Effectiveness of the Timing of

SEASONAL FERTILIZER RESTRICTIONS on URBAN LANDSCAPES

Specific Appropriation 146
Final Report

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LIST OF ABBREVIATIONS

BMPs = Best Management Practices

C = Carbon

FDEP = Florida Department of Environmental Protection

FFL = Florida-Friendly Landscaping™

HOA = Homeowners Association

IFAS = Institute of Food and Agricultural Sciences, University of Florida

IRL = Indian River Lagoon

lb = pound

n = sample size of the population

N = Nitrogen

NH_4^+ = Ammonium

NO_3^- = Nitrate

NO_3–N = Nitrate-nitrogen

O = Oxygen

P = Phosphorus

PON = Particulate organic N

UF/IFAS = University of Florida, Institute of Food and Agricultural Sciences

EXECUTIVE SUMMARY

Increasing inputs of nitrogen (N) and phosphorus (P) in aquatic systems are primary contributors to the decline in water quality across Florida. While both natural occurrences and human activities contribute to the transport of N and P into Florida's surface and groundwater, N and P inputs via landscape fertilizers have been a particular focus for local communities.

Since May 2000, at least 36 counties and 98 additional municipalities have established official urban landscape fertilizer ordinances, also called “fertilizer bans”, fertilizer “blackout” periods, “restrictive periods”, or “restricted season”. There is concern over whether fertilizer ordinances are effective at reducing pollution or providing ecological benefits, particularly given their ubiquity throughout the state and the variety of different ordinance types. This concern led to a fertilizer ordinance development moratorium until July 1, 2024, through the Florida Senate - 2023, Bill No. SB 2502, Lines 2455 – 2460. Via this legislation, and from funds in the Specific Appropriation 146, the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) shall “…evaluate the effectiveness of the timing of seasonal fertilizer restrictions on urban landscapes toward achieving nutrient target objectives for waterbodies statewide.”

Therefore, the purpose of this document is to provide a literature review of the most recent and relevant studies linking fertilization of urban landscapes with nutrient export to the environment, and potential subsequent water quality concerns in Florida. As a specific objective, this document discusses the effectiveness of seasonal fertilizer restrictions in decreasing nutrient contributions to aquatic ecosystems. Finally, this report summarizes the published studies, details recommendations regarding the current fertilizer ordinances, and identifies areas where further research is required to understand the effect of fertilizer ordinances on Florida’s waterbodies.

The literature review summarizes and relates studies performed mainly in Florida, with some additional studies from other states when deemed relevant. The following are the main points analyzed:

- Studies relating nutrient export from urban landscapes, the resulting water quality, and the environmental, public health, economic, and social impacts of nutrient-driven water quality responses.

- The history and evolution of fertilizer ordinances in an attempt to counteract the detrimental effects of nutrient pollution on Florida waterbodies.
- The sources of nutrients to waterbodies, where it is clear that fertilizers are not the only source of the nutrients N and P. Additional sources include septic systems; reclaimed water, stormwater pond, and wastewater treatment plant outflows; atmospheric deposition (via lightning, rain, and dry deposition of fine particulates); organic materials such as grass clippings and other yard waste, compost, and animal wastes; erosion and weathering of soils or geologic materials. The main sources are then analyzed separately, with a special section regarding fertilizers and their nutrient exports from the landscape.
- The few studies performed in Florida regarding the efficacy of fertilizer ordinances are detailed and analyzed.
- Finally, human behavior related to the awareness and compliance of fertilizer ordinances is analyzed.

This document ends with a summary and recommendations. A key takeaway message of the recent studies is that there is no single source of urban nutrients to Florida's waterbodies, and that the task then becomes to place the various sources in context with each other to learn which sources might be the most important in a given location and time.

There have been six studies (five published as peer-reviewed scientific articles) on the efficacy of fertilizer restrictions in Florida. These six studies are detailed and analyzed. Except for one study, they were performed in small or specific areas and analyzed fertilizer ordinance impacts in relatively short time scales (less than 5 years). Varied and sometimes contradictory findings were reported by these studies, which can be attributed to the fact that not all ordinances exert the same influence on the water quality parameters analyzed. In addition, because there are many sources of nutrients in waterbodies, it is often difficult in short term or small scale studies to resolve the effect of fertilizer ordinances from other potential causes of altered nutrient inputs into a waterbody, whether due to natural or human causes. Furthermore, waterbodies can respond in a variety of different ways to increasing nutrient inputs. There are natural processes occurring within waterbodies that can temporarily or permanently remove nutrients, reducing their impact on other water quality metrics and potentially obscuring changes in watershed nutrient management.

The difficulty in pin-pointing specific causes of water quality responses is exacerbated when studies are conducted at small scales, over limited time frames, and without a comprehensive measure of watershed hydrology and water quality parameters. Moreover, the divergence in the effectiveness of fertilizer restrictions depends on various factors, including the specific regulations in place, the (lack of) enforcement, education, or awareness of those regulations, the willingness of the local community to comply, and the ecological and environmental conditions of the area. Thus, the existing evidence to date does not conclusively indicate that fertilizer ordinances are effective in solving water quality problems. This is not necessarily indicative of the ordinances not achieving their intended goals; rather, the current lack of comprehensive evidence makes it challenging to assess the ecological impact of these ordinances.

Further studies are necessary to identify the relative contribution of different sources of nutrients into waterbodies. Additional studies that include the timing, type, and amount of fertilizer applied in urban/suburban areas and their ecological impact on waterbodies are necessary. At the same time, these studies should address the knowledge of and the compliance with the local ordinances. These additional studies would facilitate the development of site-specific strategies to reduce N and P contributions from different sources to waterbodies and make better decisions regarding future regulations and public funding to remediate this ongoing problem statewide.

BACKGROUND

Increasing inputs of nitrogen (N) and phosphorus (P) into aquatic systems are primary contributors to the decline in water quality across Florida. While both natural occurrences and human activities contribute to the transport of N and P from terrestrial environments into Florida's surface waters and groundwater, N and P inputs from landscape fertilizers have been a particular focus for local communities. (Note: the terms “landscape” and “urban landscape” are used interchangeably in this document to mean the installed or existing plant material that is maintained around urban/suburban built structures for aesthetic or functional purposes.)

Turfgrass is the dominant plant material in urban and suburban landscapes and is a prominent feature of urban watersheds. Milesi et al. (2005) estimated that turfgrass covered 1.9% of the total continental U.S. surface area in 2001 and 6.8% of Florida’s surface area. Since 2001, the amount of housing in Florida has increased from 7,477,001 units (US Census Bureau, 2023a) to 10,257,426 units in 2022 (US Census Bureau, 2023b), a 37% increase. Therefore, the area of turf and landscapes has likely increased with housing increases.

Urban soils, whether native or disturbed/mixed due to the urban development process, often lack sufficient N and occasionally lack sufficient P to support the healthy growth and desired quality of turfgrass and other landscape plants. To overcome this nutritional deficiency, fertilizer is commonly applied. However, if not done correctly, fertilization associated with high rainfall and/or excess irrigation can mobilize excess nutrients to the environment, potentially impairing water quality (Carey et al., 2012).

In Florida, the first municipal fertilizer regulation was adopted by St. Johns County in May 2000. Since then, at least 36 counties and 98 additional municipalities have established official urban landscape fertilizer ordinances (FFL, 2023a). In general, these fertilizer ordinances include application standards, enforcement, exemptions, and applicator training. Fertilizer application restrictions are also called “fertilizer bans”, fertilizer “blackout” periods, “restrictive periods” or “restricted season”. These restrictions are often seasonal or encompass periods during the year when the application of fertilizers containing N or P or both on urban landscapes is prohibited. The premise behind these ordinances is that N and P associated with the fertilizer product may be leached through the soil profile into groundwater or directly runoff from the soil during the rainy season, or that excess N and P not taken up by plants during the dormant season (in the case of winter seasonal restrictions) may be susceptible to leaching or runoff losses and transported to waterbodies.

As an artifact of their local implementation, fertilizer ordinances vary across the state in their timing and other regulatory requirements. Due to these varied ordinances and regulations, there is concern over whether certain ordinances are more or less effective than others. This concern led to a fertilizer ordinance development moratorium through the Florida Senate – 2023, Bill No. SB 2502, Line 2455, Pg. 86, Section 85, which established: "In order to implement Specific Appropriation 146 of the 2023-2024 General Appropriations Act, a county or municipal government may not adopt or amend a fertilizer management ordinance, pursuant to s. 403.9337, Florida Statutes, which provides for a prohibited application period not in existence on June 30, 2023. This section expires July 1, 2024."

Via this legislation, and using funds from Specific Appropriation 146, the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) should "…evaluate the effectiveness of the timing of seasonal fertilizer restrictions on urban landscapes toward achieving nutrient target objectives for waterbodies statewide. IFAS must submit a final report, including results and recommendations by December 31, 2023, to the chair of the Senate Appropriations Committee and the chair of the House Appropriations Committee."

Therefore, the main purpose of this document is to provide a literature review of the most recent and relevant studies linking fertilization of urban landscapes with nutrient export to the environment, and potential subsequent water quality concerns in Florida. As a specific objective, this document discusses the effectiveness of seasonal fertilizer restrictions in decreasing nutrient contributions to aquatic ecosystems. Finally, based on the published studies, this report details recommendations regarding the current fertilizer ordinances and identifies areas where further research is required to understand the effect of fertilizer ordinances on Florida's waterbodies.

LITERATURE REVIEW

Nutrients and water quality

Nutrients such as N and P are naturally occurring elements that form the building blocks of life and are essential for plant growth. However, excess nutrient inputs into waterbodies can cause degradation and are often responsible for the proliferation of plants, algae, and cyanobacteria (blue-green algae) within waterbodies through a process known as eutrophication. Eutrophication impairs ecosystem health and the beneficial services provided by healthy waterbodies. Additionally, eutrophication contributes to harmful algal blooms (including cyanobacterial blooms and brown tides), reduced water clarity, seagrass die-offs, decreased or depleted oxygen levels (hypoxia/anoxia), fish and wildlife die-offs, and loss of biodiversity (including species important for commerce and recreation) (Gobler et al., 2013; Lapointe et al., 2015; Phlips et al., 2015; Lapointe et al., 2020; Herren et al., 2021; Morris et al., 2021; Phlips et al., 2021; Allen et al., 2022; Landsberg et al., 2022; Lapointe et al., 2023). In addition to these environmental effects, elevated nutrients may impair the use of water for drinking, industry, agriculture, tourism and recreation, and other purposes leading to public health, social, and economic impacts (Abbott et al., 2021; Dodds et al., 2006).

Fertilizer ordinances

In an attempt to counteract the detrimental effects of nutrient pollution on Florida waterbodies, almost all of Florida's highly urbanized counties and/or municipalities have implemented fertilizer ordinances (Figure 1). These ordinances typically apply to every residential landscape, restricting the use of N and P fertilizers during specific times (e.g., summer or winter), with exemptions for agricultural properties, vegetable gardens, golf courses, and athletic fields (FFL, 2023b).

