Seasonal & Spatial Variations of Nutrient Concentrations in the Sanibel Slough: Implications for Watershed Management

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Abstract— **The Sanibel Slough is the most important surface water river on Sanibel Island and the water from it is often reclaimed for other uses by weirs that separate it into two basins, west and east respectively. However, water quality should always be under constant monitoring and study to ensure that it is safe for use by the public and monitoring water quality can be used to detect possible contamination. In this study, the nutrient concentrations for both the dry and wet seasons and between the west and east basins were evaluated using discharge data from weirs and nutrient concentration data from monitoring wells located at selective sites in the slough. Two key components of water contamination that are crucial and must be observed when reclaiming water are the macro elements nitrogen and phosphorous. This study focused on total nitrogen, inorganic nitrogen, total phosphorous, orthophosphate, and ammonia. The results of this study showed that these parameters were significantly different for the seasons while the west basin had significantly higher total nitrogen and ammonia. While these nutrients concentrations are different, there needs to be additional analysis with regards to groundwater, runoff, and precipitation.**

I. INTRODUCTION

Sanibel and Captiva Island are part of a barrier island chain in Southwest Florida, specifically the lower west coast of Lee County, Florida. The population of Sanibel Island was 7,401 in 2019, according to the U.S. Census. Sanibel Island is also the home to the nonprofit research and conservation facility of the SCCF (Sanibel Captiva Conservation Foundation), and the organization has worked in partnership with the City of Sanibel on preserving the environment on the island.

With southwest Florida experiencing development during the past few decades, the area is undergoing substantial growth and thus is causing geological strain on its aquifers that supply water to the local populace. Fresh ground water on Sanibel and Captiva through two main aquifers, the Hawthorn and Suwannee aquifers (Boggess 1974). Today, 15 wells are primarily used to obtain water and are dug between 500 to 700 feet in depth and still use these two aquifers. Those wells have been shown to yield no quantities of fresh, usable water and typically provide brackish water, particularly in the dry season. This saline water was treated in the past through the process of electrodialysis to make it consumable for the public but is now done with the process of reverse osmosis (Force 2018).

In the mid-1940s, the Sanibel Slough was a natural series of canals on the island that were not connected. The Sanibel Slough saw construction started in the late 1950's for the purpose of mosquito control after Wayne Miller founded Lee County Mosquito Control in 1956 (Lee County Hyacinth Control District). Most of the drainage and dredging channels between wetlands on the interior of the island to serve the purpose of a drainage system and assist in controlling mosquito by having water flow occurred in the early 1960s. and was completed in 1971. The Sanibel Slough stretches in a predominantly east–west orientation through the island's ecosystem. Today is it commonly referred to as the Sanibel River. The early stages of the slough being created have been archived with aerial photographs by the U.S. Department of Agriculture in 1944, Figure 1.

Figure 1: Sanibel Slough in 1944 (Flores and Albright 2017).

In the southeastern US, the presence of organic carbon and other electron donors in soils and shallow groundwater has been shown to be an important control on redox conditions and hence the fate of contaminants in surficial aquifers (Tesoriero et al. 2004). Sanibel soil mainly consists of sand, shells, limestone, and clay and overall is very poorly drained sandy soils with organic surfaces that form in rapidly permeable marine sediments. With the passage of time, nutrients, and a high water table, these soils have formed into very thick beds of various sands that are beneath a thin mantle of organic materials. Nutrient concentrations in Sanibel's surface and groundwater are critical in determining the chemical, mass balance of the island for maintaining the environment. The surficial aquifers consist of the saturated part of the upper sequence of unconsolidated, unconfined sediments on Sanibel and are also known as the water table aquifer (Missimer 1976).

Substantial effects on both surface and ground water quality can be observed with changes in the seasons. The fluctuations of the water table have a distinctive, seasonal pattern. The water levels in these surficial aquifers are at their maximum towards the end of the wet season, which is considered October, and are at their minimum towards the end of the dry season, which is considered April. These changes in seasonal water levels can be crucial in determining how nutrients like the macro elements nitrogen and phosphorus are transported in Sanibel Island's groundwater and surface waters.

