Summary Report for the Southern Big Bend Region

Contacts:

Paul R. Carlson Jr., Elizabeth Johnsey, and **Laura A. Yarbro**
Fish and Wildlife Research Institute
Florida Fish and Wildlife Conservation Commission

Timothy Jones and **Jamie Letendre**
Big Bend Seagrasses Aquatic Preserve
Florida Department of Environmental Protection

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EDITED BY LAURA A. YARBRO AND PAUL R. CARLSON JR.

Florida Fish and Wildlife Conservation Commission
Fish and Wildlife Research Institute
100 Eighth Avenue Southeast
St. Petersburg, Florida 33701
MyFWC.com

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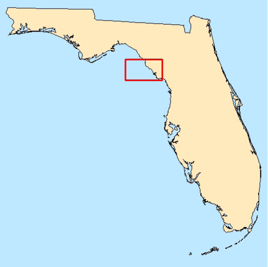

Contacts: Paul Carlson (mapping and monitoring), Elizabeth Johnsey (mapping), and Laura Yarbro (monitoring), Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission; Timothy Jones and Jamie Letendre, Big Bend Seagrasses Aquatic Preserve, Florida Department of Environmental Protection (monitoring)

General assessment

Seagrass acreage in the southern Big Bend region declined between 2006 and 2015 (Table 1), and historical change analyses indicate that losses began as long as 30 years ago. In 2015, seagrasses covered 48,299 acres, mostly as continuous beds (31,857 acres). Between 2006 and 2015, southern Big Bend lost 7,939 acres (16%) of seagrass. Continuous beds lost 12,319 acres, while patchy beds gained 4,380 acres. In 2015, 85% of the seagrass beds were in the Steinhatchee South and Horseshoe West subregions, and the Steinhatchee South subregion had lost the most seagrass (4,508 acres). In 2013 and 2014, field assessments determined that very little seagrass remained near the mouth of the Suwannee River. Improved water clarity conditions in 2015 resulted in an increase of 766 acres in the Suwannee subregion, most of which was shoalgrass (*Halodule wrightii*) located on an offshore shoal (Figure 1). Turtlegrass (*Thalassia testudinum*) is the most common seagrass species in the region, followed closely by manateegrass (*Syringodium filiforme*). Shoalgrass, stargrass (*Halophila engelmannii*), and widgeongrass (*Ruppia maritima*) occur at low frequencies. Seagrass density in beds has declined in the past 10 years throughout the region. Stressors include reduced optical water quality, which has resulted from elevated phytoplankton concentrations and increased water color in the region, as well as variable salinity over seagrass beds due to heavy rainfall events each year since 2012. Tropical storms Debby and Andrea in early summers of 2012 and 2013, respectively, and continuing heavy rains cause local rivers to discharge large volumes of darkly colored, nutrient-rich waters, reducing water clarity and dramatically increasing phytoplankton levels in the coastal region. Propeller scarring in seagrass beds is evident near and to the south of the mouth of the Steinhatchee River where it is extensive in some locations.

Geographic extent

The southern Big Bend extends from the mouth of the Suwannee River north to the mouth of the Steinhatchee River (Figure 1). Dark and light-green polygons in Figure 1 show, respectively, the extent of mapped continuous and patchy seagrass in 2015. Seagrass beds also extend a considerable distance into deeper water but have not been mapped and are not shown in Figure 1. This region is heavily influenced by discharge from the Suwannee River. Headwaters of the Suwannee River begin in the mountains of northern Georgia and in the Okefenokee Swamp in southern Georgia. The river drains 11,020 square miles, 4,150 square miles (38%) of which is in Florida. Average discharge at the gage at Wilcox, Florida, near the mouth, is 10,540 cubic feet per second, and discharge from the river is estimated to be 60% of the freshwater inflow for the entire Big Bend coastal area (Montague and Odum 1997). Peak water flow generally occurs in March and April. Land use in the Suwannee watershed is primarily silviculture (49%) and agriculture (29%). In Florida, 56% of the watershed is rangeland and forests, 10% is developed, and 17% is wetlands, located in the lower watershed (Suwannee River Water Management District 2017b). Extensive measurements since the 1980s show that nitrogen is increasing in river waters, while levels of phosphorus are stable or decreasing (Suwannee River Water Management District 2017a, b). More information about the Suwannee River and its watershed is available from the Suwannee River Basin Surface Water Improvement

1. General status of seagrasses in the Southern Big Bend Region

Status and stressors	Status	Trend	Assessment, causes
Seagrass acreage	🟥 Red	Loss	16% loss, 2006–2015
Seagrass density	🟥 Red	Thinning	Reduced water clarity
Water clarity	🟥 Red	Reduced	River runoff, phytoplankton blooms
Natural events	🟧 Orange	Significant impacts	Tropical cyclones, heavy rains
Propeller scarring	🟨 Yellow	Localized	Steinhatchee River mouth, Horseshoe Beach

Table 1A. Seagrass acreage in southern Big Bend, 2006, 2015.

Subregion	Continuous	Patchy	Total
	2006		
Steinhatchee S	16,786	3,081	19,867
Horseshoe W	24,177	3,167	27,344
Horseshoe E	3,021	4,973	7,994
Suwannee	192	840	1,032
Total	44,176	12,062	56,238
	2015		
Steinhatchee S	10,057	5,302	15,359
Horseshoe W	18,544	7,213	25,757
Horseshoe E	3,045	2,339	5,385
Suwannee	211	1,587	1,798
Total	31,857	16,442	48,299

Table 1B. Change in seagrass acreage, 2006–2015, and the percentage of seagrass acreage that was patchy in 2006 and 2015.

	Change, 2006–2015		% Patchy	
Subregion	Acres	%	2006	2015
Steinhatchee S	−4,508	−29%	16%	35%
Horseshoe W	−1,587	−6.2%	12%	28%
Horseshoe E	−2,609	−48%	62%	43%
Suwannee	766	43%	81%	88%
Total	−7,939	−16%	21%	34%

and Management (SWIM) Plan (Suwannee River Water Management District 2017b).

