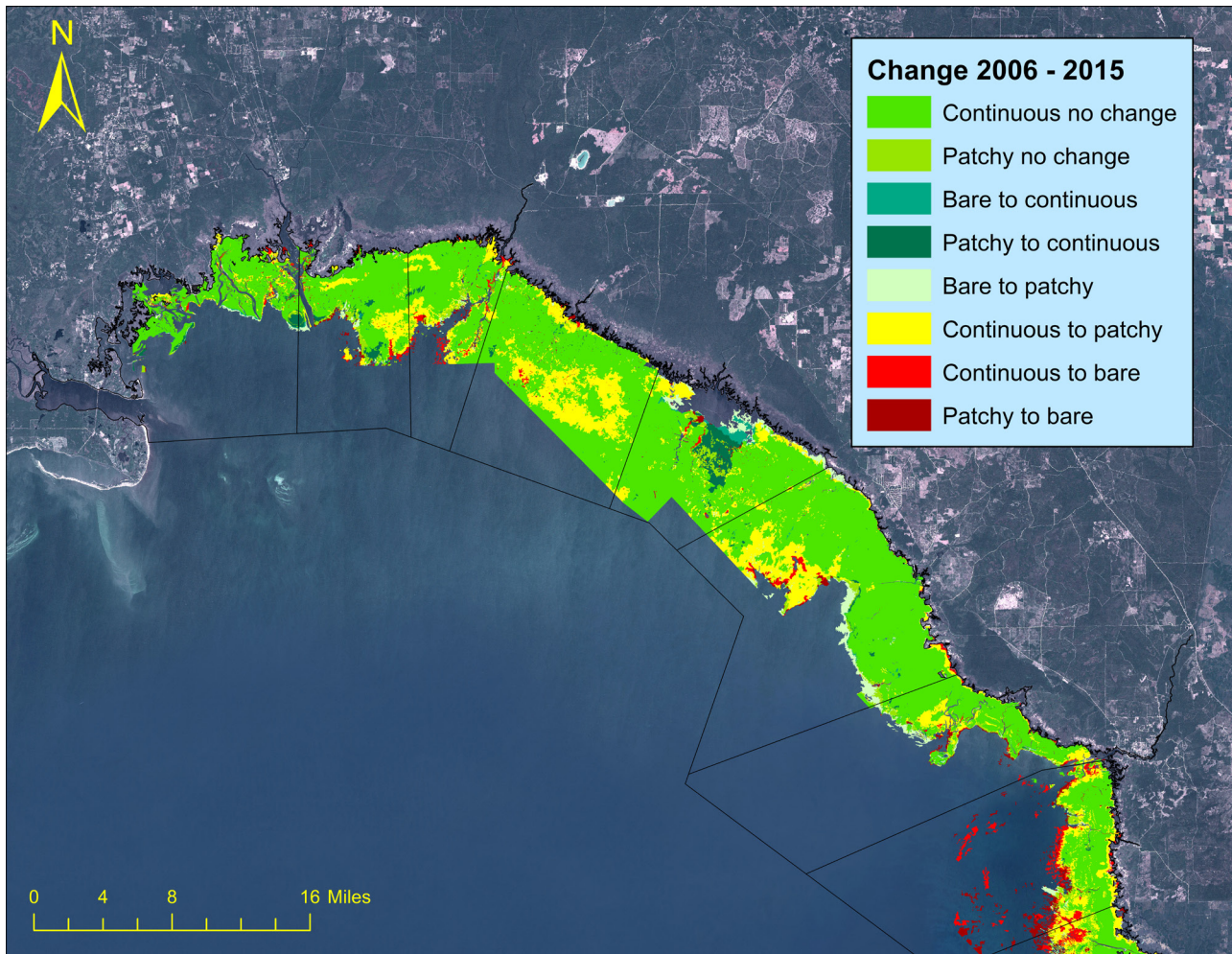


Figure 2. Change in seagrass cover in northern Big Bend, 2006–2015.

not returned to values observed before 2013 (data not shown). The Econfinia subregion also experienced large losses in seagrasses in the 1970s and 1990s (Livingston 2015) and recovered dramatically beginning in 2002, showing that, at least in the past, the seagrass community in this subregion rebounded when conditions improved.

While frequency of occurrence is a measure of the abundance of each seagrass species, quadrat cover (similar to the assessment made using the Braun-Blanquet method; see methods below) adds an assessment of plant density at each site. We calculated average cover for each seagrass species using only those quadrats for which a species was present. Mean cover of turtlegrass has been the highest or nearly the highest of all the seagrasses, but it has decreased substantially in Northern Big Bend since 2011 (Figure 5). In contrast, mean cover of manateegrass has varied between 6% and 12% during the same period, with a slight downward trend. Shoalgrass densities dropped sharply in 2013 and 2014 when water quality was poor, but densities have recovered somewhat. Mean cover of stargrass has varied between 1 and 12% from 2011 through 2018,

with minima also observed in 2013 and 2014. The general downward trend in seagrass density and the observation that mean cover of all species was less than 10% in 2017 and 2018 strongly suggests 1) that conditions for growth and bed expansion are not improving and 2) that recovery after periods of diminished light due to poor optical water quality is not complete. These data also agree with and support the mapping data generated from 2015 imagery that showed large increases in patchy beds of seagrass.

Staff members of the FDEP Big Bend Seagrasses Aquatic Preserve have monitored seagrass beds in three areas of the Northern Big Bend: near the mouth of the Steinhatchee River, near Keaton Beach, and east of the mouth of the St. Marks River. All sites were in seagrass beds when the monitoring program began. These locations correspond to the FWRI Steinhatchee North, Keaton, Aucilla, and St. Marks East subregions. Monitoring was done once annually during the summer (June–September) except in 2010, when sites were visited in May. The cover of seagrass and macroalgal species in 1-m² quadrats was evaluated using the Braun-Blanquet method.