Inorganic nitrogen, like ammonia, is a better indicator for pollution than the amount of total nitrogen in a system because that type of nitrogen is easily available for primary producers, such as algae, after it has been loaded into surface water. Organic nitrogen, like nitrogen oxides, in groundwater is primarily composed of dissolved organic matter and isn't readily available for uptake by primary producers. The decomposition of heterotroph matter in soil and surface water is the central source of dissolved organic matter in the Sanibel Slough.

Phosphorus though is a commonplace component of fertilizers used for agriculture, manure, and organic wastes in raw sewage and industrial waste. It is a critical part of a plant's lifecycle, but when it is in excess, it can speed up the process of eutrophication, a reduction in dissolved oxygen in bodies of water that is caused by an increase of organic, mineral, and chemical nutrients (USGS 2011). Soil erosion is another primary contributor of phosphorus to aquifers. Also, bank erosion that occurs during sudden, large downpours of water can transport a large magnitude of phosphorus from the surface soil into deeper parts of the vadose zone.

This study is focused on the surficial aquifers of Sanibel, but specifically the Sanibel Slough and the concentration of nutrients in it. Nitrogen and phosphorus in surface water all play a factor in the barrier island's ecology. Nitrogen will be broken into inorganic nitrogen and total nitrogen and phosphorus will be further broken down into orthophosphate and total phosphate. The purpose is to find the difference in quantity of these chemical contaminants and intrinsic elements of water between the wet and dry seasons and the east and west basin since they play such a critical role in Sanibel's environment and water supply. Comparisons between the results of 2020 and previous years will be done to measure if nutrient concentrations have decreased or increased over time.

II. METHODS

The Sanibel Slough is separated from San Carlos Bay and the Gulf of Mexico by a series of control weirs at Sanibel-Captiva Road, the west basin, and beach road, the east basin. The Sanibel Slough is further split into eastern and western basins by another weir, which is located at Tarpon Bay Road (Thompson & Milbrandt 2016). This divide is the basis for the division of the slough into the east and west basins and the reason for this is because water rarely passes from the west basin to the east basin. The reason for this is because land use and development and water quality between the two basins differ significantly. The land of the eastern basin is more urban, and the land of the west basin is less developed area. The land adjacent to the west basin has multiple acres of preserves that helps to provide the slough with a buffer of vegetation from the more developed sections of the island (Flores and Albright 2017). Figure 2 shows the general outline of these two basins and the location of these weirs in relation to the Sanibel Slough.

Figure 2: Separation of east & west basin and location of weirs (Thompson & Milbrandt 2016).

In the early 1990's, Sanibel instituted a weir control policy to help control surface water. This policy is meant to assist in retaining as much fresh, surface water as possible as it is being processed through weirs and the water management system (City of Sanibel). This is for the benefit of the environment's interior wetlands and it will continue to be implemented if more urban areas aren't severely impacted. Figure 3 shows an example of the type of weir used on Sanibel. These weirs were used to periodically measure the discharge for almost every month of the year 2020. The Beach Road and Tarpon Bay Road weirs are where the discharge data originates from.

Figure 3: Control weir on Sanibel (City of Sanibel).

Monitoring wells were placed along the Sanibel Slough to provide a general idea of how the groundwater interacts with the Sanibel Slough. These monitoring wells were installed at six locations, Figure 4, to provide nutrient concentration data of the surficial aquifer discharge zone to the Sanibel Slough. Three monitoring wells were distributed in the east basin and three were placed in the west basin.

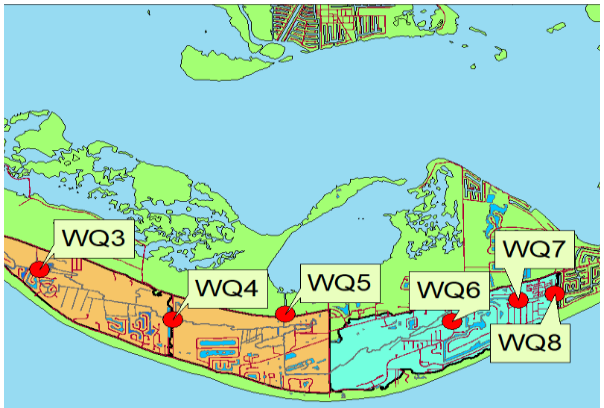


Figure 4: Location of monitoring wells for measuring nutrients.

Table 1 shows the latitudes and longitudes for the exact locations of the monitoring wells that are mapped in Figure 4.