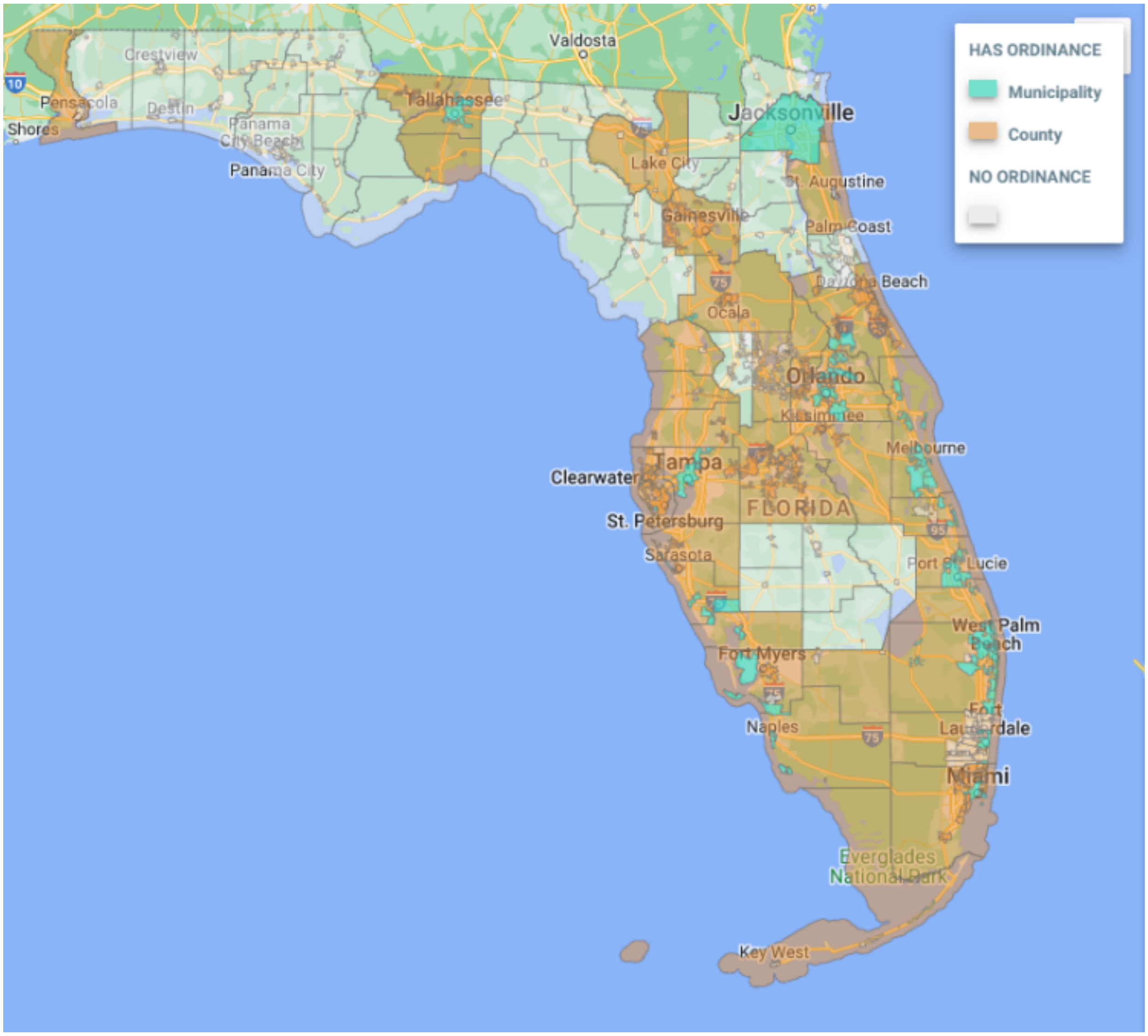

Figure 1. Florida fertilizer ordinances. (Source: FFL, 2023a.)

The implementation of fertilizer ordinances was started by St. Johns County in May 2000 (Ordinance NO. 2000-60) and in September 2003 the Florida Department of Environmental Protection (FDEP) published the "Guidelines for Model Ordinance Language for Protection of Water Quality and Quantity Using Florida Friendly Lawns and Landscapes". However, large-scale adoption of fertilizer ordinances did not occur until 2007, triggered by a 13-month long *Karenia brevis* red tide bloom along Florida's southwest coast and the adoption of a model ordinance for fertilizer regulation by the Southwest Florida Regional Planning Council (Hartman et al., 2008).

Beyond residential ordinances, the Urban Turf Fertilizer Rule (Florida Administrative Code 5E-1.003) was implemented in December 2007. This rule established label language requirements for fertilizer products for urban turf or lawns, packaged in containers or bags such that the net weight is 49 pounds or less, and distributed for home and garden use. Furthermore, the rule required printed directions for use for N that adhered to UF/IFAS annual fertilization guidelines for established turfgrass lawns in north, central, and south Florida. The rule also required industry professionals to follow relevant Best Management Practices (BMPs) for the appropriate industry segment (e.g., green industry and golf).

In 2009, the Model Ordinance for Florida-Friendly Fertilizer Use on Urban Landscapes was adopted into state law (Florida Statute 403.9337) as a mechanism intended to reduce the export of nutrients from urban landscapes to Florida's groundwater and surface waters (FFL, 2023b). The statute encourages county and municipal governments to adopt the Model Ordinance or equivalent. Local governments located within the watershed of an impaired water body, shall, at a minimum, adopt FDEP's Model Ordinance or they may adopt additional or more stringent standards than the model ordinance if the following criteria are met:

- "The local government has demonstrated—as part of a comprehensive program to address nonpoint sources of nutrient pollution, which is science based, and economically and technically feasible—that additional or more stringent standards than the model ordinance are necessary in order to adequately address urban fertilizer contributions to nonpoint source nutrient loading to a water body."
- "The local government documents that it has considered all relevant scientific information, including input from the department, the institute, the Department of Agriculture and Consumer Services, and UF/IFAS, if provided, on the need for additional or more stringent provisions to address fertilizer use as a contributor to water quality degradation. All documentation must become part of the public record before adoption of the additional or more stringent criteria."

Key provisions of the FDEP's Model Ordinance include:

- Prohibition of fertilizer application containing N or P to turf or landscape plants during the "Prohibited Application Period, or to saturated soils";
- Surface water setbacks (within a certain distance of a waterbody);
- The use of deflector shields on application equipment;
- The use of slow-release fertilizers;
- Low maintenance zones;
- Soil testing before applying P fertilizer;
- Fertilizer nutrient content and application rates;
- Application rates and practices;
- Training requirements;
- Licensing of commercial applicators.

Current ordinances generally include these key provisions or variants. Furthermore, law SB 494, from June 2009 requires all commercial fertilizer applicators to have a Florida Department of Agriculture and Consumer Services (FDACS) fertilizer license by January 1, 2014. In addition, optional BMPs, like the Florida-Friendly Landscaping™ (FFL) Program, have been introduced in some ordinances to further curb nutrient leaching and/or runoff from urban settings (Momol et al., 2021).

As of May 2023, there were 36 counties and 98 additional municipalities in Florida that have enacted residential fertilizer ordinances (FFL, 2023a). Some of these county ordinances apply to unincorporated areas only, which are sometimes complemented by individual municipalities within a county. Among the 36 counties that have fertilizer ordinances, 18 have specific summer bans.

Sources of nutrients to waterbodies

Nitrogen and P are both fundamental nutrients required by every living organism on Earth. However, they are often in short supply and can be the limiting factor for the growth of microbes, plants, and animals within an ecosystem.

Florida-specific studies of the sources of N and P in urban watersheds are growing in number and spatial coverage. Badruzzaman et al. (2012) published one of the earliest summaries of nutrient sources and their transport to Florida waterbodies, based on a synthesis of a small number of peer-reviewed and grey literature studies. Since then, new research has expanded the evidence-base of how various N and P sources are contributing to waterbodies in the state. These new studies, which are largely peer-reviewed, are continuing to become more geographically inclusive of the state, and to date have focused on N and P contributions to watersheds.

From these studies and selected studies from outside of Florida, it is clear that fertilizers are not the only source of N and P. Other sources include septic systems; reclaimed water; stormwater pond and wastewater treatment plant outflows; atmospheric deposition (via lightning, rain, and dry deposition of fine particulates); organic materials such as grass clippings and other yard waste, compost, and animal wastes; erosion and weathering of soils or geologic materials (Nixon, 1995; Howarth et al., 2000; Nixon, 2009; Hochmuth et al., 2012; Badruzzaman et al., 2012; Lapointe et al., 2015; Glibert and Burford, 2017; Hobbie et al., 2017; Yang and Toor, 2017; Jani et al., 2020; Lusk et al., 2020; Reisinger et al., 2020; Krimsky et al., 2021; Lapointe et al., 2023; Lusk et al., 2023). Geologic weathering is a particularly important source of P in Florida, where there are naturally occurring P-rich geological formations throughout parts of the state (e.g., central Florida phosphate mines), providing naturally elevated P concentrations in surface water and groundwater ecosystems.

A key takeaway message of the recent studies is that there is no single source of urban nutrients to Florida's waterbodies, and that the task then becomes to place the various sources in context with each other to learn which sources might be the most important in a given location and time. Nutrient source tracking methods such as the use of stable isotopes have been the most common means of identifying nutrient sources. For example, the isotopic composition of N and oxygen (O) in NO_3^- (nitrate) have been used to infer the relative contributions of atmospheric deposition, fertilizers, pet wastes, and human wastewater (including septic systems) to stormwater runoff N in studies in the Indian River Lagoon and in coastal urban areas around Tampa Bay (Lapointe et al., 2015; Yang and Toor, 2017; Krimsky et al., 2021, Jani et al., 2020; LaPointe et al., 2023). In other studies, the isotopic composition of N and carbon (C) in organic materials have been used to estimate the contributions of materials such as grass clippings and leaf litter to the total N loads of stormwater in Tampa Bay (Lusk et al., 2020). Another promising source tracking method for waters impacted by human waste is the use of trace organic compounds such as sucralose, pharmaceuticals, hormones, and steroids, all of which are not typically fully removed by the wastewater treatment process and may be used as indicators of wastewater as a potential nutrient source in waterbodies. However, matching concentrations of wastewater tracers with potential nutrient impacts to receiving waters remains an important research need.

In the following discussion, we summarize findings of nutrient source studies conducted mainly over the last decade, with an emphasis on Florida-specific studies but also focusing on other locations, when doing so adds to the broader understanding of nutrient fate and transport in urban areas. Many of the studies identified for this review use one or more source tracking methods described above.

N and P cycles in urban environments

To identify the different N and P inputs into an urban watershed, it is necessary to review the contributing sources of those nutrients. Afterward, it is important to assess how these nutrients are transformed and mobilized toward waterbodies in urban settings (Figures 2 and 3). Typical inputs of N and/or P in urban environments include fertilizers, atmospheric deposition, septic systems, wastewater treatment plant outflows (including reclaimed water), plant residues (e.g., grass clippings, tree leaves, and other yard waste), compost, and animal waste. These components containing N and P can be transformed into more simple molecules, and then lost from the soil by plant uptake, denitrification and volatilization (in the case of N), erosion (in the case of P), or they could be transported towards water bodies through runoff or leaching.

