# Jekyll Island Marsh Fragments: Assessing ecological function and health for strategic restoration planning

**Final report for the Coastal Incentive Grant Cycle 17 funded project administered by The Jekyll Island Authority in partnership with the University of Georgia.**

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## Executive Summary

During the modern development of Jekyll Island, Georgia in the first half of the 20th century, construction of hard infrastructure resulted in hydrologic alteration and fragmentation of a tidal system that was historically known as First Creek (Figure 1). These alterations were drastic enough that First Creek no longer appears on modern maps. The modification of this system has impacted modern ecology, hydrology, and visitor experiences. One fragment of the former First Creek system, known as Fortson Pond, persists in a chronically impaired state adjacent to the island entryway. Fortson Pond encompasses an area of approximately 1.84 hectares and was formed when Ben Fortson Parkway was constructed in 1954 to provide vehicle access to Jekyll Island. This road now completely obstructs the natural flow of tidal water to the south and the pond receives restricted tidal inflow solely from the north when flood tides exceed approximately 2.13 m (7 ft.) above average mean lower low water (MLLW).

Prior to this study, ecological impairment of Fortson Pond had been suspected based on observations of unsightly, gelatinous muck dominating a significant area of the pond and excluding emergent or submerged aquatic vegetation. Exploratory, pre-study dissolved oxygen

measurements indicating hypoxia and a strong unpleasant odor associated with the pond were the initial cause for concern. The follow-on work presented here represents the first structured, holistic evaluation conducted over an appropriate time scale to adequately characterize the conditions in Fortson Pond along with the larger system of marsh fragments and brackish ponds surrounding it. The purpose of this effort was to support restoration planning for Fortson Pond and potentially for other elements of the former First Creek system. In this report, we present the assessments of wildlife, vegetation, macroinvertebrate communities, hydrology, and water quality in Fortson Pond and associated marsh fragments and brackish ponds. These findings are followed by the summary proceedings of an expert-panel workshop (Appendix A), in which the scientific findings were presented and restoration strategies were critically evaluated.
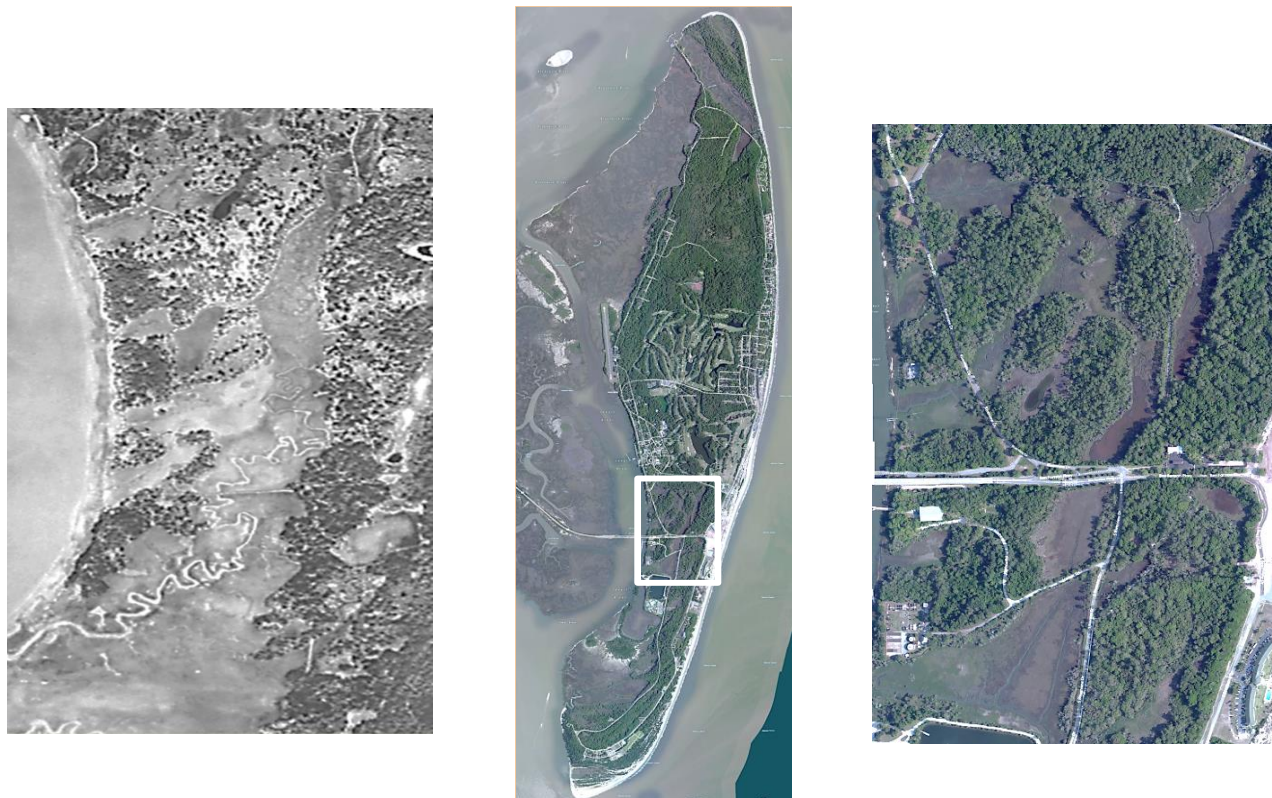


Figure 1. The First Creek system in 1948 (left), 2014 (right), and an image of Jekyll Island showing the site location (middle). Ben Fortson Parkway is the large road crossing East to West in the middle of the 2014 image. These images and all other geographic imagery presented in this report are displayed with North oriented toward the top of the page and south oriented toward the bottom of the page.

## Site Overview

When the State of Georgia purchased Jekyll Island in 1947, it began to develop infrastructure to make the island more accessible. The entryway to the island, the Downing Musgrove Causeway and Ben Fortson Parkway, was constructed in 1954. Hereafter we refer to the portion of this road that is on Jekyll Island and bisects the study system as Ben Fortson Parkway. The water treatment plant and the road leading to it, the next road crossing the marsh south of Ben Fortson Parkway, were built in 1957. Further to the south, a failed harbor project, started in 1967, severed any connection to the original mouth of First Creek. Prior to this, the Jekyll Island Club initially altered the upper reaches of the First Creek system with a diked road, visible in the Northeast corner of the 1948 aerial (Figure 1), and construction of a tidal ditch in the 1920's or 1930's which created a new inflow point of tidal waters into the northern part of the system. The remains of water control structures and dikes are evident in this area which likely served as a managed impoundment to attract waterfowl for hunting. Over time, historic water control structures were abandoned and ceased to function, culverts were added reconnecting tidal waters to some of the fragments of the system, and one of the historic dikes was breached. However, since the construction of Fortson Parkway there has been no hydrologic connection from north to south across this barrier. The result is that Fortson Pond, immediately north of the parkway, effectively became an elevated retention basin with muted tidal influence from the North, enough to maintain brackish conditions but not enough to flush accumulated nutrients and algal biomass.

In addition to Fortson Pond, this study included three adjacent fragments of the former First Creek system. North Marsh lies to the north of Fortson Pond and the two are connected by a 24 inch culvert. Small Marsh and Big Marsh lie south of Fortson Pond and Ben Fortson Parkway and are connected to one another by a 36-inch culvert, but are not to connected Fortson Pond. In this report, we refer collectively to North Marsh, Small Marsh, and Big Marsh as "marsh fragment" study areas (Figure 3). Two additional study areas, Cabin Pond and Hidden Pond, fall outside of the main stem of the former First Creek system and have muted tidal connections to the system (Figure 3). At certain tidal amplitudes, estuarine waters flow into Cabin Pond through an artificial ditch and into Hidden Pond through inundation of the surrounding the marsh. There is no distinct tidal channel, natural or artificial, flowing into Hidden Pond. These ponds were included as points of reference to compare with Fortson Pond and are hereafter referred to collectively as "reference ponds". Fortson Pond and the reference ponds all have a mix of open water, emergent vegetation, and variable salinities with both fresh and saltwater

influence. Hidden Pond has not been subject to any modern anthropogenic alterations, is surrounded by relatively robust naturally vegetated buffers, and does not receive any direct storm water runoff (Figure 4). By contrast, Fortson Pond and Cabin Pond both receive storm water runoff through culverts, have relatively narrow natural buffers separating them from neighboring developed land, and are adjacent to sewer system infrastructure (Figure 4).



Figure 2. The current First Creek system with specific locations of altered connectivity including road/bridge obstructions, culvert systems and channel alterations.
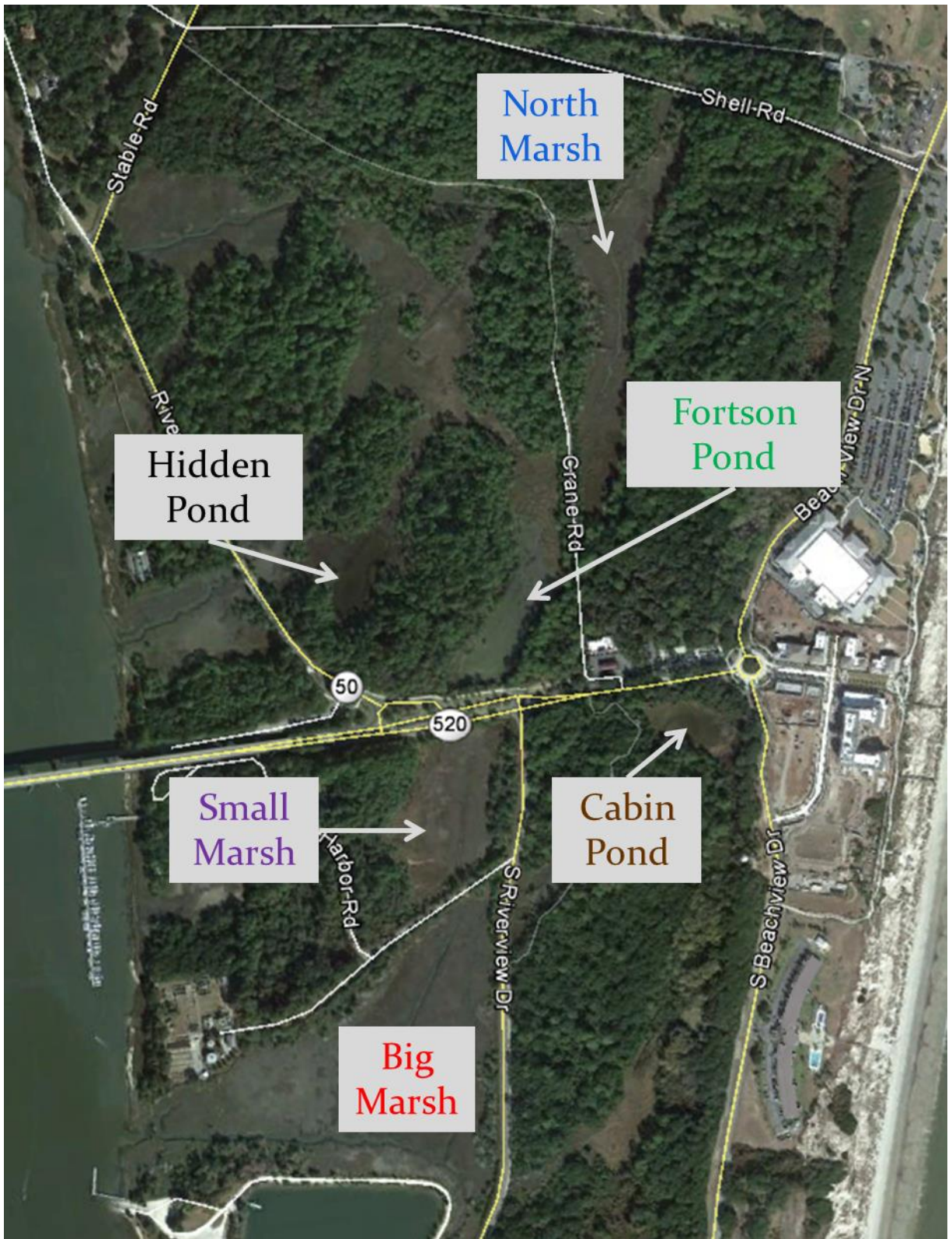
Figure 3. North Marsh, Fortson Pond, Small Marsh, and Big Marsh study areas fragmented by anthropogenic infrastructure and two reference ponds (Hidden and Cabin Ponds).
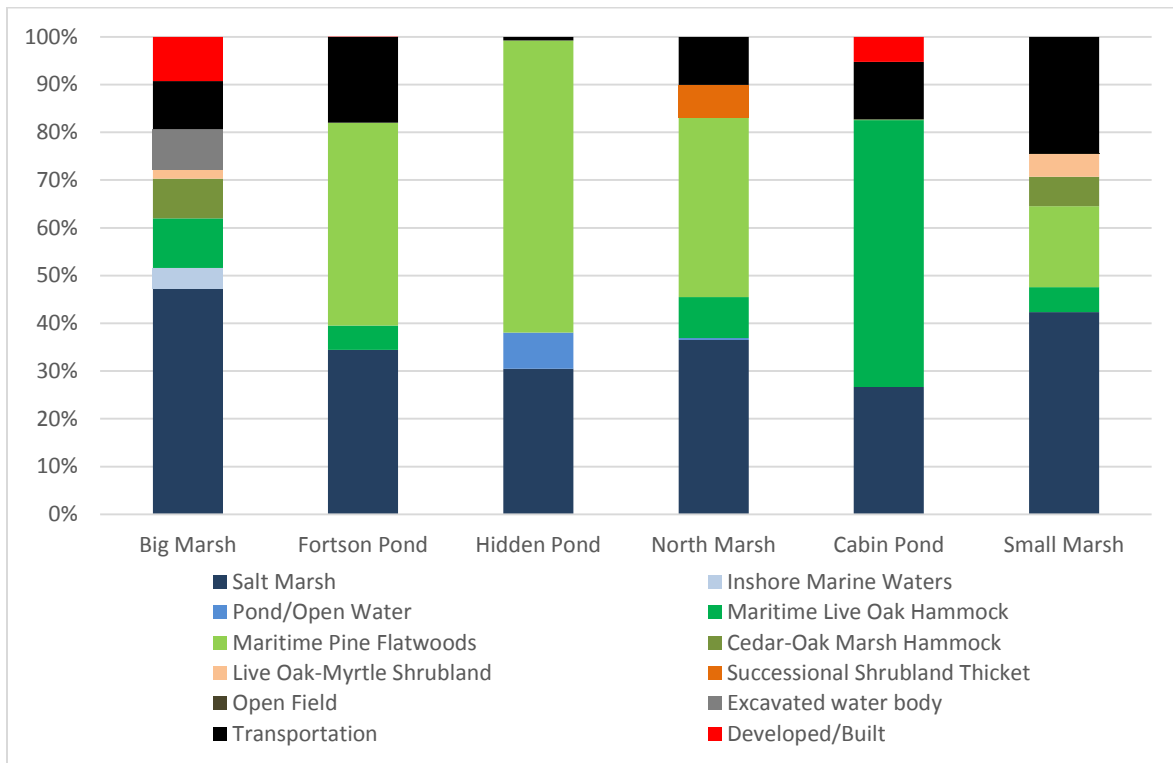
# Habitat Characterization



