BIG CYPRESS REMAP

REGIONAL ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM

2023 Water Quality, Nutrients, Mercury, and Soils

EPA - Region 4
Water Division
Atlanta, Georgia

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency's Everglades and Big Cypress Regional Environmental Monitoring and Assessment Program (REMAP) is a comprehensive, long-term initiative designed to provide critical scientific data for the restoration and management of these unique South Florida ecosystems. Since its inception in 1993, REMAP has completed five phases of sampling across 1,288 locations, collecting extensive data on water quality, soil composition, and vegetation. This report presents findings from the October 2023 sampling event in eastern Big Cypress National Preserve (BCNP), extending the data available for documenting conditions ahead of proposed restoration efforts, including the Western Everglades Restoration Project (WERP).

THE STUDY

Objective and Scope:
The study was conducted in the eastern portion of BCNP. Study objectives include documenting environmental conditions and determining if they are improving or declining. A probability-based sampling design was used to quantitatively assess conditions at 38 marsh sites within a 106 square-mile open marsh footprint. This design ensures that every part of the sampled area has an equal chance of selection, providing statistically robust and spatially optimal estimates of water quality and biogeochemical conditions.

Field and Laboratory Methodology:
Utilizing advanced field protocols and helicopter-accessible site selection, the 11-day sampling event generated nearly 1,900 field measurements and 700 samples across a suite of media: surface water, soil, floc, periphyton (algal communities), mosquitofish and sawgrass vegetation. Samples were analyzed for key indicators of environmental health such as phosphorus, nitrogen, sulfur, carbon and mercury. Rigorous quality assurance protocols ensured data reliability.

Data Analysis:
USEPA REMAP 2023 data were compared to REMAP 1995-96 data, South Florida Water Management District canal and marsh data from long-term networks (2012-2025 and 1994-2011), and soils (2003) data. Rigorous statistical procedures were used to determine whether there were latitudinal gradients across space, differences between datasets, and relationships with other parameters.

KEY FINDINGS

Phosphorus Gradients:
There was a strong latitudinal gradient in surface water total phosphorus (TP) concentrations with lower concentrations in the southern marshes (< 8 parts per billion), an area driven primarily by rainfall and sheetflow, and higher concentrations in the northern areas (15 to 33 parts per billion). About 78% of the marsh had a soil TP concentration below 500 parts per million, a concentration of environmental interest. There were also strong correlations between TP in soil and other soil constituents, such as nitrogen, carbon and organic matter.

Nitrogen and Chlorophyll:
Nitrogen and chlorophyll *a* concentrations in surface water further elucidate nutrient-related conditions, which are critical for understanding ecosystem health and the potential for eutrophication. Although there were areas with higher nitrogen concentrations in both the north and south, there was no overall latitudinal gradient. The southernmost stations also had the highest chloride concentrations and may indicate estuarine influence. Chlorophyll *a* did not have a latitudinal gradient, and concentrations were all below those of ecological concern.

Sulfur Low Overall:
Sulfur has been of concern in the adjacent Everglades for the role it may play, along with other factors, in mercury bioaccumulation. Only one BCNP station had bottom water sulfide detected, with all other stations below 15 parts per billion. Only 4 stations had surface water sulfate detected, with all other stations below 21 parts per billion. Overall, these data did not indicate a sulfur enrichment concern.

Dissolved Oxygen and pH:
Dissolved oxygen (DO) in the surface water of these shallow marshes ranged from 0.9 to 12.32 mg/L (10% to 170% saturation). DO had a significant relationship with time of day and temperature, consistent with the influence of natural daily photosynthesis and respiration. Surface water pH had

a significant relationship with time of day, temperature, and DO. Overall, there were no DO or pH results of concern.

Water Quality Seasonality:
Dry season water quality data had higher concentrations than the wet season for total phosphorus, chloride, specific conductance and total organic carbon. As the wet season progresses into the dry season and the input of clean rainfall diminishes, these constituents tend to concentrate as the water becomes shallower.

Other Water Quality and Soil Results: Surface water specific conductance and dissolved carbon did not have a significant longitudinal gradient. There were no concentrations of concern for specific conductance or chloride. Among soil analytes there were strong relationships among nutrients, and there were no significant longitudinal gradients.

Mercury Continues to be a Concern:
Mercury concentrations were elevated in some mosquitofish. Mosquitofish are a key food item for other fish, which are then consumed by gamefish and wading birds. Therefore, mosquitofish are important indicators of risk to both human and ecological health. About 36% of the marsh area had prey fish with total mercury concentrations above 77 parts per billion, the maximum level USEPA recommends as being protective of predators such as birds and mammals. These mercury concentrations did not have a latitudinal gradient. Florida has posted consumption advisories for gamefish throughout BCNP to protect human health.

The 2023 REMAP data document the current state of the Big Cypress marsh ecosystem, highlighting spatial patterns in water quality, nutrient distribution, and mercury bioaccumulation. The REMAP initiative continues to be a valuable tool for ecosystem management in South Florida. These data support decision-making by Tribes, and federal and state agencies. Results presented here illuminate environmental challenges and underscore the importance of sustained, collaborative restoration efforts across agencies and stakeholders. Continued, science-based monitoring is essential for documenting conditions, identifying challenges and opportunities, and elucidating changes over time.

USEPA REMAP data and reports are available at: **www.epa.gov/everglades/environmental-monitoring-everglades**

ABBREVIATIONS

cc = cubic centimeters, cm^3
cm = centimeters
ft = feet
g = grams
g/cc = grams per cubic centimeter
n = number or count
ppb = parts per billion (µg/L)
ppm = parts per million (mg/L) or (mg/kg)
mg/kg = milligrams per kilogram (parts per million, ppm)
mg/L = milligrams per liter (parts per million, ppm)
ng/g = nanograms per gram (parts per billion, ppb)
ng/L = nanograms per liter (parts per trillion, ppt)
µg/cc = micrograms per cubic centimeter
µg/g = micrograms per gram (parts per million, ppm)
µg/kg = micrograms per kilogram (parts per billion, ppb)
µM = micromolar = 1 micromole per liter (µmol/L)
µmhos/cm = micromhos per centimeter
AGM = Annual Geometric Mean
APA = Alkaline Phosphatase Activity
BCFm = Bioconcentration Factor
BCNP = Big Cypress National Preserve
BICY = Big Cypress National Preserve
BD = Bulk Density
CDF = Cumulative Distribution Function
CERP = Comprehensive Everglades Restoration Plan
CI = Confidence Interval
DIN = Dissolved Inorganic Nitrogen
DO = Dissolved Oxygen
DOC = Dissolved Organic Carbon
DON = Dissolved Organic Nitrogen
DOM = Dissolved Organic Matter
DQO = Data Quality Objective
ENP = Everglades National Park
EMAP = Environmental Monitoring and Assessment Program
FDEP = Florida Department of Environmental Protection
FDHRS = Florida Department of Health and Rehabilitative Services
FDOH = Florida Department of Health
FIU = Florida International University

FWM = Flow-Weighted Mean
HAB = Harmful Algal Bloom
LSASD = USEPA Region 4 Laboratory Services and Applied Science Division
MAAR = Miccosukee Tribe of Indians of Florida's Alligator Alley Reservation
MDL = Method Detection Limit
MeHg = Methylmercury
N = Nitrogen
NADP = National Atmospheric Deposition Program
NASEM = National Academies of Sciences, Engineering, and Medicine
NPS = National Park Service
OFW = Outstanding Florida Water
OM = Organic Matter
ORD = USEPA Office of Research and Development
ORP = Oxidation Reduction Potential
P = Phosphorus
QA = Quality Assurance
QAPP = Quality Assurance Project Plan
RECOVER = Restoration Coordination and Verification
REMAP = Regional Environmental Monitoring and Assessment Program
S = Sulfur
SBCR = Seminole Tribe of Florida's Big Cypress Reservation
SFWMD = South Florida Water Management District
SRP = Soluble Reactive Phosphorus
SSAC = Site-Specific Alternative Criterion
STA = Stormwater Treatment Area
TC = Total Carbon
THg = Total Mercury
TIN = Total Inorganic Nitrogen
TOC = Total Organic Carbon
TON = Total Organic Nitrogen
TMDL = Total Maximum Daily Load
TN = Total Nitrogen
TP = Total Phosphorus
USACE = United States Army Corps of Engineers
USDOI = United States Department of Interior
USEPA = United States Environmental Protection Agency
USFWS = United States Fish and Wildlife Service
USGS = United States Geological Survey
WCA = Everglades Water Conservation Area
WD = Water Depth
WY = Water Year, May to April (e.g., WY 24 is May 1, 2023 to April 30, 2024)

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This report was reviewed by: Stacie Flood, SFWMD; Mallory Hunt, Florida Department of Environmental Protection (FDEP); Jodie Hutchins, SFWMD; Nenad Iricanin, SFWMD; Susan Janssen, United States Geological Survey; Brett Poulin, University of California, Davis; Mark Shafer, US Army Corps of Engineers; and Mailin SotoLongo-Lopez, FDEP.

THE FOLLOWING INDIVIDUALS HELPED MAKE THIS PROGRAM POSSIBLE:

Alion, Inc.
Don Fortson - base lab manager
Michael Keller – data review supervisor
Alexander Greer – data reviewer
Young Chul Park - data reviewer

Florida International University
Yong Cai – principal investigator, mercury
Yan Ding – nutrient laboratory director
Daniel Gann – principal investigator, remote sensing
Ingrid Ley – nutrient laboratory quality assurance officer
Guangliang Liu – principal investigator, mercury
Pedro Lorenzo – analytical laboratory
Paulo Olivas – principal investigator, soil biogeochemistry

HMC Helicopters, Inc.
William Graham – pilot
Alejandro Lasso - pilot
Carlos Luque- Chief Pilot
Lenny Montas - mechanic/fuel truck driver

Miccosukee Tribe of Indians of Florida
Kevin Cuniff- helicopter refueling zone
Gene Duncan - support

South Florida Water Management District
John Mitnik – helicopter landing zone permits

US Department of the Interior

National Park Service

Big Cypress National Preserve
Tom Forsyth – Superintendent
Steve Schulze - permitting

Everglades National Park
Donatto Surratt - project administration, data statistics, report writing team.

Aviation
Nicholas Connolly – BCNP Assistant Aviation Program Manager
Josh Dozmati – ENP Lead Helitack
Tom Fielden – Helicopter Manager
Ashlee Giradi – BCNP Lead Helitack
Andrew Gill – ENP Aviation Program Manager
Fred Goodwin – BCNP fleet rotor wing pilot
Jeff Kemper - BCNP Lead Helitack
Micheal Roof – BCNP Aviation Program Manager
Richard Seferian – helicopter crewmember
J. R. Sullivan – Unit Aviation Manager

Administration
Tylan Dean – Biological Sciences Branch Chief
Melodie Naja – South Florida Natural Resources Center Director
Pedro Ramos – Superintendent
Erik Stabenau – Restoration Sciences Branch Chief

US Department of the Interior
Office of Aircraft Services
Cannon Mix – helicopter safety training
Travis Touchette - helicopter safety training

USEPA Office of Research and Development
National Health and Environmental Effects Research Laboratory
Michael Dumelle – program sampling design
Tony Olsen – program sampling design

USEPA Region 4
Office of Public Affairs
Linda Purvis – Public Affairs Specialist, Graphic Designer

Water Division
Becky Allenbach – Senior Advisor to the Director
Jon Becker – geographic information systems
Kathlene Butler - Division Director
Chris Decker – Assistant Program Leader
Denisse Diaz - Deputy Division Director
Austin Fitzgerald – base lab support, field sampling
Jeaneanne Gettle - Division Director
Chris McArthur – base lab support, field quality assurance officer
Daniel Scheidt – Associate Program Leader
Jennifer Shadle - administration
Alison Van Wyk – field sampling
Chelsea Weiskerger – base lab, field quality assurance, field sampling, data statistics

Laboratory Services and Applied Science Division
Sandra Aker – Field Services Branch Chief
Tony Carroll - laboratory analysis
Wildelys Colon-Jusino – laboratory analysis
John Davis – field sampling, program sampling design
Sue Dye – field sampling, project quality assurance plan, field data and stepwise procedure, training
Morris Flexner – base lab support, instrument manager
Denise Goddard - data quality assurance
Peter Kalla - Program Leader
Tearrany Jackson – field chemist
Hunter Johnson - Division Director
Yvette Lane-Walcott – base lab support
Derek Little – field equipment procurement and preparation, field sampling, project quality assurance plan, field data and stepwise procedure
Stephanie McCarthy – Quality Assurance Manager
Daniel McCay - field sampling
Christopher McHugh – field chemist
Jon McMahan - field sampling
Austin Murray – laboratory analysis
Joel Owen – field sampling
Mel Parsons – field sampling

Doug Peters – field sampling
Darren Porter – administration
Michael Roberts - field chemist
John Ruiz – field sampling
Asher Sampong – field sampling
Kevin Simmons – sample manager
Bill Simpson – laboratory analysis
Eric Taylor – field chemist, method development and training
Jeff Wilmoth – laboratory data quality assurance
Greg White - Field Services Section Chief
Kayle Whiten – laboratory analysis
Paula Whiting – base lab manager
Stephanie Wimpey – data quality assurance

INTRODUCTION AND PURPOSE

The United States Environmental Protection Agency (USEPA) Everglades and Big Cypress Regional Environmental Monitoring and Assessment Program (REMAP) is a unique, comprehensive, long-term monitoring and assessment effort. Its goal is to provide critical scientific information for decisions about the protection, management and restoration of the Everglades and Big Cypress ecosystems. Since 1993, five phases of marsh sampling and one phase of canal sampling have been completed at 1288 different locations throughout the freshwater Everglades and Big Cypress landscape. REMAP is unique to South Florida environmental monitoring in consistently combining several aspects of scientific study: a probability-based sampling design which makes it possible to make quantitative statements across space about conditions; multi-media sampling (water, soil, vegetation, fish); and extensive spatial coverage. By comparing the results from different sampling events, it is possible to determine whether conditions improved, did not change, or degraded. REMAP data have been used for various purposes by over 30 entities including federal and state agencies, Tribes, agriculture, the public, non-governmental organizations, and the National Academies of Sciences, Engineering and Medicine.

This report documents conditions in eastern Big Cypress National Preserve (Photo 1) during October 2023 and compares them to the 1995-96 REMAP sampling efforts and SFWMD historic sampling. These results provide a snapshot of conditions prior to future restoration efforts. Comparisons are made to data from sampling efforts by Federal and Florida agencies.

Photo 1. Cypress dome in Big Cypress National Preserve - Station 2009.

BACKGROUND

BIG CYPRESS NATIONAL PRESERVE

Big Cypress National Preserve encompasses 729,000 acres of a largely freshwater wetland ecosystem that offers refuge to a wide variety of plants and animals. The Preserve was established for the preservation, conservation, and protection of the natural, scenic, hydrologic, floral and faunal, and recreational values of the Big Cypress watershed, and to provide for the enhancement of public enjoyment (Photo 2, Photo 3). Water is the unifying force of the Preserve, connecting its five habitats: hardwood hammocks, pinelands, prairies, cypress swamps, and estuaries. These diverse habitats are home to many plants and animals that are listed by Florida or the United States as threatened or endangered. The Preserve protects the flow of freshwater from the Big Cypress Swamp into estuaries of neighboring Everglades National Park and the Ten Thousand Islands National Wildlife Refuge (National Park Service 2016).

Photo 2. Big Cypress National Preserve – view from helicopter.

Photo 3. Cypress swamp - Loop Road.

Davis (1943, pages 48-49) described the largely undisturbed Big Cypress region as about 1200 square miles. “The eastern boundary of the Big Cypress extends over into the Everglades basin, but these cypress forest areas, even if in the Everglades basin, are not considered a part of the Everglades. The term Big Cypress does not mean swamp forests of large cypress trees but rather large areas with mostly small to medium sized cypress trees where swamps of tall trees may occur. Moreover, cypress forests do not cover the whole region as pine forests and marl soil wet-prairies cover large areas.”

The Big Cypress area delineated by Davis in 1943 was generalized into a 2200 square mile area by USGS (Parker et al. 1955). The eastern 65% of this area (366,311 hectares or about 729,000 acres)

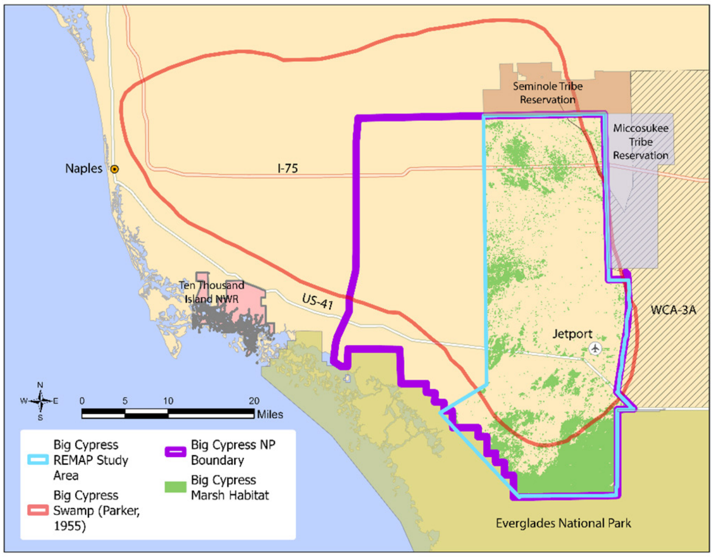


Figure 1. The Big Cypress Region and 2023 REMAP marsh habitat sampling area.

was included within the boundary of Big Cypress National Preserve when it was established in 1974 and expanded in 1988. The 2023 Big Cypress REMAP study area encompasses the eastern 48% of Big Cypress National Preserve (176,932 hectares or 437,209 acres) (Figure 1). This study area is bounded on the east by Everglades Water Conservation Area 3A (WCA3A) and the Miccosukee Tribe of Indians of Florida's Federal Reservation in WCA3A, and on the north by the Seminole Tribe of Florida's Big Cypress Reservation. The western boundary approximates both the Western Everglades Restoration Plan (WERP) project area western boundary (USACE 2024), and the boundary for REMAP 1995-96. The southern boundary approximates the southern edge of the freshwater marsh, and was determined by using GoogleEarth (accessed December 2022) to estimate the southern edge of freshwater vegetation.

RESTORATION EFFORTS

Natural areas in the Everglades ecosystem compete for water with urban and agricultural areas, and degraded water quality adversely affects several South Florida waterbodies. Declines in environmental quality, combined with threats to the health of the remaining Everglades ecosystem, led to extensive restoration planning in the 1990s and the authorization of the Comprehensive Everglades Restoration Plan (CERP) by the U. S. Congress in 2000. This unprecedented plan, the most ambitious ecosystem restoration effort in the nation, involves the expenditure of $23 billion (USACE and USDOI 2020) in a multidecadal effort to achieve ecological restoration by reestablishing the hydrologic characteristics of the 18,000-square mile Everglades ecosystem, and managing the water system to simultaneously meet the needs of the natural and growing human systems. The U. S. Army Corps of Engineers (USACE) is the lead federal agency and the South Florida Water Management District (SFWMD) is the lead state agency. The Plan has 68 components (USACE and SFWMD 1999), some of which are in the planning, design, construction, or operational phase (NASEM 2024).

WERP is a project within the CERP plan. The purposes of WERP, as described in the final project Environmental Impact Statement (USACE 2024), are to improve the quantity, quality, timing, and distribution of water needed to restore and reconnect the western Everglades ecosystem while ensuring that water quality standards are met. The WERP study area includes the Seminole Tribe of Florida's Big Cypress Reservation (SBCR), the Miccosukee Tribe of Indians' Alligator Alley Reservation (MAAR), and Big Cypress National Preserve (BCNP, Figure 2).

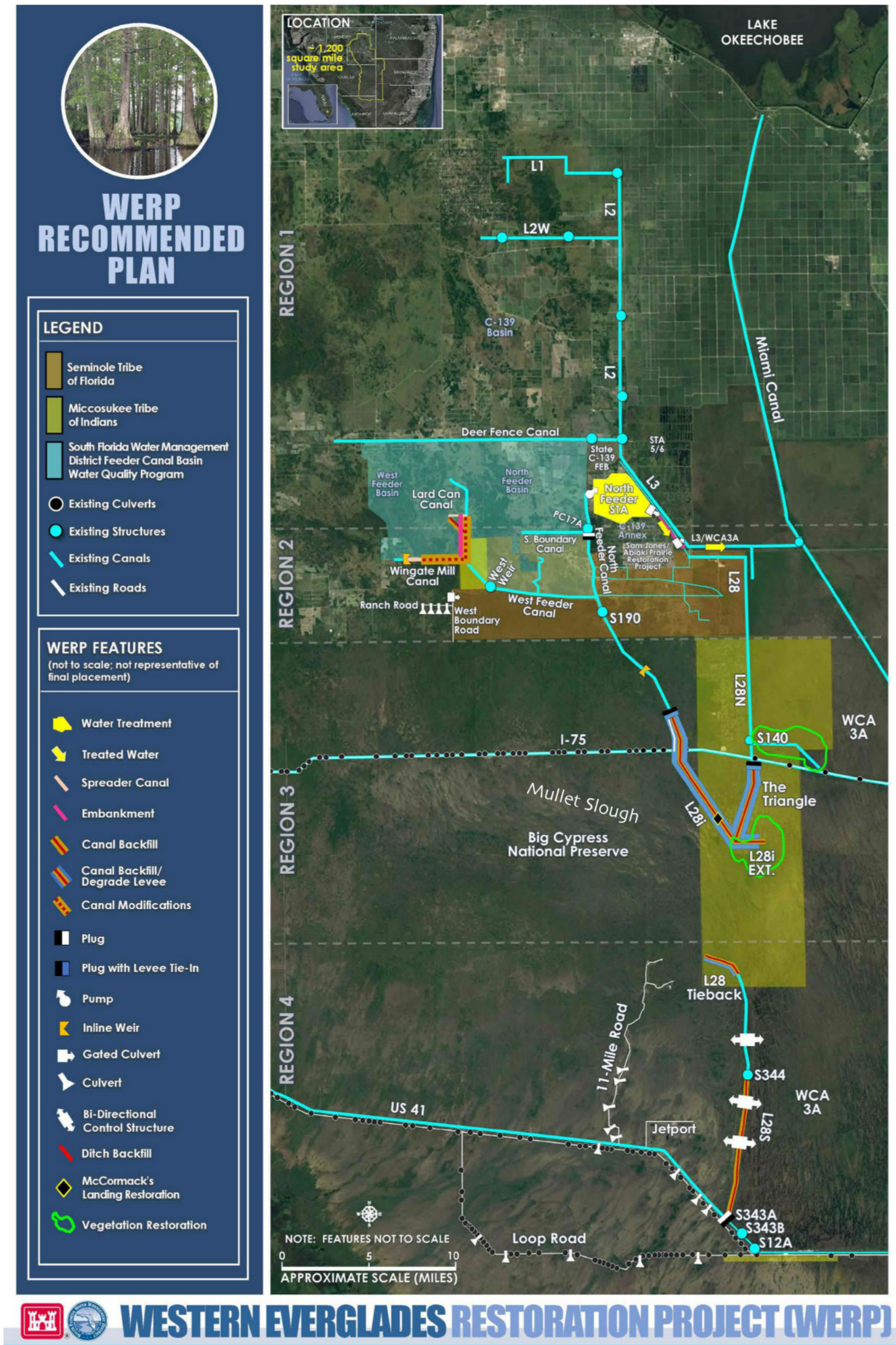


Figure 2. Map of WERP recommended plan features (adapted from USACE 2024).

Planning began in 2016 and culminated with the completion of the final Project Implementation Report and Environmental Impact Statement in 2024. Later in 2024 the U.S. Army Corps of Engineers Commanding General and Chief of Engineers signed the Chief's Report for WERP. The recommended plan will begin the process of federal review and congressional consideration for inclusion in future Energy and Water Appropriations Acts legislation to fund implementation.

WERP includes multiple features that would redistribute water to several major remnant flow-ways upstream and within BCNP (Figure 2). A Stormwater Treatment Area north of BCNP will remove phosphorus and direct treated water from agricultural basins to the northwest portion of WCA3A. West of the SBCR, rerouting water from an agricultural sub-basin south into forested wetlands by filling canals will facilitate hydropattern restoration in portions of the SBCR, BCNP, and MAAR. Backfilling portions of the L-28I Canal and the L-28N Canal in the northeast portion of BCNP, in combination with degrading associated levees, will re-establish a flowing system in areas adjacent to Mullet Slough within BCNP. On the eastern boundary of BCNP, the L28 Levee will be degraded and the canal will be filled reconnecting portions of BCNP to western WCA3A. Southern portions of BCNP are expected to receive increased flows (USACE 2024).

HISTORY OF WATER QUALITY SAMPLING IN BIG CYPRESS NATIONAL PRESERVE

The historical water quality monitoring in Big Cypress National Preserve (BCNP) described here is largely based on summaries from the U.S. Geological Survey (USGS) (Miller et al. 2004) and Schneider et al. (1996). In the 1960s, the area that would become the Preserve was threatened by multiple forms of development. The most prominent threat was a proposal to construct the Dade Collier Transition and Training Airport, a.k.a. "the Jetport", which would have been the largest airport in the world at that time (NPS 2016). In a 1969 report on the environmental impact of the jetport (Photo 4), the United States Department of Interior (USDOI) stated that "many intricate and sensitive interrelationships between the various components of the Big Cypress ecosystem are largely unknown, but almost certainly they are integrated around a common need for water quality" (USDOI 1969, page 67). The study indicated that the proposed Jetport would adversely affect not only the ecosystem of Everglades National Park, but South Florida as well. The federal government and others opposed the construction of the jetport at that location.

USDOI then undertook a broader ecological study of South Florida, resulting in 51 reports, which are summarized in McPherson et al. (1976). At the request of the Secretary of the Interior, the USGS undertook an evaluation of the hydrologic and water quality characteristics of the Big Cypress

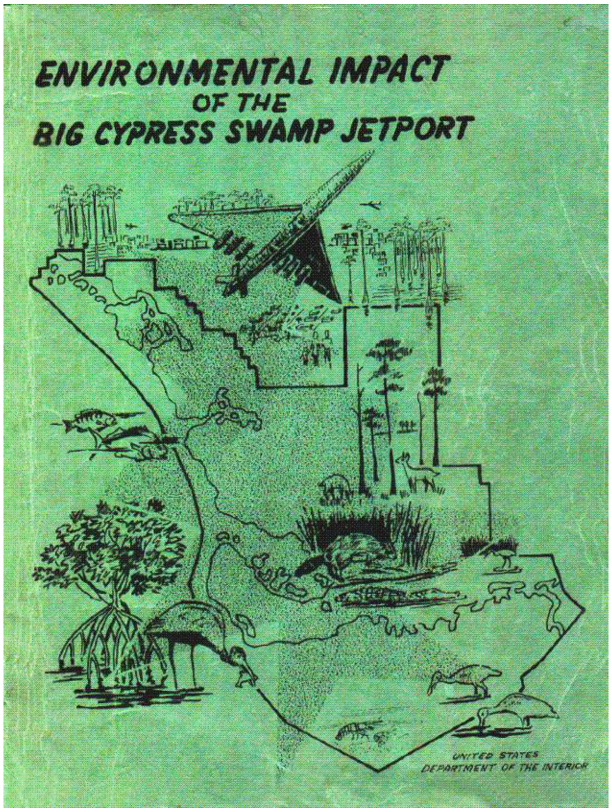


Photo 4. Cover of 1969 DOI Report.

Swamp from 1969-70. The resulting report (Klein et al. 1970) documents conditions in the Big Cypress Swamp prior to establishment of the Preserve by the U. S. Congress in 1974. Much of the early USGS water quality data were collected in the vicinity of the Jetport (McPherson 1969, 1971). USEPA also undertook water quality and ecological studies (Little et al. 1970, USEPA 1973). USGS continued water quality monitoring work for several decades, often in collaboration with the National Park Service (NPS): Kolipinski and Higer 1969; Kolipinski et al. 1971; Freiberger 1972; Waller 1982; Klein et al. 1970, 1975. These data are generally concentrated in areas near roads and canals, and may reflect some minor human influences on water quality. Many of these efforts are summarized in Duever et al. (1986) and McPherson and Halley (1996).

In the 1990s NPS and SFWMD established a collaborative water quality marsh monitoring program that was active from 1994-2011 (Sobczak 2002, NPS 2011), and a Loop Road canal monitoring program that began in 2012 and continued in 2025.

REMAP

BIOGEOCHEMICAL SAMPLING

The elements carbon, nitrogen, phosphorus, oxygen, hydrogen and sulfur are essential components of living organisms. Each of these elements cycles through ecosystems, plants, animals, air, water, and soil. These cycles are called biogeochemical cycles because they include a variety of biological, geological, and chemical processes. A major focus of REMAP is documenting conditions for these elements. These data are referred to as biogeochemical data, and they are the focus of this report.

PROGRAM HISTORY

Photo 5. Helicopters were used to access sample stations in BCNP.

USEPA REMAP began sampling in the freshwater portion of the Everglades and Big Cypress in 1993 (Phase I). REMAP was the first effort to sample canals at randomly located probability-based stations away from water control structures. Everglades and Big Cypress canals were sampled during the wet season in September 1993 and 1994, and during the dry season in May 1994 and 1995 (about 50 sites per sampling cycle) (Figure 3, Table 1, Stober et al. 1995, 1998; Scheidt et al. 2000). Four Everglades marsh transects (45 stations) along phosphorus gradients downstream of water discharge structures were sampled during April 1994. Marshes were sampled at random locations in Phase I during the dry season (April 1995 and May 1996) and wet season (September 1995 and 1996), at about 120 sites per sampling cycle (Stober et al. 1998). Wetlands in the eastern portion of Big Cypress National Preserve, the Seminole Tribe of Indians' Big Cypress Federal Reservation, and the Miccosukee Tribe of Indians of Florida's Federal Reservation in Everglades WCA3A were also sampled during Phase I. During Phase II (May 1999 and September 1999), the Everglades marsh was sampled at another 119 sites per cycle (Stober et al. 2001a, 2001b). Phase III was conducted in May and November of 2005 at another 228 Everglades marsh sites (Richards and Philippi 2005; Scheidt and Kalla 2007; Richards et al. 2008). Phase IV was conducted during September 2013 at 51 marsh sites (USEPA 2014; Richards et al. 2017) and September of 2014 at 118 marsh sites (Kalla and Scheidt 2017; Scheidt, Kalla and Surratt 2021).

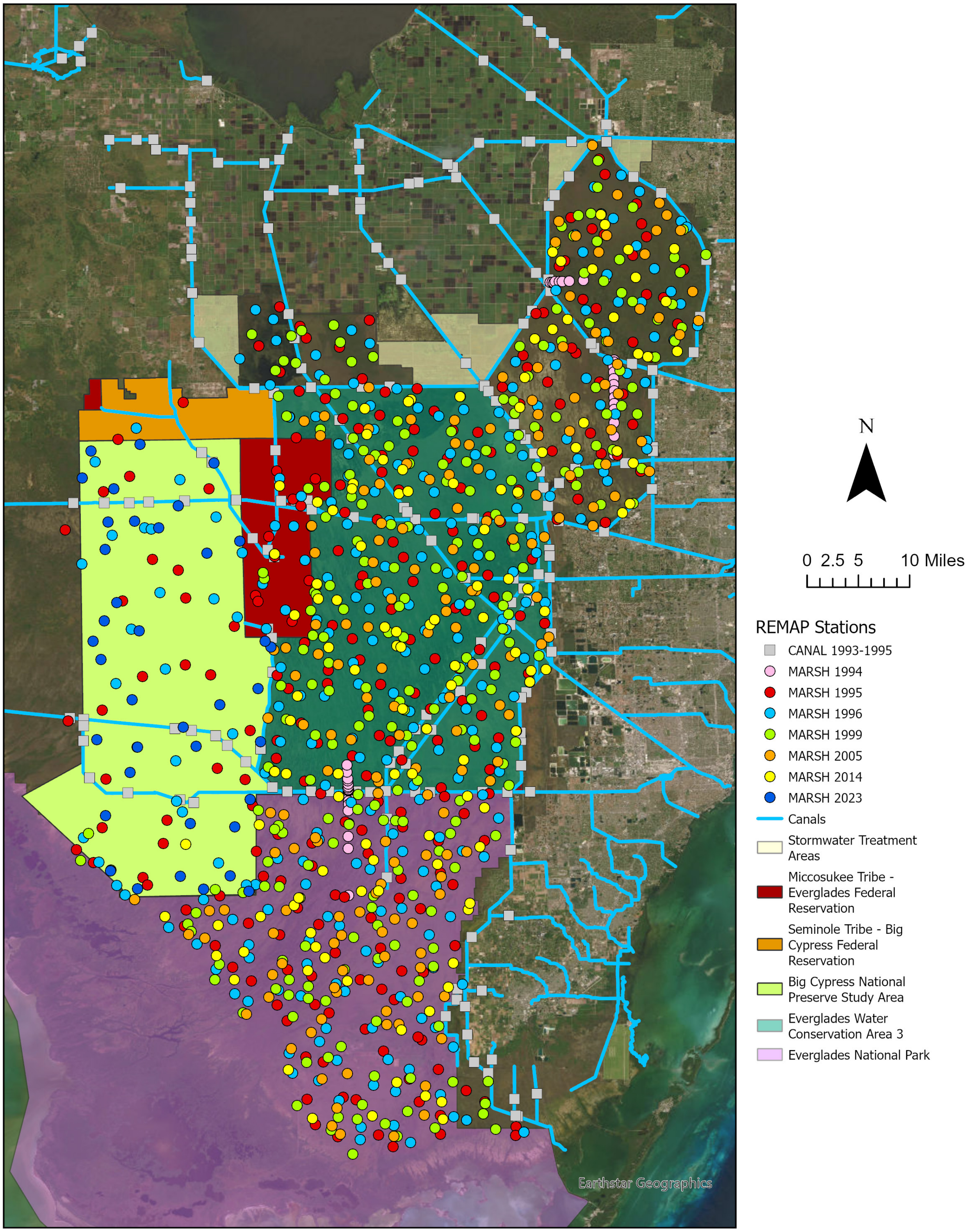


Figure 3. All 1288 stations sampled by REMAP from 1993-2023. Canals - 199 randomly located stations (4 sampling events 1993-1995), and marsh - 45 transects stations (1994) and 1044 randomly located stations (11 sampling events across 5 phases 1995-2023). See Table 1.

REMAP Phase V provides a snapshot of conditions within Big Cypress during an 11-day sampling window, October 16 - 26, 2023 (Photo 5). This wet season sampling was the first REMAP event in Big Cypress since 1995-1996. Conclusions about conditions are based on the freshwater marsh study area represented by the station locations. Surface water constituents such as sulfate, specific conductance, and nutrients can change quickly due to local rain events. Surface water depth at a marsh location may be several feet during the wet season and zero or only a few inches during the winter dry season (Klein et al. 1970, Schneider et al. 1996). The concentrations observed during an 11-day REMAP sampling period may not represent conditions during other weeks in the same wet season. Consequently, statements or inferences should not be made about conditions during time periods that were not sampled. Long-term monitoring networks at fixed stations sampled more frequently (such as Big Cypress water quality monitoring efforts conducted by the SFWMD, USGS, or NPS) are better suited for making statements about surface water conditions at a location throughout the year and for identifying trends across consecutive years. Traditional water quality trend analyses are not included in this report.

With completion of the Phase V Big Cypress sampling in 2023, REMAP has sampled 1089 different marsh locations and 199 canal locations throughout the freshwater Everglades and Big Cypress, representing the ecological condition in about 3,000 square miles of freshwater marsh and over 750 miles of canals.

Phase	I	II	III	IV	V
Year(s)	1993 -1996	1999	2005	2013 - 2014	2023
Distinguishing features	Baseline data. Multiple stressors. Big Cypress & canals included.	Change detection. Added periphyton assessment & plant studies. Omitted Big Cypress & canals.	Change detection. Added food web studies & invasive plant survey.	Change detection. Wet season only. Omitted aquatic community ecology & some macrophytic plant studies.	Change detection. Wet season only. Big Cypress only.
Canal Stations	199	0	0	0	0
Everglades Marsh Stations	217 dry season 216 wet season 433 total	119 dry season 119 wet season 238 total	109 dry season 119 wet season 228 total	51 wet season 2013 118 wet season 2014 169 total	0
Big Cypress Marsh Stations	23 dry season 24 wet season 47 total	0	0	0	38 wet season
	Biogeochemical Media				
Surface water	X	X	X	X	X
Floc		X	X	X	X
Porewater		X	X		
Bottom water				X	X
Soil	X	X	X	X	X
Periphyton	X	X	X	X	X
Mosquitofish	X	X	X	X	X
Macrophytic Vegetation		X		X	X
	Macrophytic Plants				
Qualitative habitat categorization	X	X	X	X	X
Species frequency		X	X		
Classified vegetation mapping		X	X	X	X
Invasive plant survey			X		
	Aquatic Community Ecology				
Periphyton assemblage		X	X		
Mosquitofish food habits		X			
Macroinvertebrate assemblage			X		
Isotope studies			X		

Table 1. Big Cypress and Everglades REMAP history showing phases, media and indicators.

PROGRAM COORDINATION

Throughout REMAP planning, emphasis has been placed on assuring that data meet key information needs of managers and scientists involved with ecosystem protection and restoration. REMAP Program leaders met with Florida and Federal managers and scientists involved with CERP and Everglades phosphorus and mercury control efforts, including Everglades National Park (Park), Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge), USACE, SFWMD and the Florida Department of Environmental Protection (FDEP). REMAP study plans have been subject to external scientific peer review by these agencies and by the USEPA REMAP national program office. Efforts have been coordinated across agencies to avoid redundancy and maximize the utility of the information gained. Funding for various REMAP phases has been provided by USEPA, the Park, Refuge, USACE, and FDEP.

Everglades REMAP Program data have been used for many purposes by environmental decision makers and scientists from over 30 Florida or federal agencies, the Miccosukee and Seminole Tribes, non-governmental organizations, agricultural and environmental interests and the National Academies of Sciences, Engineering and Medicine's Committee on Independent Scientific Review of Everglades Restoration Progress. Program data have been used in over 40 peer-reviewed scientific journal publications or agency reports. REMAP Program reports or publications with REMAP data have been cited thousands of times (see summary in Scheidt, Kalla and Surratt, 2021).

CERP has a multi-agency team of scientists, modelers, planners and resource specialists (Restoration Coordination and Verification, RECOVER) who organize and apply scientific and technical information in ways that are essential in supporting the objectives of the restoration program. RECOVER is organized by the USACE and SFWMD and includes representatives from 10 participating federal and state agencies and Tribes. RECOVER has established a Southwest Florida module, and is updating a Big Cypress Conceptual Ecological Model that illustrates drivers, stressors, ecological effects and attributes in the region. In September 2021, RECOVER stated that REMAP: "is an invaluable assessment tool for quantifying environmental health and evaluating large-scale foundational trends"; there is "no other systemwide monitoring program like REMAP"; and "REMAP helps environmental protection and water managers, ecologists, and biologists to understand attributes in light of…anthropogenic impacts, such as the interplay of soil, sulfur, nutrients, fish and mercury" (RECOVER 2021).

The U. S. Congress established the South Florida Ecosystem Restoration Task Force in the Water Resources Development Act of 1996. The Task Force's objectives include: exchange information to promote ecosystem restoration and maintenance, facilitate the resolution of conflicts, and coordinate scientific and other research. The Task Force established a 25-member Working Group representing Tribal, local, state and federal entities, that assists the Task Force. An additional 14-member Science Coordination Group, comprised of Tribal, federal, state and local government groups, assists the Task Force in coordinating scientific research and restoration activities. In 2021 the Working Group and Science Coordination Group unanimously passed a resolution stating that REMAP has produced unique and valuable scientific information relevant to south Florida scientists and managers, and fully supporting the concept of a another REMAP sampling effort.

PROBABILITY SAMPLES AND SITE SELECTION

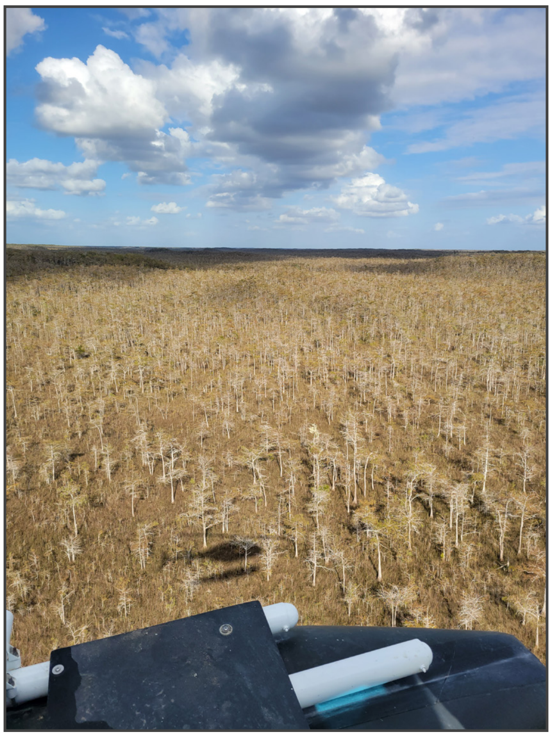


Photo 6. Dense tree cover poses risk for landing helicopters.

The objective of the 2023 sampling was to quantitatively estimate current conditions within the Big Cypress REMAP subarea across space. These data can be used to: 1) detect change, or lack thereof, compared to the 1995-96 REMAP sampling; and 2) document conditions prior to future restoration work such as WERP. For this purpose, REMAP used a statistical, probability-based sampling strategy, similar to polls or surveys. This approach was employed by USEPA throughout the United States in the 1990s (USEPA 1993, Thornton et al. 1994, Diaz-Ramos et al. 1996, Stevens 1997), and has been applied to lakes, rivers, streams, wetlands, estuaries, forests, arid ecosystems, and agroecosystems (Olsen et al. 1999, USEPA 1993, 1995). The overall approach has been reviewed by the National Academies of Sciences, Engineering and Medicine, and can be used to identify associations between human-induced stresses and ecological condition.

The specific probability-based design was developed from the Environmental Monitoring and Assessment Program (EMAP) base grid, a generalized random-tessellation stratified approach (Stevens and Olsen 2004). Because this approach selects sampling locations at random, every member of the population has a quantifiable and equal chance of being selected. Probabilistic designs have two strengths: (a) the results represent the spatial distributions of the environmental parameters that were measured; and (b) the results can be used to estimate, with known confidence, the proportion of the study area that was in any given condition, and how much this proportion changed from other sampling events.

The Phase V REMAP sampling design process began in 2021 with similar proposed densities of sampling stations for all five Program subareas (Big Cypress, Everglades National Park, Arthur R. Marshall Loxahatchee National Wildlife Refuge, and Everglades WCA 2 and WCA 3). This resulted in 42 target stations within the eastern portion of Big Cypress National Preserve. To select these stations, USEPA employed a modified site selection criteria relative to previous phases of REMAP. The Big Cypress study area is a mix of diverse habitat types with a high density of trees and shrubs, which are hazardous for helicopter landing operations (Photo 6). It was necessary to screen for sampling locations that could safely accommodate helicopter landings. Open marsh vegetation was identified as the best vegetation class for that purpose. In addition, marsh habitat, such as wet prairie - (also referred to as slough, Payne et al. 2003), marl prairie or dry prairie (NPS 2011) is of ecological interest in that it has been demonstrated in the Everglades to be more sensitive to phosphorus enrichment than other vegetation classes (USEPA 2000, Payne et al. 2003, Gaiser et al. 2005). Marshes also have longer hydroperiods than most other Big Cypress habitats, increasing the likelihood that surface water samples could be collected. Therefore, the probabilistic sampling design implemented an *a priori* selection criterion that defined sampleable habitat as open marsh vegetation.

This modified design approach first quantified the spatial extent of all vegetation classes throughout the eastern Big Cypress subarea based on the most recent NPS classified vegetation map (2014 vegetation imagery, Ruiz et al. 2019), which was then processed using ArcMap Desktop (ESRI v10.8) to extract the spatial extent of the 20 vegetation types classified as marsh vegetation (Table 2 and Figure 4).

Marsh Vegetation Class	Area (acres)	Acre (hectares)	Area Percent
Graminoid Freshwater Marsh	43640.83	17660.89	64.41
Graminoid Freshwater Prairie	23601.19	9551.08	34.83
Mixed Graminoid-Broadleaf Freshwater, Broadleaf Emergent, Floating Emergent, Herbaceous Freshwater, Graminoid Saltwater	457.02	184.95	0.68
Total	67,589.04	27,396.92	99.92

Table 2. Marsh vegetation classes within the Big Cypress REMAP subarea based on Ruiz et al. (2019). The third row encompasses 18 smaller marsh classifications which cumulatively represent only 0.68% of the subarea.

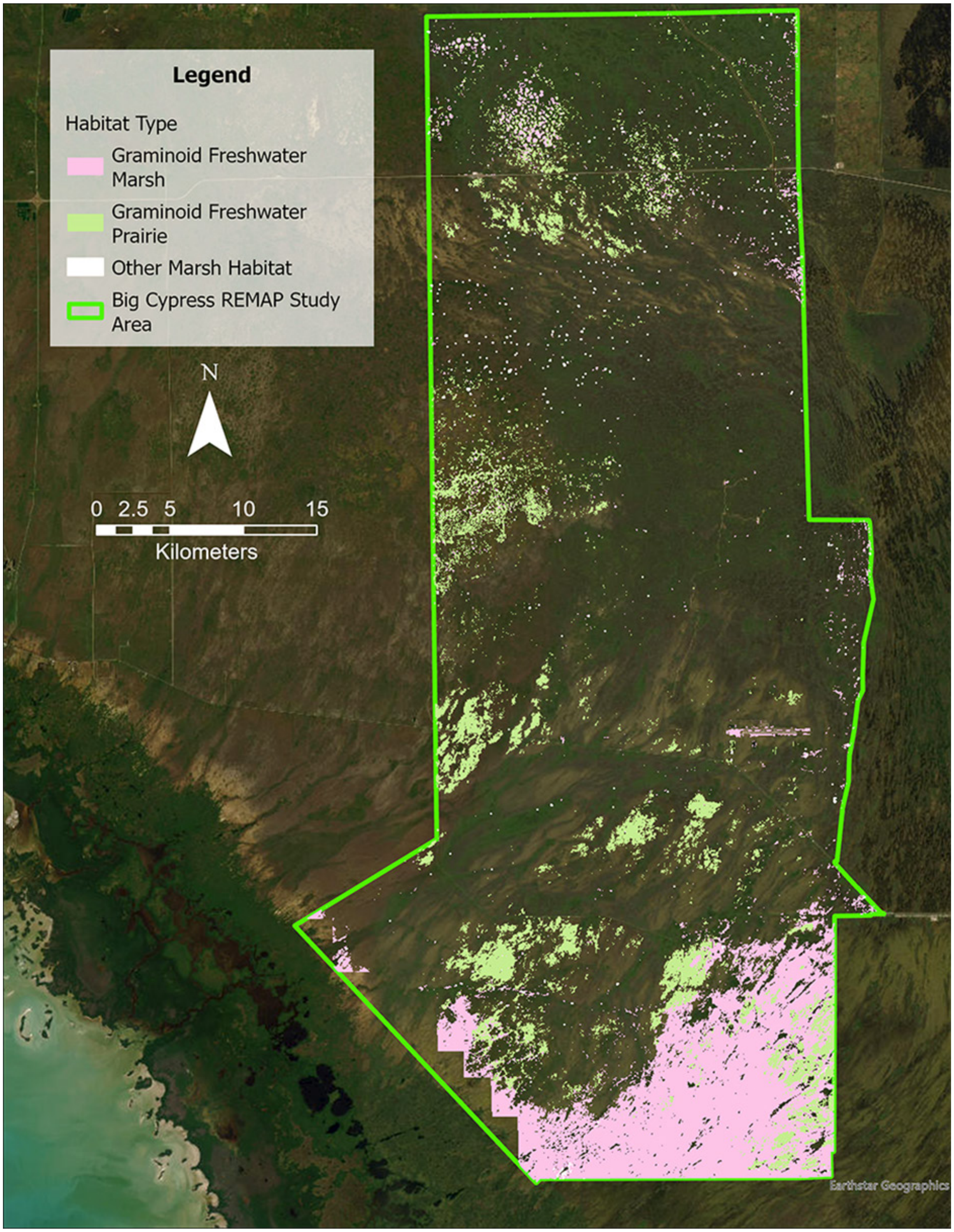


Figure 4. Eastern Big Cypress National Preserve marsh vegetation distribution in 2014, based on Ruiz et al. (2019). Pixels are 50 meters by 50 meters and not all pixels are evident on this image due to limited resolution.

This preprocessed sample frame was imported into the R statistical software package (v4.2.2). The USEPA ORD ‘spsurvey’ package (Dumelle et al. 2023) and generalized random tessellation stratified algorithm (grts) were used to generate a suite of 42 randomly distributed base station locations and 10 alternate nearest-n locations for each of these 42 base sites (minimum distance = 3500 m, point density = 100, number of near sites = 10, and maximum tries = 100). Specifically, a random number was used to set the initial sampling grid, which the algorithm then used to iteratively select sampling locations until 42 random base locations were selected that were no closer than the minimum distance threshold of 3500 meters. If no solution could be found within 100 attempts, a new grid was generated based on a new random number and the process was repeated. Once a solution was found that met the selection criteria, an aerial image survey (GoogleEarth, accessed June 2023) of the potential sampling locations was conducted to confirm whether they were helicopter accessible.

Follow up on-site aerial reconnaissance was conducted by helicopter in August 2023, the month prior to the sampling event. Any site where it was determined that a helicopter could not safely land within a 50-meter radius of the base location in the same habitat was rejected and the next nearest-n site was then assessed. Each base location and its associated nearest-n locations were evaluated until 42 sampling locations were identified. Two of the 42 stations were rejected during the helicopter reconnaissance as not landable due to safety concerns, and two stations that were sampled were later rejected for not meeting Program criteria for representativeness or randomness (USEPA 2024a). This resulted in 38 stations that were successfully sampled. These 38 stations have a sample density about 5.8 times that of the original 2021 design. All sampling stations are within the Preserve, with the exception of station 2030, which is within Everglades National Park about 180 meters south of the Preserve (Figure 5). The 2023 REMAP sampling is the most intense synoptic water quality and multi-media biogeochemical assessment performed in the Big Cypress marsh.

After processing and excluding non-marsh vegetation, the spatial extent of open marsh vegetation within the Big Cypress subarea was 27,419 hectares (67,753 acres, 105.78 square miles) or 15.5% of the subarea. Although this additional selection criteria allowed for the safe operation of helicopters, it also limited the conclusions and assessment of conditions to open marsh vegetation. Statements in this report about a condition observed, such as “yy.y ± yy.y % of the marsh had a TP concentration less than x µg/L”, apply only to the 27,419-hectare marsh footprint where the sampling stations were located. Accordingly, the y-axis on the cumulative distribution frequency (CDF) curves is labeled as ‘percent of marsh area’ and represents this open marsh footprint.

This Project makes no statements about conditions in other common vegetation habitats that were not sampled, such as forests, woodlands, shrublands, or scrub (Ruiz et al. 2019). In this report, ‘Big Cypress’ refers to the Big Cypress Swamp ecosystem, ‘BCNP’ refers to Big Cypress National Preserve, ‘Big Cypress subarea’ refers to the entire REMAP subarea.

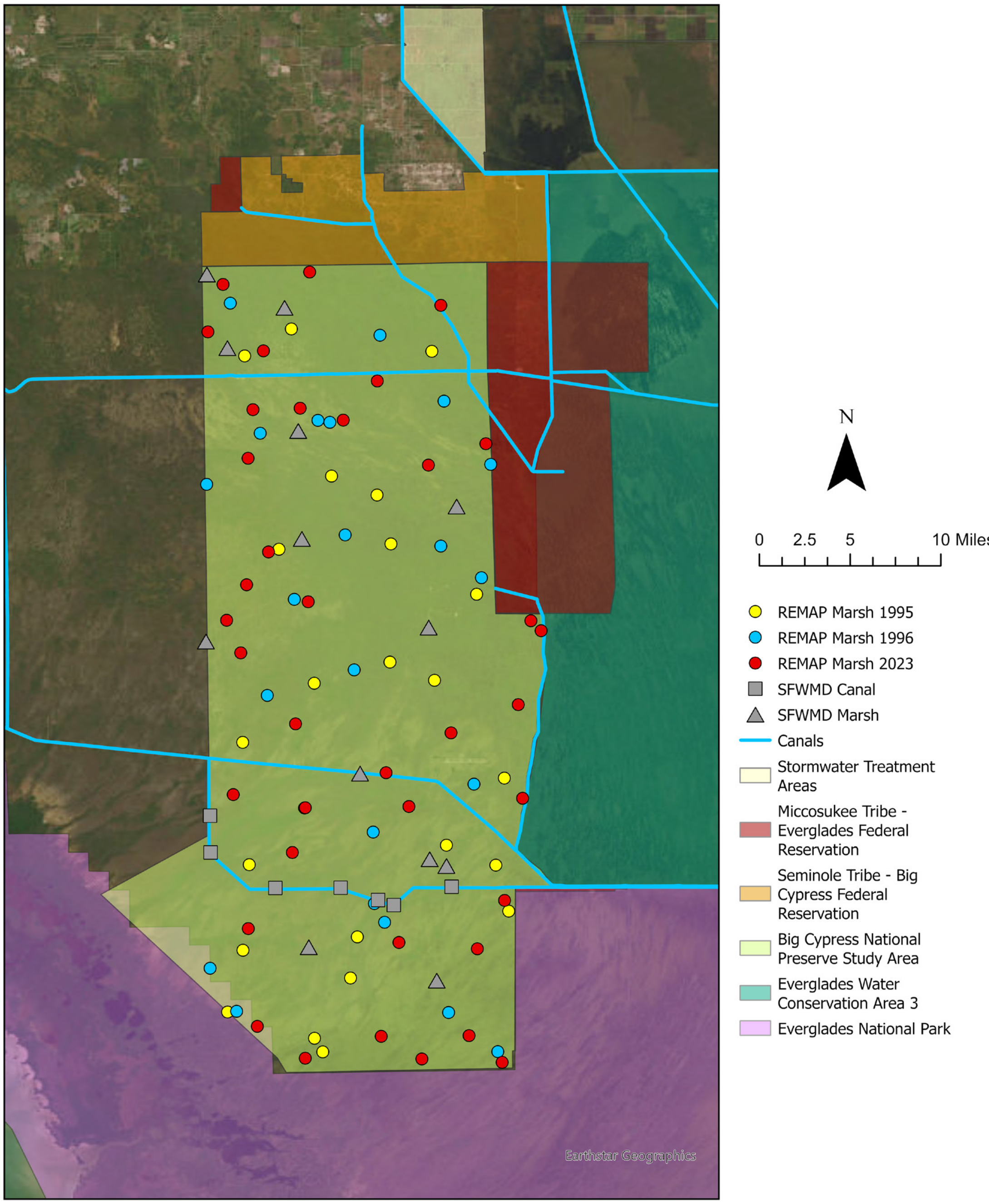


Figure 5. SFWMD and REMAP 1995, 1996 and 2023 Big Cypress surface water quality sampling stations. Canal stations are only in the Loop Road canal.

PHASE V BIG CYPRESS SAMPLING

Photo 7. Processing and splitting water samples into bottles on station.

Photo 8. Water samples were filtered and collected using a specially designed vacuum chamber.

The biogeochemical sampling effort included seven media (Table 3, Appendix 1) that were sampled concurrently and consistently (Photos 7 and 8). Field methods and quality control are described in USEPA (2023, 2024). USEPA field crews sampled 38 stations that met project design objectives over 11 days in October 2023 (Figure 5). None of the stations had all media present. Prey fish (mosquitofish) were collected at 30 stations, but six stations were not included because they did not meet the Program protocol of 7 fish or more. REMAP field crews sample at all water depths, even shallow depths, because of the importance of shallow conditions in understanding local cycling processes for nutrients and mercury. The shallowest water depth where surface water samples were taken was 0.2 feet (~2.4 inches, ~8 cm). SFWMD long-term water quality monitoring programs in Big Cypress and the Everglades collect samples when the water depth is greater than 10 cm (about 0.33 feet, or 3.9 inches).

Sixteen digital photographs were taken to document conditions at each sampling location: ground view of the area sampled to the left of the helicopter, nine panoramic photos at 45-degree increments, each of the three soil cores, and three aerial photos at 100 to 200 feet above ground level. For each station, photo-documentation, classified vegetation maps, and biogeochemical and physical data are available at the USEPA Everglades REMAP website (https://www.epa.gov/everglades/environmental-monitoring-everglades, or search for "USEPA Everglades REMAP").

WorldView-2 satellite imagery of a 100 x 100-meter area centered on each REMAP sampling station is being used to produce classified vegetation community maps, similar to Richards et al. (2017) and Ruiz et al. (2019). Vegetation mapping provides a landscape context for REMAP biogeochemical and biotic information.

Media	Number of Samples
Surface Water	35
Soil	38
Bottom water at the soil surface	35
Flocculant layer above the soil surface analyzed for nutrients	10
Flocculant layer above the soil surface analyzed for mercury	25
Benthic periphyton from soil core or quadrat analyzed for nutrients	21
Benthic periphyton from soil core or quadrat analyzed for mercury	24
Periphyton composite floating in the water column or attached to plants	27-28
Sawgrass clippings analyzed for nutrients	25
Whole sawgrass plants analyzed for mercury	10
Mosquitofish analyzed for mercury	24

Table 3. Media and number of samples collected.

DATA QUALITY OBJECTIVES

Photo 9. Samples stored in refrigerator prior to shipping.

Big Cypress REMAP has defined Data Quality Objectives (DQOs) to ensure that data are of known and documented quality that satisfy predefined uses and requirements. Data quality is an essential component of the Program throughout planning, field sampling, laboratory analyses, and final data review and validation. An independently reviewed Quality Assurance Project Plan (QAPP, (USEPA 2023)) was developed in accordance with USEPA protocol (USEPA 2002, 2014b). The Program followed 25 USEPA Region 4 Laboratory Services and Applied Science Division (LSASD) Policies, Plans, Manuals, and Standard Operating Procedures (USEPA 2023). USEPA R4 LSASD is accredited for field and laboratory operations by the American National Standards Institute - American Society for Quality National Accreditation Board.

During the October 2023 sampling, USEPA field personnel took about 1900 measurements at the 38 stations. About 700 samples were collected and shipped to four analytical laboratories that are accredited by the National Environmental Laboratory Accreditation Program (Photo 9). Laboratory analytical methods and minimum detection limits are identified in the Project QAPP (USEPA 2023). About 20 laboratory analytical tests were performed for forms of phosphorus, nitrogen, sulfur, carbon, mercury, ions and physical parameters (Appendix 1). Approximately 140 laboratory analytical sample results were produced by the USEPA LSASD lab, and 1600 results were produced by three Florida International University labs. Laboratory data were reviewed independently by LSASD Quality Assurance staff, at a rate of 100% for critical parameters (sulfate and total phosphorus in surface water, total phosphorus in soil, and total mercury in fish), 20% for mercury in surface water and sulfide in bottom water, and 10% for all other parameters. All 1800 analytical results met project DQOs, and none of the results were rejected during the review. About 10% of the REMAP Program budget was invested in independent analytical laboratory data quality assurance and verification.