At the northern boundary of the region, the Steinhatchee River begins in Mallory Swamp in Lafayette County and runs 35 miles to its mouth. It drains 582 square miles of low-lying land and wetlands (U.S. Geological Survey Florida Water Science Center). Historically, the watershed was mostly wetlands, but by 2010, most of the area was tree plantations (Suwannee River Water Management District 2017a). Total nitrogen and total phosphorus concentrations have remained below the Numeric Nutrient Concentration (NNC) criteria of the Florida Administrative Code, except in 2004, when high levels of total nitrogen were measured after the tropical cyclones of that fall. The river and Bevins Creek, a tributary, are listed as impaired for bacteria by the Florida Department of Environmental Protection (FDEP). More information about the Steinhatchee River and its watershed is available from the Coastal Rivers Basin Surface Water Improvement and Management (SWIM) Plan (Suwannee River Water Management District 2017a).

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 the two rivers. The discharge of the Suwannee River usually flows north or northwest in spring and summer due to prevailing winds and currents. Waters in the coastal areas closest to the mouth of the Suwannee are often turbid, have high chlorophyll-a concentrations (indicative of phytoplankton), and are darkly colored; with distance from the mouth, these characteristics diminish. Water clarity improves, and acreage of seagrass increases along a gradient from south to north as a result.

For this report, the southern Big Bend is divided into four subregions (Figure 2). Steinhatchee South begins at the mouth of the Steinhatchee River and extends southeast to near the Pepperfish Keys. The Horseshoe West subregion begins near the Pepperfish Keys and covers the coastal area to the Horseshoe Channel near Horseshoe Beach. Horseshoe East begins at the Horseshoe Channel and extends southeast to Little Bird Island, about halfway between Horseshoe Channel and the mouth of the Suwannee River. The Suwannee subregion extends from Little Bird Island to the mouth of the south channel of the Suwannee River.

Mapping and monitoring recommendations

- Continue acquiring and mapping aerial imagery every five years.
- Continue the annual field monitoring program conducted by staff from the Fish and Wildlife Research Institute (FWRI) of the Fish and Wildlife Conservation Commission and the FDEP Big Bend Seagrasses Aquatic Preserve.
- Evaluate changes in the quantity and quality of runoff entering the region.
- Map and monitor seagrasses in water too deep for conventional aerial photography and field methods.

Management and restoration recommendations

- Monitor nutrient loads carried by the Suwannee River, and evaluate the effects of changing coastal optical water quality on the extent and location of seagrass beds.
- Assess the impacts on seagrasses of herbicides used to control hardwood species in pine plantations.

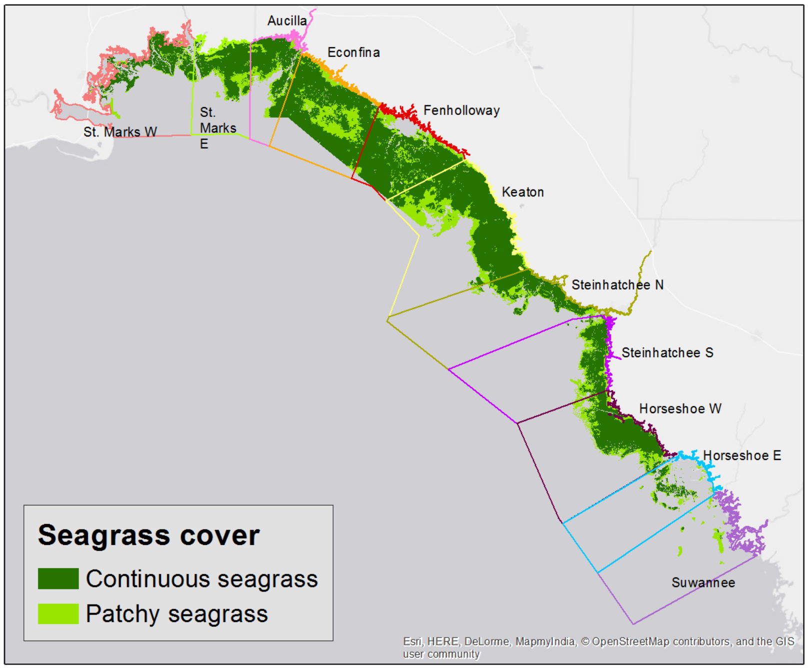

Figure 1. Seagrass acreage in Big Bend, 2015.

- Recommend and carry out nutrient management strategies outlined in the Suwannee River SWIM plan (Suwannee River Water Management District 2017b) for the Suwannee River and in the Coastal Rivers SWIM Plan (Suwannee River Water Management District 2017a) with the goal of reducing nutrient inputs to coastal seagrass ecosystems.
- Obtain data to model and predict coastal water circulation in the region, to better understand the timing and impacts of river runoff on seagrass beds.

Summary assessment

Seagrass acreage in the southern Big Bend declined significantly between 2006 and 2015. Mapping data from 1984 suggest that seagrass loss has been under way for more than 30 years. Conversion of continuous seagrass beds to patchy beds is also cause for concern. Stressors include elevated nutrients in runoff from the Suwannee River, which in turn stimulate phytoplankton growth, as well as increased water color and turbidity in coastal waters, originating in river discharge. These stressors reduce the light available to seagrass beds. Impacts of the Suwannee River plume extend as far as 40 km north and west of the river mouth and probably contribute to the observed decrease in seagrass acreage and species occurrence in southern Big Bend. Spatial changes in the distribution of seagrass species that are attributable to light stress have also been observed. Declines in the density of seagrass shoots in beds and reductions in the species diversity and distribution of seagrass and macroalgal species since 2007 indicate that environmental conditions, most likely water clarity, are deteriorating in the region. Extreme storm events in the winter of 2009–2010, tropical storms Debby and Andrea in June 2012 and 2013, respectively, and excessive rainfall since July 2013 increased the color and chlorophyll-a concentration in coastal waters in southern Big Bend for months after the weather events. Heavy propeller scarring is evident near the mouth of the Steinhatchee River.