Figure 4. Habitat characterization of each study site. The amount of hard infrastructure (developed, transportation) within a 50-m buffer surrounding each pond varied from 0.73% (Hidden Pond) to 27.8% (Big Marsh).
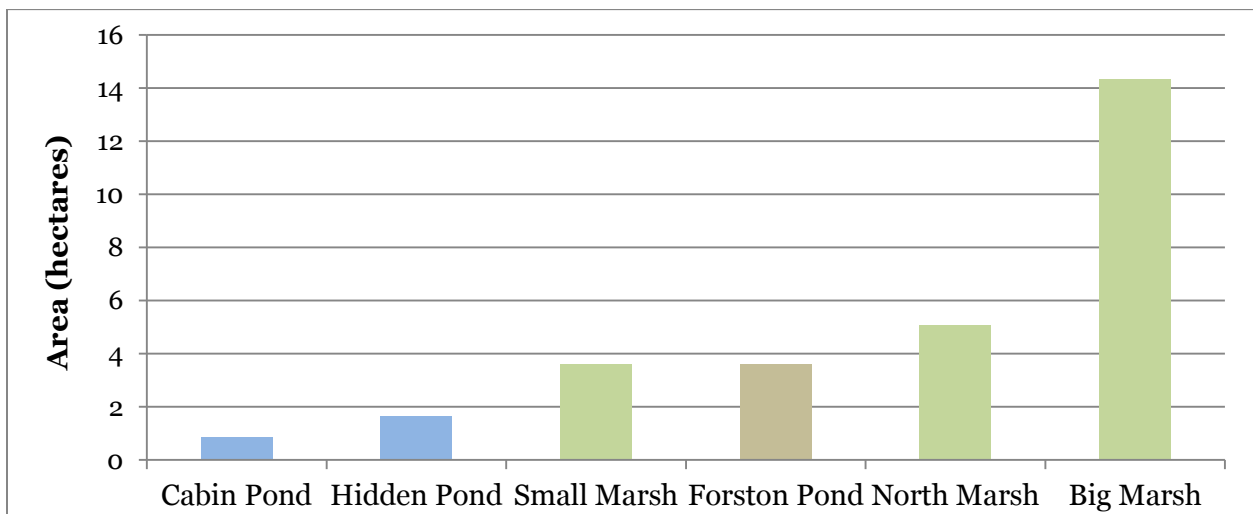


Figure 5. The total area of all fragments (green) and reference (light blue) ponds (range: 0.84 - 14.33 ha). Fortson Pond, our focal site, is denoted by tan.
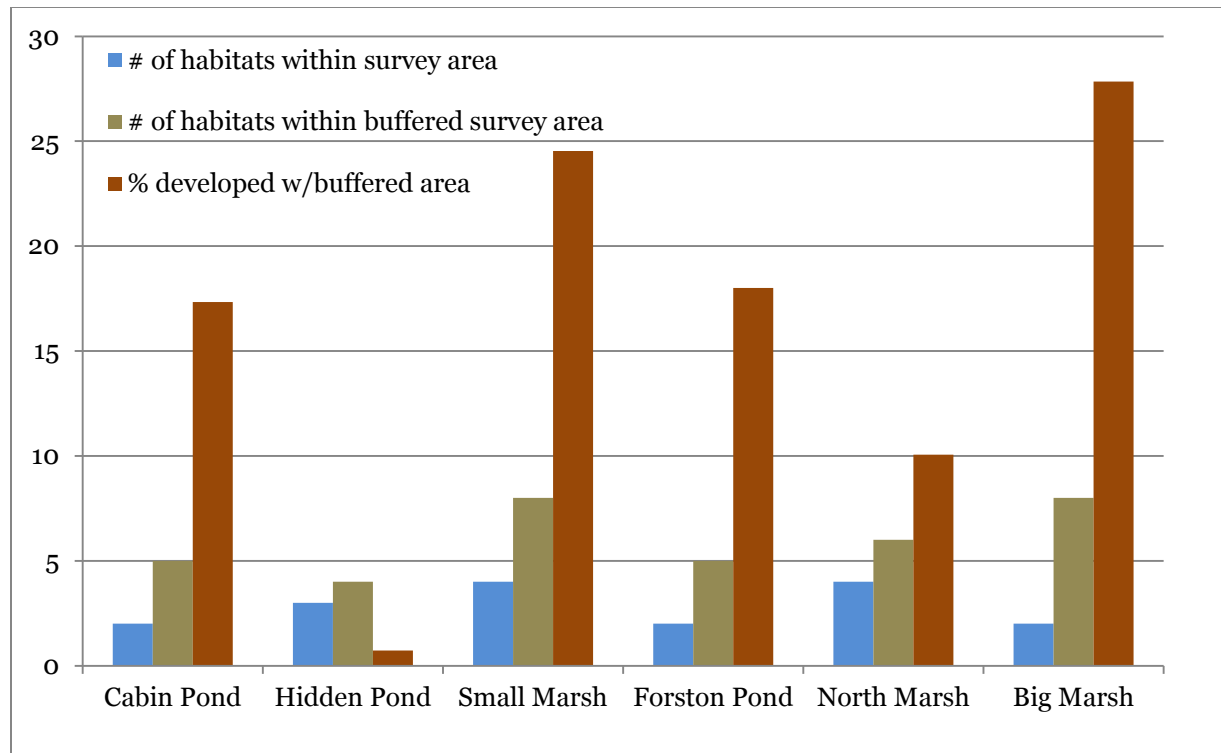
Figure 6. The total number of habitats within the survey area and buffer of each fragment and reference pond as well as the percent of the total area classified as developed when including the buffer area.

## Wildlife Observations

Purpose

Prior to this structured monitoring project, we had the impression that Fortson Pond was attracting less conspicuous-bird activity than some other areas of brackish, open water on the coast. For instance, Myrtle Pond on Little Saint Simons Island or the impoundments on Raccoon Key in St. Andrews Sound both provide highly productive habitat for a diverse array of avifauna including ducks, stilts, rails, and wading birds. We also noted that alligators had not been documented within Fortson Pond, although they are known to use other brackish ponds on Jekyll Island. The protocol described in this section was designed to systematically evaluate whether Fortson Pond differed from the other study areas in the diversity and abundance of conspicuous wildlife.

<u>Methods</u>

From 18 October 2013 to 9 February 2015, we conducted 33 biweekly wildlife observations that consisted of 14 point-count locations distributed across the system (Figure 7). Ten minutes were spent at each point count location during which time the observer identified and recorded any animal species seen using the survey area. There were 3 point-count locations in North Marsh, Fortson Pond, and Big Marsh, 2 point-count locations in Small Marsh and Cabin Pond, and 1 in Hidden Pond. The survey area included the marsh surface out to the adjacent upland edge and vertically to the height of the tallest tree along that edge. The observer was equipped with binoculars and a spotting scope. Observation start time was varied to include observations taken across a representative range of tidal amplitudes and times of day. Equal number of count locations could not be established in each study area due to differences in size and visibility area. Therefore, it was not our intention with this portion of the study to conduct direct, statistically-valid comparisons of richness and diversity among fragment and reference ponds. As our objective with the wildlife counts was to determine whether we were detecting species that are sensitive to landscape and hydrological alterations, or if we only detected species highly tolerant of disturbance, this variability in count locations among sites was deemed acceptable for our study design.

<u>Results and Discussion</u>

Only eight species of mammals and reptiles were observed associated with the marsh habitat, the large majority (94%) of the species counted during bi-weekly observation periods were birds (Table 1). American alligators were documented only in the unrestricted marsh systems (North, Small, Big) and North Marsh had the highest number of non-avian species (6), while only two very tolerant mammals were observed in Fortson Pond (raccoons and gray squirrels). Consequently, only avian species are included in the following species richness and foraging group analysis.

The highest total avian species richness observed over the course of the study was in North Marsh (25 species), and next highest was Big Marsh (22; Figure 8). Small Marsh had the lowest total species richness with only 12 species documented over the course of the study. There were more species documented in Fortson Pond (18), than in reference ponds, Cabin Pond (15) and Hidden Pond (16).

When considering only those species that were likely to have been seeking forage within marsh or brackish-pond habitats, piscivores were the predominant foraging group observed in all study

areas (Table 1, Figure 8). Great Egrets, Osprey, and Great Blue Herons were the most common avian piscivore species observed. Omnivorous species most frequently counted were the Belted Kingfishers and Pied-billed Grebes, and Hidden Pond had the highest number omnivore sightings (25). Birds that forage on invertebrates observed most frequently in North Marsh, and the most common invertivore species was the Hooded Merganser. Fortson Pond and Hidden Pond were the only two study areas in which we documented herbivores (Figure 9). Abundance and diversity of herbivores was low in each instance, consisting only of a pair of Canada Geese that flew into the observation area at Fortson Pond but did not land and a few ducks, a single Redhead and a pair of Blue-winged Teal, that were observed swimming on Hidden Pond.

These results are notable in that they do not support our pre-study perceptions about bird-use in Fortson Pond. We had hypothesized that persistently poor water quality and chronically overabundant cyanobacteria were leading to reduced habitat value across trophic levels and faunal assemblages, including birds. While it may nonetheless be true that other brackish ponds in coastal Georgia support more abundant and diverse bird communities, Fortson Pond's diversity of conspicuous avifauna falls in the middle of the range of what we observed within the same watershed on Jekyll Island. We do not however interpret this to mean that the habitat value of Fortson Pond, Small Marsh and the entire First Creek system, could not be improved for birds or other vertebrates if tidal connectivity were restored.

Figure 7. There were 14 total wildlife point count observation locations within North Marsh (3), Fortson Pond (3), Small Marsh (2), Big Marsh (3), Cabin Pond (2) and Hidden Pond (1).

Table 1. Total sightings of wildlife species including marsh birds, birds of prey, terrestrial bird species, mammals and reptiles. Fortson Pond, indicated in tan, is our focal site and the surrounding marsh fragments are highlighed in green. Reference ponds are highlighted in light blue.

| Location | Marsh avian feeding groups | | | | Totals | | |
| | Piscivores | Invertivores | Herbivores | Omnivores | All Avian* | non-Avian** | Grand Total |
|---|---|---|---|---|---|---|---|
| North Marsh | 72 | 3 | 0 | 18 | 222 | 7 | 229 |
| 1 | 24 | 0 | 0 | 4 | 17 | 1 | 18 |
| 2 | 34 | 3 | 0 | 11 | 107 | 3 | 110 |
| 3 | 14 | 0 | 0 | 3 | 98 | 3 | 101 |
| Fortson Pond | 58 | 6 | 2 | 9 | 58 | 7 | 65 |
| 1 | 17 | 3 | 0 | 5 | 35 | 6 | 41 |
| 2 | 21 | 3 | 2 | 3 | 23 | 1 | 24 |
| 3 | 20 | 0 | 0 | 1 | 172 | 5 | 177 |
| Small Marsh | 6 | 0 | 0 | 0 | 51 | | 51 |
| 1 | 2 | 0 | 0 | 0 | 72 | 3 | 75 |
| 2 | 4 | 0 | 0 | 0 | 49 | 2 | 51 |
| Big Marsh | 127 | 5 | 0 | 22 | 79 | 1 | 80 |
| 1 | 9 | 1 | 0 | 2 | 79 | 1 | 80 |
| 2 | 53 | 2 | 0 | 11 | 146 | 18 | 164 |
| 3 | 65 | 2 | 0 | 9 | 68 | 7 | 75 |
| Cabin Pond | 30 | 4 | 0 | 17 | 58 | 9 | 67 |
| 1 | 16 | 2 | 0 | 12 | 20 | 2 | 22 |
| 2 | 14 | 2 | 0 | 5 | 83 | 12 | 95 |
| Hidden Pond | 37 | 17 | 4 | 25 | 42 | 7 | 49 |
| 1 | 37 | 17 | 4 | 25 | 41 | 5 | 46 |
| Grand Total | 330 | 35 | 6 | 91 | 760 | 50 | 810 |

*All Avian total includes terrestrial birds, birds of prey, and other birds not identified to species level.