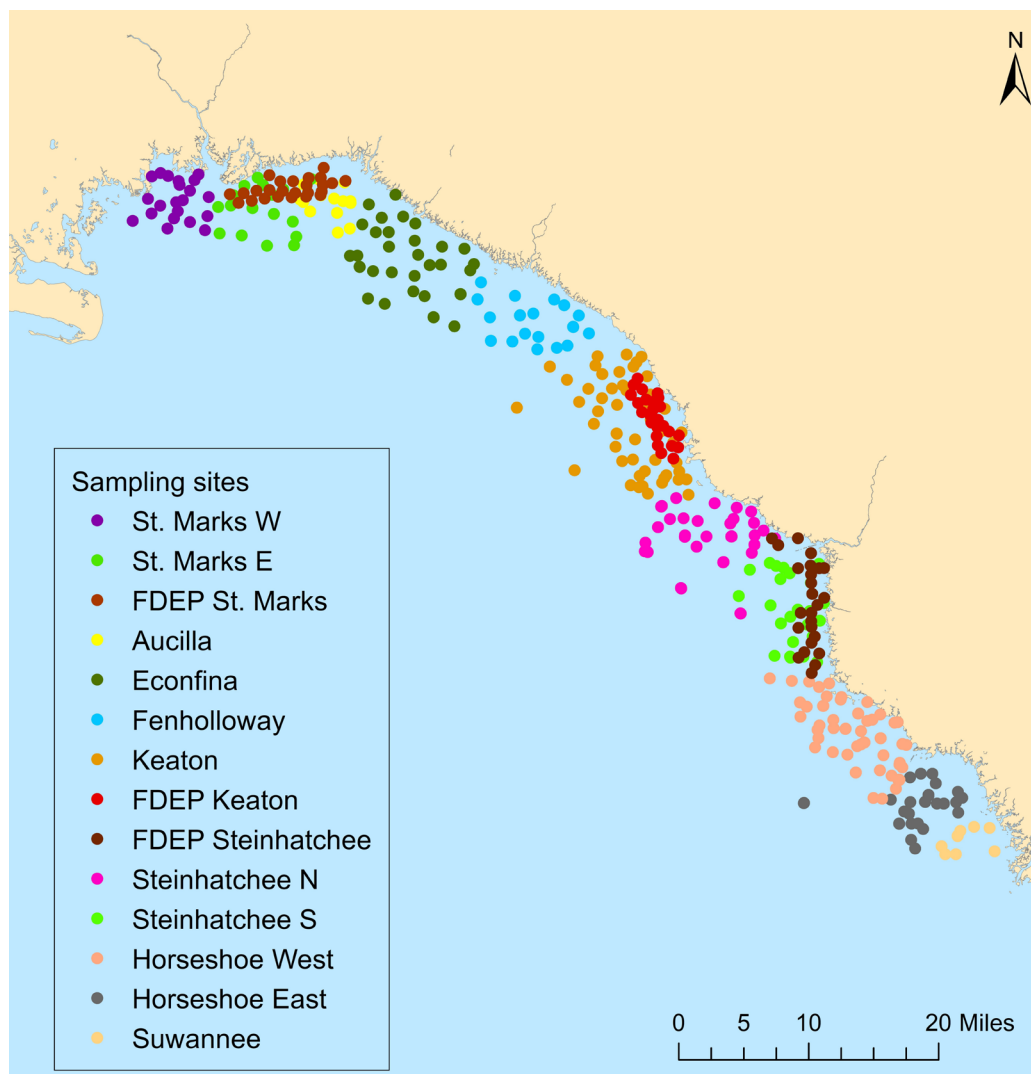


Figure 3. Locations of sampling sites in northern and southern Big Bend visited by FWRI and FDEP in 2018.

The monitoring program at Steinhatchee began in 2000. Only three FDEP sites were in the Steinhatchee North subregion; the rest were in the Steinhatchee South subregion of the southern Big Bend region. Turtlegrass has been most common at these sites since 2000 (Figure 6). Manateegrass occurred commonly from 2000 to 2009, but its occurrence dropped off sharply in 2010 and has remained low. Shoalgrass was present at low levels in quadrats from 2000 to 2007, was very low or absent from 2008 to 2013, and has increased in occurrence since then. Species of *Caulerpa*, a genus of green macroalgae, and the calcareous macroalga *Halimeda incrassata* were commonly found in the Steinhatchee quadrats (Figure 6).

The FDEP monitoring program at Keaton began in 2013, where 25 sites were established nearshore in seagrass beds. These sites were not sampled in 2016, but sampling resumed in May 2017. Data are not shown for this

effort. The FDEP established 25 sites in seagrass beds near the mouth of the St. Marks River in 2006, and these sites are nearly equally distributed between the FWRI Aucilla and St. Marks East subregions. Monitoring occurred from 2006 to 2011 and resumed in 2014. Turtlegrass was the most common seagrass, followed closely by manateegrass (Figure 7). Shoalgrass and widgeongrass were present every year, but at low levels. *Caulerpa* species and *H. incrassata* were the most common attached macroalgae observed every year.

Water quality and clarity

As part of the field monitoring program conducted in June of each year, FWRI staff routinely measure water temperature, salinity, Secchi depth, pH, dissolved oxygen concentration, and light attenuation with depth (using

Table 2. Frequency of occurrence (% of all quadrats) of seagrass and the green alga *Caulerpa prolifera* in the northern Big Bend region, 2002–2018.

Year	# quadrats	Turtle-grass	Manatee-grass	Shoal-grass	Star-grass	Widgeon-grass	<i>C. prolifera</i>	Bare
2002	236	36.0	56.4	33.9	16.1	1.27	10.6	9.75
2004	248	36.3	56.0	29.4	8.87	4.84	2.82	16.5
2005	360	46.7	50.3	29.4	8.33	0.28	8.06	13.1
2006	96	45.8	50.0	13.5	40.6	15.6	19.8	3.13
2007	508	39.4	54.7	13.6	18.5	1.97	10.8	16.3
2008	1,170	35.6	58.5	16.5	16.7	0.09		21.8
2009	1,167	42.2	60.6	15.9	11.0	0.86	12.5	22.4
2010	1,327	41.6	58.8	19.3	8.82	1.51	3.69	19.2
2011	1,430	43.1	61.0	15.0	13.1	3.29	2.87	16.5
2012	1,618	43.2	62.2	16.1	18.2	2.90	5.19	17.4
2013	1,660	41.5	62.8	18.4	4.34	0.96	6.08	19.2
2014	1,635	38.5	43.1	8.93	2.94	1.53	14.4	29.7
2015	1,590	37.9	44.3	9.31	11.1	1.57	8.55	29.1
2016	1,690	36.3	53.0	15.3	20.2	1.48	6.27	22.7
2017	1,680	39.9	57.9	15.1	19.5	2.26	3.81	20.8
2018	1,700	41.8	61.0	12.2	17.4	3.24	1.65	21.2
Mean		40.4	55.7	17.6	14.7	2.7	7.8	18.7
Std. dev.		3.34	5.88	6.98	8.48	3.53	4.89	6.38
R2				0.53				0.45
P value		n.s	n.s	0.002	n.s	n.s	n.s	0.004

