# ASSESSING THE INFLUENCE OF LAND USE AND CLIMATE VARIABILITY ON NUTRIENT CONCENTRATIONS IN FLORIDA LAKES

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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To my parents

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Geology and physiographic characteristics are factors that determine background nutrient concentrations in lakes. This research examined the impact of land use type (agriculture, urban, forest and wetland) on nutrient concentrations (total phosphorus [TP] and total nitrogen [TN]) in Florida lakes, after accounting for local geology. Static relations between land use type and lake nutrient concentrations were examined for 87 lakes within individual phosphorus zones (TP zones established for Florida's numeric nutrient criteria) for two discrete time periods (1989/1990 and 2009/2010). Agriculture and wetland land uses showed the most significant positive correlations between static percent area and nutrient concentrations within each time period. Surprisingly, urban land use showed multiple significant relations, but they were negative, displaying lower nutrient concentrations related to higher percent urban area. Forest cover also showed primarily negative significant correlations with nutrient concentrations. Examination of concurrent changes in nutrients and land use over time (1889/1990 to 2009/2010) showed only two significant positive relations (one each with agriculture and wetland) out of a possible 24, suggesting other factors may have influenced lake nutrient concentrations through time. Adjusted cumulative rainfall deviation (ACRD), calculated

from data collected at the nearest weather station, was correlated with nutrient concentrations within individual lakes over time. Multiple significant negative (seven for TP and 11 for TN) and positive (25 for TP and 11 for TN) relations were found between nutrient concentrations and ACRD. Discovery of both positive and negative correlations between rainfall and lake nutrient concentrations over time suggests that mechanisms other than cumulative rainfall influence lake trophic status. This research suggests that land use and other factors can impact nutrient concentration in Florida lakes and a thorough investigation of individual lakes must be considered before adopting a nutrient management plan that can be applied generally to Florida lakes.

CHAPTER 1
# INTRODUCTION

Regional conditions, such as geology, have been long recognized by limnologists as factors that influence lake trophic status (Naumann 1929). Deevey (1940) found significant differences in relations between lake trophic status (phosphorus and chlorophyll concentrations) in four distinct physiographic and geologic regions of Connecticut. Moyle (1956) and Heiskary et al. (1987) found that geographical conditions base on geology drives most of the variation in water chemistry throughout Minnesota. Canfield and Hoyer (1988) also found strong correlations between water quality variables and geology and physiography of Florida Lakes.

Whereas geology accounts for significant variance in the water chemistry of lakes, many studies have shown that anthropogenic activities, including land use practices within watersheds, can significantly impact water quality (Uttormark et al. 1974, McFarland and Hauck 1999, Cuffney et al. 2000, Berka et al. 2001, Wang 2001, Hascic and Wu 2006, Houlahan and Findlay 2004). The United States Environmental Protection Agency addressed anthropogenic impacts after the Cuyahoga River, Cleveland, Ohio, caught on fire in 1969, as a consequence of uncontrolled discharge of volatile petroleum into the waterway (Oberstar 2002). The fire caught national attention and was the tipping point in the creation of the Clean Water Act (CWA). The objective of the CWA is to “restore and maintain the chemical, physical, and biological integrity of the nation’s waters” by controlling point-source discharge of pollutants to navigable waters, attaining reasonable goals of water quality standards, controlling levels of toxic pollutants, providing funds to construct wastewater treatment facilities, increasing research efforts to improve water quality and developing programs to control non-point-source pollution (USEPA 2002). Through time, the CWA has been successful in controlling point-source pollution, given the jurisdiction of the Environmental Protection Agency in controlling direct discharges from known sources; however, non-point-source pollution remains the unfinished agenda of the CWA (Oberstar 2002). This is a consequence of the difficulty of effectively regulating or controlling non-point sources, which are usually associated with land use within watersheds (Carpenter et al. 1998). Identifying the impacts of various land use practices will provide guidelines to help achieve the overall goal of the CWA.

Agricultural and urban land uses have been identified as the land uses that exert the greatest influence on nutrient concentrations in water bodies (Foley et al. 2005). Agricultural practices such as livestock rearing and cropping usually involve surplus manure and chemical fertilizer applications, resulting in excess nutrient runoff into nearby water bodies during rainfall events (McFarland and Hauck 1999, Berka et al. 2001). Urbanization and industrialization usually involve waste-water discharge and enhanced stormwater runoff from impervious surfaces (Wang 2001). Water bodies dominated by urban land uses are often reported to have higher nutrient concentrations, caused by nutrient runoff during rainfall events and inefficiency of waste-water treatments (Lenet and Crawford 1994, Wang 2001, Carey and Migliaccio 2009).

Conversely, forest and wetland land uses are generally thought to have a positive influence on water quality (Johnston 1991, Detenbeck et al. 1993, Sliva and Williams 2001). Nutrient uptake and storage in forest stands reduces nutrient loading into nearby water bodies, thus maintaining quality (Lowrance 1984). Wetlands, in general, are considered retention ecosystems that work as natural filters, trapping nutrients before they reach the receiving water body, but their efficiency is dependent upon hydrology, sedimentation dynamics and nutrient sources (Johnston 1991).

Climate variability (i.e., rainfall) is another factor that should be considered when assessing drivers of water quality (Whitehead et al. 2009). Impacts of land use on water quality are evident, but some studies suggest that precipitation variability can also influence lake water quality and even overshadow the effects of land use (Park et al. 2010, Tasdighi et al. 2017). There is evidence that rainfall could have either positive or negative relationships with lake water nutrient concentrations (Kleinman et al. 2006, Jeppesen et al. 2009).

Some studies suggest that increased rainfall intensity can lead to increased nutrient loading to water bodies through greater influx of water, thereby increasing the concentration of nutrients in the lake (Kleinman et al. 2006, Chen et al. 2016, Ockenden et al. 2016). Jeppesen et al. (2009), however, indicated that lakes in warm and dry regions experience high nutrient concentrations despite low inputs of water and suggested that increased loading of nutrients during rainfall events may not affect mean annual nutrient concentrations. Canfield et al. (2016) also found that rainfall has an inverse relationship with nutrient concentrations in some Florida lakes. Although rainfall variation can influence water nutrient concentrations, whether that influence is positive or negative seems to be a function of internal lake mechanisms, suggesting that more work must be done in individual lake systems to better understand the relation between rainfall and lake nutrients (Hoyer et al. 2005).

The main purpose of this study was to assess the impacts of land use within Florida watersheds, on lake water nutrient concentrations, after accounting for the effects of local geology. Regional rainfall deviation was also evaluated as a potential factor influencing nutrient concentrations in lake waters. The objectives of this study were to: 1) determine if there were correlations between percent land use (agriculture, urban, forest and wetland) and nutrient concentrations (TP and TN) in lakes throughout Florida in two discrete time periods (1989/1990 and 2009/2010), 2) determine if there were significant relations between changes in percent land use and nutrient concentrations (TP and TN) through time, from 1989/1990 to 2009/2010, and 3) compare water nutrient data (TP and TN) to regional rainfall data for individual lakes throughout Florida from 1989/1990 to 2009/2010 to determine if there are significant correlations between rainfall amount and nutrient status of individual lakes.

# CHAPTER 2
# METHODS

## Study Sites

Lakes used in this analysis were chosen from the LAKEWATCH, long-term monitoring database. Lakes that had 20 years (1989/1990 to 2009/2010) or more of continuous nutrient data were selected for analysis. Those lakes span the state of Florida, from Walton County in the Panhandle, to Highlands County, at the southern end of the Lake Wales Ridge (Figure 2-1). The majority of the lakes are in north-central and central Florida, with fewer lakes in the Panhandle and south Florida. The relative abundance of lakes from each region in this study corresponds with the distribution of lakes throughout the state (Griffith et al. 1997), so the studied sample population of lakes is representative of the statewide lake population. Lake size ranged from <1 to >7000 ha and watershed size ranged from <10 to >180,000 ha. Lakes also spanned the full trophic state spectrum, from oligotrophic to hyper-eutrophic. There were 97 lakes in the dataset for which I could obtain watershed, land use and long-term water chemistry data; 10 lakes, however, were not included in the analysis because they had been treated with aluminum sulfate (n = 2), were infested with hydrilla, *Hydrilla verticillata* (n = 4), hosted exotic grass carp (n =3) or had a low number of samples within their respective TP zone (n = 1).

## Water Chemistry Data

Nutrient data were obtained from the Florida LAKEWATCH database. Florida LAKEWATCH is a citizen-based volunteer program created in 1986 to help monitor lakes throughout Florida. The program has three main objectives: 1) collect quality water quality data with minimal cost and effort from lakes throughout Florida, 2) maintain a long-term water quality database for Florida lakes, and 3) build connections between citizens and aquatic scientists (Hoyer et al. 2014). Volunteers have collected monthly water quality data for many lakes throughout Florida since the late 1980s and the database has been used as the basis for many publications. Since its inception, LAKEWATCH has accumulated data on >1100 lakes in its core database, which includes TP, TN, CHL, water clarity, color and conductivity.

Procedures used for sample collection and data generation for the LAKEWATCH database are outlined in Canfield et al. (2002) and Hoyer et al. (2012). Every month volunteers collect water samples from their designated lakes and store them at designated pick-up locations. Samples are collected at three locations in each lake, which are identified by LAKEWATCH staff members and volunteers during training sessions. When sampling at each site, volunteers collect surface water samples in 250-mL, pre-washed Nalgene bottles. Filtration for CHL analysis is done on site or at the volunteer's home, by filtering a measured volume of water through a Gelman Type A-E glass fiber filter. Water clarity at each sampling site is measured on-site using a Secchi disk. Water samples and filters are placed in a freezer at a set location, where they will be retrieved, usually every two to four months, for delivery to the lab. Samples are brought to the LAKEWATCH laboratory at University of Florida Fisheries and Aquatic Sciences facility (Gainesville) for analysis.

Total phosphorus concentrations (µg/L) in water samples are measured by persulfate digestion (Menzel and Crowin 1965) followed by colorimetric determination, as outlined in Murphy and Riley (1962). For total nitrogen concentrations (µg/L), samples were subjected to a persulfate digestion in an autoclave to oxidize all N forms to nitrate. Samples were then measured using a spectrophotometer and are reported as total nitrogen (Bachmann and Canfield 1996). Values are reported to 1 µg/L for TP and 10 µg/L for TN. Mean annual TP and TN concentrations for each lake were determined by averaging measurements from the three sampling stations each month to get a monthly mean, and then averaging the 12 monthly means to yield the annual mean.

**Land Use/Watershed Data**

Watershed data were provided by Brian Beneke and Jennifer Bock at the Florida Fish and Wildlife Conservation Commission (FWC,). Watersheds for each individual lake were delineated using Esri's ArcMap software. Digital elevation maps (DEM) were used, along with a series of hydrological tools in the ArcMap software to create each water basin. DEMs are raster files that contain an array of individual pixels that cover a geographic area, and each pixel represents the elevation at a specific point. Elevations in the DEM work as a general guide, and hydrologic tools enable creation of a flow simulation that starts from the highest elevation, and pixel by pixel, works its way to the lowest elevation. Running through all the pixels creates a series of flows, and connecting the starting point of each flow delineates the individual watershed.

The Land Use/Land Cover data were provided by the Florida Department of Environmental Protection (FDEP) and the five Florida Water Management Districts (WMDs). The FDEP oversees classification of aerial images for the Northwest Florida (NWFWMD) and Suwannee River Water Management Districts (SRWMD) because of insufficient resources in those two WMDs. The St. Johns River (SJRWMD), South Florida (SFWMD) and Southwest Florida Water Management Districts (SWFWMD) classify their own images. The FDEP, however, is responsible for compositing all the classified land use maps from the five WMDs into a single, seamless statewide map.

Generally, an updated version of the Land Use/Land Cover map is produced every five years from maps provided by each of the WMDs. Each WMD follows a similar procedure during the classification step to create their Land Use/Land Cover map. Sources and specific procedures associated with collected aerial images used for the classification process, however, differ slightly from one WMD to another.