Surface water duplicates were collected at 5% of the stations. The relative percent differences (RPDs) between each sample and duplicate were below the 30% threshold specified in the project QAPP (USEPA 2023), with the exception of methylmercury (MeHg). However, those surface water MeHg samples and duplicates were all below the analytical laboratory Minimum Reporting Limit (MRL). Split soil samples were prepared from soil cores at two stations after they were homogenized in the base laboratory. These split samples were analyzed for soil parameters. The RPDs between all pairs of split samples were below the 60% threshold for soil, as specified in the project QAPP (USEPA 2023), with the exception of MeHg. MeHg was at relatively low concentrations in soil, with several samples below the MRL, and may have been spatially variable at these low concentrations despite homogenization.

DATA ANALYSIS AND PRESENTATION

There are two main sources of available water quality data within Big Cypress: REMAP and the SFWMD DBHYDRO database. For this report, Big Cypress REMAP 2023 marsh data are compared to REMAP 1995-96 marsh data, and to historic long-term marsh and Loop Road canal data within the REMAP study area reported by SFWMD. SFWMD data were retrieved from the DBHYDRO database in 2024 - 2025. The SFWMD database has recurring monitoring throughout the year at 13 fixed long-term marsh locations and 7 canal locations along the Loop Road (Figure 5, Table 4). The marsh monitoring program was a collaborative SFWMD - NPS effort that was active from 1994-2011, while the canal program began in 2012 and continued in 2024. The SFWMD data are identified in figures as ‘Historic Canal’ or ‘Historic Marsh’. REMAP Big Cypress is a synoptic program that has sampled different stations only once: 47 in 1995-96 and 38 in 2023. For statistical analyses and report presentation, data were divided into wet season (May-October) and dry season (November-April).

Program	Waterbody	Season	Years	Stations	Sampling Frequency	Maximum Data Count
USEPA REMAP	Marsh	Wet	1995, 1996	24	Once	24
	Marsh	Dry	1995, 1996	23	Once	23
	Marsh	Wet	2023	38	Once	38
SFWMD Historic	Marsh	Wet	1994 – 2011 if available	BCWQA- 4, 5, 6, 9, 9A, 10, 12, 13A, 15, 18, 20, 21; BCAP3	Up to bimonthly	328 - 382
	Marsh	Dry	1994 – 2011 if available	BCWQA- 4, 5, 6, 9, 9A, 10, 12, 13A, 15, 18, 20, 21; BCAP3	Up to bimonthly	125 - 136
	Canal	Wet	2012 – 2024 if available	BCWQL – 1, 2, 3, 4, 5, 6, 7	Up to monthly	265 - 289
	Canal	Dry	2012 – 2024 if available	BCWQL – 1, 2, 3, 4, 5, 6, 7	Up to monthly	65 - 66

Table 4. SFWMD and REMAP surface water quality data stations.

ATMOSPHERIC DEPOSITION

Photo 10. Wet deposition event.

The National Atmospheric Deposition Program (NADP) monitors precipitation (Photo 10) to determine the rate or flux of atmospheric constituents moving into the biosphere as rainfall (wet deposition) (NADP 2024a). Annual average results for pH, specific conductance, sulfate, and chloride in precipitation are summarized for the Everglades National Park Research Station FL11, 19 miles southeast of the REMAP BICY study area (Figure 6). Mercury is also monitored at FL11 and in Western Broward County at FL97, 4 miles east of the study area. Mercury data at each location are reported as weekly or annual precipitation-weighted mean concentration (ng/L) and deposition ($\mu g/m^2$) values.

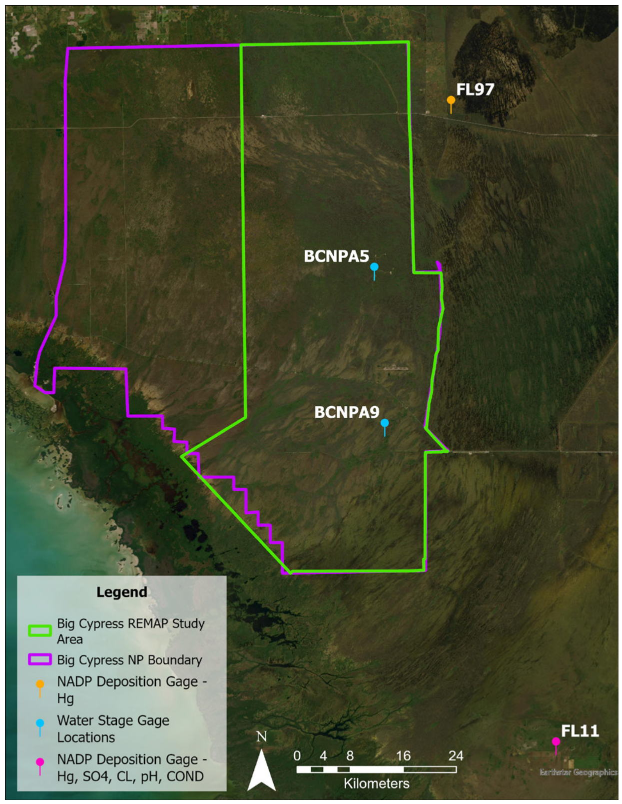


Figure 6. Big Cypress REMAP study area, atmospheric deposition (NADP) stations FL11 and FL97, and water level stations BCNPA5 and BCNPA9.

BOX AND WHISKER PLOTS

A box and whisker plot (i.e., Figure Surface Water Phosphorus 1) is a graphical method of displaying the variation, or general shape, of a data set. The large box contains the middle 50% (the interquartile range between the 25th and 75th percentiles) of the data values. The median is shown by the horizontal line within the box. The whiskers or vertical lines include values outside the interquartile range that are not considered outliers or extremes. Outliers are defined as values that are smaller than the 25th percentile or larger than the 75th percentile, respectively, by at least 1.5 times the interquartile range.

The non-parametric Kruskal-Wallis rank sum test (kruskal.test from stats package in R computational environment) was used to determine if there were significant parameter differences (significance level of $p < 0.05$) among sampling programs and periods. Where significance was found, the determination of which results were different was based on Dunn's test (dunn.test from dunn.test package in R) with p-value adjustment using the Bonferroni multiple comparison adjustment method. When only two parameters were compared, the analysis reverted to a Mann–Whitney U test. The results are shown in the box and whisker plots and the adjacent table.

STATISTICAL ASSESSMENT OF RELATIONSHIPS BETWEEN VARIABLES

Assessment of how different variables affect one another can be useful to understanding the holistic conditions of the Big Cypress environment. Biogeochemical reactions and kinetics can affect these relationships, so it is important to explore what the data suggest about these relationships and how they may change over time. This can be done by visualizing the data via plots and assessing the strength and directions of relationships with parametric linear regression models or nonparametric statistical analyses.

All statistical analyses are contingent upon the data meeting assumptions specific to the analysis. In the case of parametric linear regression, the results of the model must meet four assumptions to be valid for data analysis. These four assumptions are linearity, independence, normality and homoskedasticity, and they confirm that the results of a linear regression are in fact linear. In the case that data violate any of these assumptions, non-parametric statistical analyses such as Spearman's rank correlation are more scientifically sound. Data exploration indicated that relationships between REMAP data for dissolved oxygen, dissolved oxygen saturation, pH, time of day and water temperature were either non-linear, not normally distributed or influenced by potential outliers. Therefore, non-parametric Spearman's rank correlations were used for determining all data relationships, latitudinal chemical gradients, and correlation matrices.

Results of a Spearman's rank correlation are the p-value indicating the statistical significance and rho (ρ), an estimate of the strength and directionality of correlation between two variables. A positive rho suggests a directly proportional relationship between variables while a negative rho indicates an inversely proportional relationship, with values closer to ± 1 (farther from 0) representing stronger correlations between variables, or a stronger gradient with latitude. The magnitude of rho as absolute values can be interpreted as: negligible for 0 to 0.09; weak for 0.1 to 0.39; moderate for 0.4 to 0.69; strong for 0.7 to 0.89; and very strong for 0.9 to 1 (Schober et al. 2018). Significance was evaluated using a p-value relative to an $\alpha = 0.05$, with p-values < 0.05 considered statistically significant.

IMPROVING ANALYTICAL LABORATORY METHODS AND LOWER METHOD DETECTION LIMITS

This report includes data comparisons from the 1990s to present. For some analytes, laboratory analytical methods have greatly improved over these four decades, resulting in lower Method Detection Limits (MDLs, the lowest number that is possible to accurately report). For these analytes, comparing historic data to contemporary data may erroneously indicate a downward trend simply due to the current analytical lab's ability to report lower results, rather than a real environmental condition. Data exploration indicates that improving MDLs over time occur with several REMAP or SFWMD surface water analytes: total phosphorus, soluble reactive phosphorus, sulfate, total mercury and methylmercury. For these analytes, either no comparisons are made to historic data, or data reported at lower MDLs were changed upward so all data across time and laboratories have a common lowest possible result. Details are provided in each section of the results.

SPATIAL INTERPOLATION

A strength of REMAP is its spatial coverage. However, spatial interpolations of 2023 Big Cypress National Preserve data are not presented in this report. Only the marsh habitats that constituted 15.5% of eastern BCNP were sampled. Providing spatial interpolations of data across the entire study area and depicting conditions throughout BCNP across areas with great habitat heterogeneity (Ruiz et al. 2019), many of which were either dry or not accessible for sampling by helicopter, would misrepresent the data, provide incorrect visual data depictions, and lead to erroneous statements and conclusions. Therefore, three-dimensional map graphics are used with no data interpolation. Quintiles are used for the data intervals, unless a specific concentration of interest is identified.

CDFS AND AREA ESTIMATES

One way to visually portray survey statistics is to plot the cumulative distribution function (CDF) of the data. A CDF curve can be used to estimate the proportion of the marsh where a given analyte was found at a concentration above or below any value of interest. This is a key strength of REMAP's probability-based sample design. Non-parametric CDF calculations and plots were generated using a bootstrapping approach in R via R Studio. This accounted for the non-normality of the observational data. For each analyte of interest, bootstrapping was used to resample each observation 100 times.

The replacement CDF estimates and associated 95% confidence intervals around the CDF estimates for the y-axis were then calculated based on the resampled data. The resulting upper and lower 95th percentiles are not necessarily equidistant from the median (Appendix 2).

All CDF curves in this report are for Big Cypress REMAP 2023 wet season data. The CDF curve is shown in red. By reading from any concentration of interest on the x-axis up to the CDF curve, and then to the left across from the curve horizontally to the y-axis, one can find the corresponding proportion of the sampled marsh that falls at or below the concentration of interest. Bounding the CDF are two lines representing the upper and lower 95% confidence limits, calculated as the 2.5th and 97.5th percentiles of the distribution from the resampled dataset at the CDF value of interest. These limits show the confidence interval (CI) around the marsh area estimate (y-axis), not the concentration estimate (x-axis). This interval indicates the precision of the estimate: narrower intervals represent more precise estimates. At the 95% confidence level, there is a 1 in 20 chance that the true value for the study area was outside the range defined by the confidence interval. For the October 2023 data, the stations represent only 15.5% of the area within eastern Big Cypress. Therefore, estimates of the condition shown in the CDF curves are limited to only the area sampled (Figure 4), and do not represent all of eastern Big Cypress.

Portions of the CDF curve for seven of 77 analytes (Appendix 2) did not meet the Project's ± 10% DQO tolerance limits for 95% confidence intervals (USEPA QAPP 2023). For these seven analytes the confidence interval magnitudes were 20.6% to 22.2%, very close to the < 20% goal. Meeting this DQO tolerance limit in future Big Cypress surveys may require increasing the number of stations. The tighter tolerance limit gained by increasing the number of stations can be estimated using the 2023 data. Tradeoffs between falling within ± 10% DQO tolerance limits should be evaluated analyte by analyte and take into consideration higher cost, field sampling time and personnel. The REMAP design from the 1990s required the ± 10% DQO limits because the data were envisioned to be decision-based and compared to regulatory action levels, rather than focusing solely on estimates of environmental conditions (Stober et al. 1996, USEPA 2006). Resource managers and scientists should collaboratively determine how critical this level of precision is for future Big Cypress REMAP surveys and data uses.

OVERVIEW AND FINDINGS - WATER CONDTIONS

RAINFALL

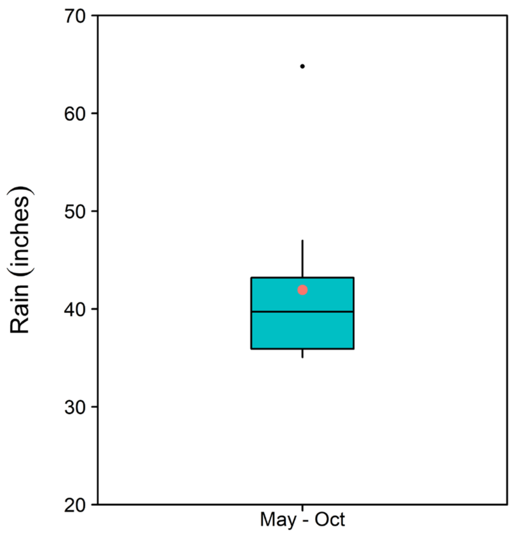


Figure Rainfall 1. Wet season (May to October) 2014-2023 average rainfall, and 2023 rainfall (red circle).

From 1982 to 2011, BCNP received an average of 55 inches of rainfall per year (Photo 11). The 6-month wet season (May to October) accounted for 78% (43 inches) of the Preserve's annual rain, with only 22% (12 inches) falling during the 6-month dry season (November to April). June was the wettest month with 10.2 inches, followed by August and September with 8.7 and 8.3 inches, respectively. November, December, January, and February were the driest months, each with less than 2 inches of rainfall (NPS 2011). Rainfall within BCNP during the 2023 May to October wet season was 42 inches, which was not different ($p = 0.728$, Mann-Whitney U test) than the previous 10-year (2014 to 2023) wet season averages (Figure Rainfall 1).

Photo 11. The wet season in South Florida lasts from May to October.

STAGE AND WATER DEPTH

From lowest to highest elevation, the BCNP landscape varies and includes dry season refugia, pond apple forests and marshes, tall cypress, wet prairies, hydric uplands, mesic uplands, and xeric uplands (NPS 2011). REMAP 2023 sampled only marshes and prairies. Depths and hydroperiods (duration of surface water) vary with habitat in undisturbed portions of the Preserve. Dry season refugia remain flooded for 11-12 months. Pond apple forests and marshes hold the deepest (18-24 inches) surface water and longest (9-11 months) hydroperiods of any wetland type in the Preserve. Marl prairies hold standing water for 5-7 months at a wet season depth of 6 to 12 inches (NPS 2011).

The shallowest water depths occur from April to May due to the cumulative effect of months with little rain and increasing rates of evapotranspiration. As the dry season progresses, dry land is revealed: pinelands, followed by marl prairies, resulting in water only in the lowest-lying strands, domes, and marshes. Around June the swamp becomes flooded with water that interconnects to form sheetflow, a shallow, expansive and slowly flowing waterbody caused by the flatness and naturally poor drainage of the swamp landscape. The underlying geology is slightly tilted (1 foot per mile) to the southwest, allowing water to flow slowly in that direction. Sheetflow covers virtually the entire swamp and lasts a few months, gradually disappearing in the fall and winter. Pinelands and marl prairies go dry, and the cycle proceeds into the dry season (NPS 2011).

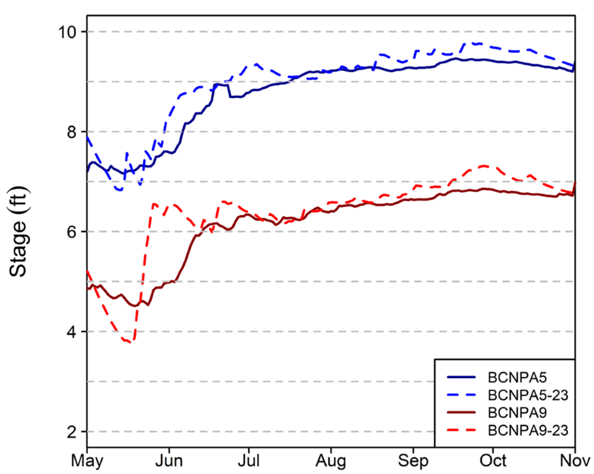
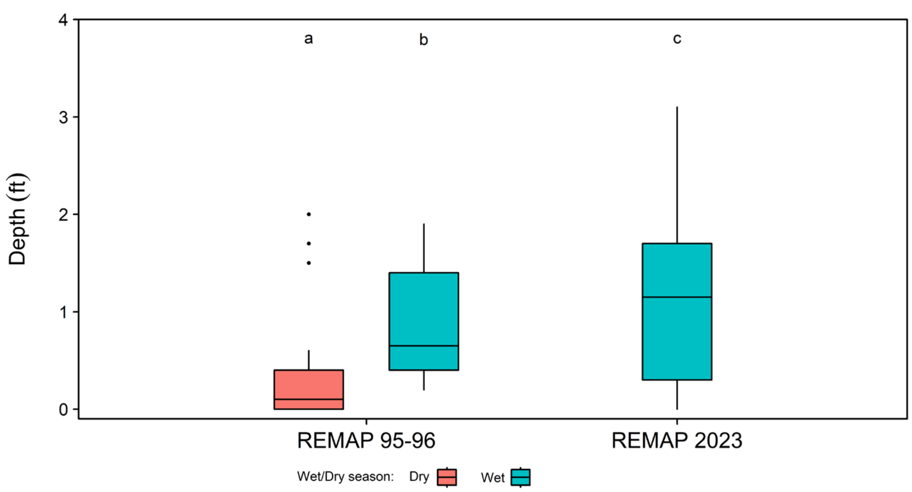


Figure Water Depth 1. Daily stage at marsh recorders BCNPA5 (blue) and BCNPA9 (red) (accessed DBHYDRO March 2025). Dotted lines are 2023, solid lines are the 10-year average of 2014-2023.

Historic wet season daily stage (water level) at marsh recorders BCNPA5 and BCNPA9 (Figure 6) varied by about three feet as the wet season progressed from May into October (2014-2023 daily average, Figure Water Depth 1). There was no significant difference between water levels in 2023 and the 10-year period of record ($p > 0.05$, Dunn's test). During the 2023 wet season, stage was lowest during May, and generally increased from June into October. REMAP sampling occurred during the last 2 weeks of October 2023, when stage was receding.

REMAP 2023 water depth (WD) ranged from dry at three stations to 3.10 feet, with a median of 1.15 feet (Photos 12 and 13, Figures Water Depth 2 and 3). The deepest location was a pond near the Preserve's northern boundary. Water depths during the 1995-96 and 2023 REMAP wet season events were greater than the 1995-96 dry season depth ($p < 0.05$) (Figure Water Depth 2). REMAP 2023 data had a significant but weak latitudinal gradient ($p < 0.05$, rho = -0.35, Figure water depth 4), with deeper water to the south. The seven southernmost stations all had WD > 1.3 feet, while all 11 stations with WD < 0.3 feet were north of US-41. The 1995-96 data did not have a gradient (p = 0.45). About 50% of the marsh area sampled had WD at or below 1.30 feet, with a 95% confidence interval of 45.0% to 58.3% (Figure Water Depth 5).

Photos 12 and 13. REMAP 2023 sampling fish at station 2017, WD = 0.30 feet (left) and periphyton assessment at station 2020, WD = 1.8 feet (right).



Group	Letter	N	Significantly Different
REMAP 1995-96 dry	a	23	bc
REMAP 1995-96 wet	b	24	a
REMAP 2023 wet	c	38	a

Figure Water Depth 2. Water depth (feet) comparisons across programs.

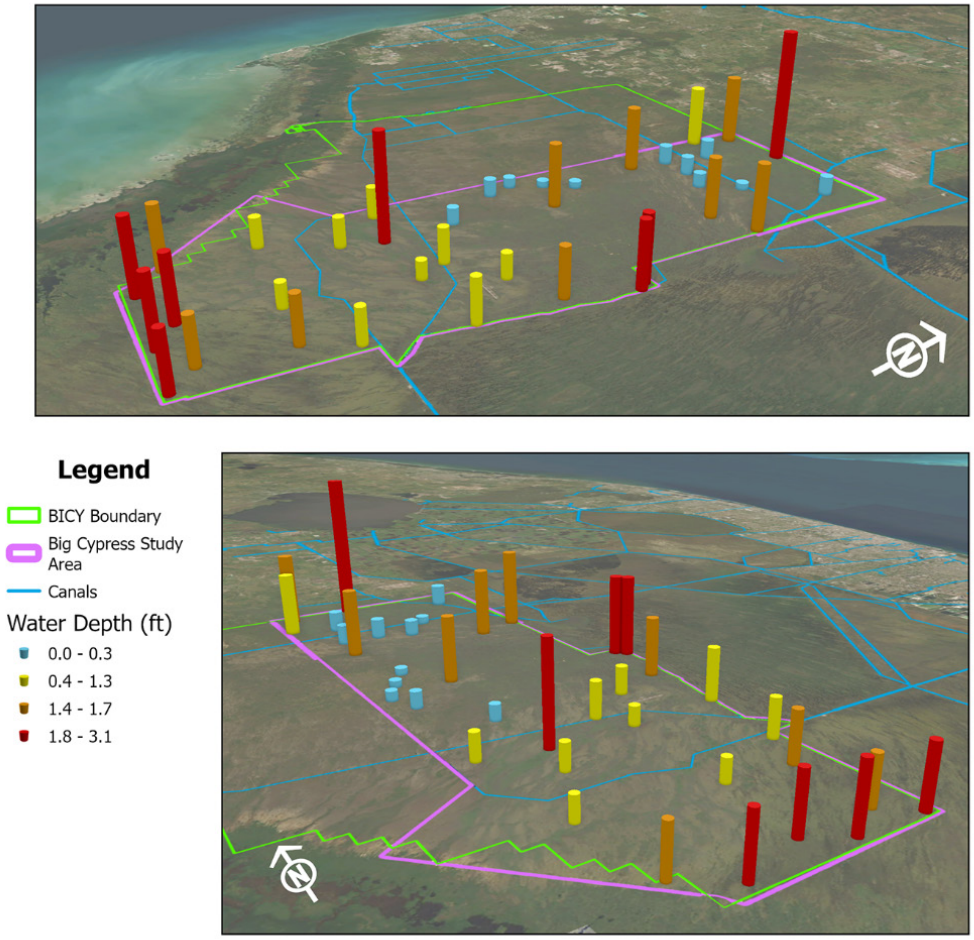


Figure Water Depth 3. REMAP 2023 Surface water depth (feet).

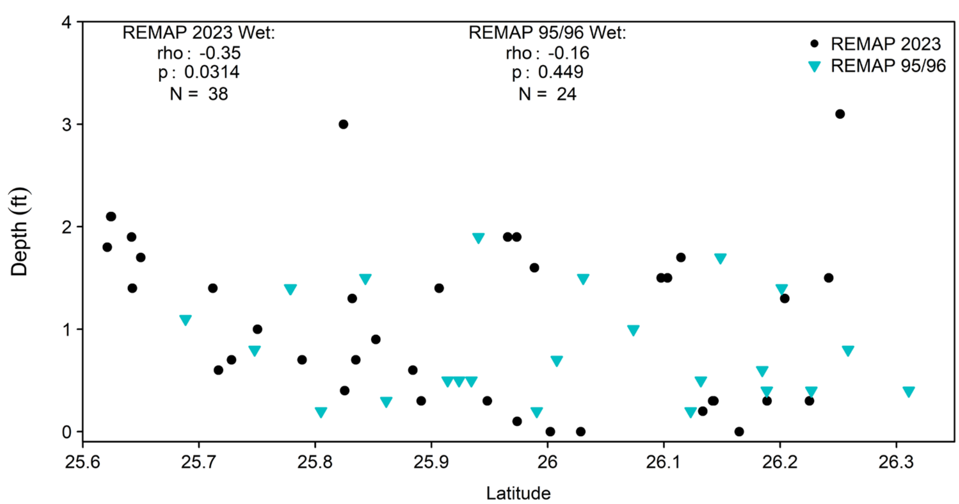


Figure Water Depth 4. Surface water depth (feet) by latitude during the wet season. North is to the right and south is to the left.

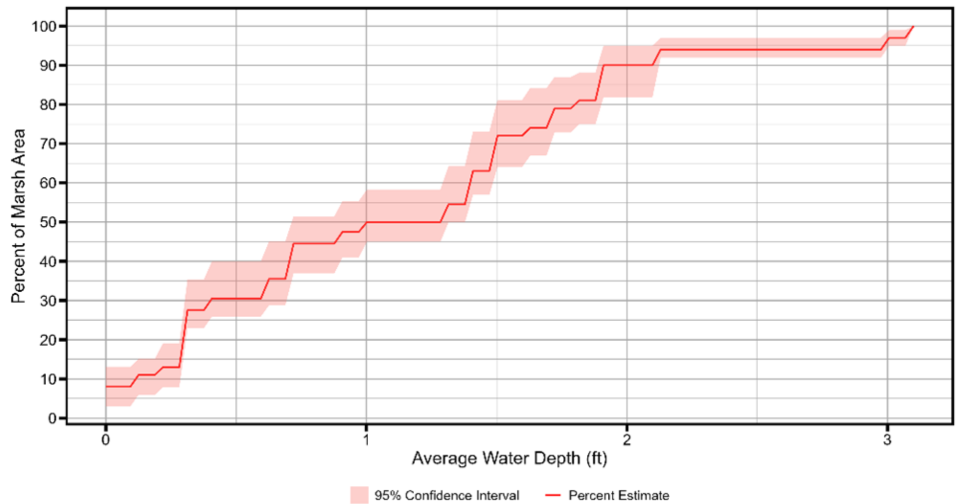


Figure Water Depth 5. Surface water depth (feet) estimates of marsh area.

OVERVIEW AND FINDINGS – WATER QUALITY

PHOSPHORUS

Phosphorus and nitrogen are essential to the existence and growth of aquatic organisms in surface waters. Phosphorus (P), nitrogen (N), and potassium are considered the primary nutrients, and they are the most common nutrients in fertilizer used to stimulate plant growth. In aquatic systems excess nutrients can cause undesirable changes (USEPA 2025).

Since the 1960s, prior to the establishment of BCNP, concerns were raised about the potential for elevated nutrients from agricultural or developed lands to adversely impact Big Cypress natural resources (USDOI 1969, Schneider et al. 1996). Forty years later USGS (Miller et al. 2004) stated that the threat posed to water quality in BCNP by upstream sources had increased because: (a) new areas to the northeast and west were included in the Preserve's boundaries by Congressional legislation that expanded the Preserve in 1974, including lands that either abut or encompass canals (b) future restoration plans included diverting a portion of the canal waters into the Preserve; and (c) land use activities that could impair water quality intensified in the upstream watersheds. These concerns continue (Duever 2005, FDEP 2017, USACE 2024), and in a 2016 Big Cypress foundation document the NPS reiterated them. Agricultural Best Management Practices and Stormwater Treatment Areas could remove TP and improve downstream water quality (Khare et al. 2000; Julian and Davis 2024). The WERP recommended plan notes the importance of addressing nutrients from the watershed and assuring that BCNP native plants and animals are protected (USACE 2024).

The USGS began Big Cypress water quality and nutrient monitoring efforts around 1970. Results or summaries that include surface water TP are reported in Klein et al. 1970; Schneider et al. 1996; Stober et al. 1998; Lietz 2000; McPherson et al. 2000; Scheidt et al. 2000; McPherson and Miller 2003; Miller et al. 2004; FDEP 2017; NPS 2011; McBride and Sifuentes 2018.

Surface water TP data prior to the 1980s are of limited use due to the combination of the waterbody's low background TP concentrations (as low as single digits in µg/L), and higher analytical laboratory method detection limits (tens of µg/L). Consequently, these data often are not low enough to accurately identify spatial or temporal trends. Comparison of data from the 1970s to contemporary data may erroneously indicate a downward trend simply due to the current analytical lab's lower minimum reporting level, rather than a real environmental condition. TP data reported here are limited to programs capable of reporting TP down to 4 µg/L.

The L-28I canal (Background Figure 2) cuts diagonally through the northeast corner of BCNP. Downstream this canal water penetrates directly into the marsh within the Miccosukee Tribe's Everglades Reservation, resulting in phosphorus-induced impacts. Surface water flow into BCNP from the north is primarily as sheet flow from the Seminole Tribe's Big Cypress Reservation and the lands to the west. There are no levees along BCNP's northern boundary to inhibit surface water flow from the agricultural watershed. In contrast, TP at interior marshes in the central and southern portion of BCNP are likely dominated by rainfall and marsh sheetflow.

Florida has designated the waters in the marshes and canals within BCNP as Class III: Fish Consumption, Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife (commonly referred to as "fishable and swimmable"). Florida has not adopted numeric nutrient criteria for south Florida canals or wetlands, therefore BCNP does not have a numeric water quality criterion for TP or TN. Florida's narrative no imbalance nutrient criterion applies: "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna." (FAC 62-302.530(48)(b)).

As a National Preserve, waters within BCNP have an additional level of protection known as Outstanding Florida Waters (OFW). The OFW designation is an antidegradation provision designed to help preserve the exceptional ecological or recreation significance of the waters relative to the waterbodies' baseline condition. Baseline water quality conditions for OFWs are typically identified as the existing ambient water quality in the year prior to designation (March 1, 1979 for BCNP) or the water quality that existed during the year prior to the date of a permit application (FAC 62-302.700(8) and FAC 624.242(2)(c)).

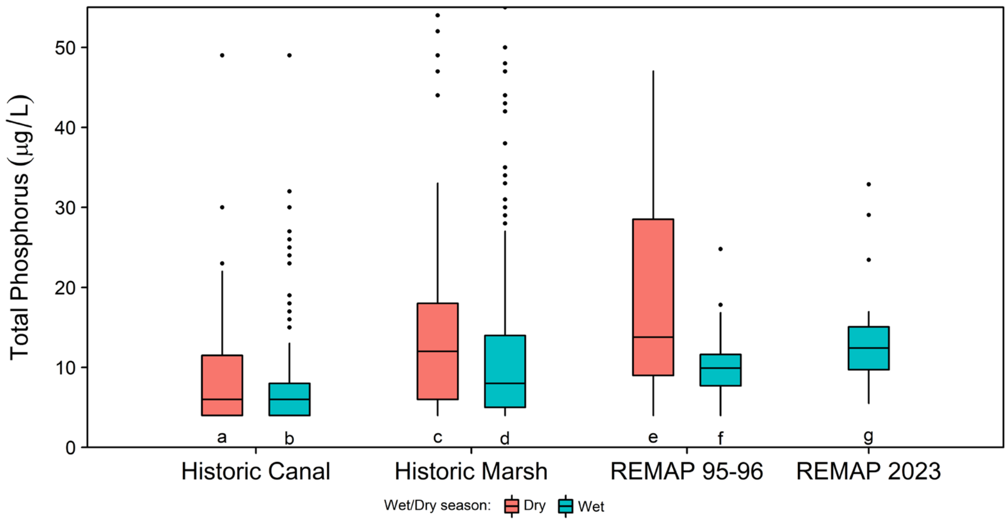
The adjacent Everglades marsh is the most studied wetland in the world, with hundreds of journal articles or agency reports about nutrients. The natural balance of flora and fauna in the marshes of the Everglades are adapted to low nutrient conditions. Therefore, relatively small additions of nutrients, especially phosphorus, can cause the flora and fauna to change (Noe et al. 2001). The Everglades is phosphorus-limited (McCormick et al. 1999; McCormick et al. 2002), which means that very low concentrations of P naturally limit undesirable biological growth.

All of the Everglades has a numeric water quality criterion of 10 µg/L for TP. In 1999 the Miccosukee Tribe of Indians of Florida adopted, and under the Clean Water Act USEPA approved, a 10 µg/L TP criterion for the Everglades portion of the Tribe's Federal Reservation in WCA3 (Miccosukee Tribe 2010), adjacent to BCNP on the east (Background Figure 2). In 2005 Florida adopted and USEPA approved a 10 µg/L water quality criterion (10-year long-term geometric mean) for TP in the Everglades Protection Area (FAC 62-302.540), which includes WCA3A and Everglades National Park, adjacent to BCNP on the east and south. The objective of both of these 10 µg/L water quality criteria is to prevent nutrient-induced imbalances in natural populations of aquatic flora or fauna. Some portions of the Everglades where scientific studies were conducted to derive the 10 µg/L criterion have habitats that are similar to those within portions of BCNP where REMAP sampling was conducted (Payne et al. 2001, 2002; Ruiz et al. 2019). Systemic impacts of TP enrichment in the Everglades are summarized in Scheidt et al. (2021). These cascading impacts include altered periphyton communities, loss of water column dissolved oxygen, increased soil phosphorus content, conversion of the wet prairie-sawgrass mosaic to tall, dense single-species stands of cattail with minimal open water, and subsequent loss of wading bird foraging habitat. These collective changes impact the structure and function of the aquatic ecosystem (USEPA 2000, Payne et al. 2003, Gaiser et al. 2005). Portions of Big Cypress have the same marsh vegetation communities as the Everglades.

The northern portion of BCNP has indicators that are consistent with nutrient enrichment. FDEP (2017) found that SFWMD marsh water quality stations in the northwest portion of BCNP had low dissolved oxygen. NPS scientists reported that from 2009 - 2013 the relative abundance of diatom indicator species for some basins in the northwest corner of BCNP, west of the REMAP study area, were eutrophic taxa that favor high-nutrient environments or mesotrophic taxa that can tolerate a broader range of nutrient concentrations. Other basins had oligotrophic taxa that favor habitats with low-nutrient conditions (NPS 2017). Diatom assemblages from 2013 - 2020 were strongly influenced by TP gradients, and TP had a strong correlation with diatom assemblage compositional variability (Solomon et al. 2025).

One of the goals of the WERP is to improve the quantity, quality, timing and distribution of water in the Big Cypress region to restore aquatic low nutrient (oligotrophic) conditions and reestablish and sustain native flora and fauna (USACE 2024). A combination of agricultural best management practices and constructed wetlands (STAs) could remove TP and improve downstream water quality (Khare et al. 2000, Julian and Davis 2024).

REMAP 2023 surface water TP concentrations ranged from 5.5 to 32.9 µg/L with a median of 12.4 µg/L, and a geometric mean of 12.2 µg/L (Figures Phosphorus 1 and 2). The data indicate a strong and significant north to south TP gradient ($rho = 0.81$, $p < 0.05$), with higher TP concentrations in the north (Figures Phosphorus 2 and 3). All five concentrations lower than 8 µg/L were at the southernmost stations far removed from canals and external phosphorus sources. This area is driven by rainfall and sheetflow of water across marshes. TP > 15 µg/L occurred at the northern stations which are closest to agricultural and developed lands. The highest concentration of 32.9 µg/L occurred at station 2035, an isolated pond. This station also had the lowest dissolved oxygen (0.9 mg/L, 10.1% saturation), the lowest oxidation reduction potential of -20 mV, and is the only station where soluble sulfide, indicative of low oxygen, was detected in bottom water near the soil



Group	Letter	N	Significantly Different
Historic Canal Dry	a	60	ceg
Historic Canal Wet	b	276	cdefg
Historic Marsh Dry	c	137	abd
Historic Marsh Wet	d	374	bcg
REMAP 95-96 Dry	e	14	ab
REMAP 95-96 Wet	f	24	b
REMAP 2023 Wet	g	35	abd

Figure Phosphorus 1. Surface water TP (µg/L) comparisons across programs.

surface (51 µg/L, lab MDL < 15 µg/L). Historic SFWMD marsh data also exhibited this latitudinal TP gradient, with wet and dry season TP showing moderate and significant ($p < 0.05$) north to south gradients (wet season rho = 0.44; dry season rho = 0.39, Figures Phosphorus 3 and 4).

Across the historic and 2023 programs, historic canal data had the lowest wet and dry season TP concentrations (Figure Phosphorus 1). Wet season data tended to be lower than dry season data.

Based on the 2023 data, about 30.6% of the marsh area sampled had a surface water TP concentration at or below 10 µg/L, with a 95% confidence interval of 23.8% to 36.6% (Figure Phosphorus 5). Although these values have no regulatory bearing, given REMAP's probability-based design it is appropriate to make statements for informational purposes about the area of the marsh that was at or below the 10 µg/L concentration of interest during this individual REMAP sampling event.

FDEP (2017) used a subset of SFWMD historic marsh data (1996-2010) to evaluate TP conditions within BCNP for WERP planning purposes. Annual DO data were used to verify that the location achieved the DO water quality criterion. TP data were excluded for being inconsistent with

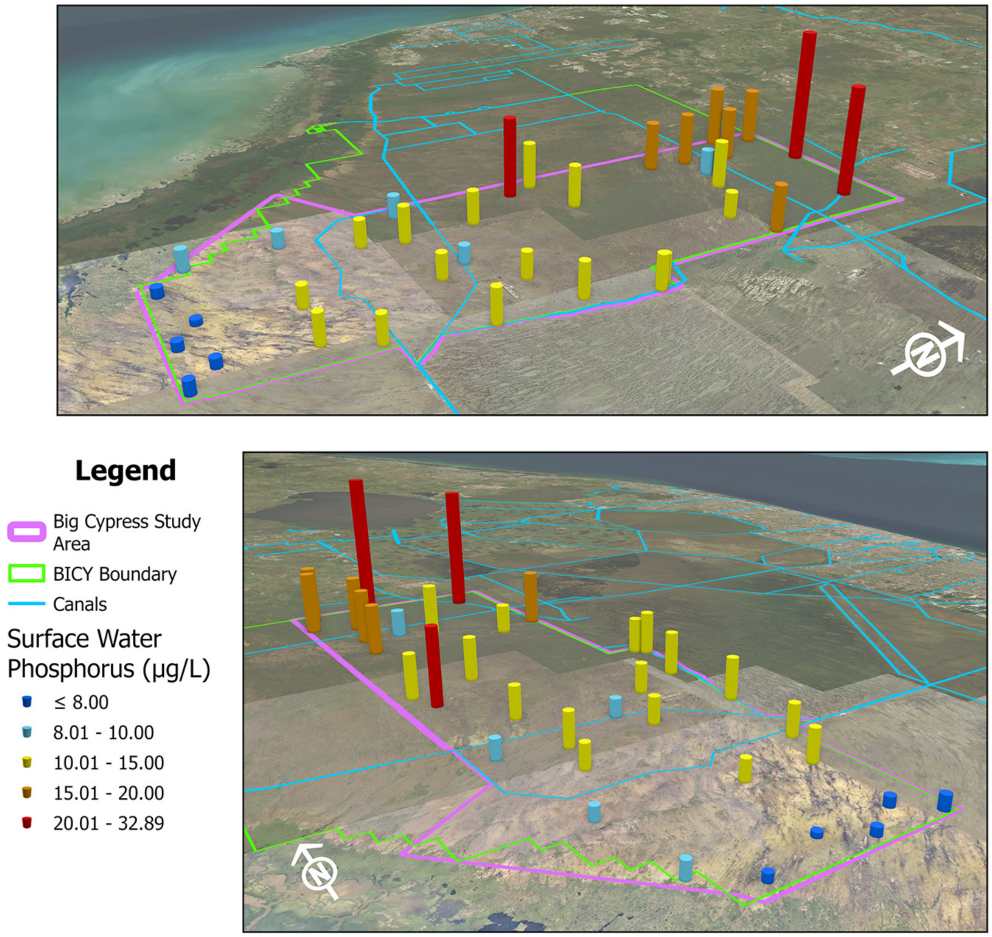


Figure Phosphorus 2. REMAP 2023 surface water TP (µg/L).

restoration goals if the station-year did not meet the DO criterion. Annual geometric mean (AGM) TP concentrations at individual stations ranged from 3.6 µg/L to 25.0 µg/L. The long-term TP limit of 9.5 µg/L was derived as an arithmetic average of AGM TP concentrations (n = 31 station years, 13 of which were west of the REMAP study area), with a standard deviation of the AGM of 5.8 µg/L.

REMAP station 2019, about 130 meters east of the L-28I canal, had a TP concentration of 29 µg/L (Figure Phosphorus 2). At water control structure S-190, 3.2 miles upstream from BCNP within the L28I canal (Figure 2), there was a flow-weighted annual mean of 111 µg/L during WY2024 (Wang et al. 2025). USGS reported that from 2014-2016 at the L28I canal where water passes from the Seminole Tribe's Big Cypress Reservation into BCNP, the TP median was 49 µg/L (McBride and Sifuentes 2018). While these statistical metrics are not directly comparable, they offer perspective. Since the BCNP marsh is separated from the L28I canal by a levee that prevents surface water flow, TP transport from the enriched canal by groundwater is a likely explanation for this high marsh TP concentration.

From 1999 - 2024 SFWMD data for TP at water control structure S-190, 3.2 miles upstream from BCNP within the L28IN canal, ranged from 11 to 340 µg/L, median = 33 µg/L, count = 1085 (DBHYDRO, accessed October 2024). During the October 2023 sampling TP was 90 µg/L. TP at L28I within the boundary of BCNP just north of I-75, ranged from 13 to 307 µg/L, median = 52 µg/L, count = 303. During October 2023 TP was 76 µg/L.

Soluble Reactive Phosphorus (SRP) is an inorganic, soluble form of phosphorus readily utilized by biological organisms and it can have a rapid effect on waterbodies. SRP at all 35 REMAP stations was not detected at or above the laboratory MDL of 1.92 µg/L, including the three stations where TP was 20 to 32 µg/L.

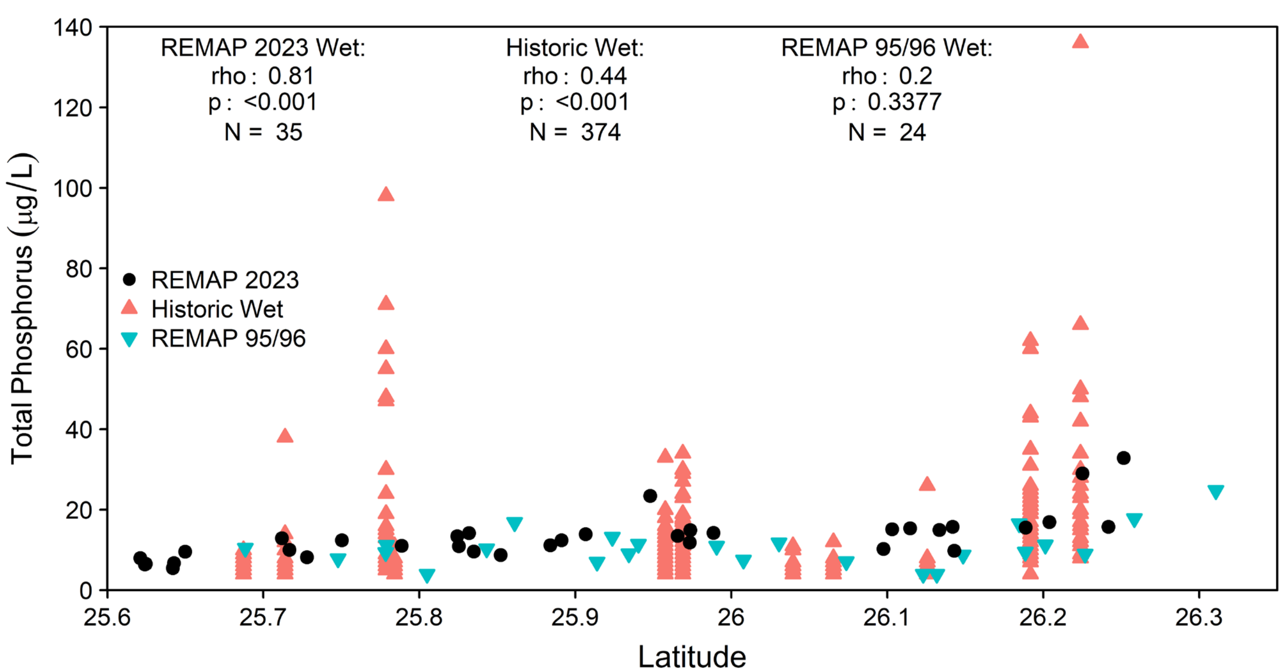


Figure Phosphorus 3. Surface water TP (µg/L) by latitude during the wet season. North is to the right and south is to the left.

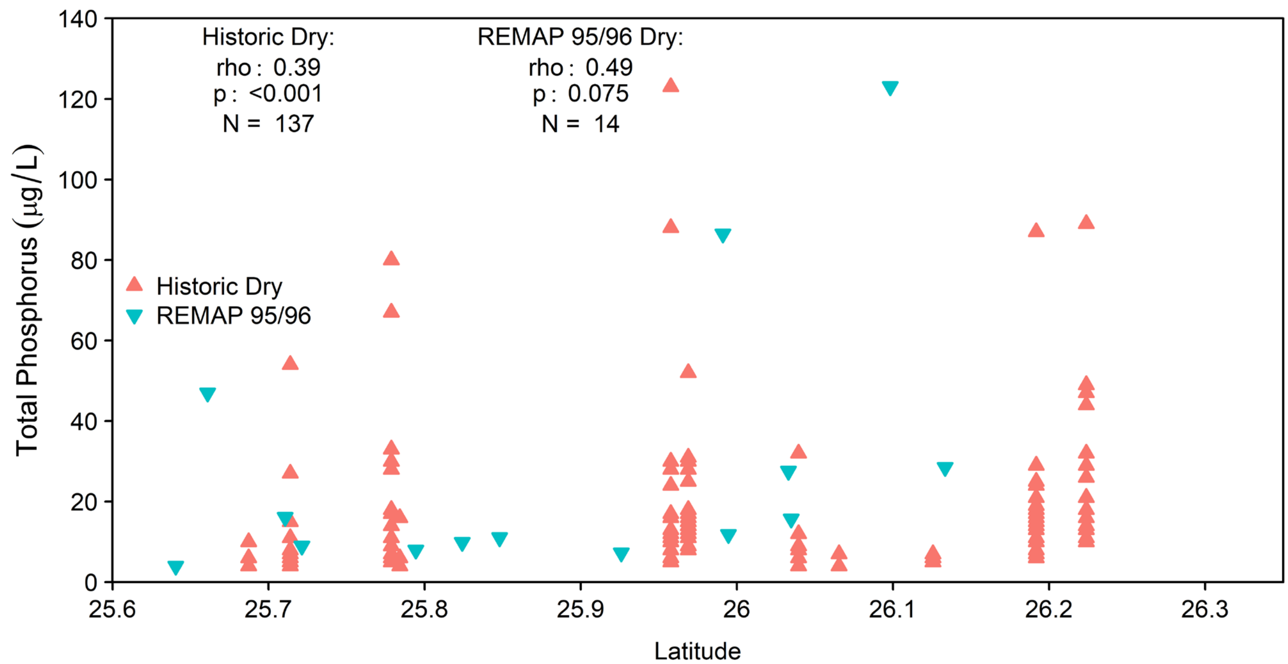


Figure Phosphorus 4. Surface water TP (µg/L) by latitude during the dry season. North is to the right and south is to the left.

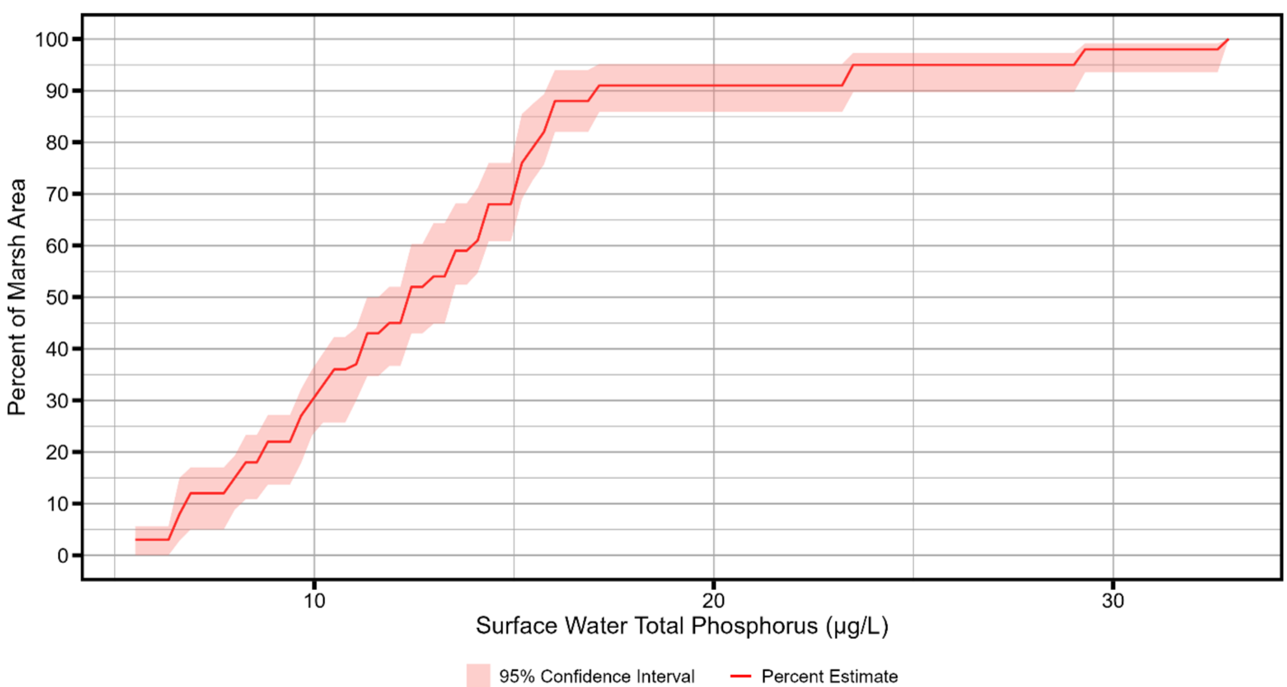


Figure Phosphorus 5. Surface water TP (µg/L) estimates of marsh area.

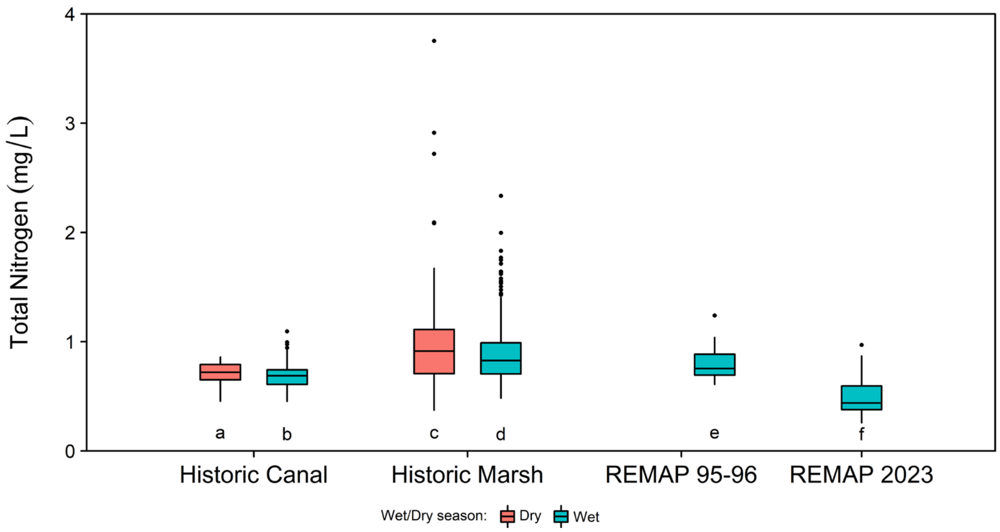
OVERVIEW AND FINDINGS – WATER QUALITY

NITROGEN

Nitrogen (N) is a critical nutrient required for life, and an essential component of amino acids, proteins, and DNA. Nitrogen cycles within water bodies in organic and inorganic forms. The most common forms of nitrogen used by biological organisms are inorganic forms such as ammonia, nitrate, and nitrite. Nitrification is the oxidation of ammonium to nitrate, the form of N that is most easily assimilated by plant species. Denitrification reduces nitrate to N gas, which can leave the waterbody. In phosphorus-impacted areas with high P, N can become the nutrient that limits undesirable biological growth (McCormick et al. 1996; Inglett et al. 2004, Inglett et al. 2011). Many coastal marine systems are N-limited. It is important to holistically understand restoration efforts and the potential effects that increased flows may have on nitrogen processes (Inglett et al. 2011). The Florida water quality criterion for Total Nitrogen (TN) that applies to BCNP is a narrative: “nutrient concentrations shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna” (FAC 62-302.530(48)(b)).

Nitrogen in BCNP surface water has been monitored beginning with the USGS in the 1960s, SFWMD in the 2000s, and others. Results or summaries are reported in Klein et al. (1970); Schneider et al. (1996); Stober et al. (1998); Lietz (2000); McPherson et al. (2000); Scheidt et al. (2000); McPherson and Miller (2003); Miller et al. (2004); FDEP (2017); and McBride and Sifuentes (2018).

REMAP 2023 surface water TN concentrations ranged from 0.26 to 0.97 mg/L. These concentrations were lower (Dunn’s test < 0.05) than all previous wet season data (REMAP 1995-96, and SFWMD historic marsh and canal data, Figure Nitrogen 1). Historic marsh data had a greater range, coincident with a much larger database ($n = 349$) reflecting a greater range in water depths. For the wet season, overall there was no significant ($p < 0.05$) latitudinal gradient in REMAP data (Appendix 4), coincident with higher concentrations in both the north and the south (Figure Nitrogen 2). The higher concentrations in the south are concomitant with higher chloride levels that tend to be associated with levels indicative of estuarine waters, as these southern locations also had higher chloride concentrations (Figure Chloride 2). Historic SFWMD marsh data had a significant, but weak ($p < 0.05$, $rho = 0.31$) latitudinal gradient, with lower concentrations to the south (Appendix 4). For the dry season, only historic marsh data were available, and they also show a significant, but weak ($p < 0.05$, $rho = 0.34$; Appendix 4) latitudinal gradient, with lower concentrations to the south. About 50.0% of the marsh area sampled had a TN concentration at or below 0.44 mg/L, with a 95% confidence interval of 39.9% to 59.7% (Figure Nitrogen 3).



Group	Letter	N	Significantly Different
Historic Canal Dry	a	16	c
Historic Canal Wet	b	47	cdf
Historic Marsh Dry	c	118	abf
Historic Marsh Wet	d	349	bf
REMAP 95-96 Wet	e	12	f
REMAP 2023 Wet	f	35	bcde

Figure Nitrogen 1. Surface water TN (mg/L) comparisons across programs.

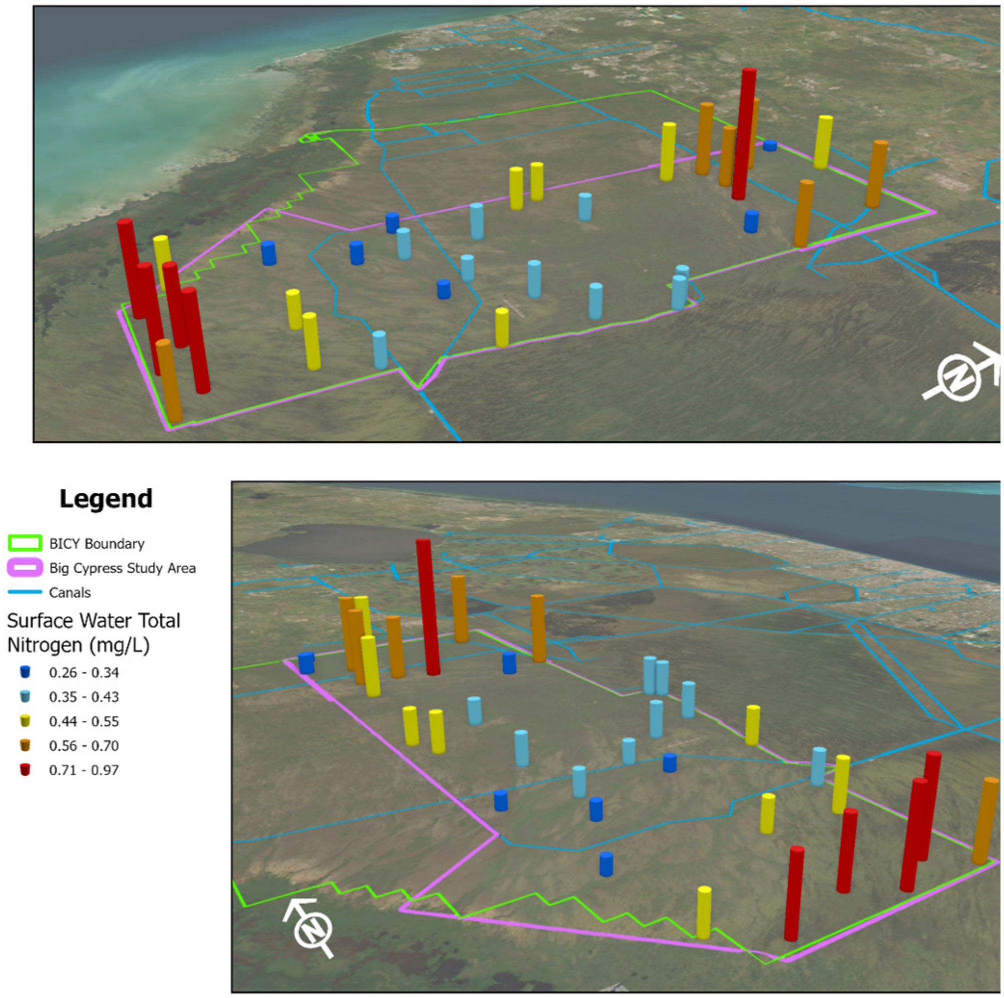


Figure Nitrogen 2. REMAP 2023 surface water TN (mg/L).

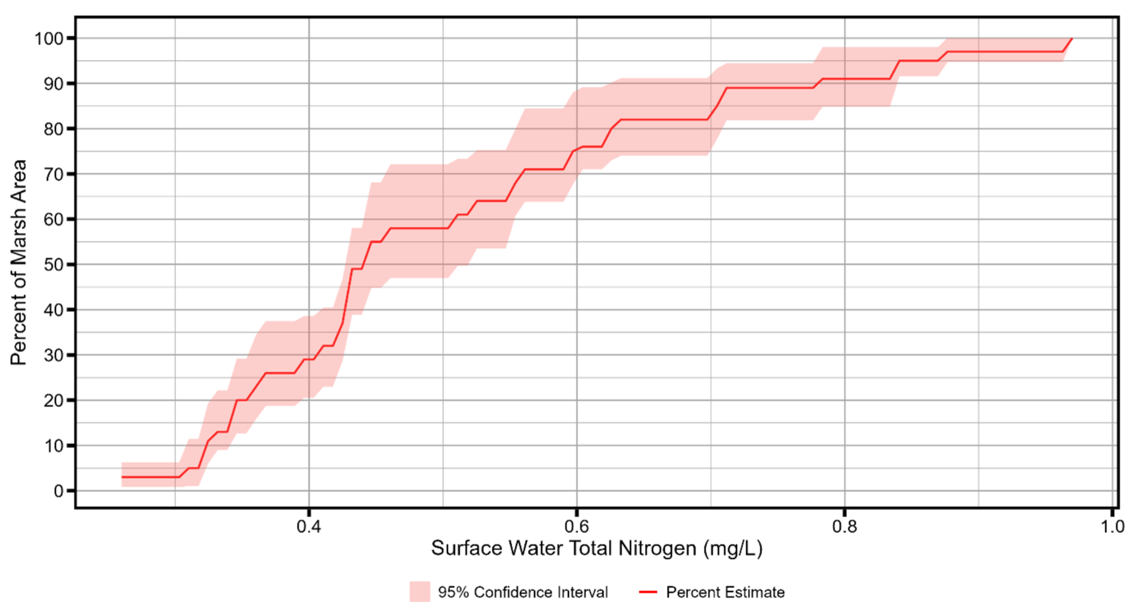


Figure Nitrogen 3. Surface water TN (mg/L) estimates of sampled area.

