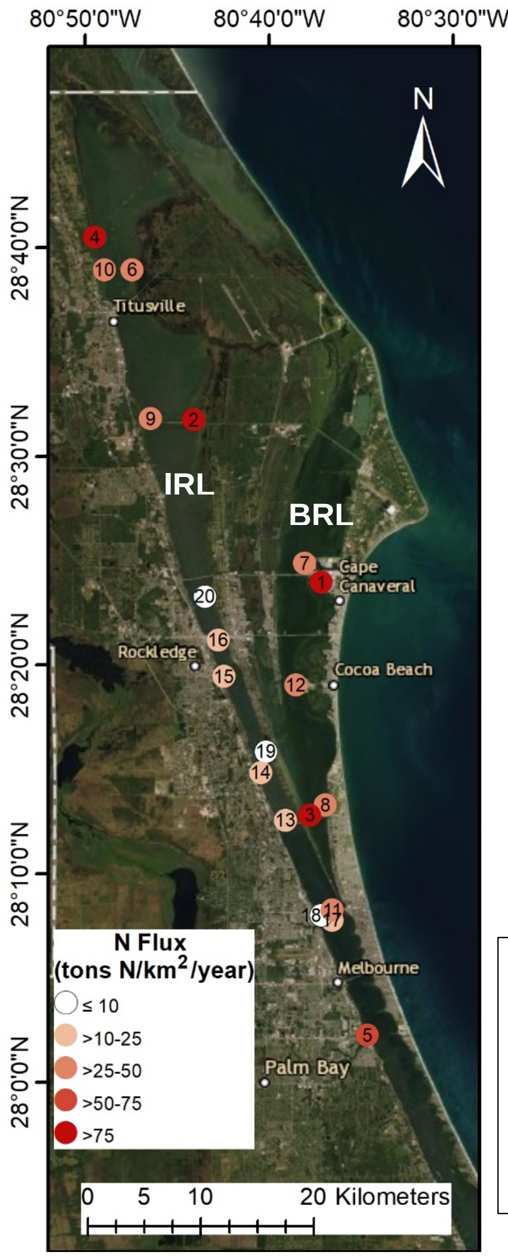
Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)



Map of Indian River Lagoon (IRL) and Banana River Lagoon (BRL) in Brevard County showing 20 optimal sites for muck projects with the highest priority site (#1) having the highest flux of dissolved nitrogen from sediments and the second lowest diversity in benthic fauna.

John H. Trefry, Kevin B. Johnson, Austin L. Fox, Xiao Ma
Florida Institute of Technology, Melbourne, Florida 32901
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Impacts of Environmental Muck Dredging 2017-2018

Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)

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Co-Principal Investigators: John H. Trefry and Kevin B. Johnson
Indian River Lagoon Research Institute
Florida Institute of Technology
150 West University Boulevard
Melbourne, Florida 32901

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Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)

John H. Trefry, Kevin B. Johnson, Austin L. Fox, Xiao Ma
Florida Institute of Technology, Melbourne, Florida 32901

Executive Summary

Fine-grained, organic-rich sediments, locally called Indian River Lagoon (IRL) muck, are anoxic and uninhabitable to benthic fauna and seagrasses. At the same time, rich bacterial communities thrive on the organic matter in IRL muck to produce large amounts of dissolved nitrogen (N) and phosphorus (P) that are released to the overlying water. These nutrient releases (fluxes) account for 30–40% of the N and P added to the lagoon from all sources including runoff, direct discharges and atmospheric deposition. Muck management has thus become an important part of restoration plans for the lagoon system. To date, dredging has been the dominant mechanism for removing IRL muck; however, sand capping, aeration and other techniques are being evaluated. Irrespective of the technique used for muck management, selection of optimal sites for mitigation is a priority.

The goal of this project was to choose and rank 20 optimal sites in the IRL and Banana River Lagoon (BRL) in Brevard County for muck projects, ostensibly from the standpoint of muck removal. Metrics for optimization presented here were based on geochemical and biological data for samples collected during this study. Initially, 53 sites were chosen for geochemical investigation during a Grand Survey. These sites included previously identified muck deposits, as well as locations near upland sources and deeper water; both settings favor muck accumulation. Twenty sites were chosen for further investigation based on organic matter content (>10%), maximum muck thickness (>0.8 m) and muck surface area (>20,000 m^2).

Data from detailed geochemical and biological surveys of the 20 sites were used to create independent rankings of sites for muck management. These rankings described below provide a scientific perspective for selecting muck projects that are intended to be applied in concert with other considerations. Additional factors include, but are not limited to, the following: cost, proximity to a dredged material management area, potential for muck to spread out from a site, formation of a sump (trap) for future inputs, and project constructability.

Geochemical data for sediment fluxes of dissolved N from several locations in each site were used to rank sites from highest (#1) to lowest (#20) fluxes (Table ES1; Figures ES1 and ES2). Overall, 15 of 20 sites were in the IRL; however, the five sites in the BRL contained 37% of the total muck volume (4.3 million m^3) and 52% of the total sediment flux of N (123 tons/y) for the top 20 sites.

Data also were collected from biological studies of the top 20 sites. Ranking was based on the

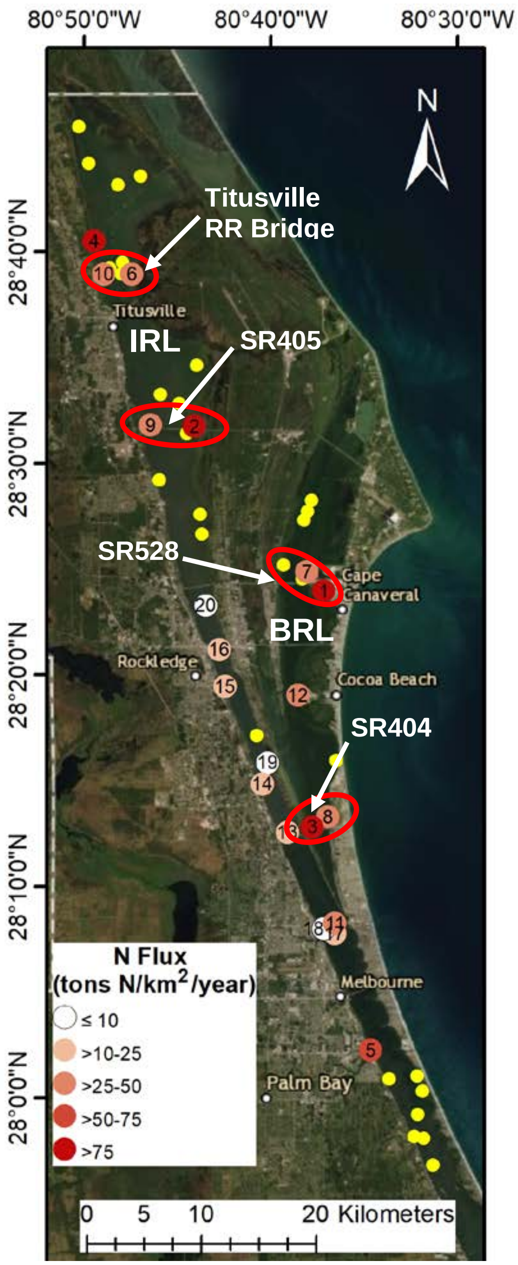

Figure ES1. Map of Indian River Lagoon (IRL) and Banana River Lagoon (BRL) showing sites ranked from 1–20 for muck projects based on sediment nitrogen (N) flux (color-coded, numbered circles). The highest ranked site (#1) had the highest N flux. Numbers on map correspond with data by rank in Table ES1. Yellow circles show additional 33 sites from the Grand Survey. Red ovals identify eight optimal sites that cluster within areas noted for the onset of algal blooms and large benthic fluxes of N.

Table ES1. Ranking of sites in Banana River Lagoon (BRL) and Indian River Lagoon (IRL) based on the geochemical property of sediment nitrogen (N) fluxes in metric tons/km^2/y. Station rankings match locations on Figure ES1.

Rank	Site ID	Site Identification	Mean N Flux (t/km^2/y)
1	BRL8-399	SR528 SE (Beachline Exprwy)	101
2	IRL8-529	SR405 NE (NASA Cswy)	100
3	BRL8-213	SR404 NW (Pineda Cswy)	83
4	IRL8-675	Mims Boat Ramp	77
5	IRL8-037	Turkey Creek	69
6	IRL8-649B	Titusville RR SE	42
7	BRL8-414	SR528 NE (Beachline Exprwy)	41
8	BRL8-221	SR404 NE (Pineda Cswy)	38
9	IRL8-530	SR405 NW (NASA Cswy)	32
10	IRL8-649A	Titusville RR SW	30
11	IRL8-137	SR518 NE (Eau Gallie Cswy)	29
12	BRL8-317	Cocoa Beach Country Club	27
13	IRL8-209	SR404 NE (Pineda Cswy)	20
14	IRL8-247	Rockledge A	16
15	IRL8-324	Cocoa South	13
16	IRL8-353	SR520 South (Merritt Is. Cswy)	11
17	IRL8-129	SR518 South (Eau Gallie Cswy)	10
18	IRL8-133	SR518 NW (Eau Gallie Cswy)	7.5
19	IRL8-264	Rockledge B	6.4
20	IRL8-388	SR 520–528	6.2

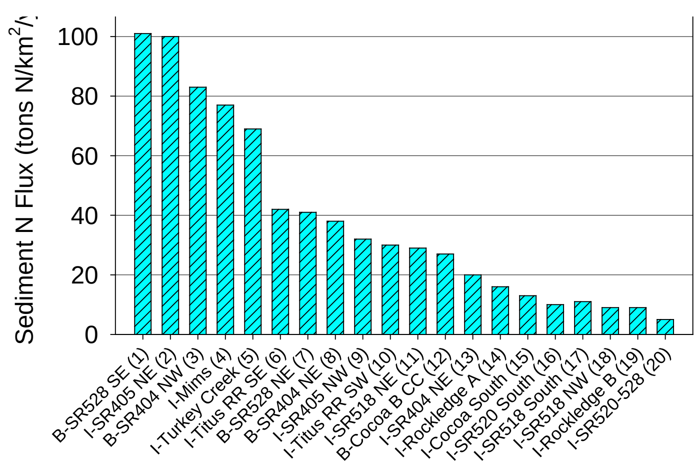

Figure ES2. Rankings for top 20 sites based on sediment nitrogen (N) flux. Numbers in parentheses on x-axis show rank where #1 is for site with highest N flux. Site rankings match listing on Table ES1. (I = Indian River Lagoon; B = Banana River Lagoon)

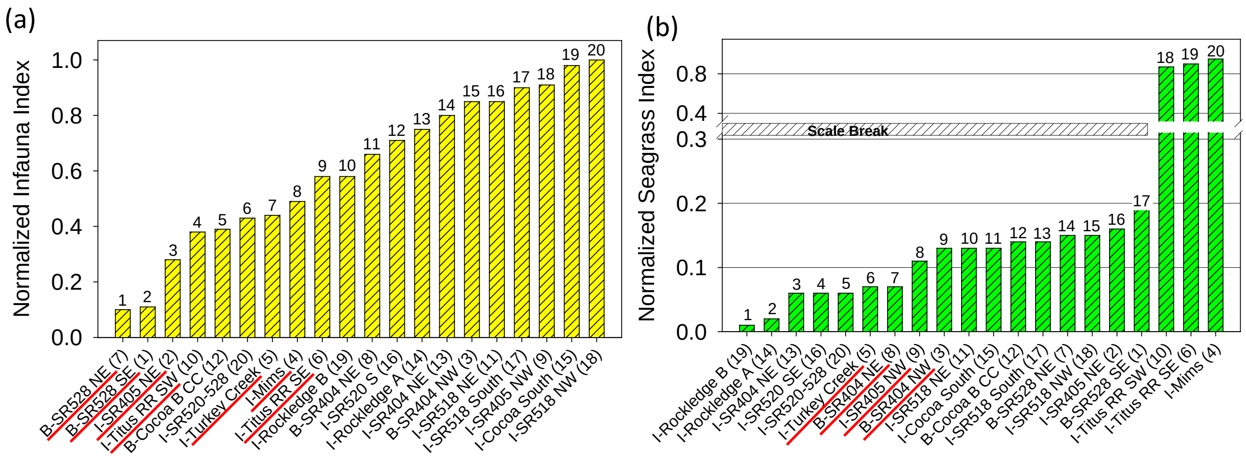

Figure ES3. Rankings for normalized (a) diversity index for benthic fauna and (b) seagrass index. The highest ranked site (#1 above bars on each graph.) had the lowest index value (y-axis) and thus the least viable ecological environment. Numbers in parentheses on x-axes show rankings based on sediment nitrogen flux as identified in Table ES1. Underlined site identifications among top 10 biological indicators also were among top 10 sites based on sediment nitrogen fluxes (Figure ES2). (I = Indian River Lagoon; B = Banana River Lagoon)

Shannon Wiener diversity index for benthic fauna and a combined seagrass index (% seagrass cover and distance from muck to nearest seagrass bed). The highest ranked site (#1) for benthic fauna and seagrasses had the lowest index values (lowest abundance and diversity) and thus were considered the least viable ecological environments (Figure ES3). Such sites will likely benefit from muck projects.

When biological rankings for benthic fauna and seagrasses were each juxtaposed with geochemical rankings based on sediment N flux, the top 10 sites based on geochemistry also were ranked among the top 10 sites for benthic fauna and/or seagrasses (low abundance and diversity; Figure ES3). Four of the top 10 sites were in the BRL between State Road (SR) 404 (Pineda Causeway) and SR 528 (Beachline Expressway) plus the adjacent IRL to the west (Figure ES1). An additional four of the top 10 sites were located in the IRL between SR 405 (NASA Causeway) and the Titusville Railroad Bridge (Figure ES1). These optimal areas for muck projects cluster within key zones for the onset of algal blooms (Figure ES1). The other two top 10 sites based on sediment N flux (#4, Mims and #5 Turkey Creek) were known muck deposits that were recently dredged.

The geochemical and biological rankings discussed in this report provide scientific evidence to guide management decisions regarding key sites for muck projects, including dredging. We encourage, where possible, that muck remediation efforts be carried out in optimal areas as ranked here, especially when they are noted for the onset of major algal blooms. A combined effort for muck projects at closely-spaced sites also may yield a greater degree of success. Moreover, the geochemical and biological rankings from this study must be considered in context with other pertinent variables (e.g., cost and project constructability as listed above).

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Acknowledgments

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Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)

John H. Trefry, Kevin B. Johnson, Austin L. Fox, Xiao Ma
Florida Institute of Technology

1.0. Introduction

Indian River Lagoon (IRL) muck is anoxic and uninhabitable to seagrasses and benthic fauna. Furthermore, bacterial decomposition of organic matter in muck leads to releases (fluxes) of dissolved nitrogen (N) and phosphorus (P) to the overlying water, thereby adding 30–40% of the total N and P to the lagoon from all sources including runoff, direct discharges and atmospheric deposition (Tetra Tech, 2019). Dredging has been the primary process used to remove IRL muck; however, sand capping, aeration and other techniques are being evaluated. To earn continued public support, funding from Save Our Indian River Lagoon (SOIRL) and other sources must be successfully used to help restore portions of the IRL. Due to insufficient funds to address all major muck deposits, it is critical to target locations for improvements that hold the greatest promise for lasting recovery of lagoon ecosystems.

Muck management is a major part of the SOIRL Project Plan (Tetra Tech, 2019). Scientifically-sound criteria based on physical, geochemical and biological metrics can help identify optimal sites for dredging or other muck management activities. This field and laboratory project, along with accompanying optimization models, was designed to (1) refine metrics for identifying sites for muck management using data for geochemical and biological parameters and (2) generate a prioritized list of the 20 most promising sites for muck management in the IRL and Banana River Lagoon (BRL) in Brevard County. The science-based rankings provided by this study are intended to be used in coordination with other parameters including, but not limited to, cost, proximity to a dredged material management area, potential for IRL muck to spread out from a site, formation of a sump (trap) for future inputs, and project constructability.

The search for IRL muck began in the late 1980s in the Melbourne area and south to Sebastian Inlet and Fort Pierce (Sisler, 1986; Trefry et al., 1987). At that time, muck layers with thicknesses of <1 to 55 cm were found in the Intracoastal Waterway (ICW) as well as other depressions and channels between Sebastian and Melbourne. Thicker deposits were identified in adjacent creeks and tributaries. Little or no IRL muck was found in shallower sites where water depths were <2 m. In the Sebastian area, muck in the IRL was restricted to the ICW. Essentially no muck was found in the IRL in the Fort Pierce area. During these early observations, muck was reported to contain >50% silt and clay and >10% organic matter (Trefry et al., 1987).

During 1989, results from ~500 sediment cores and hundreds of additional observations in the IRL and BRL provided the first detailed account of muck in the lagoon (Trefry et al., 1990). In Brevard County, the IRL from Turnbull Creek to Haulover Canal was described as containing sandy sediments, lush seagrass and only minor deposits of fine-grained sediment. Muck layers of 10–40 cm were confined to the ICW. The most abundant and thickest muck deposits (~2 m) were found near developed areas including Titusville, Cocoa and Melbourne (Trefry et al., 1990). A series of maps was prepared and muck was estimated to cover <10% of the lagoons in Brevard County.

The first efforts to identify and rank muck deposition zones in the IRL (Steward, 2004) were based on results from the limited database of Trefry et al. (1987, 1990). Steward (2004) looked for cost-effective approaches that would increase seagrass coverage and improve water and sediment quality. Clusters of major muck deposits were identified using available data. Ranking was based on the following: (1) water quality (WQ) from long-term average turbidity and dissolved oxygen concentrations, (2) the modal value of water depth to muck and (3) differences in seagrass coverage between 1994 and (a) the 1943 benchmark year and (b) the maximum seagrass coverage possible to a depth of 1.7 m (Virnstein and Morris, 1999). Point scales and rankings were developed for each parameter. Rankings by zone were based on (1) total points and (2) highest ranking for each of the three parameters. When ranked by cumulative rank totals (Table 1), a lower number (e.g., 1–3) predicted a priority outcome. These rankings by Steward (2004) will be discussed further after rankings from our study are presented in Section 3.

The main difference between the rankings by Steward (2004) and the present study was use of a large dataset for N fluxes from muck sediments in 2017–2018; such data were not available for the earlier ranking effort. There also were a few differences in study sites. Our 2017–2018 survey focused on Brevard County and did not include Vero Beach. Furthermore, muck dredging was

Table 1. Rankings of muck zones based on cumulative rank totals (Steward, 2004).

Muck Zone	WQ[b]	Depth to Muck	Seagrass Coverage	Total Score	Ranking
Vero Beach	1	2	3	6	1
South Tropical Trail	8	1	1	10	2
Eau Gallie River	5	3	2	10	2
Crane Creek	3	3	5	11	4
Turkey Creek	2	3	7	12	5
Barge Canal – MP[a]	4	6	4	14	6
Eau Gallie, Melbourne	9	5	3	17	7
Sebastian River	6	3	10	19	8
Titusville	7	4	9	20	9
South BRL	10	5	6	21	10
Cocoa – Rockledge	9	7	8	24	11

[a]Magnolia Point.

[b]Water quality.

carried out in the Eau Gallie River, Crane Creek, Turkey Creek and St. Sebastian River between the study by Steward (2004) and our 2017–18 effort. Turkey Creek was the only dredged area included in the 2017–2018 study because a large program to evaluate muck dredging was carried out there (e.g., Fox and Trefry, 2018) and we wanted to determine whether Turkey Creek would have been considered one of the top 20 sites based on our criteria.

Rankings by Steward (2004) were restricted to available data from Trefry et al. (1987, 1990) for the locations and thicknesses of muck deposits throughout the lagoon system. More data were added in 2006–7 when a survey of 73 sites studied in 1989 was carried out by Trefry and Trocine (2011). Muck layers >100 cm thick were found at 22 sites in 2006–7 relative to only one site in 1989. In contrast, 7 of 11 stations that contained no muck in 1989 also contained no muck in 2006–7. The average muck thickness for 73 stations during 2006–7 was ~63 cm/site. This mean muck thickness for 2006–7 was 67% greater than the 1989 value of ~38 cm/site. These results showed that muck deposition in the IRL had continued.