TABLE 1. LATITUDES AND LONGITUDES FOR MONITORING WELLS

SITE	SITE_DESCR	LAT	LONG
WQ3	Sanibel River Gulf Pines Drive	26.44745800000	-82.13169200000
WQ4	Sanibel River Rabbit Rd.	26.43768300000	-82.10789400000
WQ5	Sanibel River Tarpon Bay Wier	26.43880800000	-82.08788100000
WQ6	Sanibel River casa ybel	26.43736400000	-82.05823300000
WQ7	Sanibel R. Donax Rd	26.44161100000	-82.04639700000
WQ8	Sanibel R. W. Side Beach Rd We	26.44271700000	-82.03994200000

The monitoring wells were constructed with 1.25-inch diameter PVC and were inserted approximately far enough into the ground so that they were 1 meter in the surficial aquifer zone. A hand auger with up to 15 feet of extensions was utilized to drill bore holes so that the wells could be placed. After initial installation, each well was completed by pumping water using a Masterflex tubing pump with a capacity of 200 ml/minute. A schedule was developed to sample each well once a month with that pump, thus, allowing assessment of differences in concentrations. Samples were preserved according to the Florida DEP SOP 1000 and were then shipped to a NELAC certified laboratory for nutrient analysis within the allotted holding times for storage.

The slough is monitored and observed to keep the interior wetlands hydrated and to prevent flooding for the more urban areas of the island. This tactic results in minimal discharges from the weirs themselves, except in situational storm events, such as hurricanes, cyclones, or excessive rainfall. It has the added benefit of helping to prevent the spread of invasive species, such as Brazilian Pepper, due to the seeds traversing through the waterway of the Sanibel Slough to germinate.

Nutrient concentrations for the slough were estimated by multiplying discharges of the weirs (ft^3) by average nutrient concentrations (mg/L) obtained from sampling events at the well sites every month; the discharge rate was converted from (ft^3) to (L). This way the approximate quantity of certain nutrients could be determined in the slough at any time. An annual, total nutrient concentration was estimated from this method and was used to provide estimates of the mass of nutrients that travel in the Sanibel Slough between the wet and dry seasons and between the west and east basin. Finally, a paired, two tail t-test was used to determine if the differences between the wet and dry season for nutrient concentrations were significant at all.

The biggest challenge for this project was dividing this data into so many different classifications, such as whether this data belonged to either the east or the west basin, or if it was part of the wet or dry season. To address this issue, multiple different dataframes were created so that this data could be categorized so that it could easily be graphed and compared to each other for the final report. That, and simple calculations can be applied to the dataframe to find intended values. Also, for nutrient concentration there were some missing gaps in data, particularly for the months of August and September. To compensate for this, nutrient concentration data from the previous ten months was averaged for both months. This was to give a more comprehensive analysis of both watershed basins of Sanibel.

III. RESULTS

Table 2 displays the discharge volume through the usage of the Beach Road weir representing the east basin and Tarpon Bay Road weir representing the west basin when there were discharges for the year of 2020 for the Sanibel Slough.

TABLE 2. DISCHARGE DATA FOR EAST AND WEST BASINS

	WEST BASIN DISCHARGE (L)	EAST BASIN DISCHARGE (L)
JAN-20	8,776,594	7,200,991
FEB-20	17,558,000	4,831,186
MAR-20	-	-
APR-20	-	-
MAY-20	2,407,013	-
JUN-20	-	-
JUL-20	-	175,141,300
AUG-20	272,125,800	214,989,800
SEP-20	4,153,785,000	2,435,046,000
OCT-20	462,240,000	215,616,800
NOV-20	311,586,800	272,560,800
DEC-20	51,441,970	743,329,500
SUM	5,279,921,220	4,068,716,766

Figures 5 & 6 show the volume of the discharges, measured in liters, from both the west and east basins respectively.