FDEP (2017) used a subset of the SFWMD historic marsh data (1996 - 2010) to evaluate TN conditions within BCNP with a goal of developing a TN target for WERP planning purposes. To determine if stations were considered nutrient-impacted, annual DO data were used to verify that the location achieved the DO water quality criterion, and data that did not meet the criterion were excluded for being inconsistent with restoration goals. Annual geometric mean (AGM) TN concentrations at the remaining individual stations ranged from 0.55 to 1.38 mg/L. The long-term TN limit of 0.91 mg/L was derived as an arithmetic average of AGM TN concentrations (n = 26 station years of data, 12 of which were west of the REMAP study area), with a standard deviation of the AGM of 0.17 mg/L. Similarly, from 1969 to 1970, USGS reported TN at Big Cypress locations ranging from 0.19 to 1.85 mg/L, with a mean of 0.82 mg/L (n = 26) (Klein et al. 1970).

Nitrogen in surface water exists in organic (Total Organic Nitrogen, TON) and inorganic (Total Inorganic, TIN) forms. TON and TIN include particulate nitrogen. REMAP 2023 water samples were analyzed for TN. Samples were filtered (0.45 µm) and analyzed for Dissolved Inorganic Nitrogen (DIN): nitrite (NO2), nitrate (NO3) and ammonium (NH4). TIN and TON were not analyzed.

Most N within Big Cypress surface water is in the organic form. Inorganic forms are of interest because they are more bioavailable than organic forms. REMAP 2023 surface water dissolved nitrate plus nitrite (NOx) ranged from 0.001 to 0.024 mg/L, with a median of 0.002 mg/L. Dissolved surface water ammonium (NH4) ranged from 0.003 to 0.082 mg/L, with a median of 0.008 mg/L. DIN had a median of 0.0018 mg/L, accounting for only 0.8 to 10.8 percent of the TN across stations with a median of 2.3 percent (Figure Nitrogen 4, TN median = 0.44 mg/L). Total Organic Nitrogen (TON) was estimated by subtracting DIN from TN, and accounted for 89.2% to 99.2% of the TN pool across stations, with a median of 97.7%. Dissolved Organic Nitrogen (DON) was not analyzed, but has been reported to account for approximately 90% (Noe et al. 2007) to 95% (Inglett et al. 2011) of TN in surface water of the Everglades.

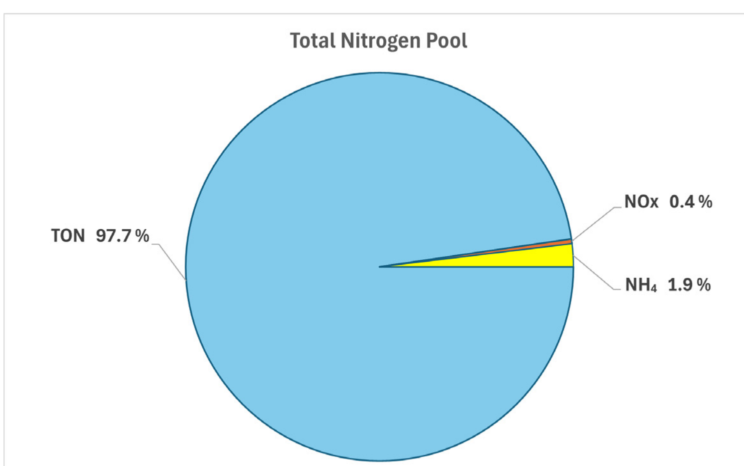


Figure Nitrogen 4. Surface water total nitrogen pool.

OVERVIEW AND FINDINGS - WATER QUALITY

CHLOROPHYLL *a*

Chlorophyll allows plants, including algae, to use sunlight to convert simple molecules into organic compounds (photosynthesize). Chlorophyll *a* is the predominant type of chlorophyll found in green plants and algae. Although algae are a natural part of freshwater ecosystems, too much algae can cause green scums, blooms and odors, and can result in decreased levels of dissolved oxygen. Blooms with the potential to harm human health or aquatic ecosystems are referred to as Harmful Algal Blooms (HABs). HABs can produce toxins that present wide-ranging risks to people, animals, and aquatic ecosystems. HABs can also affect the economy, drinking water supplies, property values, commercial and industrial fishing, and recreational activities like swimming (USEPA 2024d). One of the symptoms of degraded water quality is the increase of algal biomass as measured by the concentration of chlorophyll *a*. Waters with high levels of nutrients may have high concentrations of chlorophyll *a,* indicating excessive amounts of algae.

Florida's numeric water quality standard for chlorophyll *a* in surface water for BCNP is not to exceed 20 µg/L, assessed as an annual geometric mean with at least 4 samples at a location (FAC 62-302.531, 62-303.450, 62-303.351). The water quality standard is mentioned here only as a point of reference since REMAP sampled locations only once.

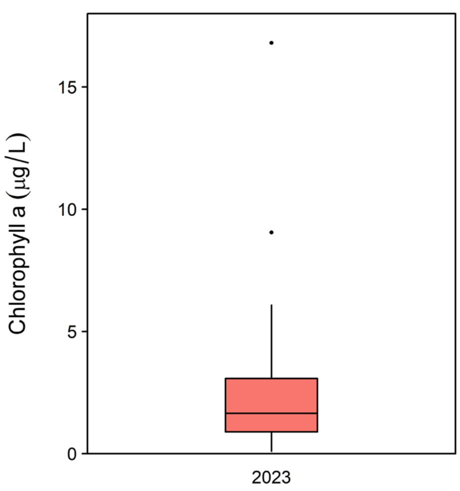


Figure Chlorophyll *a* 1. Surface water chlorophyll *a* (µg /L).

REMAP 2023 surface water chlorophyll *a* ranged from < 0.1 to 16.8 µg/L (Figure Chlorophyll *a* 1). There were several stations in the northwest corner of the study area that had chlorophyll *a* concentrations higher than 3.63 µg/L (Figure Chlorophyll *a* 2). This area also had surface water TP concentrations in the highest two TP quintiles. Nutrient enrichment from the watershed has been a concern since the 1960s (USDOI, 1969). Among the 35 stations, station 2020 at the southeastern edge of the study area had the highest concentration of chlorophyll *a* (16.81 µg/L, 100th percentile, about eight times the interquartile range of the data). This station was a wet prairie habitat dominated by spike rush and bladderwort with abundant periphyton. Surface water TP was 8 µg/L (20th percentile), and TN was

0.7 mg/L (80th percentile). Water depth was 1.8 feet and DO percent saturation was 40% at 13:06. There were no other indicators of nutrient enrichment at this station.

There are no chlorophyll *a* data for comparison from REMAP 1995-96, or from the SFWMD DBHYDRO database at canal or marsh locations. The REMAP 2023 data indicate no latitudinal gradient with latitude (p = 0.56, rho = 0.1, Appendix 4). About 50% of the marsh area sampled had a chlorophyll *a* concentration at or below 1.65 µg/L, with a 95% confidence interval of 42.4% to 55.9% (Figure Chlorophyll *a* 3).

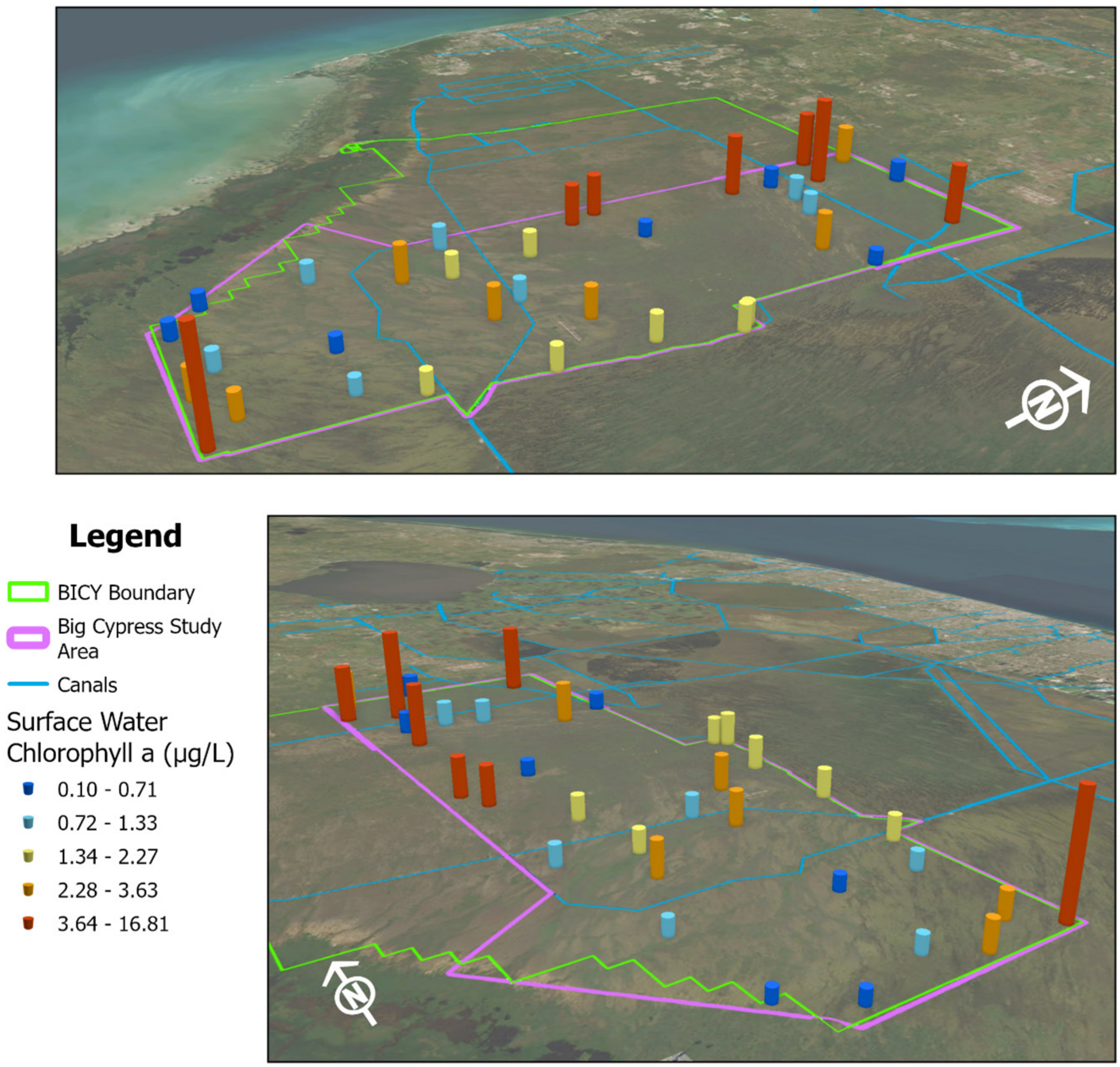


Figure Chlorophyll *a* 2. Surface water chlorophyll *a* (µg /L).

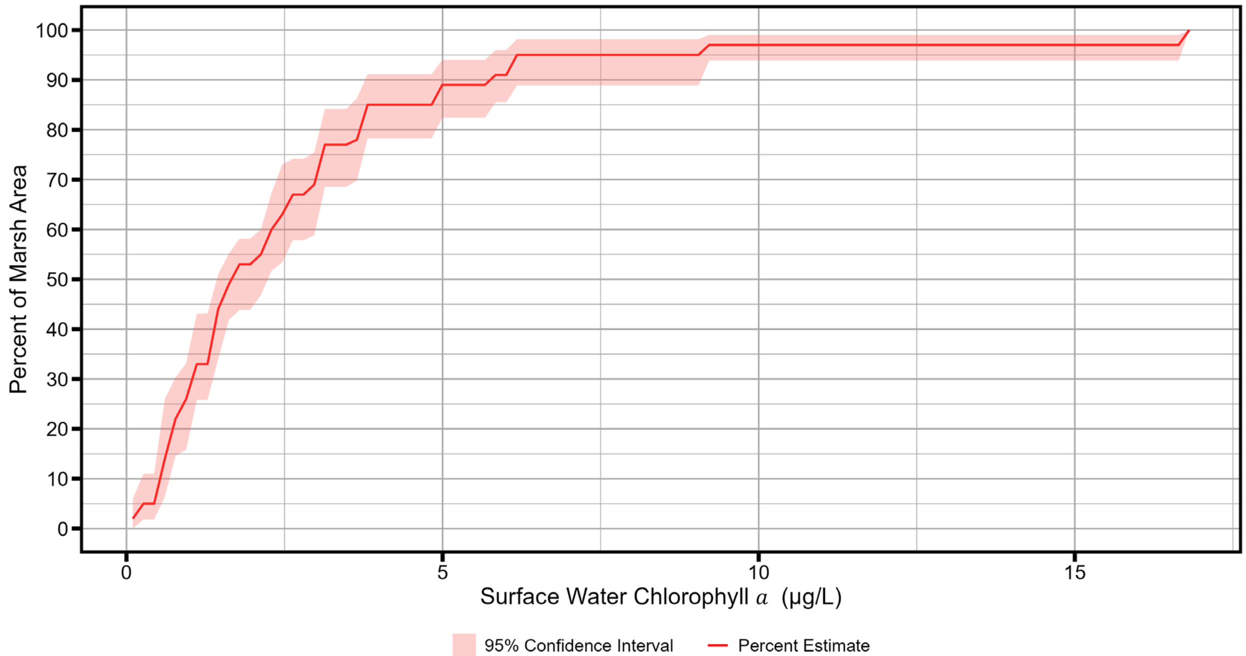


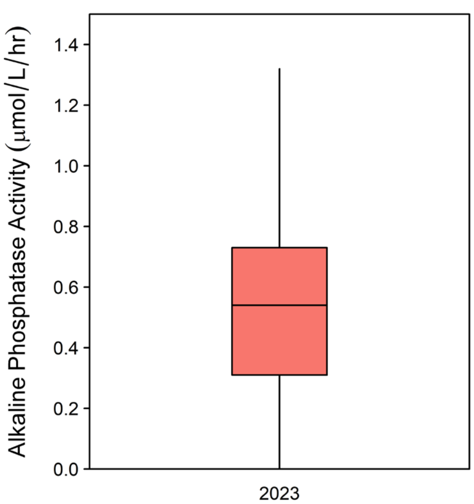
Figure Chlorophyll *a* 3. Surface water chlorophyll *a* (µg /L) estimates of sampled area.

OVERVIEW AND FINDINGS - WATER QUALITY

ALKALINE PHOSPHATASE ACTIVITY

Phosphatase activity can be a useful early warning indicator of eutrophication in wetlands when used in combination with other indicators (Newman et al. 1997). The Alkaline Phosphatase Activity (APA) assay measures the activity of alkaline phosphatase, an enzyme used by microbes such as bacteria and microscopic algae to mineralize phosphate from organic compounds into bioavailable P (Kang et al. 2019). APA is measured in waterbodies with very low total phosphorus concentrations, such as marine waters (Kang et al. 2019, Mahaffey et al. 2014). APA is induced at low phosphate concentrations (Mahaffey et al. 2014), and has been shown to increase in some waterbodies when there are low amounts of phosphate (Kang et al. 2014). Environmental parameters other than phosphate (such as nitrogen, dust and metals) also have been shown to regulate APA (Mahaffey et al. 2014).

Analytical laboratories throughout the world perform APA analyses, but there is no standard laboratory analytical method for determining APA in surface water, and methods vary. Therefore, in this report USEPA Region 4 LSASD APA results are not compared to results reported by other investigators or programs, such as SFWMD. The focus here is reporting results across space with data from one laboratory using a single analytical method.



Alkaline Phosphatase Activity 1. Surface water alkaline phosphatase activity (µmol/L/hour).

REMAP 2023 surface water APA ranged from 0 to 1.32 micromoles per liter per hour (µmol/L/hr), with a median of 0.54 µmol/L/hr (Figures Alkaline Phosphatase Activity 1 and 2). There was no latitudinal gradient ($p = 0.90$, $rho = 0.02$, Appendix 4). About 50% of the marsh area sampled had an APA rate at or below 0.54 µmol/L/hr, with a 95% confidence interval of 45.0% to 58.0% (Figure Alkaline Phosphatase Activity 3).

Surface water phosphate was not detected above the lab MDL of 1.92 µg/L, even at the highest TP concentration of 32.9 µg/L. Consequently, a relationship between phosphate and APA could not be explored. There was no relationship between surface water TP and APA (p = 0.77, Appendix 3). REMAP Everglades data were used previously in generalized boosted models to identify covariates that could explain mercury in mosquitofish. Among 45 REMAP environmental variables, APA in surface water had the largest mean influence of 10% on mercury bioaccumulation from surface water to mosquitofish (Kalla et al. 2021). REMAP 2023 Big Cypress data indicate no relationship between surface water APA and the total mercury bioaccumulation factor from surface water to mosquitofish (p = 0.42, Appendix 3).

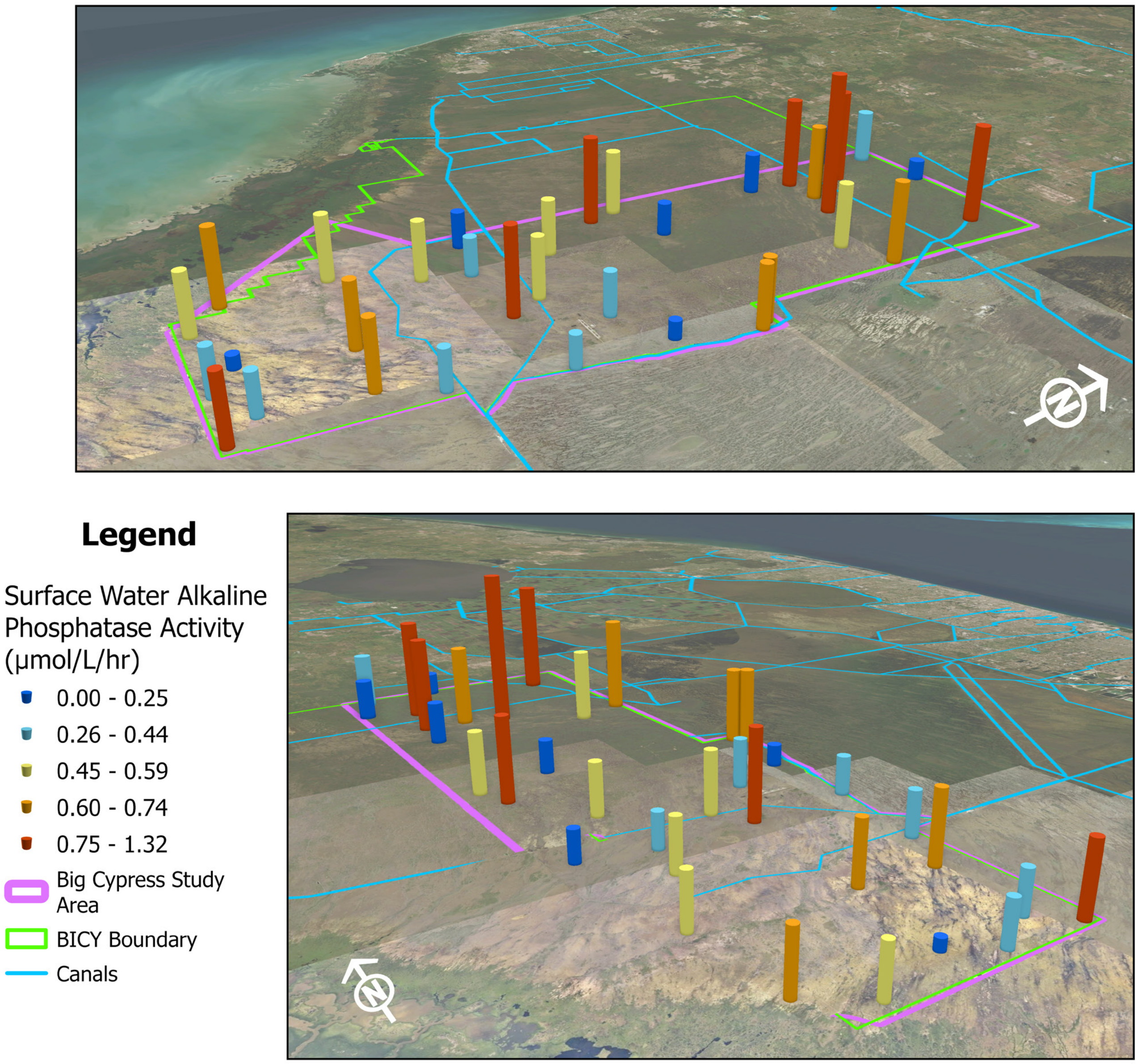


Figure Alkaline Phosphatase Activity 2. Surface water alkaline phosphatase activity (μmol/L/hour).

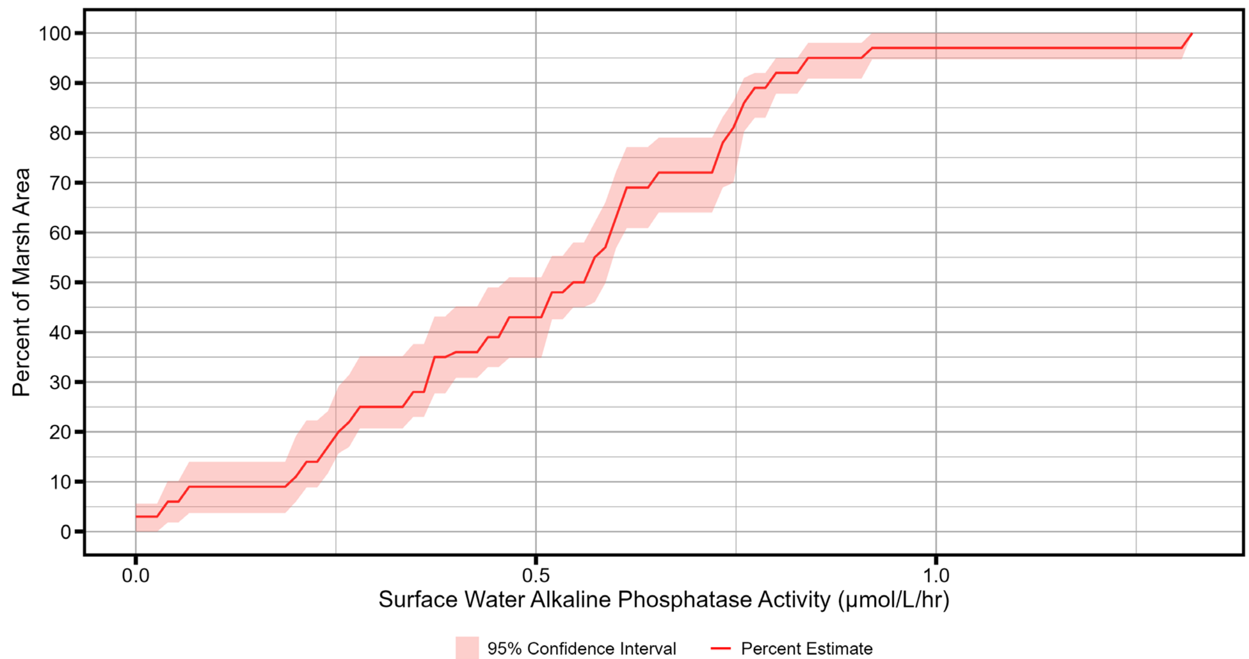


Figure Alkaline Phosphatase Activity 3. Surface water alkaline phosphatase activity (µmol/L/hour) estimates of sampled area.

OVERVIEW AND FINDINGS - WATER QUALITY

SPECIFIC CONDUCTANCE

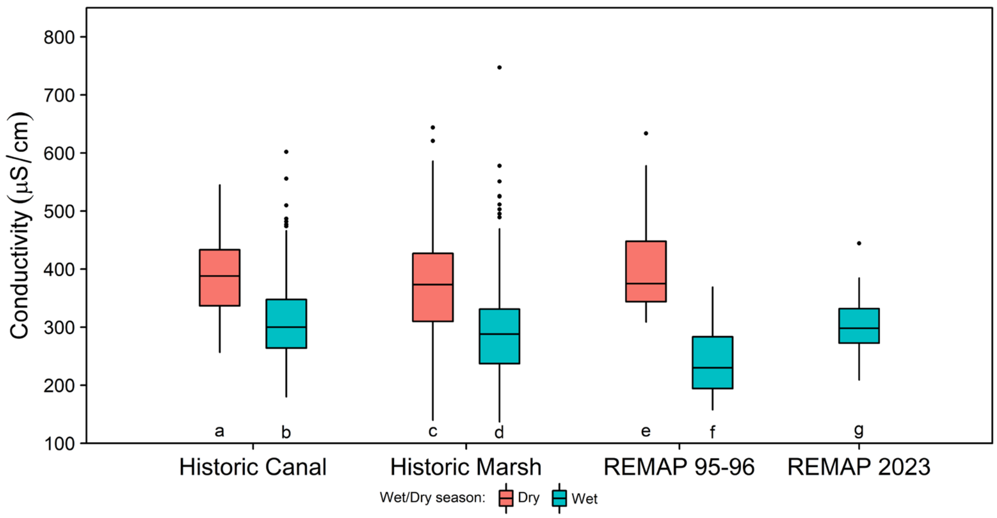
Surface water specific conductance is a parameter of interest because it serves as a general measure of water quality, a potential tracer of hydrologic flow, and an indicator of water sources and potential pollutants (Scheidt et al. 2021). In addition, increased specific conductance has been shown to alter the development of periphyton communities in the Greater Everglades system (Gaiser et al. 2011, McCormick et al. 2011).

Specific conductance is an indirect measure of the total concentration of dissolved ions or minerals in water, such as calcium, sodium, magnesium, chloride, bicarbonate and sulfate. It is defined as the electrical conductance of 1 cubic centimeter (cm^3) of a solution at 25°C. The terms “specific conductance”, “electrical conductivity”, and “conductivity” have been used interchangeably in recent decades to report the same measurement. The units of electrical conductivity are mhos per centimeter (mhos/cm), which are equivalent to microSiemens per centimeter (µS/cm). Specific conductance does not provide information about the ionic composition, only the overall concentration of ions. Pure water has extremely low electrical conductivity of a few hundredths of a µS/cm (generally, less than 0.05 µS/cm) (Hem 1985, USGS 2019). The terms ‘soft water’ and ‘hard water’ are used to describe waters containing relatively low or high concentrations of dissolved ions, respectively. As the concentration of dissolved ions increases, so do the specific conductance and hardness of the water.

Specific conductance values are affected by the relative contribution of rainwater, groundwater, stormwater, and canal water. The parameter is considered conservative as it is generally not biologically reactive (Harwell et al. 2008). Therefore, specific conductance can be useful for understanding the source of water and its flow path. Florida’s water quality criteria for Class III freshwater allow for a 50% increase above background conditions in specific conductance or 1,275 µS/cm, whichever is greater (FAC 62-302.200(22)).

Precipitation in the Everglades region has very low specific conductance, with 2013 - 2022 calendar year annual averages ranging from 6.7 to 11.9 µS/cm (NADP 2024b). REMAP 2023 surface water specific conductance ranged from 209.2 to 444.5 µS/cm (n = 35, Figures Specific Conductance 1 and 2). From 1999 - 2024 SFWMD data for specific conductance at water control structure S-190, 3.2 miles upstream from BCNP within the L28IN canal, ranged from 215 to 845 µS/cm, median

= 554 µS/cm, n = 1081. During October 23, 2023 specific conductance was 418 µS/cm. Specific conductance at the L28I canal within the boundary of BCNP just north of I-75 was 446 µS/cm during October 23, 2023, and from 1999 – 2024 ranged from 209 to 799 µS/cm, average = 595 µS/cm, n = 595 (DBHYDRO, accessed October 2024).



Group	Letter	N	Significantly Different
Historic Canal Dry	a	65	bcdfg
Historic Canal Wet	b	265	acdef
Historic Marsh Dry	c	131	abdfg
Historic Marsh Wet	d	349	abcef
REMAP 95-96 Dry	e	13	bdfg
REMAP 95-96 Wet	f	23	abcdeg
REMAP 2023 Wet	g	35	acef

Figure Specific Conductance 1. Surface water specific conductance (µS/cm) comparisons across programs.

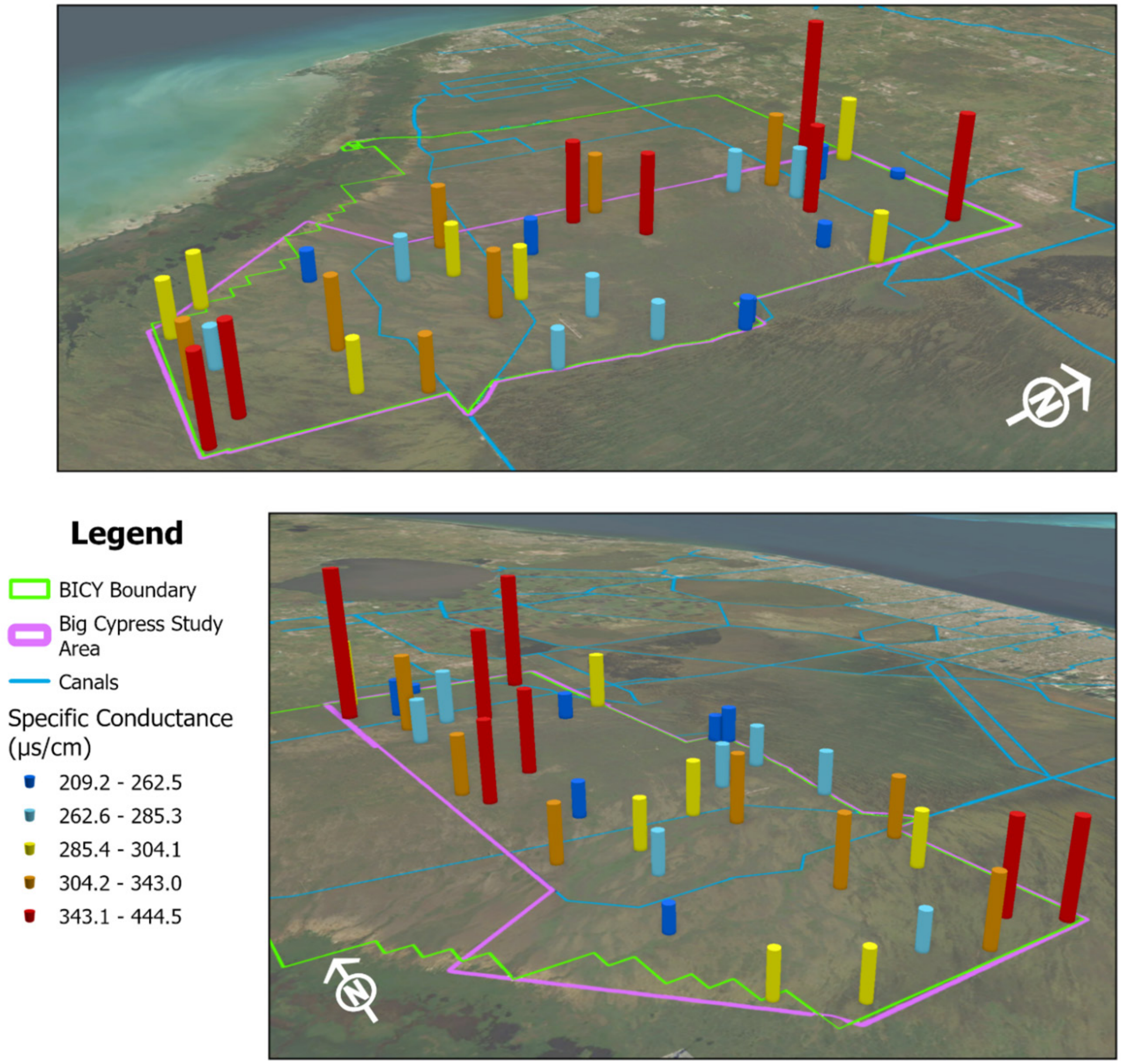


Figure Specific Conductance 2. Surface water specific conductance (µS/cm).

The 2023 marsh wet season results are comparable to SFWMD historic results ($p > 0.05$) at wet season marsh and canal stations. Across all programs, wet season marsh and canal results were lower than dry season results (Figure Specific Conductance 1, Dunn's test < 0.05). Rainfall dilutes surface water dissolved solids, and as rainfall diminishes and water depth decreases during the dry season, ions tend to concentrate in shallower water resulting in higher specific conductance. This seasonality was also true of Everglades REMAP data (Scheidt et al. 2021). The 1995-96 Big Cypress REMAP wet season measurements at different marsh locations (range 158 to 369 µS/cm, median = 168 µS/cm, n = 23) were lower than ($p < 0.05$) all other wet season data.

Historic SFWMD dry season and wet season data had a weak latitudinal gradient with higher concentrations to the south ($p < 0.05$, rho = -0.38 and -0.25, respectively). REMAP data did not have a latitudinal gradient (Appendix 4). About 50% of the marsh area sampled had specific conductance at or below 298.2 µS/cm, with a 95% confidence interval of 41.6% to 56.7% (Figure Specific Conductance 3). These Big Cypress results are similar to Everglades REMAP results at marsh locations away from canal inflows (Scheidt et al. 2021).

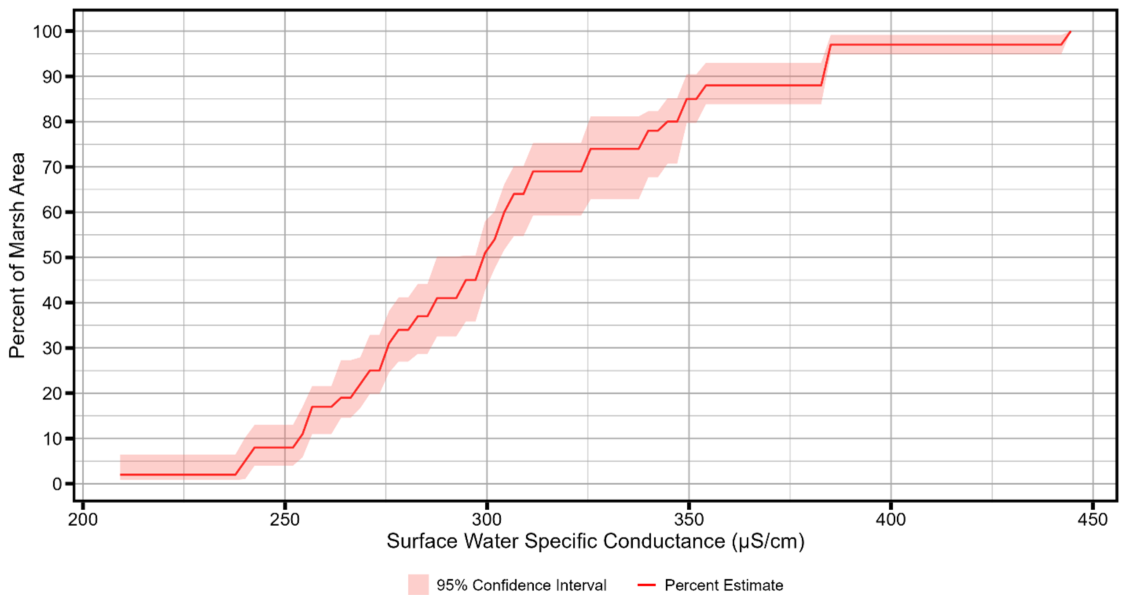


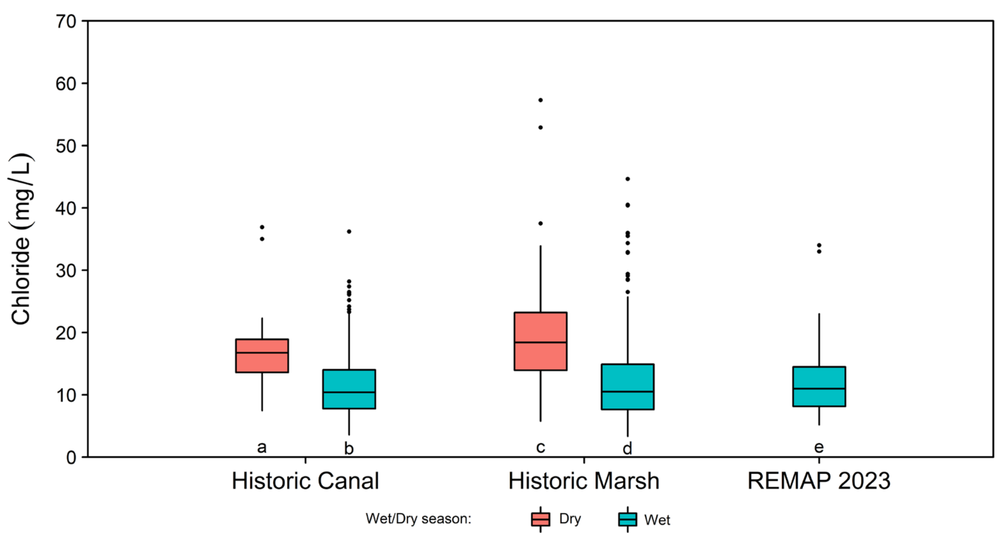
Figure Specific Conductance 3. Surface water specific conductance (µS/cm) estimates of marsh area.

OVERVIEW AND FINDINGS - WATER QUALITY

CHLORIDE

Chloride is an ion common to surface water and groundwater. Chloride ions can come from sodium chloride or other chloride salts. Saltwater has very high natural concentrations of chloride, and in coastal areas, estuarine waters contain more chloride than freshwater due to the influence of saltwater. Chloride is a conservative ion, meaning its concentration does not readily change under biological influences. Therefore, chloride can be a useful indicator of a water's source.

The concentration of chloride can vary greatly depending on the relative influence of rainwater, groundwater and stormwater. Florida defines predominantly fresh waters as waters in which the chloride concentration is less than 1,500 mg/L or specific conductance is less than 4,580 µS/cm (FAC 62-302.200(29)). Florida does not have a numeric chloride water quality criterion for Class III freshwater.



Group	Letter	N	Significantly Different
Historic Canal Dry	a	66	bde
Historic Canal Wet	b	289	ac
Historic Marsh Dry	c	136	bde
Historic Marsh Wet	d	382	ac
REMAP 2023 Wet	e	35	ac

Figure Chloride 1. Surface water chloride (mg/L) comparisons across programs.

Between 2013 and 2022, precipitation in the Everglades region had annual calendar year average chloride concentrations ranging from 0.63 to 1.68 mg/L (NADP 2024b). REMAP 2023 surface water chloride in Big Cypress ranged from 5 to 34 mg/L (Figures Chloride 1 and 2). There were five higher values ranging from 19 to 34 mg/L at the southern end of the study area. This could indicate estuarine influence (Figure Chloride 2), as these same locations also had high total nitrogen. However, these stations did not have high specific conductance (Figures Nitrogen 2 and Specific Conductance 2). From 1999 - 2024 SFWMD data for chloride at water control structure S-190, 3.2 miles upstream from BCNP within the L28IN canal, ranged from 12.7 to 108 mg/L, median = 35.3, count = 209. During October 23, 2023 chloride was 22.1 mg/L. Chloride in the L28I canal within the boundary of BCNP just north of I-75 was 21.4 mg/L during October 23, 2023, and from 1999 - 2024 ranged from 8 to 130.8 mg/L (average = 34.2 mg/L, n = 595; DBHYDRO, accessed October 2024).

Across REMAP and SFWMD Big Cypress programs, wet season marsh and canal chloride results were comparable, dry season results were comparable ($p > 0.05$), and wet season results were lower than dry season results ($p < 0.05$; Figure Chloride 1). Rainfall dilutes surface water chloride, and as rainfall diminishes and water depth drops during the dry season, ions tend to concentrate in shallower water resulting in higher chloride concentrations. REMAP 2023 data had a significant but weak latitudinal gradient ($p < 0.05$, rho = -0.36, Appendix 4). About 50% of the marsh area sampled had a chloride concentration at or below 11.0 mg/L, with a 95% confidence interval of 39.2% to 58.4% (Figure Chloride 3). REMAP 2023 Big Cypress chloride concentrations were similar to REMAP wet season concentrations at Everglades interior marsh locations, and Everglades wet season concentrations were also lower than dry season concentrations (Scheidt et al. 2021).

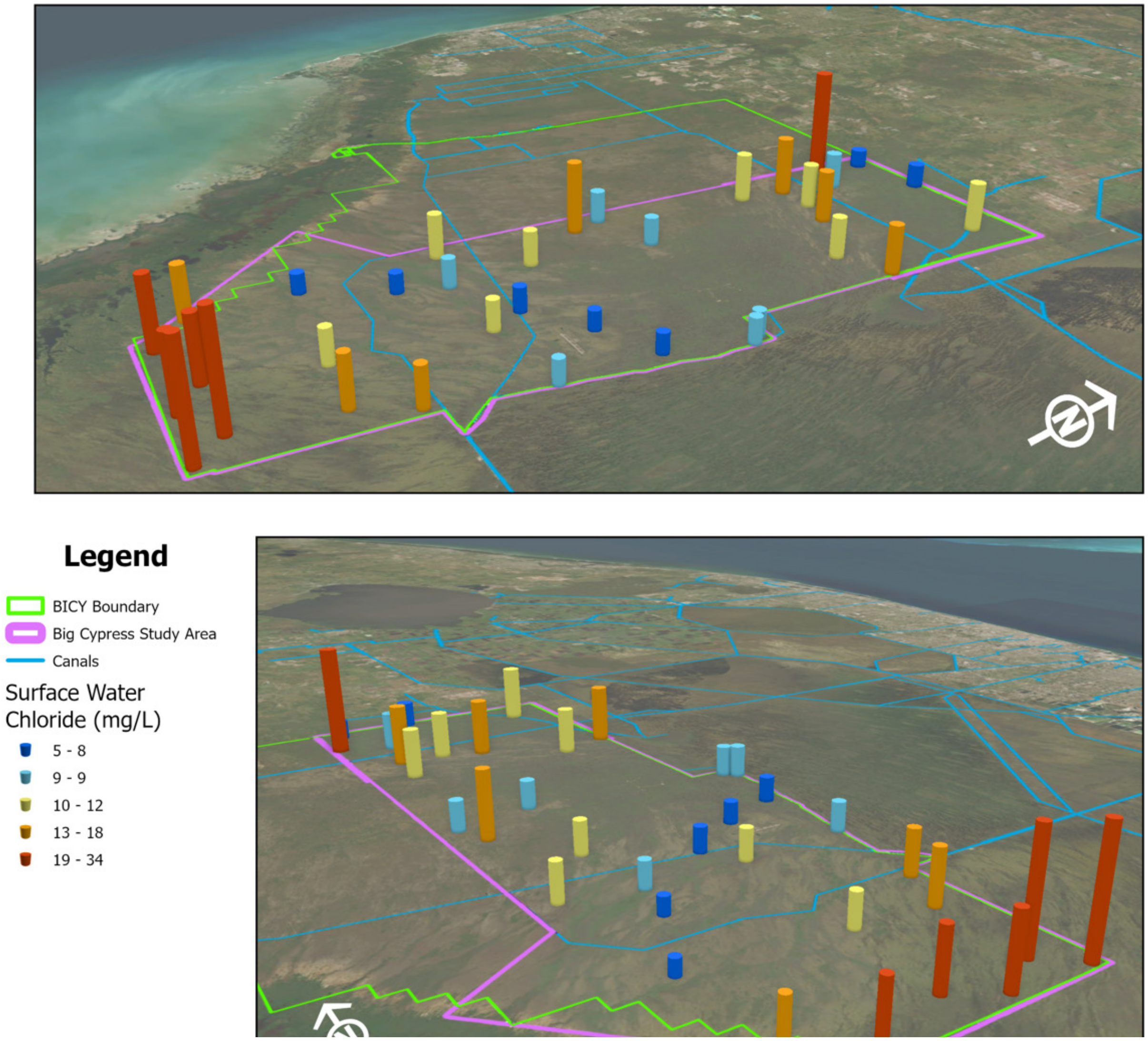


Figure Chloride 2. REMAP 2023 Surface water chloride (mg/L).

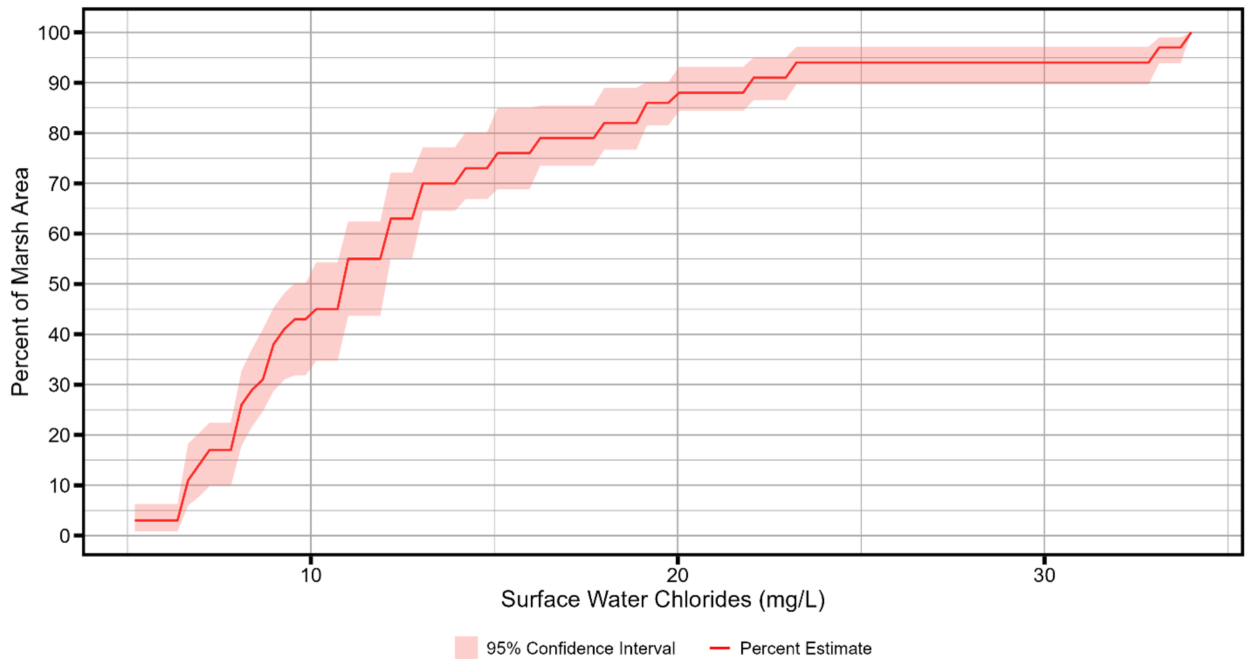


Figure Chloride 3. Surface water chloride (mg/L) estimates of marsh area.

OVERVIEW AND FINDINGS - WATER QUALITY

SULFUR

Sulfur is an element that exists in several forms in water bodies. Sulfur generally occurs in surface water in the oxidized state as sulfate, an ion that is common in nature. Sulfate is a natural ingredient of rainfall, surface water and groundwater. The form of sulfur that exists in water where there is no oxygen is the reduced form, sulfide, which is associated with sulfate reduction by anaerobic bacteria (Orem et al. 2019).

Sulfur is of ecological interest for three reasons: sulfate and sulfide are associated with mercury methylation and subsequent biomagnification in gamefish and wildlife (Pollman 2014, 2019; Orem et al. 2019, Rumbold 2019a; Sotolongo-Lopez et al. 2025); elevated sulfate can mobilize phosphorus in some water bodies (Smolders et al. 2006, Lamers et al. 1998, Lamers et al. 2002, Beltman et al. 2000); and sulfide at elevated concentrations can be toxic to or adversely affect plants (Smolders et al. 2006, Lamers et al. 1998, Lamers et al. 2002; Li et al. 2009) and animals (USEPA 1986). Because of these ecological concerns CERP adopted a restoration performance measure for surface water sulfate: maintain or reduce sulfate concentration to 1 mg/L or less throughout the Everglades marsh (RECOVER 2007).

Florida does not have numeric surface water quality criteria for sulfate or sulfide in Class III waters, and USEPA does not have a recommended surface water criterion for sulfate. For sulfide in surface water, USEPA recommends a continuous concentration criterion of less than 0.002 mg/L (2 µg/L) for protection of aquatic life (USEPA 1986). Florida water quality standards require that no substances shall be present “in concentrations which injure, are chronically toxic to, or produce adverse physiological or behavioral response in humans, plants or animals” (FAC 62-302(62)). This is referred to as the ‘free from’ requirement.

REMAP 2023 measured soluble sulfide in bottom water - water collected near the soil surface. Only one out of 35 stations (2.9%) had a result that exceeded the sulfide analytical Method Detection Limit (MDL) of 15 µg/L (Figure Sulfur 1). This was station 2035, a pond, which also had the lowest dissolved oxygen (0.9 mg/L, 10.8% saturation), the lowest pH in surface water and soil, and the lowest redox potential of -20 mV, indicative of a reducing environment. There are no previous bottom water sulfide data in BCNP for comparison.

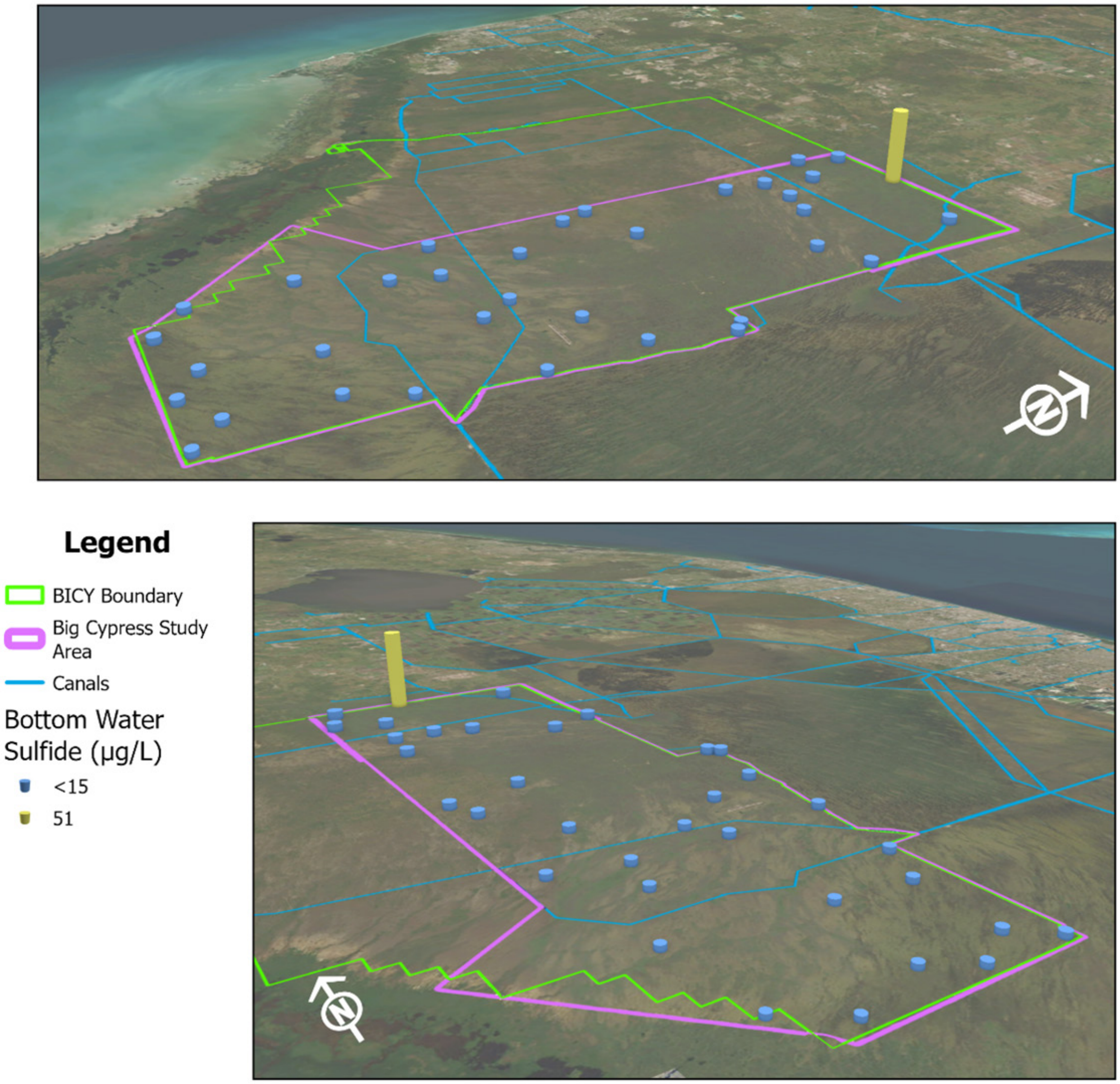
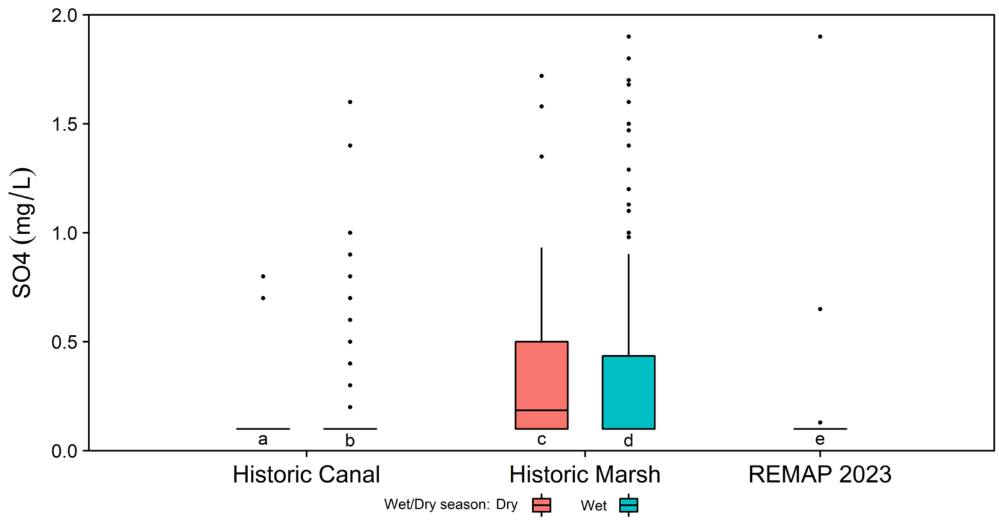


Figure Sulfur 1. REMAP 2023 bottom water sulfide (µg/L).



Group	Letter	N	Significantly Different
Historic Canal Dry	a	66	cde
Historic Canal Wet	b	284	cde
Historic Marsh Dry	c	102	abe
Historic Marsh Wet	d	331	abe
REMAP 2023 Wet	e	35	abcd

Figure Sulfur 2. Surface water sulfate (mg/L) comparisons across programs. Data are included only when the analytical lab had an MDL at or less than 0.1 mg/L. All data were revised to have a common floor of 0.1 mg/L.

Comparison of surface water sulfate results across decades within and across programs is complicated by improving analytical laboratory methods, which have made it possible over time for labs to detect lower concentrations as MDLs change. This is a common issue with certain analytes in long-term databases (Miller et al. 2004, Scheidt et al. 2021). The data below the MDL concentration are left- censored, and if the concentration is in fact lower than the MDL, the true concentration is unknown. The REMAP program sulfate MDL has improved across four decades from 5 mg/L in 1994 to 2 mg/L in 1995 to 0.5 mg/L in 1996 to 0.021 mg/L with the 2023 data – a 238-fold improvement in detectability. Since 1999 the SFWMD data have had an MDL of 0.1 mg/L. In order to make valid comparisons across these databases and time, all data must have the same possible minimum result, or floor. Consequently, for making comparisons across datasets in this report, the REMAP 2023 results below 0.1 mg/L were changed to 0.1 mg/L to coincide with the SFWMD MDL. Pre-1999 REMAP and SFWMD data with an MDL > 0.1 mg/L were excluded. Statements about the REMAP 2023 database alone use the data with the reported MDL of 0.021 mg/L.

REMAP 2023 surface water dissolved sulfate concentrations ranged from below the MDL of 0.021 mg/L to 1.9 mg/L (Figures Sulfur 2 and 3). Thirty-one of 35 results (88.6%) had concentrations reported as lower than the MDL. These concentrations are lower than rainfall concentrations.

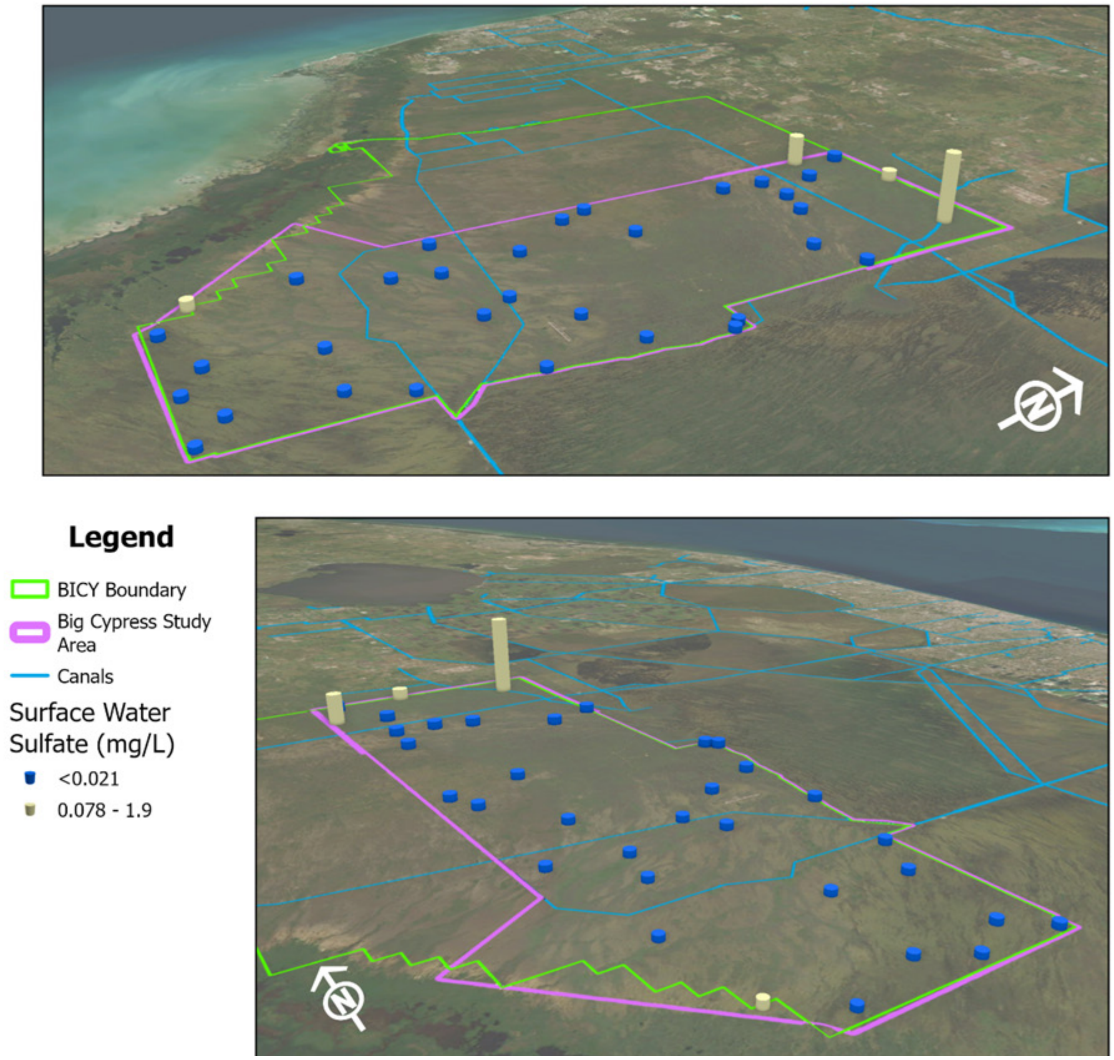


Figure Sulfur 3. REMAP 2023 surface water sulfate (mg/L).