Riegl et al. (2009) carried out acoustic surveys that greatly expanded the database for muck deposits. Maps from the most recent study (Riegl et al. 2015) showed rather widespread occurrences of bottom deposits that were identified as muck using acoustic techniques (e.g., Figure 1). These maps were invaluable to the present study because they identified the major muck areas in the BRL and the IRL from the Melbourne Causeway to Mosquito Lagoon.

An important component of the 2017–18 optimization study was to confirm the presence and extent of previously identified muck deposits throughout the lagoon and thereby enhance the existing database and better quantify the surface area and volume of lagoon muck. Riegl et al. (2015) identified numerous sites in both Mosquito Lagoon and the northernmost IRL where their acoustics data supported the presence of muck deposits (e.g., Figure 1). The acoustic technique was limited to water depths greater than ~1.5 m and constrained by the sensitivity of the algorithm for interpreting the acoustic data. Using probing techniques, Trefry et al. (2007) found <1 cm of muck at 54% of the 319 stations surveyed in Mosquito Lagoon (Figure 2a). Muck layers thicker than 50 cm were found at 38 (12%) of the locations probed; two thirds of these sites were south of Haulover Canal (Trefry et al., 2007). The map for Mosquito Lagoon produced from acoustic surveys (Riegl et al., 2015; Figure 1) showed a larger area of muck than the study by Trefry et al. (2007, Figure 2a), most likely due to overestimates using acoustic methods. At present, Mosquito Lagoon is not being considered for muck projects. One reason for this decision was that a recent study found that fluxes of N and P from one of the larger muck deposits were low, possibly due to the age and redox state in surface layers of the deposit (Trefry et al., 2017). Additional comparisons between Riegl's maps and the results of this study will be shown as our new data are introduced.

Several muck-probing surveys were carried out from 2014–2017 at higher resolution (30–200 m) than previously used; furthermore, muck thicknesses were confirmed by sediment sampling

(Figure 2). These recent muck maps, in concert with maps from Riegl et al. (2015), helped shape the approach and goals of this study of optimum sites for muck dredging/management. To date, we are not aware of any continuous survey techniques that have successfully mapped the distribution and thickness of muck deposits in the IRL system. Such capability would be valuable.

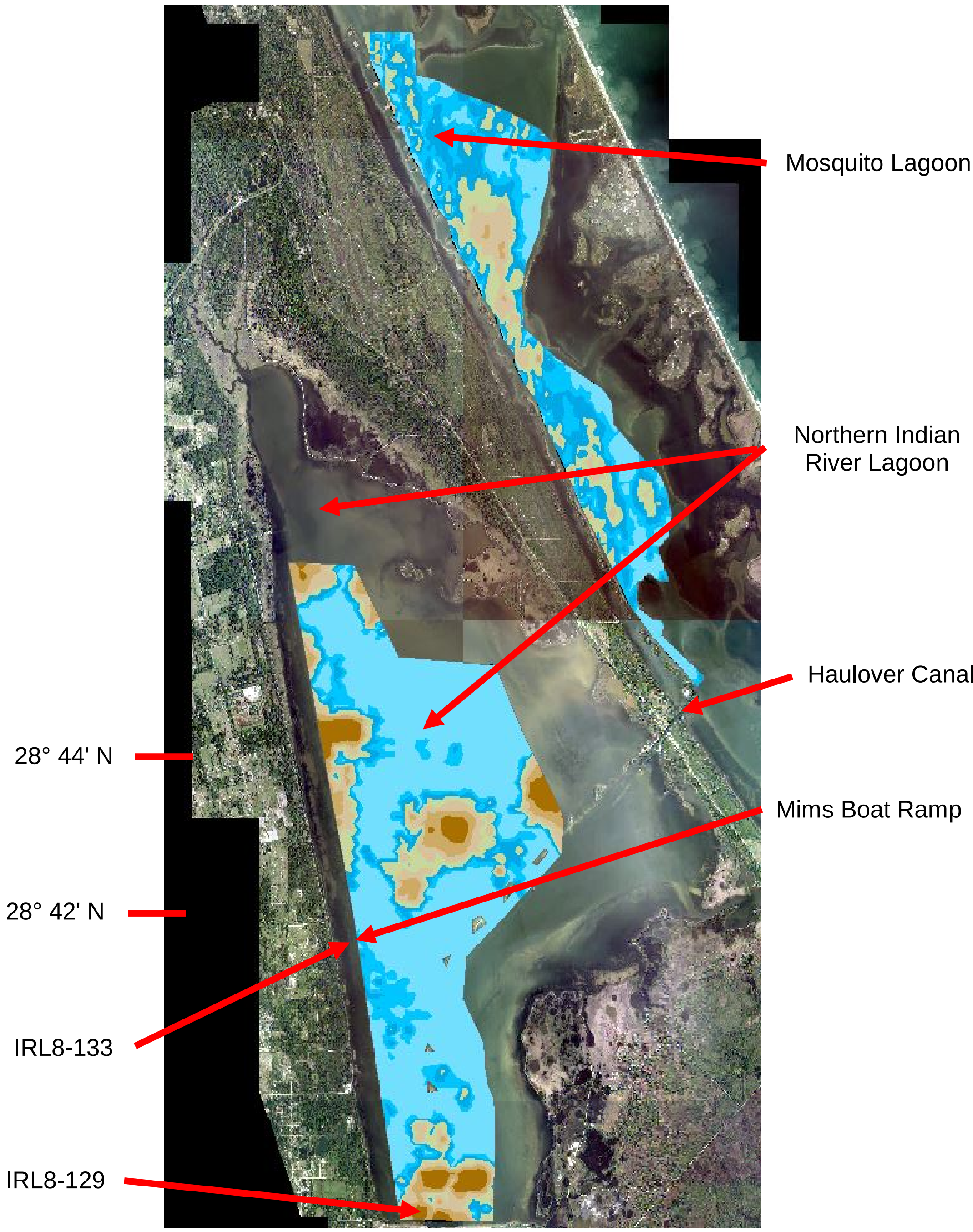


Figure 1. Contour map showing potential or acoustically-defined muck deposits (tan to brown shading) in Mosquito Lagoon and the Indian River Lagoon north of Titusville. Figure from Riegl et al., 2015. Some notations on figure refer to areas and sites to be discussed later in this report.

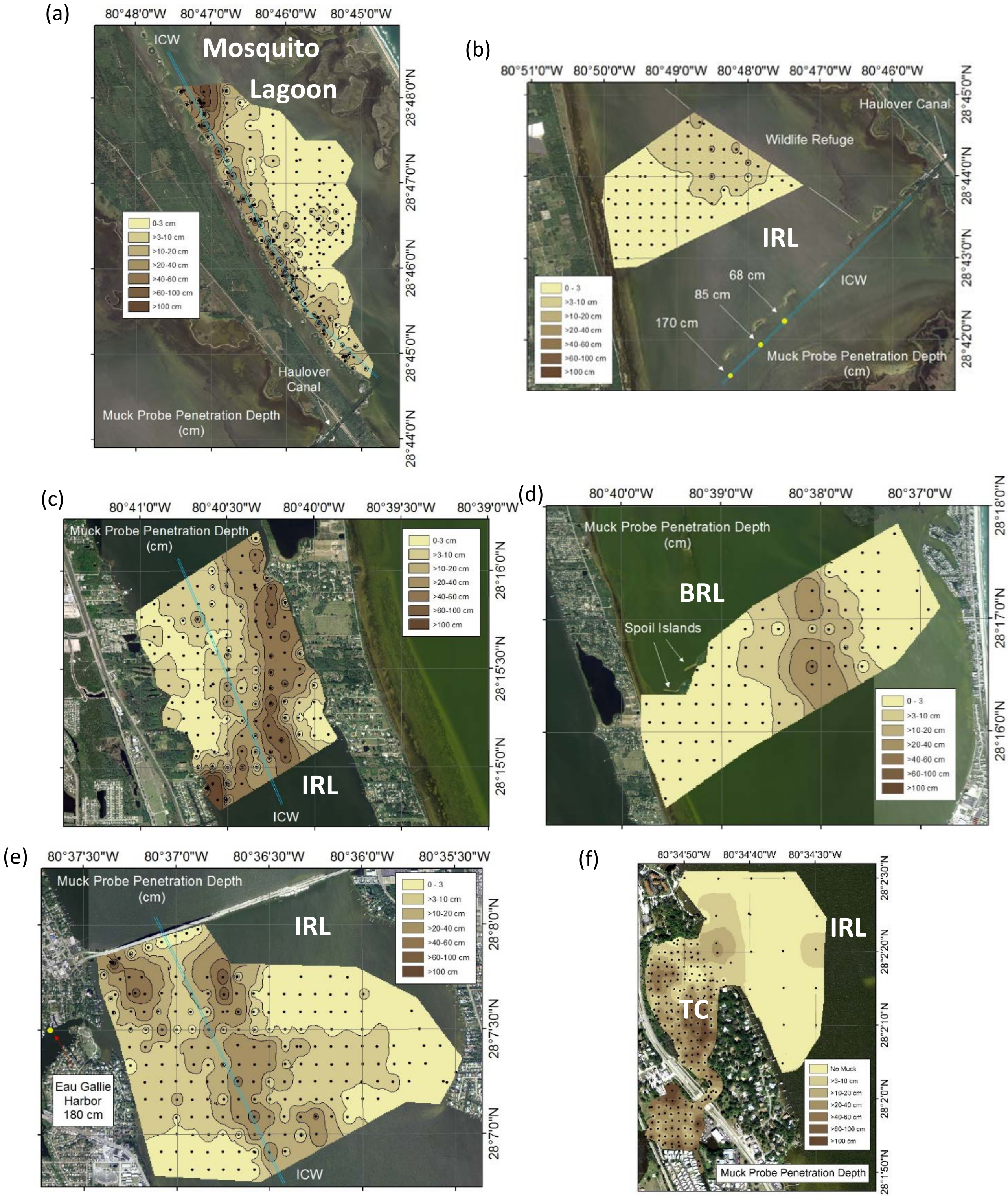


Figure 2. Contour maps of muck thicknesses in (a) Mosquito Lagoon, (b) northern Indian River Lagoon (IRL), (c) IRL at Rockledge, (d) Banana River Lagoon (BRL) near Cocoa Beach, (e) IRL, just south of Eau Gallie Causeway and (f) Turkey Creek (TC), March 2018. (a–e) from Trefry et al., 2015; (f) from Fox and Trefry (2018).

2.0. Approach

2.1. Overview of Strategy

This study was carried out in a three-part, tiered approach as summarized below.

Part 1, the *Grand Survey*, consisted of identifying 53 sites from the IRL and BRL in Brevard County using the best available data from acoustic surveys by Riegl et al. (2015) and probing methods by Trefry et al. (1990, 2015). Each site was surveyed to determine water depth, muck area and thickness, and to collect samples for geochemical analysis.

Part 2, *Detailed Geochemical and Biological Surveys of the Top 20 Sites* were initiated by choosing 20 of the 53 sites identified during the Grand Survey for further geochemical and biological evaluation. The top 20 sites were determined based on organic matter content (≥10%), maximum muck thicknesses (>0.8 m) and area of the muck deposit (>20,000 m^2).

Part 3 involved establishing *Prioritization Scales* for the 20 sites studied in more detail during Part 2. The scales were based on geochemical and biological parameters that were used to rank the optimal sites for dredging or other muck management strategies.

2.2. Part 1: Sampling and Analysis for Physical and Geochemical Parameters during the Grand Survey

Possible muck deposits at 53 sites were selected based on previous results (e.g., Trefry et al., 1990; Riegl et al., 2009, 2015) plus new sites where bathymetry showed water depths >3 m, a common water depth for muck deposits. During this Grand Survey, 5 to >20 muck-depth determinations were made in each area reported to contain muck. The first probe determination was made at the predicted center of the deposit. A polyvinyl chloride (PVC) pole was used for muck measurements as described in Trefry and Trocine (2011). Then, 2–5 sediment samples were collected from each area that contained muck using an Ekman grab. Samples also were collected at selected locations that did not contain muck to provide supporting data for representative non-muck locations. Water content, Loss on Ignition (LOI) at 550˚C (organic matter), followed by 950˚C ($CaCO_3$) were determined for each sediment sample following techniques of Heiri et al. (2001). Data from the Grand Survey were tabulated in Excel and a map was prepared in GIS to identify the 53 sites sampled (Figure 3). Florida state routes (SR) and related causeways were often used as a frame of reference for describing muck sites. Then, the 20 sites were chosen for Detailed Surveys based on OM content (>10%), maximum muck thickness (>0.8 m) and area of the muck deposit (>20,000 m^2).

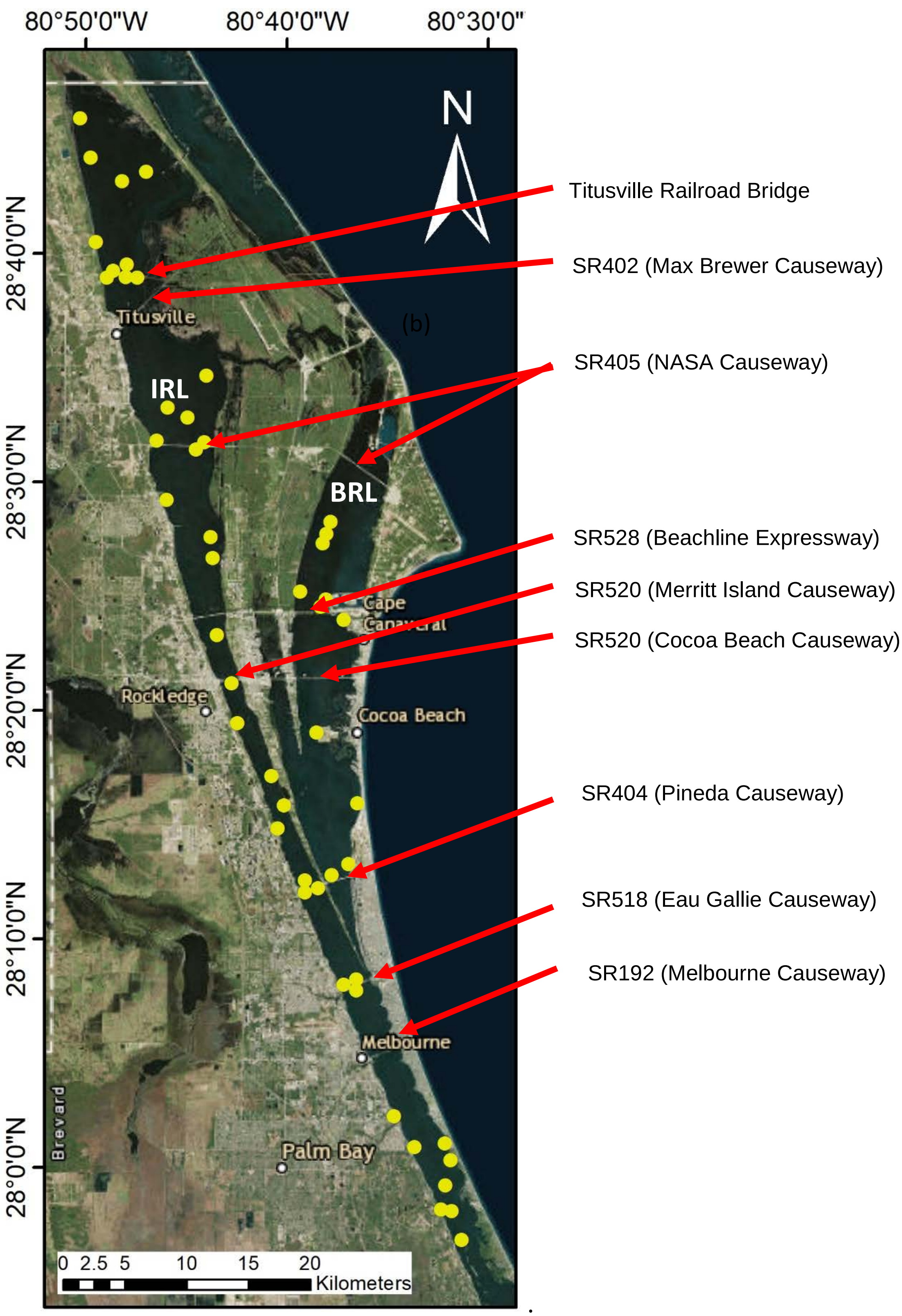


Figure 3. Maps showing 53 sites chosen for the Grand Survey of the Indian River Lagoon (IRL) and Banana River Lagoon (BRL). State roads (SR) and associated causeways, as well as railroad (RR) bridges, were often used as a frame of reference for describing muck sites.

2.3. Part 2: Sampling and Analysis for Detailed Surveys of the Top 20 Sites

2.3.1. Geochemical Sampling and Analysis

Detailed muck surveys (area and thickness) were carried out for the top 20 sites. The resolution of probing varied from 0.03–1 km, based on past knowledge of the area and the predicted size of the muck deposit. Sediments were collected at 2–5 stations in each area and analyzed for the following: grain size, water content, OM and $CaCO_3$. The N and P fluxes from muck also were determined via the Quick Flux technique (Fox and Trefry, 2018). Additionally, the means and ranges of water depth at all sites were recorded because of the importance of depth limitations to seagrass growth and the potential for re-suspension of muck in shallower (<1.5 m) water.

Details for laboratory analysis for bottom sediment nutrients and other chemicals have been previously described in Trefry et al. (2015, 2016) and Fox and Trefry (2018). All techniques included careful instrument standardization, analysis of reference standards, lab replicates, procedural blanks and additional QA/QC procedures. Data were stored in Excel. Muck thicknesses are displayed in GIS format as in past examples for Turkey Creek (Figure 2f). Data analyses were carried out using Systat 13 and Sigma Plot 10 (Systat Software), Excel 2016 (Microsoft) and ArcGIS. Statistical significance was set at $\alpha = 0.05$ for tests and regressions. Least squares linear regressions were calculated to determine relationships between individual pairs of parameters. Equations, 95% prediction intervals, correlation coefficients and p values were determined for each relationship.

2.3.2. Biological Sampling and Analysis

The primary objective was to identify and quantify benthic faunal populations and seagrasses to determine which areas are most likely to have improved benthic fauna and seagrasses following muck dredging or other muck management activities. Salinity, temperature, pH and dissolved oxygen were determined for surface and bottom water at each station using a Yellow Springs Instruments sonde.

Six benthic fauna grab stations (n = 3 grabs per station) were sampled at each of the 20 sites. Three of those stations were selected randomly in and around the muck, including (1) the approximate center of the muck deposit, (2) the edge within the muck deposit and (3) a sandier station just beyond the muck deposit. The other three benthic fauna stations were located at the 50-m mark along seagrass transects as discussed below. At each benthic fauna station, an additional (4^{th}) grab was collected for sediment characterization.

Sediments were collected using a Wildco Petite Ponar Grab (surface area 225 cm^2). Sediments were sieved through a 500-µm mesh sieve; retained organisms were frozen for lab analysis.

Aliquots of each benthic fauna sample (¼ or ⅛, depending on sample volume) were identified to the lowest possible taxonomic level and counted via stereomicroscopy (8 to 35x).

Three seagrass (SG) and drift algae (DA) transects were surveyed in seagrass beds nearest to the muck area. The seagrass transects extended ~100 m perpendicular from shore; data were collected every 10 m along the transect. Seagrass surveys followed the standard seagrass field survey guide from St. Johns River Water Management District (Morris et al., 2001), and included collecting data for water depth, drift algae % cover, drift algae biomass, drift algae canopy height, seagrass % cover, seagrass biomass, seagrass epiphytes, seagrass canopy height, and seagrass shoot counts. Transects were truncated when depth or muck conditions prevented full evaluation of the transect.

Methods for laboratory processing were analogous to those reported for seagrasses and benthic fauna in Windsor (2016). Sediments were analyzed for % OM as LOI 550°C (Heiri et al., 2001), % water by weight, and % silt-clay content (dry weight) by sieving 10–30 g of wet sample through a 63-µm sieve (Folk, 1974). Retained material from sieving was then heated at 60°C for 24 hours and re-weighed.