The classification procedure involves two steps: an aerial fly-over and a classification phase. The fly-over phase is done using an aircraft that has a mounted sensor that takes aerial images of the landscape in both true color and infrared. This process is usually carried out by an outside contractor, which differs from one WMD to another. The classification phase is done manually by a trained photo-interpreter using geographic information system (GIS) software. In all cases, classification was done in ESRI's ArcMap software with specific versions differing depending on the WMD and year of the classification. Aerial images are imported into ArcMap as a backdrop layer, usually at a scale of 1:12,000 or less. Photo interpreters then go in and classify the image by digitizing or drawing polygons over the aerial backdrop, with each polygon representing a different landscape feature on the image. Photo-interpreter keys (PI keys) assist photo interpreters during the classification process. PI keys describe what features to expect in each land use type based on an aerial perspective. Once all the landscape features on the aerial backdrop are filled in with polygons, the over-layer becomes a mosaic of shapes and figures, with each representing a land use type. The mosaic layer can then be exported as a shapefile that has attached attribute data, which explain what each figure represents (i.e., land use type, area of polygon, etc.).

Classifications in all WMDs were based on the 1999 Florida Land Use, Cover and Forms Classification System (http://www.fdot.gov/geospatial/documentsandpubs/fluccmanual1999.pdf) by the Florida Department of Transportation (FDOT).

Three hierarchical levels of classification were used in the land use maps; however, for this analysis it was condensed to just one level with four different land uses (agriculture, urban, forest and wetland). The 158 land use types in level three were combined into 27 in level two, and further combined into four in level one (Table 2-1). Condensing the land use levels was accomplished by exporting the attribute data from the land use maps into an Excel spreadsheet and then summing the individual acreages within the level-three tier based on their relation to the level-one categories (agriculture, urban, forest or wetland). Agriculture, urban, forest and wetland were the only four land use categories employed in this analysis because a literature review suggested that those land use types are the most influential on aquatic systems (Uttormark et al. 1974).

## Rainfall Data

Rainfall data (1985-2010) were obtained from the Florida Climate Center site maintained by the Florida State University (http://climatecenter.fsu.edu/climate-data-access-tools/downloadable-data). Rainfall data five years prior to the time span of this study (1989/1990-2009/2010) were also obtained to assess patterns before the time of interest. Precipitation values at each site were obtained from long-term, National Weather Service first-order stations. There are approximately 100 such stations throughout the state of Florida that monitor weather daily. Rainfall data were downloaded from stations near the lakes in this study. The rainfall data are considered regional and represent an approximation of precipitation on the lakes.

Precipitation data were manipulated to derive an adjusted, cumulative rainfall deviation (ACRD). Annual rainfall values for each lake were averaged to yield the mean rainfall value for the period of record from the Florida Climate Center. The long-term mean rainfall value was then subtracted from the individual annual rainfall values to get the precipitation surplus or deficit in each year. Consecutively adding and reporting the annual surplus and deficit deviations year by year throughout the 25-year time span will give an annual cumulative series. Values within the annual cumulative series were then averaged and the absolute value of that long-term average either was added, if the long-term average was negative, or subtracted, if the long-term average was positive, from each annual cumulative value in the series. The latter process scales the annual rainfall surplus and deficit to the long-term precipitation mean with the zero value being the center of the annual deviations (Canfield et al. 2016).

## Data Analysis

Statistical analyses were conducted in the R statistical software version 3.2.2. (R Core Team 2015) and the JMP12 software (SAS Institute Inc. 2007). Analyses were conducted for two distinct time periods (1989/1990 and 2009/2010) using a Pearson correlation coefficient matrix to assess the static relationship between watershed land use (%) and lake water nutrient concentrations (µg/L). In the static assessment, TP and TN were tested individually against each of the four land uses (agriculture, urban, wetland and forest) within individual TP zones (TP2, TP3 and TP4). Land use represented the independent variable and nutrient concentration represented the dependent variable. Nutrient concentration data were LOG-transformed and percent land use data were arcsine-transformed to increase normality of the data distribution (Gotelli and Ellison 2013). Lakes were analyzed only according to TP zones because majority of the lakes within the dataset had a total nitrogen to phosphorus ratio (weight) >10, which indicates that nitrogen is not a limiting nutrient in these systems (Sakamoto 1966). Furthermore, Smith (1982) suggest that nitrogen to phosphorus ratio (weight) >20 indicates phosphorus limiting lakes which 90% of the lakes in the dataset had nitrogen to phosphorus ratio >20 (median = 43). Thus, more emphasis was put into accounting for the natural variability of phosphorus concentration by using TP zones instead of TN zones.

A separate analysis was conducted with a Kruskal-Wallis one-way analysis of variance to evaluate the relationship between temporal changes in percent land use and TP and TN concentration (1989/1990 to 2009/2010), again within TP zones. Prior to the Kruskal-Wallis test, regression coefficients (i.e., p-value and slope) were used to test for significant changes in lake nutrient concentration over time (1989/2010 to 2009/2010). Lakes were assigned to groups based on whether they displayed increasing (positive slope and $p<0.05$), decreasing (negative slope and $p<0.05$) or no change ($p>0.05$) in nutrient concentration. The above lake groups represented the independent variable in the Kruskal-Wallis test. The dependent variable was the change in percent land use; which was calculated by taking the difference between the percent land use in 1989/1990 and 2009/2010.

An additional analysis was conducted to assess relations between changes in ACRD (rainfall) and changes in nutrient concentration over time (1989/1990 to 2009/2010) within individual lakes. Pearson correlation coefficient matrices were used, with ACRD (rainfall) representing the independent variable and annual mean nutrient concentration (TP or TN) representing the dependent variable. Nutrient concentration data were natural LOG-transformed to increase normality of the data distribution (Gotelli and Ellison 2013). For all the analyses performed, an alpha level of 0.05 was used to assess the significance of each statistical test.

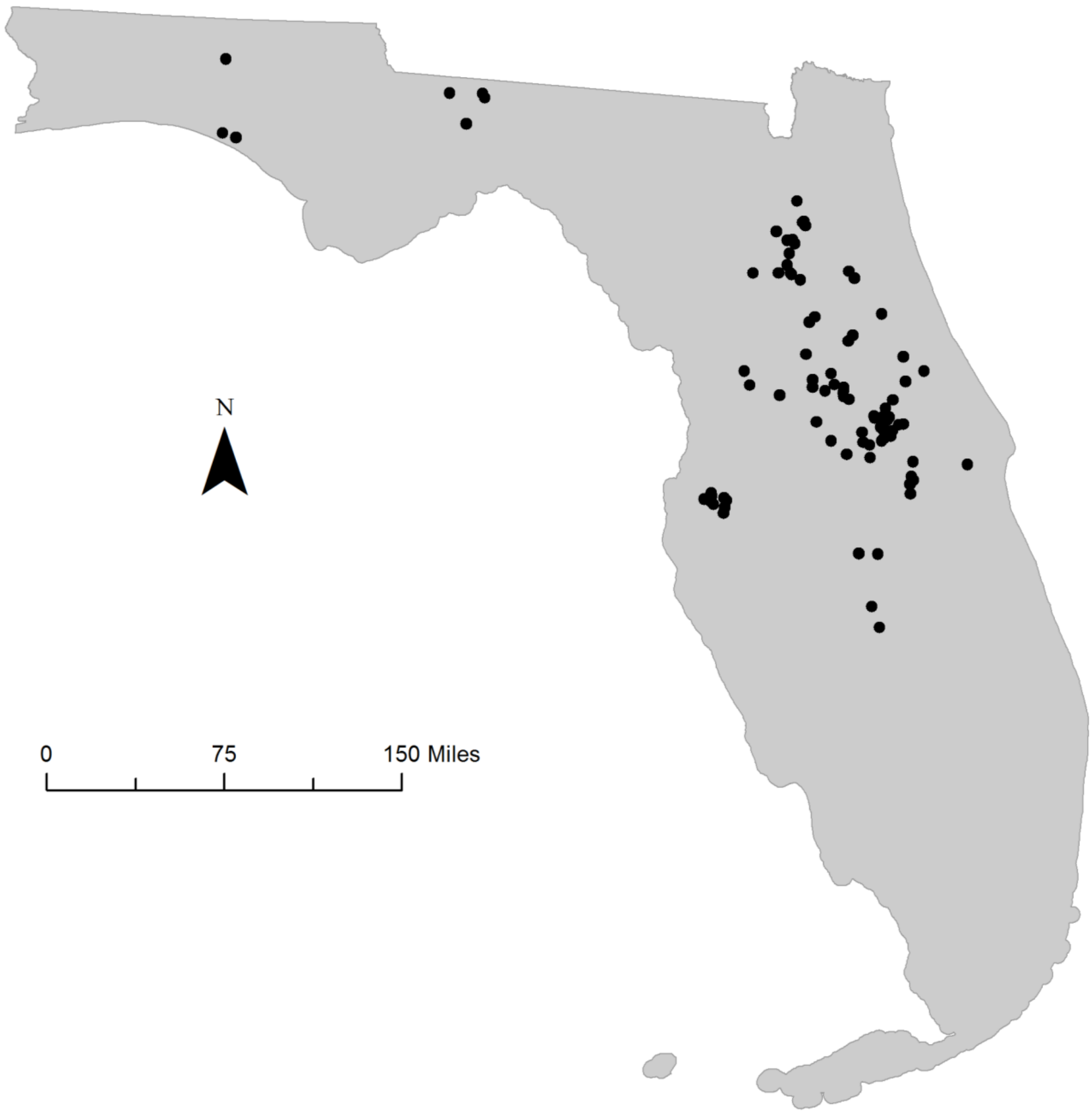


Figure 2-1. Distribution of lakes

Table 2-1. Hierarchical levels of land use classification

| Level 1 | Level 2 |
|---|---|
| 1000/8000 Urban | 1100 RESIDENTIAL, LOW DENSITY |
| | 1200 RESIDENTIAL, MEDIUM DENSITY |
| | 1300 RESIDENTIAL, HIGH DENSITY |
| | 1400 COMMERCIAL AND SERVICES |
| | 1500 INDUSTRIAL |
| | 1600 EXTRACTIVE |
| | 1700 INSTITUTIONAL |
| | 1800 RECREATIONAL |
| | 1900 OPEN LAND |
| | 8100 TRANSPORTATION |
| | 8200 COMMUNICATIONS |
| | 8300 UTILITIES |
| 2000 Agriculture | 2100 CROPLAND AND PASTURELAND |
| | 2200 TREE CROPS |
| | 2300 FEEDING OPERATIONS |
| | 2400 NURSERIES AND VINEYARDS |
| | 2500 SPECIALTY FARMS |
| | 2600 OTHER OPEN LANDS (RURAL) |
| 4000 Forest | 4100 UPLAND CONIFEROUS FORESTS |
| | 4200 UPLAND HARDWOOD FORESTS |
| | 4300 UPLAND HARDWOOD FORESTS |
| | 4400 TREE PLANTATIONS |
| 6000 Wetland | 6100 WETLAND HARDWOOD FORESTS |
| | 6200 WETLAND CONIFEROUS FORESTS |
| | 6300 WETLAND FORESTED MIXED |
| | 6400 VEGETATED NON-FORESTED WETLANDS |
| | 6500 NON-VEGETATED WETLANDS |

Note: The level-three tier had 158 land use types and were not included in this table

# CHAPTER 3
# RESULTS

## Descriptive Statistics

Nutrient and land use categories varied widely among the lakes. Total phosphorus concentration ranged from 4 to 91 µg/L in 1989/1990 and 4 to 127 µg/L in 2009/2010 with a mean of 20 µg/L (SD = 16 µg/L) and 22 µg/L (SD = 20 µg/L), respectively. Total nitrogen concentration ranged from 63 to 3628 µg/L in 1989/1990 and 148 to 3001 µg/L with a mean of 763 µg/L (SD = 597 µg/L) and 869 µg/L (SD = 542 µg/L), respectively. Agricultural land uses within watersheds ranged from 0% to 63% in 1989/1990 and 0% to 49% in 2009/2010 with a mean of 16% (SD = 19%) and 10% (SD = 13%), respectively. Urban land uses within watersheds ranged from 0% to 100% in both time periods with mean values of 42% (SD = 33%) in 1989/1990 and 50% (SD = 32%) in 2009/2010. Forest land uses within watersheds ranged from 0% to 100% in 1989/1990 and 0% to 97% in 2009/2010 with mean values of 21% (SD = 25%) and 20% (SD = 24%), respectively. Wetland land uses within watersheds ranged from 0% to 46% in 1989/1990 and 0% to 45% in 2009/2010 with mean values of 12% (SD = 12%) and 14% (SD = 12%), respectively.