Licor sensors, to calculate k_{par}) and collect water and seagrass samples for laboratory analysis. In the laboratory, we measure the optical water quality (OWQ) parameters chlorophyll-a, color, turbidity, and total suspended solids (TSS). Mean values of chlorophyll-a concentrations, color, turbidity, TSS, and k_{par} , estimated with a spherical sensor, are shown in Figures 8 and 9 for 2011–2018 for subregions of Northern Big Bend. All subregions had increased mean values of OWQ parameters and k_{par} in June 2014, following a year of heavy rains in the watershed. In the northern part of the region, St. Marks West had the highest chlorophyll-a concentrations and turbidity, except in 2014 and 2018, when levels of chlorophyll-a were greatest in the Econfinia subregion. In contrast, color was usually greatest in Aucilla and Econfinia and least in the St. Marks subregions. Because of elevated OWQ parameters, k_{par} was also high in 2014 throughout the northern part of the region. Higher levels of k_{par} in 2017 and 2018 are a concern. Low light availability is a stressor that likely led to the observed reduced mean cover values. The steeper reduction in mean cover of turtlegrass might be linked to the metabolic demand of a larger portion of biomass as belowground tissues in this species. To survive, belowground tissues depend on oxygen gener-

ated by photosynthesis in seagrass blades; reduction of photosynthesis due to limiting light levels reduces oxygen available to belowground tissues, leading to stress and death.

In the southern part of the region, the Fenholloway, Keaton, and Steinhatchee North subregions showed similar patterns of OWQ and k_{par} (Figure 9). All subregions had sharply increased levels of OWQ and k_{par} in 2014, but in 2015 values returned to levels measured in 2013 and in earlier years. In 2018, OWQ and k_{par} were much greater in Fenholloway than in than in Keaton or Steinhatchee North.

Discharge from the Suwannee River also affects OWQ in the Northern Big Bend because of prevailing regional water-circulation patterns. From spring through fall, winds and resulting water circulation on the west Florida shelf drive the Suwannee River discharge plume north and west (Yang and Weisberg 1999; He and Weisberg 2003); as a result, water from the much larger Suwannee River affects coastal ecosystems across large areas of the northeastern Gulf of Mexico. The dark, sometimes turbid, discharge from the Suwannee River is easily observed in satellite imagery during and following periods of high river flow (see https://optics.marine.usf.edu/cgi-bin/optics_data?roi=BIGBEND¤t=1).

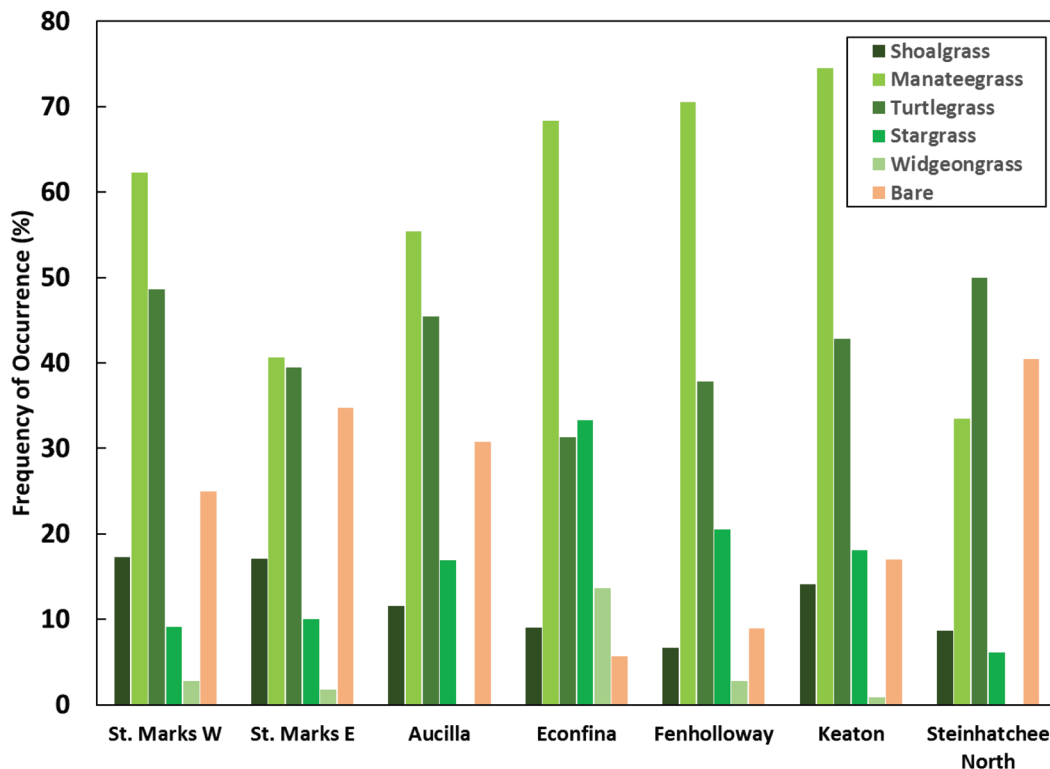


Figure 4. Frequency of occurrence (% of all quadrats) of seagrasses and bare areas in subregions of the northern Big Bend, 2018.

Deterioration of seagrass habitat in the Northern Big Bend is a serious concern, especially because bay scallops (*Argopecten irradians*) support an important recreational fishery in this region and need turtlegrass beds as habitat. Seagrass losses would affect scallop populations where they have historically been at their most abundant (Bert et al. 2014).