2.4. Prioritization Scales

The geochemical ranking index for the top 20 stations was based on fluxes of dissolved nitrogen from muck sediments as metric tons of nitrogen per square kilometer of muck per year (t N/km^2/y). Nitrogen was chosen because fluxes of P are more variable and complex due to influences from adsorption/desorption and precipitation/dissolution in sediments as a function of pH and redox conditions (e.g., Wu et al., 2014). Fluxes of N were determined using >200 data points that have been acquired by us since 2014 (Trefry et al., 2015, 2017; Fox and Trefry, 2018, 2019). Fluxes of N from the sediments were adjusted to 25°C using equations from Fox and Trefry (2018). The site with the highest benthic flux of N was given the highest rank (#1). Thus, sites favored for muck projects would be those where the largest decrease in the release of nutrients could occur.

Complementary data for surface area and volume of muck at each site were obtained to support calculation of sediment N fluxes as a function of the total area and volume of each deposit. Such deposit-wide N fluxes (i.e., t N/muck site area in m^2/y or t N/muck-site volume in m^3/y) provided alternate approaches to ranking optimal sites. Additional details and calculations are provided when results for the prioritization scale are introduced in Section 3.2.1.

The goal of the biological ranking index for this study was to help confirm site ranking established with the geochemical scale (i.e., benthic N flux). The biological index was developed using (1) the Shannon Wiener diversity index of benthic fauna adjacent to, but outside the muck border, and (2) a seagrass index, which was the distance from the muck edge to the nearest seagrass bed multiplied by the highest seagrass % cover along the nearest seagrass transect. Ranking the relative severity of sediment contamination from the presence of potentially toxic metals and organic substances via the Shannon Wiener Index has been used in various forms (e.g., Weis et al., 2004; Paz-Alberto, 2015). The same general format has been used here with sediment N fluxes as the contaminant.

Because sampling occurred in different seasons, benthic faunal diversity indexes and highest seagrass % cover were adjusted to the summer values according to the mean seasonal changes of benthic fauna and seagrass % cover from the nearest ongoing monitoring sites of the same year. Data for the Shannon Wiener diversity index and highest seagrass % cover were normalized via a linear model with the highest value converted to 1 and the lowest value to 0.1. Seagrass distances were normalized via a logarithmic equation with the shortest distance converted to 0.1 and the longest distance to 1.

Ranking of biological indicators was based on the premise that the site with the lowest diversity and abundance may have the best chance for significant improvement from nearby muck projects and therefore should get the highest ranking (#1). Alternate ranking schemes also were considered. For example, sites with greater abundance and diversity could have been ranked higher, especially if they were proximal to areas where muck remediation might spur re-colonization. Application of the biological indices is discussed in more detail in Section 3.2.2.

2.5. Quality Assurance Plan

A revised detailed Quality Assurance Plan (QA Plan) with responses to comments for the second year of this study was submitted during January 2017. This plan meets the minimum requirements for description of Research Field and Laboratory Procedures according to Rule 62-160.600, F.A.C. The 33 page document (plus a long list of SOWs) covers all project plans, objective and analyses for the dredging component of the EMD study. As a continuation project, the January 2017 QA Plan covers the activities and analyses of this third year of study.

3.0. Results and Discussion

3.1. The Grand Survey

The Grand Survey was completed during December 2017. Twenty-nine of the 53 sites surveyed contained muck with an OM content ≥10% and muck thicknesses ≥0.8 m, including 10 of 13 locations in BRL (Table 2). No evidence of muck was found at 11 of the 53 locations; only thin layers (<10 cm) were detected at 9 locations (Table 2). The 20 top sites were chosen from the 29 sites where OM content was >10% and maximum muck thickness was ≥0.8 m. The final factor in the selection of the top 20 sites was muck surface area >20,000 m^2 which reduced the number of sites to 20 (Table 2, shaded listings of locations).

Site identifications were based on the lagoon (IRL or BRL) and the second digit of the latitude (e.g., 8 for 28°) and then the decimal fraction for fractional degrees x 1000 (e.g., 129 for 0.129°). Therefore, a site in the Indian River Lagoon at 28.129° was given a site identification of IRL8-129. The site description was based on a reference state road (SR) and/or causeway as appropriate (see Figure 3, page 7, for list of SRs and causeways) and then the compass direction of the site relative to the route. When sites were not near a causeway, a variety of basic descriptors were used.

An overview of sites visited during the Grand Survey, beginning with the IRL in southern Brevard County, is outlined below and summarized in Table 2. Descriptions of the BRL sites follow the tour of sites in the IRL. Where available, reference is made to the maps from Riegl et al. (2015) that extend from the Melbourne Causeway to Mosquito Lagoon. No acoustic data were collected by Riegl et al. (2015) south of the Melbourne Causeway or at water depths less than ~1.5 m.

The southern-most site of the 53 chosen for study was in a small area near Grant-Valkaria (IRL7-947, Table 2) where a maximum muck thickness of 55 cm was identified adjacent to and in the ICW. Moving north, muck as thick as 2.6 m was found in an area <20,000 m^2 adjacent to the mouth of Goat Creek in the IRL (IRL7-969, Table 2). Muck was found in only one of four sites selected for the Grand Survey, between Goat Creek and Turkey Creek (Malabar, Table 2). Although dredged in 2016 and well-studied (e.g., Fox and Trefry, 2018), Turkey Creek was listed as an area to be considered for investigation as a retrospective evaluation of the previously chosen sites from muck dredging (Table 2). Next in the Grand Survey, three muck sites in the Eau Gallie area were identified as being large enough (>20,000 m^2, areas in Table 2). Two locations (IRL8-129 and IRL8-137) were visible and one (IRL8-133) was not identified on maps (Figure 4) prepared by Riegl et al. (2015; Figure 4). Muck was previously reported in the ICW between Pineda Causeway and Melbourne Causeway, with thicker deposits in selected areas (e.g., Trefry et al., 1990; Riegl et al., 2015); however these deposits generally had areas <20,000 m^2. Numerous nearshore deposits in shallow water (<1 to 1.5 m) have been previously identified by us and are included in our comprehensive GIS maps.

Table 2. Summary data for the Grand Survey in the Indian River Lagoon (IRL) and Banana River Lagoon (BRL) showing site identifications (ID), locations (latitude and longitude), mean volume % water in sediment (porosity), mean organic matter (OM) content of sediment, maximum muck thickness, muck area and site description. Results for the top 20 sites chosen for the detailed survey are shaded.

ID[a]	Lat (N)	Long (W)	Water (Vol %)	OM (%)	Max muck thickness (m)	Muck Area (1000s m^2)[c]	Site Description
Indian River Lagoon (IRL)							
IRL7-947[a, b]	27˚56'48"	80˚31'34"	0.88	-	0.55[b]	<20	Near ICW
IRL7-968	27˚58'4"	80˚32'3"	0.65	3.1	0.25	None[d]	S. Brevard, ICW
IRL7-969[b]	27˚58'9"	80˚32'34"	0.86	12.4	2.6[b]	<20	Goat Creek
IRL7-986	27˚59'11"	80˚32'21"	0.85	7.1	0.7	None[d]	Malabar
IRL8-005	28˚0'18"	80˚32'6"	0.48	1.1	0	None[d]	
IRL8-015	28˚0'52"	80˚33'52"	0.52	1.1	0		
IRL8-017	28˚1'1"	80˚32'22"	-	0.8	0		
IRL8-037	28˚2'13"	80˚34'52"	0.94	18.9	1.4	100	Turkey Creek
IRL8-129	28˚7'44"	80˚36'43"	0.89	15.7	0.85	300	SR518 S (Eau Gallie Cswy)
IRL8-133	28˚7'59"	80˚37'19"	0.89	15.8	>2	240	SR518 NW (Eau Gallie Cswy)
IRL8-137	28˚8'13"	80˚36'43"	-	>10	>2	290	SR518 NE (Eau Gallie Cswy)
IRL8-200[b]	28˚12'2"	80˚39'14"	0.94	19.9	>2.3[b]	<20	2 km SW SR404 (Pineda Cswy)
IRL8-203[b]	28˚12'12"	80˚38'35"	0.93	17.6	>1.3[b]	<20	2 km SE SR404 (Pineda Cswy)
IRL8-209	28˚12'32"	80˚39'14"	0.87	15.3	0.95	140	SR404 NE (Pineda Cswy)
IRL8-247	28˚14'49"	80˚40'34"	0.85	16.2	>2	125	Rockledge A
IRL8-264	28˚15'50"	80˚40'16"	0.78	12.7	0.95	570	Rockledge B
IRL8-285	28˚17'7"	80˚40'52"	0.61	3.2	0	None[d]	Rockledge
IRL8-324	28˚19'26"	80˚42'32"	0.80	13.8	0.9	110	Cocoa South
IRL8-353	28˚21'11"	80˚42'50"	0.85	15.6	1.0	460	SR520 SE (Merritt Island Cswy)
IRL8-386	28˚23'10"	80˚43'34"	0.85	15.4	0.2	<20	Cocoa
IRL8-388	28˚23'17"	80˚43'34"	0.88	18.4	0.85	78	Between SR520 and 528
IRL8-444	28˚26'39"	80˚43'46"	0.50	1.6	0	None[d]	Between SR528 and 405
IRL8-460	28˚27'35"	80˚43'51"	0.47	0.9	0	None[d]	
IRL8-487[b]	28˚29'12"	80˚46'1"	0.62	21.3	>2.3[b]	<20	
IRL8-523	28˚31'24"	80˚44'34"	0.52	1.3	0	None[d]	

[a]ID listed as IRL7-947 = Indian River Lagoon 27.947°N.
[b]Small area (<20,000 m^2).
[c]Area is for muck deposits thicker than 30 cm (1 foot). Details on p. 23.
[d]No muck present (OM<10%).

Table 2 (continued). Summary data for the Grand Survey in the Indian River Lagoon (IRL) and Banana River Lagoon (BRL) showing site identifications (ID), locations (latitude and longitude), mean volume % water in sediment (porosity), mean organic matter (OM) content of sediment, maximum muck thickness, muck area and site description. Results for the top 20 sites chosen for the detailed survey are shaded.

ID[a]	Lat (N)	Long (W)	Water (Vol %)	OM (%)	Max muck thickness (m)	Muck Area (1000s m^2)[c]	Site Description
IRL8-529	28°31'44"	80°44'10"	0.94	26.8	>1	140	SR405 NE (NASA Cswy)
IRL8-530	28°31'48"	80°46'30"	0.91	19.8	>2	100	SR405 NW (NASA Cswy)
IRL8-547	28°32'49"	80°44'58"	0.56	2.6	0.1	None[d]	Titusville Area [between SR 402 (Max Brewer Cswy) and Titusville RR Bridge]
IRL8-554	28°33'15"	80°45'58"	0.54	2.2	0.1		
IRL8-577	28°34'38"	80°44'2"	0.46	1.0	0		
IRL8-649	28°38'57"	80°48'2"	0.93	0	0.4		
IRL8-649A	28°38'56"	80°48'58"	0.85	17	>2	150	Titusville RR SW
IRL8-649B	28°38'56"	80°47'28"	0.93	24.4	>2	280	Titusville RR SE
IRL8-654	28°39'14"	80°48'39"	0.64	3.8	0.2	None[d]	South of Mims to Titusville RR Bridge
IRL8-658	28°39'30"	80°47'58"	0.60	3.7	0.1		
IRL8-675	28°40'30"	80°49'30"	0.80	16	1.0	26	Mims Boat Ramp
IRL8-719	28°43'10"	80°48'13"	0.50	2.1	0.1	None[d]	Northernmost IRL
IRL8-726	28°43'34"	80°47'0"	0.49	1.1	0		
IRL8-737	28°44'11"	80°49'46"	0.50	-	0		
IRL8-765	28°45'55"	80°50'17"	0.64	2.8	0		
Banana River Lagoon (BRL)							
BRL8-213[b]	28°12'45"	80°37'56"	0.90	16.0	>2.1	<20	SR404 NW
BRL8-213	28°12'47"	80°37'55"	0.93	24.0	2	110	SR404 NW (Pineda Cswy)
BRL8-221	28°13'16"	80°37'5"	0.94	22.5	>2	100	SR404 NE (Pineda Cswy)
BRL8-222[b]	28°13'20"	80°37'7"	0.94	-	2.6[b]	<20	~3 km N SR404 (Pineda Cswy)
BRL8-265[b]	28°15'55"	80°36'38"	0.82	7.6	0.55[b]	<20	~8 km N SR404 (Pineda Cswy)
BRL8-317	28°19'1"	80°38'38"	0.90	>10	>2	570	Cocoa Beach Country Club
BRL8-399	28°23'56"	80°37'16"	0.92	20.5	>1.0	220	SR528 SE (Beachline Exprwy)
BRL8-409	28°24'31"	80°38'24"	0.77	8.2	0.35	None[d]	
BRL8-414	28°24'50"	80°38'10"	0.91	20.5	>2	99	SR528 NE (Beachline Exprwy)
BRL8-420[b]	28°25'11"	80°39'24"	0.92	22.0	3[b]	<20	North BRL in or adjacent to channel
BRL8-455[b]	28°27'18"	80°38'18"	0.83	21.8	1.1[b]		
BRL8-462[b]	28°27'43"	80°38'7"	0.92	22.1	0.9[b]		
BRL8-470[b]	28°28'13"	80°37'55"	-	13.3	1.7[b]		

[a]ID listed as IRL8-529 = Indian River Lagoon 28.529°N.

[b]Small area (<20,000 m^2).

[c]Area is for muck deposits thicker than 30 cm (1 foot). Details on p. 23.

[d]No muck present (OM<10%).

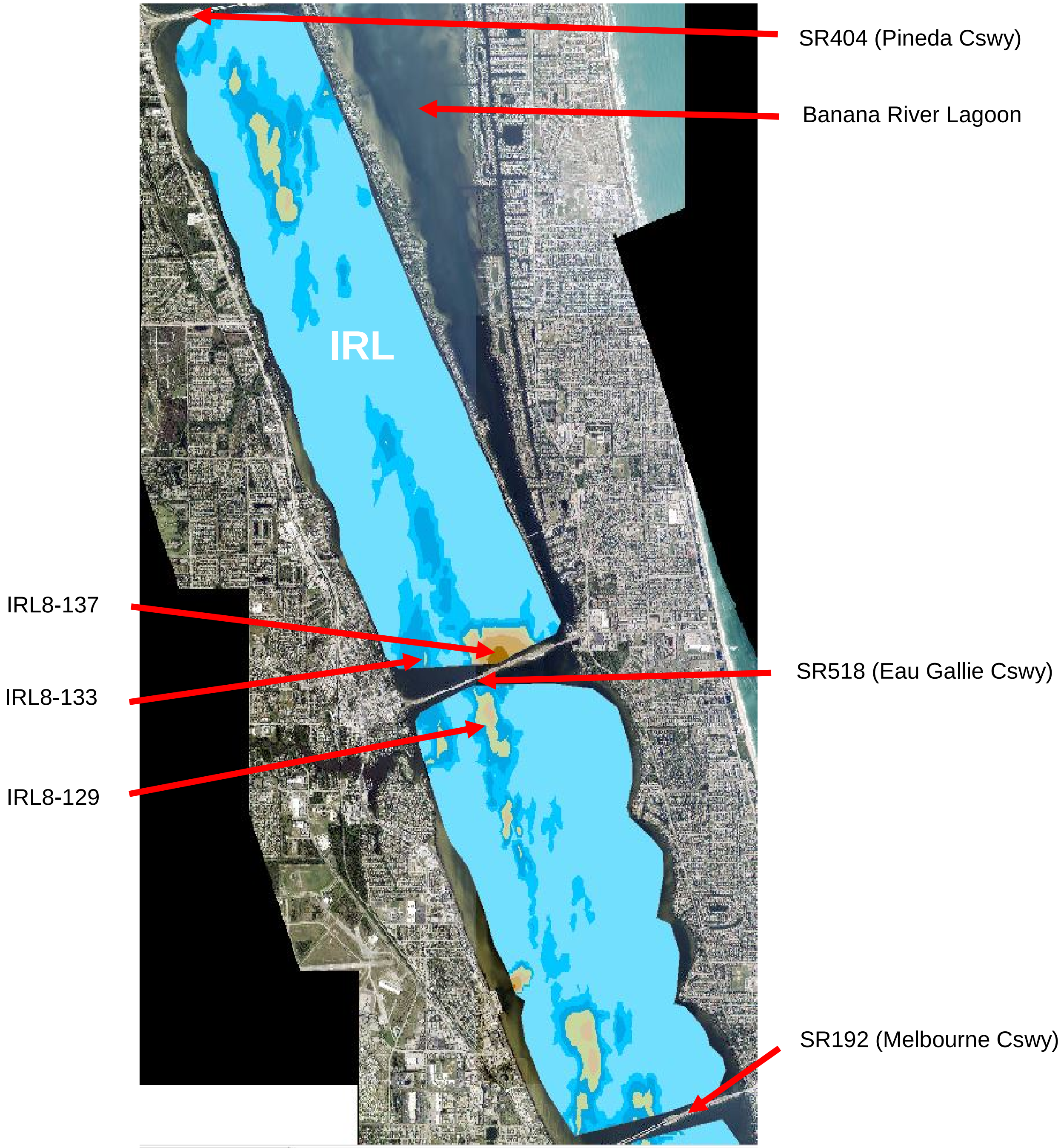


Figure 4. Contour map showing potential or acoustically-defined muck deposits (tan to brown shading) in the Indian River Lagoon (IRL) from Pineda Causeway (Cswy) to Melbourne Causeway. Selected muck sites identified using IDs from Table 2. For station IDs (e.g., location of IRL8-129 = 28.129°N = 28°7'44"N). Figure from Riegl et al. (2015).

Several sites in the IRL near Pineda Causeway contained muck; the largest area (IRL8-209) was identified by Reigl et al. (2015) and is listed among our top 20 locations (Table 2, Figure 5). At 4–5 km north of Pineda Causeway, significant muck deposits were identified on the western and eastern margins of the IRL by Riegl et al. (2015) and us; they are included in the top 20 sites (IRL8-247, Rockledge A and IRL8-264, Rockledge B; Table 2 and Figure 5). Two additional sites were surveyed south of SR520 in the IRL (IRL8-324 and IRL8-353, Table 2 and Figure 5). These two locations were included in our top 20 sites and were previously well marked on maps from Riegl et al. (2015) and Trefry et al. (1990). Another area of significance (IRL8-388) was confirmed near Cocoa between SR520 and SR528 and listed among the top 20 sites (Table 2, Figure 5).

Limited observations of muck were found north of the SR528 causeway to the NASA Causeway, except in the ICW (Figure 6). One site noted by Riegl et al. (2015) contained >2 m of muck but was relatively small (IRL8-487, Table 2, Figure 6). Areas to the west and east of the ICW (north of the NASA Causeway) had sizeable muck deposits that were listed in our top 20 locations (IRL8-529 and IRL 8-530, Table 2, Figure 5). We did not find as much muck in the Titusville area (e.g., IRL8-547, 554, 577, Table 2) as suggested by numerous north-south striations of brown on maps by Riegl et al. (2015). Two borrow pits adjacent to the Titusville Railroad Bridge contained thick muck deposits (IRL8-649A, B; Table 2; Figure 6). North of the Titusville Railroad Bridge in the IRL, little muck was found other than at the Mims Boat Ramp and in the ICW (Table 2). Several areas in the IRL north of the Mims Boat Ramp had been identified as muck deposits by Riegl et al. (2015). We did not find muck there; instead; the fine, wet sand and bottom algae with high water content likely gave acoustic signals that were interpreted as muck (Table 2; Figure 1. Page 4, 28°42' N and 28°44' N).

In the Banana River Lagoon, from SR528 to ~8 km north where we stopped sampling due to closure of the area to boat traffic, muck was identified in the channel (BRL8-470); however, we did not find the extent of muck suggested on the Riegl et al. (2015) maps (Figure 6). Muck deposits of note in the BRL were found north and south of SR528 at sites BRL8-414 and BRL8-399 (Figure 6). Moving south in the BRL, a large muck deposit was identified around the Cocoa Beach Country Club (IRL8-317, Table 2 and Figure 5). This deposit was identified by Trefry et al. (1990), but not by Riegl et al. (2015). Farther south in the BRL, a large area identified by Riegl et al. (2015) was mostly wet fine sand and shell with some admixed muck (BRL88-265, Table 2 and Figure 5). The final two sites surveyed in the BRL were north of Pineda Causeway (SR404) on the west and east sides of the ICW; these deposits were listed in the top 20 were BRL8-213 (west) and BRL8-221 (east) (Table 2, Figure 4).