Although individual lakes showed significant changes in nutrient concentration (e.g., TP and TN significantly increased in Alligator Lake) and percent land use (e.g., 79% urban increase within Lake Bennett's watershed) over time, statistics for the population of sampled lakes as a whole showed few changes (Table 3-1). The average TP concentration among all the sampled lakes in 1989/1990 was not significantly different from the average TP concentration in 2009/2010 ($p = 0.23$). The average TN concentration was also not significantly different among the two-time periods ($p = 0.07$).

Average percent agriculture within the watersheds of the sampled lakes, however, was significantly lower in 2009/2010 than in 1989/1990 ($p = 0.03$). Average percent urban ($p = 0.09$), forest ($p = 0.89$) and wetland ($p = 0.27$) were not significantly different between 1989/1990 and 2009/2010.

## Static Land Use and Nutrient Comparison

Total phosphorus and total nitrogen among lakes were evaluated against percent agriculture, urban, forest and wetland within two-time periods (1989/1990 and 2009/2010) and within TP zones (TP2, TP3 and TP4 only). Pearson correlation coefficients (r and *p*-values) are reported for both time periods (Table 3-2, Table 3-3). A total of 48 different assessments (24 within each time period) were evaluated among all the lakes for significant correlations between nutrient concentration and percent land use (Table 3-2, Table 3-3).

Four out of the six evaluations between percent agriculture and TP concentrations had significant correlations across all TP zones through both time periods. There was one significant correlation between percent agriculture and TP concentration in 1989/1990 and three in 2009/2010. All the percent agriculture and TP correlations were positive, with the highest correlation ($r = 0.66$) in 2009/2010 in TP2 (Figure 3-1B). All six evaluations between percent agriculture and TN concentrations across all TP zones and through both time periods had significant correlations. The highest correlation ($r = 0.62$) between percent agriculture and TN was in 1989/1990 in TP2 (Figure 3-1A). All correlations between percent agriculture and TN concentrations were also positive.

Significant correlations between percent urban and TP concentration occurred in only two ($p = 0.02$, $p < 0.01$) out of the six evaluations across all TP zones through both time periods (Figure 3-2B, Figure 3-3B). The two significant correlations occurred in TP3 and TP4 and only in 2009/2010, with both correlations being negative (r = -0.39, r = -0.47). Four out of the six total correlations were significant between percent urban and TN concentration across all TP zones through both time periods with the highest correlation (r = 0.67, $p$ = 0.01) occurring in 1989/1990 in TP2 (Figure 3-1A). With exception of one positive significant correlation, all other significant correlations between percent urban and TN concentration were negative.

Significant correlations occurred for only two ($p$ = 0.02 for both correlations) of the six total evaluations between percent forest and TP concentration across all TP zones through both time periods (Figure 3-1B, Figure 3-3B). Both significant correlations occurred in 2009/2010 and in TP2 and TP4; however, one correlation was positive (r = 0.40) and the other was negative (r = -0.61). Significant correlations between percent forest and TN concentration also only occurred in two ($p$ <0.01 and $p$ = 0.04) of six evaluations, with one occurring in 1989/1990 in TP2 (Figure 3-1A) and the other in 2009/2010 in TP4 (Figure 3-3B). Both significant correlations between percent forest and TN concentrations were negative (r = -0.88 and r = -0.53).

Four of the six correlations between percent wetland and TP concentration were significant across all TP zones through both time periods. Two of those four significant correlations were in 1989/1990 in TP2 and TP3 and the other two were in 2009/2010 in TP3 and TP4. The highest correlation (r = 0.76) between percent wetland and TP concentration was in 1989/1990 in TP2 (Figure 3-1A). All the significant correlations between percent wetland and TP were positive. Significant correlations also occurred in four of six evaluations between percent wetland and TN concentration across all TP zones through both time periods. Two of those correlations were in 1989/1990 in TP2 and TP3 and the other two were in 2009/2010 in TP3 and TP4. The highest correlation (r = 0.67) between percent wetland and TN concentration was in 1989/1990 in TP3 (Figure 3-2A). All correlations between percent wetland and TN concentration were positive.

**Temporal Changes in Land Use and Nutrient Concentration**

Descriptive statistics are presented for percent land use changes among groups of lakes with significant changes (+/-) and or no change in nutrient concentration over time (Table 3-4). Multiple lakes across all TP zones had significant negative (n = 15) or positive (n = 29) changes in TP concentration between 1989/1990 and 2009/2010. Many lakes, however, displayed no significant change (n = 43) in TP concentration between 1989/1990 and 2009/2010. Total nitrogen concentration significantly decreased in several lakes (n = 15), but also increased significantly in many (n = 49) lakes across all TP zones between 1989/1990 and 2009/2010. Some lakes (n = 23) had no significant change in TN concentration between 1989/1990 and 2009/2010.

Lakes with significant negative change (n = 15) in TP concentration between 1989/1990 and 2009/2010 had an average negative change in percent agriculture (mean = -5, SD = 10) and percent forest (mean = -3, SD = 10) land uses. Within the same group of lakes, however, the average change in percent urban (mean = 6, SD = 11) and percent wetland (mean = 2, SD = 3) land uses were positive. Among the group of lakes with no significant change in TP concentration (n = 43), the average percent change in agricultural land use was negative (mean = -6, SD = 14), whereas the average percent change in urban (mean = 7, SD = 20) and wetland (mean = 1, SD = 3) land uses were positive. On average, there was no change in percent forest land use among the lakes with no change in TP concentration (mean = 0, SD = 14). Lakes with significant positive changes in TP concentration (n = 29) had a negative average percent change in agriculture (mean = -9, SD = 15) and forest (mean = -1, SD = 12) land uses. Average percent changes in urban (mean = 9, SD = 14) and wetland (mean = 3, SD = 4) were positive among the lakes with significant positive changes in TP concentration.

Lakes with significant decreasing TN concentration (n =15) had a negative average percent change in agriculture land use (mean -16, SD = 19), but a positive average change in percent urban (mean = 14, SD = 22), percent forest (mean = 1, SD = 7) and percent wetland (mean = 2, SD = 3). Among the lakes with no significant change in TN concentration (n = 23) the average percent change of agriculture land use was negative (mean = -6, SD = 12). Among the same lakes, however, average percent changes in urban (mean = 4, SD = 18), forest (mean = 1, SD = 17) and wetland (mean = 1, SD = 3) were positive. Lakes with significant increasing TN concentration (n= 49) had mean negative percent changes in agriculture (mean = -4, SD = 12) and forest (mean = -3, SD = 12) land uses. Average percent urban (mean = 8, SD = 14) and wetland changes (mean = 2, SD = 4) were positive among the lakes with significant increasing TN concentration.

A Kruskal-Wallis one-way analysis of variance was used to test for significant differences in percent land use change (dependent variable) among the three groups of lakes with significant changes (+/-) and or no change in nutrient concentration (independent variable) over time (1989/1990 to 2009/2010). Changes in percent agricultural, urban and forest land uses were not significantly different among lakes with significant change (+/-) or no change in TP concentration. Change in percent wetland was significantly different (p-value = 0.03) among groups of lakes with varying TP changes, but only occurred under TP zone four (Figure 3-4B). Changes in percent urban, forest and wetland land uses were not significantly different among groups of lakes with changing (+/-) or no change in TN concentration. Percent agricultural change, however, was significantly different ($p = 0.01$) among the groups of lakes with different changes in TN concentration, but only occurred under TP zone three (Figure 3-4A). Overall, only two of the 24 total evaluations showed significant differences between changes in percent land use among the groups of lakes with different changes in nutrient concentration overtime

**Temporal Fluctuations in Rainfall and Nutrient Concentrations**

Total phosphorus and total nitrogen were evaluated against the ACRD for individual lakes over time (1989/1990 to 2009/2010). Pearson correlation coefficients are presented in Table 3-6. Multiple lakes (n = 32) had significant correlations between ACRD and TP concentration across all TP zones. Among those lakes with significant correlations, both negative (n = 7) and positive correlations (n = 25) were found. The highest positive correlation (r = 0.75, $p < 0.01$) between ACRD and TP concentration occurred in Lake Marsha, Orange County (Figure 3-2B). The highest negative correlation between ACRD and TP (r = -0.81, $p < 0.01$) occurred in Lake Tallavana, Gadsden County (Figure 3-2A).

Many lakes (n = 22) also showed a significant correlation between ACRD and TN concentration across all TP zones. Significant correlations between ACRD and TN concentration among these lakes also showed both positive (n = 11) and negative (n = 11) relations. The greatest positive correlation (r = 0.61, $p < 0.01$) between ACRD and

TN concentration occurred in Lake Bessie, Orange County (Figure 3-2D). The greatest negative correlation (r = -0.87, $p < 0.01$) occurred in Lake Tallavana, Gadsden County (Figure 3-2C).

Table 3-1. Summary statistics of nutrient and land use data

| | Mean | | Minimum | | Maximum | | SD | |
|---|---|---|---|---|---|---|---|---|
| | 1989/ 1990 | 2009/ 2010 | 1989/ 1990 | 2009/ 2010 | 1989/ 1990 | 2009/ 2010 | 1989/ 1990 | 2009/ 2010 |
| Watershed (ha) | 7685 | - | 12 | - | 181512 | - | 24968 | - |
| Lake SA (ha) | 367 | 382 | 1 | 1 | 7271 | 7392 | 936 | 960 |
| TP (µg/L) | 20 | 22 | 4 | 4 | 91 | 127 | 16 | 20 |
| TN (µg/L) | 763 | 869 | 63 | 148 | 3628 | 3001 | 597 | 542 |
| % Agriculture * | 16 | 10 | 0 | 0 | 63 | 49 | 19 | 13 |
| % Urban | 42 | 50 | 0 | 0 | 100 | 100 | 33 | 32 |
| % Forest | 21 | 20 | 0 | 0 | 100 | 97 | 25 | 24 |
| %Wetland | 12 | 14 | 0 | 0 | 46 | 45 | 12 | 12 |

Note: SD = Standard deviation, SA = Surface area, ha = hectares
Note: N = 87
*Significant at $p \leq 0.05$ between mean values in 1989/1990 and 2009/2010

Table 3-2. Pearson correlation coefficients for static land use and lake nutrient concentration in 1989/1990

| | | Agriculture (%) | | Urban (%) | | Forest (%) | | Wetland (%) | |
|---|---|---|---|---|---|---|---|---|---|
| Zone | Nutrient (µg/L) | r | *p*-value | r | *p*-value | r | *p*-value | r | *p*-value |
| TP2 | LOG TP | -0.05 | 0.87 | 0.50 | 0.06 | -0.48 | 0.07 | 0.76 | 0.00* |
| TP2 | LOG TN | 0.62 | 0.01* | 0.67 | 0.01* | -0.88 | 0.00* | 0.63 | 0.01* |
| TP3 | LOG TP | 0.39 | 0.02* | -0.26 | 0.12 | -0.13 | 0.46 | 0.43 | 0.01* |
| TP3 | LOG TN | 0.46 | 0.00* | -0.45 | 0.01* | -0.19 | 0.26 | 0.67 | 0.00* |
| TP4 | LOG TP | 0.15 | 0.38 | 0.01 | 0.97 | -0.02 | 0.91 | 0.12 | 0.47 |
| TP4 | LOG TN | 0.38 | 0.02* | -0.18 | 0.30 | -0.16 | 0.34 | 0.25 | 0.13 |

