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Research Paper

Forging linkages between social drivers and ecological processes in the residential landscape

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ABSTRACT

Residential lawn fertilization is estimated to be the 2nd largest source of household nitrogen in the US causing environmental damage that may be irreversible unless alternative residential landscape practices are adopted in the future. Understanding residential landscape practices and the associated impact on water quality can inform the discourse on residential landscape reform and evaluate the effectiveness of strategies to reduce the impacts of residential landscapes. Our research collected residential awareness, knowledge and behavior data as well as stormwater and pond water nitrogen concentrations and loads in three counties where varying urban fertilizer ordinances were in place. We found that in the county with the strictest fertilizer control ordinance, residents were more aware of the ordinance and they were applying fertilizer less frequently. In the county with the least restrictive ordinance, residents were applying fertilizer more frequently and nitrogen loads were higher. We found seasonal variability associated with N source/sink dynamics that can confound N concentrations and loads. We conducted a power analysis to recommend monitoring needed to confidently measure a reduction in N concentrations in community stormwater and pond water. The results contribute to a critical missing gap of inter-disciplinary research to link a socio-political driver (fertilizer ordinance) to human behavior change and potential environmental effects.

1. Introduction

The amount of human-related reactive nitrogen (N) entering the environment has increased exponentially with human population growth over the last century, (Galloway, Townsend, Erisman, Bekunda, & Zucong, 2008). The resulting environmental impacts include nitrate contamination of ground and surface waters, more numerous harmful algal blooms, accelerated eutrophication of lakes and estuaries, and increasing nitrous oxide emissions contributing to climate change (Baker, Hope, Xu, Edmonds, & Lauver, 2001; Driscoll, Whitall, Aber, Boyer, & Castro, 2003; Howarth, Billen, Swaney, Townsend, & Jaworski, 1996; Law, Band, & Grove, 2004). At the same time, human growth patterns have changed from residential occupation of high-density, centralized city centers to low-density, decentralized suburban sprawl where turfgrass is the most common land cover (Gillham, 2002, p. 8; Robbins & Birkenholtz, 2003). Fissore, Baker, Hobbie, King, and McFadden (2011) found that residential landscape fertilizer was the second largest contributor of household N in the United States (26%), contributing less than human dietary sources (40%) and slightly more than travel-related N emissions created during combustion (25%). Society's continued preoccupation with the residential turfgrass landscape in the face of worldwide population growth and expanding suburban sprawl may cause irreversible environmental damage unless alternative residential landscape practices are adopted to reduce lawn fertilizer-related N inputs (Fraser, Bazuin, Band, & Grove, 2013; Robbins & Birkenholtz, 2003). The extent that residential landscapes contribute excess N to the environment is influenced by social structures, institutional drivers, household decisions, and ecological factors acting at multiple scales (Fissore et al., 2011; Kaye, Groffman, Grimm, Baker, & Pouyat, 2006; Law et al., 2004). Understanding the social drivers of residential landscape practices and the associated ecological impacts can guide strategies to create an alternative residential landscape and inform the discourse on lawn care chemical controls.

Society has adopted the manicured and chemical dependent turfgrass lawn as a class aesthetic communicating an expectation of purity, conformity, and status that defines good community citizens (Feagan & Ripmeester, 1999; Nassauer, 1995, 2011; Robbins & Sharp, 2003; Shern, 1994). The social expectation has been perpetuated by institutional and market influences. Regional planning, landscape design, development processes, and community governance have evolved over the past five decades to reinforce the turfgrass aesthetic. An expansive global market has emerged including landscape planners, developers, architects, realtors, lawn care professionals, turfgrass growers, chemical industries, turfgrass scientists, etc. benefiting financially from the continued use of turfgrass as the prevalent ground cover in the urban landscape (Chowdhury, Larson, Grove, Polsky, & Cook, 2011; Fraser

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et al., 2013; Milesi et al., 2005; Robbins, 2007; Robbins & Sharp, 2003; Whitney, 2010). The governance and market forces at the time of development have a tremendous influence on the potential for residents to maintain a green, weed-free lawn. High landscape fertilizer use has been associated with higher household income, educational attainment, and property values and with newer, larger houses (Boyer, Goodale, Jaworski, & Howarth, 2002; Fraser et al., 2013; Hope, Gries, Weixing, Fagan, & Redman, 2003; Robbins, Polderman, & Birkenholtz, 2001; Robbins & Sharp, 2003; Souto & Listopad, 2013).