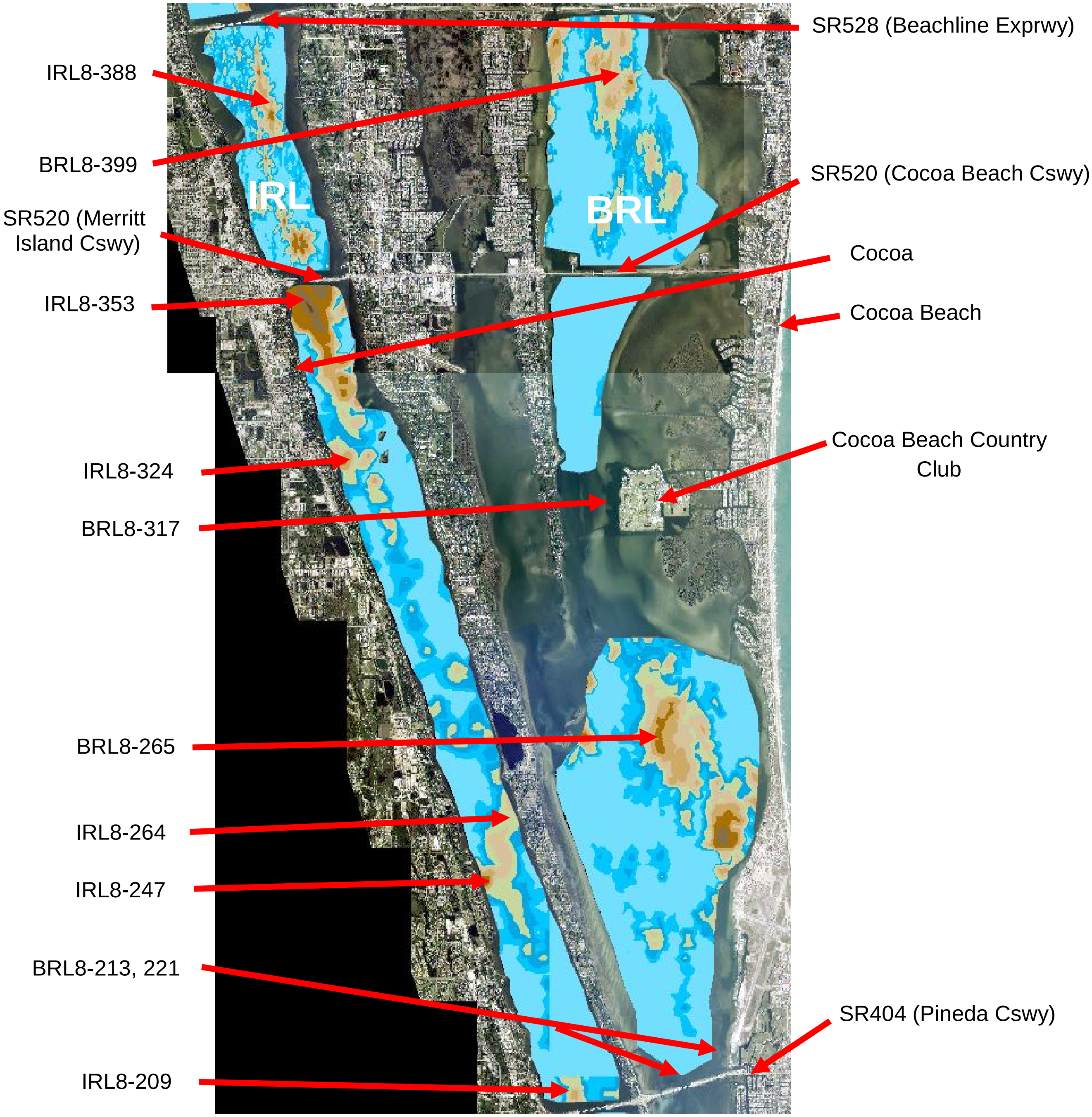


Figure 5. Contour map showing potential or acoustically-defined muck deposits (tan to brown shading) in Banana River Lagoon (BRL) and Indian River Lagoon (IRL) from SR528 (Beachline Expressway) to SR404 (Pineda Causeway [Cswy]). Selected muck sites identified using IDs from Table 2. For station IDs (e.g., location of IRL8-209 = 28.209°N = 28°12'32"N). Figure from Riegl et al., 2015.

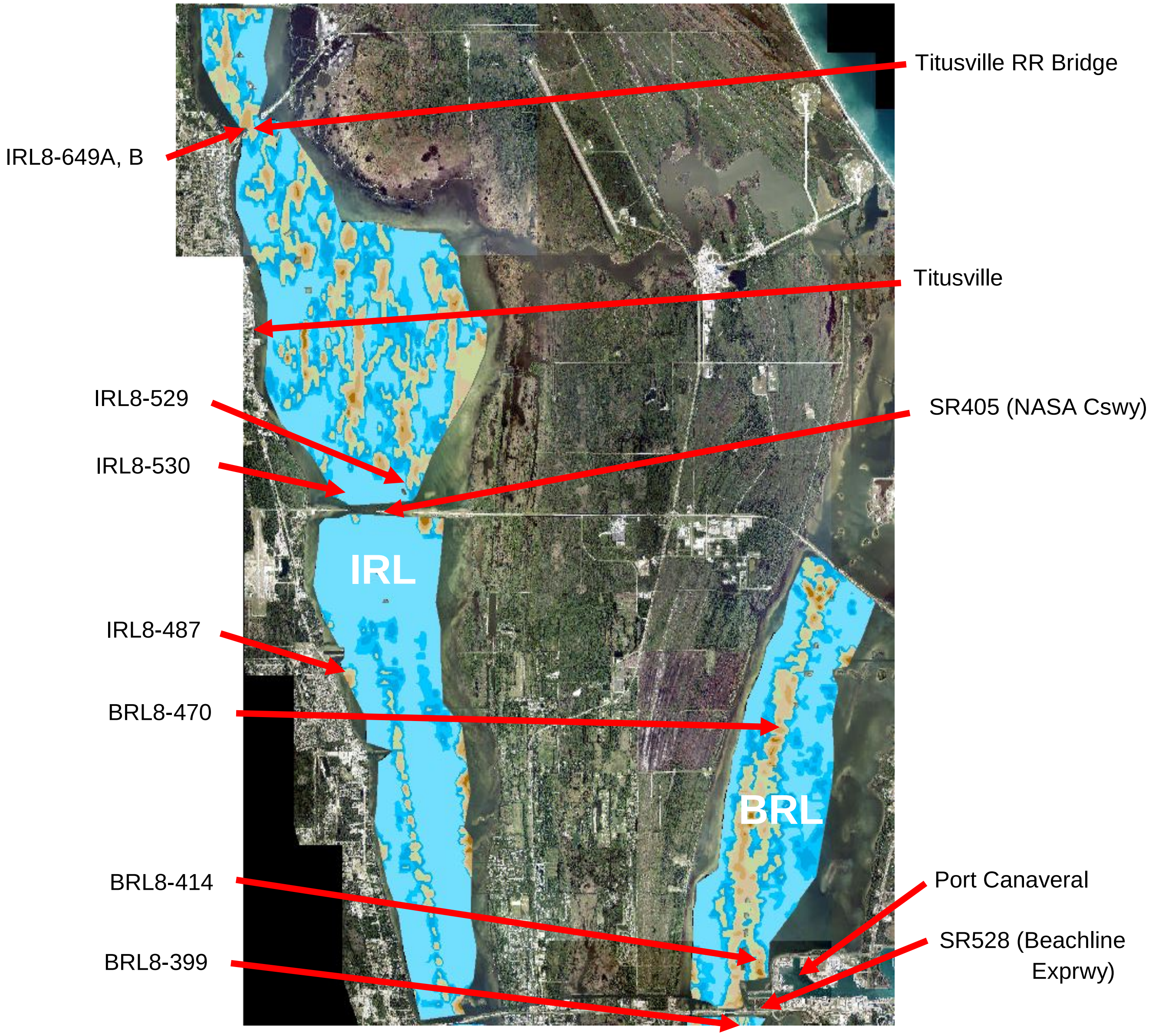


Figure 6. Contour map showing potential or acoustically-defined muck deposits (tan to brown shading) in Banana River Lagoon (BRL) and Indian River Lagoon (IRL) from Titusville to SR528 (Beachline Expressway). Selected muck sites identified using IDs from Table 2. For station IDs (e.g., location of BRL8-399 = 28.399°N = 28°23'56"N). Figure from Riegl et al. (2015).

3.2. Detailed Surveys and Ranking of the Top 20 Sites

The 20 sites chosen for detailed geochemical and biological surveys span the IRL from Mims to Turkey Creek and the BRL from north of the Beachline Expressway (SR528) to Pineda Causeway (SR404). All 20 sites chosen for comprehensive study contained >10% OM and maximum muck thicknesses >0.8 m (Table 2). The surface areas of the 20 top sites ranged from 26,000 m^2 at Mims (IRL8-675) to 570,000 m^2 at Cocoa Beach Country Club (BRL8-317) and Rockledge B (IRL8-264, Table 3). The total area of the top 20 sites was 4.2 million m^2 (4.2 km^2) and total volume was 4.3 million m^3 (Table 3). We presently estimate that the top 20 sites represent ~40% of the total area (~10 km^2) and volume of muck (~10 million m^3), respectively, in the BRL plus IRL in Brevard County. The additional muck is in the ICW and numerous minor deposits, including shallow-water sites near canals and storm drains.

3.2.1 Geochemical Studies

The range of OM content for muck deposits in the top 20 sites was 13–27% (as LOI at 550°C, Table 3). These values were all greater than a previously cited minimum value of 10% OM in a definition of IRL muck (Trefry et al., 1990). Values for LOI (at 550°C) in IRL sediments, including muck, are strongly correlated with TOC, total N, P, Al and Fe (r>0.95, Figure 7). Therefore, the basic parameter of LOI can be used to calculate values for several important variables (e.g., TOC, TN) that are otherwise obtained via additional instrumentation and expense. For example, for an LOI of 15%, the sediment N concentration is 0.50% [N = 0.035(15%) – 0.029 = 0.50%] (equation in Figure 7b).

Concentrations of $CaCO_3$ shell material (LOI at 950°C) ranged from 5–15% and were independent of LOI and less predictable due to the irregular occurrence of shell deposits (Figure 7e). Silicon (Si) is present in silt and clay minerals (e.g., $Al_2Si_2O_5(OH)_4$, kaolinite) and in quartz sand (SiO_2). The highest value for Si in this study (42.3%, (Figure 7f) is equivalent to 90.4% quartz sand (Si/SiO_2 = 0.468). Sediments from the IRL show a negative relationship between Si and Al with more Al relative to Si in clay minerals and vice versa in sand.

A primary objective of environmental muck dredging is to decrease fluxes of dissolved N and P from sediment to the overlying water. Therefore, the parameter chosen for the geochemical prioritization scale was sediment fluxes of N. Nitrogen was chosen because fluxes of P are more variable and complex due to influences from adsorption/desorption and precipitation/dissolution in sediments as a function of pH and redox conditions (e.g., Wu et al., 2014). Even though N fluxes are less influenced by sorption and precipitation than P, they are greatly affected by temperature with as much as a 6–10% increase per 1°C increase in sediment temperature (Fox and Trefry, 2018). We used a temperature coefficient (Q_{10}) of 1.8 for IRL muck (Fox and Trefry, 2019) to normalize N fluxes from this study.

Table 3. Site identification (ID), description, latitude (lat), longitude (long), muck surface area, muck volume and organic matter (OM) content for top 20 sites selected for detailed surveys.

Grand Survey ID	Site Description	Lat (N)	Long (W)	Muck Surface Area (m^2)[a]	Muck Volume (m^3)[a]	OM (%)
IRL8-037	Turkey Creek	28˚2'13"	80˚34'52"	100,000	110,000	19
IRL8-129	SR518 SW (Eau Gallie Cswy)	28˚7'44"	80˚36'43"	300,000	130,000	16
IRL8-133	SR518 NW (Eau Gallie Cswy)	28˚7'59"	80˚37'19"	240,000	260,000	16
IRL8-137	SR518 NE (Eau Gallie Cswy)	28˚8'13"	80˚36'43"	290,000	130,000	>10
IRL8-209	SR404 NE (Pineda Cswy)	28˚12'32"	80˚39'14"	140,000	110,000	15
IRL8-247	Rockledge A	28˚14'49"	80˚40'34"	125,000	86,000	16
IRL8-264	Rockledge B	28˚15'50"	80˚40'16"	570,000	310,000	13
IRL8-324	Cocoa South	28˚19'26"	80˚42'32"	110,000	86,000	14
IRL8-353	SR520 SE (Merritt Is. Cswy)	28˚21'11"	80˚42'50"	460,000	360,000	16
IRL8-388	SR520–528	28˚23'17"	80˚43'34"	78,000	35,000	18
IRL8-530	SR405 NW (NASA Cswy)	28˚31'48"	80˚46'30"	100,000	120,000	27
IRL8-529	SR405 NE (NASA Cswy)	28˚31'44"	80˚44'10"	140,000	220,000	20
IRL8-649A	Titusville RR SW	28˚38'56"	80˚48'58"	150,000	290,000	17
IRL8-649B	Titusville RR SE	28˚38'56"	80˚47'28"	280,000	450,000	24
IRL8-675	Mims Boat Ramp	28˚40'30"	80˚49'30"	26,000	22,000	16
Banana River Lagoon						
BRL8-414	SR528 NE (Beachline Exprwy)	28˚24'50"	80˚38'10"	99,000	200,000	20
BRL8-399	SR528 SE (Beachline Exprwy)	28˚23'56"	80˚37'16"	220,000	320,000	20
BRL8-317	Cocoa Beach Country Club	310,000	80˚38'38"	570,000	750,000	>10
BRL8-221	SR404 NE (Pineda Cswy)	28˚13'16"	80˚37'5"	100,000	160,000	22
BRL8-213	SR404 NW (Pineda Cswy)	28˚12'47"	80˚37'55"	110,000	150,000	24
Top 20 sites		Sum		4.2×10^6	4.3×10^6	-
		Mean		212,000	215,000	18
		Maximum		570,000	750,000	27
		Minimum		26,000	22,000	13

[a]Area is for muck deposits thicker than 30 cm (1 foot). Details on p. 23.

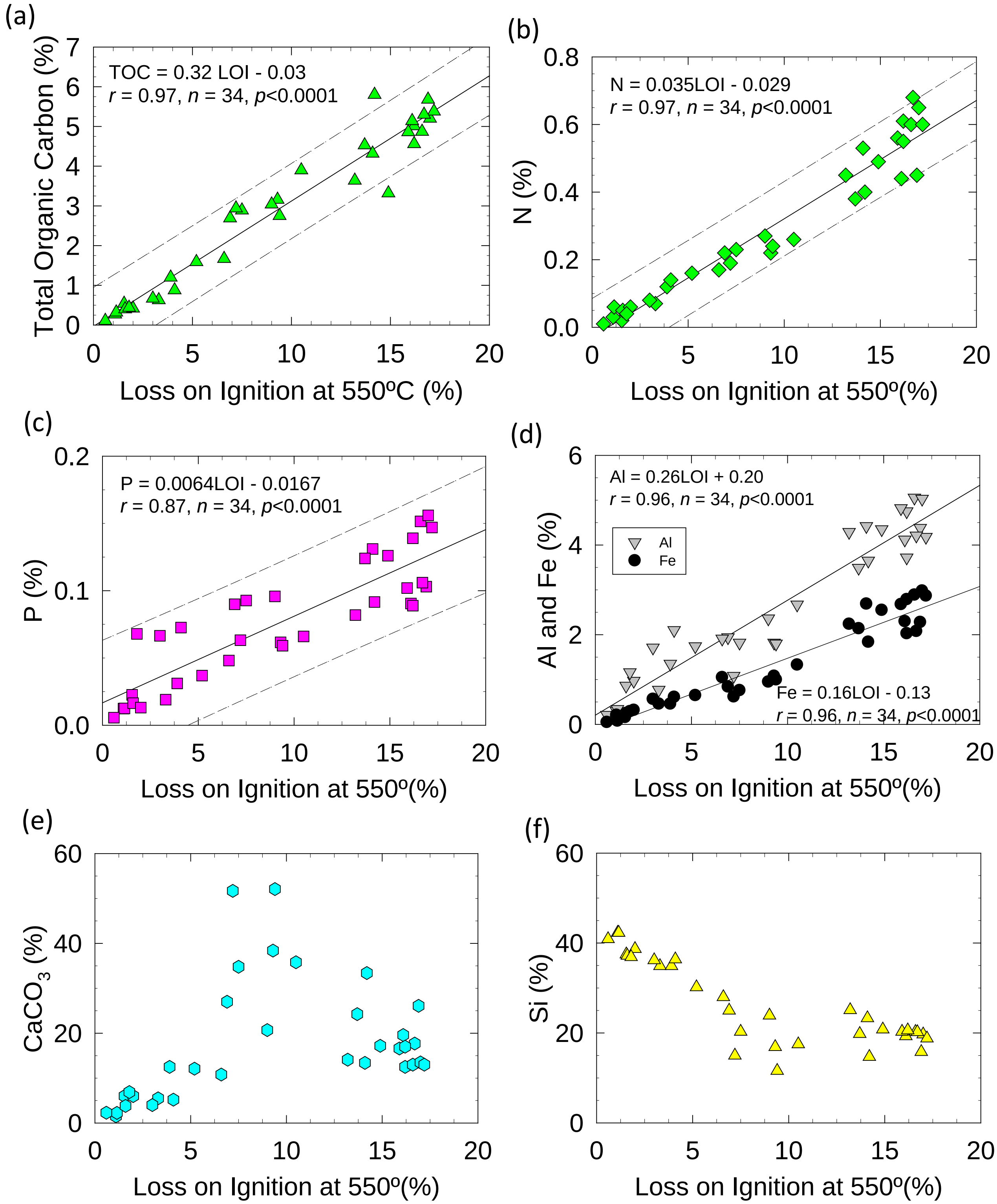


Figure 7. Loss on Ignition at 550°C for sediments versus (a) total organic carbon, (b) nitrogen, (c) phosphorus, (d) aluminum and iron, (e) calcium carbonate shell material ($CaCO_3$ as LOI at 950°C) and (f) silicon. Solid lines and equations from linear regression, correlation coefficient (*r*), number of data points (*n*) and *p* statistic (*p*); dashed lines show 95% prediction intervals.

Sediment fluxes of N were determined using the Quick-Flux technique that has been validated by comparisons with other methods (Fox and Trefry, 2018, 2019). Values from this study, normalized to 25°C, ranged from 6 to ~100 metric tons N/km^2/y, with a tendency for higher fluxes in the BRL (Table 4). Fluxes were lower (<10 MT N/km^2/y) for sediments when OM concentrations were <10% (i.e., log [LOI] = 1, Figure 8a). When OM content increased above 10% (log [OM] = 1.0), sediment fluxes of N increased exponentially to >100 MT N/km^2/y. At OM values ≥20% (log [OM] = 1.30), N fluxes averaged 60 ± 35 MT N/km^2/y relative to 19 ± 14 MT N/km^2/y when OM content was 13–19% (log [OM] = 1.11–1.28; Figure 8a). A moderately strong correlation coefficient (r = 0.76) was calculated for [1/(Flux N)] versus log [LOI] (Figure 8c). Similarly, fluxes of N correlated strongly (r = 0.80) with porosity (Figure 8d).