Note: Percent land use was arcsine transformed
Note: 0.00 = $p < 0.01$
Note: TP2 (n = 15), TP3 (n = 36), TP4 (n = 36)
*Significant at $p \leq 0.05$

Table 3-3. Pearson correlation coefficients for static land use and lake nutrient concentration in 2009/2010

| | | Agriculture (%) | | Urban (%) | | Forest (%) | | Wetland (%) | |
|---|---|---|---|---|---|---|---|---|---|
| Zone | Nutrient (µg/L) | r | *p*-value | r | *p*-value | r | *p*-value | r | *p*-value |
| TP2 | LOG TP | 0.66 | 0.01* | 0.41 | 0.13 | -0.61 | 0.02* | 0.04 | 0.90 |
| TP2 | LOG TN | 0.51 | 0.05* | 0.36 | 0.19 | -0.53 | 0.04* | 0.26 | 0.35 |
| TP3 | LOG TP | 0.45 | 0.01* | -0.39 | 0.02* | -0.04 | 0.84 | 0.52 | 0.00* |
| TP3 | LOG TN | 0.51 | 0.00* | -0.43 | 0.01* | -0.15 | 0.37 | 0.64 | 0.00* |
| TP4 | LOG TP | 0.33 | 0.05* | -0.47 | 0.00* | 0.40 | 0.02* | 0.45 | 0.01* |
| TP4 | LOG TN | 0.60 | 0.00* | -0.58 | 0.00* | 0.28 | 0.10 | 0.57 | 0.00* |

Note: Percent land use was arcsine transformed
Note: 0.00 = $p < 0.01$
Note: TP2 (n = 15), TP3 (n = 36), TP4 (n = 36)
*Significant at $p \leq 0.05$

Table 3-4. Mean and standard deviation of percent land use change among groups of lakes with change (+/-) and or no change in nutrient concentration across all TP zones between 1989/1990 and 2009/2010

| | | | Δ % Agriculture | | Δ % Urban | | Δ % Forest | | Δ % Wetland | |
|---|---|---|---|---|---|---|---|---|---|---|
| Nutrient | n | Δ Nutrient | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| TP | 15 | Negative | -5 | 10 | 6 | 11 | -3 | 10 | 2 | 3 |
| TP | 43 | No Change | -6 | 14 | 7 | 20 | 0 | 14 | 1 | 3 |
| TP | 29 | Positive | -9 | 15 | 9 | 14 | -1 | 12 | 3 | 4 |
| TN | 15 | Negative | -16 | 19 | 14 | 22 | 1 | 7 | 2 | 3 |
| TN | 23 | No Change | -6 | 12 | 4 | 18 | 1 | 17 | 1 | 3 |
| TN | 49 | Positive | -4 | 12 | 8 | 14 | -3 | 12 | 2 | 4 |

Note: SD = Standard deviation
Note: n = number of lakes in each group

Table 3-5. *p*-values for differences between changes in percent land use among groups of lakes with significant change (+/-) and or no change in nutrient concentration across all TP zones between 1989/1990 and 2009/2010

| Zone | Δ Nutrient (µg/L) | Δ % Agriculture | Δ % Urban | Δ % Forest | Δ % Wetland |
|---|---|---|---|---|---|
| TP2 | TP | 0.95 | 0.86 | 0.78 | 0.81 |
| TP2 | TN | 0.35 | 0.85 | 0.64 | 0.80 |
| TP3 | TP | 0.85 | 0.60 | 0.56 | 0.50 |
| TP3 | TN | 0.01* | 0.06 | 0.17 | 0.77 |
| TP4 | TP | 0.26 | 0.57 | 0.57 | 0.03* |
| TP4 | TN | 0.47 | 0.84 | 0.27 | 0.21 |

*Significant at $p \leq 0.05$

Table 3-6. Pearson correlation coefficients for individual lakes with a significant relationship ($p < 0.05$) between ACRD and TP or TN concentration (n = 41)

| | | | *p*-value | | r | |
|---|---|---|---|---|---|---|
| Lake | County | Zone | TP | TN | TP | TN |
| Alligator | Osceola | TP3 | 0.00 | 0.02 | 0.68 | 0.50 |
| Armistead | Hillsborough | TP4 | 0.03 | ns | 0.47 | ns |
| Bessie | Orange | TP3 | 0.01 | 0.00 | 0.61 | 0.65 |
| Bradford | Leon | TP3 | 0.00 | ns | -0.68 | ns |
| Brick | Osceola | TP3 | 0.03 | ns | 0.50 | ns |
| Broken Arrow | Volusia | TP3 | ns | 0.05 | ns | -0.45 |
| Camp Creek | Walton | TP3 | 0.01 | ns | 0.56 | ns |
| Carroll | Hillsborough | TP3 | 0.03 | ns | 0.49 | ns |
| Center | Osceola | TP3 | ns | 0.03 | ns | 0.46 |
| Charles | Marion | TP4 | ns | 0.03 | ns | 0.53 |
| Crooked | Polk | TP3 | 0.04 | ns | 0.51 | ns |
| Deerback | Marion | TP2 | 0.00 | ns | -0.60 | ns |
| Diane | Leon | TP4 | ns | 0.03 | ns | -0.54 |
| Emma | Lake | TP3 | 0.02 | 0.04 | 0.51 | 0.45 |
| Forest | Brevard | TP4 | 0.00 | ns | 0.72 | ns |
| Formosa | Orange | TP4 | 0.04 | ns | -0.47 | ns |
| Georgia | Orange | TP4 | 0.01 | 0.00 | 0.56 | 0.60 |
| Hiawatha | Hillsborough | TP3 | 0.00 | ns | 0.64 | ns |
| Ivanhoe | Orange | TP4 | 0.02 | 0.03 | -0.56 | -0.51 |
| Johnson | Clay | TP2 | ns | 0.03 | ns | -0.52 |
| Keystone | Hillsborough | TP3 | 0.00 | ns | 0.67 | ns |
| Little Fairview | Orange | TP4 | ns | 0.01 | ns | -0.56 |
| Little Orange | Alachua | TP4 | 0.03 | ns | 0.45 | ns |
| Lizzie | Osceola | TP3 | 0.00 | 0.00 | 0.62 | 0.61 |
| Lorraine | Lake | TP4 | 0.05 | 0.01 | -0.44 | -0.58 |
| Louisa | Lake | TP3 | 0.00 | 0.05 | 0.66 | 0.49 |
| Magdalene | Hillsborough | TP3 | 0.03 | ns | 0.48 | ns |

Table 3-6. Continued.

| | | | *p*-value | | r | |
|---|---|---|---|---|---|---|
| Lake | County | Zone | TP | TN | TP | TN |
| Marsha | Orange | TP3 | 0.00 | 0.02 | 0.75 | 0.54 |
| Mary | Seminole | TP3 | 0.02 | 0.04 | 0.55 | 0.49 |
| Mary Jane | Orange | TP3 | 0.05 | 0.05 | 0.44 | 0.44 |
| Panasoffkee | Sumter | TP4 | 0.01 | ns | 0.56 | ns |
| Persimmon | Highlands | TP4 | ns | 0.00 | ns | -0.73 |
| Ribbon North | Flager | TP4 | 0.00 | ns | 0.65 | ns |
| Rock | Seminole | TP3 | 0.03 | ns | 0.49 | ns |
| Spring | Walton | TP3 | ns | 0.01 | ns | -0.56 |
| Star | Putnam | TP4 | 0.02 | ns | 0.51 | ns |
| Tallavana | Gadsden | TP4 | 0.00 | 0.00 | -0.81 | -0.87 |
| Todd | Citrus | TP3 | 0.03 | 0.04 | -0.49 | -0.46 |
| Willis | Orange | TP3 | 0.03 | ns | 0.47 | ns |
| Wilson | Hillsborough | TP3 | 0.00 | ns | 0.69 | ns |
| Woods | Seminole | TP4 | ns | 0.01 | ns | -0.60 |

Note: ns = not significant
Note: 0.00 = $p < 0.01$
Note: Correlations significant at $p < 0.05$

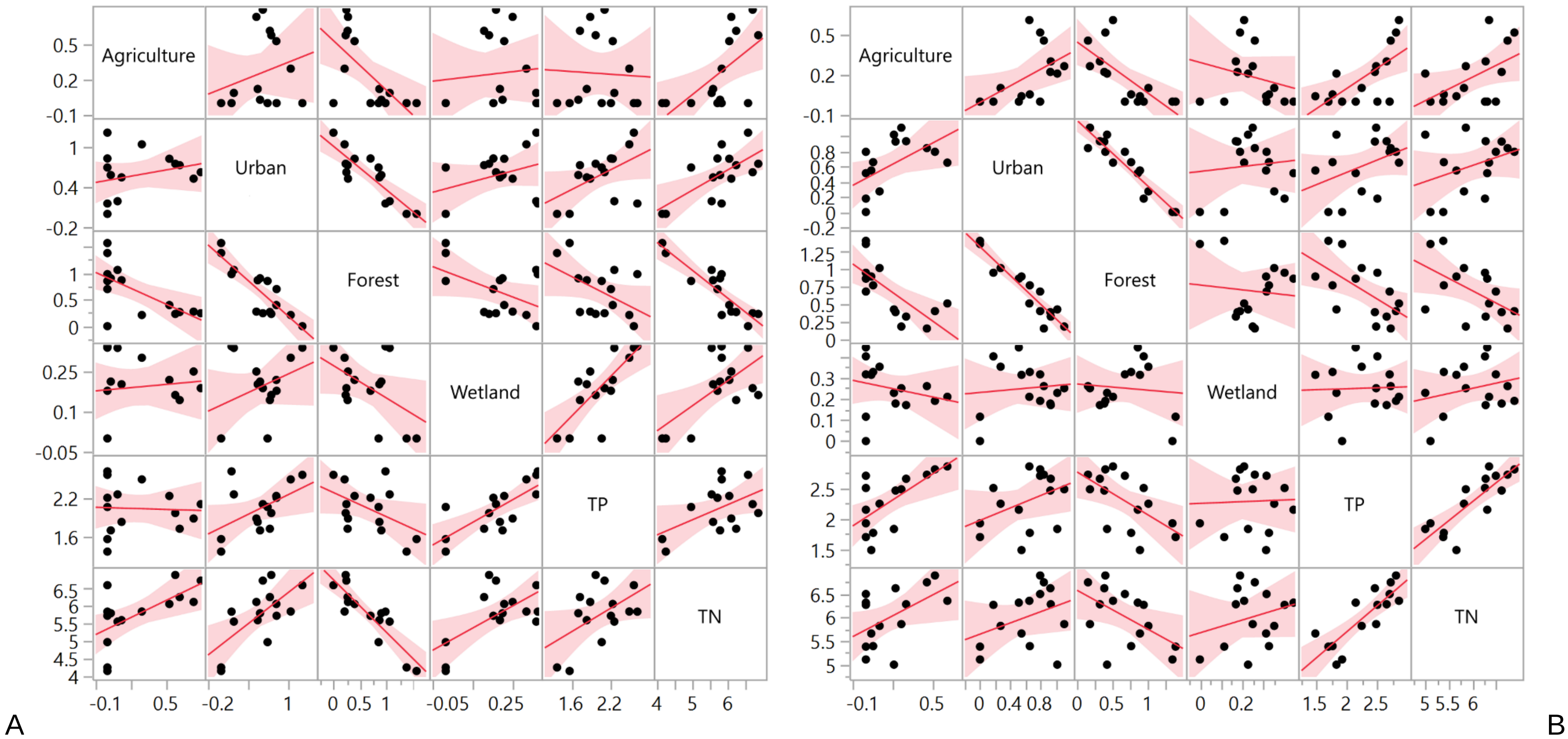


Figure 3-1. Pearson correlation matrix showing the relationship between land uses and nutrient concentration in TP zone2. A) Correlations in 1989/1990 B) Correlations in 2009/2010. (Note: n = 15, TP and TN were natural LOG transformed, Percent land uses were arcsine transformed)

