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Southeast Florida Reef Tract Water Quality Assessment

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Southeast Florida Reef Tract Water Quality Assessment

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Background

Water quality problems, including sedimentation and over enrichment of nutrients, are a major threat to coral reefs worldwide, especially in near shore reefs. Coral reefs evolved in oligotrophic waters, but over the past century have been subjected to increasing levels of nutrients due to human activities. Excess nutrient loads can cause increases in macroalgal growth which can have deleterious effects on corals, such as the macroalgae outcompeting and overgrowing corals (D'Angelo and Wiedenmann 2014). Furthermore, nitrogen and phosphorus can impact corals directly by lowering fertilization success (Harrison and Ward 2001), and reducing both photosynthesis and calcification rates (Marubini and Davies 1996). However, water quality threshold values, above which coral impacts are likely, have not been well established.

Land based contributions of nutrients to coastal systems originate from a variety of sources. Phosphorus and reactive nitrogen can enter the environment from chemical fertilizers (residential, commercial and agricultural uses), industrial sources, animal waste, and human waste (Galloway et al. 2003). Additionally, nitrogen can be contributed from biological nitrogen fixation and atmospheric nitrogen deposition (originating from fossil fuel combustion and ammonia volatilization from agriculture; Mathews et al. 2002). Coral exposure to nutrients varies widely with differing spatial and temporal scales. Exposure forms include particulate matter, as well as dissolved inorganic and organic nutrients. Rapid assimilation of dissolved inorganic nutrients, phosphorous and nitrogen, leaves only a fraction of dissolved organic nutrient bio-available for corals (Cooper and Fabricius 2007). Watershed land use, including human population, plays a large role in nutrient delivery to coastal ecosystems.

Elevated sedimentation levels have been linked to several types of reef degradation including fewer coral species, less live tissue cover, reduced recruitment, lower growth rates and calcification, increased prevalence of disease, altered species composition and lower rates of reef accretion (Rogers 1990; Harvell et al. 1999). Sedimentation can cause burial and smothering of corals and tissue necrosis (Erftemeijer et al. 2012). Fine, colloidal sediments dredged from the Fort Thompson and Anastasia formations at the Port Miami entrance channel proved particularly difficult for corals to shed and resulted in extensive partial and likely complete mortality of many coral colonies (Miller et al. 2016).

The study region, referred to here as the southeast Florida Reef Tract, extends from Biscayne Bay National Park in the south to St. Lucie Inlet in the north. The adjacent watersheds encompass four counties (Miami-Dade, Broward, Palm Beach and Martin) populated by 1.63 million people (United States Census Bureau 2019) and there are nine major inlets that contribute freshwater inflows, containing land based sources of pollution, to coastal waters. These inlets are, from south to north: Government Cut (GOC), Baker's Haulover (BAK), Port Everglades (PEV), Hillsboro (HIL), Boca Raton (BOC), South Lake Worth (Boynton Inlet) (BOY), Lake Worth (ILW), Jupiter (JUP) and St. Lucie (STL; Figure 1). Because the hydrology of the area has been heavily altered by human activity, the areas that drain to these inlets are often called inlet contributing areas (ICAs) rather than watersheds; this terminology will be used hereafter. Land use/land cover varies between ICAs with the southern ICAs having more urban development than the northern ICAs, and the northern ICAs having a larger agricultural footprint (Table 1).

The reef ecosystems in the study region provide habitat to important fisheries (Ferro et al. 2005, SAFMC 2009, Kilfoyle et al. 2015). The ecosystem consists of a mix of contiguous coral reefs, soft substrate habitats (e.g. tidal sand flats and mud flats), seagrass, oyster reefs, mangroves, offshore hardbottom and nearshore hardbottom (Walker and Klug 2014). The reefs generally occur within 3 to 4 km from shore (Banks et al. 2007, Gilliam 2010), and include limestone ridges colonized by reef organisms such as sponges, octocorals, macroalgae and stony corals. Nearshore hardbottom habitats range from flat expanses of exposed rock with little relief to patch reef-like vertical mounds in depths from 0 to 4 m. The benthic assemblages of nearshore hardbottom habitat include octocoral, macroalgae, sponge and stony corals (Gilliam 2010).

Table 1: Land Use/Land Cover by ICA (area is in km^2). Derived from Pickering and Baker (2015).

	Urban	**Crop**	**Animal**	**Water/wetlands**	**Forest/open**	**Total**
STL	454.4	1115.5	9.1	433.9	259.0	2271.9
JUP	180.0	70.2	0.7	305.8	174.9	731.7
ILW	371.3	70.8	4.1	246.2	130.9	823.4
BOY	279.5	37.7	3.0	43.3	9.7	373.2
BOC	219.5	17.2	1.2	37.7	16.3	291.9
HIL	185.1	0.0	0.0	18.9	4.0	208.0
PEV	384.9	2.7	0.5	48.7	14.0	450.7
BAK	342.2	4.0	0.0	82.8	13.7	442.6
GOC	581.5	10.6	0.0	339.8	30.8	962.7

Local stakeholder perception is that water quality is negatively impacting the reef (Shivani and Villanueva 2007). However, there is currently little evidence to support that contention, partially due to a relative lack of water quality data in the reef habitats (Boyer et al. 2011). Stakeholder perception may be a result of inshore water quality data extrapolations, lack of coral reef related data, or public health advisories related to algal blooms or bacteria levels informing coastal public beach closures.

Land based sources of pollution (LBSP) can reach the southeast reef tract via multiple pathways including both point and non-point sources (Caccia and Boyer 2005, Trnka et al. 2006, SFWMD 2009a). Wastewater disposal methods in Florida include: ocean outfalls, surface discharges, deep well injection, and water reuse (Bloetscher and Gokgoz 2001). Pollution, such as nutrients from septic systems and agricultural runoff, reaches the coastal ocean via inlets or groundwater discharge (Trnka et al. 2006, Singh et al. 2009, Bloetscher et al. 2010). Stormwater discharges, associated with urban development (Caccia and Boyer 2005, BCEPD 2007) carry excess nutrients (e.g. from lawn chemicals and pet waste), suspended and dissolved organic matter, and other pollutants to the near coastal ocean (Caccia and Boyer 2005, BCEPD 2007, SFWMD 2009b, Carsey et al. 2010).

The hydrology of the land area draining to the coast is highly modified by agricultural drainage canals and urban flood control systems. These modifications serve as vectors for pollutants to southeast Florida estuarine waters (Caccia and Boyer 2005, SFWMD 2009a, Carsey et al. 2010).

Discharge from water management canals can lead to rapid salinity changes, and increases in turbidity (SFWMD 2009a, SFWMD 2009b), sedimentation and siltation (PBC 2008). Coastal inlets are an important component of water dynamics in southeast Florida, representing a major flux of runoff and associated pollutants from the estuaries to the near coastal waters. Previous studies have shown that the outgoing tides leaving inlets contained significant amounts of pollutants (Carsey et al. 2011; Stamates et al. 2015; see Image 1). While there is an existing network of water quality monitoring stations within the freshwater canals, remnant major rivers, adjacent estuaries, and the Atlantic Intracoastal Waterway, there is no offshore water quality monitoring program that would be relevant to reef health. Additionally, Florida Department of Health's Florida Healthy Beaches Program monitors *Enterococcus* bacterial levels as an indication of fecal pollution resulting from stormwater runoff, pets and wildlife, and human sewage at public coastal beaches. This program provides advisories to swimmers but does not represent a dataset for coral reef health monitoring.

Image 1: Aerial image of plume at Boca Inlet. Photo courtesy of Florida DEP.

Submarine groundwater discharge (SGD) may also be an important flux of nutrients and other pollutants to the coastal environment, although there is very little data available on the quantity and composition of groundwater inputs offshore from southeast Florida (Trnka et al. 2006, Bloetscher et al. 2010). Because the reefs can be up to several kilometers offshore, and there is no sampling program to measure the impact, it is not clear whether the groundwater is being transported all the way to the reef (Paytan et al. 2006).

Wastewaster outfall discharges to the coastal ocean are also a source of nutrients and other pollutants to the system (Carsey et al. 2010). There are currently six wastewater effluent outfalls in the study area (Figure 2); one outfall (Delray) has recently been decommissioned (although it is still permitted to discharge during high rainfall/runoff events). These outfalls discharge wastewater that has undergone secondary treatment to remove biodegradable organics and suspended solids (DEP 2010), but does not remove dissolved nutrients, pharmaceuticals, heavy metals or personal care products (Bloetscher and Gokgoz 2001). Proximity of sewage outflow has been correlated to Black Band Disease in at least one quantitative study in the Virgin Islands (Kaczmarsky et al. 2005) and the human pathogen *Serratia marcescens* was documented to cause white pox disease in *Acropora palmata* near the Key West outfall (Sutherland et al. 2011). All outfalls are scheduled to be decommissioned by 2025.

Physical oceanographic processes are critical driving factors behind the rate at which nutrients and other pollutants are diluted or taken up in the offshore environment. Due in part to relatively low relief watershed and low erosional rates, sedimentation may be more related to beach nourishment projects, port development and re-suspension than due to watershed sources. Recent studies (Miller et al. 2016; Barnes et al. 2015, Cunning et al. 2019) have shown that sediment from the recent Miami dredging project has negatively impacted corals, but the linkages have not been demonstrated region wide.

Project History and Goals

In 2003, in response to concerns about pollution impacts on the reef and with guidance from the US Coral Reef Task Force, the Florida Department of Environmental Protection (FDEP), and the Florida Fish and Wildlife Conservation Commission (FWC) established the Southeast Florida Action Strategy Team (SEFAST) to develop Local Action Strategies targeting the coral reefs off mainland southeast Florida, from the northern border of Biscayne National Park in Miami-Dade County to the St. Lucie Inlet in Martin County. In 2004, SEFAST's membership was expanded by FDEP Coral Reef Conservation Program (CRCP) to include non-agency representatives; in 2005, SEFAST was renamed the Southeast Florida Coral Reef Initiative (SEFCRI) Team. The mission of the SEFCRI is to develop and support the implementation of an effective strategy to preserve and protect southeast Florida's coral reefs and associated reef resources, emphasizing balance between resource use and protection, in cooperation with all interested parties.
The SEFCRI Team was established to formulate, coordinate and provide recommendations to the FDEP CRCP Manager regarding the development and implementation of the SEFCRI Local Action Strategy (LAS) program, targeting coral reefs and associated reef resources in the southeast Florida region (Miami-Dade, Broward, Palm Beach, and Martin counties). Note that in 2018, the Florida Legislature designated this region as the South-East Florida Coral Reef Ecosystem Conservation Area.

In 2014, the FDEP began preliminary discussions with National Oceanic and Atmospheric Administration (NOAA) scientists about the need for more water quality monitoring data for the southeast Florida Reef Tract. A state-federal partnership was developed with the intent of using NOAA resources and expertise to initiate the water quality assessment, and then gradually transition the day to day operations to FDEP. This document represents the first three years (2016 to 2018) of this assessment, and captures this transition.

Overall Goal: This project seeks to develop and implement a water quality assessment program that will provide data and information to evaluate water quality and to track trends over time such that appropriate management measures can be implemented to protect and sustain reef health.

Project Goals: In addition to the overall goal (above), the following outputs were highlighted by the design team.

1. Develop a nutrient baseline, including the current status of nutrients in the system, recognizing that the reef is impaired from 100+ years of human related inputs. This is important for change detection and for use in performance metrics for evaluating the effectiveness of management actions.
2. Determine the interactions and potential synergistic effects of turbidity, sediments and nutrients, and evaluate the potential for stress from multiple pollutants.

3. Explore sources and pathways for nutrients and sediment reaching the reefs, including groundwater nutrients. If possible, determine natural versus anthropogenic sources of nutrients.
4. Gather data in such a way as to support our understanding of cause and effect relationships, i.e. measuring the biological impact of the measured water quality stressors.

Materials and Methods

Sampling Design

The most useful design to address the desired outputs stated above is one that considers both trends over time, as well as the current status of the system. The former is best achieved using fixed and/or targeted sites and the latter can be assessed using a stratified random design. As such, this sampling design includes both fixed and random sites.

Previous work (Pickering and Baker 2015) has delineated the inlet contributing areas (ICAs) for the region (Figure 3). Within each ICA, a subset of sites was randomly selected from pre-existing National Coral Reef Monitoring Program (NCRMP; NOAA 2016) sites. Each of these sites has biological data associated with the NCRMP program, and although the biological sampling is not reoccurring (i.e. each site is only sampled once by the NCRMP), co-locating the water quality sites allows for leveraging of these important data.

Reef sampling sites are limited to relatively shallow reefs (10m depths or less) due to limitations of sampling equipment (water samples will be collected from both surface and bottom), although it should be noted that shallower reefs may be more likely to be impacted by land based sources of pollution (LBSP). In addition to these randomly selected sites, targeted sites were also selected to capture the influences of point sources (inlets and outfalls). Outfall sites were sampled “at the boil” (i.e. where the outfall water is bubbling to the surface), when visible, but we acknowledge that the exact location of the outfall was not sampled each time because the location of the boil is not static. The sites were visited once per month for water sampling.

The number of samples required to provide statistical robustness depends on the variability of the system (in both space and time), the willingness to reject the null hypothesis when it is in fact true (α value) and our desire to statistically assess relatively weak environmental correlations (see Table 2). The number of samples is also limited by resources/logistics, i.e. the project partners do not have infinite resources or staff to conduct this monitoring. Given the need to balance logistical constraints with statistically robust sampling design, the authors acknowledged that the entire study region would not be able to be sampled in the first year of the assessment. Year one (2016/2017) focused on a proof of concept for two of the ICAs: Government Cut and St. Lucie. These two were selected given the available greater resource support (i.e. boats and personnel, supplemental funds for sampling gear and lab reagents, bottles, etc.) available in those places than in the other locations and as well, to represent the geographical range of the sampling (northern most ICA and southern most ICA). During year one, additional funding was obtained from the state of Florida which allowed the program to expand to all nine ICAs starting in year two (2017/2018). Sampling sites are shown in Figures 3 through 10.

Field Collections
Sample Timing
Water quality samples were collected starting in September 2016 (St. Lucie and Government Cut only; other ICAs began in September 2017) on a monthly time step. This report covers sampling through December 2018, but sampling has continued under the direction of FDEP and is ongoing at the time of publication. For each sampling date, all sites across the region were collected within a day or two, with an effort made to sample the inlet sites on the outgoing tide in order to best capture the flux of pollutants from the land. In order to make data gathered during this effort as useful as possible to both state and local management agencies, field and lab practices were aligned with pre-existing Standard Operating Procedures (SOPs) from the state of Florida, except where noted.

Table 2: Number of samples needed to detect a given strength of correlation (α=0.05)

n	Minimum detectable correlation
4	0.950
5	0.878
6	0.811
7	0.754
8	0.707
9	0.666
10	0.632
11	0.602
12	0.576
13	0.553
14	0.532
15	0.514
16	0.497
17	0.482
18	0.468
19	0.456
20	0.444
25	0.396
50	0.279
100	0.196

Grab samples were collected from both surface (collected approximately 0.5 m below surface) and bottom (via Niskin bottle) at all sites, with the exception of the outfall sites, at which only surface water was collected because the depth of these sites exceeded the sampling ability of the equipment. Secchi depth and salinity (via refractometer) measurements were made on site. Sampling equipment was rinsed with deionized water three times between sites and then three times with site water once on site. Field clean equipment blanks were collected (at least one per day and at least one per 20 samples collected). The above SOPs adhere to the following FDEP SOPs for sampling of surface waters: FC 1000 (Cleaning & Decontamination Procedures); FS 2000 (General Aqueous Sampling); and FS 2100 (Surface Water Sampling).

Analytes

There are a multitude of water quality and biological variables that would enhance our understanding of the southeast Florida Reef Tract. This study focuses on the most critical water quality parameters as identified by a panel of experts that was convened in 2015.
Table 3 shows the parameters selected for monitoring. The complete list of analytes represents discussions among technical experts and stakeholders; only a subset of these analytes were measured as part of this study due to limited resources. Additionally, Table 3 notes whether the parameter is a field measurement or if a grab sample is taken for analysis at the laboratory.

Due to the timing and nature of the funding for this project (i.e. federal and state funding arriving at different times), it was necessary to employ two labs for water quality chemistry. When the project initially started sampling (Government Cut and St. Lucie ICAs only), the Geochemical Environmental Research Group (GERG, subcontracted by TDI Brooks International) at Texas A&M University was used for analyses because of an existing contract with NOAA and a long (20+ year) history of providing excellent environmental data for NOAA research. That lab continued with the Government Cut and St. Lucie ICA sampling for the duration of this data set (until NOAA sampling ended in late 2018) to ensure within site continuity of data.
When FDEP expanded the sampling program (using state funding) to include all nine ICAs, the decision was made to use a local lab for those seven newly added ICAs. The Broward County Environmental Monitoring Laboratory, a National Environmental Laboratory Accreditation Conference (NELAC) certified lab, was chosen for this purpose. Method detection limits for each analyte are shown for both labs in Table 4.
In order to assess potential differences between the laboratories, an interlaboratory comparison was conducted on selected split field samples. See Appendix A for additional discussion of the interlaboratory comparison.

GERG Analytical Chemistry Methods

At GERG, water samples were analyzed for a standard suite of nutrient analytes: nitrate (NO_3^-), nitrite (NO_2^-), orthophosphate ($HPO_4^{=}$), ammonium (NH_4^+), urea ($(NH_2)_2CO$), silica (SiO_2), total nitrogen and total phosphorus (Table 4).

Nitrate and nitrite analyses were based on the methodology of Armstrong et al. (1967). Orthophosphate was measured using the methodology of Bernhardt and Wilhelms (1967) with the modification of hydrazine as reductant. Silicate determination was accomplished using the methods of Armstrong et al. (1967) using stannous chloride. Ammonium analysis was based on the method of Harwood and Kuhn (1970) using dichloro- isocyanurate as the oxidizer. Urea was measured using diacetyl-monoximine and themicarbozide. The total concentrations of nitrogen and phosphorus were determined after an initial decomposition step. This method involves persulfate oxidation while heating the sample in an autoclave (115°C, 20 minutes) (Hansen and Koroleff 1999). After oxidation of the samples, nutrient determination was conducted on the Astoria Pacific analyzer for nitrate and orthophosphate. Total suspended solids (TSS) was measured by Standard Method 2540D (comparable to USEPA Method 160.1), which utilizes pre-weighed filters, a known volume of filtered material and then final weighing of dried filters, with the sample mass being determined by difference and adjusted for volume to arrive at a TSS concentration (USEPA 1983).

Table 3: Routine monitoring parameters. Parameters with an asterisk were measured from 2016 to 2018. Other parameters are not included in this study, but may be useful to add in the future.

Analyte	**Category**	**Type**	**Rationale**
Total Nitrogen (or TKN)*	Chemical	grab sample	Nutrient impacts
Nitrate/nitrite*	Chemical	grab sample	Nutrient impacts
Ammonium*	Chemical	grab sample	Nutrient impacts
Total Phosphorus*	Chemical	grab sample	Nutrient impacts
Orthophosphate*	Chemical	grab sample	Nutrient impacts
Silica*	Chemical	grab sample	indicator of freshwater sources
Chlorophyll a	Biological	grab sample	Water column phytoplankton affects light attenuation
Total Suspended Solids* (TSS) *	Physical	grab sample	Sedimentation and light attenuation
Dissolved Oxygen	Chemical	Field/probe	Potential hypoxia/anoxia issues
Salinity*	Physical	Field/probe	Influence of freshwater inputs
Temperature	Physical	Field/probe	Important for coral bleaching; needed for salinity calculation
Conductivity	Physical	Field/probe	Needed for salinity calculation.
pH	Chemical	field/probe	Important for carbonate chemistry
Secchi depth*	Physical	Field/disc	Simple measure of light penetration
Sucralose	Chemical	grab sample	Indicator of human waste
Photosynthetically Active Radiation (PAR)	Physical	Field/meter	Light penetration for photosynthesis by zooxanthellae and benthic algae
Turbidity	Physical	Field/probe	Light attenuation
Current measurements	Physical	field/meter	Important to understand water movement
CDOM	Chemical	grab sample	Light attenuation

Broward Lab Analytical Methods

At the Broward County Environmental Lab, ammonium was analyzed using USEPA Method 350.1 (revision 2), which reacts alkaline phenol and hypochlorite with ammonia to form indophenol blue in amounts that are proportional to the ammonia concentration. The blue color intensifies with sodium nitroprusside and is measured colorimetrically (USEPA 1993a).

Nitrate plus nitrite are determined via USEPA Method 353.2, which uses copper-cadmium to reduce nitrate to nitrite, then measures the resulting nitrite by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly colored azo dye which is measured colorimetrically. This process is then repeated without the copper-cadmium oxidation step to yield nitrite only (USEPA 1993b).

Total Kjeldahl Nitrogen (TKN) was determined using USEPA Method 351.2, which converts organic nitrogen to ammonium via digestion with sulfuric acid (USEPA 1993c). The resulting ammonium is then analyzed as above. Note that TKN represents the sum of organic nitrogen plus ammonium.

Orthophosphorus was analyzed via USEPA Method 365.1 in which ammonium molybdate and antimony potassium tartrate react in an acid medium with phosphorus to form an antimony-phosphomolybdate complex. Ascorbic acid then reduces this complex to a blue colored complex, with the intensity of the blue being proportional to the phosphorus concentration (USEPA 1993d).

Total phosphorus was quantified using USEPA Method 365.4, which converts all phosphorus to inorganic phosphorus via a sulfuric acid digestion (USEPA 1974). Orthophosphorus in then measured as above.

Silicate was determined with Standard Method 4500-SiO_2 F, in which silicate reacts with molybdate under acidic conditions to form yellow beta-molybdosilicic acid. This acid then undergoes a reduction (using ascorbic acid rather than stannous chloride as a reducing agent) to form a blue colored complex that is measure colorimetrically (NEMI 2019).

Turbidity was determined via USEPA Method 180.1, in which a nephelometer is used to measure the refraction of light, as caused by suspended material in a sample as compared to known values (USEPA 1993e).

Data Storage/Access

All data from this monitoring program are publicly available and will be housed in the FDEP Watershed Information Network (WIN) database and NOAA’s National Centers for Environmental Information (NCEI). Data will also be linked through NOAA’s Coral Reef Information System (CoRIS).

Table 4: Method detection limits for the laboratories used in this study. Units are mg/L

	Broward	GERG
TSS	3.15	3
Silicate	0.016	0.00196
Nitrate	0.01	0.00154
Nitrite	0.003	0.000168
Ammonium	0.016	0.000798
Orthophosphate	0.003	0.00035
TKN/TN	0.105	0.00154
TP	0.026	0.00035

Ancillary Data

In order to assess the link between freshwater inflows from the land, specifically, flow through the canals into the Intercoastal Waterway, and eventually out through the inlets, flow data was downloaded from the South Florida Watershed Management District's DBHydro database (https://www.sfwmd.gov/science-data/dbhydro). Flow sites employed for this analysis can be seen in Figure 3. Flows that equaled or exceeded one standard deviation above the mean for a given flow site were operationally defined as "high flow." All other flows were considered to be "base flows." Each water quality sampling event was then categorized based on the flow characteristics for the sites within that ICA so that the offshore water quality data could be compared with the flow regime. To account for the time it takes for a water mass to travel from the canals to the offshore waters, a window of three days prior to the water quality sampling date up until the water sampling date was considered for the binning exercise. Note that for ICA's with more than one flow measurement site, any one site categorized as high flow for a given offshore sampling date would result in that sampling date being binned as high flow. Two ICA's (Port Everglades and Jupiter) did not have flow sites with adequate data for this analysis.

Previously collected biological data from NOAA's National Coral Reef Monitoring Program (NCRMP) (https://www.coris.noaa.gov/monitoring/) were also compiled. NCRMP sites from the 2016 sampling year that were within an operationally defined 500m buffer from water quality sites were selected for comparison. Percent benthic cover (by categorical type) was compared with both mean (chronic) and maximum (acute) water quality concentrations.

Table 5: Location of flow sites from DBHydro database.

Site Name	ICA	Latitude	Longitude
S49	STL	27.2614	-80.3593
S48	STL	27.2017	-80.2993
S80	STL	27.1087	-80.2873
S44	ILW	26.8172	-80.0806
S155	ILW	26.6447	-80.0550
S41	BOY	26.5391	-80.0568
S40	BOY	26.4216	-80.0725
G56	BOC	26.3279	-80.1309
G57	HIL	26.2312	-80.1242
S37A	HIL	26.2061	-80.1317
S29	BAK	25.9291	-80.1515
S28	BAK	25.8729	-80.1809
S27	BAK	25.8510	-80.1882
S25B	GOV	25.7940	-80.2622
S22	GOV	25.6696	-80.2837
S700	GOV	25.6233	-80.3117
S123	GOV	25.6107	-80.3082

Statistical Analysis

Analytical values that were below the method detection limit were treated with the statistical methods described in Flynn (2010). Briefly, the dataset for each analyte was transformed to near normality (e.g. using a ln transform) and the below MDL data was then fitted to the curve below the MDL cutoff. The Shapiro Wilk W statistic was maximized using an iterative solving process, which assigns "dummy" values to each value below the detection limit, ranging from zero to the detection limit. This creates a dataset in which the data that are below the MDL have unique values with the same statistical distribution as the data set as a whole and can therefore be analyzed statistically without biasing the data (e.g. without assigning all below MDL data to one half of the MDL value).

Because the datasets were not perfectly normal, even with transformation, non-parametric statistics were used to evaluate relationships with the dataset. A Wilcoxon test, with post-hoc Dunn's analysis was used to examine differences between sites, between site types (e.g. reef vs inlet), between ICAs, between individual sites and between flow regimes. Spearman correlations were used to examine relationships between analytes and between water quality parameters and biological metrics. Mean and maximum values were also calculated for each site, as well as aggregated data among site types (e.g. reef/inlet/outfall). JMP statistical software was used for all statistical analysis.

Results and Discussion

Spatial Patterns

Figures 11 to 46 present maps of the mean and maximum values for each analyte by site for both surface and bottom samples. Maximum values show the potential acute effects of nutrients and mean values show the chronic effects. These maps qualitatively demonstrate the importance of the inlets and outfalls on the biogeochemistry of this system. Furthermore, there are statistically significant differences between site types (Wilcoxon with post-hoc Dunn's test, α=0.05, Figures 47 to 56, Table 6), which clearly show the impact of inlets and outfalls on the water quality of the SEFCRI region. In general, inlets have statistically higher concentrations than outfalls and reefs for silica and nitrate.

Table 6: Differences between site types, across all ICAs. Only statistically significant relationships are shown (Wilcoxon with post-hoc Dunn's test, α=0.05)

Analyte	Location1	Location2	Score Mean Difference	Std Err Dif	Z	p-Value
NH_4^+	Reef	Outfall	-653.74	63.02	-10.37	9.82E-25
NH_4^+	Outfall	Inlet	604.16	65.88	9.17	1.41E-19
NO_2^-	Reef	Outfall	-476.24	63.05	-7.55	1.27E-13
NO_2^-	Outfall	Inlet	440.41	65.92	6.68	7.11E-11
NO_3^-	Reef	Inlet	-183.39	38.64	-4.75	6.23E-06
PO_4^{2-}	Reef	Outfall	-197.97	62.78	-3.15	0.00484
PO_4^{2-}	Outfall	Inlet	194.48	65.64	2.96	0.00914
Si	Reef	Inlet	-337.87	38.65	-8.74	6.85E-18
Si	Outfall	Inlet	-338.75	65.54	-5.17	7.08E-07
TKN	Reef	Inlet	-68.67	23.95	-2.87	0.012406
TN	Reef	Outfall	-193.64	54.11	-3.58	0.001037
TN	Reef	Inlet	-117.16	32.85	-3.57	0.001086
TSS	Reef	Inlet	-169.65	38.67	-4.39	3.44E-05
TSS	Outfall	Inlet	-276.30	65.64	-4.21	7.69E-05
Turb	Outfall	Inlet	-702.39	50.53	-13.90	1.85E-43
Turb	Reef	Inlet	-376.05	30.47	-12.34	1.64E-34
Turb	Reef	Outfall	326.34	48.44	6.74	4.87E-11
Urea	Reef	Inlet	-73.90	22.45	-3.29	0.002981

Interestingly, the highest turbidity and TSS values occur at the reef sites. This could be a function of organic (biologically derived) materials being resuspended during wind events, rather than erosional sediment fluxes. Outfalls have elevated total nitrogen, ammonium and urea values, which reflects that the wastewater in the outfall pipes is high in organic nitrogen, which gets converted to ammonium, but the nitrification process (ammonium to nitrate) is inhibited by the anoxic environment within the outfall pipe. Relatively high nitrite (compared to other site types) at the outfalls also reflects this incomplete nitrification process. Outfalls also have statistically higher orthophosphate values when compared to inlets and reefs.

Differences between Depths

Across all sites, surface concentrations were significantly greater than bottom concentrations for all analytes (Wilcoxon with post-hoc Dunn's test, α=0.05) except for TSS and TP (Figures 56-64). This difference could reflect the influence of freshwater (lower density) plumes laden with pollutants and/or the impact of the outfalls (which discharge low salinity effluent that is less dense than the surrounding seawater). This also suggests that the system is not well mixed, and reinforces the need to sample both surface and bottom water. This stratification has also been visually observed by the authors while diving for other studies.

Spatial Differences (among ICAs)

There are statistically significant differences (Wilcoxon with post-hoc Dunn's test, α=0.05) for many analytes among ICAs (see Table 7 and Figures 65 to 73). Land use differences among ICAs may explain some of these observed patterns. Correlations between total land area in an ICA by land use/land cover (see Table 7) versus mean concentration show many statistically significant relationships with Spearman rho values ranging from 0.45 to 0.86 (Figures 74 to 91; only figures for which there was a statistically significant relationship are shown). While the positive relationships are relatively intuitive (e.g. urban correlated with ammonium), less clear are the three statistically significant negative relationships for nitrite and water/wetlands, nitrite and total watershed area, and TN and urban. Outfalls do appear to be a big driver of differences for some analytes (ammonium, total N), but there are no statistically significant differences (Wilcoxon, α=0.05) between ICAs with outfalls (the southernmost five) with those without outfalls (the northernmost four). It is also possible that localized differences in physical oceanography or biological uptake/processing could be contributing to these observed patterns.

Temporal Differences as Related to Flow

Figures 92 through 102 show the differences between flow regime (high flow vs base flow) for each analyte in each ICA. Table 8 shows the statistically significant differences (Wilcoxon, α=0.05) in these relationships. For a number of analytes in a number of ICAs, there is a significant, positive relationship between flow regime and observed concentration (see Table 8). This is consistent with the increased mass flux of nutrients/sediments during high flow events resulting in higher water column concentrations. Conversely, there are also some analytes in some ICAs that demonstrate a significant negative relationship between flow and observed concentration. It is possible that some of these patterns are a result of infrequent high flow conditions for certain ICAs (e.g. Boca only had one sampling time point with high flow, which may not be statistically representative of the system), but it is also possible that dilution effects can explain this pattern; if the relationship between water volume and analyte mass isn't linear, additional freshwater could dilute existing nutrients in the water column resulting in lower observed concentrations.

Table 7: Spearman correlations between land use/land cover (see Table 1) by ICA and mean analyte values. Only statistically significant relationships are shown (α=0.05) and are listed by strength of statistical relationship.

LULC	Analyte	Prob>|t|	RSquare	Relationship
Crop	Silica	0.0003	0.861	positive
Total	Silica	0.0007	0.825	positive
Total	Orthophosphate	0.0011	0.802	positive
Water/wetlands	Turbidity	0.0130	0.740	positive
Forest/open	Turbidity	0.0214	0.686	positive
Total	Total Phosphorus	0.0078	0.659	positive
Crop	Orthophosphate	0.0083	0.654	positive
Urban	Total Phosphorus	0.0129	0.610	positive
Water/wetlands	Orthophosphate	0.0134	0.606	positive
Urban	Ammonium	0.0154	0.592	positive
Water/wetlands	Total Phosphorus	0.0156	0.590	positive
Animal	Silica	0.0232	0.545	positive
Urban	Orthophosphate	0.0399	0.476	positive
Water/wetlands	Silica	0.0404	0.474	positive
Crop	Total Phosphorus	0.0495	0.445	positive
Urban	Total Nitrogen	0.0054	0.693	negative
Water/wetlands	Nitrite	0.0073	0.666	negative
Total	Nitrite	0.0172	0.579	negative

Putting These Data into Context

Comparison with other regional data

Previous researchers (Sinigalliano et al. 2016) at NOAA's Atlantic Oceanographic and Meteorological Laboratory collected similar data in the southern portion of the SEFCRI region from 2013 to 2015. NOAA-AOML sites that occurred within 500 m of water quality sites from this study were selected for comparison. The AOML study reported TSS, nitrate+nitrite, total nitrogen and total phosphorus at their laboratory in Miami. In general, mean values for each site were qualitatively very similar between the two studies (Table 10). Potential reasons for small differences include relatively small scale (0.5 km) spatial differences, differences attributable to analytical methods and potential changes between the two studies' time frames. The only analyte which was relatively different was turbidity, which was an order of magnitude higher at similar sites in the AOML study. This may be due to fundamental differences in methodology, with the AOML data being generated *in situ* via sonde and this study determining turbidity in the laboratory from a discrete water sample.

Table 8: Statistically significant (Wilcoxon, α=0.05) differences between flow regimes. Bold values are positive relationships; values in italics are negative relationships. Note: only statistically significant relationships are shown.

ICA	Analyte	Flow1	Flow2	Z	p-Value
BAK	Ammonium	High	Base	**3.129852**	**0.001749**
BAK	Nitrate	High	Base	**6.839655**	**7.94E-12**
BAK	TKN	High	Base	**2.908219**	**0.003635**
BAK	Total Phosphorus	High	Base	*-6.01941*	*1.75E-09*
BAK	TSS	High	Base	**6.453107**	**1.1E-10**
BOC	Ammonium	High	Base	**3.153451**	**0.001614**
BOC	Nitrate	High	Base	**4.067631**	**4.75E-05**
BOC	Orthophosphate	High	Base	**2.233569**	**0.025511**
BOC	Total Phosphorus	High	Base	*-2.08144*	*0.037394*
BOC	TSS	High	Base	*-2.736*	*0.006219*
BOC	Turbidity	High	Base	**3.733503**	**0.000189**
BOY	Ammonium	High	Base	*-5.13253*	*2.86E-07*
BOY	Nitrite	High	Base	**9.803185**	**1.09E-22**
BOY	Nitrate	High	Base	*-4.57032*	*4.87E-06*
BOY	Silica	High	Base	**4.993881**	**5.92E-07**
BOY	TKN	High	Base	**4.339811**	**1.43E-05**
BOY	Total Phosphorus	High	Base	**8.3106**	**9.52E-17**
BOY	TSS	High	Base	**9.807502**	**1.05E-22**
BOY	Turbidity	High	Base	**3.556498**	**0.000376**
GOC	Ammonium	High	Base	**4.219608**	**2.45E-05**
GOC	Orthophosphate	High	Base	*-4.83252*	*1.35E-06*
GOC	Total Nitrogen	High	Base	*-4.07474*	*4.61E-05*
GOC	Total Phosphorus	High	Base	**8.465047**	**2.56E-17**
GOC	TSS	High	Base	*-2.5013*	*0.012374*
GOC	Urea	High	Base	*-7.27796*	*3.39E-13*
HIL	Nitrate	High	Base	**2.685496**	**0.007242**
HIL	Silica	High	Base	**3.077371**	**0.002088**
HIL	TKN	High	Base	**2.584812**	**0.009743**
ILW	Ammonium	High	Base	**3.253544**	**0.00114**
ILW	Nitrate	High	Base	**3.879916**	**0.000104**
ILW	Nitrite	High	Base	**6.703207**	**2.04E-11**
ILW	Orthophosphate	High	Base	*-3.22381*	*0.001265*
ILW	Si	High	Base	*-1.96664*	*0.049225*
ILW	TKN	High	Base	**5.32809**	**9.93E-08**
ILW	Total Nitrogen	High	Base	**6.117029**	**9.53E-10**
ILW	Total Phosphorus	High	Base	**3.725775**	**0.000195**
ILW	TSS	High	Base	**2.510323**	**0.012062**
STL	Nitrite	High	Base	**8.192759**	**2.55E-16**
STL	Nitrate	High	Base	**9.720846**	**2.46E-22**
STL	Orthophosphate	High	Base	**7.764741**	**8.18E-15**
STL	Silica	High	Base	**6.859437**	**6.91E-12**
STL	Total Nitrogen	High	Base	**5.640662**	**1.69E-08**
STL	Total Phosphorus	High	Base	**9.736105**	**2.12E-22**

Table 9: Statistically significant differences in analytes between ICAs (Wilcoxon, post-hoc Dunn's test, α=0.05)

Analyte	ICA1	ICA2	Z	p-Value	Analyte	ICA1	ICA2	Z	p-Value
NO3	ILW	GOC	14.09	1.6E-43	**Si**	GOC	BOC	14.40	1.9E-45
NO3	ILW	BOY	4.60	0.00015	**Si**	HIL	BOY	7.82	1.91E-13
NO3	ILW	BOC	4.20	0.00096	**Si**	HIL	GOC	-12.64	4.68E-35
NO3	ILW	HIL	3.28	0.03783	**Si**	HIL	BAK	4.95	2.73E-05
NO3	JUP	GOC	9.90	1.5E-21	**Si**	ILW	GOC	-22.19	1.5E-107
NO3	JUP	BAK	-4.13	0.00129	**Si**	ILW	HIL	-9.17	1.77E-18
NO3	JUP	ILW	-3.56	0.01331	**Si**	ILW	BOC	-7.68	5.91E-13
NO3	PEV	GOC	12.98	5.4E-37	**Si**	ILW	BAK	-4.43	0.000336
NO3	STL	BAK	-14.49	4.9E-46	**Si**	JUP	GOC	-17.65	3.48E-68
NO3	STL	ILW	-13.30	7.8E-39	**Si**	JUP	HIL	-5.11	1.15E-05
NO3	STL	PEV	-12.17	1.7E-32	**Si**	JUP	ILW	3.89	0.003622
NO3	STL	HIL	-10.26	3.9E-23	**Si**	JUP	BOC	-3.62	0.010462
NO3	STL	JUP	-9.25	8.4E-19	**Si**	PEV	GOC	-18.63	6.68E-76
NO3	STL	BOC	-9.24	9.1E-19	**Si**	PEV	HIL	-5.42	2.09E-06
NO3	STL	BOY	-8.77	6.6E-17	**Si**	PEV	ILW	3.90	0.003417
PO4	BOC	BAK	4.86	4.1E-05	**Si**	PEV	BOC	-3.88	0.003757
PO4	BOY	BAK	6.96	1.2E-10	**Si**	STL	ILW	26.15	3.6E-149
PO4	GOC	BAK	26.71	1E-155	**Si**	STL	BOY	25.74	1.6E-144
PO4	GOC	BOC	21.26	1E-98	**Si**	STL	PEV	22.85	5.3E-114
PO4	GOC	BOY	19.05	2.5E-79	**Si**	STL	BAK	22.50	1.5E-110
PO4	HIL	GOC	-20.23	2.1E-89	**Si**	STL	JUP	21.75	2.6E-103
PO4	HIL	BAK	5.90	1.3E-07	**Si**	STL	BOC	18.80	2.72E-77
PO4	ILW	GOC	-20.56	2.2E-92	**Si**	STL	HIL	17.10	5.28E-64
PO4	ILW	BAK	4.13	0.00133	**Si**	STL	GOC	5.74	3.49E-07
PO4	JUP	GOC	-16.89	1.9E-62	**TKN**	BOC	BAK	5.43	1.21E-06
PO4	JUP	BAK	7.35	6.9E-12	**TKN**	BOY	BAK	7.43	2.23E-12
PO4	PEV	GOC	-18.70	1.8E-76	**TKN**	HIL	BAK	8.02	2.17E-14
PO4	PEV	BAK	7.23	1.8E-11	**TKN**	ILW	BAK	8.67	9.31E-17
PO4	STL	BAK	28.37	2E-175	**TKN**	ILW	BOC	3.35	0.017019
PO4	STL	BOC	23.10	2E-116	**TKN**	JUP	BAK	9.14	1.34E-18
PO4	STL	ILW	22.36	3E-109	**TKN**	JUP	BOC	3.82	0.002796
PO4	STL	HIL	22.11	9E-107	**TKN**	PEV	BAK	5.83	1.14E-07
PO4	STL	BOY	20.97	4E-96	**TKN**	PEV	JUP	-3.40	0.014168
PO4	STL	PEV	20.64	4.7E-93	**TN**	BOC	BAK	5.96	9.19E-08
PO4	STL	JUP	18.80	2.9E-77	**TN**	BOY	BAK	8.32	3.27E-15
Si	BOC	BAK	3.39	0.02526	**TN**	GOC	BOY	-14.51	3.66E-46
Si	BOY	BOC	-6.26	1.4E-08	**TN**	GOC	BOC	-11.59	1.61E-29
Si	GOC	BOY	21.56	1E-101	**TN**	GOC	BAK	-4.21	0.000921
Si	GOC	BAK	18.23	1E-72	**TN**	HIL	GOC	14.26	1.47E-44

Table 9 (continued): Statistically significant differences in analytes between ICAs (Wilcoxon, post-hoc Dunn's test, α=0.05)

Analyte	ICA1	ICA2	Z	p-Value	Analyte	ICA1	ICA2	Z	p-Value
TN	HIL	BAK	8.11	1.83E-14	**TP**	STL	BOC	20.76	3.47E-94
TN	ILW	GOC	15.61	2.2E-53	**TP**	STL	BOY	19.82	7.77E-86
TN	ILW	BAK	9.40	2E-19	**TP**	STL	JUP	19.69	9.34E-85
TN	ILW	BOC	3.56	0.01337	**TSS**	GOC	BOC	-9.86	2.21E-21
TN	JUP	GOC	15.52	8.69E-53	**TSS**	GOC	BAK	-9.70	1.05E-20
TN	JUP	BAK	9.33	3.94E-19	**TSS**	GOC	BOY	-8.08	2.31E-14
TN	JUP	BOC	3.49	0.017529	**TSS**	HIL	GOC	11.04	8.76E-27
TN	PEV	GOC	12.10	4.01E-32	**TSS**	ILW	GOC	9.01	7.37E-18
TN	PEV	BAK	6.38	6.2E-09	**TSS**	JUP	GOC	13.66	6.32E-41
TN	STL	ILW	-9.97	7.7E-22	**TSS**	JUP	BOY	5.37	2.82E-06
TN	STL	JUP	-9.88	1.82E-21	**TSS**	JUP	BAK	4.03	0.002032
TN	STL	BOY	-8.72	1E-16	**TSS**	JUP	ILW	3.97	0.002613
TN	STL	HIL	-8.47	8.84E-16	**TSS**	JUP	BOC	3.85	0.004282
TN	STL	GOC	7.76	2.98E-13	**TSS**	PEV	GOC	11.36	2.42E-28
TN	STL	PEV	-6.38	6.43E-09	**TSS**	STL	GOC	17.94	2.12E-70
TN	STL	BOC	-5.87	1.6E-07	**TSS**	STL	BOY	7.45	3.34E-12
TP	BOC	BAK	5.44	1.92E-06	**TSS**	STL	BAK	5.91	1.25E-07
TP	BOY	BAK	6.19	2.2E-08	**TSS**	STL	ILW	5.71	4.08E-07
TP	GOC	BAK	25.90	2.6E-146	**TSS**	STL	BOC	5.69	4.52E-07
TP	GOC	BOC	19.37	5.28E-82	**TSS**	STL	HIL	4.59	0.000159
TP	GOC	BOY	18.40	4.86E-74	**TSS**	STL	PEV	4.18	0.001051
TP	HIL	GOC	-24.90	2.8E-135	**Turb**	BOC	BAK	-7.56	8.34E-13
TP	HIL	BOY	-5.34	3.4E-06	**Turb**	BOY	BAK	-13.42	9.12E-40
TP	HIL	BOC	-4.59	0.000162	**Turb**	BOY	BOC	-5.86	9.57E-08
TP	ILW	GOC	-23.80	1.1E-123	**Turb**	HIL	BAK	-10.26	2.36E-23
TP	ILW	BOY	-5.04	1.69E-05	**Turb**	HIL	BOY	3.17	0.032089
TP	ILW	BOC	-4.31	0.000598	**Turb**	ILW	BAK	-7.53	1.09E-12
TP	JUP	GOC	-18.30	2.95E-73	**Turb**	ILW	BOY	5.27	2.82E-06
TP	JUP	BAK	5.61	7.31E-07	**Turb**	JUP	BOY	9.78	2.91E-21
TP	JUP	HIL	4.78	6.36E-05	**Turb**	JUP	HIL	6.76	2.9E-10
TP	JUP	ILW	4.50	0.000242	**Turb**	JUP	ILW	4.32	0.000329
TP	PEV	GOC	-22.95	4.9E-115	**Turb**	JUP	BOC	4.19	0.000575
TP	PEV	BOY	-3.75	0.006372	**Turb**	PEV	BOY	8.98	5.84E-18
TP	PEV	JUP	-3.23	0.044774	**Turb**	PEV	HIL	5.81	1.33E-07
TP	STL	BAK	27.12	2.1E-160	**Turb**	PEV	BAK	-4.45	0.000183
TP	STL	HIL	26.15	3.7E-149	**Turb**	PEV	ILW	3.29	0.02131
TP	STL	ILW	25.06	5.2E-137	**Turb**	PEV	BOC	3.11	0.038707
TP	STL	PEV	24.25	2.2E-128	**Urea**	STL	GOC	-2.18	0.029348

Although geographically different, it is also informative to compare data from this study with an existing dataset for the Florida Keys National Marine Sanctuary's (FKNMS) Water Quality Monitoring Project (FKNMS 2019), to provide regional context. The FKNMS project is operated by the Southeast Environmental Research Center (SERC) at Florida International University (FIU). The mean data from FKNMS for 2017 were compared to this study (mean data; Table 11). In general, mean concentrations from this study are qualitatively higher (sometimes by an order of magnitude, e.g. for ammonium) than mean concentrations from the Florida Keys. While some differences could be attributed to methodological differences, this is not surprising given the larger population centers, and therefore greater pollution fluxes (e.g. the wastewater outfalls) in the SEFCRI region. Exceptions to this pattern were bottom water turbidity, and TN, which were both higher in FKNMS than SEFCRI.

Table 10: Comparison of data from this study with NOAA AOML study. Units are NTU, mg-N/L and mg-P/L.

Site	Depth	Turb This Study	Turb AOML	Nitrate+Nitrite This Study	Nitrate+Nitrite AOML	TN This Study	TN AOML	TP This Study	TP AOML
BAK030	Surface	0.430	1.530	0.054	0.006	0.147	0.082	0.040	0.010
BAK030	Bottom	NA	1.220	NA	0.006	NA	0.053	NA	0.008
BAK032	Surface	0.387	1.030	0.015	0.008	0.069	0.085	0.032	0.011
BAK032	Bottom	NA	1.240	NA	0.007	NA	0.054	NA	0.008
GOC008	Surface	NA	1.770	0.006	0.008	0.030	0.075	0.259	0.008
GOC008	Bottom	NA	1.600	0.005	0.009	0.034	0.090	0.305	0.008
GOC012	Surface	NA	0.950	0.006	0.005	0.042	0.093	0.402	0.010
GOC012	Bottom	NA	1.000	NA	0.010	NA	0.059	NA	0.008
GOC014	Surface	NA	1.180	0.018	0.008	0.068	0.444	0.861	0.033
GOC014	Bottom	NA	1.010	NA	0.011	NA	0.058	NA	0.008
GOC015	Surface	NA	1.270	0.009	0.005	0.038	0.189	0.488	0.018
GOC015	Bottom	NA	1.080	NA	0.008	NA	0.055	NA	0.008
PEV 040	Surface	0.920	2.700	0.018	0.022	0.099	0.128	0.050	0.011
PEV 040	Bottom	0.570	1.810	0.014	0.008	0.086	0.069	0.052	0.008
PEV 044	Surface	0.463	1.080	0.013	0.005	0.051	0.066	0.043	0.007
PEV 044	Bottom	0.513	0.900	0.013	0.007	0.071	0.060	0.054	0.008

Comparison with Thresholds

Previous studies in a variety of geographies have attempted to identify water quality threshold values above which deleterious effects to coral reef ecosystems can be expected (e.g. Lapointe 1997; De'ath G and Fabricus 2008). Identifying one universal threshold is unrealistic due to differences between species, synergistic effects with other stressors and knowledge gaps about the mechanisms for water quality degradation of corals. However, it is useful to have a benchmark value against which to compare field data. For this study, values were compared to the soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN) values proposed by Lapointe (1997); 0.0095 mg/L SRP and .0014 mg/L DIN. This set of thresholds was selected as they were proposed specifically for south Florida. These are values above which is was hypothesized that benthic algae would begin to outcompete/overgrow coral reefs. It should be noted that these values are not regulatory, nor is it being proposed that these are the "correct" threshold values for the SEFCRI region. More research is needed to quantify threshold values for this region, but these values are employed here as a useful comparative tool.