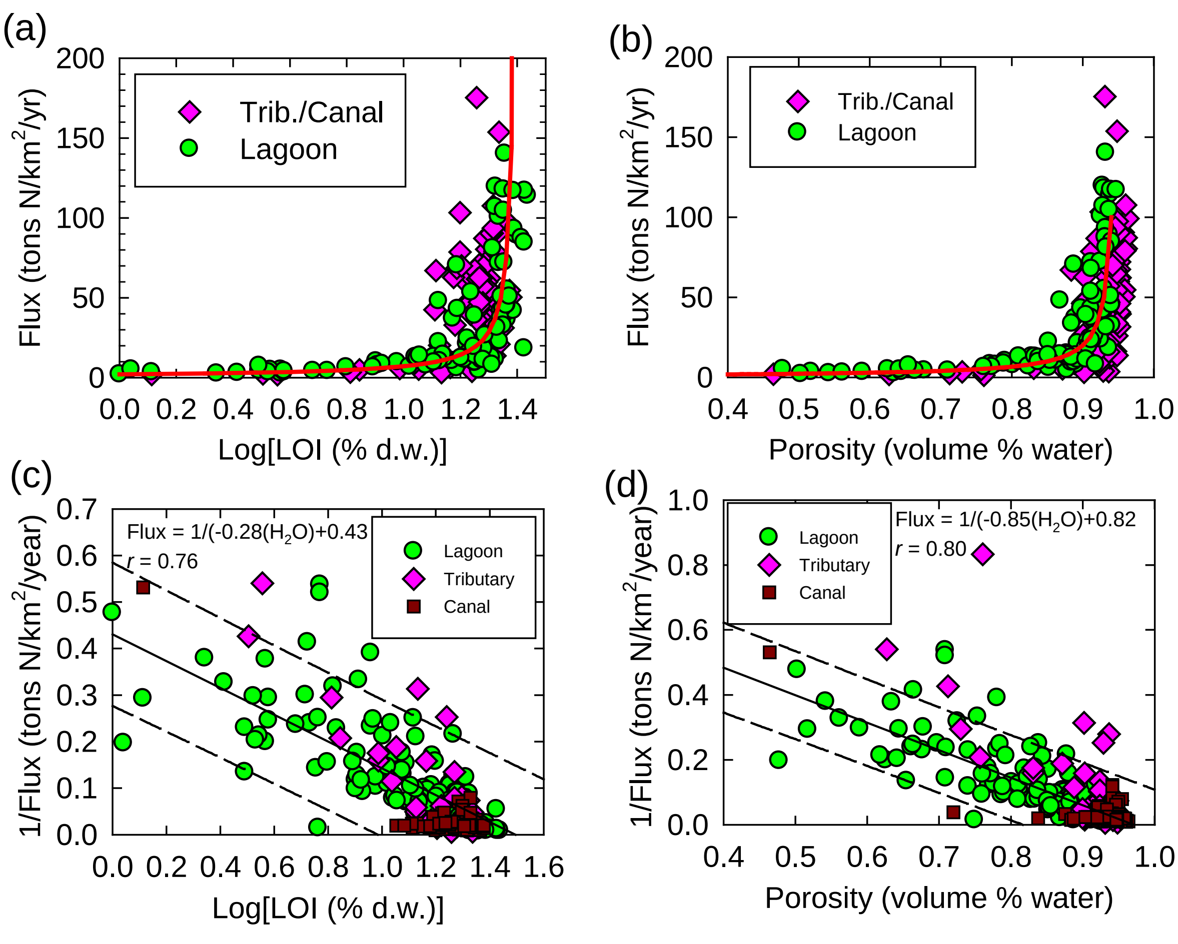


Figure 8. Sediment fluxes of nitrogen versus (a) log [Loss on Ignition (LOI) at 550°C] and (b) porosity (volume % water). [1/(sediment flux of nitrogen)] versus (c) log [LOI at 550° C] and (d) porosity. (from Fox and Trefry, 2019). Masses of nitrogen (N) in metric tons.

Table 4. Site identification (ID), description, muck surface area, muck volume, sediment nitrogen fluxes (metric tons/km^2/y), plus ranking based on sediment nitrogen flux for the top 20 sites.

Grand Survey ID	Site Description	Muck Surface Area (m^2)[b]	Muck Volume (m^3)[b]	Sediment N Flux t/km^2/y (25°C)	Rank (N Flux)
BRL8-399[a]	SR528 SE (Beachline Exprwy)	220,000	320,000	101 ± 27	1
IRL8-529[a]	SR405 NE (NASA Cswy)	140,000	220,000	100 ± 17	2
BRL8-213[a]	SR404 NW (Pineda Cswy)	110,000	150,000	83 ± 47	3
IRL8-675[a]	Mims Boat Ramp	26,000	22,000	77 ± 39	4
IRL8-037	Turkey Creek	100,000	110,000	69 ± 49	5
IRL8-649B[a]	Titusville RR SE	280,000	450,000	42	6
BRL8-414[a]	SR528 NE (Beachline Exprwy)	99,000	200,000	41 ± 12	7
BRL8-221[a]	SR404 NE (Pineda Cswy)	100,000	160,000	38 ± 8	8
IRL8-530	SR405 NW (NASA Cswy)	100,000	120,000	32 ± 15	9
IRL8-649A[a]	Titusville RR SW	150,000	290,000	30 ± 13	10
IRL8-137[a]	SR518 NE (Eau Gallie Cswy)	290,000	130,000	29 ± 11	11
BRL8-317[a]	Cocoa Beach Country Club	570,000	750,000	27 ± 14	12
IRL8-209[a]	SR404 NE (Pineda Cswy)	140,000	110,000	20 ± 19	13
IRL8-247	Rockledge A	125,000	86,000	16 ± 4	14
IRL8-324	Cocoa South	110,000	86,000	13 ± 10	15
IRL8-353	SR520 SE (Merritt Island Cswy)	460,000	360,000	11 ± 3	16
IRL8-129	SR518 South (Eau Gallie Cswy)	300,000	130,000	10 ± 4	17
IRL8-133[a]	SR518 NW (Eau Gallie Cswy)	240,000	260,000	7.5 ± 4.3	18
IRL8-264	Rockledge B	570,000	310,000	6.4 ± 3.9	19
IRL8-388	SR520–528	78,000	35,000	6.2 ± 2.3	20
	TOTAL IRL	3.21×10^6	2.72×10^6		
	TOTAL BRL	1.10×10^6	1.58×10^6		
	TOTAL	4.22×10^6	4.30×10^6		

[a]Site includes a sediment borrow pit.

[b]Area is for muck deposits thicker than 30 cm (1 foot).

Geochemical data for sediment fluxes of dissolved N (in t/km^2/y) from several locations within each site were used to rank the top 20 sites from highest (#1) to lowest (#20) flux (Table 4, Figure 9). This approach stresses the importance of surface area to N inputs from muck. Overall, 15 of the 20 sites were in the IRL; however, the five sites in the BRL contained 37% of the total muck volume (4.3 million m^3, Table 4) and 52% of the total sediment flux of N (123 t/y) for the top 20 sites.

The five highest ranked sites had mean N fluxes >60 t/km^2/y (Table 4, Figure 9b). The first and third ranked sites were in BRL between SR528 (Beachline Expressway) and SR404 (Pineda Causeway, Figure 9). An IRL site on the northeast side of SR405 (NASA Causeway) was ranked second (Figure 9). Turkey Creek, the fifth ranked site, was dredged during 2016–2017 (e.g., Fox and Trefry, 2018). The high ranking for Turkey Creek confirms the value of dredging this location. The Mims Boat Ramp (ranked 4th) was dredged during 2018 after data for this project were collected. The choice of Mims for dredging also seems valuable (Figure 9).

Detailed muck maps, plus a map showing the locations of each area in the lagoon (Figures 10 and 12–20), show optimal sites for muck removal in the order of ranking. Overall, 12 of the top 20 sites included borrow pits where sand was removed for construction of causeways and other land features (Table 4). Satellite imagery of two borrow pits (SR528 SE and Cocoa Beach Country Club) shows the distinct matches between the borrow pits and the muck deposits (Figure 11).

Data for surface area and volume of muck deposits are listed for muck deposits with thicknesses >5 cm (2") and >30 cm (1 foot) for each of the 20 sites (Figures 10, 12–20). Calculations of total area and volume were based on our selection of a reasonable lower limit for detection and confirmation of a non-transient muck deposit. If we included values of <5 cm our calculations, we would overestimate the fraction of the lagoon that was covered with muck. Calculations of area and volume based on 30 cm (1 foot) were used for Table 4 because dredging muck deposits of <30-cm thick is not practical with generally available technology. Furthermore, dredging a thin (30 cm) layer of muck plus overdredging a 15 cm (6") layer of sand yields 66% muck and 33% sand; this percentage shifts to 93% muck and 7% sand when overdredging a 200-cm thick muck deposit. Overdredging is among the additional considerations made in estimating volume of material removed during dredging. The relative amount of overburden removed increases as the thickness of the muck deposit decreases. Considerations such as overdredging can be included in our model along with other factors. They were not used in the rankings reported here.

Rankings based on sediment N fluxes were used to identify sites where muck dredging or other management strategy could help improve water quality. Biological indicators are introduced in the next section (3.2.2) with the added goal of identifying where muck projects may also lead to an improved ecological environment.

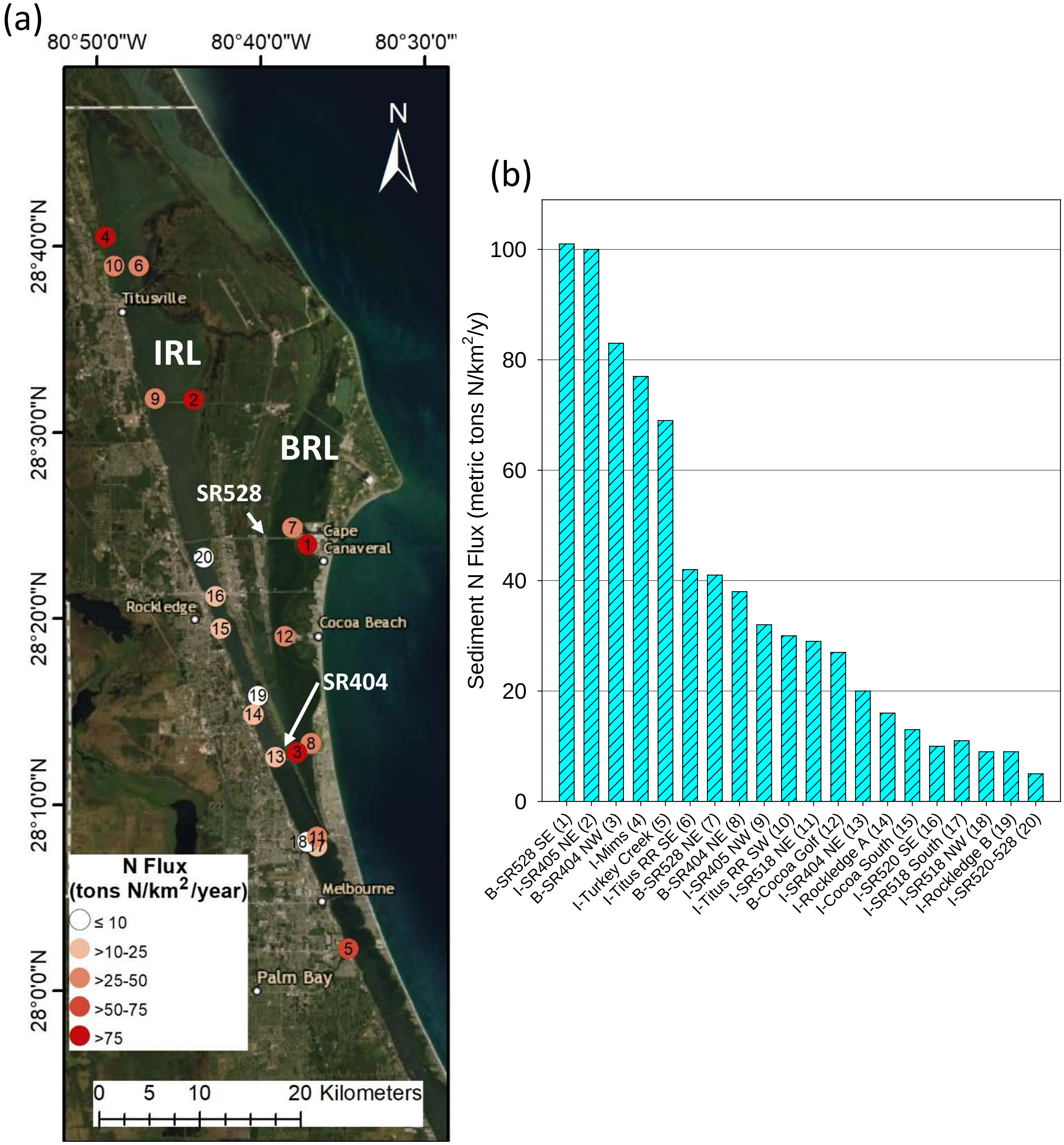
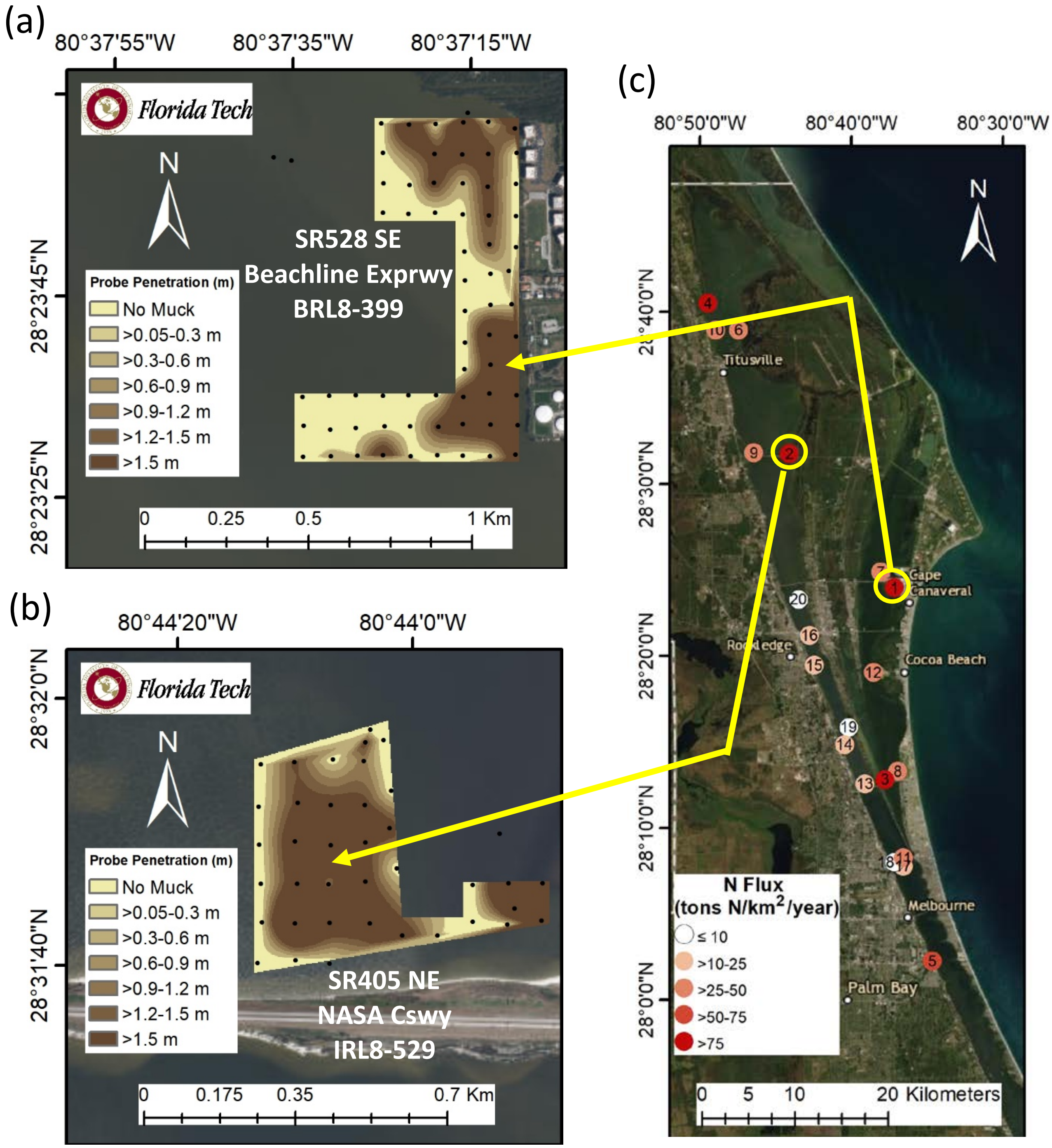


Figure 9. (a) Map of the study area from Sebastian Inlet to northern Indian River Lagoon (IRL) and adjacent Banana River Lagoon (BRL) with color-coded, numbered markers that correspond with rankings for the top 20 locations for muck projects based on the sediment nitrogen (N) flux at 25°C and (b) sediment N flux for top 20 sites. Numbers in parentheses on x-axis show rank where #1 indicates the highest N flux and corresponds with number on adjacent map. (B = Banana River Lagoon, IRL = Indian River Lagoon; 1 metric ton N/km^2/y = 0.114 mg N/m^2/hr)



Rank & Map #	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
1	BRL8-399	SR528 SE (Beachline Exprwy)	290,000	220,000	330,000	320,000
2	IRL8-529	SR405 NE (NASA Cswy)	150,000	140,000	220,000	220,000

Figure 10. Maps of muck thicknesses for optimal dredging sites at (a) SR528 SE (Beachline Expressway, BRL8-399) and (b) SR405 NE (NASA Causeway, IRL8-529), plus (c) site locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)