**Non-Avian species included American Alligator, Blue crab, Cottonmouth, Gray Squirrel, Mink, Opossum, Raccoon and White-tailed deer.
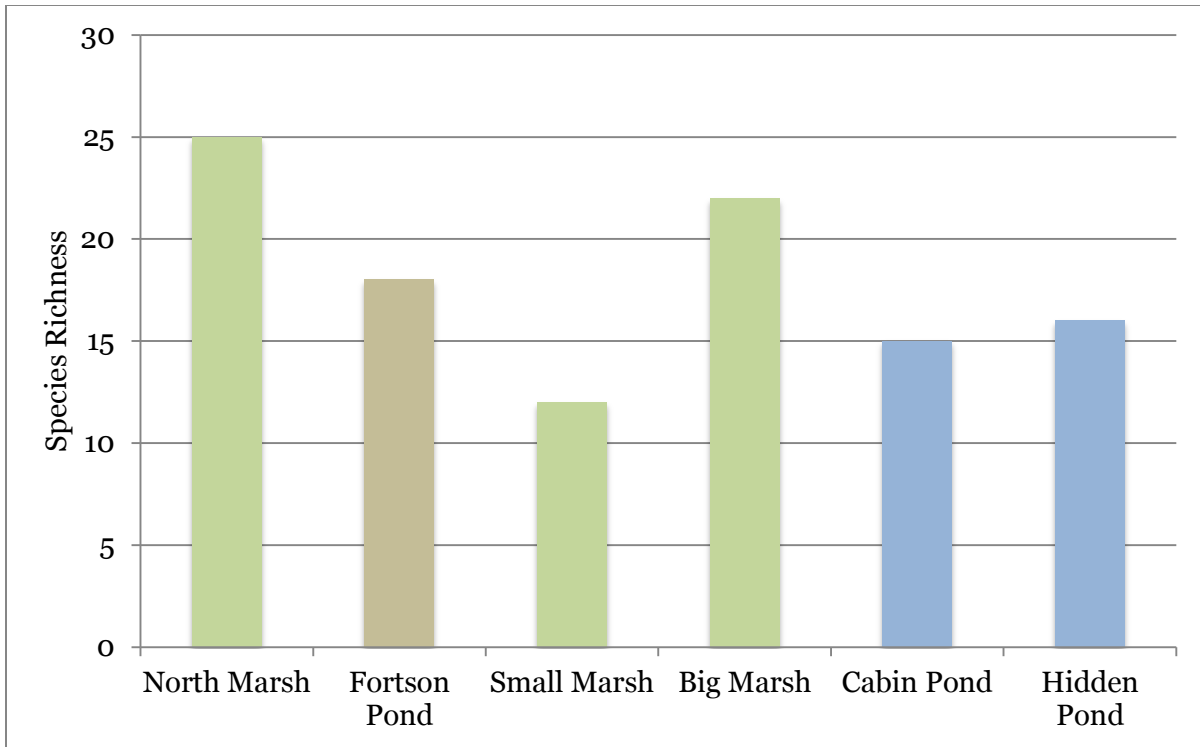
Figure 8. Total number of avian species detected over the course of the project in each study area. Fortson Pond, indicated in tan, is our focal site and the surrounding marsh fragments are highlighted in green. Reference ponds are highlighted in light blue.
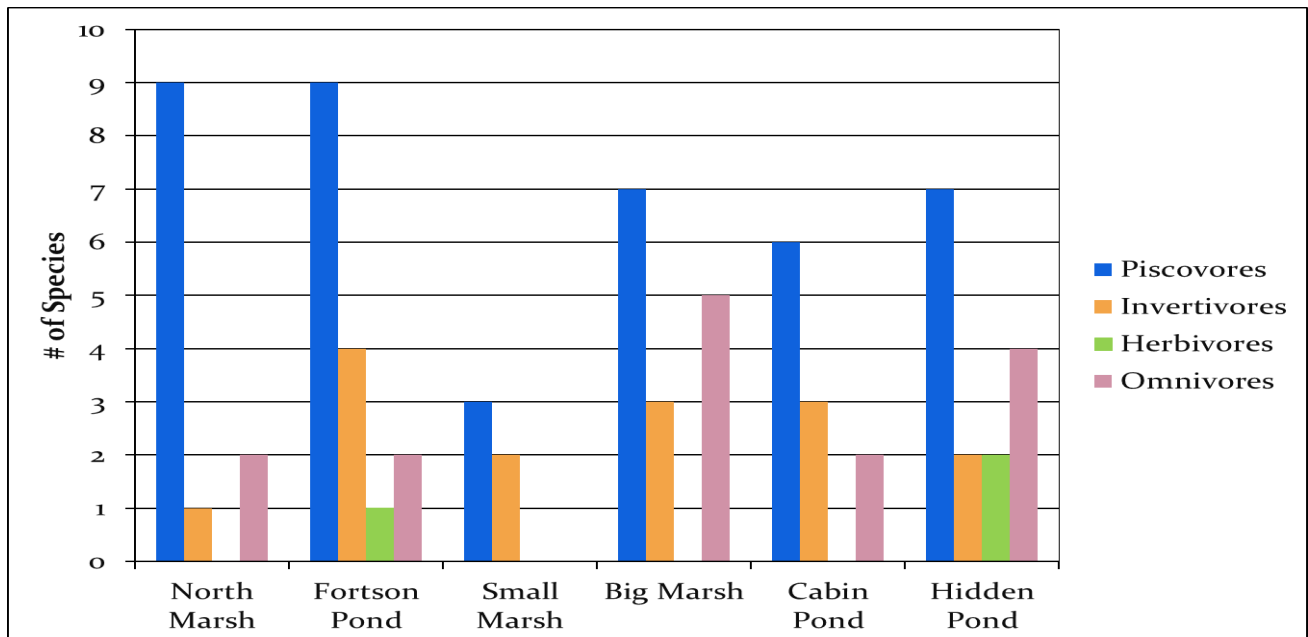


Figure 9. Avian marsh-foraging species richness across all fragments classified by primary diet.

## Vegetation and Macroinvertebrate Communities

<u>Purpose</u>

Prior to this work, there had been no assessment or characterization of vegetation and macroinvertebrate communities within any of the study areas. This component of the study was designed to systematically document vegetation-community composition and structure over time to allow for comparison among study areas and reveal correlations with other variables. In association with this vegetation data, we also evaluated use by select macroinvertebrates including marsh periwinkle snails, ribbed mussels, and fiddler crabs, to better understand the dynamics of primary consumers within the study areas. We anticipated that both vegetation community structure and invertebrate indicators would reflect differences in water quality, nutrient enrichment, and tidal fluctuation, between study areas.

<u>Methods</u>

We established fourteen transects for our vegetation and macroinvertebrate assessments throughout the study system. We used a stratified design to spatially distribute two to four sampling transects in each marsh or pond study area (Figure 10). Transects were laid out roughly perpendicular to the channel-edge for marsh sites or basin-edge for pond sites and extended to the interface between wetland and upland vegetation. Transects were surveyed starting at the channel or basin edge, placing a 0.5 m x 0.5 m sampling frame every 5 meters (marsh transects) or 2 meters (pond transects) along each transect to define the survey plot for vegetation-cover estimates, species identification, and invertebrate counts. Within each plot, all plant species were identified and visual estimates of total cover and percent cover for each species were recorded. For the invertebrates, marsh periwinkle snails were counted individually or recorded as 25+ when more than 25 individuals were observed. Fiddler crabs were noted as present or "not detected" based on direct visual observations in situ of one or more crabs or the presence of crab burrows within the plot. Finally, ribbed mussels were also noted as present or "not detected" as determined by direct visual observations in situ of either live mussels or mussel shells within the plot. We surveyed these transects three times yearly in 2013 and 2014. For data analysis, plot locations were converted to relative distances between water edge (relative distance=0) and upland margin (relative distance=1) to normalize differences in transect length and steepness of elevation gradient.

Results and Discussion

Fortson Pond study plots had the highest percent cover of *Spartina alterniflora* and *Juncus roemerianus* near to the channel/basin edge of any fragment (Figure 11). Total plant species richness over the course of the study varied between five species (Hidden Pond) and 11 (Cabin Pond) species in the study areas (Figure 12a). Fortson Pond and Small Marsh were intermediate with seven plant species documented for each. The average number of plant species detected in plots was lowest in Small Marsh and highest in Cabin Pond (Figure 12b). Cabin Pond exhibits the most freshwater influence of any of the study areas and receives storm water runoff from adjacent developed areas. The freshwater influence likely resulted in higher diversity of freshwater associated plants such as cattails, mallow, hyssop, and morning glory. Vegetation community composition and structure changed little over the course of the study period except at Cabin Pond where species less tolerant of high salinity became more common through the course of the study.

The macroinvertebrate data reveals that Fortson Pond and the reference ponds generally exhibited similarity with one another and marked difference from the other marsh fragment study areas (Figures 13, 14). Big Marsh, Small Marsh, and North Marsh transects had high abundances of marsh periwinkle snails while the reference and Fortson pond study areas had almost no marsh periwinkle snails. Of note, *Melampus bidentatus*, the common marsh snail, was encountered in pond areas. This species is typically associated with higher elevation marshes, including brackish areas, and is relatively small and cryptic. Observations of marsh snails were opportunistically recorded but they were not formally monitored due to low detectability and initial observations coming well into the study period. Snail abundance showed little variation among seasons, except an increase observed over time in Small Marsh (Figure 14).

The probability of encountering fiddler crabs or ribbed mussels was much greater in the marsh fragment areas than in the pond areas. The probability of encountering crab burrows or live crabs in any plot in Fortson Pond was less than 20% (Figure 15a). Mussels were never observed in Fortson Pond or either of the reference ponds (Figure 15b), but were present in all of the marsh fragment sites. Overall, Fortson Pond's estuarine macroinvertebrate community, or lack thereof, more closely resembles that of the reference ponds than the marsh fragment areas.

Figure 10. Fourteen vegetation and macroinvertebrate monitoring transects distributed throughout the study system (white bars).
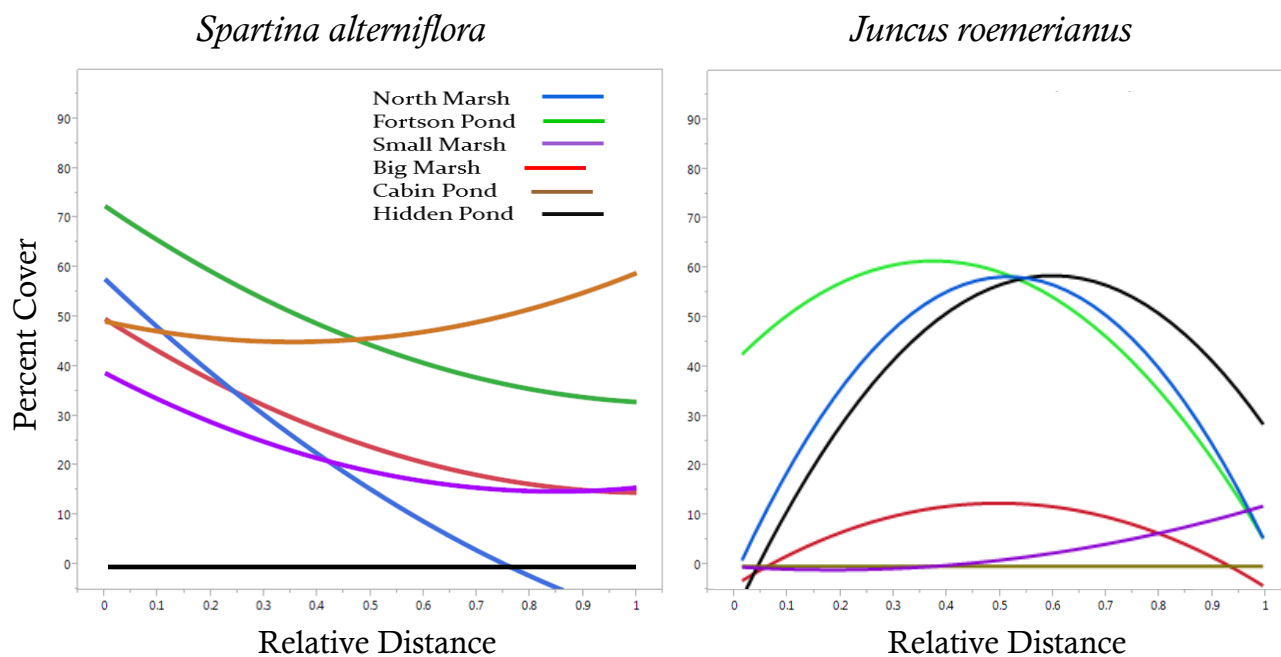
Figure 11. Relationships between percent cover of relative distance relationship between *Spartina alterniflora* (left) and *Juncus roemerianus* (right), the two most common marsh grass species, and relative distance from the water's edge (distance 0 is adjacent to water and 1 is at wetland-upland margin). Hidden Pond did not contain *S. alterniflora* and Cabin Pond did not contain any *J. roemerianus* within the transects. Quadratic curves (shown) were fitted to the seasonally averaged quadrat data.
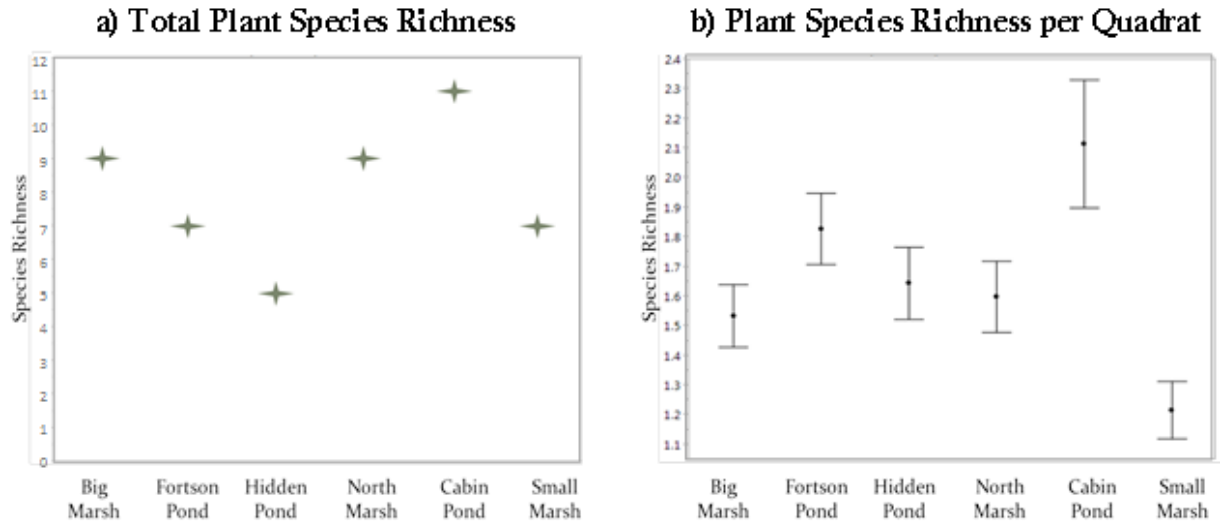
**Figure 12.** Plant species richness at each study site. (a) The total number of species observed throughout the study in each study area. (b) The average number of species per 0.5 x 0.5 m quadrat. Error bars are 95% CI.
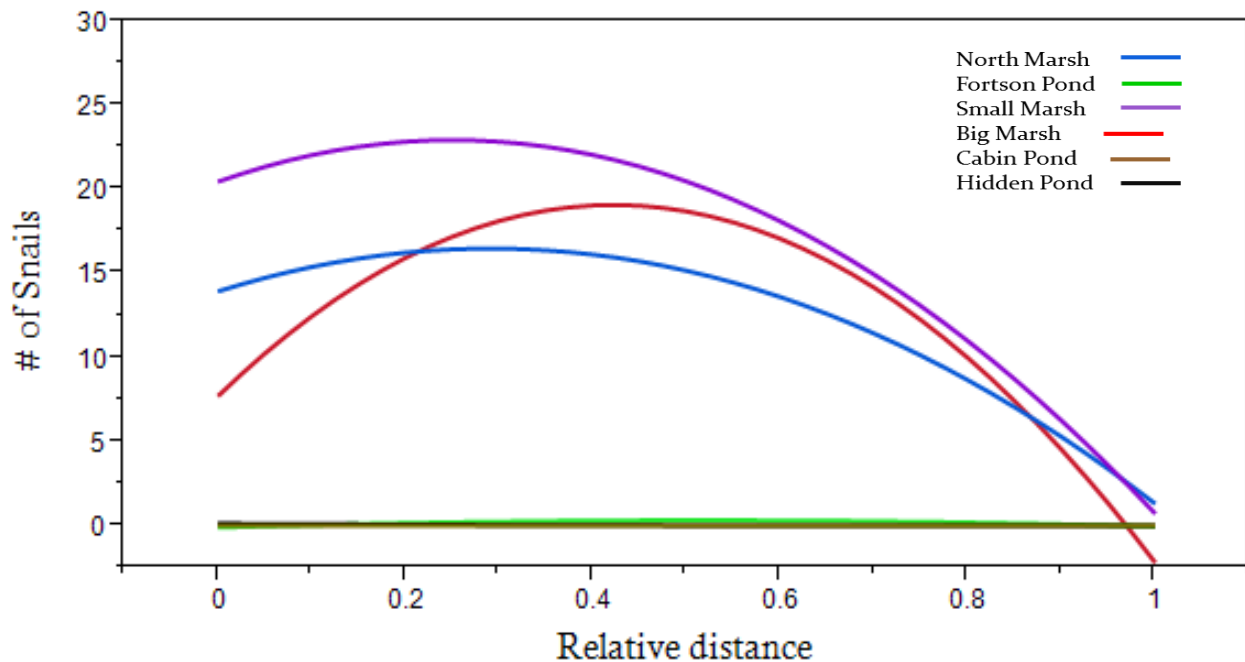