The rapidly expanding Homeowners Association (HOA) governed suburban community provides the new market for emerging middle class citizens worldwide to cooperatively maintain their property market values. In 2012, there were 323,600 HOAs in the United States, most of which (90%) were built since the year 1990 (Institute, 2012). A similar expansion of HOAs has occurred in China since 2007, when the enactment of the Chinese Real Right Law legally endorsed the collective property rights of Homeowners Associations. In less than five years, the majority of Shanghai neighborhoods were managed by HOAs (Yip & Jiang, 2011). HOAs have the authority to demand resident fees, regulate residential behavior, and enforce rules to restrict activities that cause conflict or reduce property values (Low, Donovan, & Gieseking, 2012; McCabe & Tao, 2006). Because HOAs strive to maintain marketable aesthetics (McCabe & Tao, 2006), high maintenance landscapes with high chemical inputs of fertilizer are expected and enforced (Institute, 2012). There is evidence that HOA residents apply more fertilizer than residents living in similar homes in non-HOA governed communities (Fraser et al., 2013; Souto & Listopad, 2013). Changing the household demand for fertilizer requires a change in the HOA-reinforced need for a green, weed-free lawn.

Understanding the interaction of the human-oriented actions and biogeochemical cycles requires interdisciplinary research methods and complex models to integrate human choices and biogeochemical cycling across spatial and temporal scales (Baker et al., 2001; Kaye et al., 2006; Pickett, Cadenasso, Grove, Groffman, & Band, 2008; Redman, Grove, & Kuby, 2004). Gaps exist in understanding the linkages between social landscape drivers and ecological functions across scales, (Chowdhury et al., 2011; Cook, Hall, & Larson, 2012). How added nitrogen integrates into the landscape, leaches into groundwater or runs off into surface waters depends on ecological characteristics like soil type and chemistry, plant types, root density and depth, and nutrient supply and demand (Petrovic, 1990) as well as meteorological conditions like rainfall and temperature (Bijoor, Czimczik, Pataki, & Billings, 2008; King, Balogh, Agrawal, Tritabaugh, & Ryan, 2012). Individual landscape management practices such as fertilizer type, application rates, timing, and irrigation are also important predictors of nitrogen impacts (Erickson, Cisar, Snyder, Park, & Williamset, 2008; Law et al., 2004; Raciti, Groffman, & Fahey, 2008). For example, nutrient losses from turfgrass fertilizer are higher with soluble rather than slow-release fertilizers (Guillard & Kopp, 2004; King et al., 2012), or if fertilizer is applied before or during heavy rain or irrigation (Bowman & Devitt, 1998; Morton, Gold, & Sullivan, 1988; Snyder, Augustin, & Davidson, 1984; Soldat & Petrovic, 2008).

Educational programs that promote the use of slow-release fertilizers and proper fertilizer application timing have been implemented for decades as well as environmentally-friendly landscape maintenance practices such as native and drought-tolerant plants, efficient irrigation, integrated pest management, rainwater harvesting, and others (Florida Department of Environmental Protection, 2008; State Agriculture Extension Offices; U.S. EPA Greenscapes Program). Even with education, the manicured lawn culture perpetuated by a class-driven market has been nearly impossible to reform (Feagan & Ripmeester, 1999). Policy actions can help enable a change to more sustainable landscape alternatives.

In the City of Ann Arbor, MI, USA a residential fertilizer ordinance was implemented that prohibited the application of phosphorous to lawns unless a soil test confirmed a deficiency. Three years after the ordinance was passed, Lehman et al. (2009, 2011) demonstrated a significant reduction in phosphorus (P) concentrations in the receiving Huron River. They predicted a sampling regime and timeframe to confidently measure a 20% decrease in dissolved nutrient concentrations relative to a control and met that level (Lehman et al., 2009, 2011). Few policies have been implemented to specifically reduce the input of N to the residential landscape (Baker et al., 2001).

In response to increasing nitrate levels in ground and surface waters (St. Johns River Water Management District, 2007; U.S. Geological Survey Florida Water Science Center, 2010; Williams, 2012) and the need to meet nutrient load reductions required by the Clean Water Act of 1972 (2002), local governments in the State of Florida, U.S.A. passed residential lawn fertilizer ordinances that restricted the application of both P and N. The ordinances encouraged the use of slow-release N fertilizers, defined a restricted application period during Florida's rainy season, required a soil test before applying P, and established a set-back from surface water bodies. More information is needed to evaluate the effectiveness of such residential fertilizer ordinances, especially those that attempt to reduce the amount of N entering receiving water bodies from residential lawns.