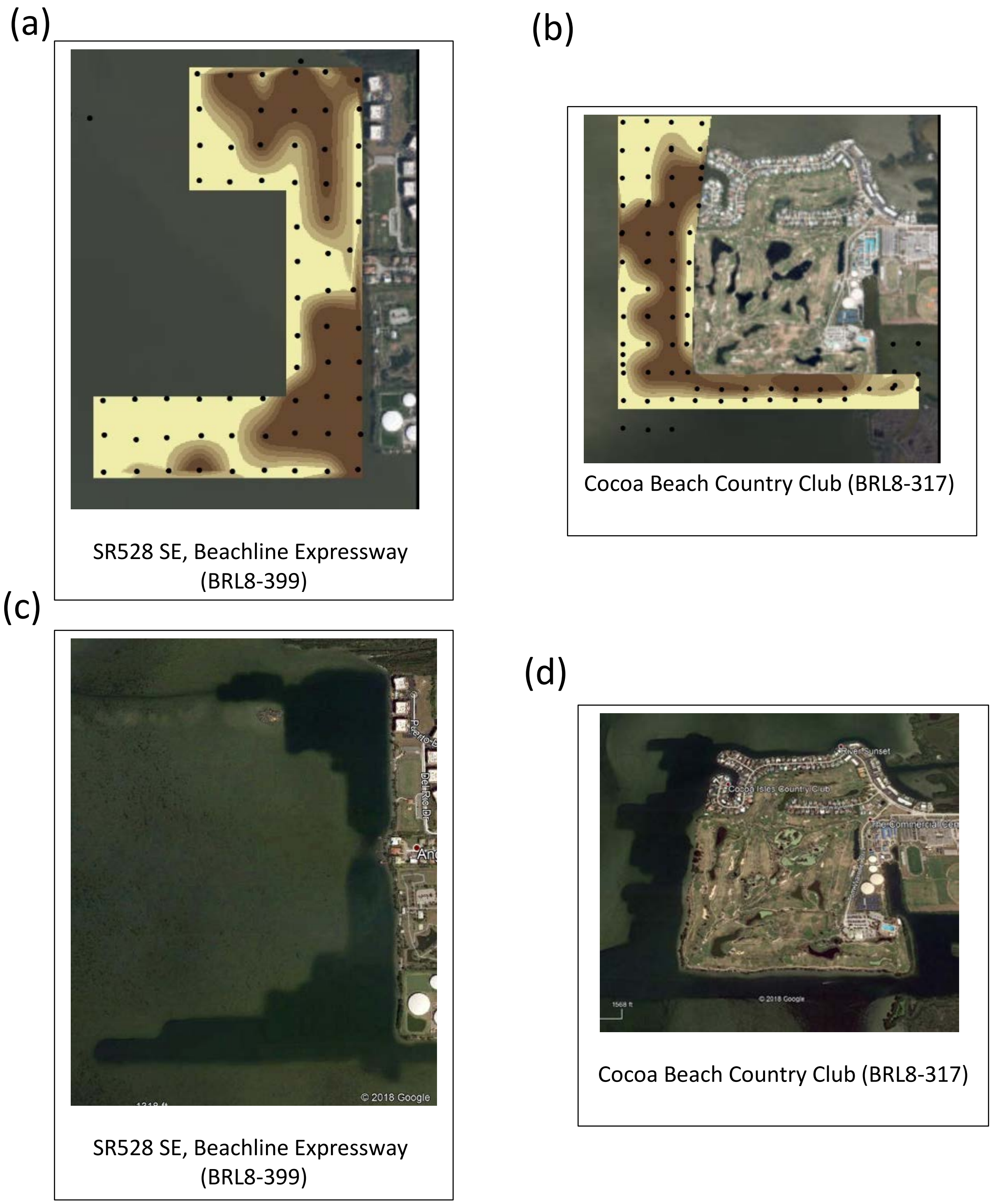
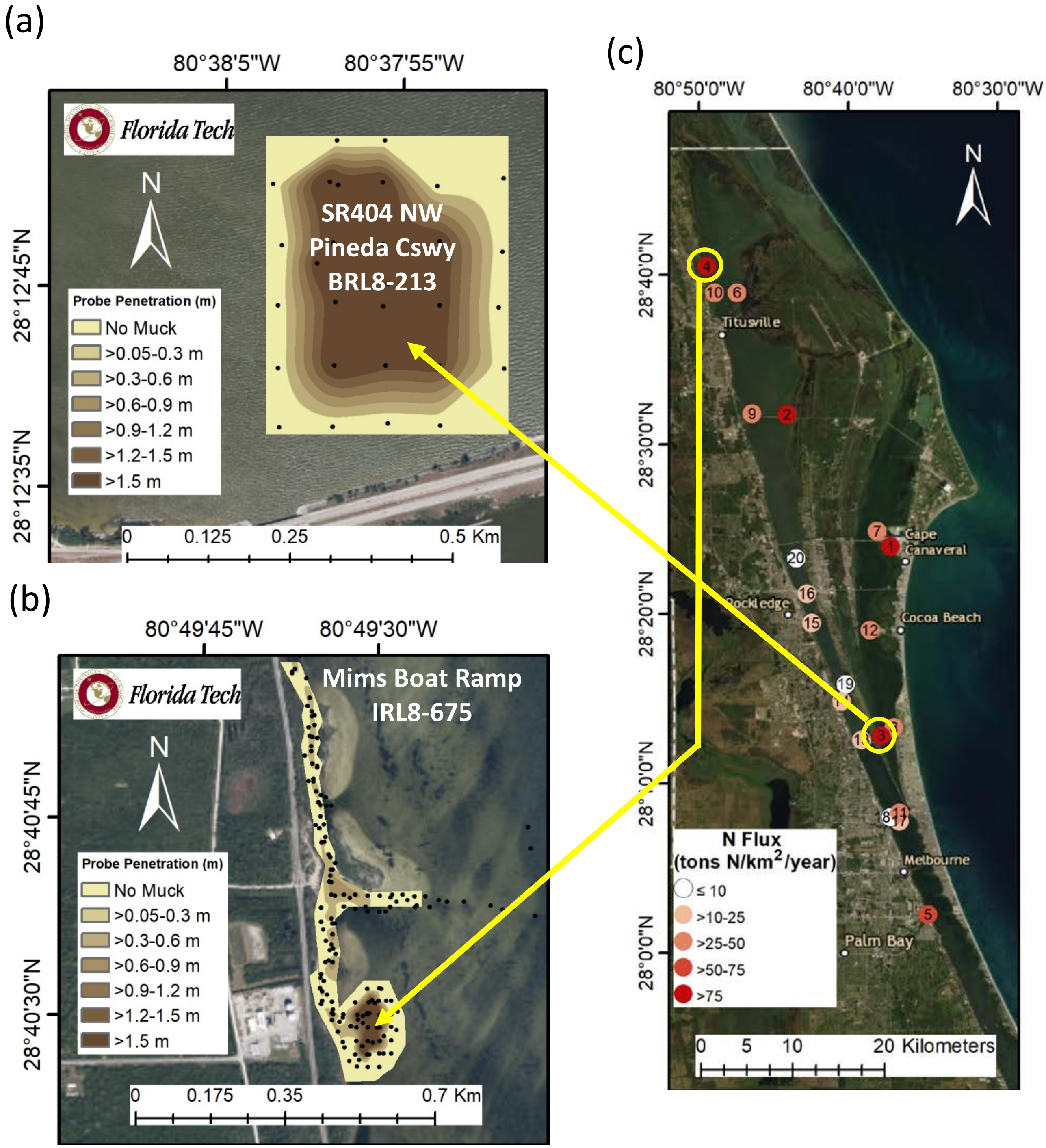
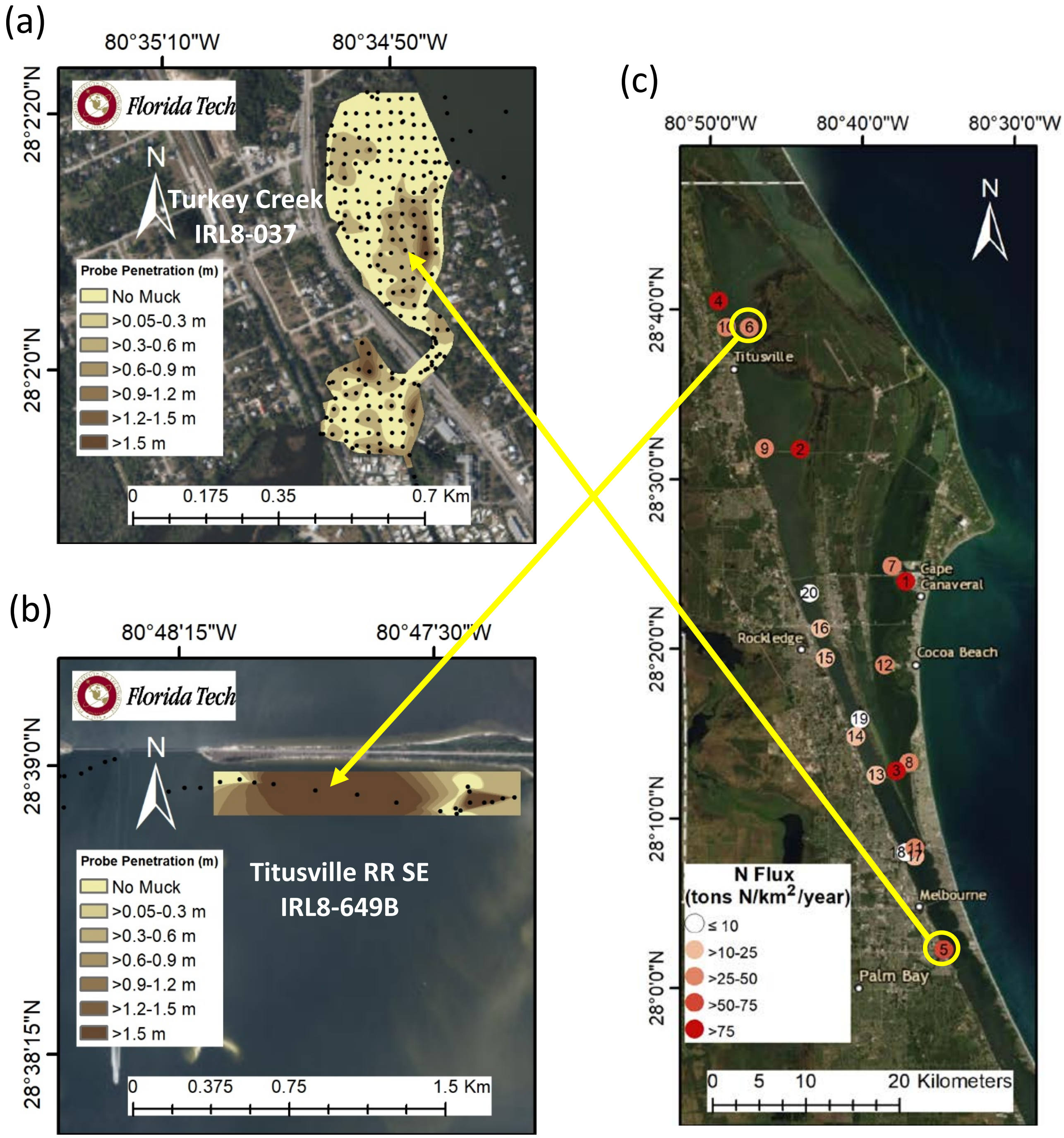


Figure 11. Maps of muck thicknesses at (a) SR528 SE (Beachline Expressway, BRL8-399) and (b) Cocoa Beach Country Club (BRL8-317) plus satellite images showing borrow pits at (c) SR528 SE (Beachline Expressway, BRL8-399) and (d) Cocoa Beach Country Club (BRL8-317). Darker color on (c) and (d) shows deeper water overlying black muck in borrow pits.



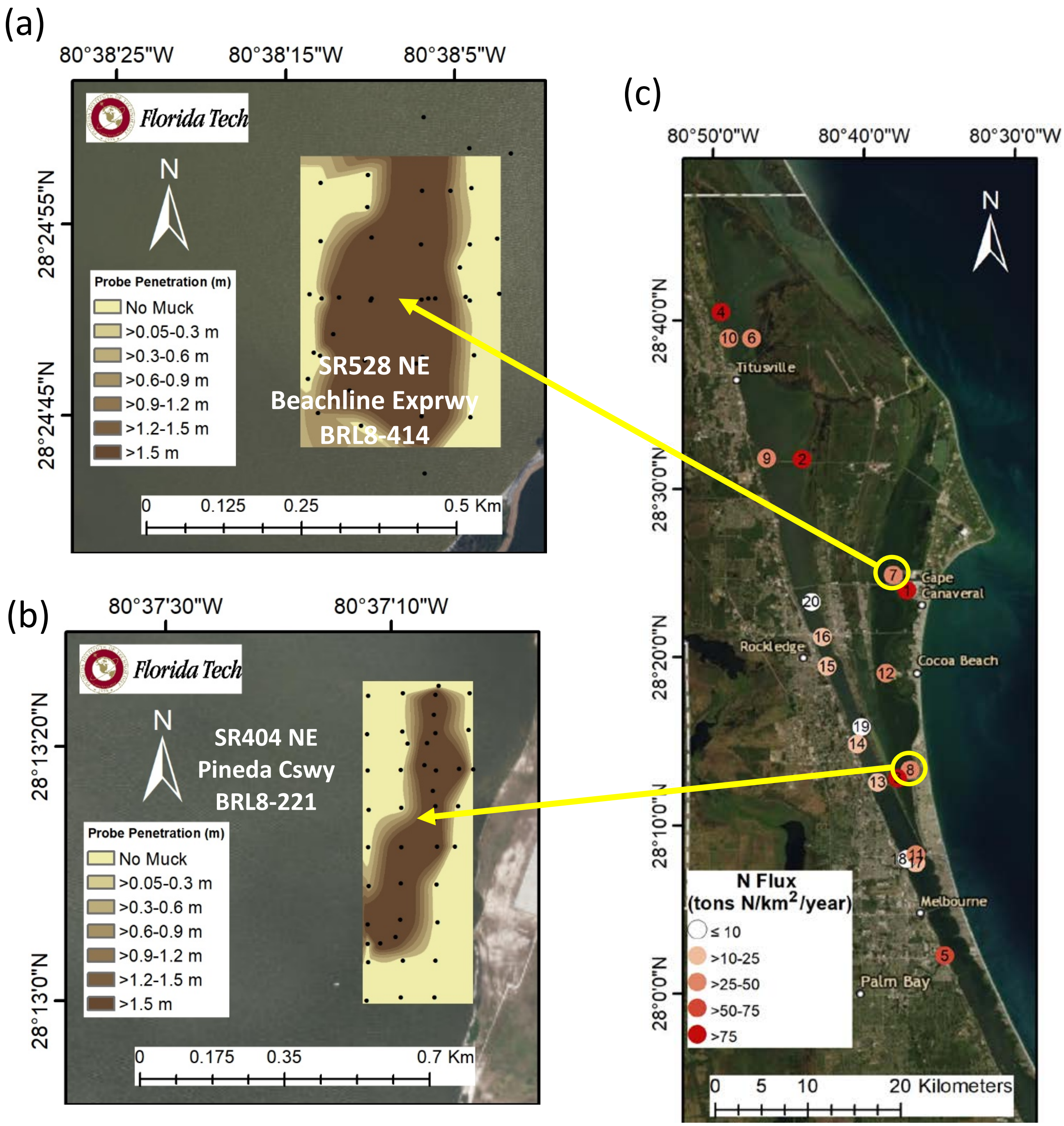
Rank & Map #	ID	Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
3	BRL8-213	SR404 NW (Pineda Cswy)	130,000	110,000	150,000	150,000
4	IRL8-675	Mims Boat Ramp	48,000	26,000	25,000	22,000

Figure 12. Maps of muck thicknesses for optimal dredging sites at (a) SR404 NW (Pineda Causeway, BRL8-213) and (b) Mims Boat Ramp (IRL8-675), plus (c) site locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



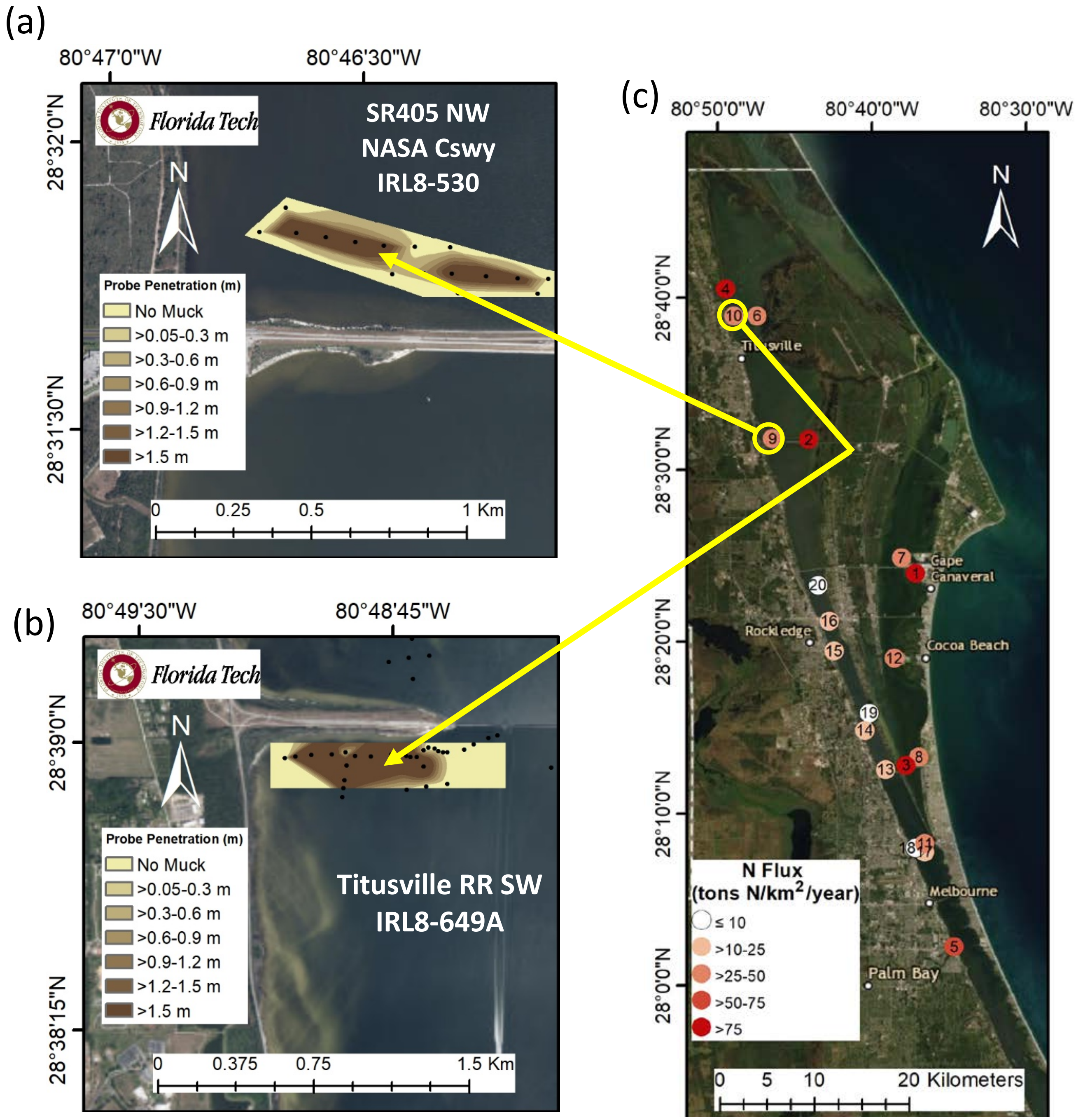
Rank & Map #	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
5	IRL8-037	Turkey Creek	150,000	100,000	110,000	110,000
6	IRL8-649B	Titusville RR SE	310,000	280,000	450,000	450,000

Figure 13. Maps of muck thicknesses for optimal dredging sites at (a) Turkey Creek (IRL8-037) and (b) Titusville Railroad Bridge (RR) SE (IRL8-649B), plus (c) site locations in lagoon. Areas and volumes for muck for thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



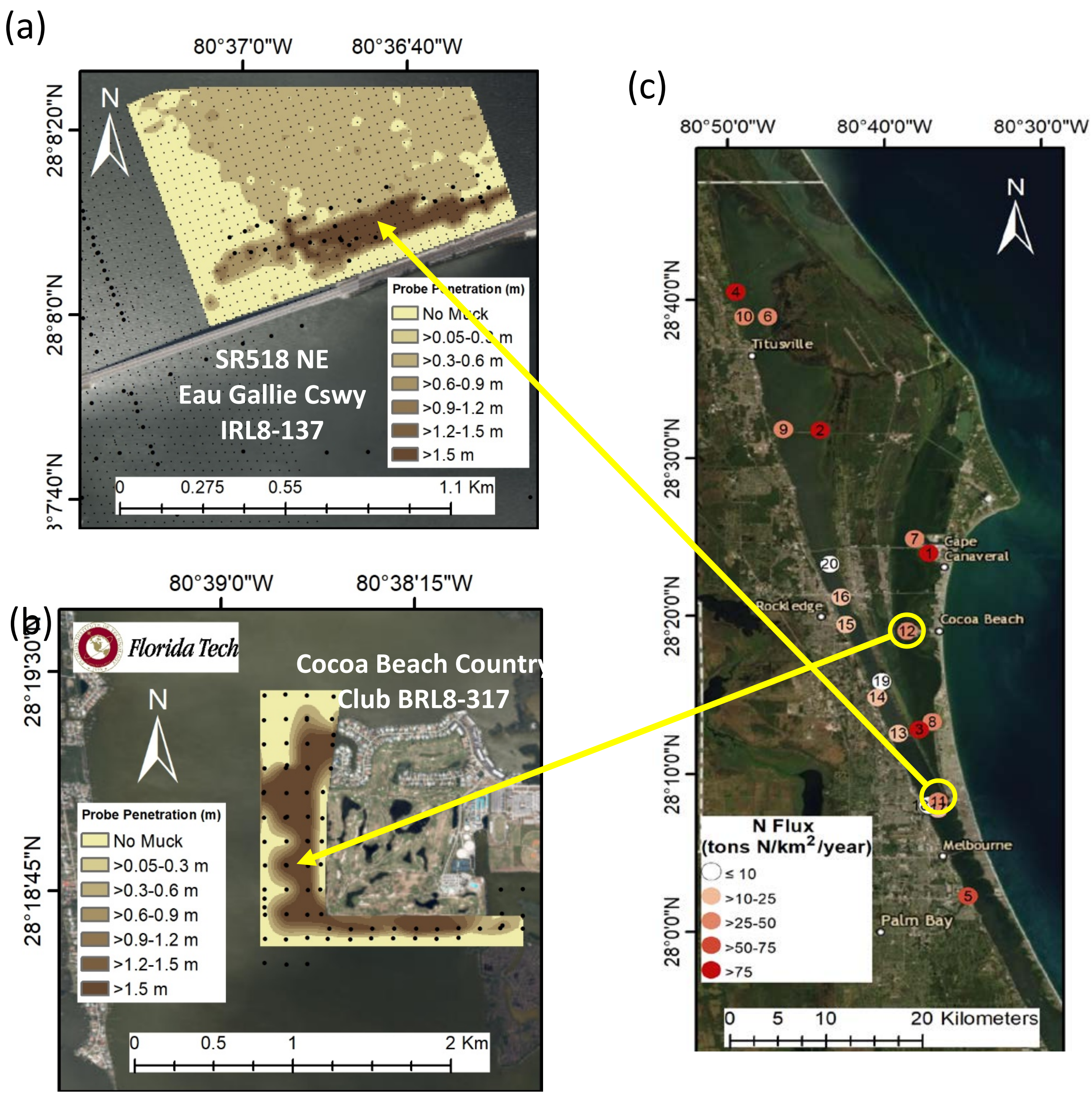
Rank & Map #	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
7	BRL8-414	SR528 NE (Beachline Exprwy)	120,000	99,000	210,000	200,000
8	BRL8-221	SR404 NE (Pineda Cswy)	130,000	100,000	160,000	160,000