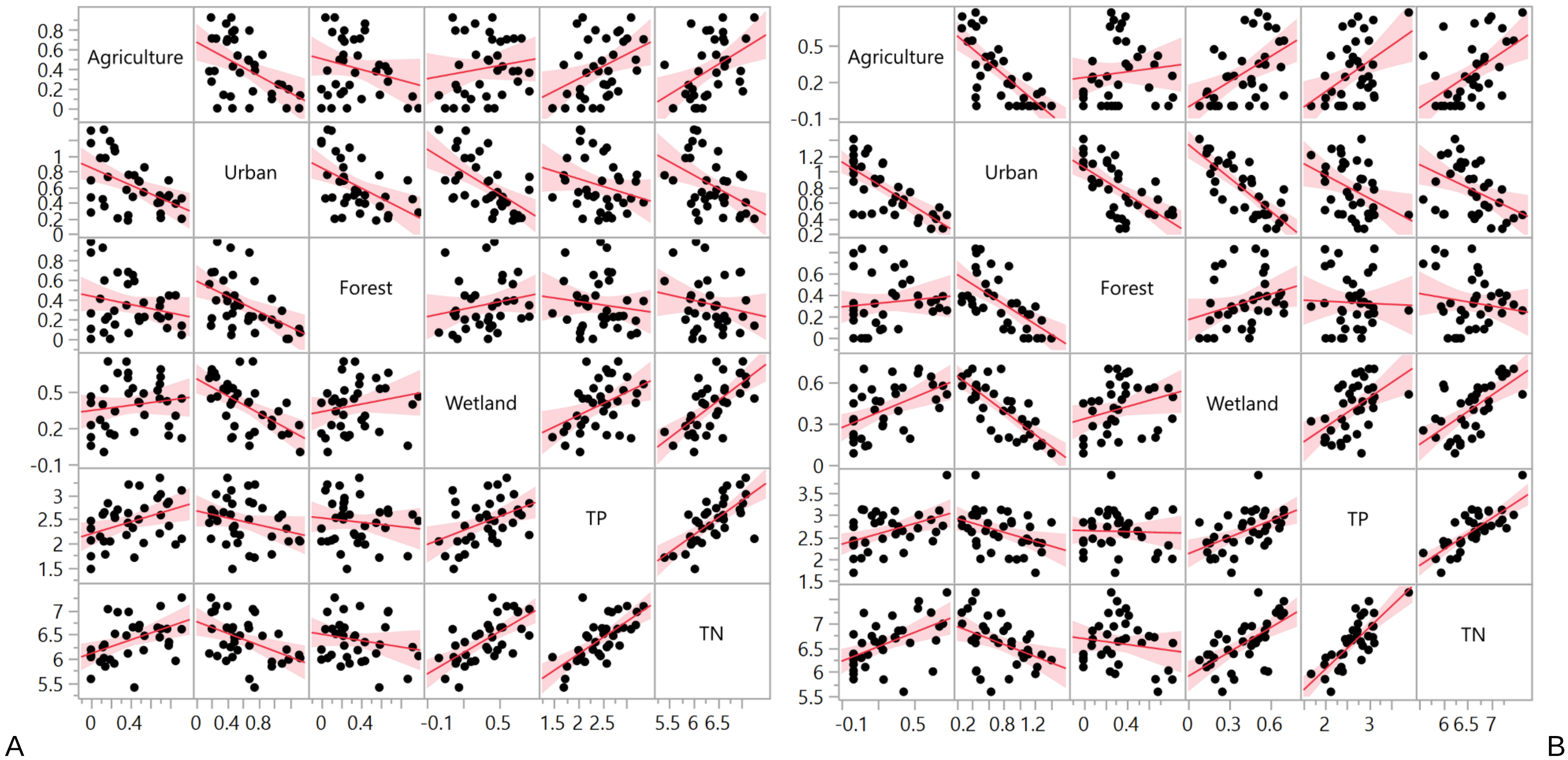


Figure 3-2. Pearson correlation matrix showing the relationship between land uses and nutrient concentration in TP zone 3. A) Correlations in 1989/1990 B) Correlations in 2009/2010. (Note: n = 36, TP and TN were natural LOG transformed, Percent land uses were arcsine transformed)

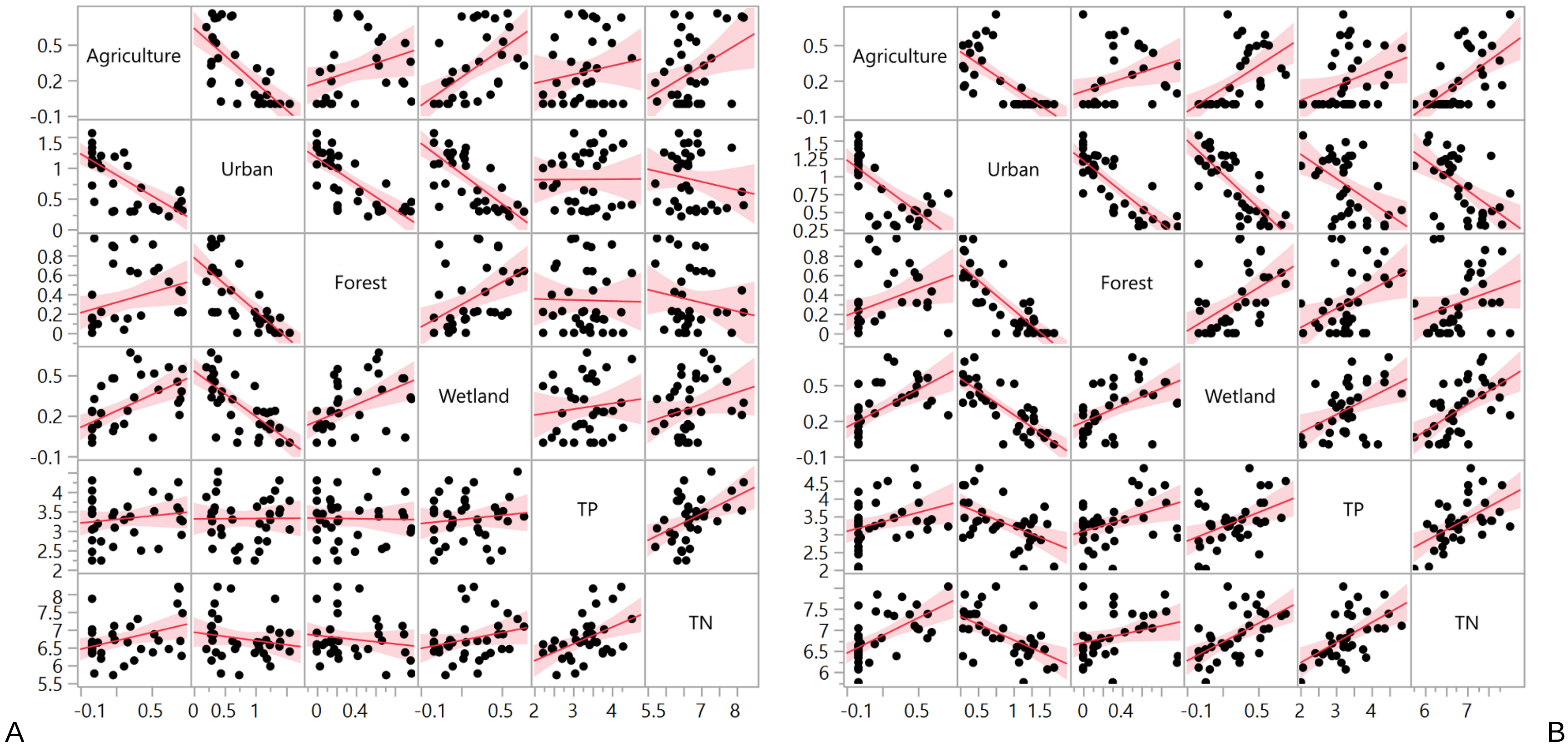


Figure 3-3. Pearson correlation matrix showing the relationship between land uses and nutrient concentration in TP zone 4. A) Correlations in 1989/1990 B) Correlations in 2009/2010. (Note: n = 36, TP and TN were natural LOG transformed, Percent land uses were arcsine transformed)

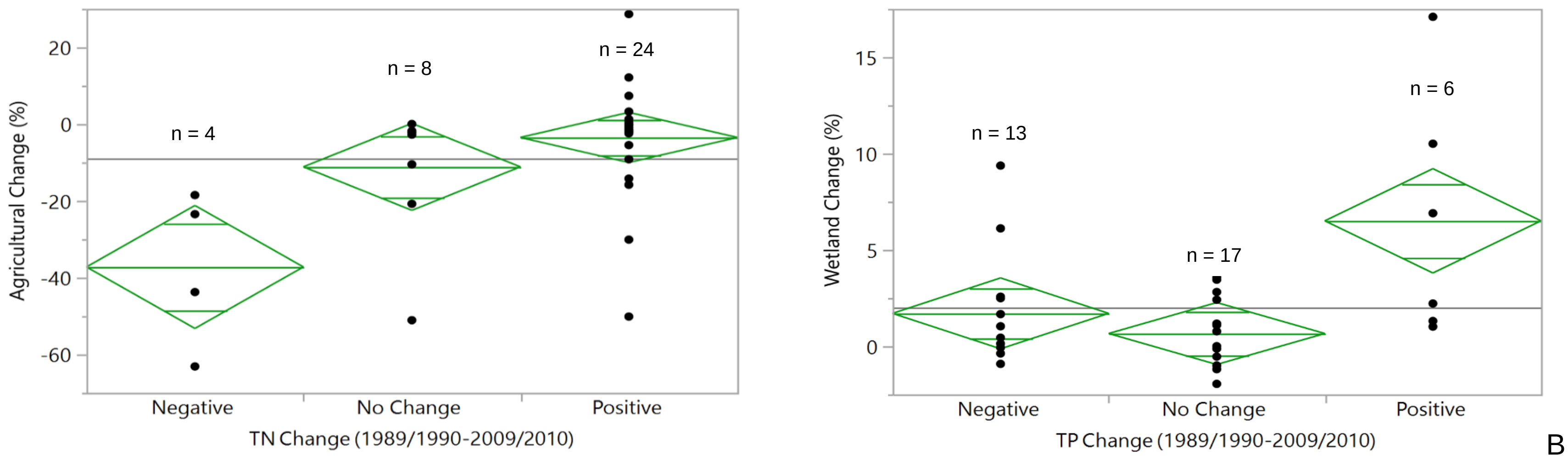


Figure 3-4. Plots showing significant changes in percent land use among groups of lakes with different changes in nutrient concentrations over time. A) Significant changes of percent agriculture among groups of lakes with different changes in TN concentration over time B) Significant changes of percent wetland among groups of lakes with different changes in TP concentration over time.

