# Summary Report for the Southern Indian River Lagoon

Contacts:

**Amanda Kahn,** South Florida Water Management District

in

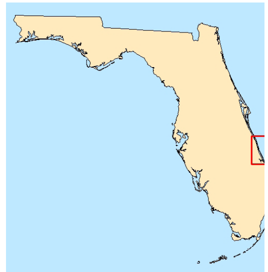
Seagrass Integrated Mapping and Monitoring Program
Mapping and Monitoring Report No. 3

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

Technical Report 17, Version 3 • 2018
DOI10.13140/RG.2.2.12366.05445

## Summary Report for the Southern Indian River Lagoon



**Contact:** Amanda Kahn, South Florida Water Management District.

## General assessment

In 2017, seagrasses covered 7,606 acres of the bottom of the Southern Indian River Lagoon (SIRL), 2,688 acres (26%) less than the 10,294 acres mapped using imagery acquired in 2015 (see Figure 2). More than 1,000 acres disappeared from the portion of the lagoon just south of the Fort Pierce Inlet (segment IR23). Weather extremes of high temperatures and precipitation, beginning in the fall of 2015 and extending through 2016, and physical impacts from Hurricane Michael in 2016 likely contributed to these seagrass losses. Species diversity of seagrass beds also declined during 2015–2017, with losses in the occurrence of manateegrass (*Syringodium filiforme*) and turtlegrass (*Thalassia testudinum*). These two canopy-forming species have been co-dominant in areas near inlets or farthest from estuary headwaters due to their preference for moderate to oceanic salinities. The diminutive paddlegrass (*Halophila decipiens*) is also found in the lagoon and shows the same salinity preference as manateegrass and turtlegrass (Dawes et al. 1989, Lirman and Cropper 2003). The other short-bladed species, Johnson's seagrass (*Halophila johnsonii*), tolerates a broader range of salinity (Kahn et al. 2013) and is dominant, along with shoalgrass (*Halodule wrightii*), in areas more strongly affected by tide-induced salinity variation where there is freshwater inflow. These two species also grow in shallow areas, as Johnson's seagrass has a high desiccation tolerance if exposed at low tides (Kahn and Durako 2009).

## Geographic extent

The Southern Indian River Lagoon (SIRL), located in the South Florida Water Management District (SFWMD), extends from the northern boundary of St. Lucie County 37 km (~23 miles) south through Martin County to the northern portion of Palm Beach County (Figure 1). The SIRL receives tidal flow from three inlets: Fort Pierce Inlet in the north, St. Lucie Inlet in the central region, and Jupiter Inlet at the southern boundary. Seagrass habitat in this region also includes a lower portion of the St. Lucie River Estuary and the Loxahatchee River Estuary. Based on shared hydrodynamics and water quality characteristics, for management assessment the region is divided into five segments, numbered IR22–IR26 (Steward et al. 2003).

The size and character of the watersheds draining into the SIRL were greatly modified during the early to middle 20th century. Creation of canals draining water eastward into the lagoon increased the watershed area and hastened the delivery of runoff to the estuary. The

| General status of seagrasses in the Southern Indian River Lagoon | | | |
|---|---|---|---|
| **Indicators and stressors** | **Status** | **Trend** | **Assessment, causes** |
| Seagrass acreage | Orange | After a 22% recovery from 2013 to 2015, a 26% loss from 2015 to 2017 | Unprecedented wet dry season of 2016. Prolonged periods of reduced salinity and increased CDOM reduced light; physical impacts from Hurricane Matthew in 2016 |
| Seagrass species composition | Orange | Reduced diversity from 2015 to 2017 | Losses in *Syringodium filiforme, Thalassia testudinum* |
| Seagrass cover | **Red** | Losses | Many beds lost completely; cover reduced at all sites that still had seagrass |
| Water clarity and light attenuation effects | Orange | | Surges in watershed runoff and freshwater inflow from record rainfall decreased light availability. Light attenuation due to prolonged periods of increased CDOM and periods of increased turbidity after stochastic storm events |
| Salinity effects | Yellow | | Surges in watershed runoff and freshwater inflow from record rainfall during a dry season; stochastic storm events caused episodic periods of low salinity. Recovery to usual estuarine salinity gradient took several weeks poststorm. |

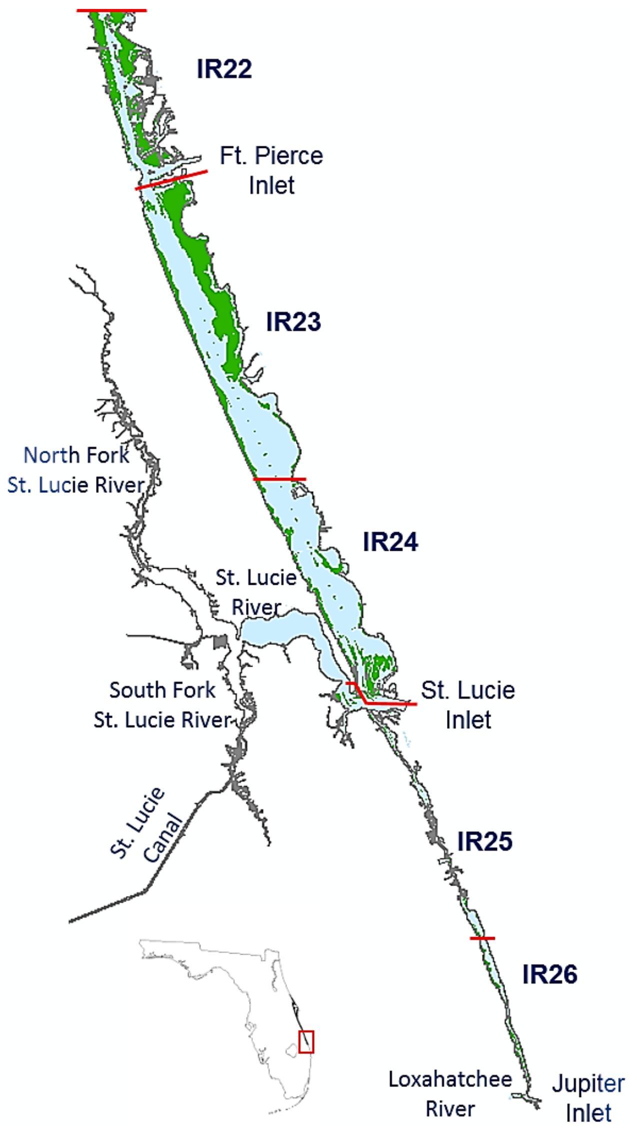



**Figure 1.** The Southern Indian River Lagoon (SIRL) system, extending from St. Lucie County in the north to the northern part of Palm Beach County in the south, divided into five segments. Seagrass mapped from 2015 imagery is depicted in green.