Precipitation in nearby Everglades National Park has low annual mean sulfate content, with 2013 - 2022 annual calendar year averages ranging from 0.41 to 0.73 mg/L (NADP 2024b). Three marsh detections (1.9 mg/L, 0.65 mg/L and 0.078 mg/L) above the MDL occurred at northern stations, with a fourth detection (0.13 mg/L) to the southwest. The highest sulfate concentration of 1.9 mg/L was at station 2019, about 130 meters east of the L-28IN canal (Figure Sulfur 3). This station had the second highest TP concentration. Since the marsh is separated from the canal by a levee that prevents surface water flow, transport from the canal by groundwater is a potential explanation for this high sulfate concentration.

Comparing across datasets using the MDL screening described above indicates that historic wet and dry season marsh data were higher than all other datasets (Figure Sulfur 2, Dunn's test < 0.05), possibly due to the much larger database reflecting 25 years and varying wet season hydrological conditions and water depths. Historic marsh data results up to about 1.0 mg/L were not uncommon. REMAP 2023 data did not have a significant ($p > 0.05$) latitudinal gradient. Historic wet and dry season data had significant ($p < 0.05$) and weak ($rho = 0.3$) latitudinal gradients (Appendix 4). About 97.0% of the marsh area sampled had a surface water sulfate concentration at or below the Everglades target concentration of 1.0 mg/L, with a 95% confidence interval of 94.0% to 99.2% (Figure Sulfur 4).

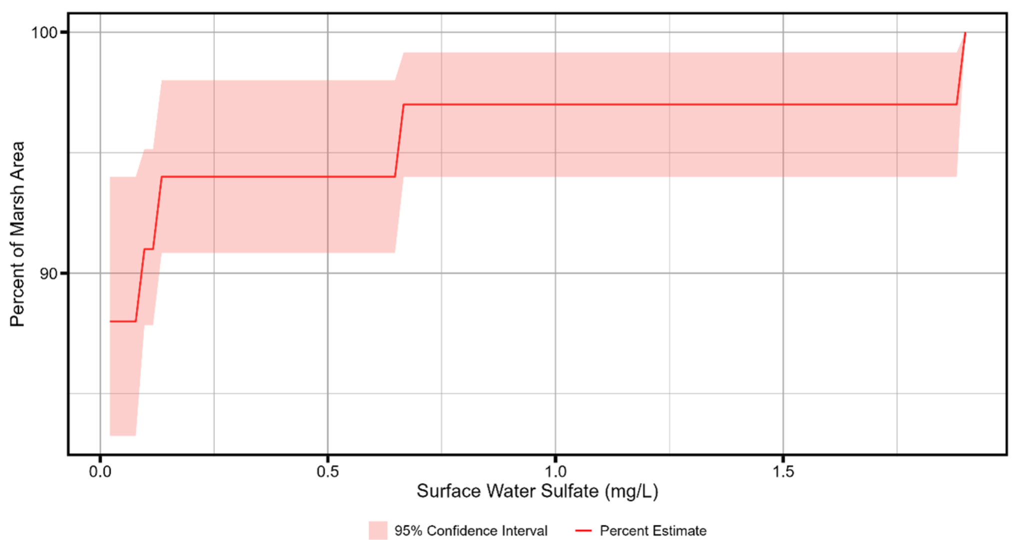


Figure Sulfur 4. Surface water sulfate (mg/L) estimates of marsh area. Note that the y-axis range is 80% to 100% since 31 of 35 stations were at or below the MDL of 0.021 mg/L.

Portions of the Everglades have much higher sulfate concentrations than BCNP, and pronounced sulfate gradients throughout canals and marshes have been a concern for decades. Sulfate concentrations in the Everglades marsh depend upon proximity to agricultural land use, canal conveyance, and the relative influence of rainwater, stormwater, and groundwater. Sulfate gradients in marsh and canal surface water since the 1990s have been documented by USEPA (summarized in Scheidt et al. 2021), USGS (Orem et al. 2011) and SFWMD (Sotolongo-Lopez et al. 2025). REMAP 2014 sulfate levels varied from below the MDL of 0.021 mg/L at interior marsh locations to 48 mg/L in WCA2A near agricultural stormwater inputs. Concentrations in the Everglades progressively decrease to the south and west. Surface water sulfate is higher during the wet season due to the movement of water throughout the Everglades for flood control (Scheidt et al. 2021).

During water year 2024, inflow sulfate was higher than outflow sulfate ($p < 0.05$) at STA 1-W, STA-3/4 and STA-5/6. STA-5/6 removed sulfate from an annual flow-weighted mean of 6.2 mg/L at the inflow to 1.9 mg/L at the outflow (Thourot and others 2025).

The role of sulfate in the biogeochemical cycling of mercury in the adjacent Everglades is complex and has been under investigation since the 1990s. REMAP data from 1995-2005 were used to explore the relationship between mercury in prey fish (mosquitofish) and many biogeochemical analytes by using structural equation modeling and data acquired by observation (empirical data). The role of sulfate was found to be complex in terms of its total effect on mosquitofish mercury and was one of several factors that were found to be important (Pollman 2014). REMAP data from 1995-2014 were used in generalized boosted models to identify covariates that could explain mercury in mosquitofish. Among 45 REMAP environmental variables, sulfate in surface water had the seventh highest mean influence of 7% on mercury bioaccumulation from surface water to mosquitofish (Kalla et al. 2021). In an Everglades STA that is managed to remove phosphorus, inflow sulfate along with chloride had a significant correlation with mosquitofish mercury, suggesting that sulfate input may be a factor influencing mercury (Feng et al. 2014). Inflow sulfate, chloride, DOC, and dissolved oxygen were factors related to outflow MeHg and THg (Zheng et al. 2013). Modeling has been conducted to predict changes in mosquitofish mercury that would result from potential changes in sulfate export from the Everglades Agricultural Area. Reductions in excess sulfate were projected to result in, depending on location, either increases or decreases in mosquitofish mercury, with the overall shifts in mosquitofish mercury expected to be small, regardless of the magnitude of reduction in sulfate (Pollman 2012).

The relationship between mercury, sulfur, and organic carbon is complex. Sulfide reacts with Dissolved Organic Matter (DOM) to form organic sulfur, which impacts mercury methylation and subsequent bioconcentration (Poulin et al. 2017). A 2008 – 2018 USGS study at 76 sites throughout the Park found strong regionality in mosquitofish MeHg concentrations, resembling patterns observed for surface water Dissolved Organic Carbon (DOC) and sulfate (Janssen et al. 2022). A microbial assessment showed that the Hg methylation genes were not present in sulfate reducing bacteria in the Everglades, but these bacteria played an important role in Hg methylation by stimulating overall microbial metabolism (Peterson et al. 2023). In addition, a multi-year field study in the WCAs confirmed that sulfate is a key factor in Hg methylation, due to effects on DOM chemistry, inorganic Hg speciation, and microbial processes (Poulin et al. 2025).

The question of whether to manage, mitigate or control sulfate because of concern about impacts to the Everglades has been debated since the 1990s. Many scientists state that it is clear sulfate contributes to mercury methylation. Although high and low fish mercury are found across the spectrum of surface water sulfate concentrations, peak fish mercury occurs between about 1 and 20 mg/L sulfate, so decreasing sulfate loading to background sulfate (<1 mg/L) would reduce MeHg risk (Gabriel et al. 2014a, 2014b; Orem et al. 2011, 2019, 2020; Corrales et al. 2011; Pollman and Axelrad 2014, Rumbold 2019a). Sulfate can influence the mercury-methylmercury cycle under a suite of ambient conditions (Janssen et al. 2022; Poulin et al. 2025; Sotolongo-Lopez et al. 2025).

However, other scientists argue that: a) sulfate is one of many factors that can influence mercury accumulation in gamefish such as largemouth bass; b) multiple water quality factors such as pH, specific conductivity and alkalinity also may be factors; c) there is not enough quantitative information to justify sulfur management strategies (Julian and Gu 2014, Julian et al. 2015); d) the mercury-related end products of these complexities must be predictable and quantified before an effective control or management strategy can be considered; and e) it is uncertain that reduction of sulfur inputs can reduce mercury methylation or shift methylation hot spots in the Everglades landscape or on a regional scale (Julian et al. 2016).

Florida has a gamefish consumption advisory throughout BCNP to protect human health. Women of childbearing age and young children should not eat largemouth bass, and other individuals should limit gamefish consumption to one meal per month. All people should limit warmouth consumption to one meal per month (FDOH 2025). Only four of 35 stations had sulfate greater than the MDL of 0.021 mg/L. Nine of 24 stations had total mercury (THg) concentrations in mosquitofish greater than the USFWS 77 ng/g predator protection level. Only one of these 9 had sulfate detected. Overall, the REMAP 2023 wet season marsh sulfide and sulfate data did not provide an indication of sulfur enrichment or concern at those locations at that time.

Sulfate concentrations are higher in some canals near or within BCNP and may be an issue for gamefish caught within these canals. From 1999 - 2024 SFWMD data for sulfate at water control structure S-190, 3.2 miles upstream from BCNP within the L28IN canal, ranged from 0.8 to 40.8 mg/L (MDL of 0.1 mg/L, median = 9.2 mg/L, count = 112). During the October 2023 REMAP sampling, sulfate was 3.4 mg/L at that location. Sulfate at L28I within the boundary of BCNP just north of I-75 ranged from 2.0 to 15.0 mg/L from 1999-2024 (median = 6.5 mg/L, count = 106). Sulfate was 3.2 mg/L in October 2023 at that location (DBHYDRO accessed October 2024). A levee prevents this canal surface water from flowing into BCNP marshes.

OVERVIEW AND FINDINGS - WATER QUALITY

CARBON

The element carbon plays an important role in biology by acting as the building block of proteins, amino acids, and DNA. It is present in all living organisms on Earth, from bacteria to plants and animals. Organic matter is a generic term referring to the carbon-based compounds found in terrestrial and aquatic environments and is primarily derived from the decomposition of plants and animals. Dissolved Organic Matter (DOM) is defined as the fraction of organic matter in a water sample that passes through a 0.45 µm filter (Bolan et al. 2011). DOM is of interest because it plays a role in many biogeochemical and ecological processes, such as nutrient transport, aquatic food web dynamics, light absorption, precipitation of minerals, and transport and reactivity of metals such as mercury. The amount of DOM present in an aquatic system can be affected by microbial and geochemical processes, along with larger landscape scale factors such as peat drainage and oxidation, water movement and management, and marsh dry-down and re-wetting. DOM sources include peat, vegetation, periphyton, and detritus. In aquatic science, dissolved organic carbon (DOC) is the most commonly measured form of DOM (Aiken et al. 2011, Graham 2019).

Water samples were analysed for Total Organic Carbon (TOC) and DOC (0.45 µm filter). Almost all of the organic carbon was in the dissolved form ($p < 0.01$, rho = 0.94; n=35, Figure Total Organic Carbon 1). TOC values ranged from 14 to 28 mg/L, with a median of 18 mg/L (Figures Total Organic Carbon 1 to 3), while DOC ranged from 14 to 26 mg/L, with a median of 18 mg/L. There are no SFWMD TOC data for comparison to REMAP data. Among REMAP data, 1995-96 dry season data exhibited the highest TOC values, while 1995-96 wet season data showed the lowest values (Dunn's test < 0.05; Figure Total Organic Carbon 2). REMAP 2023 data did not have an overall latitudinal gradient with latitude ($p = 0.48$, rho = 0.12, Figure Total Organic Carbon 4), although the two northernmost stations had the highest concentrations. However, 1995-96 data had a significant and very strong latitudinal gradient, with higher concentrations to the north ($p < 0.05$, rho = 0.91). In 2023 about 50% of the marsh area sampled had a surface water TOC concentration at or below the median of 18.0 mg/L, with a 95% confidence interval of 37.1% to 59.3% (Figure Total Organic Carbon 5). These observed TOC values are comparable to those measured in Big Cypress in 1969-70 (range = 4-27 mg/L, mean = 11 mg/L) by Klein et al. (1970). Most of the Everglades also has DOC concentrations less than 20 mg/L, and concentrations are also lower in the wet season than the dry season (Scheidt et al. 2021).

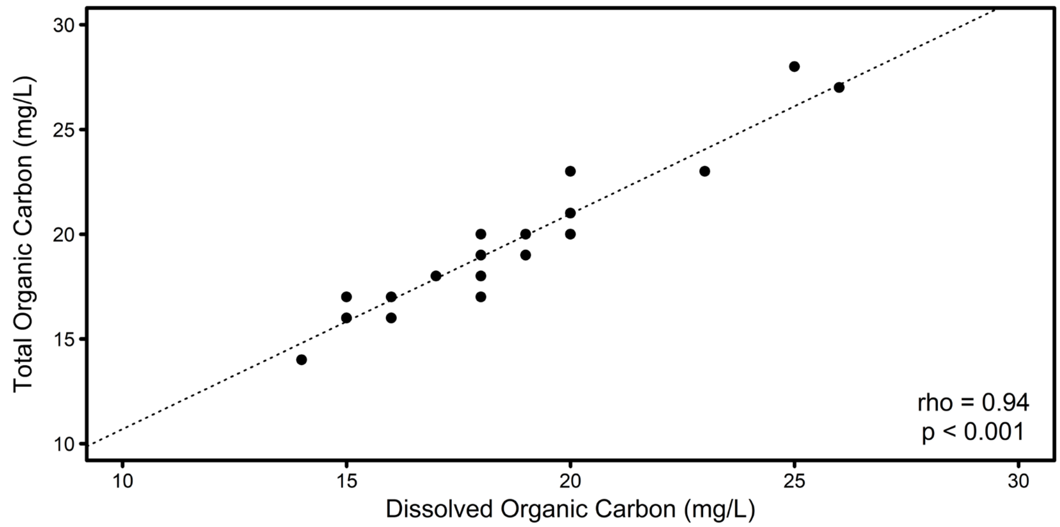
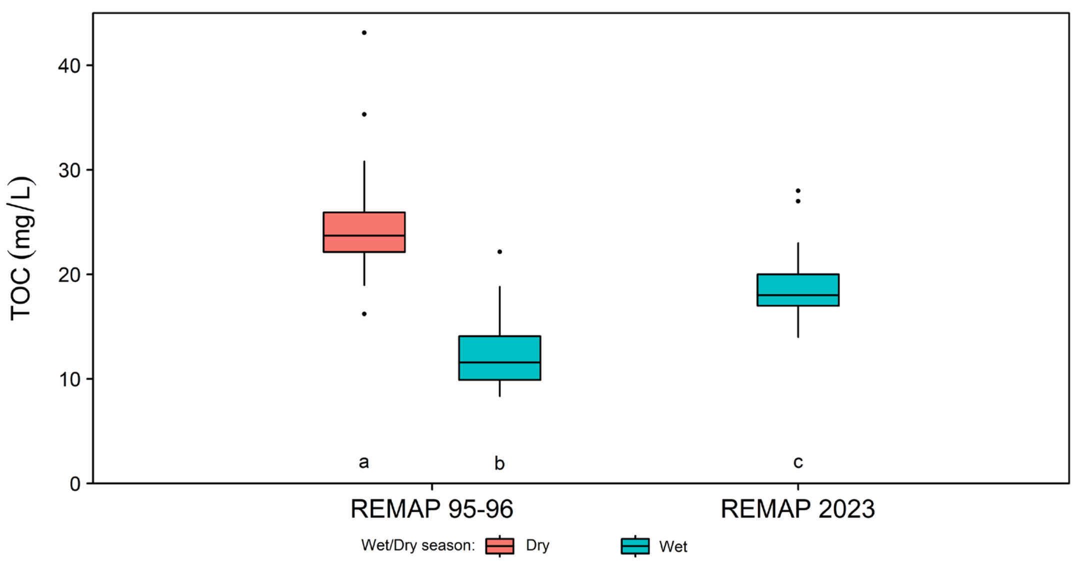


Figure Total Organic Carbon 1. Surface water dissolved organic carbon (mg/L) versus total organic carbon.



Group	Letter	N	Significantly Different
REMAP 95-96 Dry	a	14	bc
REMAP 95-96 Wet	b	24	ac
REMAP 2023 Wet	c	35	ab

Figure Total Organic Carbon 2. Surface water total organic carbon (mg/L) comparisons across programs.

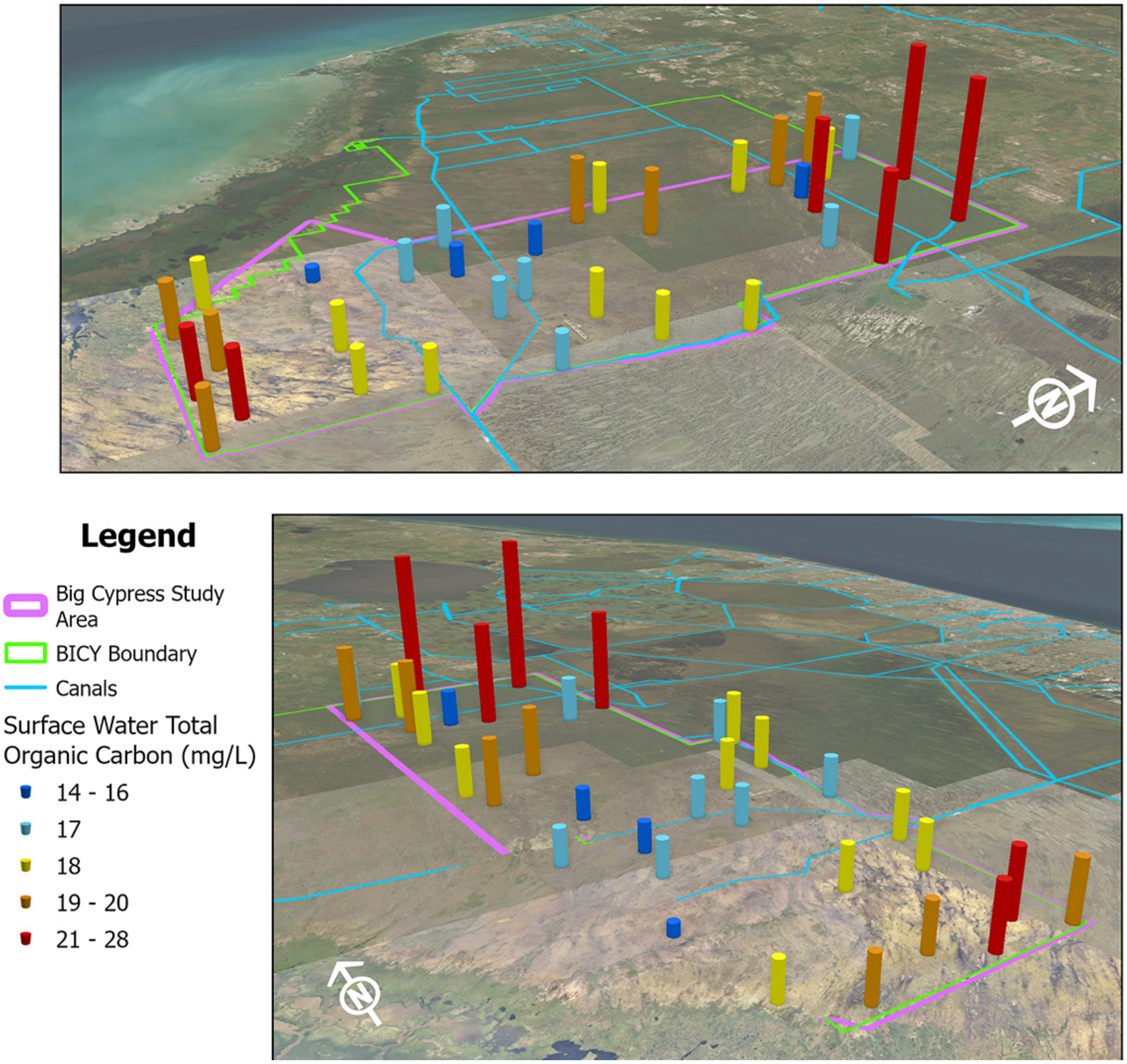


Figure Total Organic Carbon 3. Surface water total organic carbon (mg/L).

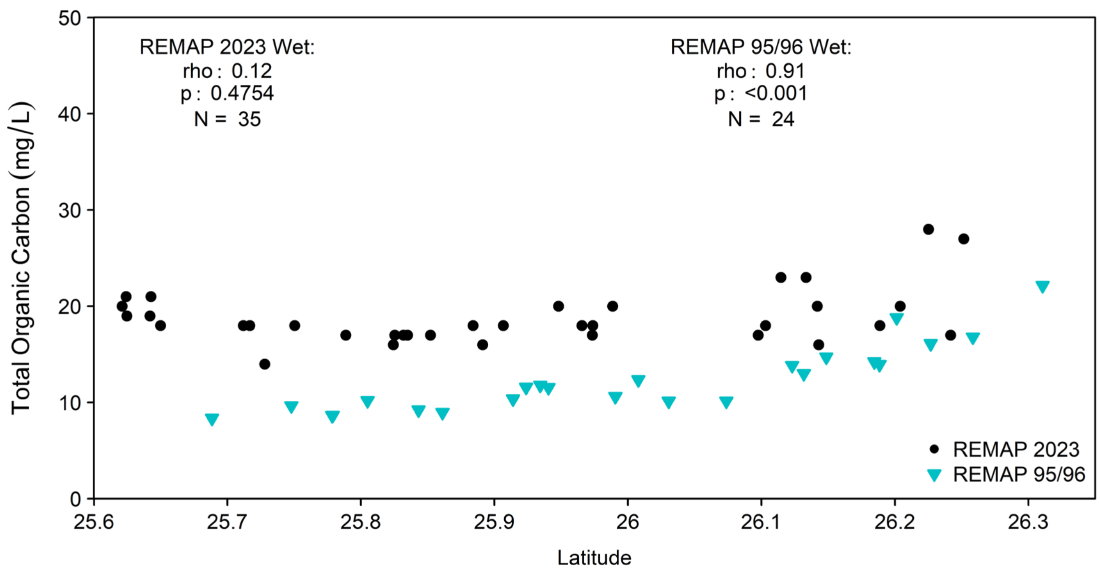


Figure Total Organic Carbon 4. Surface water total organic carbon (mg/L) during the wet season. North is to the right and south is to the left.

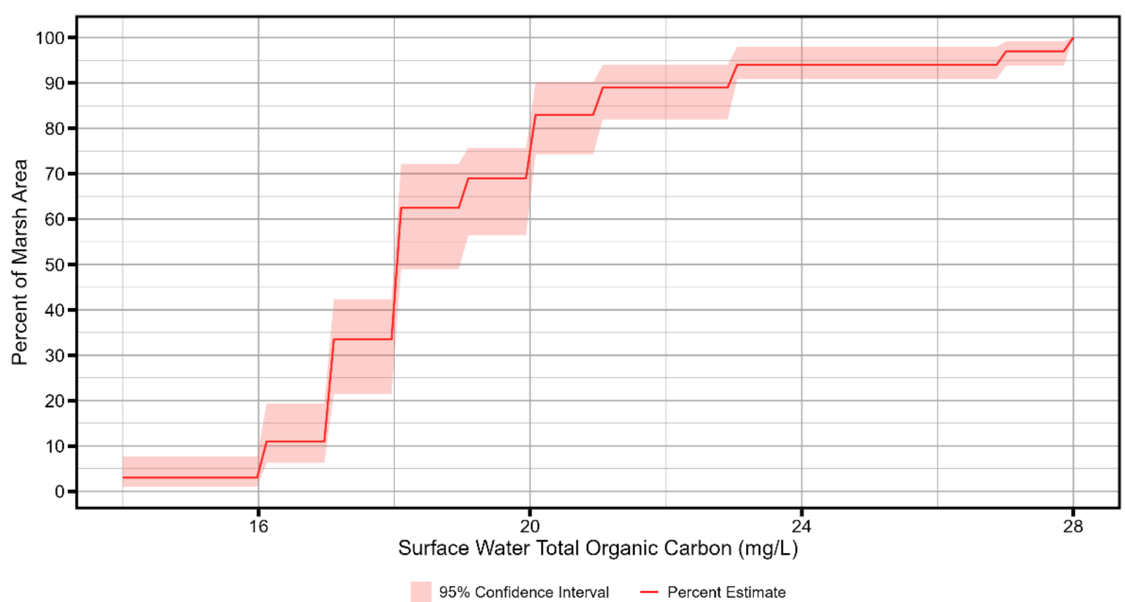


Figure Total Organic Carbon 5. Surface water total organic carbon (mg/L) estimates of marsh area.

OVERVIEW AND FINDINGS - WATER QUALITY

DISSOLVED OXYGEN

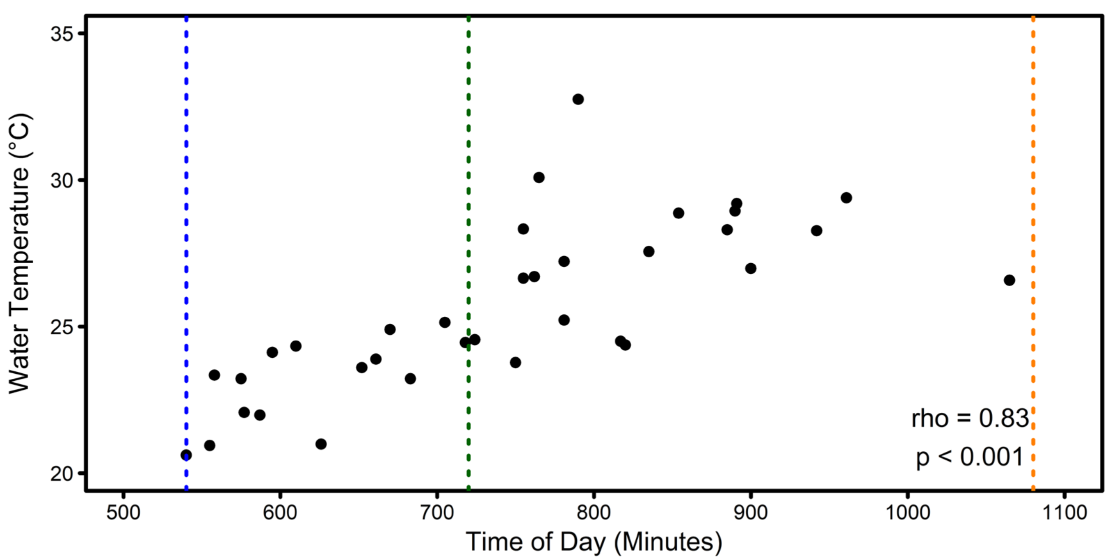
The concentration of dissolved oxygen (DO) within the water column is a critical indicator of water quality. Aquatic life such as fish depend on oxygen for survival. While every organism has its own DO tolerance range, generally, DO levels less than 5 mg/L are considered stressful for fish and levels less than 3 mg/L are too low to support fish populations. DO levels below 1 mg/L are considered hypoxic, and places with such low DO are usually devoid of life (USEPA 2024c). In waterbodies, during photosynthesis, plants use the sun's energy to convert carbon dioxide and water into oxygen and cellular material (growth). During respiration, animals and algae remove oxygen from the water and use it to produce energy, releasing carbon dioxide and water as by-products (Michaud 1991).

At the 35 REMAP marsh sampling locations with surface water, 32 were categorized by field crews to be wet prairie or sawgrass marsh. In similar Everglades habitats, submerged plants such as bladderwort and associated algal communities release oxygen during the day through photosynthesis. During daylight, photosynthesis exceeds respiration, and DO levels increase. At night, respiration exceeds photosynthesis and DO decreases (Belanger et al. 1989; McCormick and Laing 2003). Natural background areas of the Everglades exhibit a strong daily fluctuation in DO; at a single marsh location DO can range from 1 mg/L (10% saturation) around sunrise to 9 mg/L (157% saturation) around sunset (Scheidt et al. 1985). At some locations DO does not reach 5.0 mg/L until the afternoon (McCormick and Laing 2003).

Dense emergent aquatic vegetation such as sawgrass and cattail contribute little oxygen to the water. In contrast, open water sloughs with submerged plants produce a surplus of DO, which can flow into adjacent habitats such as sawgrass. DO concentrations in sawgrass marshes tend to be lower than in open water, but within sawgrass marshes oxygen remains throughout the night. In contrast, phosphorus-enriched cattail areas become void of DO during the night (Belanger et al. 1989). At phosphorus-enriched locations DO may never exceed 1 mg/L (McCormick et al. 1997, McCormick and Laing 2003). Among 833 REMAP Everglades marsh locations sampled between 1995 and 2014, cattail had the lowest percent DO saturation compared to wet prairie and sawgrass (Scheidt et al. 2021). DO concentrations also can be affected by elevated surface water sulfate, in that sulfate loading increases microbial sulfate reduction in soils. This can lead to chemically-reducing conditions, increased sulfide, and lower water column DO concentrations, compared to locations with lower levels of sulfate (Orem et al. 2011).

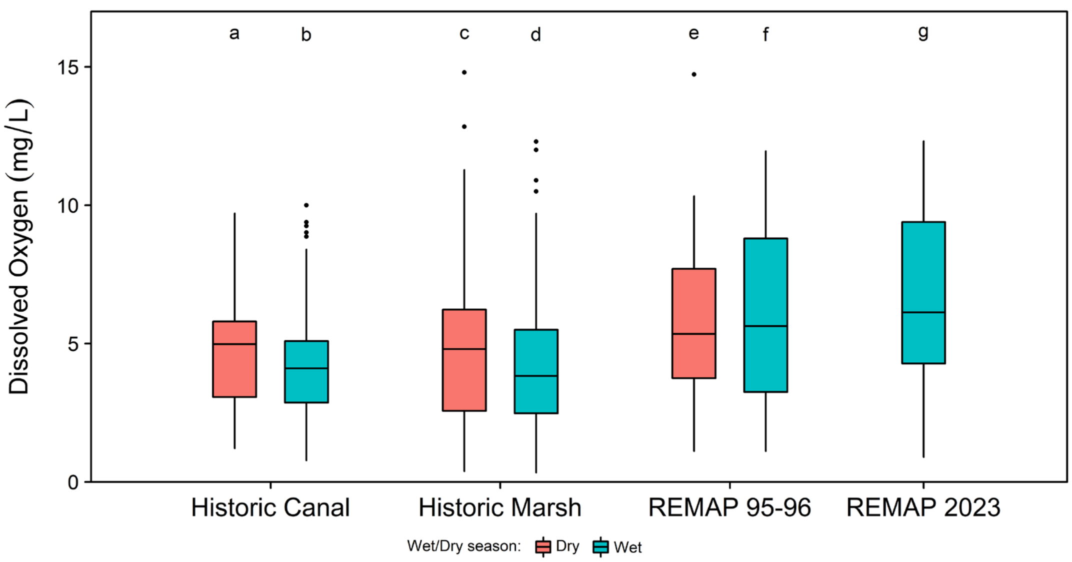
Because of the natural daily variation in DO in Everglades marshes related to photosynthesis and respiration, in 2004 FDEP adopted a Site-Specific Alternative Criterion (SSAC) for DO to replace the 5.0 mg/L minimum requirement that did not reflect natural variation. Data from marsh reference sites with low TP and away from canal and groundwater influences were used to define natural background DO levels and variation (Weaver 2004). DO concentration varies naturally with time and water temperature. As water temperature increases, the water is able to hold less oxygen (lower DO saturation capacity). Thus, the DO concentration expected at a station can be calculated from the water temperature and sampling time. The annual SSAC for the station is assessed based on comparing the annual average measured DO concentration to the average of the corresponding DO SSAC limits. In 2023-24 the lowest annual DO concentration required by the SSAC in the Everglades marsh varied from 1.98 mg/L to 3.11 mg/L depending upon location (Sotolongo-Lopez and Fischer 2025b). As expected, phosphorus-impacted Everglades marsh sites had lower DO concentrations than those not impacted by phosphorus, and they usually did not meet the SSAC.

Big Cypress REMAP 2023 data had a significant and strong relationship between time of day and water temperature. Water temperature at the 35 stations ranged from 20.6° to 32.8°C and was warmer during the afternoon than in the morning in these shallow marshes (Figure Temperature 1, $p < 0.05$; $\rho = 0.83$, median water depth 1.15 feet). Sonde field measurements of water temperature, DO and pH were made from 9:00 to 17:45 hours (540 to 1065 minutes).



Temperature 1. Time of day versus water temperature (°C). The blue dotted vertical line indicates 540 minutes, or 9:00 am, the green dotted vertical line represents 720 minutes or 12:00 noon, and the orange dotted vertical line references 1080 minutes or 6:00 pm.

DO concentration ranged from 0.9 to 12.32 mg/L, with a median of 6.13 mg/L. REMAP 2023 DO concentrations were comparable to the REMAP 1995-96 dry and wet seasons but were higher than SFWMD historic marsh and canal concentrations ($p < 0.05$; Dunn's test, Figure Dissolved Oxygen 1). Diurnal variation at each sampling location would be expected, as described above. REMAP data also had greater variability as indicated by the middle 50% of the data distribution, even though the SFWMD sample sizes were much larger. Historic canal data have a tighter distribution than the marsh data. This finding could be explained by the diurnal DO swings due to periphyton and vegetation photosynthesis having a relatively greater influence in the shallower marsh water column than in the deeper canal water column. The tighter distribution in historic marsh data could potentially be explained by different marsh habitats than REMAP, or if the recurring sampling occurred during a tighter time window.



Group	Letter	N	Significantly Different
Historic Canal Dry	a	65	g
Historic Canal Wet	b	265	fg
Historic Marsh Dry	c	125	g
Historic Marsh Wet	d	347	fg
REMAP 95-96 Dry	e	13	
REMAP 95-96 Wet	f	24	bd
REMAP 2023 Wet	g	35	abcd

Figure Dissolved Oxygen 1. Dissolved oxygen (mg/L) across programs.

There was a moderate relationship between time of day and DO concentration (Figure Dissolved Oxygen 2, $p < 0.05$, rho = 0.69), as expected due to photosynthesis as described above.

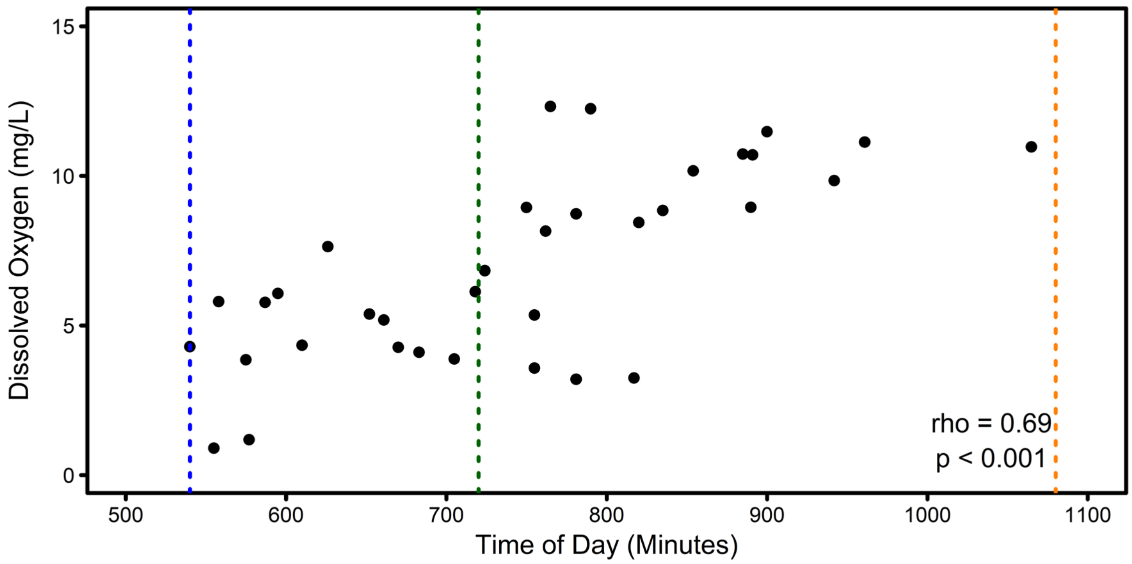


Figure Dissolved Oxygen 2. Time of day versus REMAP 2023 dissolved oxygen (mg/L). The blue dotted vertical line indicates 540 minutes, or 9:00 am, the green dotted vertical line represents 720 minutes or 12:00 noon, and the orange dotted vertical line references 1080 minutes or 6:00 pm.

REMAP 2023 data show that time of day, water temperature and DO were all correlated, with higher DO concentrations observed at stations that were sampled later in the day and during periods of higher water temperature (Figure Dissolved Oxygen 3).

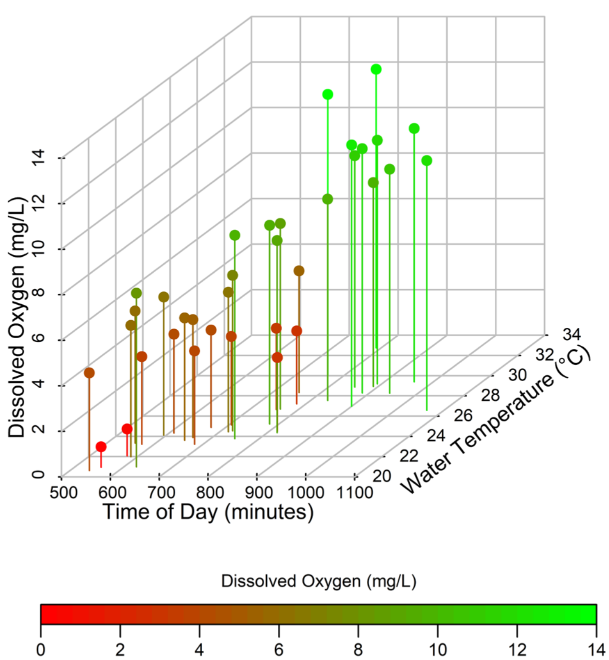


Figure Dissolved Oxygen 3. Three-dimensional plot comparing time of day against observations of water temperature and DO concentration. On the x-axis 9:00 am is 540 minutes, 12:00 noon is 720 minutes and 6:00 pm is 1080 minutes.

Given elevation and barometric pressure, the DO 100% saturation in water can be calculated from water temperature. The resulting DO 100% saturation for water at the temperatures observed during sampling ranged from 9.0 mg/L at 20.6°C to 7.2 mg/L at 32.8°C. Observed percent DO saturations ranged from 10% to 170% with a median of 73%. There was a significant and strong relationship between time of day and DO percent saturation ($p < 0.05$, rho = 0.71; Figure Dissolved Oxygen 4). All 15 results with a saturation greater than 100% occurred after 12:00 (noon, or 720 minutes). Although water at higher temperatures can hold less oxygen, higher DO concentrations were observed in the afternoons when the water tended to be warmer. The 2023 marsh wet season DO percent saturation results are similar to REMAP wet season measurements at 24 other Big Cypress marsh locations in 1995-96: percent saturation 14% to 169%, median 73% (Figure Dissolved Oxygen 1), with most values greater than 100% occurring after noon. These data also had a significant and strong relationship with between time of day and DO percent saturation (Figure Dissolved Oxygen 5, $p < 0.05$, rho = 0.82). USGS (Klein et al. 1970) reported similar DO percent saturation in Big Cypress during 1969-70, ranging from 20% to 150%.

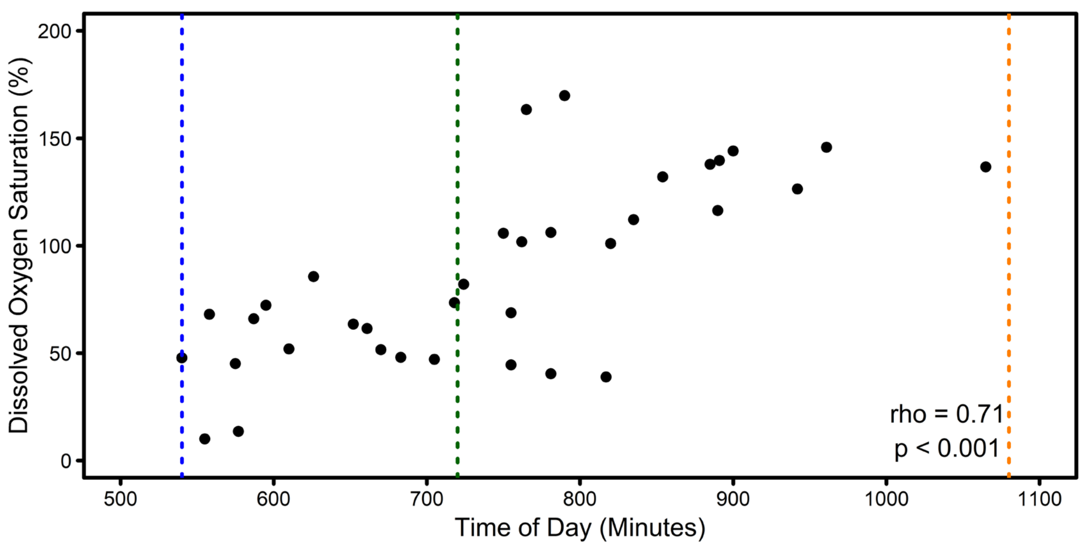


Figure Dissolved Oxygen 4. Time of day versus REMAP 2023 dissolved oxygen (percent saturation). The blue dotted vertical line indicates 540 minutes, or 9:00 am, the green dotted vertical line represents 720 minutes or 12:00 noon, and the orange dotted vertical line references 1080 minutes or 6:00 pm.

Big Cypress is within the Everglades bioregion. Florida's Class III DO water quality criterion for the Everglades bioregion requires that no more than 10% of the daily average percent DO saturation values shall be below 38% (FAC 62-302.533). At each REMAP station, only one DO measurement was made, so it is not possible to calculate daily averages. However, for informational purposes, only 6% (2 of 35) of the DO percent saturation results were below 38%. During the 1995-96 wet season, REMAP data showed that 17% (4 of 24) of the DO percent saturation results were less than 38%. About 50% of the 2023 marsh area sampled had a DO concentration at or below 6.13 mg/L, with a 95% confidence interval of 40.2% to 60.1% (Figure Dissolved Oxygen 6). About 50% of the marsh area sampled had a DO percent saturation at or below 73.4%, with a 95% confidence interval of 40.2% to 60.1% (Figure Dissolved Oxygen 7).

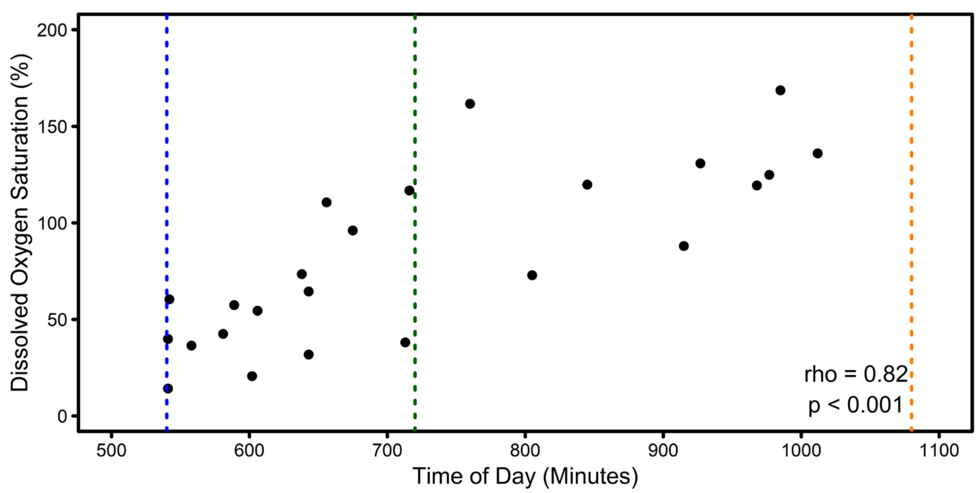


Figure Dissolved Oxygen 5. Time of day versus REMAP 1995-96 dissolved oxygen (percent saturation). The blue dotted vertical line indicates 540 minutes, or 9:00 am, the green dotted vertical line represents 720 minutes or 12:00 noon, and the orange dotted vertical line references 1080 minutes or 6:00 pm.

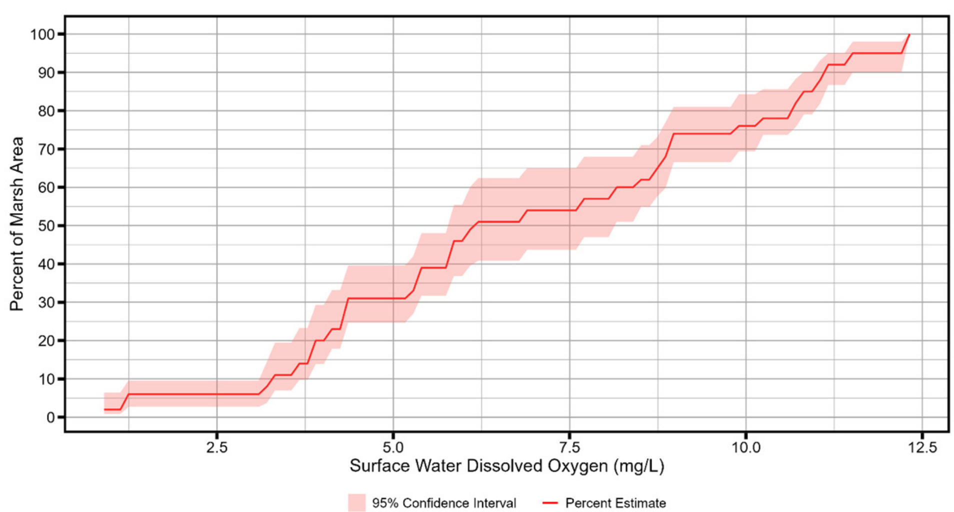


Figure Dissolved Oxygen 6. Surface water dissolved oxygen (mg/L) estimates of sampled area.

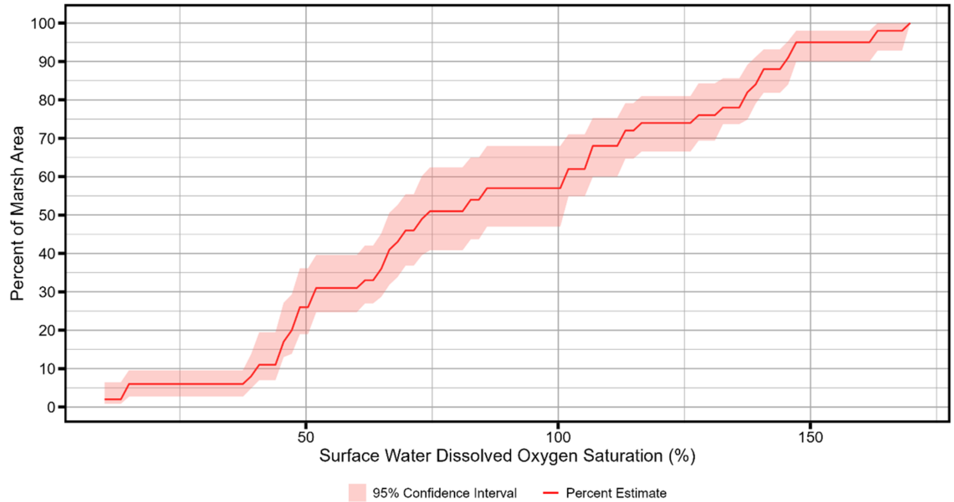


Figure Dissolved Oxygen 7. Surface water dissolved oxygen (percent saturation) estimates of sampled area.

OVERVIEW AND FINDINGS - WATER QUALITY

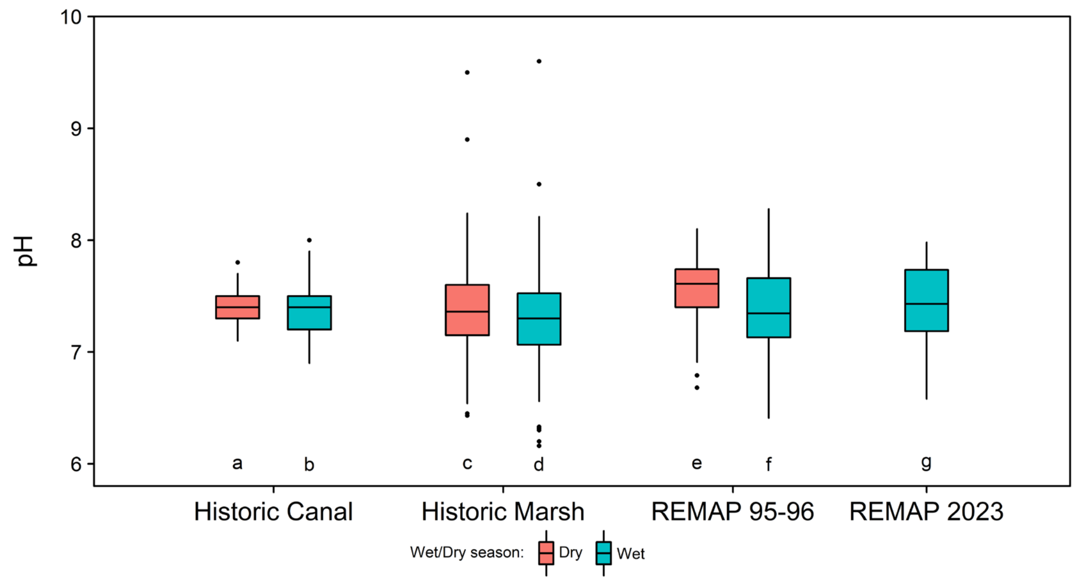
pH

Water and soil pH can influence water quality and chemical processes. The pH is defined as the base 10 logarithm of the reciprocal of hydrogen ion activity or concentration (pH = -log[H+]). The pH scale ranges from 0 to 14, with pure water having a neutral pH of 7. Increased hydrogen ion activity lowers the pH and makes the water more acidic, while decreased activity increases the pH, making the water more basic. The pH of natural waters is usually between 6.0 and 8.5 (Hem 1985).

Photosynthesis by aquatic plants and algae removes carbon dioxide from the water column during daylight hours, which increases surface water pH. During the night, aquatic plants and algae release carbon dioxide through respiration, which decreases pH (Hem 1985, Gleason and Spackman 1974). Carbon dioxide influences pH because when it dissolves in water it creates carbonic acid, a weak inorganic acid. Warmer temperatures can increase the rate of photosynthesis and respiration, which can lead to greater diurnal pH variation. In a natural Everglades wet prairie marsh with peat soils, dominant spikerush and bladderwort plants and extensive periphyton mats, pH at a single location fluctuated from 7.1 at midnight to 8.5 in the afternoon. Corresponding DO fluctuated between 1.0 and 10.0 mg/L (10% to 157% saturation) (Scheidt et al. 1985). Similar habitats are found in Big Cypress, so similar diurnal pH variations are expected at these locations.

In 2023,Big Cypress REMAP surface water pH ranged from 6.58 to 7.98 (n = 35, Figure pH 1). There was a significant and moderate relationship between time of day and pH (Figure pH 2, $p < 0.05$, $\rho = 0.69$), consistent with the influence of photosynthesis. Measurements taken later in the day tended to have higher water temperatures, higher pH values (Figure pH 3), and higher DO, as discussed above. For pH values > 7.5, 15 of 16 results occurred after noon (time of day 720 minutes). Of these 16 stations, 14 also had DO > 100% saturation. Rainwater at the closest monitoring location, FL11 within Everglades National Park, had slightly acidic calendar year annual average pH during 2013-2022. Rainwater annual average pH values ranged from 5.1 to 5.4 (NADP 2024b), substantially lower than in the ambient marsh water.

REMAP 2023 Big Cypress marsh pH data were similar to all other data (Dunn's test < 0.05; Figure pH 1). Historic marsh wet season data were different than historic canal data. Historic canal water pH tended to have a tighter distribution than historic wet season marsh data, consistent with the tighter canal DO distribution. Some diurnal variation in pH at each sampling location would be expected, as described above.



Group	Letter	N	Significantly Different
Historic Canal Dry	a	65	d
Historic Canal Wet	b	274	d
Historic Marsh Dry	c	133	
Historic Marsh Wet	d	352	ab
REMAP 95-96 Dry	e	13	
REMAP 95-96 Wet	f	24	
REMAP 2023 Wet	g	35	

Figure pH 1. Surface water pH comparisons across sampling programs. Blank cells in the Significantly Different column of the table indicate that the sampling event was similar to all others ($p > 0.05$).

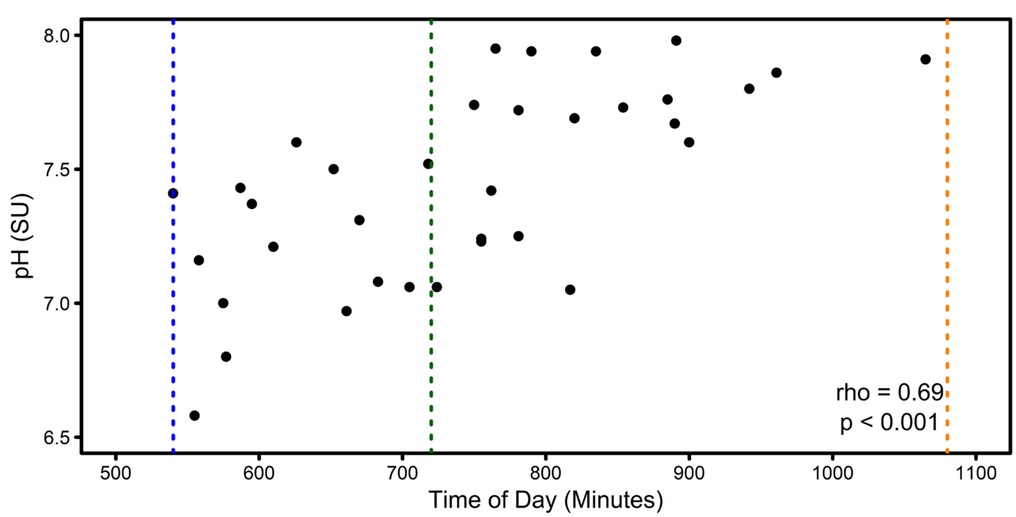


Figure pH 2. Time of day versus pH (SU). The blue dotted vertical line indicates 540 minutes, or 9:00 am, the green dotted vertical line represents 720 minutes or 12:00 noon, and the orange dotted vertical line references 1080 minutes or 6:00 pm.

Florida's water quality criterion for pH generally requires that pH shall be between 6.0 and 8.5 and shall not vary more than one unit above or below natural background (FAC 62-302.530(52)(c)). None of the 35 pH readings were outside of this range.

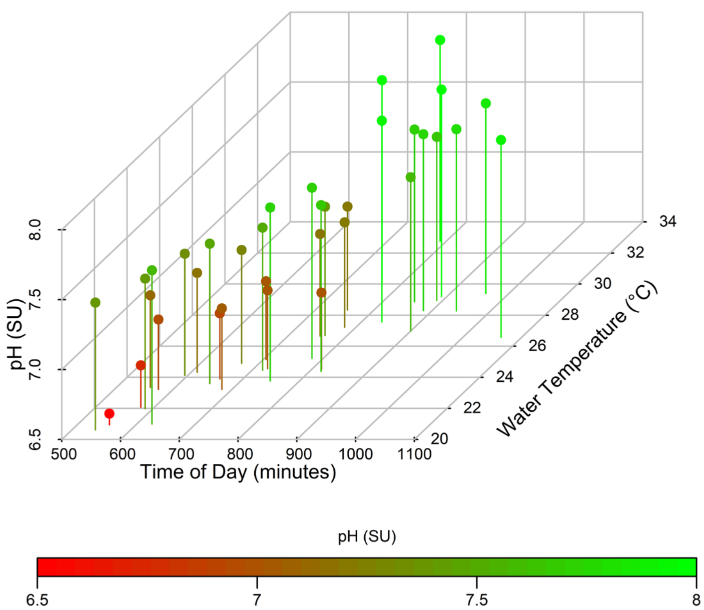


Figure pH 3. Three-dimensional plot comparing time of day and water temperature and pH. On the x-axis, 540 minutes represents 9:00 am, noon is 720 minutes and 1080 minutes indicates 6:00 pm.

There was also a significant and strong relationship between pH and DO percent saturation (Figure pH 4, $p < 0.05$, $\rho = 0.88$). This relationship was also significant and strong during the 1995-96 wet season (Figure pH 5, $p < 0.05$, $\rho = 0.78$).

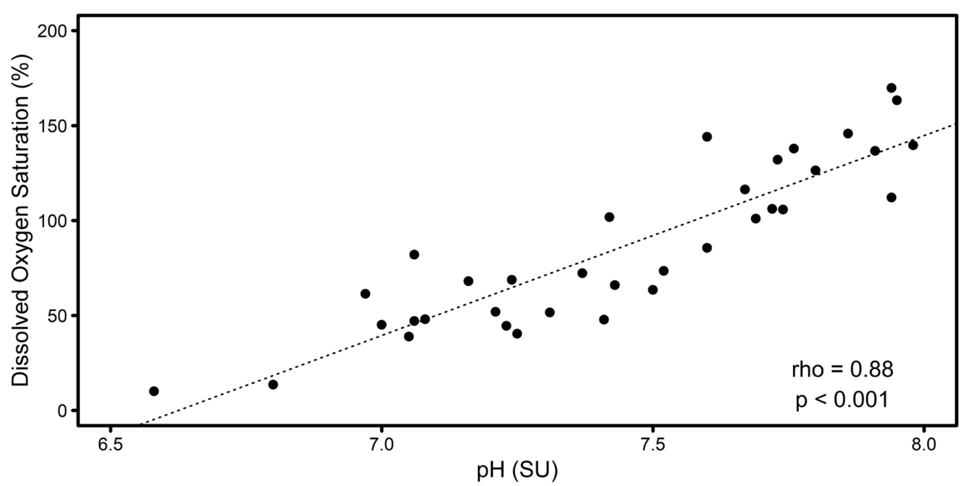


Figure pH 4. 2023 pH (SU) versus dissolved oxygen (% saturation).