**Figure 13.** General trends of snail abundance with relative distance from the water's edge. Both reference ponds and Fortson Pond lacked snails almost entirely. Quadratic curves (shown) were fit to seasonally averaged quadrat data from each study site.
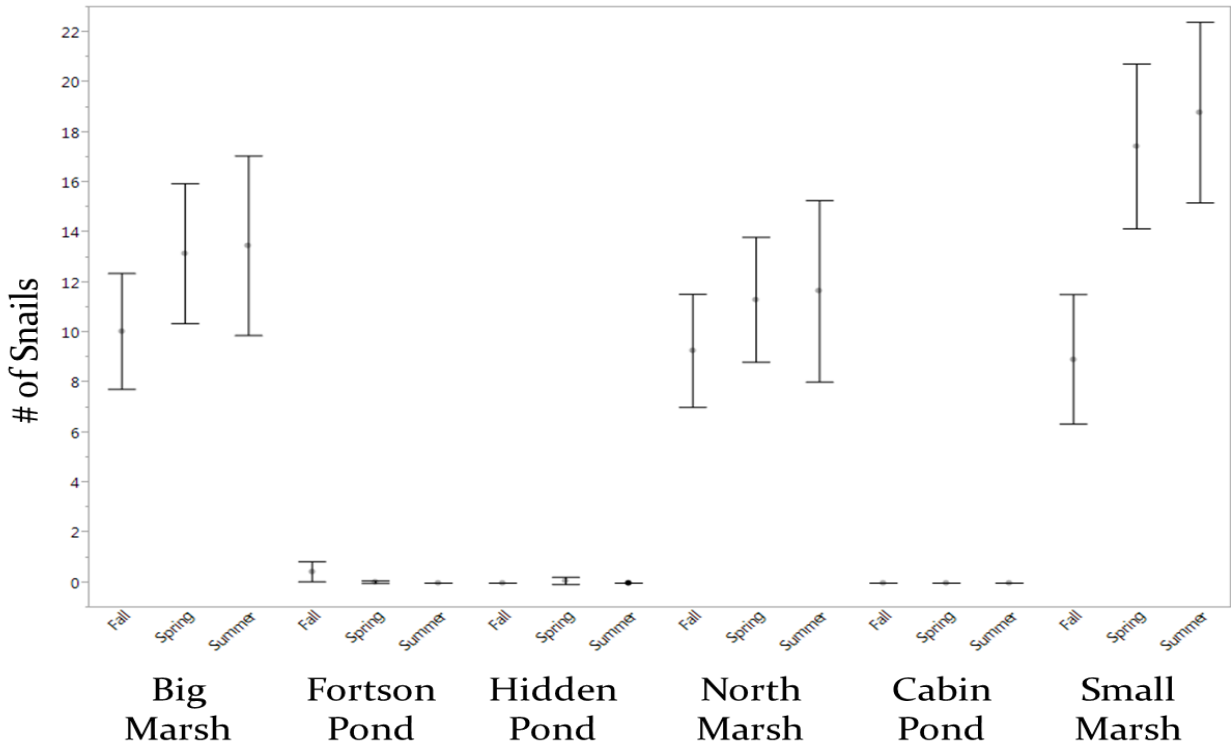
Figure 14. The average number of periwinkle snails encountered in each quadrat from one season to the next. Again notice Hidden Pond and Fortson Pond here at the bottom with very low snail numbers as well as the complete lack of snails in Cabin Pond throughout the entire project.
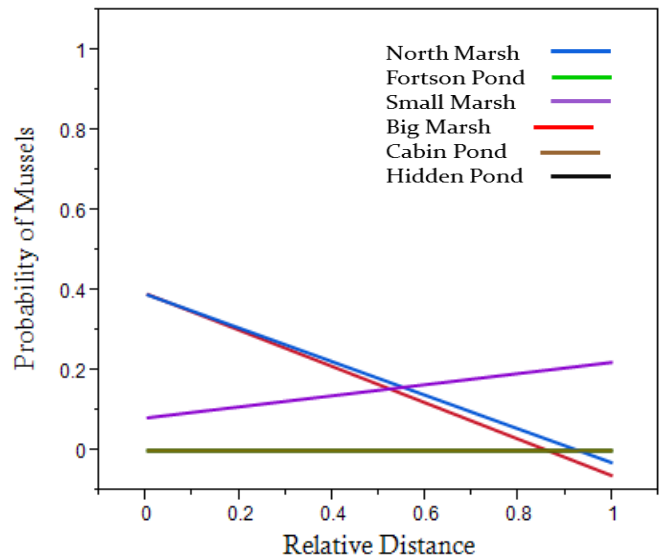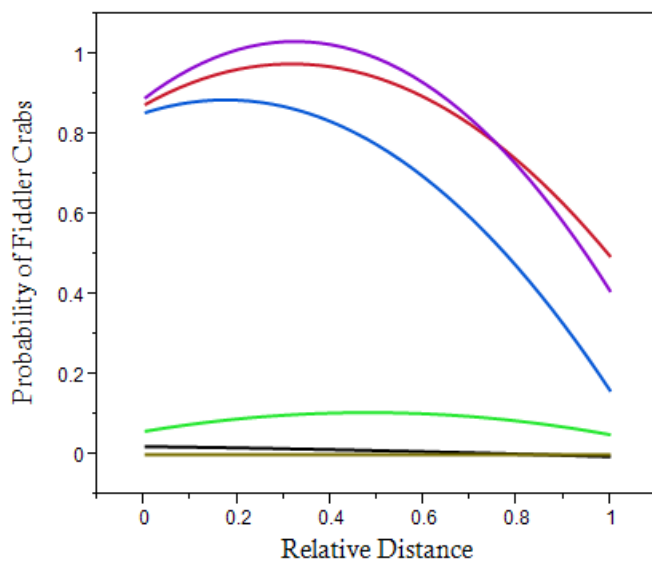
Figure 15. The probability of encountering (a) fiddler crabs or crab burrows, or (b) mussels, within a quadrat based on distance from the water's edge. Quadratic and linear curves (shown) provided the best fit for the fiddler crab data and the mussel data, respectively.


## Water Level

<u>Purpose</u>

Previous observations of Fortson Pond had led to the hypothesis that tidal flooding of Fortson Pond only occurs on the highest of high tides. To understand water-level fluctuations in Fortson Pond and throughout the study system accurately and in fine detail, we deployed water-level loggers across the study system. This information provides a foundation that is a critical to evaluating the feasibility of possible restoration scenarios.

<u>Methods</u>

Water level was measured with nine HOBO pressure transducer water level data loggers January 2014 through May 2015 (Figure 16). WL-4b was a temporary logger that was removed after the first three months as part of a preliminary assessment. Each data logger was set to measure pressure every five minutes. Each logger was mounted inside a 2" PVC pipe and secured above the sediment surface. Data were downloaded periodically. Water-level data was managed and analyzed using HOBOWare Pro software. The data was standardized using barometric pressure readings from a station on the east side of Jekyll Island near the north end of the study system. All loggers were within 1.26 km of the barometer.

<u>Results and Discussion</u>

The average daily tidal range calculated from the water-level data for each study area is shown in Figure 17. The major water restriction points, blockages, and elevation differences are apparent in this data. The significant difference in tidal range between water-level logger 2 (WL-2) and water-level logger 3 (WL-3) reflects the impact of the 24-inch culvert that connects North Marsh to Fortson Pond. Likewise, the difference in tidal range between WL-5 and WL-4 reflects the impact of the 48-inch culvert that connects Big Marsh and Small Marsh. Tidal range differences are also notable between WL-3 and WL-3B within Fortson Pond and between WL-4 and WL-4B in Small Marsh and reflect differences in elevation within these areas, with lower average daily tidal range WL-3B and WL-4B indicative of higher elevation. WL-3B recorded the lowest tidal range of any station along the main axis of the former First Creek (Fortson Pond and the Marsh

Fragments). However, tidal ranges recorded for the reference ponds at WL-6 (Cabin Pond) and WL-7 (Hidden Pond) were the lowest in the study.

An important objective of this study was to evaluate the feasibility of increasing tidal flow to Fortson Pond by reconnecting Fortson's south end with Small Marsh via a water conveyance under Fortson Parkway. This mitigation action would be expensive and disruptive, which calls for a high degree of confidence that the action would achieve clearly outlined goals. To begin to build that confidence, we first asked the questions: Would construction of a water conveyance under Fortson Parkway result in movement of water between Small Marsh and Fortson Pond? How often? What would be the direction of flow?

The water-level data show that the daily maximum water level in Small Marsh (WL-4) exceeded the daily maximum at the south end of Fortson Pond (WL-3B) 80.66% of all days (Figure 18). Whether and how often water would pass through a conveyance under Fortson Parkway depends on the elevation of the lowest interior surface, or "invert", of the structure. At an invert elevation of 2.50 feet (NAVD88), a invert proposed by a consulting engineer, the structure would convey water about 63% of the time. If the invert were lowered to 2.33 feet, the approximate surface elevation of the muck that has accumulated in Fortson Pond, water would be conveyed about 96% of the time.