Our project titled "Forging linkages between social drivers and ecological processes in the residential landscape" was an applied research study that investigated residential landscape behavioral and environmental response to fertilizer ordinance implementation in the Tampa Bay, Florida, U.S.A. region. The research goals were to collect evidence to evaluate the effectiveness of local fertilizer ordinances and contribute to the burgeoning literature focused on linking social drivers and ecological processes. The research was conducted in three adjacent counties (Pinellas, Manatee, Hillsborough) within the watershed of Tampa Bay located on the central, west coast of Florida, U.S.A. where varying urban fertilizer ordinances were in effect (Fig. 1). In 2010, Pinellas County passed the most restrictive urban fertilizer ordinance in the State of Florida. The ordinance required that residential fertilizer contain at least 50% slow-release N, it required that a soil test confirm the need for P before it could be applied; it established a 10-foot setback from the water, and it restricted the application and sale of nitrogenous fertilizer during the rainy season. During the rainy season, fertilizer distributors were required to remove nitrogenous fertilizer from the shelves. By requiring the removal of non-compliant products from the retail stores, Pinellas County effectively "banned" the sale of nitrogenous fertilizer from June 1 to September 30, a regulation that would be pre-empted by state legislation a year later as requested by turfgrass and agrichemical interests. A year later, Manatee County passed a similar ordinance, which contained the seasonal restriction, but could not include the retail sales "ban". Hillsborough County passed an ordinance that prohibits the application of P without a soil test, requires a 10′ set-back from water bodies, implements and enforces lawn care professional training, and prohibits the application of fertilizer during or within 36 hours of a rain event. The Hillsborough County ordinance does not include a seasonal restriction, does not require 50% slow-release nitrogen, and does not "ban" the sale of nitrogenous fertilizer during the rainy season.

The research conducted in these counties focused at the household-community level, collecting individual, community, and environmental data to assess trends in N reductions resulting from community education and policy interventions designed to reduce the impact of nitrogenous lawn fertilizer on water quality. The research was guided by socio-behavioral and ecological theory and used natural and social science methods to collect and analyze data.

2. Methods

2.1. Study site selection

To examine the effects of the various fertilizer ordinances, four neighborhoods were selected after careful consideration of confounding