Turtlegrass has been the most frequently occurring seagrass throughout the region, followed closely by manateegrass. But occurrence of manateegrass has declined since monitoring began in 2003 (see Table 2). The occurrence of bare sampling quadrats across the region has increased significantly since 2010. Subregions of the southern Big Bend vary widely in seagrass composition and the frequency of occurrence (FO) of each species (Figure 3). When field monitoring by FWRI began in 2003, seagrasses in the Suwannee subregion, closest to the mouth of the Suwannee River, included shoalgrass, manateegrass, and turtlegrass. Since 2010, shoalgrass has usually been the only seagrass species observed, and that

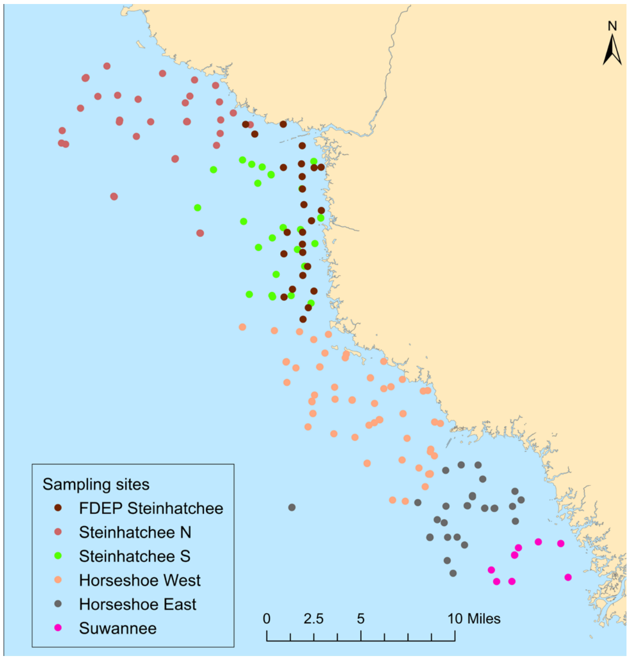

Figure 2. Location of sampling sites in the southern Big Bend visited by FWRI and FDEP in 2018.

at very low FOs. In the Horseshoe East subregion, turtlegrass is the most common seagrass, but manateegrass, shoalgrass, and stargrass are also present, at low levels. The FO of turtlegrass has declined since 2014, while the frequency of bare quadrats has increased significantly. In Horseshoe West, turtlegrass and manateegrass are the most common seagrasses, but the FO of manateegrass dropped 25% between 2013 and 2014 and has remained near 30% since then. In Steinhatchee South, turtlegrass occurs more than twice as frequently as manateegrass, but its FO has been stable since 2010. Shoalgrass and stargrass were infrequently observed in Horseshoe West and Steinhatchee South.

The general status of seagrasses (Status graphic 1) is poor in southern Big Bend and has not changed since the second edition of this chapter. Recent mapping efforts show that losses of seagrass beds have continued since 2006. Density of seagrass beds is declining, and water clarity remains low, reducing the light available to benthic habitats. A detailed assessment of seagrass status (Status graphic 2) also shows no changes in status and potential stressors.

Seagrass mapping assessment

Seagrass acreage in the southern Big Bend has declined since at least 2001, and earlier mapping efforts in 1984 indicate that losses have occurred for at least the past 30 years. Seagrasses covered 59,674 acres in 2001 (Yarbro et al. 2016) and 48,299 acres in 2015, a loss of 11,375 acres (19%) in 14 years. However, continuous seagrass acreage decreased 38% between 2001 and 2015, from 51,244 to 31,857 acres. Some of the bed fragmentation might have resulted from the 2004 and 2005 hurricanes and poor optical water quality beginning in 2013 and continuing to the present. Most (85%) of the region's seagrass beds occur in the Steinhatchee South and Horseshoe West subregions; the smallest area of beds (1,798 acres) are found near the mouth of the Suwannee River. However, the Suwannee subregion gained 766 acres of seagrass between 2006 and 2015. Between 2006 and 2015, most of the seagrass losses occurred in the Steinhatchee South subregion (4,508 acres; 35%), but the Horseshoe West and Horseshoe East subregions also lost substantial amounts of seagrass (4,197 acres). Extensive, but sparse, beds of paddlegrass (*Halophila decipiens*) offshore of the region are too deep to be mapped using conventional aerial photography. These beds probably serve as a corridor for grouper and other important fish and shellfish species as they migrate inshore and offshore.

Monitoring assessment

Two agencies, FWRI and the FDEP Big Bend Seagrasses Aquatic Preserve, carry out annual field monitoring of seagrasses using somewhat different methods. Since 2003, FWRI staff and collaborators have monitored seagrass beds each summer, using a spatially distributed randomly located network of sites located in water shallow enough to support seagrass growing on the bottom (Figure 2). 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 24 to 90 (Table 2), but since 2011, >80 sites (usually with 10 quadrats per site) have been evaluated each year. Staff from the Big Bend Seagrasses Aquatic Preserve monitor seagrasses once a year in the summer at 25 sites near the mouth of the Steinhatchee River (Figure 2); 22 of the FDEP sites are located south of the mouth of the Steinhatchee River and are part of the Steinhatchee South subregion.

2. Seagrass status and potential stressors in the Southern Big Bend Region

Status indicator	**Status**	**Trend**	**Assessment, causes**
Seagrass acreage	Red	Loss	16% loss, 2006–2015
Seagrass meadow texture	Red	Fragmenting, thinning	Reduced water clarity
Seagrass species composition	Orange	Sharp declines	Loss of shoalgrass, manateegrass, turtlegrass in southern areas
Overall seagrass trends	Red	Declining	Reduced water clarity
Seagrass stressor	**Intensity**	**Impact**	**Explanation**
Water clarity	Red	Reduced	River runoff, phytoplankton blooms
Nutrients	Orange	Likely increasing	Storm driven river runoff
Phytoplankton	Orange	Increasing	Storm driven river runoff
Natural events	Orange	Significant impacts	Tropical cyclones, heavy rains
Propeller scarring	Yellow	Localized	Steinhatchee River mouth, Horseshoe Beach

Table 2. Frequency of occurrence (FO; % of all quadrats) of seagrasses and the green alga *Caulerpa prolifera* **in the southern Big Bend region, 2003–2018.**