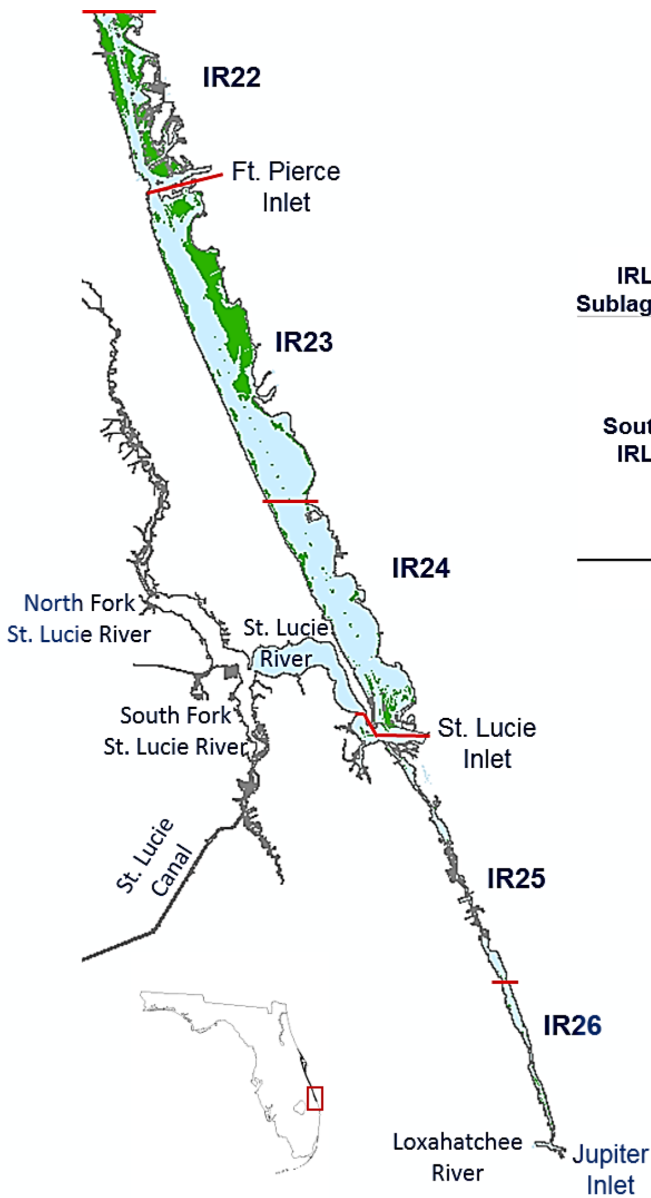
Fort Pierce Inlet was first dredged in 1920–1921, and the St. Lucie Inlet was deepened by dredging in 1892. Both inlets are still maintained. The region developed quickly, and much of the coastal area became densely populated. Resulting nutrient inputs degraded the ecosystems of the Indian River, leading to the passage of the Indian River Lagoon Act by the Florida Legislature in 1990. The act required diversion of treated sewage waste from the lagoon, but regional waters still receive nutrient inputs from more than 60,000 septic systems (Barile 2018). As of 2012, approximately 1.8 million people lived in the three counties bordering the SIRL.

## Assessment

From 2011 to 2015, seagrass acreage in the SIRL recovered from the 2009–2011 loss of ~2,000 acres, with a gain of 2,887 acres (Figure 2). This aerial extent was almost the same as that observed in 1943, although the acreage in the 2015 survey (compared to 1943) was greater in the northern segments (IR22, IR23) than in the central (IR24) and southern (IR25, IR26) segments (Figure 2). This suggests that some factors are compromising the resilience of the seagrass community in the central and southern segments but are not problematic in the northern segments. Recovery of seagrass acreage from 2011 to 2015 was not long-term, with a 2,688-acre loss observed from 2015 to 2017 (Figure 3). Seagrass decline was also observed in the data from monitoring transects, with a decline from 2015 to 2017 in mean transect length, from shore to edge of the seagrass bed, and percent cover of seagrass (Figure 4). To clarify the dynamics of this loss in seagrass along the SIRL, we further examine each segment individually.

The northernmost segment, IR22, which extends from the line between Indian River and St. Lucie counties to the Fort Pierce Inlet, lost the smallest fraction (13%; 372 acres) of seagrass between 2015 and 2017 (Figure 2). This segment has also exhibited the most stable acreage over the period of aerial survey records. The footprint of the seagrass canopy in segment IR23, which extends from the Fort Pierce Inlet south to Nettles Island, decreased 21% since 2015, with a loss of 1,035 acres (Figure 2). Much of this loss was along the western shoreline and off the northwest shore of Hutchinson Island (Figure 5). Segment IR24 extends from Nettles Island to the St. Lucie Inlet, where seagrass beds decreased by 50% from 2015 to 2017 with a loss of 878 acres (Figure 2). Much of this loss was observed along the western shore, but also in a central patch southeast of the Jensen Beach Causeway and in several patches north of the St. Lucie Inlet (Figure 6). Segment IR25 has had the greatest losses since the 1943 coverage, and it also had the greatest percentage loss from 2015 to 2017, 82% (231 acres). This segment extends from St. Lucie Inlet to Hobe Sound, and the footprint in 2017 was down to 50 acres from 281 acres in 2015 (Figure 2), with extensive seagrass loss throughout the segment (Figure 7). The southernmost segment, IR26, continues from Hobe Sound to Jupiter Sound and Jupiter Inlet; seagrass acreage decreased 45% from 2015 to 2017, from 379 to 207 acres (Figure 2), most of which was along the western shoreline (Figure 8).