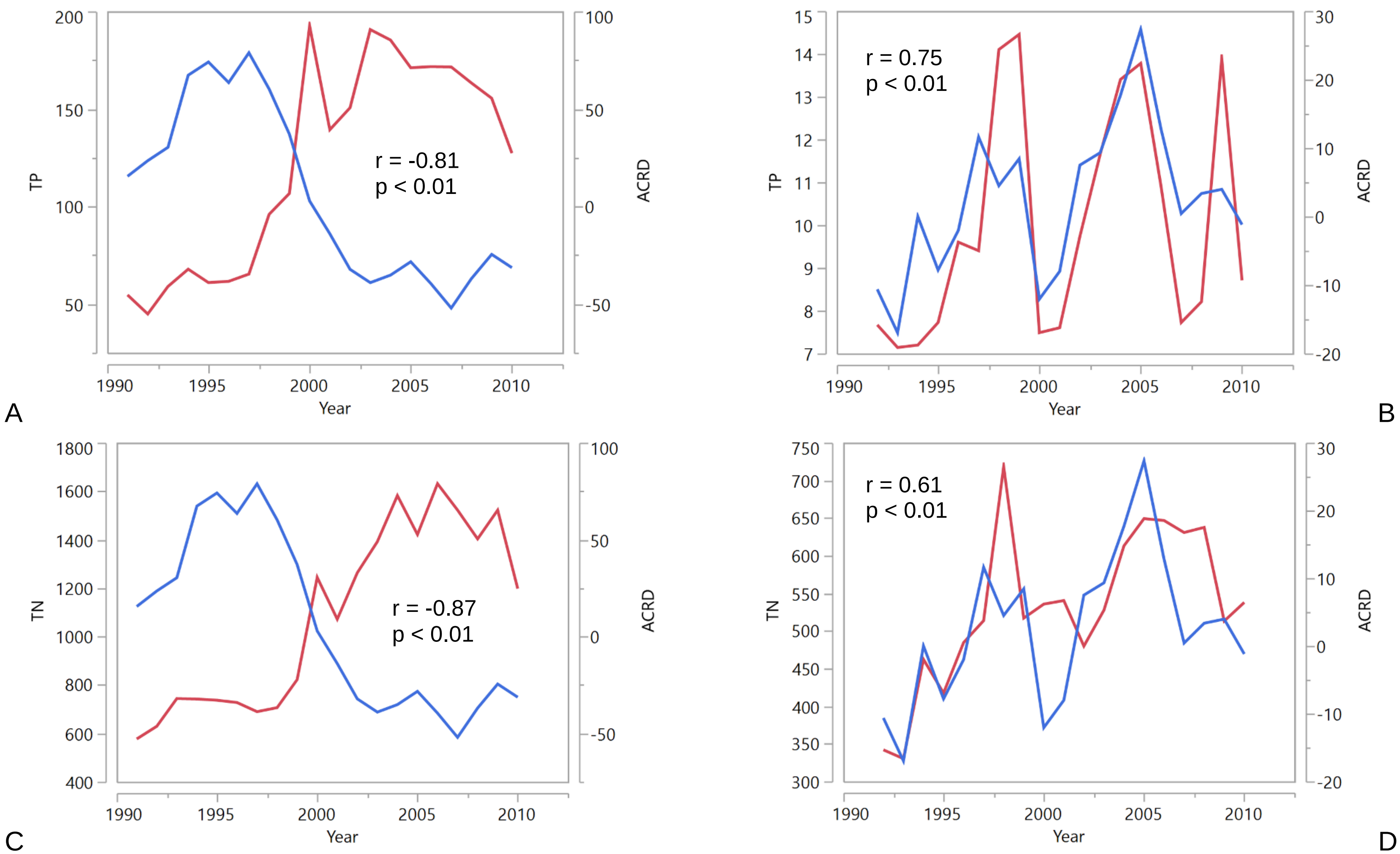


Figure 3-5. Strongest positive and negative relationships between ACRD and nutrient concentration (µg/L) over time. A) Negative relationship between ACRD and TP concentration for Lake Tallavana, Gadsden County, B) Positive relationship between ACRD and TP concentration for Lake Marsha, Orange County, C) Negative relationship between ACRD and TN concentration for Lake Tallavana, Gadsden County, D) Positive relationship between ACRD and TN concentration for Lake Bessie, Orange County. (Note: ACRD = Blue, Nutrient = Red

# CHAPTER 4
# DISCUSSION

## Impacts of Static Land Uses

There were many significant relationships between individual land uses and nutrient concentrations among all TP zones within each of the time periods (1989/1990 and 2009/2010). Percent agriculture showed positive correlations with TP and TN concentration among lakes. All significant correlations were positive, supporting previous studies that concluded agriculture has a negative impact on nutrient concentration in some lakes (McFarland and Hauck 1999, Berka et al. 2001, Cross and Jacobson 2013). There were, however, more significant correlations between percent agriculture and TN concentration than between percent agriculture and TP concentration. Similar results have been found in other studies (Dunn et al. 2014, Wang et al. 2014, Chen et al. 2016), suggesting that agriculture, although it may influence both TP and TN in lakes, has a greater influence on TN concentration. The stronger correlation between agriculture and TN concentration also argues for different transport mechanisms of phosphorus and nitrogen in agricultural settings (Logan 1982, Follett and Delgado 2002).

Phosphorus in soils occurs mainly in the stable or fixed form because of its tendency to be tightly adsorbed onto soil particles or bound with other geological constituents (Hansen et al. 2002). Because of the high association of phosphorus with soil particles, soil erosion in surface runoff is typically the main phosphorus transport mechanism (Sharpley et al. 1996). Nitrogen in mineral soils occurs mostly in a soluble form (e.g., nitrate), enabling high mobility in both surface and ground water (Wall 2013). Various management practices has been able to decrease soil-loss from agricultural fields (Mass et al. 1988), thereby hindering the transport of phosphorus and, to an extent, nitrogen to nearby water bodies. However, managing the hydrogeology of agricultural fields can be difficult and since nitrate can travel underground, this makes it hard to mitigate the impacts of groundwater nitrogen inputs to downstream water bodies. Domagalski et al. (2008) did a comparative study of nutrient transport rates in agricultural basins and showed that nitrate in all cases had higher yields than phosphate, allowing greater inputs of nitrate to nearby water bodies which supported the stronger correlation of agriculture with TN rather than with TP in this study.

Percent urban land use was also correlated significantly with TP and TN concentration among several lakes, but similar to agriculture, more significant correlations were found with TN concentrations. In the case of urban land use, however, all significant correlations with TP and TN, with the exception of one, were negative. The inverse relationship between percent urban land use and nutrient concentration in this study does not support conventional wisdom, which suggests that as urban development increases within watersheds, nutrient concentrations in the receiving waters should increase as well (Bonansea et al. 2016, Ferreira et al. 2017). Findings from this study are contrary to the claim that urban development is a major factor contributing to increases in nutrient concentration of lakes (Ding et al. 2015, Tasdighi et al. 2017).

The negative correlation between percent urban land use and nutrient concentration could be a result of high efficiency of wastewater treatment. Novel methods, such as the use of micro-algae, are being used in municipal treatment facilities to reduce nutrient concentrations in wastewater (Rajasulochana and Preethy

2016). Although new wastewater treatments are gaining popularity, conventional wastewater treatment methods, such as septic tanks, are still used widely and can be a major source of nutrients, especially nitrogen, in urban areas (Reay 2004; Withers et al. 2011). Spirandelli (2015), however, evaluated wastewater infrastructure along an urbanization gradient and found that septic tank density decreased as urbanization increased, suggesting that septic tanks may have less impact in highly urbanized areas. Use of natural or man-made wetlands for wastewater treatment has also been popular in Florida and studies show that the method improves waste-water quality significantly (Boyt et al. 1977). Investment in stormwater infrastructure within urbanized areas has also been shown to reduce the amount of nutrients that enter downstream water bodies (Bernhardt et al. 2008).

Percent forest land use had the lowest number of significant correlations with nutrient concentration, all of which were negative. Tasdighi et al. (2017) also found that forest land uses had weaker correlations with water quality compared to agriculture and urban. Nonetheless, the significant negative correlations that did occur between forest land uses and nutrient concentration support previous studies (Tu 2013, Kändler et al. 2017) that suggested forest land use has a positive influence, i.e. it helps maintain low nutrient concentrations in lakes. Forest stands reduce surface runoff and water infiltration by intercepting rainfall before it hits the ground, thus also reducing soil erosion and groundwater movement (Norton and Fisher 2000). By acting as a sediment trap and reducing water movement, forested land can hinder the transport of nitrate and phosphate, and serve as a nutrient sink (Lowrance 1984).

Multiple significant positive correlations occurred between static percent wetland cover and lake water nutrient concentrations.  Similar to urban land use, the relationship between percent wetland and nutrient concentration does not support previous findings. Several previous studies suggest that wetlands are nutrient retention areas and act as nutrient sinks, thereby preventing nutrients from reaching downstream water bodies (Bratli et al. 1999, Zhang et al. 2000, Jordan et al. 2003).  All significant correlations between percent wetland and nutrient concentration in this study were positive, suggesting that wetlands may contribute to water nutrient concentrations in some Florida lakes.  Fisher and Acreman (2004) reviewed wetland studies from around the world and concluded that under certain situations wetlands do increase TP and TN loading to downstream water bodies.

Fisher and Acreman (2004) suggested that vegetation was among the most important factors that determine the nutrient retention ability of wetlands.  Howard-Williams (1985) suggests that rooted plants in wetlands can act as “pumps,” taking up nutrients from the wetland sediments and releasing them into the water column when they senesce.  A survey conducted in 1996 reported that 98% of Florida’s wetlands were vegetated with woody plants, swamps being the dominant wetland type (Dahl 2005).  Johnston (1991) indicated that leaching of nutrients from decomposing herbaceous and woody wetland plants can be a source of high nutrient flux within wetland systems.  The high amount of wetlands in Florida rooted vegetation, and the nutrient flux that occurs when they decay, may account for the unconventional relationship between wetland cover and water nutrient concentrations found in this study.

## Impacts of Land Use Change

Examination of temporal changes in land use and shifts in TP and TN concentrations showed few significant relations (two out of 24, Table 3-5). This was somewhat surprising because the static comparison between land use and nutrient concentrations within the two discrete time periods (1989/1990 and 2009/2010), showed that percent land use was correlated significantly with TP and TN concentration across multiple lakes. It is possible that land use changes that occurred over the time span dealt with in this study (~20 years) were not large enough to impact nutrient concentrations in the lakes. Khare et al. (2012) conducted a similar study on the Hillsborough River and Alafia River watersheds in Florida over a 33-year time span and found similar results. These results are in agreement with the findings of Canfield et al. (2016) and suggest that other factors may overshadow the influence of land use change overtime on nutrients in Florida lakes.

Aside from land use, there are multiple mechanisms that had been shown to control nutrient concentrations in lakes (Blindlow 1992, Nagid et al. 2001, Scheffer 2004, Hoyer et al. 2005). As water level changes in a lake (i.e., rainfall) multiple limnological mechanisms can work together or individually to influence nutrient concentration (Hoyer et al. 2005). As water levels decreases in some shallow lakes, strong winds can sometimes re-suspend bottom sediments and release sediment-bound nutrients back into the water column (Nagid et al. 2001). Reduced water levels in other lakes can expose more of the littoral zone and increase macrophyte abundance, thus leading to lower nutrient concentrations (Blindlow 1992, Scheffer 2004). Sediment resuspension and abundance of aquatic macrophytes were not evaluated in this study but could possibly overshadow the impacts of land use change.

## Influences of Climate Variability

Multiple lakes in this study showed significant correlations between ACRD patterns and nutrient concentration over time. This finding supports the conclusions of Whitehead et al. (2009), which suggested that climate variability can have a significant impact on water-column nutrient concentrations. The relation between ACRD and lake trophic status is complex, as some lakes had higher nutrient concentrations during wetter years (e.g., Lake Marsha), whereas some lakes had lower nutrient concentrations in wet years (e.g., Lake Tallavana). Concurrent positive and negative correlations between rainfall and nutrient concentration has been reported in other studies as well (Kleinman et al. 2006, Jeppesen et al. 2009).

Ockenden et al. (2016) suggested that nutrient concentrations will increase in water bodies during times of high rainfall because of the influx of nutrients in runoff water. Others, however, suggest that nutrient concentrations will decrease when rainfall increases, because of dilution from increasing water levels (Moyle 1956, Jeppesen et al. 2009). Hoyer et al. (2005) suggested that when water level changes (i.e., inputs from rainfall), internal lake mechanisms can cause changes in nutrient concentrations. Whether rainfall causes an influx of nutrients, serves to dilute in-lake nutrients, or triggers internal mechanisms that influence nutrient concentrations in lake water, the relation between rainfall and water nutrient concentrations is complex, requiring thorough investigation of individual lake systems before conclusions about the relationship can be drawn.

## Conclusions

Land use within discrete time periods was correlated with water nutrient concentration among certain lakes. Lakes in agricultural areas showed high TP and TN concentrations, though correlations with TN concentration were stronger because of different nutrient-transport mechanisms.  Lakes surrounded by urban land uses showed low TP and TN concentrations, suggesting positive influence of waste water treatment facilities and stormwater remediation.  Although forest land use had the least number of significant correlations, watersheds dominated by forest land uses had lakes with low TP and TN concentration, reflecting the nutrient-buffering capabilities of forest stands. Lakes in watersheds with greater wetland coverage had high TP and TN concentration, contradicting previous studies and reflecting the complex nutrient-related processes that occur within wetlands.