Year	# quadrats	Turtle-grass	Manatee-grass	Shoal-grass	Stargrass	Widgeon-grass	*C. prolifera*	Bare
2003	352	29.0	30.4	12.5	1.99		5.40	46.3
2004	248	43.1	40.3	12.1	2.02	3.23	3.63	31.9
2005	310	46.5	41.0	6.77	0.65		5.16	35.5
2006	175	38.3	33.1	2.29	1.14		7.43	47.4
2007	252	44.0	33.3	11.5	5.95		3.57	38.5
2008	600	41.5	34.7	6.33	7.00			43.5
2009	560	41.8	33.9	6.96	4.46	0.71	10.5	44.1
2010	715	43.6	28.3	3.50	6.57	1.12	4.90	46.3
2011	822	38.4	28.3	5.11	3.53		6.57	42.2
2012	884	45.4	28.8	6.22	7.47	2.94	6.56	36.8
2013	886	51.1	29.7	4.29		2.03	2.14	49.9
2014	898	40.5	18.2	1.89	0.78	1.22	8.80	46.1
2015	870	39.2	22.0	3.68	1.95	0.80	0.23	47.8
2016	875	40.1	20.3	6.86	5.26	1.49	0.23	50.5
2017	890	36.5	24.8	6.52	6.18	1.35	2.58	48.7
2018	900	38.0	26.0	7.44	2.11	0.78	2.33	51.2
	Mean	41.1	29.6	6.50	3.80	1.57	4.67	44.2
	Std. dev.	4.77	6.28	3.13	2.35	0.85	2.89	5.58

Since 2003, turtlegrass has been the most commonly observed seagrass species in the region, but manateegrass is abundant as well, with average FO about 75% of that of turtlegrass. These two species also frequently occurred in the same bed. The FO of turtlegrass in southern Big Bend has remained fairly stable over the past 10 years, but manateegrass has declined in FO during the same time. The FO of shoalgrass has varied between 2% and 12% since 2003, but in the last 10 years has averaged 5%. This loss is a serious concern because shoalgrass typically grows at the deep edge of seagrass beds and is subject to light stress when water clarity is reduced. The FOs of stargrass, widgeongrass, and the green macroalga *Caulerpa prolifera* are low and variable. Since 2003, the average occurrence of bare quadrats has ranged from 32% to 51%, increasing since 2014. Compared with data from the northern Big Bend region, all seagrasses and algae occurred less frequently in the southern Big Bend, and differences between regions were especially striking for shoalgrass, stargrass, widgeongrass, and drift red algae.

Species composition and the FO of seagrasses differ among subregions, with numbers of species and FO increasing with distance from the mouth of the Suwannee River (Figure 3). Since 2010, most quadrats in the Suwannee subregion were bare and fewer than 15% of quadrats contained shoalgrass. Manateegrass was observed only in 2011 and 2016. All quadrats were bare in 2010, and, in 2017, 87% of quadrats were bare and 13% were covered only with macroalgae. (Figure 3). The percentage of bare quadrats has increased since 2010 in both Horseshoe subregions, but the rate of increase has been four times greater in the Horseshoe West subregion. In the Steinhatchee South subregion, which is farthest from the mouth of the Suwannee, the percentage of bare quadrats has remained stable, between 40% and 50% since 2010. The occurrence of shoalgrass remained low throughout southern Big Bend, and in 2014 stargrass was observed only in Horseshoe East. Turtlegrass was the most common seagrass species in all subregions except Suwannee, and it occurred most frequently in Horseshoe West where it was present in 54% of all quadrats. Manateegrass was the second most common seagrass species everywhere but Suwannee, and it often occurred with turtlegrass. Widgeongrass occurred only in Horseshoe West and at very low levels (3%).

A closer look at the FO of seagrasses and bare quadrats in subregions in summer 2018 highlights the differ-

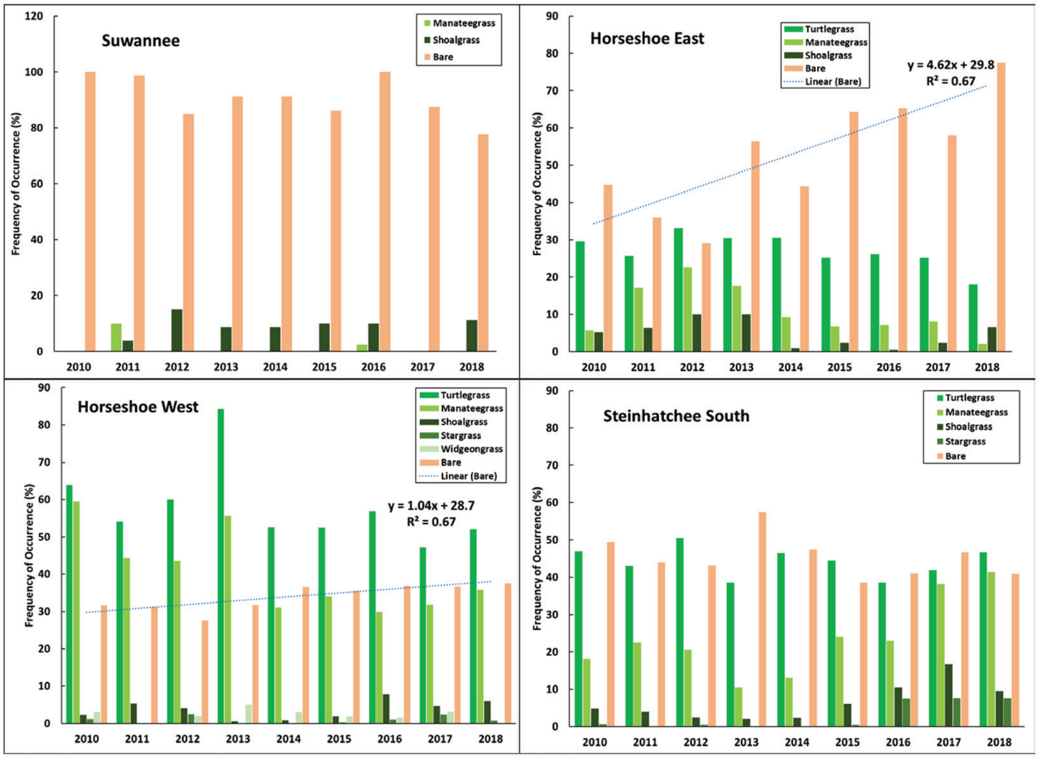

Figure 3. Frequency of occurrence (FO; %) of seagrass species and bare quadrats in subregions of southern Big Bend, 2010–2018. Trendlines show trends in the FO of bare quadrats along with slope, y-intercept, and R^2 of the linear regression.