For most of the SIRL, salinity conditions have been stable over the long-term, with water circulation and height driven by semi-diurnal tides. Salinity ranges differ with distance from openings to the ocean and weather




Mapping years

| IRL Sublagoon | IRL Segment | 1943 | 1992 | 1994 | 1996 | 1999 | 2003 | 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| South IRL | IR22 | 2,144 | 2,310 | 2,300 | 2,649 | 2,977 | 2,910 | 2,806 | 2,878 | 2,875 | 2,506 | 2,772 | 2,859 | 2,487 |
| | IR23 | 3,546 | 4,273 | 5,004 | 5,187 | 2,856 | 3,238 | 3,335 | 4,081 | 4,349 | 2,646 | 2,926 | 5,039 | 4,004 |
| | IR24 | 3,822 | 1,521 | 1,567 | 1,589 | 1,520 | 1,342 | 1,189 | 1,299 | 1,640 | 1,623 | 1,675 | 1,736 | 858 |
| | IR25 | 625 | 406 | 277 | 136 | 134 | 167 | 156 | 172 | 167 | 195 | 283 | 281 | 50 |
| | IR26 | 683 | 365 | 341 | 303 | 320 | 336 | 334 | 330 | 322 | 437 | 417 | 379 | 207 |
| | TOTAL | 10,820 | 8,875 | 9,488 | 9,864 | 7,807 | 7,993 | 7,820 | 8,760 | 9,353 | 7,407 | 8,073 | 10,294 | 7,606 |

**Figure 2.** Acres of seagrass mapped in segments of the Southern Indian River Lagoon. Seagrass mapped in 2017 imagery is depicted in green.

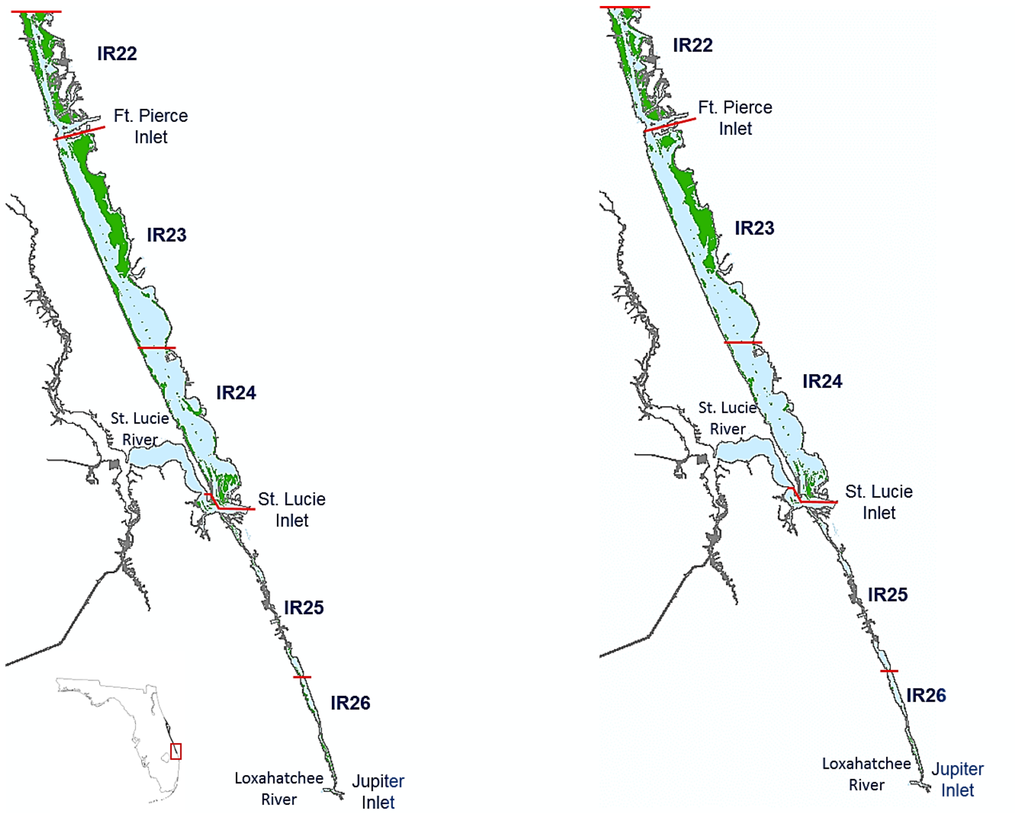



**Figure 3.** Maps of seagrass in the Southern Indian River Lagoon, illustrating changes in the footprint of the canopy from 10,294 total acres in 2015 (left) to 7,606 total acres in 2017 (right).

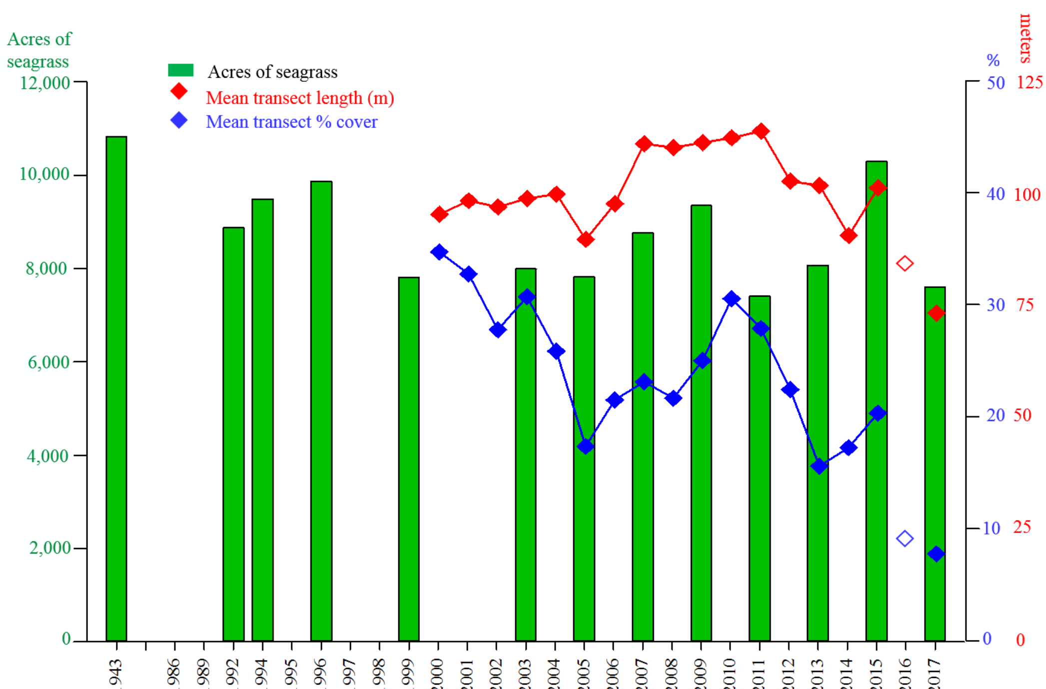



**Figure 4.** Acres of seagrass (left axis), mean transect lengths (red right axis), and mean percent cover (blue right axis) for the Southern Indian River Lagoon. Not all sites were sampled in 2016, and data are represented by open diamonds, as they are not representative of a complete data set for the year.