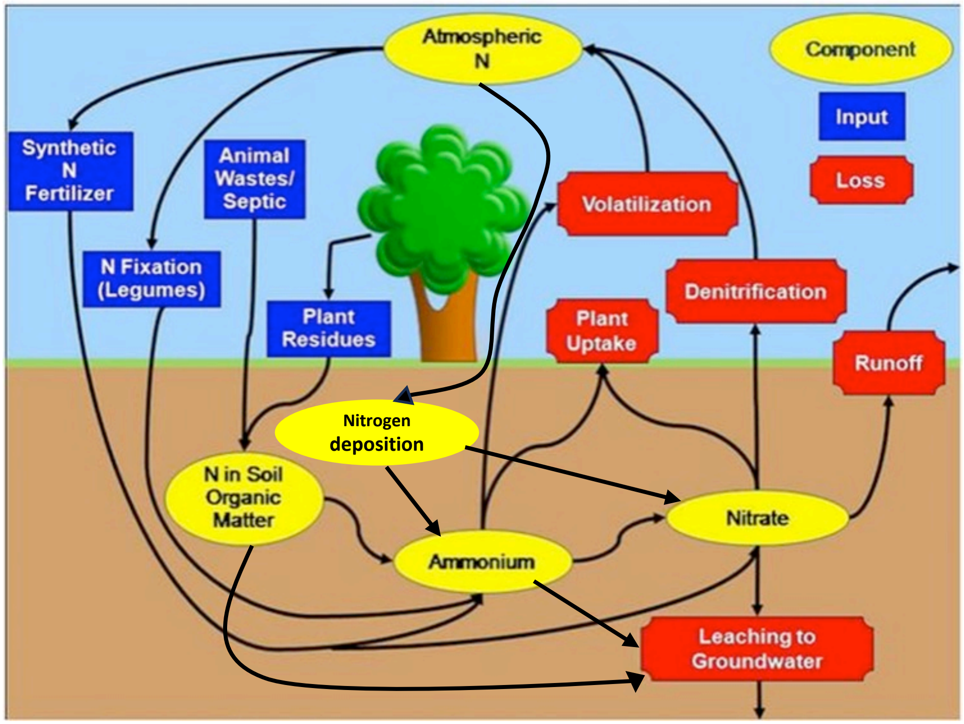

Figure 2. The nitrogen cycle in urban environments. Credit: Modified from UF/IFAS. Source: Shober and Reisinger (2022).

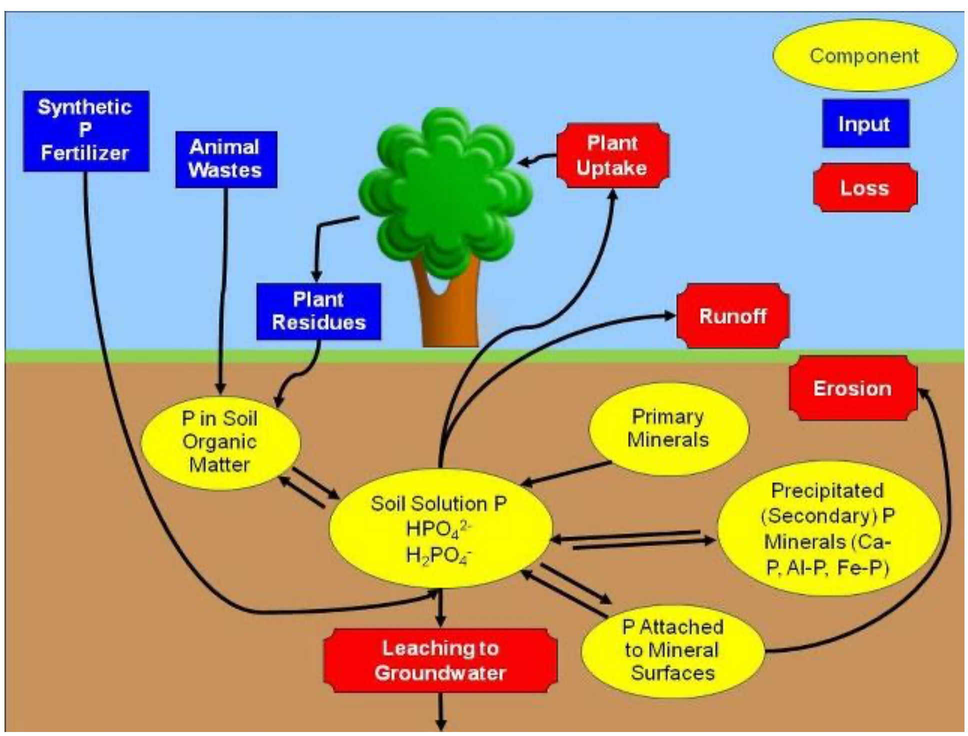

Figure 3. The phosphorous cycle in urban environments. Credit: UF/IFAS. Source: Shober, 2018).

For example, researchers in Minneapolis, MN, conducted a nutrient budget study where they quantified various pathways by which N moves into and out of urban watersheds. They found that residential fertilizer was the largest input of N into the watershed, whereas household pet waste was the largest source of P. Atmospheric deposition was also an important source of N and P across multiple watersheds that were studied (Hobbie et al., 2017).

At the regional or watershed scale, urban watersheds can be highly effective at retaining N under certain circumstances. Natural processes within waterbodies can temporarily or permanently remove nutrients, reducing their influence on other water quality indicators and possibly masking changes in watershed nutrient management. There is a history of research investigating the influence of urbanization and human actions on nutrient export in Baltimore, MD, through a long-funded National Science Foundation research project. For example, Bettez et al. (2015) found that urban watersheds in Baltimore, MD, can typically retain 70% to more than 90% of the total nitrate inputs into the watershed on an annual basis. However, the degree of urbanization and increasing annual precipitation can reduce this level of N retention (Bettez et al., 2015). Among numerous other studies on lawn, forest, stream, and wetland nutrient cycling studies from Baltimore, MD, Suchy et al. (2021) found that N export from residential lawns may not be driven by N fertilization rates. Additional work in Baltimore has revealed that the implementation of green infrastructure to capture and treat stormwater runoff, coupled with a reduction of unintentional discharges of untreated wastewater can reduce annual N and P export to coastal water bodies (Reisinger et al., 2019). In addition, residential lawns can accumulate both C and N at degrees comparable to or even higher than nearby forests (Raciti et al., 2011).

We note that although these studies provide important information about how nutrient cycles interact with various urban factors, the environmental contexts of Minneapolis, MN, and Baltimore, MD, are much different than in Florida due to differences in geology, soils, climate, and social factors. To date, a comprehensive study to understand N and P sources and pathways within Florida’s urban watersheds has not been conducted. Having such information would better inform landscape maintenance recommendations, including fertilizer management.

Septic systems

Around 80% of Florida's residents live within 10 miles of the coast. Approximately 30% of Florida's residents rely on septic systems for their wastewater disposal needs, with around 2.6 million systems in operation. Of those 2.6 million septic systems, around 40% are in coastal areas with high water tables (FDEP, 2023). Under these circumstances, septic systems (Figure 4) have been reported as the main contributor of the N load in coastal locations of Florida (Lapointe et al., 2015; Lapointe et al., 2017; Barile, 2018; Herren et al., 2021; Brewton et al., 2022; Tyre et al., 2023; Lapointe et al., 2023), as well as in urbanized estuaries of the northeastern US (Sham et al., 1995; McClelland et al., 1997; Valiela et al., 1997; Valiela et al., 2000; Kinney and Valiela, 2011; Lloyd, 2014).

For example, a recent study by Brewton et al. (2022) reported that more than 80% of the sampled conventional septic systems in the Caloosahatchee River and Estuary, in Lee County, Florida, were too shallow for an adequate filtration function (Figure 5). While they did not analyze nutrients from fertilizers, they found that both groundwater and surface water were contaminated by septic system effluent, impairing the water quality and intensifying harmful algal blooms.

A large-scale study was conducted by Tyre et al. (2023) in various drainage basins throughout Lee County, Florida (Figure 6), where they collected surface water samples as well as particulate organic matter and macrophyte (aquatic plant) tissue samples at 25 sites, between January 2020 and January 2021. They reported that fecal bacteria were elevated in 66% of the samples, while stable isotope analyses revealed sources of N derived from human waste at 44%, 68%, or 100% of locations based on isotopic analyses of nitrate-nitrogen (NO_3–N), particulate organic matter, and plant tissue, respectively. These results provide evidence of widespread human waste contamination in the basins of Lee County, Florida (Figure 7). The authors recommend infrastructure improvements to improve water quality and minimize harmful algal blooms.

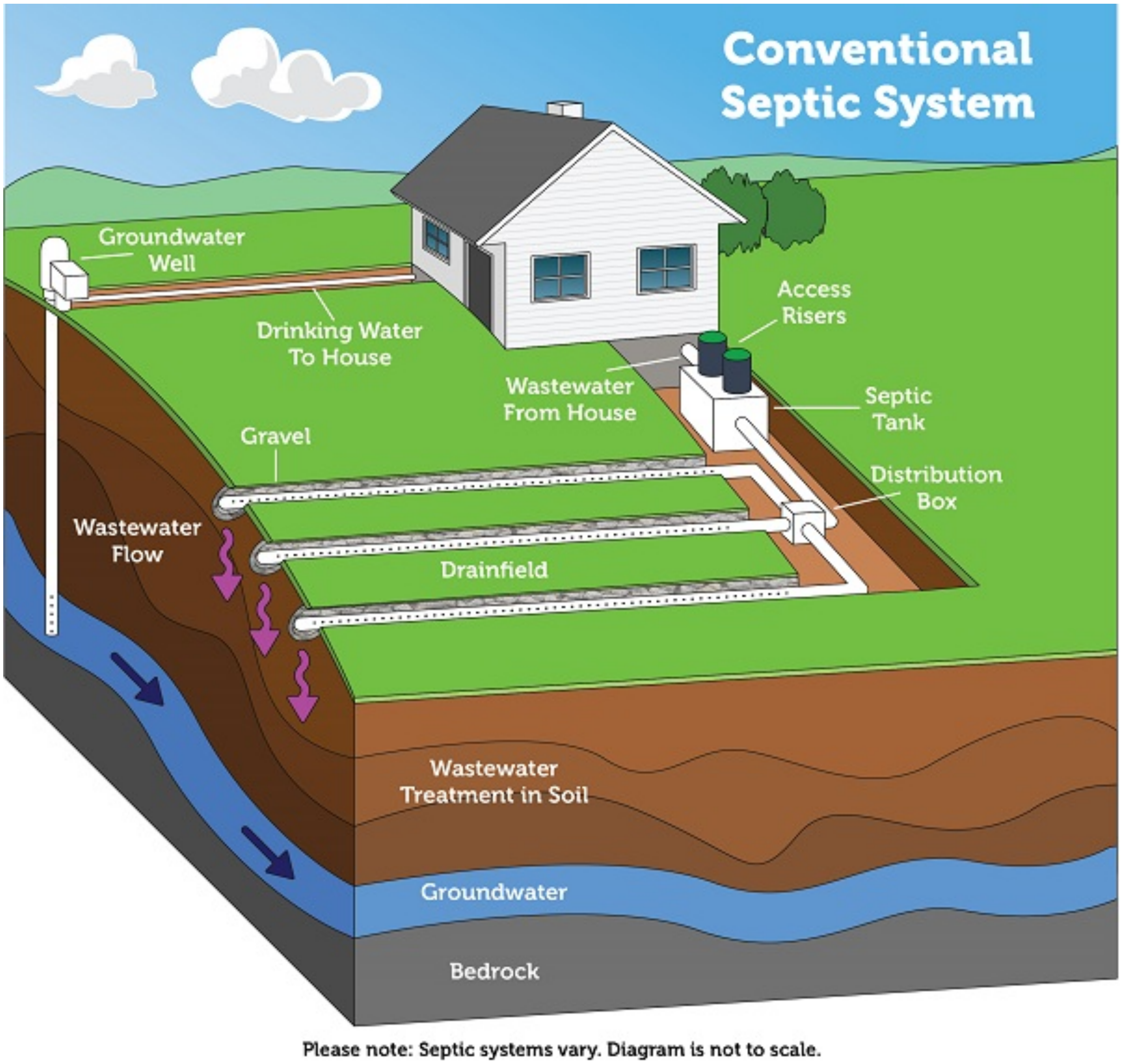

Figure 4. A conventional septic system consisting of a septic tank and drainfield. The septic tank is buried in the soil and collects household waste. As waste collects in the septic tank, solids settle to the bottom of it and the liquid (called effluent) flows out through perforated pipes to the drainfield, or soil area through which effluent percolates downward. (Source: EPA, 2023a)

