Landscape-scale status of seagrasses in the Loxahatchee River Estuary:

2007 and 2010 to 2018 comparisons

Prepared by:

Jerry L. Metz

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Loxahatchee River District (LRD)
WildPine Ecological Laboratory
(561) 747-5700
www.loxahatcheeriver.org

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Executive Summary

Seagrasses play an important role as part of the mosaic of habitats that thrive in shallow coastal regions and are well known for the many ecosystem services that they provide. However, many seagrass communities are experiencing the effects of a rapidly growing human population where seagrasses are becoming increasingly vulnerable to impacts from activities associated with population growth. Altered hydrology through flood control, coastal construction, dredging and fill operations, and boating activities have all demonstrated to have detrimental impacts on seagrass habitat. The decline observed in seagrasses around the world underscores the need to assess the presence of seagrass in local ecosystems and to quantify changes over long time periods.

The Loxahatchee River estuary (LRE) is a relatively small estuary that supports seagrasses. Like many coastal regions, the LRE and surrounding watershed is experiencing a growing human population that puts increased stress on coastal habitats. Since 2003 the Loxahatchee River District (LRD) has conducted bimonthly monitoring at fixed sites within the LRE and has documented a substantial decline in the occurrence of seagrasses. To gain an understanding of how widespread the decline was, a landscape-scale assessment covering the full extent of seagrass presence was needed. To our knowledge, no such seagrass report exists for the LRE that compares changes in landscape-scale seagrass presence over a substantial time period. To bridge this information gap, we conducted an assessment during the summer of 2018 using a subset of sample points collected in 2007 and 2010 to compare the current status of seagrass in the LRE and gain understanding of how seagrasses have changed from the period of 2007 and 2010 to 2018.

Our goal for the 2018 assessment was to capture a snapshot of seagrass presence throughout the LRE and compare the data to previous assessments. To do this, we randomly selected a subset of 656 sample sites from the pooled 2007 and 2010 sample sites. We did this for a direct comparison of seagrass presence from 2007 or 2010 to that of 2018, and thus able to quantify changes in seagrass presence and the co-occurrence of seagrass species.

The 2018 sampling took place between April 27 and October 30, 2018. The seagrasses *Halodule wrightii* (Shoal grass), *Halophila johnsonii* (Johnson's seagrass), *Halophila decipiens* (Paddle grass), *Syringodium filiforme* (Manatee grass), and *Thalassia testudinum* (Turtle grass) were present during 2007, 2010, and 2018. Overwhelmingly, the seagrass community in the LRE is composed of mixed *H. wrightii* and *H. johnsonii* beds, although some monospecific beds were noted. The remaining species were found in scattered patches primarily in the central and eastern regions of the LRE.

Total seagrass frequency of occurrence declined by 50% between 2007 or 2010 and 2018. All seagrass species had declined in percent frequency with losses ranging from 37% to 60%. Loss of seagrass occurrence was observed in all regions of the LRE, especially in the southwest fork (SWF) which experienced a complete loss of seagrass by 2018. Incidentally, 50% sample sites assessed in summer 2018 experienced complete loss of seagrass compared to 2007 or 2010.

At sample sites where seagrass was encountered in 2018, seagrass averaged between 5 – 25% vegetative cover. Almost 90% of sample sites were at 50% vegetative cover or less. The seagrasses *H. wrightii* and *H. johnsonii* were by far the most common and widely distributed seagrasses appearing in 78% and 65% of

the 2018 sample sites that had seagrass present respectively. Additionally, these two species were found co-occurring at 47% of the sample sites. Seagrass species compositions and co-occurrence were mostly unchanged between 2007 or 2010 and 2018. The results of this report stress the need to periodically assess seagrass at the landscape-scale to gain a better understanding of seagrass loss so that stakeholders and policy makers can make informed decisions regarding protection of this vulnerable and valuable habitat.

1.0 Introduction

Seagrasses are a true flowering vascular plant adapted to life in a submerged marine environment. There are about 60 species of seagrasses found in shallow coastal regions world-wide except Antarctica (Green and Short 2003). Seven seagrass species are known to inhabit Florida's east coast which includes the Loxahatchee River Estuary (LRE) (Dawes *et al*. 1995). As a valued ecosystem component, seagrasses fulfill many ecological functions such as providing nursery habitat for juvenile fishes and shellfish, food for grazers like manatees and sea turtles, stabilizing sediments, and alleviating some near shore wave energy (Orth *et al*. 2006; Waycott *et al.*). However, these services are at risk of being lost due to seagrasses declining on a global scale and at an alarming rate (Orth *et al*. 2006). Investigations into the cause of seagrass decline often cite human activities such as altered terrestrial hydrology like stormwater runoff, dredge and fill operations, coastal construction, and impacts associated with boating (Orth *et al*. 2006; Ridler *et al*. 2006; Waycott *et al.,* 2009). Seagrass' vulnerability and their sessile nature has led them to be identified as a biological indicator of water quality and overall ecosystem health (Montague and Ley 1993; Lirman and Cropper 2003). State and local agencies often conduct monitoring programs that document the distribution, abundance, and composition of impacted seagrass communities so that best management decision can be made regarding the protection of this important habitat component.

The LRE is relatively small, subtropical estuary (26° 57' N, 80° 60' W) that drains a watershed of approximately 620 km^2 and is connected to the southern terminus of the Indian River Lagoon and the northern reach of the Lake Worth Creek (Figure 1). The LRE receives freshwater input primarily from the northwest fork (NWF) of the Loxahatchee River, a federally designated "Wild and Scenic" river. Historically, the northwest fork received water provided by rainfall from nearby Loxahatchee and Hungryland Sloughs. However, throughout the twentieth century, a series of canals and levees along with fixed weirs and control gates have been constructed to provide drainage and flood control to facilitate development (SFWMD 2006). During times of intense rainfall such as during major storms, excess freshwater is diverted to the southwest fork (SWF) of the LRE via the South Florida Water Management District's C-18 canal and through the S-46 flood control structure. Lastly, the north fork (NF) of the LRE is much smaller than the other forks and primarily drains freshwater from Jonathan Dickinson State Park. The estuary is connected to the Atlantic Ocean via the Jupiter inlet which is the primary source of saltwater to the estuary. During flood tides some saltwater also enters through the estuary's connectivity to the southern Indian River Lagoon and northern Lake Worth creek which are part of the intracoastal waterway (ICWW).

The balance of fresh and saltwater has long made the estuary suitable for seagrass establishment and growth. Since at least early 1980's, seagrass presence and species composition have been documented within the LRE (McPherson *et al*. 1982, Klemm and Vare 1985). Throughout the 1990's and into the 2000's, the Jupiter Inlet District (JID) mapped seagrass distribution within the Loxahatchee River central embayment (CB) on a biannual schedule. In 1998, the Loxahatchee River District (LRD) began conducting more detailed biannual seagrass assessments utilizing aerial photography and Geographic Information System (GIS) technology to document the occurrence of seagrass communities in the central and eastern portions of the LRE (Ridler *et al*. 2003). In 2007 and 2010, LRD once again used GIS to document the occurrence of seagrasses in a project that recorded over 2,500 sample sites within the LRE (Howard et al, 2011). This mapping project proved critical in two ways. First, because mapping grade Global Positioning System (GPS) technology with sub-meter accuracy was used, researchers were able to accurately map and document detailed information regarding seagrass occurrence in the LRE. And second, these mapping efforts tracked the upstream extent of seagrass into each of the river forks. To our knowledge, no landscape-scale mapping of seagrasses within the LRE has been conducted since the mapping of 2010 (Howard *et al*. 2011). Furthermore, we could find no record of any temporal comparison that showed the long-term trend of seagrass health within the LRE. A rapidly expanding population within the Loxahatchee River watershed, coupled with the major storm events subsequent to the 2010 seagrass mapping project, warrant a critical evaluation of seagrass distribution in the LRE.

Bimonthly seagrass monitoring conducted by LRD since 2003 at preselected seagrass beds within the estuary has indicated that seagrasses are declining. To better understand the extent of this decline, a much broader landscape-scale approach was explored. After much careful planning and consideration, a sampling strategy was developed that upon completion, would provide insight to not only current seagrass status, but could be directly compared to the data from the 2007 and 2010 mapping.

This report fulfils three primary goals: 1) to map the 2018 seagrass occurrence within the LRE; 2) examine changes to seagrasses since 2007 and 2010; and 3) to provide groundwork for future assessments to gauge the continued status of seagrasses within the LRE.

2.0 Methods

2.1 Sample Site Selection

Using ArcGIS (ESRI’s ArcMap ver 10.6), the LRE was first divided into five subregions based on geographical position and distance to the Jupiter Inlet. The five regions include **CB** (Central Bay), **ERR** (East of Railroad bridge), **NWF** (Northwest Fork), **NF** (North Fork), and **SWF** (Southwest Fork) (Figure 1). Dividing the estuary into subregions ensured that all areas of the river received adequate representation and provided a spatial reference for general assessment.

The framework for the 2018 seagrass assessment was based on previous landscape-scale mapping work conducted in 2007 and again in 2010. During the 2007 and 2010 assessments, weighted buoys were haphazardly deployed throughout the estuary. These regions were identified as potentially supporting seagrass either through aerial photography, bathymetry, or ground-level visual checks.

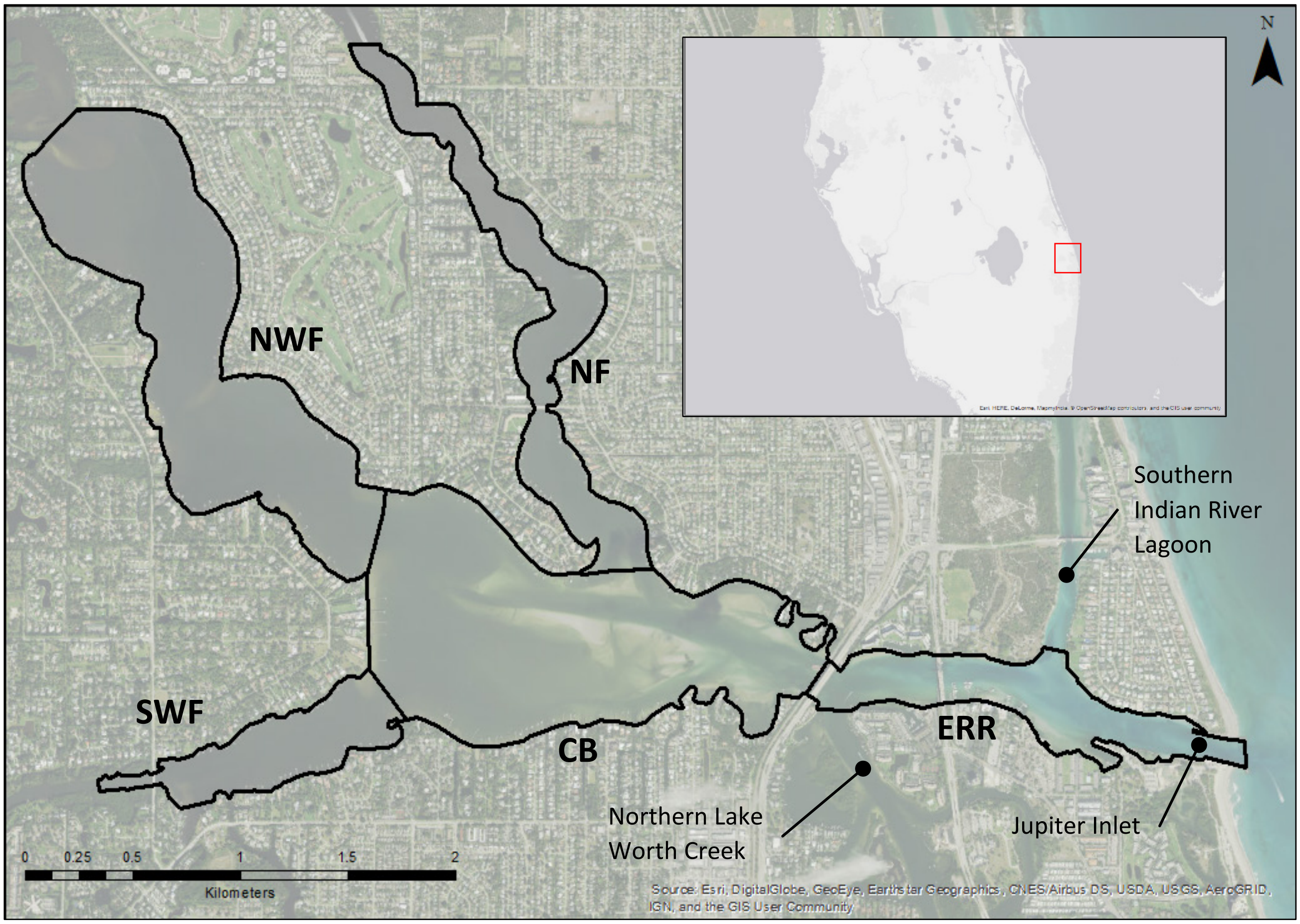

Figure 1. Map showing the Loxahatchee River estuary with the five regions indicated as **CB** (Central Bay), **NWF** (Northwest Fork), **SWF** (Southwest Fork), **NF** (North Fork), and **ERR** (East of Railroad bridge). Also shown are key features of the estuary.

Divers equipped with a 9 m^2 (3m x 3m) collapsible quadrat centrally located on each buoy weight recorded seagrass presence/absent data (Figure 2). Seagrass presence was scored based on the number of meter squares (1 through 9) occupied by total seagrass and by each seagrass species. Scores were assigned categories based on the number of squares occupied by seagrass to describe the abundance of seagrass within each quadrat. The categories and their corresponding score range include “Continuous” (7-9 square occupied by seagrass), “Patchy” (4-6), and “Sparse” (1-3). A quadrat with no seagrass present (0) was categorized as “Absent”. The exact location of each sample site along with seagrass presence data was recorded using a mapping grade GPS. The 2007 assessment resulted in 1,076 sample sites and the 2010 assessment recorded 1,476 sample sites.

The sample sites from the 2007 and 2010 assessments were pooled into a single dataset of 2,552 sample sites. The 2007 and 2010 mapping data was merged to increase the numbers of sites and the spatial evenness of the sampling sites for comparisons. We then created a 5 X 10 rectangular array whereby each column was one of the five subregions from where each sample site was located and each row was the 0 – 9 total seagrass presence scores of the sample sites (i.e. 0, 1, 2, 3,… 9) (Table 1). We separated the sample sites by presence score because a close review of the data showed that total seagrass scores were overwhelmingly biased toward either 0 or 9, with far fewer intermediate scores. We used a stratified random design for site selection and used the total seagrass score as the strata, which helped ensure a more even representation for assessment in 2018. Based on finite time and staff resources available for the 2018 assessment, we selected 25% the sampling sites from each cell of the 5 X 10 array using a web-based random sequence generator (www.random.org/sequences/). For array cells represented by fewer than 5 sample sites, we included all sites from that cell.

Figure 2. A 9m^2 collapsible sampling quadrat, centered on weighted marker buoy. The smaller 1m^2 quadrat is shown for scale. Seagrass categories were based on the number of 1-meter squares within the quadrat occupied by seagrass and include Continuous (7-9), Patchy (4-6), Sparse (1-3), and Absent (0).

A final review of the selected sample sites on a recent aerial photo indicated that some sites were deemed either unsafe (i.e. now reside within a navigation channel) or inaccessible (i.e. under a subsequently constructed dock). Such sample sites were removed from the dataset and replaced with the next randomly chosen sample site from within the respective array cell. Table 1 shows the distribution of the final 656 sample sites selected for the 2018 sampling. Sample site locations were loaded onto a Trimble mapping grade GPS (Geo XH) using real-time differential correction to navigate to each site. Throughout this report, the term “2007/2010” will be used when referring to the sample sites originating from this pooled dataset. In doing so, we were able to evaluate the changes in seagrass occurrence from 2007 or 2010 (as one pooled dataset) to 2018.

Table 1. Sample sites assessed in 2018 were drawn at random from the pooled (2,552) sample sites from the 2007 and 2010 landscape-scale seagrass assessment using a 5 X 10 array (5 regions X 10 possible quadrat scores). The distribution of the number of sample sites within each cell of the array is shown. Each cell represents approximately 25% of the available sample sites.

Abundance Score	CB	NWF	NF	ERR	SWF
0	65	40	26	17	21
1	7	3	2	2	3
2	8	2	3	1	3
3	8	3	5	2	2
4	6	4	4	2	3
5	10	3	3	1	2
6	8	5	5	3	2
7	12	6	4	3	2
8	20	5	4	1	3
9	195	37	47	24	9
Total	339	108	103	56	50

2.2 Field data collection

Data were collected in the field by teams of two. One team member used the GPS to locate each pre-selected sample site and deploy a weighted marker buoy affixed with a pre-labeled, waterproof paper ticket while another team member, using snorkeling gear, placed a collapsible 9 m^2 (3 x 3 m) quadrat centered on each buoy weight. The diver then counted the total number of 1m^2 squares (out of nine) that contained at least one shoot of seagrass. This procedure documenting occurrence was performed for total seagrass and each seagrass species. The diver then used the Braun-Blanquet cover abundance (BBCA) scale (Braun-Blanquet 1932; Table 2) to estimate the abundance/percent cover within each quadrat for both total seagrass and individual species. The field data was entered into an electronic database for geospatial analysis.

Table 2. The Braun-Blanquet Cover Abundance scoring scale used for the 2018 seagrass assessment to estimate seagrass density (D) within each 9 m^2 collapsible quadrat.

Braun-Blanquet Cover Abundance Scale

Score	% cover	Interpretation
0	0	Species absent from quadrat
0.1	<< 1%	Present as 1 to 10 shoots; bare minimum presence
0.5	< 1%	Species present as only a few shoots (>10)
1	1-5%	Several shoots; enough density to cover 1-5% of quadrat
2	5-25%	Present as many shoots; covers 5-25% of quadrat
3	25-50%	Present as many shoots; covers 25-50% of quadrat
4	50-75%	Present as many shoots; covers 50-75% of quadrat
5	> 75%	Present as many shoots; covers more than 75% of quadrat

2.3 Data Processing

Each diver collected two pieces of information at each sample point: 1) number of 1-meter squares (0-9) occupied by seagrass and 2) estimated abundance/percent cover as viewed from above based on the BBCA scale (Table 2). From these two parameters, we were able to examine the frequency, abundance, and species composition of seagrass within the LRE.

It is important to clarify here that the sample sites from the 2007 and 2010 assessments were pooled together into a single dataset. The period between 2007 and 2010 was "quiet" in terms of significant storm events; LRDs bimonthly monitoring data showed that seagrass presence remained relatively stable between 2007 and 2010 (LRD, unpublished data). Additionally, the method used to collect data for both assessments was identical. For these reasons, the two datasets were merged to expand the number of sample points and improve spatial evenness. Throughout this report, the nomenclature used in-text to refer to this dataset is "2007/2010". The 2007/2010 dataset only includes the 0-9 scores (Braun-Blanquet density estimates were not performed during this time), thus only 2007/2010 seagrass occurrence (the 0-9 scores) can be compared to the 2018 data.

2.3.1 Frequency of Occurrence

Frequency of occurrence, also referred to as percent occurrence, is a common measure used to quantitatively describe the presence of seagrass as a percentage. Frequency of occurrence is also among the coarsest scales of data collection and answers the question of "how often", or "how frequently", seagrass was encountered. In this report, frequency of seagrass occurrence was determined by adding the number of sample sites at which each seagrass species *i* was present divided by the total number of sample sites visited and then multiply by 100 to get a percent frequency (F):

$$\mathrm{F}i = \frac{\text{Number of sites where seagrass species } i \text{ was present}}{\text{Total number of sample sites}} \text{ X } 100$$

where $0 \leq \mathrm{F}i \leq 1$.