**Figure 5.** Maps of seagrass in segment IR23 in 2015 (left) and 2017 (right).

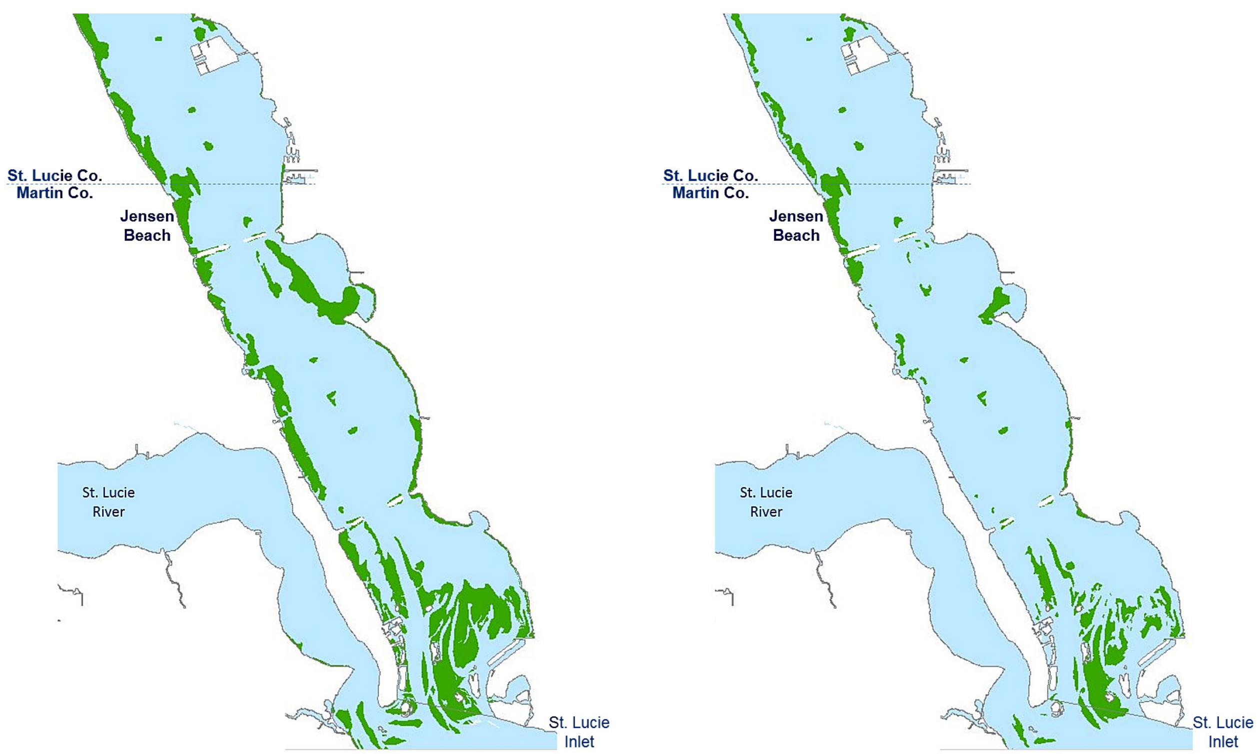



**Figure 6.** Maps of seagrass in segment IR24 in 2015 (left) and 2017 (right).

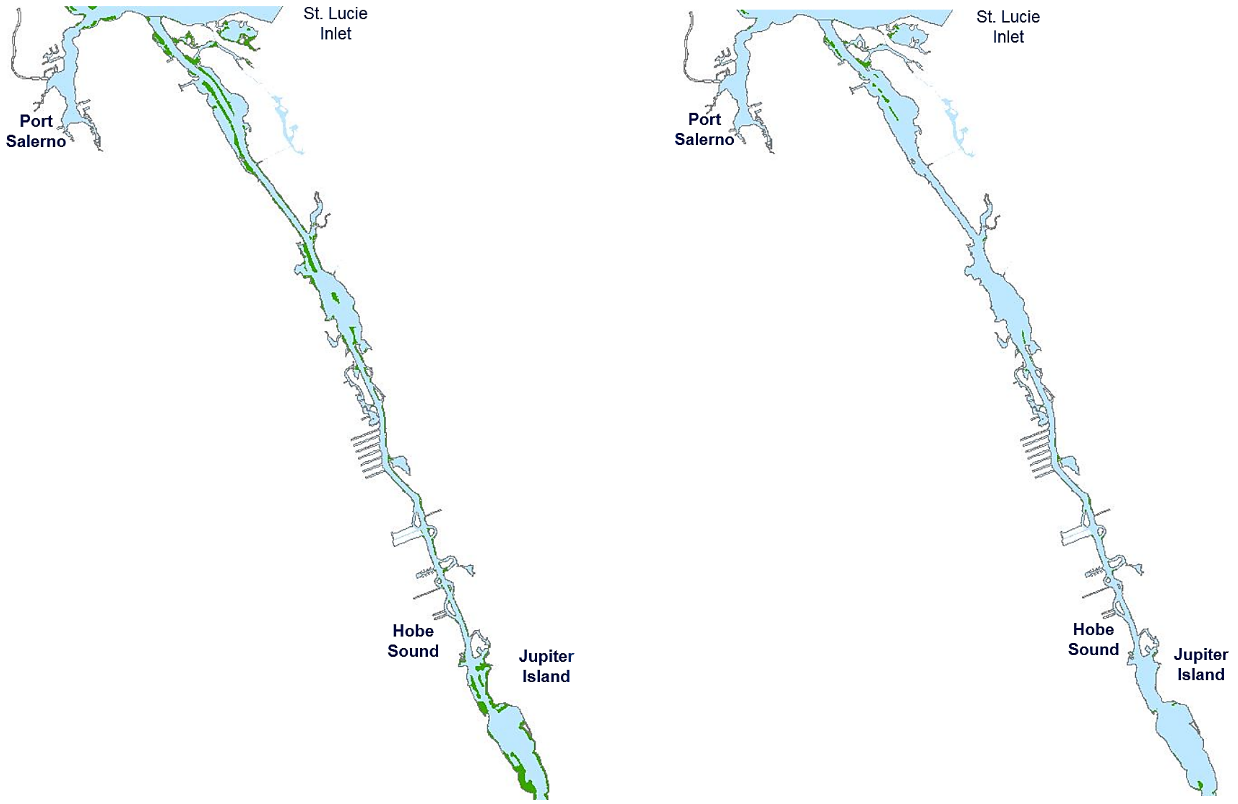



**Figure 7.** Maps of seagrass in segment IR25 in 2015 (left) and 2017 (right).

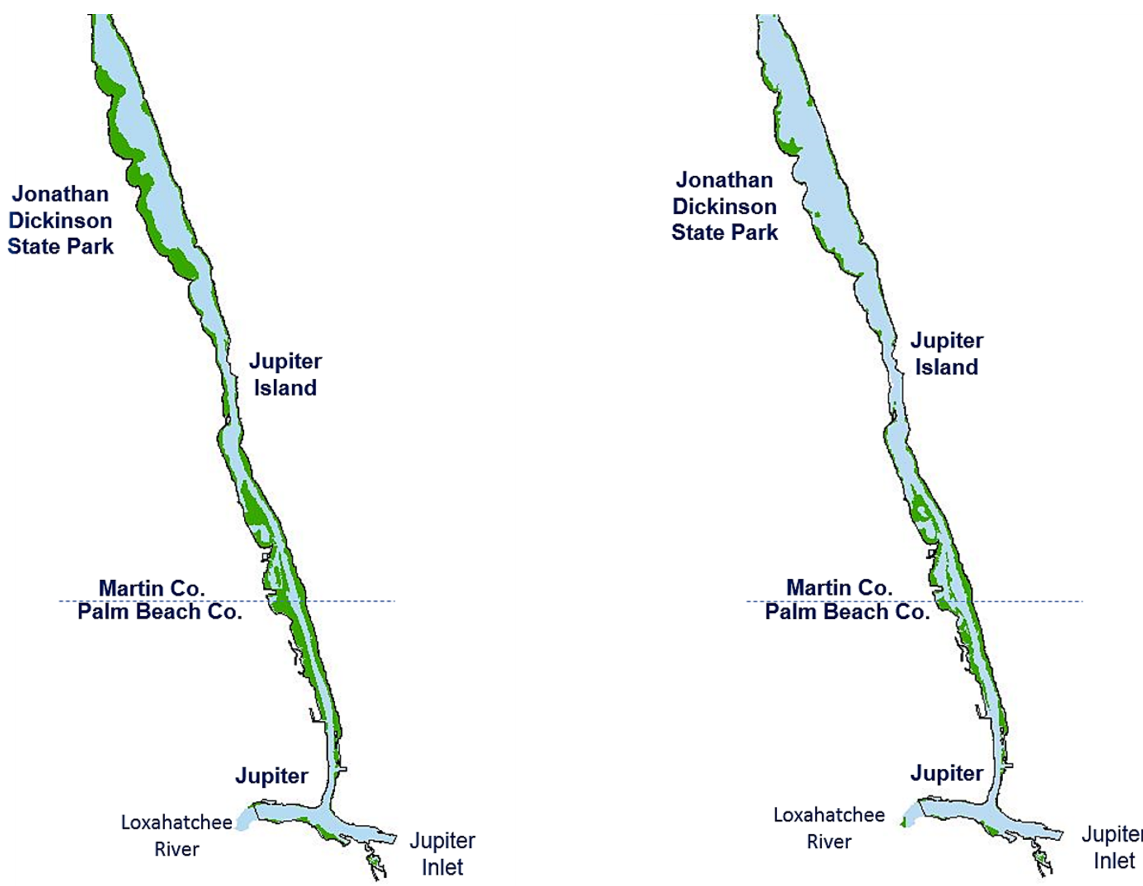