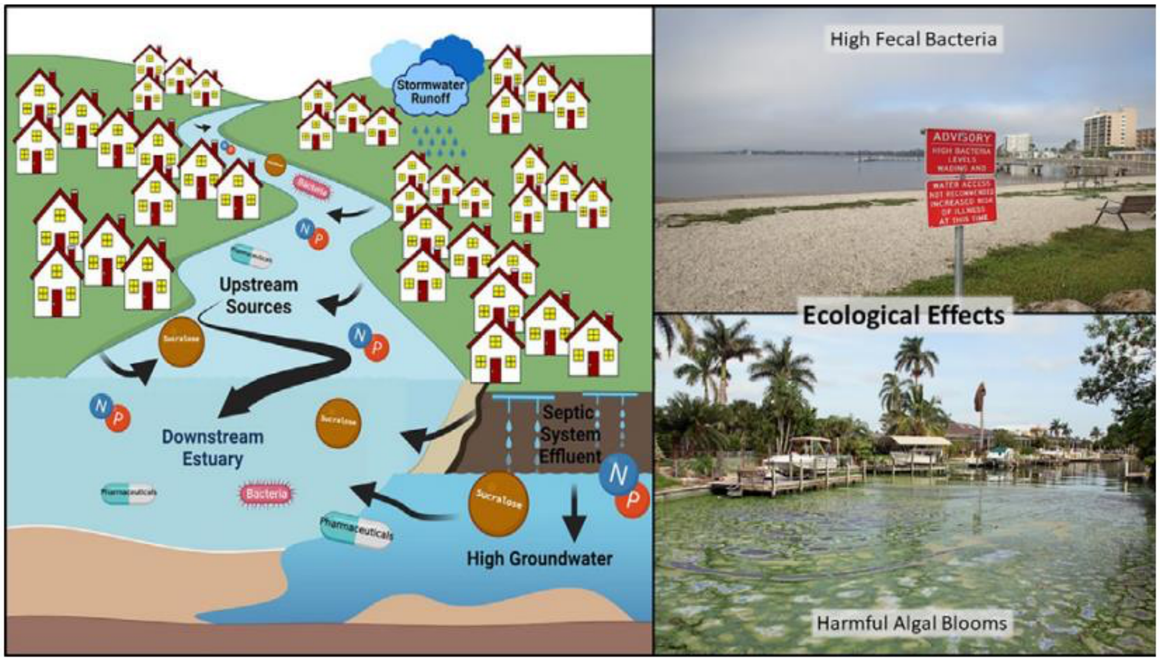

Figure 5. Septic system–groundwater–surface water couplings in waterfront communities. (Source: Brewton et al., 2022)

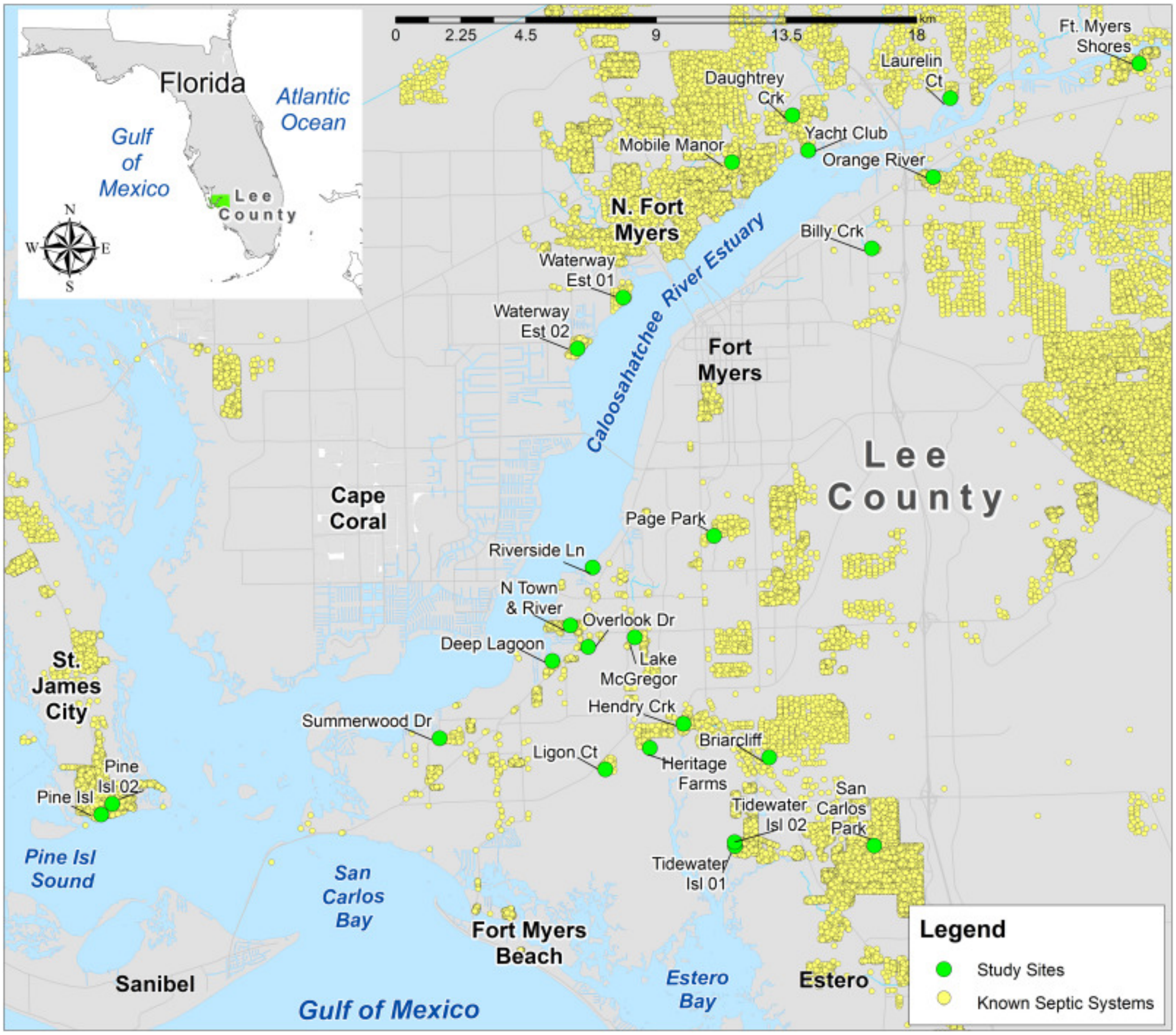

Figure 6. Surface water study sites (green circles) and known septic systems (yellow dots) in Lee County, Florida, from a study conducted by Tyre et al. (2023).

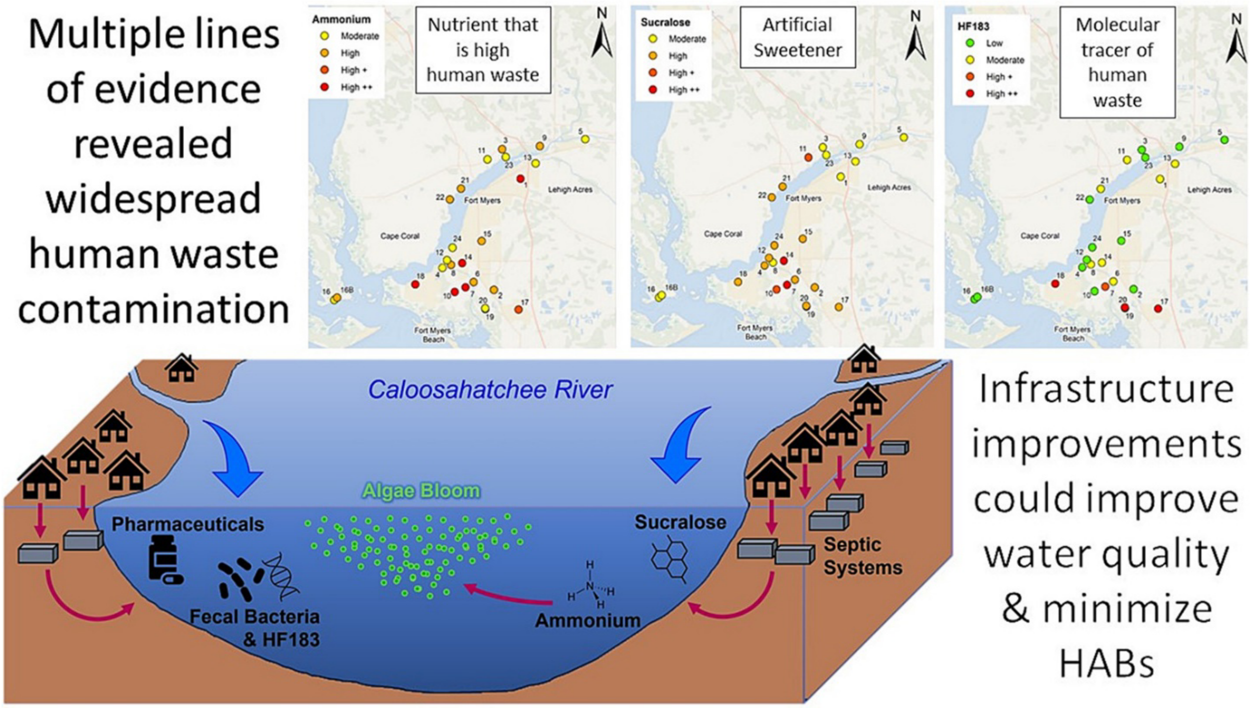

Figure 7. Graphical abstract of the study by Tyre et al. (2023).

Moreover, a recent study by Lapointe et al. (2023) concluded that in Florida's Indian River Lagoon (IRL) 79% of the N loading was from septic systems, while residential fertilizers contribution was 21%. The authors conclude that current fertilizer restrictions are insufficient to mitigate the ongoing eutrophication at the IRL and that it would be prudent to prioritize reducing human waste nutrient inputs.

Other studies in urbanized estuaries of the northeastern US have reported that the largest N source driving eutrophication and harmful algal blooms come from septic systems (Sham et al., 1995; McClelland et al., 1997; Valiela et al., 1997; Valiela et al., 2000; Kinney and Valiela, 2011; Lloyd, 2014). For example, in Waquoit Bay, MA, 48% of the N load to estuaries came from septic systems, 29% from atmospheric deposition and 16% from fertilizer (Sham et al., 1995; Valiela et al., 1997). Likewise, on different bays of Long Island, NY, around 50% of the N loads came from septic system effluent (Kinney and Valiela, 2011; Lloyd, 2014).