ences among subregions and the increase in numbers of species and the FO of the species present with distance from the mouth of the Suwannee River (Figure 4). The percentage of bare quadrats was the same in Suwannee and Horseshoe East subregions, but turtlegrass, manateegrass, and shoalgrass were observed in Horseshoe East and only low frequencies of shoalgrass were found in Suwannee. The species present and the FO of those species were similar in Horseshoe West and Steinhatchee South in summer 2018. Shoalgrass and stargrass occurred more frequently in Steinhatchee South, and widgeongrass was observed only in Steinhatchee South at very low levels.

While frequency of occurrence is a measure of the spatial distribution and frequency of observing each seagrass species, quadrat cover (similar to the Braun-Blanquet method) adds an assessment of plant density at each site. We calculated means of cover using only those quadrats where a species was present. Mean cover of all seagrass species across southern Big Bend has decreased since 2011 (Figure 5). The decrease in cover of turtlegrass appears linear with an r^2 of 0.89. Mean cover of manateegrass and shoalgrass reached minima in 2014 and has recovered somewhat since that time. Mean percent cover of stargrass and widgeongrass was also low in 2014, but these species have rebounded to levels observed in 2011 and 2012. Both species have lower light requirements and faster colonization rates that do turtlegrass and manateegrass.

The monitoring program of the FDEP Big Bend Seagrasses Aquatic Preserve near the mouth of the Steinhatchee River began in 2000, but no data were collected in 2005 and 2012 (Figure 6). From 2000 through 2009, turtlegrass and manateegrass were about equally abundant, but beginning in 2010, the FO of turtlegrass was much greater and the FO of manateegrass decreased. The occurrence of shoalgrass dropped sharply after 2007 but has increased since 2014. Beginning in 2010, 3–16% of quadrats have been devoid of vegetation. Stargrass and widgeongrass have had low and sporadic occurrence. A variety of macroalgal genera and species have been observed in quadrats in the Steinhatchee area, consisting mostly of *Caulerpa* species and drift red algae.

Water quality and clarity

As part of the field monitoring program, FWRI staff routinely measure water temperature, salinity, Secchi depth, pH, dissolved oxygen concentration, and light attenuation with depth (k_{par}, using Li-cor sensors), and they collect water and seagrass samples for laboratory

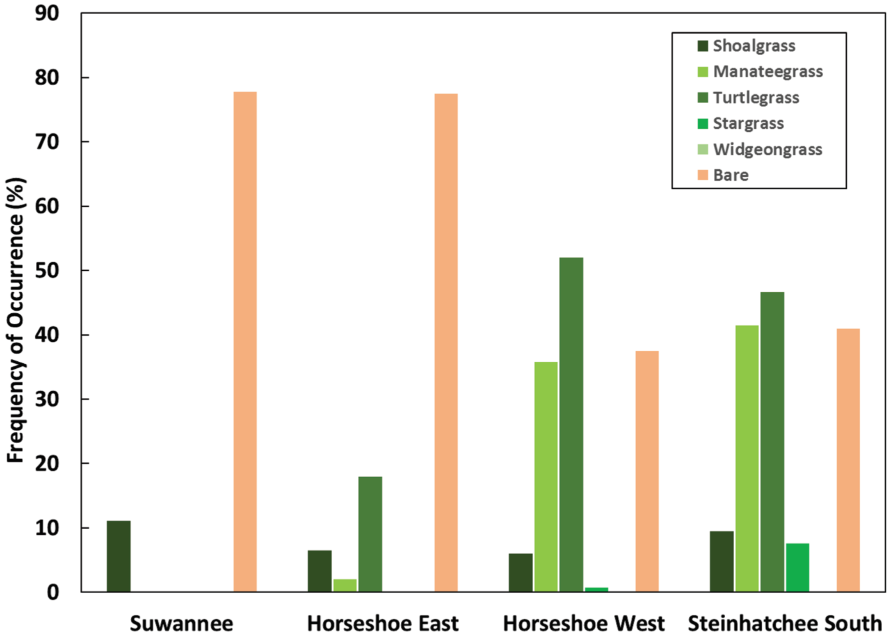

Figure 4. Frequency of occurrence (FO; % of all quadrats) of seagrasses and bare areas in the Southern Big Bend, 2018.

analyses. In the laboratory, we measure the optical water quality (OWQ) parameters chlorophyll-a, color, turbidity, and total suspended solids (TSS). Figure 7 shows means of these parameters for 2010–2018 for each subregion. Chlorophyll-a concentrations were frequently highest in the Suwannee subregion (chlorophyll-a was not measured in 2015), except in June 2018, and mean values among subregions decreased with distance from the mouth of the Suwannee River. Lowest chlorophyll-a values were measured in Steinhatchee South. Highest means were measured in 2014, during the period of high levels of freshwater runoff, and lowest values were calculated in 2011, a period of drought. Chlorophyll-a concentrations are an indicator of phytoplankton abundance, and the abundance of phytoplankton responds to available nutrients in the water column. Prevailing winds and resulting water circulation on the west Florida shelf drive the Suwannee River discharge north and west from spring through fall (Yang and Weisberg 1999; He and Weisberg 2003); as a result, water from the Suwannee River affects coastal ecosystems across large areas of the northeastern Gulf of Mexico. Tropical Storm Andrea affected the region in early June 2013, primarily by sharply increasing river runoff, and precipitation in July 2013 exceeded 20 inches at many locations in the Steinhatchee and Suwannee watersheds, causing exceptionally high runoff of very dark water. Water samples were collected twice in August 2013 during a visit to 14 sites in Horseshoe East and West; average chlorophyll-a concentrations had risen to a mean of 23 µg/l on August 10 and to a mean of 45 µg/l on August 24 (data not shown). Storminess and high runoff continued through the fall of 2013 and throughout most of 2014.