For example, if 50 sample sites are assessed and 40 of them had some amount of seagrass present, then seagrass occurrence (F) would be 80%. This measure ignores how much seagrass is present, a single shoot within the quadrat counts as seagrass being present at that site. Appendices 1 and 2 at the end of this report provides maps for the assessments of 2018 and 2007/2010 respectively that show all sample sites visited and indicate sites where seagrass was present.

2.3.2 Seagrass Co-occurrence

Species co-occurrence is derived from the seagrass occurrence data and is used to describe the co-existence patterns of multiple species. The examination of species co-occurrence can help in understanding seagrass species interactions as well as provide insight into abiotic environmental factors such as light, salinity, and hydrodynamics.

During both assessments, an individual sample site with seagrass present was either composed of a single species or had more than one species present. In this way we looked at species co-occurrence as proxy of community structure. We first determined all observed combinations of seagrass species reported in the LRE for both 2007/2010 and 2018 determined as:

$$\%\ \text{co} - \text{occurrence} = \frac{\text{number of each observed species combination}}{\text{number of sample sites with seagrass present}}\ X\ 100$$

where the sum of all observed combinations is equal to 100%. A histogram is shown in the Results section of this report highlighting the distribution of seagrass species combinations during both the 2007/2010 and 2018 assessments.

2.3.3 Categorical Abundance

Categorical Abundance (CA), as used in this report, is one of two components that answer the question of "how much" seagrass is present. CA is a finer scale of seagrass presence and describes seagrass patchiness at each site by using the non-zero (i.e. 1-9) score of each seagrass species *i* from each $9m^2$ quadrat. The 1-9 score is evenly divided into three categories that include "Sparse" = 1 – 3, "Patchy" = 4 – 6, and "Continuous" = 7 – 9. Sites with a score of 0 are categorized as "Absent". By converting the 0-9 scores to a categorical value, we generalized the data in order to making meaningful statements comparing between assessments.

Categorical Abundance (CA*i*) of each species is calculated as:

$$\text{CA}i = \frac{\text{number of sites with each category for species } i}{\text{number of sample sites where species } i \text{ was present}}\ \text{X } 100$$

where $0 \le \text{CA}i \le 1$ and the sum of Sparse + Patchy + Continuous for each seagrass species equals 100%.

Appendix 1 at the end of this report provides maps showing location of all sample sites visited during the 2018 assessment along each site's respective CA score for each seagrass species. Appendix 2 also contains maps showing the location of the same sample sites visited in 2018 but shows data from the 2007/2010 assessments associated with each sample site.

CA is a common component among the 2007/2010 and 2018 data and is the finest scale at which we were able to make direct site by site comparison between the two assessments. We used the hierarchy of the abundance categories to determine the direction of change at each site between 2007/2010 and 2018. Four categories are used to indicate the direction of categorical change between 2007/2010 and 2018 and include "Gain", "Loss", or "No Change". The fourth category is "Loss to Absent" and describes sample sites where seagrass species completely disappeared from a sample site where previously it had been present. Sample sites that went from "Absent" to "Absent" between the two assessments were not considered in the side by side comparison. Appendix 4 at the end of this report shows the location of all sample sites visited and indicate the direction of change at each site. Appendix 4 also includes sites where seagrass was absent during both assessments and are labeled “Always Bare”.

2.3.4 Braun-Blanket Cover Abundance (BBCA) Score

Abundance/Percent Cover measured using the Braun-Blanket Cover Abundance (BBCA) is another component that answers the question of “how much” seagrass is present. It is based on the established BBCA eight-point scale (Table 2) that is widely used in plant studies and is a field estimate of vegetative cover as viewed from above (Braun-Blanquet 1932). In the field, the diver estimates the abundance/percent cover of each seagrass species inside the entire quadrat and assigns an appropriate BBCA score from the table that corresponds to the estimated percent cover. This report looks at average BBCA score across sample sites and calculated as:

$$\text{BBCA}i = \frac{\text{sum of BBCA scores for species } i}{\text{number of sample sites where species } i \text{ was present}}$$

The BBCA is an added measure for the 2018 assessment only. Because BBCA data was not collected in the 2007/2010 assessment, no comparison can be made between assessments. Instead, the BBCA score is used in this report to convey another indicator of seagrasses health in the LRE relative to other studies that use the BBCA scale. Additionally, the BBCA score can be used in future landscape-scale assessments so that density comparisons can be made. Appendix 3 at the end of this report provides maps showing the location and BBCA score of all non-bare sample sites.

3.0 Results

3.1 Total Seagrass in 2018

The landscape-scale seagrass assessment for 2018 was completed in fifteen field days between April 27 and October 30.

3.1.1 Total Seagrass Frequency of Occurrence

Total seagrass frequency of occurrence was 37.5% of the 656 sample sites (Table 3). There were five seagrass species encountered throughout the estuary and include, in descending order of frequency, *Halodule wrightii* (29.4%), *Halophila johnsonii* (24.5%), *Halophila decipiens* (3.5%), *Syringodium filiforme* (3.4%), and *Thalassia testudinum* (1.1%). All five seagrass species were present in the CB, ERR, and NF regions while only *H. wrightii* and *H. johnsonii* were observed in the NWF region. Seagrass was absent from the SWF region.

Table 3. Frequency of occurrence (F*i*) for total seagrass and for each species for the 2018 assessment. The lower portion of the table shows seagrass occurrence within each subregion. Absence of a seagrass species indicated as "0". CB (Central Bay), NWF (Northwest Fork), SWF (Southwest Fork), NF (North Fork), and ERR (East of Railroad bridge).

Frequency of Occurrence (F)

Fraction of all sites sampled (%)

	Total Seagrass	*H. wrightii*	*H. johnsonii*	*H. decipiens*	*S. filiforme*	*T. testudinum*
Estuary	37.5	29.4	24.5	3.5	3.4	1.1
CB	50.7	40.4	36.0	4.4	4.1	1.2
ERR	44.6	33.9	33.9	1.8	7.1	3.6
NF	33.0	23.3	17.5	6.8	3.9	1.0
NWF	13.9	12.0	1.9	0	0	0
SWF	0	0	0	0	0	0

3.1.2 Total Seagrass Categorical Abundance

Categorical Abundance (A*i*) among sample sites throughout the estuary tended to have a somewhat bimodal distribution among the three categories (Table 4). This means that at sites where seagrass was present, there was either Continuous seagrass (62.2%) or Sparse seagrass (24.4%) with far fewer sites showing as Patchy (13.4%). The seagrasses *H. wrightii*, *H. johnsonii*, and *S. filiforme* all had this bimodal pattern. In addition to *H. decipiens* and *T. testudinum* having low frequency of occurrence, these two seagrasses were most often Sparse (78.3% and 71.4% respectively) at sites where they were found. Appendix 1 provides a map showing spatial representation of the data in Table 3.

Table 4. Categorical Abundance (CA*i*) as percentage of sites with seagrass species present for each category for the 2018 assessment. Maps in Appendix 1 show the spatial distribution of seagrass abundance.

Categorical Abundance (CA*i*)

Fraction of sites with species present (%)

		All Seagrass	*H. wrightii*	*H. johnsonii*	*H. decipiens*	*S. filiforme*	*T. testudinum*
Estuary	Continuous	62.2	62.2	58.4	4.3	40.9	0
	Patchy	13.4	14.0	15.5	17.4	22.7	28.6
	Sparse	24.4	23.8	26.1	78.3	36.4	71.4

3.1.3 BBCA Score

Seagrass BBCA score at most sample sites was low regardless of presence category (see Table 5). The average seagrass BBCA score across the estuary was 1.7 which indicates an average vegetative cover of 5 - 25%. The BBCA range of between 5 – 25% for total seagrass was the most frequently observed score and accounted for 24.8% of all sample sites where seagrass was present. Across the estuary, 88.6% of all sample sites were below 50% vegetative cover based on the BBCA score.

Table 5. Braun-Blanquet Cover Abundance (BBCA) score for each species during the 2018 seagrass assessment. Columns indicate the percent of sample sites where species was present within each percent cover class (see Table 2). The "0" column indicates the percent of sample sites where seagrass was absent.

Braun-Blanquet Cover Abundance Score

Fraction of all sites with each species present (%)

			BBCA value						
	0	Mean Score	**<< 1%**	**< 1%**	**1 - 5%**	**5 - 25%**	**25 - 50%**	**50 - 75%**	**> 75%**
All SG	62.5	**1.7**	20.7	9.8	17.5	24.8	15.9	8.1	3.3
H.wrightii	70.5	**1.5**	19.2	12.4	20.7	26.4	16.6	4.7	0
H.johnsonii	75.5	**1.4**	17.4	16.8	26.7	23.0	11.8	3.7	0.6
H.decipiens	96.5	**0.5**	52.2	26.1	8.7	13.0	0	0	0
S.filaforme	96.6	**0.8**	36.4	27.3	13.6	18.2	4.5	0	0
T.testudinum	98.9	**0.2**	71.4	28.6	0	0	0	0	0

3.2 2018 Seagrass by Species

3.2.1 *Halodule wrightii* (Shoal grass)

Halodule wrightii was the most widely distributed and most frequently observed seagrass during the 2018 assessment. This species was found in four of the five river subregions that had seagrass and overall was present at 29.4% of the sample sites (Table 3). Generally, *H. wrightii* was found along the shallow shorelines and on or near shoals throughout its distribution (see map in Appendix 1b). The highest frequency of occurrence was in the CB region where *H. wrightii* was present at 40.4% of sites. The lowest frequency of occurrence at 12.0% was in the NWF.

The Categorical Abundance (CA) of *H. wrightii* was also generally high with 62.2% of the sample sites categorized as Continuous. Regions of highest CA were ERR and CB where 73.7% and 68.6% of the sample sites were respectively categorized as Continuous. In the NF and NWF regions, CA of *H. wrightii* was lower with 33.3% and 30.8% of the sites categorized as continuous respectively. A higher fraction of the sample sites were Sparse in the NF and NWF regions at 45.8% and 38.5% respectively.

Overall, *H. wrightii* has the highest BBCA score of the seagrass species observed in the assessment. Across all regions of the estuary, the mean BBCA of *H. wrightii* was in the 5 – 25% range (BBCA score = 1.5). The most frequently recorded (i.e 'mode') BBCA score was 2 which was noted at 26.5% of sample sites with *H. wrightii* present. Only 21.3% of sample sites had a BBCA score equal to greater than 50% and no observed *H. wrightii* BBCA score was greater than 75%.

3.2.2 *Halophila johnsonii* (Johnson's Seagrass)

Halophila johnsonii was the second most widely distributed and frequently observed seagrass and was present at 24.5% of all sample sites throughout the estuary (Table 3). Like *H. wrightii*, *H. johnsonii* was found in all river regions (except SWF) and was most often encountered along the shallow shorelines and on shoals (see map in Appendix 1c). The highest frequency of *H. johnsonii* was reported in the CB (36.0%) and ERR (33.9%) regions. The region with the lowest frequency of occurrence was in the NWF where it occupied 1.9% of the sample sites.

At sample sites where *H. johnsonii* was present, 58.4% were categorized as Continuous. Though *H. johnsonii* was widely distributed throughout the estuary, it was most frequently present in the CB and ERR regions where it occupied 43.3% and 46.3% of the sites respectively. Additionally, in the CB and ERR where *H. johnsonii* was present, it was categorized as Continuous at 59.0% and 73.7% of the sites respectively. *H. johnsonii* was found far less frequently in the NF and NWF regions occupying 23.1% and 2.6% of the sites respectively.

Halophila johnsonii was observed at a wide range of cover abundance classes but where *H. johnsonii* was present the average BBCA scores were equal to less than 25% abundance cover. The highest cover abundance was found in the CB and ERR averaging 5 – 25%. Abundance cover in the NWF region was also 5 – 25%. However, *H. johnsonii* was only observed at two sample sites. In the NF region, 83.3% of the sample sites had less than 5% cover abundance.

3.2.3 *Halophila decipiens* (Paddle grass)

Halophila decipiens was present at 3.5% of the sample sites within the estuary and was found mostly as isolated sample sites with the highest frequency of occurrence in the CB (4.4%) and NF (6.8%) regions. This species was also found in the ERR region and occupied only 1.8% of the sample sites. *H. decipiens* was absent from NWF and SWF regions.

In the regions where *H. decipiens* was found, the categorical abundance was generally very low. Across the estuary, 4.3% of sample sites were considered Continuous while 78.3% of sample sites were Sparse. The Patchy category comprised of 17.4% of the sample sites.

Halophila decipiens also had a low BBCA score throughout its range within the estuary, consistent with the low frequency of occurrence and categorical abundance. Overall, the average BBCA score was 0.5 indicating <1% vegetative cover while no sample sites reported a density greater than 25%.

3.2.4 *Syringodium filiforme* (Manatee grass)

Syringodium filiforme was infrequently encountered during the assessment and occupied 3.4% of the sample sites. This species was found in three of the river subregions with ERR having the highest fraction of sample points with a frequency of 7.1%. the fraction of sample points in the CB and NF were slightly less at 4.1% and 3.9% respectively.

While *S. filiforme* had a low frequency of occurrence, the categorical abundance was comparatively high, with 40.9% of the sample points reported as Continuous and slightly fewer sample points reported as Sparse. In the ERR regions where *S. filiforme* was most frequently encountered, the categorical abundance was Continuous at 100% of the sample sites. 35.7% of the sample points in CB were categorized as continuous. In the NF region no sample points were continuous while 75% of the sample points here were Sparse.

The average BBCA score for *S. filiforme* was 0.8 indicating vegetative cover of 1 – 5%. The most frequently reported BBAC score in the estuary was 0.1, indicating a cover <<1% at 36.4% of the sample sites where *S. filiforme* was present. No sample sites reported a cover greater than 50% for *S. filiforme*.

3.2.5 *Thalassia testudinum* (Turtle grass)

Thalassia testudinum was the least frequently encountered seagrass species and was present in only 1.1% of the sample sites. This seagrass was mostly found as small isolated beds in the ERR and CB regions where frequency was 3.6% and 1.2% respectively and a solitary site in the NF region accounting for only 1.0% of the sample sites there. *T. testudinum* was absent from NWF.

Five of the seven sites (71%) where this species was present were categorized as Sparse while the remaining two were categorized as Patchy indicating that even when present was not very abundant. The BBCA score for this species was also very low with 100% of the sample sites reporting <1% vegetative cover.

4.0 Seagrass change; 2007/2010 to 2018

This section compares the Frequency of Occurrence, Categorized Abundance, and species co-occurrence between the 2007/2010 and 2018 assessments. These three attributes are common among all years thus provide useful insight into changes in the seagrass community over the past decade. Seagrass BBCA score was not a parameter included in the 2007/2010 data so it is not compared in this section.

Results, tables, and figures in this section compare 2018 data to data from the 2007/2010 assessments. It is outside the scope of this report to make comparisons between the individual years (i.e. 2007 to 2010; 2007 to 2018, etc.). As discussed in the Data Processing section, the 2007 and 2010 assessments are combined and are thus treated as a single dataset.

4.1 Frequency of Occurrence; 2007/2010 to 2018

Substantial declines in seagrass frequency (% occurrence) were observed throughout the estuary and among all species. Total seagrass frequency went from 74.2% occurrence in the 2007/2010 assessment down to 38.0% in 2018 for a decrease of 49%. All seagrass species showed decline between the two assessment periods but, interestingly, the decline does not appear to affect any one seagrass species. For example, the decline among all species throughout the estuary ranged from 37% for *H. wrightii* to 60% for *H. johnsonii*. Even *T. Thalassia*, which was the least frequently encountered seagrass throughout both assessment periods, declined by 52% from 2.3% in 2007/2010 to only 1.1% by 2018. Perhaps the most striking decline in seagrass frequency was observed in the SWF region where in 2018 none of the sites had seagrass at sites that seagrass had been documented in 2007/2010. Most of the seagrass lost in the SWF was comprised primarily of *H. johnsonii* while *H. wrightii*, also present, was present in much smaller fraction of the sample sites.

Similar, albeit less drastic, losses were observed in the NWF where total seagrass declined from 63% to 14% by 2018. Also, like the SWF, seagrasses in the NWF was comprised mostly of *H. johnsonii* which had a frequency of 54% in 2007/2010 decreased to only 2% by the 2018 assessment. As shown in Table 6, only *H. decipiens* in the ERR experienced a minimal gain while all other species in all subregions experienced varying degrees of loss in observed frequency.

Table 6. Percent frequency (Fi) by species and by subregion is shown here for a side-by-side comparison between the assessments of 2007 or 2010 (bold) and 2018 (italicized). Absence of seagrass is noted by "0". **CB** (Central Bay), **NWF** (Northwest Fork), **SWF** (Southwest Fork), **NF** (North Fork), and **ERR** (East of Railroad bridge).

Frequency of Occurrence (F*i*)

Fraction of all sites sampled (%)

	All Seagrass		*H. wriightii*		*H. johnsonii*		*H. decipiens*		*S. filiforme*		*T. testudinum*	
	2018	2007/ 2010	*2018*	2007/ 2010	*2018*	2007/ 2010	*2018*	2007/ 2010	*2018*	2007/ 2010	*2018*	2007/ 2010
Estuary	*38.0*	**74.2**	*29.4*	**46.6**	*24.5*	**60.5**	*3.5*	**8.1**	*3.4*	**6.4**	*1.1*	**2.3**
CB	*50.7*	**80.8**	*40.4*	**59.3**	*36.0*	**65.8**	*4.4*	**9.7**	*4.1*	**9.1**	*1.2*	**2.7**
ERR	*44.6*	**69.6**	*33.9*	**50.0**	*33.9*	**51.8**	*1.8*	**0**	*7.1*	**8.9**	*3.6*	**7.1**
NF	*33.0*	**74.8**	*23.3*	**41.7**	*17.5*	**57.3**	*6.8*	**18.4**	*3.9*	**5.8**	*1.0*	**2**
NWF	*13.9*	**63.0**	*12.0*	**28.7**	*1.9*	**53.7**	*0*	**1.0**	*0*	**0**	*0*	**0**
SWF	*0*	**58.0**	*0*	**6.0**	*0*	**56.0**	*0*	**0**	*0*	**0**	*0*	**0**

4.2 Seagrass Species Co-occurrence; 2007/2010 to 2018

By far, the most frequently observed seagrass species co-occurrence during both assessments was between *H. wrightii* and *H. johnsonii* (Figure 3). Not only was this species combination the most frequently encountered, it remained mostly unchanged between the 2007/2010 and 2018 assessments occupying 42% and 47% of the sample sites respectively. There was however, a notable difference of frequency of monospecific sites between these two species. During the 2007/2010 assessments, monospecific sites of *H. wrightii* occupied 10% of the sites while during the 2018 assessment, that fraction increased to 23%. Conversely, monospecific sites of *H. johnsonii* sharply decreased from 28% during 2007/2010 to 10% during the 2018 assessment.

The seagrass *H. decipiens*, closely related to *H. johnsonii* and similar in appearance, was most often found as small monospecific patches during both the 2007/2010 and 2018 assessments and occupied 4% and 8% of the sample sites respectively. This seagrass was rarely observed with other species. Remaining seagrass species co-occurrence combinations, including monospecific sites, each accounted for less than 5% of all sample sites for each assessment.