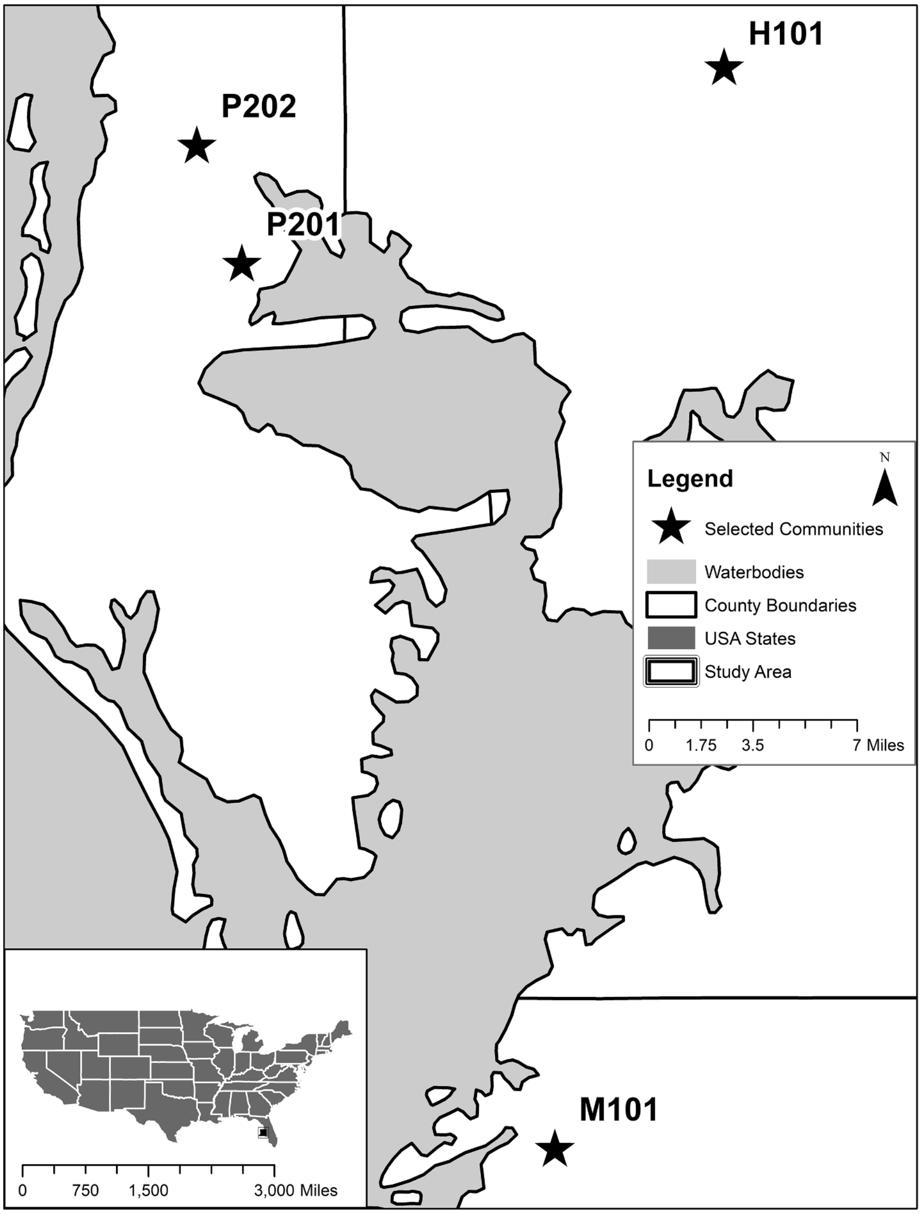


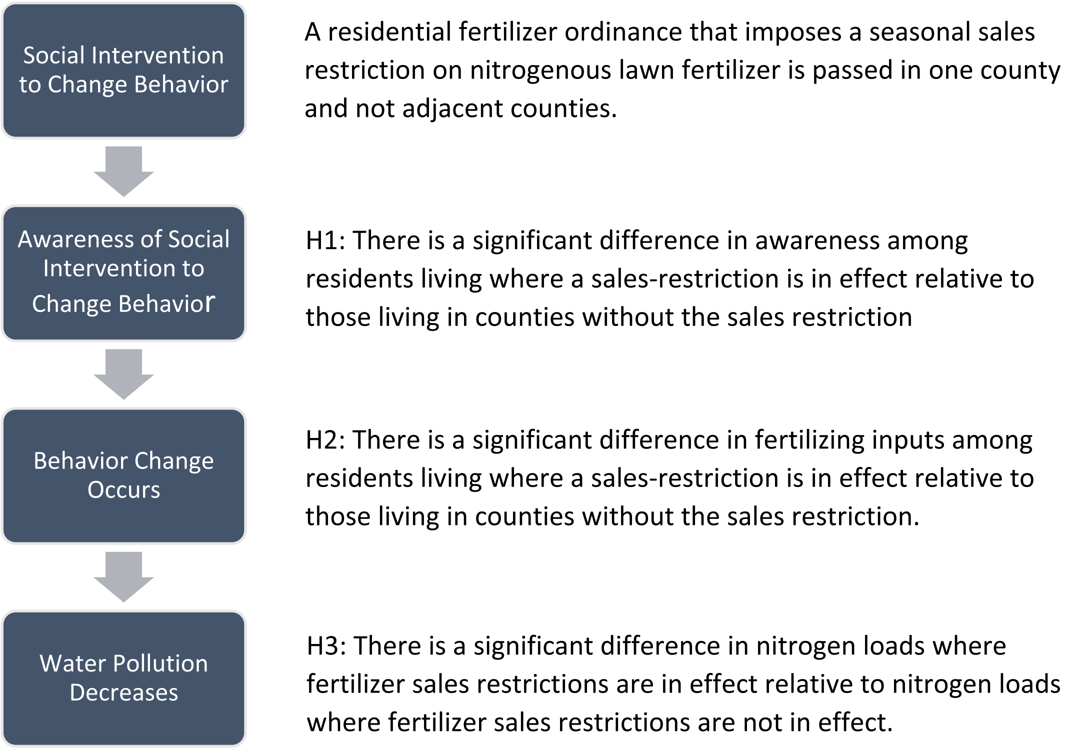
Fig. 1. Study site map.