**Figure 8.** Maps of seagrass in segment IR26 in 2015 (left) and 2017 (right).

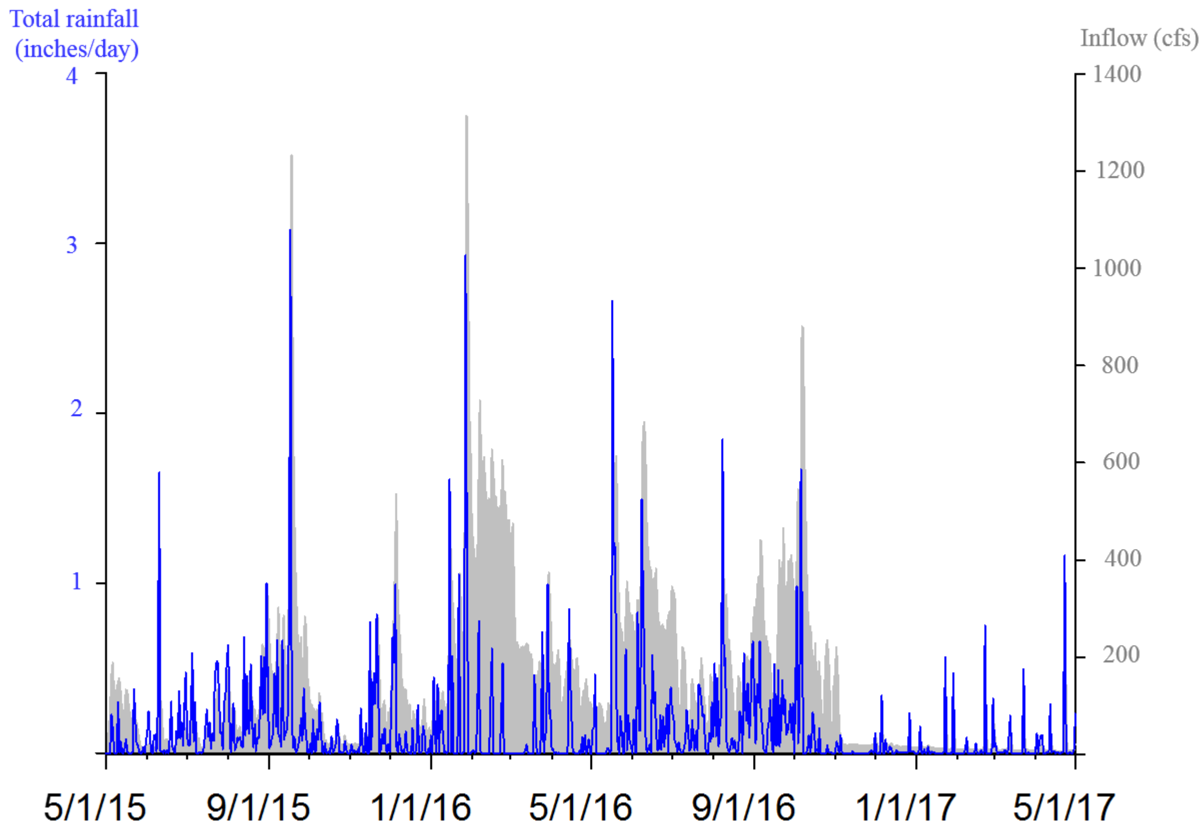



**Figure 9.** Total rainfall for the St. Lucie River basin (blue, left axis, inches per day) and total water inflow (gray, right axis, cubic feet per second) to the St. Lucie Estuary, May 2015–May 2017.