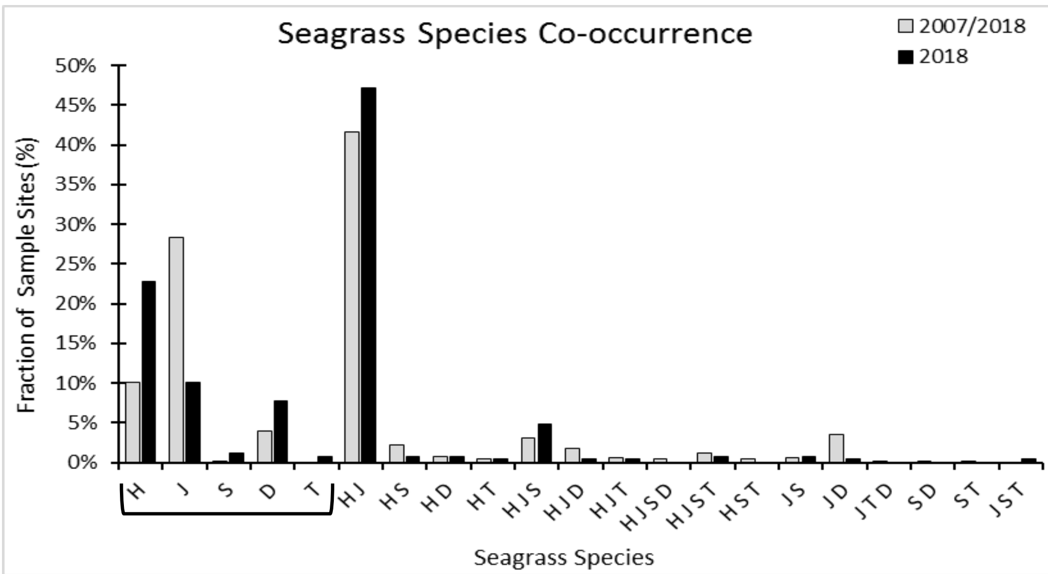

Figure 3. Combinations of seagrass species observed within each sample site for both 2007/2010 (gray) and 2018 (black) were plotted showing the fraction of sample sites having each species combination. Bracket indicates fraction of sites with a single species present. H= *H. wrightii*, J= *H. johnsonii*, S= *S. filiforme*, D= *H. decipiens*, T= *T. testudinum*.

4.3 Categorical Abundance; 2007/2010 to 2018

Whereas changes in frequency gives a broad notion of seagrass distribution within the estuary, changes in Categorical Abundance examines more closely the "patchiness" of seagrass presence within each sample site. To reiterate, this metric compares individual sites that contained seagrass in at least one of the assessment periods; sites that did not have seagrass in either 2007/2010 or 2018 were not used for categorical abundance changes.

Categorical seagrass abundance experienced substantial declines between 2007/2010 and 2018. Overall, 66% of sample sites experienced a decrease in categorical abundance between 2007/2010 and 2018 while 51% of sample sites experienced a complete loss of seagrass ("Loss to Absent" in Table 7). 30% of the sample sites experienced No Change between periods while 4% of sample sites experienced a Gain in categorical abundance.

All seagrass species experienced substantial, but similar, declines in abundance between the two assessments. Losses ranged from 57% for *H. wrightii* to 73% for *H. johnsonii*. Complete losses, or "Loss to Absent" were comparable ranging from 42% complete loss of *H. wrightii* to 68% for *T. testudinum*. Some sites experienced no change in species categorical abundance. For example, *H. wrightii* had the highest fraction (31%) of sites which did not experience change, while all sites with *T. testudinum* showed a change in categorical abundance. Some seagrasses experienced a notable gain in abundance between assessment periods. For example, *H. decipiens* showed a gain in abundance at 24% of the sites where it was present, while *T. testudinum*, the species found the least frequently, gained in abundance at 33% of the sites.

Table 7. Comparison of within site change of categorical abundance between 2007/2010 and 2018 assessments. The first column is number of sites where each seagrass was present at least once during both the 2007/2010 and 2018 assessments. "Gain" indicates fraction of sites which had an increase of Categorical Abundance (i.e. went from "Sparse" to Patchy"); "Loss" indicates fraction of sites which had a decrease of Categorical Abundance (i.e. went from Patchy" to Sparse"). "Loss to Absent" is a subset of the Loss column and indicates fraction of sites that previously had seagrass but was absent during the 2018 assessment. "No Change" indicates fraction of sites that did not experience a change of Categorical Abundance between the 2007/2010 and 2018 assessments.

Change of Categorical Abundance (ΔCAi) from 2007/2010 to 2018

	# sites with species present (non-bare)*	Gain	Loss	Loss to Absent	No Change
Total Seagrass	500	**4.6%**	**65.6%**	**50.8%**	**29.8%**
H. wrightii	331	**11.5%**	**57.1%**	**41.7%**	**31.4%**
H. johnsonii	436	**12.4%**	**72.9%**	**63.1%**	**14.7%**
S. filiforme	52	**21.2%**	**63.5%**	**57.7%**	**15.4%**
H. decipiens	95	**24.2%**	**69.5%**	**60.0%**	**6.3%**
T. testudinum	21	**33.3%**	**66.7%**	**66.7%**	**0.0%**

5.0 Discussion

It is unknown how long seagrasses have persisted in the Loxahatchee River Estuary (LRE). Given the history of hydrologic alterations throughout the 20th century, current seagrass beds likely established sometime after 1947 when the Jupiter inlet was permanently opened and maintained (McPherson *et al*. 1982). The salinity within the estuary resulting from a permanent inlet eventually facilitated the establishment of seagrasses. By the 1980s, seagrasses presence had been documented and had established as a valuable ecosystem component of the estuary (McPherson *et al*. 1982). Throughout the 1990's, the Jupiter Inlet

District (JID) conducted biannual seagrass surveys that documented seagrass in regions within and immediately adjacent to the central embayment of the estuary. This region continues to have the most coverage of seagrass, which coincides with the influx of clear marine water through Jupiter Inlet into the estuary during flood tide. Seagrass mapping efforts by the Loxahatchee River District (LRD) in the late 90s and in 2003 documented seagrass within the central bay as well as seagrass' extent into each of the river forks; the first known documentation of seagrass extent into the freshwater river.

This report offers a current snapshot of the distribution, abundance, patchiness, and composition of seagrasses in the LRE as of the summer of 2018. Seagrass continues to persist in the LRE in regions historically documented to support seagrass. These areas mostly include the central bay (CB), lower reaches of the north fork (NF), and along the shallow shoreline from the railroad bridge east (ERR) to just inside the Jupiter Inlet. These regions have shallow bathymetry and generally good water quality (i.e. good clarity), particularly during flood tide.

However, seagrass in the LRE has experienced substantial changes since the assessments of 2007 and 2010. The most striking change has been in the overall loss of seagrass. For example, half of the sample sites assessed in 2018 experienced a complete absence of seagrass where seagrass had been present. While all regions of the estuary experienced a decline in seagrass, nowhere was seagrass loss more apparent than in the southwest fork (SWF) where during 2007 and 2010 up to 58% of the sample sites evaluated had seagrass present, but by 2018, seagrass was absent from all sites assessed within this river fork. The northwest fork (NWF) of the LRE is where the federally designated "Wild & Scenic" river enters the estuary and in 2007 and 2010 had seagrass present well upstream. However, during the 2018 assessment, seagrass here experienced a substantial decline and had largely retreated downstream. Data from the Loxahatchee River District (LRD)s long-term bimonthly monitoring project at a site in the NWF (26° 57.52' N, 80° 7.22' W) show that seagrass in this area declined rapidly following tropical storm Isaac in August 2012. During and following tropical storm Isaac, excess stormwater was released through the S-46 control structure for flood control resulting in 7 days of more than 1,000 cubic feet per minute and a sustained rate of greater than 500 cfs for 18 days of freshwater into the SWF which substantially reduced mean salinity and increased salinity fluctuation in the SWF (LRD unpublished data). The extended period of low and highly variable salinity has been shown to negatively impact seagrasses in the LRE (Ridler *et al* 2006) and was likely detrimental to the seagrasses in both the NW and SW forks of the LRE and the seagrass have subsequently failed to re-establish (compare Appendix 1a to Appendix 2a).

The average BBCA score across the LRE in 2018 was very low. Nearly 90% of sites with seagrass had a BBCA equal to less than 50% while only a few sites had a score equal to greater than 75% (see maps in Appendix 3). The total seagrass BBCA scores are driven by the seagrasses *H. wrightii* and *H. johnsonii*, the two most frequently encountered and widely distributed seagrasses. These were also the only seagrasses during the assessment to have a BBCA score equal to greater than 50%. The remaining seagrasses, *H. decipiens*, *S. filiforme*, and *T. testudinum*, in addition to occurring in small isolated patches also had minimal vegetative cover.

The observation that *H. wrightii* and *H. johnsonii* frequently occurred together at the same site suggests that both exhibit similar tolerances to the physical conditions, though it should be noted that these same two species also formed substantial monospecific beds. The seagrass *H. decipiens* was typically found in monospecific patches and tended to be found deeper than other seagrasses, demonstrating their ability to grow in lower light conditions.

Given the observations presented in this report, it would seem natural for one to ask “why?”. However, it is well beyond the scope of this report to investigate potential drivers of seagrass decline as that is a subject of further study. However, the LRE experiences many of the factors often attributed to global seagrass decline (Orth et al. 2006). The LRE is especially susceptible to periods of reduced salinity associated with flood control releases of stormwater during and following storms and major rain events which can significantly alter the salinity of the estuary (Ridler *et al*. 2006). The LRE also experiences erosion and scour effects associated with increased boat traffic, and significant sediment accretion throughout the lower estuary; although such impacts to seagrass in the LRE remain to be quantified. This report should serve as a starting point from which to launch much needed investigations into the decline in seagrass in the LRE. At the very least, we have documented a substantial decline in the presence of seagrasses in the LRE and added a waypoint in the timeline of seagrass presence and health. At most, we hope that these results come to the attention of stakeholders and policy makers in such a way that informed decision can be made to better protect this valuable habitat.

Acknowledgements

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References

Braun-Blanquet, J. 1932. Plant sociology. The study of plant communities. *Plant sociology. The study of plant communities. First ed.* 539 pp.

Dawes, C.J., D. Hanisak, and J.W. Kenworthy. 1995. Seagrass biodiversity in the Indian River Lagoon. Bul. Mar. Sci. 57(1), 59–66.

Green, E. P., F. T. Short, & T. Frederick. 2003. *World atlas of seagrasses*. Univ of California Press.

Howard, B., L. Bachman, J. Metz, and D. A. Arrington. 2001. Loxahatchee River seagrass monitoring and mapping report. Task 4: Final Report; in fulfillment of Agreement No. 4600001907. https://loxahatchee-qnewmedia.netdna-ssl.com/pdf/DSG-2009-2010.pdf

Klemm, J. and C. Vare. 1985. Seagrass distribution map of the Loxahatchee River basin area. Palm Beach County Dept. Environmental Resource Management.

Lirman, D., W. P. Cropper. 2003. The influence of salinity on seagrass growth, survivorship, and distribution within Biscayne Bay, Florida: Field, experimental, and modeling studies. Estuaries 26 (1) 131-141.

McPherson, B. F. and M. Sabanskas. 1980. Hydrologic and landcover features of the Loxahatchee River basin, Florida, USA. USGS (No. 80-1109).

McPherson, B. F., Sabanskas, M., & Long, W. A. 1982. Physical, hydrological, and biological characteristics of the Loxahatchee River Estuary, Florida. USGS (No. 82-350).

Montague, C.L., Ley, J.A., 1993. A possible effect of salinity fluctuation on abundance of benthic vegetation and associated fauna in Northeastern Florida Bay. Estuaries 16,703–717.

Orth, R.J., T.J.B. Carruthers, W.C. Dennison, C.M. Duarte, J.W. Fourqurean, K.L.A. Heck, R. Hughes, G.A. Kendrick, W.J. Kenworthy, S. Olyarnik, F.T. Short, M. Waycott, and S.L. Williams. 2006. A global crisis for seagrass ecosystems. Bioscience 56(12), 987–996.

Ridler, M.S., Dent, R.C., Bachman L.R., 2003. Viability and variability of seagrass communities in the Loxahatchee Estuary and associated reach of the Indian River Lagoon. Loxahatchee River District. Jupiter FL. 28pp.

Ridler, M.S., Dent, R.C., Arrington, D.A., 2006. Effects of two hurricanes on *Syringodium filiforme*, manatee grass, within the Loxahatchee River Estuary, Southeast Florida. Estuaries Coast. 29, 1019–1025.

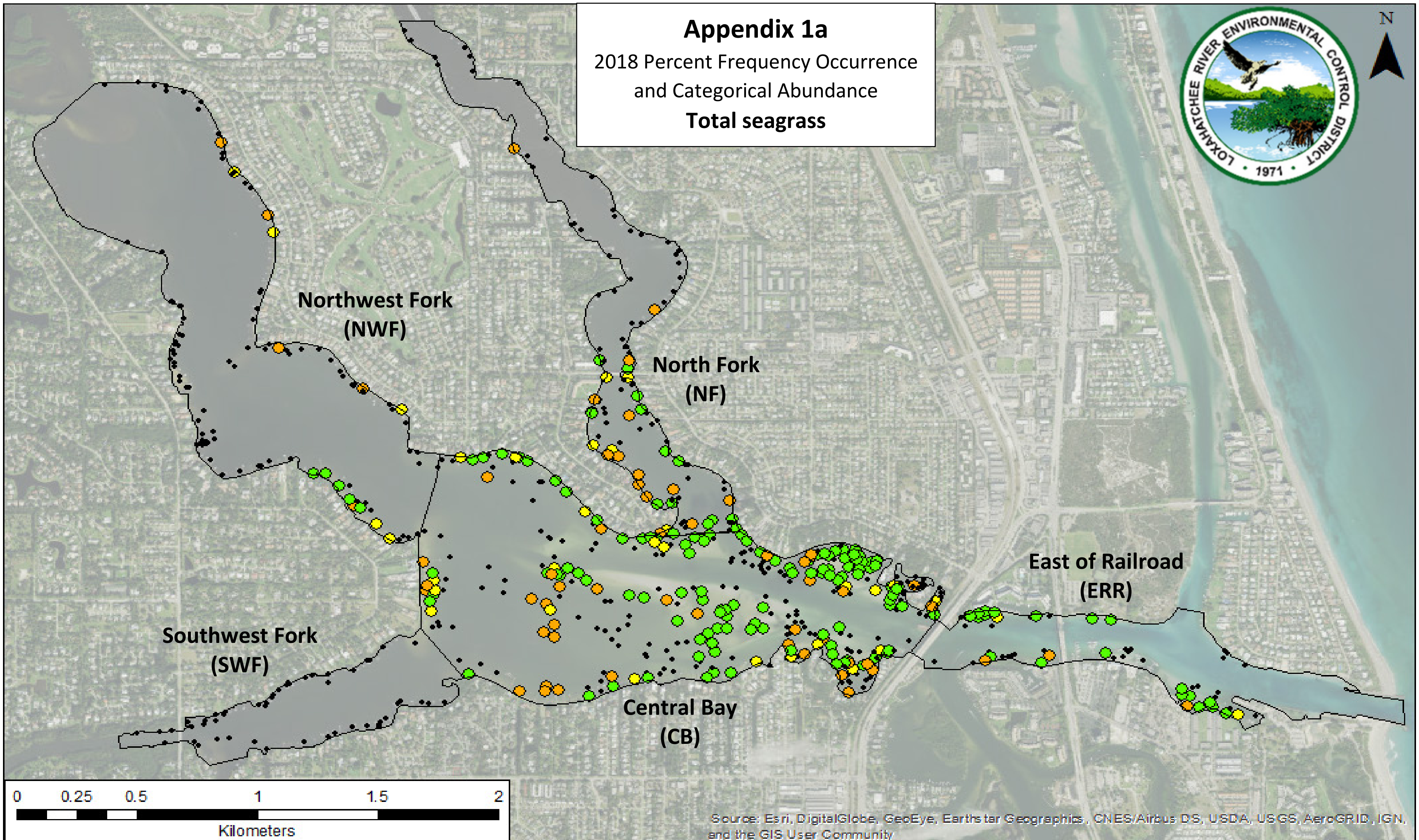
SFWMD, 2006. Restoration plan for the northwest fork of the Loxahatchee River.

Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck, A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, F.T. Short, and S.L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. PNAS 106(30), 12377–12381.

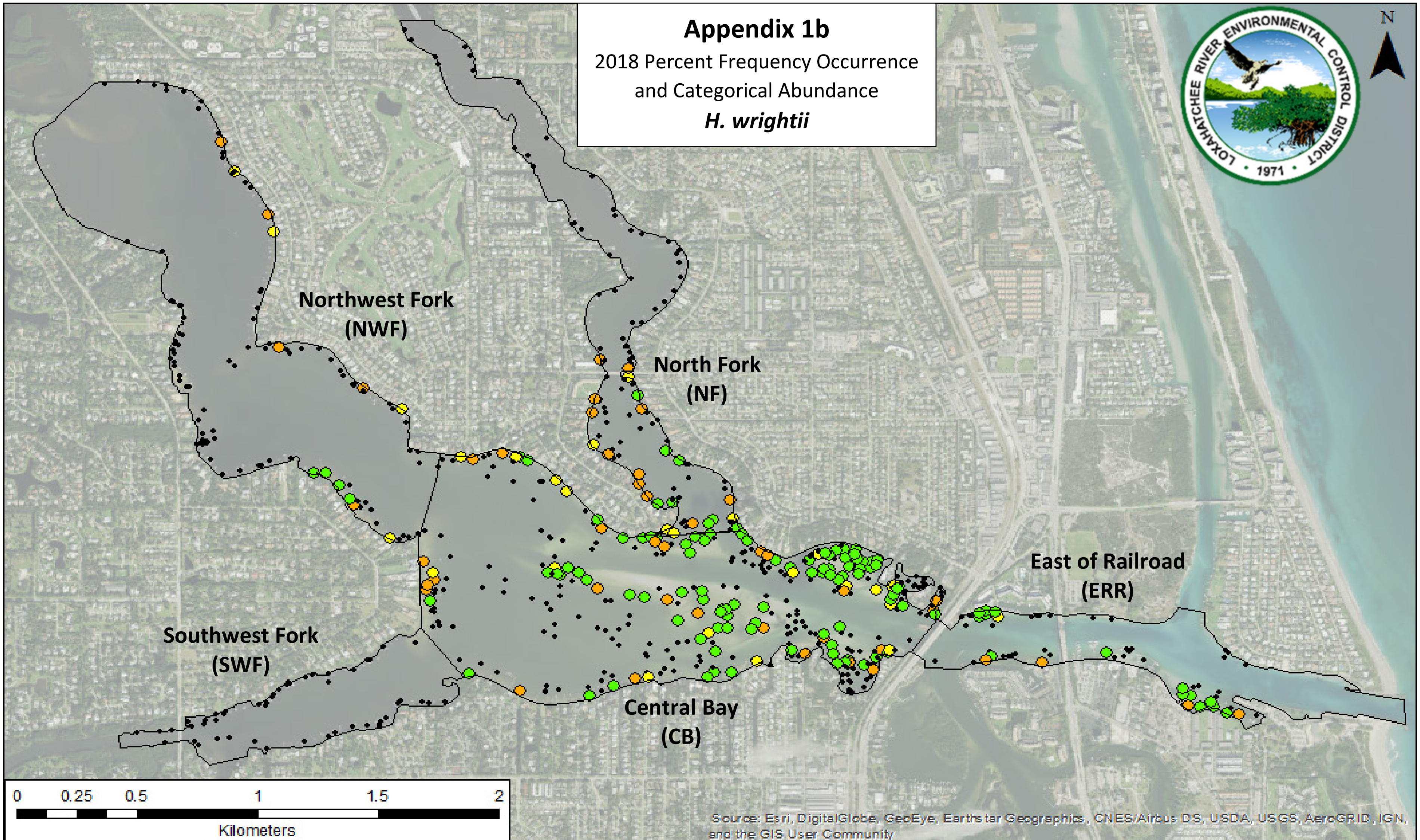
Appendix 1a

2018 Percent Frequency Occurrence and Categorical Abundance

Total seagrass



	Fraction of sites with seagrass present:	2018 Seagrass	
Continuous (7–9)	Continuous: **62.2%**	Percentage of all sites (n=656) occupied by seagrass: **37.5%**	Map showing the location of sample sites assessed during summer 2018. The color of each site indicates the category of **total seagrass** abundance based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.
Patchy (4-6)	Patchy: **13.4%**		
Sparse (1-3)	Sparse: **24.4%**		
Absent (0)			