Therefore, septic systems close to waterbodies (or shallow water tables) might result in widespread human waste contamination. Herren et al. (2021), who studied nutrients loadings to the IRL, concluded that low-lying septic systems should be removed. Accordingly, Cox et al. (2019) warned that the functionality of an increasing number of septic systems in coastal areas will be compromised by sea level rise in the future, highlighting the need for alternative wastewater management approaches to protect coastal water quality. In addition, Tyre et al. (2023) suggested the replacement of septic systems in coastal areas of Lee County, Florida, with centralized sewer (or other alternatives) and include adequate wastewater infrastructure with advanced nutrient removal capabilities.

Reclaimed water

Reclaimed water used for urban irrigation has varying levels of both N and P, in both inorganic and organic forms. The concentrations of nutrients in reclaimed water depend on the nutrient removal technology used at the wastewater treatment plant, as well as storage of the water that takes place before it is used as irrigation. Only a few studies have investigated the role of reclaimed water in nutrient transport to waterbodies in Florida. In ideal circumstances, the reclaimed water is applied only to lawns and other urban green spaces, where nutrients may be assimilated by plant roots and soil organic matter. However, urban irrigation can be highly inefficient. A recent study showed that approximately 34% of the total irrigation volume being wastefully applied to adjacent impervious surfaces such as streets and sidewalks (Barr, 2023). Application of irrigation in this way may be problematic especially for waterfront communities where neighborhood stormwater systems quickly route runoff of reclaimed water with elevated N and P to canals or bays.

In a study in Martin County, FL, Barr (2023) collected reclaimed water at sprinkler heads in two residential communities multiple times over 12 months and estimated (based on the assumption that 34% of all irrigation volume was wastefully applied to streets and sidewalks) that yearly N loads from irrigation-driven runoff ranged from about 0.3 to 3.0 lbs N/lawn. For a watershed with several thousand homes using reclaimed water for irrigation, this can translate to thousands or tens of thousands of pounds of N per year. Continued studies are needed to better understand the extent to which irrigation-driven runoff of reclaimed water is impacting downstream waterbodies, and how that varies by the level of wastewater treatment in a watershed and by homeowner behaviors (such as how efficiently they operate their sprinkler systems).

Nutrients from reclaimed water may also be a source of N and P leaching in urban landscapes, if not all the irrigation water's nutrient load is assimilated by plant roots or soil organic matter. It is reasonable to conclude that some fraction of the nutrient load in reclaimed water used for irrigation is taken up by turfgrass or other landscape plants, but studies are lacking on the extent to which all of the nutrient load is taken up, how much of it may leach on short time frames, and how much of it may be incorporated into soil organic matter and leach more slowly over long time periods. A study performed by Cardenas and Dukes (2016) in the locality of Palm Harbor, FL, found that homes irrigating with reclaimed water, and no additional technology other than their irrigation timer, over-irrigated 4.4 times more than the calculated gross irrigation requirement (water needed by the turfgrass). Thus, leaching of nutrients is possible if not likely.

Atmospheric deposition

Rainfall and atmospheric dust naturally contain both N and P. Atmospheric deposition of N is especially recognized as a source of N to waterbodies in Florida, with it accounting for 0.39 lb N/acre in one single storm event in the Tampa Bay area, according to a study by Lusk et al. (2023). Work by the Tampa Bay Estuary Program (TBEP, 2023) estimated that 17% of the total N load (566 tons per year) to Tampa Bay during the 2010s was deposited directly to Bay waters from atmospheric deposition.

Grass clippings and landscape wastes

In established lawns, recycling grass clippings improves the sequestration of N in the soil (Hull and Liu, 2005; Qian et al., 2003; Starr and DeRoo, 1981), since clippings can store between 25% and 60% of the applied N (Petrovic and Easton, 2005). In addition, when clippings are returned to the lawn, turf quality may not be adversely impacted when decreasing N fertilization by 50% to 75% (Heckman et al., 2000; Kopp and Guillard, 2002). Regarding P, returning clippings did not affect P runoff (Bierman et al., 2010).

Grass clippings and other vegetation that is allowed to stay on impervious surfaces can be a source of nutrients for stormwater runoff. Grass clippings and seasonal leaf litter (live oak leaves) that accumulated on urban impervious surfaces were identified as a major source of total N in stormwater runoff from a residential community in Hillsborough County (Lusk et al., 2020). In this case, the N fraction from grass clippings and leaves was in the form of organic N, and while the inorganic forms of N (nitrate and ammonium) are known to be bioavailable and drivers of algal blooms in receiving water bodies, there is a growing body of evidence that organic N in stormwater can also be highly bioavailable (Lusk and Toor, 2016; Muni-Morgan et al., 2023). The Lusk et al. (2020) study also observed that particulate organic N (PON) displayed a seasonal first flush, in which the majority of PON was carried by stormwater early in the summer rainy season, presumably as early summer rains mobilized and transported organic materials that had accumulated on urban impervious surfaces during the preceding dry season. Thus, an important best management practice for nutrients in urban landscapes is to keep grass clippings and landscape wastes from accumulating on impervious surfaces, through practices such as street sweeping, composting, or removal.

Compost amendments

Addition of organic compost increases the potential for N and P leaching, with the majority of nutrient leaching occurring within the first 30 days of incorporation (Radovanovic and Bean, 2020). When applying compost to lawns, Easton and Petrovic (2004) found a higher P loss, on a percent applied P basis, compared to synthetic fertilizer. Time course or chronosequence studies focused on the long-term effects of compost incorporation are needed.

Fertilizers

The amount of fertilizers purchased in the state of Florida containing N declined 64% between 2003 and 2017, from 204,000 tons to 73,000 tons, respectively (Figure 8). Fertilizers containing phosphorus (as P_20_5) have declined 70% over the same period, from 70,000 tons to 21,000 tons, respectively (EPA, 2023b). [Note: P_20_5 (or phosphate) is 44% phosphorus. By convention, the amount of phosphorus in fertilizers is expressed in this form.]

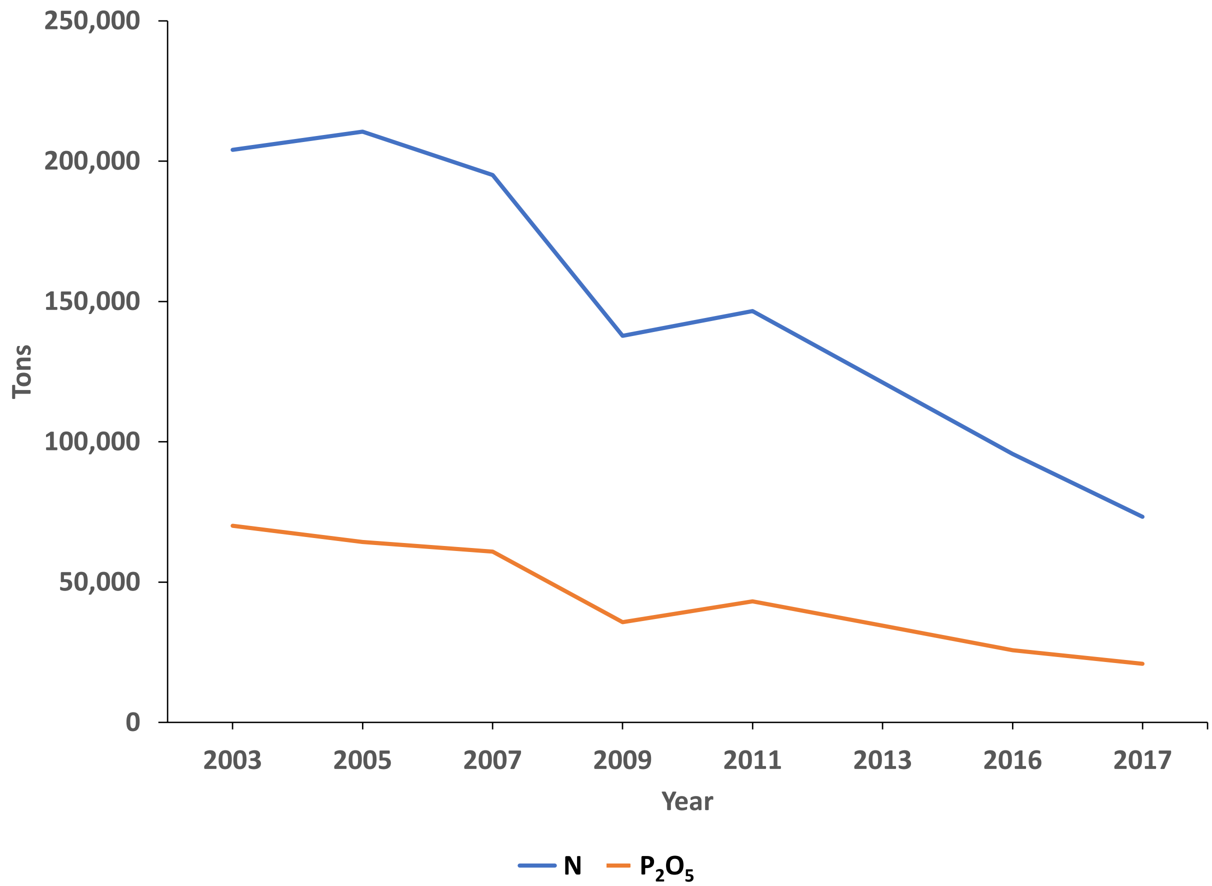

Figure 8. Amounts of fertilizers containing nitrogen (as N) or phosphorus (as P_2O_5) purchased in the state of Florida between 2003 and 2017, in terms of sales or shipments, as submitted by state fertilizer control offices. (From data extracted from EPA, 2023b.)

These reported amounts of fertilizers purchased involve all market sectors. Between July 2011 to June 2012, the major consumer of fertilizers was the farm sector, with 83% of the N and 87% of the phosphate fertilizers (Figure 9). Conversely, the lawn sector represented only 6% for the N and 3% for the phosphate market at that time (FDACS, 2017).

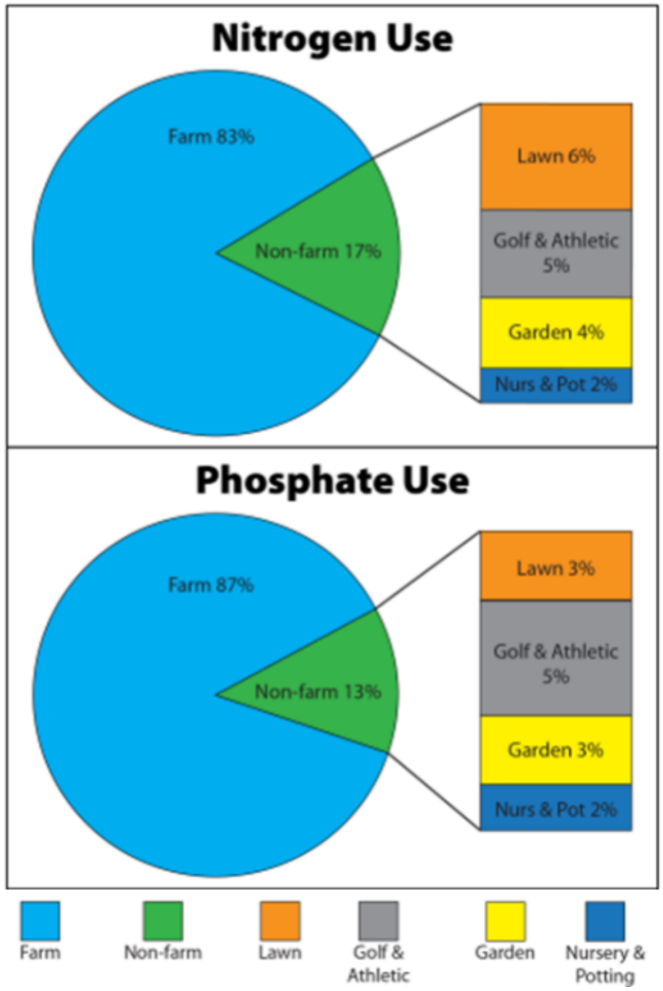

Figure 9. Percentage of total nitrogen and phosphate use by Florida market sector from July 2011 to June 2012. Credit: Shaddox and Unruh, 2017. Source: FDACS (2017).