variability such as drought and storm events. The St. Lucie Estuary (in segment IR24) receives pulses of freshwater from the St. Lucie Canal, which empties into the South Fork of the St. Lucie River. The estuary adjacent to Taylor Creek, west of the Fort Pierce inlet (in segment IR22), also receives freshwater discharge from canals draining into the creek. Leading up to the decline in seagrasses in 2017 were several weather extremes. The National Oceanic and Atmospheric Administration's Oceanic Niño Index defined conditions from late 2015 into 2016 as one of the strongest El Niños ever recorded (https://www.climate.gov/enso). Florida had record high temperatures in 2015, and after the aerial imagery was acquired in spring 2015, the region experienced an abnormally hot autumn, with a large rain event in September. (https://www.ncdc.noaa.gov/sotc/national/201511). The wet season (May 1–October 31, 2015) was followed by an abnormally wet dry season (November 1, 2015–April 30, 2016), with a record-breaking rain event in January 2016 (Figure 9, Armstrong et al. 2019). Discrete sampling of water quality by SFWMD was suspended at stations located near seagrass monitoring transects from November 2015 through July 2016. Data were available, however, from measurements of salinity and colored dissolved organic matter (CDOM) made by land/ocean biogeochemical observatory (LOBO) units (http://fau.loboviz.com/) deployed at several locations in the northern and central sections of the SIRL by the Indian River Lagoon Observatory operated by Florida Atlantic University's Harbor Branch Oceanographic Institute. Salinity and CDOM during this period of abnormally high rainfall in the beginning of 2016 were examined at the stations IRL-Fort Pierce, IRL-Jensen Beach, and IRL-St. Lucie Estuary (http://fau.loboviz.com/loboviz/). Salinity was far below average for several weeks, coincident with a prolonged period of high CDOM that reduced light available to the bottom. In addition to precipitation and runoff, high volumes of freshwater were released from the St. Lucie Canal into the St. Lucie Estuary, extending the period of reduced salinity (Stockley et al. 2018). Canal discharges continued from May through June 2016, during which time a cyanobacterial bloom occurred in Lake Okeechobee. By July, a severe cyanobacterial bloom persisted for several weeks in the upper St. Lucie Estuary and tributary canals and in the South Fork of the St. Lucie River. While concentrations of cyanobacterial pigments were highest in the brackish areas of the estuary, Kramer et al. (2018) observed lower concentrations where salinities were higher, near the St. Lucie Inlet and at the southernmost point of the St. Lucie River Estuary (the border between segments IR24 and IR25). Concentrations of cyanobacterial pigment were not high in the SIRL itself, and cyanobacterial blooms were limited to areas near the St. Lucie River Estuary. Declining seagrass conditions from 2015 to 2017 were likely due to chronic concurrent salinity reductions and light limitation, mostly due to increased CDOM and acute periods of high turbidity.

The loss of seagrass along the western shore of the lagoon in 2017 may indicate physical impacts by Hurricane Matthew, which passed by in October 2016. Seagrass may have been lost by burial or erosion (Fourqurean and Rutten 2004). Though studies in the Indian River Lagoon showed that hurricane impacts to seagrass were minimal after the storms of 2004 (Steward et al. 2006), the authors noted that chronic exposure to water quality-induced stress can negatively impact resilience. The seagrasses present at the time of Matthew in October 2016 had been exposed to months of thermal extremes and abnormally high precipitation. Heavy rainfall increased runoff, and high freshwater inflow reduced salinity and light availability. The combination of salinity fluctuations and light limitation may have reduced the ability of beds to recover after the passage of Hurricane Matthew.

Based on data from the LOBO units deployed in the SIRL and from other SFWMD studies, salinity and the water column parameters affecting light (CDOM, turbidity, chlorophyll-a) were improving by the end of 2016 and continued to improve through the spring of 2017. Biennial imagery acquisition is conducted in late spring and was last completed in April 2017 when salinity and light availability were likely suitable for seagrass recovery. Both the photography and transect monitoring were done well before Hurricane Irma in September 2017, which brought physical impacts, after which salinities decreased and CDOM increased relative to average values. These conditions persisted for several weeks or months in some locations, (Hanisak and Davis 2018; Kahn et al. in review) further stressing the remaining seagrasses in the system. Responses of seagrasses to these latest events will be tracked at the scale of seagrass beds by monitoring along established transects, and lagoon-wide changes will be assessed from acquisition and mapping of aerial imagery scheduled for spring 2019.

## Methods

### *Mapping*

Surface water improvement and management (SWIM) plans of the St. Johns River Water Management District (SJRWMD) and the SFWMD direct those agencies to map seagrasses in the Indian River Lagoon every 2–3 years (Steward et al. 2003). Accordingly, maps were prepared for 1986, 1989, 1992, 1994, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, and 2017, as well as 1943 (Figures 2 and 3). Mapping is based on a contractor's interpretation of aerial photographs primarily at a 1:24,000 scale and, less often, at a 1:10,000 scale. Features in the aerial photographs are identified with the aid of stereoscopic analysis, photo-interpretation keys, and ground truthing. Features are classified according to Florida Land Use, Cover and Forms Classification System codes (Florida Department of Transportation 1999) as modified by the SJRWMD and SFWMD. Features are delineated, and the resulting polygons are connected to create a GIS data layer of seagrass extent. Reports evaluating the accuracy of classifications have been generated since 1999. Further information, along with the data, are at: http://data-floridaswater.opendata.arcgis.com/datasets?group_id=adb3f173bb1b44c181def265bdf2526f.