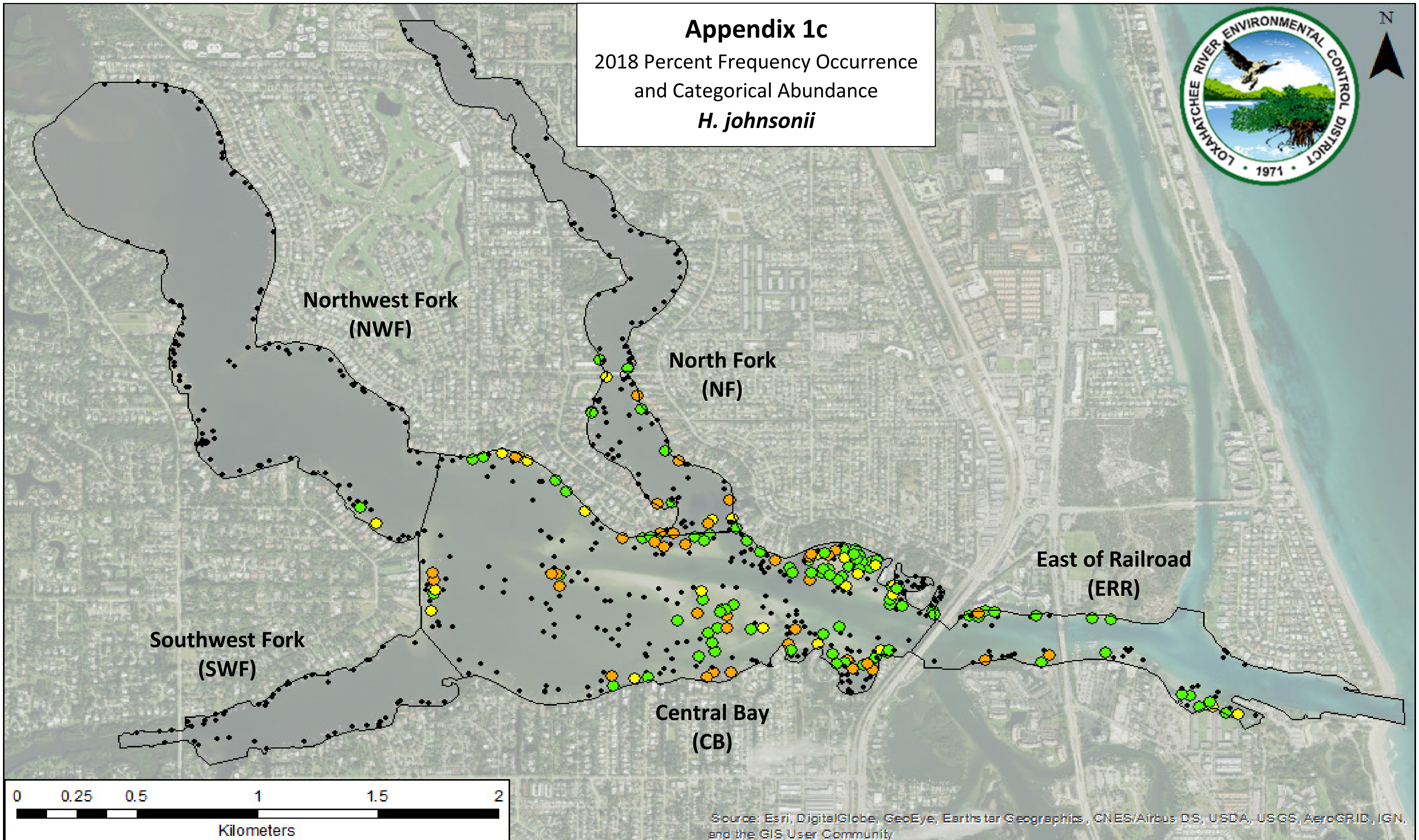


Continuous (7–9) Patchy (4-6) Sparse (1-3) • Absent (0)	Fraction of sites with *H. wrightii* present: Continuous: **62.2%** Patchy: **14.0%** Sparse: **23.8%**	2018 Seagrass Fraction of all sites (n=656) occupied by *H. wrightii*: **29.4%**	Map showing the location of sample sites assessed during summer 2018. The color of each site indicates the category of ***H. wrightii*** abundance based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

Appendix 1c

2018 Percent Frequency Occurrence and Categorical Abundance

H. johnsonii



Continuous (7–9)
Patchy (4-6)
Sparse (1-3)
Absent (0)

Fraction of sites with *H. johnsonii* present:

Continuous: **58.4%**
Patchy: **15.5%**
Sparse: **26.1%**

2018 Seagrass

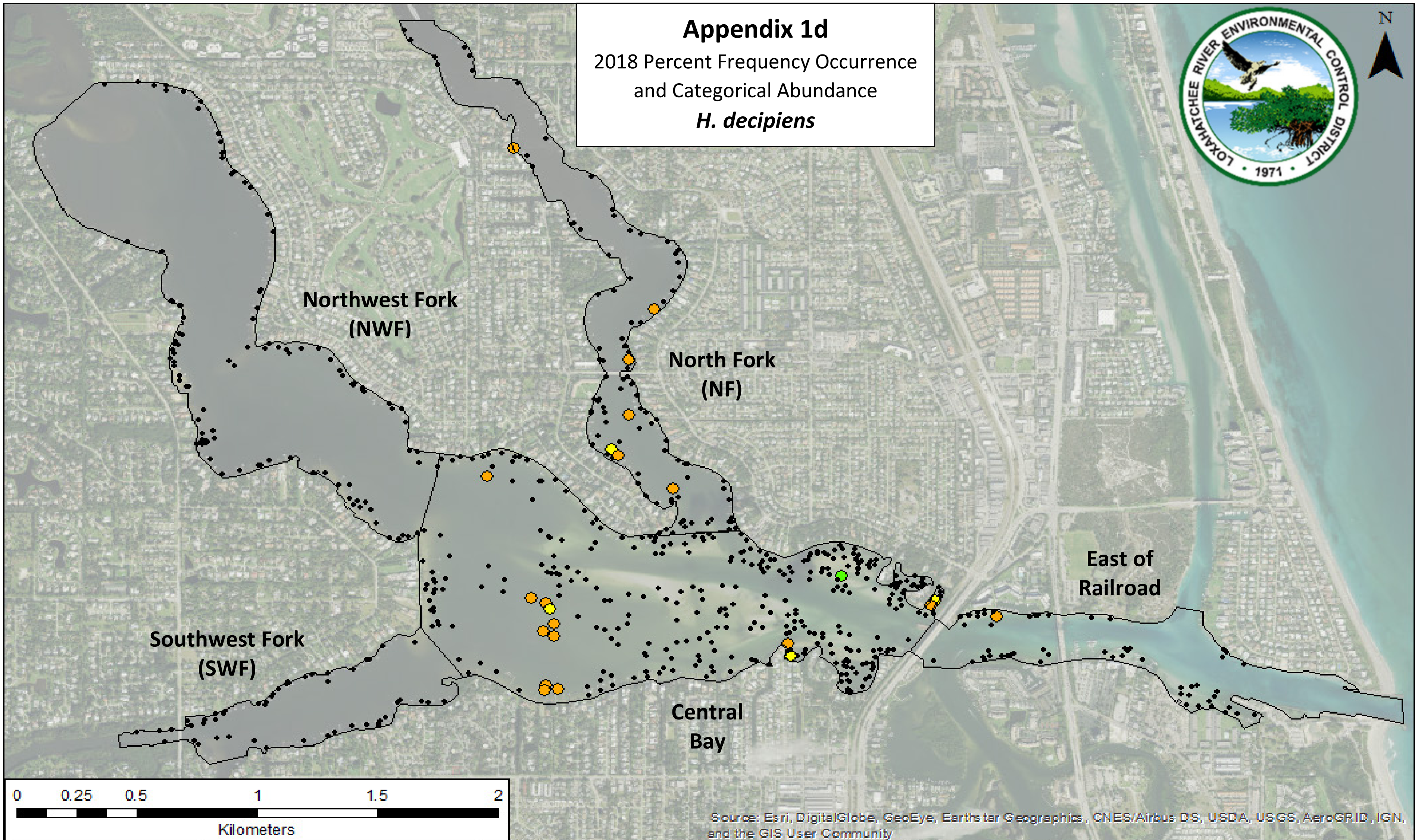
Fraction of all sites (n=656) occupied by *H. johnsonii*: **24.5%**

Map showing the location of sample sites assessed during summer 2018. The color of each site indicates the category of ***H. johnsonii*** abundance based on the count of 1 m^2 cells (0–9) occupied by seagrass within the $9m^2$ collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

Appendix 1d

2018 Percent Frequency Occurrence and Categorical Abundance

H. decipiens

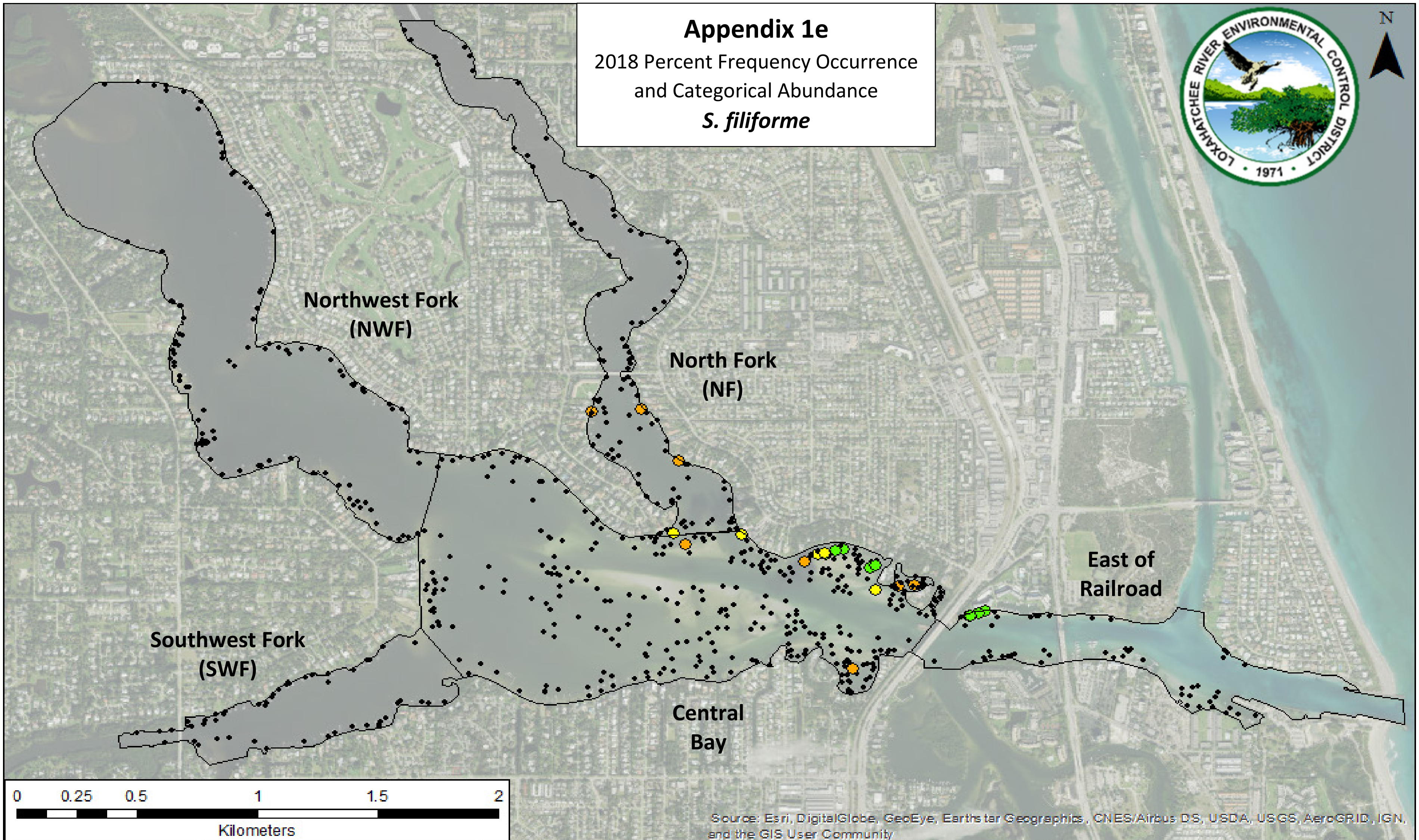


	Fraction of sites with *H. decipiens* present:	2007 Seagrass	
Continuous (7–9)	Continuous: **4.3%**	Fraction of all sites (n=656) occupied by *H. decipiens*: **3.5%**	Map showing the location of sample sites assessed during summer 2018. The color of each site indicates the category of ***H. decipiens*** abundance based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.
Patchy (4-6)	Patchy: **17.4%**		
Sparse (1-3)	Sparse: **78.3%**		
Absent (0)			

Appendix 1e

2018 Percent Frequency Occurrence and Categorical Abundance

S. filiforme



- Continuous (7–9)
- Patchy (4-6)
- Sparse (1-3)
- Absent (0)

Fraction of sites with *S. filiforme* present:

Continuous: **40.9%**
Patchy: **22.7%**
Sparse: **36.4%**

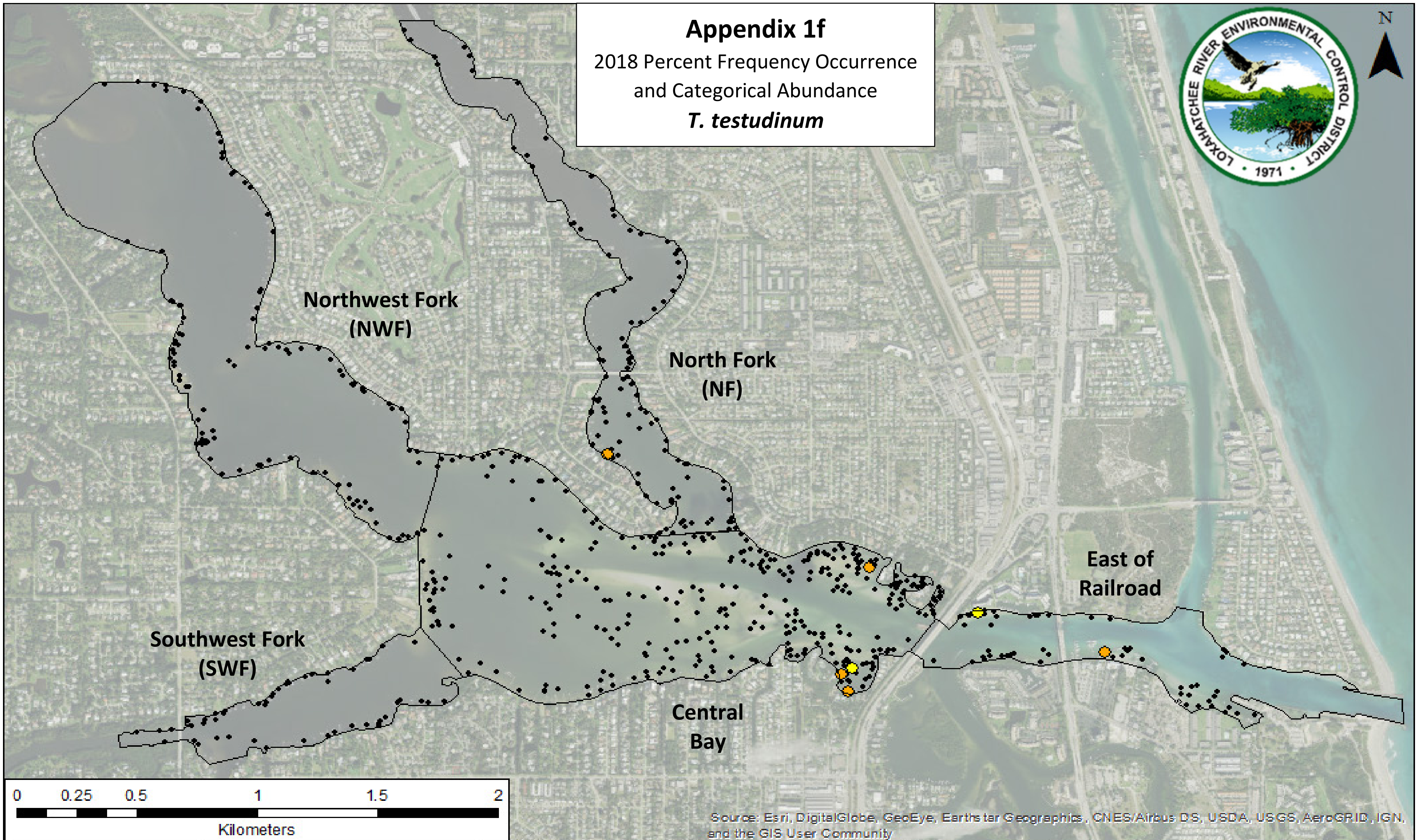
2018 Seagrass

Fraction of all sites (n=656) occupied by *S. filiforme*: **3.4%**

Map showing the location of sample sites assessed during summer 2018. The color of each site indicates the category of ***S. filiforme*** abundance based on the count of 1 m^2 cells (0–9) occupied by seagrass within the $9m^2$ collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