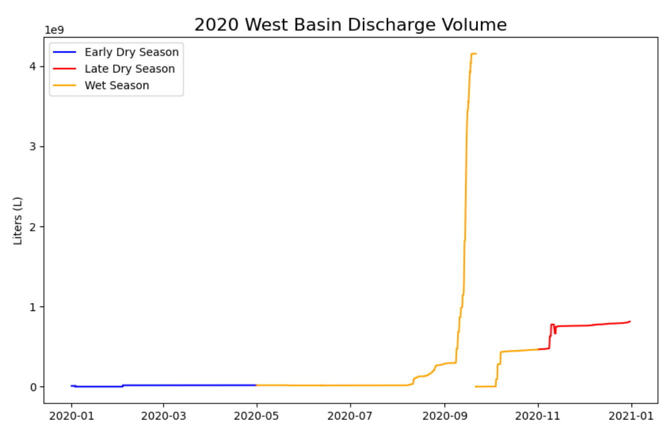


Figure 5: West Basin Volume Discharge.

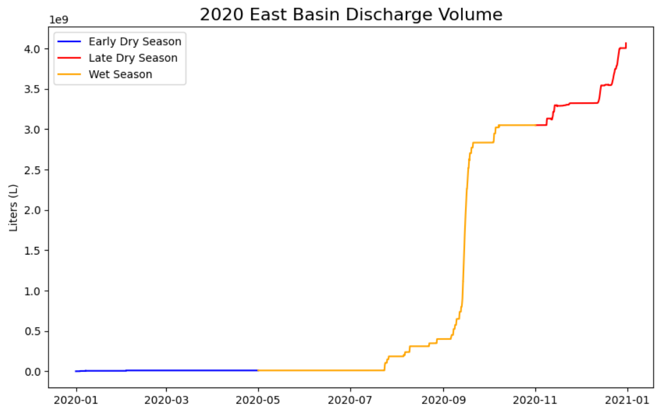


Figure 6: East Basin Volume Discharge.

Tables 3 & 4 display the average nutrient concentration data calculated from the data the three monitoring wells for each month of the year 2020.

TABLE 3. NUTRIENT CONCENTRATIONS AVERAGES FOR WEST BASIN

WEST BASIN					
	TN (mg/L)	TP (mg/L)	IN (mg/L)	OP (mg/L)	NH^3 (mg/L)
JAN-20	2.3	0.073	0.021	0.03	0.015
FEB-20	2.150	0.074	0.015	0.065	0.008
MAR-20	2.020	0.103	0.024	0.079	0.018
APR-20	2.533	0.290	0.025	0.072	0.019
MAY-20	2.377	0.086	0.202	0.038	0.196
JUN-20	2.427	0.090	0.032	0.061	0.026
JUL-20	2.247	0.114	0.070	0.085	0.064
AUG-20	2.302	0.111	0.056	0.059	0.051
SEP-20	2.302	0.111	0.056	0.059	0.051
OCT-20	3.240	0.084	0.027	0.082	0.021
NOV-20	1.847	0.067	0.096	0.057	0.090
DEC-20	1.877	0.130	0.070	0.021	0.055

TABLE 4. NUTRIENT CONCENTRATIONS AVERAGES FOR EAST BASIN

EAST BASIN					
	TN (mg/L)	TP (mg/L)	IN (mg/L)	OP (mg/L)	NH^3 (mg/L)
JAN-20	1.887	0.123	0.032	0.056	0.026
FEB-20	1.763	0.113	0.014	0.087	0.008
MAR-20	1.703	0.121	0.014	0.115	0.008
APR-20	2.617	0.139	0.029	0.049	0.023
MAY-20	2.640	0.127	0.027	0.089	0.011
JUN-20	2.383	0.175	0.021	0.097	0.015
JUL-20	1.923	0.138	0.275	0.107	0.037
AUG-20	2.079	0.126	0.050	0.084	0.020
SEP-20	2.079	0.126	0.050	0.084	0.020
OCT-20	2.907	0.130	0.016	0.105	0.010
NOV-20	1.627	0.118	0.033	0.095	0.027
DEC-20	1.337	0.078	0.047	0.036	0.040

Table 5 displays the average nutrient data from both basins for TN (Total Nitrogen), TP (Total Phosphorous), IN (Inorganic Nitrogen), OP (orthophosphate), and NH^3 (ammonia) for the wet and dry seasons of the Sanibel Slough. These results were gathered by multiplying the discharge of the weirs, the amount of water flowing through the weir, with the nutrient concentration averages for the basins and further averaging that data for the dry and wet seasons. For a study like this, flow data would have been more optimal, but that data was unfortunately that data wasn't very consistent and very sparse in obtaining.