The University of South Florida Optical Oceanography Laboratory (USF OOL) has developed a powerful tool called the Virtual Buoy System (VBS) for decision support, education, and assessment of restoration activities in seagrass ecosystems (Hu et al. 2013). The VBS project was funded by National Aeronautics and Space Administration (NASA), resulted from the collaboration of staff from USF OOL, FWRI, and FDER, and uses seagrass and OWQ data from the FWRI monitoring program to interpret and validate daily satellite imagery collected by the MODIS (moderate resolution imaging spectroradiometer) sensor on the Aqua satellite operated by NASA. VBS has a user-friendly web interface that presents, in near real time, OWQ data interpreted from the MODIS sensor. The Suwannee River Estuary VBS website (<http://optics.marine.usf.edu/cgi-bin/vb?area=St&station=01>) has a click-through map interface that provides access to near-real-time remote sensing measurements and time series data for the three principal

components affecting water clarity (CDOM, or colored dissolved organic matter, an estimate of water color; phytoplankton chlorophyll; and turbidity), as well as an overall estimate of water clarity, K_{d488} (a measurement of light attenuation in the water at a wavelength of 488 nm). The web page for each VBS site has seven tabs with data on individual water quality parameters and links to the data. The first tab for each site is a dashboard table showing current values for each parameter compared to data collected the previous year and to the long-term average for each parameter. More information about VBS is available from Hu et al. (2013).

Watershed management

Watersheds draining into Northern Big Bend are in the jurisdiction of two water management districts. The Northwest Florida Water Management District (NFWFMD) manages land areas draining into the Ochlockonee and St. Marks rivers, and the Suwannee River Water Management District (SRWMD) manages land areas drained by the Aucilla River and the smaller coastal rivers to the east and south. The NFWFMD, <http://nwfwater.com/>, through the Surface Water Improvement and Management (SWIM) program, identifies and addresses issues of water resource concern within the SWIM planning basins. The

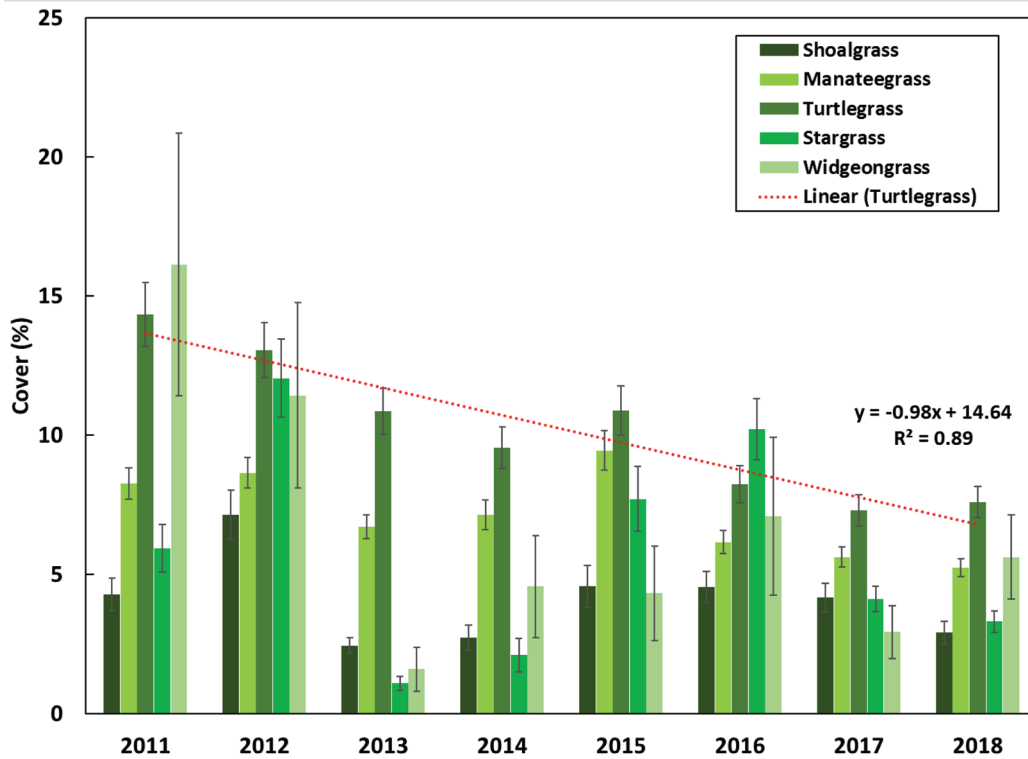


Figure 5. Mean quadrat cover (± 2 standard error) of seagrass species in northern Big Bend, 2011–2018. The trendline was calculated for mean cover of turtlegrass.

St. Marks River and Apalachee Bay SWIM plan (<https://www.nfwfwater.com/Water-Resources/Surface-Water-Improvement-and-Management/St.-Marks-River>) lists objectives including to:

- Protect water quality basin wide and restore water quality in impaired waters.
- Meet or exceed the goals of basin management action plans (BMAPs) for the upper Wakulla River and Wakulla Springs.
- Gain understanding of the variables that affect water clarity in Wakulla Spring and Apalachee Bay.
- Reduce nutrient and bacteria concentrations in receiving water bodies.
- Reduce water quality impacts from legacy pollutants.
- Reduce loading of nutrients and other pollutants from onsite treatment and disposal systems (OSTDS).
- Expand the reuse of reclaimed water.
- Improve the treatment of urban stormwater.
- Reduce basin-wide non-point source (NPS) pollution.
- Protect and, where needed, restore wetland hydrology, vegetation, and functions.
- Protect and restore estuarine benthic habitats
- Ensure restoration projects are compatible with coastal change.
- Protect and restore the function of vegetated riparian buffers.
- Protect and enhance fish and wildlife habitats, including the designated critical habitats for listed species
- Restore Wakulla Spring and the upper Wakulla River ecosystem.
- Protect and restore the St. Marks River ecosystem.
- Evaluate and correct hydrological alterations where necessary.
- Control erosion and sedimentation.
- Protect and restore riparian habitats.
- Protect and restore stream and lake habitats.
- Protect and re-establish functional floodplains.
- Protect or restore stream, lacustrine, wetland, and coastal floodplain functions.
- Continue to make data and information publicly available to enable communities to reduce flood risk.
- Create long-term partnerships among stakeholders, including government, academic institutions, nongovern-