Appendix 1f

2018 Percent Frequency Occurrence
and Categorical Abundance
T. testudinum

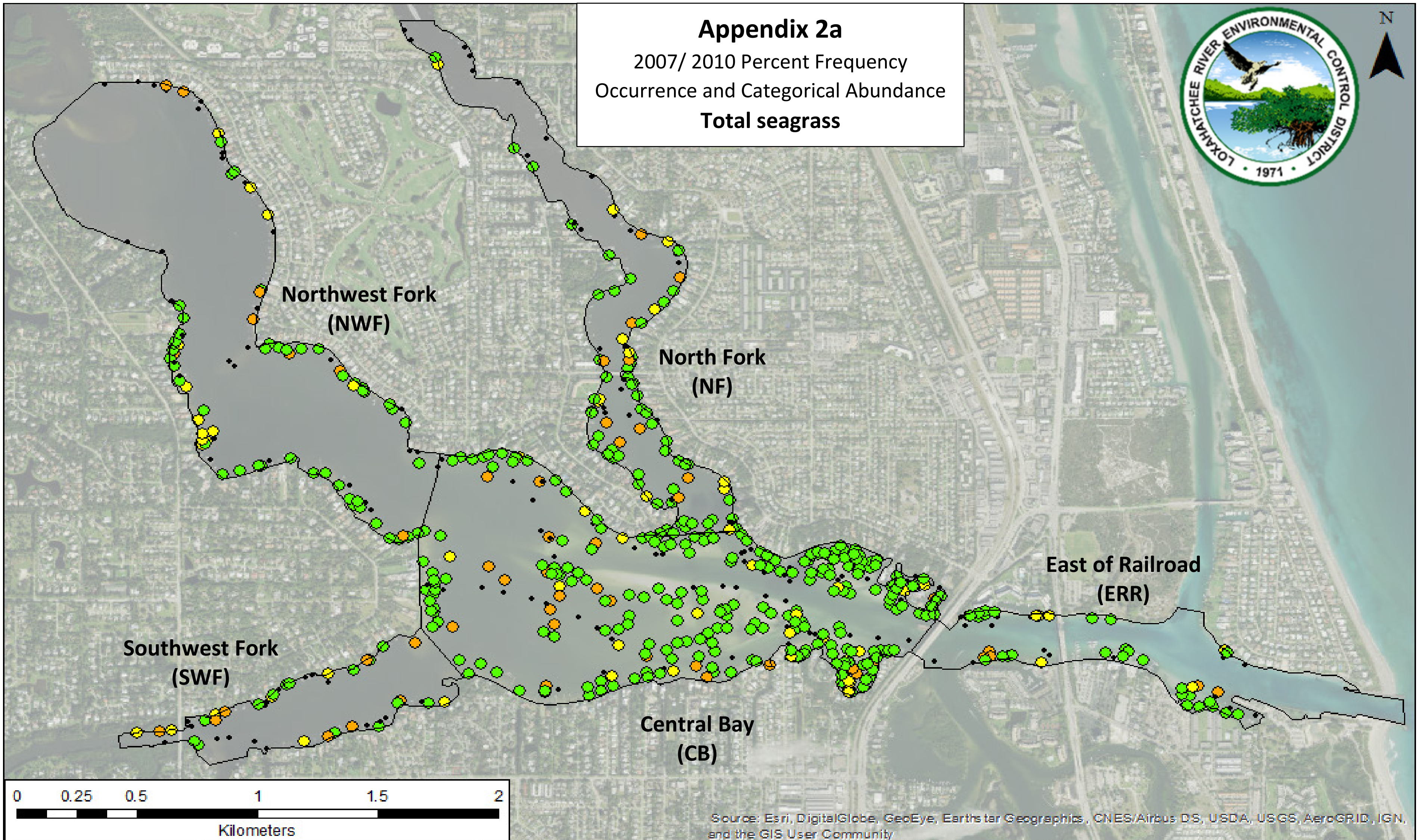


Continuous (7–9) Patchy (4-6) Sparse (1-3) • Absent (0)	Fraction of sites with *T. testudinum* present: Continuous: **0%** Patchy: **28.6%** Sparse: **71.4%**	**2018 Seagrass** Fraction of all sites (n=656) occupied by *T. testudinum*: **1.1%**	Map showing the location of sample sites assessed during summer 2018. The color of each site indicates the category of ***T. testudinum*** abundance based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

Appendix 2a

2007/ 2010 Percent Frequency Occurrence and Categorical Abundance

Total seagrass

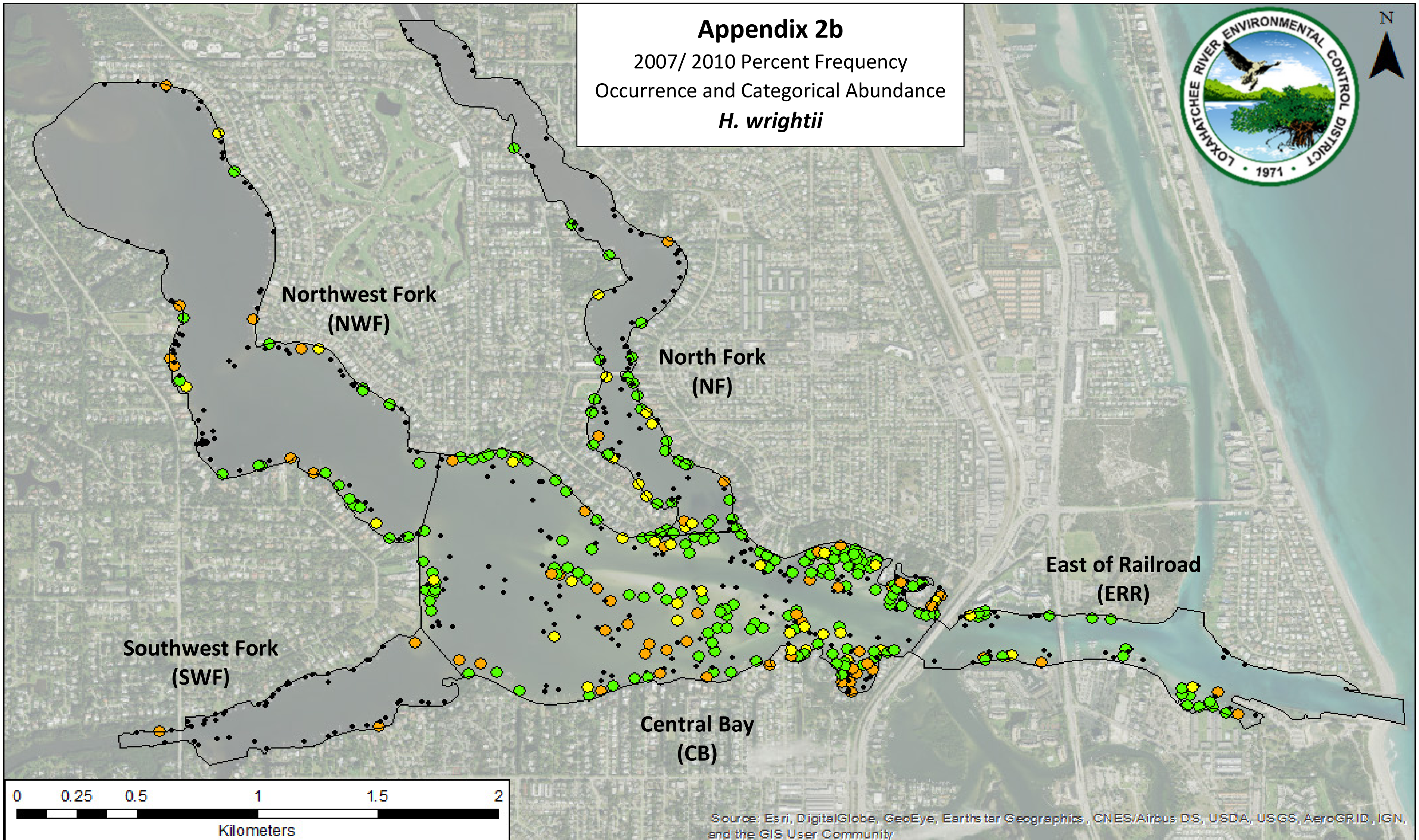


Continuous (7–9) Patchy (4-6) Sparse (1-3) Absent (0)	Fraction of sites with seagrass present: Continuous: **76.4%** Patchy: **12.5%** Sparse: **11.1%**	2007/2010 Seagrass Fraction of all sites (n=656) occupied by seagrass: **74.2%**	Map showing location of sample sites assessed in 2018 displayed with respective data from the 2007/2010 assessments. Displayed are the presence (and absence) of **total seagrass** based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

Appendix 2b

2007/ 2010 Percent Frequency Occurrence and Categorical Abundance

H. wrightii



- Continuous (7–9)
- Patchy (4-6)
- Sparse (1-3)
- Absent (0)

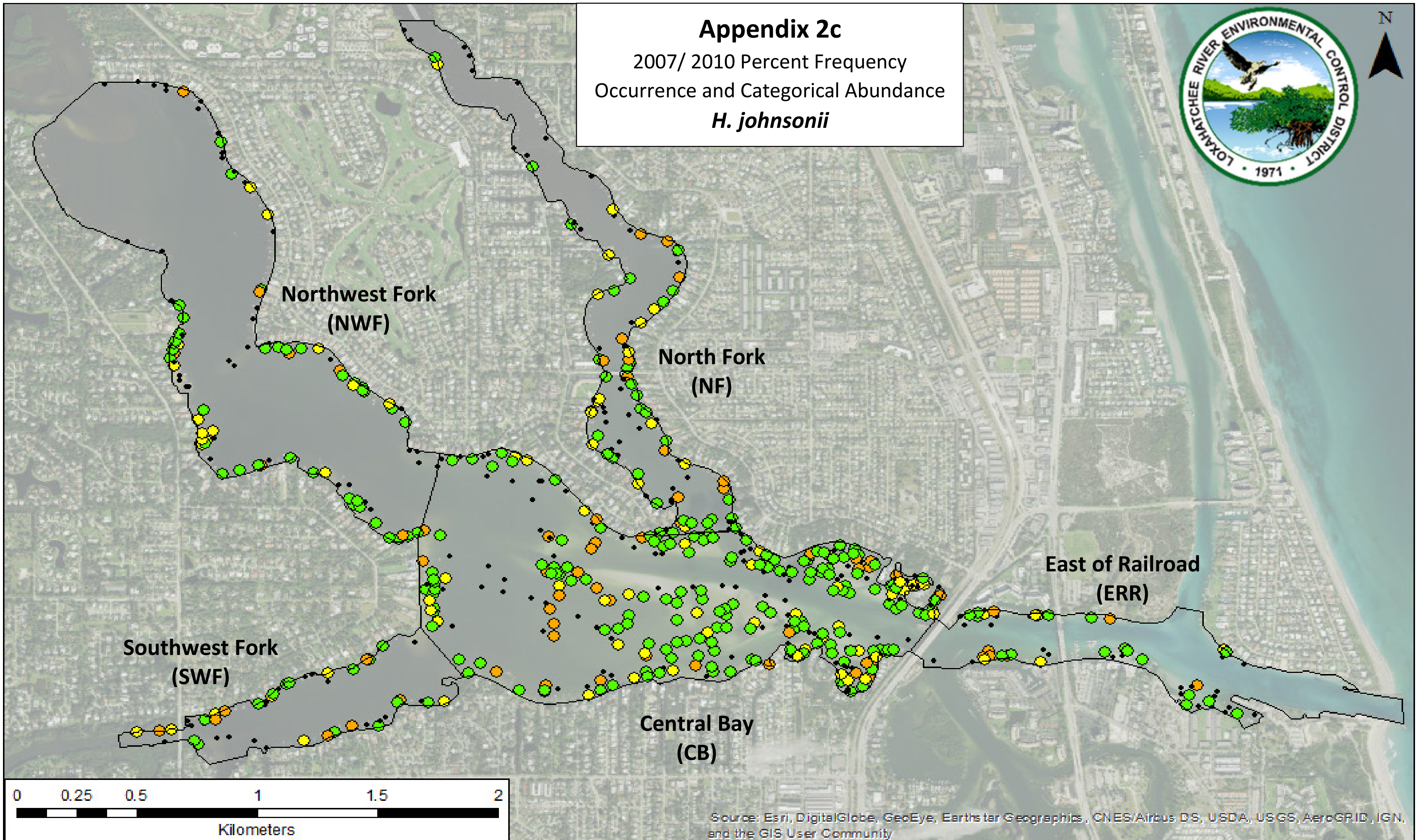
Fraction of sites with H. wrightii present:

Continuous: **67.3%**
Patchy: **13.4%**
Sparse: **19.3%**

2007/2010 Seagrass

Fraction of all sites (n=656) occupied by seagrass: **46.6%**

Map showing location of sample sites assessed in 2018 displayed with respective data from the 2007/2010 assessments. Displayed are the presence (and absence) of ***H. wrightii*** presence based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

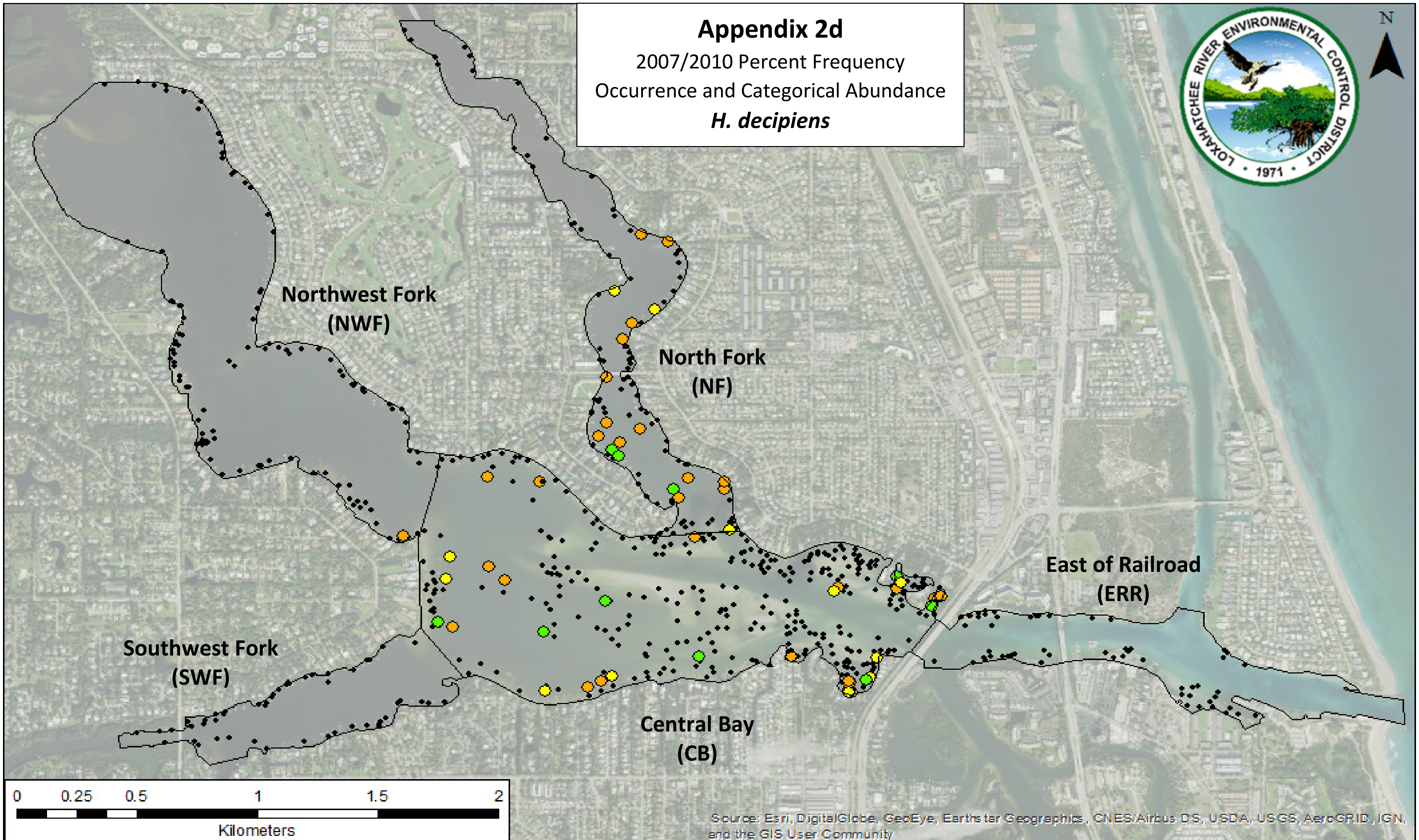


	Fraction of sites with *H. johnsonii* present:	2007/2010 Seagrass	
Continuous (7–9) Patchy (4-6) Sparse (1-3) • Absent (0)	Continuous: **62.5%** Patchy: **20.4%** Sparse: **17.1%**	Fraction of all sites (n=656) occupied by seagrass: **60.5%**	Map showing location of sample sites assessed in 2018 displayed with respective data from the 2007/2010 assessments. Displayed are the presence (and absence) of ***H. johnsonii*** presence based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

Appendix 2d

2007/2010 Percent Frequency Occurrence and Categorical Abundance

H. decipiens

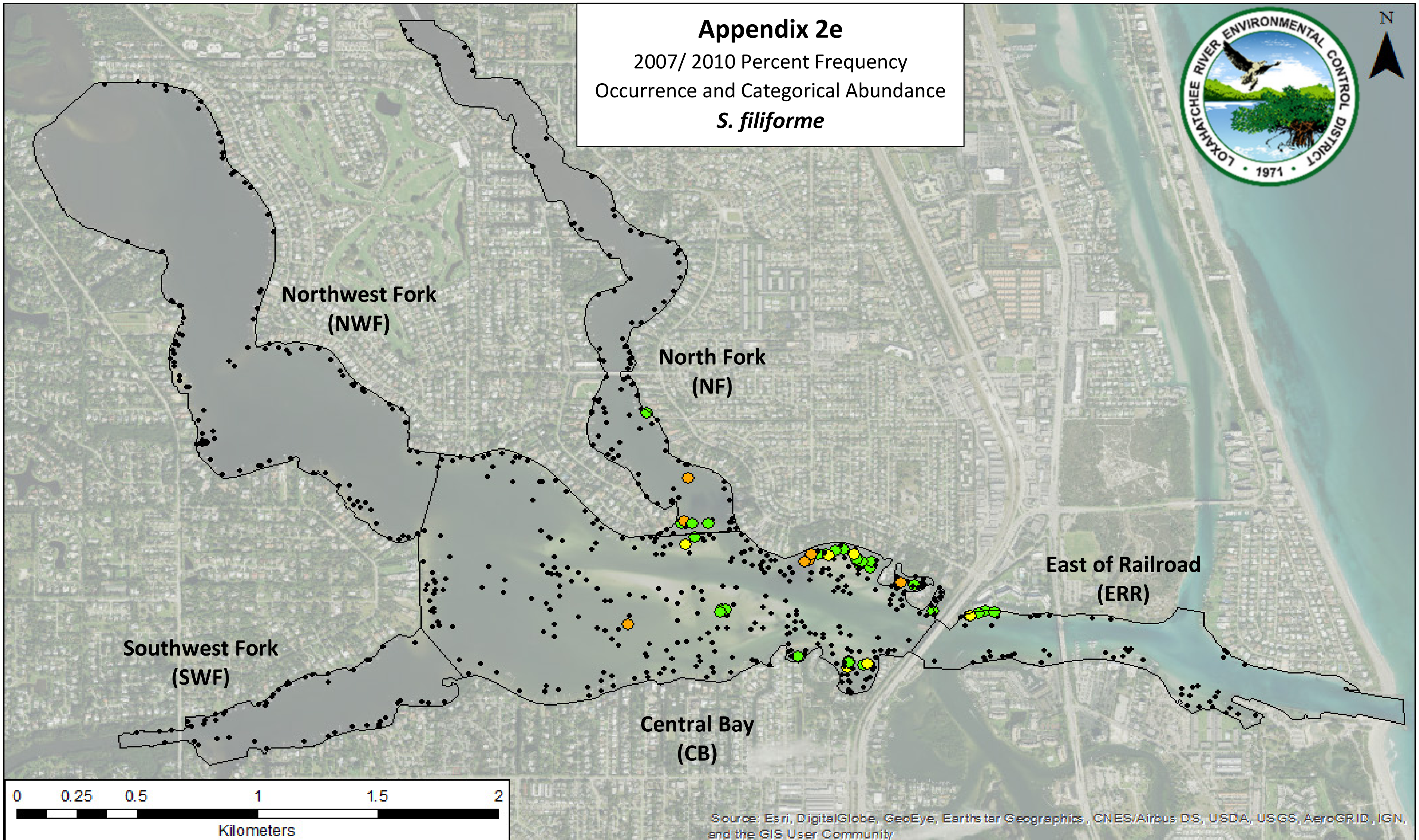


Continuous (7–9) Patchy (4-6) Sparse (1-3) • Absent (0)	Fraction of sites with *H. decipiens* present: Continuous: **18.9%** Patchy: **24.5%** Sparse: **56.6%**	2007/2010 Seagrass Fraction of all sites (n=656) occupied by seagrass: **8.1%**	Map showing location of sample sites assessed in 2018 displayed with respective data from the 2007/2010 assessments. Displayed are the presence (and absence) of ***H. decipiens*** presence based on the count of 1 m^2 cells (0–9) occupied by seagrass within the 9m^2 collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