Table 11: Qualitative comparison of data from this study with data from Florida Keys National Marine Sanctuary (FKNMS).

Analyte	Depth	Units	Mean FKNMS	Mean SEFCRI
Nitrate	Surface	mg-N/L	0.003	0.008
Nitrate	Bottom	mg-N/L	0.003	0.007
Nitrite	Surface	mg-N/L	0.001	0.004
Nitrite	Bottom	mg-N/L	0.001	0.004
Ammonium	Surface	mg-N/L	0.005	0.035
Ammonium	Bottom	mg-N/L	0.004	0.022
Total N	Surface	mg-N/L	0.170	0.067
Total N	Bottom	mg-N/L	0.133	0.057
Total P	Surface	mg-P/L	0.007	0.175
Total P	Bottom	mg-P/L	0.006	0.160
Silica	Surface	mg-Si/L	0.077	0.207
Silica	Bottom	mg-Si/L	0.043	0.148
Turbidity	Surface	NTU	0.662	0.617
Turbidity	Bottom	NTU	2.771	0.707

For the data from this study, DIN was calculated by summing the concentration of each inorganic nitrogen analyte (ammonium, nitrate, nitrite). Orthophosphate is roughly equivalent to SRP. Bottom water values (most relevant to reef health) were used. Figures 103-105 show the maximum and mean values for DIN and orthophosphate as they related to the thresholds. Dots in red exceed the threshold. It should be noted that both the mean and maximum DIN values at all sites exceeded the threshold (Figure 103 shows mean values). For phosphorus, the majority of the sites do not exceed the threshold values, but there are exceedances for both the mean and maximum values (Figures 104 and 105), especially in the northern (St. Lucie ICA) and southern (Government Cut ICA) portions of the study area. These comparisons are most relevant at reef sites, although exceedances at inlet sites could indicate the potential for benthic algae problems in those areas.

Comparison with Biological Data

In order to assess the potential link between water quality and coral reef ecosystem health, benthic habitat data from the National Coral Reef Monitoring Program (NCRMP; https://www.coris.noaa.gov/monitoring/) were compared to bottom water concentration data from this study. Table 12 shows the statistically significant pairings. Note that there are both positive and negative relationships, some of which are relatively straightforward (e.g. high nitrate is correlated with high turf algae) and others are less intuitive. It needs to be reinforced that correlation does not equal causation, and in reality, it is very likely that a host of forcing factors (disease, thermal stress, overfishing of grazers, physical damage from storms or boats) in addition to water quality are driving ecosystem level biological patterns. Additional research is needed to better assess the role of water quality may play in coral reef ecosystem health.

Table 12: Spearman correlation coefficients (rho) and P values for bottom water parameters (this study) versus benthic cover percentages (NCRMP). Only statistically significant relationships are shown.

Water Quality	Benthic Habitat	rho value	P value
Ammonium_max	Palythoa	0.8	0.009628
TN_max	Halimeda	0.785496	0.012115
Orthophosphate_max	Palythoa	0.75	0.019942
Orthophosphate_max	Rhodophyta	0.75	0.019942
Orthophosphate _max	Other species	0.75	0.019942
Ammonium_mean	Palythoa	0.733359	0.024547
Silica_mean	Palythoa	0.733359	0.024547
TN_max	Gorgonians	0.715025	0.030373
TSS_max	Encrusting gorgonian	0.705952	0.033563
TSS_mean	Encrusting gorgonian	0.705952	0.033563
Nitrate_max	Turf_Algae	0.694567	0.037864
Silica_mean	*Siderastrea siderea*	-0.68437	0.042004
Nitrate_mean	Encrusting gorgonian	-0.69601	0.0373
Ammonium_max	Millepora	-0.7	0.03577
TN_mean	Turf Algae	-0.7113	0.031657
Orthophosphate_mean	*Stephanocoenia intersepta*	-0.72761	0.026287
Silica_mean	Millepora	-0.73336	0.024547
Nitrite_mean	Palythoa	-0.73336	0.024547
Orthophosphate_mean	Cliona	-0.73336	0.024547
TSS_max	Other species	-0.73336	0.024547
TSS_mean	Other species	-0.73336	0.024547
Orthophosphate_mean	Halimeda	-0.73578	0.023837
Silica_max	Millepora	-0.73646	0.02364
Nitrite_max	Palythoa	-0.746	0.020991
Ammonium_max	Encrusting gorgonian	-0.7701	0.015192
Nitrate_max	Encrusting gorgonian	-0.7855	0.012115

Summary, Conclusions and Lessons Learned

This report summarizes three years of water quality data for the SEFCRI region. Key findings include:

- The biogeochemical signal of the inlets is readily apparent in near coastal water, and the discharge from the canals generally drives water chemistry to the system.

- The wastewater outfalls result in elevated levels of certain nutrients (e.g. urea, ammonium) that are different from the signals observed from freshwater inflows from the inlets.

- Observed levels of nutrients in the SEFCRI region are elevated when compared to previously published threshold values above which corals are likely to be outcompeted by benthic algae.

- Spatial patterns in water quality are correlated with indices of biological reef health, but more research is needed to better understand this relationship, especially given that corals reefs are being subjected to multiple stressors (nutrients, toxics, disease, thermal stress, etc.)

This project quantified water quality conditions that will allow us to assess the current status of water quality in the coral reef ecosystem and to track changes in water quality over time. Having this baseline of current conditions also allows managers to evaluate the efficacy of implemented management actions to improve reef water quality by using data collected in the future. Additional research on water quality thresholds for coral reef ecosystem health are needed. As this research moves forward, it is important that analytical method detection limits are carefully verified and sufficiently low to capture ecologically relevant levels.

In addition to stressors related to water quality, corals can also be affected by ocean acidification, disease, overfishing and physical damage from boats or divers. It is important to acknowledge that coral health is a multiple stressor issue, and while this study focuses on water quality, this may have additive and/or synergistic relationships with other stressors. The authors also encourage future studies (e.g. coral genetics, toxic pollutants) to add to the sampling framework established here, as the co-location and leveraging of existing data will make for stronger scientific conclusions. It is also acknowledged that water quality issues vary throughout the SEFCRI region, and the data required to support related management decisions may vary as well. As such, additional data beyond what has been collected here may be required to fulfill the needs of a specific sub-region or inlet contributing area.

This project is an excellent example of the power of state and federal partnerships. The assessment would not have been started without technical and financial contributions from NOAA, and it could not have been expanded, or continued without technical and financial contributions from Florida DEP. This project also demonstrates the importance of involving local stakeholders early on in the planning process and this greatly increases stakeholder buy in. thereby increasing the likelihood of project success, as well as utilizes existing local knowledge of individual ICAs, both in terms of scientific issues and management needs.

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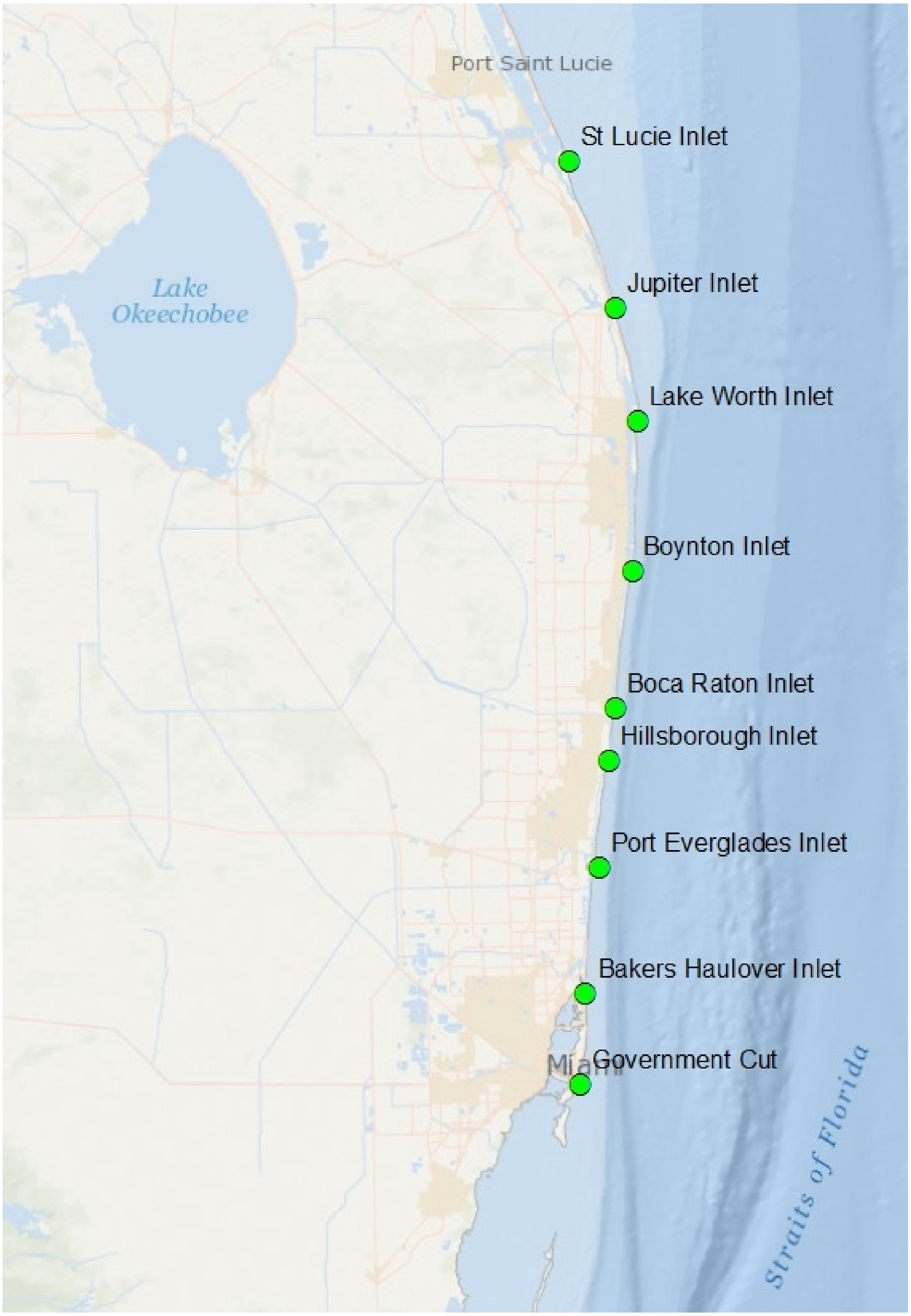

Figure 1: Inlet locations in SEFCRI region.

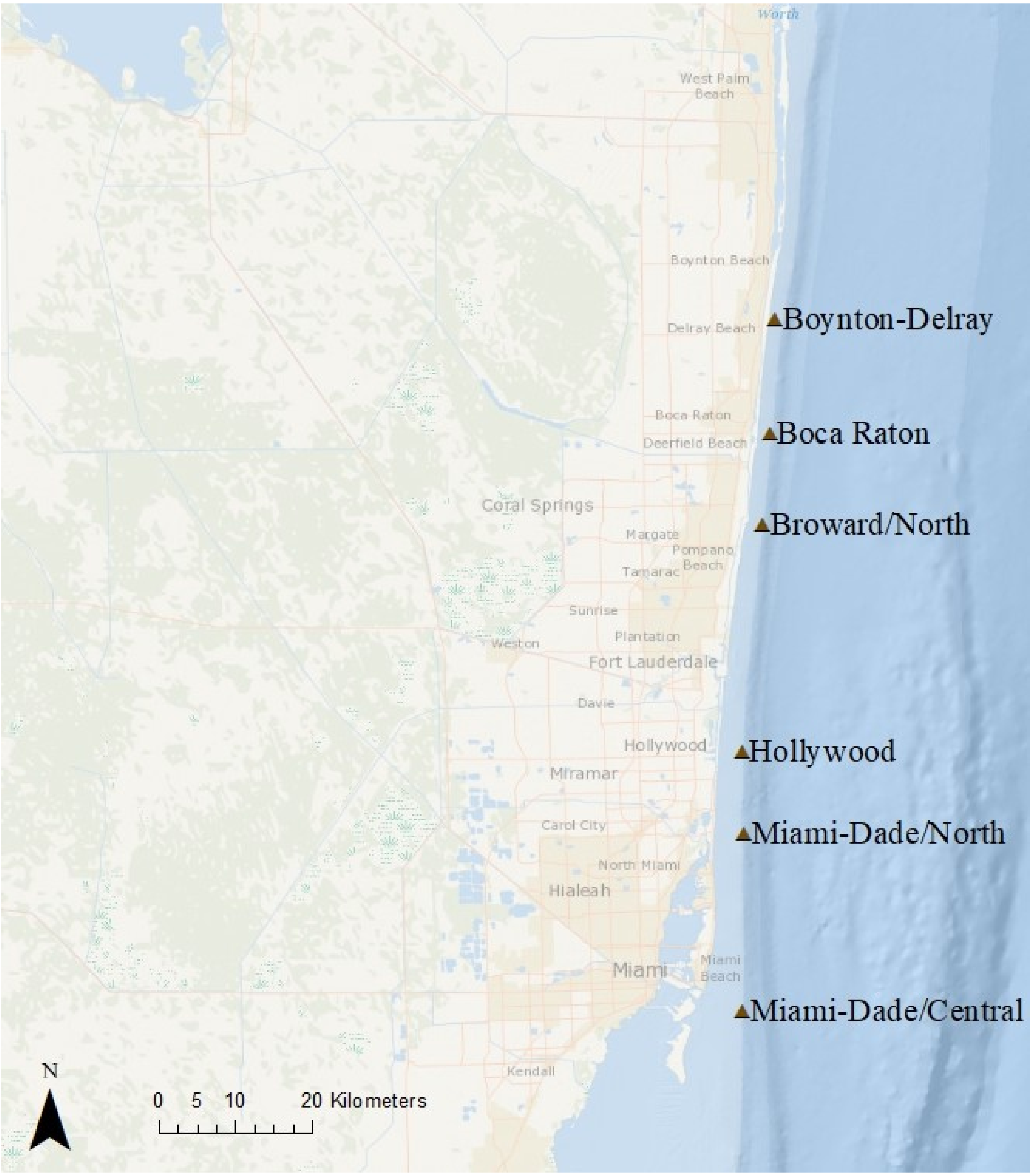

Figure 2: Outfall locations in SEFCRI region.

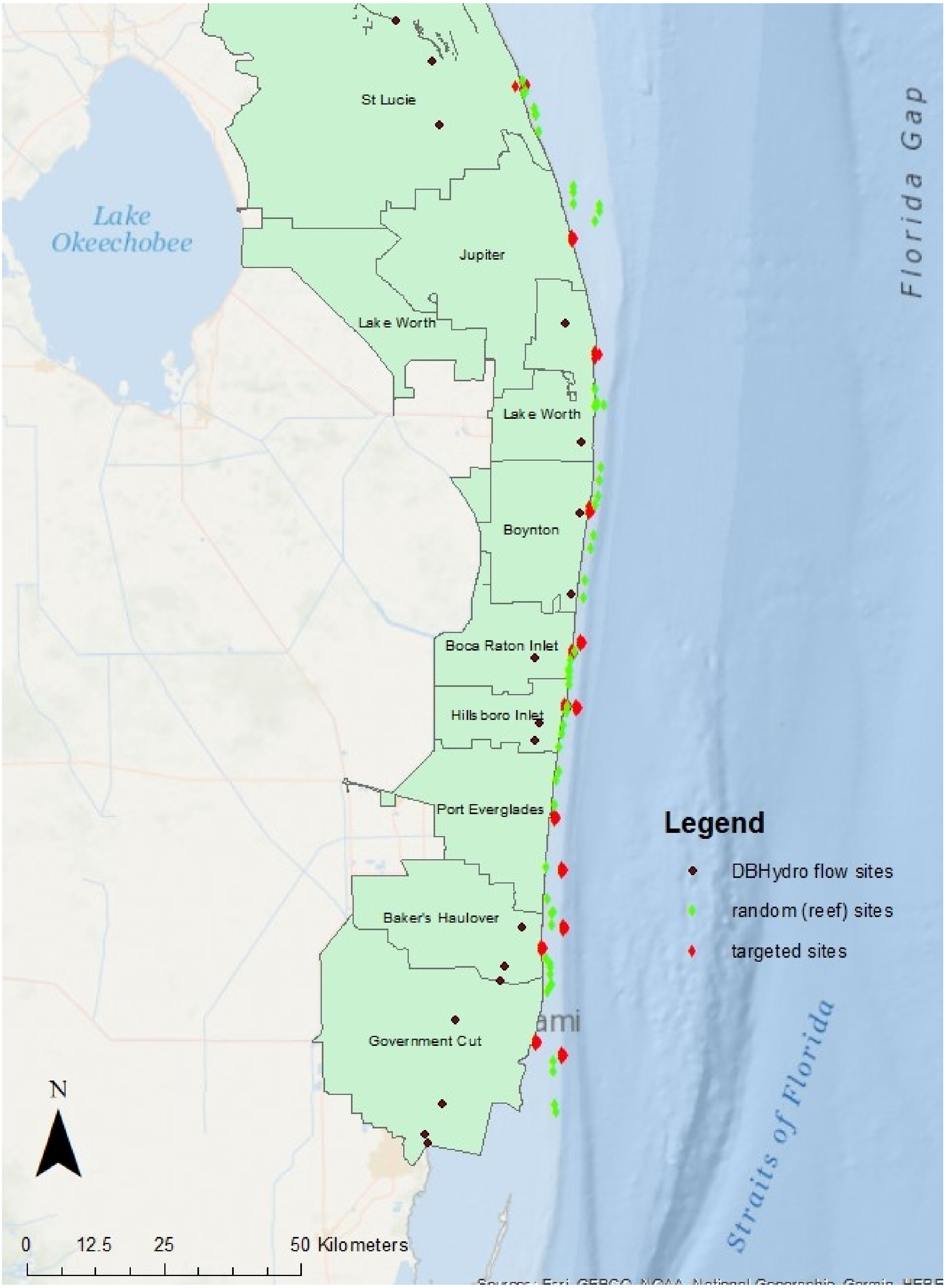

Figure 3: Inlet contributing areas (ICA) boundaries, inland flow sites (from DBHydro) and all water quality sampling sites.

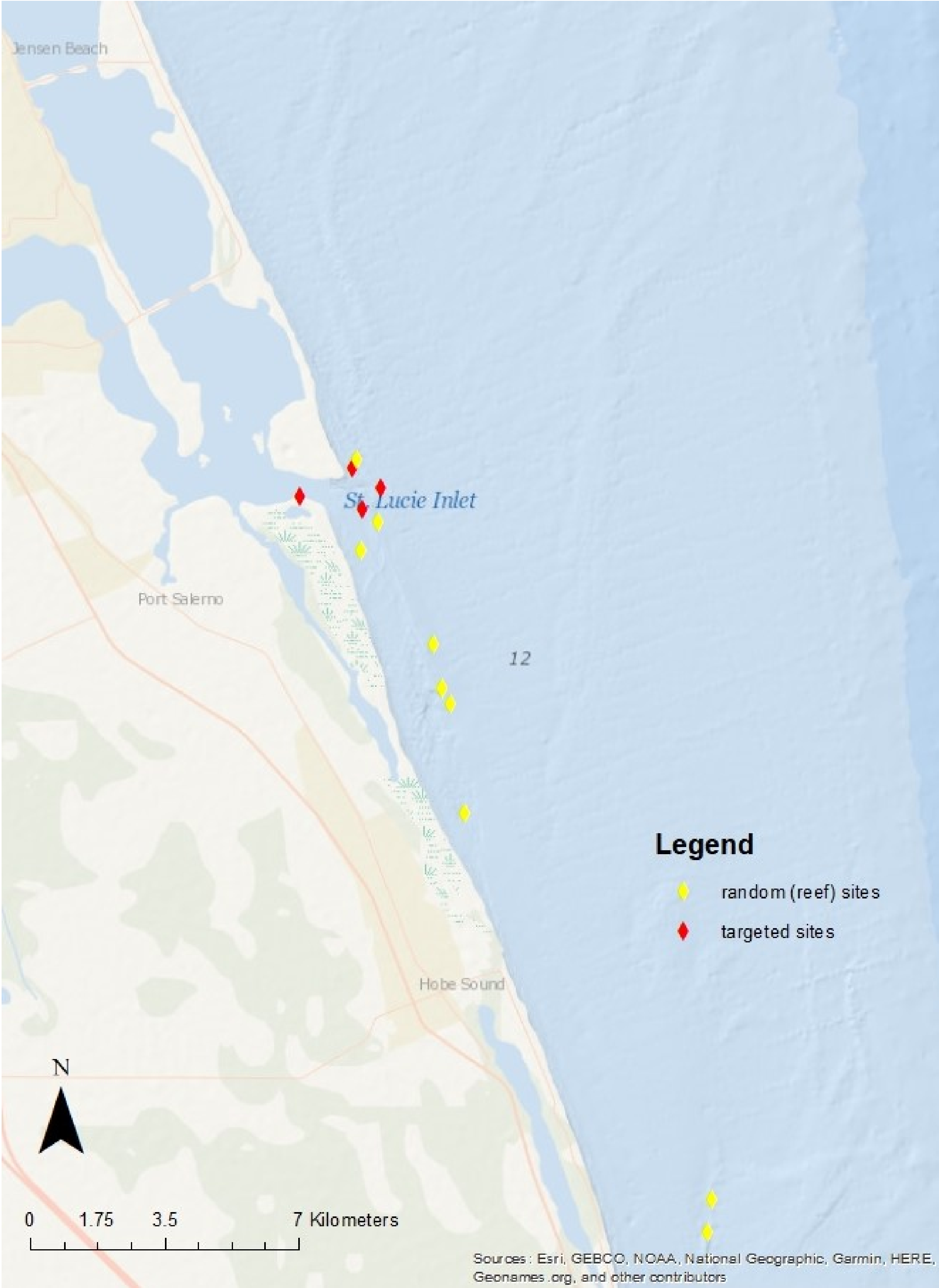

Figure 4: Sampling sites for St. Lucie ICA.

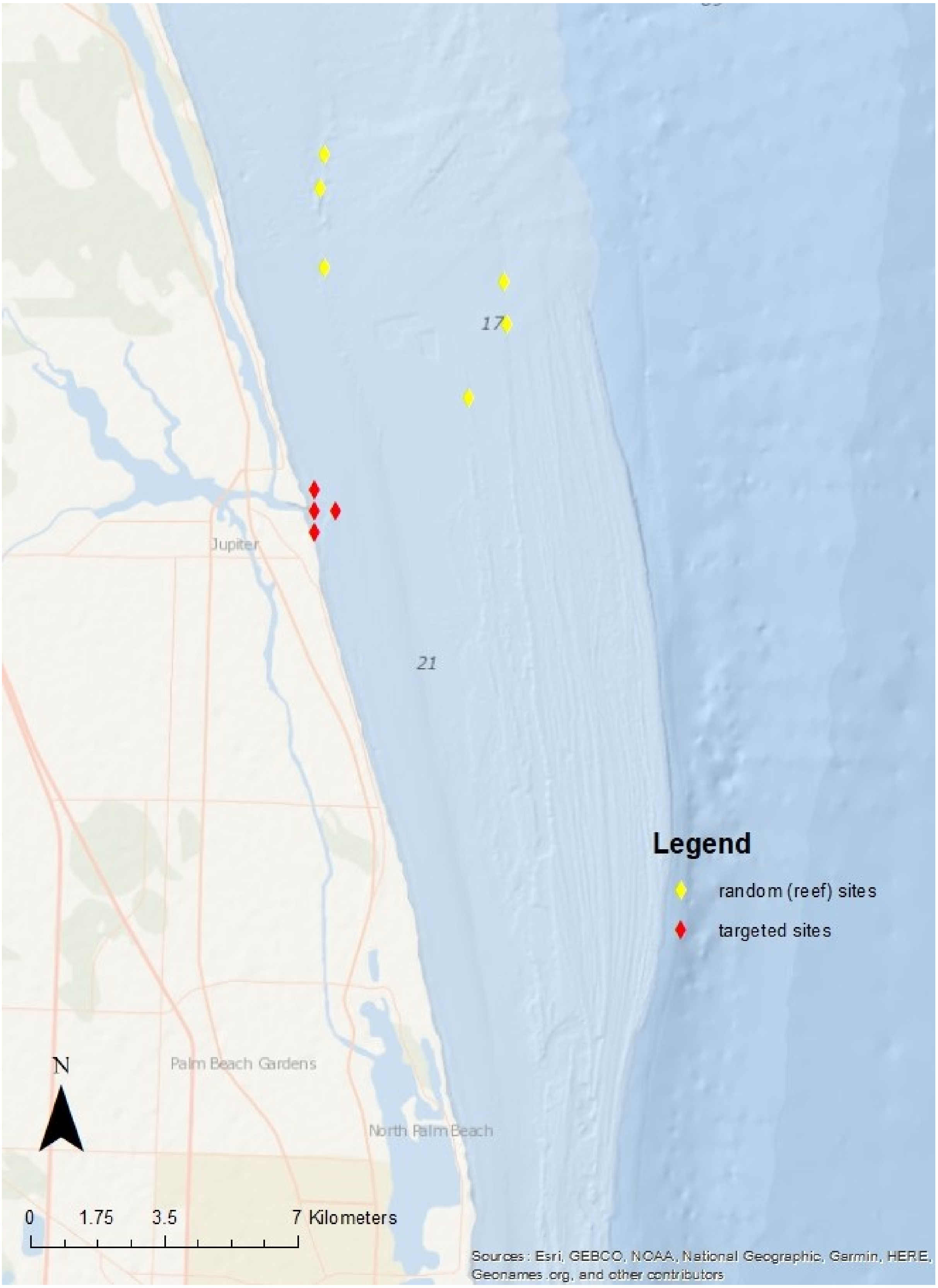

Figure 5: Sampling sites for Jupiter ICA.

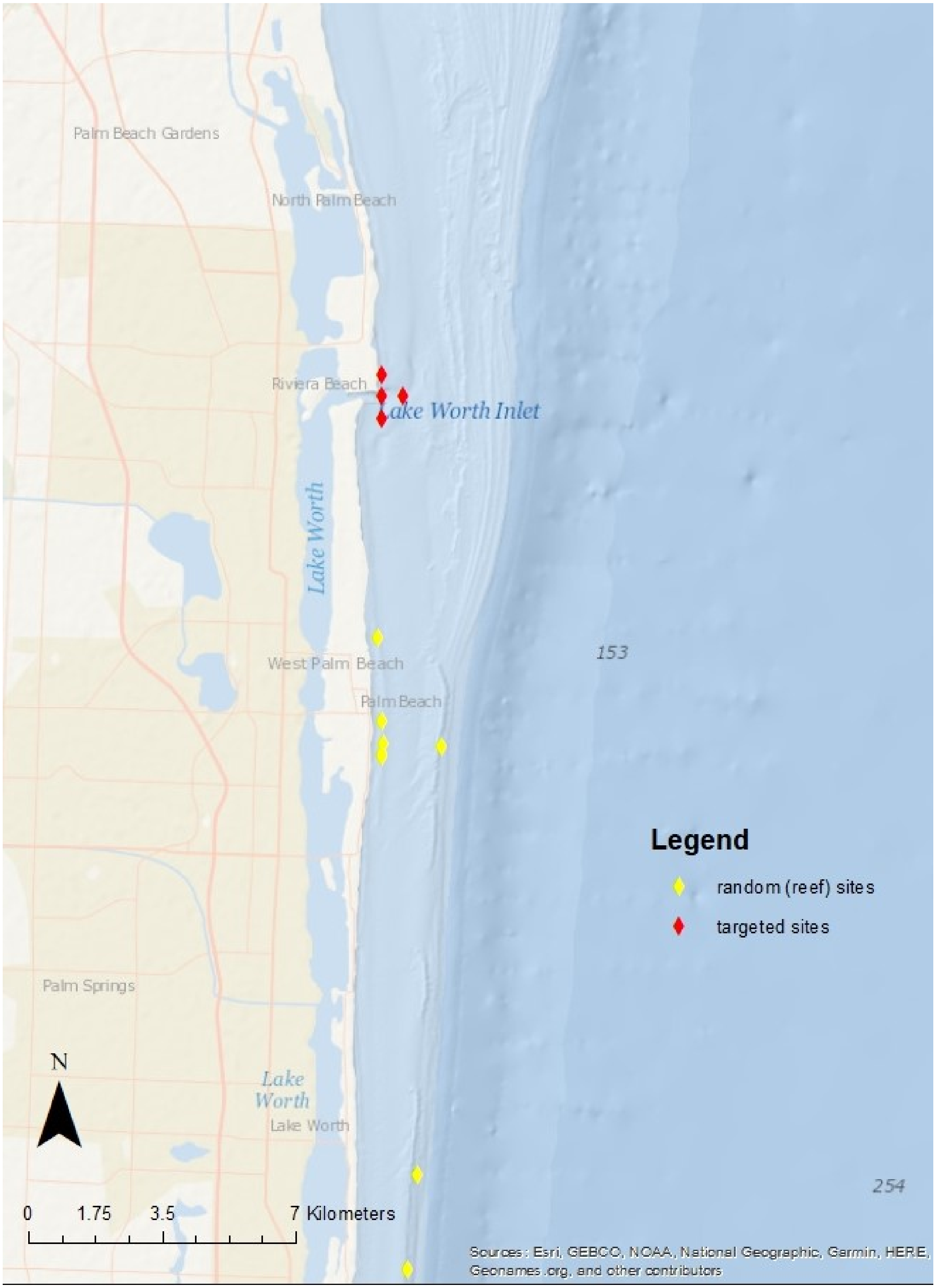

Figure 6: Sampling sites for Lake Worth ICA.

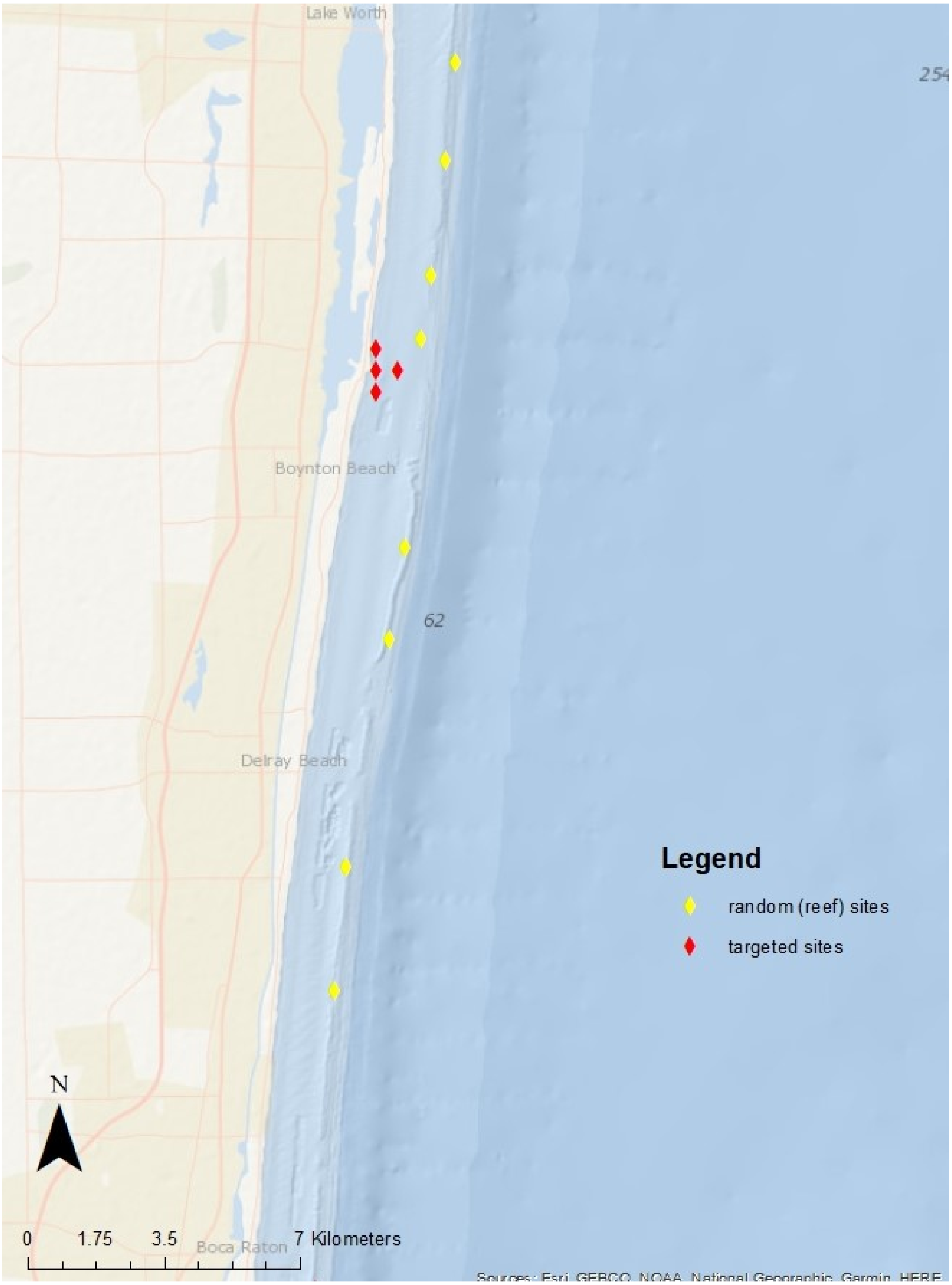

Figure 7: Sampling sites for Boyton ICA.

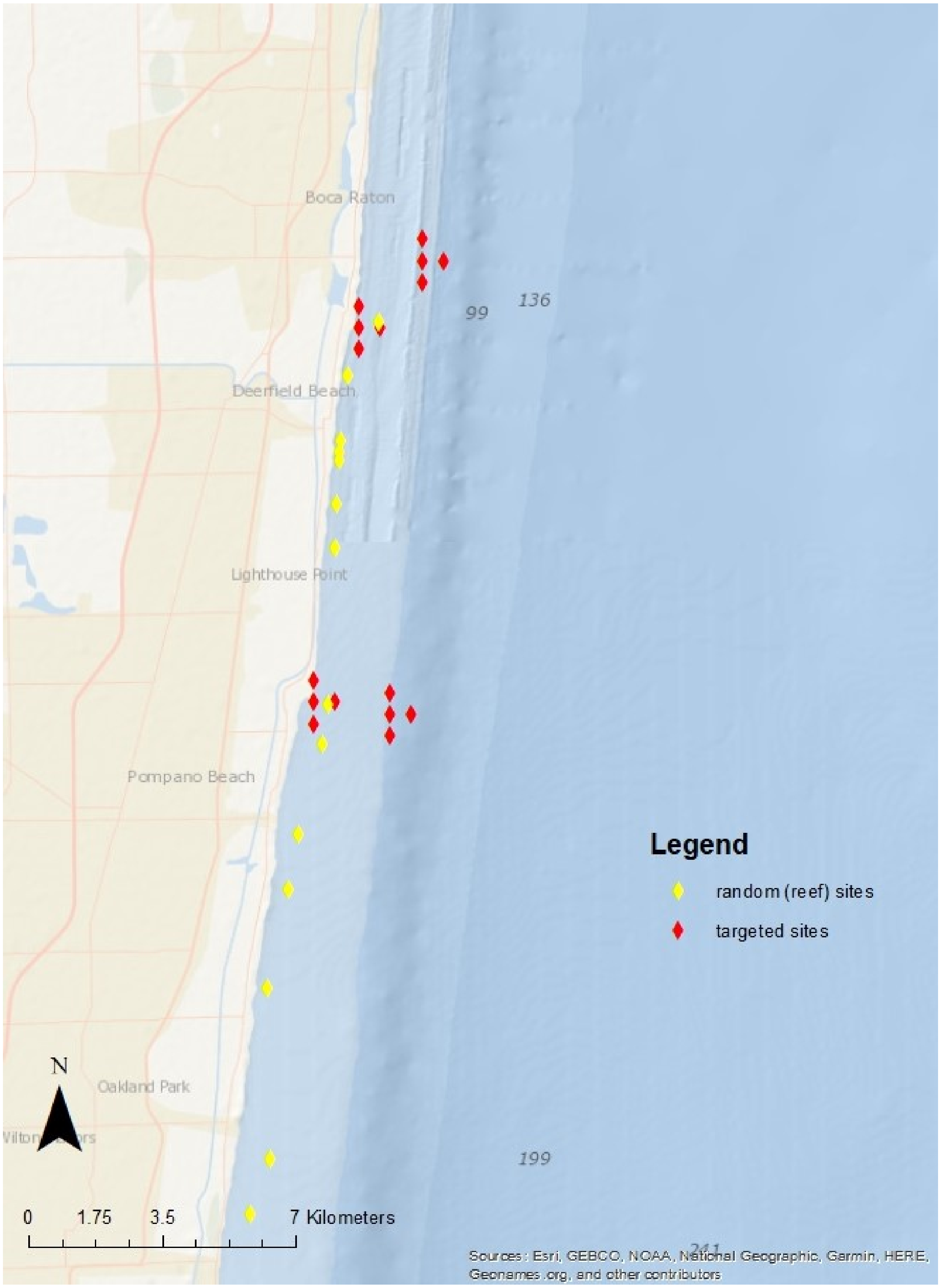

Figure 8: Sampling sites for Boca Raton and Hillsborough ICAs.

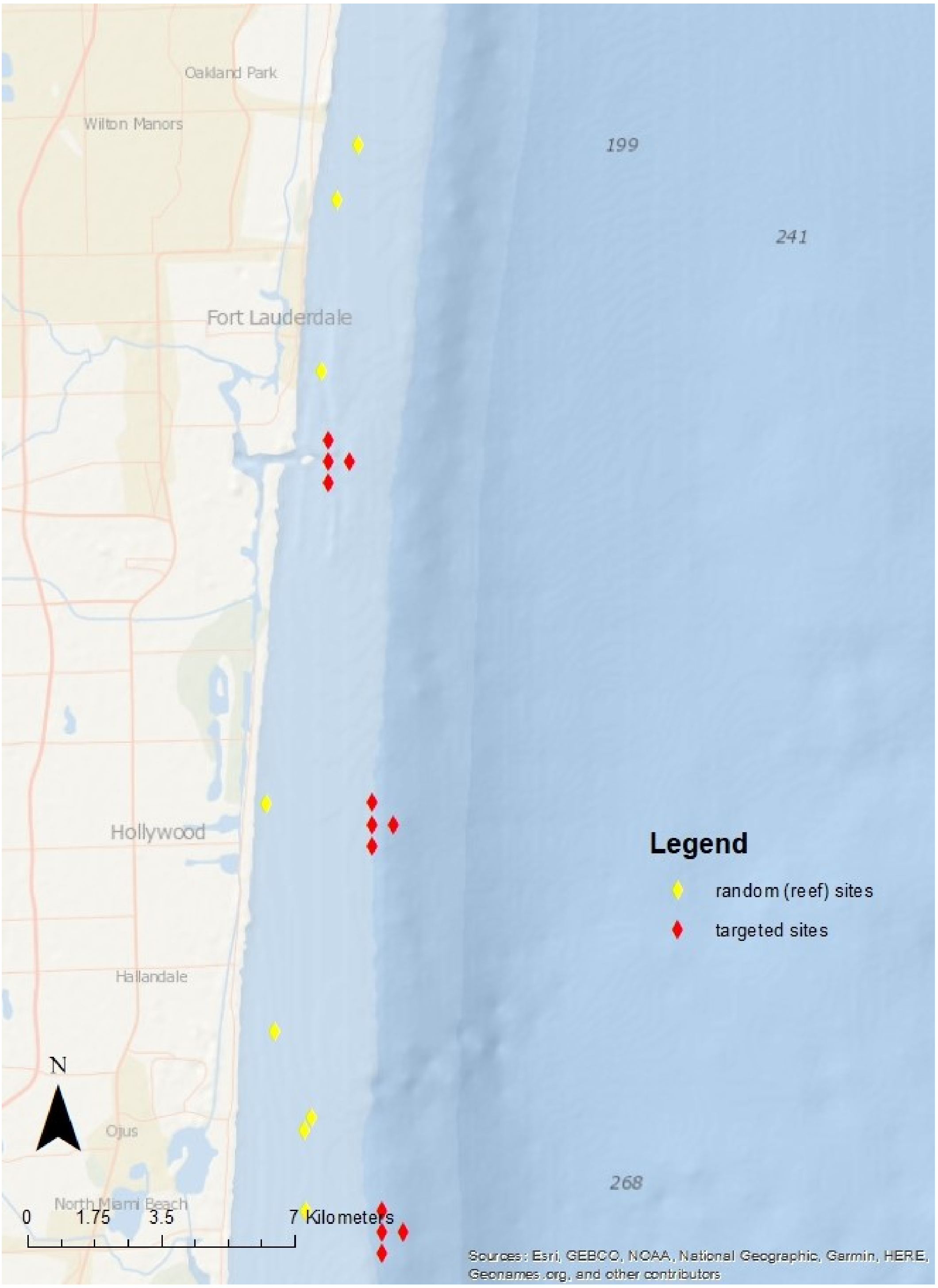

Figure 9: Sampling sites for Port Everglades ICA.

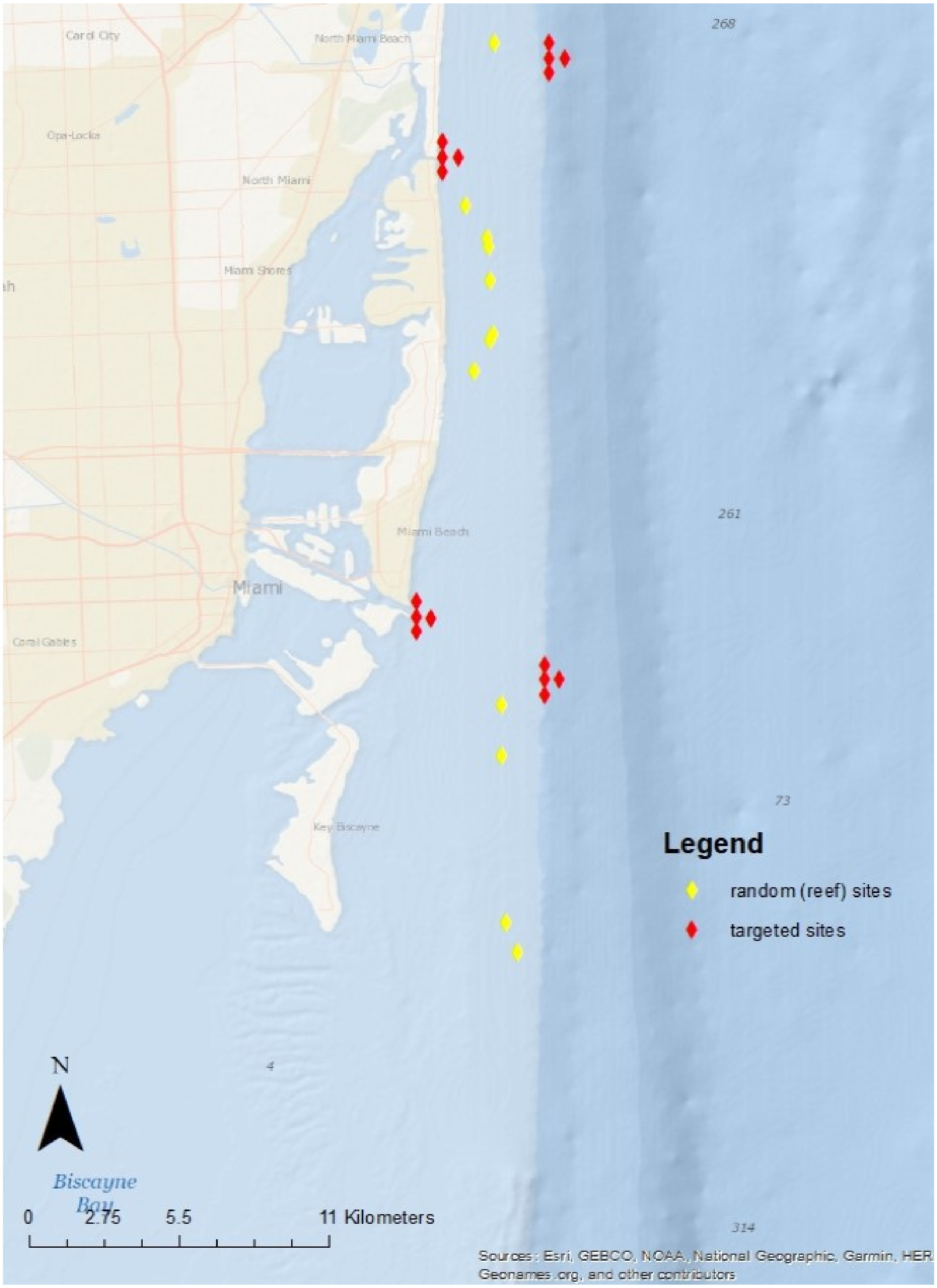

Figure 10: Sampling sites for Baker's Haulover and Government Cut ICAs.

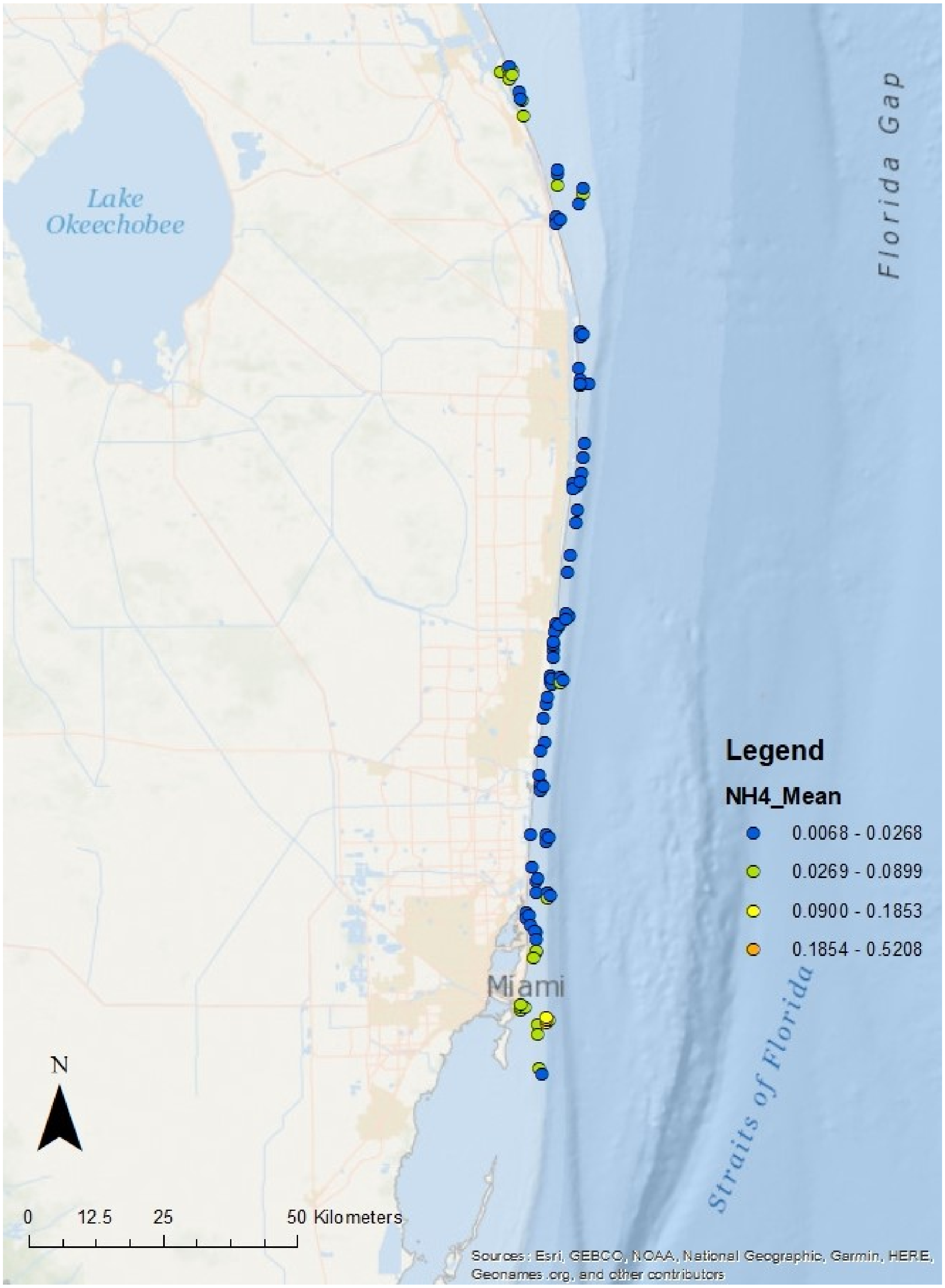

Figure 11: Mean surface ammonium concentrations by site. Units are mg-N/L.