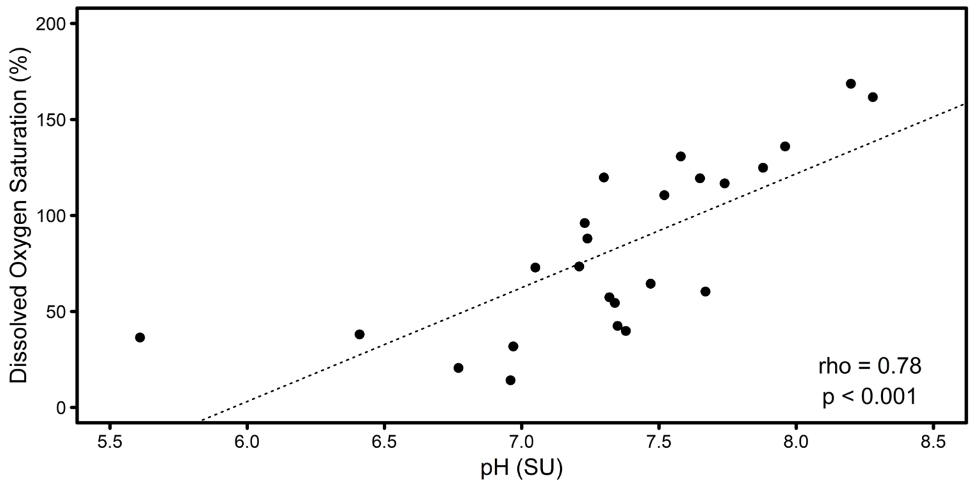


Figure pH 5. 1995-95 wet season pH (SU) versus dissolved oxygen (% saturation).

About 50% of the marsh area sampled had a pH at or below the median of 7.43, with a 95% confidence interval of 41.7% to 59.2% (Figure pH 6).

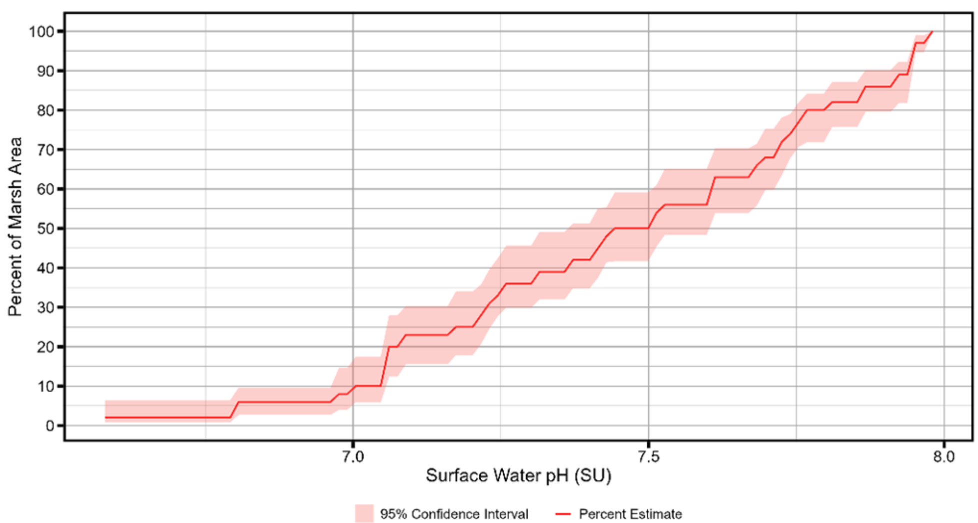


Figure pH 6. Surface water pH (SU) estimates of sampled area.

OVERVIEW AND FINDINGS - WATER QUALITY

OXIDATION REDUCTION POTENTIAL

Oxidation Reduction Potential (ORP), or redox potential, quantifies the general chemical environment at a station and characterizes the degree of anoxic conditions, which have implications for nutrient availability and multiple other water quality conditions (Reddy et al. 2023). ORP can affect the forms of sulfur, nitrogen, iron, carbon and manganese that are present in a waterbody (Phelps and Osborne 2019; Dodds and Whiles 2000).

The transfer of electrons is essential to fundamental chemical reactions of life, such as respiration. Reactions that result in the transfer of electrons are collectively known as oxidation-reduction reactions, or more simply, redox reactions. In redox reactions, a compound is considered oxidized if it gives up an electron and it is considered reduced if it accepts an electron. The availability of electrons has a large effect on which chemical reactions can occur spontaneously, which reactions require energy inputs, and what chemical constituents are ultimately favored in the environment (Dodds and Whiles 2020).

Oxidation and reduction reactions play a significant role in regulating biogeochemical reactions. In wetlands, the oxidation of organic substrates results in the release of electrons, which if not quickly removed, create an electron “pressure” within the system. If oxygen is present it acts as the superior electron acceptor for aerobic microbes. The free electrons are easily removed, and the electron pressure does not rise. However, if oxygen is not present, then the electron pressure increases which enables facultative microbes to use nitrogen oxides to remove the electrons. Once the nitrogen oxides are depleted the electron pressure rises again, encouraging the use of other electron acceptors. The depletion cycle continues through alternative receptors with rising electron pressure, and ultimately culminates with the use of sulfate and carbon dioxide by obligate anaerobic bacteria (Reddy et al. 2023)

ORP is the most common parameter used to measure the intensity of anaerobic conditions. ORP is measured in electromotive force units expressed as millivolts (mV) and typically ranges from +700 mV to -300 mV in wetlands. Generally, lower ORP values indicate higher electron activity and lower oxygen levels, as compared to higher values. Therefore, negative values represent the highest electron activity and intense anaerobic conditions. Positive values represent low electron activity and aerobic or moderately anaerobic conditions (Reddy et al. 2023).

In the Big Cypress REMAP sampling ORP was measured in-situ 2 to 3 cm above the soil surface at each station via glass electrode on a YSI EXO2 data sonde calibrated daily with Zobell Solution. ORP readings measured at the soil-water interface can be reasonably assumed to reflect the redox conditions within the 0-10 cm soil core profile (personal communication, P. Inglett, December 9, 2024).

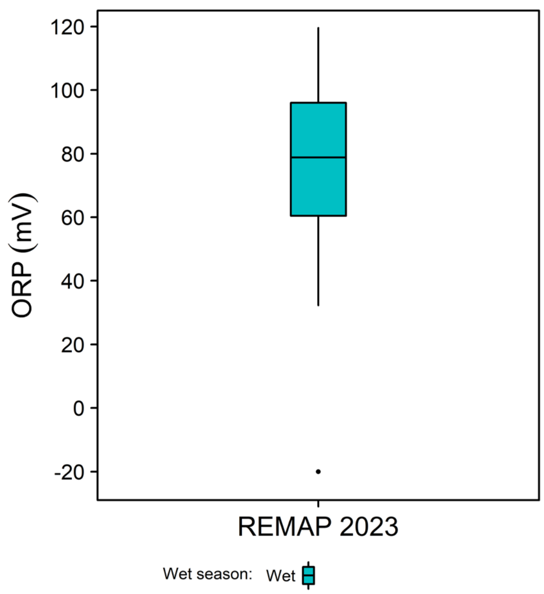


Figure ORP 1. Oxidation reduction potential (mV) in water near soil surface.

Big Cypress 2023 surface water ORP ranged from +119.6 mV to -20 mV, with a median of 78.8 mV (n = 35, Figures ORP 1 and 2). Only 1 station (2035) had a negative ORP value, -20 mV. This station, a pond within a a cypress dome, had several characteristics that were different than the other 34 sites including: the only detection of sulfide in bottom water (51 µg/L); the deepest water (3.1 feet); the lowest surface water pH (6.58), DO saturation (10%), and conductivity (209.2 µS/cm); the second highest TOC (27 mg/L); and the lowest soil pH (6.65). Overall, ORP data indicate that conditions at the Big Cypress REMAP stations were in the moderately reduced to reduced zone for flooded soils. ORP values less than 100 mV indicate that oxygen is absent and that the reduction of nitrogen oxides, manganese and iron would be expected to occur (Reddy et al. 2023).

There was a significant but weak ORP trend with latitude (Figure ORP 3, $p < 0.05$, rho = 0.38), with lower values to the south. About 50% of the marsh area sampled had ORP at or below 78.8 mV, with a 95% confidence interval of 41.8% to 58.8% (Figure ORP 4).

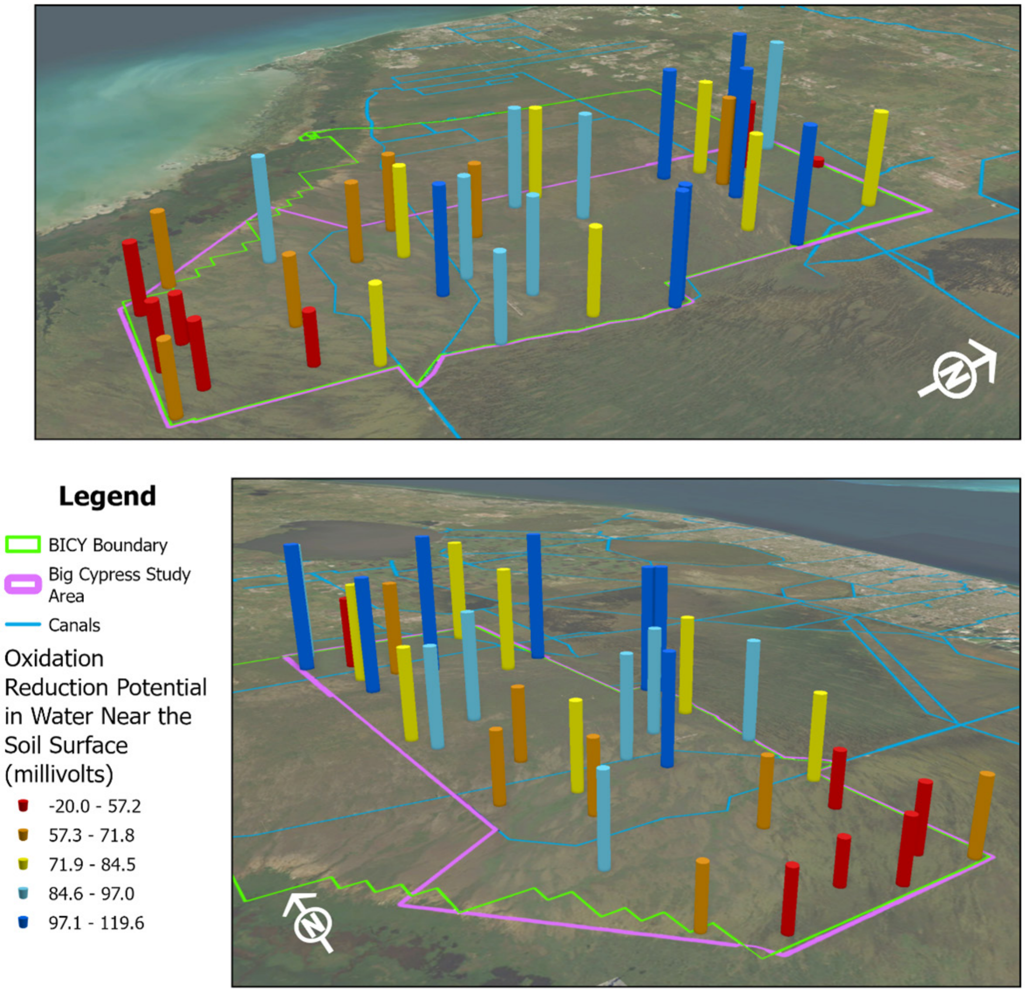


Figure ORP 2. Oxidation reduction potential (mV) in water near soil surface.

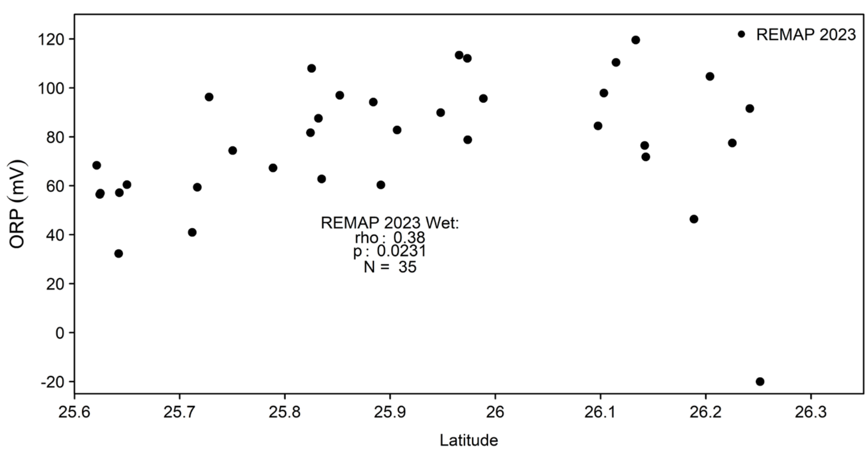


Figure ORP 3. Oxidation reduction potential (mV) in water near soil surface by latitude. North is to the right and south is to the left.

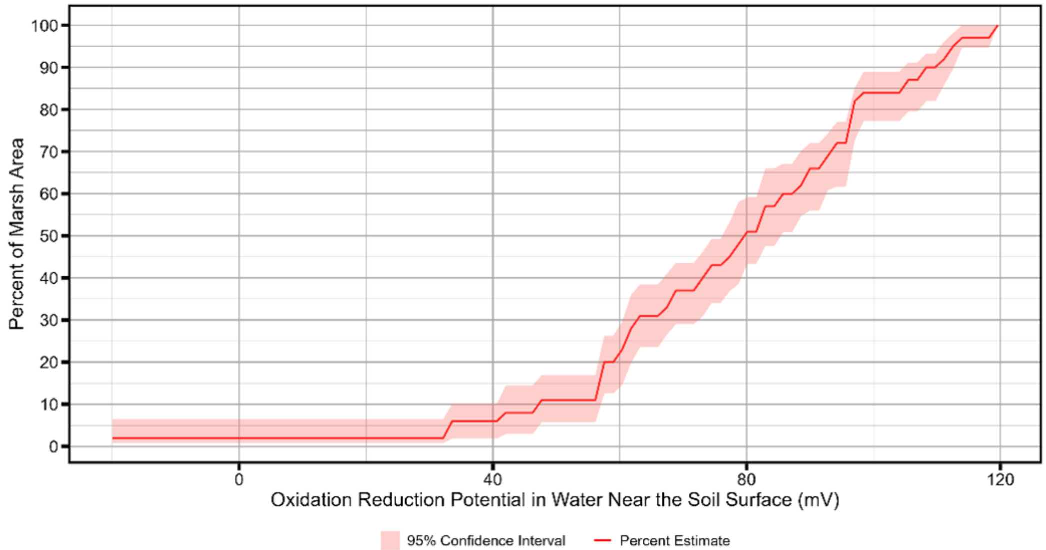


Figure ORP 4. Oxidation reduction potential (mV) estimates of marsh area.

OVERVIEW AND FINDINGS - WATER QUALITY

CORRELATION MATRIX

A Spearman rank correlation matrix was developed to assess the relative relationships between the surface water analytes (Figure Surface Water Quality Correlation 1). The Spearman correlation approach allowed for non-parametric analysis of non-normally distributed data. An expanded multi-media correlation matrix is in Appendix 5, and pairwise correlation plots are in Appendix 3.

	Depth (ft)	Sp. Cond. (µS/cm)	Chloride (mg/L)	Temperature (°C)	pH	DO (mg/L)	DO Saturation (%)	Turbidity (FNU)	ORP (mV)	APA (µmol/L/hr)	Chlorophyll a (µg/L)	TP (µg/L)	TOC (mg/L)	DOC (mg/L)	TN (mg/L)	DNO2 (mg/L)	DNO3 (mg/L)	DNN (mg/L)	DNH4 (mg/L)	THg (ng/L)
MeHg (ng/L)	0.04 ns	-0.26 ns	-0.05 ns	0.41 *	0.09 ns	0.20 ns	0.18 ns	0.08 ns	0.01 ns	0.01 ns	0.24 ns	-0.23 ns	-0.28 ns	-0.35 *	-0.09 ns	0.03 ns	-0.07 ns	0.07 ns	0.21 ns	-0.02 ns
THg (ng/L)	0.03 ns	0.30 ns	0.23 ns	-0.25 ns	-0.09 ns	-0.33 ns	-0.36 *	0.13 ns	-0.24 ns	0.10 ns	0.07 ns	-0.11 ns	0.29 ns	0.29 ns	0.23 ns	0.04 ns	0.02 ns	0.08 ns	-0.01 ns	
DNH4 (mg/L)	0.27 ns	0.01 ns	0.40 *	0.03 ns	0.08 ns	-0.04 ns	-0.04 ns	0.06 ns	-0.05 ns	0.21 ns	-0.34 *	-0.26 ns	0.17 ns	0.13 ns	0.40 *	0.29 ns	0.38 *	0.57 ***		
DNN (mg/L)	-0.13 ns	0.06 ns	0.13 ns	0.15 ns	0.13 ns	-0.05 ns	-0.03 ns	-0.08 ns	0.04 ns	0.43 **	-0.33 ns	-0.14 ns	-0.13 ns	-0.16 ns	0.11 ns	0.45 **	0.57 ***			
DNO3 (mg/L)	-0.08 ns	-0.10 ns	0.08 ns	0.00 ns	0.06 ns	-0.04 ns	-0.01 ns	-0.24 ns	0.01 ns	0.25 ns	-0.15 ns	0.08 ns	0.04 ns	0.06 ns	0.27 ns	0.14 ns				
DNO2 (mg/L)	-0.11 ns	0.20 ns	0.15 ns	0.17 ns	-0.18 ns	-0.31 ns	-0.27 ns	0.13 ns	0.26 ns	0.23 ns	0.15 ns	0.36 *	0.12 ns	0.20 ns	0.03 ns					
TN (mg/L)	0.06 ns	0.22 ns	0.60 ***	-0.05 ns	0.17 ns	0.01 ns	0.00 ns	0.24 ns	-0.41 *	0.31 ns	-0.11 ns	-0.09 ns	0.63 ***	0.59 ***						
DOC (mg/L)	0.13 ns	0.47 **	0.51 **	-0.31 ns	-0.19 ns	-0.34 *	-0.33 *	0.26 ns	-0.19 ns	0.07 ns	0.02 ns	0.34 *	0.94 ***							
TOC (mg/L)	0.13 ns	0.50 **	0.51 **	-0.33 ns	-0.24 ns	-0.38 *	-0.38 *	0.28 ns	-0.13 ns	0.12 ns	-0.02 ns	0.30 ns								
TP (µg/L)	-0.26 ns	0.01 ns	-0.23 ns	-0.20 ns	-0.46 **	-0.39 *	-0.37 *	0.21 ns	0.31 ns	0.05 ns	0.15 ns									
Chlorophyll a (µg/L)	-0.21 ns	0.11 ns	0.07 ns	0.30 ns	-0.06 ns	-0.10 ns	-0.07 ns	0.12 ns	0.10 ns	0.02 ns										
APA (µmol/L/hr)	-0.42 *	0.25 ns	0.25 ns	0.18 ns	0.25 ns	0.18 ns	0.18 ns	0.24 ns	0.14 ns											
ORP (mV)	-0.12 ns	-0.01 ns	-0.30 ns	0.00 ns	-0.43 **	-0.24 ns	-0.20 ns	-0.19 ns												
Turbidity (FNU)	-0.39 *	0.24 ns	0.22 ns	0.19 ns	0.08 ns	0.05 ns	0.03 ns													
DO Saturation (%)	-0.39 *	-0.09 ns	0.02 ns	0.69 ***	0.88 ***	0.99 ***														
DO (mg/L)	-0.36 *	-0.10 ns	0.04 ns	0.64 ***	0.88 ***															
pH	-0.38 *	0.07 ns	0.21 ns	0.63 ***																
Temperature (°C)	-0.48 **	-0.04 ns	-0.06 ns																	
Chloride (mg/L)	0.06 ns	0.60 ***																		
Sp. Cond. (µS/cm)	-0.22 ns																			

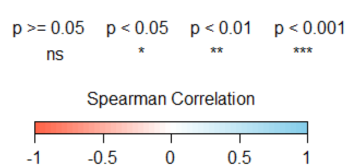


Figure Surface Water Quality Correlation 1. Surface water correlation matrix. Numbers represent the Spearman rho value for each pairwise correlation, indicating the strength of the correlation. Red indicates a negative correlation, and blue indicates a positive correlation. Significance levels are indicated by the number of asterisks.

Twenty analytes were included in the analysis, yielding 210 pairwise Spearman correlations. The significance of these correlations varied, with 13 at $p < 0.001$, 8 at $0.001 \leq p < 0.01$, 20 at $0.01 \leq p \leq 0.05$, and 169 at $p > 0.05$. Two correlation strengths were categorized as very strong ($0.90 \leq rho \leq 1.0$), with two strong ($0.7 \leq rho \leq 0.89$), 23 moderate ($0.40 \leq rho \leq 0.69$), 135 weak ($0.1 \leq rho \leq 0.39$), and 67 negligible.

The only very strong correlations were between TOC and DOC, and between DO concentration and DO saturation. The only strong correlations were between pH and DO concentration, and pH and DO saturation. TP was negatively correlated with pH and DO. Positive correlations included: TN with TOC, DOC, chloride; DOC and TOC with conductivity and chloride; and conductivity with chloride. MeHg was positively correlated with temperature, while conversely, THg was negatively correlated with DO. DO showed positive correlations with temperature and pH. Water depth had negative correlations with temperature, DO, pH, turbidity, and alkaline phosphatase activity. This analysis highlights the complex interplay of environmental factors affecting water quality.

OVERVIEW AND FINDINGS – SOILS

SOIL SAMPLING

Some soils in BCNP are simple geological and biological products that have not had enough time or suitable environmental conditions for evolution into true soils. Marl, sand, organic matter, and rock are the four major substrate types in the Preserve (Duever et al. 1986, NPS 2021). Big Cypress soils were characterized and generally mapped in the 1930s, 1950s, and 1970s, often for the purpose of determining suitability for agriculture. Discussion of soil types is complicated by the fact that soil classification systems have undergone major revisions, and it is difficult to relate older classification data to more recent data (Duever et al. 1986). REMAP 2023 soil cores were not compared to the U. S. Department of Agriculture soil classification system, as REMAP protocols did not include the methodology required to determine these soil types.

Formation and stabilization of soils are dependent on the natural hydrologic regime. Carbonate marls are the most widespread unconsolidated soil type. They occur as thick lenses in sloughs and as thin sheets over prairies. Sands are also commonly found in association with marls (Duever et al. 1986). Marls are formed in shorter hydroperiod areas by the physiochemical or biochemical processes of periphytic calcareous algae growing as mats on the bottom or as sheaths covering vegetation (Gleason and Spackman 1974).

Organic soils such as peat are formed when plant litter builds up. In drier areas, decay, fire, and oxidation destroy biological debris, and traces of dark material in the soil may be all that remain. In inundated areas where the oxygen necessary for decay processes is lacking, as in the bottom of sloughs, plant fragments accumulate as peat. During the 1900s, organic soils were lost or reduced in many areas of Big Cypress due to drainage, oxidation, drought and fire (Duever et al. 1986). Davis (1946) concluded that peat deposits in Big Cypress were generally not thick or extensive enough to be mined profitably.

Stations sampled by REMAP in 2023, which were pre-selected from marsh habitat, had soil cores from 8 to 10 cm thick (Figure Soil 1). REMAP field protocol in 1995-96 and 2023 was to collect the 0 to 10 cm profile in triplicate cores. During 2023 85% of the 114 cores were approximately 10 cm thick. SFWMD funded the University of Florida to conduct extensive soil sampling throughout BCNP and the Everglades in 2003-2004 (Osborne et al. 2011b, 2015). A stratified random design was used to identify 1405 sampling locations. There were 209 stations sampled in BCNP from April to December 2003, a subsample of which were in marsh habitat (Bruland et al. 2006, Cohen et al. 2009a). The 2003 SFWMD data were screened by core thickness to be consistent with REMAP data, keeping 117 stations where core thickness was 8 to 10 cm, and excluding 92 stations where core thickness was 1 to 7 cm. The upper 10 cm soil profile is representative of the most recent conditions, the most common profile sampled in the Everglades region, and the soil profile specified in the Everglades to determine phosphorus-impacted conditions (FAC 62-302.540). Soil analytes from REMAP 1995-96, REMAP 2023 and SFWMD 2003 were compared using Dunn's test, $p < 0.05$.

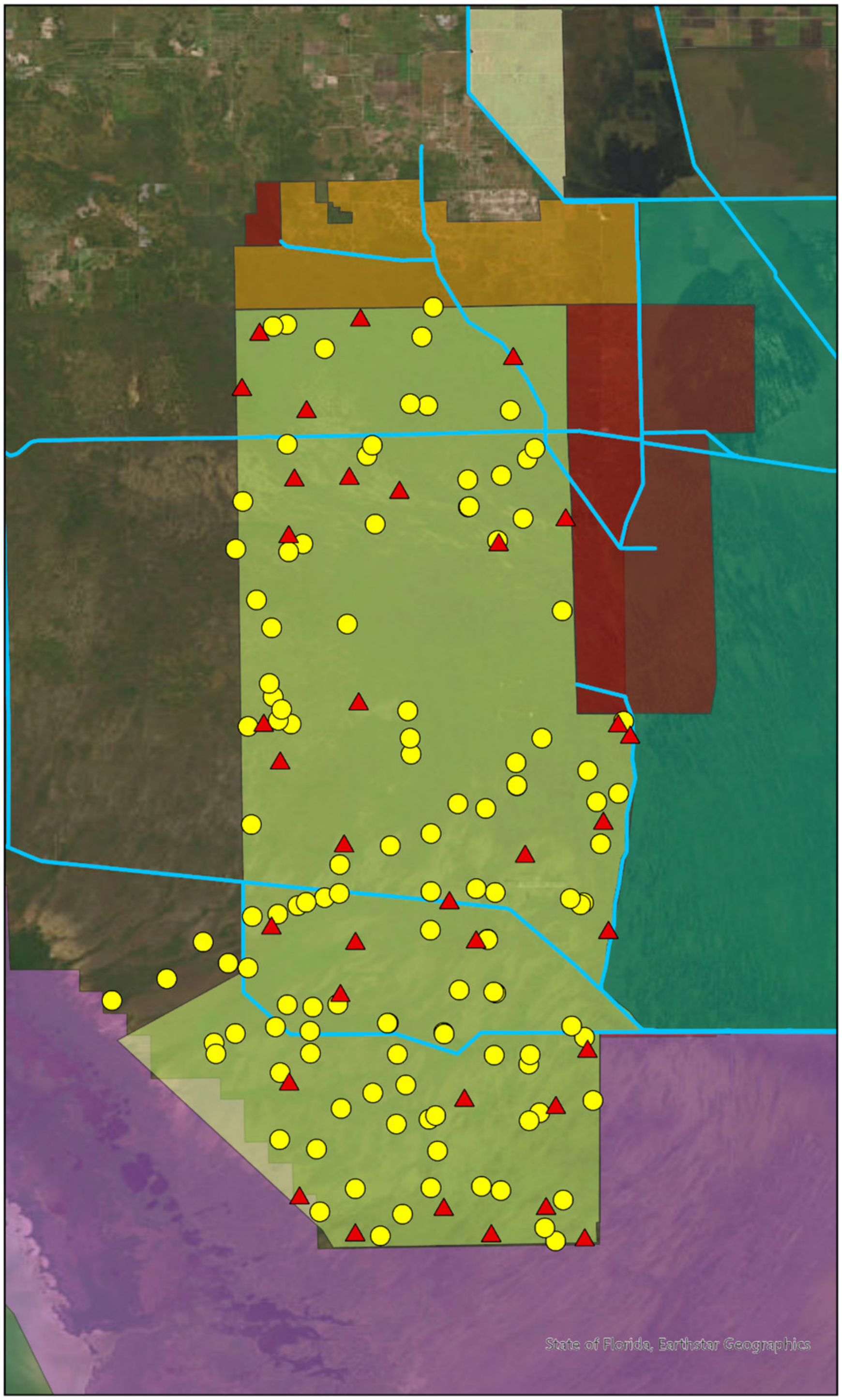


Figure Soil 1. REMAP 2023 and SFWMD 2003 soil sampling locations. Some gaps in coverage are due to areas that were not accessible or were not marsh.

OVERVIEW AND FINDINGS - SOILS

CORRELATION MATRIX

A Spearman rank correlation matrix was created to evaluate the relationships between various soil analytes, including pH, Moisture Content (MC), Bulk Density (BD), Organic Matter (OM), Total Carbon (TC), Total Nitrogen (TN), Total Phosphorus (TP), Total Mercury (THg), and methylmercury (MeHg). This non-parametric method provided analysis of non-normally distributed data. The correlation coefficients' direction and strength were compared with findings from Everglades National Park soils (Steinmuller et al. 2020). An expanded multi-media correlation matrix is in Appendix 5, and pairwise correlation plots are in Appendix 3.

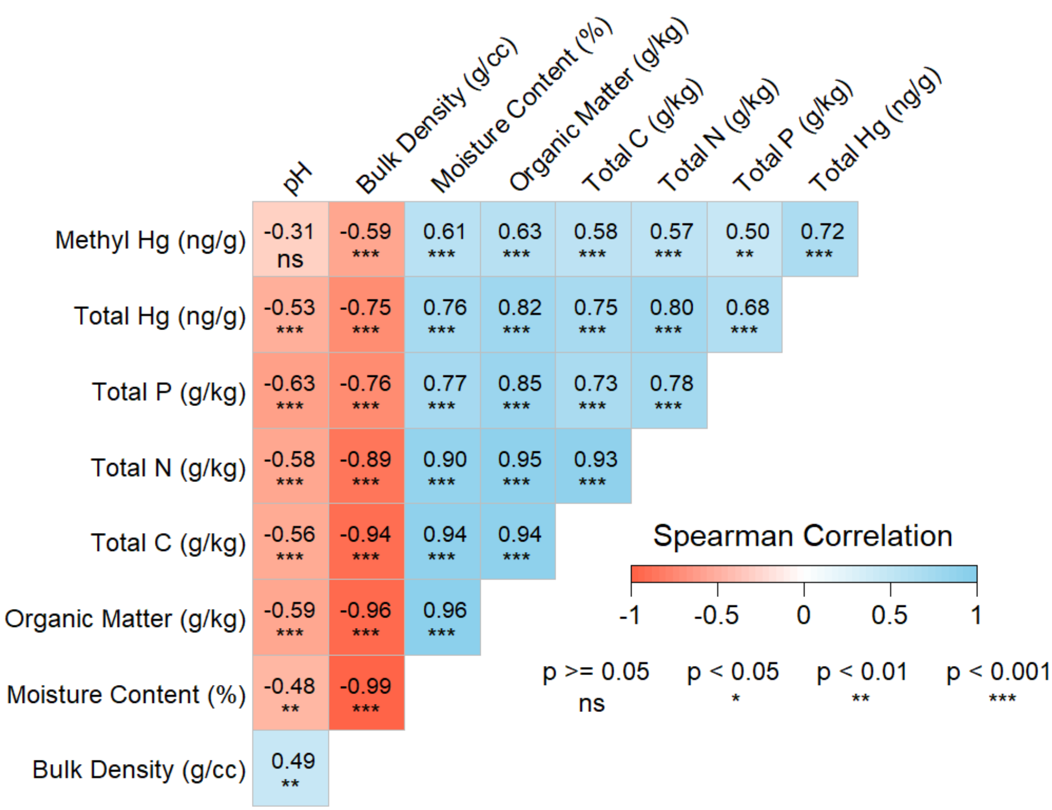


Figure Soil Correlation 1. Soil correlation matrix. Numbers represent the Spearman rho value for each pairwise correlation, indicating the strength of the correlation. Red indicates a negative correlation, and blue indicates a positive correlation. Significance levels are indicated by the number of asterisks.

All correlations were statistically significant ($p < 0.05$, Appendix 3). Among them, nine were very strong ($0.90 \leq \rho \leq 1.0$), twelve were strong ($0.7 \leq \rho \leq 0.89$), fourteen were moderate ($0.40 \leq \rho \leq 0.69$), and one was weak ($0.10 \leq \rho \leq 0.39$). TP had strong positive correlations with TN, TC, OM, and MC, and moderate correlations with both THg and MeHg. TP also had a strong negative correlation with bulk density and a moderate negative correlation with pH. Soil pH had a moderate positive correlation with BD and moderate negative correlations with MC, OM, TC, TN, TP, and THg, while its correlation with MeHg was weak. BD had very strong negative correlations with MC, OM, and TC, and strong negative correlations with TN, TP, and THg, with a moderate correlation with MeHg.

Soil MC displayed very strong positive correlations with OM, TC, and TN, strong correlations with TP and THg, and a moderate correlation with MeHg. OM was very strongly correlated with TC and TN, strongly with TP and THg, and moderately with MeHg. TC had strong positive correlations with TN, TP, and THg, and a moderate correlation with MeHg. TN was strongly correlated with TP, TC and THg, and moderately with MeHg. THg had a strong positive correlation with MeHg.

While the direction of the 2023 correlations matched those from Steinmuller et al. (2020) for ENP soils, only 8 (38.1%) were similar in strength, while the remaining correlations (61.9%) were stronger in the 2023 BCNP data. Steinmuller et al. (2020) did not include mercury in their analysis.

OVERVIEW AND FINDINGS - SOILS

THICKNESS

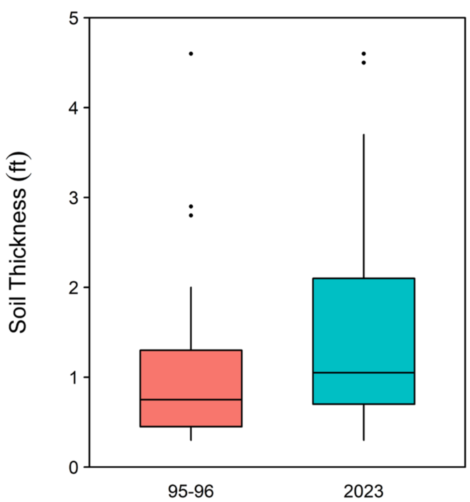


Figure Soil Thickness 1. Soil thickness (feet).

Photo 14. Soil thickness measurements were collected with a soil rod.

Soils in BCNP have highly variable thickness. Limestone forms a hard 1- to 2-foot-thick crust called cap rock that functions as the bedrock for the BCNP ecosystem. The cap rock is irregular, pocked with solution holes, and less permeable to water flow than the underlying rock formation (Duever et al. 1979). Although it can be exposed as craggy pinnacle rock at the surface, cap rock is typically covered with a thin layer of sand, marl, or peat soils (NPS 2021). Differences in elevation, hydrology and plant communities are related to undulations in the underlying bedrock (Lodge 2016). The underlying bedrock is irregular, and depending on location can be exposed at the surface or buried by as much as 10 feet of soil and organic matter (Schneider et al. 1996). Soil thickness is greatest at the lowest bedrock elevations, and soils are thinner at the highest bedrock elevations (Watts et al. 2014). Davis (1946) concluded that peat deposits in Big Cypress were generally not thick or extensive enough to be mined profitably.

REMAP soil thickness data were collected as the average of three measurements to the point of refusal (Photo 14). REMAP 1995-96 thickness ranged from 0.75 to 4.60 ft with a median of 0.75 ft. REMAP 2023 soil thickness ranged from 0.3 to 4.6 feet with a median of 1.1 ft (Figures Soil Thickness 1 and 2). The 2023 thickness values were greater than the 1995-96 values ($p < 0.05$). The close proximity of deeper and shallower soils (Figure Soil Thickness 2) could be explained by undulations in underlying bedrock and differences in hydroperiod described above. Soil thickness had a significant ($p < 0.05$) and moderate relationship with water depth (rho = 0.43), and significant and weak correlations with organic matter and bulk density (rho = 0.34 and -0.38, respectively, Figures Soil Thickness 3 to 5).

Deeper water is indicative of longer hydroperiods and less frequent drying. These wetter conditions are conducive to the formation of deeper soils, such as peat, with higher organic matter and carbon content and lower bulk density. There were no significant latitudinal gradients in soil thickness in REMAP 1995-96 or 2023 data ($p = 0.53$ for 1995-1996 and $p = 0.18$ for 2023; rho = 0.13 and 0.22, respectively, Appendix 4). About 50% of the marsh area sampled had a soil thickness at or below 1.1 feet, with a 95% confidence interval of 41.9 to 62.5% (Figure Soil Thickness 6).

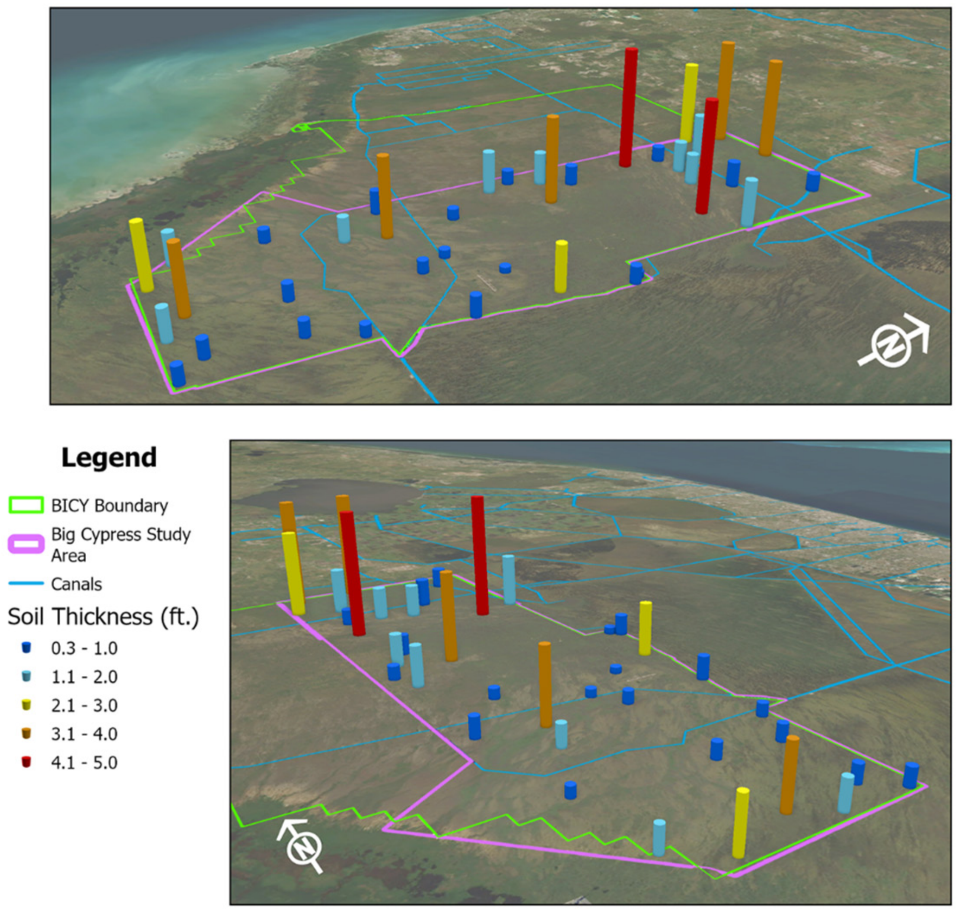


Figure Soil Thickness 2. REMAP 2023 soil thickness (feet).

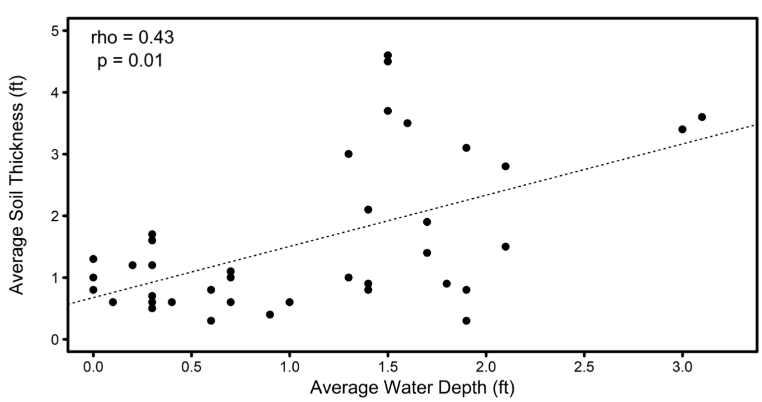


Figure Soil Thickness 3. Average water depth (feet) versus average soil thickness (feet).

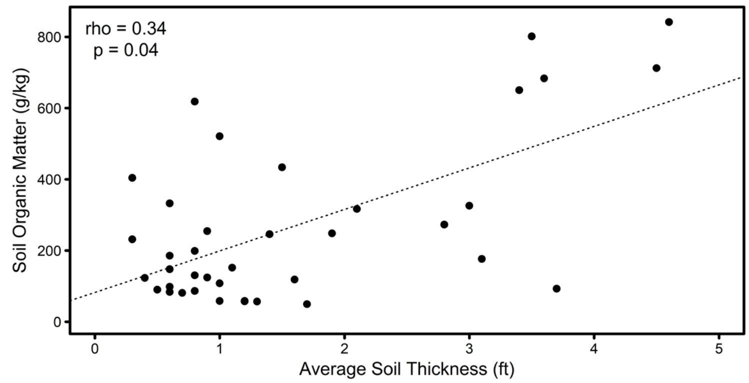


Figure Soil Thickness 4. Average soil thickness (feet) versus soil organic matter (g/kg).

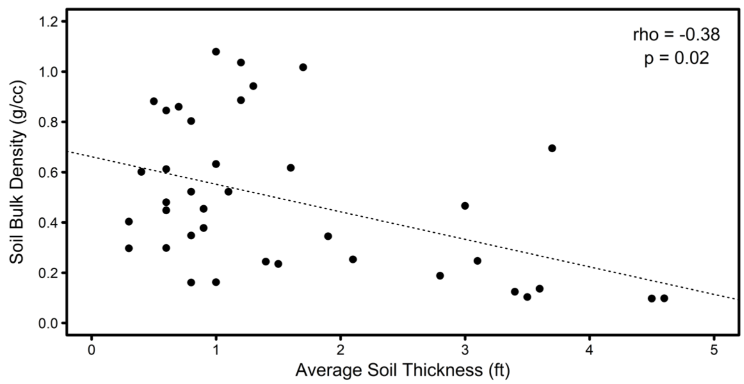


Figure Soil Thickness 5. Average soil thickness (feet) versus soil bulk density (g/cc).

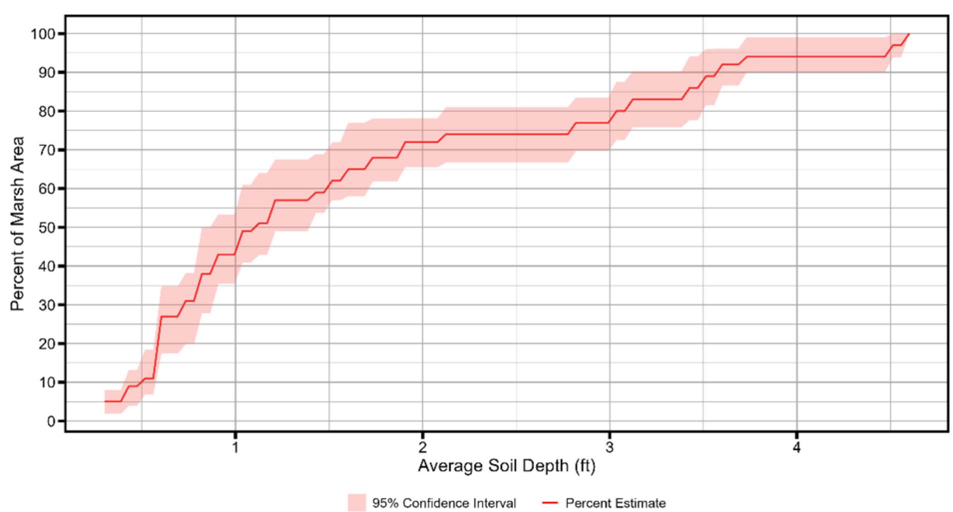
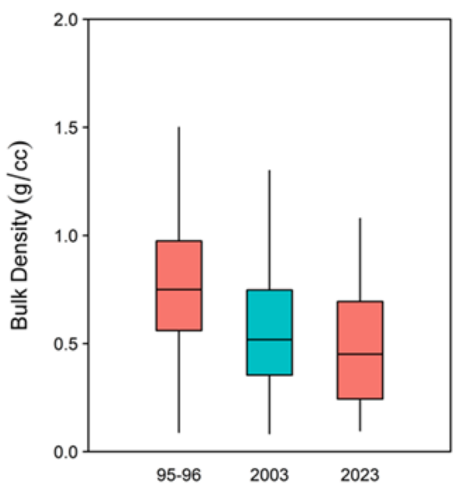


Figure Soil Thickness 6. Soil thickness (feet) estimates of sampled area.

OVERVIEW AND FINDINGS - SOILS

BULK DENSITY

Soil bulk density (BD) is a commonly measured soil property, defined as the dry weight of soil material per unit volume. Soils that are loose and porous, such as organic soils, tend to have bulk density values less than 0.5 g/cc. In contrast, soils that are more compact, such as mineral soils, tend to have higher values generally ranging from 1.0 to 2.0 g/cc (Mitsch and Gosselink 2015). REMAP 2023 soil BD ranged from 0.097 to 1.079 g/cc, with a median of 0.448 g/cc (Figures Bulk Density 1 and 2). REMAP 2023 and 2003 SFWMD data were not different ($p = 0.18$, Dunn's test, Figure Bulk Density 1) while 1995-96 REMAP data were higher than both other years ($p < 0.05$). All program data had significant ($p < 0.05$) but weak latitudinal gradients with higher bulk density values in the north (REMAP 2023 rho = 0.33, SFWMD 2023 rho = 0.32, REMAP 1995-96 rho = 0.35, Figure Bulk Density 4).



GROUP	Letter	N	Significantly Different
REMAP 1995-96	a	24	bc
SFWMD 2003	b	117	a
REMAP 2023	c	38	a

Figure Soil Bulk Density 1. Soil bulk density (g/cc) comparisons across programs.

There were significant ($p < 0.05$) and very strong inverse relationships between soil BD and soil organic matter (g/kg), total carbon (g/kg), and moisture content (%) (rho = -0.96, -0.94 and -0.99, respectively). There were also strong and significant inverse relationships between soil BD and both soil total nitrogen (g/kg) and soil total phosphorus (g/kg) (rho = -0.89 and -0.76, respectively). These results are similar to those reported in coastal Everglades National Park soils (Steinmuller et al. 2021). There was a significant but weak (rho = -0.38) inverse relationship between bulk density and soil thickness. About 50% of the marsh area sampled had a bulk density of 0.448 g/cc, with a 95% confidence interval of 41.0 to 58.3% (Figure Bulk Density 5).

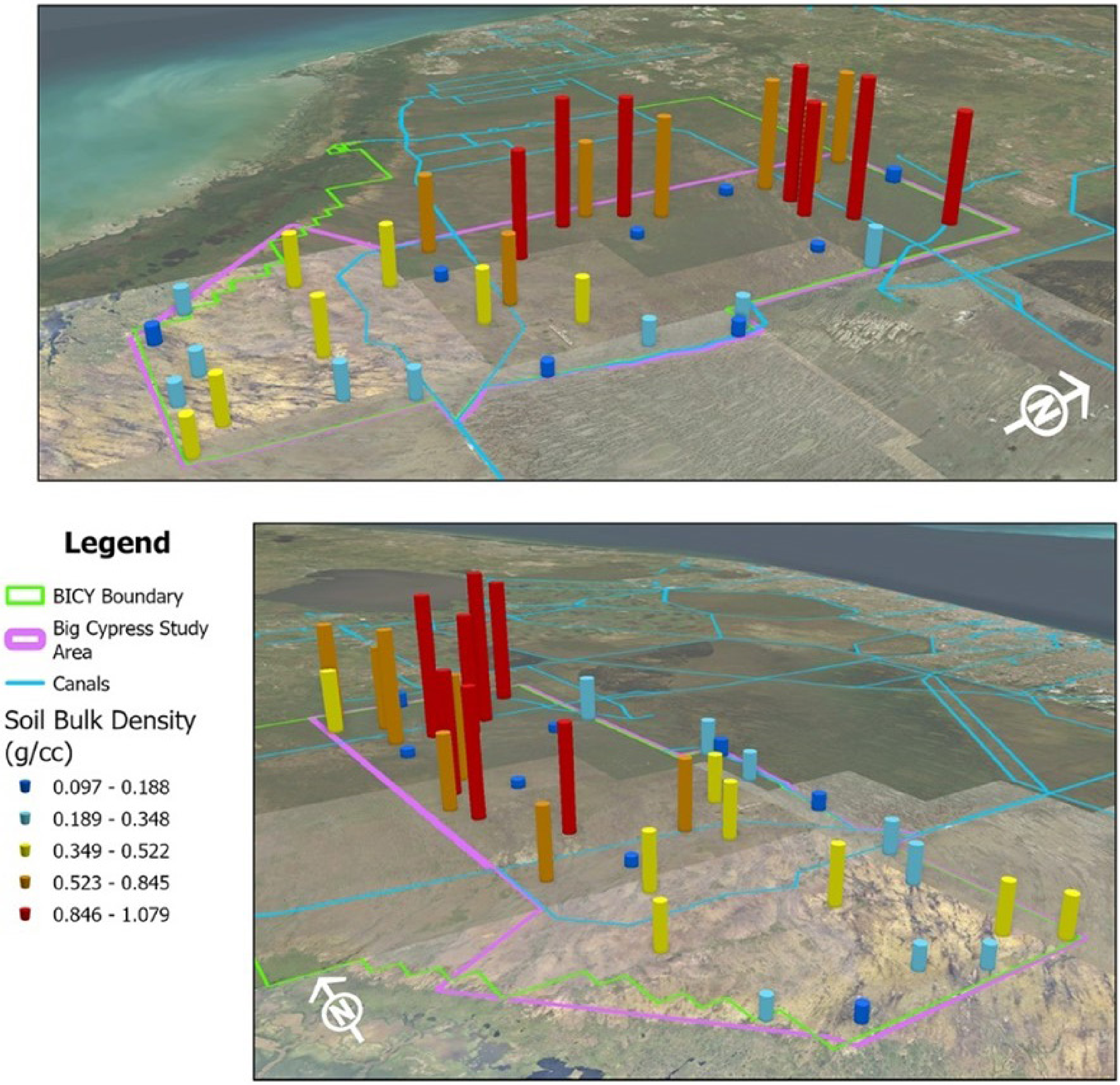


Figure Soil Bulk Density 2. 2023 REMAP soil bulk density (g/cc).

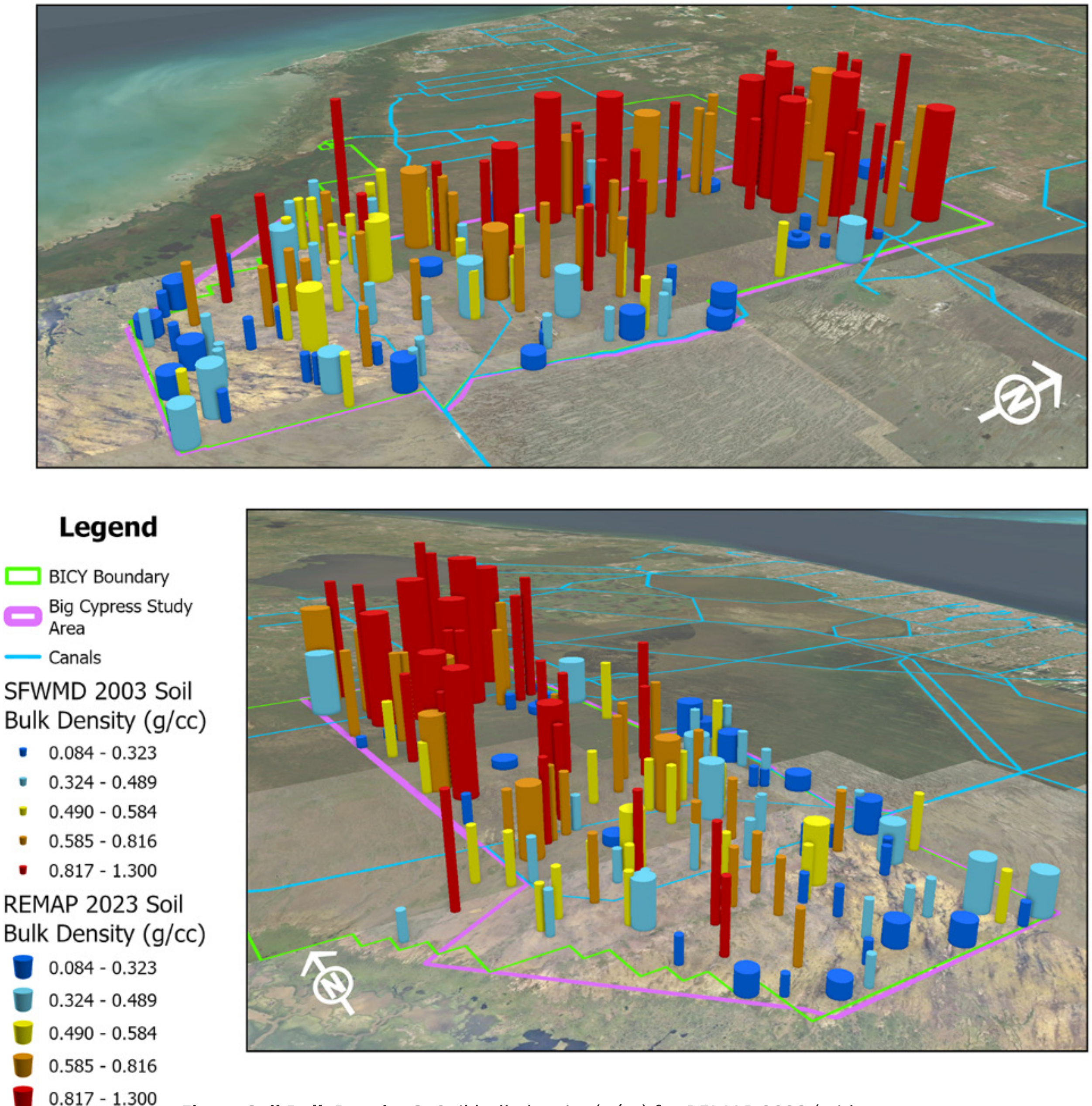


Figure Soil Bulk Density 3. Soil bulk density (g/cc) for REMAP 2023 (wider diameter columns) and SFWMD 2003 (narrower diameter columns).

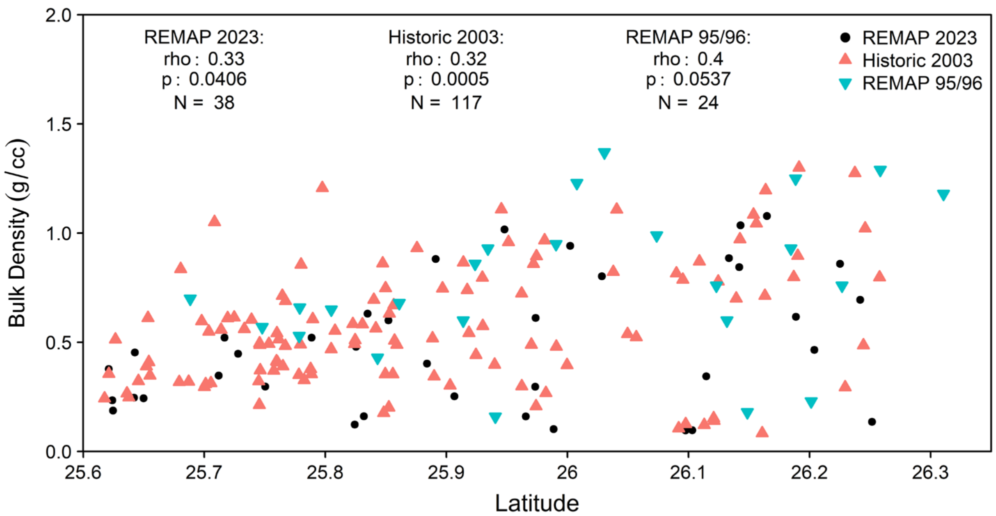


Figure Soil Bulk Density 4. Soil bulk density (g/cc) by latitude during the wet season. North is to the right and south is to the left.

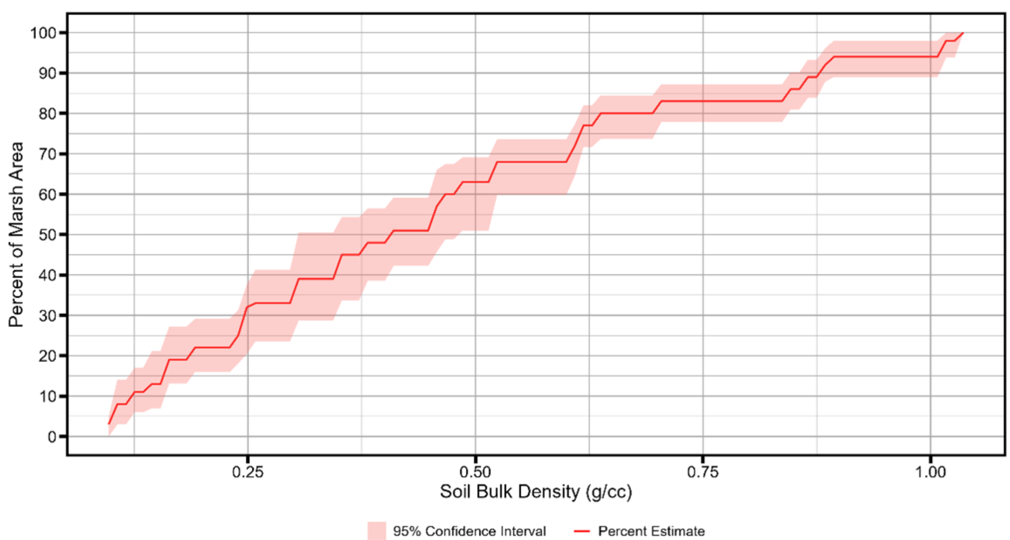


Figure Soil Bulk Density 5. Soil bulk density (g/cc) estimates of sampled area.

OVERVIEW AND FINDINGS - SOILS

ORGANIC MATTER

Soil type and organic matter (OM) content vary throughout BCNP. Soil types include marl and sand of low OM content and peat with higher OM content (Duever et al. 1986). REMAP 2023 data were reported as g/kg ash free dry matter, while REMAP 1995-96 data were reported as percent ash free dry weight and SFWMD 2003 data were reported as percent loss on ignition. Uncertainty on the methodologies prevents the accurate comparison of 2023 REMAP data to 1995-96 REMAP data or SFWMD 2003 data.