Figure 16. The locations of nine water-level loggers used throughout the project. WL-4b was part of a short-term preliminary study and was removed after only 3 months. The rest were deployed in January 2014 and recorded water-level data every five minutes through July 2015.
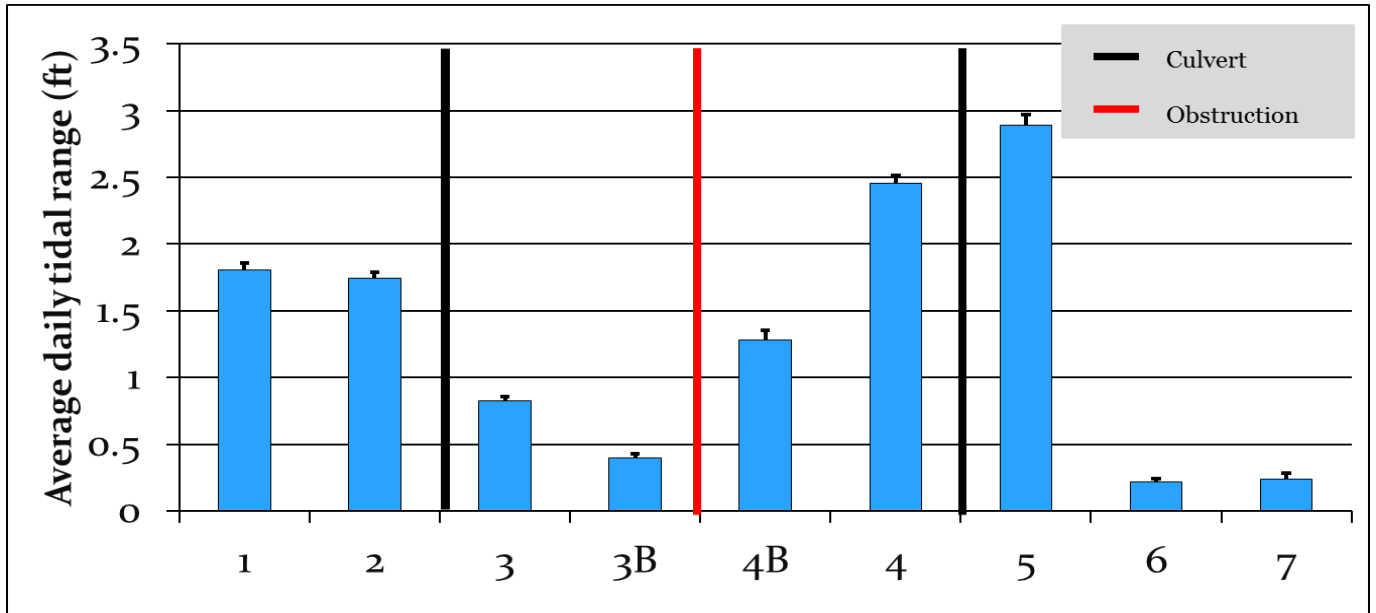
Figure 17. Average daily tidal range for all water level loggers. Logger sites 1 to 5 are arranged sequentially from North to South through the system, showing that tidal range is most restricted in the middle of the sequence, at the southern end of Fortson Pond (site 3B). Error bars are 95% C.I.
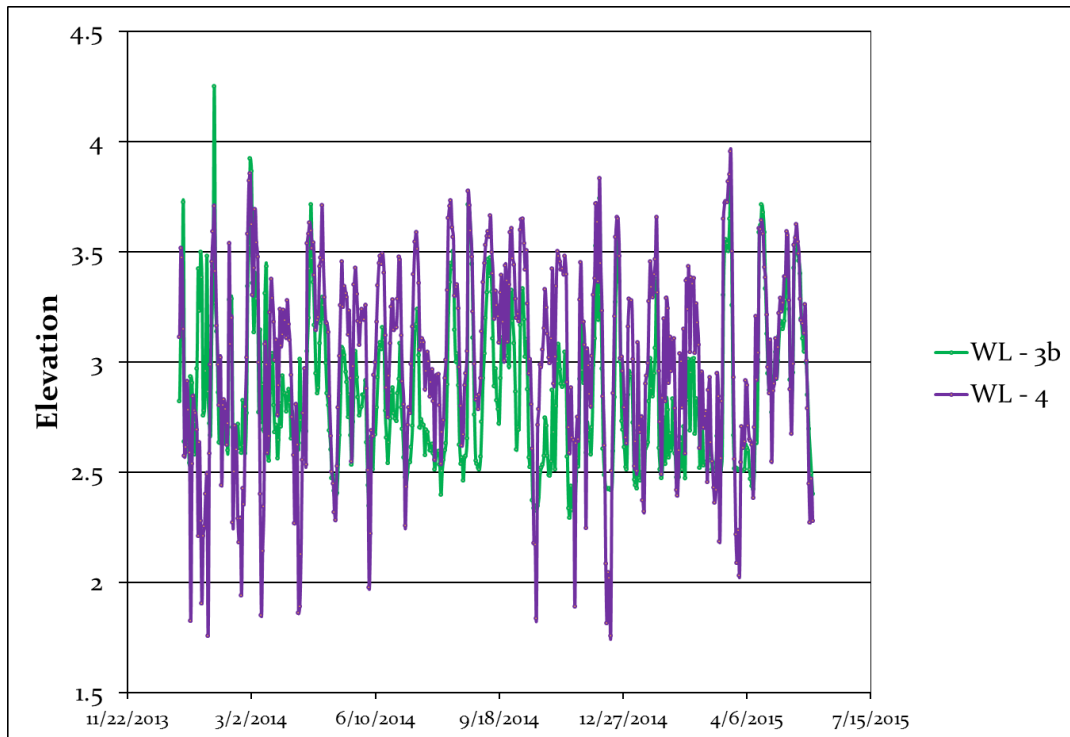


Figure 18. The daily maximum water levels recorded in Fortson Pond (WL-3b) and in Small Marsh (WL-4). Daily maximum were higher in Small Marsh 80.66% of days.

**Water Quality and Algal Composition**

**Purpose**

Estuarine impairment is typically initiated by an increase in nutrient discharge into a water body, often resulting in accelerated primary production. Elevated nutrients and low flow conditions can result in high density nuisance and toxic algal/cyanobacterial blooms, depleting dissolved oxygen from excess respiration/decomposition and subsequent loss of habitat loss for benthic invertebrates and fish. Standard parameters used to assess the characteristics of nutrient enrichment and eutrophic conditions in the nation's estuaries include nutrient levels, Chlorophyll a, and dissolved oxygen (DO). Comprehensive assessments include algal composition as a biotic component that can provide additional temporal and spatial integration of physical and chemical water quality data.

The following categories were used to report the level of risk associated indicators of estuarine eutrophic status:

| Parameter | Reference | Moderate | Hypereutropic | |
|---|---|---|---|---|
| | Optimal | Biological stress | Hypoxic | Anoxia |
| Dissolved Oxygen (mg/L) | >5 | 2-5 | <2 | 0-2 |
| | Low | Intermediate | High | |
| Total phosphorus (mg/L) | 0.05 | >0.05-0.1 | >0.1 | |
| Total nitrogen (mg/L) | <0.5 | >0.5-1.0 | >1.0 | |
| Chlorophyll a (ug/L) | 0-5 | 5-20 | >20 | |

Bricker et al. 2008. Effects of nutrient enrichment in the nation's estuaries: A decade of change. Harmful Algae: 8:21-32.

Prior to this study, eutrophication was suspected to be a proximate factor in Fortson Pond's condition and was indicated by a lack of vegetation, frequently low dissolved oxygen, and large accumulations of organic material, but seasonal dynamics, driving factors, and ranges of variation were not well understood. The purpose of this component of the study was to provide a seasonal evaluation of the water quality conditions, nutrient levels, and community composition within Fortson Pond, the marsh fragment study locations, and the reference ponds. Typically, nitrate, nitrite, and ammonia are at very low levels in estuarine water unless there are relatively recent loadings of sewage or fertilizer present in runoff from the watershed or if nitrogen is not limiting to algal growth. These forms are rapidly used by algae and aquatic plants or converted to other forms of nitrogen. Low total Nitrogen (TN) to total Phosphorous (TP) ratios are typically the result of very high TP loads from point or nonpoint sources in the watershed in estuaries receiving significant amounts of sewage effluent.

## Methods

Dissolved oxygen and salinity measurements were taken biweekly at water access points in association with wildlife observations (Figure 19). Nutrient and algal samples were collected from the water column in November 2013, July 2014, September 2014, November 2014, May 2015, and June 2015. Samples were taken during midday low tides from mid-depth at the thalweg of a channel if present. Additionally, during September 2014 and May 2015, supplementary sampling was conducted over an extended tidal cycle before and after the midday low tide.
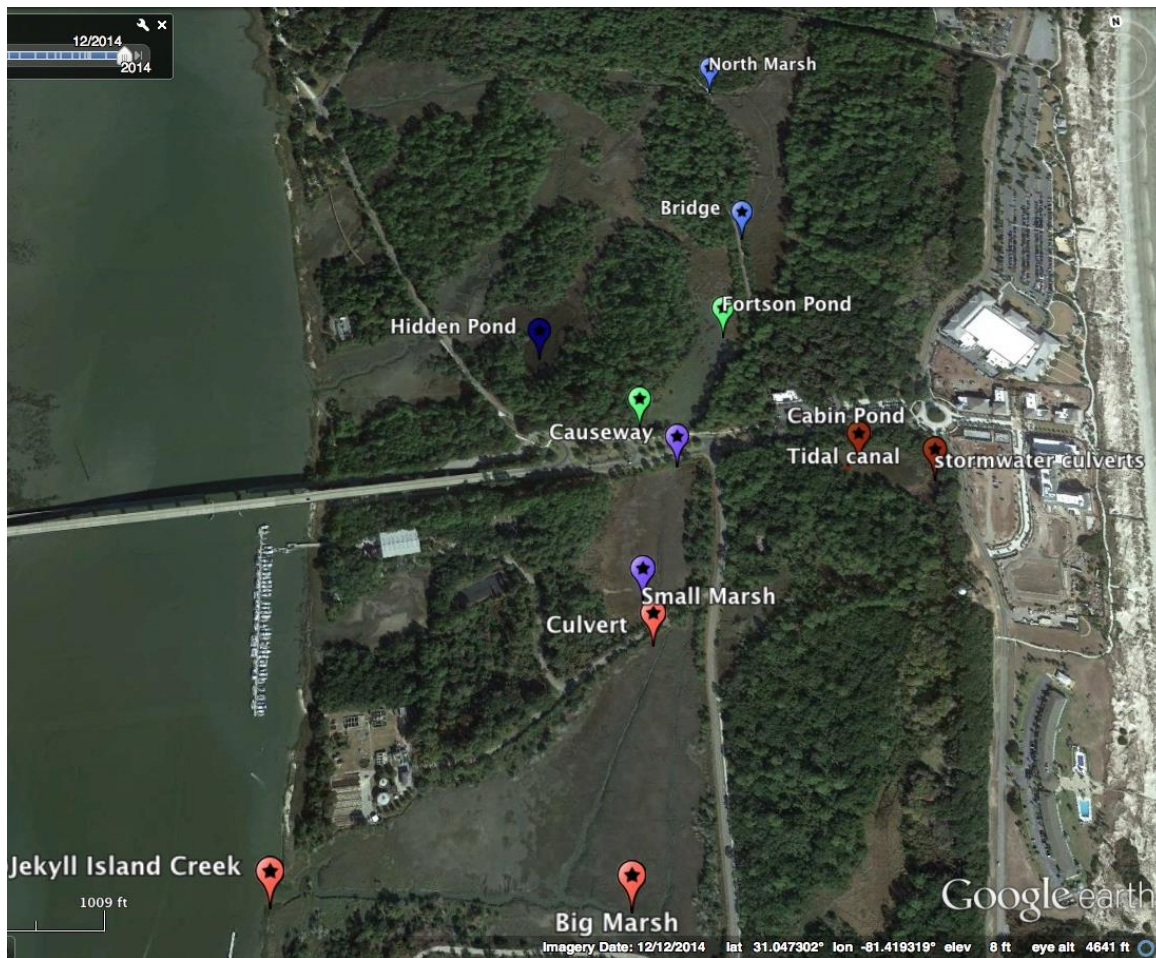


Figure 19. In-situ water quality and water sampling locations within marsh fragments and ponds.

Water samples (250 ml) for nutrient analysis were kept cold in the dark and transported on ice to the University of Georgia Stable Isotope Ecology Lab in Athens, GA. Nitrate-N, ammonium-N, orthophosphate-P were analyzed on samples filtered with glass fiber filters. These filters were

then extracted for flourometric analysis of Chlorophyll a. Total phosphorus was evaluated from whole water samples as orthophosphate following an acid-persulfate digestion (EPA 365.2). Total nitrogen (TN) was evaluated following conversion of all forms to NO3 using alkaline persulfate digestion (APHA, 1998). Nutrient levels were measured colorimetrically using an automated continuous-flow analyzer (Alpkem).

Algal community composition was assessed in whole water subsamples (10 ml) fixed in Lugols preservative. Replicate 1-ml aliqouts were counted by individual taxa in a Sedgewick-Rafter counting chamber using a compound microscope. Phytoplankton species were then summarized to evaluate the relative abundance of potentially harmful groups versus beneficial phytoplankton. Dinoflagellates, Rhaphidophytes and Cyanobacterial can form dense blooms under reduced flow, high nutrient and elevated temperature conditions. Some dinoflagellate species produce neurotoxins and can form dense blooms in higher salinity estuarine environments. Rhaphidophytes include toxin-producing species and bloom in brackish water. Cyanobacterial species are the most common toxin producing group in freshwater, but several toxic cyanobacteria are adapted to low/variable salinity. Generally, diatoms are considered a beneficial group and are most prevalent in systems with lower nutrients and more flow.

In order to investigate microbiological pollution, fecal coliform bacteria colony abundance was measured from water samples collected in November 2013 and August 2014. Samples were kept cold and analyzed within 24hrs by membrane filtration and enumeration of colony-forming units (per 100 mls) following 48hr incubation at 45°C.

In July 2014 and June 2015, sediment samples were collected and analyzed for Coprostanol, a steroid that is formed during bacterial reduction of cholesterol in the intestines of most vertebrates and is present in feces. Samples were stored frozen until extracted by liquid-liquid extraction using dichloromethane, then analyzed using gas chromatography-mass spectrometric (GC-MS) determination.

Additional bacterial samples were collected on November 17, 2015 from Cabin Pond, Hidden Pond, Small Marsh, North Marsh, and Fortson Pond. A total of 18 samples were collected into 1 L sterile Nalgene bottles during low tide to limit dilution from uncontaminated estuarine waters. Samples were kept on ice until transported back to the laboratory and analyzed within 24 hr of collection. Culturable FIB were detected by Colilert-18® (IDEXX, Westbrook, ME). Total coliform and E. coli were reported as MPN/100 ml. For molecular analyses, samples were filtered through 0.4µm polycarbonate filters. DNA was extracted by bead beating method

(USEPA 2013), followed by purification by a commercial kit. Sewage pollution marker (Bacteroides 16S rDNA gene HF183 marker) was detected by qPCR.

**Results and Discussion**

Collectively, water quality, nutrient levels, microbial assessments and algal data provide evidence that this fragmented saltmarsh system is eutrophic, and parameters indicate Fortson Pond should be classified as hypereutrophic. Hypoxic conditions were documented in all but the most tidally influenced monitoring locations. Average dissolved oxygen values in Fortson Pond area were consistently well below biological stress levels (Figure 20).