TABLE 5. COMPARISON OF NUTRIENT DATA BETWEEN WET AND DRY SEASONS FOR COMBINED EAST AND WEST BASIN VALUES

Outcome Data		
Outcome	**Wet Season**	**Dry Season**
TN (kg)	18162.47	2188.93
TP (kg)	916.95	120.95
IN (kg)	447.20	78.05
OP (kg)	565.06	74.06
NH^3 (kg)	299.41	68.57

Figure 7 displays a graphical representation for the nutrient concentrations between the wet season and the dry season of 2020 for the Sanibel Slough based on the data shown in Table 5.

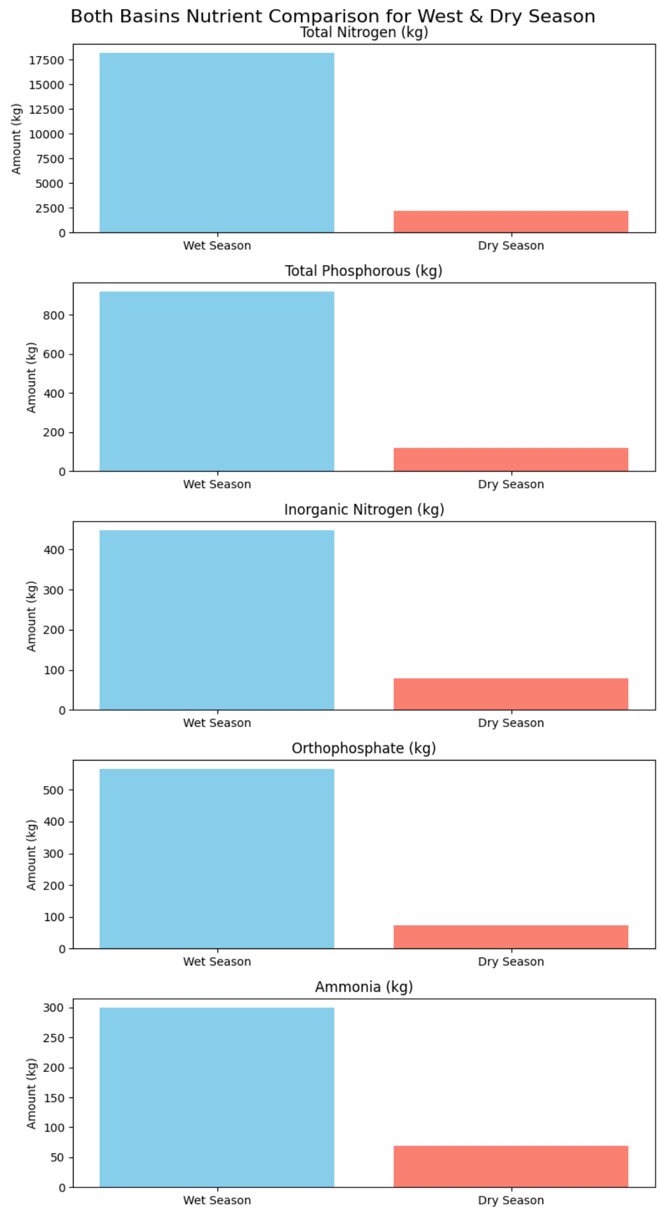


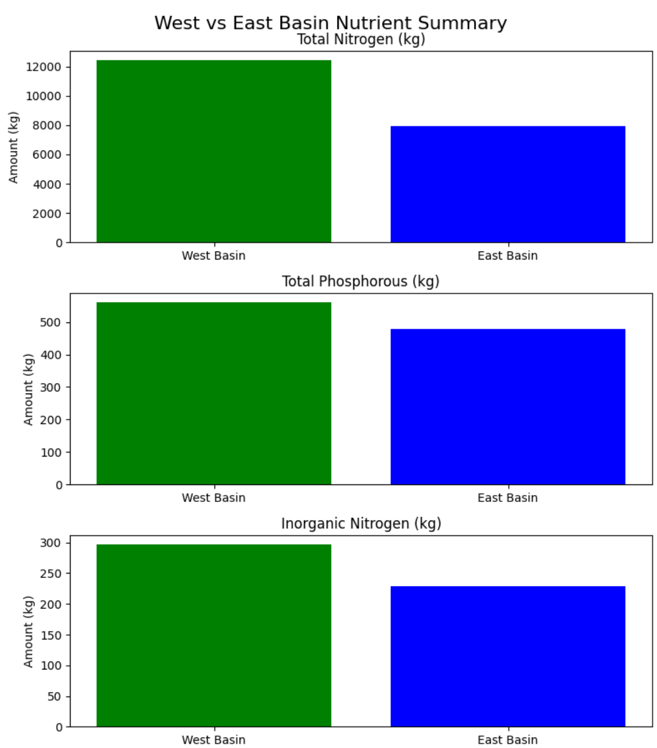
Figure 7. Comparison of both basins for the Wet & Dry seasons.