Mean color showed a strong response to the storminess and high runoff in 2013 and 2014: color was much greater in all subregions during that time and showed a trend of increasing values with proximity to the mouth of the Suwannee River. However, by June 2015, mean color values had dropped to levels like those observed in 2010. Mean color was also elevated in June 2018 and likely reflected the wet conditions in the early summer. Mean turbidity did not show the same patterns as seen in chlorophyll-a and color. Mean turbidities (and standard errors) were very high in the Suwannee subregion in June 2011 and 2012 and likely contributed to the high and variable k_{par} values measured at the same time. Generally, mean turbidity was lowest in Steinhatchee South and did not increase in 2013 and 2014 in the same manner as did chlorophyll-a and color. But higher mean turbidities were observed in 2017 when mean chlorophyll-a concentrations were also elevated. Turbidity is a measure of the number of particles in the water and the amount of light scattering by the particles. In 2017, phytoplankton likely caused greater light scattering than in 2013 and 2014.

Light attenuation with water depth, estimated by k_{par}, results from light absorption by water and by phytoplankton, other particles, and color in the water col-

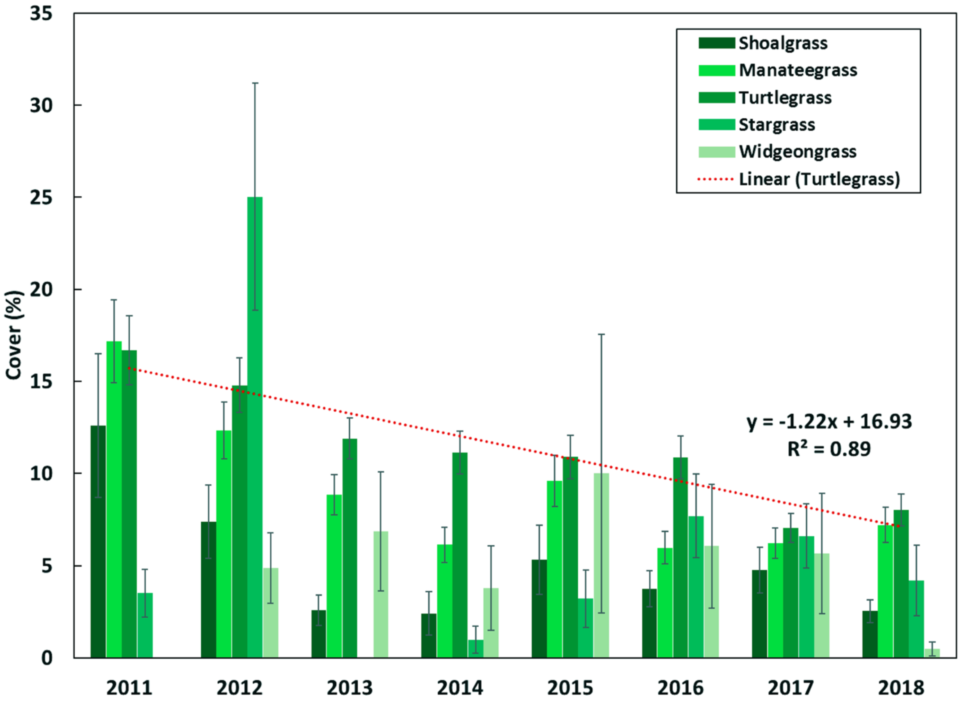

Figure 5. Mean quadrat cover (±2 standard error) of seagrass species in southern Big Bend, 2011–2018.

umn. The measurement of chlorophyll-a provides an estimate of the amount of phytoplankton, turbidity measures light scattering and absorption by all particles in the water, and the spectrophotometric measurement of color used by SIMM estimates the intensity of the yellow-brown color in the water. These measurements, along with the measurement of total suspended solids (TSS) provide estimates of OWQ. K_{par} is an integrated estimate of the contribution of the four OWQ parameters to light attenuation, but each parameter's contribution to k_{par} varies over time and with location. Generally, light attenuation in southern Big Bend was least in the Steinhatchee South subregion and was highest throughout the region in June 2013 and 2014. Large amounts of particles in the water in the Suwannee subregion elevated k_{par} in 2011 and 2012 (Figure 7). Mean k_{par} decreased across the region in 2015 and 2016 when storminess abated, but rose again in 2017, when mean chlorophyll-a and turbidity were elevated. Poor OWQ in southern Big Bend likely contributed to the continuing deterioration of seagrass habitat, as indicated by the low mean cover and occurrence values observed for seagrasses in 2014, and the lack of full recovery since that time.

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. 2014). The VBS project was funded by the National Aeronautics and Space Administration (NASA), resulted from the collaboration of staff from USF OOL, FWRI, and FDEP, and uses seagrass and OWQ data from the FWRI monitoring program to interpret and validate daily data from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery. VBS has a user-friendly web interface that shows, in near real time, optical water quality 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 download links for 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. (2014).