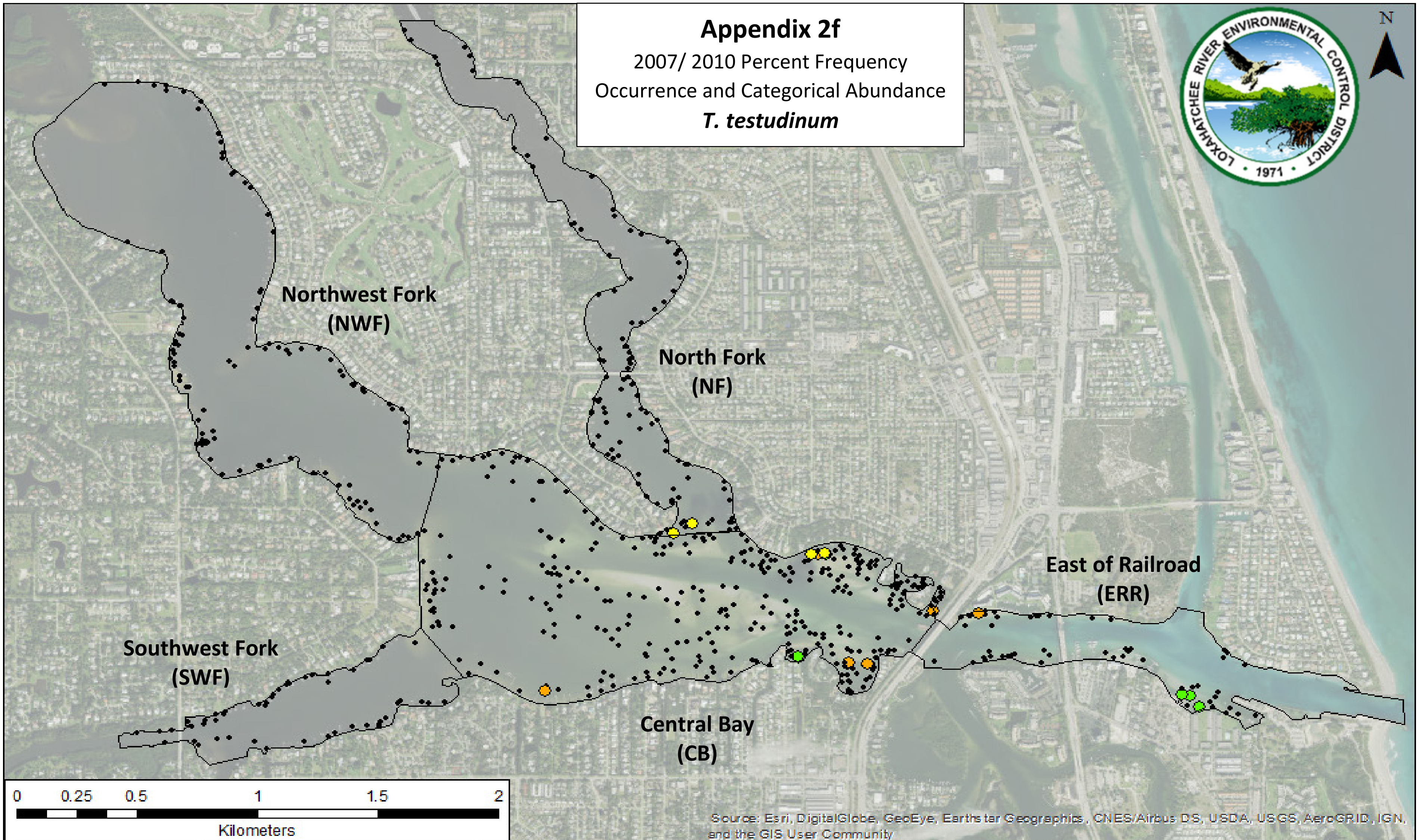
Appendix 2e

2007/ 2010 Percent Frequency Occurrence and Categorical Abundance

S. filiforme

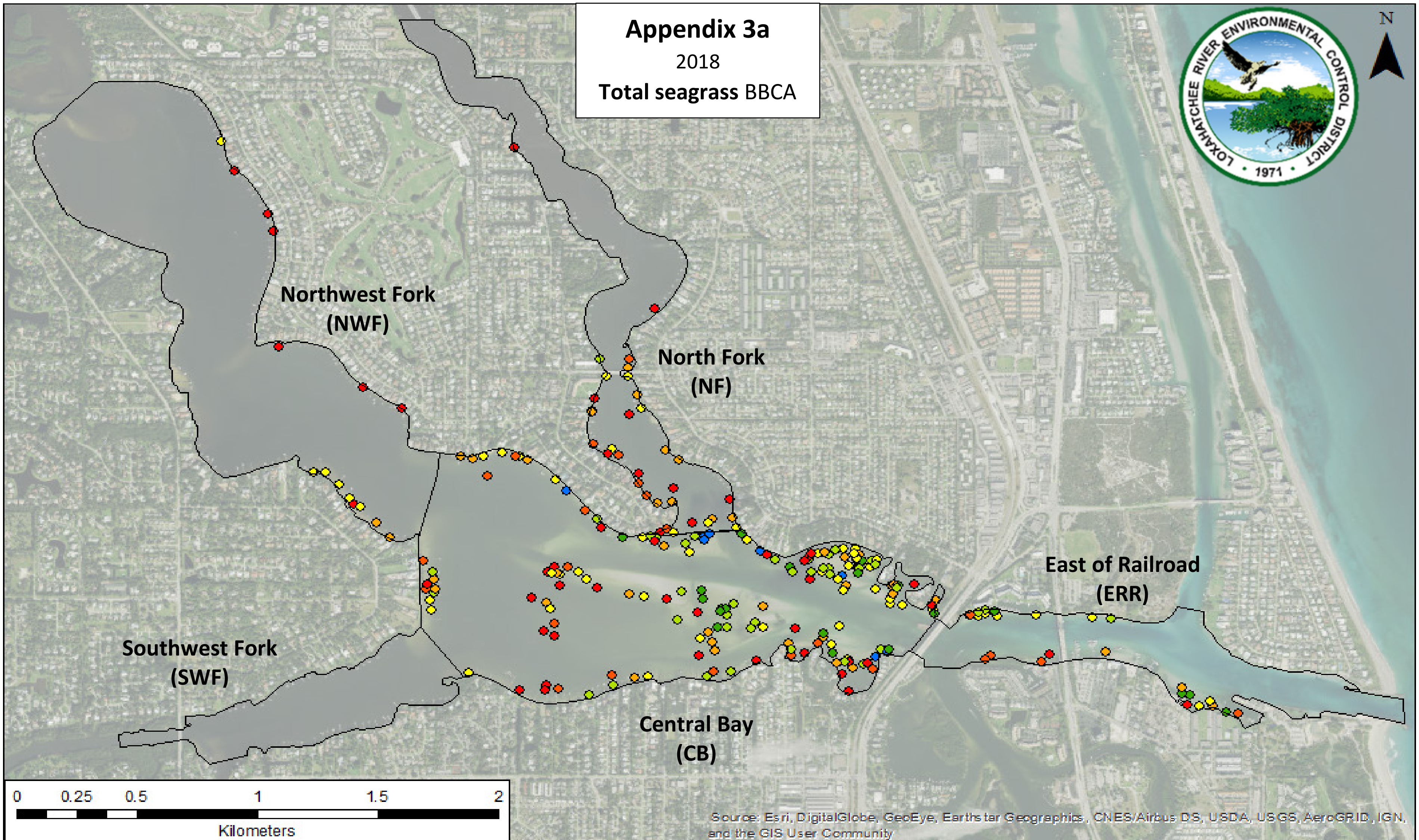


	Fraction of sites with *S. filiforme* present:	2007/2010 Seagrass	
Continuous (7–9)	Continuous: **69.0%**	Fraction of all sites (n=656) occupied by seagrass: **6.4%**	Map showing location of sample sites assessed in 2018 displayed with respective data from the 2007/2010 assessments. Displayed are the presence (and absence) of ***S. filiforme*** presence based on the count of 1 m^2 cells (0–9) occupied by seagrass within the $9m^2$ collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.
Patchy (4-6)	Patchy: **14.3%**		
Sparse (1-3)	Sparse: **16.7%**		
Absent (0)			



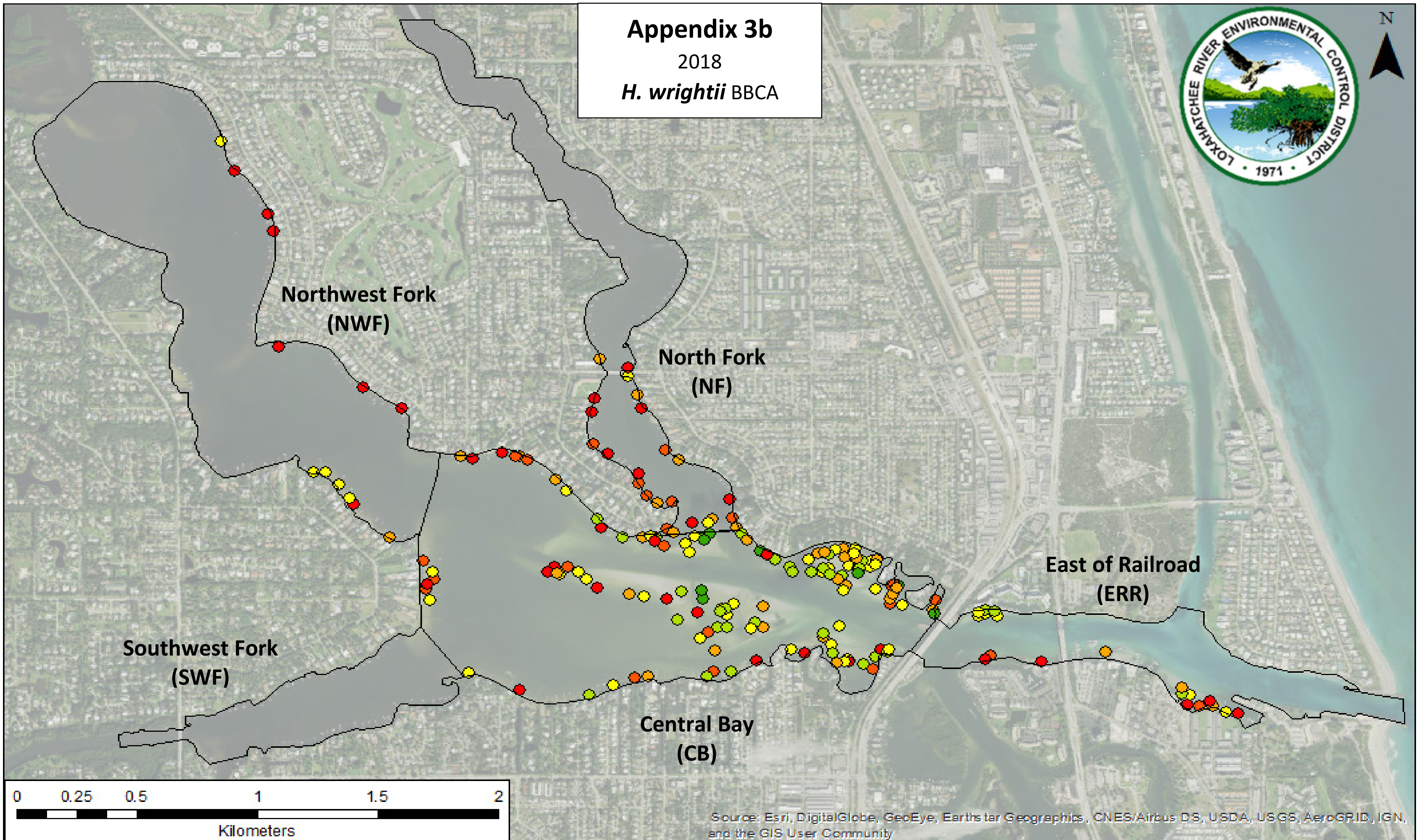
Continuous (7–9) Patchy (4-6) Sparse (1-3) Absent (0)	Fraction of sites with *T. testudinum* present: Continuous: **33.3%** Patchy: **26.7%** Sparse: **40.0%**	2007/2010 Seagrass Fraction of all sites (n=656) occupied by seagrass: **2.3%**	Map showing location of sample sites assessed in 2018 displayed with respective data from the 2007/2010 assessments. Displayed are the presence (and absence) of ***T. testudinum*** presence based on the count of 1 m^2 cells (0–9) occupied by seagrass within the $9m^2$ collapsible quadrat deployed at each site. Table at left indicates percent of sample sites represented by each abundance category and table at center indicates percent frequency.

Appendix 3a
2018
Total seagrass BBCA



	Fraction of sites with each class where seagrass is present:
<< 1	<< 1: **20.7%**
< 1	<1: **9.8%**
1-5	1-5: **17.5%**
5-25	5-25: **24.8%**
25-50	25-50: **15.9%**
50-75	50-75: **8.1%**
> 75	>75: **3.3%**

Map showing location of the 2018 sample sites where seagrass was present and the associated density estimate. The color of each sample site indicates estimated percent cover of **total seagrass** based on the 8-point Braun-Blanquet Cover Abundance scale shown in legend at far left. Table on left indicates the percent of sample sites that fall into each percent cover range.



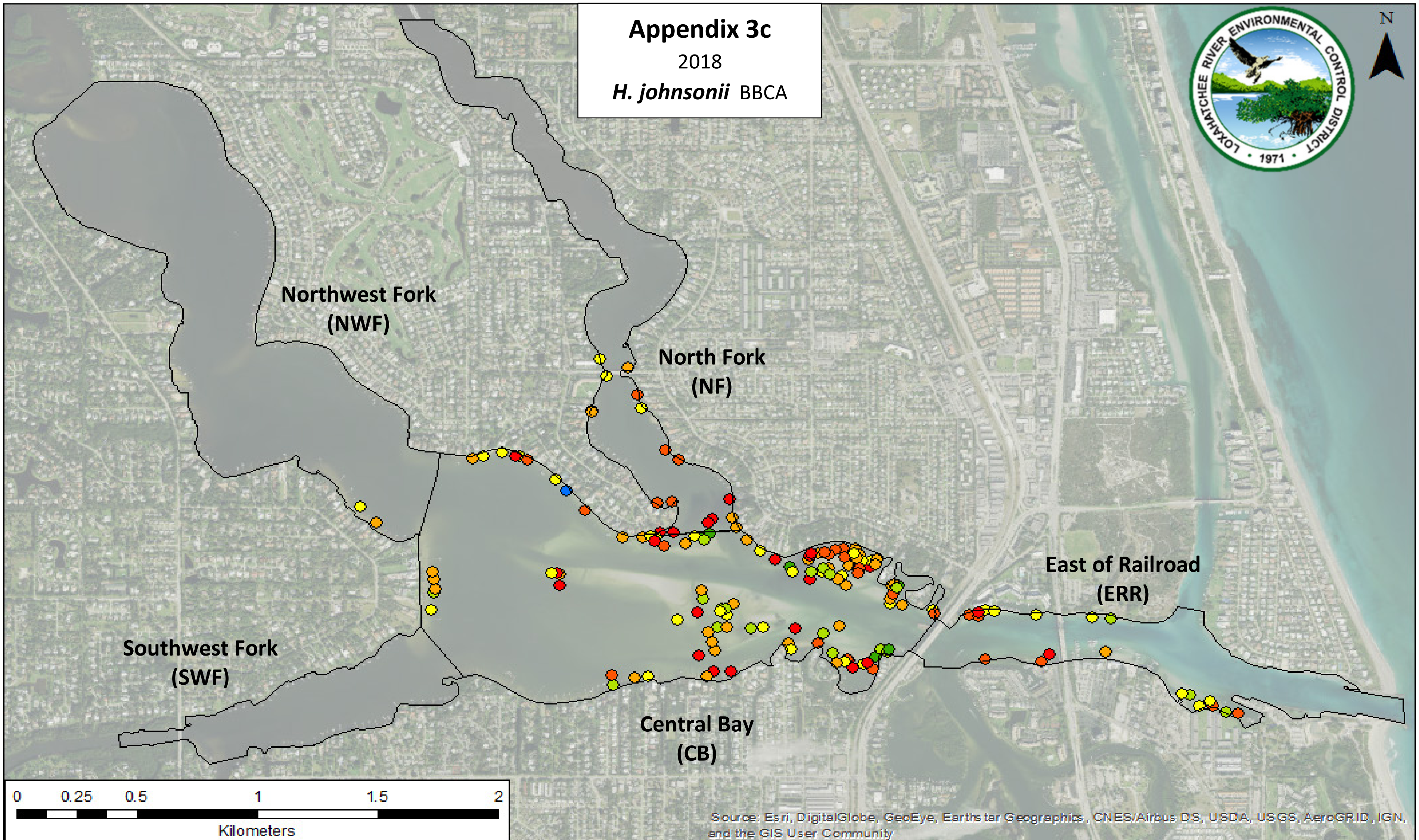
- << 1
- < 1
- 1-5
- 5-25
- 25-50
- 50-75
- > 75

Fraction of sites with each class where *H. wrightii* was present:

<< 1: **19.2%** 25-50: **16.6%**
<1: **12.4%** 50-75: **4.7%**
1-5: **20.7%** >75: **0%**
5-25: **26.4%**

Map showing location of the 2018 sample sites where seagrass was present and the associated density estimate. The color of each sample site indicates estimated percent cover of ***H. wrightii*** based on the 8-point Braun-Blanquet Cover Abundance scale shown in legend at far left. Table on left indicates the percent of sample sites that fall into each percent cover range.