Changes in land use in relation to changes in nutrient concentration over time showed few correlations, despite the several significant correlations found in the static comparison. A longer period of time may be required to express the influence of land use change on nutrient concentrations in lakes.  Of course, many other mechanisms (i.e., sediment resuspension, macrophyte density, lake morphology) that were not evaluated in this study have been shown to impact water quality, and may have overshadowed the impacts of land use change among the population of lakes in this study.

Changes in rainfall were correlated with changes in nutrient concentration over time in multiple lakes.  Nevertheless, previous studies came to different conclusions about the impact of rainfall on water nutrient concentrations, illustrating the complexity of the relationship.  The influence of rainfall on nutrient concentrations in lakes can be difficult to determine without detailed study of individual lake systems.  Rainfall, although its specific impact may vary from lake to lake, appears to be an important factor that can overshadow the impacts of land use change over time. This study suggests that land use and other mechanisms drive nutrient concentrations in Florida lakes, but a thorough investigation of individual lakes should be considered before applying a standard nutrient management plan to the water body.

APPENDIX
LAND USE RAW DATA

Table A-1. Land use data and surface area for all the lakes in 1989/1990

| Lakes | County | TP Zones | Surface Area ($km^2$) | Agriculture ($km^2$) | Urban ($km^2$) | Forest ($km^2$) | Wetland (km) |
|---|---|---|---|---|---|---|---|
| Alligator | Osceola | 3 | 13.5 | 14.0 | 7.6 | 3.6 | 6.2 |
| Alto | Alachua | 3 | 2.3 | 0.0 | 0.2 | 0.6 | 0.5 |
| Armistead | Hillsborough | 4 | 0.1 | 4.7 | 11.5 | 0.9 | 6.9 |
| Arrowhead | Leon | 4 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| Ashby | Volusia | 4 | 3.7 | 26.2 | 3.1 | 18.3 | 20.7 |
| Bear | Seminole | 3 | 1.2 | 0.1 | 2.2 | 0.2 | 0.1 |
| Beauclaire | Lake | 4 | 4.4 | 248.6 | 64.8 | 23.8 | 45.1 |
| Bennett | Orange | 3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Bessie | Orange | 3 | 0.7 | 0.1 | 3.9 | 0.2 | 0.3 |
| Bradford | Leon | 3 | 0.6 | 0.7 | 9.2 | 31.9 | 7.4 |
| Brant | Hillsborough | 3 | 0.2 | 0.4 | 1.5 | 0.0 | 0.7 |
| Brick | Osceola | 3 | 2.5 | 7.4 | 1.1 | 2.5 | 5.9 |
| Broken Arrow | Volusia | 3 | 0.0 | 0.0 | 0.2 | 0.3 | 0.0 |
| Broward | Putnam | 3 | 1.8 | 1.1 | 2.7 | 1.8 | 0.2 |
| Camp Creek | Walton | 3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Carroll | Hillsborough | 3 | 0.8 | 0.2 | 3.6 | 0.0 | 0.1 |
| Center | Osceola | 3 | 1.5 | 9.3 | 3.4 | 3.1 | 6.4 |
| Charles | Marion | 4 | 1.4 | 5.7 | 14.2 | 99.4 | 35.7 |
| Crooked | Lake | 2 | 0.1 | 0.0 | 0.1 | 2.3 | 0.4 |
| Crooked | Polk | 3 | 11.8 | 21.1 | 8.0 | 2.9 | 12.9 |
| Dead Lady | Hillsborough | 3 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Deer | Clay | 2 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 |
| Deerback | Marion | 2 | 0.3 | 0.0 | 1.0 | 0.0 | 0.1 |
| Diane | Leon | 4 | 0.3 | 0.1 | 1.8 | 1.7 | 0.0 |

Table A-1. Continued.

| Lakes | County | TP Zones | Surface Area ($km^2$) | Agriculture ($km^2$) | Urban ($km^2$) | Forest ($km^2$) | Wetland (km) |
|---|---|---|---|---|---|---|---|
| Disston | Flagler | 4 | 7.7 | 36.3 | 29.1 | 128.1 | 141.1 |
| Dora | Lake | 4 | 17.6 | 259.9 | 85.7 | 26.2 | 51.2 |
| Dorr | Lake | 4 | 6.9 | 7.1 | 4.9 | 40.1 | 6.6 |
| East Crooked | Lake | 2 | 0.6 | 1.3 | 2.1 | 0.2 | 0.1 |
| Eaton | Marion | 4 | 1.2 | 5.7 | 15.4 | 120.0 | 42.0 |
| Emma | Lake | 3 | 1.9 | 204.5 | 31.0 | 17.3 | 164.4 |
| Eola | Orange | 4 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 |
| Eustis | Lake | 4 | 31.5 | 786.9 | 206.8 | 80.0 | 352.3 |
| Farrar | Orange | 4 | 0.0 | 0.1 | 2.6 | 0.1 | 0.0 |
| Forest | Brevard | 4 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 |
| Formosa | Orange | 4 | 0.1 | 0.0 | 12.1 | 0.3 | 0.8 |
| Georgia | Orange | 4 | 0.2 | 0.0 | 0.5 | 0.0 | 0.1 |
| Gertrude | Lake | 2 | 1.0 | 3.5 | 4.7 | 0.7 | 0.2 |
| Giles | Orange | 4 | 0.1 | 0.0 | 0.5 | 0.0 | 0.0 |
| Harris | Lake | 4 | 72.7 | 491.0 | 91.8 | 46.4 | 283.5 |
| Henderson | Citrus | 3 | 2.2 | 0.3 | 4.5 | 0.5 | 4.7 |
| Hiawatha | Hillsborough | 3 | 0.5 | 0.4 | 0.9 | 0.1 | 0.2 |
| Hickorynut | Orange | 3 | 1.9 | 38.4 | 2.2 | 1.1 | 11.2 |
| Holden | Orange | 4 | 1.1 | 0.6 | 7.4 | 0.2 | 0.2 |
| Ivanhoe | Orange | 4 | 0.4 | 0.0 | 8.6 | 0.0 | 0.1 |
| Jackson | Highlands | 2 | 12.2 | 1.7 | 15.6 | 0.9 | 1.9 |
| James | Hillsborough | 3 | 0.1 | 0.3 | 0.1 | 0.0 | 0.1 |
| Joanna | Lake | 2 | 1.2 | 2.5 | 1.4 | 0.4 | 0.3 |
| John's | Orange | 3 | 5.9 | 37.8 | 14.5 | 2.7 | 13.3 |
| Johnson | Clay | 2 | 0.4 | 0.1 | 0.4 | 7.7 | 1.1 |
| Keystone | Hillsborough | 3 | 1.7 | 4.0 | 4.0 | 2.0 | 3.4 |

Table A-1. Continued.

| Lakes | County | TP Zones | Surface Area (km$^2$) | Agriculture (km$^2$) | Urban (km$^2$) | Forest (km$^2$) | Wetland (km) |
|---|---|---|---|---|---|---|---|
| Kingsley | Clay | 2 | 6.2 | 0.0 | 3.7 | 7.4 | 0.5 |
| Lily | Clay | 2 | 0.4 | 0.0 | 0.6 | 1.3 | 0.1 |
| Little Bear | Seminole | 3 | 0.1 | 0.3 | 0.3 | 0.0 | 0.0 |
| Little Fairview | Orange | 4 | 0.3 | 0.0 | 8.1 | 0.1 | 0.2 |
| Little Orange | Alachua | 4 | 2.4 | 16.0 | 6.8 | 22.5 | 15.7 |
| Lizzie | Osceola | 3 | 3.3 | 1.6 | 1.9 | 3.4 | 2.3 |
| Lochloosa | Alachua | 4 | 22.6 | 25.6 | 13.1 | 114.8 | 45.3 |
| Lorraine | Lake | 4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Louisa | Lake | 3 | 12.9 | 138.4 | 13.0 | 14.0 | 131.0 |
| Lurna | Orange | 4 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 |
| Magdalene | Hillsborough | 3 | 0.7 | 0.2 | 2.0 | 0.1 | 0.3 |
| Marsha | Orange | 3 | 0.4 | 0.0 | 1.5 | 0.0 | 0.0 |
| Mary | Seminole | 3 | 0.3 | 0.0 | 1.2 | 0.3 | 0.1 |
| Mary Jane | Orange | 3 | 4.2 | 9.0 | 3.6 | 26.1 | 24.8 |
| Minnehaha | Orange | 4 | 0.4 | 0.8 | 6.7 | 0.2 | 0.5 |
| Ola | Orange | 3 | 1.7 | 18.8 | 8.3 | 6.7 | 1.7 |
| Panasoffkee | Sumter | 4 | 5.4 | 413.9 | 174.0 | 147.8 | 124.0 |
| Persimmon | Highlands | 4 | 0.1 | 0.3 | 0.2 | 0.1 | 0.0 |
| Powell | Bay | 3 | 2.5 | 0.0 | 2.7 | 26.2 | 7.4 |
| Ribbon North | Flagler | 4 | 0.1 | 0.0 | 1.0 | 0.2 | 0.0 |
| Riley | Putnam | 2 | 0.2 | 0.0 | 0.2 | 0.1 | 0.0 |
| Rock | Seminole | 3 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 |
| Rosa | Putnam | 2 | 0.4 | 0.0 | 0.3 | 0.4 | 0.0 |
| Santa Fe | Alachua | 3 | 18.1 | 3.8 | 0.8 | 7.9 | 9.4 |
| Sarah | Orange | 4 | 0.1 | 0.0 | 0.9 | 0.0 | 0.0 |
| Sellers | Lake | 2 | 2.3 | 0.0 | 6.7 | 66.3 | 6.0 |

Table A-1. Continued.

| Lakes | County | TP Zones | Surface Area ($km^2$) | Agriculture ($km^2$) | Urban ($km^2$) | Forest ($km^2$) | Wetland (km) |
|---|---|---|---|---|---|---|---|
| Seminary | Seminole | 3 | 0.2 | 0.0 | 0.5 | 0.0 | 0.0 |
| Shannon | Orange | 4 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| Sheelar | Clay | 2 | 0.1 | 0.0 | 0.0 | 0.6 | 0.0 |
| Spring | Walton | 3 | 0.6 | 0.0 | 0.2 | 0.9 | 0.0 |
| Star | Putnam | 4 | 0.9 | 0.0 | 1.5 | 5.5 | 0.8 |
| Sunset | Hillsborough | 3 | 0.1 | 0.6 | 1.1 | 0.1 | 0.4 |
| Susannah | Orange | 4 | 0.3 | 0.0 | 1.0 | 0.0 | 0.0 |
| Tallavana | Gadsden | 4 | 0.6 | 4.0 | 2.1 | 10.4 | 0.0 |
| Todd | Citrus | 3 | 6.7 | 12.8 | 29.2 | 11.5 | 47.6 |
| Trout | Osceola | 3 | 1.1 | 4.7 | 2.5 | 25.8 | 24.6 |
| Unity | Lake | 4 | 0.4 | 1.4 | 1.1 | 0.2 | 0.3 |
| Wauberg | Alachua | 4 | 0.9 | 0.8 | 0.9 | 1.9 | 2.0 |
| Waunatta | Orange | 4 | 0.3 | 0.0 | 4.9 | 0.3 | 0.3 |
| Weir | Marion | 2 | 22.2 | 60.3 | 41.2 | 7.0 | 4.2 |
| Weohyakapka | Polk | 5 | 28.4 | 80.2 | 19.5 | 56.7 | 30.7 |
| Willis | Orange | 3 | 0.5 | 4.0 | 11.3 | 2.0 | 0.3 |
| Wilson | Hillsborough | 3 | 0.2 | 0.5 | 0.9 | 0.1 | 0.4 |
| Winnemissett | Volusia | 3 | 0.7 | 1.2 | 0.3 | 0.4 | 0.2 |
| Winnott | Putnam | 2 | 0.6 | 0.5 | 1.0 | 0.3 | 0.1 |
| Woods | Seminole | 4 | 0.2 | 0.0 | 2.0 | 0.0 | 0.1 |
| Yale | Lake | 4 | 15.6 | 39.9 | 13.0 | 54.7 | 21.1 |