### *Seagrass surveys*

Seagrasses in the SIRL have been surveyed along fixed transects twice a year (summer and winter) in most years since 1994. Surveys were not conducted at all sites in the summer of 2016. Each transect is delineated by a graduated line extending from the shore, perpendicular to the shoreline, out to the deep edge of the seagrass bed. Every 10 m along this line, standardized, nondestructive measurements are made in a 1-$m^2$ quadrat divided by strings into 100 0.01-$m^2$ cells. Measurements include: 1) species composition documented as the number of cells occupied by at least one shoot of a species; 2) average canopy height for each species; 3) percent cover for each species and for all species combined, which correlates strongly with density as estimated by shoot counts; 4) percent cover of drift macroalgae and an index characterizing its biomass (Morris et al. 2001); 5) a visual estimate of epiphyte biomass (Miller-Myers and Virnstein 2000); 6) water depth; and 7) total transect length (measured from shore to the deep edge of the seagrass canopy). In addition, seagrass shoots are counted in a set of quadrats selected in advance as a direct measure of density; these data are used to generate a relationship between percent cover and density (Morris et al. 2001). At present, 96 transects (69 in the Northern Indian River Lagoon and 27 in the SIRL) are surveyed in the summer and winter to target maximum and minimum levels of biomass in seagrass beds (Virnstein and Morris 1996). Work in the SIRL is conducted by the South Florida Water Management District (SFWMD) in coordination with the St. Johns River Water Management District's seagrass mapping and monitoring program in the Northern Indian River Lagoon, with additional field assistance from the Loxahatchee River District and Florida Department of Environmental Protection.

### *Water quality*

Water quality monitoring in the SIRL was conducted quarterly by SFWMD at 40 sites from October 1990 through July 1999. In January 2000, new sites were selected and reduced to 13, located along seagrass transects, and since then stations have been monitored seven times annually, in January, February, April, June, July, August, and October. Data are available at [https://www.sfwmd.gov/science-data/dbhydro](https://www.sfwmd.gov/science-data/dbhydro). Temporary sampling reductions occurred in 2015, leading to a gap in data between 2015 and mid-2016.

## Mapping and monitoring recommendations

- Continue mapping seagrasses. Lagoon-wide aerial mapping is completed approximately every two years, allowing for analyses of long-term trends throughout the system.
- Continue surveying seagrass transects. Monitoring has been conducted by the SJRWMD and SFWMD and partners each winter and summer since 1994. Maintenance of this collaborative monitoring effort continues to build a long-term data record of important meadow-scale responses such as shifts in species diversity and changes in shoot density and water depth at the deep edge of the bed. These data can be used in modeling to elucidate seagrass responses to environmental parameters and the effects of environmental changes on seagrass ecosystem services.
- Optimize the temporal scale of water quality monitoring, and assess the success of different models to forecast future conditions and to replicate data collected in previous efforts.
- Continue lagoon-wide monitoring (started in 2018) done at the beginning and end of the growing season. This is part of the Comprehensive Everglades Restoration Plan's (CERP) Restoration Coordination Verification (RECOVER) program.
- Incorporate the transect data gathered by the CERP RECOVER monitoring program with existing transect data to reassess regional and species-specific relationships between above-ground biomass, shoot density, and percent cover of seagrasses. These empirical relationships should help in optimizing monitoring while obtaining information on seagrass responses to changes in the environment.

## Management and restoration recommendations

- Work with collaborators to develop an Indian River Lagoon-wide map of light attenuation and the parameters CDOM, turbidity, and chlorophyll to help develop targets for seagrass acreage and to recommend locations where planting seagrass would be most likely to succeed.
- To improve models and develop additional simulation models for single-species response and recovery, identify gaps in the understanding of the response of seagrass species to water management regimes.
- Coordinate with the Northern Estuaries program of CERP RECOVER to delineate optimal salinity zones for seagrass species.
- Develop targets for the quality of seagrass beds. Targets for percent cover, species diversity, or other metrics of quality will support a more complete evaluation of the health and ecological contributions of seagrass beds and improve the likelihood of identifying times and places for implementing management actions.
- Identify conditions impeding recovery of seagrasses. Evaluate the spatial variation of salinity, light, and other region-specific drivers of seagrass recovery to assist in developing restoration strategies.
- Continue coordination of state and federal restoration programs. Seagrasses are identified as a critical habitat in Florida's SWIM Program, the U.S. Environmental Protection Agency's National Estuary Program, the U.S. Army Corps of Engineers' North Indian River Lagoon Feasibility Study, and three of the Florida Department of Environmental Protection's basin management action plans.
- Prepare for a need to replant or otherwise rehabilitate seagrasses. Even after water quality becomes again suitable, seagrasses may not recover rapidly because the losses have been so extensive. Therefore, developing nurseries, evaluating different techniques for planting, establishing criteria for assessing sites for rehabilitation, and exploring other techniques for promoting regrowth of seagrasses should begin as soon as possible to ensure that answers to relevant questions will be available when water quality improves.

## Pertinent reports and scientific publications


Armstrong C, Baldwin L, Chen Z, Kahn A, Wachnicka A. 2019. Chapter 8C: St. Lucie and Caloosahatchee Estuary Watershed Research and Water Quality Monitoring Results and Activities. Pp. 8C1–44 in South Florida Environmental Report, Volume I. South Florida Water Management District, West Palm Beach. https://apps.sfwmd.gov/sfwmd/SFER/2019_sfer_final/v1/chapters/v1_ch8c.pdf. Accessed March 2019.

Barile PJ. 2018. Widespread sewage pollution of the Indian River Lagoon system, Florida (USA) resolved by spatial analyses of macroalgal biogeochemistry. Marine Pollution Bulletin 128:557–574.

Buzzelli C, Wachnicka A, Zheng CF, Chen Z, et al. 2018. St. Lucie and Caloosahatchee Estuary watershed research and water quality monitoring results and activities. Pp. 8C1-48 in Volume I, Chapter 8C in South Florida Environmental Report. South Florida Water Management District, West Palm Beach. http://apps.sfwmd.gov/sfwmd/SFER/2018_sfer_final/v1/chapters/v1_ch8c.pdf. Accessed September 2018.

Dawes CJ, Lobban CS, Tomasko DA. 1989. A comparison of the physiological ecology of the seagrasses *Halophila decipiens* Ostenfeld and *H. johnsonii* Eiseman from Florida. Aquatic Botany 33:149–154.

Dewberry Inc. 2012. Final project report to the St. Johns River Water Management District and South Florida Water Management District, 2011 Indian River Lagoon seagrass mapping, September 2013.

Dewberry Inc. 2014. Final project report to the St. Johns River Water Management District and South Florida Water Management District, 2013 Indian River Lagoon seagrass mapping, September 2014.

Dewberry Inc. 2018. Final project report to the St. Johns River Water Management District and South Florida Water Management District, 2017 Indian River Lagoon seagrass mapping, May 2018.

Florida Department of Transportation. 1999. Florida Land Use, Cover and Forms Classification System, a Handbook. Division of Surveying and Mapping, Geographic Mapping Section, Tallahassee.

Fourqurean JW, Rutten LM. 2004. The impact of Hurricane Georges on soft-bottom, back reef communities: site- and species-specific effects in south Florida seagrass beds. Bulletin of Marine Science 75:239–257.