Oxygen values (minimum/maximum levels) give insights into the dynamic fluctuations in primary production, respiration, and decomposition in this high nutrient and constricted flow tidal system. Coupled with the fluctuating salinity data, we can detect the influence of seasonally and spatially variable freshwater inflows. Fortson Pond (causeway side) and Cabin Pond (storm water culvert side) have average salinities below 6 ppt (Figure 21).
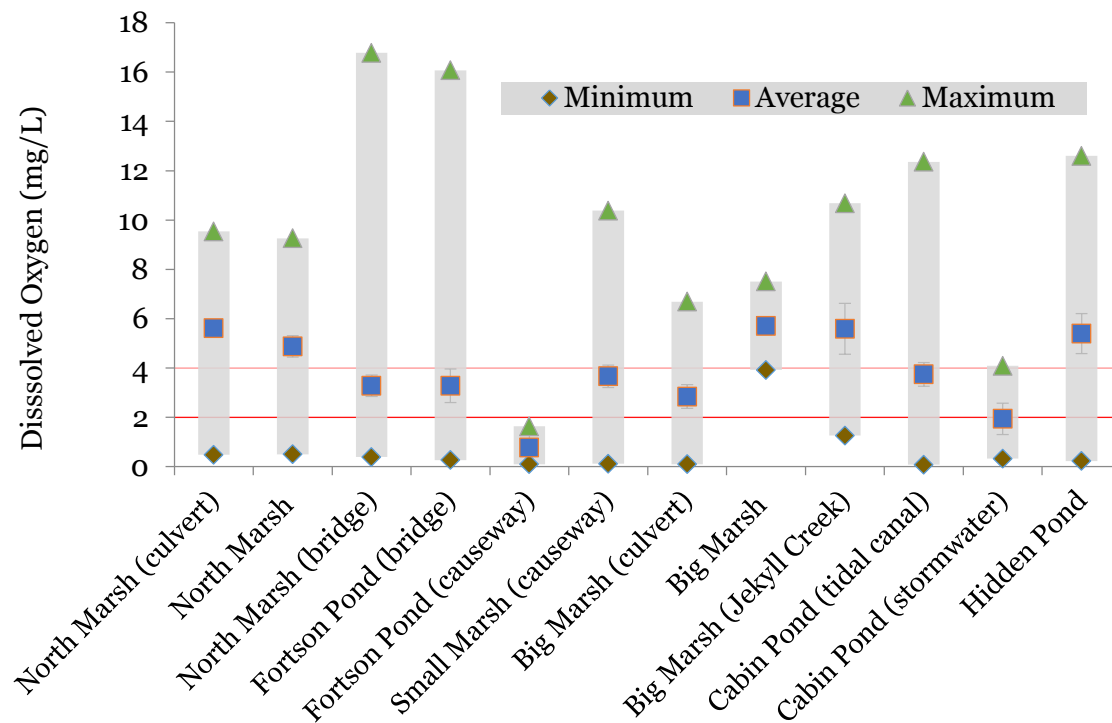


Figure 20. The extreme values (minimum/maximum) levels of dissolved oxygen indicate wide fluctuations in primary production, respiration, and decomposition in this high nutrient and constricted flow tidal system. The red grid lines (<4 mg/L oxygen stress, <2 mg/L hypoxic) indicate levels of risk for fish.
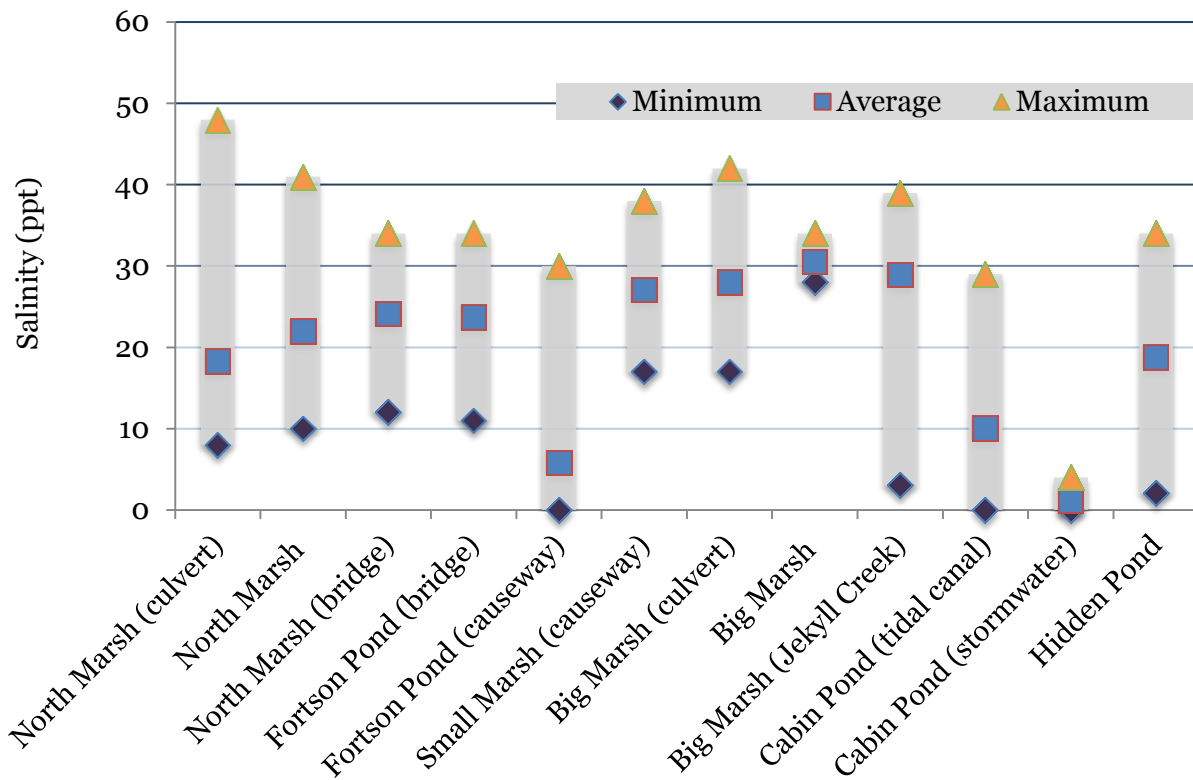
Figure 21. Seawater is generally ~30 ppt. Constricted tidal marsh creeks exhibited hypersaline conditions during the summer due to high evaporation. Low salinity levels (<5 ppt) in Fortson Pond and Cabin Pond reflect freshwater inflows through storm water culverts and possibly from surficial ground water sources influenced by irrigation and runoff from developed areas.

While all of the tidal creek fragments have total nitrogen levels in excess of the 0.5 mg/L intermediate eutrophy level, Fortson Pond's total nitrogen levels are in hypereutrophic range (average >6 mg/L; Figure 22). Total phosphorus levels are also in excess of the 0.05 mg/L reference level and the upper range of total phosphorus levels measured in Fortson Pond (4.8 mg/L) are among the highest reported in estuarine systems (Figure 23). Maximum Chlorophyll a levels exceeded the high range on eutrophic scale at all but the upper North Marsh site. Even the lowest Chlorophyll a values at Fortson Pond were always in the highly eutrophic range (>20 ug/L; (Figure 24).

Total phytoplankton cell counts were highest in water collected from Fortson Pond (causeway) and Small Marsh (culvert). Cyanobacteria were highest in Fortson Pond, but also present in some Hidden Pond samples. The most common species of cyanobacteria from Fortson Pond and Cabin Pond was *Aphanothece stagnina*. *Aphanothece stagnina* is not known to be toxic, but

produces a polysaccharide gel-like compound that fills the water column with suspended oxygen-demanding biomass in senescent stage. Dinoflagellates were most prevalent in North Marsh, but also high in Fortson Pond (Figure 25).

Fecal coliform colony counts were highest in Fortson Pond, exceeding 200 colonies per mL in November 2013 and 189 colonies per mL in August 2014. Small Marsh samples also returned high fecal coliform colony counts (47/mL in November 2013 and 193/mL in August 2014). Hidden Pond samples had much lower counts (6/mL in November 2013 and 0/mL in August 2014) (Table 2).

Coprostanol can be used as a biomarker for the presence of fecal contamination in sediments and can remain stable for hundreds of years, allowing for the detection of past fecal contamination. Sediment samples collected from Fortson Pond and from Cabin Pond contained Coprostanol concentrations indicative of significant sewage contamination (>500 ng/g). However, this data does not confirm the presence of ongoing or recent human sewage pollution because the coprostanol source could be historic. Furthermore, the analysis of Coprostanol alone is not sufficient to confirm human sewage pollution because it can derive from in-situ production in anoxic sediments or from wildlife feces. Nonetheless, these results, along with the fecal coliform data and the close proximity of sewage infrastructure, particularly to Fortson Pond, Cabin Pond, and Small Marsh, led us to the conclusion that ongoing sewage pollution could be a real possibility that needed to be confirmed or rejected.

Of the18 additional samples taken during November 2015 to further investigate microbial sources, 10 were collected from Fortson Pond (Ashlan report, Appedix B). Of these, six samples had total coliform counts above the detection limit effectively quantified by the Colilert-18® assay (>2420/MPN/100ml). Half (9/18) of the samples were also above the recreational criteria for *E. coli* ( >126 CFU/100 ml; USEPA, 2012). Five of these were from Fortson Pond. However, only two points (North Marsh and Fortson Pond) were positive for the HF183 marker, indicating the presence of recent sewage contamination at these sites (Table 2). The positive result from Fortson Pond was a low-level positive indicating a significant dilution effect. Contamination for a source external to Fortson Pond (e.g. North Marsh) is therefore considered a possibility.
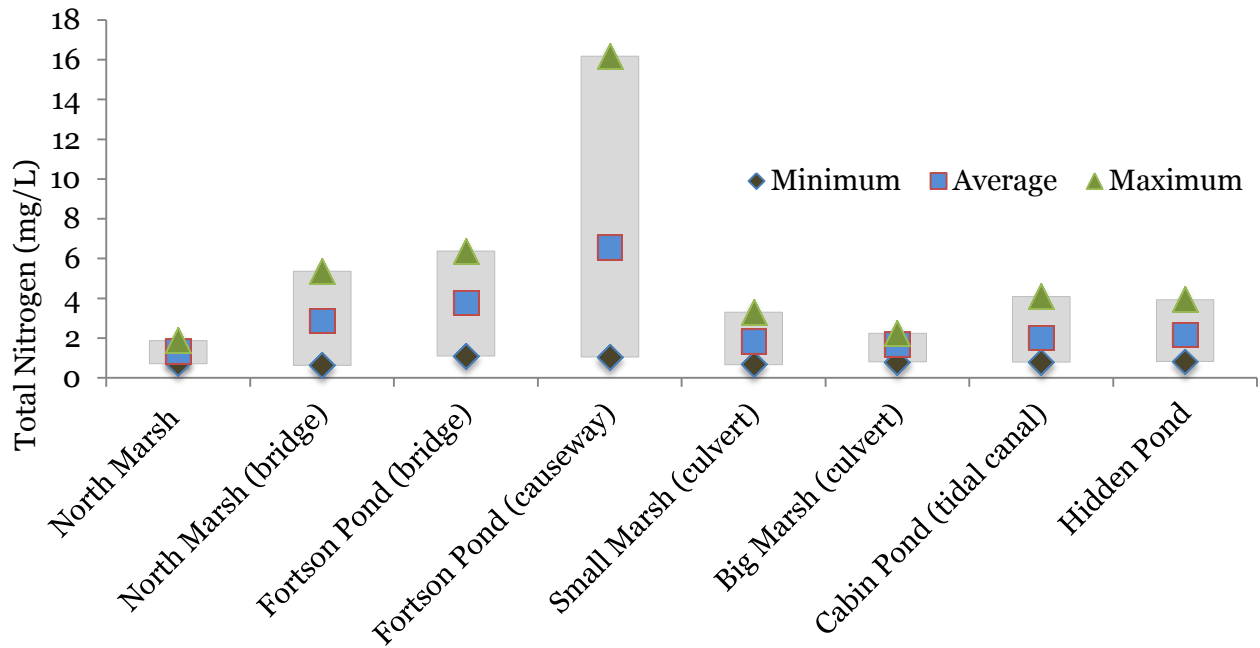
Figure 22. While all of the tidal creek fragments have total nitrogen levels in excess of the 0.5 mg/L (reference), Fortson Pond total nitrogen levels are in hypereutrophic range.
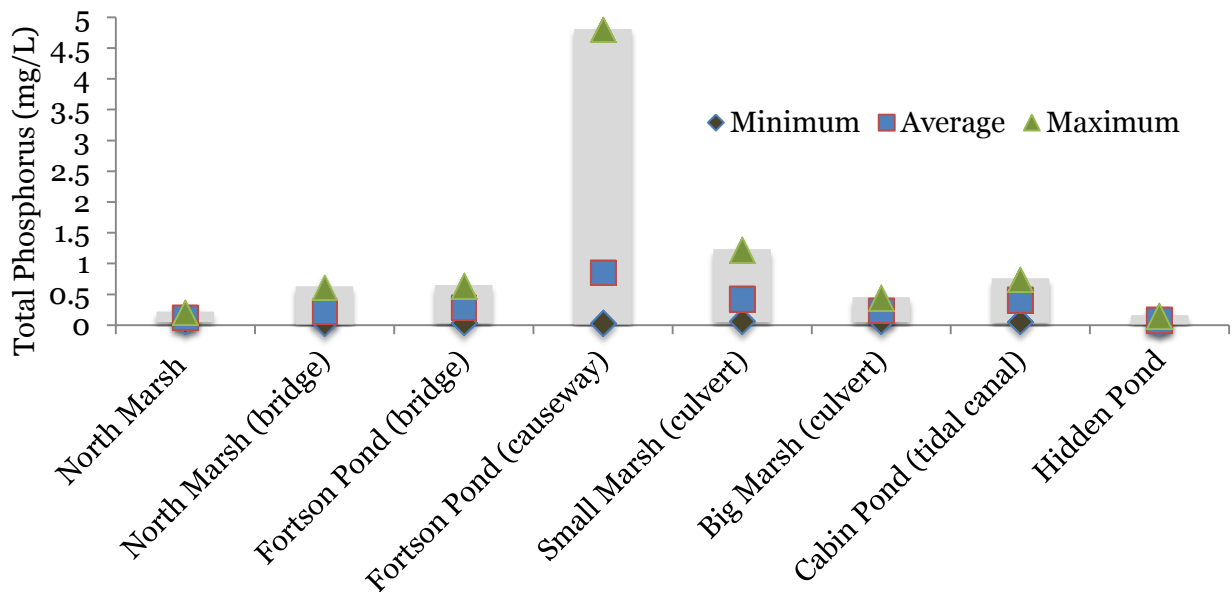