The nutrient concentration results demonstrate there is a numerical difference between the months of November-April and May-October. The results of the several two tailed paired *t*-tests comparing individual month nutrient data between the wet season and dry seasons showed a significant difference calculated with a $\alpha = 0.05$. This demonstrates a significant difference in all nutrient concentration data between the wet season and the dry season for the Sanibel Slough in the year 2020. Table 6 displays the total nutrient data for TN, TP, IN, OP, and NH^3 between the east and west basins for the Sanibel Slough in kgs for 1 year with measurements occurring roughly every month.

TABLE 6. COMPARISON OF NUTRIENT DATA BETWEEN WEST AND EAST BASIN

Outcome Data		
Outcome	**West Basin**	**East Basin**
TN (kg)	12420.22	7931.18
TP (kg)	559.92	477.98
IN (kg)	296.60	228.64
OP (kg)	320.99	318.13
NH^3 (kg)	268.19	99.80

Figure 8 is a graphical representation of the differences in nutrient amounts between the different basins for the year 2020 and is based off the data in Table 6. For this figure, it is comparing the total amounts of nutrients for both the wet and dry seasons.



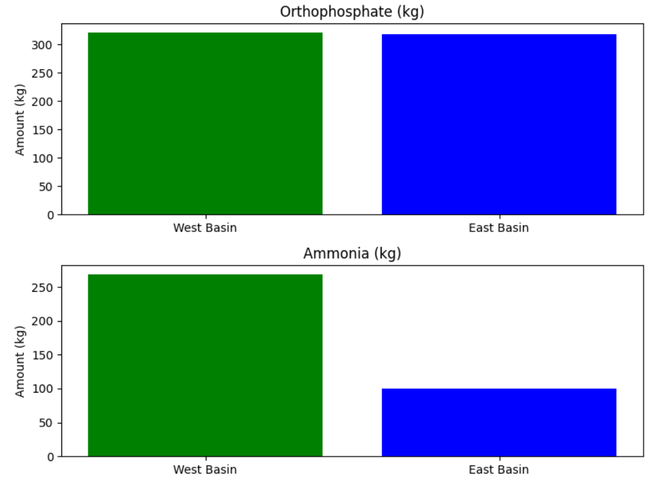


Figure 8. Nutrient Comparison between East & West basins.

The results show there is a numerical difference between the east and west basins, but to varying degrees. The results of the several two tailed paired *t*-tests comparing individual month nutrient data between the east and west basin show difference calculated with a $\alpha = 0.05$. This shows a significant difference between total nitrogen and ammonia, but not a significant difference for the other nutrients.

IV. DISCUSSION

Both Tables 2 & 6 show that there is a significant difference between the nutrient concentrations between both the wet and dry seasons and the west and east basins of the Sanibel Slough. There are some similar trends and some minor inconsistencies though. Nutrient concentrations consistently increase dramatically during the wet season as opposed to the dry season. The reason for this is primarily the significant change in precipitation, which increases the amount of horizontal discharge for the weirs, and increased evapotranspiration, the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

Sites with higher rates of evapotranspiration are usually found to have significantly greater concentrations of TN, TP, OP, and IN (Thompson & Milbrandt 2016). Higher rates of evapotranspiration are associated with sites of dense vegetation and therefore have a larger concentration of organics in the soils. As a result of these nonmetallic ligands and molecules being lodged in the soil, it has a higher ionic holding capacity for other molecules (Shuler 2019). This combined with aeration, the process by which air is circulated and mixed with a liquid, helps immobilize those nutrients, preventing them from spreading and and causing local concentrations of those nutrients (Silveira 2019). That helps explain why there is a thin, organic layer that adsorbs on the surface of the soil on Sanibel. Also, the fact that water rarely crosses from the west basin to the east basin outside of discharges allows us to get an accurate representation of nutrients for the Sanibel Slough.