Appendix 3c
2018
H. johnsonii BBCA



- << 1
- < 1
- 1-5
- 5-25
- 25-50
- 50-75
- > 75

Fraction of sites with each class where *H. johnsonii* was present:

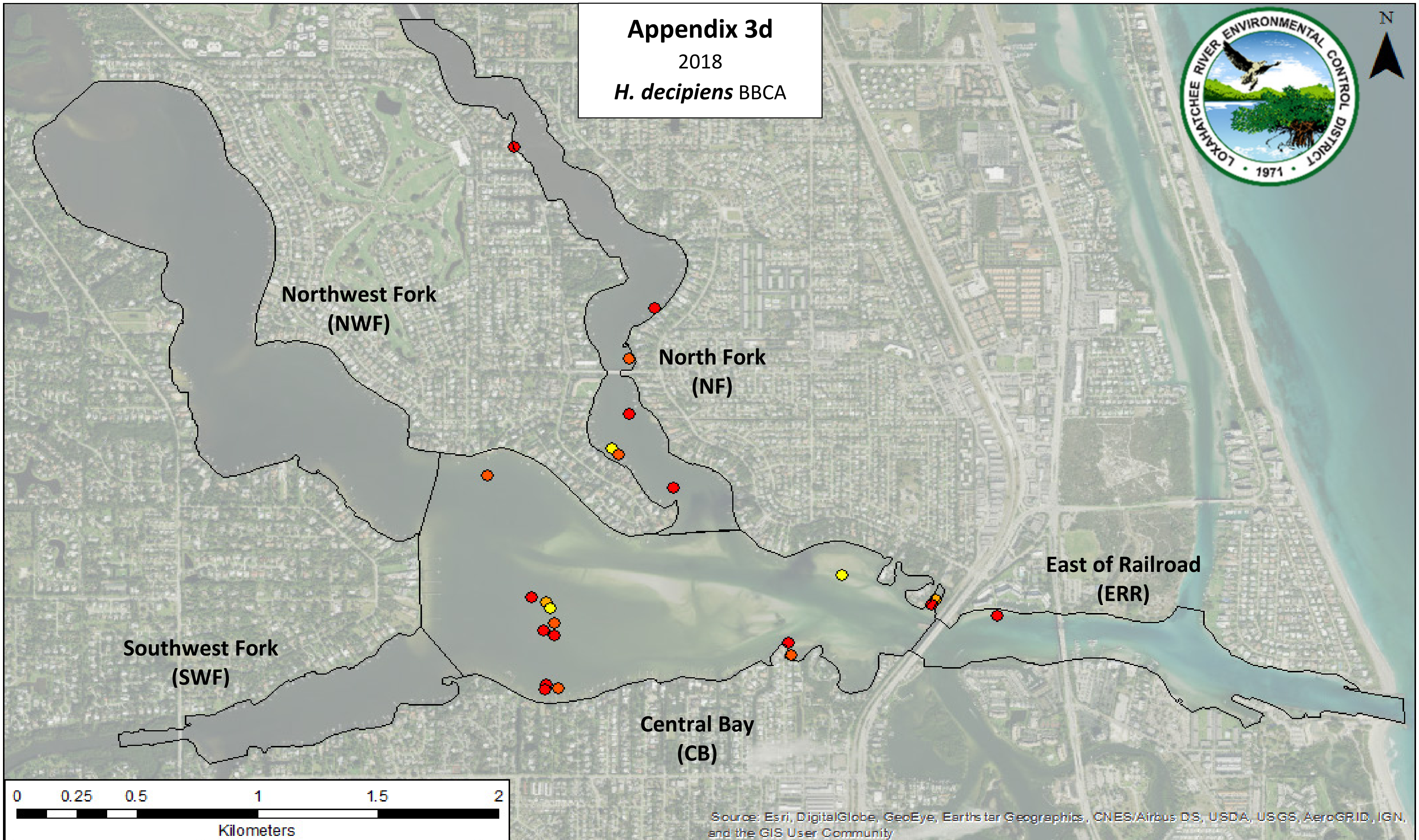
<< 1: **17.4%** 25-50: **11.8%**
<1: **16.8%** 50-75: **3.7%**
1-5: **26.7%** >75: **0.6%**
5-25: **23.0%**

Map showing location of the 2018 sample sites where seagrass was present and the associated density estimate. The color of each sample site indicates estimated percent cover of ***H. johnsonii*** based on the 8-point Braun-Blanquet Cover Abundance scale shown in legend at far left. Table on left indicates the percent of sample sites that fall into each percent cover range.

Appendix 3d

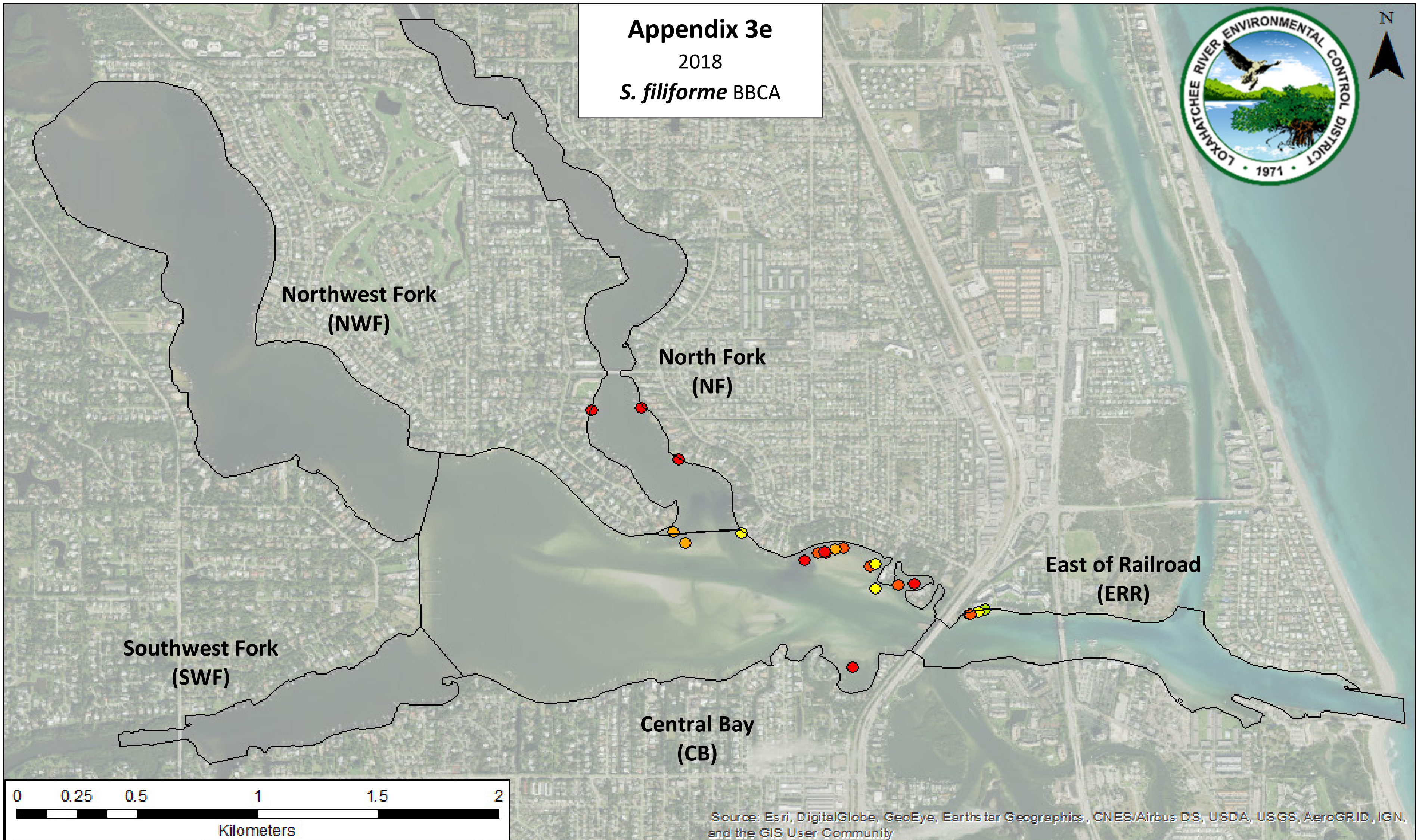
2018

H. decipiens BBCA



<< 1	Fraction of sites with each class where *H. decipiens* was present:
< 1	<< 1: **52.2%** 25-50: **0%**
1-5	<1: **26.1%** 50-75: **0%**
5-25	1-5: **8.7%** >75: **0%**
25-50	5-25: **13.0%**
50-75	
> 75	

Map showing location of the 2018 sample sites where seagrass was present and the associated density estimate. The color of each sample site indicates estimated percent cover of ***H. decipiens*** based on the 8-point Braun-Blanquet Cover Abundance scale shown in legend at far left. Table on left indicates the percent of sample sites that fall into each percent cover range.



<< 1
< 1
1-5
5-25
25-50
50-75
> 75

Fraction of sites with each class where *S. filiforme* was present:

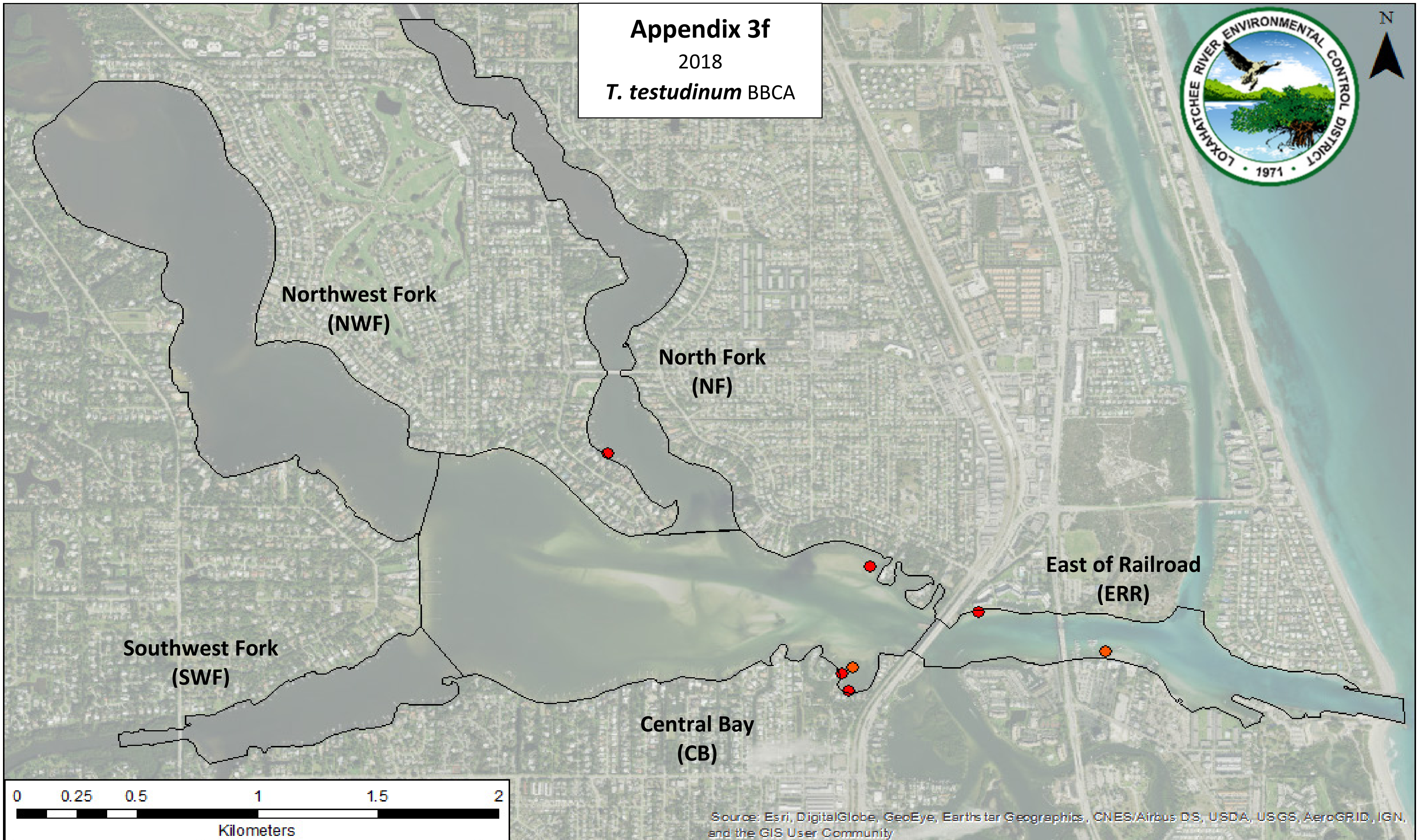
<< 1: **36.4%** 25-50: **4.5%**
<1: **27.3%** 50-75: **0%**
1-5: **13.6%** >75: **0%**
5-25: **18.2%**

Map showing location of the 2018 sample sites where seagrass was present and the associated density estimate. The color of each sample site indicates estimated percent cover of ***S. filiforme*** based on the 8-point Braun-Blanquet Cover Abundance scale shown in legend at far left. Table on left indicates the percent of sample sites that fall into each percent cover range.

Appendix 3f

2018

T. testudinum BBCA

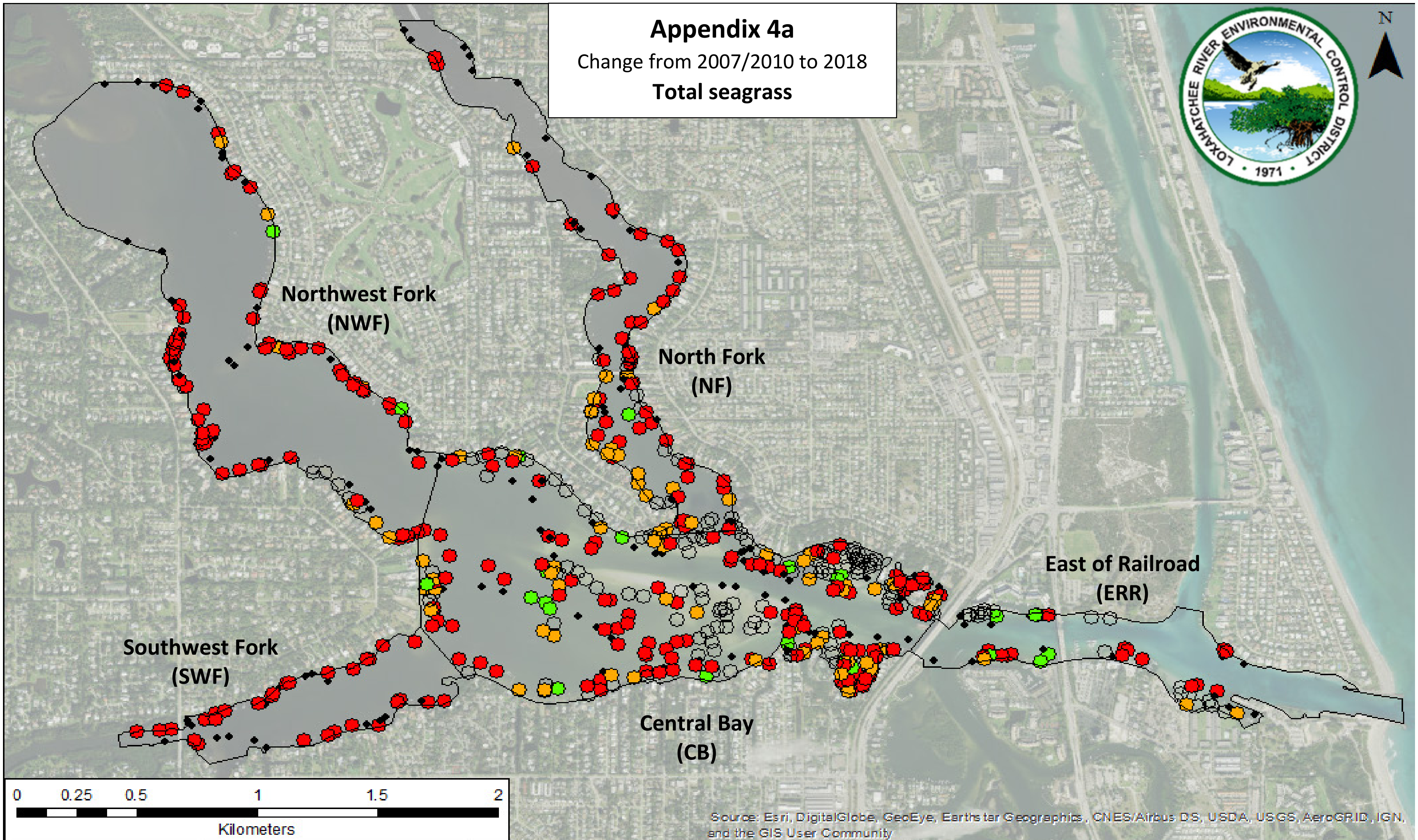


- << 1
- < 1
- 1-5
- 5-25
- 25-50
- 50-75
- > 75

Fraction of sites with each class where *T. testudinum* was present:

<< 1: **71.4%**	25-50: **0%**
<1: **28.6%**	50-75: **0%**
1-5: **0%**	>75: **0%**
5-25: **0%**	

Map showing location of the 2018 sample sites where seagrass was present and the associated density estimate. The color of each sample site indicates estimated percent cover of ***T. testudinum*** based on the 8-point Braun-Blanquet Cover Abundance scale shown in legend at far left. Table on left indicates the percent of sample sites that fall into each percent cover range.



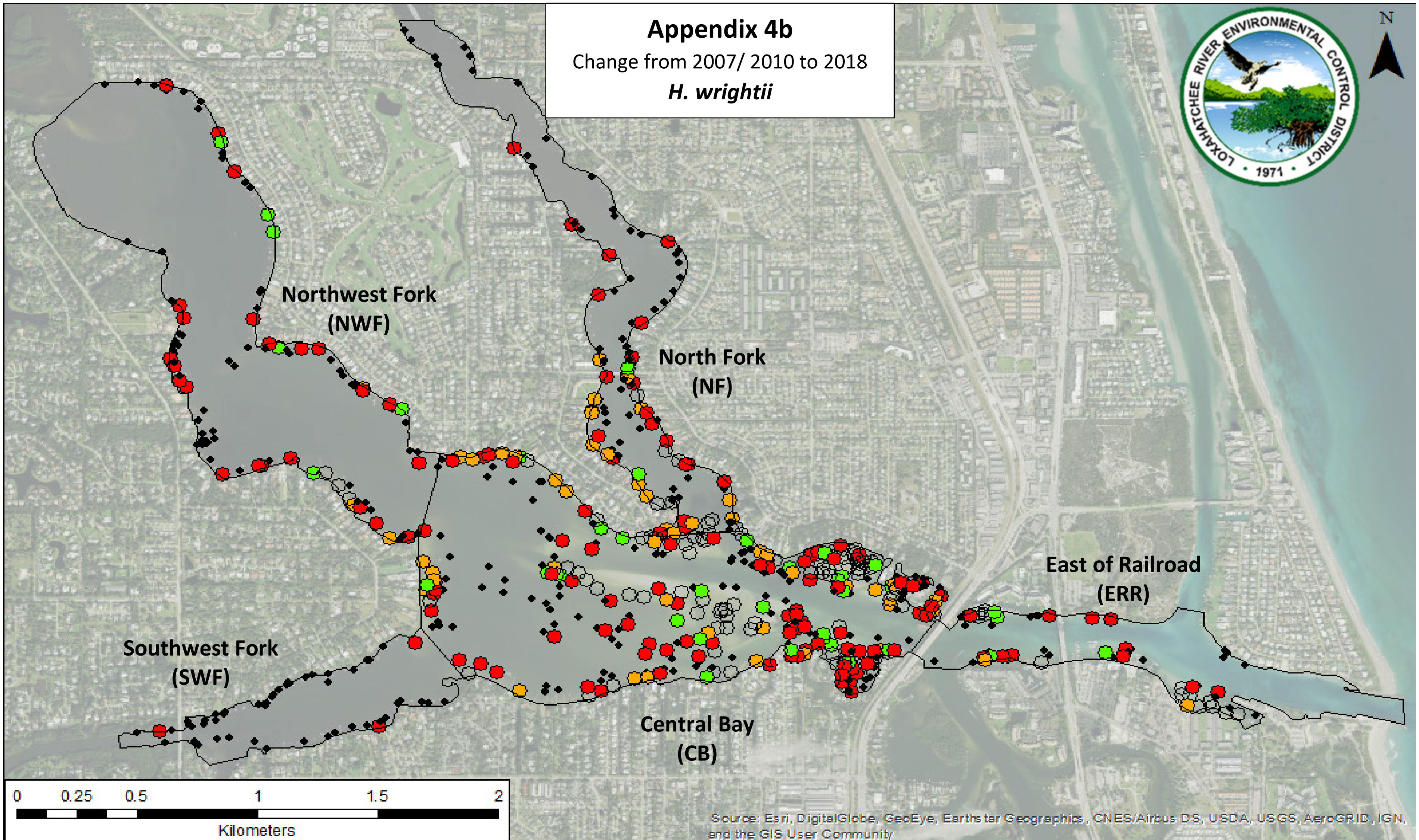
Gain	Gain: **4.2%**
Loss	Loss: **64.0%**
Loss-Absent	Loss to Absent: **49.6%**
No Change	No Change: **29.8%**
Always Bare	

Map showing location of all sample sites assessed in 2018 and their associated change. Color of each sample site indicates direction of change of **total seagrass** presence between 2007/2010 and 2018 based on categorical values. “Loss to Absent” is a subset of the “Loss” category and indicates sites where seagrass was present in 2007/2010 but was absent in 2018. “Always Bare” indicates sites where seagrass was not found during either assessment. Table at left indicates the fraction of sites that fall into each change category.