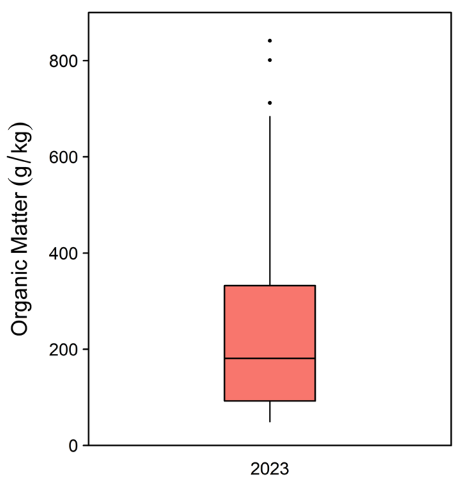


Figure Soil Organic Matter 1. Soil organic matter results (g/kg).

REMAP 2023 soil OM (g/kg) ranged from 49.5 to 841.5 g/kg, with a median of 198.83 g/kg. (Figure Soil Organic Matter 1). Steinmuller et al. (2021) used OM content to sort soil type in marshes in ENP coastal areas. The extremes were reported as marl with the lowest OM content of 82.8 ± 2.80 g/kg and peat with the highest OM content of 868 ± 6.80 g/kg, similar to the ranges for REMAP 2023 results. REMAP 2023 data did not have a significant latitudinal gradient ($p = 0.16$, $rho = -0.23$, Appendix 4). Soil OM had a significant ($p < 0.05$) and strong ($rho = 0.81$) relationship with water depth (Figure Soil Organic Matter 3). Soils that are flooded provide conditions conducive to the preservation of plant matter, less oxidation, and accretion of soils that tend to be more organic. About 50% of the marsh area sampled had a soil OM content at or below 192.1 g/kg, with a 95% confidence interval of 44.0% to 56.8% g/kg (Figure Soil Organic Matter 4).

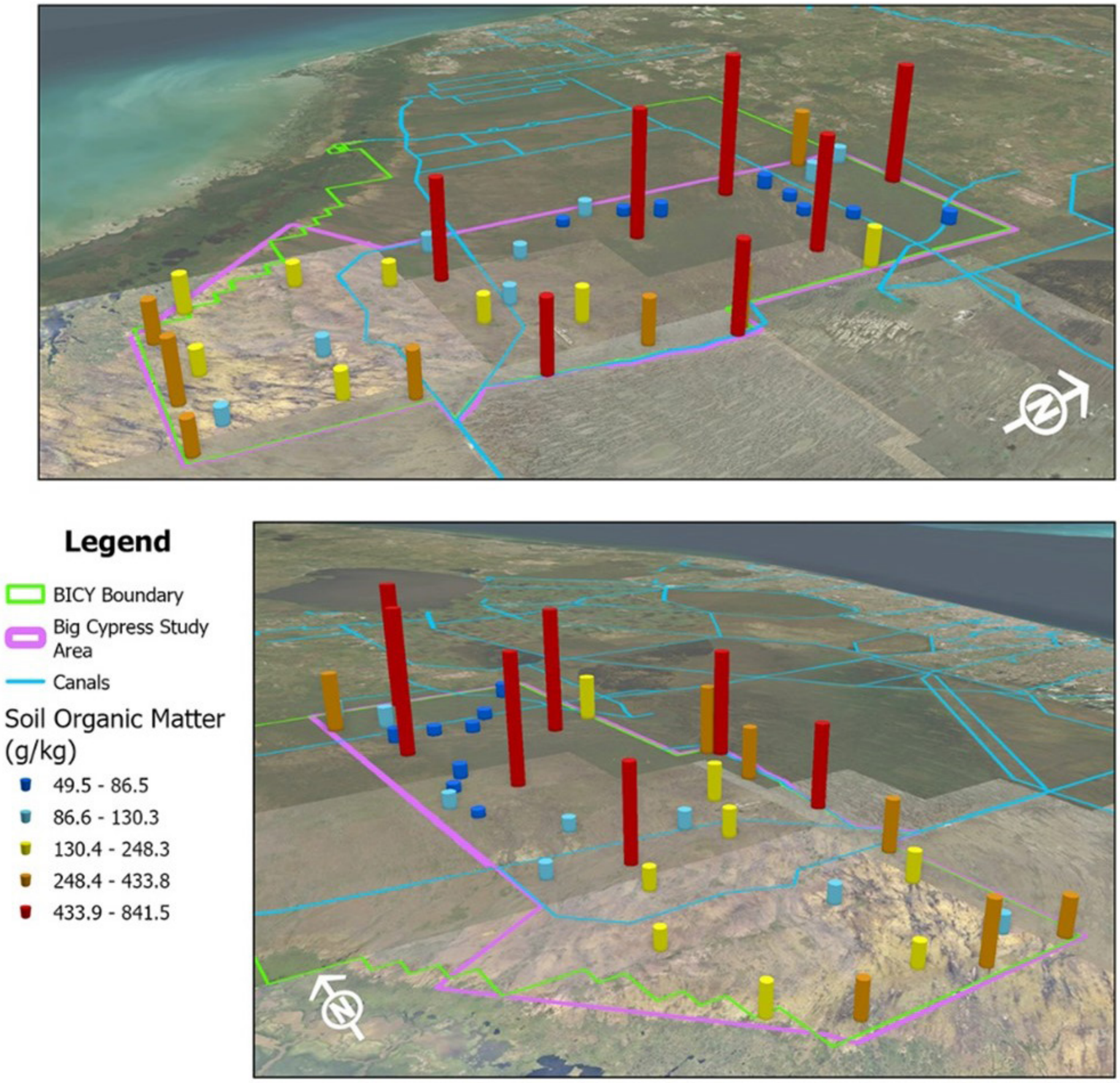


Figure Soil Organic Matter 2. REMAP 2023 Soil organic matter (g/kg).

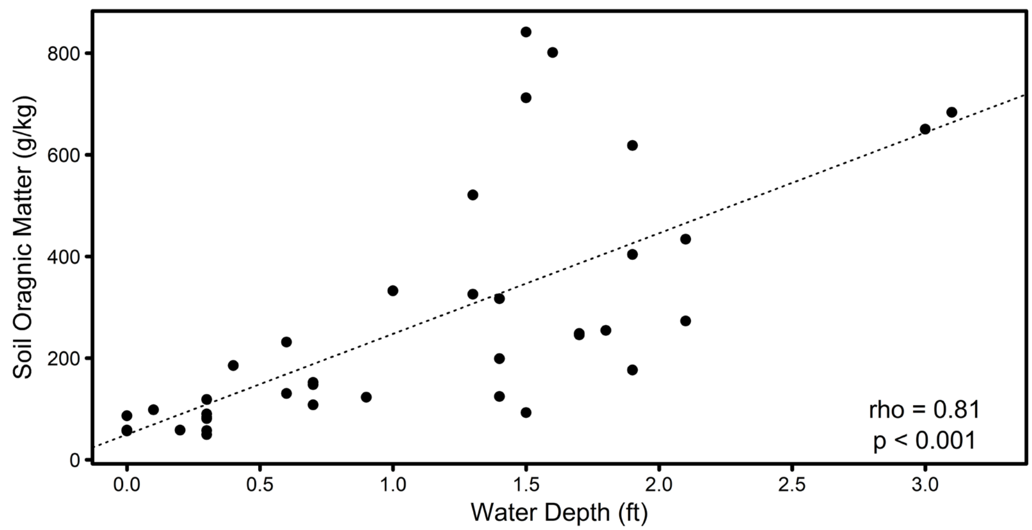


Figure Soil Organic Matter 3. Water depth (feet) versus soil organic matter (g/kg).

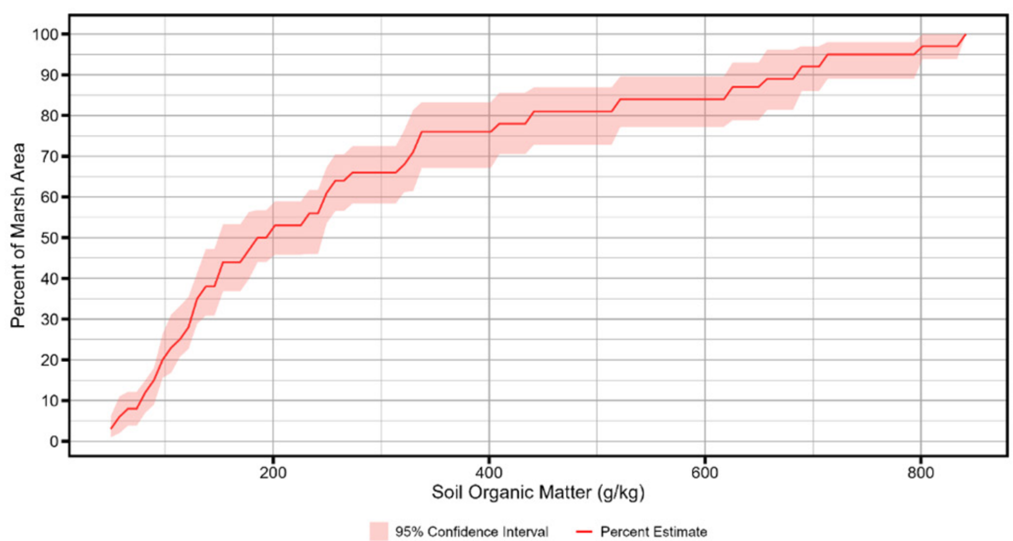


Figure Soil Organic Matter 4. Soil organic matter (g/kg) estimates of sampled area.

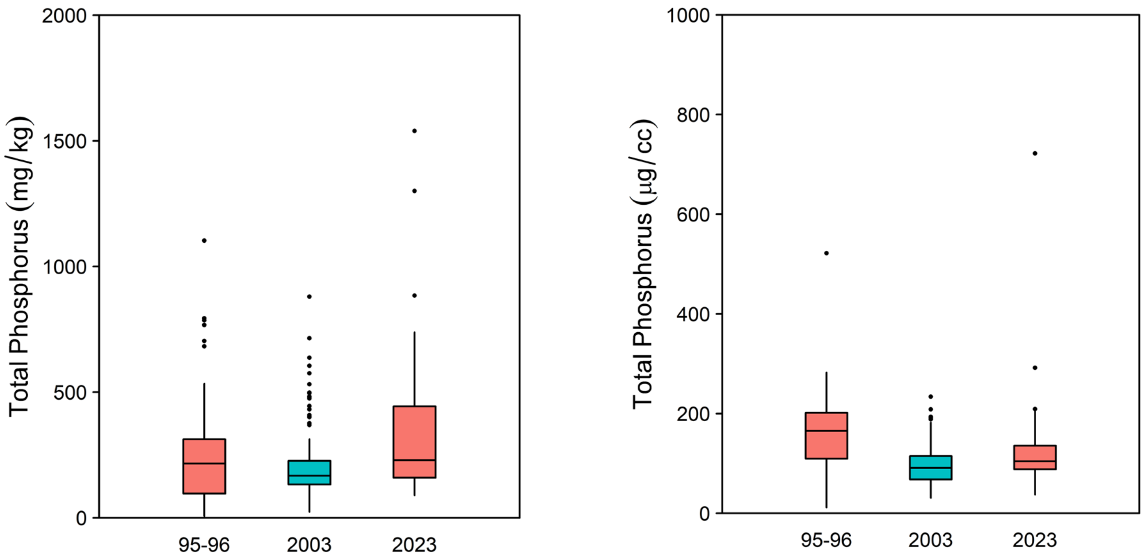
OVERVIEW AND FINDINGS - SOILS

PHOSPHORUS

Total Phosphorus (TP) in marsh soils is a useful aggregate indicator of TP conditions over a longer time scale than water column TP. REMAP 2023 soil TP concentrations expressed as per mass ranged from 89.80 to 5823.76 mg/kg, with a median of 239.97 mg/kg. The highest result was almost four times greater than the next highest value of 1539.59 mg/kg. This highest value was reanalyzed and confirmed by the analytical lab, so it was not removed from the analyses as an outlier. SFWMD 2003 concentrations ranged from 23.84 to 880.60 mg/kg, with a median of 167.49 mg/kg. REMAP 2023 TP concentrations were higher ($p < 0.05$; Dunn's test) than SFWMD 2003 concentrations (Figure Soil Phosphorus 1). REMAP 1995-96 data had a significant but weak latitudinal gradient ($p < 0.05$, rho = -0.39, Appendix 4), while REMAP 2023 and SFWMD 2003 data did not show significant gradients ($p = 0.47$ and 0.32, respectively). REMAP 2023 TP had strong positive correlations with TN, TC, organic matter and moisture content ($p < 0.05$, rho = 0.78, 0.73, 0.85 and 0.77, respectively). About 50% of the marsh area sampled had a soil TP concentration at or below 234.1 mg/kg, with a 95% confidence interval of 43.2% to 59.6% (Figure Soil Phosphorus 6). In comparison, the median soil TP concentration for REMAP Everglades was 390 mg/kg in both 2005 and 2014 (Scheidt, Kalla and Surratt 2021).

In portions of the Everglades with peat soils, there is an association between higher soil TP and indicators of enrichment, such as cattail expansion (see summary in Scheidt, Kalla and Surratt, 2021). Florida's 10 µg/L TP surface water criterion rule for the Everglades defines areas as P-impacted when soil TP exceeds 500 mg/kg in the 0-10 cm soil profile (FAC 62-302.540(3)(d)). CERP has a restoration goal of decreasing the areal extent of the Everglades with soil TP > 500 mg/kg, along with maintaining or reducing long-term average concentrations to 400 mg/kg or less (RECOVER 2007). Although these concentrations are not required in BCNP, comparing them to BCNP results provides perspective since BCNP has some similar marshes with peat soil. About 69.4% of the BCNP marsh area sampled in 2023 had a soil TP concentration at or below the Everglades restoration goal of 400 mg/kg, with a 95% confidence interval of 63.9% to 76.0%. About 78.2% of the marsh area sampled had a soil TP concentration at or below the Everglades restoration goal of 500 mg/kg, with a 95% confidence interval of 72.8% to 85.3% (Figure Soil Phosphorus 6).

On a concentration per volume (µg/cc) basis, REMAP 2023 TP in soil ranged from 37.5 to 722.1 µg/cc, with a median of 103.60 µg/cc. REMAP 1995-96 TP in soil ranged from 10.59 to 522.02 µg/cc, with a median of 130.05 µg/cc. SFWMD 2003 concentrations ranged from 30.99 to 234.19 µg/cc, with a median of 91.21 µg/cc. REMAP 2023 TP concentrations were higher ($p < 0.05$; Dunn's test) than SFWMD 2003 concentrations (Figure Soil Phosphorus 1). Only 2003 data had a significant, though weak, latitudinal gradient ($p < 0.05$, rho = 0.24, Appendix 4). During 2023 about 50% of the marsh area sampled had a soil TP concentration at or below 103.6 µg/cc, with a 95% confidence interval of 42.0% to 61.2% (Figure Soil Phosphorus 7).



Group	Letter	N	Significantly Different
1995-96 REMAP	a	24	
2003 SFWMD	b	117	c
2023 REMAP	c	38	b

Group	Letter	N	Significantly Different
1995-96 REMAP	a	24	b
2003 SFWMD	b	117	ac
2023 REMAP	c	38	b

Figure Soil Phosphorus 1. Total Phosphorus in soil compared across programs, per mass (mg/kg, left) and per volume (ug/cc, right). The highest REMAP 2023 value of 5823.8 mg/kg is not shown.

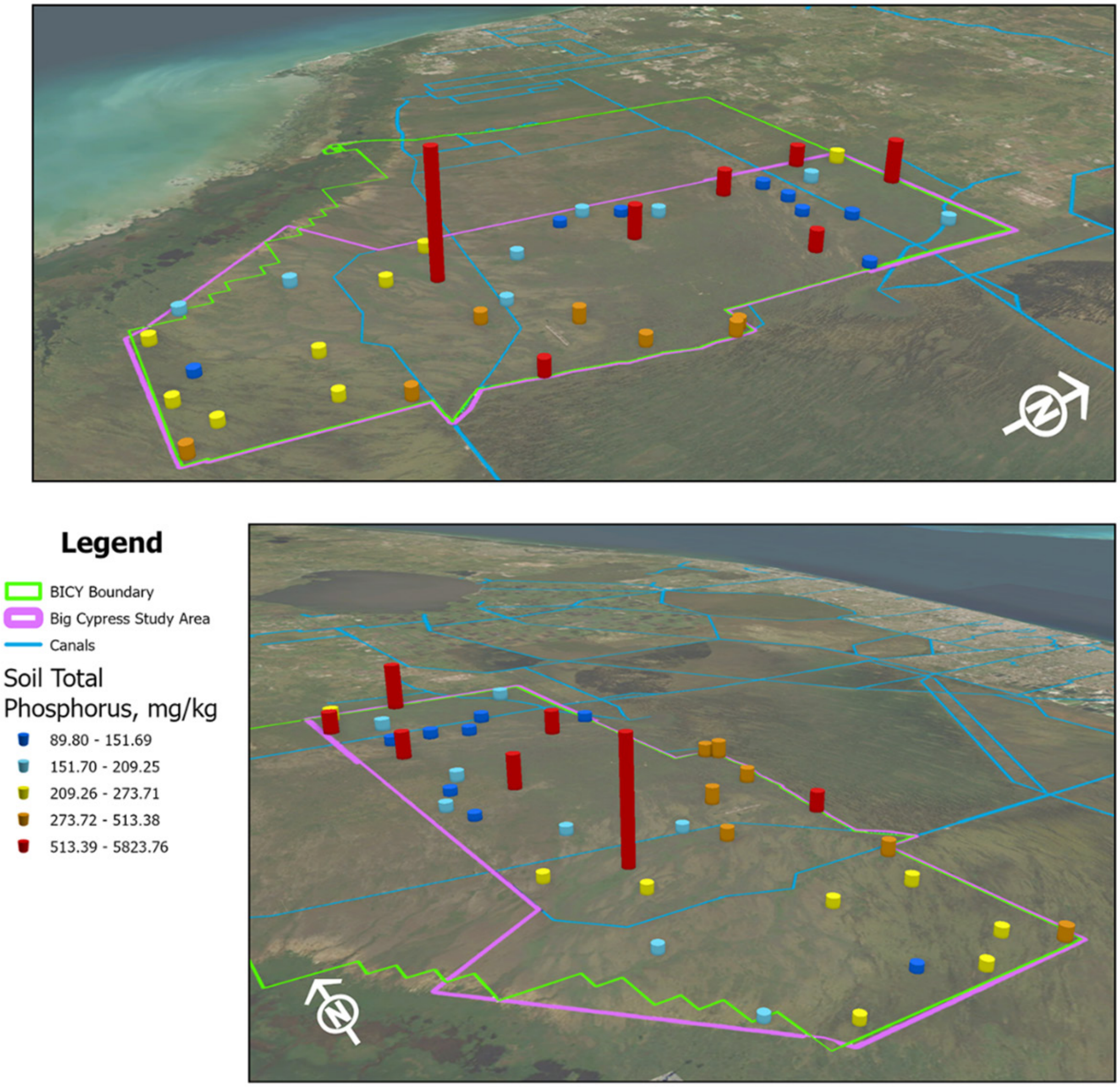


Figure Soil Phosphorus 2. 2023 REMAP total phosphorus in soil per mass (mg/kg).

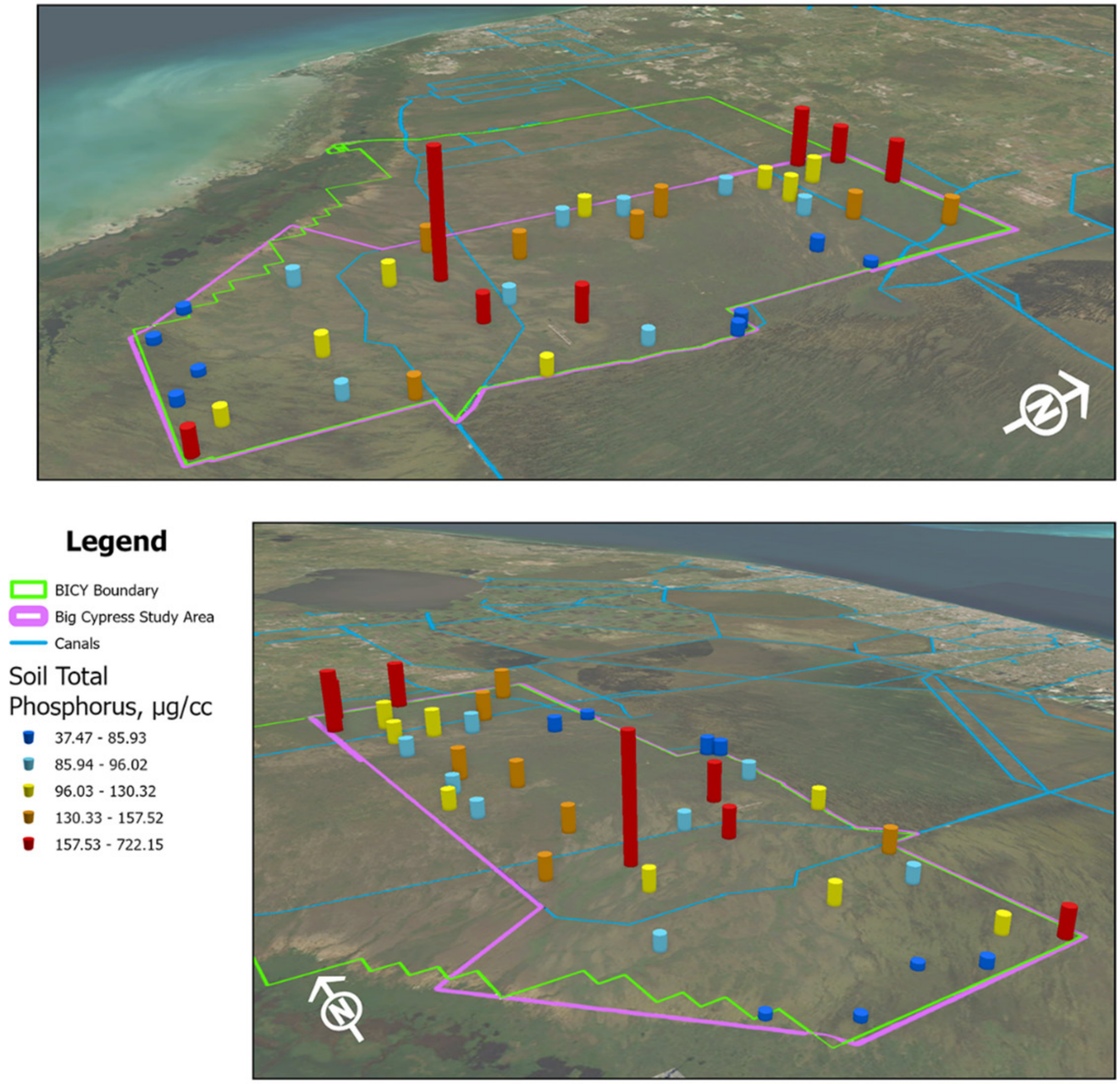


Figure Soil Phosphorus 3. 2023 REMAP total phosphorus in soil per volume (µg/cc).

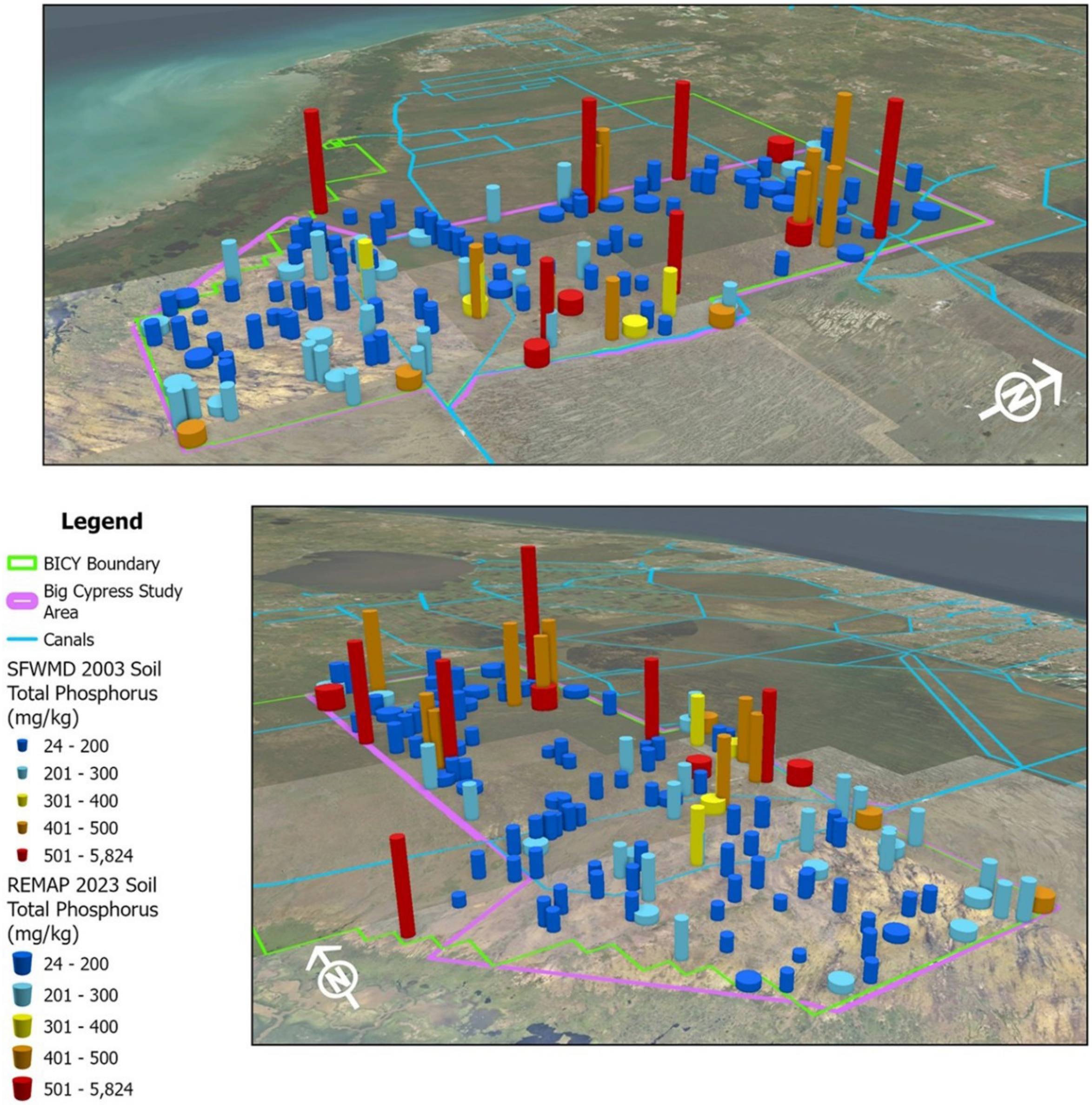


Figure Soil Phosphorus 4. Total phosphorus in soil per mass (mg/kg) for REMAP 2023 (wider diameter columns) and SFWMD 2003 (narrower diameter columns).

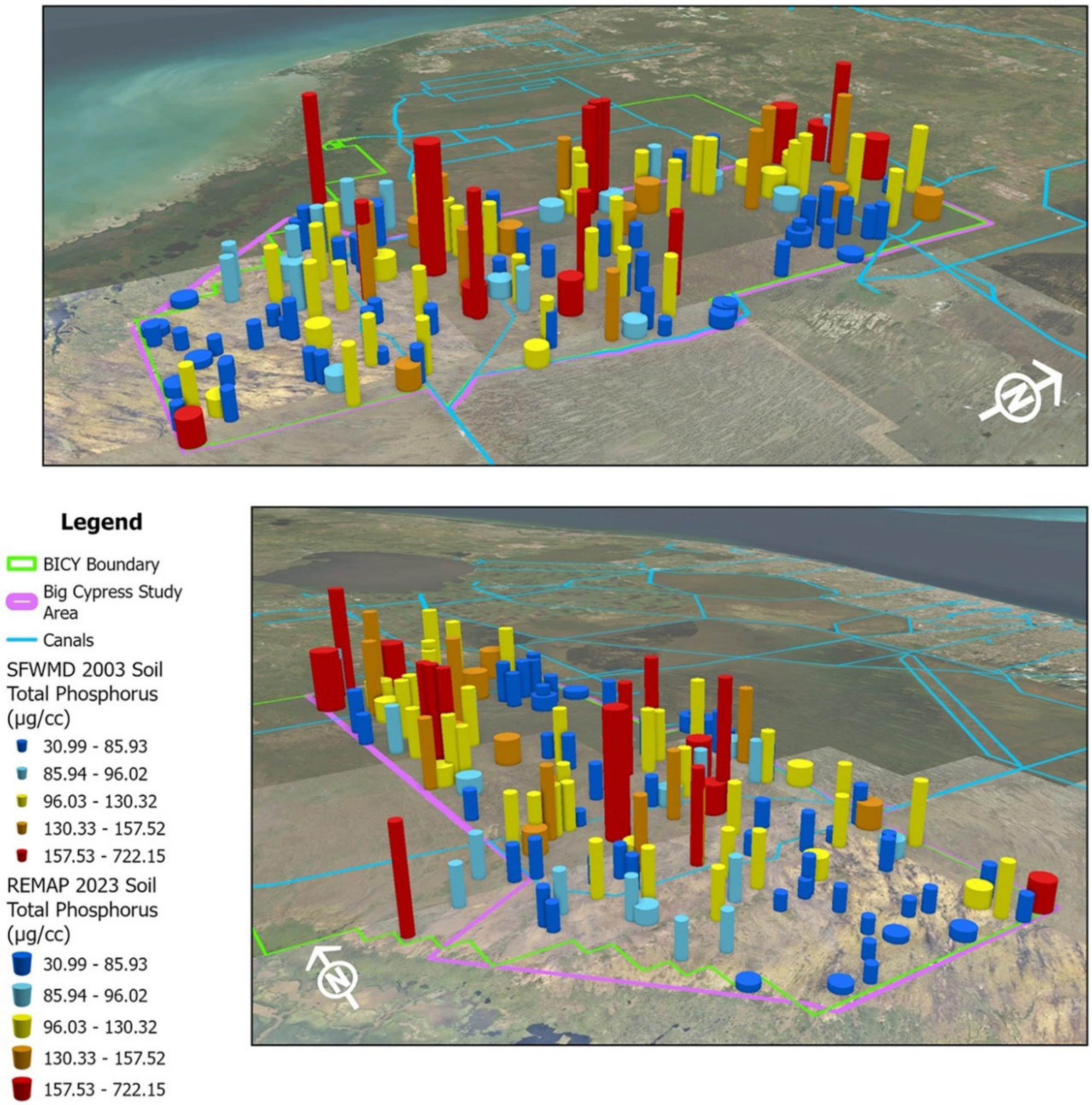


Figure Soil Phosphorus 5. Total phosphorus in soil per volume (µg/cc) for REMAP 2023 (wider diameter columns) and SFWMD 2003 (narrower diameter columns).

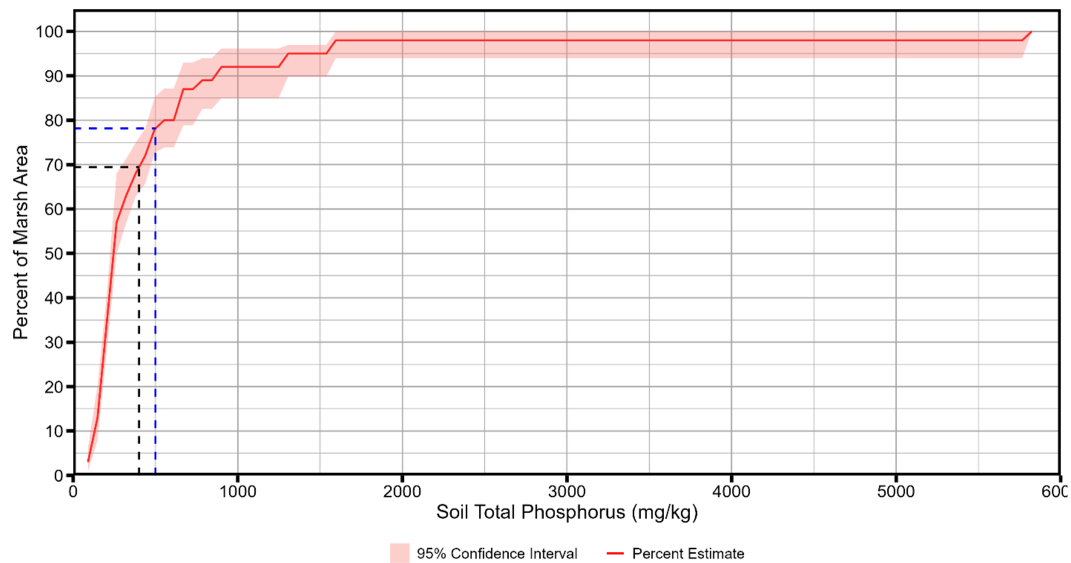


Figure Soil Phosphorus 6. Total phosphorus in soil per mass (mg/kg) estimates of sampled area. Dotted lines represent the sampled marsh area with TP concentrations at or below the two Everglades restoration goal concentrations of 400 (black line) and 500 (blue line) mg/kg.

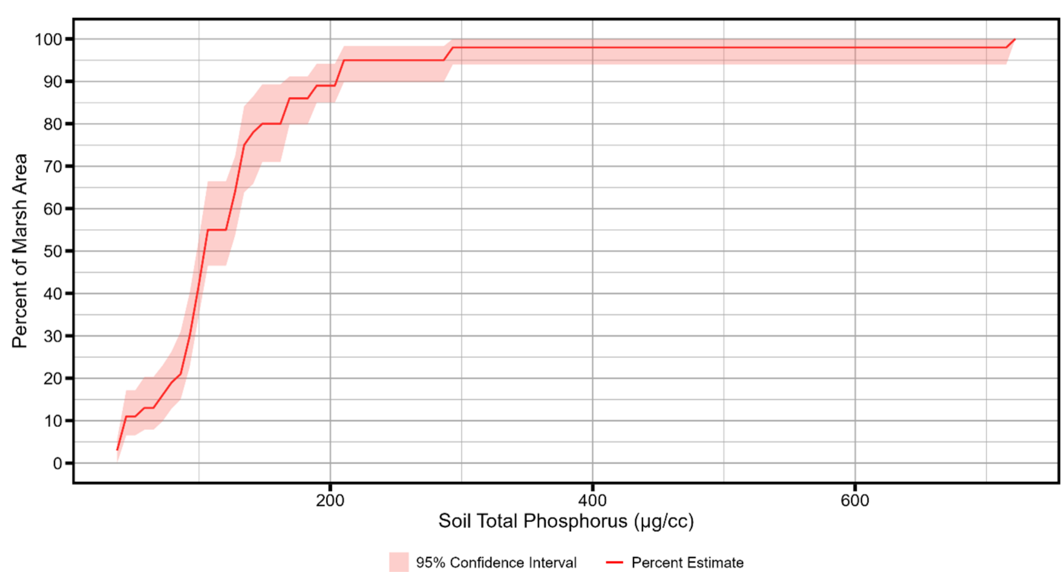


Figure Soil Phosphorus 7. Total phosphorus in soil per volume (µg/cc) estimates of sampled area.

OVERVIEW AND FINDINGS - SOILS

NITROGEN

Soil nitrogen cycling in wetland ecosystems is complex. Greater than 95% of the total N in wetland soils is present as organic N, and the remaining inorganic N is primarily in the form of ammonium. Major sources of N include atmospheric deposition, biological nitogen fixation, and sediment and nutrient loading. The amount of N accumulated in wetland soils depends on the balance between plant production and decomposition as well as the import and export of particulates. Most N fixation occurs in the aerobic water column by N-fixing species of cyanobacteria, although some bacteria can fix N in anaerobic soil. Biological nitrogen fixation contributes as much N to wetlands as atmospheric deposition (0.5 to 1.0 g/m^2/year) (Orem et al. 2014).

REMAP 2023 Soil Total Nitrogen (TN) concentrations expressed per mass ranged from 3.49 to 35.76 g/kg, with a median of 11.16 g/kg. SFWMD 2003 concentrations ranged from 0.26 to 29.6 g/kg, with a median of 6.82 g/kg. REMAP 2023 TN concentrations were higher ($p < 0.05$; Dunn's test) than SFWMD 2003 concentrations (Figures Soil Nitrogen 1 and 2). REMAP did not determine soil TN in 1995-96. REMAP 2023 data did not have a significant latitudinal gradient ($p = 0.24$, $rho = -0.19$), while SFWMD 2003 marsh data had a significant, but weak, ($p < 0.05$, $rho = -0.19$) latitudinal gradient with lower concentrations to the north (Figure Soil Nitrogen 6). Although both datasets had a rho of the same direction and magnitude, the 2023 REMAP data did not have a significant gradient, perhaps due to the smaller sample size (38 versus 117). REMAP 2023 TN had very strong positive correlations with total carbon, organic matter, and moisture content ($p < 0.05$, $rho > 0.90$ to 0.95). The spatial distribution of TN in Everglades soils was similar to soil carbon (Osborne et al. 2011a; Osborne et al. 2015). About 50% of the Big Cypress marsh area sampled had a soil TN concentration at or below 11.16 g/kg, with a 95% confidence interval of 42.9% to 57.9% (Figure Soil Nitrogen 7).

On a concentration per volume (mg/cc) basis, TN in soil ranged from 2.43 to 9.73 mg/cc, with a median of 4.47 mg/cc (Figures Soil Nitrogen 1 and 3). REMAP 2023 TN concentrations were higher ($p < 0.05$; Dunn's test) than SFWMD 2003 concentrations (Figure Soil Nitrogen 1). Neither the REMAP nor the SFWMD data had a significant latitudinal gradient ($p = 0.14$ and 0.10, Appendix 4). About 50% of the marsh area sampled had a soil TN concentration at or below 4.47 mg/cc, with a 95% confidence interval of 43.2% to 58.5% (Figure Soil Nitrogen 8).

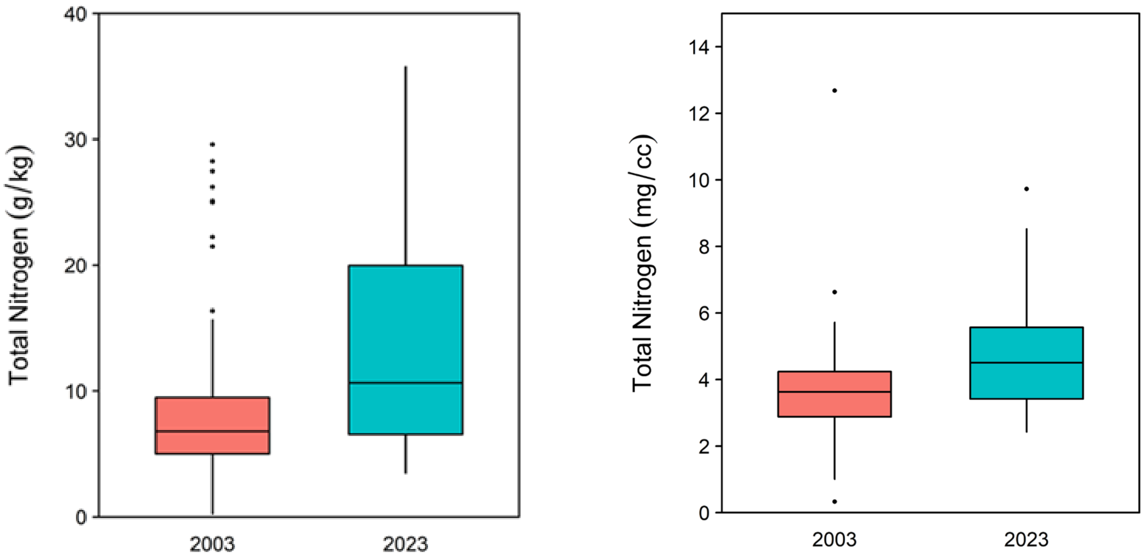


Figure Soil Nitrogen 1. Total nitrogen in soil comparisons across programs (per mass, g/kg, left) and (per volume, mg/cc, right).

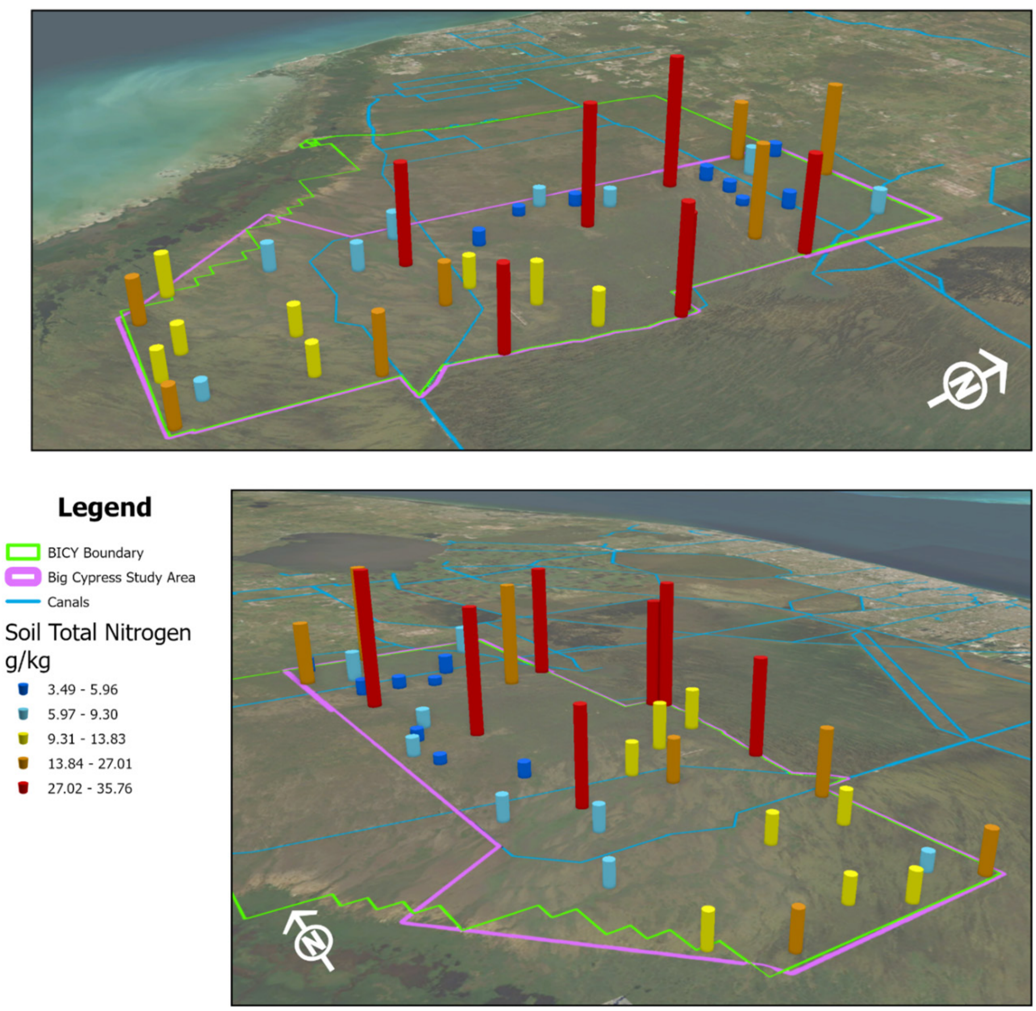


Figure Soil Nitrogen 2. 2023 REMAP total nitrogen in soil per mass (g/kg).

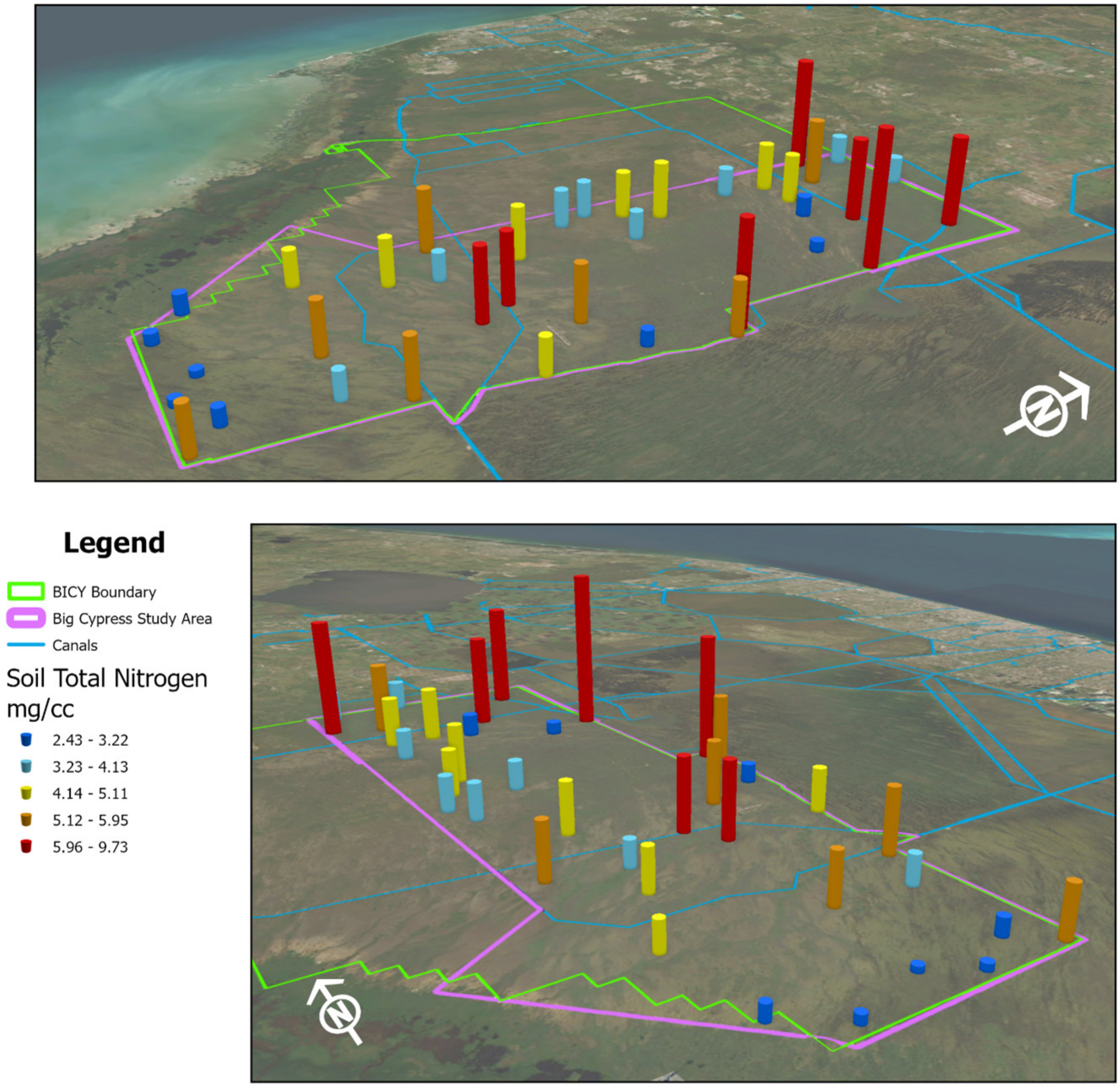


Figure Soil Nitrogen 3. 2023 REMAP total nitrogen in soil per volume (mg/cc).

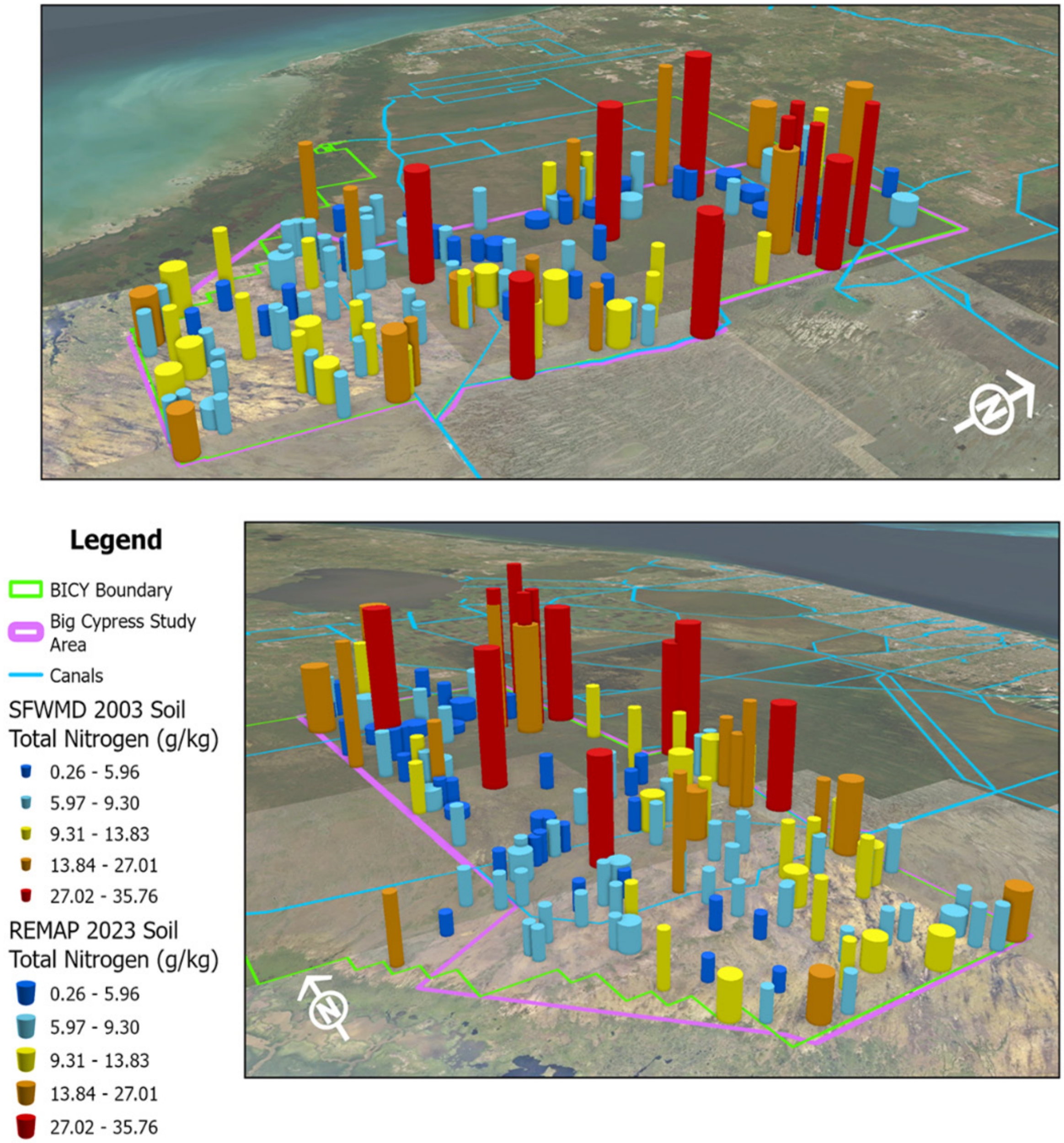


Figure Soil Nitrogen 4. Total nitrogen in soil per mass (g/kg) for REMAP 2023 (wider diameter columns) and SFWMD 2003 (narrower diameter columns).

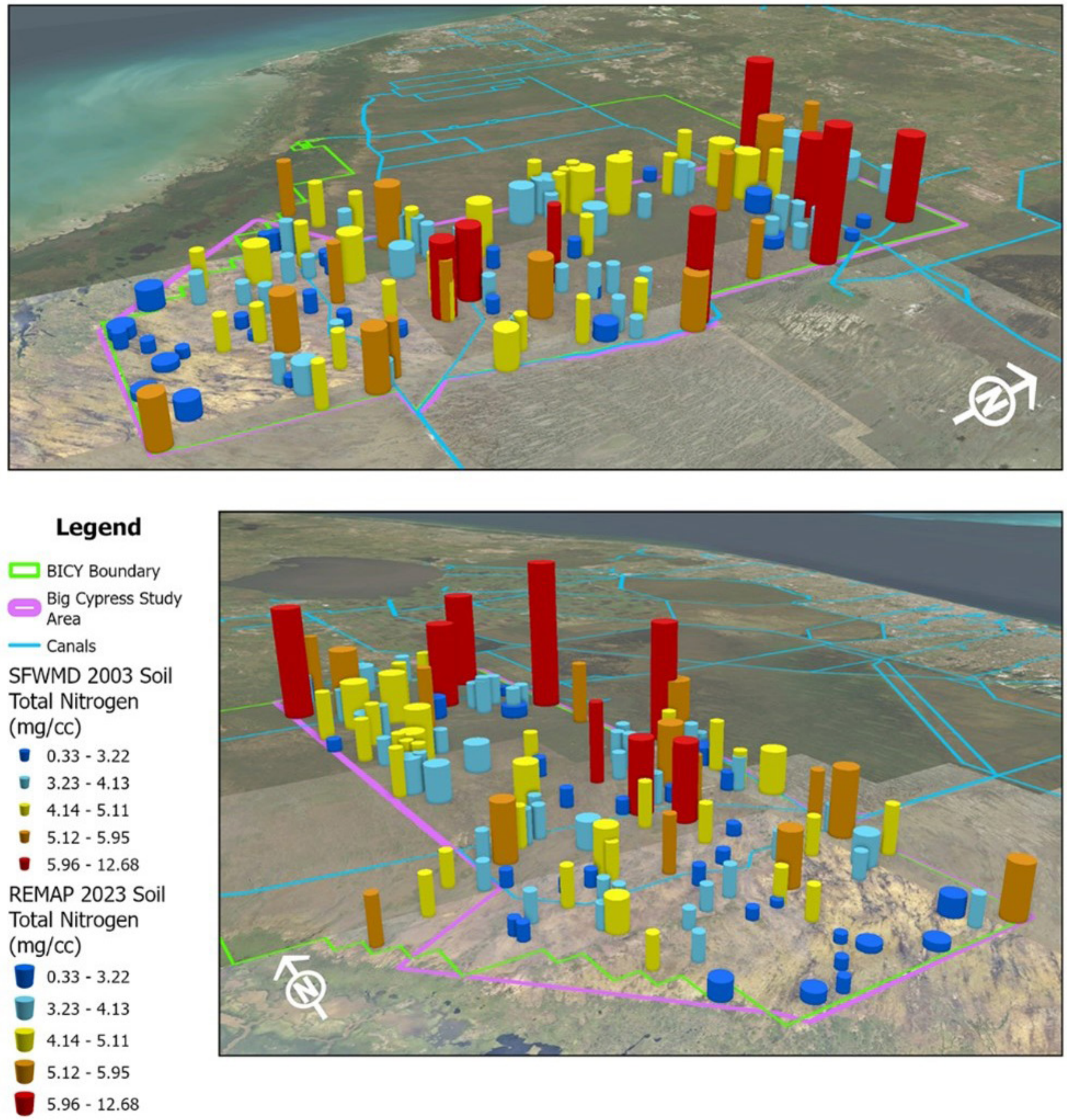


Figure Soil Nitrogen 5. Total nitrogen in soil per volume (mg/cc) for REMAP 2023 (wider diameter columns) and SFWMD 2003 (narrower diameter columns).

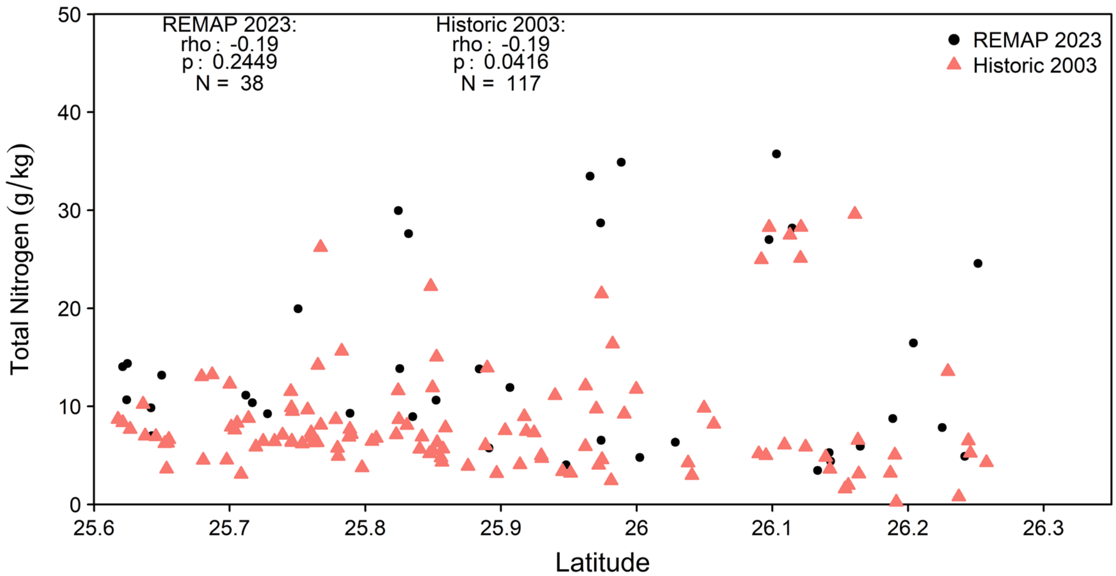


Figure Soil Nitrogen 6. Soil total nitrogen per mass (g/kg) by latitude during the wet season. North is to the right and south is to the left.

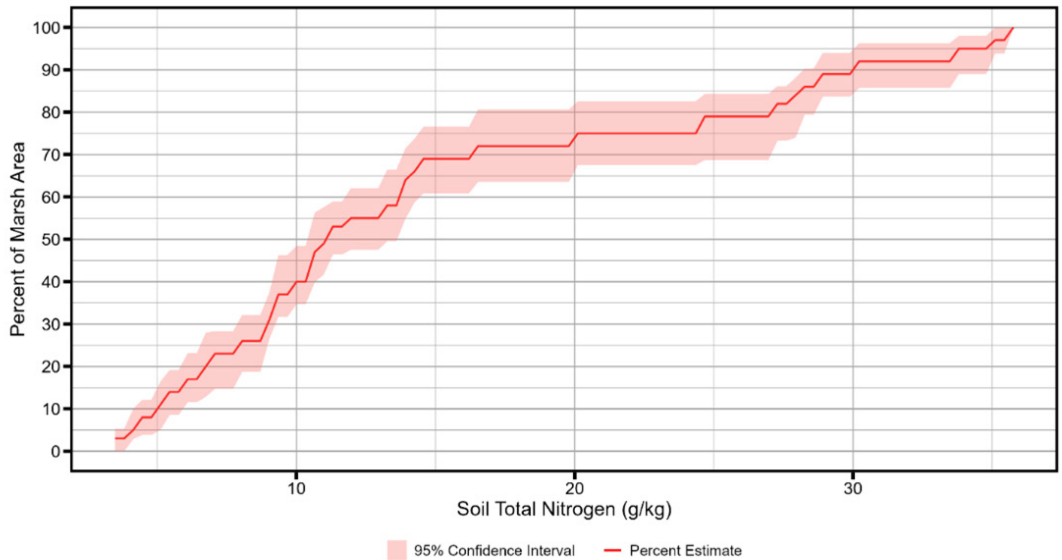


Figure Soil Nitrogen 7. Total nitrogen in soil per mass (g/kg) estimates of sampled area.