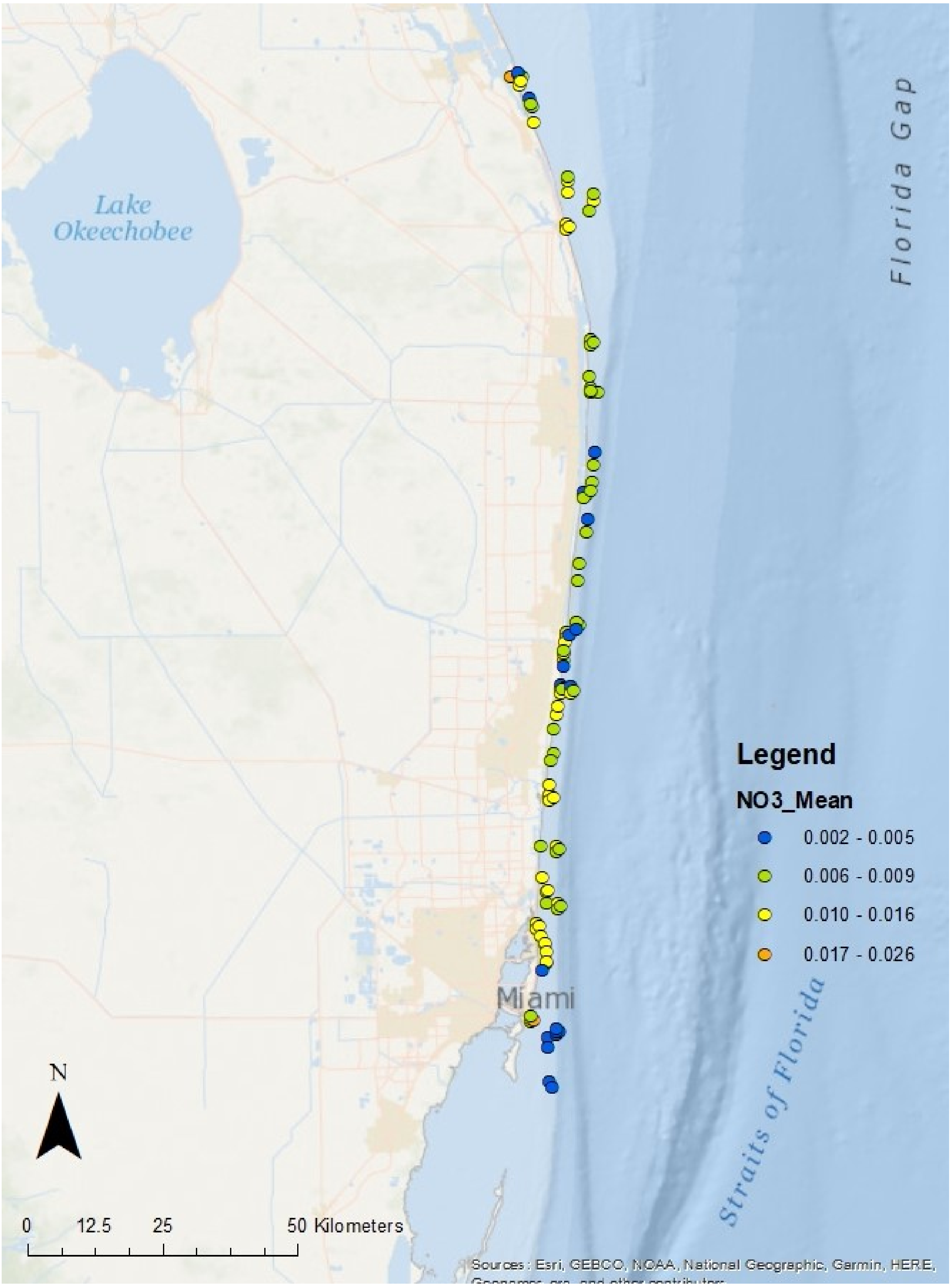

Figure 12: Mean surface nitrate concentrations by site. Units are mg-N/L.

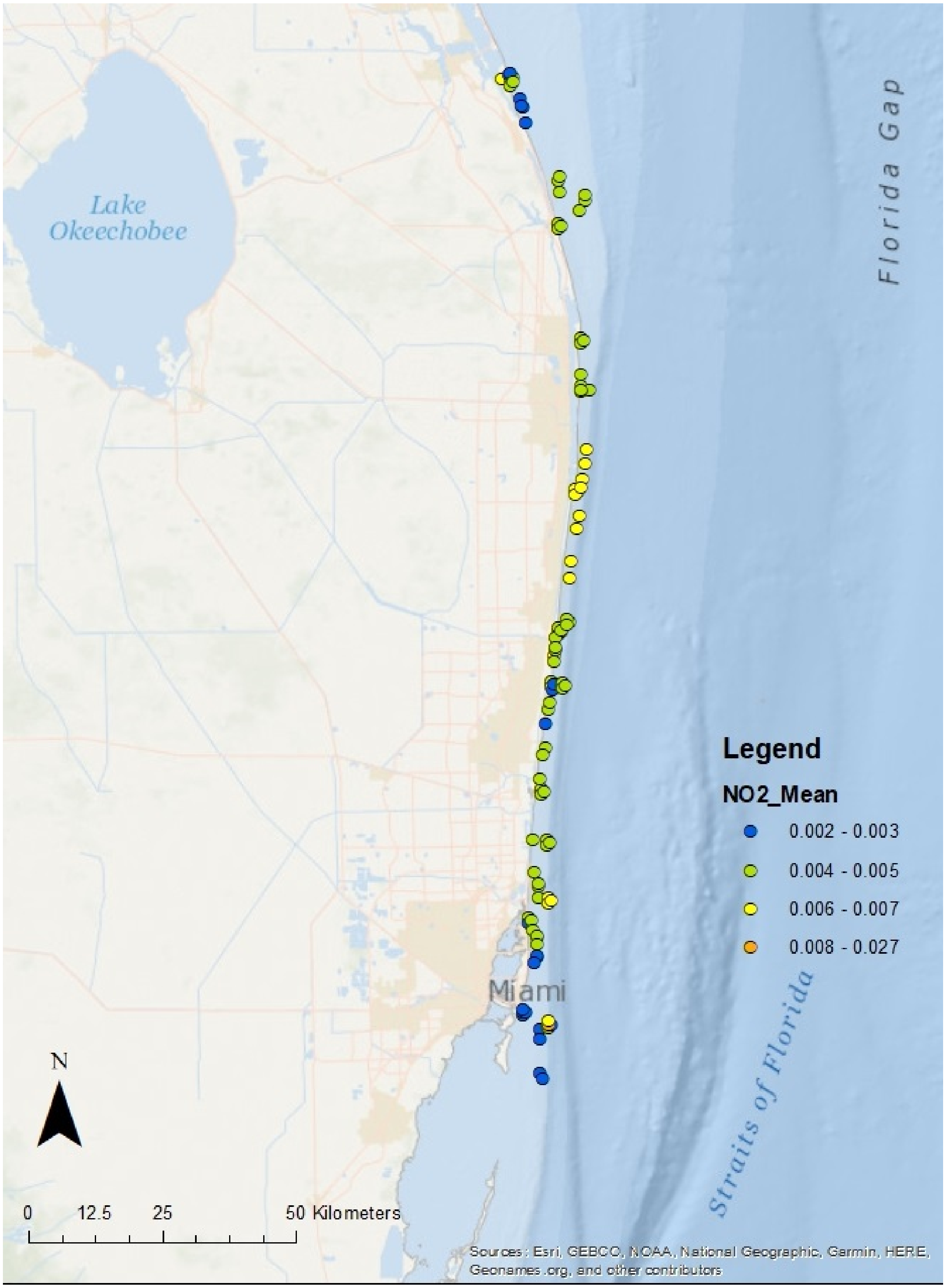

Figure 13: Mean surface nitrite concentrations by site. Units are mg-N/L.

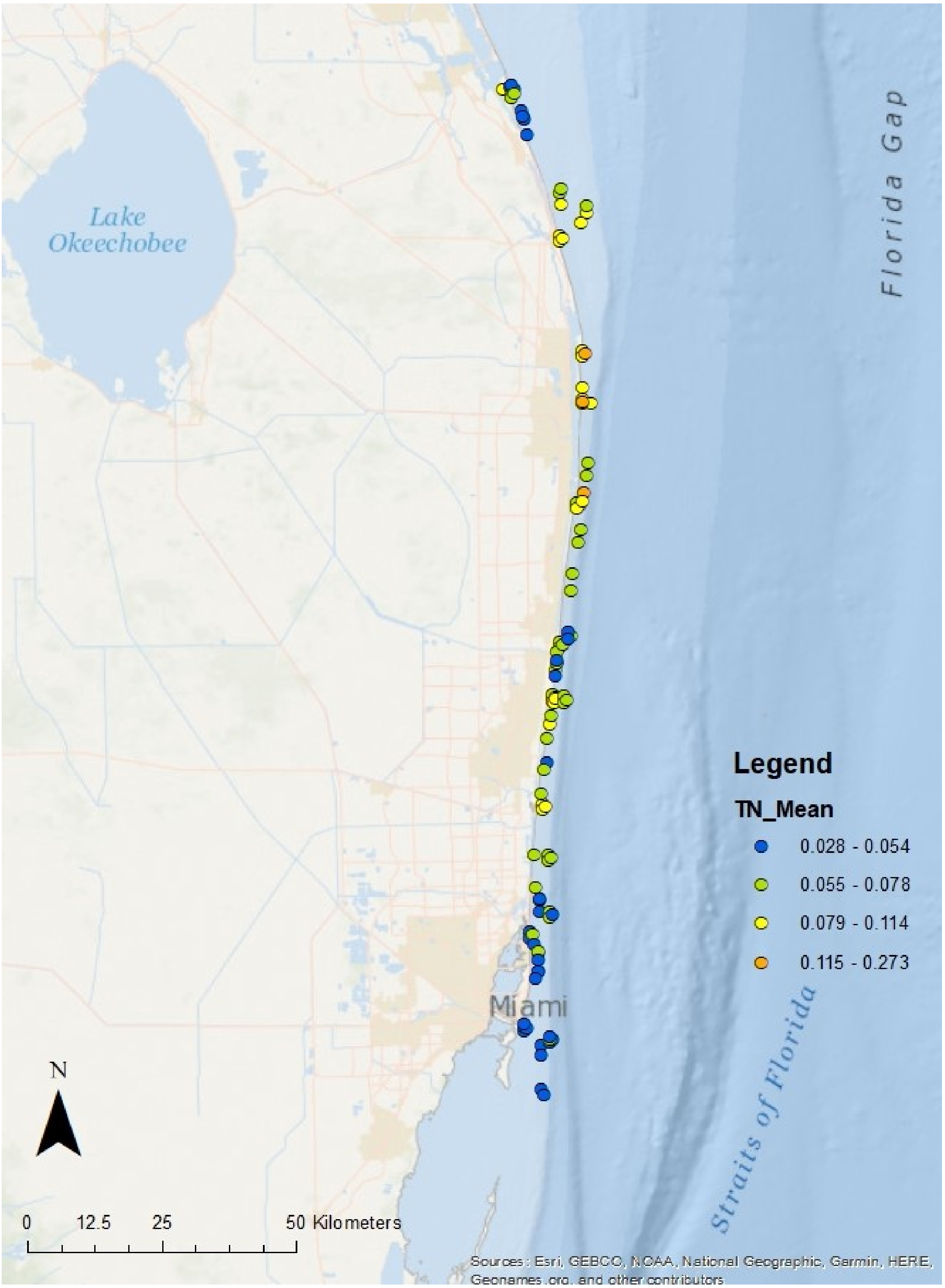

Figure 14: Mean surface total nitrogen concentrations by site. Units are mg-N/L. Note that for all sites except STL and GOC, total nitrogen was calculated by summing TKN, nitrate and nitrite.

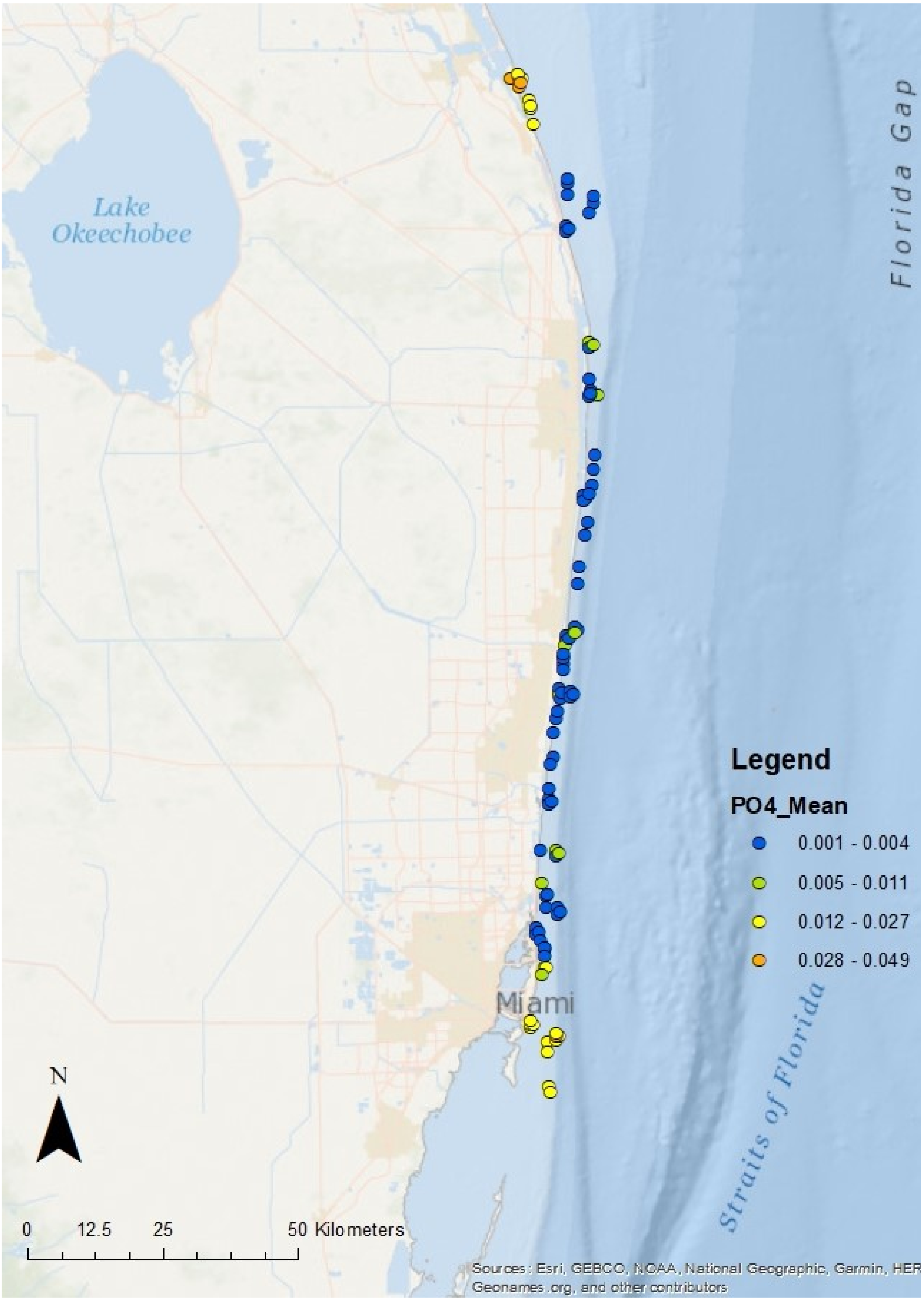

Figure 15: Mean surface orthophosphate concentrations by site. Units are mg-P/L.

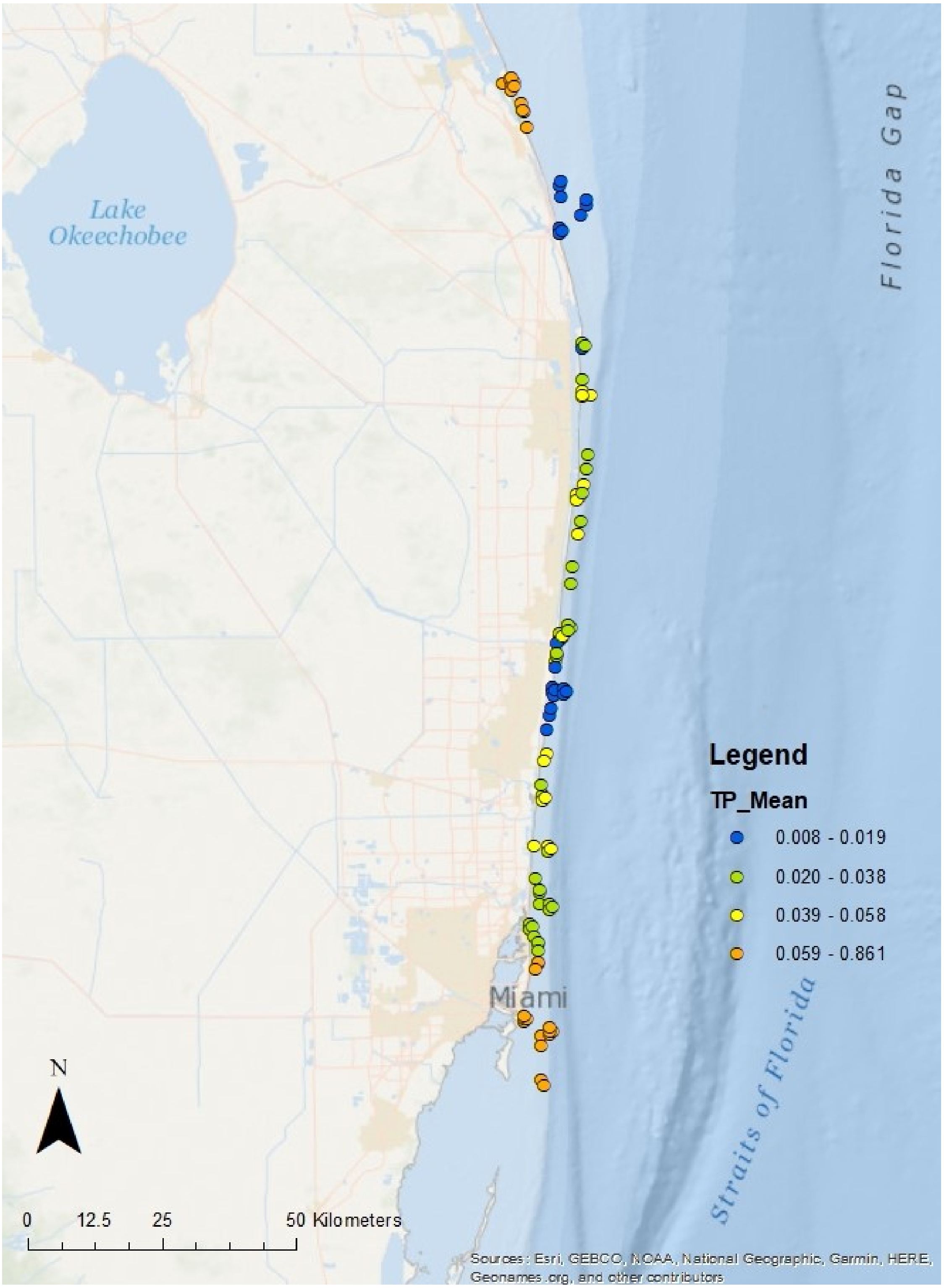

Figure 16: Mean surface total phosphorus concentrations by site. Units are mg-P/L.

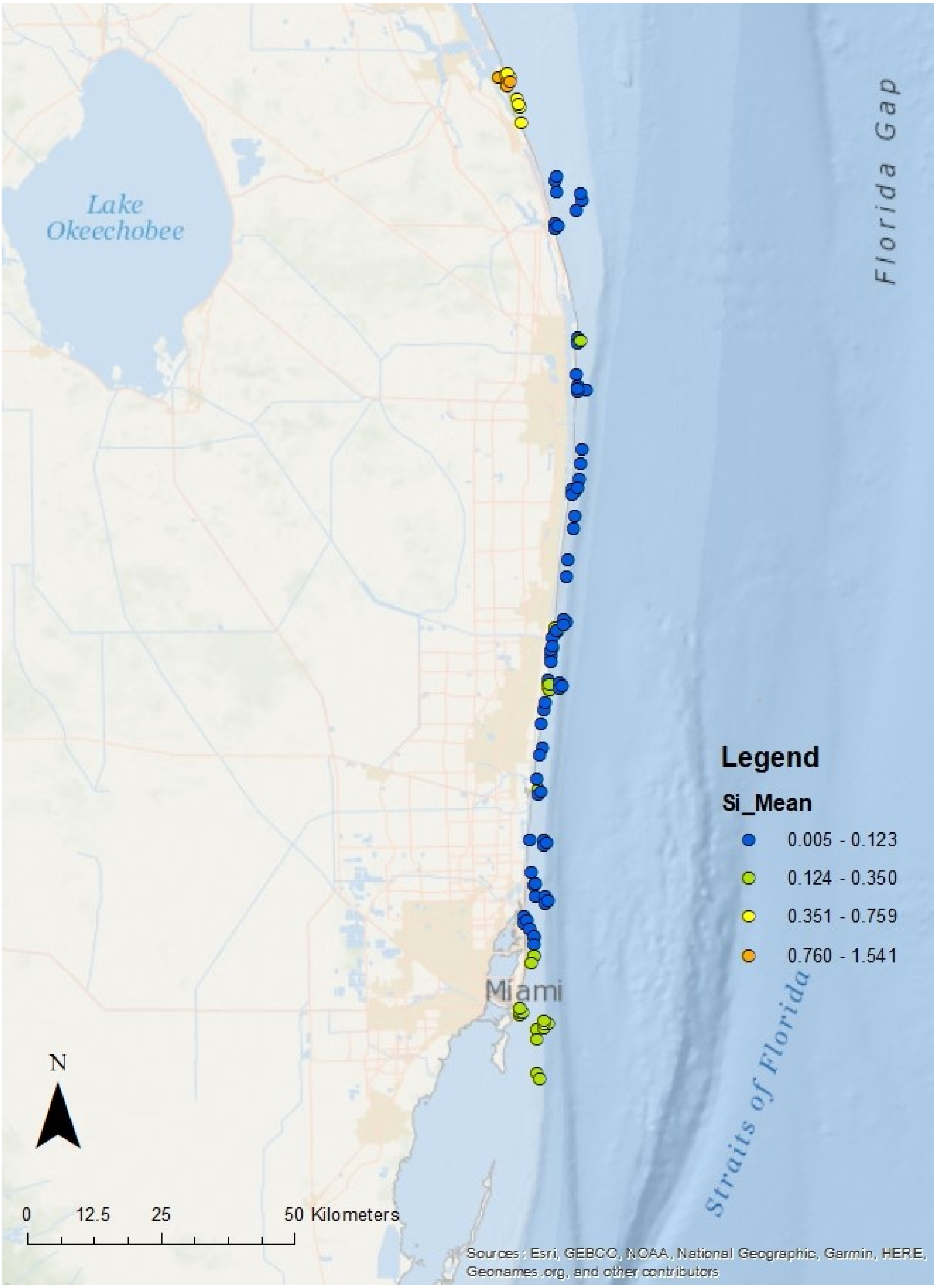

Figure 17: Mean surface silica concentrations by site. Units are mg-Si/L.

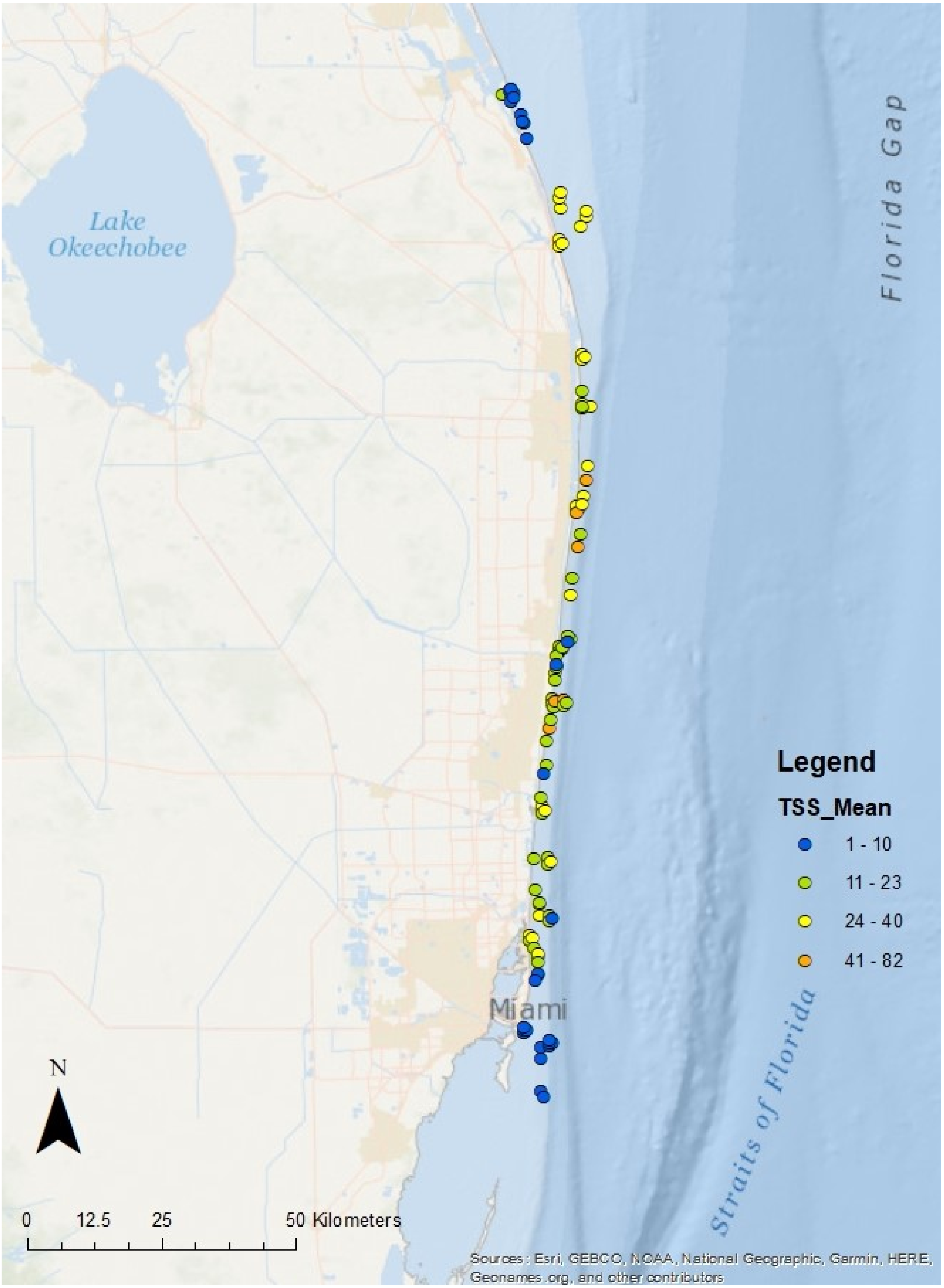

Figure 18: Mean surface total suspended solids concentrations by site. Units are mg/L.

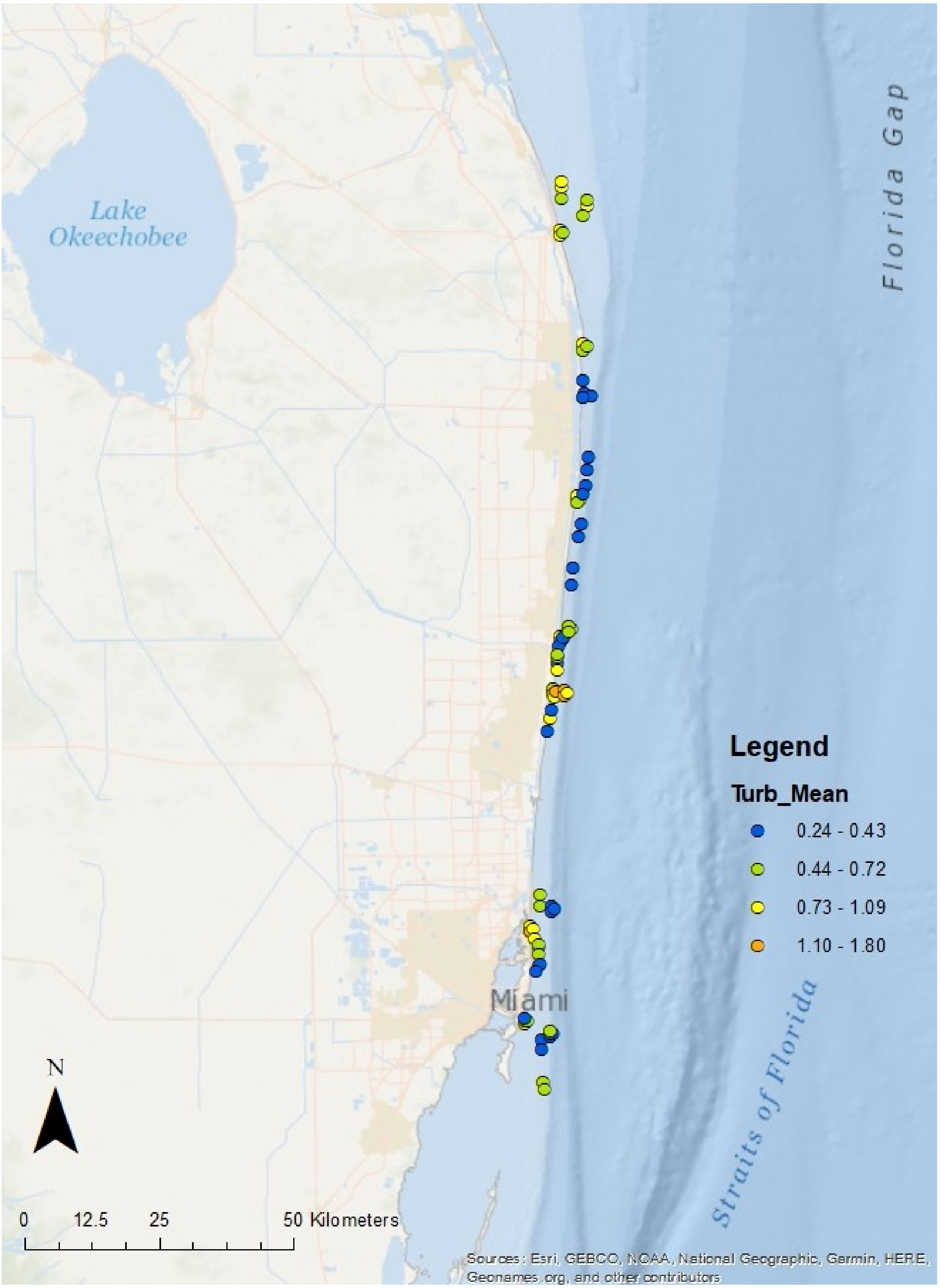

Figure 19: Mean surface turbidity by site. Units are NTU. Note that turbidity was not measured at STL and GOC.

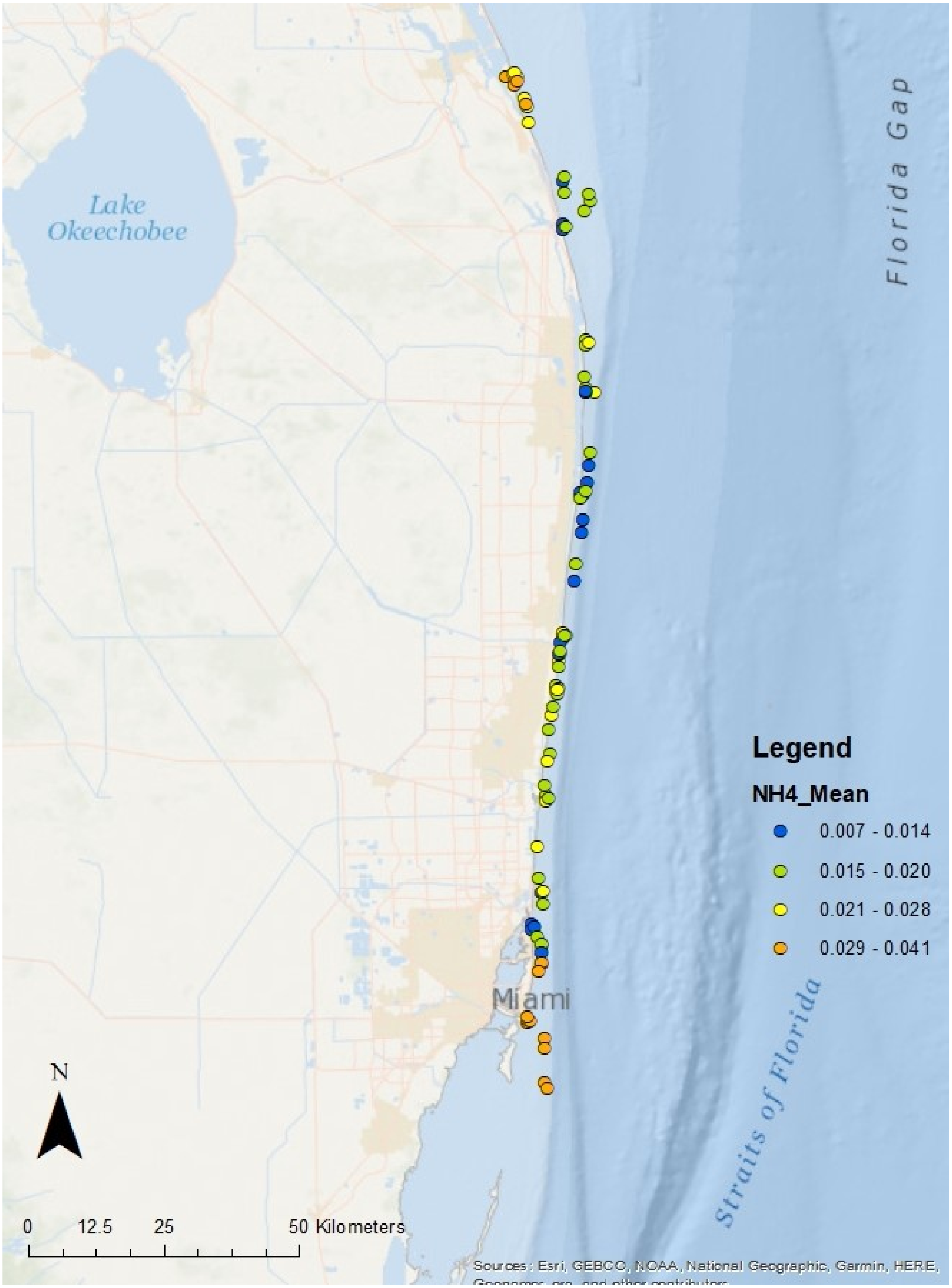

Figure 20: Mean bottom ammonium concentrations by site. Units are mg-N/L.

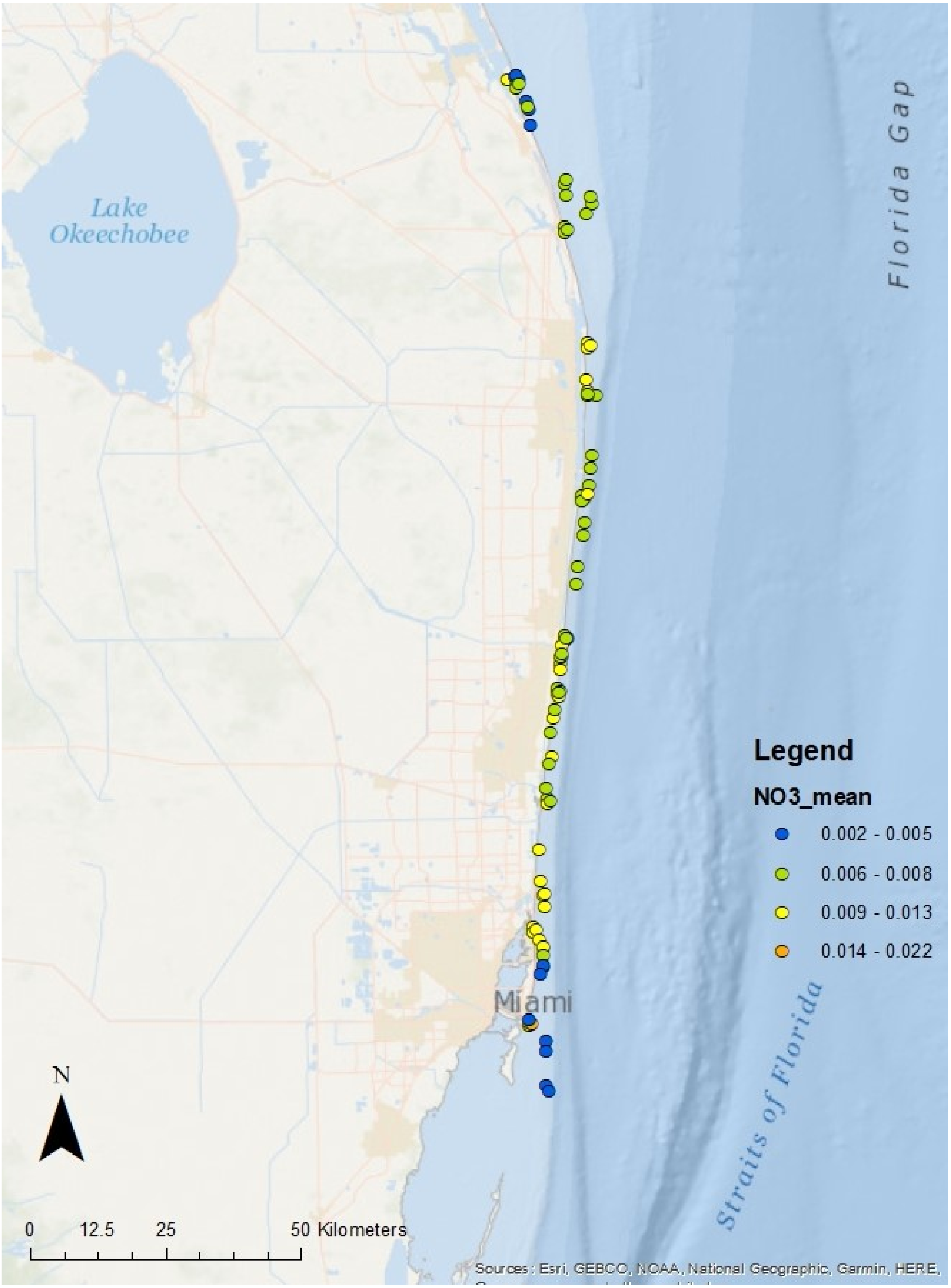

Figure 21: Mean bottom nitrate concentrations by site. Units are mg-N/L.

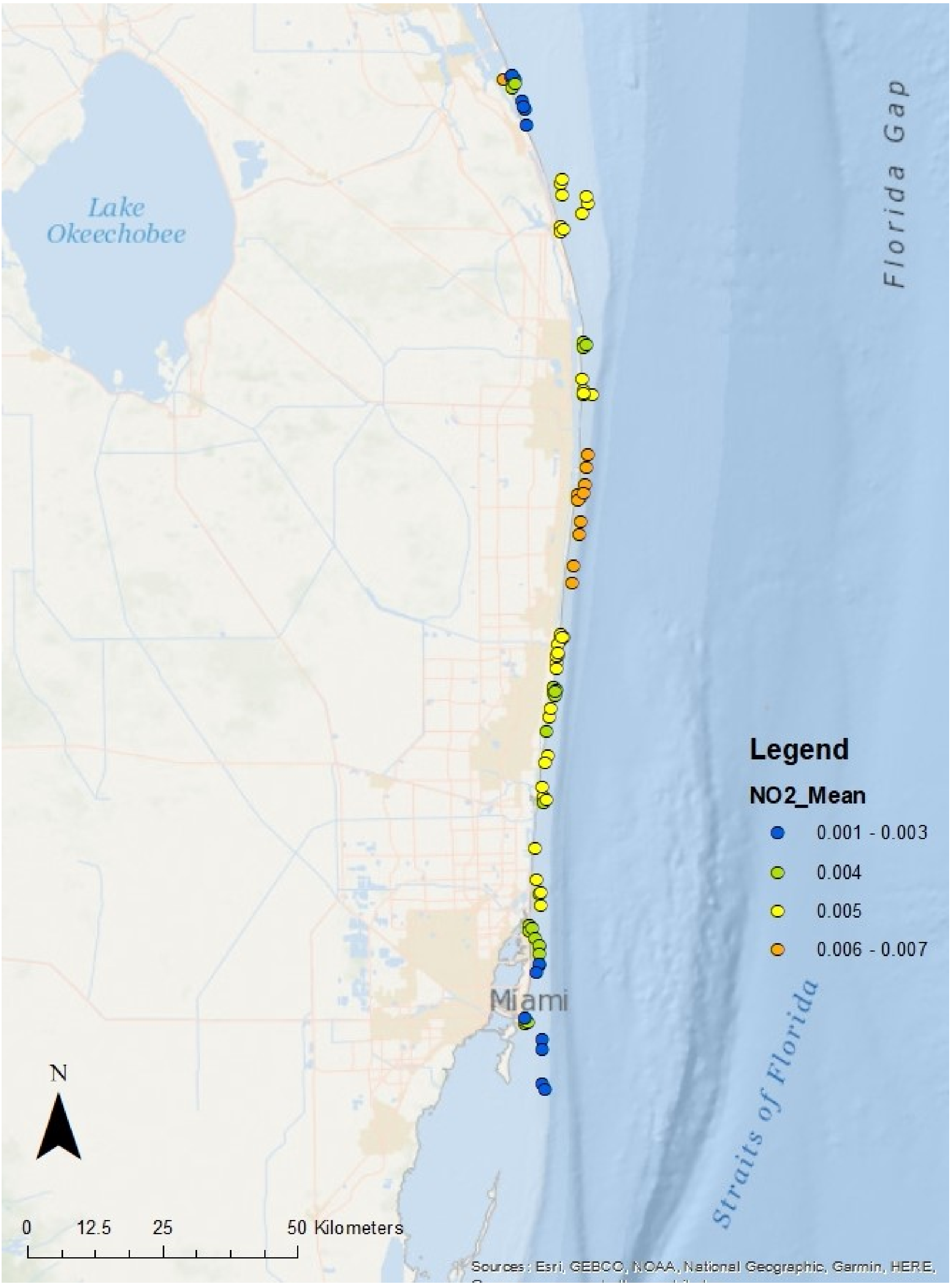

Figure 22: Mean bottom nitrite concentrations by site. Units are mg-N/L.

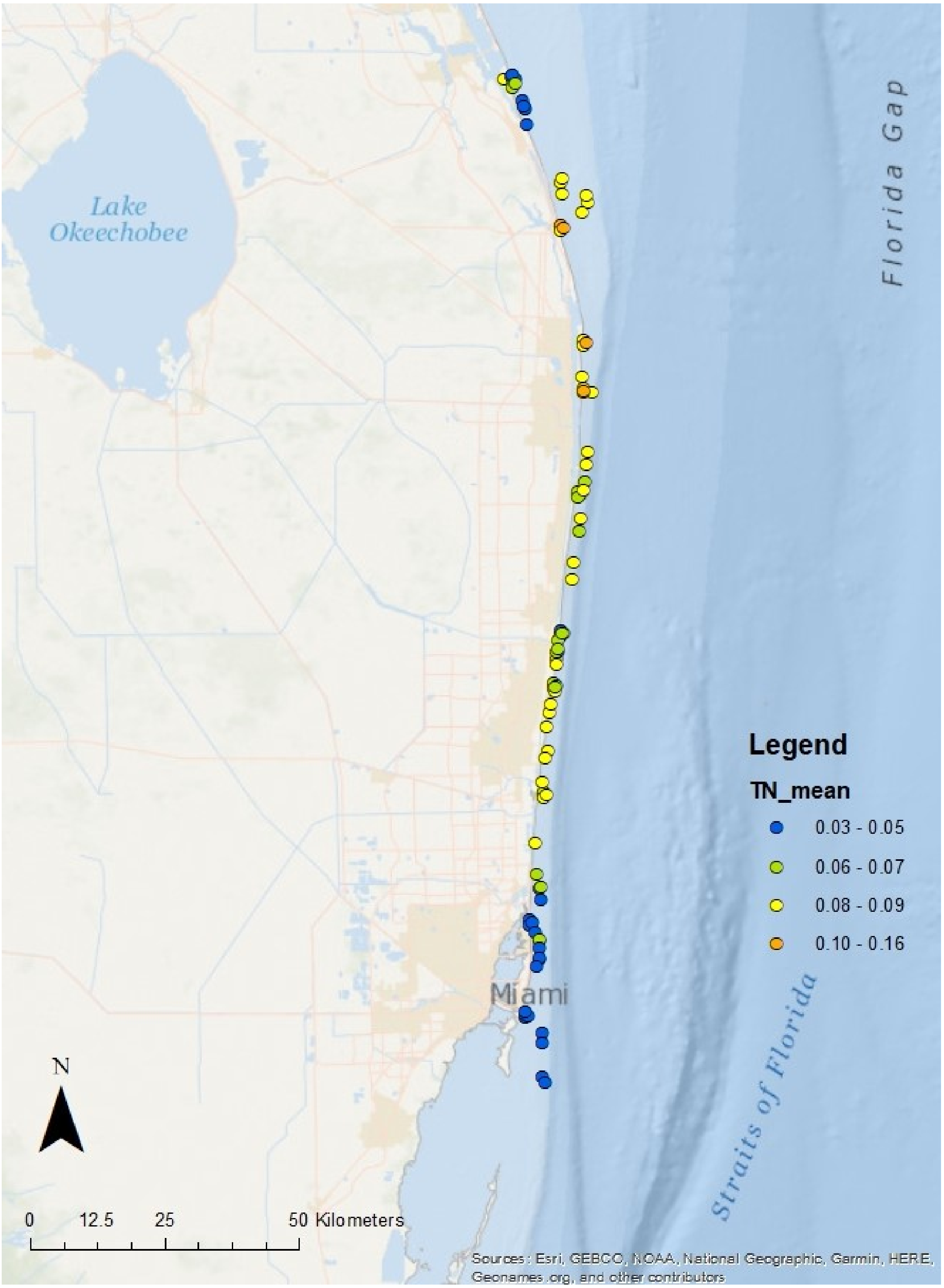

Figure 23: Mean bottom total nitrogen concentrations by site. Units are mg-N/L. Note that for all sites except STL and GOC, total nitrogen was calculated by summing TKN, nitrate and nitrite.