Figure 14. Maps of muck thicknesses for optimal dredging sites at (a) SR528 NE (Beachline Expressway, BRL8-414) and (b) SR404 NE (Pineda Causeway, BRL8-221), plus (c) site locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



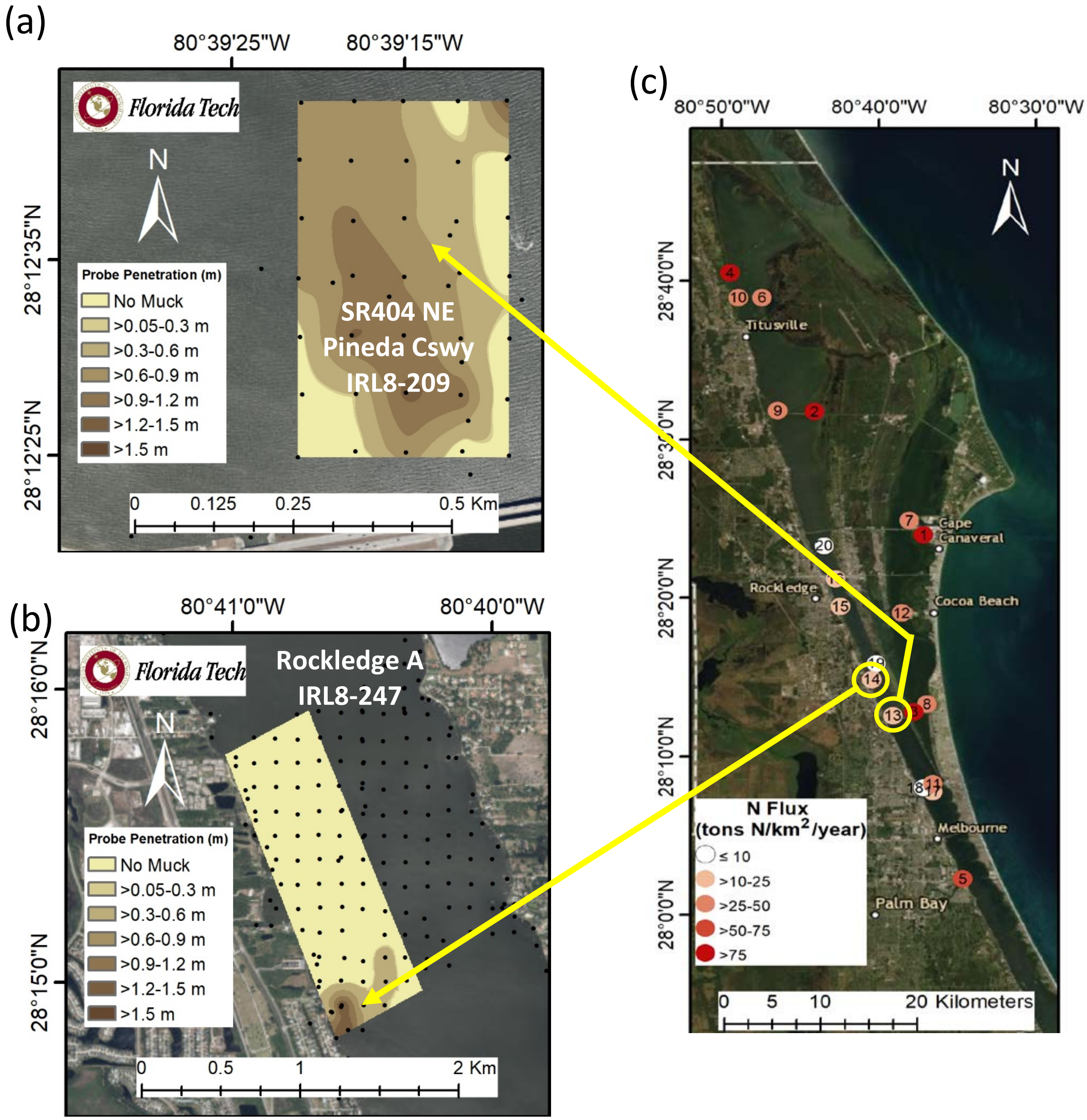
Rank & Map #	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
9	IRL8-530	SR405 NW (NASA Cswy)	440,000	100,000	170,000	120,000
10	IRL8-649A	Titusville RR SW	180,000	150,000	300,000	290,000

Figure 15. Maps of muck thicknesses for optimal dredging sites at (a) SR405 NW (NASA Causeway, IRL8-530) and (b) Titusville Railroad Bridge (RR) SW (IRL8-649A), plus (c) site locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



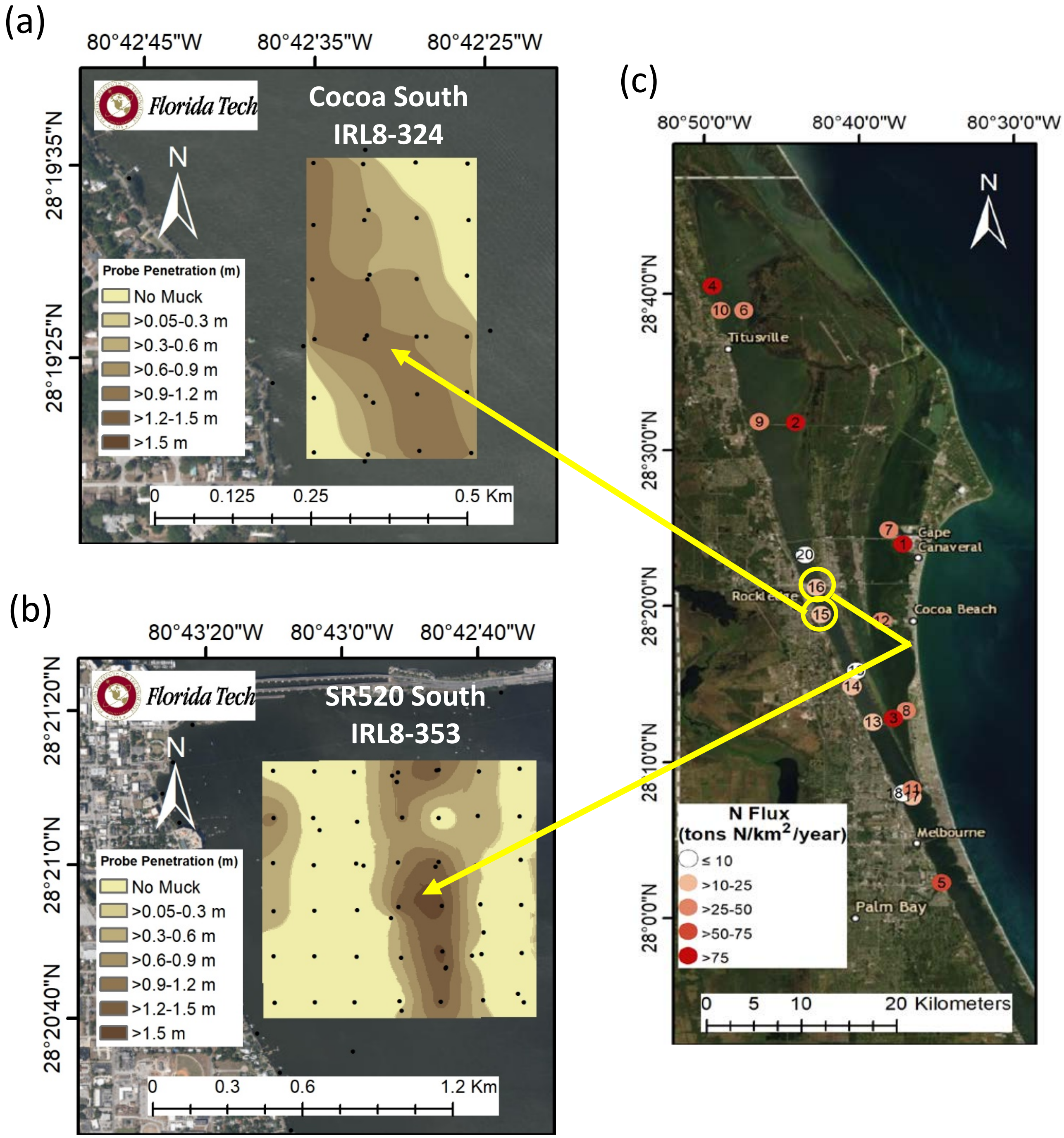
Rank & Map #	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
11	IRL8-137	SR518 NE (Eau Gallie Cswy)	-	-	290,000	130,000
12	BRL8-317	Cocoa Beach Country Club	690,000	570,000	770,000	750,000

Figure 16. Maps of muck thicknesses for optimal dredging sites at (a) SR518 NE (Eau Gallie Causeway, IRL8-137) and (b) Cocoa Beach Country Club (BRL8-317), plus (c) site locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



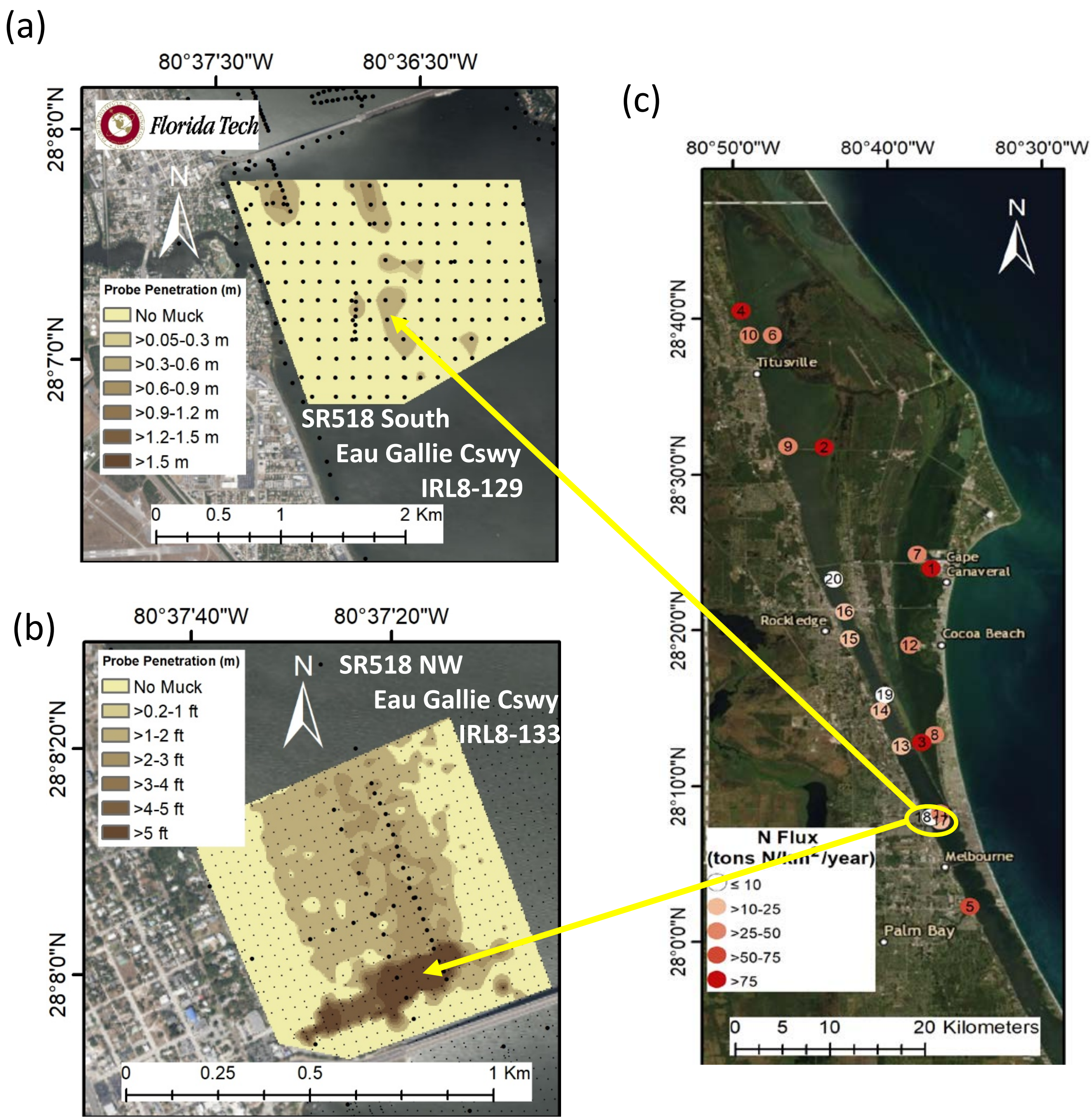
Rank & Map #	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
13	IRL8-209	SR404 NE (Pineda Cswy)	180,000	140,000	120,000	110,000
14	IRL8-247	Rockledge A	640,000	125,000	160,000	86,000

Figure 17. Maps of muck thicknesses for optimal dredging sites at (a) SR404 NE (Pineda Causeway, IRL8-209) and (b) Rockledge A (IRL8-247), plus (c) site locations in lagoon. Areas and volumes for muck for thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



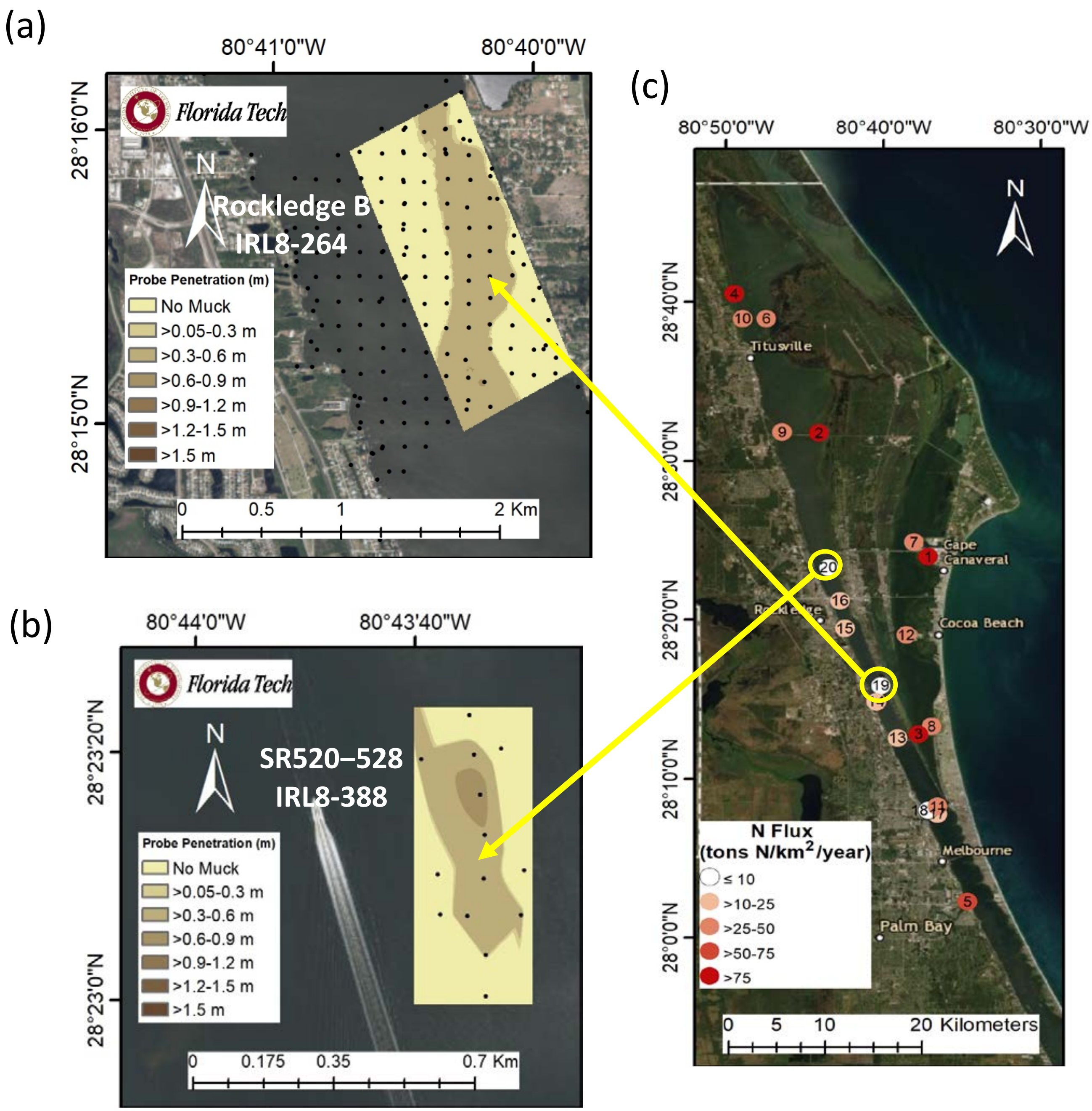
Rank & Map #	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
15	IRL8-324	Cocoa South	290,000	110,000	330,000	86,000
16	IRL8-353	SR520 SE (Merritt Is Cswy)	730,000	460,000	410,000	360,000

Figure 18. Maps of muck thicknesses for optimal dredging sites at (a) Cocoa South (Site IRL8-324) and (b) SR520 SE (Merritt Island Causeway, IRL8-353), plus (c) locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



Rank & Map ID	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
17	IRL8-129	SR518 South (Eau Gallie Cswy)	2,100,000	300,000	360,000	130,000
18	IRL8-133	SR518 NW (Eau Gallie Cswy)	-	240,000	-	260,000

Figure 19. Maps of muck thicknesses for optimal dredging sites at (a) SR518 South (Eau Gallie Causeway, IRL8-129) and (b) SR518 NW (Eau Gallie Causeway, IRL8-133), plus (c) locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)



Rank & Map ID	ID	Site Description	Surface Area (m^2)		Volume (m^3)	
			>5 cm	>30 cm	>5 cm	>30 cm
19	IRL8-264	Rockledge B	1,000,000	570,000	380,000	310,000
20	IRL8-388	SR520–528	150,000	78,000	48,000	35,000

Figure 20. Maps of muck thicknesses for optimal dredging sites at (a) Rockledge B (IRL8-264) and (b) SR520–528 (IRL8-388), plus (c) locations in lagoon. Areas and volumes for muck thicknesses >5 cm (>2") and >30 cm (>1'). (1 m^2 = 1.2 yd^2 and 1 m^3 = 1.3 yd^3)

3.2. Biological Studies

Thirteen parameters were investigated for benthic fauna and seagrass beds near muck (Table 5). The following three parameters were chosen as key indicators of the recovery potential in the IRL and BRL: (1) Shannon Wiener diversity index for benthic fauna, (2) seagrass % cover and (3) distance to nearest seagrass (Table 5). These parameters are described in more detail below.

The main goal of the biological studies was to complement the rankings based on geochemistry and to help identify sites where muck projects, including dredging, would be most beneficial to the ecosystem. Ranking of biological indicators was based on the premise that the site with the lowest diversity and abundance may have the best chance for significant improvement from nearby muck projects and therefore should get the highest ranking (#1).

The Shannon Weiner diversity index for benthic fauna adjacent to, but not in, muck sediments was selected to represent the health of benthic fauna around each muck area. Diversity indices for candidate sites based upon the benthic faunal community ranged from 0.53 at SR528 NE (Beachline Expressway) to 2.12 at SR518 NW (Eau Gallie Causeway; Table 6). These values were similar to those found for other sandy sampling stations in the IRL (e.g., Beckett, 2016). As a point of reference, a diversity value of zero shows one species present ($e^0 = 1$); at 2.12, the value shows ~8 ($e^{2.12}$) species are present. A value of 4.5 (90 species) is considered unusually high and was not observed in the IRL adjacent to muck deposits.