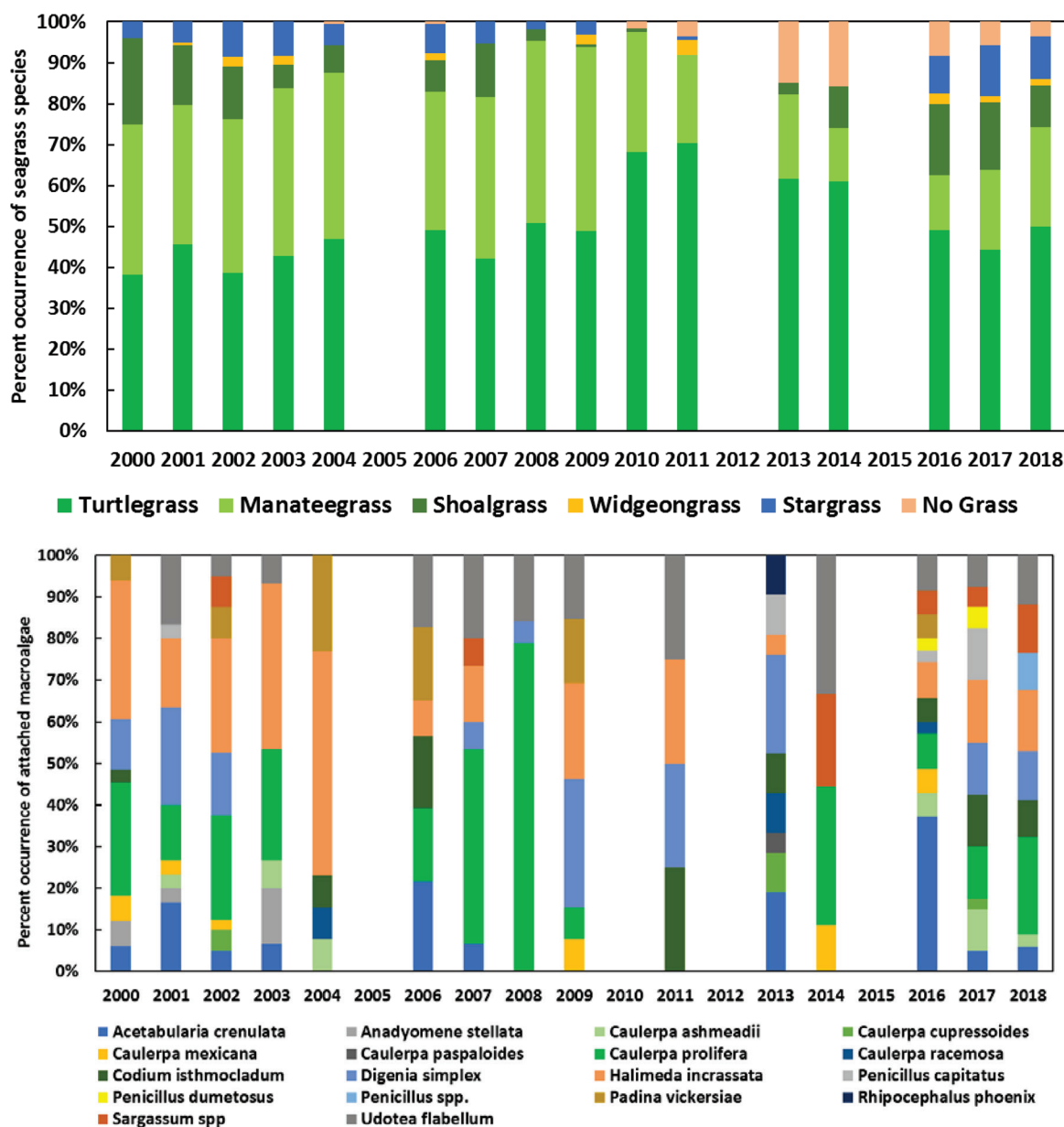


Figure 6. Frequency of occurrence (%) of seagrasses and attached macroalgae at the FDEP monitoring sites in Steinhatchee, 2000–2018.

mental organizations, businesses, residents, and others, to maximize the effectiveness of project implementation.

- Conduct education and outreach about watershed resources and personal practices to protect water and habitat quality.
- Build the capacity of landowners, agricultural producers, and others to protect watershed resources, functions, and benefits.
- Support agricultural, silvicultural, and urban best management practices (BMPs).

The Ochlockonee River and Bay SWIM plan (<https://www.nwfwater.com/Water-Resources/Surface-Water-Improvement-and-Management/Ochlockonee-River-and-Bay/>), lists several objectives, including:

- Protect water quality basin wide and restore water quality in impaired waters.
- Reduce nutrient and bacteria concentrations in receiving water bodies.
- Prioritize water quality protection in areas that contribute groundwater to springs.