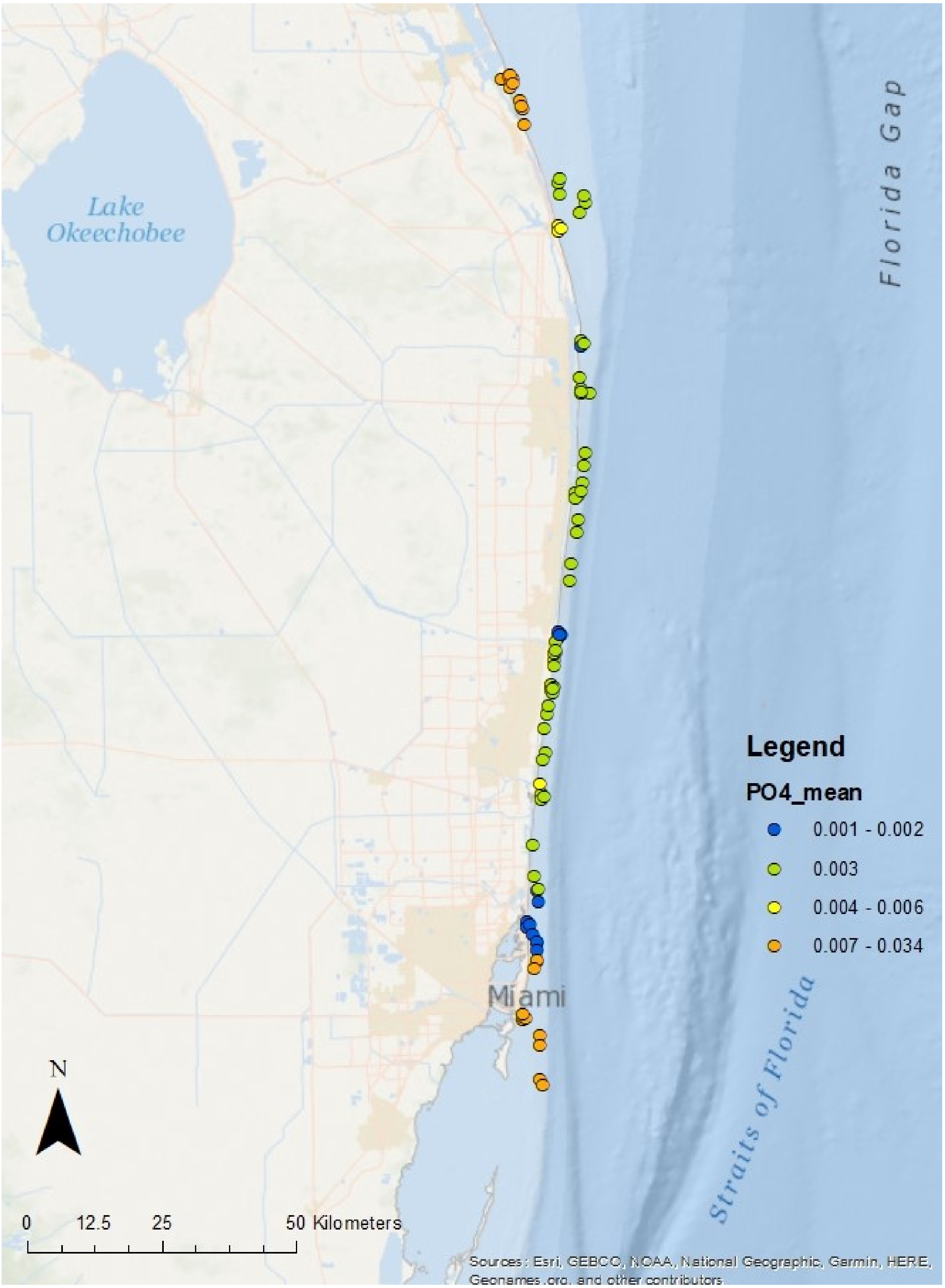

Figure 24: Mean bottom orthophosphate concentrations by site. Units are mg-P/L.

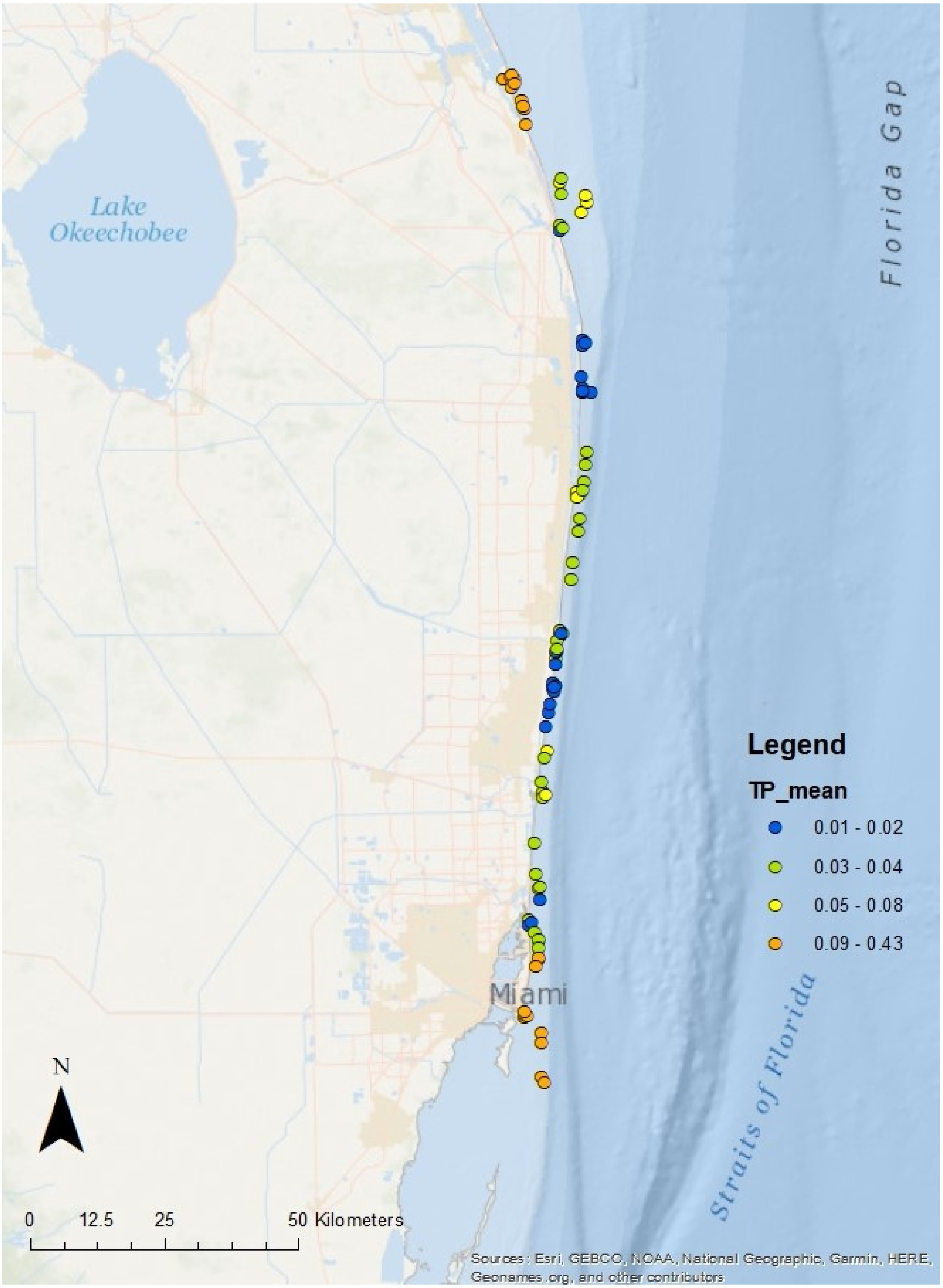

Figure 25: Mean bottom total phosphorus concentrations by site. Units are mg-P/L.

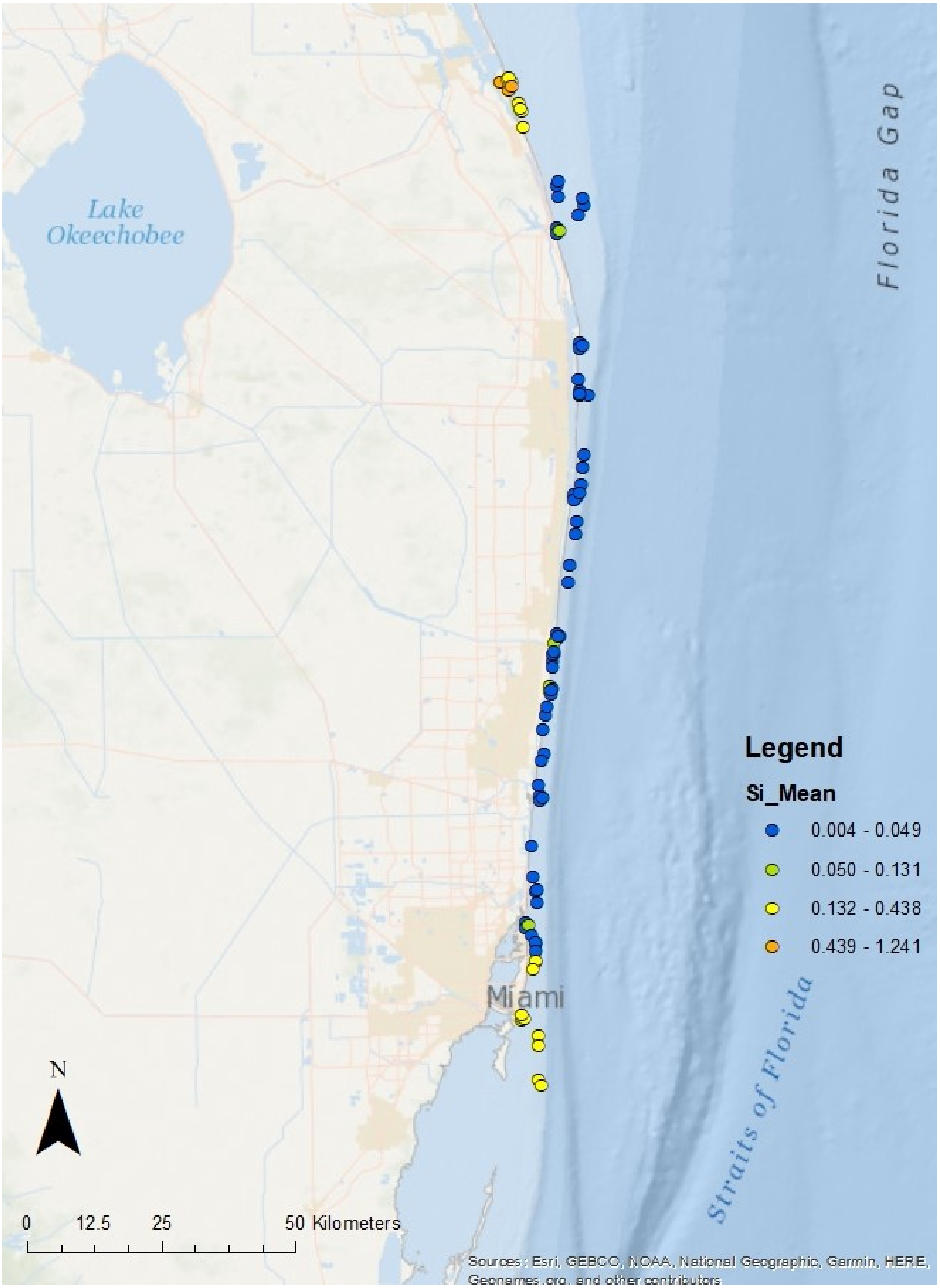

Figure 26: Mean bottom silica concentrations by site. Units are mg-Si/L.

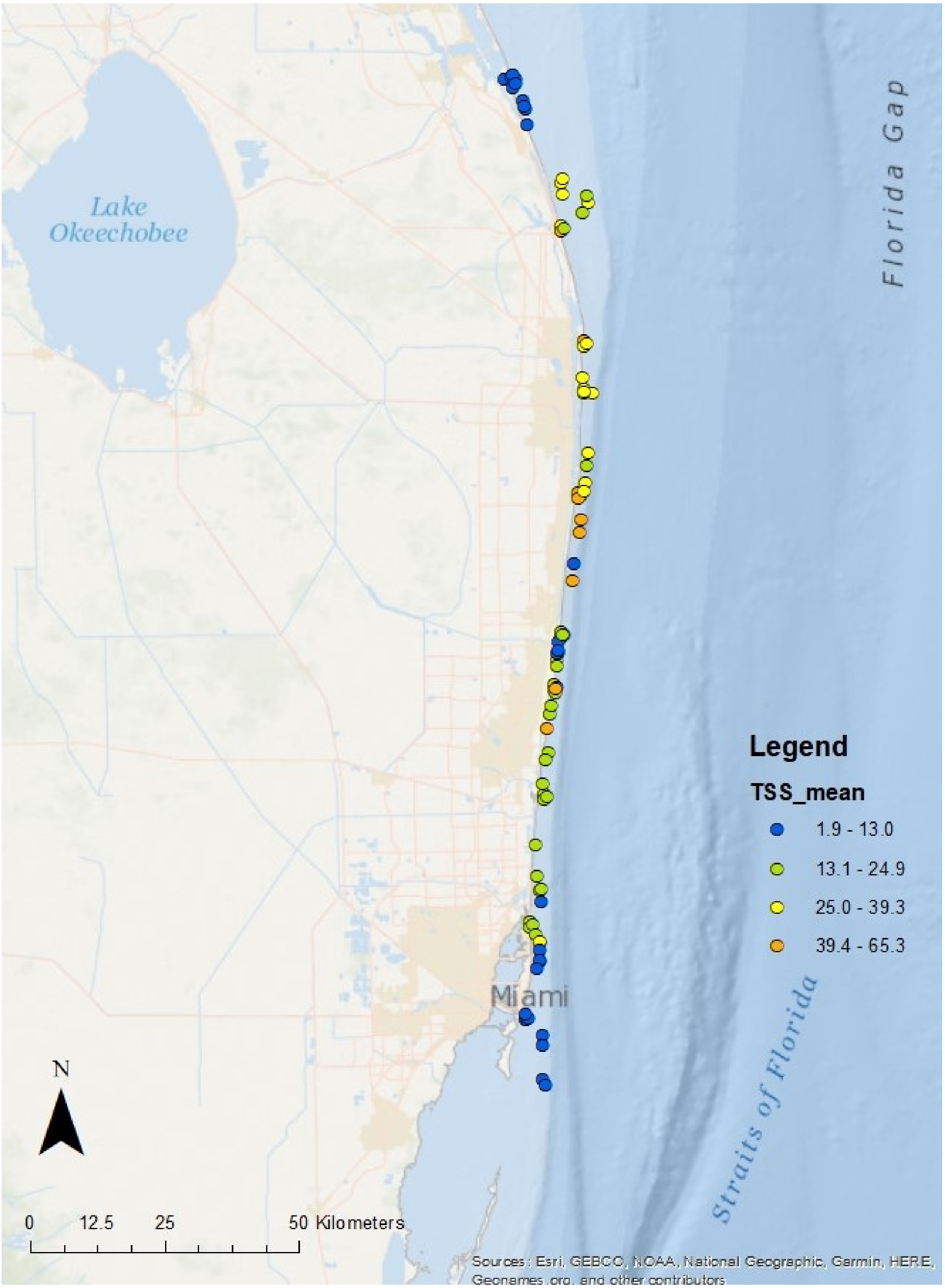

Figure 27: Mean bottom total suspended solids concentrations by site. Units are mg/L.

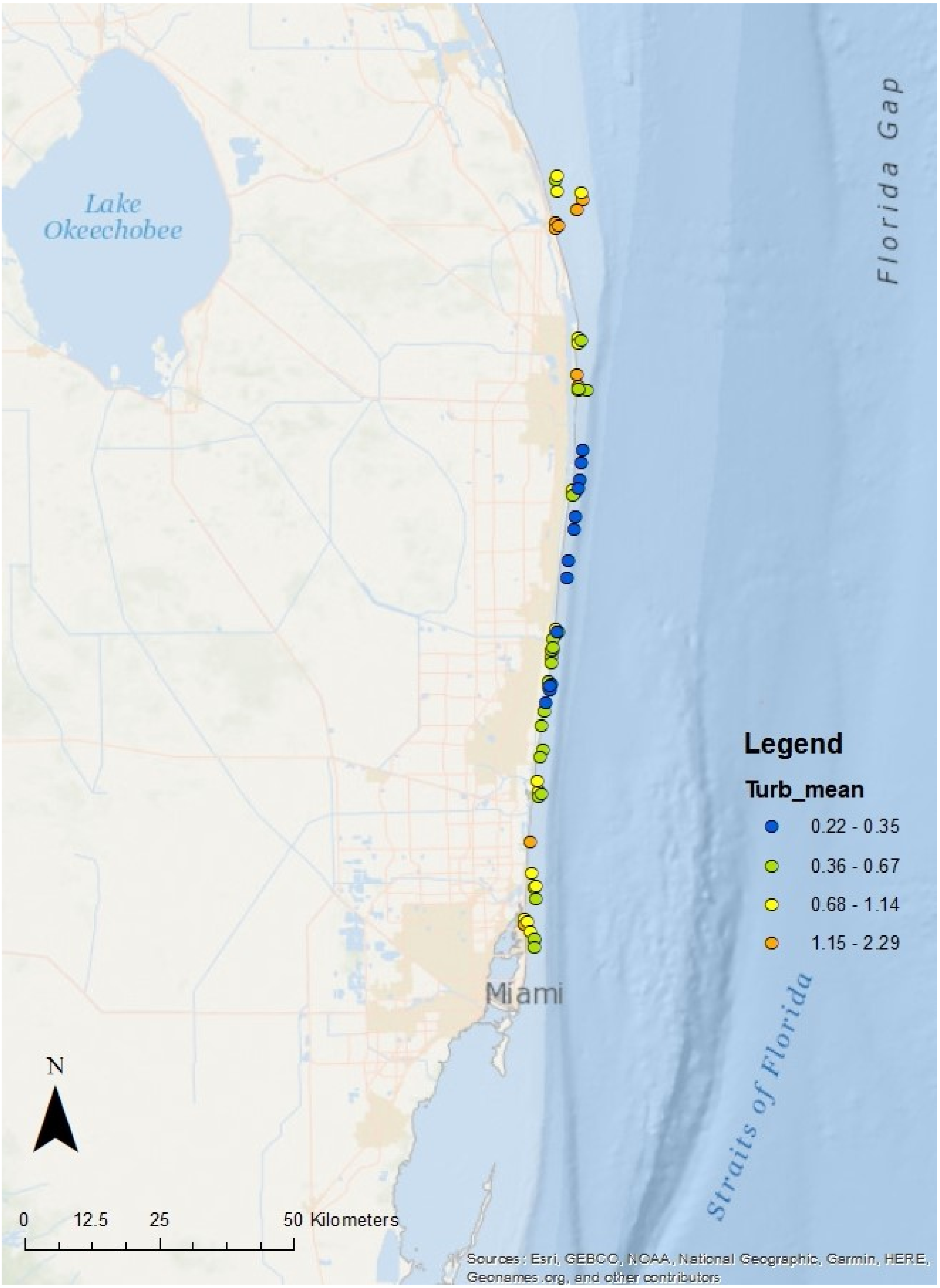

Figure 28: Mean bottom turbidity by site. Units are NTU. Note that turbidity was not measured at STL and GOC.

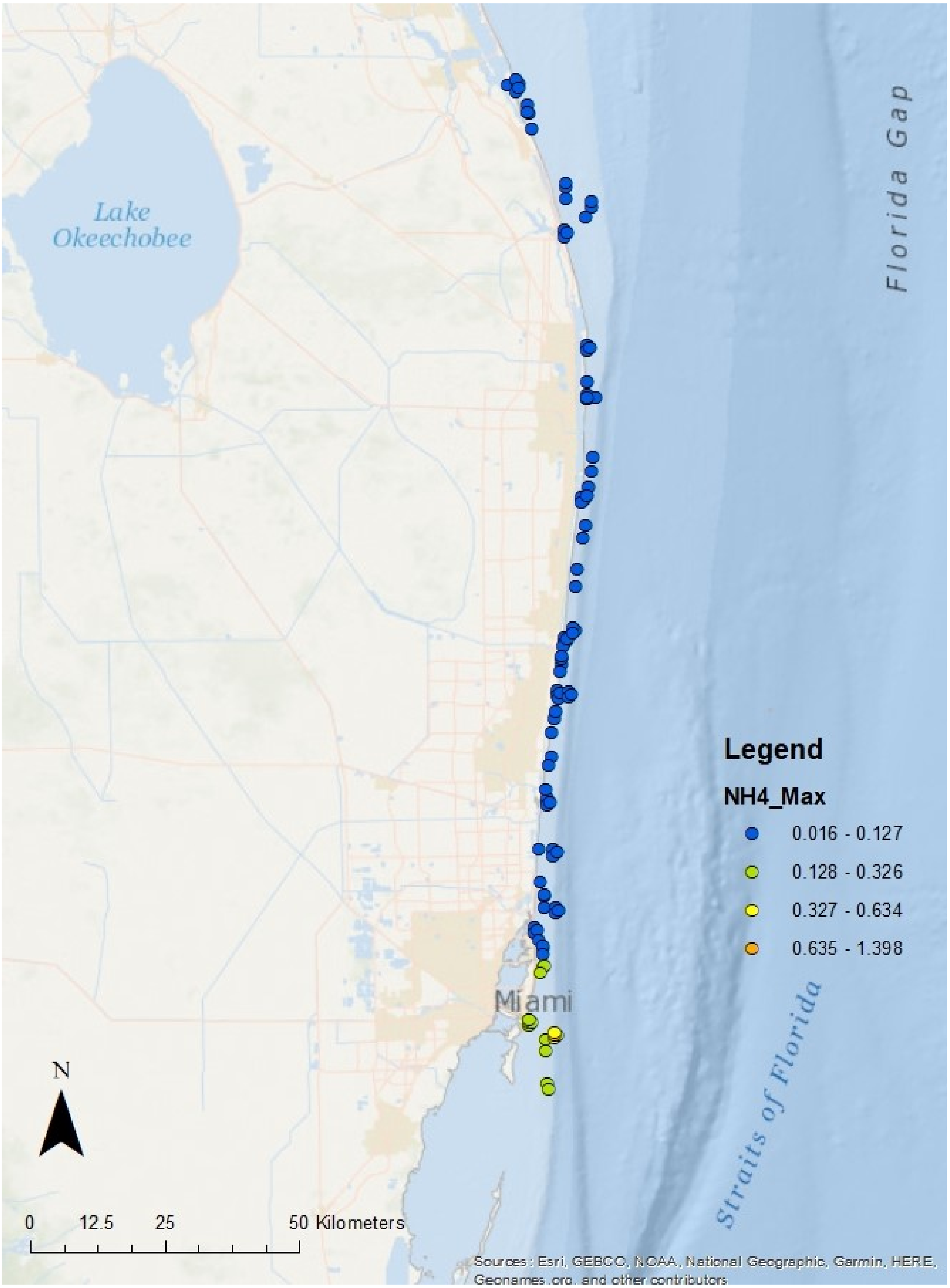

Figure 29: Maximum surface ammonium concentrations by site. Units are mg-N/L.

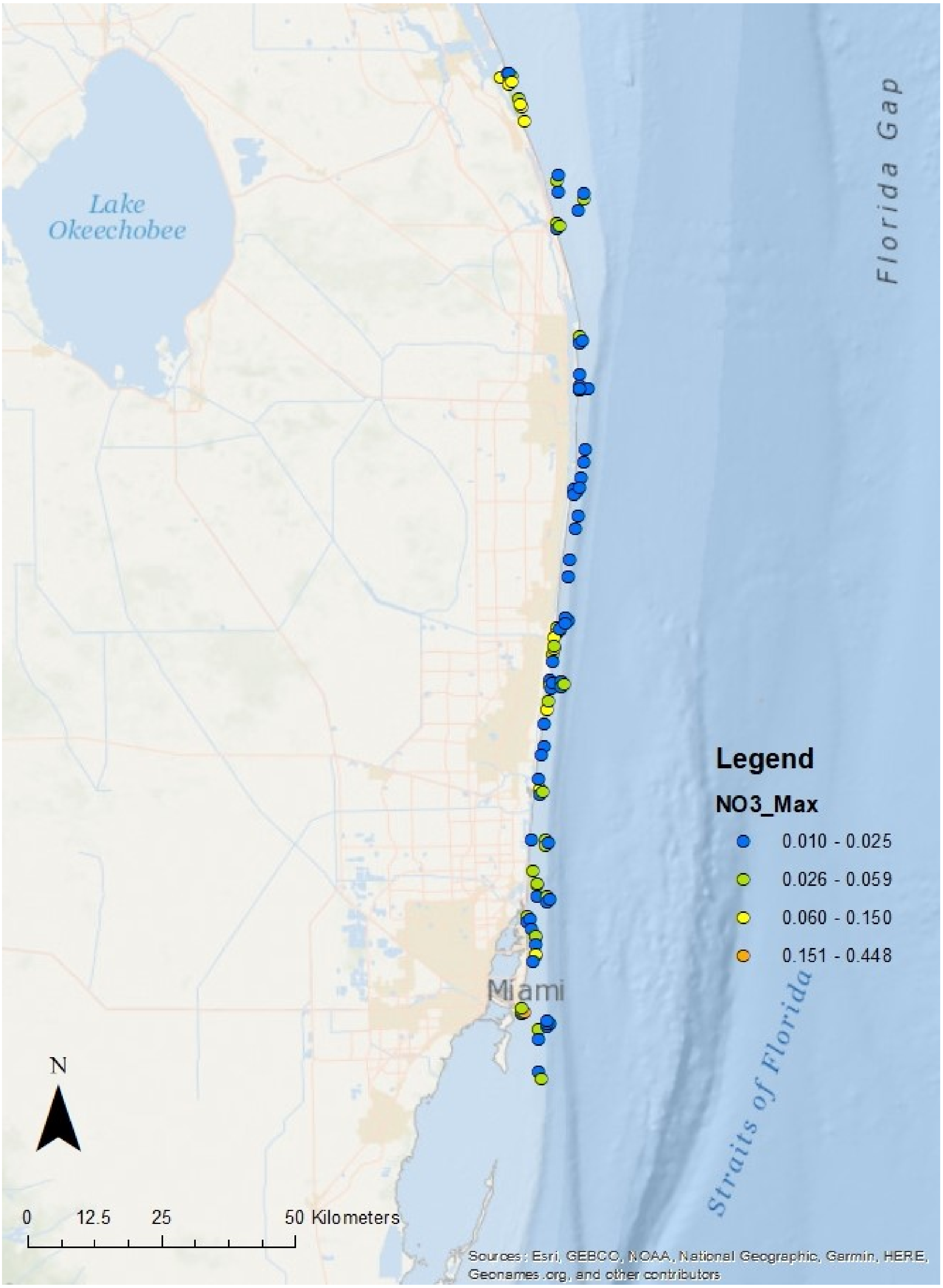

Figure 30: Maximum surface nitrate concentrations by site. Units are mg-N/L.

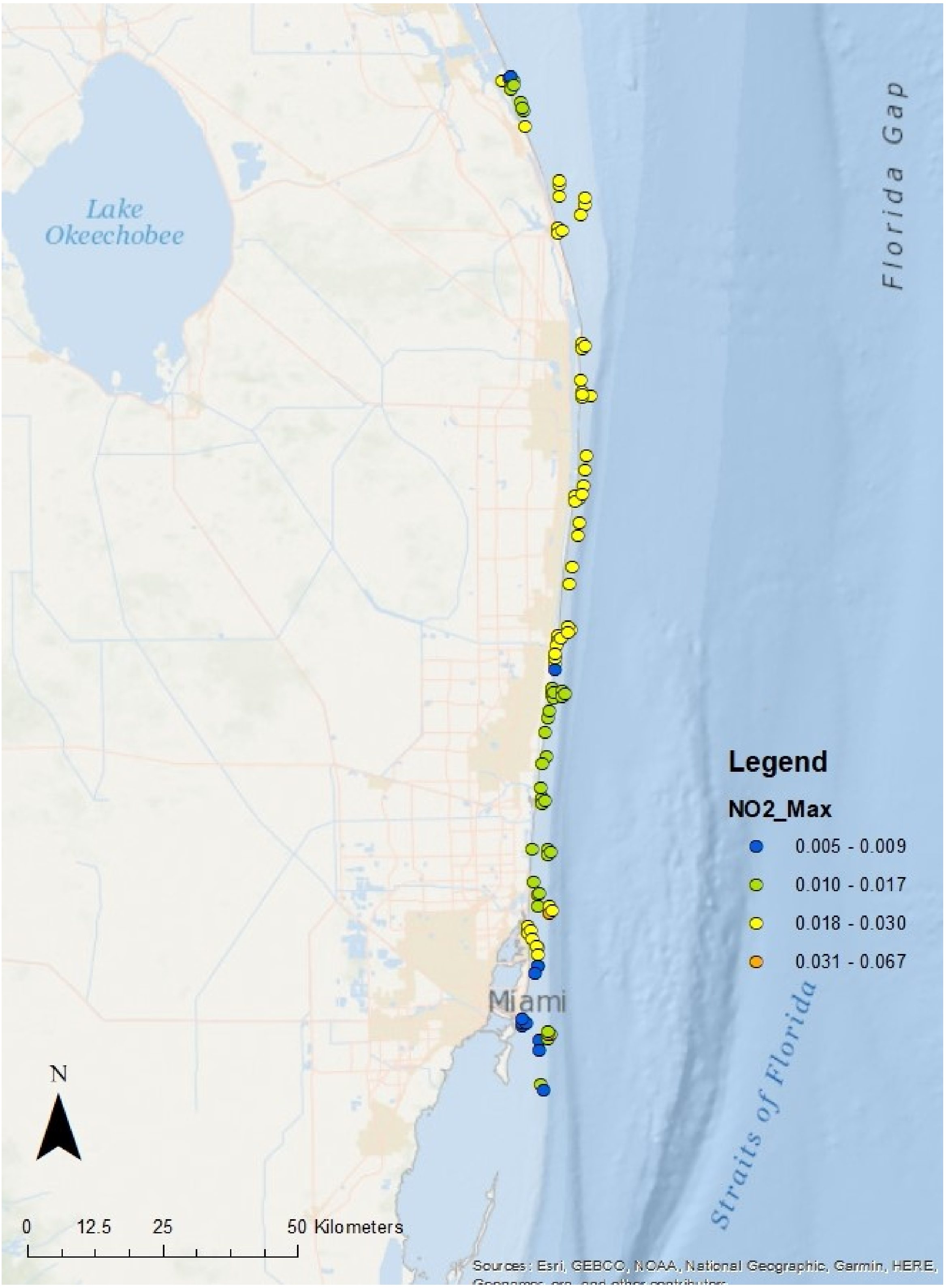

Figure 31: Maximum surface nitrite concentrations by site. Units are mg-N/L.

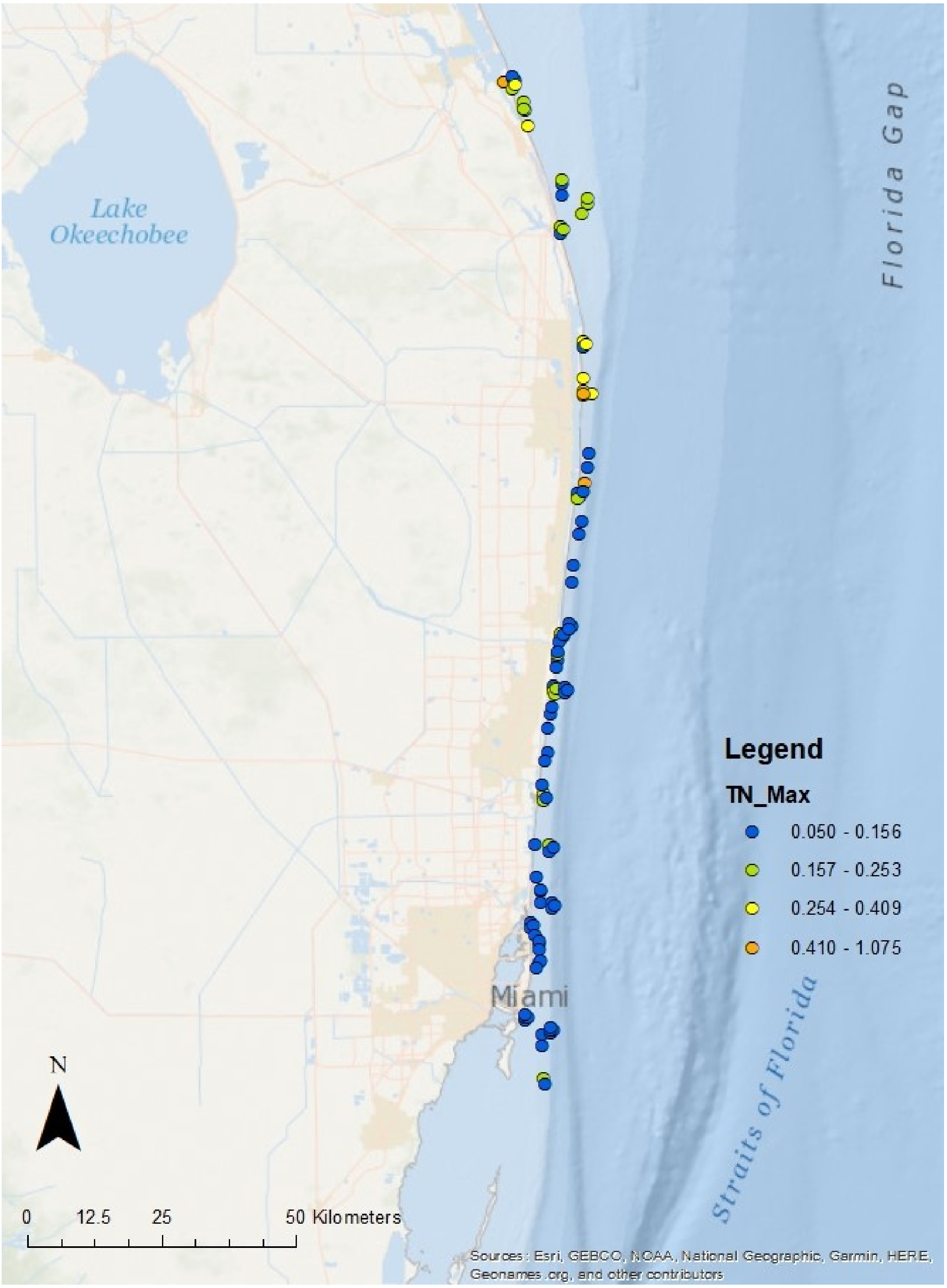

Figure 32: Maximum surface total nitrogen concentrations by site. Units are mg-N/L. Note that for all sites except STL and GOC, total nitrogen was calculated by summing TKN, nitrate and nitrite.

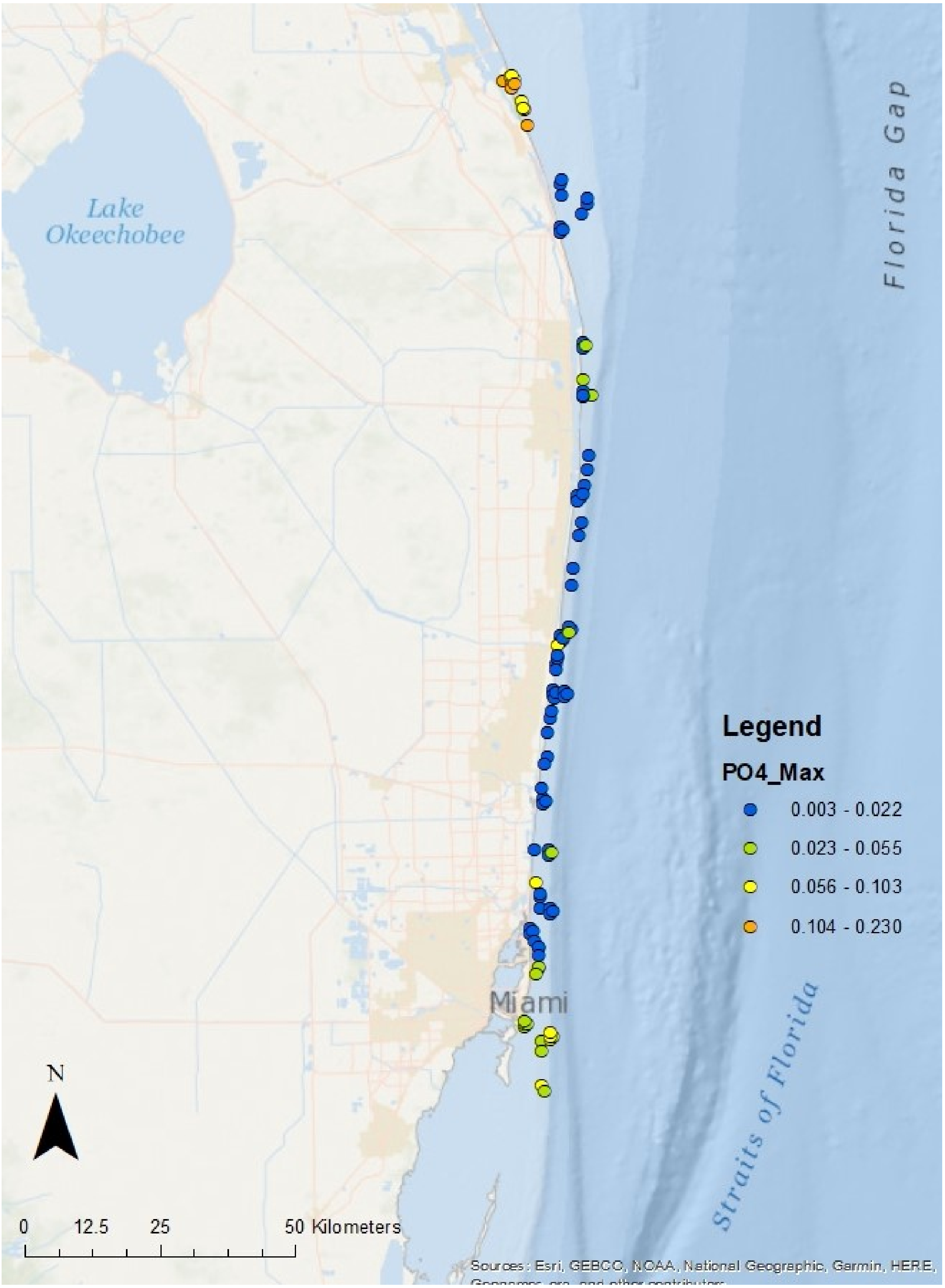

Figure 33: Maximum surface orthophosphate concentrations by site. Units are mg-P/L.

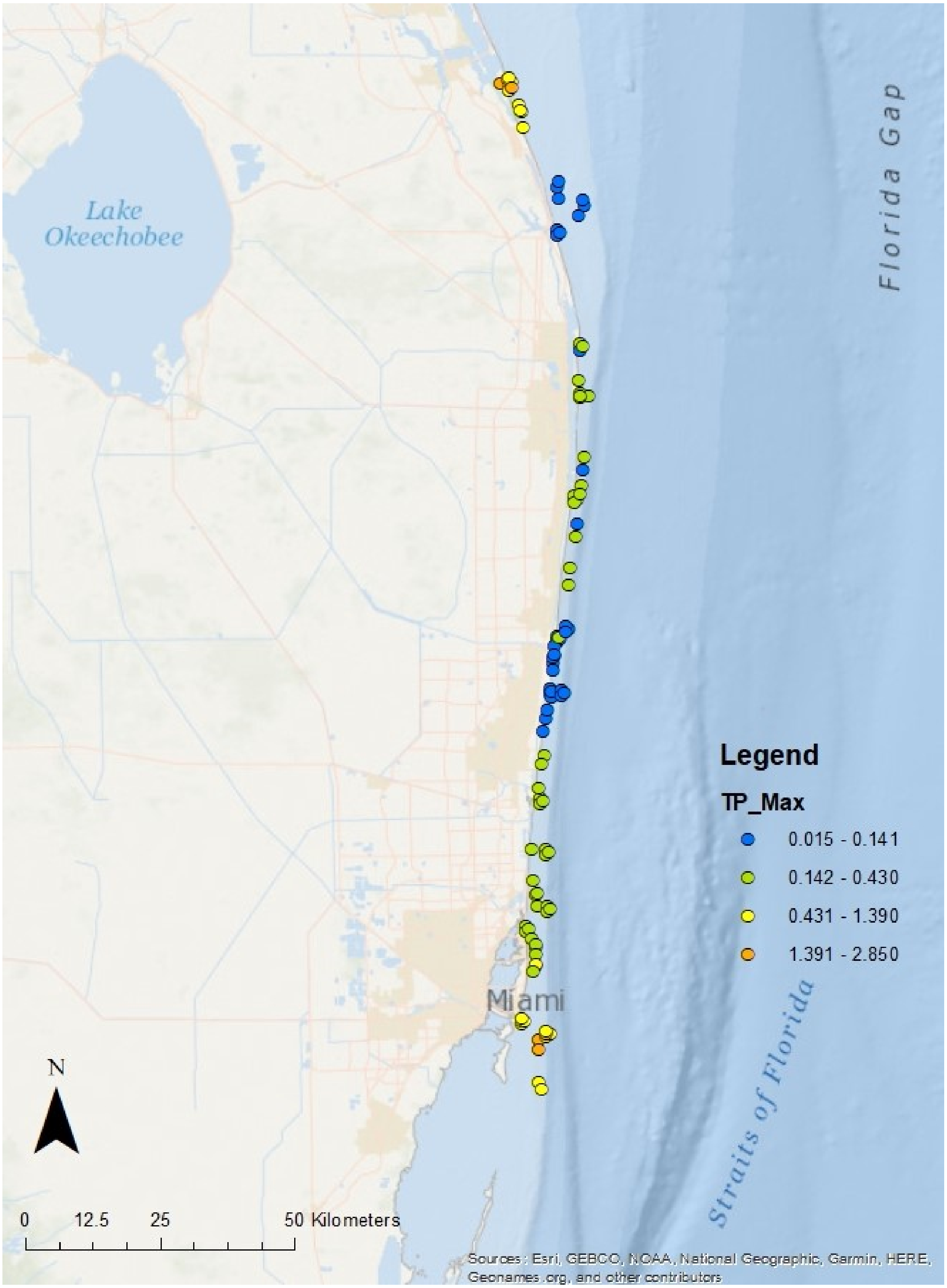

Figure 34: Maximum surface total phosphorus concentrations by site. Units are mg-P/L.

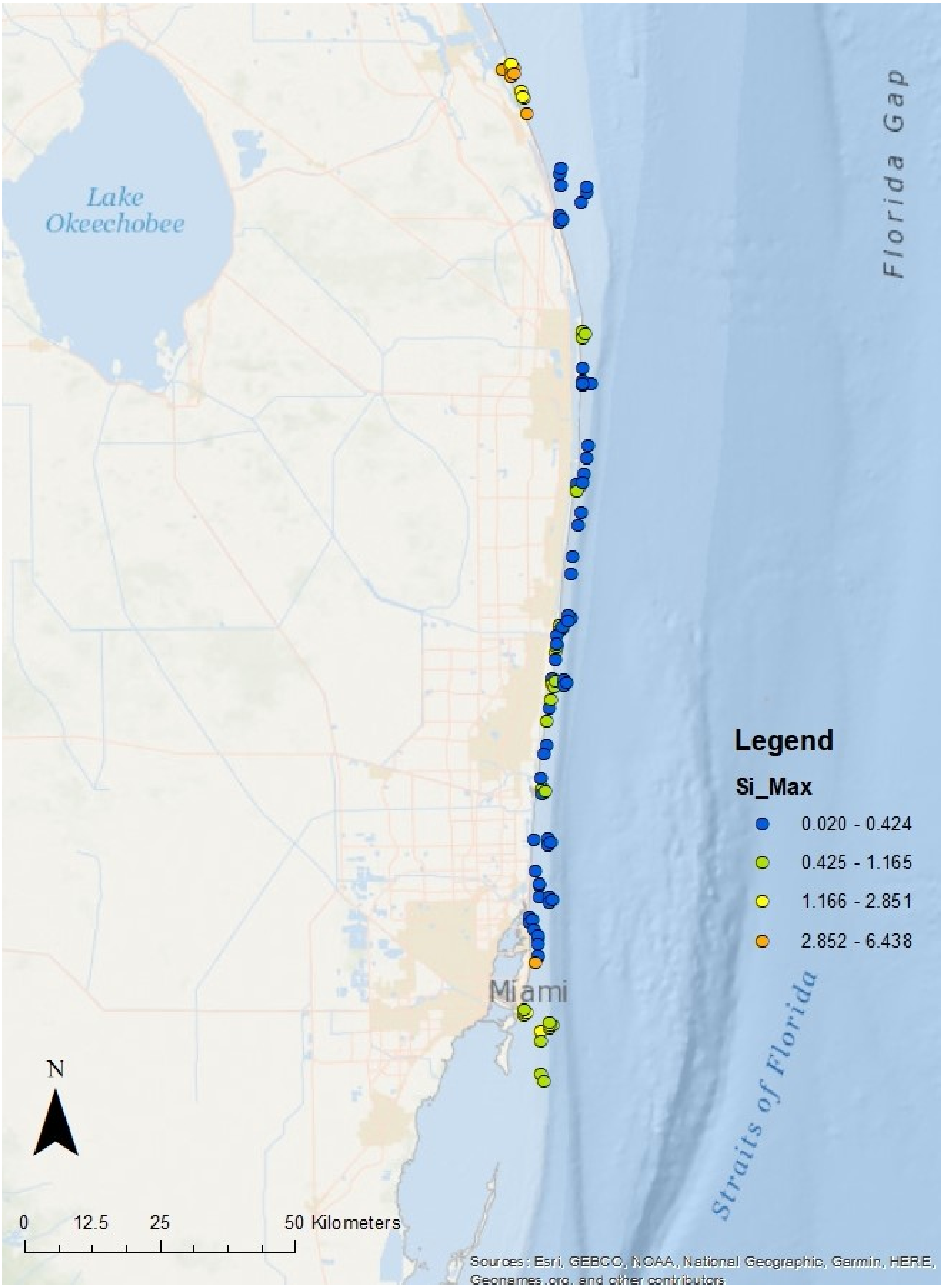

Figure 35: Maximum surface silica concentrations by site. Units are mg-Si/L.

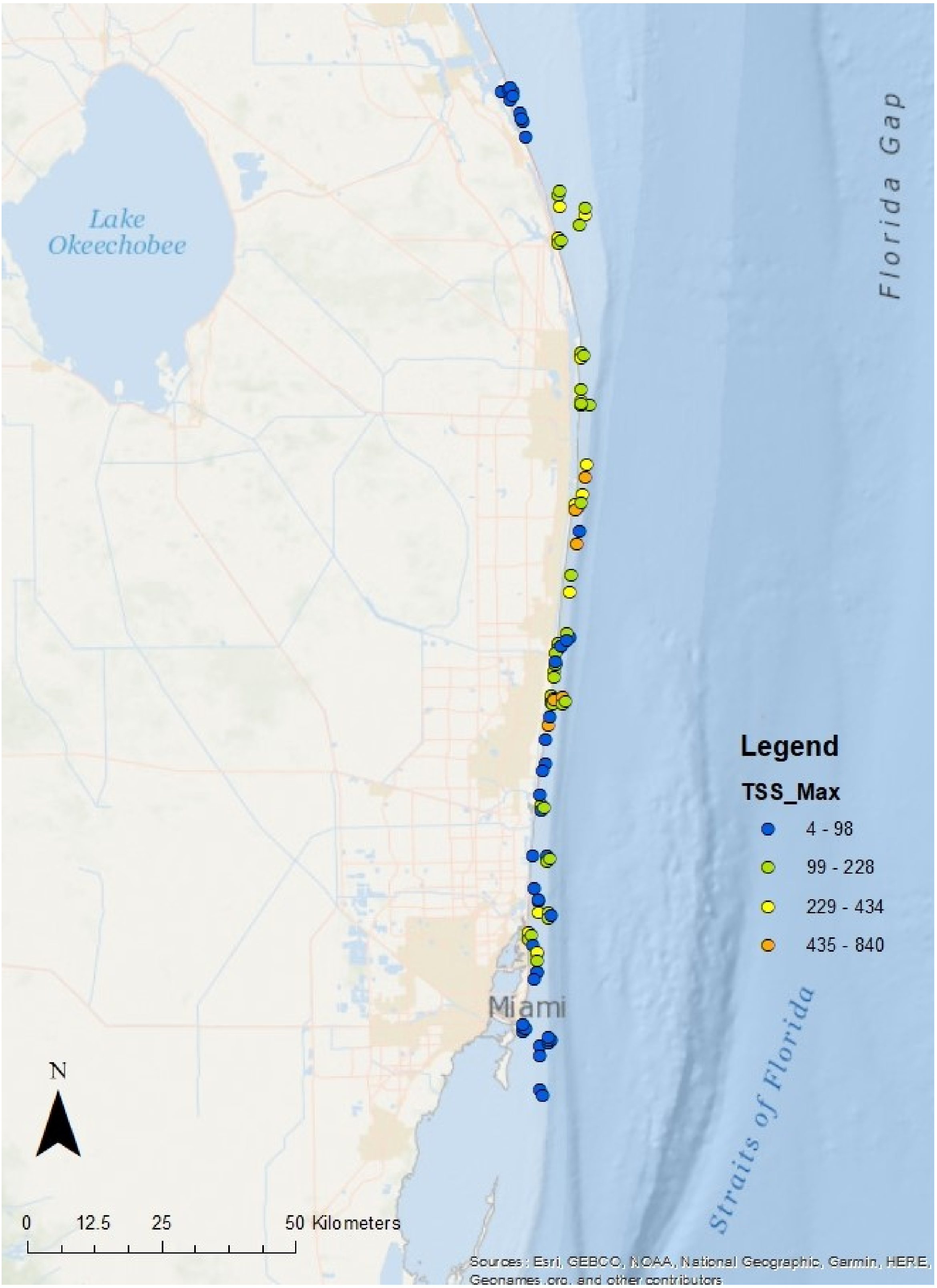

Figure 36: Maximum surface total suspended solids concentrations by site. Units are mg/L.