Table 1
Characteristics of the four research neighborhoods.

Neighborhood	H101	M101	P201	P202
County	Hillsborough	Manatee	Pinellas	Pinellas
Total area (hectares)	23.9	18.6	7.3	41.7
HOA present	Yes	Yes	Yes	Yes
Housing Units	95	118	60	290
Unit Density/Hectare	3.97	6.34	8.22	6.95
Year Built	2002	2003	2003	1984
Property Value ($1000)	$170	$110	$313	$176
Pervious area (hectares)	14.2	10.9	4.4	25.1
Golf Course	No	No	No	No
HOA self-maintained	No	No	No	No
Average lot size (hectares)	0.15	0.09	0.07	0.10
Average built area (sq. meter)*	241.2	161.5	238.4	207.0
Irrigation Source	Well	City	City	City

* Average built area corresponds to the mean house area per lot for all residential parcels within each community. This area is defined by the Property Appraiser and typically includes garage, porches, and the built area under air conditioning.

ecological, drainage, and socio-demographic variables that are well-described in the literature (Table 1). All of the neighborhoods ultimately drained to Tampa Bay after receiving treatment in a wet retention pond or skimmer on site. Ecological features that were considered included soil type, land topography, vegetation canopy and cover, and turfgrass coverage. Drainage basin characteristics such as drainage area, impervious cover, lot sizes, lake and inlet elevations, and stormwater infrastructure were considered, as well as other confounding sources of N such as the presence of septic tanks or reclaimed irrigation water sources. Drainage basins used for monitoring within the selected communities varied in size from 5.35 ha (P202) to 16.32 ha (H101) and neighborhoods were selected that had city sewer and no reclaimed irrigation, a challenge in some areas. Socio-demographics that could be confounding had to be considered that included house age, property value, and Homeowners Association governance. To be consistent, all of the selected neighborhoods were within HOA governed communities. Two neighborhoods were selected in Pinellas County (P201 and P202), one in Manatee County (M101), and one in Hillsborough County (H101). The neighborhoods and all human subject



A residential fertilizer ordinance that imposes a seasonal sales restriction on nitrogenous lawn fertilizer is passed in one county and not adjacent counties.

H1: There is a significant difference in awareness among residents living where a sales-restriction is in effect relative to those living in counties without the sales restriction

H2: There is a significant difference in fertilizing inputs among residents living where a sales-restriction is in effect relative to those living in counties without the sales restriction.

H3: There is a significant difference in nitrogen loads where fertilizer sales restrictions are in effect relative to nitrogen loads where fertilizer sales restrictions are not in effect.

Fig. 2. Hypotheses and assumptions that link intervention with outcome.

data were coded to maintain anonymity and confidentiality as described by survey ethics and required by academic Institutional Review Board procedures (40 CFR Part 26, CITI – Collaborative Institutional Training Initiative).

2.2. *Hypotheses*

The research questions were based in evaluation theory that links the intervention to benchmark outcomes (Rossi & Freeman, 1999). The main difference between fertilizer ordinances in the three counties was the seasonal restriction and “sales ban” on nitrogenous fertilizer. Our hypotheses investigated whether the target audience had been adequately reached with the ordinance information, if the ordinance accomplished the desired behavior change, and if the expected outcome of reduced nitrogen loads was achieved. Socio-demographic, behavioral, and environmental data were collected to evaluate the effectiveness of the fertilizer reduction ordinances and associated education campaign. The hypotheses that link evaluation assumptions from service utilization to outcome are provided in Fig. 2.

2.3. *County-wide telephone surveys*

A ten-minute long telephone survey of adult residents of Hillsborough, Pinellas, and Manatee counties was conducted in April and May 2012 to collect information on residents’ landscape management practices and ordinance awareness. A sample of over 8900 prescreened cell phones (20%) and landline (80%) telephone numbers were random digit dialed (RDD) resulting in a total of 835 completed interviews. For population sizes of 300,000 and higher (applicable to all Counties in this study), the number of completed interviews generates 95% confidence intervals around ± 5 percentage points for any results within and across counties. The survey questionnaire and research protocol were reviewed and deemed exempt by the University of Central Florida Institutional Review Board (IRB Exempt Approval FWA 00000351, IRB00001138, March 2012) as defined by U.S. Environmental Protection Agency Common Rule (2001) and Code of Federal Regulations, 40 CFR 26.