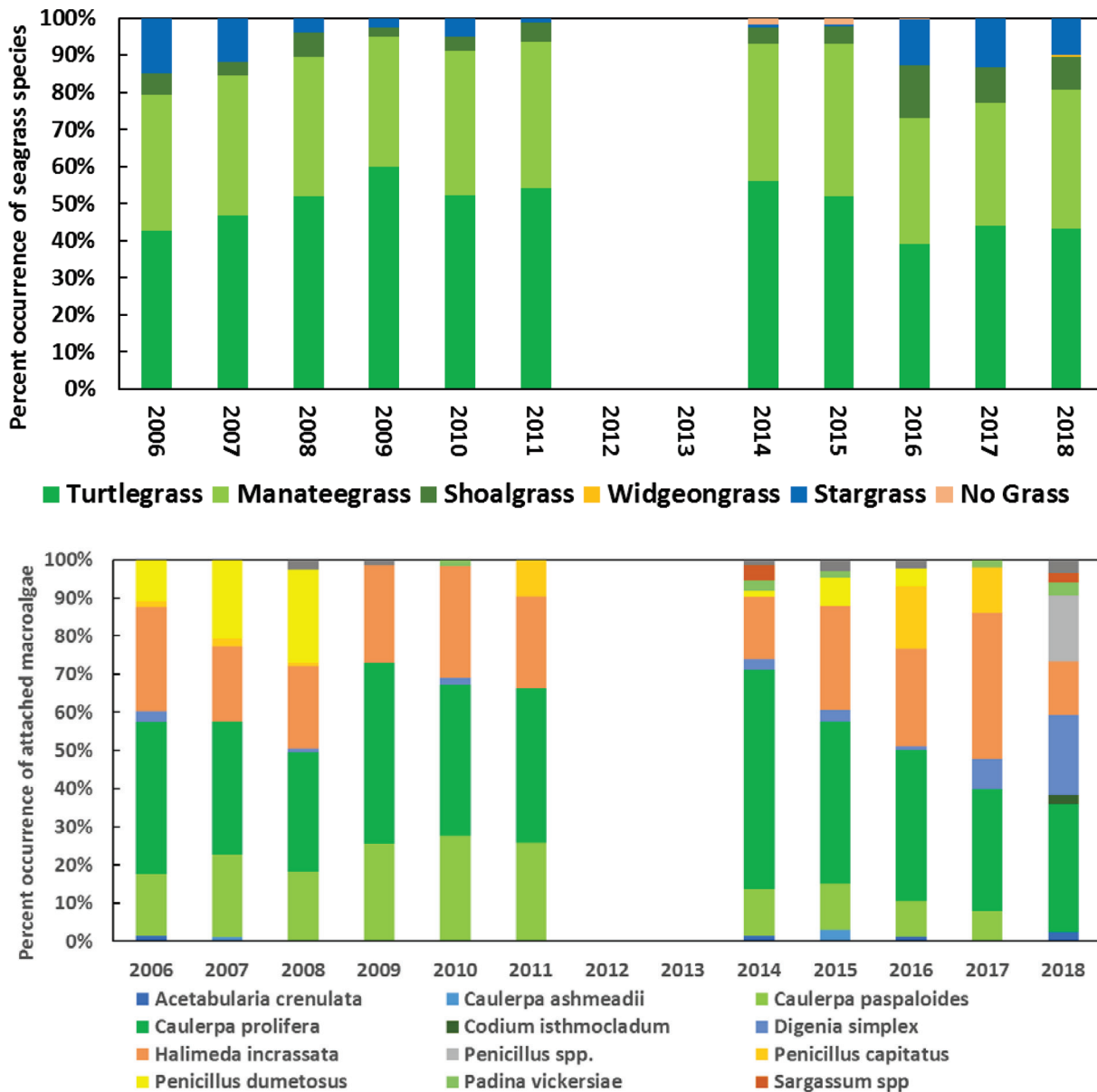


Figure 7. Frequency of occurrence (%) of seagrasses and attached macroalgae at the FDEP monitoring sites in the St. Marks subregion, 2000–2018.

- Reduce water quality impacts from legacy pollutants.
- Reduce loading of nutrients and other pollutants from OSTDS.
- Expand the reuse of reclaimed water.
- Reduce pollutant loading from aging infrastructure.
- Continue to improve treatment of urban stormwater.
- Reduce basin-wide NPS pollution.
- Reduce sedimentation from unpaved roads and erosion.
- Protect and, where needed, restore wetland hydrology, vegetation, and functions.
- Restore and enhance estuarine benthic habitats.
- Ensure restoration projects are compatible with coastal change.
- Protect and restore the function of vegetated riparian buffers on public and private lands.
- Protect and enhance fish and wildlife habitats, including the designated critical habitats of listed species.
- Evaluate and correct hydrological alterations where necessary.
- Restore impacted stream, wetland, and lacustrine habitats.

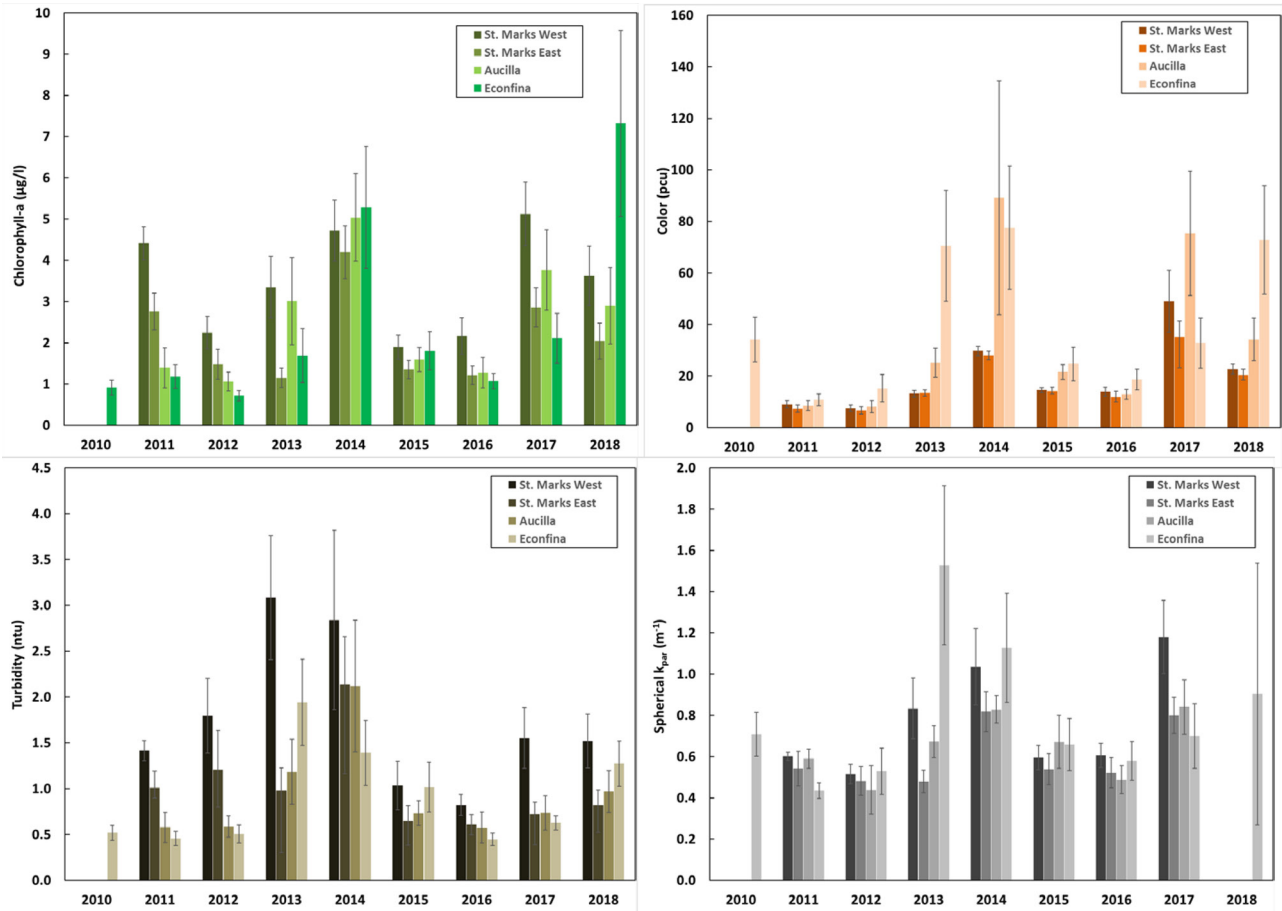


Figure 8. Means (± 2 standard error) of chlorophyll-a concentration, color, turbidity, and spherical k_{par} in St. Marks West, St. Marks East, Aucilla, and Econfinia subregions of northern Big Bend, 2010–2018.