Table A-2. Land use data and surface area for all the lakes in 2009/2010

| Lakes | County | TP Zones | Surface Area ($km^2$) | Agriculture ($km^2$) | Urban ($km^2$) | Forest ($km^2$) | Wetland ($km^2$) |
|---|---|---|---|---|---|---|---|
| Alligator | Osceola | 3 | 13.4 | 14.5 | 8.9 | 2.6 | 5.6 |
| Alto | Alachua | 3 | 2.3 | 0.0 | 0.4 | 0.7 | 0.6 |
| Armistead | Hillsborough | 4 | 0.1 | 1.1 | 15.5 | 1.0 | 7.2 |
| Arrowhead | Leon | 4 | 0.0 | 0.0 | 0.2 | 0.2 | 0.0 |
| Ashby | Volusia | 4 | 3.7 | 16.3 | 5.9 | 21.1 | 22.4 |
| Bear | Seminole | 3 | 1.2 | 0.0 | 2.5 | 0.1 | 0.1 |
| Beauclaire | Lake | 4 | 4.5 | 72.4 | 138.5 | 54.6 | 81.2 |
| Bennett | Orange | 3 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| Bessie | Orange | 3 | 0.7 | 0.0 | 4.3 | 0.0 | 0.2 |
| Bradford | Leon | 3 | 0.6 | 0.2 | 9.1 | 26.9 | 11.4 |
| Brant | Hillsborough | 3 | 0.2 | 0.1 | 1.8 | 0.1 | 0.6 |
| Brick | Osceola | 3 | 2.5 | 7.9 | 1.2 | 2.5 | 5.3 |
| Broken Arrow | Volusia | 3 | 0.0 | 0.0 | 0.3 | 0.2 | 0.0 |
| Broward | Putnam | 3 | 1.7 | 1.0 | 2.1 | 2.4 | 0.4 |
| Camp Creek | Walton | 3 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 |
| Carroll | Hillsborough | 3 | 0.8 | 0.0 | 3.7 | 0.0 | 0.1 |
| Center | Osceola | 3 | 1.5 | 10.9 | 4.1 | 1.4 | 5.5 |
| Charles | Marion | 4 | 1.4 | 4.2 | 16.4 | 93.0 | 41.6 |
| Crooked | Lake | 2 | 0.1 | 0.0 | 0.1 | 2.2 | 0.5 |
| Crooked | Polk | 3 | 16.3 | 18.5 | 9.3 | 2.9 | 15.3 |
| Dead Lady | Hillsborough | 3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Deer | Clay | 2 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 |
| Deerback | Marion | 2 | 0.3 | 0.0 | 0.3 | 0.7 | 0.2 |
| Diane | Leon | 4 | 0.2 | 0.0 | 3.3 | 0.4 | 0.0 |
| Disston | Flagler | 4 | 7.5 | 31.8 | 34.7 | 123.4 | 149.2 |
| Dora | Lake | 4 | 17.6 | 76.4 | 165.6 | 57.8 | 87.2 |
| Dorr | Lake | 4 | 6.9 | 5.9 | 4.9 | 40.7 | 7.0 |
| East Crooked | Lake | 2 | 0.6 | 0.2 | 2.8 | 0.6 | 0.1 |

Table A-2. Continued.

| Lakes | County | TP Zones | Surface Area (km²) | Agriculture (km²) | Urban (km²) | Forest (km²) | Wetland (km²) |
|---|---|---|---|---|---|---|---|
| Eaton | Marion | 4 | 0.9 | 4.2 | 17.6 | 112.0 | 48.9 |
| Emma | Lake | 3 | 0.7 | 117.5 | 93.9 | 38.6 | 173.7 |
| Eola | Orange | 4 | 0.1 | 0.0 | 0.3 | 0.0 | 0.0 |
| Eustis | Lake | 4 | 31.4 | 404.2 | 426.8 | 170.0 | 398.9 |
| Farrar | Orange | 4 | 0.0 | 0.0 | 2.9 | 0.0 | 0.0 |
| Forest | Brevard | 4 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 |
| Formosa | Orange | 4 | 0.1 | 0.0 | 12.2 | 0.2 | 0.7 |
| Georgia | Orange | 4 | 0.2 | 0.0 | 0.6 | 0.0 | 0.2 |
| Gertrude | Lake | 2 | 1.0 | 0.9 | 6.8 | 1.0 | 0.3 |
| Giles | Orange | 4 | 0.1 | 0.0 | 0.5 | 0.0 | 0.0 |
| Harris | Lake | 4 | 73.9 | 313.1 | 221.5 | 99.4 | 290.8 |
| Henderson | Citrus | 3 | 2.6 | 0.1 | 4.7 | 0.5 | 4.1 |
| Hiawatha | Hillsborough | 3 | 0.6 | 0.1 | 1.3 | 0.1 | 0.1 |
| Hickorynut | Orange | 3 | 1.0 | 24.5 | 8.9 | 7.4 | 13.1 |
| Holden | Orange | 4 | 1.0 | 0.2 | 7.9 | 0.1 | 0.3 |
| Ivanhoe | Orange | 4 | 0.4 | 0.0 | 8.6 | 0.0 | 0.1 |
| Jackson | Highlands | 2 | 12.8 | 1.4 | 16.3 | 0.7 | 1.2 |
| James | Hillsborough | 3 | 0.0 | 0.0 | 0.3 | 0.0 | 0.1 |
| Joanna | Lake | 2 | 1.3 | 1.1 | 3.1 | 0.1 | 0.4 |
| John's | Orange | 3 | 8.9 | 12.1 | 36.1 | 5.9 | 10.1 |
| Johnson | Clay | 2 | 0.2 | 0.1 | 0.8 | 7.4 | 1.2 |
| Keystone | Hillsborough | 3 | 1.7 | 1.8 | 6.1 | 2.2 | 3.9 |
| Kingsley | Clay | 2 | 6.6 | 0.0 | 3.1 | 7.0 | 1.1 |
| Lily | Clay | 2 | 0.4 | 0.0 | 0.8 | 1.1 | 0.2 |
| Little Bear | Seminole | 3 | 0.1 | 0.0 | 0.5 | 0.0 | 0.0 |
| Little Fairview | Orange | 4 | 0.3 | 0.0 | 8.2 | 0.0 | 0.2 |
| Little Orange | Alachua | 4 | 2.3 | 15.2 | 8.5 | 19.0 | 17.5 |
| Lizzie | Osceola | 3 | 2.9 | 1.5 | 2.8 | 2.2 | 2.8 |

Table A-2. Continued.

| Lakes | County | TP Zones | Surface Area ($km^2$) | Agriculture ($km^2$) | Urban ($km^2$) | Forest ($km^2$) | Wetland ($km^2$) |
|---|---|---|---|---|---|---|---|
| Lochloosa | Alachua | 4 | 21.9 | 22.1 | 14.1 | 112.1 | 51.7 |
| Lorraine | Lake | 4 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Louisa | Lake | 3 | 12.8 | 86.6 | 49.2 | 30.4 | 137.6 |
| Lurna | Orange | 4 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 |
| Magdalene | Hillsborough | 3 | 0.8 | 0.1 | 2.0 | 0.0 | 0.2 |
| Marsha | Orange | 3 | 0.3 | 0.0 | 1.5 | 0.0 | 0.0 |
| Mary | Seminole | 3 | 0.3 | 0.0 | 1.3 | 0.1 | 0.2 |
| Mary Jane | Orange | 3 | 3.8 | 17.2 | 7.4 | 9.7 | 25.9 |
| Minnehaha | Orange | 4 | 0.4 | 0.2 | 7.3 | 0.1 | 0.6 |
| Ola | Orange | 3 | 1.7 | 7.6 | 16.7 | 9.7 | 1.4 |
| Panasoffkee | Sumter | 4 | 13.2 | 293.5 | 290.9 | 152.0 | 112.4 |
| Persimmon | Highlands | 4 | 0.1 | 0.3 | 0.3 | 0.0 | 0.0 |
| Powell | Bay | 3 | 2.6 | 0.0 | 7.1 | 18.7 | 10.7 |
| Ribbon North | Flagler | 4 | 0.1 | 0.0 | 1.2 | 0.1 | 0.0 |
| Riley | Putnam | 2 | 0.2 | 0.0 | 0.2 | 0.1 | 0.0 |
| Rock | Seminole | 3 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 |
| Rosa | Putnam | 2 | 0.4 | 0.0 | 0.6 | 0.1 | 0.0 |
| Santa Fe | Alachua | 3 | 17.0 | 3.3 | 5.4 | 10.9 | 8.5 |
| Sarah | Orange | 4 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 |
| Sellers | Lake | 2 | 3.2 | 0.1 | 6.7 | 64.8 | 5.4 |
| Seminary | Seminole | 3 | 0.2 | 0.0 | 0.4 | 0.0 | 0.0 |
| Shannon | Orange | 4 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 |
| Sheelar | Clay | 2 | 0.1 | 0.0 | 0.0 | 0.6 | 0.0 |
| Spring | Walton | 3 | 0.6 | 0.1 | 0.3 | 0.8 | 0.0 |
| Star | Putnam | 4 | 0.9 | 0.1 | 1.4 | 5.4 | 0.9 |
| Sunset | Hillsborough | 3 | 0.1 | 0.4 | 1.4 | 0.0 | 0.4 |
| Susannah | Orange | 4 | 0.2 | 0.0 | 1.0 | 0.0 | 0.1 |
| Tallavana | Gadsden | 4 | 0.6 | 3.5 | 4.2 | 5.7 | 2.9 |

Table A-2. Continued.

| Lakes | County | TP Zones | Surface Area ($km^2$) | Agriculture ($km^2$) | Urban ($km^2$) | Forest ($km^2$) | Wetland ($km^2$) |
|---|---|---|---|---|---|---|---|
| Todd | Citrus | 3 | 8.7 | 10.0 | 31.9 | 16.5 | 40.2 |
| Trout | Osceola | 3 | 1.0 | 23.8 | 4.5 | 7.1 | 24.2 |
| Unity | Lake | 4 | 0.4 | 0.9 | 1.3 | 0.2 | 0.3 |
| Wauberg | Alachua | 4 | 1.0 | 0.3 | 1.1 | 1.4 | 2.6 |
| Waunatta | Orange | 4 | 0.3 | 0.0 | 5.2 | 0.1 | 0.2 |
| Weir | Marion | 2 | 22.7 | 29.4 | 60.4 | 18.0 | 4.2 |
| Weohyakapka | Polk | 5 | 30.0 | 71.9 | 56.8 | 19.7 | 31.6 |
| Willis | Orange | 3 | 0.5 | 0.0 | 14.4 | 1.9 | 0.8 |
| Wilson | Hillsborough | 3 | 0.2 | 0.1 | 1.5 | 0.2 | 0.4 |
| Winnemissett | Volusia | 3 | 0.7 | 0.1 | 0.5 | 1.1 | 0.2 |
| Winnott | Putnam | 2 | 0.6 | 0.6 | 0.7 | 0.5 | 0.1 |
| Woods | Seminole | 4 | 0.2 | 0.0 | 2.0 | 0.0 | 0.1 |
| Yale | Lake | 4 | 16.0 | 24.8 | 20.8 | 61.6 | 22.9 |

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# BIOGRAPHICAL SKETCH

Chao Xiong was born and raised in Minnesota. He completed his undergraduate studies at the University of Wisconsin-River Falls where he received his bachelor's degree in conservation. Upon graduation in 2014, he was offered a fisheries technician position with Dr. Mike Allen in his lab at the University of Florida. After a year of working for the Allen Lab he was offered a graduate assistantship under Dr. Mike Allen and Mark Hoyer of LAKEWATCH. Throughout his time as a graduate student, on top of working on his graduate project, he also participated in many other projects and assisted with an introductory fisheries course. Aside from his education, he enjoys fishing, building aquaria, and exploring the outdoors.