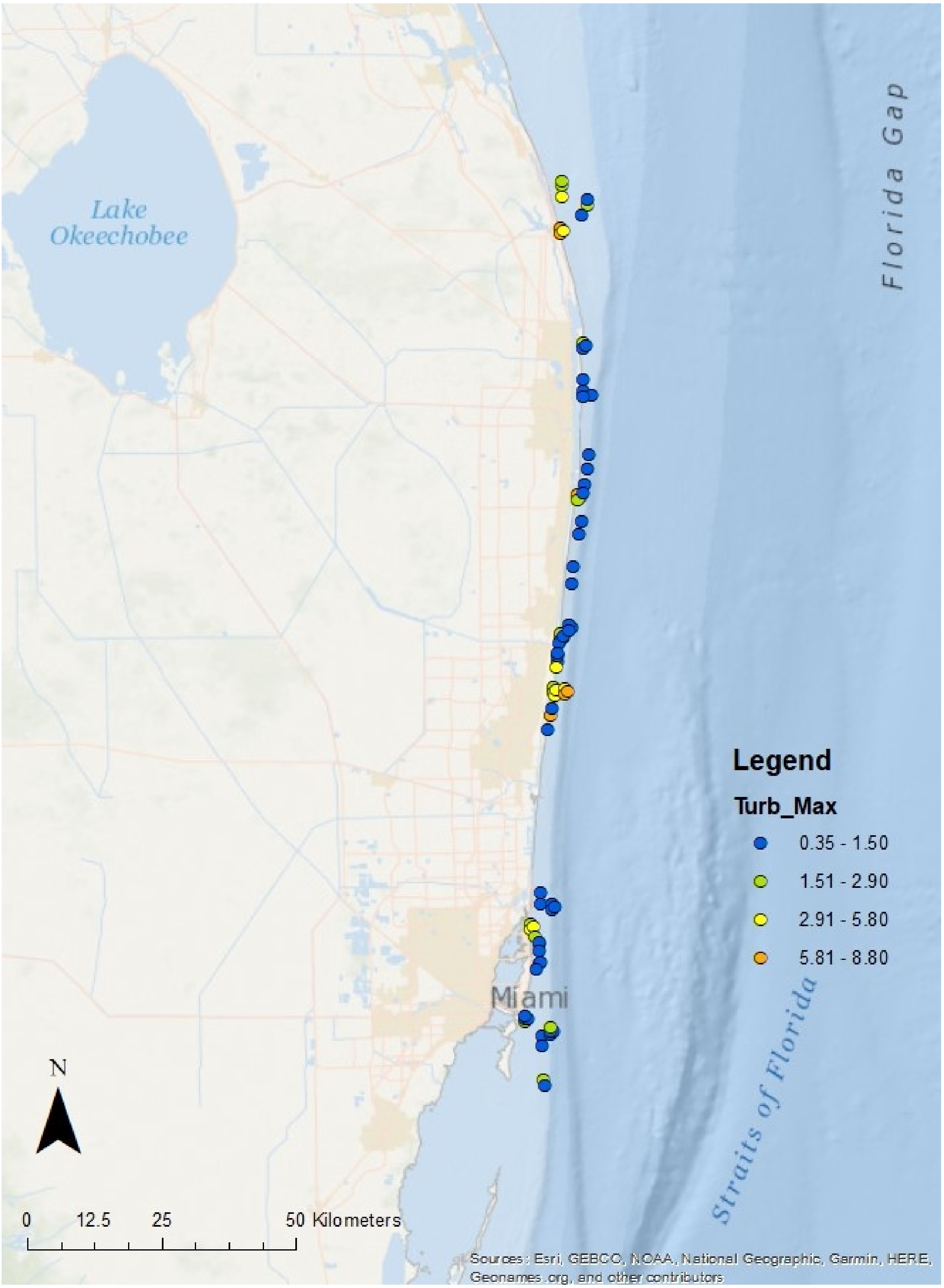

Figure 37: Maximum surface turbidity by site. Units are NTU. Note that turbidity was not measured at STL and GOC.

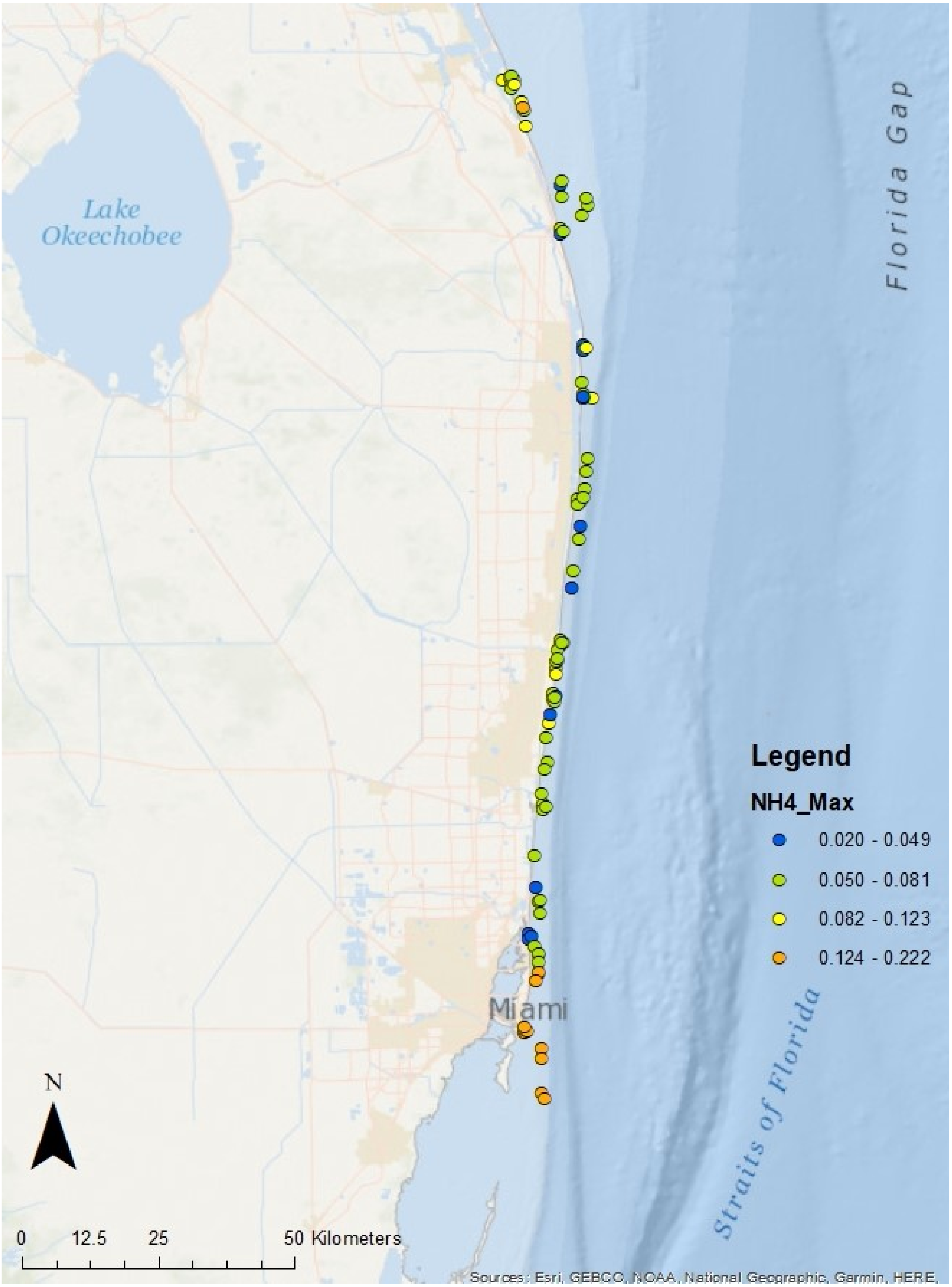

Figure 38: Maximum bottom ammonium concentrations by site. Units are mg-N/L.

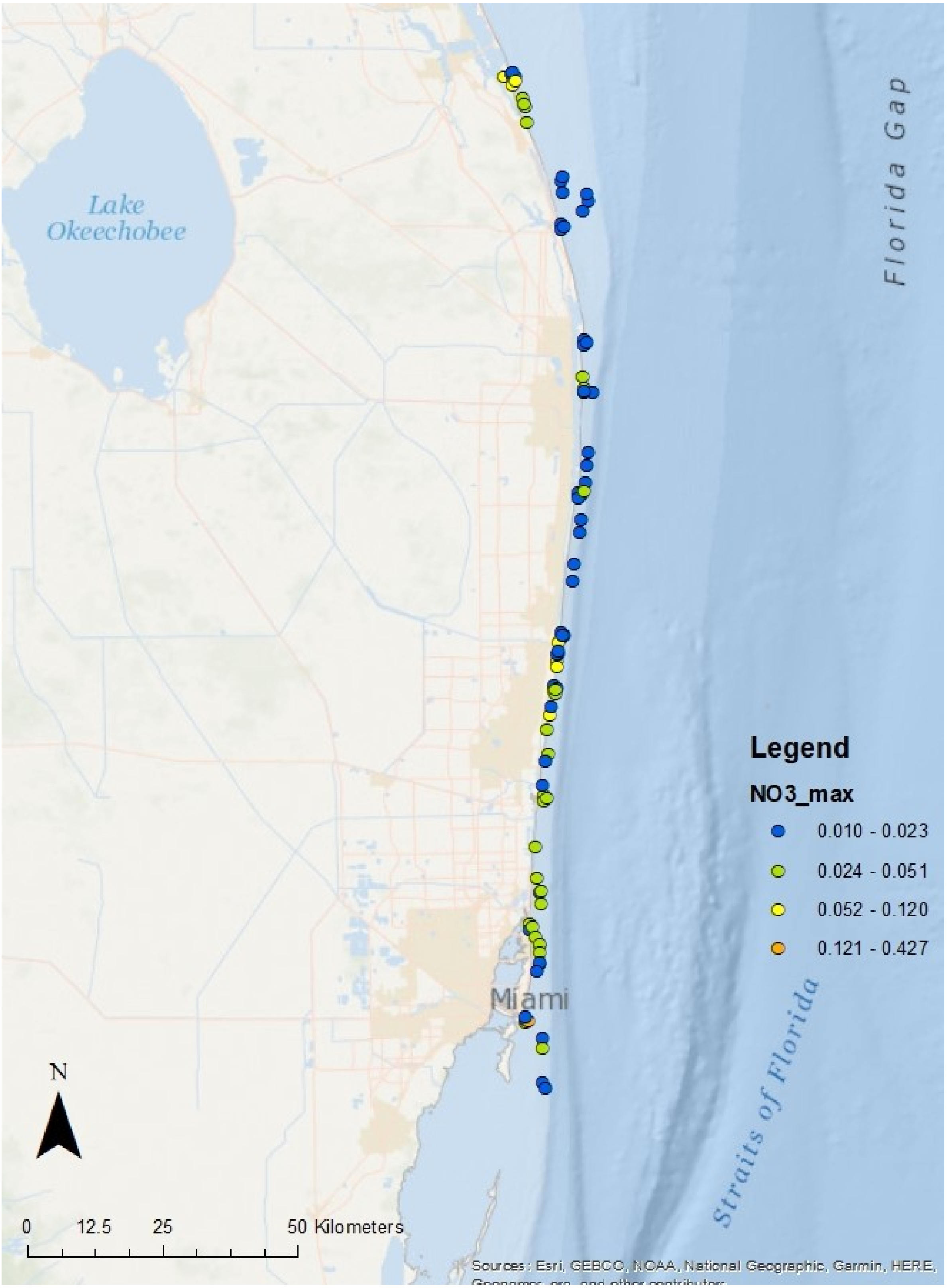

Figure 39: Maximum bottom nitrate concentrations by site. Units are mg-N/L.

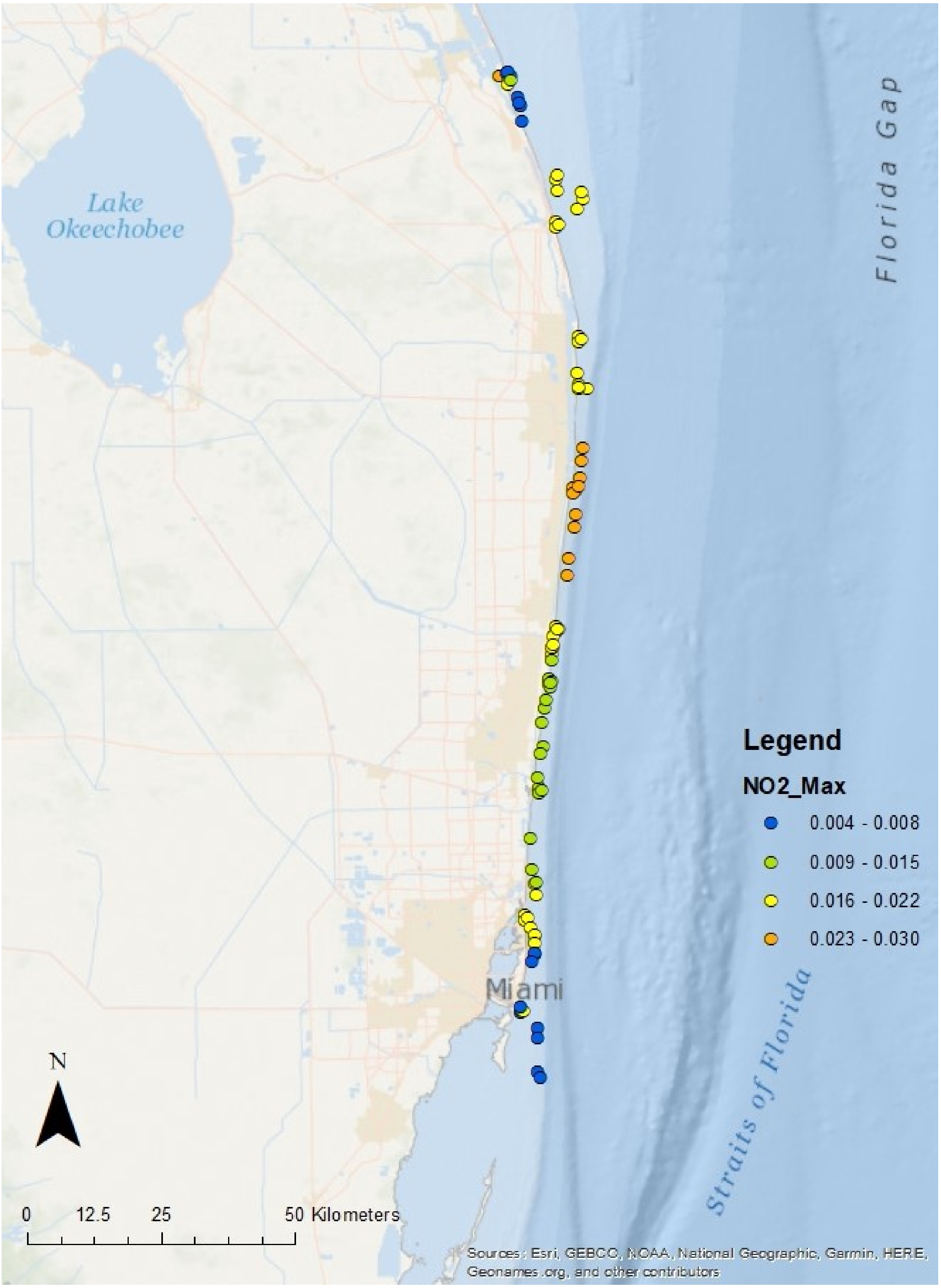

Figure 40: Maximum bottom nitrite concentrations by site. Units are mg-N/L.

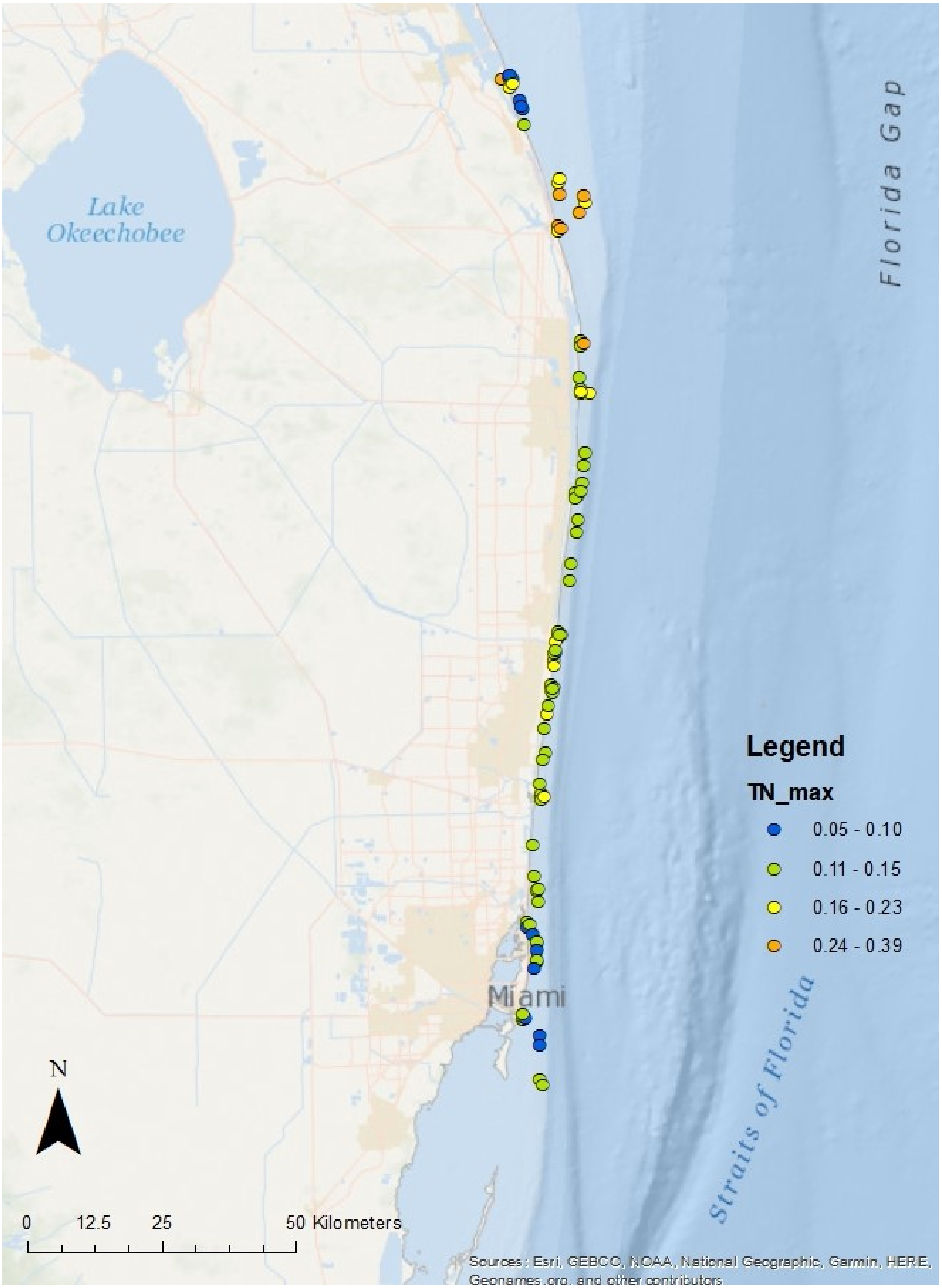

Figure 41: Maximum bottom total nitrogen concentrations by site. Units are mg-N/L. Note that for all sites except STL and GOC, total nitrogen was calculated by summing TKN, nitrate and nitrite.

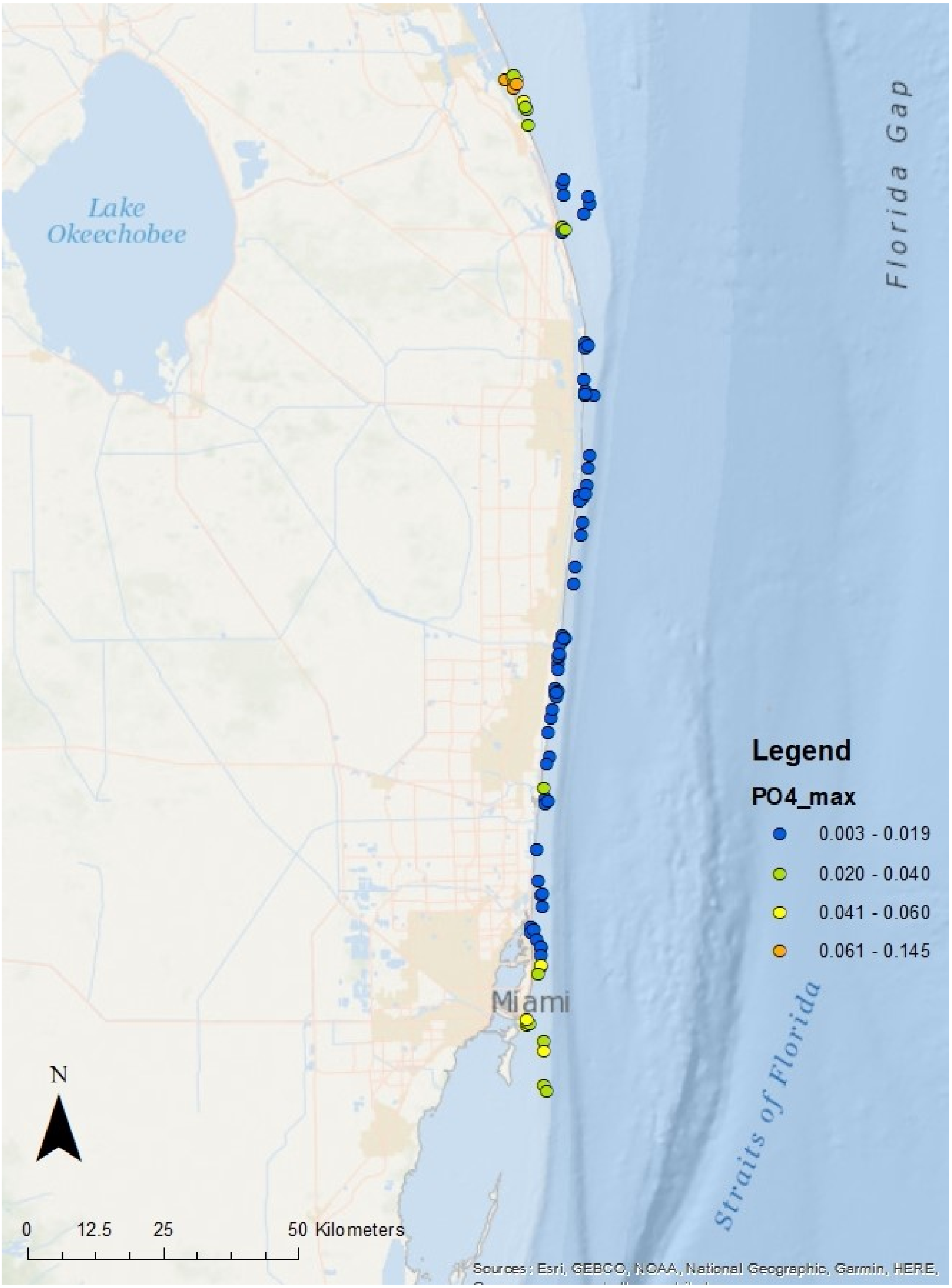

Figure 42: Maximum bottom orthophosphate concentrations by site. Units are mg-P/L.

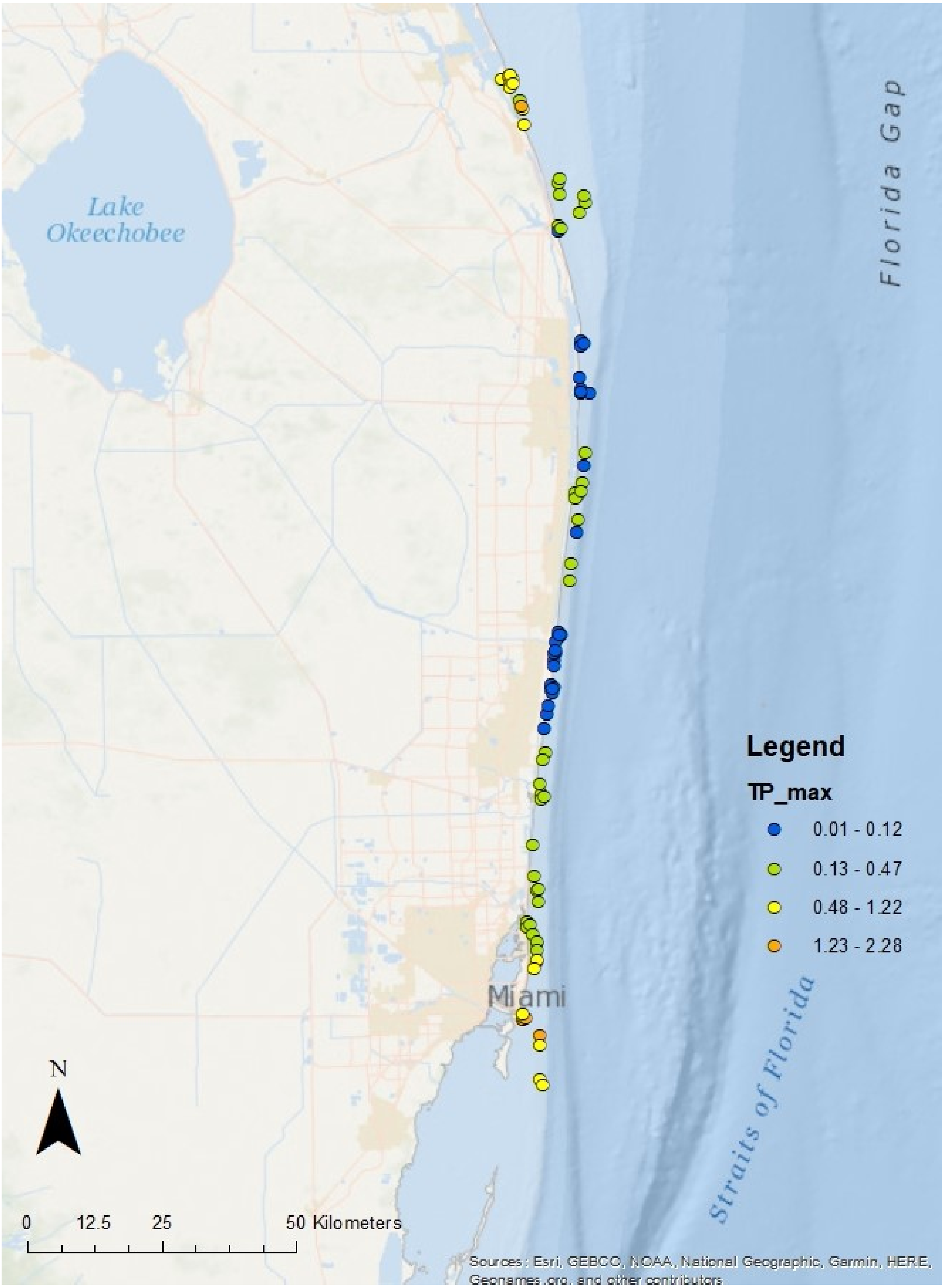

Figure 43: Maximum bottom total phosphorus concentrations by site. Units are mg-P/L.

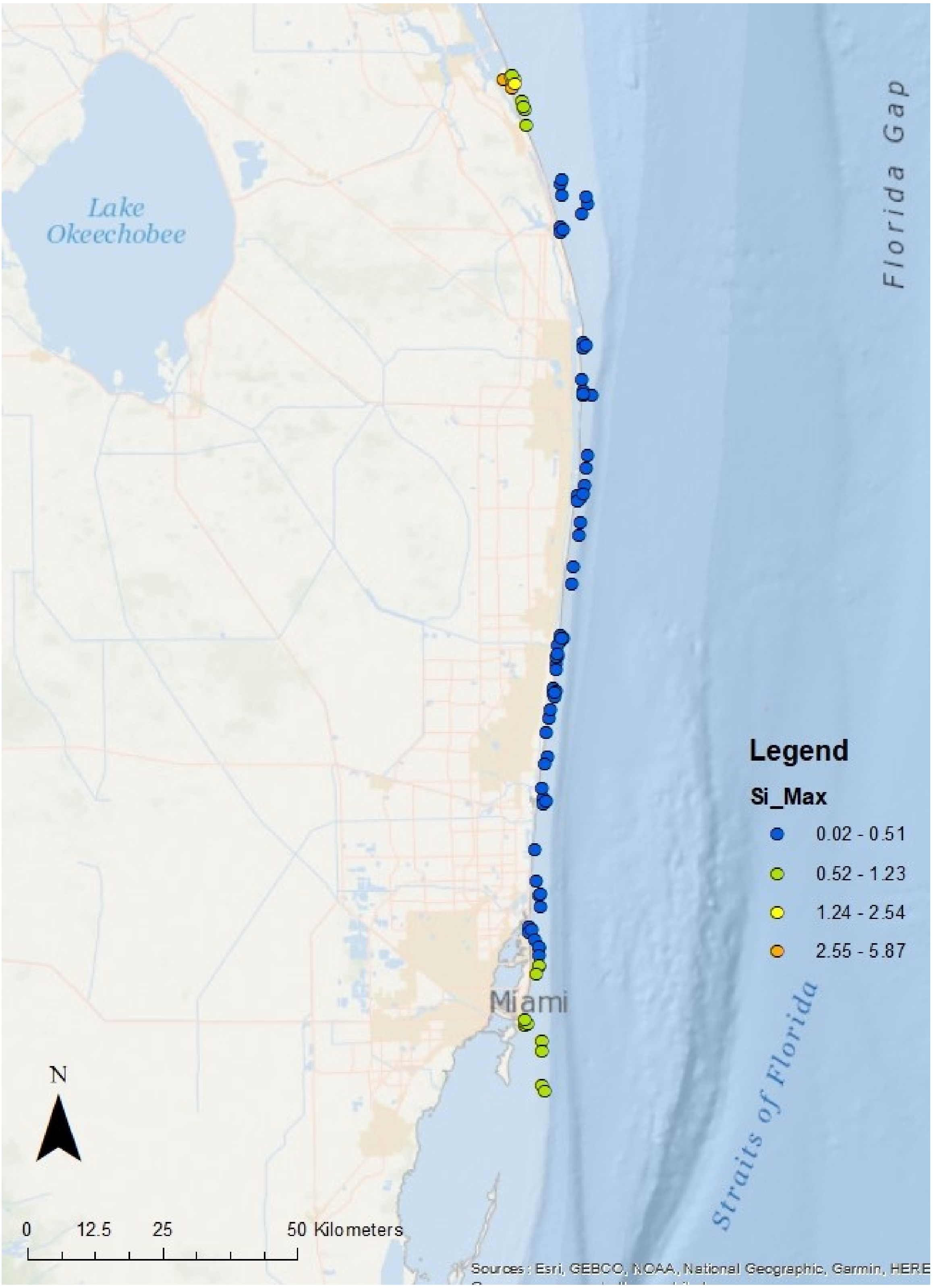

Figure 44: Maximum bottom silica concentrations by site. Units are mg-Si/L.

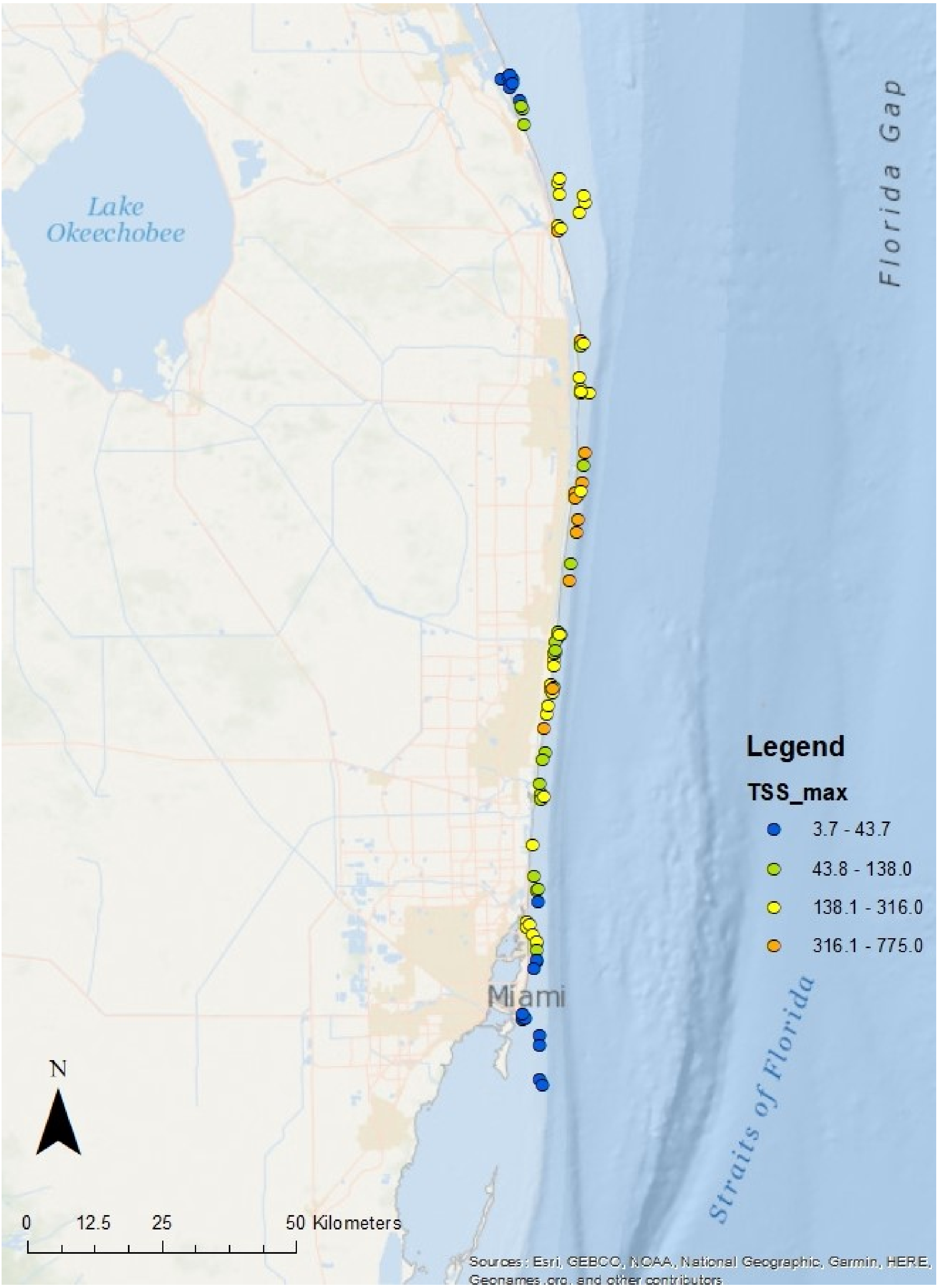

Figure 45: Maximum bottom total suspended solids concentrations by site. Units are mg/L.

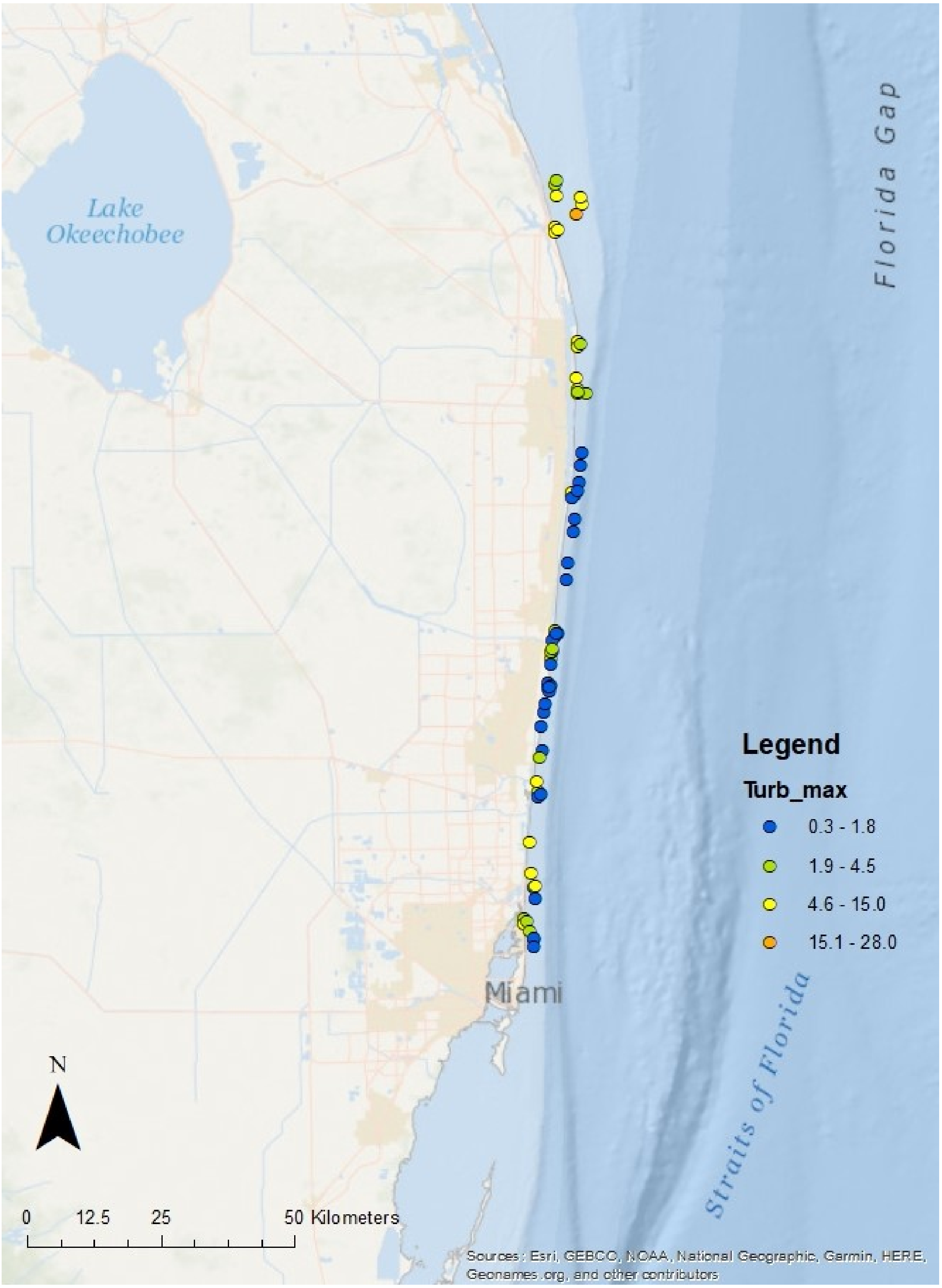

Figure 46: Maximum bottom turbidity by site. Units are NTU. Note that turbidity was not measured at STL and GOC.

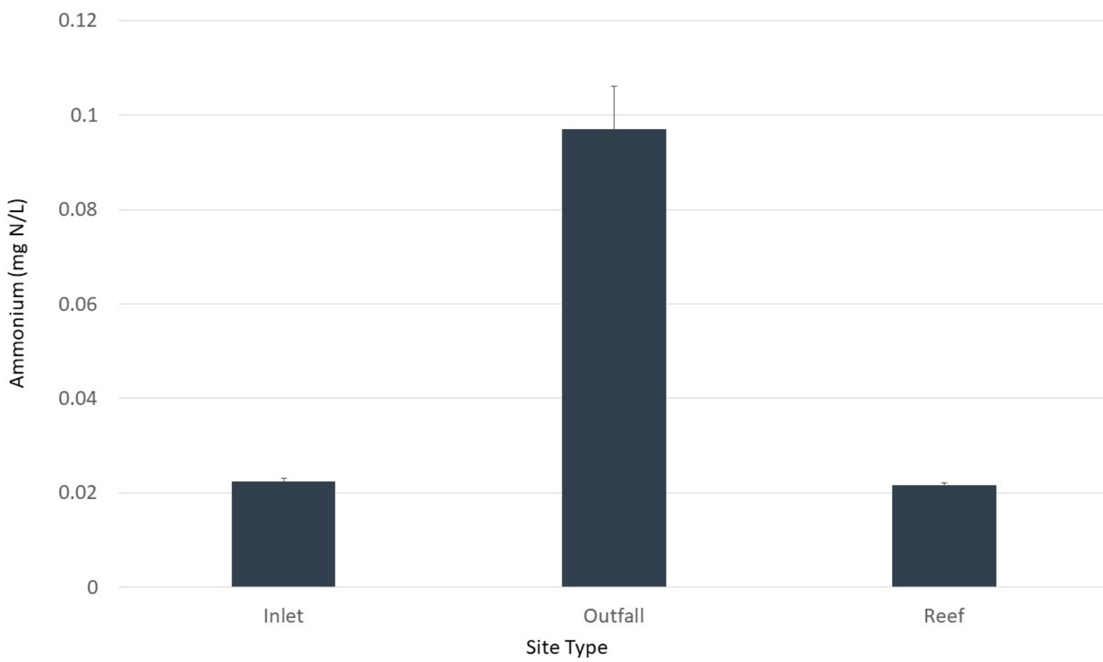

Figure 47: Mean ammonium concentrations by site type (inlet, outfall, reef). Units are mg-N/L. Error bars denote standard error. Outfalls sites are statistically higher than inlet or reef sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

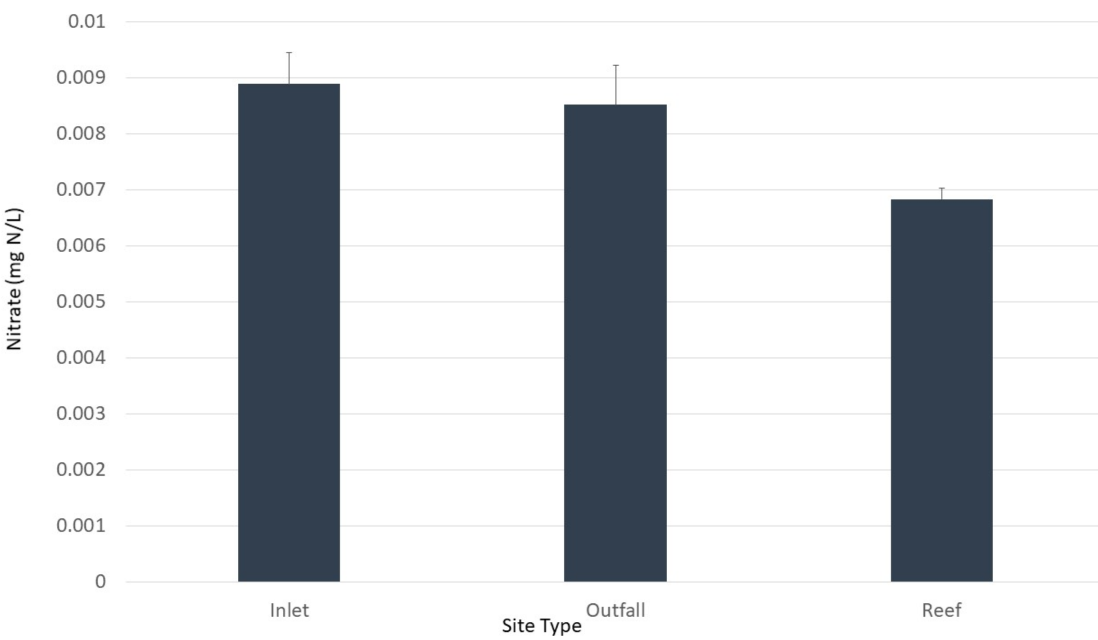

Figure 48: Mean nitrate concentrations by site type (inlet, outfall, reef). Units are mg-N/L. Error bars denote standard error. Inlet sites are statistically higher than reef sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

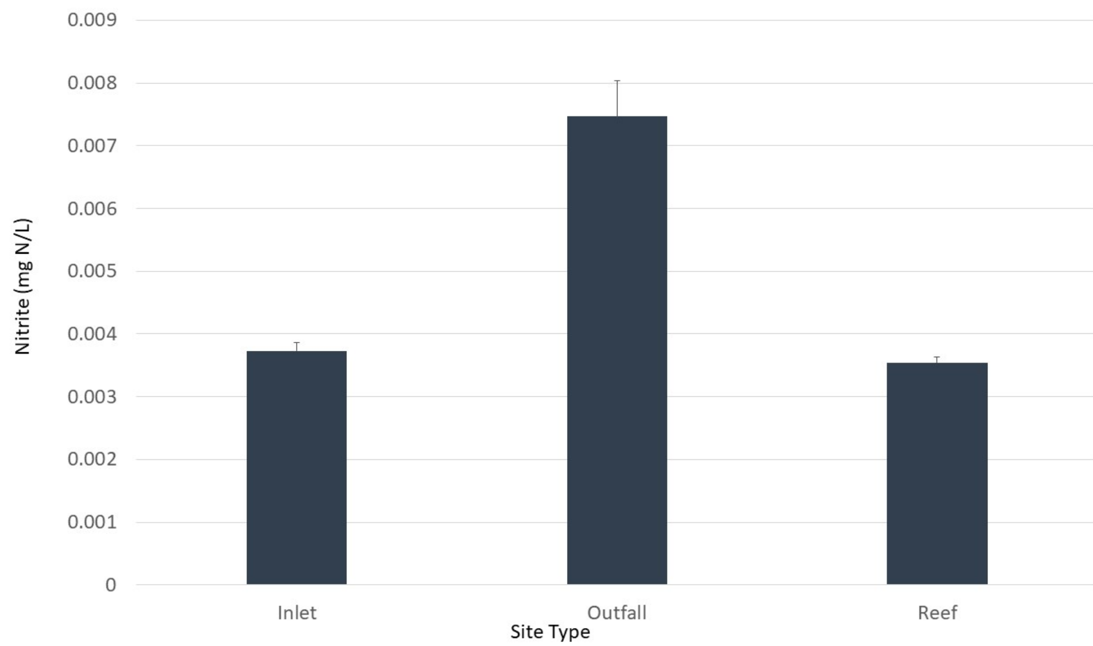

Figure 49: Mean nitrite concentrations by site type (inlet, outfall, reef). Units are mg-N/L. Error bars denote standard error. Outfalls sites are statistically higher than inlet or reef sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

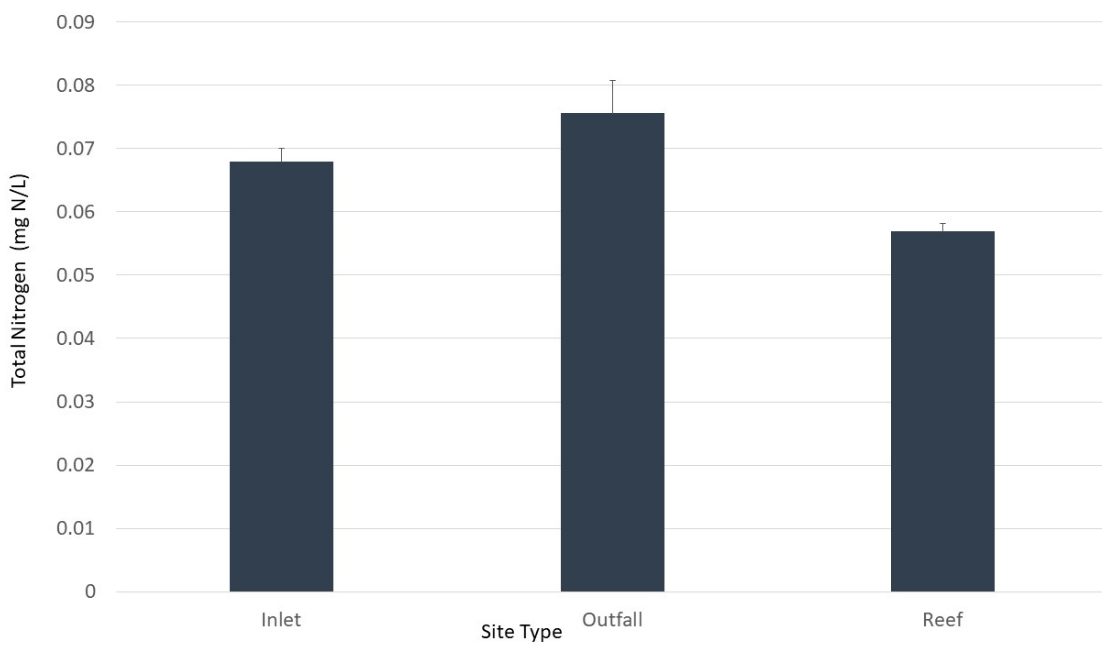

Figure 50: Mean total nitrogen concentrations by site type (inlet, outfall, reef). Units are mg-N/L. Note that for all sites except STL and GOC, total nitrogen was calculated by summing TKN, nitrate and nitrite. Error bars denote standard error. Outfalls and inlet sites are statistically higher than reef sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

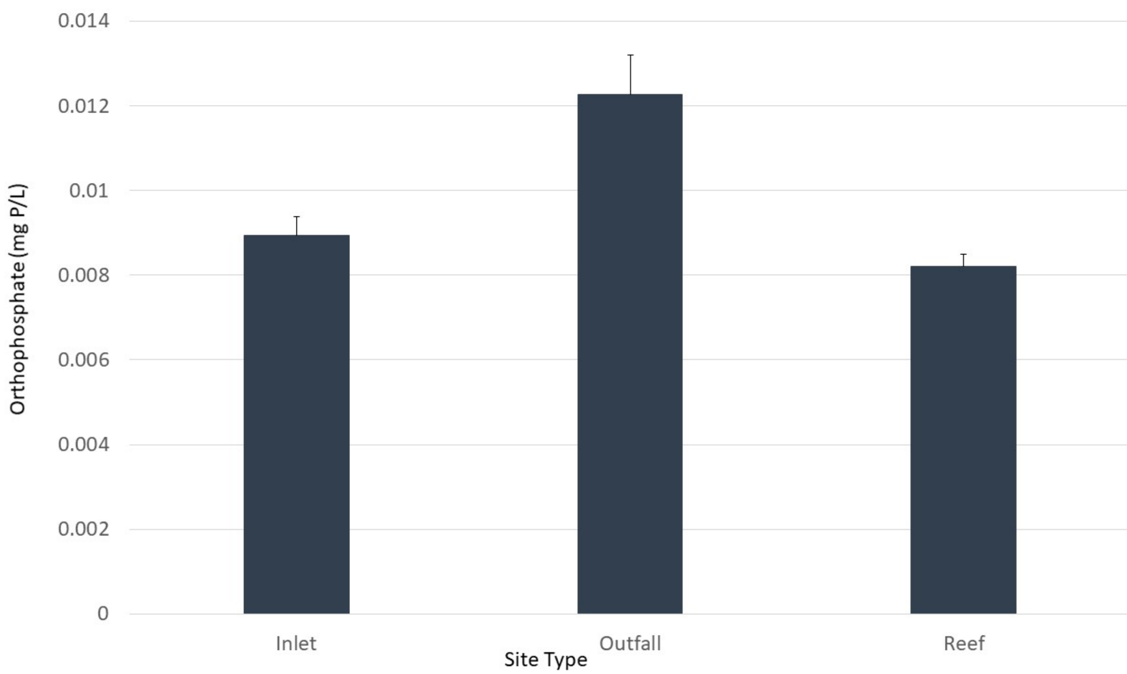

Figure 51: Mean orthophosphate concentrations by site type (inlet, outfall, reef). Units are mg-P/L. Error bars denote standard error. Outfalls sites are statistically higher than inlet or reef sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

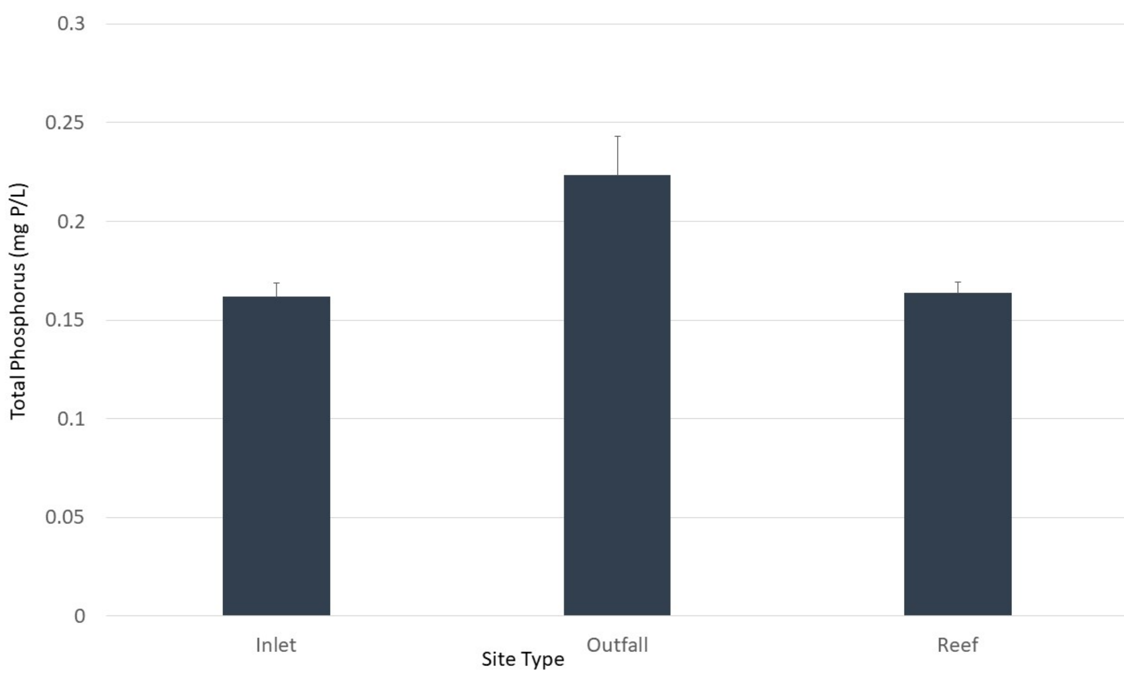

Figure 52: Mean total phosphorus concentrations by site type (inlet, outfall, reef). Units are mg-P/L. Error bars denote standard error. There were no statistically significant differences between site types (Wilcoxon with post-hoc Dunn's test, α=0.05).