Figure 23. Fortson Pond total phosphorus levels are in hypereutrophic range (eutrophic >0.1 mg/L). Only North Marsh and Hidden Pond have average phosphorus levels below eutrophic range.
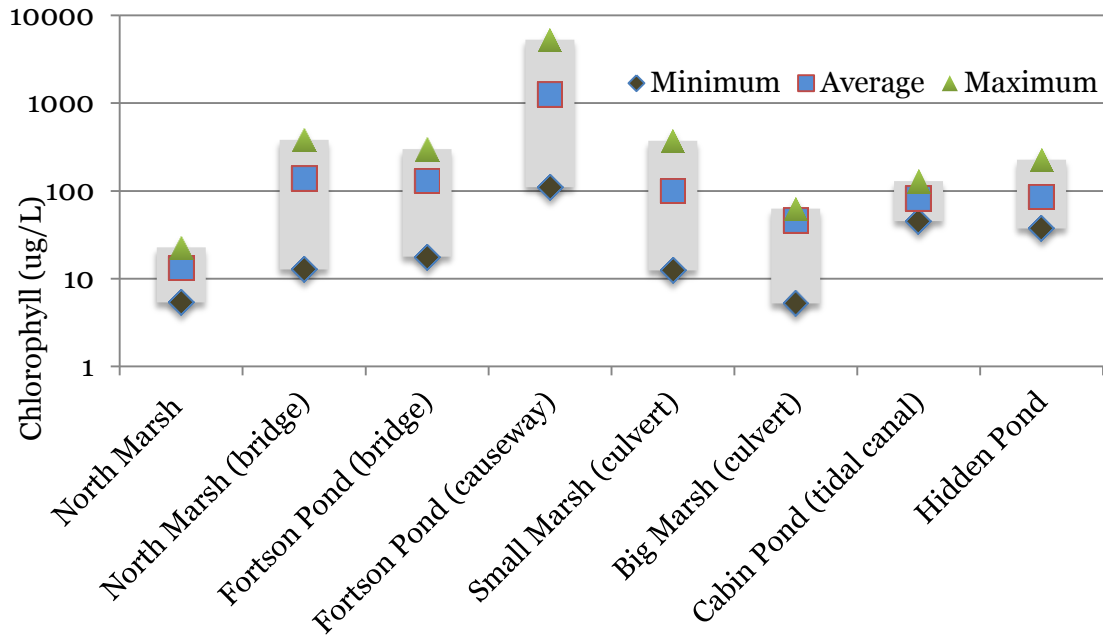
Figure 24. Maximum Chlorophyll a levels exceeded the high range on eutrophic scale at all but the upper North Marsh site. Even the lowest Chlorophyll a values at Fortson Pond were always in the highly euthrophic range (>20 ug/L).



Figure 25. Total phytoplankton cell counts by group in marsh fragments and ponds.

Table 2. Fecal bacteria was commonly detected at high levels throughout the project area. However, detection of definitive human sewage markers was limited to two locations.

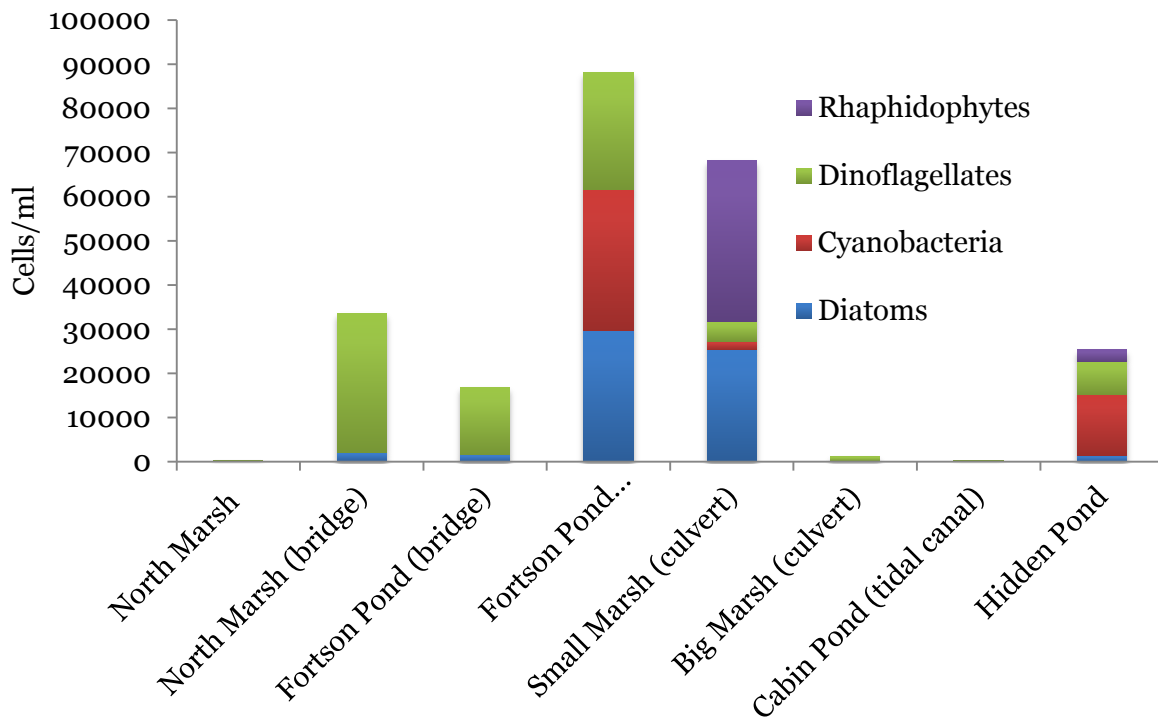| Location | | 11/26/13 Fecal coliform | 08/06/14 Fecal coliform | E. coli | 11/17/15 Total coliform | HF183 (CCE/100mls) |
|---|---|---|---|---|---|---|
| | | (CFU/100 mls) | | | | |
| North Marsh | bridge | - | 1800 | 1986 | >2419.6 | - |
| | tidal canal | - | 200 | 252 | >2419.6 | 157 |
| | bridge | 400 | 100 | 224 | >2419.6 | - |
| | bridge | | 200 | 200 | 1917 | - |
| | bridge | | | 96 | >2419.6 | - |
| | bridge | | | 1573 | >2419.6 | - |
| Fortson | bridge | | | 72 | >2419.6 | - |
| | causeway | >20000 | 18900 | 63 | >2419.6 | - |
| | causeway | | | 91 | 2203 | - |
| | causeway | | | 119 | >2419.6 | - |
| | causeway | | | 100 | 2203 | - |
| Fortson | causeway | | | 228 | 1860 | 40 |
| Small Marsh | causeway | 4700 | 19300 | 77 | 1770 | - |
| | causeway | - | 2300 | 202 | 951 | - |
| Cabin Pond | stormwater | - | 1700 | 223 | >2419.6 | - |
| | tidal canal | | | 157 | >2419.6 | - |
| Hidden Pond | upper | 60 | 0 | 32 | 1210 | - |
| | lower | | | 100 | 550 | - |

## Technical Synthesis

The two-year data gathering effort made possible by the Cycle 17 Coastal Incentive Grant supporting this project, has vastly improved our understanding of the ecosystem dynamics influencing Fortson Pond and the neighboring marsh fragments and ponds.

Collectively, the water quality and nutrient data indicate that the marsh fragments and ponds exhibit impaired water quality. The combination of high nutrient loading from development and the anthropogenic alteration of tidal circulation patterns on Jekyll Island has resulted in both tidal marshes and brackish ponds with characteristics of eutrophic estuarine systems. Interestingly, Hidden Pond, which had higher average salinities and less developed area within its buffer than Fortson Pond and Cabin Pond, did not exhibit eutrophic conditions and supports submerged aquatic vegetation, including widgeon grass and musk grass, rather than a chronically overabundant phytoplankton community. Hidden Pond therefore serves as an important reference, demonstrating that eutrophic conditions and resulting harmful algal

blooms are not necessarily inherent to all small, shallow marsh ponds with very limited tidal influence, characteristics common to Fortson Pond and both reference ponds. The commonalities shared by Fortson Pond and Cabin Pond, but not by Hidden Pond, include direct storm water runoff input from adjacent developed areas and adjacent buried sewage conveyance infrastructure. These factors, alone or in combination, are likely to be the causative agents behind the hypereutrophic conditions in Fortson Pond.

We now view Fortson Pond as an elevated retention basin with exceptionally high nutrient load. Fortson Pond's expanse of unvegetated mucky sediment is the accumulated dead biomass resulting from decades of overabundant phytoplankton blooms. A non-toxic colonial cyanobacteria species, *Aphanothece stagnina,* is believed to be the dominant over-abundant species. Importantly, we discovered that Cabin Pond appears to be along a similar ecological trajectory to Fortson Pond, but is not yet exhibiting an extreme accumulation of dead cyanobacterial biomass. Rather, it is experiencing an ongoing year round *Aphanothece stagnina* bloom. Consistent freshwater input at both sites is believed to be a contributing factor to this species' prolific abundance.

Despite that lack of detectable differences in the abundance or diversity of conspicuous wildlife relative to the other study areas, we remain convinced that Fortson Pond is in need of restoration. Evidence of impairment is clear in the poor water quality data, the paucity of macroinvertebrates, the overabundance of harmful algae.

The proximate drivers of these harmful algal blooms are evident in the water-level, nutrient, and salinity data. Relatively little tidal influence, along with lower salinity and high nutrient loads are conditions that both Fortson Pond and Cabin Pond have in common. Our bacteriological results do not indicate current sewage pollution directly discharging into either Fortson Pond or Cabin Pond. However, one weak positive result for human sewage contamination within Fortson Pond does suggest that Fortson Pond could be receiving tidal water contaminated by sewage from North Marsh. Even in dilute amounts, if an external sewage contamination source regularly is mixed with tidal water that then flows into Fortson Pond, the accumulated contamination could be a significant contributing factor to the Eutrophication problem. Historic sewage inputs may also be a possibility as evidenced by the Coprostanol analysis. This seems particularly likely at Cabin Pond, the name of which reflects the historical location of a home site. Regardless, we are cautiously confident that there is no "smoking gun" sewage leak directly discharging into either Fortson Pond or Cabin Pond that could simply be repaired and thus solve the problems of eutrophication and harmful algal blooms for either site.

**Appendix A.**

## Proceedings of the Fortson Pond Marsh Restoration Planning Advisory Workshop
## July 28th, 2015

### Participants

Kimberly Andrews, Ph.D. – Research Coordinator, the Jekyll Island Authority / Georgia Sea Turtle Center / UGA Odum School of Ecology

Ben Carswell – Director of Conservation, the Jekyll Island Authority

John Carswell – Satilla Riverkeeper (retired), Jekyll Island resident

Scott Coleman  - Ecological Manager, Little Saint Simons Island

Denis Frazel, Ph.D. – Principle Consultant at Frazel Inc., lead editor - Estuarine Habitat Restoration Planning Guide for Florida.

Lauren Gingerella –Ecological Technician, Little Saint Simons Island

Lizzy King, Ph.D. – Assistant Professor, UGA Warnell School of Forestry and Natural Resources and the Odum School of Ecology

Clay Montague, Ph.D. – Associate Professor Emeritus, University of Florida, Satilla Riverkeeper Board member

Guy Moore – Conservation Coordinator, the Jekyll Island Authority

Norm Shea – Expert in brackish pond management

Katy Smith – University of Georgia Marine Extension Service and Georgia Sea Grant

Skye Stockel – Georgia Department of Natural Resource, Coastal Resources Division

Lisa VanDiver, Ph.D., NOAA Restoration Center

Susan  Wilde, Ph.D., Assistant professor, UGA Warnell School of Forestry and Natural Resources

David  Zailo, Graduate Student, UGA Odum School of Ecology

### Executive Summary

On July 28th, 2015, we convened a select taskforce of experts and stakeholders to review the data collected and analyzed during the Jekyll Island Marsh Fragments research project, to provide feedback on our interpretation of the significance of these results, and to advise us as to the most productive next steps in planning for and ultimately achieving restoration goals for

Fortson Pond. The workshop consisted of a series of short presentations by the project's research partners (Ben Carswell, Yank Moore, Kimberly Andrews, Lizzy King, and Susan Wilde) to explain our interpretations of the data collected. This was followed by open discussion among the taskforce, a small group restoration planning exercise, individual prioritization of possible restoration actions, recommendations for continued data collection, discussion of challenges and knowledge gaps, and consideration of restoration possibilities for other marsh fragments included in the study area.

In discussing challenges and critical knowledge gaps, the taskforce members mostly agreed that major hydrologic engineering to restore Fortson Pond should not be pursued until the exisiting dataset is supplemented by predictive models based on the dataset and designed to predict hydrodynamic conditions that would occur following a restoration action or combination action. The workshop participants

Another important outcome of the workshop was the development of a working vision statement and statement of goals for the restoration of Fortson Pond.

## Working Vision Statement

When restored, Fortson Pond will be a continuum of mosaic habitats, supporting a diverse community of native fish, wildlife and plants, and providing connectivity with both the headwaters and the estuary.

## Goals

Improved water quality

- Reduced nutrient loads and increased average dissolved oxygen concentrations
- Zero occurrence of human source indicators of sewage pollution

Improved hydrology

- Increased frequency of tidal inundation and increased tidal range
- decreased residence time of water within Fortson Pond

Improved habitat for native invertebrates, fish, birds, mammals, reptiles, and plants

- Increased habitat complexity to support diversity and provide refugia
- Decreased dominance by and within the algal community
- Elimination of harmful algal blooms
- Enhancement of nursery value for commercially and recreationally valuable fish and invertebrates.