- Protect and restore riparian habitats.
- Reduce erosion and sedimentation from agricultural and silvicultural operations.
- Protect and reestablish functional floodplains.
- Protect or restore stream, lacustrine, wetland, and coastal floodplain functions.
- Continue to make data and information publicly available to enable communities to reduce flood risk.
- Restore the function of vegetated riparian buffers on public and private lands.
- Create long-term partnerships among stakeholders, including government, academic institutions, non-governmental organizations, businesses, residents, and others, to maximize effectiveness of project implementation.
- Conduct education and outreach about watershed resources and personal practices to protect water and habitat quality.
- Build the capacity of landowners, agricultural produc-

ers, and others to protect watershed resources, functions, and benefits.

- Support agricultural, silvicultural, and urban BMPs.

NWFWMD staff continue to help local governments develop and implement cooperative springs restoration and stormwater retrofit projects. Implementation of these projects will provide substantial benefits to the public, such as improving estuarine water quality and aquatic habitats and providing improved flood protection.

The SRWMD published a SWIM plan (SRWMD 2017a) for the water bodies and watersheds of the Aucilla, Wacissa, Econfinia, Fenholloway, and Steinhatchee rivers in the fall of 2017. After identifying issues and concerns in these watersheds, the SRWMD identified management actions and projects designed to protect or restore water quality, focusing on issues of nutrient enrichment (especially nitrogen) and abundance of pathogens in surface waters. The primary issues include:

- Increases in silviculture and more intense agricultural and urban land uses.

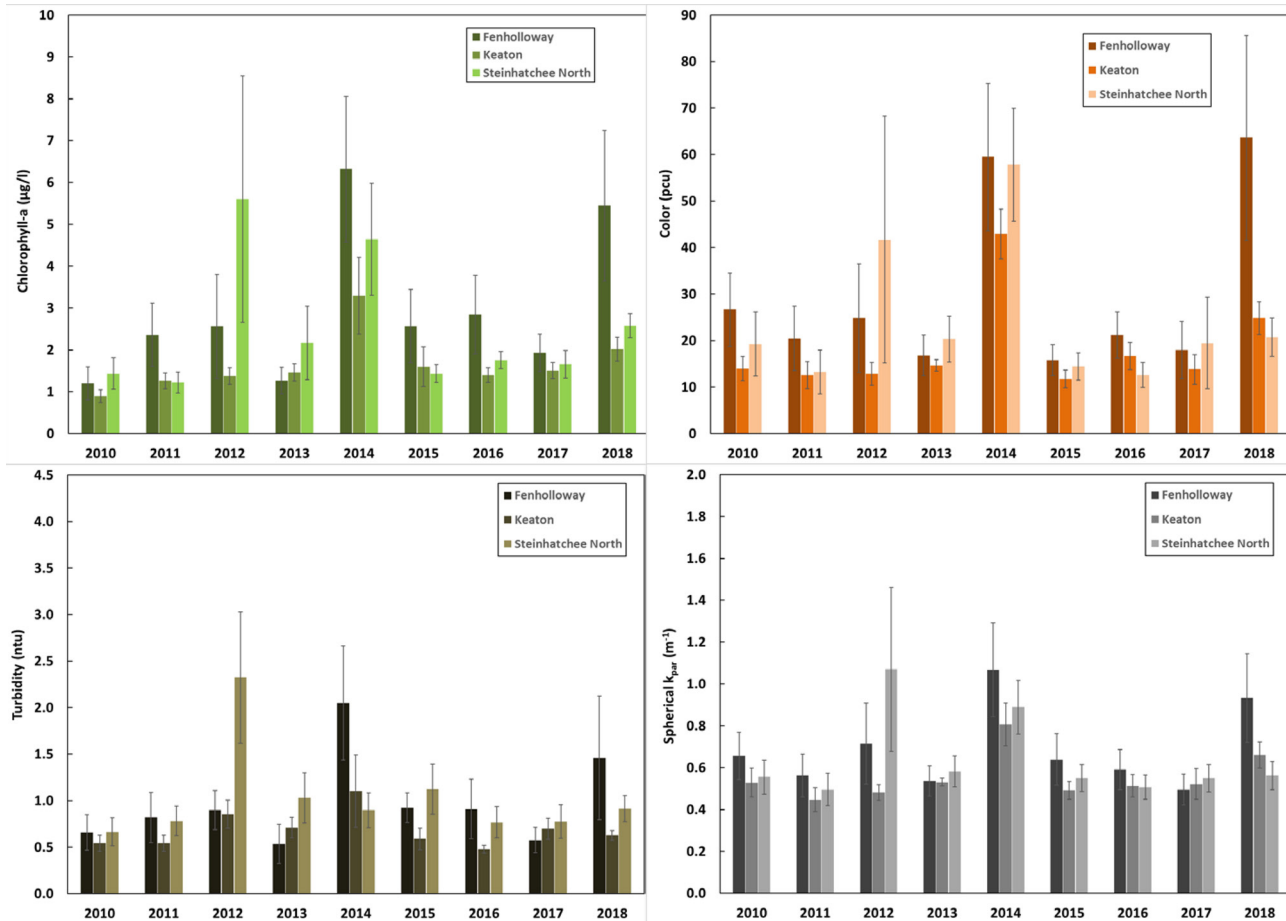


Figure 9. Means (± 2 standard error) of chlorophyll-a concentration, color, turbidity, and spherical k_{par} in Fenholloway, Keaton, and Steinhatchee North subregions of Northern Big Bend, 2010–2018.