Hanisak MD, Davis KS. 2018. Interannual variability in the Indian River Lagoon, Florida, measured by a network of environmental sensors, P. 106310A in Hou W, Arnone RA (eds.). Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE) Ocean Sensing and Monitoring X. Volume 10631: International Society for Optics and Photonics, Bellingham, Washington.

Kahn A, Bornhoeft S, Armstrong C, Chen Z. In review. Snapshots before and after Hurricane Irma: water quality patterns along the St. Lucie Estuary, Florida, USA.

Kahn AE, Beal JL, Durako MJ. 2013. Diurnal and tidal variability in the photobiology of the seagrass *Halophila johnsonii* in a riverine versus marine habitat. Estuaries and Coasts 36:430–443.

Kahn AE, Durako MJ. 2009. Photosynthetic tolerances to desiccation of the co-occurring seagrasses *Halophila johnsonii* and *Halophila decipiens*. Aquatic Botany 90:195–198.

Kramer BJ, Davis TW, Meyer KA, Rosen BH, Goleski JA, et al. 2018. Nitrogen limitation, toxin synthesis potential, and toxicity of cyanobacterial populations in Lake Okeechobee and the St. Lucie River Estuary, Florida, during the 2016 state of emergency event. PLOS ONE 13(5): e0196278. https://doi.org/10.1371/journal.pone.0196278.

Lirman D, Cropper WP. 2003. The influence of salinity on seagrass growth, survivorship, and distribution within Biscayne Bay, Florida: field, experimental, and modeling studies. Estuaries 26:131–141.

Miller-Myers R, Virnstein RW. 2000. Development and use of an epiphyte photo-index (EPI) for assessing epiphyte loadings on the seagrass *Halodule wrightii*. Pp. 115–123 in Bortone SA (ed.). Seagrasses: monitoring, ecology, physiology, and management. CRC Press, Boca Raton, Florida.

Morris LJ, Hall LM, Virnstein RW. 2001. Field guide for fixed seagrass transect monitoring in the Indian River Lagoon. Special Report, St. Johns River Water Management District, Palatka, Florida.

Morris LJ, Virnstein RW, Miller JD, Hall LM. 2000. Monitoring seagrass changes in the Indian River Lagoon, Florida, using fixed transects. Pp. 167–176 in Bortone SA (ed.). Seagrasses: monitoring, ecology, physiology and management, CRC Press, Boca Raton, Florida.

Phlips EJ, Badylak S, Lasi MA, Chamberlain R, et al. 2015. From red tides to green and brown tides: bloom dynamics in a restricted subtropical lagoon under shifting climatic conditions. Estuaries and Coasts 38:886–904.

Ridler MS, Dent RC, Arrington DA. 2006. Effects of two hurricanes on *Syringodium filiforme*, Manatee Grass, within the Loxahatchee River Estuary, southeast Florida. Estuaries and Coasts 29:1019–1025.

Steward JS, Virnstein RW, Lasi MA, Morris LJ, et al. 2006. The impacts of the 2004 hurricanes on hydrology, water quality, and seagrass in the central Indian River Lagoon, Florida. Estuaries and Coasts 29:954–965.

Steward JS, Virnstein RW, Morris LJ, Lowe EF. 2005. Setting seagrass depth, coverage, and light targets for the Indian River Lagoon system, Florida. Estuaries 28:923–935.

Stockley ND, Sullivan JM, Hanisak D, McFarland MN. 2018. Using observation networks to examine the impact of Lake Okeechobee discharges on the St. Lucie Estuary, Florida. Page 1063109 in Hou W, Arnone RA (eds.). Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE) Ocean Sensing and Monitoring X. Volume 10631, International Society for Optics and Photonics, Bellingham, Washington.

Virnstein RW, Morris LJ. 1996. Seagrass preservation and restoration: a diagnostic plan for the Indian River Lagoon. Technical Memorandum No. 14, St. Johns River Water Management District, Palatka, Florida.

Virnstein RW, Steward JS, Morris LJ. 2007. Seagrass coverage trends in the Indian River Lagoon System. Florida Scientist 70:397–404.

## General references and additional information

Central Indian River Lagoon Stakeholders. 2013. Basin management action plan for the implementation of total maximum daily loads for nutrients. Developed in cooperation with the Florida Department of Environmental Protection, Tallahassee. https://floridadep.gov/sites/default/files/central-irl-bmap.pdf. Accessed October 2018.

Indian River Lagoon National Estuary Program. http://www.irlcouncil.com/. Accessed February 2019.

South Florida Water Management District. 1994. Indian River Lagoon surface water improvement and management (SWIM) plan. Prepared by the St. Johns River Water Management District, Palatka, and the South Florida Water Management District, West Palm Beach. http://my.sfwmd.gov/portal/page/portal/pg_grp_sfwmd_watershed/portlet%20-%20coastal%20ecosystems/tab1806037/73ec5d84f811fb33e040e88d49523b6b. Accessed February 2019.

South Florida Water Management District. 2018. CERP (Comprehensive Everglades Restoration Plan) project planning. West Palm Beach. https://www.sfwmd.gov/our-work/cerp-project-planning. Accessed September 2018.

South Florida Water Management District. Northern Everglades and Estuaries Protection Program. https://www.sfwmd.gov/our-work/northern-everglades. Accessed February 2019.

St. Johns River Water Management District. 2002. Indian River Lagoon surface water improvement and management plan (SWIM) 2002 update. St. Johns River Water Management District, Palatka, Florida. https://www.sjrwmd.com/static/plans/2002_IRL_SWIM_Plan_Update.pdf. Accessed February 2019.

St. Lucie River and Estuary Basin Technical Stakeholders. 2013. Basin management action plan for the implementation of total maximum daily loads for nutrients and dissolved oxygen by the Florida Department of Environmental Protection in the St. Lucie River and Estuary Basin, Tallahassee. https://floridadep.gov/sites/default/files/stlucie-estuary-nutr-bmap.pdf. Accessed October 2018.

## Contact

**Amanda Kahn,** South Florida Water Management District, West Palm Beach, Florida, 561-682-6402, akahn@sfwmd.gov.

## Document citation

Kahn A. 2019. Summary report for the Northern Indian River Lagoon. Pp. xx–xx, in Yarbro L, Carlson PR (eds.). Seagrass Integrated Mapping and Monitoring Report No. 3. Fish and Wildlife Research Institute Technical Report TR-17 version 3, Florida Fish and Wildlife Conservation Commission, St. Petersburg, Florida.