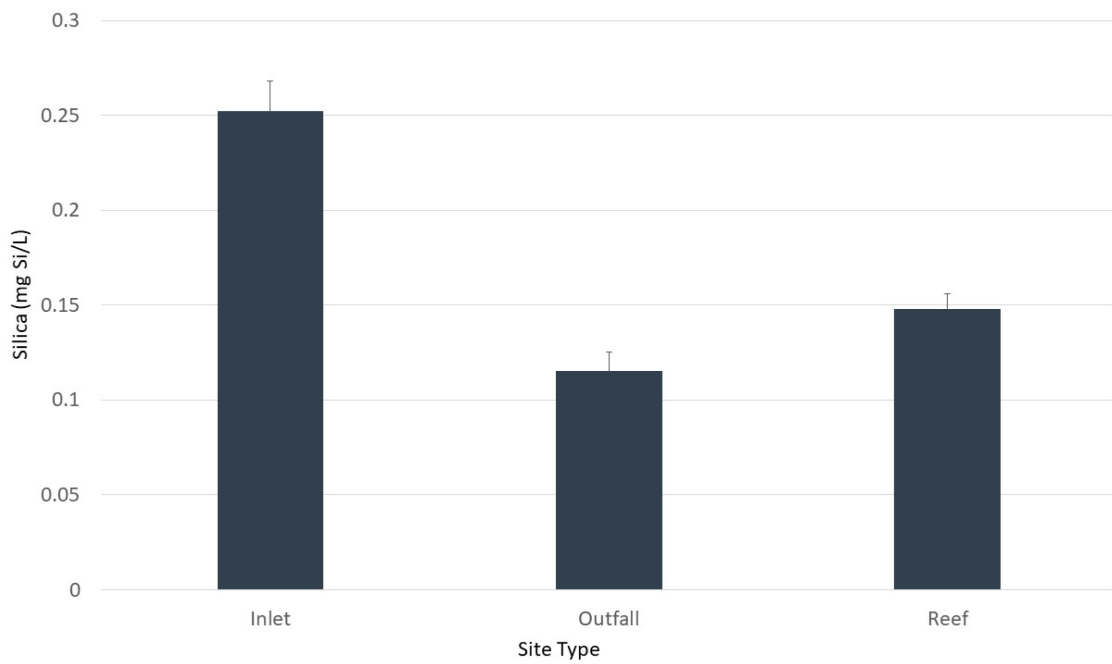

Figure 53: Mean silica concentrations by site type (inlet, outfall, reef). Units are mg-Si/L. Error bars denote standard error. Inlet sites are statistically higher than outfall or reef sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

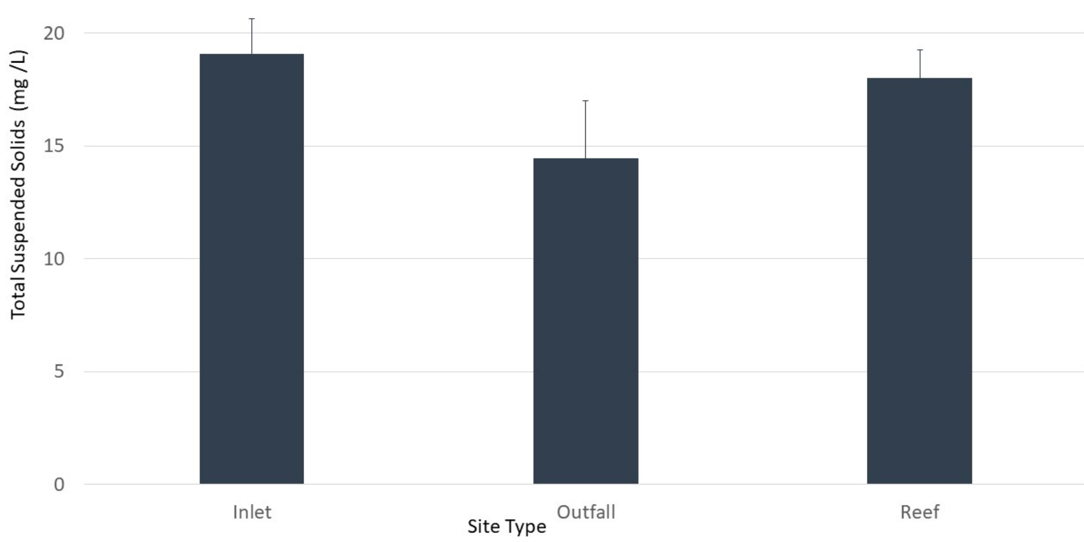

Figure 54: Mean total suspended solids concentrations by site type (inlet, outfall, reef). Units are mg/L. Error bars denote standard error. Inlet sites are statistically higher than outfall or reef sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

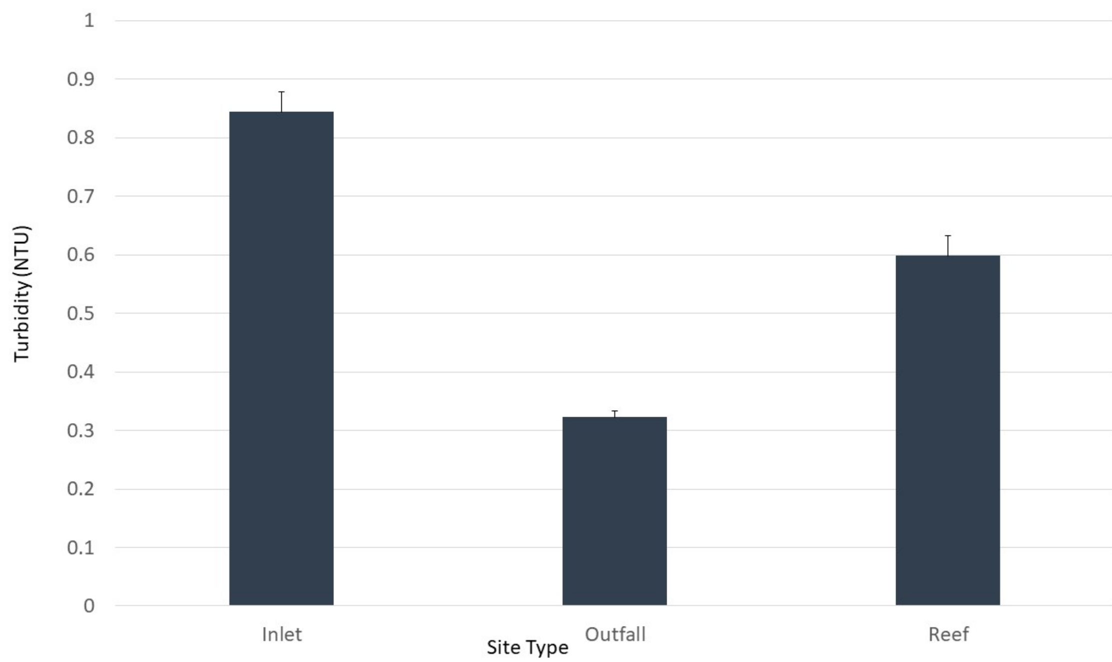

Figure 55: Mean turbidity by site type (inlet, outfall, reef). Units are NTU. Note that turbidity was not measured at STL and GOC. Error bars denote standard error. Inlet sites are statistically higher than outfall or reef sites, and reef sites are greater than outfall sites (Wilcoxon with post-hoc Dunn's test, α=0.05).

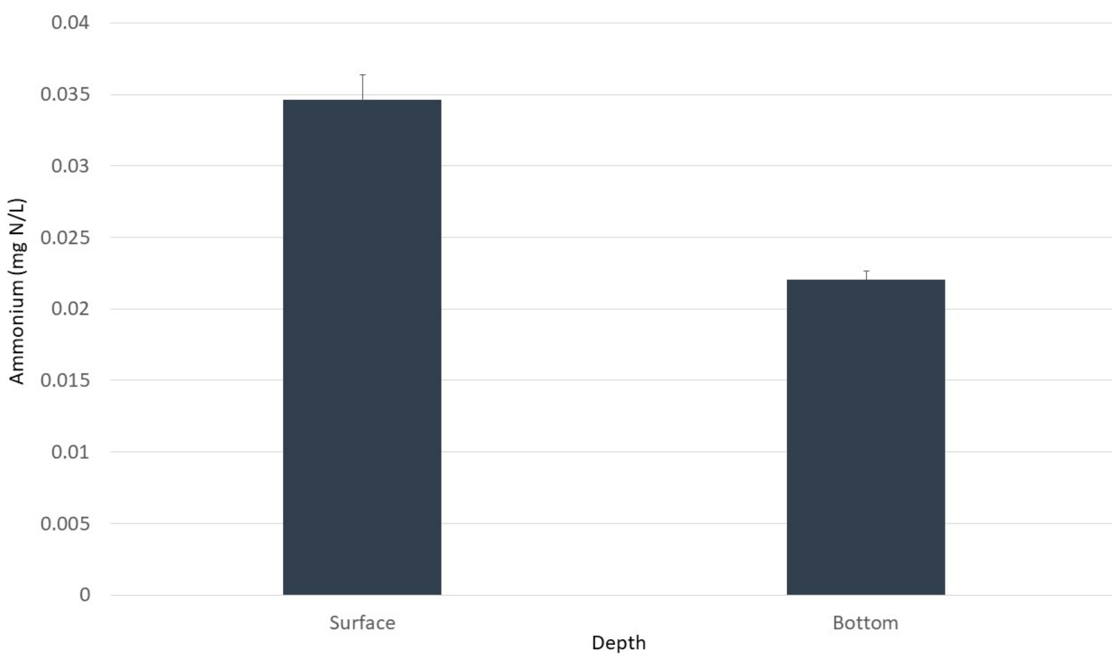

Figure 56: Mean ammonium concentrations at surface vs bottom across all sites. Units are mg-N/L. Error bars denote standard error. Surface is significantly greater than bottom (α=0.05, Wilcoxon test).

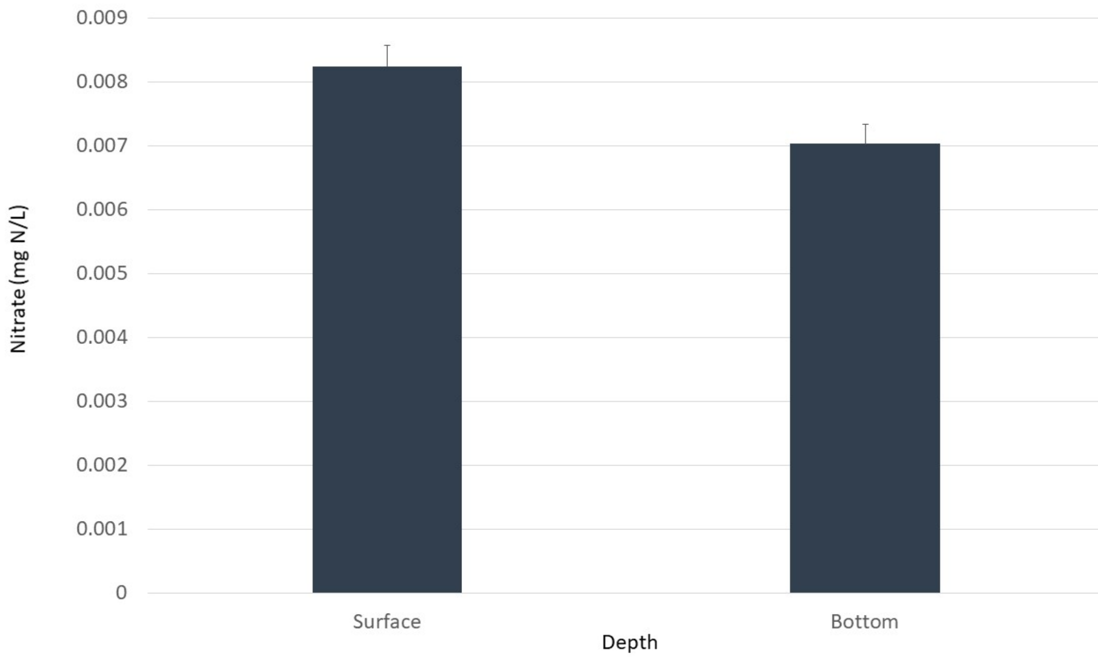

Figure 57: Mean nitrate concentrations at surface vs bottom across all sites. Units are mg-N/L. Error bars denote standard error. Surface is significantly greater than bottom (α=0.05 Wilcoxon test).

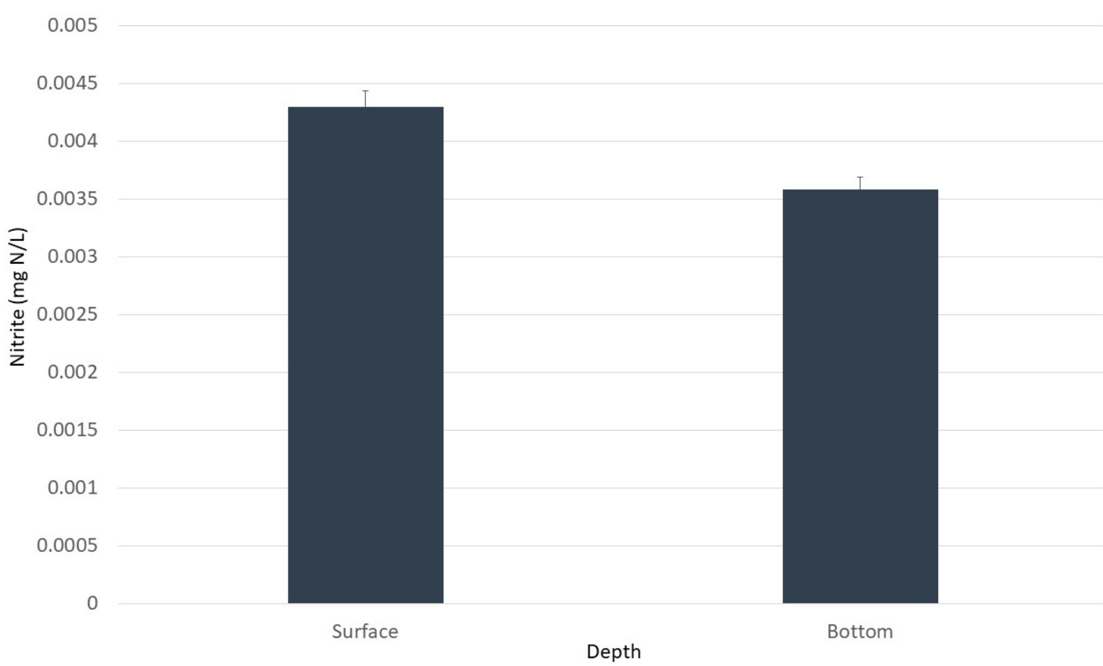

Figure 58: Mean nitrite concentrations at surface vs bottom across all sites. Units are mg-N/L. Error bars denote standard error. Surface is significantly greater than bottom (α=0.05 Wilcoxon test).

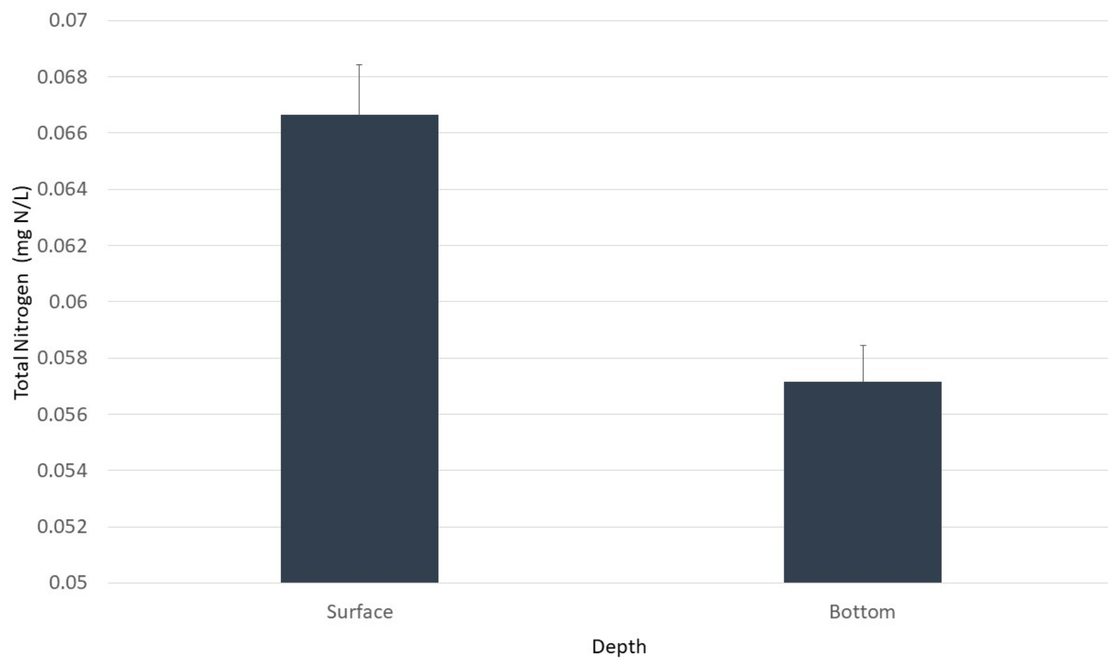

Figure 59: Mean total nitrogen concentrations at surface vs bottom across all sites. Units are mg-N/L. Error bars denote standard error. Surface is significantly greater than bottom (α=0.05, Wilcoxon test). Note that for all sites except STL and GOC, total nitrogen was calculated by summing TKN, nitrate and nitrite.

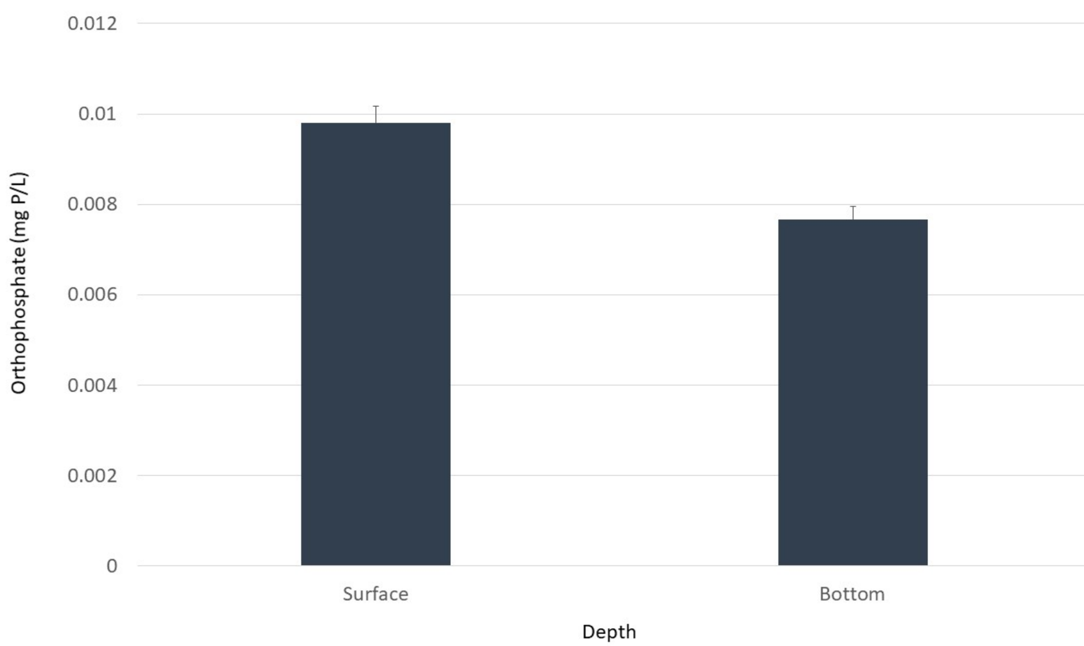

Figure 60: Mean orthophosphate concentrations at surface vs bottom across all sites. Units are mg-P/L. Error bars denote standard error. Surface is significantly greater than bottom (α=0.05 Wilcoxon test).

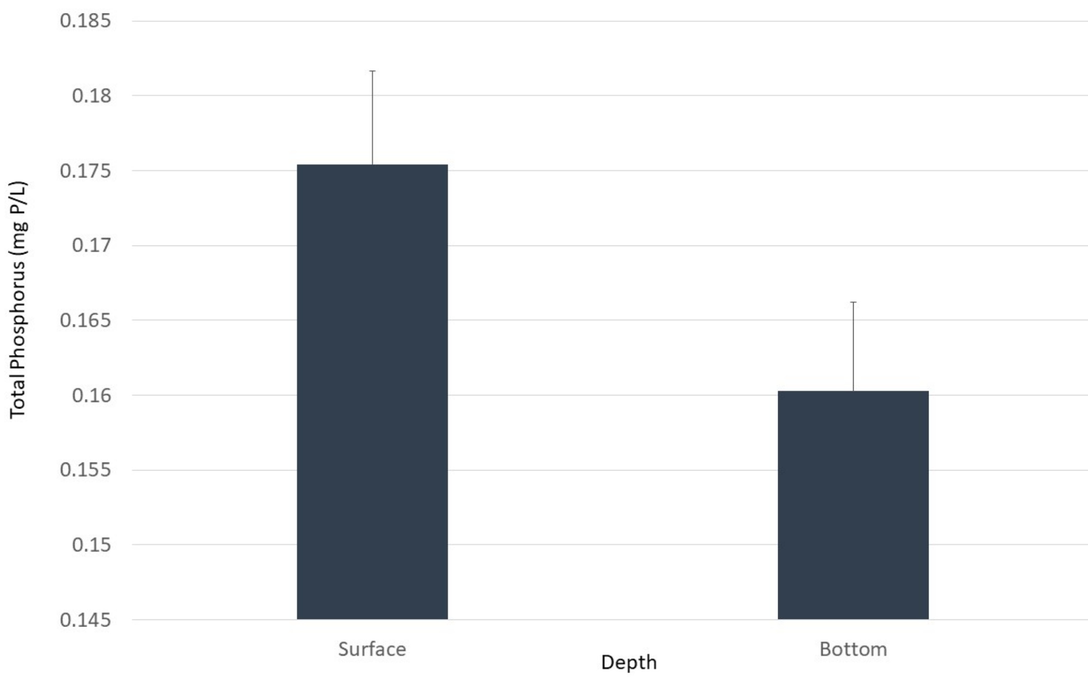

Figure 61: Mean total phosphorus concentrations at surface vs bottom across all sites. Units are mg-P/L. Error bars denote standard error. No significant difference between surface and bottom (Wilcoxon test, α=0.05)

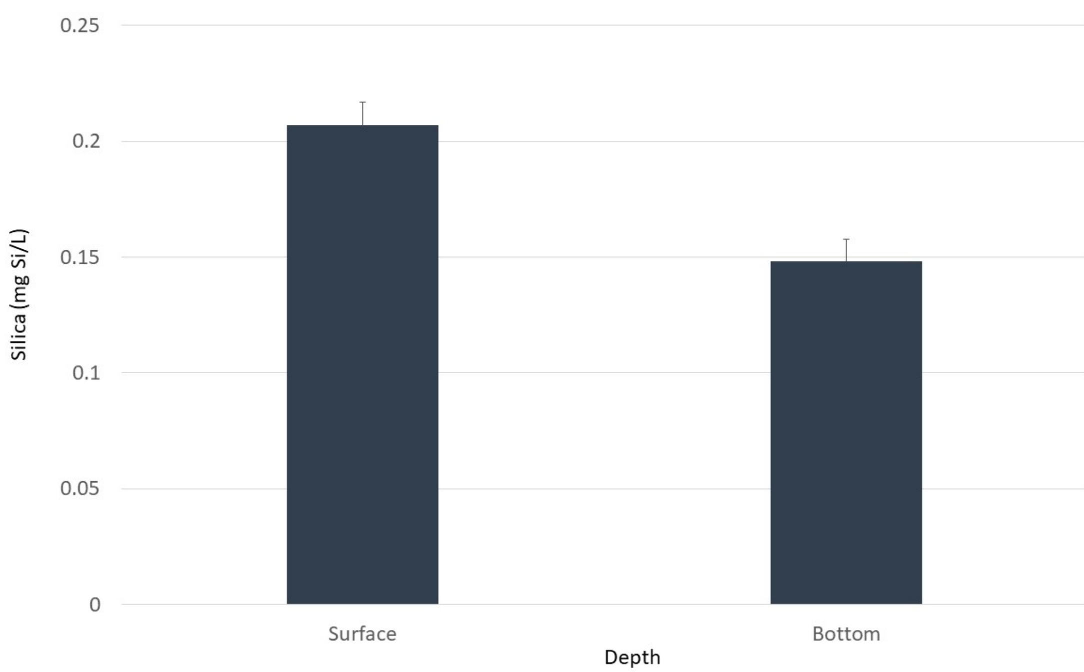

Figure 62: Mean silica concentrations at surface vs bottom across all sites. Units are mg-Si/L. Error bars denote standard error. Surface is significantly greater than bottom (α=0.05 Wilcoxon test).

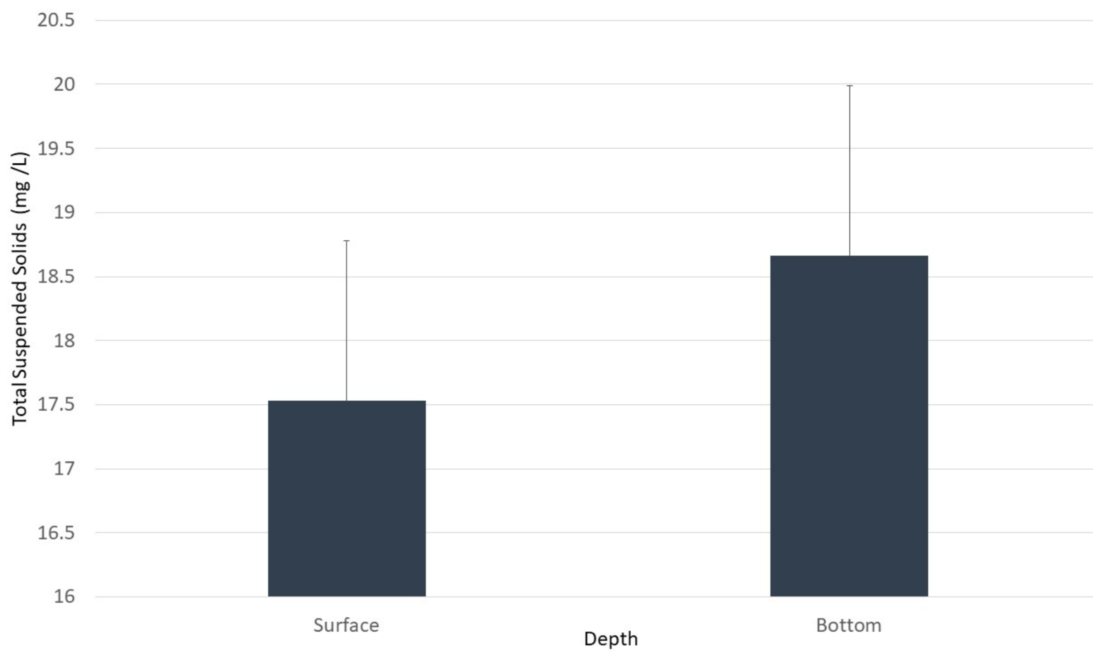

Figure 63: Mean total suspended solids concentrations at surface vs bottom across all sites. Units are mg-/L. Error bars denote standard error. No significant difference between surface and bottom (Wilcoxon test, α=0.05)

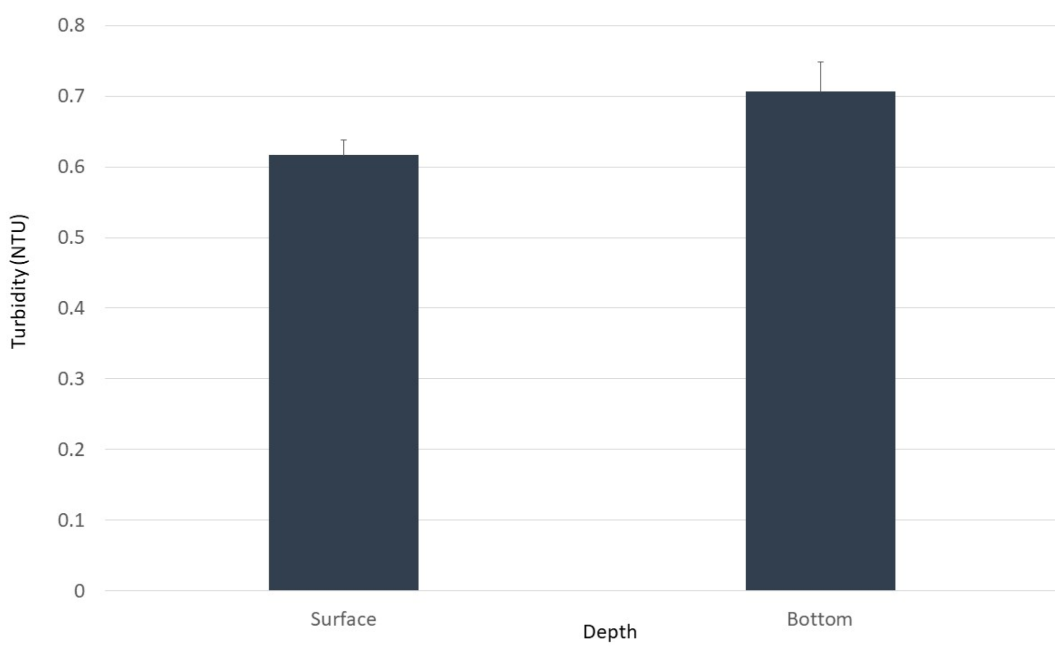

Figure 64: Mean turbidity at surface vs bottom across all sites. Units are NTU. Note that turbidity was not measured at STL and GOC. Error bars denote standard error. No significant difference between surface and bottom (Wilcoxon test, α=0.05)

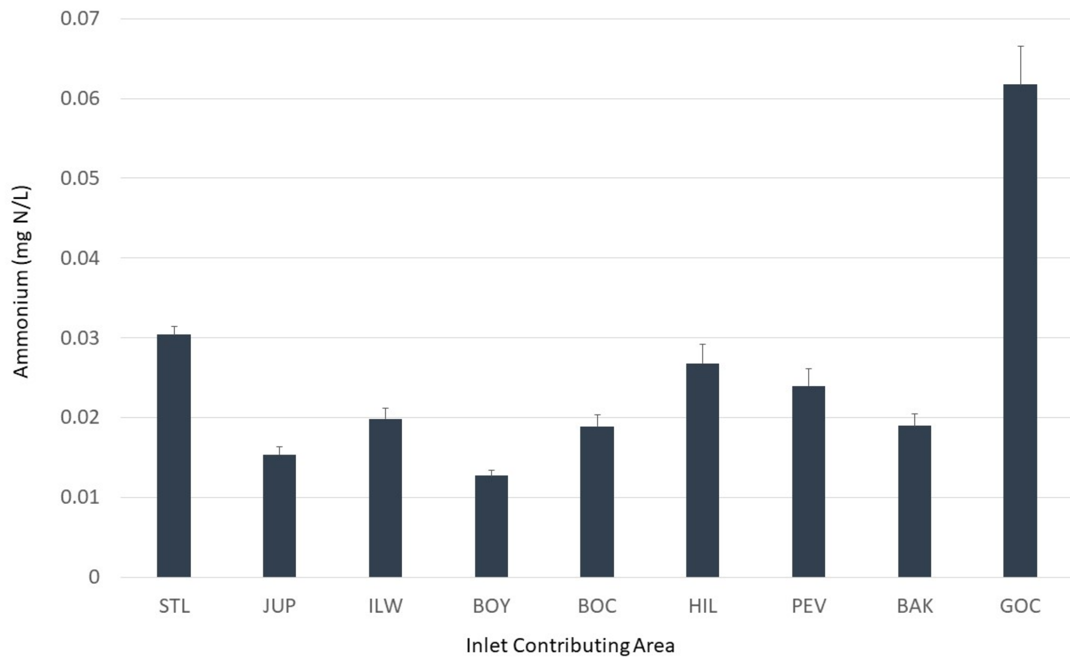

Figure 65: Mean ammonium concentrations by Inlet Contributing Area (ICA). Units are mg-N/L. Error bars denote standard error.

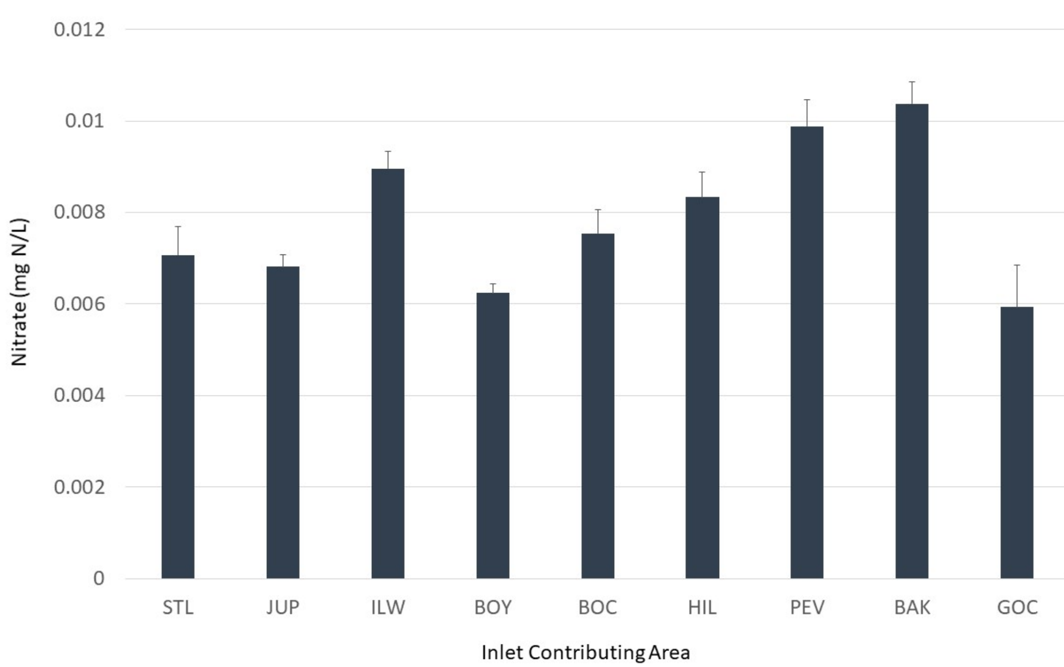

Figure 66: Mean nitrate concentrations by Inlet Contributing Area (ICA). Units are mg-N/L. Error bars denote standard error.

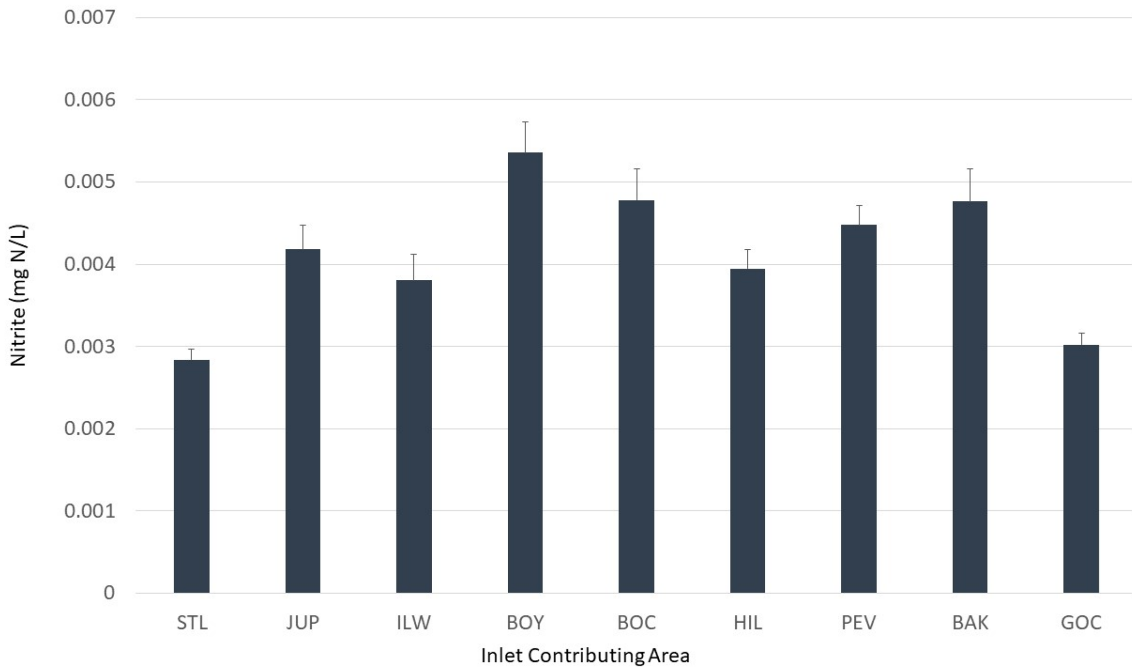

Figure 67: Mean nitrite concentrations by Inlet Contributing Area (ICA). Units are mg-N/L. Error bars denote standard error.

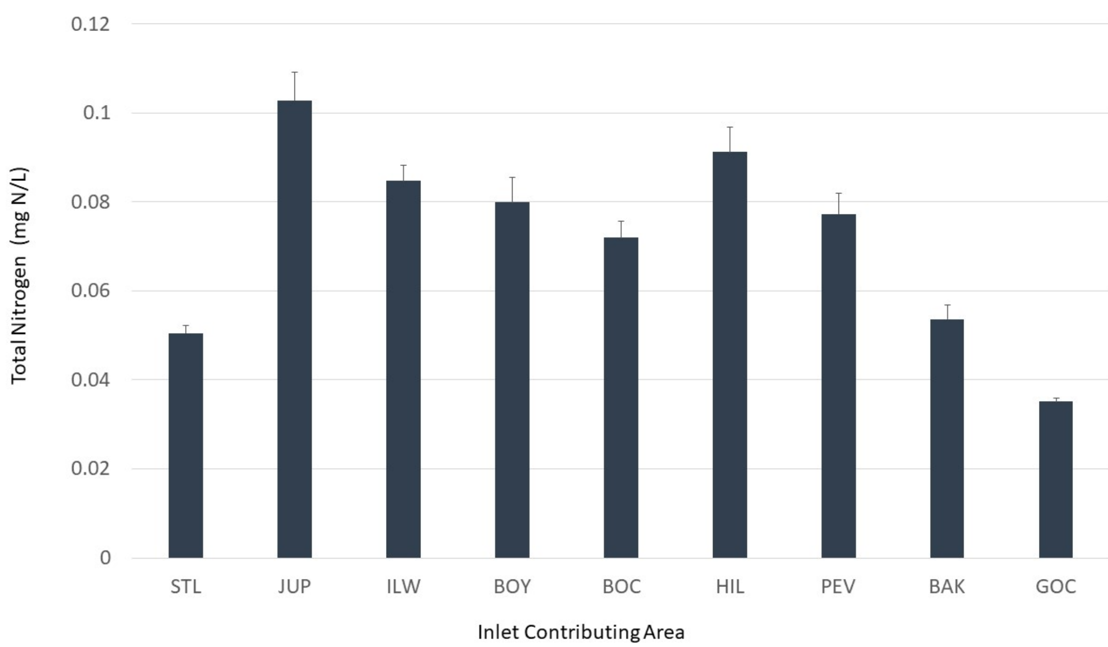

Figure 68: Mean total nitrogen concentrations by Inlet Contributing Area (ICA). Units are mg-N/L. Note that for all sites except STL and GOC, total nitrogen was calculated by summing TKN, nitrate and nitrite. Error bars denote standard error.

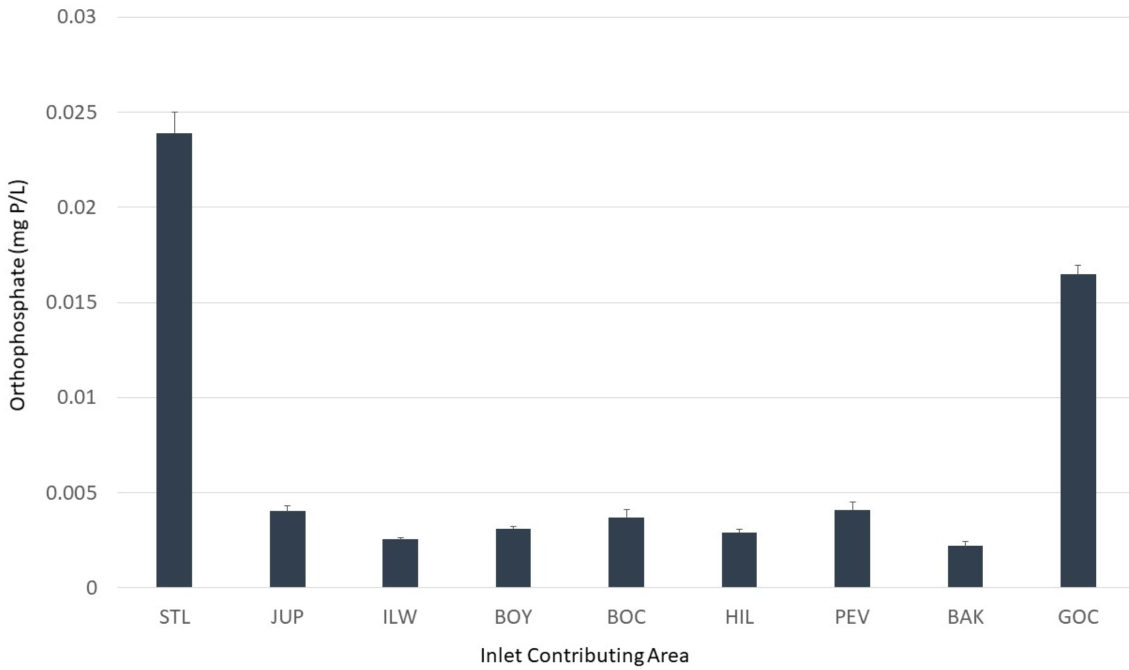

Figure 69: Mean orthophosphate concentrations by Inlet Contributing Area (ICA). Units are mg-P/L. Error bars denote standard error.