Appendix 4b

Change from 2007/ 2010 to 2018

H. wrightii



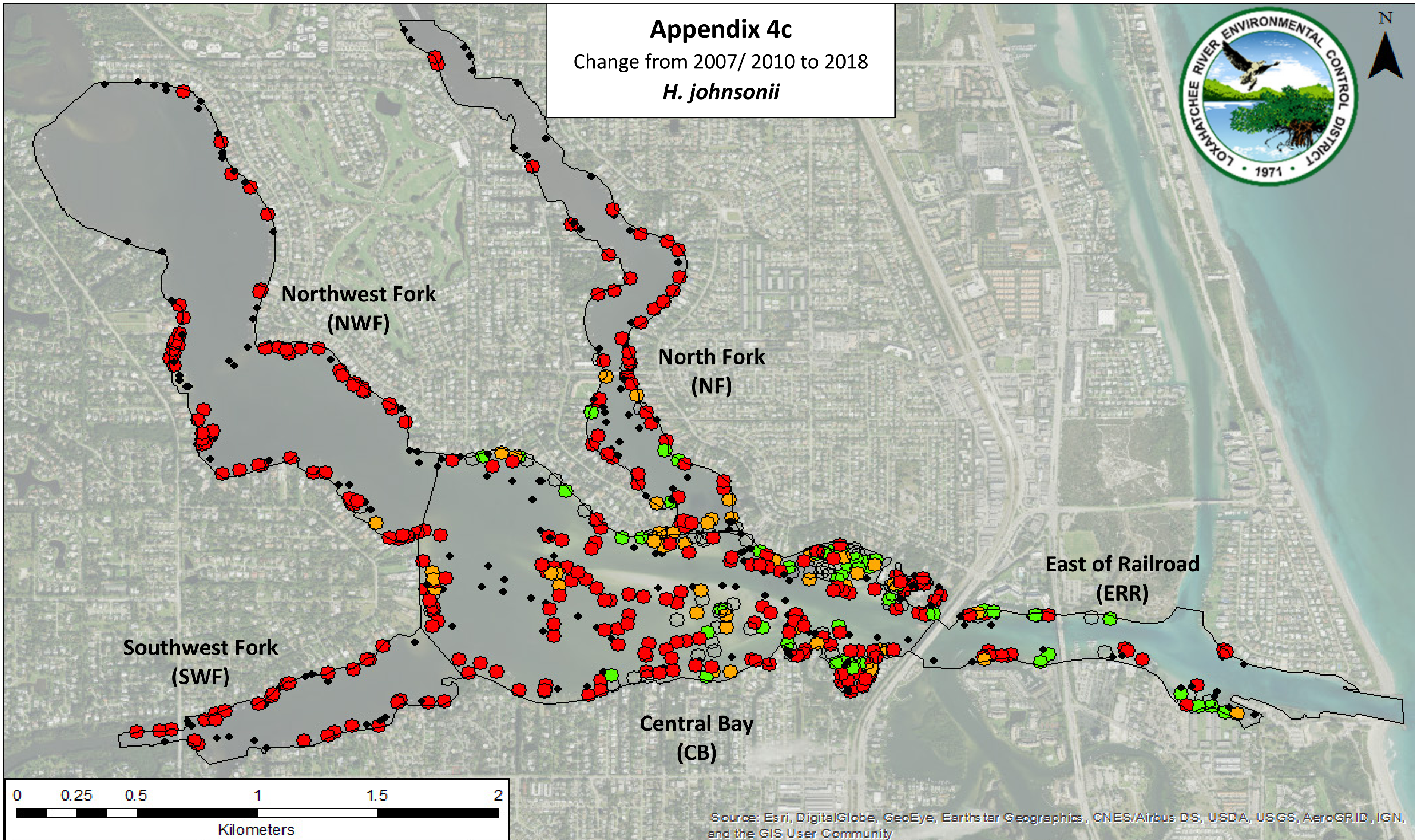
Gain	Gain: **11.5%**
Loss	Loss: **57.1%**
Loss to Absent	Loss to Absent: **41.7%**
No Change	No Change: **31.4%**
Always Bare	

Map showing location of all sample sites assessed in 2018 and their associated change. Color of each sample site indicates direction of change of ***H. wrightii*** presence between 2007/2010 and 2018 based on categorical values. “Loss to Absent” is a subset of the “Loss” category and indicates sites where seagrass was present in 2007/2010 but was absent in 2018. “Always Bare” indicates sites where seagrass was not found during either assessment. Table at left indicates the fraction of sites that fall into each change category.

Appendix 4c

Change from 2007/ 2010 to 2018

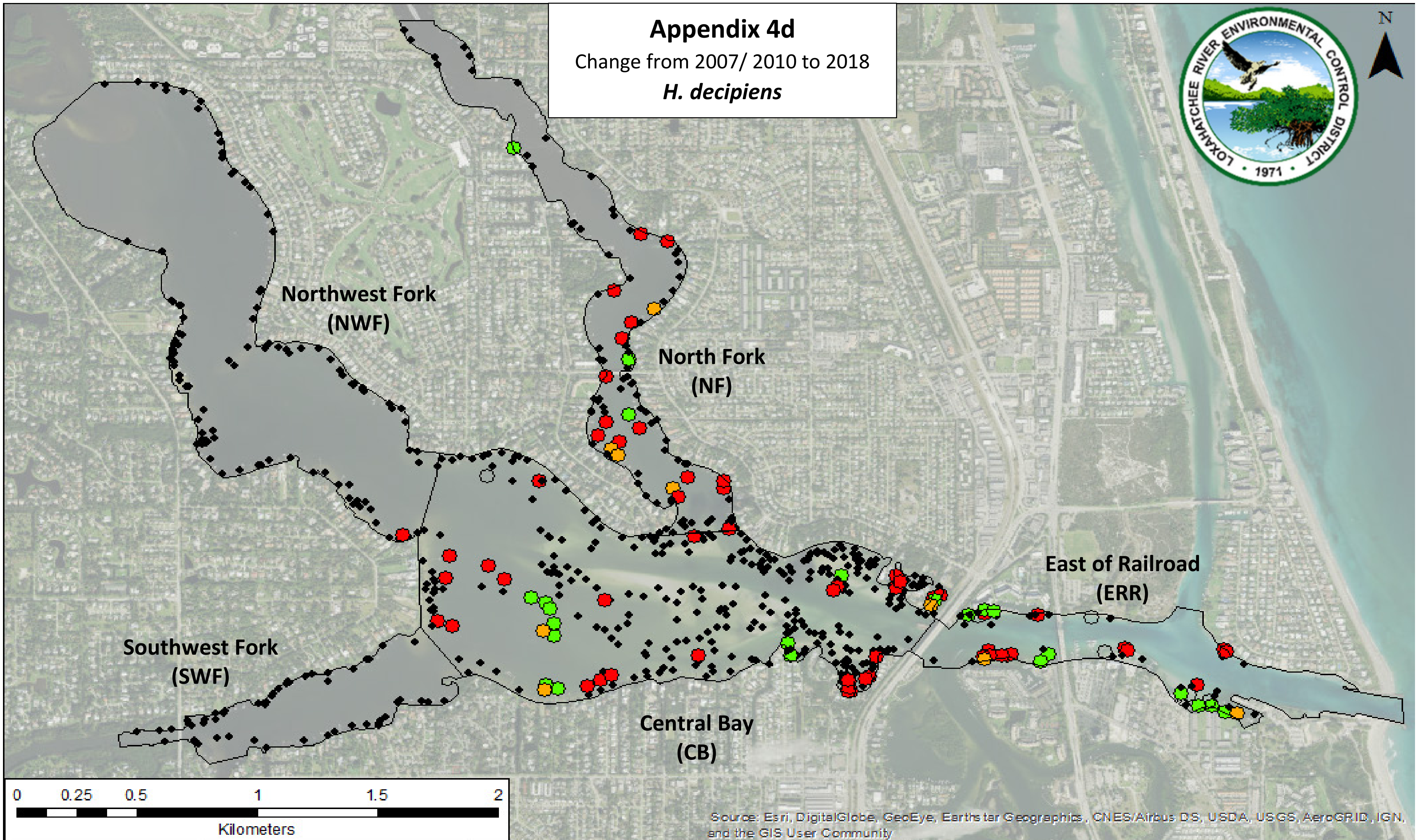
H. johnsonii



Gain	Gain: **12.4%**
Loss	Loss: **72.9%**
Loss to Absent	Loss to Absent: **63.1%**
No Change	No Change: **14.7%**
Always Bare	

Map showing location of all sample sites assessed in 2018 and their associated change. Color of each sample site indicates direction of change of ***H. johnsonii*** presence between 2007/2010 and 2018 based on categorical values. “Loss to Absent” is a subset of the “Loss” category and indicates sites where seagrass was present in 2007/2010 but was absent in 2018. “Always Bare” indicates sites where seagrass was not found during either assessment. Table at left indicates the fraction of sites that fall into each change category.

Appendix 4d
Change from 2007/ 2010 to 2018
H. decipiens



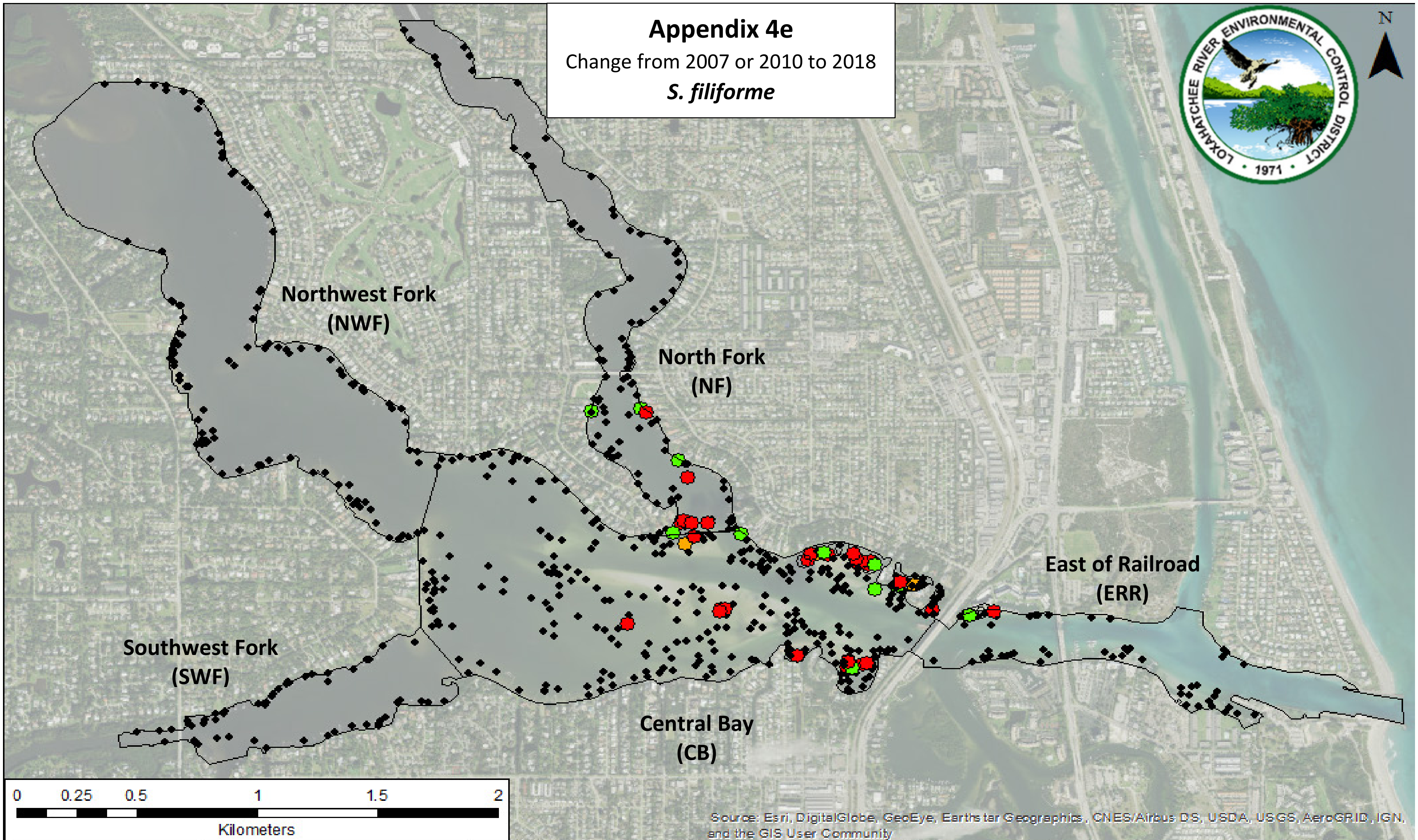
Gain	Gain: **24.2%**
Loss	Loss: **69.5%**
Loss to Absent	Loss to Absent: **60.0%**
No Change	No Change: **6.3%**
Always Bare	

Map showing location of all sample sites assessed in 2018 and their associated change. Color of each sample site indicates direction of change of ***H. decipiens*** presence between 2007/2010 and 2018 based on categorical values. “Loss to Absent” is a subset of the “Loss” category and indicates sites where seagrass was present in 2007/2010 but was absent in 2018. “Always Bare” indicates sites where seagrass was not found during either assessment. Table at left indicates the fraction of sites that fall into each change category.

Appendix 4e

Change from 2007 or 2010 to 2018

S. filiforme

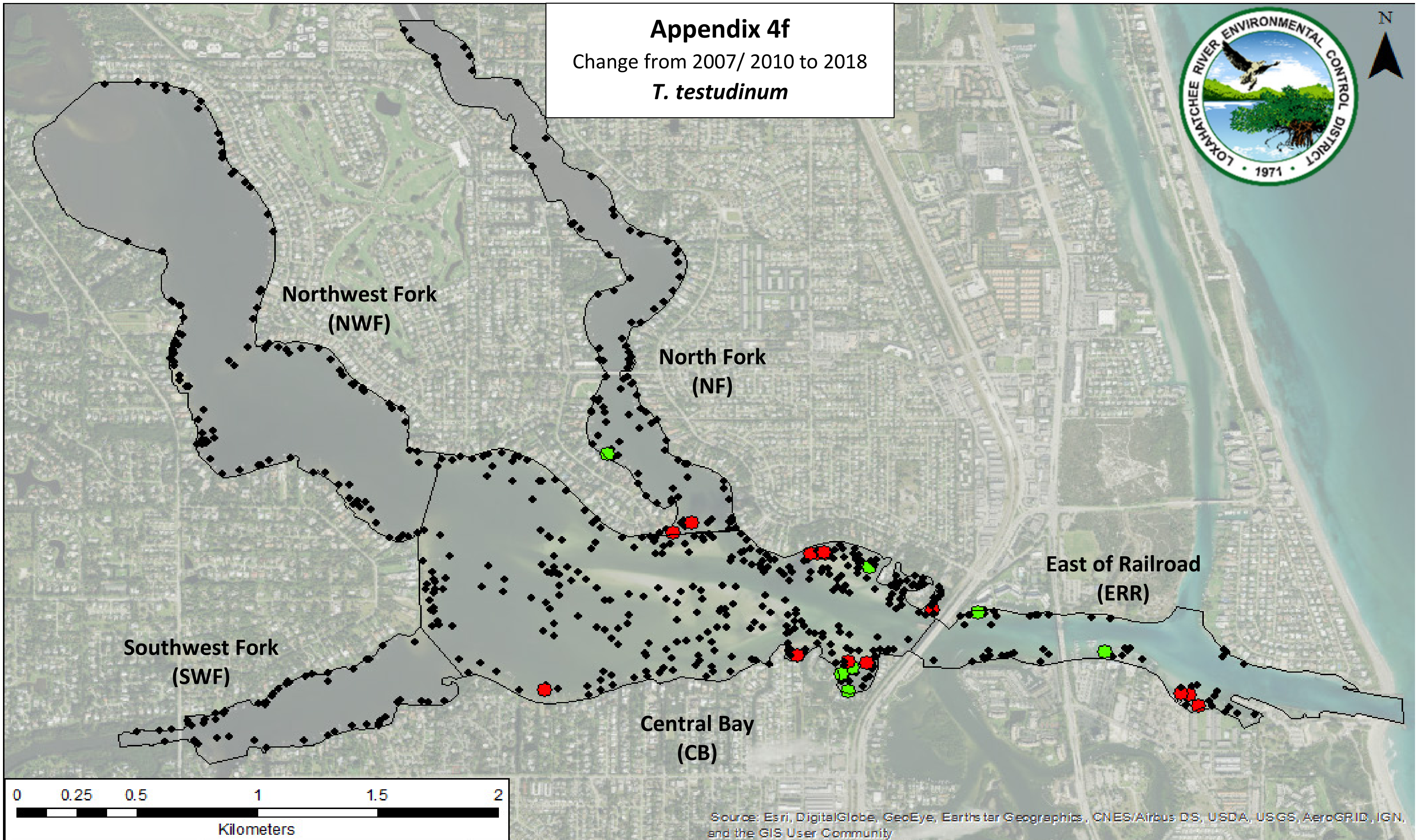


Gain Loss Loss to Absent No Change Always Bare	Gain: **21.2%** Loss: **63.5%** Loss to Absent: **57.7%** No Change: **15.4%**		Map showing location of all sample sites assessed in 2018 and their associated change. Color of each sample site indicates direction of change of ***S. filiforme*** presence between 2007/2010 and 2018 based on categorical values. "Loss to Absent" is a subset of the "Loss" category and indicates sites where seagrass was present in 2007/2010 but was absent in 2018. "Always Bare" indicates sites where seagrass was not found during either assessment. Table at left indicates the fraction of sites that fall into each change category.

Appendix 4f

Change from 2007/ 2010 to 2018

T. testudinum



Gain	Gain: **33%**
Loss	Loss: **67%**
Loss to Absent	Loss to Absent: **67%**
No Change	No Change: **0%**
Always Bare	

Map showing location of all sample sites assessed in 2018 and their associated change. Color of each sample site indicates direction of change of ***T. testudinum*** presence between 2007/2010 and 2018 based on categorical values. “Loss to Absent” is a subset of the “Loss” category and indicates sites where seagrass was present in 2007/2010 but was absent in 2018. “Always Bare” indicates sites where seagrass was not found during either assessment. Table at left indicates the fraction of sites that fall into each change category.