Despite these trends in fertilizer use, around half of homeowners apply fertilizer to their yards in any given year, according to a telephone survey across the United States to residents with yards (n = 9,480; Polsky et al. 2014). This survey included cities throughout the USA, including Miami, FL. In Miami, FL, over 50% of urban and more than 75% of suburban households self-reported the use of fertilizer in the year before the survey conducted in 2011 (Polsky et al., 2014). Fertilizer use trends by Floridians are currently unknown. Garnering this information would be useful for better understanding consumer behavior and then targeting educational messaging appropriately.

Nutrient Runoff

Runoff is the lateral movement of nutrients, beyond the target location, above or near the soil surface. When nutrients move below the root zone, the process is defined as leaching. The loss of nutrients through runoff can be influenced by factors such as irrigation rate, precipitation rate, topography, soil type, soil compaction, soil water content, and the type of fertilizer used.

Most Florida soils are sandy with a rapid water infiltration capacity, making surface water movement (i.e., runoff) less common than water percolation (i.e., leaching) into the soil. For example, Shaddox and Sartain (2001) reported that when N was applied on a 10% slope subject to intense irrigation rates, the N found in runoff was less than 0.1% of that applied. Krimsky et al. (2021) found that soil and organic N nutrient pools contributed more than one-third of the NO_3−N runoff, whereas fertilizers contributed ~10% to 30% of N runoff during both dry (no fertilizer ban) and wet seasons (fertilizer ban). Studies in the Tampa Bay region revealed that atmospheric deposition is the dominant source of N in runoff, but that fertilizer, soil, and organic sources also contribute (Yang and Toor 2017). In Minnesota, Bierman et al. (2010) reported that P runoff can be reduced by not applying a P fertilizer to soils with high P test results, while returning clippings to the lawn did not increase P runoff.

In Ohio, Cheng et al. (2014) found that disturbed soil lawns due to the urban development process had a significantly shorter runoff initiation time compared to topsoil lawns. Moreover, disturbed soil lawns showed substantially higher total runoff volume (540%) and sediment loss (410%). Gregory et al. (2006) states that construction activity increases the potential for urban runoff. In urban soils, compaction contributes to issues related to soil drainage, aeration, nutrient cycling, and plant growth. Interconnected spaces facilitate water movement through the soil. Smaller pores in compacted soil hold less water which can diminish infiltration rates and lead to increased runoff and erosion. Erosion can increase the delivery of nutrients and other pollutants to nearby water bodies. Additional investigation into the runoff of pollutants resulting from soil compaction in urban developments is needed. Likewise, further research focused on urban landscape runoff under Florida conditions (sandy, low nutrient holding capacity soils, and intense rainfall events) is lacking and should be further investigated.

Nutrient Leaching

Nutrients are considered leached from the plant system if they move vertically beyond the rootzone. There are many factors that can influence leaching from turfgrass areas which include turfgrass species, fertilizer source and application rate, irrigation management, maturity and health of the grass, and root architecture. The influence of turfgrass species on N leaching losses is largely a factor of the turfgrass root system. Deeper-rooted turfgrasses tend to reduce N leaching losses compared to shallow-rooted turfgrasses (Bowman et al., 1998). Management practices that encourage deep rooting (such as deep and infrequent irrigation) are factors that shape UF/IFAS landscape fertilizer recommendations.

Numerous turfgrass leaching studies, under different conditions and in three locations statewide, were performed by UF/IFAS with funds from the FDEP. The main findings of these studies are summarized below and were used to adjust fertilizer recommendations (Table 1).

Nutrient leaching from newly planted grasses and ornamental beds

Generally, the potential for nutrient leaching losses increases during plant establishment periods. This is likely due to the lack of an extensive root system that is capable of assimilating the applied and soil nutrients, and the increase in irrigation typically applied to establishing plants. Trenholm et al. (2013) found that NO_3–N leaching was greater during the establishment period compared to established turf regardless of N application rate or timing. Additionally, waiting to apply fertilizers containing P until 30 days after sod installation reduced orthophosphate-P leaching losses compared to fertilizing at installation (Erickson et al., 2010). Loper et al. (2012) also reported that nutrient leaching was higher for ornamental beds compared to turf areas during establishment and that the application of compost in addition to fertilizer increased nutrient loads in leachate. Results of this research indicate that N and P fertilization should be withheld for a minimum of 30 to 60 days after laying sod to reduce potential nutrient leaching.

Nutrient leaching from established grasses

Proper irrigation and fertility are essential components of producing and maintaining quality turfgrass. However, inappropriate fertilizer application timings and excessive fertilizer and irrigation rates can potentially increase nutrient leaching. In Florida, fertilizer applied at UF/IFAS's recommendations (Table 1) to a healthy stand of turfgrass resulted in negligible nutrient leaching from all the various turfgrasses used in Florida, which are bahiagrass (*Paspalum notatum* Flügge), bermudagrass (*Cynodon* spp.), centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.], St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze.], and zoysiagrass (*Zoysia* spp.) (Gonzalez et al., 2013; Maia et al., 2021; McGroary et al., 2017; Shaddox et al., 2016a and 2016b; Telenko et al., 2015; Trenholm et al., 2012). These UF/IFAS recommendations for N (Table 1) are often 50% to 75% less than the amount of N required to increase N leaching above levels as associated with unfertilized turfgrass (Trenholm et al. 2012; Shaddox et al. 2016a; McGroary et al. 2017). Consequently, these rates are considered conservative, and exceeding them is unnecessary, since any additional increase in turfgrass growth or quality is marginal and may have adverse environmental consequences (Shaddox and Unruh, 2018).

It is possible that 0% to 55% of applied N could be leached, with the higher percentages occurring when UF/IFAS recommendations are not followed (Shaddox and Unruh, 2018). Likewise, reviewing studies outside of Florida, Barton and Colmer (2006) concluded that when the irrigation and fertilizer applied matched the plant requirements, less than 5% of the N applied is lost through leaching.

Table 1. Table 1. UF/IFAS nitrogen (N) recommendations for established turfgrass in Florida, by species and region (lb N/1,000 ft^2/year). (Sources: Dukes et al., 2020 and Klein et al., 2023.)

	2004 – 2015			**2016 – present**		
	North	**Central**	**South**	**North**	**Central**	**South**
Species	---------- **(lb N/1,000 ft^2/year)** ----------					
Bahiagrass	2–3	2–4	2–4	1–2	1–2	1–2
Bermudagrass				3–5	4–6	5–7
Centipedegrass	1–2	2–3	2–3	0.4–2	0.4–3	0.4–3
St. Augustinegrass	2–4	2–5	4–6	2–4	2–5	4–6
Zoysiagrass	3–5	3–6	4–6	2–3	2–4	2.5–4.5

Notes:

- *North Florida in this example is anything north of Ocala. Central Florida is defined as anything south of Ocala to a line extending from Vero Beach to Tampa. South Florida includes the remaining southern portion of the state.*
- *Preferences for lawn quality and maintenance level vary; therefore, a range of fertility rates is recommended. Additionally, effects within a localized region (i.e., microenvironmental influences such as shade, drought, soil conditions, and irrigation) necessitate a range of fertility rates.*
- *These recommendations assume that grass clippings are left on the lawn.*

In previous studies, minimal differences in NO_3–N leaching were observed due to fertilizer source or type. However, in general, slow-release N sources further reduce N leaching losses compared with soluble N sources (Shaddox and Unruh, 2018). Slow-release N fertilizers differ from soluble N sources because over time small portions of N are released, which increases the likelihood of plant uptake of applied N and decreases potential for N leaching losses (Guillard and Kopp, 2004). For slow-release fertilizers, nutrient release rate is influenced by environmental conditions. Initial and long-term release of N is significantly different based on the slow-release source (Shaddox, 2023).

Fertilizer applications to turf stands that do not have adequate ground cover (e.g., bare patches), are stressed, or are damaged, could result in greater nutrient losses due to leaching. For example, St. Augustinegrass or zoysiagrass damaged from herbicide stress, winter kill or disease that resulted in the lack of turf cover showed a greater potential for N leaching (Shaddox et al., 2016a; Telenko et al., 2015; Trenholm et al., 2012). Normally, stresses manifest themselves as reductions in turfgrass density and growth, which correspond to a reduction in N uptake. These stresses are largely environmental, caused by pests, late-season frosts, and changes in season. However, stress can also be anthropogenic caused by misapplications of nutrients or pest control products. When stresses occur, further applications of N may not cure the problem and may, in fact, exacerbate it and increase N leaching (Shaddox and Unruh, 2018). Further research regarding how to manage nutrient applications to stressed or damaged turf is needed.

Turfgrasses can uptake a large amount of nutrients when fertilizers are applied during times when plants are actively growing (Figure 10). In South Florida, Snyder et al. (1984) found the highest N leaching during periods when turfgrass was less active. In general, from a plant physiology-perspective, once warm-season turfgrass is established, the potential for nutrient losses is lower during the summer growing period compared to spring, fall, and winter. In the spring, root growth is typically still developing, which may account for greater potential NO_3–N losses. In the fall, growth (both shoot and root) begins to taper off, which may also account for greater leaching potential. The reduction in N leaching from winter to summer is largely a factor of increased plant growth (Figure 10) and increased evapotranspiration, which reduce the amount of N in the soil solution and the amount of moisture in the rootzone, respectively (Barton and Colmer, 2006; Shaddox and Unruh, 2018). However, these seasonal patterns of nutrient losses due to changing nutrient demand by plants assumes all other factors are equal and fertilizers are applied at the right rate (Table 1), the right place, and the right times. Nonetheless, the turfgrass growth potential throughout the year varies at different latitudes in Florida (Figure 10). For example, locations with warmer winters, like Key West, have higher growth potential during the winter months than locations with cooler winters, such as Tallahassee or Pensacola.