There is a difference between the west and east basin though. The amount total phosphate and orthophosphate is almost higher in the east basin than the west basin while the opposite occurs for the nitrogen. A possible explanation of this is the fact that the land of the east basin is more urban as compared to the west basin. Golf courses, sewer systems, and reclaimed water are three factors that can be associated with higher nutrient concentrations from the surficial aquifer. Golf courses use fertilizer and reclaimed water that is nutrient-laden for irrigation of their flora to maintain the area and phosphate is a common component of fertilizer. This fact would significantly increase the amount of phosphate for one basin as opposed to the other. To reduce nutrient concentrations from these sources, a reduction in usage of this nutrient-laden, reclaimed water and usage of fertilizer should be implemented. The fact that the west basin has higher amounts of nitrogen, both total and inorganic, can also be explained by the lack of urbanization of the land on the island's west basin. The larger number of preserves equals more vegetation being present per square foot, thus, there is more organic matter dissolved into both the soil and the water. That's what ultimately leads to there being more nitrogen in the west basin, the total amount of heterotrophs as a result of less development.

Some discharge data and nutrient data is missing, particularly around the end of the wet season, the months of August and September. The reason for this is primarily because of Hurricane Sally in September 2020 and resulted in the schedule in collecting nutrient data not being followed for two months. Sanibel island is subject to the periodic influence of tropical hurricanes that occur usually during the wet season. Though the high precipitation is primarily the reason why discharges recorded by both weirs was unusually high for the month of September. There are some months where the weirs do not discharge any water at all, primarily during the dry season, because there simply was not enough water to be discharged by the weir into the next section of the slough.

However, it is important to compare the results of this study to the study conducted by Mark Thompson and Eric Milbrand in 2015-2016 about nutrient concentrations being discharged to surface waters. The reason for this is to see if Sanibel's remediation of the slough is effective in decreasing the amount of nutrients. Based on the study conducted there, there has been a significant decrease in IN, OP, & TP with 87%, 64%, and 63% decreases, respectively. Unfortunately, there has been an increase in the amount of TN, approximately a 24% increase, but the reason for that is most likely because of Hurricane Sally causing such a large amount of discharge in the weirs and placing more vegetation into the Sanibel Slough as the high force wings scattered vegetation across the island. Therefore, for a complete evaluation of the concentration of nutrients for the Sanibel Slough, future studies should include an analysis of surface runoff, precipitation, and groundwater. A GIS (geographic information system) analysis could be potentially done to identify potentially high, local concentrations of contaminants. This might be able to assist in determining why phosphate concentrations are higher for the eastern basin while nitrogen concentrations are higher for the western basin.

V. Conclusion

In summary, there is a significant difference for nutrient concentrations between the two basins and the wet and seasons for the Sanibel Slough. The wet season yields significantly more nutrient concentrations for TN, TP, IN, OP, and NH^3 than during the dry season because of the amount of rainfall/ horizontal discharge of the weirs into the river. This study has also found that all nutrient concentrations in this study have a significant difference between the basins for TN & NH^3 and the rainfall seasons due to the results of the t-tests.

TP, IN, and NH^3 are significantly higher in the west basin while TP and OP are almost higher in the east basin. The reason for this is because the east section of the island is more developed, thus leading to more phosphorous from manmade, commercial products such as fertilizer and sewage being exposed to the environment. This contrasts with the lack of development for the west section of the island which has relatively little development and has more plant life to provide nitrogen in the form of dissolved organic matter to the Sanibel Slough. Though the west basin is larger.

Based on similar studies, there have been significant decreases in TP, OP, and IN over the course of a few years, which demonstrates that remediation attempts for the Sanibel River have been effective overall. Even though TN increased that might be because of the unprecedented weather phenomenon called Hurricane Sally. If a deeper investigation is to be conducted for remediation use of the Sanibel Slough, further analysis of the ground water and runoff from precipitation should be conducted. Also, to see the effects that a hurricane has on nutrient concentrations, more data should be collected in the future immediately before and after a hurricane has hit an area.

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