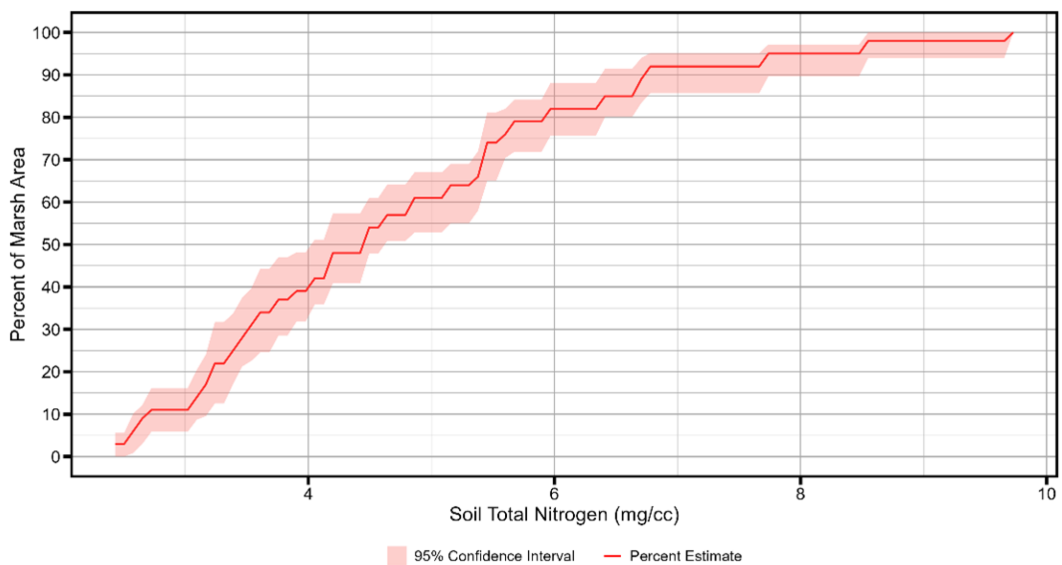


Figure Soil Nitrogen 8. Total nitrogen in soil per volume (mg/cc) estimates of sampled area.

OVERVIEW AND FINDINGS - SOILS

CARBON

In wetland soils, biogeochemical cycles of major nutrients such as nitrogen, phosphorus and sulfur revolve around the cycling of organic carbon (Osborne et al. 2011a). REMAP 2023 soil Total Carbon (TC) concentrations expressed per mass ranged from 46.60 to 474.30 g/kg, with a median of 162.40 g/kg. Historic 2003 SFWMD marsh data ranged from 4.34 to 441.1 g/kg, with a median of 107.6 g/kg. REMAP 2023 concentrations were higher ($p < 0.05$; Dunn's test) than the 2003 data (Figures Soil Carbon 1 and 2). REMAP soil TC had very strong positive correlations ($p < 0.05$, rho > 0.90) with soil TN, organic matter, and moisture content, and a very strong negative correlation with bulk density. TC also had a strong correlation with TP and THg (rho = 0.73 and 0.75, respectively) and a moderate (rho = 0.58) correlation with MeHg (Appendix 5). REMAP data did not have a significant latitudinal gradient ($p = 0.139$, rho = -0.24), but SFWMD 2003 marsh data had a significant, but weak, ($p < 0.05$, rho = -0.26) latitudinal gradient (Figure Soil Carbon 6). About 50% of the marsh area sampled had a soil TC concentration at or below 162.40 g/kg, with a 95% confidence interval of 41.9% to 59.9% (Figure Soil Carbon 7).

On a concentration per volume (mg/cc) basis, REMAP 2023 soil TC ranged from 36.0 to 97.2 mg/cc, with a median of 57.80 mg/cc. Historic 2003 SFWMD marsh data ranged from 5.64 to 156.82 mg/cc with a median of 52.55 mg/cc. REMAP 2023 TC concentrations were higher ($p < 0.05$; Dunn's test) than 2003 concentrations (Figures Soil Carbon 1 and 3). There were no significant latitudinal gradients for REMAP ($p = 0.12$, rho = 0.26) or SFWMD data ($p = 0.46$, rho = -0.07, Appendix 4). About 50% of the marsh area sampled had a soil TC concentration at or below 57.8 mg/cc, with a 95% confidence interval of 43.6% to 56.8% (Figure Soil Carbon 8).

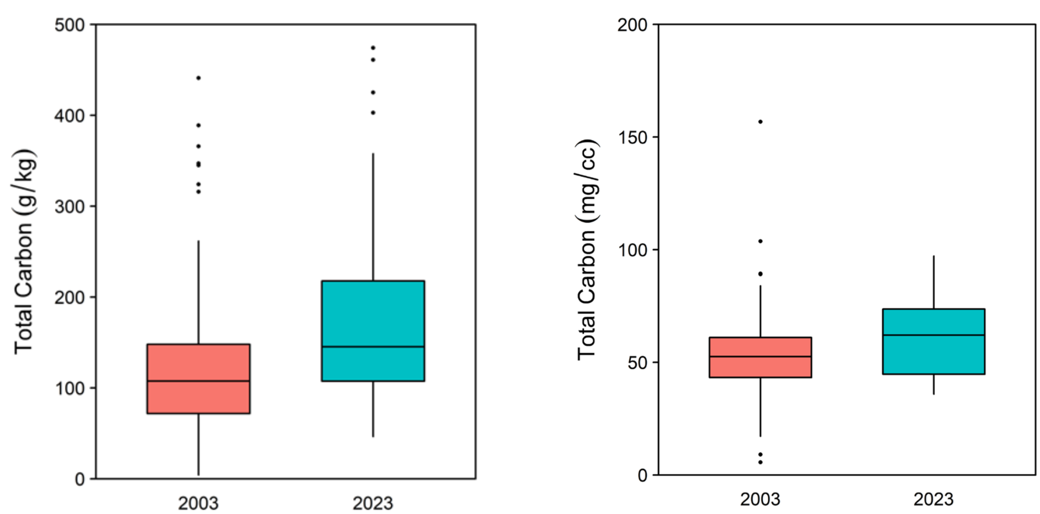


Figure Soil Carbon 1. Total carbon in soil comparisons across programs per mass (left, g/kg) and per volume (right, mg/cc).

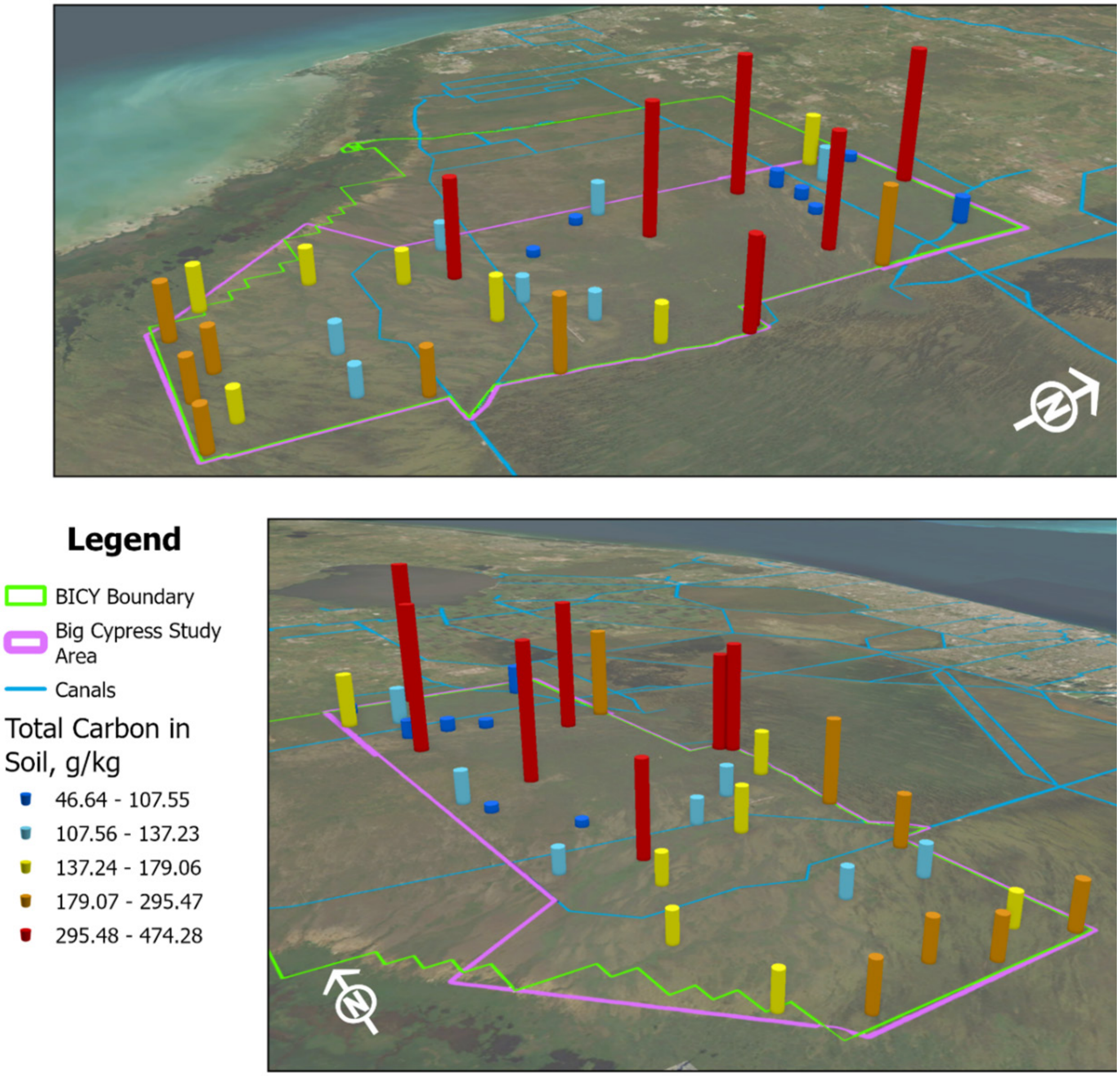


Figure Soil Carbon 2. REMAP 2023 Soil Total Carbon (g/kg).

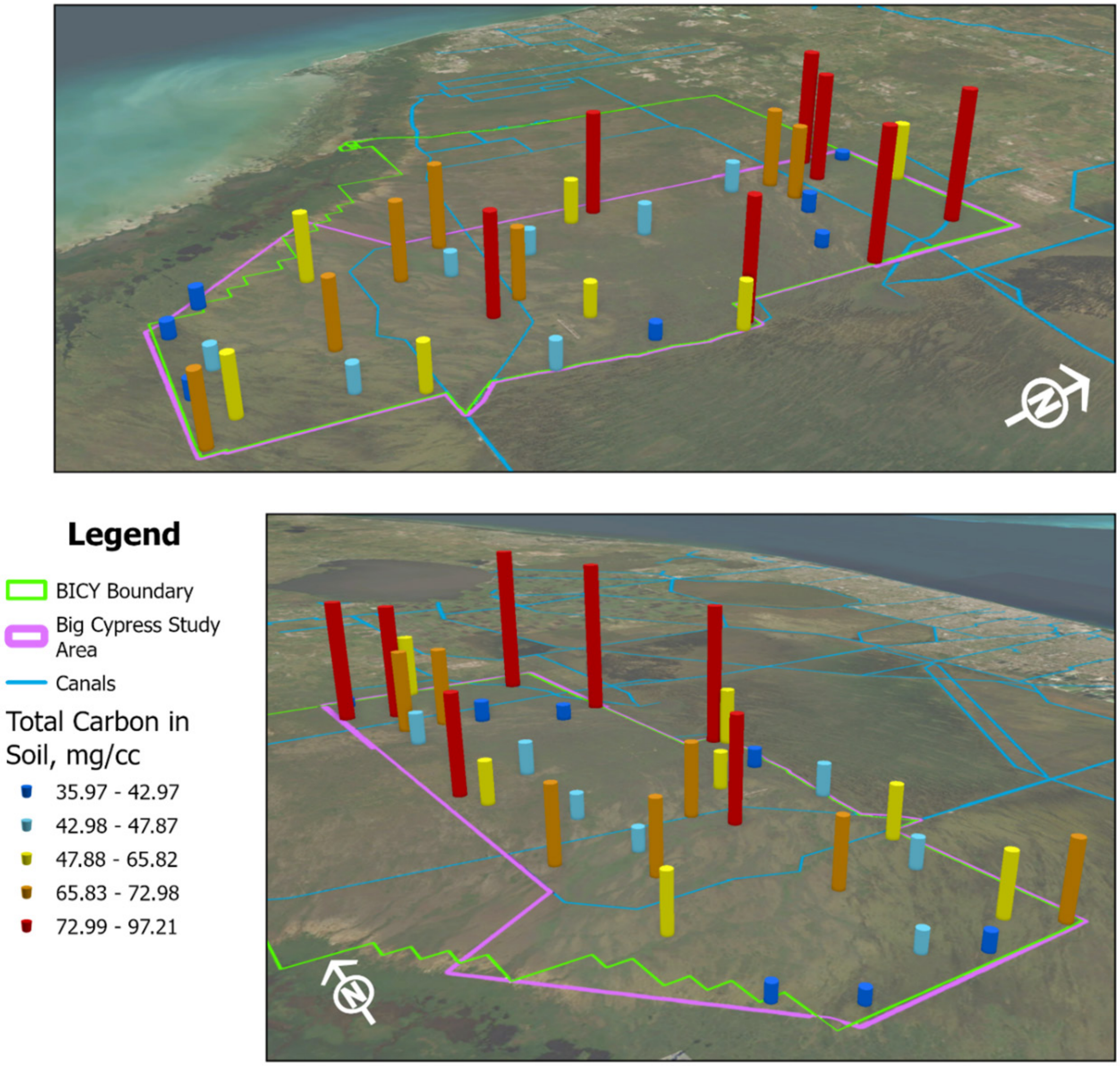


Figure Soil Carbon 3. REMAP 2023 Soil Total Carbon (mg/cc).

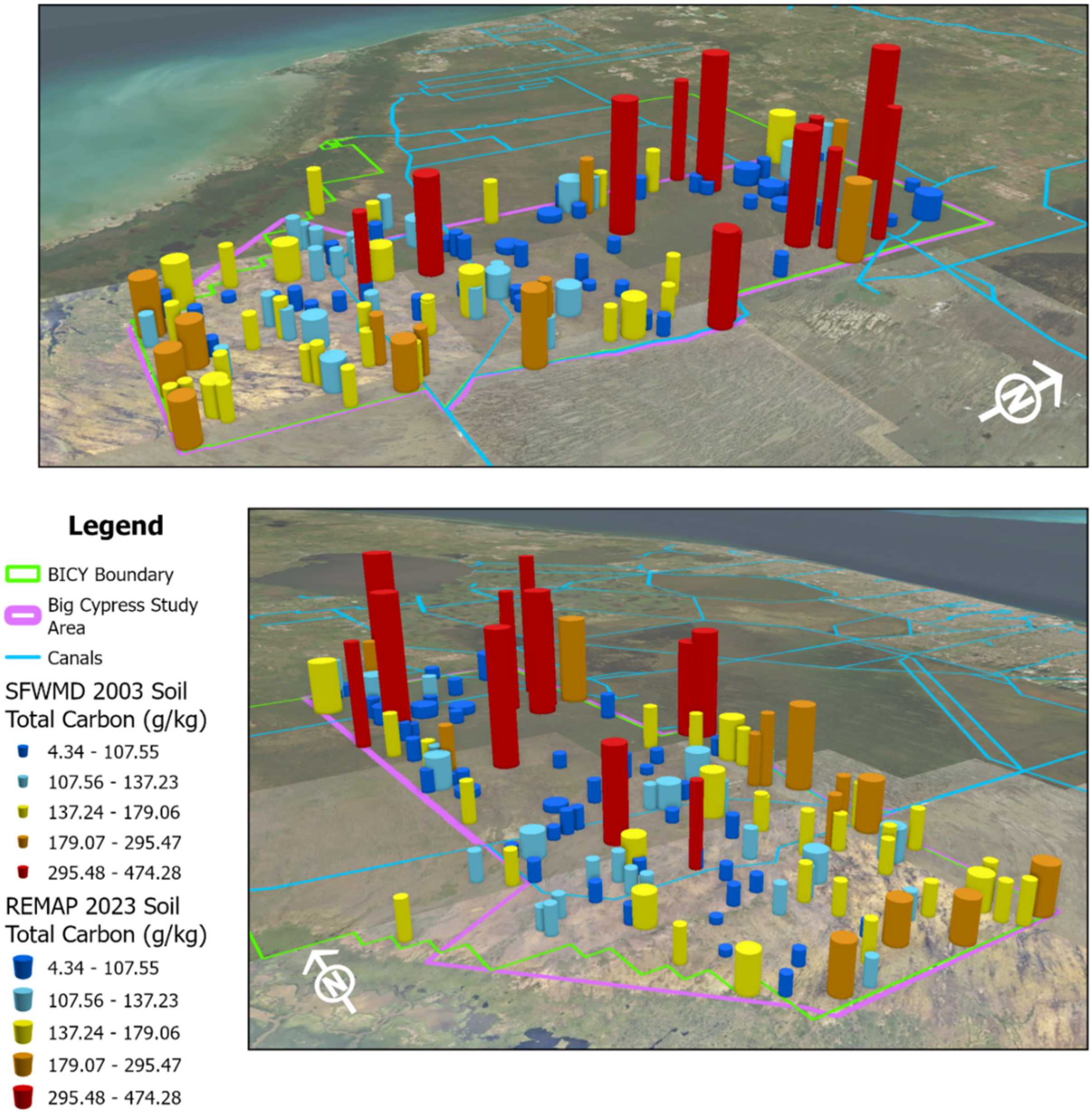


Figure Soil Carbon 4. Soil Total Carbon (g/kg) for REMAP 2023 (wider diameter columns) and SFWMD 2003 (narrower diameter columns).

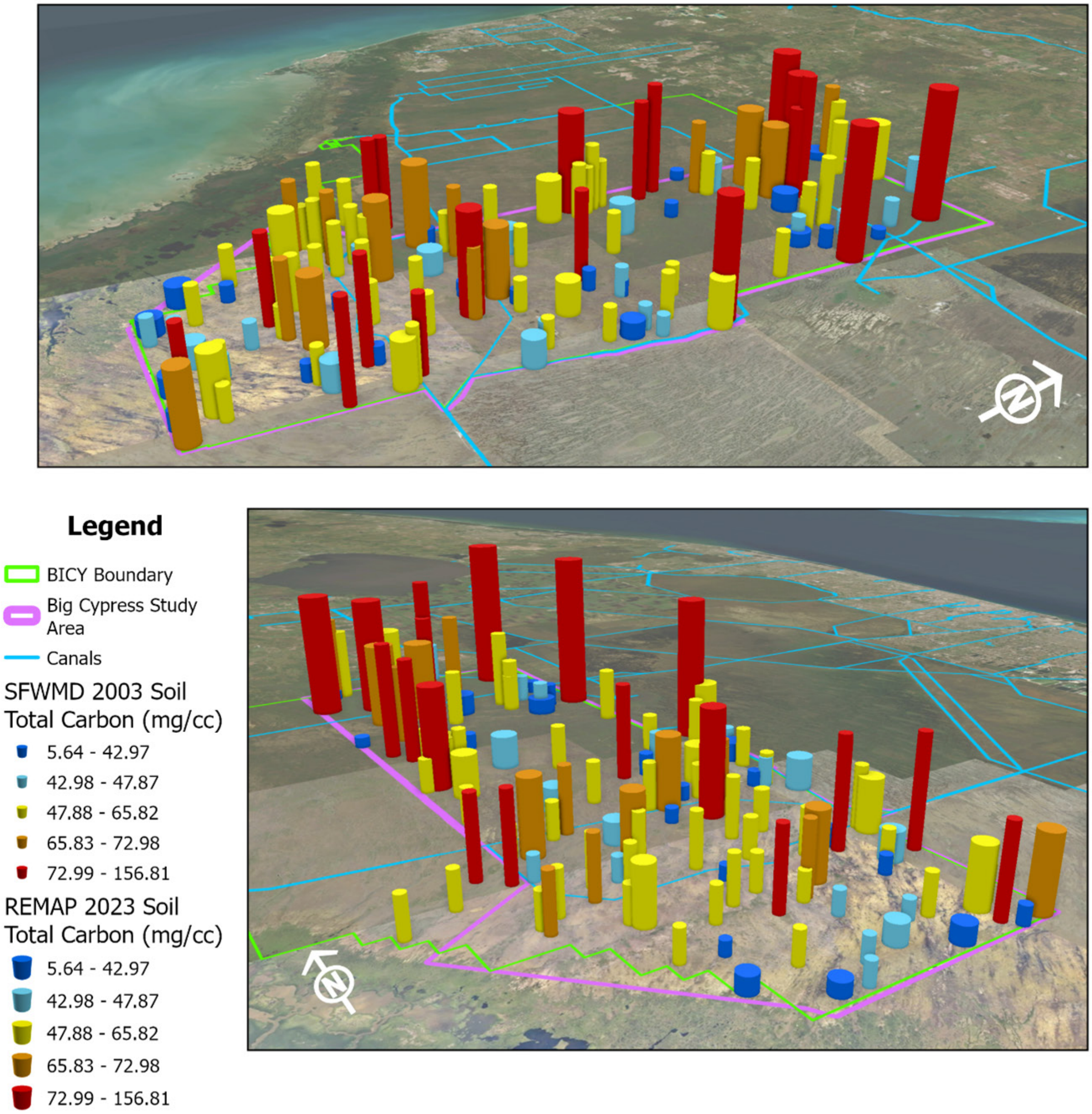


Figure Soil Carbon 5. Soil Total Carbon (mg/cc) for REMAP 2023 (wider diameter columns) and SFWMD 2003 (narrower diameter columns).

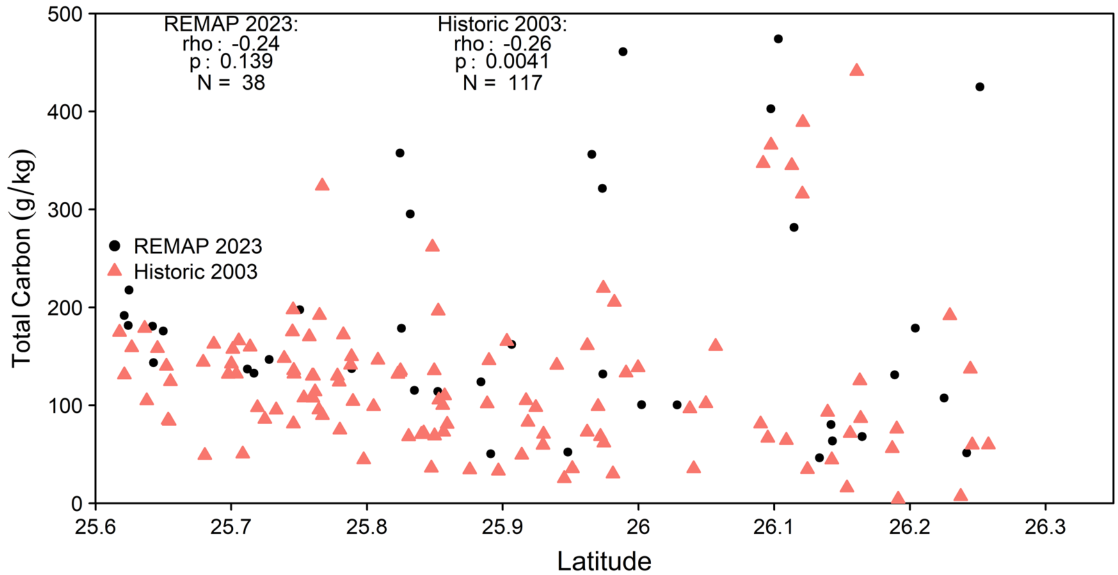


Figure Soil Carbon 6. Soil total carbon (g/kg) by latitude during the wet season. North is to the right and south is to the left.

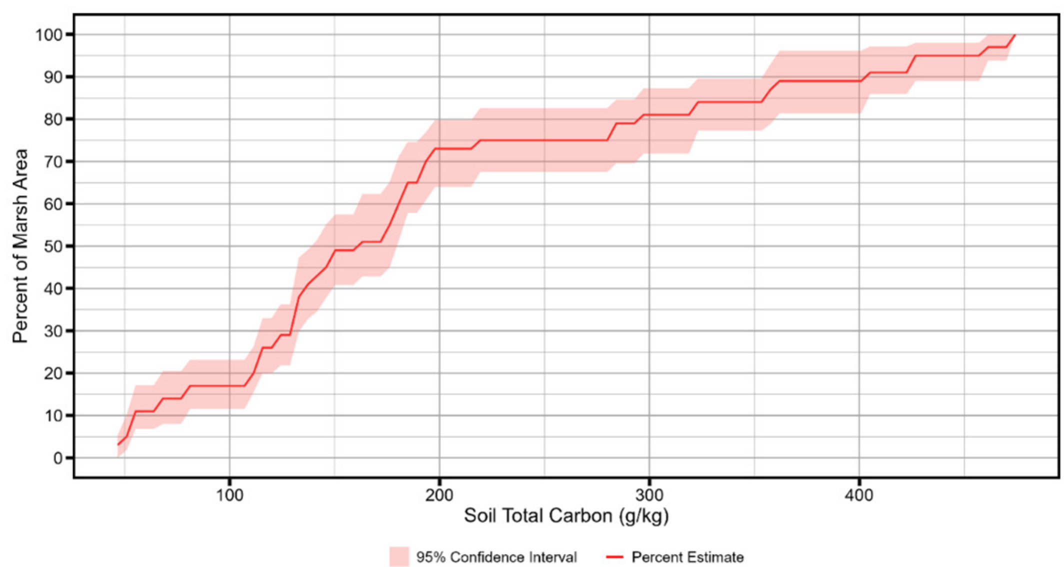


Figure Soil Carbon 7. Total carbon in soil (g/kg) estimates of sampled area.

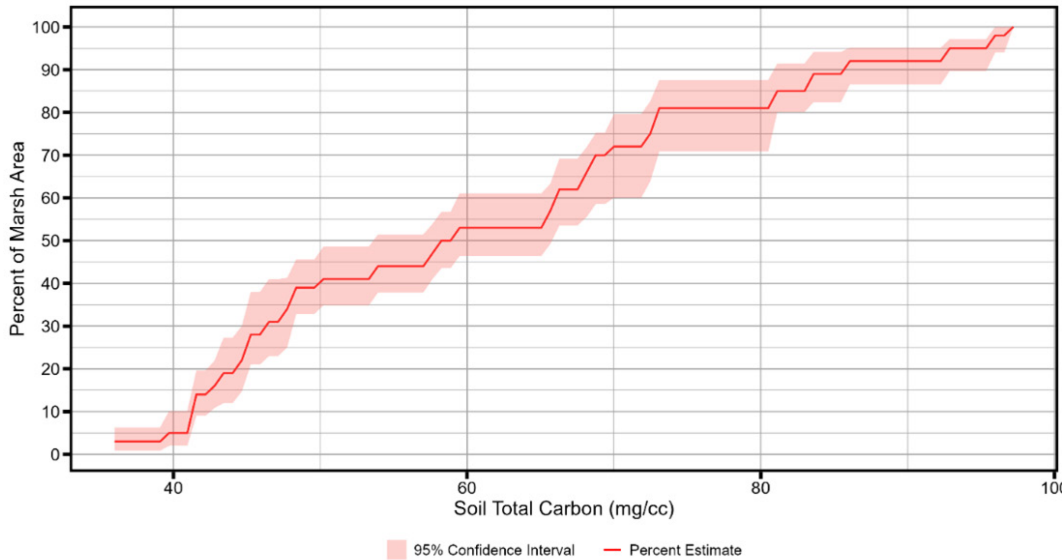


Figure Soil Carbon 8. Total carbon in soil (mg/cc) estimates of sampled area.

OVERVIEW AND FINDINGS - SOILS

pH

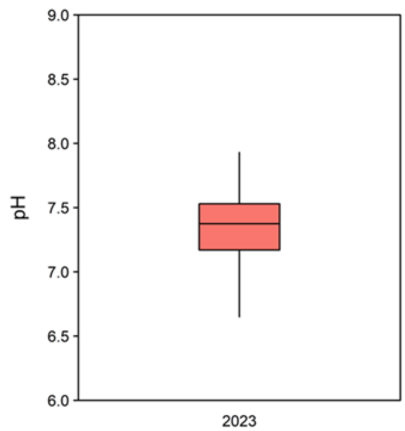


Figure Soil pH 1. 2023 REMAP soil pH (SU).

The pH of soil can influence many biogeochemical processes. REMAP 2023 soil pH values ranged from 6.65 to 7.93 standard pH units (SU), with a median of 7.35 SU (Figures Soil pH 1 and 2). There are no BCNP soil pH data from other programs for comparison. There was no latitudinal gradient ($p > 0.05$, Appendix 4). About 50% of the marsh area sampled had a pH value at or below 7.35 SU, with a 95% confidence interval of 42.3% to 60.7% (Figure Soil pH 3).

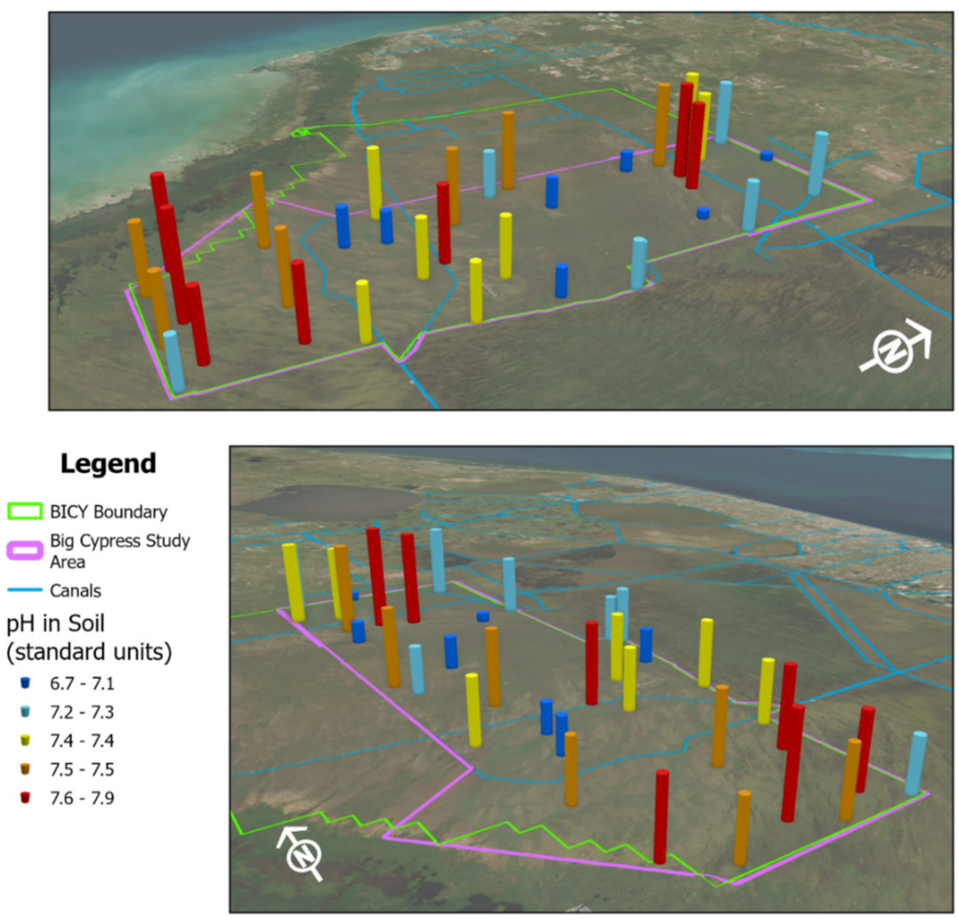


Figure Soil pH 2. 2023 REMAP soil pH (SU).

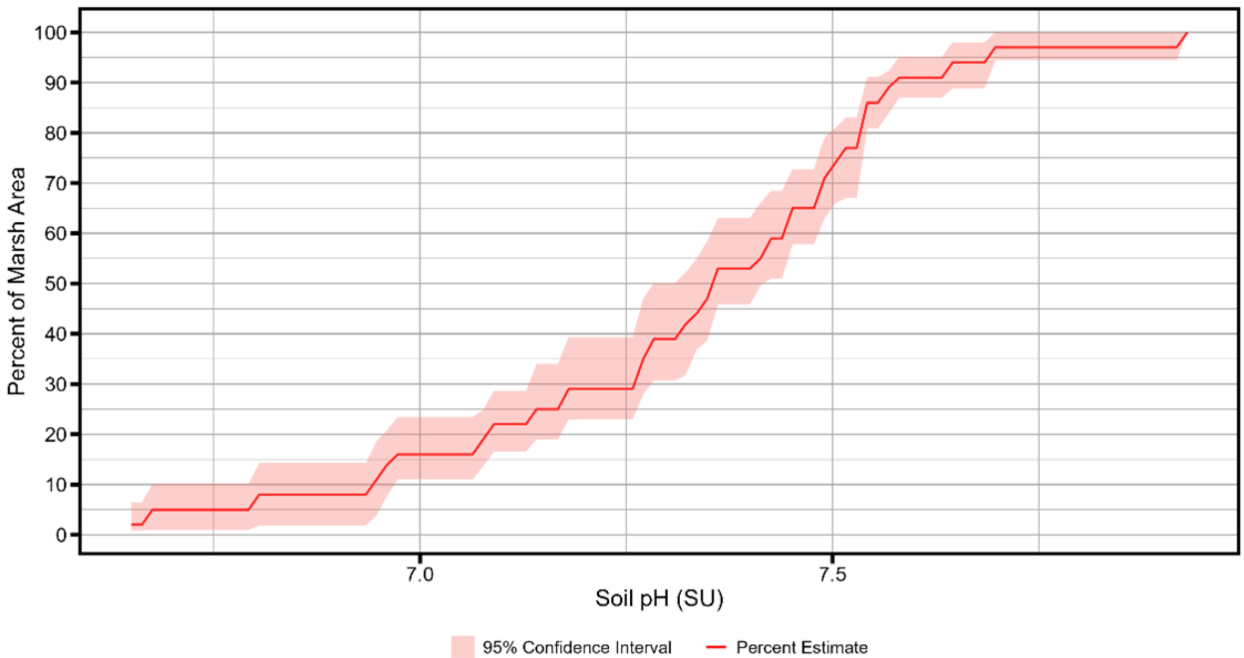


Figure Soil pH 3. Soil pH (SU) estimates of sampled area.

OVERVIEW AND FINDINGS - MERCURY

INTRODUCTION

Mercury contamination of gamefish and wildlife in the Big Cypress and Everglades region has been a management concern and focus of research and monitoring since the 1990s (Scheidt, Kalla and Surratt 2021). Mercury is a naturally-occurring element that exists in several forms: elemental (metallic), inorganic compounds, and organic compounds such as methylmercury (MeHg). As it cycles between the atmosphere, land, and water, mercury undergoes a series of complex chemical, biochemical, and physical transformations. For example, microorganisms, including bacteria and archaea, can methylate mercury, converting it to the MeHg form, which is highly toxic. Once MeHg is formed in the environment, it can rapidly bioaccumulate in organisms, leading to higher concentrations in higher trophic level organisms (Janssen 2025).

The main human exposure route for mercury is through fish and shellfish consumption. Mercury exposure at high levels can harm the brain, heart, kidneys, lungs, and immune system of people of all ages. High levels of MeHg in the bloodstream of babies developing in the womb and young children may harm their developing nervous systems, affecting their ability to think and learn. Birds and mammals that eat fish have greater exposure to MeHg than other animals in water ecosystems. Predators that eat these birds and mammals are also at risk due to bioaccumulation within media and biomagnification from water to biota. At high levels of exposure, the harmful effects of MeHg on these animals include death, reduced reproduction, slower growth and development, and abnormal behavior (USEPA 2024b).

During the early 1970s, mercury was documented in birds and gamefish in Everglades National Park and was identified as a potential ecological concern (Ogden et al. 1974). In the late 1980s, unexpectedly high levels of mercury were found in gamefish and two dead Florida panthers in the Park, and their deaths were attributed to mercury toxicosis (Roelke et al. 1991). The mercury sources were unknown. In order to protect human health, in 1989 Florida issued a consumption advisory either restricting or recommending no consumption of gamefish such as largemouth bass from Big Cypress and the Everglades (FDHRS 1989). Consumption advisories have remained in place since, with the 2025 Florida advisory recommending that women of child-bearing age and young children should not eat largemouth bass from Big Cypress National Preserve, and other individuals should limit consumption to one meal per month. All individuals should limit consumption of warmouth to one meal per month (FDOH 2025). Among 15 fish species sampled in the Everglades from 2000-2017, bowfin had the highest median concentration (0.9 mg/kg) followed by largemouth bass (median 0.6 mg/kg, Lange 2019). The existence of these advisories means that the Big Cypress waterbody does not meet the “fishable” portion of its designated use under the Clean Water Act (33 U.S.C. § 1251 (a) (2)).

Ecological risk assessments and mercury dosing studies have indicated that populations of top predators in the Everglades region could be adversely affected by mercury contamination, in that mercury bioaccumulation through the food web has the potential to reduce the health or breeding success of wading birds (Rumbold 2005, 2019c; Rumbold et al. 2001, 2008, Spalding et al. 2000, Duvall and Barron 2000, Zabala et al. 2020) and the Florida panther (Barron et al. 2004, Rumbold 2019c). Elevated mercury levels in hair, up to 67 mg/kg (ppm), were detected in Florida panthers in southern BCNP in 2004-14 (FWC, unpublished data, cited in Rumbold 2019c). A 2019 regional-scale ecological risk assessment and synthesis concluded that mercury is a risk to a variety of birds and mammals in certain South Florida sub-regions or hotspots (Rumbold 2019b).

Florida's class III surface water criterion for total mercury is 12.0 nanograms per liter (ng/L) or parts per trillion. Since 1995 REMAP has sampled 851 locations within the Everglades marsh for total mercury in surface water, and only 6 samples exceeded 12.0 ng/L. All 6 samples were collected during the dry season (1990s and 2005) at shallow marsh sites (water depths from 0.1 to 0.7 feet). REMAP data show that biomagnification and bioaccumulation of mercury to unacceptable levels in gamefish occurs even when surface water concentrations are well below the 12 ng/L criterion.

Accordingly, Florida uses fish consumption advisories based on mercury in gamefish exceeding 0.3 mg/kg (USEPA 2001b) to determine that a waterbody is impaired (is not meeting its designated use, i.e., is not fishable) (FDEP 2013). In 2013 Florida adopted a statewide mercury Total Maximum Daily Load (TMDL) to establish the allowable loadings and needed reductions of mercury into Florida's fresh and marine waters that would restore these waterbodies, so that the human health concern associated with the elevated mercury in fish tissue impairment will be addressed. The TMDL calls for an 86% reduction in mercury sources, which arrive in Florida waters predominantly by atmospheric deposition, and are from both within and outside Florida. It has been proposed that the majority of wet and dry deposition of mercury to Florida originates from long-range transport of mercury from sources outside of the United States (Vijayaraghavan and Pollman 2019). Previously, Florida's anthropogenic atmospheric mercury emissions were significantly reduced, from about 160,000 pounds per year in 1988 to 3,000 pounds in 2009, due to air pollution emission reductions required by the federal Clean Air Act and Florida's implementing rules (FDEP 2013).

The National Atmospheric Deposition Program's (NADP) Mercury Deposition Network collects mercury wet deposition data at two locations near BCNP in South Florida: one at the Everglades National Park Research Station (FL11, 19 miles southeast of the REMAP Big Cypress study area), and another in Western Broward County (FL97, 4 miles east of the study area) (Figure 6). Data at each location are reported as weekly or annual precipitation-weighted mean concentration (ng/L) and deposition (µg/m^2).

In calendar year 2023, the two mercury deposition stations collected a total of 103 weekly samples (51 at FL97 and 52 at FL11). During the REMAP sample collection timeframe, mercury deposition data were collected once at FL97 for the week of October 10-17, 2023, with a Total Mercury (THg) concentration of 12.59 ng/L and a mercury deposition of 108.73 µg/m^2. Deposition data were collected at FL11 twice during the same sampling period. Concentrations were 9.83 and 12.21 ng/L, with a mean of 11.02 ng/L. Mercury deposition data at FL11 were 12.41 and 204.74 µg/m^2, with a mean deposition rate of 108.58 µg/m^2. On a precipitation-weighted annual basis, 2023 mercury deposition at FL97 was 14.06 ng/L with a deposition rate of 19.29 µg/m^2. At FL11 the mercury deposition was 13.26 ng/L with a deposition rate of 22.96 µg/m^2. These mercury deposition concentrations are roughly an order of magnitude higher than the surface water THg concentrations observed at the 35 Big Cypress REMAP stations (median 1.30 ng/L). During 2023 these two South Florida sites had the highest mercury deposition rates out of 76 stations in the United States (NADP 2023).

SURFACE WATER

REMAP 2023 surface water THg ranged from 0.48 ng/L to 5.70 ng/L, with a median of 1.30 ng/L (n = 35, Figures Mercury 1 and 2). These data did not have a latitudinal gradient (p = 0.55, Dunn's test, Appendix 4). About 50% of the marsh area had a surface water THg concentration at or below 1.30 ng/L, with a 95% confidence interval of 42.7% to 62.6% (Figure Mercury 3).

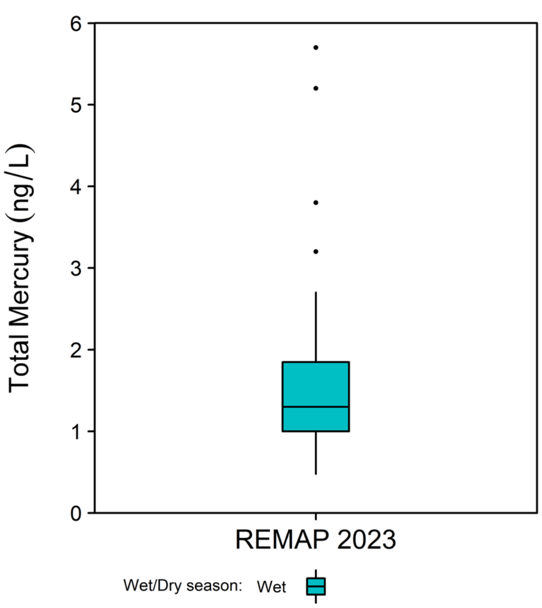


Figure Mercury 1. Surface water total mercury (ng/L).

USEPA has concluded that in order to protect human health it is more appropriate to have a water quality criterion for methymercury (MeHg) based on fish tissue concentrations, rather than on water concentrations. The MeHg water quality criterion USEPA recommended in 2001 was a fish tissue residue criterion of less than 300 micrograms per kilogram (µg/kg, or parts per billion), or 0.3 mg/kg (USEPA 2001b). Florida issues fish consumption advisories to protect human health based on mercury in gamefish exceeding 0.3 mg/kg (FDEP 2013).

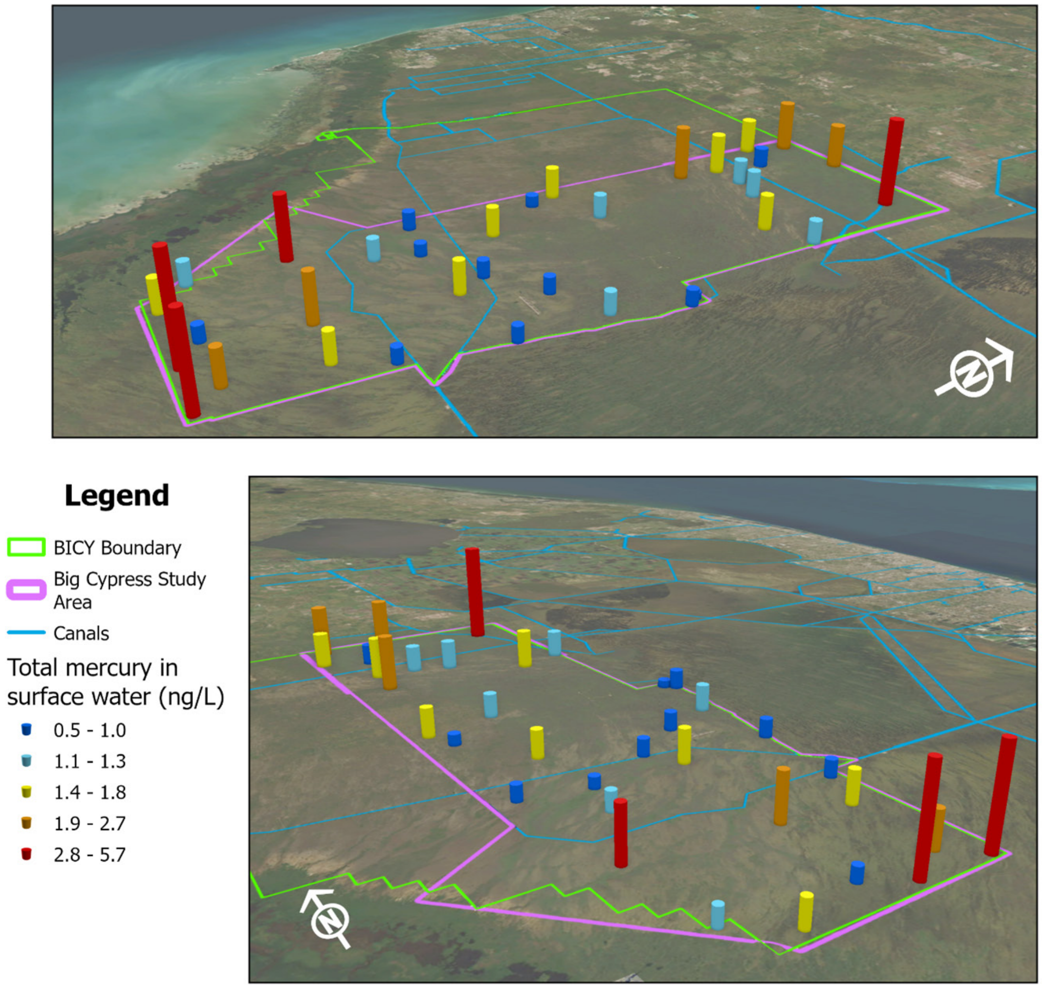


Figure Mercury 2. REMAP 2023 surface water total mercury (ng/L).

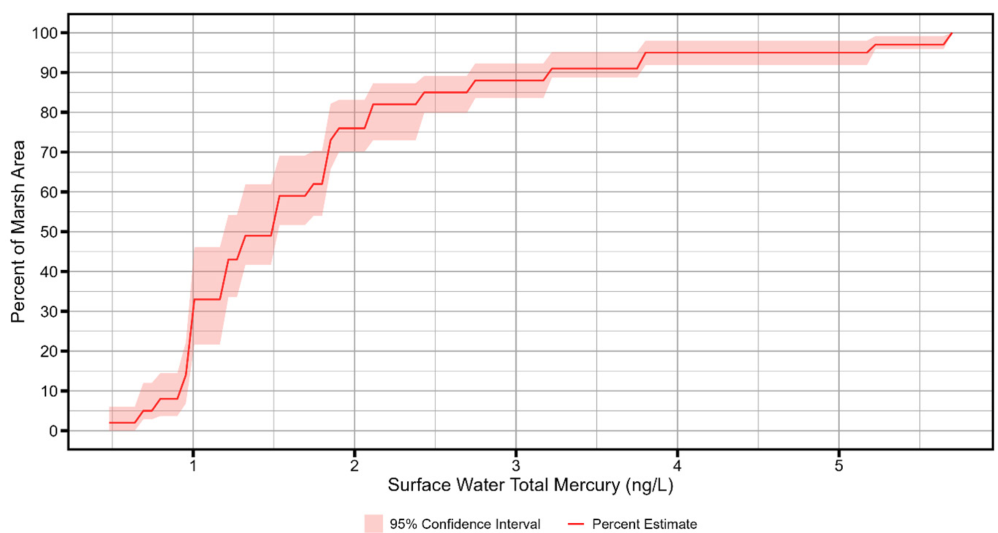


Figure Mercury 3. Surface water total mercury (ng/L) estimates of sampled area.

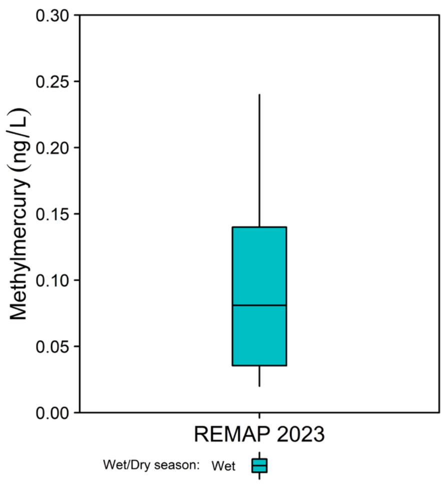


Figure Mercury 4. Surface water methylmercury (ng/L).

REMAP 2023 surface water MeHg ranged from 0.02 ng/L to 0.24 ng/L, with a median of 0.08 ng/L (n = 35, Figures Mercury 4 and 5). These data did not have a latitudinal gradient (p = 0.63, Dunn's test, Appendix 4). About 50% of the marsh area sampled had a surface water MeHg concentration at or below 0.08 ng/L, with a 95% confidence interval of 39.5% to 60.7% (Figure Mercury 6).

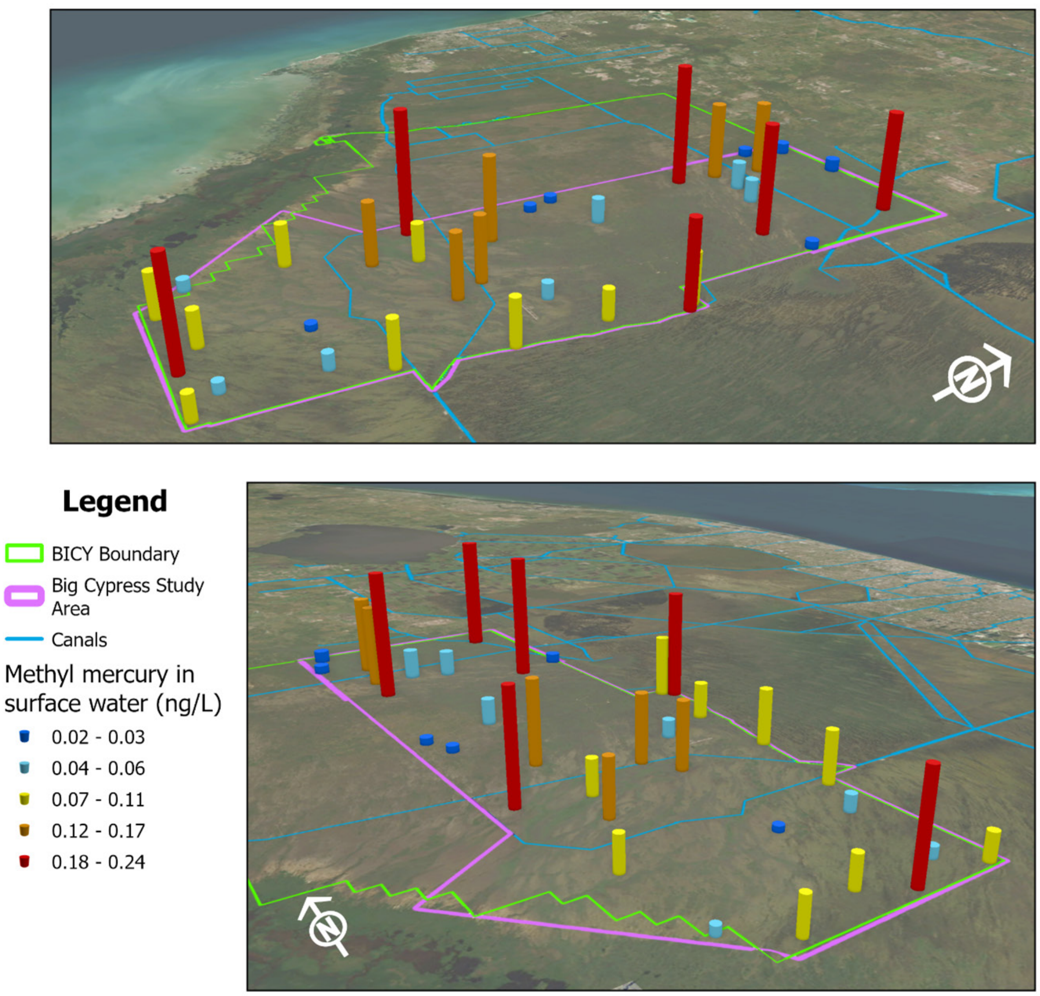


Figure Mercury 5. Surface water methylmercury (ng/L).

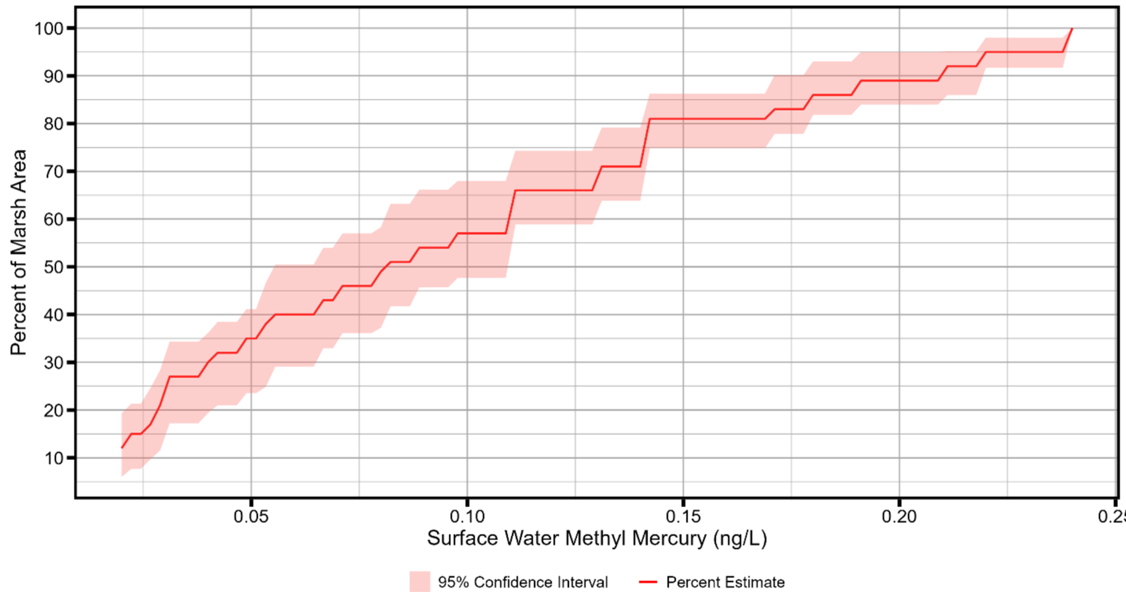


Figure Mercury 6. Surface water methylmercury (ng/L) estimates of sampled area.

TOTAL MERCURY IN SOIL

REMAP 2023 soil THg concentrations expressed per mass ranged from 11.6 to 265.5 ng/g, with a median of 59.00 ng/g. REMAP 2023 THg concentrations were higher ($p < 0.05$; Dunn's test) than 1995-96 concentrations (Figures Mercury 7 and 8). For the wet season, there was no latitudianl gradient in REMAP data ($p = 0.24$, rho = -0.19), while REMAP 1995-96 data had a significant, but weak, ($p < 0.05$, rho = -0.29) latitudinal gradient with lower concentrations to the north (Figure Mercury 10). About 50% of the marsh area sampled had a soil THg concentration at or below 57.80 ng/g, with a 95% confidence interval of 43.1% to 56.3% (Figure Mercury 11).

On a concentration per volume (ng/cc) basis, THg in soil ranged from 6.4 to 69.9 ng/cc, with a median concentration of 21.00 ng/cc (Figures Mercury 7 and 9). REMAP 2023 THg concentrations were higher ($p < 0.05$; Dunn's test) than 1995-96 concentrations (Figure Mercury 7). The data showed no significant latitudinal gradient for the 2023 observations ($p = 0.97$, Appendix 4). About 50% of the marsh area sampled had a soil THg concentration at or below 21.00 ng/cc, with a 95% confidence interval of 42.9% to 56.9% (Figure Mercury 12).

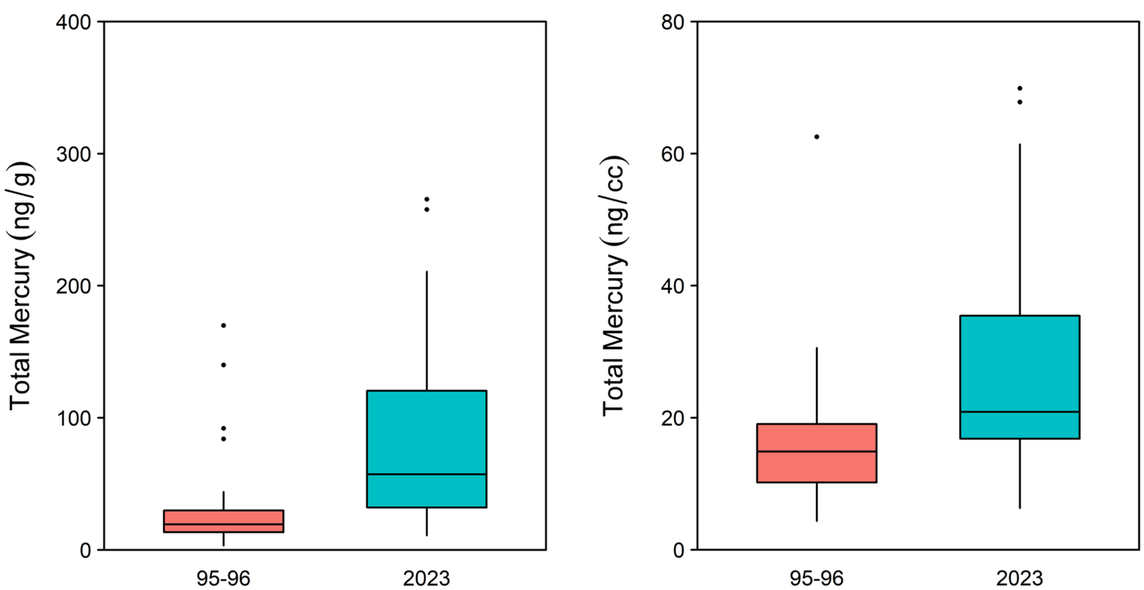


Figure Mercury 7. Wet season total mercury in soil per mass (ng/g, left) and per volume (ng/cc, right).