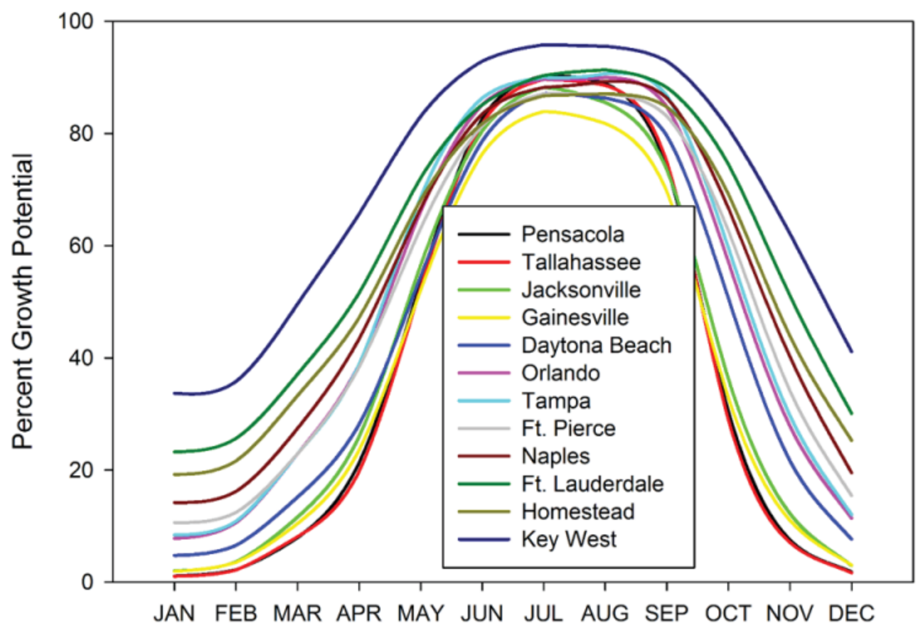

Figure 10. Potential turfgrass growth as a function of temperature throughout an entire year at different latitudes in Florida. Credit: J. Bryan Unruh, UF/IFAS, unpublished data (2023).

Fertilizer ordinances effects

The few studies performed in Florida regarding the efficacy of the fertilizer restrictions have shown mixed results. Some studies have revealed certain positive impacts on water quality (Lasso de la Vega and Ryan, 2016; Smidt et al., 2022; Lapointe et al., 2023), whereas other studies have found inconclusive results (Motsch, 2018; Souto et al., 2019) or no significant ordinance effects (Krimsky et al., 2021) in both inland and coastal environments. These varied conclusions can be attributed to the fact that not all ordinances exert the same influence on the water quality parameters analyzed. Additionally, many of these studies were focused on individual ordinances at local levels, where external factors other than fertilizer ordinances may interact with ordinance impacts, making it difficult to disentangle the causality of water quality improvements (or lack thereof).

Motsch (2018) studied two estuarine canal systems in Florida, one with a fertilizer ordinance – Cape Coral—and one without a fertilizer ordinance—Fort Lauderdale. In the three years post ordinance, Cape Coral estuarine canals exhibited a 24% reduction in total N, which initially may appear to suggest the efficacy of the fertilizer ordinance. However, in Fort Lauderdale, total N declined by 33% over the same period without a fertilizer ordinance. These results suggest that there may be other factors driving the reduction in total N within both canals, although it would be difficult to attribute an effect to the ordinance in either direction given the lack of replication and the anecdotal, case-study nature of this study. Therefore, to mitigate the impacts of nutrients at the local level, further studies are necessary to understand and manage the large-scale nutrient loading sources. The author suggests that in addition to fertilizer ordinances, other management strategies and policies might be necessary.

Research conducted by Souto et al. (2019) in three adjacent counties in Florida (Pinellas, Manatee, Hillsborough) of the Tampa Bay area focused on N reductions resulting from community education and fertilizer restrictions. They were not able to draw a conclusion on the effect of the fertilizer restrictions due to the short time frame of the study (18 months). They recommended 10 years of storm water monitoring to confidently measure a 20% reduction in N concentrations.

Smidt et al. (2022) analyzed the changes in water quality of 160 lakes throughout Florida (Figure 11) from samples collected between 1987 through 2018. This large data set was then used to analyze trends in water quality parameters not just before and after implementation of county-wide fertilizer ordinances, but relative to the type of ordinance (winter fertilizer ban, summer ban, nonseasonal ban, no ban).

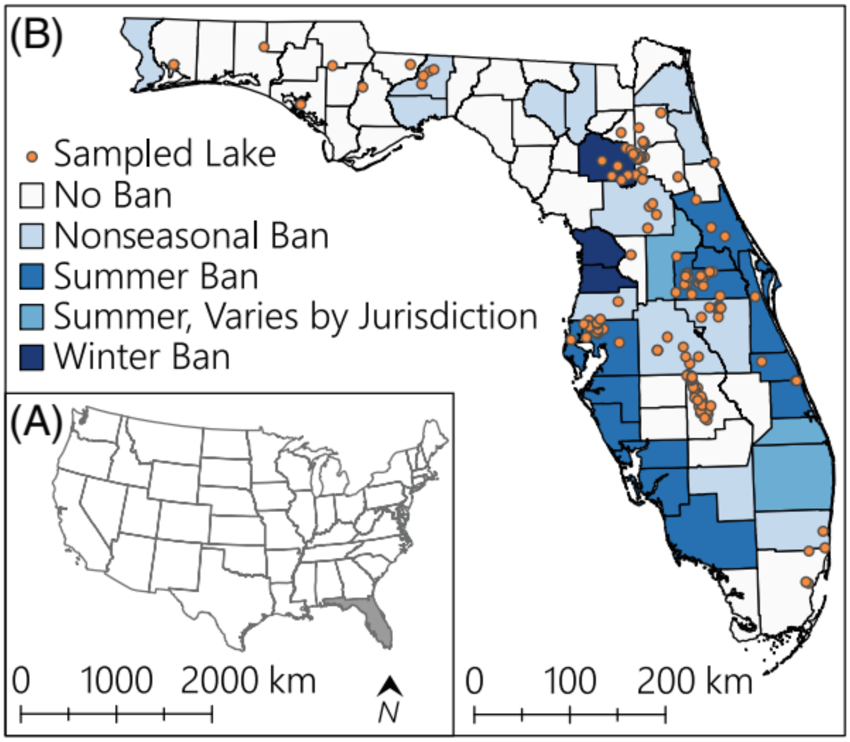

Figure 11. Florida site map (A) and county fertilizer ordinance by type (B), with lake locations of filtered LakeWatch samples, as reported in the study by Smidt et al. (2022).

A summary of the ordinance type and its effect on the different water quality parameters is shown in Table 2. Results from this study showed that winter fertilizer bans exhibited the most comprehensive and consistently positive effect (i.e., large improvement) on all water quality parameters. Summer fertilizer bans had a medium effect (e.g., medium improvement) on total P and Secchi depth (a measure of clarity of the water) but no effect on total N and chlorophyll *a* (a measure of the amount of algae growing in a waterbody). Non-seasonal fertilizer bans had a slight effect (e.g., small improvement) on total P and total N but no effect on chlorophyll *a* and Secchi depth. These results agree with other studies where most leaching of nutrients occurred during the dormant season (Shaddox et al., 2016a; Telenko et al., 2015; Trenholm et al., 2012).

Table 2. Ordinance impacts on water quality trends for different ordinance types and water quality responses. Box colors denote the trajectory (orange: degrading, blue: improving) and magnitude (darker colors denote larger effects) of ordinance impacts on water quality trends. (Source: Smidt et al., 2022).

Ban type	Ordinance impact on water quality trend			
	Total phosphorus	Total nitrogen	Chlorophyll *a*	Secchi depth
No ban	Small degradation	No change	No change	Small improvement
Non-seasonal	Small improvement	Small improvement	No change	No change
Summer	Medium improvement	No change	No change	Medium improvement
Winter	Large improvement	Large improvement	Large improvement	Large improvement

In addition, summer (wet season) fertilizer restrictions had no impact on total N and a medium effect on total P (Table 2). This result agrees with studies concluding that most nutrient uptake occurs during the active growth period, which coincides with the wet season (Carey et al., 2012; Hochmuth et al., 2012), and less nutrients are leached towards the groundwater (Gonzalez et al., 2013; Maia et al., 2021; McGroary et al., 2017; Shaddox et al., 2016a and 2016b; Telenko et al., 2015; Trenholm et al., 2012). Moreover, locations with no ban or a non-seasonal ban unexpectedly resulted in no significant impact on the water quality trend, including total P and total N. Based on the results of their study and supported by other studies, the authors recommended that counties without a winter ban should consider whether a winter ban would be useful to achieve the counties objectives with respect to water quality, particularly northern counties with significant winter dormancy (see Figure 10). However, this study was limited to the lakes monitored by the Florida LakeWatch program, and only one county with winter ordinances was included in the study (Alachua County). The winter ordinance effect could be an artifact of other behaviors/changes/programs being implemented within Alachua County. Finally, the authors stated that fertilizer restrictions are not likely to be a standalone solution.

As in the study by Smidt et al. (2022), Krimsky et al. (2021) did not find the expected influence of a summer (wet season) fertilizer ban, when measuring surface runoff from 10 homeowner lots close to the IRL. However, this research was a short-term (one year) study, and it was estimated that 5-10 years of data are necessary to confidently measure changes due to the fertilizer ban and overcome the influence of legacy nutrients from previous land uses and fertilizer applications.

Conversely, data from the volunteer monitoring Pond Watch Program was used to assess the impacts of the summer season fertilizer ban on water quality in some stormwater ponds in Lee County (Lasso de la Vega and Ryan, 2016). Levels of N, P, and chlorophyll *a* were compared across nine similar urban stormwater ponds during the wet months of 2004 through 2008 (prior to the fertilizer ordinance enforcement) and from 2009 through 2013 (post-fertilizer ordinance). The results showed a statistically significant reduction of total P and chlorophyll *a*, which decreased by 25% and 34% respectively, between pre- and post-ordinance. However, total N did not significantly differ before and after the ordinance was implemented.

Lapointe et al. (2023) collected samples at 20 sites in the IRL, before a wet season fertilizer ban and five years after. Water samples were analyzed to determine chlorophyll *a* and multiple dissolved nutrient concentrations, including NO_3^-, total dissolved nitrogen (TDN), soluble reactive phosphorus (SRP), total dissolved phosphorus (TDP), ammonium (NH_4^+), and nitrite (NO_2^-). At the same 20 sites, composite samples of the most abundant macroalgae were collected to characterize, among other analyses, stable carbon ($\delta^{13}C$) and stable nitrogen ($\delta^{15}N$) isotope values. Results indicate that the water quality and harmful algal blooms have worsened in parts of the IRL, mainly due to a change in the N source supporting algae blooms post-fertilizer bans. Sources of N, such as atmospheric deposition, fertilizers, and/or biosolids switched to more enriched N sources, such as human or animal waste. They found a 21% contribution of N from residential fertilizers compared to a 79% from septic systems. These loading estimates are similar to those reported in other septic systems impacting urbanized estuaries (Sham et al., 1995; McClelland et al., 1997; Valiela et al., 1997; Valiela et al., 2000; Kinney and Valiela, 2011; Lloyd, 2014). According to Lapointe et al. (2023), the fertilizer restrictions had been insufficient to diminish eutrophication at the IRL and, ultimately, they had diverted "attention, efforts, and funds that potentially could have been more effective if allocated to reducing human waste impacts".

The effects of fertilizer restrictions have also been studied in other states. For example, a statewide law prohibiting the use of phosphorus lawn fertilizer, except in prescribed instances, was implemented in Minnesota in 2005. A 2007 report to the Minnesota Legislature by the Minnesota Department of Agriculture stated that the improvement of surface water quality was inconclusive (MDA, 2007). In the same state, Vlach et al. (2008) compared P runoff from sites using only P-free fertilizer to other sites using P-containing fertilizer finding no difference of total P between them, but found a 17% lower soluble reactive P at the P-free sites.

In southeast Michigan, Lehman et al. (2011) studied the effect of a 2006 fertilizer ordinance restricting the application of P fertilizer (May – September), unless a soil test demonstrated the need. After three years of data collection, they reported reductions of 11 to 23% in total P and 23 to 35% for dissolved P, but no reductions in NO_3^- or dissolved organic matter which is unsurprising given that the ordinance was only related to P, not N.