Improved public access

- Enhancement of scenic and wildlife-viewing opportunities for the general public
- Enhancement of educational value

## Restoration strategies discussed and ranked during workshop

After being presented with data analysis and interpretation from the Jekyll Island Marsh Fragments project, and collaboratively developing restoration plans in small groups, the participants were asked to independently prioritize a list of prospective restoration actions that included all those proposed by the small groups. We compiled the participants' prioritization scores and the results are below in order from highest priority to lowest priority actions.

- Install a culvert or other water conveyance under Fortson Parkway to reconnect tidal influence into Fortson Pond from the south, via Small Marsh (39 pts.)
- Rehabilitate the existing 48-inch culvert that connects Small Marsh with Big Marsh, to increase tidal range in Small Marsh and thus increase the amount of water that could move through a conveyance under Fortson Parkway (30 pts.)
- Dredge and remove the cyanobacteria generated bio-muck from Fortson Pond (27 pts.)
- Install flap gates or other water-control structures, such as weirs, to manage tidal exchange with Fortson Pond (16 pts.)
- Naturalize landscaping around stormwater inputs to reduce the possibility of nutrient and contaminant laden freshwater inputs from developed area runoff (15 pts.)
- Prevent tidal water in Fortson Pond from exchanging water with North Marsh (in conjunction with #1) to establish a "one-way system" for drainage to the South (14 pts.)
- Excavate the north end of Small Marsh (in conjunction with #1) to increase the amount of water that could move through a conveyance under Fortson Parkway (6 pts.)
- Remediate human sewage inputs (5 pts.)
- Collect data on essential knowledge gaps (5 pts.)
- Install a larger culvert, bridge, or other water conveyance between North Marsh and Fortson Pond or replace the culvert with a bridge to increase the flow capacity of tidal waters that can be exchanged with Fortson Pond from the north (2 pts.)
- Replace the existing culvert connecting Small Marsh and Big Marsh with a bridge (2 pts.)

## Post-workshop survey

Following the individual prioritization exercise at the workshop, participants engaged in a lively discussion centering around the question of whether the water-level dataset and analysis produced thus far could sufficiently justify any particular restoration actions. The consensus

answer to this question seemed to be "no". Several participants with key expertise indicated that rigorous hydrodynamic modeling, built on the water-level dataset and designed by professional engineers with coastal experience, would be necessary to be competitive for restoration funding and to be confident in the physical outcomes of restoration action. It seemed likely to us that this discussion followed by time for reflection would change how participants prioritized prospective restoration actions and perhaps how they viewed other implications of the project's results, if resurveyed. We therefore followed the workshop with an online survey and asked participants to respond to the following. Eight workshop participants responded to the online survey.

1. What should be our next step? Rank the following actions in order from most important to least important to accomplish in the near term.

- Address existing tidal bottlenecks by rehabing existing culverts and reducing channel obstructions
- Engage an engineer for cost estimate of constructing a hydraulic model for the system
- Confirm and locate source of possible sewage contamination
- Measure depth of "muck" across Fortson Pond to profile underlying sediments

The order listed above best reflects the respondent's collective prioritization.

2. Based on the information presented to you at the workshop: what do you believe is the better approach for managing Fortson Pond? Rank the following management approaches from best to worst in your opinion.

- Intermediate management: return natural tidal flow, managing flow direction with some configuration of directional water control structures and open conveyances.
- Passive management: return natural tidal flow though some configuration of open culverts/bridges
- Active management: Fortson pond is managed as an impoundment with directional water control structures and riser boards at all channelized tidal connections.

The order listed above best reflects the respondent's collective prioritization.

3. Based on the information presented to you at the workshop, rank the following restoration strategies in order of priority. Do not provide a ranking for any strategies that you do not believe are advisable without further information.

Here, respondents were asked to rank the same set of restoration strategies generated and evaluated during the workshop (listed above). However, in the post workshop survey, most respondents only recommended rehabbing and/or enhancing existing tidal connections rather than pursuing any major new engineering solutions without further information. This result seems to directly reflect the call for hydrodynamic modeling that concluded the workshop.

4. Based on the information presented to you at the workshop, rank the following restoration strategies in order of priority. Assume that a hydraulic model has been produced verifying that addition of a tidal connection between Fortson Pond and Small Marsh would increase daily influx of tidal water to Fortson Pond by at least 20% over current conditions and increase average salinity at the south end of the pond above 15 ppt. Do not provide a ranking for any strategies that you do not believe are advisable without further information.

Again, respondents were asked to rank the same set of restoration strategies generated and evaluated during the workshop (listed above). In this case, when given a simplistic, hypothetical model result about tidal flow, respondents indicated support for engineering and constructing a new water conveyance under Fortson Parkway to reconnect Fortson Pond with tidal flow from the south via Small Marsh, but still ranked this action below enhancement of existing connections. Other than the Fortson Parkway culvert, prospective restoration actions that involved major engineering and construction were either not supported based on this scenario or support was contingent on the success or failure the culvert installation in achieving restoration goals.

## Restoration Plan - outlook and next steps

The outlook for restoration of Fortson Pond is very hopeful and much closer to being realized due to this project. However, rigorous and strategically designed hydrodynamic modeling is a critical next step before the strategies to be included in a restoration plan can be explicitly specified. Pending the result of these models, we believe that a Fortson Pond restoration proposal would be highly competitive for funding from granting agencies and organizations. Importantly, such a proposal should highlight the improved value of Fortson Pond for fish,

macroinvertebrates, wildlife, and accessibility for people that would be generated by its restoration. Fortson Pond's place within the former First Creek system should be emphasized and opportunities to expand the restoration vision and goals to the larger system should ultimately be pursued.

**Appendix B.**

# Identification of pollution sources in Fortson Pond

Prepared by:

## Dr. Asli Aslan

Environmental Health Sciences Department, Georgia Southern University

Funded by:

## Jekyll Island Authority

December, 2015

Introduction[1]

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The aim of this study was to identify potential sources of anthropogenic pollution at Fortson Pond, Jekyll Island. This area has historically known for high number of fecal indicator bacteria (FIB). Microbial source tracking methods were used to identify the sources of these high numbers of FIB. The source of microbiological pollution at environmental waters may originate from sewage, stormwater, wildlife, and livestock and cause waterborne illnesses such as gastrointestinal illnesses, skin, ear, and eye infections. Microbial source tracking is a technique that targets the source by quantifying the microorganism of interest to match the source of pollution. This technique is based on quantitative polymerase chain reaction (qPCR) and capable of detecting any pathogen of interest with high sensitivity.

## Material and Methods

Samples were collected by the Jekyll Island Authority, on November 17, 2015 from Cabin Pond, Hidden Pond, Small Marsh, North Marsh, and Fortson Pond (Figure 1). A total of 18 samples were collected into 1 L sterile Nalgene bottles during low tide to limit dilution from uncontaminated estuarine waters. Samples were kept on ice until transported back to the laboratory. All samples were analyzed within 24 hr upon collection.

Culturable FIB were detected by Colilert-18® (IDEXX, Westbrook, ME). Total coliform and E. coli were reported as MPN/100 ml. For molecular analyses, samples were filtered through 0.4μm polycarbonate filters. DNA was extracted by bead beating method (USEPA 2013), followed by purification by a commercial kit. Sewage pollution marker (Bacteroides 16S rDNA gene HF183 marker) was detected by qPCR by using published primer and probe set (Green et al., 2014). Method blank (molecular grade water), no template control (molecular grade water) positive control (ATCC strains) and internal amplification control were used for quality control and quality assurance purposes.
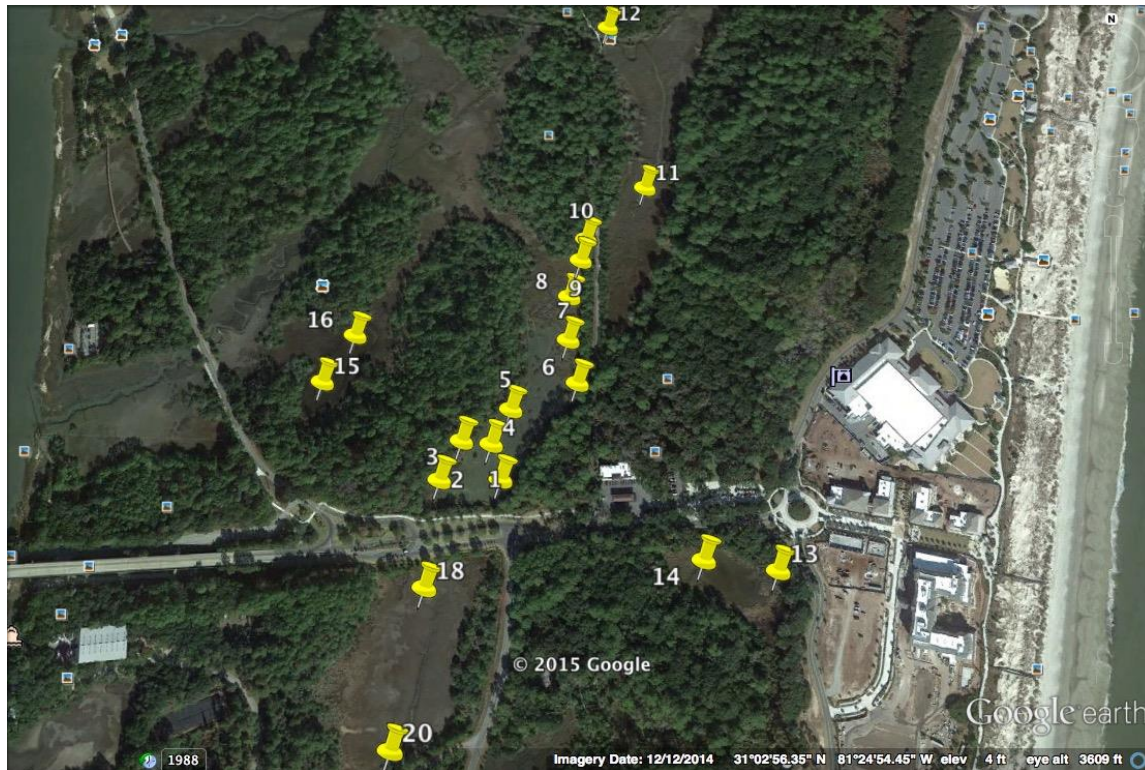
Figure 1. Location of the sampling points.

## Results

All 18 samples were analyzed for total coliform (culture), *E. coli* (culture), and HF183 (qPCR) and the results were summarized in Table 1. Total coliform was above detection limits at all points within the Fortson Pond, supporting the previous findings with fecal coliform at the same area. Coliforms had been historically used as FIB and current literature shows that this group is known as a commonly found indicator in the environment and existing naturally in the soil. Therefore, detecting high numbers of total coliform by itself would not indicate a potential fecal contamination source.

Current recreational water criteria organism for freshwater is *E. coli* and samples exceeding 126 CFU/100 ml should be reported as not appropriate for recreational activities (USPEA, 2012). According to our results from this study, 50% of the samples were not in compliance with the criteria and majority of these points were located at the Fortson Pond.

Table 1. Fecal indicator bacteria and HF183 marker concentrations at the study area.

| Sampling point | Total coliform (MPN/100 ml) | E. coli (MPN/100 ml) | HF183 (CCE/100 ml) |
|---|---|---|---|
| JST1 | >2419.6 | 1986 | BDL |
| JST2 | 2203 | 252 | BDL |
| JST3 | >2419.6 | 224 | BDL |
| JST4 | 2203 | 200 | BDL |
| JST5 | 1860 | 96 | 40 |
| JST6 | >2419.6 | 1573 | BDL |
| JST7 | 1917 | 72 | BDL |
| JST8 | >2419.6 | 63 | BDL |
| JST9 | >2419.6 | 91 | BDL |
| JST10 | >2419.6 | 119 | BDL |
| JST11 | >2419.6 | 100 | BDL |
| JST12 | >2419.6 | 228 | 157 |
| JST13 | >2419.6 | 77 | BDL |
| JST14 | >2419.6 | 202 | BDL |
| JST15 | 1210 | 223 | BDL |
| JST16 | 550 | 157 | BDL |
| JST18 | 1770 | 32 | BDL |
| JST20 | 951 | 100 | BDL |

BDL: below detection limit

Similar to total and fecal coliforms, recent literature reports that *E. coli* tends to grow and survive in the freshwater environment especially in warmer climates. In this study, we also used microbial source tracking to overcome false positives. We used a sewage-associated marker (Bacteroides HF183) that is 99% specific to human feces to identify potential sewage pollution in this area. This marker has been reported as the best indicator of sewage pollution in water

(Layton et a., 2013). Our results showed that, two points (JST5 and JST12) were positive for HF183 marker, indicating sewage contamination at these sites. The concentration of this marker also helps to understand the magnitude of the pollution. Previous studies showed that this marker exists in raw sewage in the order of $10^5$-$10^6$ CCE/100 ml and $10^1$-$10^2$ CCE/100 ml when freshly introduced in the environment as wastewater treatment plant effluent (Srinivasan et al., 2011). Bacteroides marker has relatively short persistence in the environment (Brooks et al., 2015) therefore with the dilution factor from a potential source at JST12 clearly shows a recent sewage contamination at this point.

## Conclusion

In conclusion, according to this one-time spatial sampling event results, Fortson Pond has high concentrations of *E. coli*. Detection of HF183 marker showed that there is sewage pollution in this area. The concentrations of HF183 show either a dilution effect due to the distance from a potential source or weather conditions such as temperature and tidal movements. HF183 marker was not detected in other ponds during this study, and *E. coli* concentrations were lower than the Fortson Pond.

Further analyses from the same site and its vicinity at various tidal and weather conditions (before and after rainfall, winter versus summer) are recommended to identify the location of the sewage source.

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