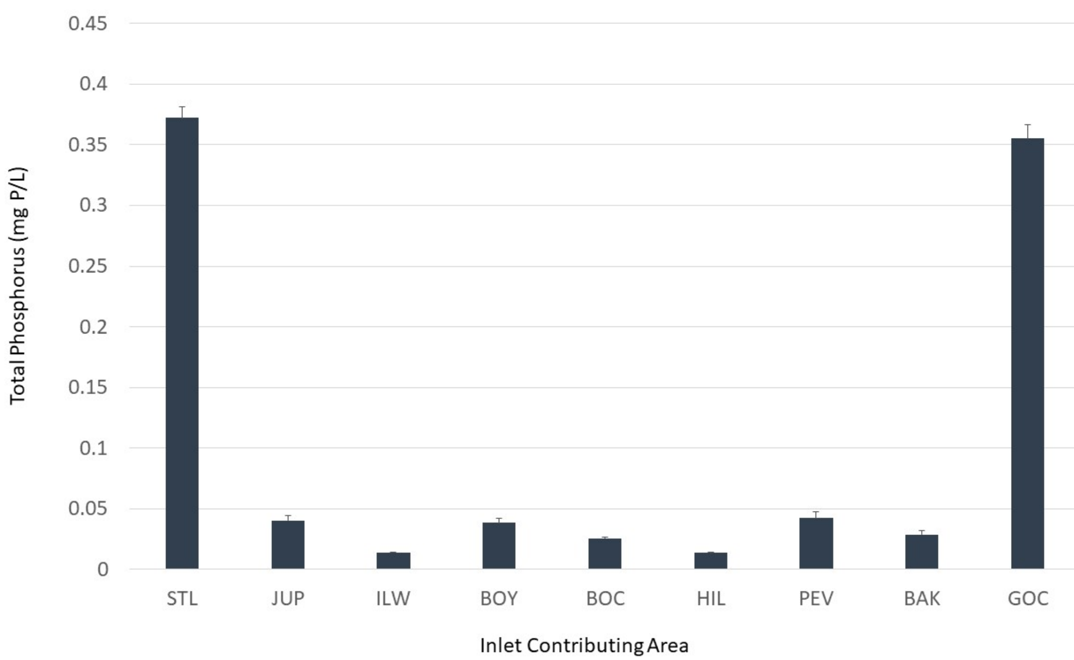

Figure 70: Mean total phosphorus concentrations by Inlet Contributing Area (ICA). Units are mg-P/L. Error bars denote standard error.

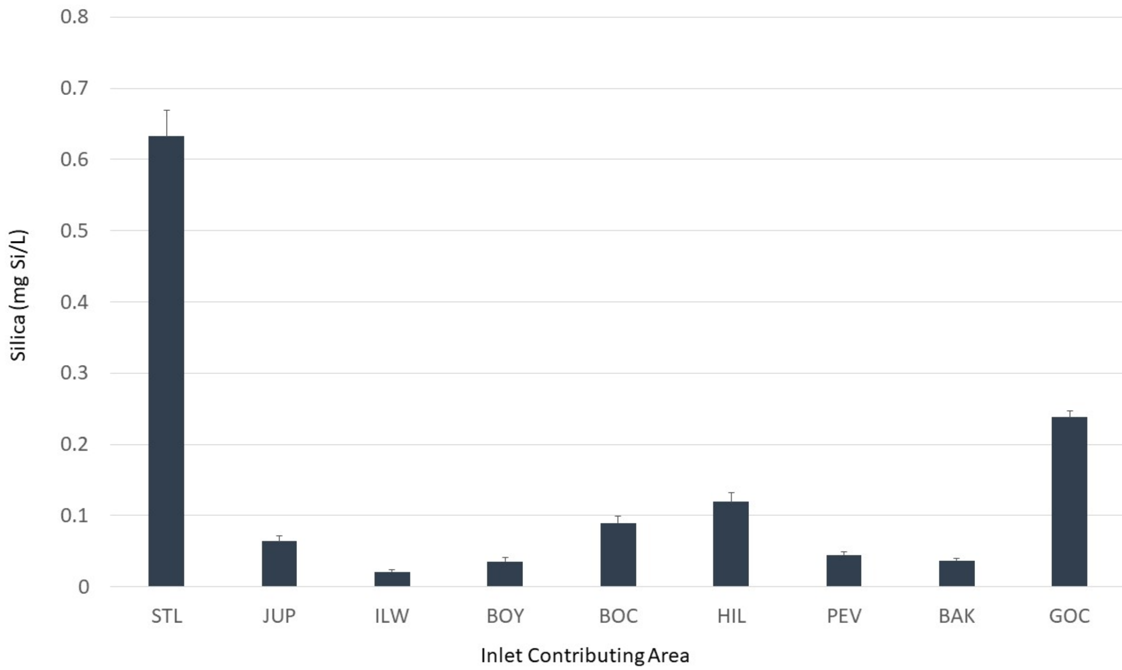

Figure 71: Mean silica concentrations by Inlet Contributing Area (ICA). Units are mg-Si/L. Error bars denote standard error.

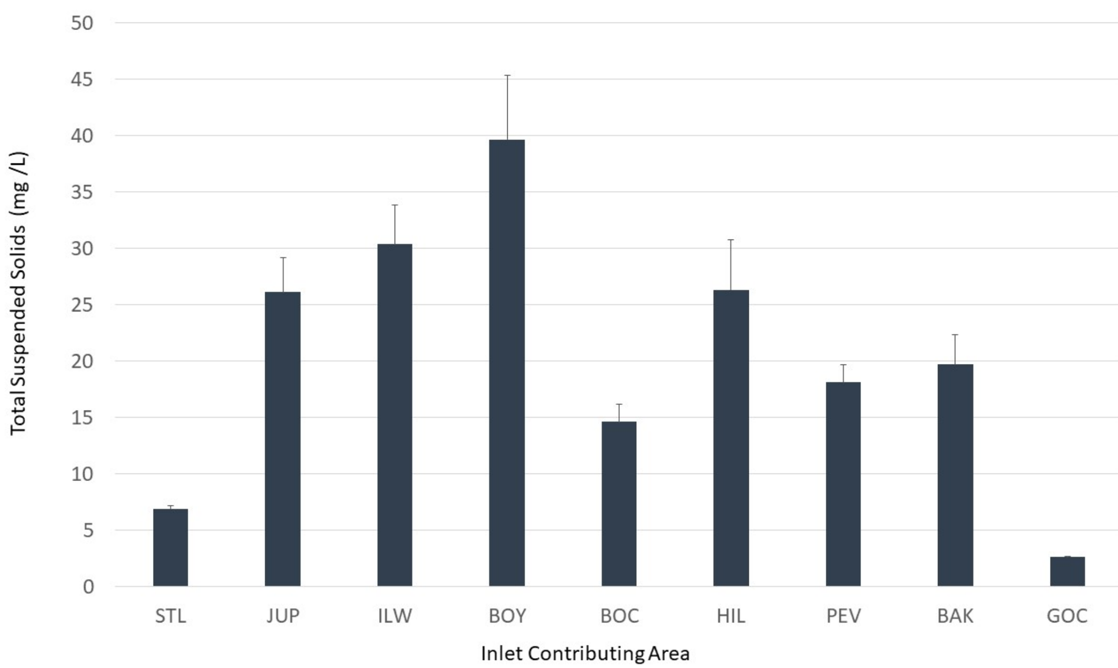

Figure 72: Mean total suspended solids concentrations by Inlet Contributing Area (ICA). Units are mg/L. Error bars denote standard error.

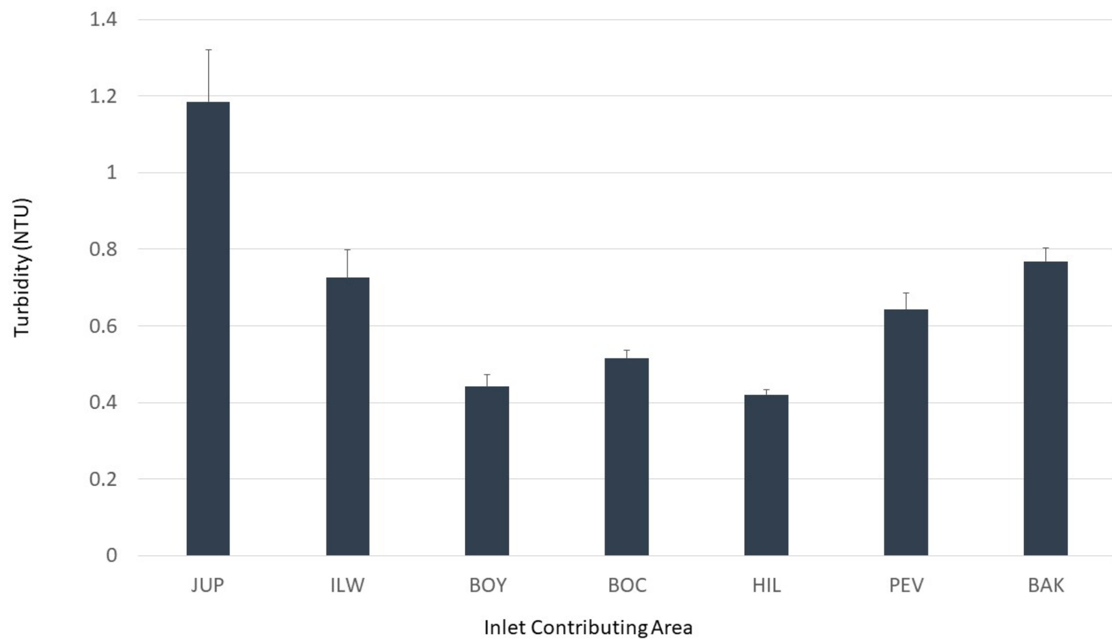

Figure 73: Mean turbidity by Inlet Contributing Area (ICA). Units are NTU. Note that turbidity was not measured at STL and GOC. Error bars denote standard error.

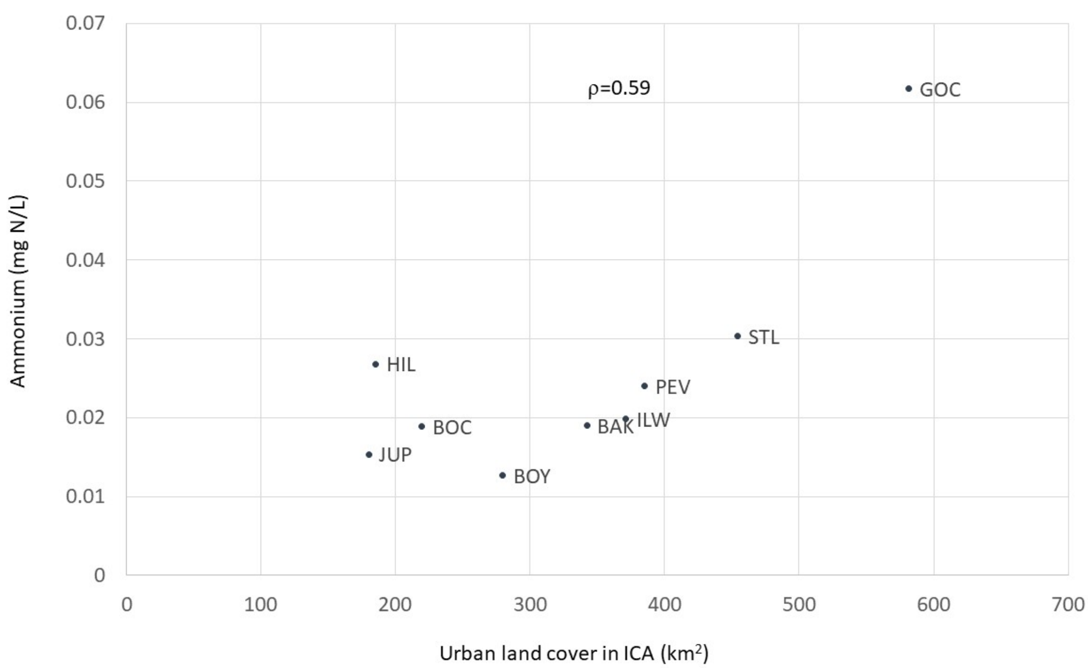

Figure 74: Scatterplot of mean ammonium concentration (mean mg-N/L) vs urban (km^2) by ICA. Spearman rho values are shown.

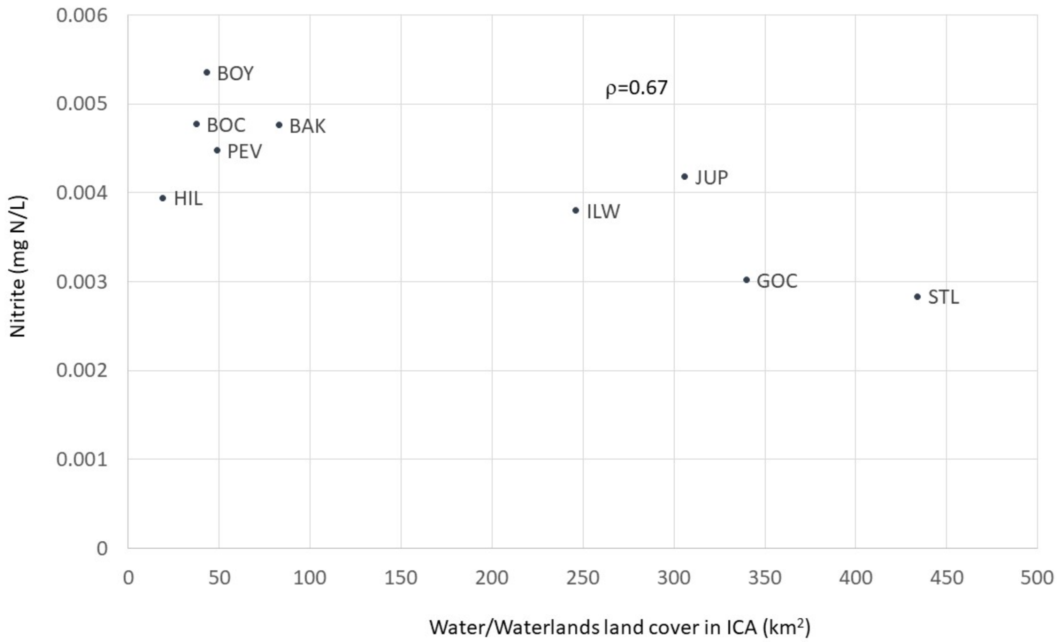

Figure 75: Scatterplot of mean nitrite concentration (mean mg-N/L) vs water/wetlands (km^2) by ICA.

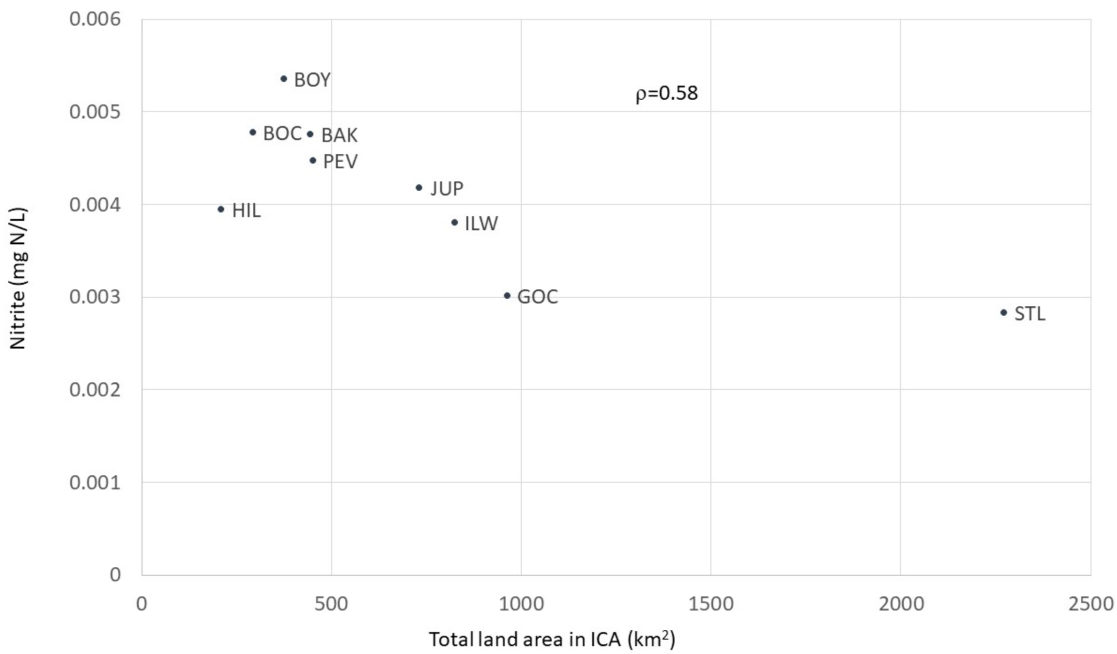

Figure 76: Scatterplot of mean nitrite concentration (mean mg-N/L) vs total (km^2) by ICA. Spearman rho values are shown.

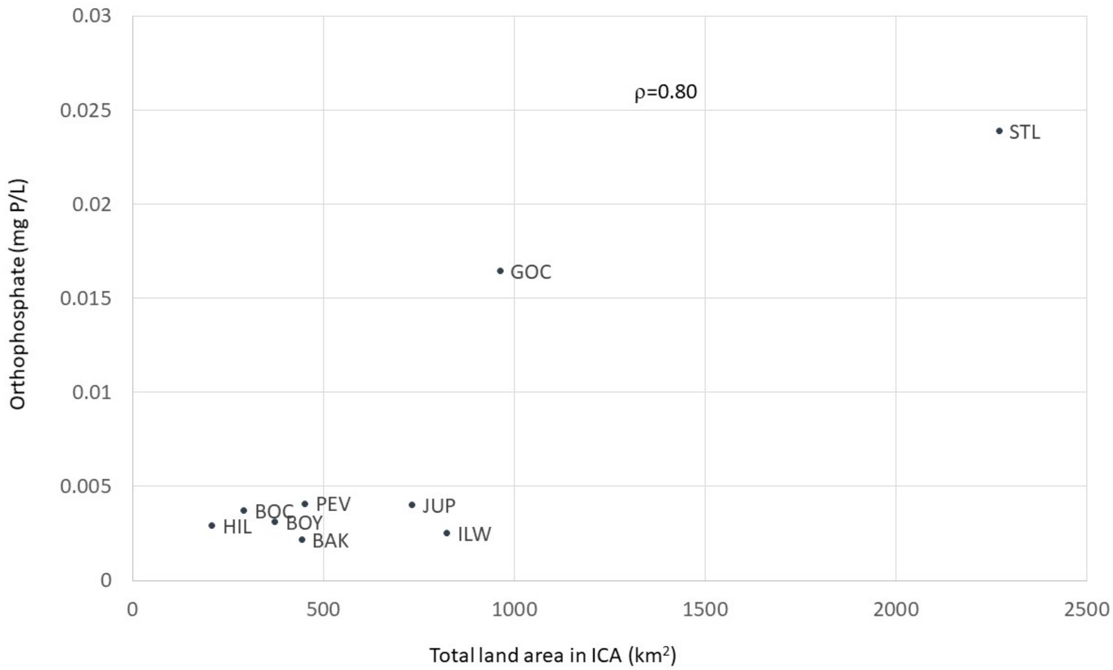

Figure 77: Scatterplot of mean orthophosphate concentration (mean mg-P/L) vs total land (km^2) by ICA. Spearman rho values are shown.

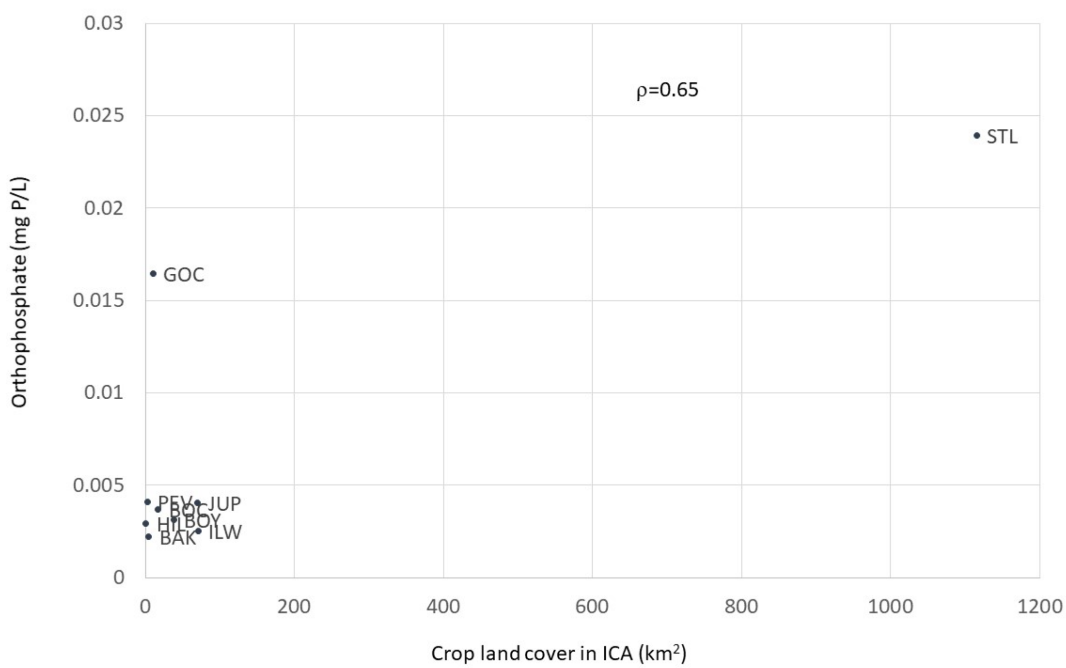

Figure 78: Scatterplot of mean orthophosphate concentration (mean mg-P/L) vs crop land (km^2) by ICA. Spearman rho values are shown.

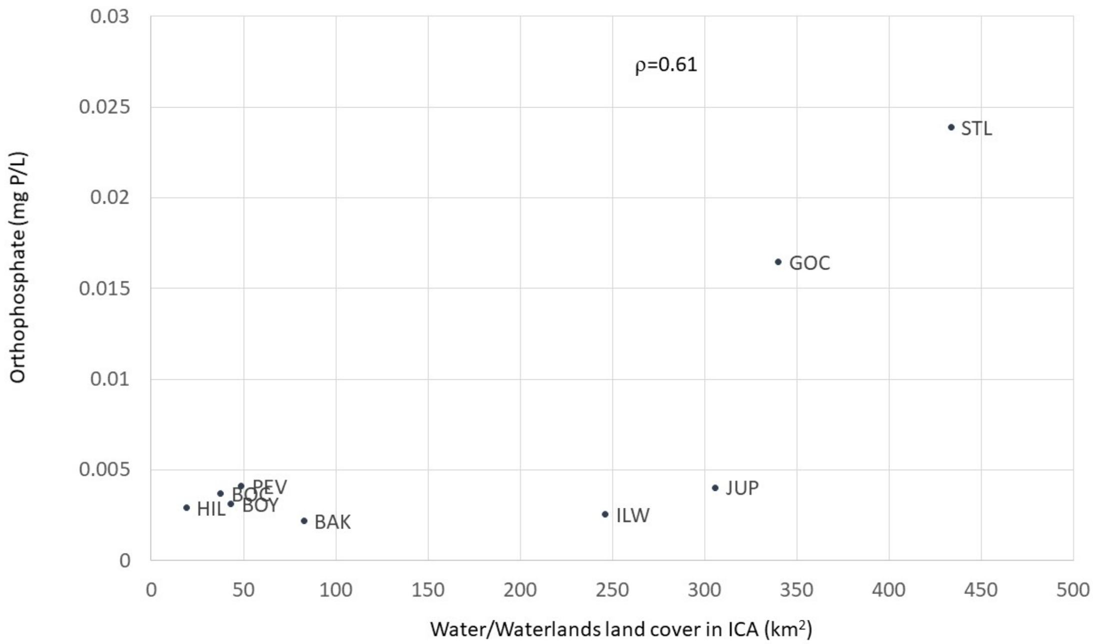

Figure 79: Scatterplot of mean orthophosphate concentration (mean mg-P/L) vs water/wetlands (km^2) by ICA. Spearman rho values are shown.

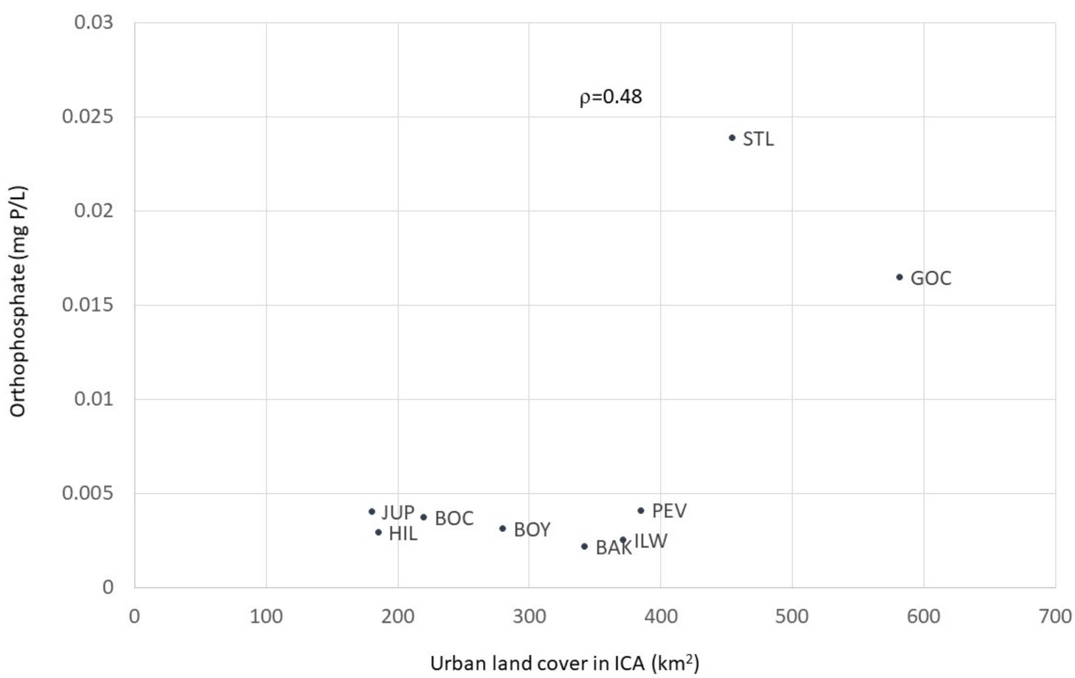

Figure 80: Scatterplot of mean orthophosphate concentration (mean mg-P/L) vs urban (km^2) by ICA. Spearman rho values are shown.

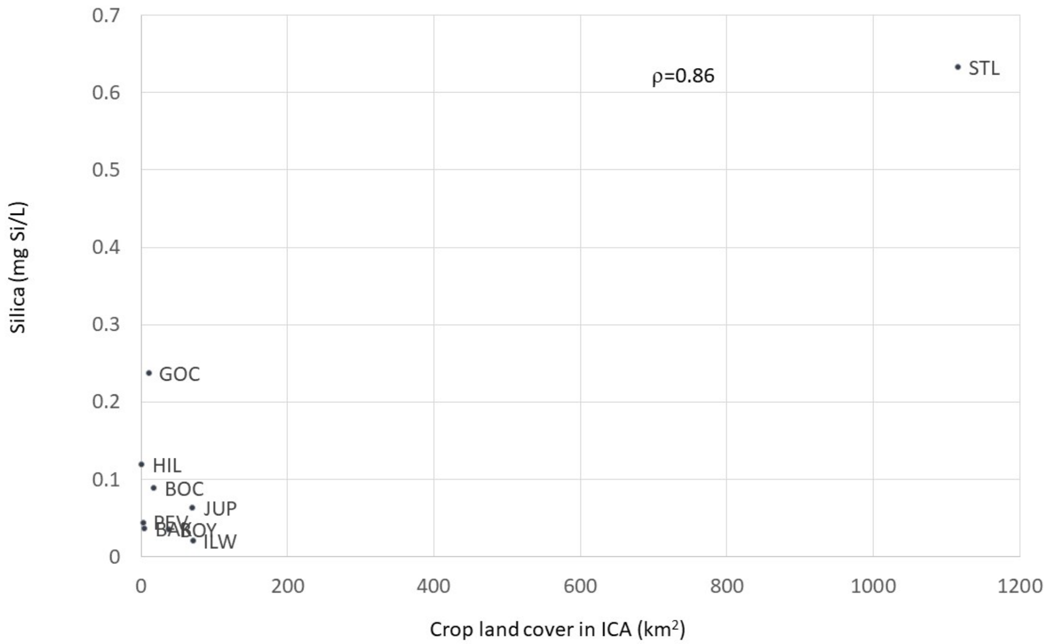

Figure 81: Scatterplot of mean silica concentration (mean mg-Si/L) vs crop land (km^2) by ICA. Spearman rho values are shown.

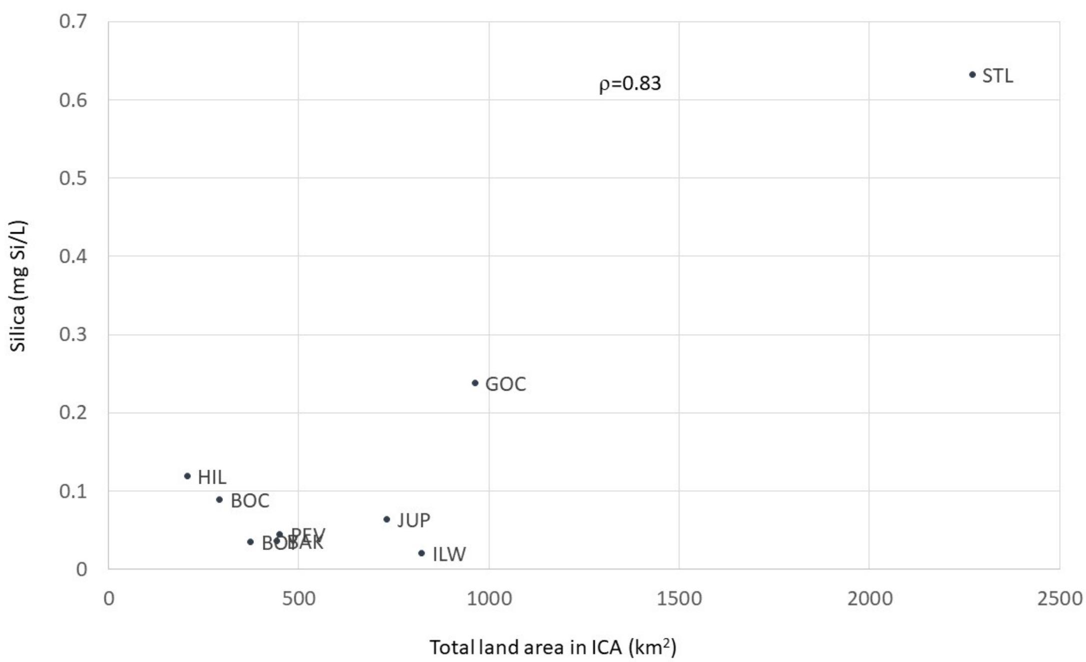

Figure 82: Scatterplot of mean silica concentration (mean mg-Si/L) vs total land (km^2) by ICA. Spearman rho values are shown.

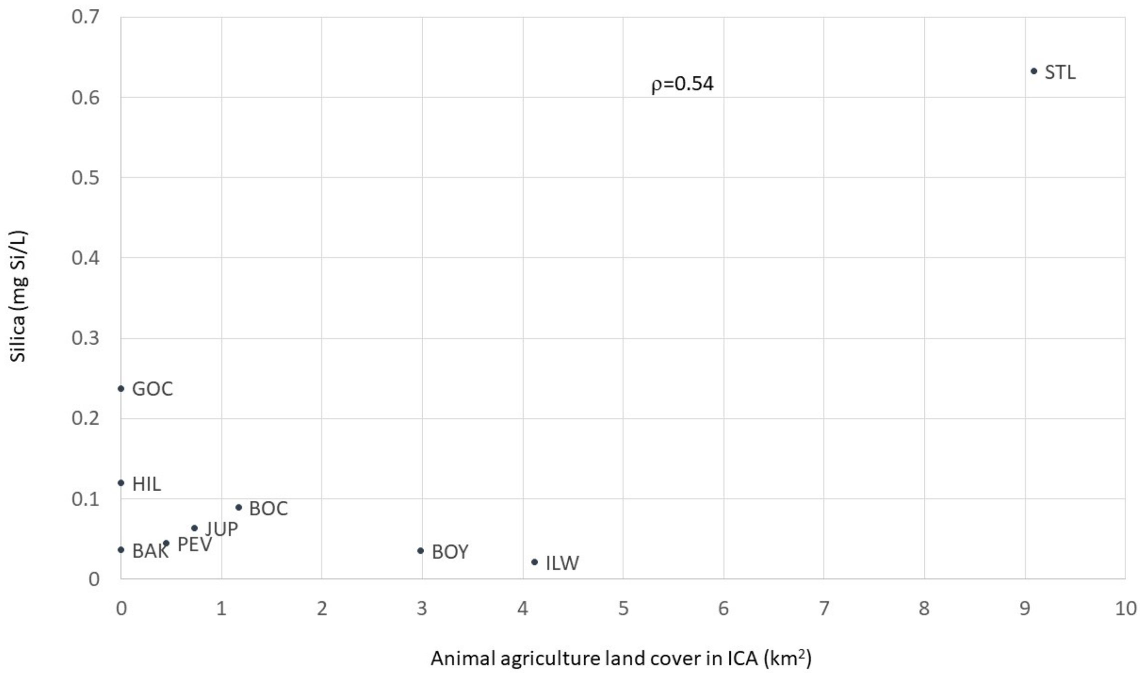

Figure 83: Scatterplot of mean silica concentration (mean mg-Si/L) vs animal agriculture (km^2) by ICA. Spearman rho values are shown.

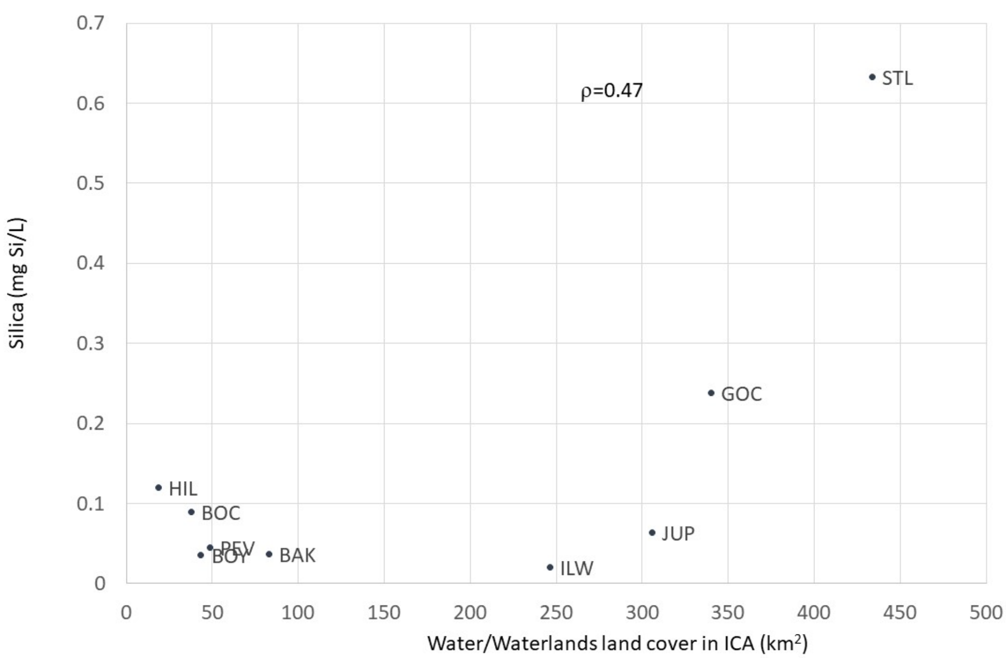

Figure 84: Scatterplot of mean silica concentration (mean mg-Si/L) vs water/wetlands (km^2) by ICA. Spearman rho values are shown.

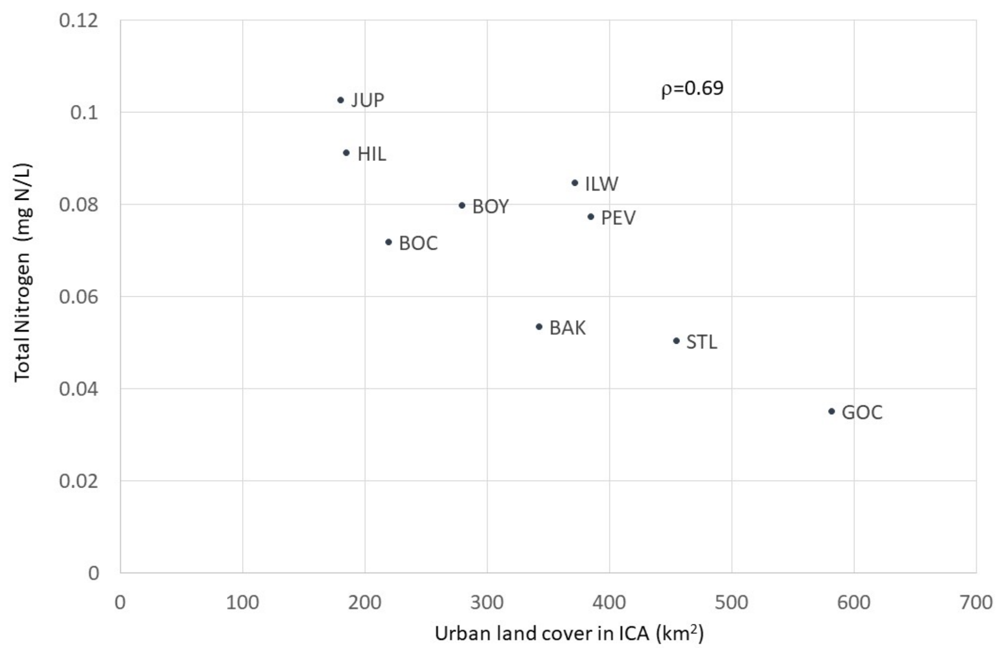

Figure 85: Scatterplot of mean total nitrogen concentration (mean mg-N/L) vs urban (km^2) by ICA. Spearman rho values are shown.

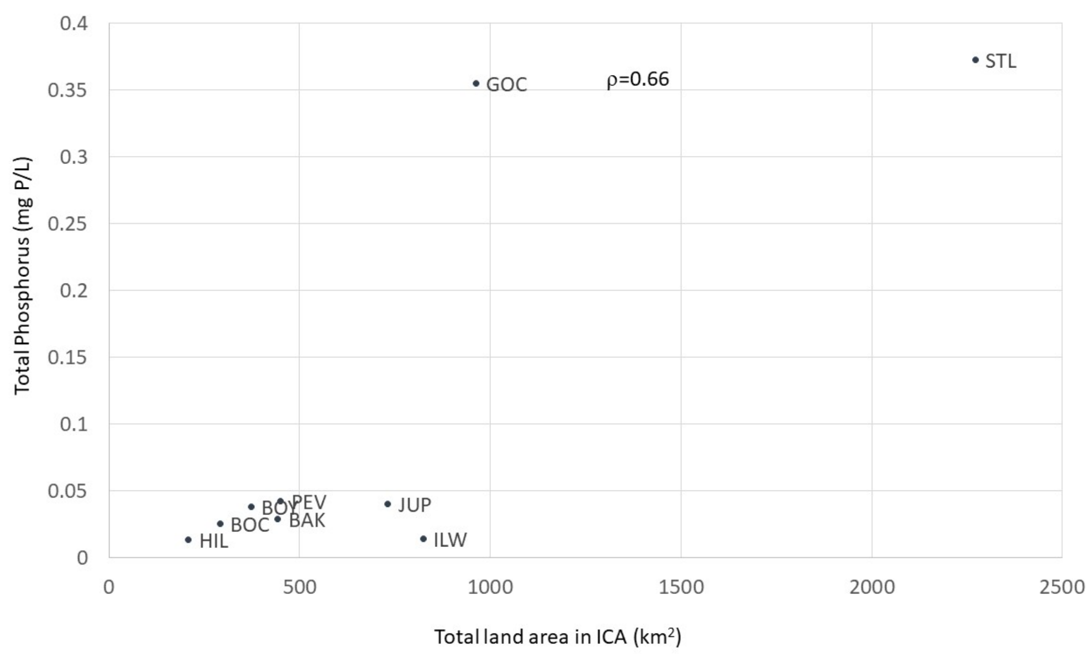

Figure 86: Scatterplot of mean total phosphorus concentration (mean mg-P/L) vs total land (km^2) by ICA. Spearman rho values are shown.

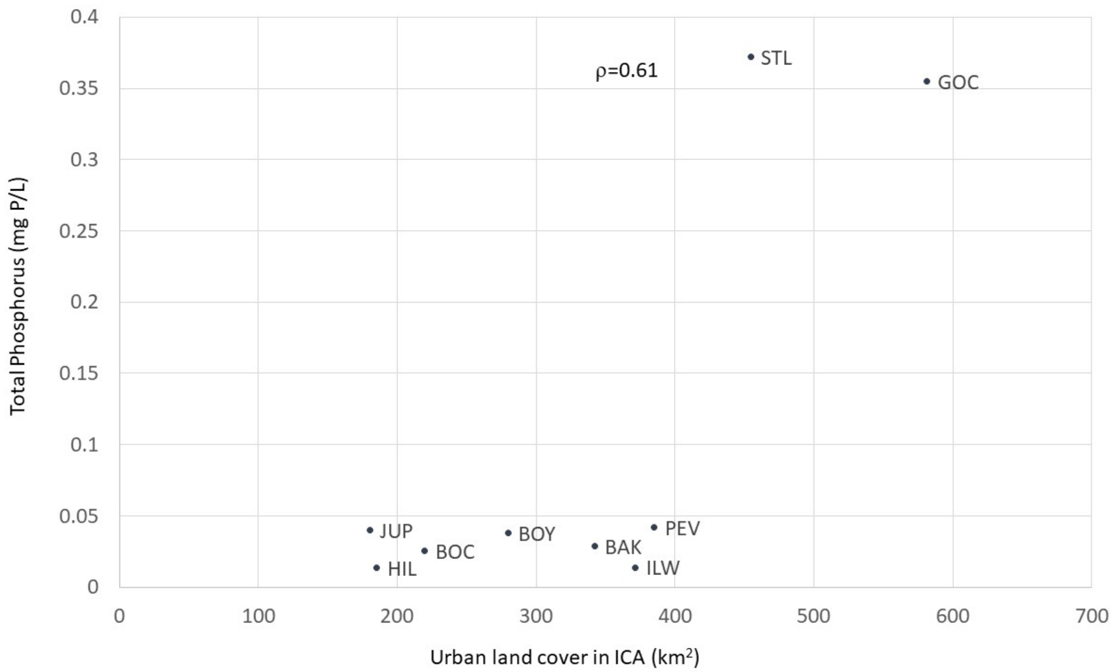

Figure 87: Scatterplot of mean total phosphorus concentration (mean mg-P/L) vs urban (km^2) by ICA.

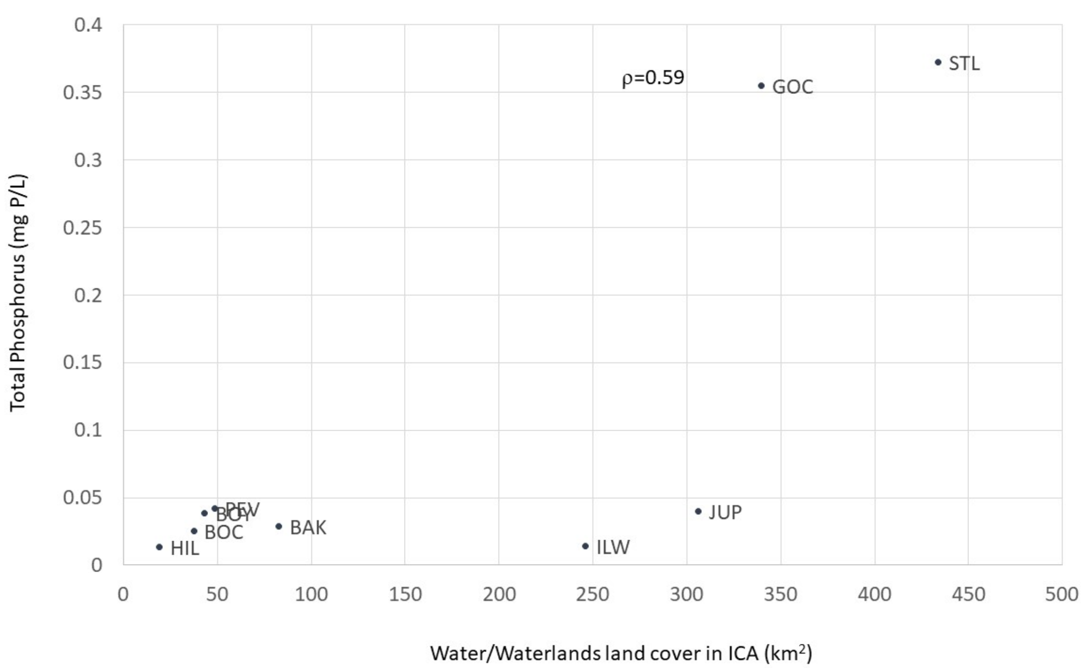

Figure 88: Scatterplot of mean total phosphorus concentration (mean mg-P/L) vs water/wetlands (km^2) by ICA. Spearman rho values are shown.

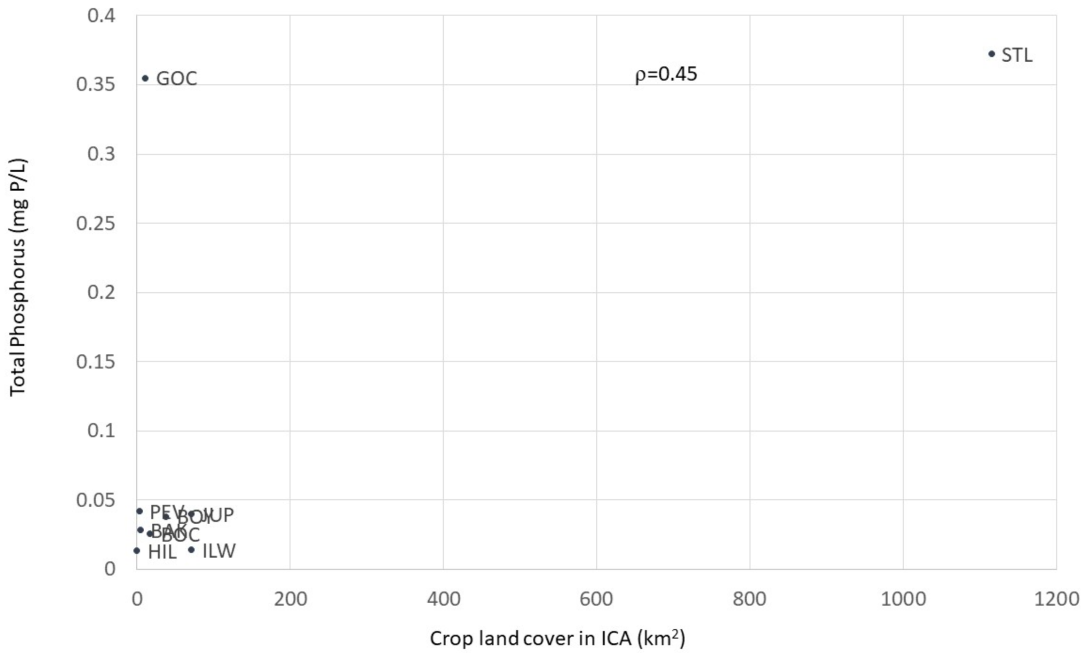

Figure 89: Scatterplot of mean total phosphorus concentration (mean mg-P/L) vs crop land (km^2) by ICA. Spearman rho values are shown.