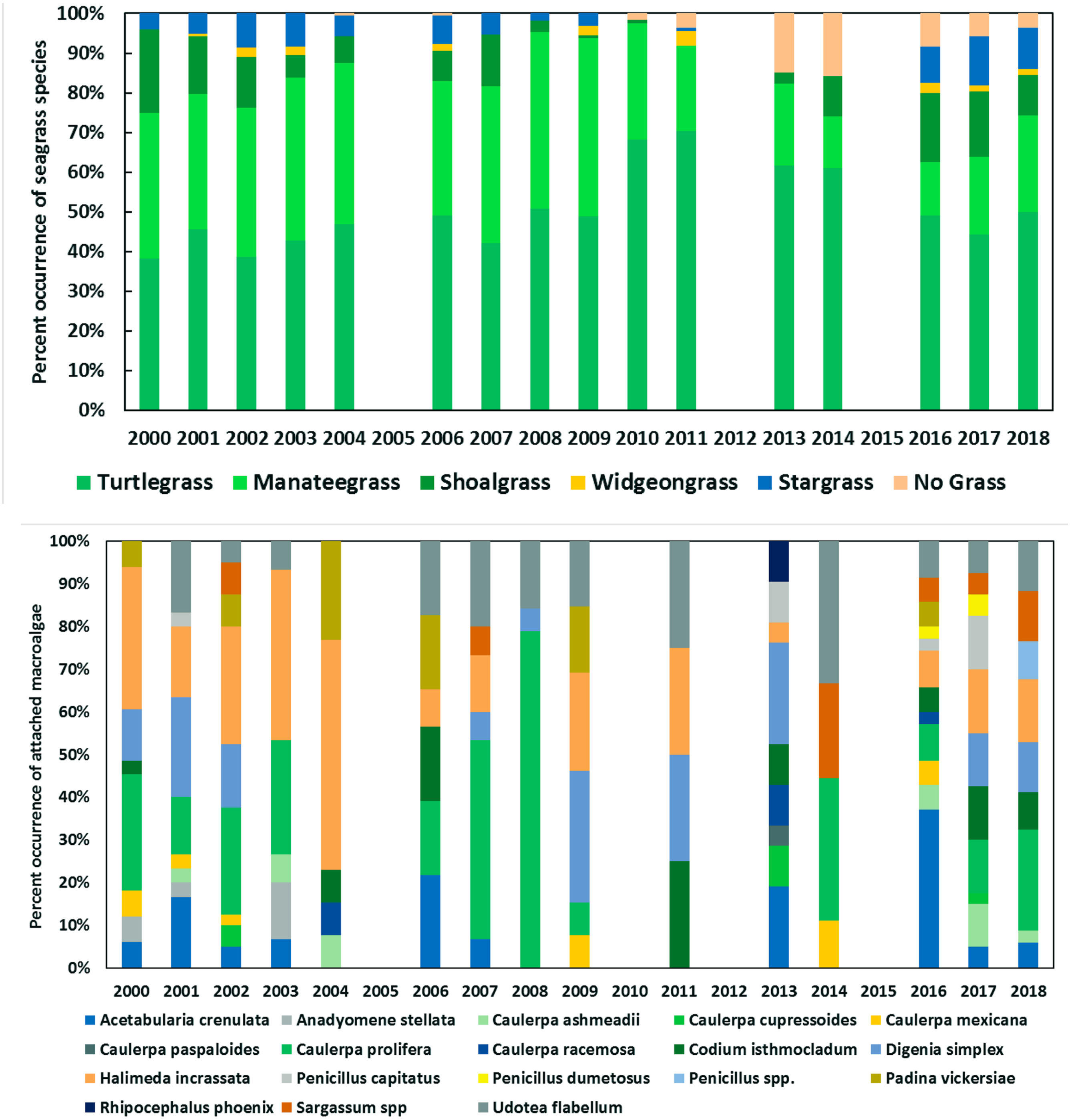

Figure 6. Frequency of occurrence (%) of seagrasses and macroalgae at the FDEP monitoring sites in Steinhatchee, 2000–2018.

Watershed management

The Suwannee River Water Management District (SRWMD) manages the watersheds and rivers in the southern Big Bend region. In 2017, with funding from the National Fish and Wildlife Federation through the Gulf Environmental Benefit Fund, the SRWMD updated the Surface Water Improvement and Management (SWIM) plans for the Suwannee River and watershed and for the watersheds of coastal rivers draining the region (Suwannee River Water Management District 2017a, b). In the Coastal Rivers SWIM plan (SRWMD 2017a) for the watersheds of the coastal rivers of the Big Bend, including the Steinhatchee River, the SRWMD identified issues and concerns in these watersheds. The SRWMD outlined management actions and projects designed to protect or restore water quality,