In central New Jersey, Qiu et al. (2014); studied the long-term water quality impacts of two P fertilizer application rates: Scenario A) decrease application rates by 25%, and Scenario B) completely eliminate P fertilizer as required by law. Scenario A resulted in 15% reduction of total P, while Scenario B achieved an even higher reduction in total P but had the unintended consequence of increasing N runoff in the watershed. In addition, the reduction in P application under both scenarios did not achieve the Total Maximum Daily Load (TMDL) standard for total P, suggesting the need for additional BMP's.

Human behavior

Even if the most effective biogeochemical approach for fertilizer ordinances is understood, efficacy ultimately hinges on compliance. The social indicators that influence whether an individual will engage in behavioral action are complex and include stakeholder awareness, social norms, perceived control, and behavioral intent. A 2015 study of Florida residents indicated that only 32% of Florida residents were accurately able to identify whether they resided in a city or county with a fertilizer blackout period, and more than half of respondents were unsure (Ryan et al., 2019). Regionally specific surveys support these results. A highly educated, older population who responded to a survey in Sarasota County, FL, similarly resulted in findings that only 35% of respondents were familiar with the county fertilizer ordinance (Kirkpatrick et al., 2014). Similarly, only 16% and 32% of residents in a master-planned community in Manatee County, FL, were aware of the year-round P ban and seasonal N ban, respectively (Persaud et al., 2019). Finally, a tri-county (Pinellas, Manatee, Hillsborough) study within the watershed of the Tampa Bay, FL, found that 24% to 44% of respondents were aware of local fertilizer regulations. Pinellas County, FL, residents, which had the most restrictive ordinance of the three counties and a substantial awareness campaign, had significantly greater ordinance awareness and knowledge (Souto et al., 2019).

Knowledge about the existence of a fertilizer ordinance does not automatically ensure that individuals will engage in those behaviors associated with the ordinance. As described above, most fertilizer ordinances are comprised of numerous individual behaviors, the application of which may not be universal. Social psychological theories can be used to determine which social factors are the greatest predictors of residents' fertilizer practices. For example, a 2018 household survey (n = 3,836) collected data on lawn fertilizer practices in the metropolitan area of Baltimore, MD (Groffman et al., 2023). They divided the sampled households in "Class 1" (households who care strongly about their lawns, ~55% of respondents) and in Class 2 (households that favor policies to reduce fertilizer use, ~45% of respondents). Class 1 households demonstrated a decreased likelihood of endorsing policies involving fertilizer surcharges and strict limitations on fertilizer application frequency (no more than one application per year). In contrast, households in Class 2 exhibited favorable inclinations toward moderate regulations, limited to no more than 3 applications of fertilizer per year and surcharges on lawn fertilizer.

A study of Florida residents measuring the likelihood of an individual's willingness to adopt fertilizer BMPs on a five-point scale from *never* to *always*, suggests that some BMPs will always have adoption by ~30% of the population whereas some BMPs are unlikely to ever be adopted. For example, more than 30% of the survey respondents indicated that they never test their soil or apply fertilizer based on soil test results, and less than 10% of the respondents were always willing to comply with these behaviors. As soil testing is a conventional requirement for the application of P in Florida's fertilizer ordinances, the water quality benefits associated with this behavior are less likely to be realized.

Similar behaviors that had low frequency of adoption were selecting slow-release N fertilizers and ensuring landscape professionals have the necessary certification to apply fertilizers (Warner et al., 2019). These results are consistent with those of a 2020 survey of more than 1,000 Florida homeowners that suggests only 23% of the survey respondents were classified as fertilizer conscious, preferring landscapes with low fertilizer requirements. While fertilizer conscious residents also indicated a moderate preference for low irrigation inputs, a greater proportion of the population (27%) prioritized low irrigation over fertilizer inputs (Knuth et al., 2023). While attitudes about fertilization are important predictors of engagement in fertilizer BMPs, this and other studies indicate that Floridians prioritize water conservation over water quality (Warner et al., 2018; Knuth et al., 2023). This prioritization of water quantity over quality may be associated with the belief that most Floridians (80%) do not believe that their landscapes have a negative impact on water quality (Ryan et al., 2019).

Social norms are the shared set of behaviors perceived to be acceptable by groups of people. There are several studies reported in the literature that indicate the social norms associated with residing in a Homeowners Association (HOA) influence the adoption of residential landscape practices, including fertilization (Fraser et al., 2013; Warner et al., 2021). This is especially important for Florida which boasts the second highest proportion of residents living within an HOA as compared with any other state (Community Associations Institute, 2021). Warner et al. (2021) also found that in addition to social norms, individuals' belief about whether they have control over their ability to engage in a behavior, referred to as perceived behavioral control, was a strong predictor of adopting fertilizer BMPs. They also found that compatibility of fertilizer BMPs with residents' existing values, yard care routines and expectations, and budget were important for adoption. This outcome is consistent with the findings that suggest that the more complicated a behavior is, or is perceived to be, the less likely it is to be adopted (Rogers, 2003).

A study on homeowners' awareness and perception of sustainable landscaping practices revealed that Florida homeowners who possess more knowledge about sustainable landscape programs, like Florida-Friendly Landscaping™, are more inclined to participate in sustainable landscaping practices (Zhang et al., 2021). In line with this, Brevard County is currently implementing an outreach program that covers topics such as fertilizer application, management of grass clippings, excess irrigation, maintenance of stormwater ponds, septic systems, and sewer laterals. This initiative is expected to contribute to raising awareness and understanding of these issues (Lapointe, 2023). Moreover, initiatives rooted in community participation, such as fertilizer restrictions, play a crucial role in engaging local populations in environmental protection endeavors (Krimsky et al., 2021).

SUMMARY AND RECOMMENDATIONS

A key takeaway message from the scientific literature (including recent studies from Florida and other parts of the USA) is that there are multiple sources of nutrients N and P in urban watersheds with the potential to contribute to nutrient pollution of Florida's waterbodies (i.e., septic systems, reclaimed water, atmospheric deposition, grass clippings and landscape wastes, compost amendments, fertilizers, nutrient runoff, and nutrient leaching). Therefore, it is important to place the various sources in context with each other to learn which sources might be the most important in a given location and time. In this document, we summarized the research conducted on these sources of N and P and analyzed their effect on water quality.

Only six studies (five in the peer-reviewed scientific literature) analyzing the efficacy (pre/post) of fertilizer ordinances in Florida were found. The first study was published in 2016, with data from five years pre- and five years post-fertilizer ordinance, from a volunteer program monitoring nine urban stormwater ponds. The results showed a post-ordinance reduction in total P and chlorophyll *a*, but not for total N.

In 2018, a second study included two estuarine canal systems in Florida, one with a fertilizer ordinance –Cape Coral—and one without a fertilizer ordinance—Fort Lauderdale. In the three years post ordinance, Cape Coral estuarine canals resulted in a reduction of 24% in total N, suggesting the efficacy of the fertilizer ordinance. However, in Fort Lauderdale, total N declined

33% over the same period, without a fertilizer ordinance. Based on the results of this study, the fertilizer ordinance did not appear to influence total N in the canals. However, the lack of true replication makes any inference drawn from this study questionable. A research study published in 2019 and conducted in three adjacent counties within the watershed of the Tampa Bay, Florida, was not able to draw a conclusion on the effect of the fertilizer restrictions due to the short sampling time frame of the study (18 months). They recommended 10 years of storm water monitoring to confidently measure a 20% reduction in N concentrations.

A study published in 2021, measured the surface runoff from 10 homeowner lots close to the IRL and found that NO_3^- and NH_4^+ -based fertilizers contributed a combined 31% to 44% of NO_3^- in lawn surface water runoff, however, it did not find the expected influence of a summer (wet season) fertilizer ban. The largest spatial area covered by a study and for the longest time frame (21 years) was published in 2022, which analyzed the changes in water quality of 160 lakes throughout Florida. This study utilized water quality data from lakes in locations with no ban, no seasonal ban, summer ban, and winter ban. Results from this study generally showed some improvement in water quality across the type of fertilizer ordinance in 8 of 12 ordinance water quality parameter trend categories. In locations with no ban or non-seasonal ban, a small or no change was found. In addition, summer bans had no impact on total N and only a medium effect in total P. The authors concluded that there was a tendency for positive impacts of fertilizer ordinances on water quality, with winter fertilizer bans being the most comprehensive and effective compared to other ordinance types. These results agree with other studies that suggest that most nutrient leaching occurs during the winter dormant season. However, the authors remarked that to prevent nutrient pollution in water bodies, fertilizer restrictions are not likely to be a standalone solution.

Conversely, a new study published in 2023 that sampled 20 sites in the Indian River Lagoon found that current N loading estimates represent a 21% contribution from residential fertilizers compared to 79% from septic systems. These results are in line with a multitude of studies highlighting the importance of multiple different N sources exporting N from urban watersheds. Furthermore, these results agree with other studies showing that human waste is often the largest contributing N source driving eutrophication and harmful algal blooms in coastal environments. The authors concluded that the fertilizer bans had "ultimately diverted attention, efforts, and funds that potentially could have been more effective if allocated to reducing human waste impacts".

These varied conclusions can be attributed to the fact that not all ordinances exert the same influence on the water quality parameters analyzed. In addition, the divergence in the effectiveness of fertilizer restrictions depends on various factors, including the specific regulations in place, the (lack of) enforcement, education, or awareness of those regulations, the willingness of stakeholders to comply, and the ecological and environmental conditions of the area. These factors may limit the efficacy of ordinances or the ability of scientific studies to separate the effects of ordinances from other natural or human-caused factors affecting water quality. Additionally, waterbodies can respond in a variety of different ways to increasing nutrient inputs. Natural processes within these waterbodies can temporarily or permanently remove nutrients, reducing their influence on other water quality indicators and possibly masking changes in watershed nutrient management.

Despite these knowledge gaps and disparate impacts, fertilizer ordinances continue to be adopted and promoted as an environmental management strategy throughout Florida. The assumption that residential fertilizer restrictions will reduce pollution to waterbodies and improve water quality remains largely unclear. The few studies that have attempted to establish the effectiveness of ordinances have been generally limited to small or specific areas and analyzed the fertilizer restriction impacts in relatively short time scales (less than 5 years). The single study that incorporated a larger area and a longer time frame was not able to directly document mechanistic effects given the opportunistic study design (i.e., the study repurposed data collected for other reasons, allowing a large dataset but an unbalanced experimental design).

To fully understand the effect of fertilizer ordinances and other strategies to mitigate nutrient pollution and improve water quality, thorough study of the topic is required. Such a study would be characterized by a comprehensive monitoring program spanning multiple watersheds that seeks to quantify sources, transport, and fate of nutrients, and ecological responses of downstream receiving waters. This study would need to be geographically distributed across a range of urban watersheds spanning social, environmental, and economic gradients. There would need to be a combination of water quality monitoring through both manual field sampling and continuously deployed electronic monitoring equipment, nutrient source tracking (e.g., with isotopic analysis and direct measurement), and experimental manipulations in the lab and in the field to assess causal mechanisms. This research would need to be carried out for multiple years to account for known annual and decadal climate patterns, shifting regulatory environments, and demographic trends throughout our state. Results from this study would facilitate better decisions regarding future regulations and public funding to remediate this ongoing problem statewide.

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