- Alterations to natural hydrology.
- Decreasing river and spring flows in some locations.
- Increasing nitrogen concentrations in river and spring flows in some locations.
- Habitat fragmentation due to land development and road construction.
- Loss of natural oyster bars.
- Climate change and sea level rise.

Proposed management actions and projects are:

- Monitoring of water quantity and quality through data collection, and research.
- Water supply planning.
- Establishment and monitoring of minimum flows and levels of rivers and streams.
- Water resource development and aquifer recharge.
- Water conservation.
- Implementation of total maximum daily loads (TMDLs) and basin management action plans (BMAPs).
- Improvements in wastewater and stormwater infrastructure.
- Conservation and restoration of habitats.
- Management of recreation activities.

Mapping methods, data, and imagery

In December 2015, the Florida Department of Transportation (FDOT) acquired high-resolution (1-ft) digital aerial imagery of coastal waters to six miles offshore from Ochlockonee Bay south to the mouth of the Suwannee River. Images were collected using a Zeiss DMC camera under nearly perfect atmospheric, wind, and water-clarity conditions. Each image had at least 50% end lap and 25% side lap with other images. Photo-interpretation and mapping were completed by Quantum Spatial Inc. (St. Petersburg). Delineated polygons of benthic habitat were mapped using the Florida Land Use Cover

Classification System (FLUCCS; Florida Department of Transportation 1999), as modified by the Southwest Florida Water Management District (SWFWMD). Identified seagrass polygons were identified as continuous seagrass (FLUCCS 9116) or as patchy seagrass (FLUCCS 9113). Estimates of seagrass occurrence and density at 100 locations visited in summer 2015 were provided to the vendor as reference points for habitat interpretation. Benthic habitats, delineated as polygonal shapefiles, were delivered to FWRI in ArcGIS format using State Plane coordinates. The minimum mapping unit was 0.1 ha or approximately 0.25 acre.

In 2006, FDOT acquired digital aerial imagery of Big Bend seagrass beds taken with a Zeiss DMC digital camera. Digital three-band color imagery is available from Paul Carlson, FWRI, and from the Marine Resources Aerial Imagery Database (MRAID) website (<http://atoll.floridamarine.org/mraid/>). Benthic habitats were classified and mapped from 2006 imagery by Photoscience Inc. (St. Petersburg; contact Richard Eastlake). ArcMap shapefiles of benthic habitats based on the 2006 imagery are also distributed on the FWRI Marine Resources Geographic Information System (MRGIS) website.

In 2001, natural-color aerial photography of the Big Bend region was flown at 1:24,000 scale for the SRWMD by U.S. Imaging (Bartow, Florida). The location of the original negatives is not known, but copies are housed at SRWMD headquarters in Live Oak, Florida. Benthic habitats were classified and mapped from this dataset by Avineon Inc. using the FLUCCS (Florida Department of Transportation 1999). ArcMap shapefiles of benthic habitats are distributed on the FWRI MRGIS website (<http://ocean.floridamarine.org/mrgis/>).

To carry out change analysis between 2006 and 2015 mapping datasets, each set of data was saved as a polygon shapefile and projected into NAD 1983 UTM Zone 17N. Maps for each year were cropped to a common spatial extent and combined into a single polygon shapefile. This shapefile was made up of individual polygons with habitat descriptions for each year. A new field was created in the attribute table to show the change between 2006 and 2015. Numeric values were used to describe this change, where negative values represent a loss in seagrass cover, positive values represent an increase in seagrass cover, and zero represents no change.

		To:		
		Bare	Patchy	Continuous
From:	Bare	0	1	2
	Patchy	-1	0	1
	Continuous	-2		0

Monitoring methods and data

FWRI and the FDEP Big Bend Seagrasses Aquatic Preserve carry out annual field monitoring of seagrasses in the Northern Big Bend region using somewhat different methods. FWRI staff and collaborators conduct field monitoring of seagrass beds each summer, using a spatially-distributed randomly located network of sites located in water shallow enough to support seagrass (<4 m); this program began in 2002. Seagrass and macroalgal cover are estimated by species in ten 0.25-m² quadrats at 120–170 sites throughout the region (see Figure 2 for location of 2018 sites). Quadrat cover is assessed using a variation of the Braun-Blanquet method, in which cover is assessed to the nearest 10% for values ≥10% and to the nearest 1% for values <10%. OWQ measurements (light attenuation, Secchi depth, turbidity, color, TSS, and chlorophyll-a concentration) and field-condition measurements (depth, water temperature, salinity, pH, dissolved oxygen concentration) are made at each site as well.

Staff members at the FDEP Big Bend Seagrasses Aquatic Preserve also conduct field monitoring annually each summer at 25 sites in three areas: near the mouth of the Steinhatchee River, near Keaton Beach, and east of the mouth of the St. Marks River. All sites were located within seagrass beds when monitoring began. These locations correspond to the FWRI Steinhatchee North, Keaton, Aucilla, and St. Marks East subregions. The FDEP monitoring program in Steinhatchee began in 2000; in Keaton the program started in 2013; and near the mouth of the St. Marks River monitoring began in 2006, lapsed in 2012 and 2013 due to poor OWQ, and resumed in summer 2014. The cover of seagrass and macroalgal species in 1-m² quadrats is evaluated using the Braun-Blanquet method. At the same time, the presence and number of bay scallops and sea urchins in each quadrat are recorded, as well as the assessment of epiphyte density on seagrass blades and the bottom sediment type. Field-condition measurements (depth, water temperature, salinity, pH, dissolved oxygen concentration, turbidity) are recorded at each site as well. These data are available upon request from Timothy Jones at Big Bend Seagrasses Aquatic Preserve.

OWQ measurements

Measurements of optical water quality parameters—chlorophyll-a, color, turbidity, 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 the most important factor determining the survival of seagrass communities, and attenuation of light in the water column results from

reflection, diffraction, and absorption by water itself, from the quantity, quality, and size of particles in the water, and from the amount of color that has been added to the water column by colored dissolved organic matter (CDOM). The quantity and character of particles in the water are estimated by the measurement of chlorophyll-a as an indicator of phytoplankton abundance, 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 number 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 filters were extracted into 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 and then nearly filling each sample bottle with water from the site. Samples were kept on ice or refrigerated until analysis. To measure color, water samples were first 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-2910 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 *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 re-weighed using a five-place Mettler balance.

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