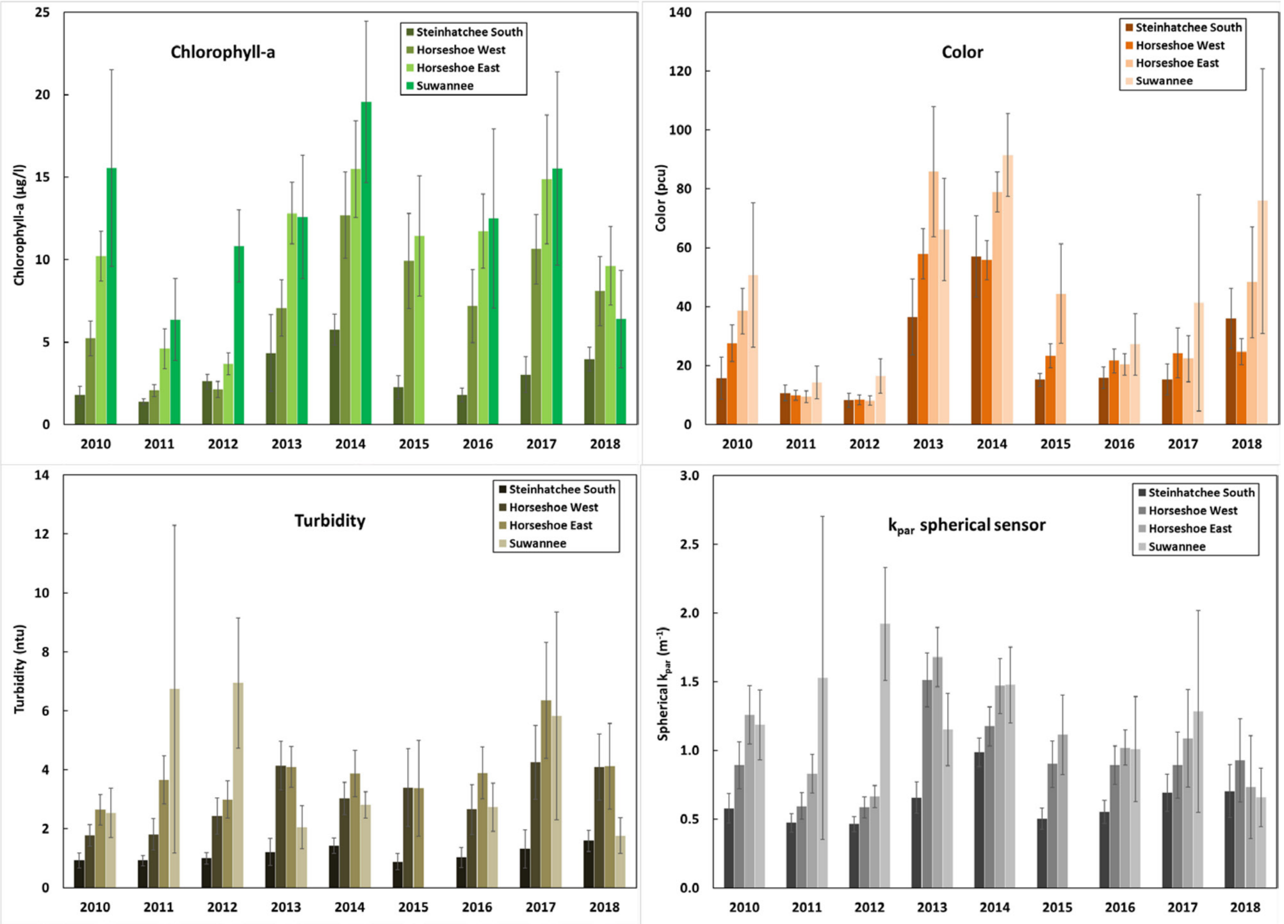

Figure 7. Means (±2 standard error) of chlorophyll-a, color, turbidity, and k_{par} in subregions of the Southern Big Bend, 2010–2018.

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.
- 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; related research.
- Water supply planning.
- Establishing minimum flows and levels; pertinent monitoring.
- Water resource development and aquifer recharge.
- Water conservation.
- Implementing total maximum daily loads (TMDLs) and basin management action plans (BMAPs).
- Improvements in wastewater and stormwater infrastructure.
- Conserving and restoring habitats.
- Management of recreational activities.

The watershed of the Suwannee River is 17 times greater in area than the watershed of the Steinhatchee River and has more land uses and challenges. In the 2017 SWIM plan, the SRWMD describes the issues, trends, and management recommendations for the Suwannee watershed where increasing demands for water use and pollutant loading, due to more intensive land uses, need to be balanced with maintaining regional environmental quality and natural systems (Suwannee River Water Management District 2017b). Recommended management actions regarding water quantity include:

- Monitoring and data collection.
- Planning for water supply.
- Reassessing adopted minimum flows and levels.
- Developing water resources and actions to recharge aquifers.
- Improving water conservation by the public and farmers.

Management actions for improving water quality include:

- Monitoring and research on water quality of springs and streams.
- Implementing Basin Management Action Plans (BMAPs) and Best Management Practices (BMPs).
- Upgrading wastewater and stormwater infrastructure.

Recommendations for improving or maintaining natural systems include:

- Continuing and expanding monitoring and mapping of natural systems.
- Monitoring and restoring animal and plant populations and their habitats, such as fish, manatees, Gulf sturgeon, the salt marsh vole, the long-leaf pine, organisms living in aquatic caves and springs, and oysters.
- Monitoring and evaluating the effects on organisms and habitats of BMAPs and BMPs, changing land uses, invasive species, sea level rise, fishing-gear use and harvesting rules, and minimum flows and levels.
- Identifying and acquiring lands for acquisition for preservation and management.
- Monitoring the effects on habitats and species of recreational tubing.

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 up 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). In-water estimates of seagrass occurrence and density for 100 locations collected 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 (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 Suwannee River Water Management District (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 data set by Avineon Inc. (St. Petersburg, Florida), using the FLUCCS (Florida Department of Transportation 1999). ArcMap shapefiles of benthic habitats are distributed on the FWRI Marine Resources Geographic Information System (MRGIS) website (http://ocean.floridamarine.org/mrgis/).

To carry out change analysis of seagrass acreage between 2006 and 2015, each set of mapping data was saved as a polygon shapefile and projected into NAD 1983 UTM Zone 17N. Maps for each set were cropped to a common spatial extent and combined into a single polygon shapefile. The resulting 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	−1	0

Monitoring methods and data

FWRI and the FDEP Big Bend Seagrasses Aquatic Preserve carry out annual field monitoring of seagrasses in the southern Big Bend region using somewhat different methods. FWRI staff conduct field monitoring of seagrass beds each summer, using a spatially distributed randomly located network of sites located in water shallow enough to support the growth of seagrass on the bottom; the program began in 2002. Seagrass and macroalgal cover are estimated by species in ten 0.25 m^2 quadrats at about 90 sites in 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, turbidity, color, TSS, and chlorophyll-a concentration) and field-condition measurements (depth, Secchi depth, water temperature, salinity, pH, dissolved oxygen concentration) are made at each site as well.

Staff of the FDEP Big Bend Seagrasses Aquatic Preserve also conduct field monitoring annually in summer at 25 sites near the mouth of the Steinhatchee River. All sites were in seagrass beds when monitoring began in 2000. Most (22) of the FDEP sites are in the Steinhatchee South subregion. The cover of seagrass and macroalgal species in 1-m^2 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 sediment type and an assessment of epiphyte density on seagrass blades. Field-condition measurements (depth, water temperature, salinity, pH, dissolved oxygen concentration, turbidity) are also recorded at each site. These data are available upon request.

Optical water quality measurements

Measurements of OWQ 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, the quantity, quality, and size of particles in the water, and 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 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 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-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 dried at 50°C for at least five days and re-weighed using a 5-place Mettler balance.

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Contacts

Mapping:

Elizabeth Johnsey and Paul R. Carlson Jr., Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, 727-896-8626, elizabeth.johnsey@myfwc.com; paul.carlson@myfwc.com.

Monitoring:

Laura Yarbro, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, 727-896-8626, laura.yarbro@myfwc.com.

Timothy Jones and Jamie Letendre, Florida Department of Environmental Protection, Big Bend Seagrasses Aquatic Preserve, 352-563-0450, Timothy.W.Jones@dep.state.fl.us, Jamie.letendre@dep.state.fl.us.

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