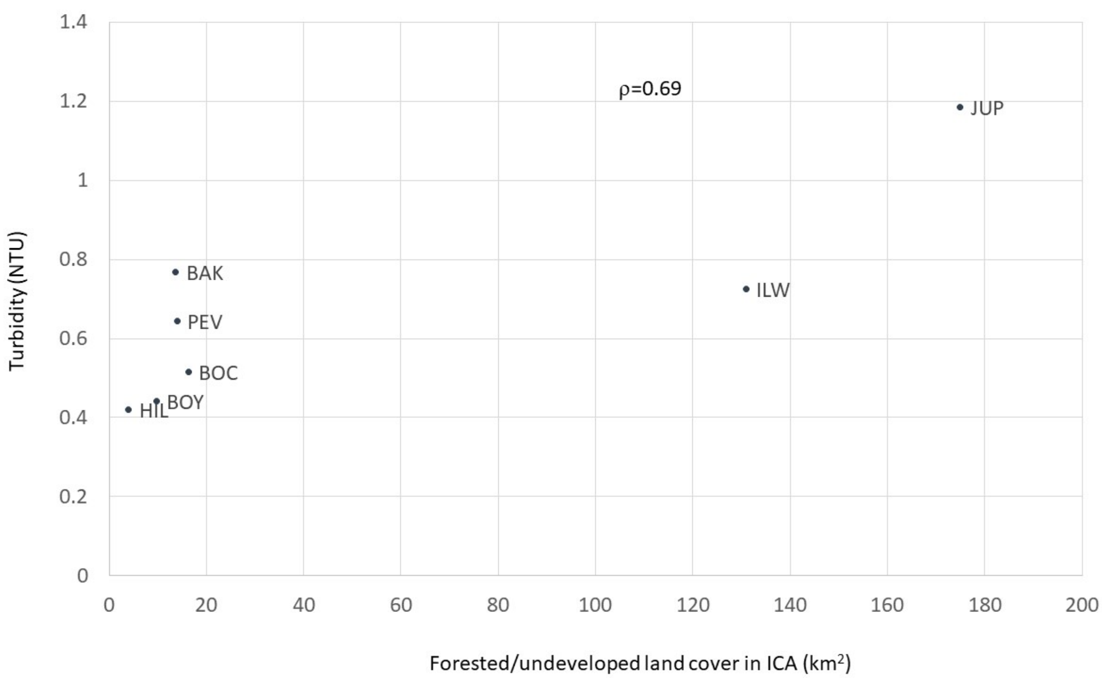

Figure 90: Scatterplot of mean turbidity (mean NTU) vs forest/open (km^2) by ICA. Spearman rho values are shown.

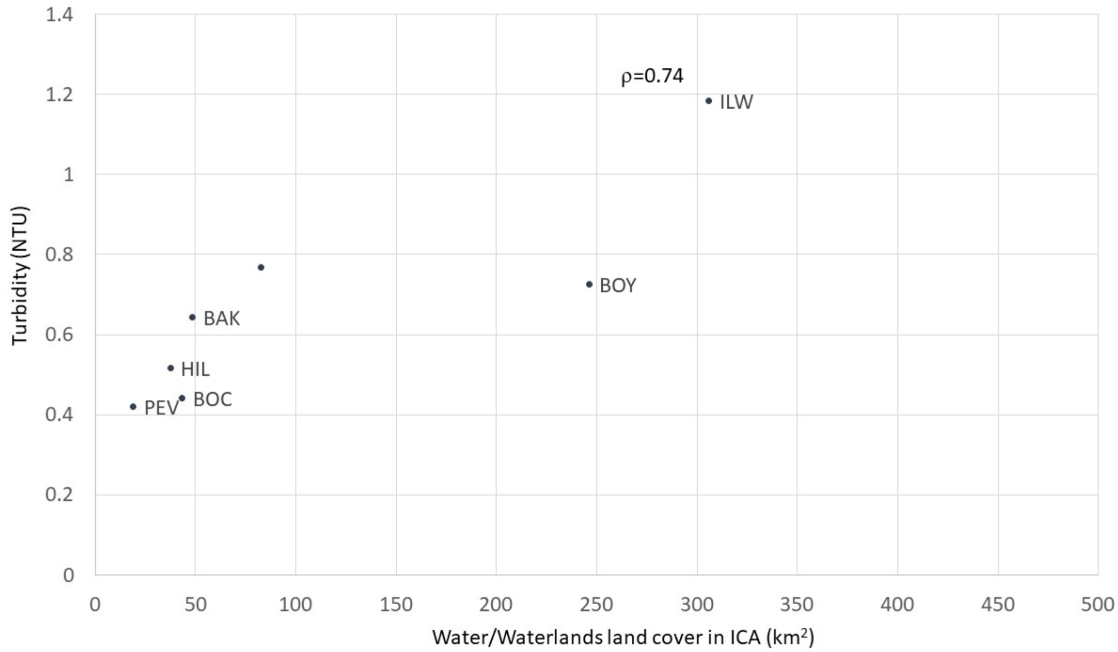

Figure 91: Scatterplot of mean turbidity (mean NTU) vs water/wetlands (km^2) by ICA. Spearman rho values are shown.

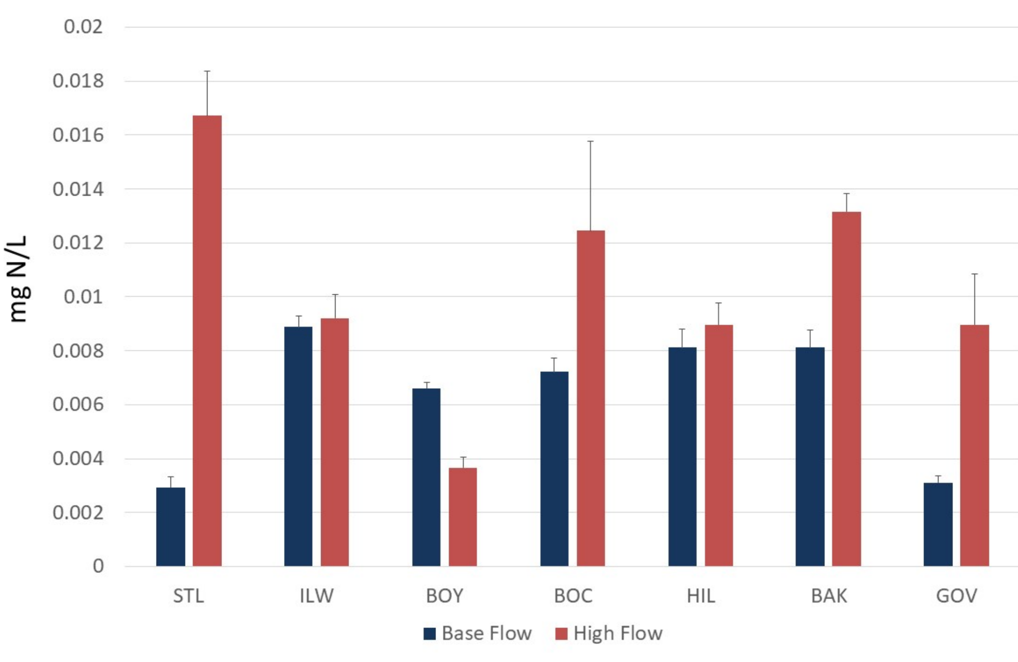

Figure 92: Mean nitrate concentrations (mg N/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

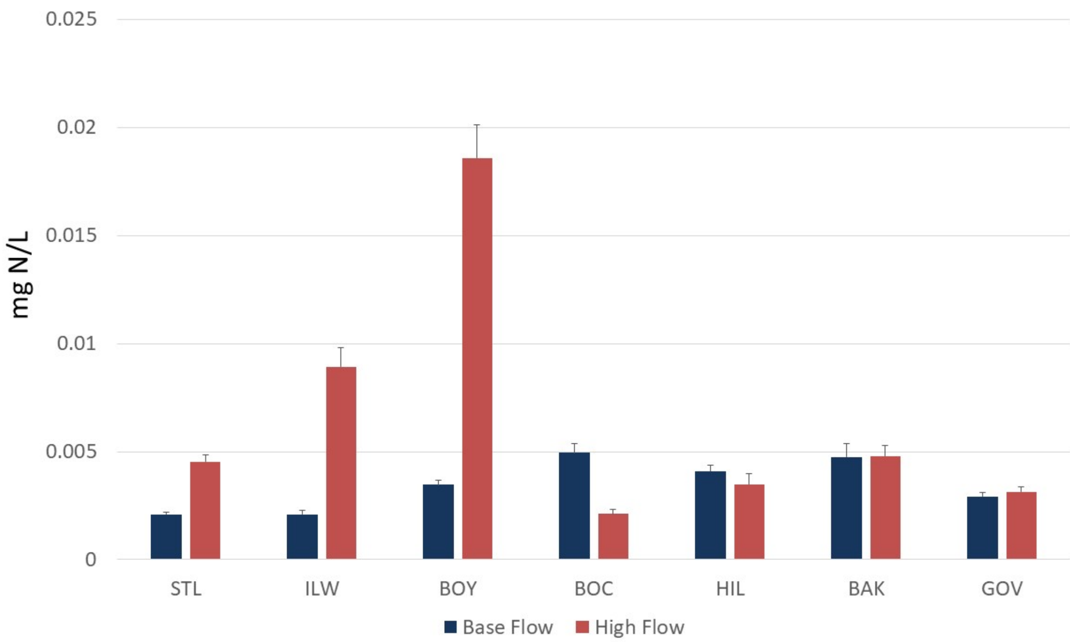

Figure 93: Mean nitrite concentrations (mg N/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

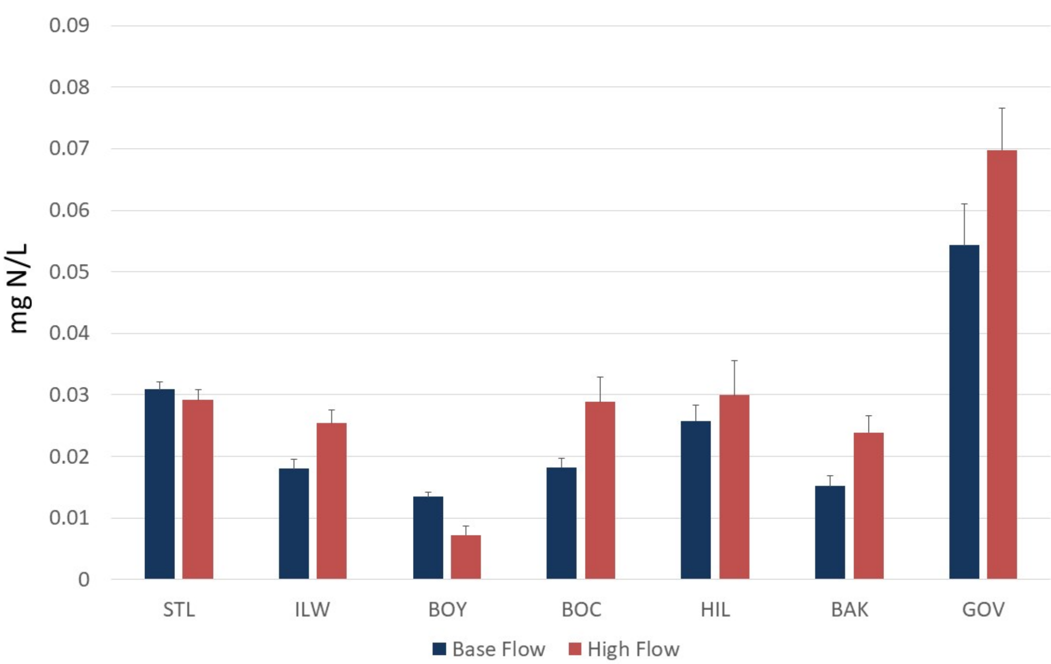

Figure 94: Mean ammonium concentrations (mg N/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

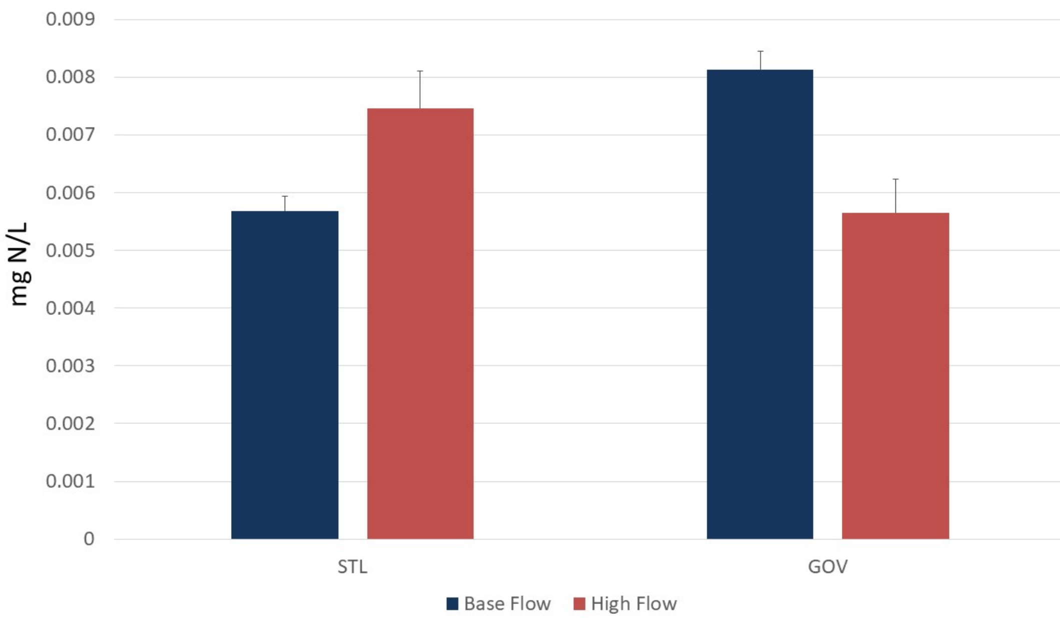

Figure 95: Mean urea concentrations (mg N/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

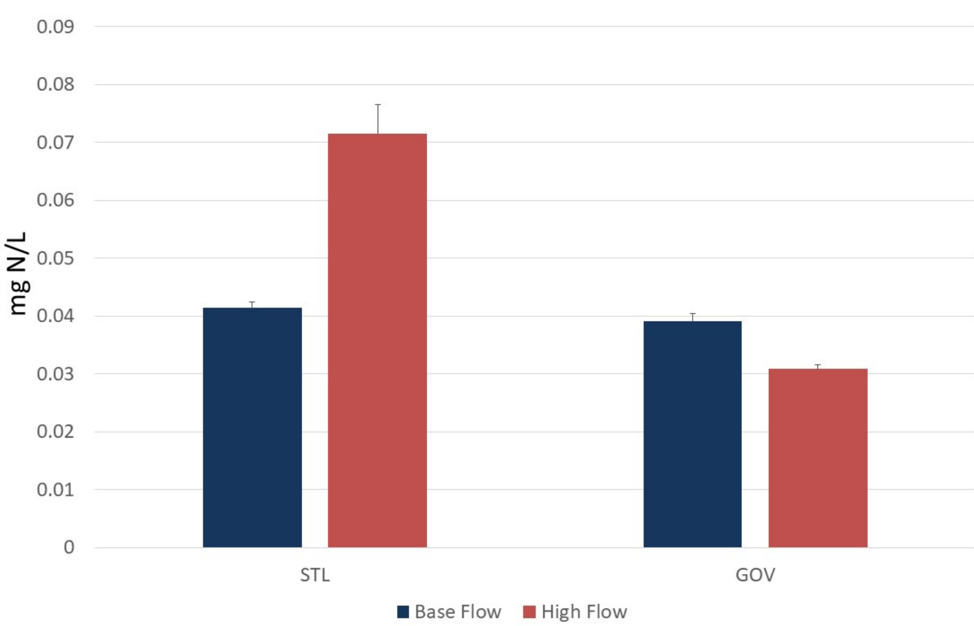

Figure 96: Mean TKN concentrations (mg N/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

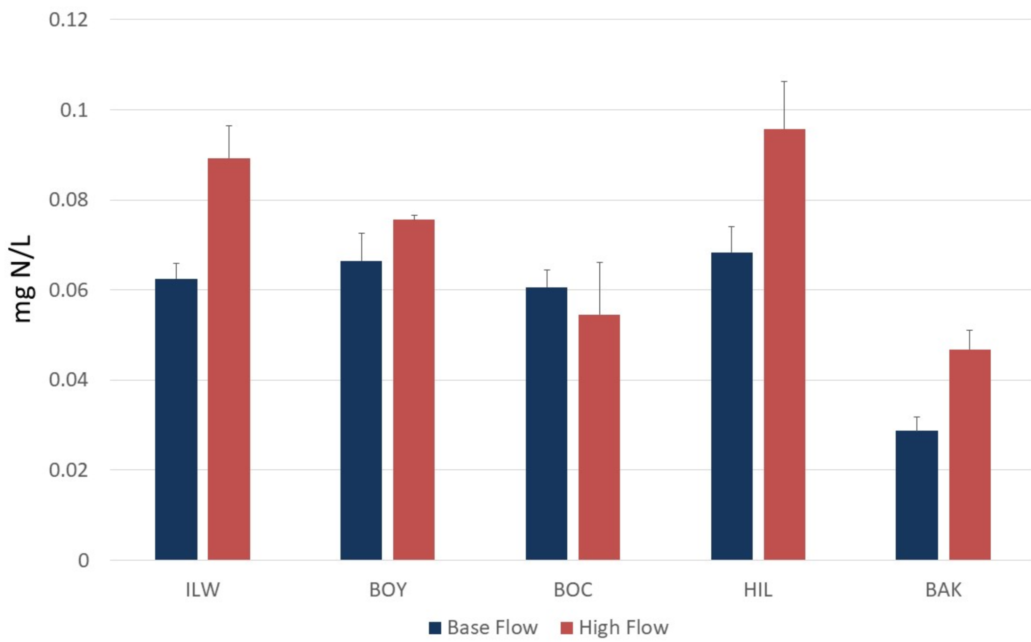

Figure 97: Mean total nitrogen concentrations (mg N/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

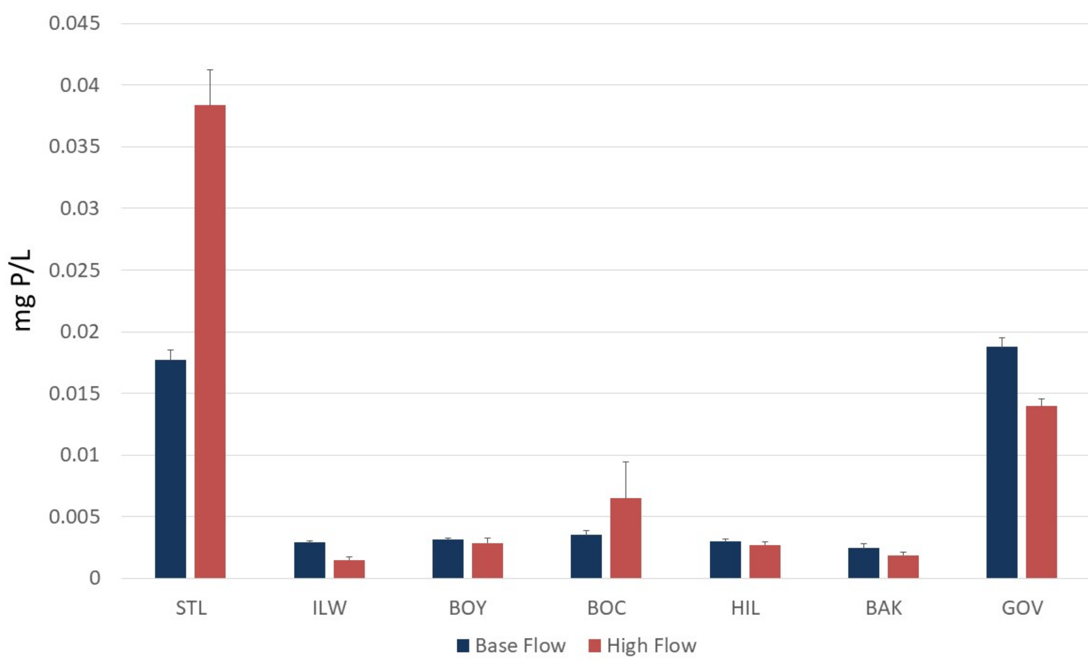

Figure 98: Mean orthophosphate concentrations (mg P/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

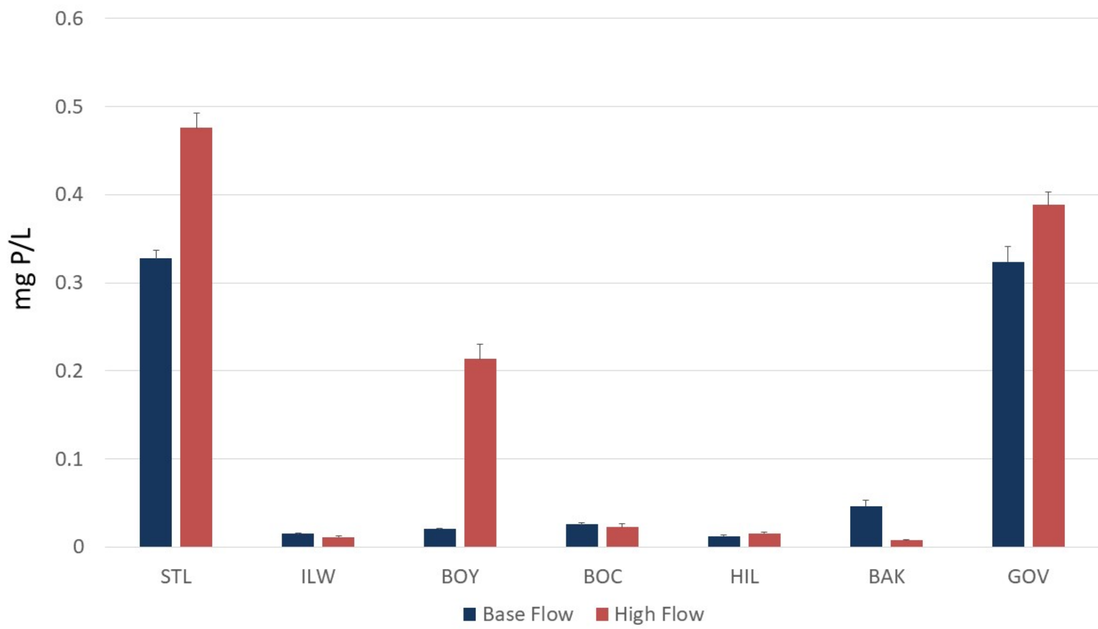

Figure 99: Mean total phosphorus concentrations (mg P/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

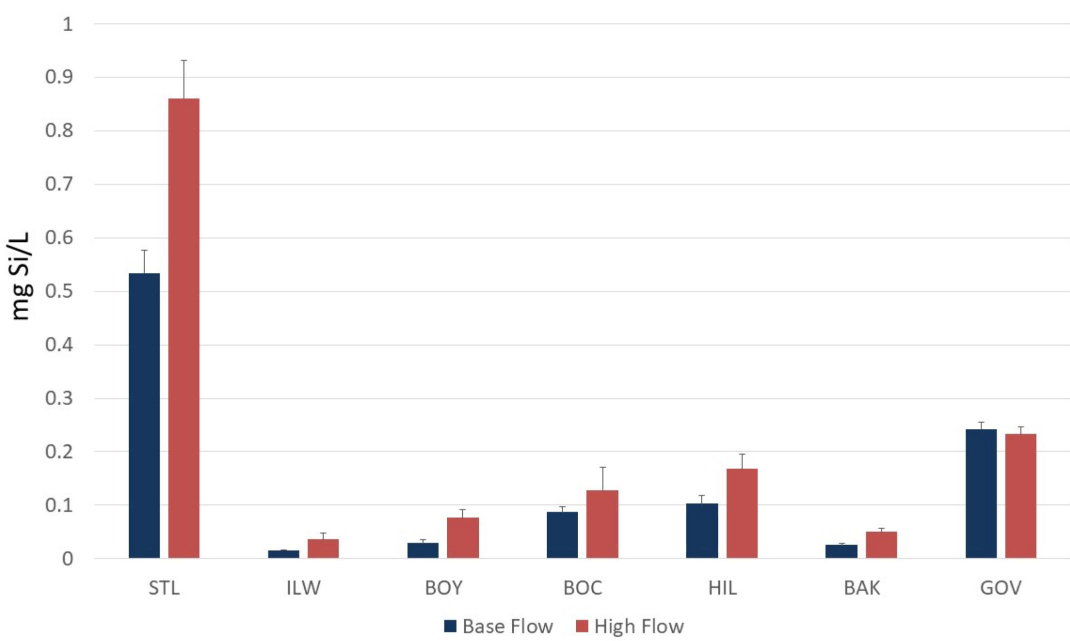

Figure 100: Mean silica concentrations (mg P/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

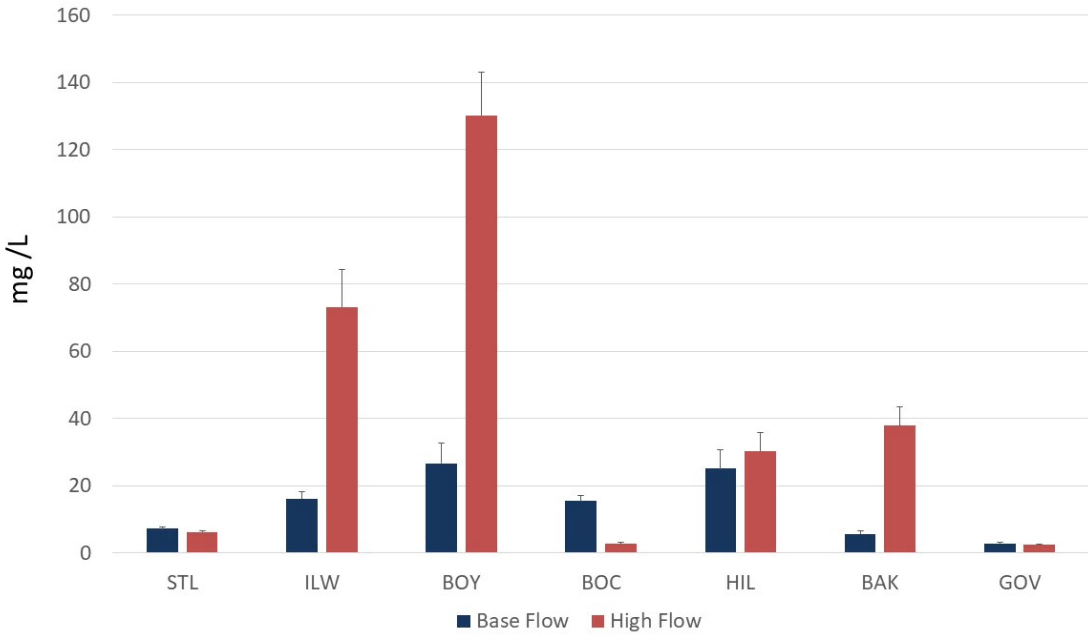

Figure 101: Mean TSS concentrations (mg/L) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

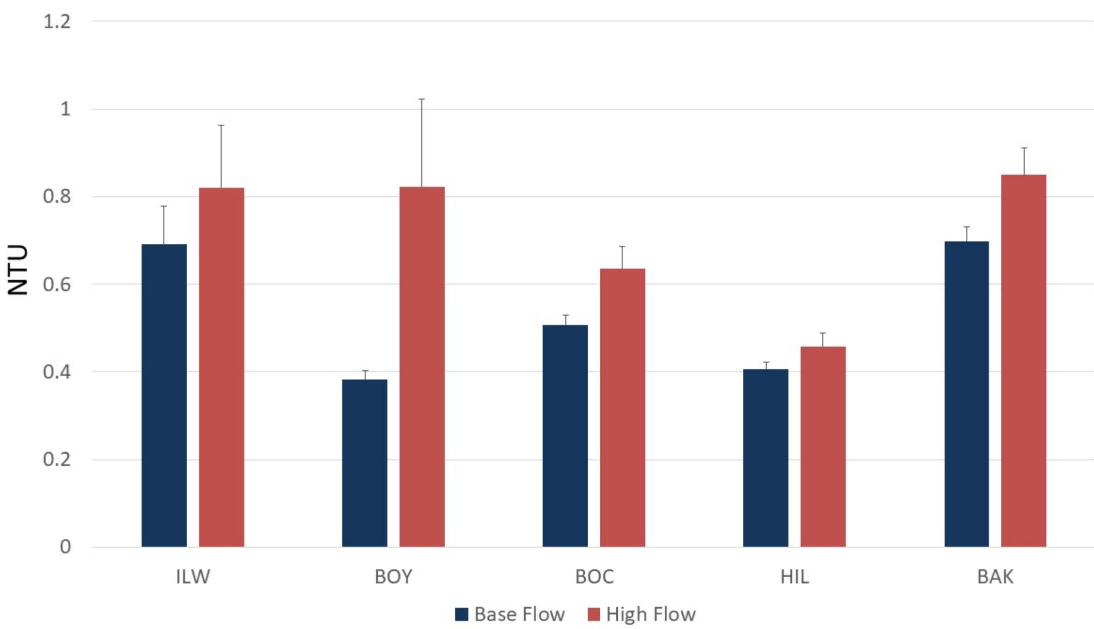

Figure 102: Mean turbidity values (NTU) by ICA for high flow conditions vs low flow conditions. Error bars are standard error.

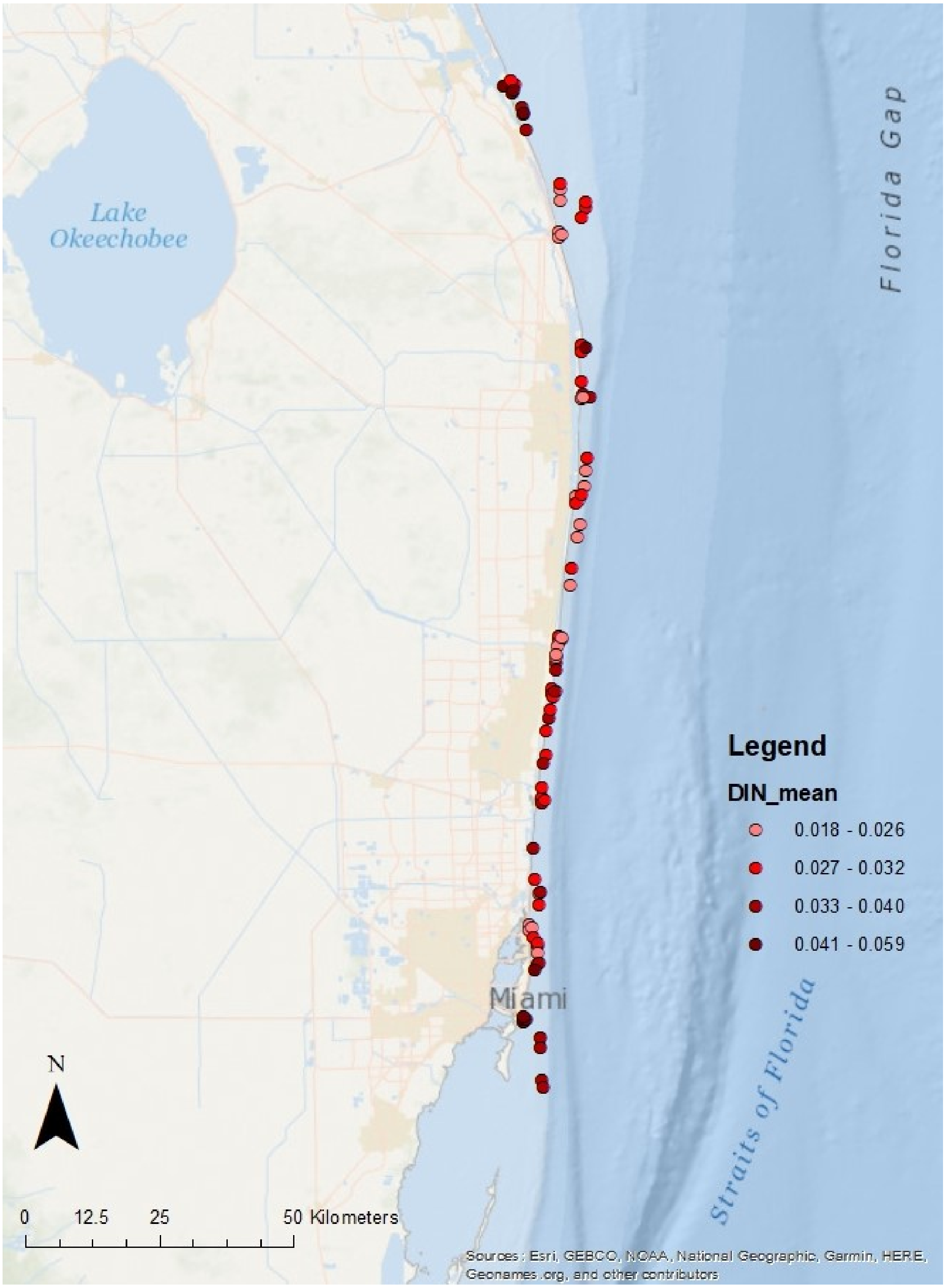

Figure 103: Mean DIN bottom water values at each site. Red dots indicate an exceedance of the threshold proposed by Lapointe (1997; 0.014 mg N/L). Note: all sites exceed this threshold for both mean and maximum values.

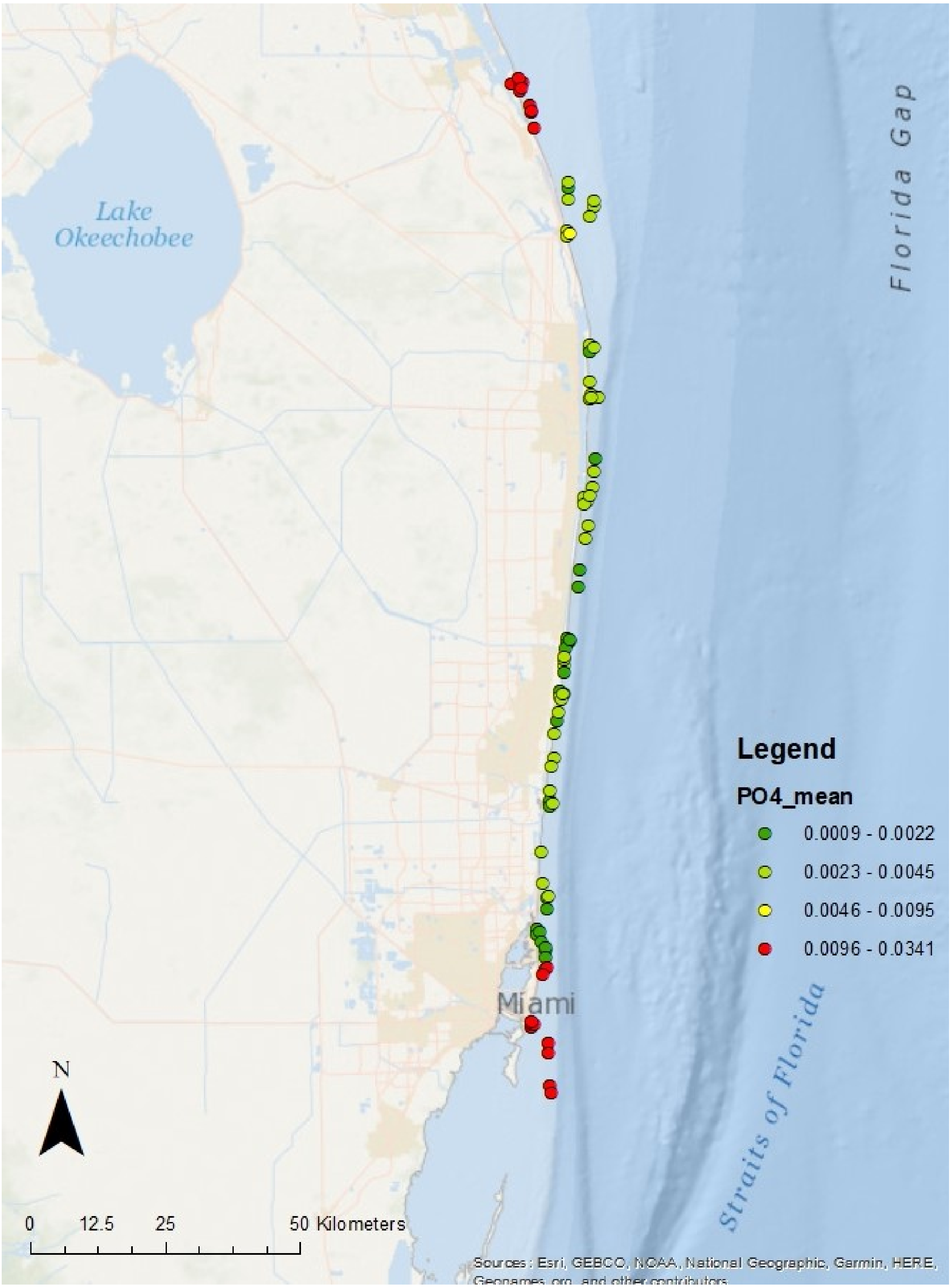

Figure 104: Mean orthophosphate bottom water values at each site. Red dots indicate an exceedance of the threshold proposed by Lapointe (1997; 0.0095 mg P/L).

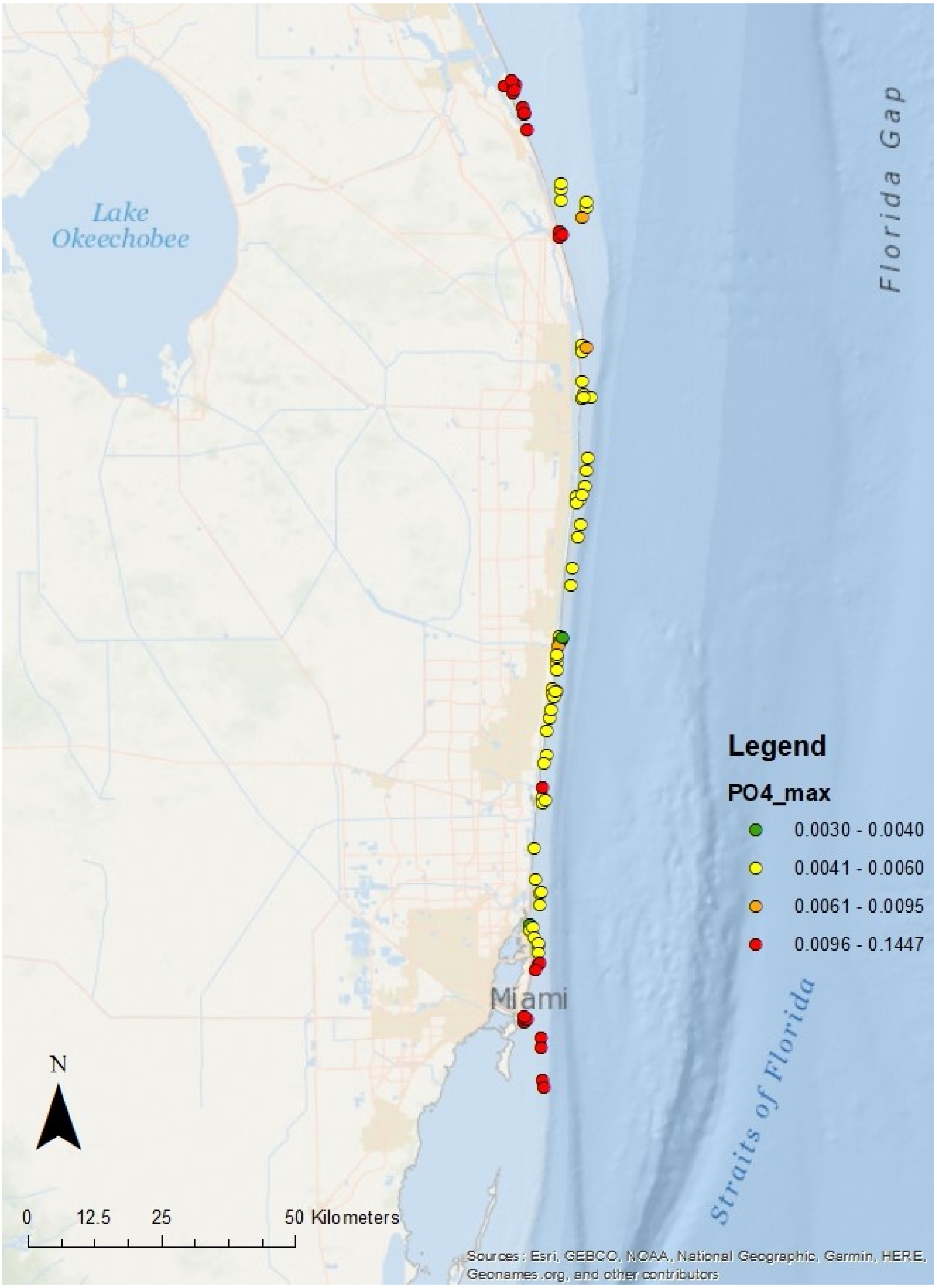

Figure 105: Maximum orthophosphate bottom water values at each site. Red dots indicate an exceedance of the threshold proposed by Lapointe (1997; 0.0095 mg P/L).

Appendix A: Inter-laboratory Comparison

In order to assess the comparability of the data from the two different analytical labs employed for this study, a total of 38 samples across multiple sampling dates were split and run at each lab and the results compared. As expected, given the relative differences in method detection limits (MDLs), there were significantly more non-detects for samples analyzed at the Broward lab. The overall percentage of non-detects make rigorous comparison problematic. Based on other measures of data quality (e.g. replicates, blanks, percent recoveries), both labs are producing quality data, however, there may be non-trivial differences between labs based on methodologies and laboratory specific protocols. The statistical analyses presented in this report that examine spatial differences between ICAs must be caveated to reflect that direct comparisons between GOC/STL ICAs and the other seven ICAs should be done carefully and with this laboratory situation in mind.

Sample	Date	GERG NO$_3^-$	Broward NO$_3^-$	GERG NO$_2^-$	Broward NO$_2^-$	GERG NH$_4^+$	Broward NH$_4^+$
BAK_FCEB_F	04/04/18	<MDL	<MDL	0.0151	<MDL	0.0682	<MDL
BAK_FCEB_F	03/01/18	<MDL	0.0110	0.0156	<MDL	0.0893	0.0250
BAK020_BF	04/04/18	0.0292	<MDL	0.0021	<MDL	0.0307	<MDL
BAK020_SF	04/04/18	<MDL	<MDL	0.0034	<MDL	0.0563	<MDL
BAK025_BF	03/01/18	0.0253	0.0220	0.0024	<MDL	0.0134	<MDL
BAK025_SF	03/01/18	0.0167	0.0200	0.0015	0.0040	0.0195	<MDL
BAK029_BF	03/01/18	0.0220	0.0220	0.0025	0.0030	0.0149	<MDL
BAK029_SF	03/01/18	0.0233	0.0160	0.0033	<MDL	0.0224	0.0220
BAK030_SF	04/04/18	0.0430	0.0830	0.0819	0.0880	0.1283	0.1040
BOC_FCEB_F	03/07/18	<MDL	<MDL	0.0137	<MDL	0.0972	0.0550
BOC070_BF	03/07/18	<MDL	<MDL	0.0026	<MDL	0.0368	0.0300
BOC070_SF	03/14/18	<MDL	<MDL	0.0093	<MDL	0.0768	0.0240
BOC080_SF	03/07/18	<MDL	<MDL	0.0064	<MDL	0.0576	0.0240
HIL_FCEB_F	04/03/18	<MDL	<MDL	0.0148	<MDL	0.0877	0.0530
HIL050_BF	04/03/18	<MDL	<MDL	0.0002	<MDL	<MDL	0.0460
HIL050_SF	04/03/18	<MDL	<MDL	0.0012	0.0030	0.0081	0.0370
HIL055_BF	04/03/18	<MDL	<MDL	<MDL	<MDL	<MDL	0.0300
HIL055_SF	04/03/18	<MDL	<MDL	0.0003	<MDL	<MDL	0.0410
HIL057_BF	04/03/18	<MDL	<MDL	0.0012	<MDL	<MDL	0.0360
HIL057_SF	04/03/18	<MDL	<MDL	0.0025	<MDL	0.0152	0.0780
HIL060_SF	04/03/18	<MDL	0.0130	0.0059	0.0050	0.1040	0.1310
ILW_FCEB_F	03/15/18	<MDL	<MDL	0.0042	<MDL	0.0953	0.0220
ILW_FCEB_F	06/03/18	0.0117	0.0160	0.0144	<MDL	0.0234	0.0680
ILW110_BF	06/03/18	0.0098	0.0180	0.0031	<MDL	0.0080	0.0230
ILW110_SF	06/03/18	0.0256	0.0130	0.0083	<MDL	0.0272	0.0260
ILW111_BF	06/03/18	0.0061	0.0120	0.0021	<MDL	0.0091	0.0200
ILW111_SF	06/03/18	0.0066	0.0140	0.0085	<MDL	0.0134	0.0270
ILW115_BF	03/15/18	<MDL	<MDL	0.0043	<MDL	0.0451	<MDL
ILW115_SF	03/15/18	<MDL	<MDL	0.0038	<MDL	0.0694	<MDL
ILW119_BF	03/15/18	<MDL	<MDL	0.0033	<MDL	0.0459	<MDL
ILW119_SF	03/15/18	<MDL	<MDL	0.0044	<MDL	0.1232	<MDL
JUP_FCEB_F	03/14/18	<MDL	<MDL	0.0135	<MDL	0.0930	<MDL
JUP120_BF	03/14/18	<MDL	0.0100	0.0007	<MDL	0.0085	<MDL
JUP120_SF	03/01/18	<MDL	<MDL	0.0005	<MDL	0.0111	<MDL
JUP124_BF	03/14/18	<MDL	<MDL	0.0036	<MDL	0.0414	<MDL
JUP124_SF	03/14/18	<MDL	<MDL	0.0021	<MDL	0.0286	<MDL
JUP128_BF	03/14/18	<MDL	<MDL	0.0010	<MDL	0.0208	<MDL
JUP128_SF	03/14/18	<MDL	0.0130	0.0034	<MDL	0.0470	<MDL

		GERG	Broward	GERG	Broward
Sample	Date	$HPO_4^{=}$	$HPO_4^{=}$	$HSIO_3^{-}$	$HSIO_3^{-}$
BAK_FCEB_F	04/04/18	0.1394	<MDL	0.0874	0.0710
BAK_FCEB_F	03/01/18	0.1752	<MDL	0.2428	0.0290
BAK020_BF	04/04/18	0.0372	<MDL	<MDL	0.0210
BAK020_SF	04/04/18	0.0235	<MDL	<MDL	0.0260
BAK025_BF	03/01/18	0.0096	<MDL	0.1376	<MDL
BAK025_SF	03/01/18	0.0090	<MDL	0.1417	<MDL
BAK029_BF	03/01/18	0.0049	<MDL	0.2323	<MDL
BAK029_SF	03/01/18	0.0062	<MDL	0.2665	<MDL
BAK030_SF	04/04/18	0.0431	0.0360	0.0880	0.0800
BOC_FCEB_F	03/07/18	0.1331	<MDL	0.1684	0.0640
BOC070_BF	03/07/18	0.0164	<MDL	0.1257	0.0280
BOC070_SF	03/14/18	0.0533	<MDL	0.2126	0.0360
BOC080_SF	03/07/18	0.0213	<MDL	0.2083	0.0930
HIL_FCEB_F	04/03/18	0.1340	<MDL	0.2358	0.1310
HIL050_BF	04/03/18	<MDL	<MDL	<MDL	<MDL
HIL050_SF	04/03/18	0.0125	<MDL	<MDL	<MDL
HIL055_BF	04/03/18	<MDL	<MDL	<MDL	<MDL
HIL055_SF	04/03/18	0.0036	<MDL	<MDL	<MDL
HIL057_BF	04/03/18	<MDL	<MDL	<MDL	<MDL
HIL057_SF	04/03/18	0.0259	<MDL	<MDL	<MDL
HIL060_SF	04/03/18	0.0284	<MDL	<MDL	0.0180
ILW_FCEB_F	03/15/18	0.1383	<MDL	0.1169	0.0840
ILW_FCEB_F	06/03/18	0.1519	<MDL	0.2316	0.0970
ILW110_BF	06/03/18	0.0268	<MDL	0.3904	0.0300
ILW110_SF	06/03/18	0.0646	<MDL	1.0581	<MDL
ILW111_BF	06/03/18	0.0211	<MDL	0.2771	<MDL
ILW111_SF	06/03/18	0.0588	<MDL	0.2871	<MDL
ILW115_BF	03/15/18	0.0297	<MDL	<MDL	<MDL
ILW115_SF	03/15/18	0.0373	<MDL	<MDL	<MDL
ILW119_BF	03/15/18	0.0323	<MDL	<MDL	<MDL
ILW119_SF	03/15/18	0.0430	<MDL	<MDL	<MDL
JUP_FCEB_F	03/14/18	0.1405	<MDL	0.1873	0.0700
JUP120_BF	03/14/18	<MDL	<MDL	0.1151	0.0190
JUP120_SF	03/01/18	<MDL	<MDL	0.1118	<MDL
JUP124_BF	03/14/18	0.0300	<MDL	0.0533	<MDL
JUP124_SF	03/14/18	0.0098	<MDL	0.0412	<MDL
JUP128_BF	03/14/18	0.0087	<MDL	0.0803	<MDL
JUP128_SF	03/14/18	0.0260	<MDL	0.0367	<MDL