Table 5. Biological parameters investigated for benthic fauna and seagrass to rank the top 20 sites for environmental muck projects.

Benthic fauna	Seagrass
Species richness	Water depth
Abundance	Drift algae % cover
Diversity (Shannon–Wiener index)[a]	Drift algae biomass
	Drift algae canopy height
	Seagrass % cover[a]
	Seagrass biomass
	Seagrass epiphytes
	Seagrass canopy height
	Seagrass shoot count
	Distance to nearest seagrass[a]

[a]Indicates parameter selected for biological ranking of top 20 sites.

Results for the Shannon Wiener index were normalized to 1.0 based on the record of seasonal changes in benthic faunal diversity at other locations in the IRL. Then, the sites were ranked from 1–20 with the highest ranking (#1) for the site with the lowest value for the normalized diversity index for benthic fauna (Table 6, Figure 21a). Six of the sites ranked in the top 10 for diversity (i.e., lowest index values) were among the top 10 sites based on the geochemical scale (i.e., highest sediment fluxes of N, Figure 21a). The two highest ranked sites for sediment N flux were ranked #2 and #3 for benthic fauna (Figure 21a, b).

Table 6. Site identification (ID), description, Shannon Weiner diversity indices for benthic fauna at top 20 muck sites, normalized diversity indices (to 1.0) and ranking for benthic fauna. The sites with the lowest diversity index was assigned the highest ranking (#1).

Site ID	Site Description	Diversity Index Benthic Fauna	Normalized Diversity Index Benthic Fauna	Rank Benthic Fauna
BRL8-414	SR528 NE (Beachline Exprwy)	0.53	0.10	1
BRL8-399	SR528 SE (Beachline Exprwy)	0.55	0.11	2
IRL8-529	SR405 NE (NASA Cswy)	0.85	0.28	3
IRL8-649A	Titusville RR Bridge SW	1.02	0.38	4
BRL8-317	Cocoa Beach Country Club	1.04	0.39	5
IRL8-388	SR520-528	1.12	0.43	6
IRL8-037	Turkey Creek	1.13	0.44	7
IRL8-675	Mims Boat Ramp	1.22	0.49	8
IRL8-649B	Titusville RR Bridge SE	1.38	0.58	9
IRL8-264	Rockledge B	1.39	0.59	10
BRL8-221	SR404 NE (Pineda Cswy)	1.52	0.66	11
IRL8-353	SR520 South (Merritt Island Cswy)	1.61	0.71	12
IRL8-247	Rockledge A	1.68	0.75	13
IRL8-209	SR404 NE (Pineda Cswy)	1.77	0.80	14
BRL8-213	SR404 NW (Pineda Cswy)	1.86	0.86	15
IRL8-137	SR518 NE (Eau Gallie Cswy)	1.85	0.85	16
IRL8-129	SR518 South (Eau Gallie Cswy)	1.95	0.90	17
IRL8-530	SR405 NW (NASA Cswy)	1.97	0.91	18
IRL8-324	Cocoa South	2.09	0.98	19
IRL8-133	SR518 NW (Eau Gallie Cswy)	2.12	1.00	20

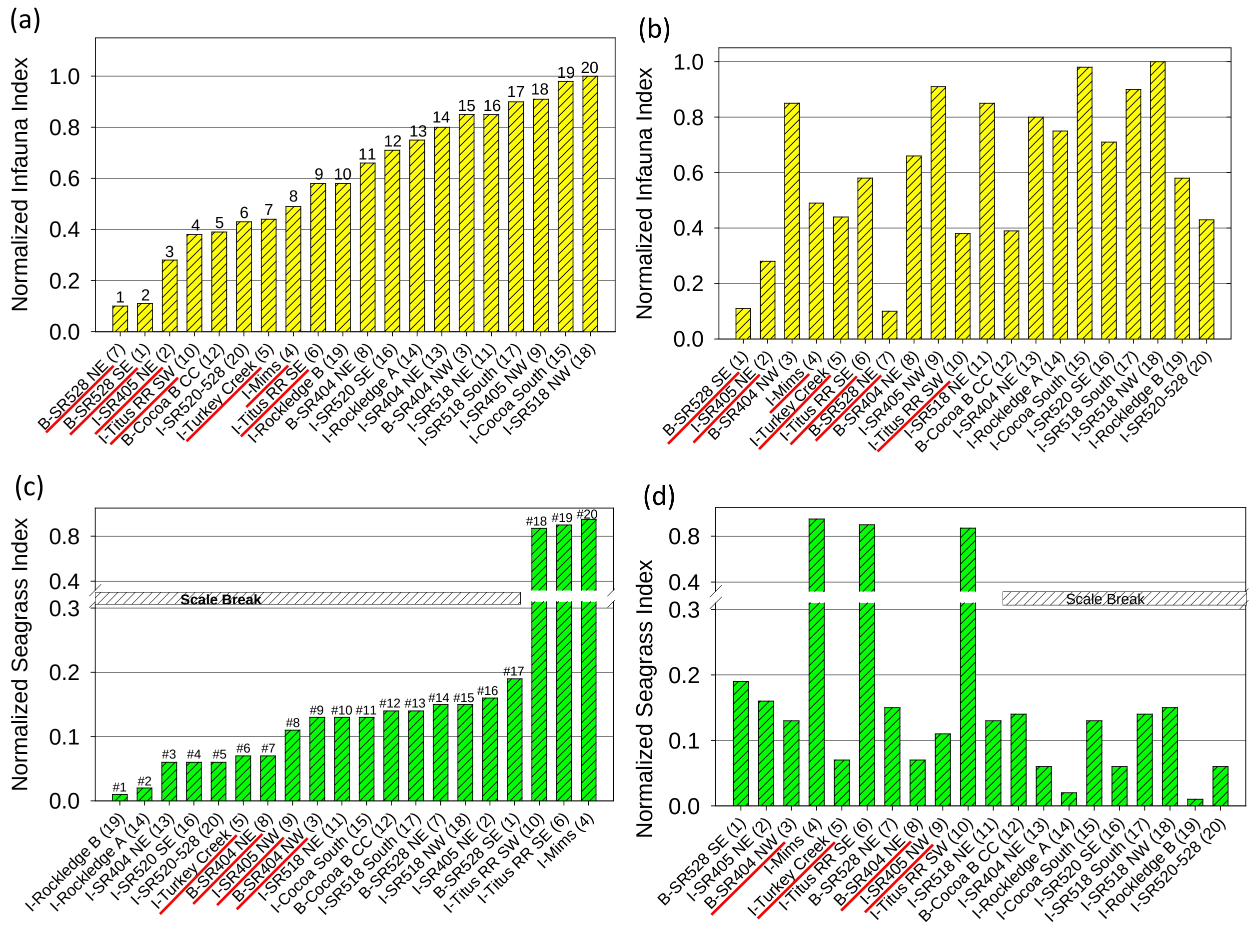


Figure 21. Normalized index for benthic fauna versus site (a) in increasing order for the index, least diverse as #1 (shown above bars on graph) to most diverse as #20 and (b) in the same order as the geochemical ranking for sediment N flux. The normalized index for seagrass versus site (c) in increasing order for the index, lowest abundance (or greatest distance to seagrass bed) as #1 to highest abundance as #20 and (d) in the same order as the geochemical ranking for sediment N flux. Numbers in parentheses on the x-axis for all graphs show ranking for sediment N flux (from Table 4 and Figure 9). Underlined site identifications on all graphs show sites ranked in the top 10 (of 20) for sediment N flux.

Seagrasses were almost always *Halodule wrightii.* Seagrass surveys also included data for associated drift algae, usually *Gracilaria* or *Chaetomorpha* species. The shortest distance between a seagrass bed to muck area was ~91 m and the longest distance was >7 km. Seagrass % cover ranged from 6% (at Turkey Creek) to 100% at Titusville Railroad Bridges SW and SE (IRL8-649A and IRL8-649B). The overall seagrass index was calculated from the normalized seagrass distance and normalized seagrass % cover indexes (Table 7).

Table 7. Site identification (ID), description and data summary and indices for seagrass. Seagrass % cover, normalized for growing season based on seasonal changes in historical Indian River Lagoon seagrasses at other locations. The site with the lowest overall seagrass index was assigned the highest rank (#1).

Site ID	Site Description	Seagrass					
		Distance (m)	Distance Norm.	% Cover	% Cover Norm.	Overall Norm	Overall Rank
IRL8-264	Rockledge B	7320	0.08	8	0.12	0.01	1
IRL8-247	Rockledge A	5770	0.13	8	0.12	0.02	2
IRL8-209	SR404 NE (Pineda Cswy)	1000	0.49	8	0.12	0.06	3
IRL8-353	SR520 SE (Merritt Is Cswy)	2120	0.34	13	0.17	0.06	4
IRL8-388	SR520-528	678	0.57	7	0.11	0.06	5
IRL8-037	Turkey Creek	451	0.66	6	0.10	0.07	6
BRL8-209	SR404 NE (Pineda Cswy)	2170	0.33	17	0.21	0.07	7
IRL8-530	SR405 NW (NASA Cswy)	466	0.65	14	0.18	0.11	8
BRL8-213	SR404 NW (Pineda Cswy)	525	0.62	17	0.21	0.13	9
IRL8-137	SR518 NE (Eau Gallie Cswy)	2340	0.32	37	0.40	0.13	10
IRL8-324	Cocoa South	229	0.79	13	0.17	0.13	11
BRL8-317	Cocoa Beach Country Club	410	0.68	17	0.21	0.14	12
IRL8-129	SR518 S (Eau Gallie Cswy)	135	0.43	29	0.32	0.14	13
BRL8-414	SR528 NE (Beachline Exp)	2600	0.30	49	0.51	0.15	14
IRL8-133	SR518 NW (Eau Gallie Cswy)	1750	0.38	37	0.40	0.15	15
IRL8-529	SR405 NE (NASA Cswy)	624	0.59	23	0.26	0.16	16
BRL8-399	SR528 SE (Beachline Exp)	227	0.80	21	0.24	0.19	17
IRL8-649A	Titusville RR SW	162	0.87	100	1.00	0.87	18
IRL8-649B	Titusville RR SE	137	0.90	100	1.00	0.90	19
IRL8-675	Mims Boat Ramp	92	0.98	96	0.96	0.95	20

Seagrasses have not been found within targeted muck areas; therefore, surveys focused on the nearby surrounding area and the nearest healthy habitats. Seagrass % cover and the shortest distance between the seagrass bed and the muck area (distance to nearest seagrass) were selected to represent the health of the seagrass beds. As with the diversity index for benthic fauna, the least healthy/most distant seagrass beds were assigned the highest rank (#1, Table 7, Figure 21c). In addition to this combined seagrass index, final consideration for choosing optimal dredge sites should be given to water depth and the viability of seagrasses at that depth. For example, *Halodule wrightii*, the primary seagrass species in this survey, is assumed to be limited to a water depth of <2 m in the IRL.

3.3. Combined Geochemical and Biological Indices

Geochemical ranking of the top 20 sites based on sediment N flux established an initial prioritization of optimal sites for muck projects (Table 8). When biological rankings for diversity of benthic fauna were juxtaposed with rankings for sediment N flux, 7 of the top 10 sites, based on a low diversity of benthic fauna, also ranked within the top 10 sites based on sediment N flux (Table 8). Four of the top 10 sites for the seagrass index (i.e., low % cover and larger distance to from muck to seagrass bed) ranked within the top 10 sites based on sediment N flux (Table 8). The smaller number of sites with top 10 rankings for both seagrasses and sediment N flux was likely because 15 of the 20 sites had normalized values with a relatively small range of 0.06–0.19 relative to an overall range of 0.01–0.95. Such grouping increased the likelihood that a given site might not rank in the top 10. Overall, neither index showed a close correspondence with the flux ratings; however, results for benthic fauna were better than those for seagrasses. Nevertheless, all top 10 sites based on geochemistry were compatible with at least one of the biological indicators that ranked in the top 10.

Table 8. Comparison of rankings for the top 20 sites based on sediment nitrogen (N) flux with biological rankings for the same sites based on diversity of benthic fauna and the combined seagrass index. Shaded rankings show a match for biological sites that ranked within the top 10 sites based on both the sediment N flux and at least one biological parameter.

Site ID	Site Description	Ranking Sediment N Flux	Ranking Benthic Faunal Index	Ranking Seagrass Index
BRL8-399[a]	SR528 SE (Beachline Exprwy)	1	2	17
IRL8-529[a]	SR405 NE (NASA Cswy)	2	3	16
BRL8-213[a]	SR404 NW (Pineda Cswy)	3	15	9
IRL8-675[a]	Mims Boat Ramp	4	8	20
IRL8-037	Turkey Creek	5	7	6
IRL8-649B[a]	Titusville RR SE	6	9	19
BRL8-414[a]	SR528 NE (Beachline Exprwy)	7	1	14
BRL8-221[a]	SR404 NE (Pineda Cswy)	8	11	7
IRL8-530	SR405 NW (NASA Cswy)	9	18	8
IRL8-649A[a]	Titusville RR SW	10	4	18
IRL8-137[a]	SR518 NE (Eau Gallie Cswy)	11	16	10
BRL8-317[a]	Cocoa Beach Country Club	12	5	12
IRL8-209[a]	SR404 NE (Pineda Cswy)	13	14	3
IRL8-247	Rockledge A	14	13	2
IRL8-324	Cocoa South	15	19	11
IRL8-353	SR520 SE (Merritt Island Cswy)	16	12	4
IRL8-129	SR518 South (Eau Gallie Cswy)	17	17	13
IRL8-133[a]	SR518 NW (Eau Gallie Cswy)	18	20	15
IRL8-264	Rockledge B	19	10	1
IRL8-388	SR520–528	20	6	5

Eight of the top 10 ranked sites, based on both sediment N flux and at least one biological indicator (Sites 1–3 and 6–10, Figure 8), were located in closely-spaced pairs in four areas (Figure 22). Two pairs of sites were in the IRL and two pairs were in the BRL (Figure 22). All eight sites were in a broad zone where the onset of algal blooms has been noted (IRL Consortium, 2015). The remaining two sites with high geochemical and biological rankings, Mims Boat Ramp and Turkey Creek, have recently been dredged.

Direct comparison of the rankings of sites for muck projects, including dredging, in this study with those presented by Steward (2004) is difficult due to differences in the selection of sites as previously discussed (pages 2–3). However, the broader lesson of thinking in clusters for muck projects seems worthy of further consideration. The #1 final ranking of Vero Beach (Indian River County) by Steward (2004, Table 1) was not part of the present evaluation of only Brevard County. The second choice by Steward (2004) included tributaries of the Eau Gallie River, Crane Creek and Turkey Creek and the seventh choice is Sebastian River; all of these tributaries have now undergone at last one round of dredging. The remaining areas from the Steward (2004) study were #3 South Tropical Trail, #5 Eau Gallie, #6 South Banana River Lagoon, #8 Titusville and #9 Cocoa-Rockledge. These areas encompass many of our top 20 locations. When looking at the optimization process from the vantage point of Brevard County in 2019, agreement of the present study with the ranking by Steward (2004) is encouraging. More importantly, the idea of thinking and planning muck remediation efforts in clusters may be useful because a focus on combining some areas may yield a greater degree of success.

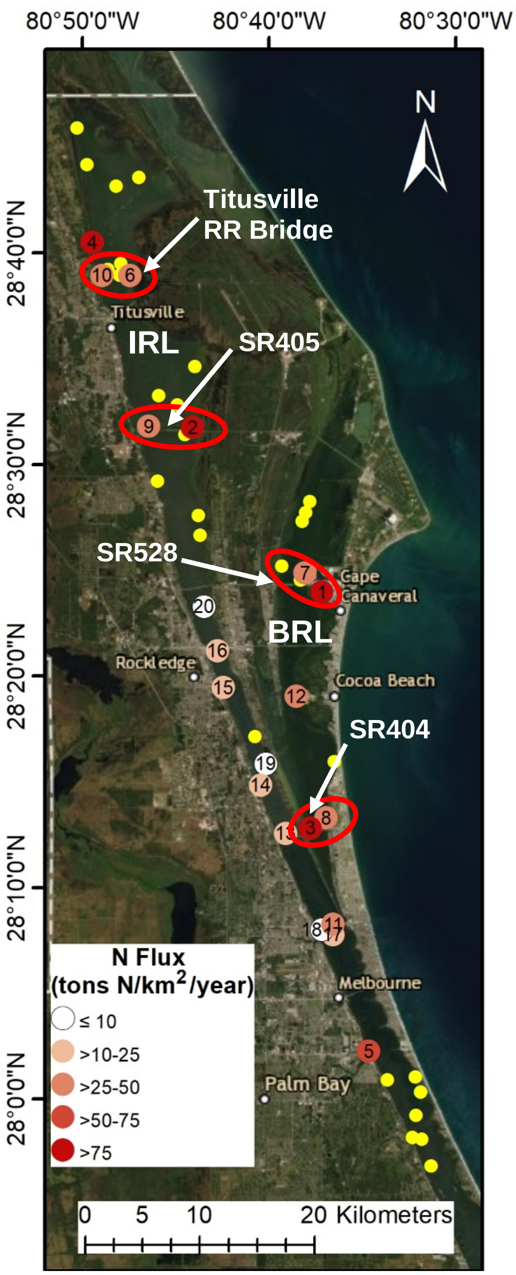


Figure 22. Map of Indian River Lagoon (IRL) and Banana River Lagoon (BRL) with top 20 sites evaluated for muck removal. Rankings (in numbered circles) were based on sediment nitrogen flux. Yellow circles show other 33 sites from the Grand Survey. Red ovals show four clusters of muck removal sites that have high sediment N fluxes and where the onset of algal blooms is large.

4.0. Conclusions

A Grand Survey of 53 sites, plus subsequent detailed geochemical and biological study of the top 20 (of 53) sites in the IRL and BRL (Brevard County), have greatly enhanced available data and perspectives on the distribution of muck in the lagoon system. The top 20 sites prioritized for muck projects were identified by first using a geochemical ranking and then confirming choices using biological indices for benthic fauna and seagrasses.

Geochemical prioritization was based on sediment fluxes of dissolved N as tons $N/km^2/y$, normalized to 25°C. The highest N fluxes, and thus the highest ranked sites for muck remediation based on geochemistry, were southeast of SR528 (Beachline Expressway) in the BRL and northeast of SR405 (NASA Causeway) in the IRL. Only five of the 20 sites were in the BRL; however, these five sites contained 37% of the total muck volume (4.3 million m^3) and 52% of the total sediment flux of N (123 tons/y) in the top 20 sites of the IRL and BRL in Brevard County.

Biological ranking was based on the Shannon Wiener diversity index for benthic fauna and a combined seagrass index. The highest ranked sites (#1) for benthic fauna and seagrasses had the lowest index values (lowest abundance and diversity) and thus were considered the least viable ecological environments. The two highest ranked sites for sediment N flux were ranked #2 and #3 for benthic fauna. Such sites will likely benefit from muck projects.

When the biological rankings for benthic fauna and seagrasses were each juxtaposed with the geochemical rankings based on sediment N flux, all of the top 10 sites based on geochemistry were ranked among the top 10 sites for benthic fauna and/or seagrasses (low abundance and diversity). Four of the top 10 sites are situated in an area that encompasses the BRL from SR404 (Pineda Causeway) to SR528 (Beachline Expressway) and the adjacent IRL to the west. An additional four of the top 10 sites are located in the IRL between SR405 (NASA Causeway) and the Titusville Railroad Bridge (Figure 22) These optimal areas for muck projects cluster within key zones for the onset of algal blooms (Figure 22). The other two top 10 sites based on sediment N flux (#4, Mims and #5 Turkey Creek) were known muck deposits that were recently dredged.

The geochemical and biological rankings discussed in this report provide scientific evidence to guide management decisions regarding key sites for muck projects, including dredging. We encourage, where possible, that muck remediation efforts be carried out in optimal areas as ranked here, especially when they are noted for the onset of major algal blooms. A combined effort for muck projects at closely-spaced sites also may yield a greater degree of success. Moreover, the geochemical and biological rankings from this study must be considered in context with other pertinent variables including cost, proximity to a dredged material management area, an assessment of likelihood for muck to migrate, benefits of formation of a sump (trap) for future muck accumulation, project constructability and other factors as applicable.

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