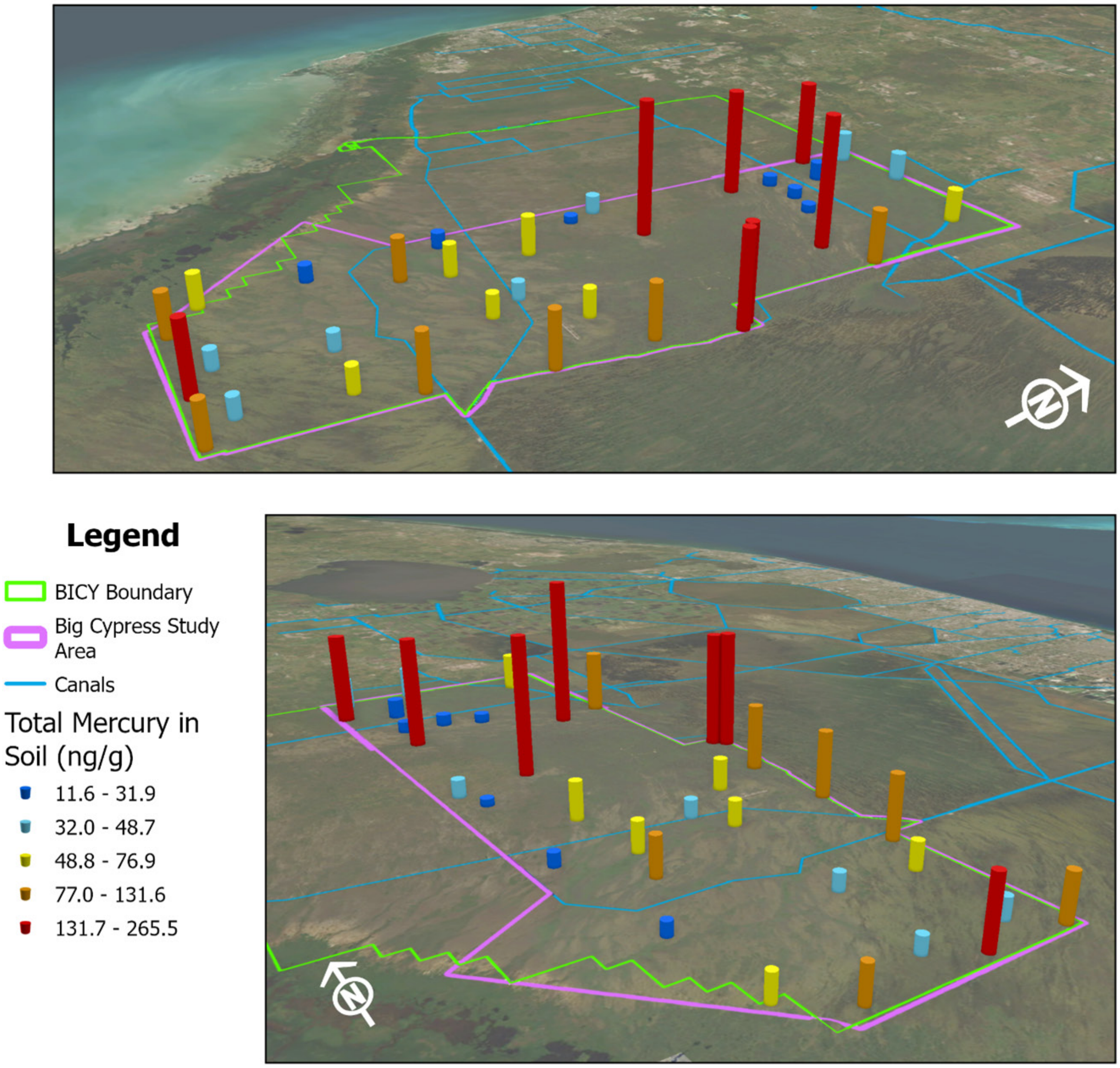


Figure Mercury 8. REMAP 2023 total mercury in soil per mass (ng/g).

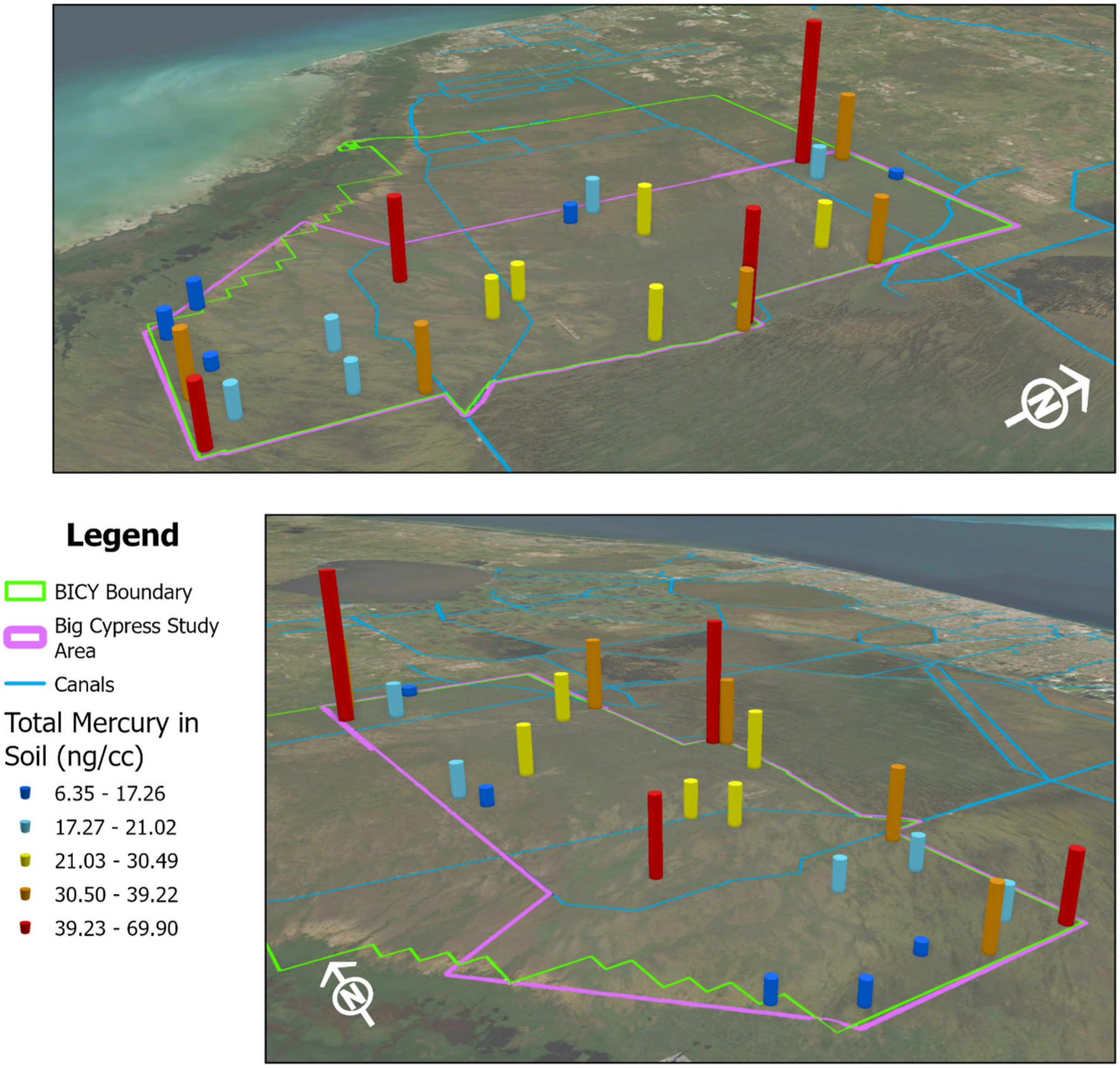


Figure Mercury 9. REMAP 2023 total mercury in soil per volume (ng/cc).

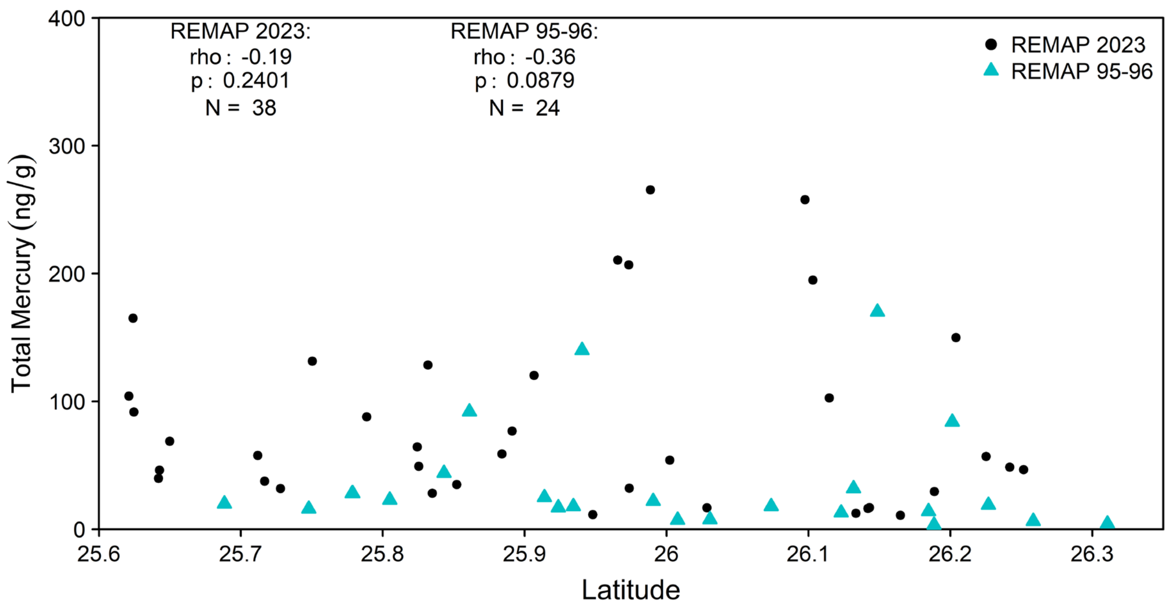


Figure Mercury 10. Wet season total mercury in soil (ng/g) by latitude. North is to the right and south is to the left.

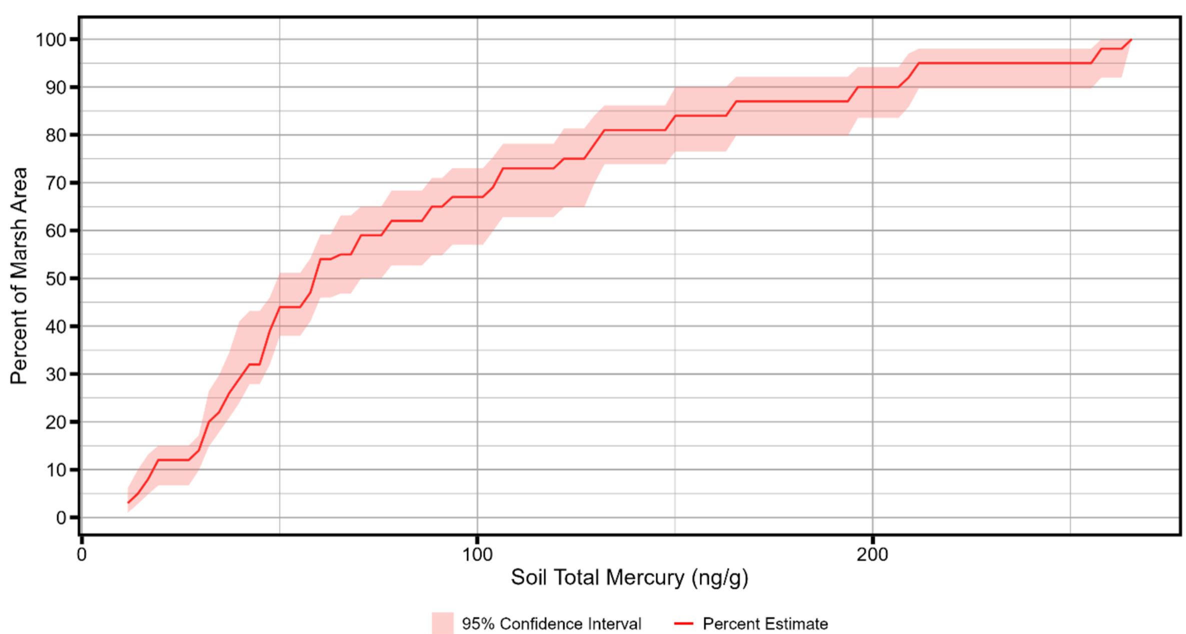


Figure Mercury 11. Total mercury in soil per mass (ng/g) estimates of sampled area.

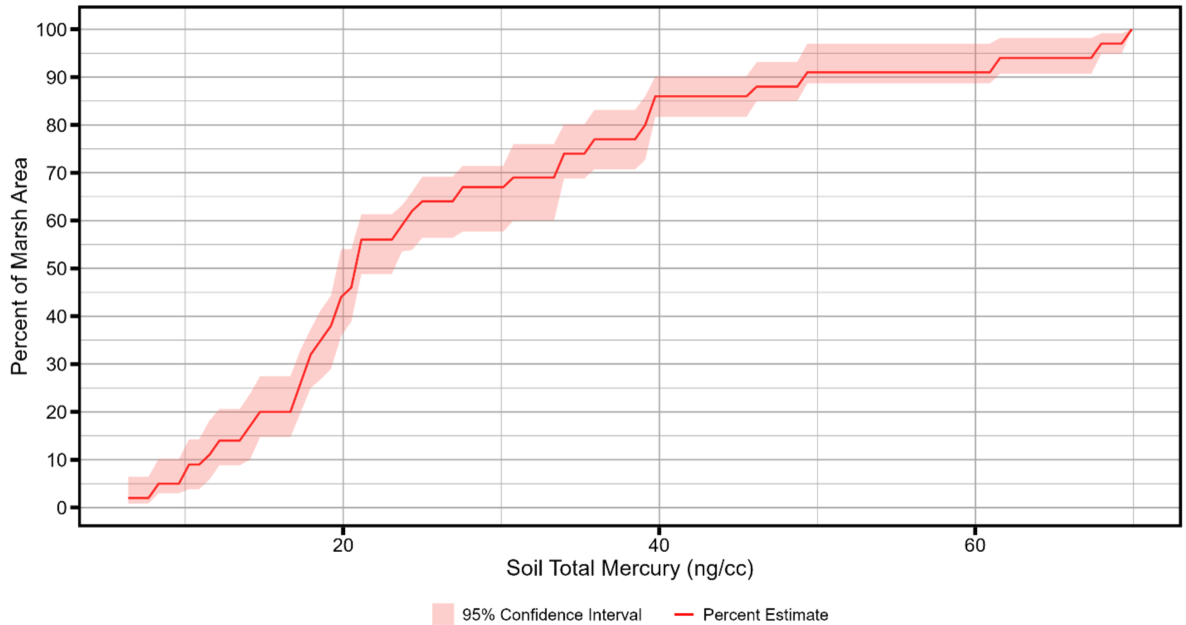


Figure Mercury 12. Soil total mercury per volume (ng/cc) estimates of sampled area.

METHYLMERCURY IN SOIL

REMAP 2023 soil MeHg concentrations expressed per mass ranged from 0.09 to 3.57 ng/g, with a median of 0.42 ng/g. REMAP 2023 MeHg concentrations were higher ($p < 0.05$; Dunn's test) than 1995-96 concentrations (Figures Mercury 13 and 14). The 2023 data showed a non-significant latitudinal relationship ($p = 0.28$, rho = -0.18), while the 1995-96 data had a significant but weak ($p < 0.05$, rho = -0.29) latitudinal gradient with higher MeHg to the south (Figure Mercury 16). About 50% of the marsh area sampled had a soil MeHg concentration at or below 0.40 ng/g, with a 95% confidence interval of 40.2% to 56.1% (Figure Mercury 17). Florida uses an action level for MeHg in soils/sediments to ensure that there are no negative impacts of a restoration project on downstream water quality (SFWMD and FDEP 2025). Concentrations should be below 0.673 ng/g, the 75th percentile for all South Florida basins (n = 214, 107 wetland sites, 1999-2023).

REMAP 2023 soil MeHg concentrations expressed per volume ranged from 0.04 to 1.66 ng/cc, with a median of 0.16 ng/cc. REMAP 2023 MeHg concentrations were higher ($p < 0.05$; Dunn's test) than 1995-96 concentrations (Figures Mercury 13 and 15). There was no significant latitudinal gradient in the REMAP 2023 data (Appendix 4). About 50% of the marsh area sampled had a soil MeHg concentration at or below 0.16 ng/cc, with a 95% confidence interval of 41.9% to 61.4% (Figure Mercury 18).

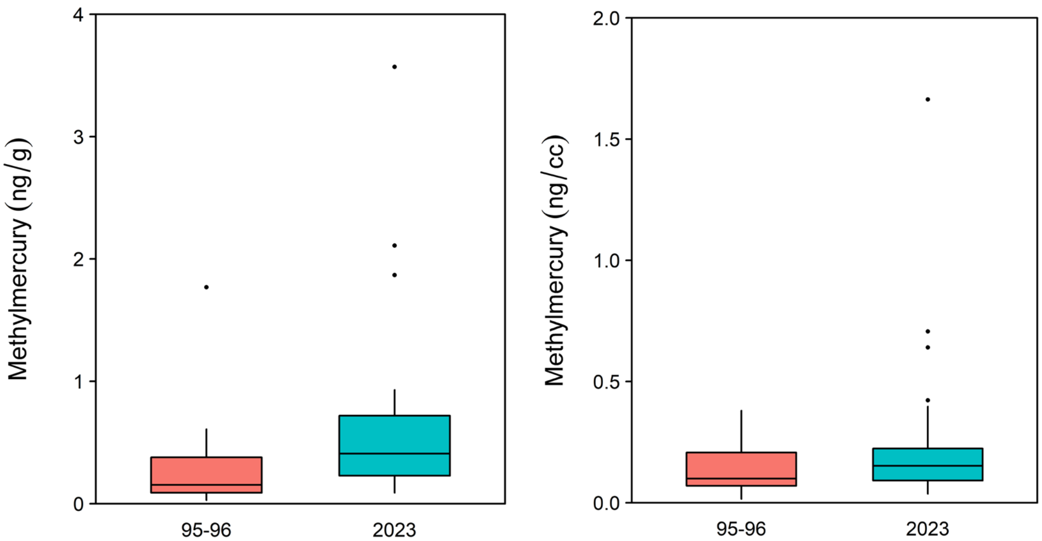


Figure Mercury 13. Methylmercury in soil per mass (ng/g, left) and per volume (ng/cc, right).

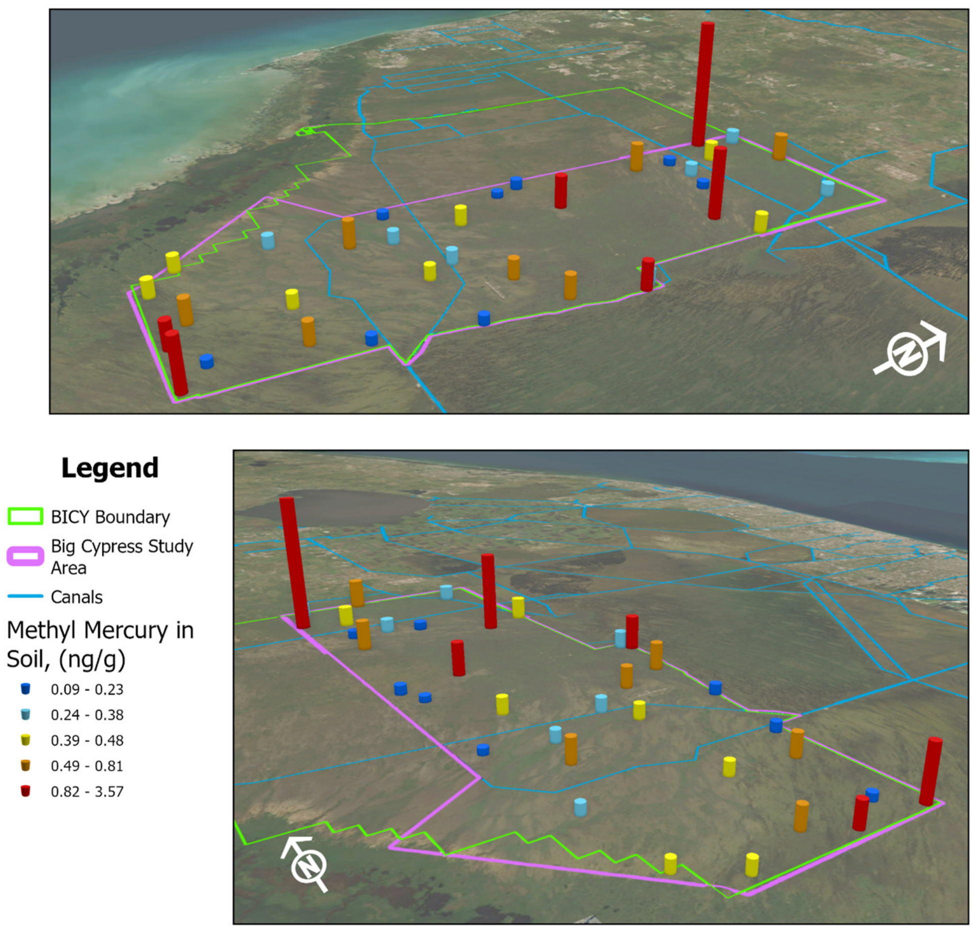


Figure Mercury 14. REMAP 2023 methylmercury in soil per mass (ng/g).

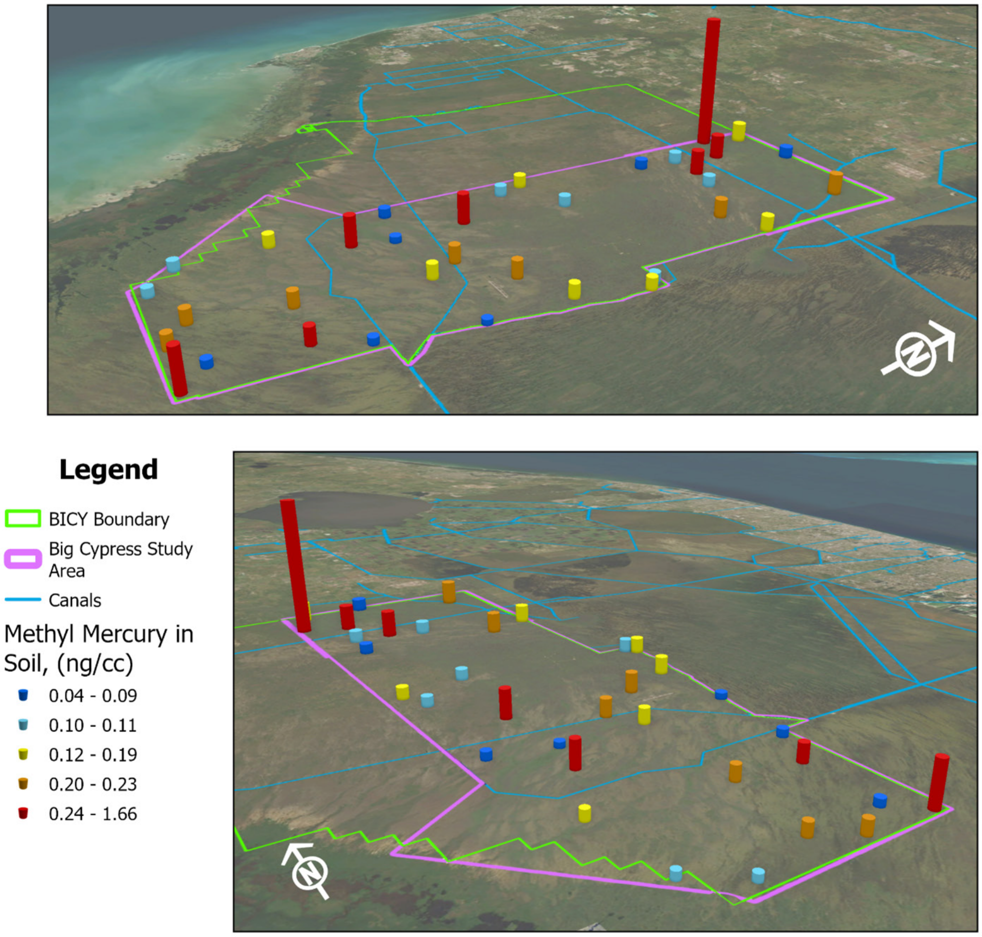


Figure Mercury 15. REMAP 2023 methylmercury in soil per volume (ng/cc).

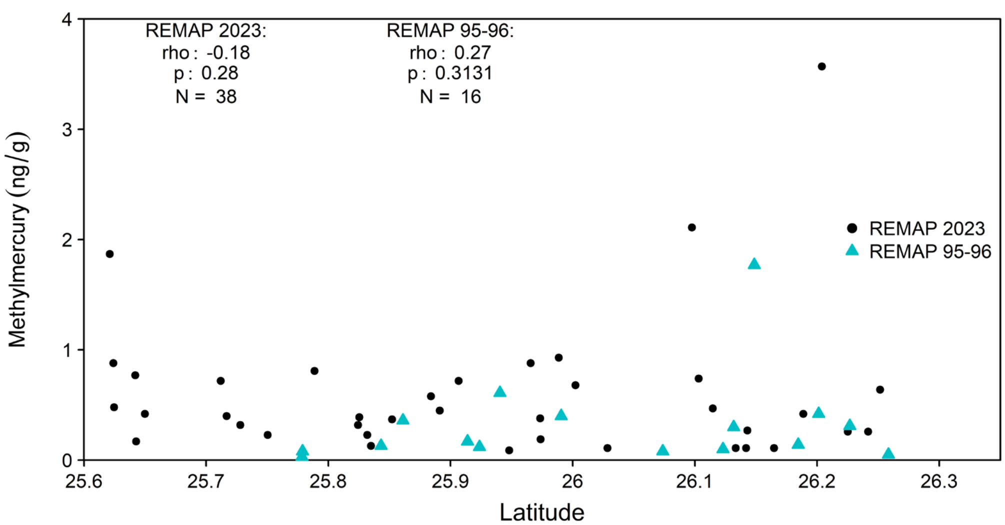


Figure Mercury 16. Wet seaon soil MeHg (ng/g) by latitude.
North is to the right and south is to the left.

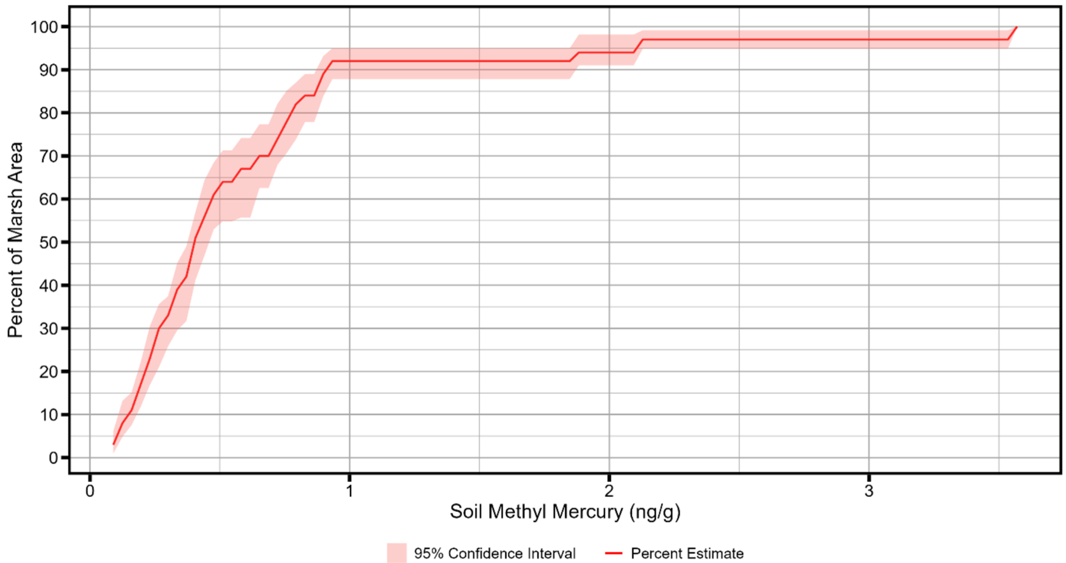


Figure Mercury 17. Methylmercury in soil per mass (ng/g) estimates of sampled area.

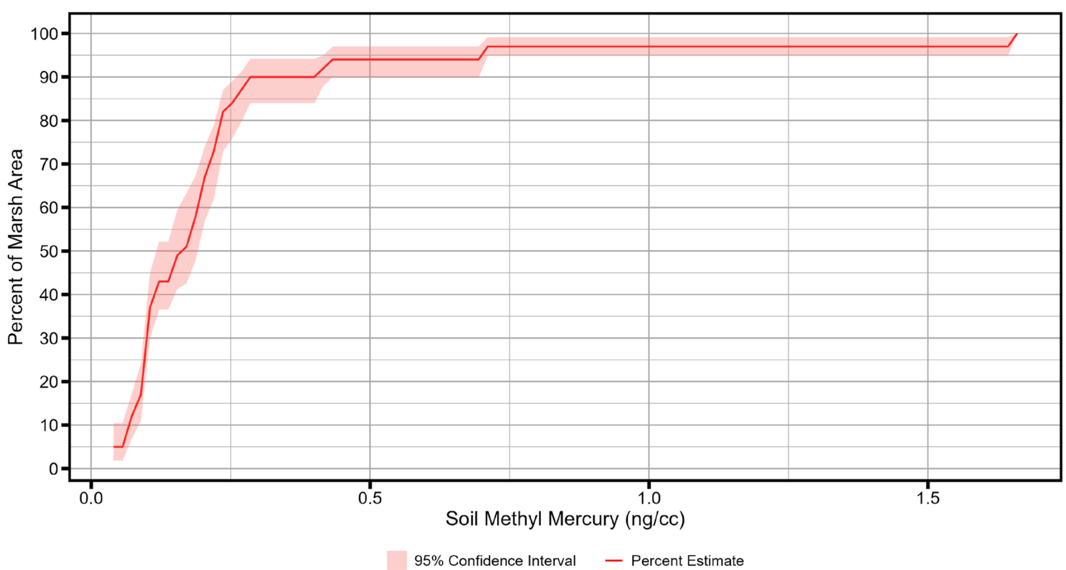


Figure Mercury 18. Methylmercury in soil per volume (ng/cc) estimates of sampled area.

FISH

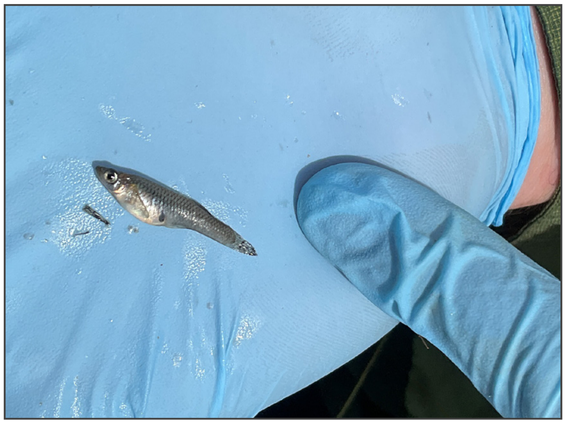
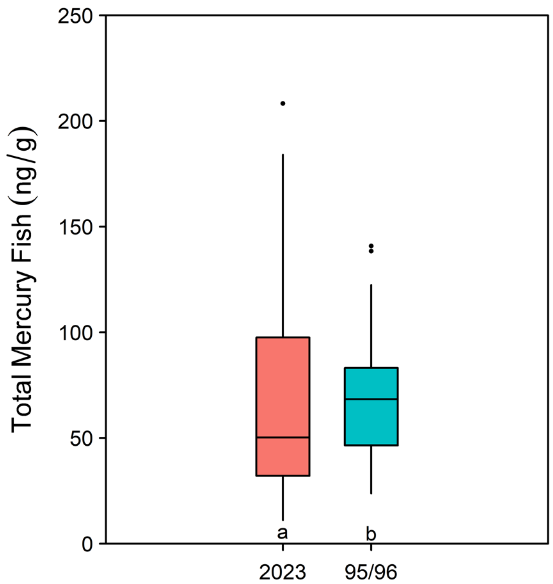


Photo 15. Mosquitofish are an ideal indicator of mercury contamination.

Mosquitofish (Photo 15) are a small preyfish (maximum length 1.5 inches, n = 1841, Everglades REMAP 2005 and 2014) that have been sampled by REMAP since the 1990s. They are an ideal indicator of mercury contamination because of several characteristics. Mosquitofish are the most abundant fish in Big Cypress and the Everglades and are found throughout the canals and in all marsh habitats. Across the five REMAP wet season sampling events, mosquitofish were collected at 94% of the 532 Everglades marsh sites, including wet prairie, sawgrass and cattail habitats. They are easily sampled and can integrate or incorporate mercury exposure over a short time frame in a discrete area because of their lifespan of months and small home range. In addition, they are a prey fish in the food web for gamefish and wading birds, so they can provide insights for both human and ecological health.

Everglades mosquitofish are a secondary consumer reported to be at trophic level 2.0 to 3.0 (Loftus et al. 1998) and 4.0 to 4.5 (Williams and Trexler 2006). They consume animal prey (crustaceans, insects, arachnids), algae, detritus and plant matter (Loftus et al. 1998). USEPA has recommended a mercury concentration of 77 ng/g at trophic level 3 for protection of birds and mammals (USEPA 1997), while the USFWS has recommended a level of 100 ng/g in prey fish in order to protect top predators such as wading birds (Eisler 1987).

REMAP 2023 mosquitofish THg ranged from 11.2 ng/g to 208.3 ng/g (wet weight), with a median of 50.25 ng/g (n = 24, Figure Mercury 19). The REMAP 1995-96 and 2023 data were comparable (Dunn's test $p > 0.05$), and these data did not have latitudinal gradients (p= 0.66 and 0.056, Appendix 4). Six of 24 stations had a concentration that exceeded the 100 ng/g protection level to protect top predators, while nine stations exceeded the 77 ng/g level (Figure Mercury 20). About 36.1% of the marsh area sampled had a fish total mercury concentration above 77 ng/g, with a 95% confidence interval of 25.2% to 45.4%. About 24.0% of the marsh area sampled had a fish total mercury concentration above 100 ng/g, with a 95% confidence interval of 16.6% to 34.4% (Figure Mercury 21). Florida uses an action level for THg in mosquitofish to ensure that there are no negative impacts of a restoration project on downstream water quality (SFWMD and FDEP 2025). Concentrations should be below 39 ng/g, the 75th percentile for all South Florida basins (n = 2191, 140 wetland sites, 1998-2023).



Group	Letter	N	Significantly Different
REMAP 95-96 Wet	b	21	
REMAP 2023 Wet	a	36	

Figure Mercury 19. Mosquitofish total mercury (ng/g) comparisons across REMAP sampling events.

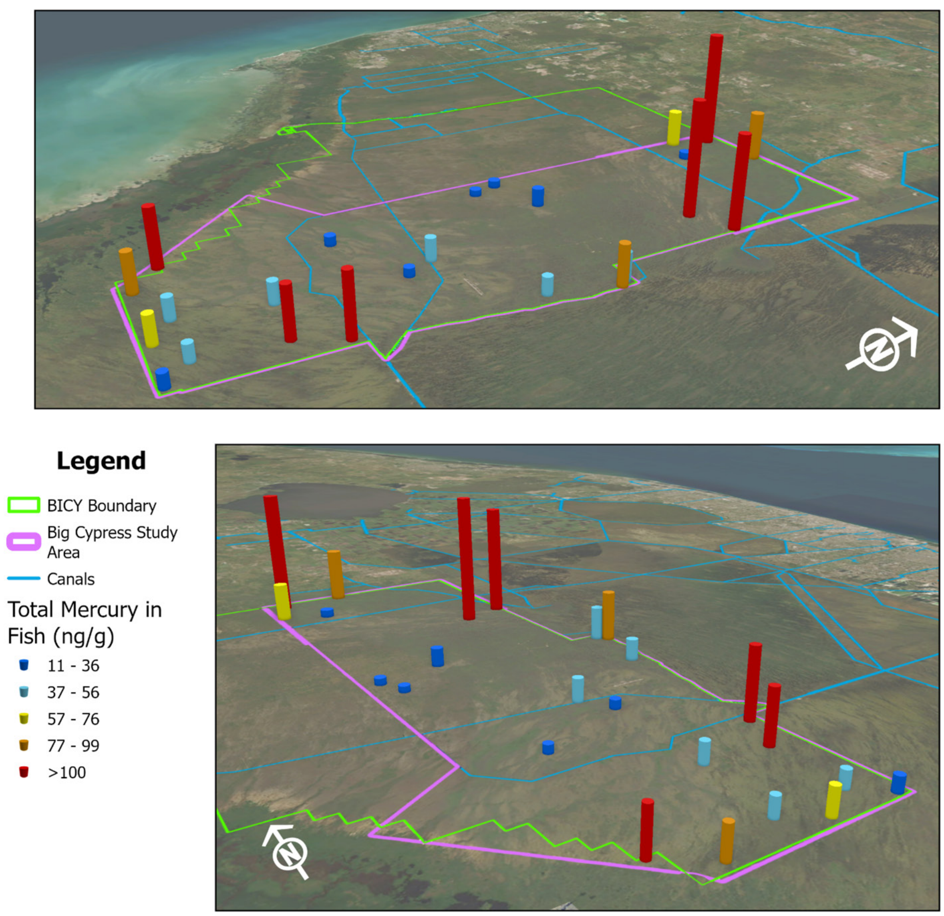


Figure Mercury 20. REMAP 2023 mosquitofish total mercury (ng/g).

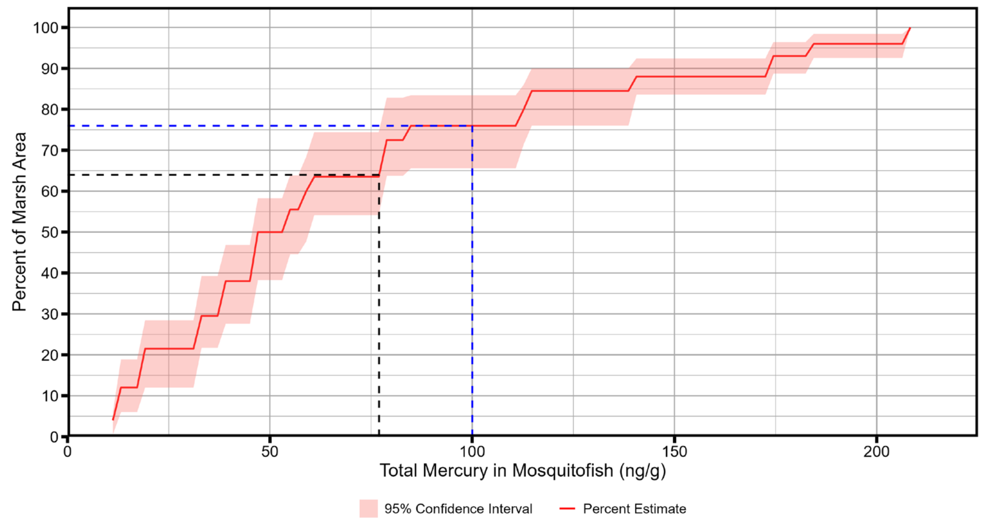
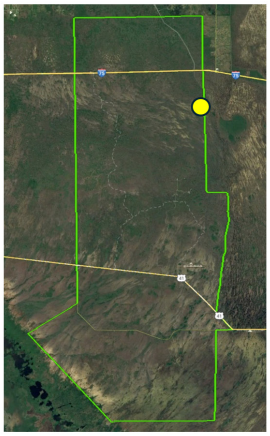


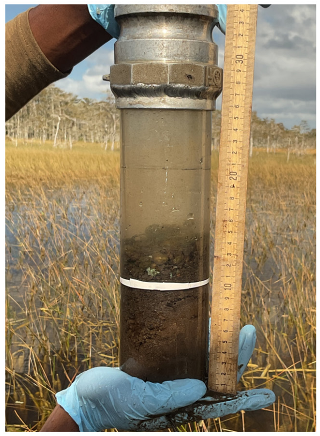
Figure Mercury 21. Mosquitofish total mercury (ng/g) estimates of sampled area. The black line indicates the USEPA 77 ng/g concentration to protect birds and mammals, and the blue line indicates the 100 ng/g USFWS concentration to protect predators.

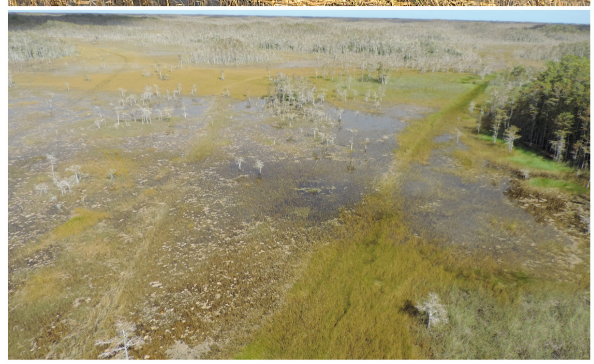
Mercury undergoes a myriad of transformations in surface waters, such as methylation which allows for rapid food web bioaccumulation. Mercury methylation is driven by a complex set of geochemical, biological, and physical factors (Janssen et al. 2022). The roles of sulfate and DOM are discussed in the sulafte section. The bioconcentration factor is the ratio of the substance in an organism to the concentration in the surrounding water. Biomagnification is an increase in concentration in animal tissues in successive members of a food chain (Rumbold 2019b). REMAP data indicate high mercury biomagnification and bioconcentration. October 2023 median concentrations for total mercury were: surface water, 1.3 parts per trillion (ppt, ng/L); water column periphyton, 27.06 part per billion (ppb, µg/kg); benthic periphyton, 43.55 ppb (µg/kg); mosquitofish, 50.25 ppb (µg/kg); floc, 75.1 ppb (µg/kg); and soil 59.00 ppb (Appendix 2). Everglades largemouth bass THg concentrations are about 1 part per million (mg/kg, Lange 2019), about 1 million times water concentrations. MeHg concentrations were: surface water 0.08 parts per trillion, water column periphyton 1.35 ppb; benthic periphyton 1.25 ppb; floc 1.5 ppb; and soil, 0.42 ppb. BCNP bioconcentration factors were calculated as the concentration of mercury in mosquitofish divided by the concentration of MeHg in surface water (BCFm). The median BCFm was 607,000. This is higher than previous Everglades REMAP data medians: 340,000 in 2014 and 410,000 in 2005 (Scheidt et al 2021).

Nonparametric Spearman rank correlations were calculated for media and analytes that could influence mercury concentrations in mosquitofish (Appendix 5). The number of samples varied from 10 to 38 depending upon media and analyte. Water depth had the highest rho value (rho = 0.68), which was moderate. The influence of water depth on fish mercury could be explained by the shallow marsh, the dryout expected throughout much of the marsh, and short lifespans. Everglades REMAP data from 2014 also showed that there was no parameter versus mosquitofish mercury with a rho > 0.7 (count up to 190, Kalla and Scheidt 2017). The same was true of 2005 Everglades data (count up to 119, Scheidt and Kalla, 2007).

SELECTED SITE CONDITIONS

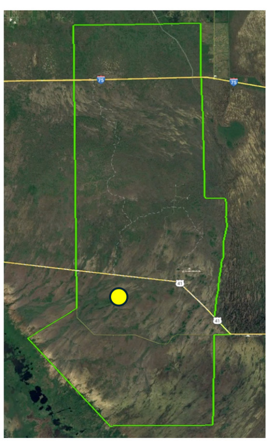






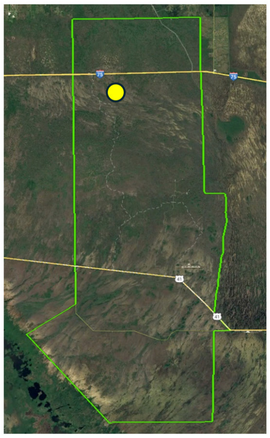
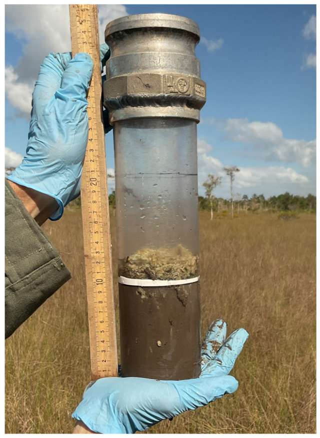
Site 2005

- Soil thickness: 1.9 ft
- Bulk Density: 0.345 g/cc
- Organic Matter: 248.3 g/kg
- Water Depth: 1.7 ft



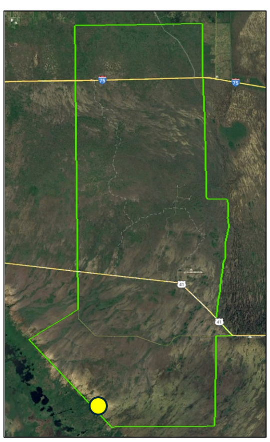
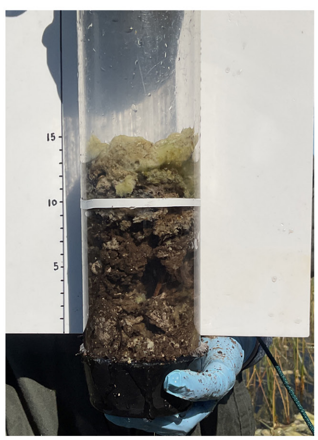
Site 2016

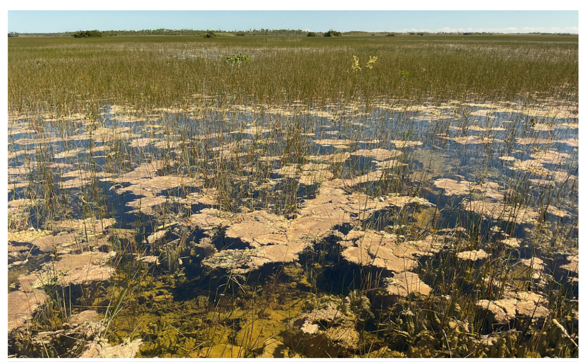
- Soil thickness: 3.4 ft
- Bulk Density: 0.124 g/cc
- Organic Matter: 650.4 g/kg
- Water Depth: 3.0 ft

Site 2029

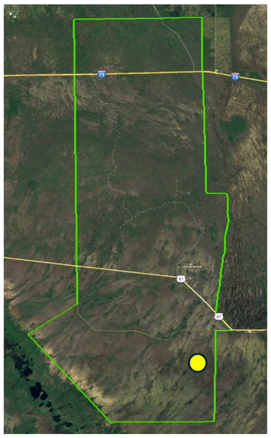
- Soil thickness: 1.2 ft
- Bulk Density: 1.036 g/cc
- Organic Matter: 57.3 g/kg
- Water Depth: 0.3 ft



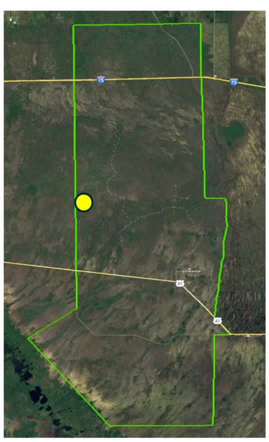

Site 2030

- Soil thickness: 1.4 ft
- Bulk Density: 0.244 g/cc
- Organic Matter: 245.7 g/kg
- Water Depth: 1.7 ft




Site 2040

- Soil thickness: 0.8 ft
- Bulk Density: 0.348 g/cc
- Organic Matter: 198.8 g/kg
- Water Depth: 1.4 ft




Site 2041

- Soil thickness: 0.6 ft
- Bulk Density: 0.612 g/cc
- Organic Matter: 98.1 g/kg
- Water Depth: 0.1 ft

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APPENDICES

APPENDIX 1. Measurements and Analytes by Media.

SURFACE WATER (SW)
Depth
Temperature
Dissolved Oxygen
pH
Conductivity (COND)
Turbidity
Total Phosphorus (TP)
Soluble Reactive Phosphorus
Alkaline Phosphatase Activity
Total Nitrogen (TN)
Total Inorganic Nitrogen (TIN)
Total Organic Nitrogen (TON)
Filtered Ammonia (FNH4)
Filtered Nitrate (FNO3)
Filtered Nitrite (FNO2)
Filtered Nitrate-Nitrite (FNN)
Dissolved Organic Carbon (DOC)
Total Organic Carbon (TOC)
Chlorophyll a (CHLA)
Sulfate (SO4)
Chloride (CL)
Methylmercury (MeHg)
Total Mercury (THg)

BOTTOM WATER (BW)
Sulfide (H_2S)

SOIL (SD)
Type
Thickness
Ash Free Dry Matter (AFDM)
Bulk Density (BD)
Water Content
pH
Total Carbon (TC)
Total Nitrogen (TN)
Total Phosphorus (TP)
Total Mercury (THg)
Methylmercury (MeHg)

FLOC (FC)
Thickness
Ash Free Dry Weight
Bulk Density
Water Content
Total Carbon (TC)
Total Nitrogen (TN)
Total Phosphorus (TP)
Total Mercury (THg)
Methylmercury (MeHg)
Chlorophyll *a*

PERIPHYTON [PB (benthic); PC = PF (floating) + PE (Epiphytic)]
Ash Free Dry Weight
Bulk Density
Total Carbon
Total Nitrogen
Total Phosphorus
Methylmercury (MeHg)
Total Mercury (THg)
Chlorophyll *a*

VEGETATION
Sawgrass Plant Total Mercury (THg)
Sawgrass Plant Methyl Mercury (THg)
Sawgrass Leaf Total Phosphorus (TP)
Sawgrass Leaf Total Carbon (TC)
Sawgrass Leaf Total Nitrogen (TN)
Vegetation Type
Dominant Macrophyte
Cattail Presence

MOSQUITOFISH (FS)
Total Mercury (THg)

APPENDIX 2. Summary Statistics – Observed Data and CDFs.

Analyte	Observed Data				Cumulative Distribution Function (CDF) Resampled Data			
	Number of Samples	Minimum Concentration	Median Concentration	Maximum Concentration	Median Concentration	Lower 95% Confidence Bound (% of sampled marsh area below the median concentration)	Upper 95% Confidence Bound (% of sampled marsh area below the median concentration)	Confidence Interval Magnitude (%)
SURFACE WATER								
Depth (Feet)	38	0.00	1.15	3.10	1.30	45.00	58.30	13.30
Dissolved Oxygen (mg/L)	35	0.90	6.13	12.32	6.13	40.20	61.30	21.10
Dissolved Oxygen (% saturation)	35	10.08	73.44	169.77	73.44	40.20	61.30	21.10
Specific Conductance (µSiemens/cm)	35	209.20	298.20	444.50	298.20	41.56	56.74	15.18
pH	35	6.58	7.43	7.98	7.43	41.70	59.15	17.45
Temperature (°C)	35	20.62	24.90	32.75	24.90	42.00	60.53	18.53
Turbidity	35	0.00	0.45	145.00	0.45	43.27	54.73	11.46
Chloride (mg/L)	35	5.20	11.00	34.00	11.00	39.20	58.38	19.18
Sulfate (mg/L)	35	0.02	0.02	1.90	0.02	N/A	N/A	N/A
Total Organic Carbon (mg/L)	35	14.00	18.00	28.00	18.00	37.14	59.32	22.18
Dissolved Organic Carbon (mg/L)	35	14.00	18.00	26.00	18.00	43.66	60.96	17.30
Chlorophyll *a* (µg/L)	35	0.10	1.65	16.81	1.65	42.35	55.90	13.55
Total Phosphorus (µg/L)	35	5.52	12.43	32.89	12.43	41.20	57.93	16.73
Soluble Reactive Phosphorus (µg/L)	35	1.92	1.92	1.92	1.92	N/A	N/A	N/A
Alkaline Phosphatase Activity (µmole/L/hour)	35	0.00	0.54	1.32	0.54	45.00	58.00	13.00
Total Nitrogen (mg/L)	35	0.26	0.44	0.97	0.44	39.85	59.73	19.88
Dissolved Nitrite/Nitrate (µg/L)	35	1.73	1.81	22.92	1.81	44.57	59.87	15.30
Dissolved Nitrate (µg/L)	35	1.26	1.73	22.23	1.73	41.49	59.28	17.80
Dissolved Nitrite (µg/L)	35	0.22	0.46	1.50	0.46	42.88	57.92	15.04
Dissolved Ammonia (µg/L)	35	2.75	8.30	82.15	8.30	40.96	57.47	16.51
Total Mercury (ng/L)	35	0.48	1.30	5.70	1.30	42.70	62.63	19.93
Methyl Mercury (ng/L)	35	0.02	0.08	0.24	0.08	39.48	60.73	21.25
Oxidation Reduction Potential in Water Near the Soil Surface (mV)	35	-20.00	78.80	119.60	78.80	41.78	58.77	16.99
BOTTOM WATER								
Soluble Sulfide (µg/L)	35	15.00	15.00	51.00	15.00	N/A	N/A	N/A
SOIL								
Thickness (Feet)	35	0.30	1.10	4.60	1.10	41.85	62.50	20.65
Bulk Density (g/cc)	35	0.10	0.45	1.08	0.40	41.02	58.25	17.23
Total Phosphorus (mg/kg)	35	89.80	239.37	5823.76	234.14	43.17	59.55	16.38
Total Phosphorus (µg/cc)	35	37.50	103.60	722.10	103.60	42.05	61.18	19.13
Total Nitrogen (g/kg)	35	3.49	11.16	35.76	11.16	42.88	57.93	15.05

Analyte	Observed Data: Number of Samples	Observed Data: Minimum Concentration	Observed Data: Median Concentration	Observed Data: Maximum Concentration	Cumulative Distribution Function (CDF) Resampled Data: Median Concentration	CDF Resampled Data: Lower 95% Confidence Bound (% of sampled marsh area below the median concentration)	CDF Resampled Data: Upper 95% Confidence Bound (% of sampled marsh area below the median concentration)	CDF Resampled Data: Confidence Interval Magnitude (%)
SOIL								
Total Mercury (ng/g)	35	11.60	59.00	265.50	57.80	43.14	56.29	13.15
Total Mercury (ng/cc)	35	6.40	21.00	69.90	21.00	42.85	56.92	14.07
Methyl Mercury (ng/g)	35	0.09	0.42	3.57	0.40	40.19	56.11	15.92
Methyl Mercury (ng/cc)	35	0.04	0.16	1.66	0.16	41.90	61.38	19.48
Organic Matter (g/kg)	35	49.52	198.83	841.52	192.07	44.00	56.75	12.75
Organic Matter (mg/cc)	35	43.59	73.93	151.77	73.93	42.94	58.16	15.22
Moisture Content	35	35.32	65.22	90.74	65.22	40.00	58.30	18.30
pH	35	6.65	7.35	7.93	7.35	42.28	60.73	18.45
SAWGRASS PLANTS ABOVE GROUND								
Total Mercury (ng/g)	9	5.70	10.40	18.00	9.80	42.13	57.90	15.77
Methyl Mercury (ng/g)	9	0.14	0.19	0.65	0.18	40.91	54.48	13.57
SAWGRASS PLANT ROOTS								
Total Mercury (ng/g)	9	4.00	11.00	27.00	13.00	44.37	57.63	13.26
Methyl Mercury (ng/g)	9	0.30	0.54	1.30	0.49	37.52	58.90	21.39
SAWGRASS LEAVES								
Total Carbon (g/kg)	25	435.00	485.10	589.80	485.10	40.56	56.72	16.16
Total Nitrogen (g/kg)	25	6.42	8.21	22.92	8.28	42.00	57.00	15.00
Total Phosphorus (mg/kg)	25	181.31	274.61	2023.30	274.61	41.84	61.72	19.88
MOSQUITOFISH								
Total Mercury (ng/g)	24	11.20	50.25	208.30	54.90	38.30	58.28	19.98
FLOC								
Average Thickness (cm)	38.00	0.00	0.83	3.17	0.67	40.88	57.15	16.28
Total Mercury (ng/g)	25	11.80	75.10	374.50	75.10	44.20	61.10	16.90
Methyl Mercury (ng/g)	25	0.50	1.50	8.00	1.50	38.30	57.50	19.20
Total Carbon (g/kg)	10	184.13	295.22	455.06	297.94	43.12	57.15	14.03
Total Nitrogen (g/kg)	10	10.18	24.76	41.45	25.52	43.71	57.86	14.15
Total Phosphorus (mg/kg)	10	156.06	440.43	1238.99	458.24	43.18	56.97	13.79
Organic Matter (g/kg)	10	205.59	560.41	896.31	586.29	43.12	57.15	14.03
Chlorophyll *a* (mg/kg)	10	10.10	26.55	1581.80	28.80	43.93	62.84	18.91
BENTHIC PERIPHYTON								
Average Thickness (cm)	38.00	0.00	0.67	4.17	0.67	42.31	59.53	17.23
Total Mercury (ng/g)	24	8.00	43.55	267.90	43.40	39.01	57.85	18.84
Methyl Mercury (ng/g)	24	0.30	1.25	14.10	1.10	43.48	60.41	16.93
Total Carbon (g/kg)	21	168.00	223.10	416.90	223.10	40.00	57.50	17.50
Total Nitrogen (g/kg)	21	9.57	13.54	35.13	13.54	38.00	58.55	20.55
Total Phosphorus (mg/kg)	21	43.19	174.27	352.98	174.27	41.00	57.00	16.00
Organic Matter (g/kg)	21	197.59	327.03	896.26	327.03	39.20	60.40	21.20
Chlorophyll *a* (mg/kg)	21	28.50	149.10	7468.40	149.10	41.53	61.26	19.73

	Observed Data					Cumulative Distribution Function (CDF) Resampled Data			
Analyte	Number of Samples	Minimum Concentration	Median Concentration	Maximum Concentration		Median Concentration	Lower 95% Confidence Bound (% of sampled marsh area below the median concentration)	Upper 95% Confidence Bound (% of sampled marsh area below the median concentration)	Confidence Interval Magnitude (%)
WATER COLUMN PERIPHYTON									
Total Mercury (ng/g)	28	10.20	27.60	128.30		27.20	41.06	56.72	15.66
Total Mercury (ng/cc)	27	0.48	1.77	3.89		1.77	40.13	56.50	16.38
Methyl Mercury (ng/g)	28	0.30	1.35	8.00		1.30	41.10	56.19	15.09
Methyl Mercury (ng/cc)	27	0.02	0.07	0.23		0.07	42.95	57.00	14.05
Total Carbon (g/kg)	27	214.10	244.30	438.00		241.20	40.53	56.99	16.46
Total Carbon (mg/cc)	27	5.50	13.40	29.80		13.40	43.48	57.38	13.90
Total Nitrogen (g/kg)	27	8.88	12.84	37.30		12.68	42.40	57.84	15.44
Total Nitrogen (mg/cc)	27	0.35	0.68	1.23		0.69	42.04	59.15	17.11
Total Phosphorus (mg/kg)	27	31.71	96.83	679.35		93.60	42.96	58.33	15.37
Total Phosphorus (µg/cc)	27	1.85	4.81	12.91		4.81	43.73	59.76	16.04
Organic Matter (g/kg)	27	30.65	403.87	909.35		384.04	42.32	57.60	15.28
Chlorophyll *a* (mg/kg)	27	18.60	249.30	2333.90		239.40	44.37	57.38	13.01
Bulk Density (g/cc)	27	0.01	0.05	0.14		0.05	41.76	56.42	14.67

Additional Appendices

These Appendices are separate .pdf files that are available at: https://www.epa.gov/everglades/environmental-monitoring-everglades

APPENDIX 3. Correlation plots.
APPENDIX 4. Latitude gradient plots.
APPENDIX 5. Correlation matrix.
APPENDIX 6. Plants and periphyton.

U. S. Environmental Protection Agency
Region 4
Water Division
Atlanta, Georgia