2.4. *Neighborhood resident interviews*

Eighty-one (81) residents were interviewed by trained and CITI (Collaborative Institutional Training Initiative) certified interviewers from June 6 – August 1, 2013. CITI training ensures that human subjects are treated with dignity and respect and data are handled anonymously and confidentially. Houses were randomly selected and approached weekdays and weekends. During the interview, residents were asked similar questions about landscape maintenance practices and fertilizer use as those asked in the telephone survey. Additionally, residents were asked to name their professional landscape management company if they used one, and they were recruited for lawn soil testing. In Pinellas County, there were 20 completed homeowner interviews in P202 and 14 completions in P201; 25 interviews were completed in the Hillsborough neighborhood (H101), and 22 interviews were completed in Manatee County.

2.5. *Neighborhood environmental sampling*

The project conducted environmental sampling that included 40 lawn soil samples (10 per neighborhood), 40 stormwater event samples (9–11 per neighborhood), and 72 stormwater pond or retention area samples (18 per neighborhood). An approved Quality Assurance Project Plan (QAPP) confirmed that sampling methods and laboratory analyses used in the project met the quality assurance standards of the U.S. Environmental Protection Agency.

Soil samples were collected from ten randomly selected front yards in each neighborhood from pre-screened and interviewed homeowners, to evaluate available soil N in surface soil. Five cores of the top 15 cm of soil were collected using a 1.5-cm steel soil corer and composited into a single soil sample for each yard. Soils were extracted with 1 M KCl, to assess inorganic N pools available for plant uptake, and possibly susceptible to leaching during storms (ISO/TS 14256-1, 2003). Extracts were analyzed by the University of Florida Analytical Research

Table 2
Telephone survey and census demographics.

Demographics	Hillsborough		Pinellas		Manatee	
	Survey	Census	Survey	Census	Survey	Census
Female (%)	59	51	61	52	62	51
Caucasian (%)	80	75	91	84	90	84
B.S. degree + (%)	42	29	44	27	50	26
Employed (%)	46	62	38	56	37	54
Median age (yrs)	59.0	35.3	60.5	44.7	60.0	44.3
Annual Income ($1000)	76.9	68.2	69.0	63.2	75.0	65.7
Number	286	1,167,116	257	915,003	292	313,011

Laboratory for NO_2/NO_3, NH_3, TKN, electrical conductivity (EC), organic matter content (loss-on-ignition), and pH.

Representative stormwater samples were collected from inlet pipes of stormwater detention ponds in each neighborhood using an ISCO® brand Avalanche Refrigerated Portable Autosampler equipped with an ISCO® Area Velocity Flow Module, ISCO® rain gauge, and a digital cell phone modem for direct notification of flow events. Once autosamplers were installed, initial rainfall and flow volumes were monitored to understand the flow pace of storm events so that a representative composite sample of stormwater could be collected for each event. Sampling took place over 18 months to assure a good representation of annual runoff concentrations. All storm runoff samples were held in the autosampler at $\leq 4\,^{\circ}C$ for no longer than 24 hours after the sampling event ended. Composite bottles were agitated to ensure a homogeneous solution and then aliquots were transferred to the preserved and labeled sample bottles. Sample pH was determined and sulfuric acid was added to adjust pH to < 2 for preservation.

Composite pond surface water samples were collected monthly from three locations within the stormwater receiving ponds or retention areas in each neighborhood. Surface water samples were analyzed for Total Kjeldahl Nitrogen (TKN, EPA Method 351.2), Ammonia (NH_3-N, EPA 350.1) and Nitrate/Nitrite (NO_2/NO_3-N, EPA 353.2). Total N (TN) was calculated from the test results.

2.6. Analysis

Summary statistics were generated for social and environmental datasets to investigate outliers. Univariate and bivariate analyses were conducted to compare and contrast respondents in the three research area counties: Hillsborough, Pinellas and Manatee. Tukey, Fisher, and Bonferroni post-hoc tests distinguished significant differences between communities and counties.

Where possible, differences in central tendencies of the summary statistics were investigated using univariate parametric or non-parametric alternatives. Seasonal trend graphics for the environmental data collection effort were also generated. Due to the lack of multiyear data, no statistical trend testing or time series analyses were conducted. Variations in means, standard deviations and other distribution characteristics were examined for wet and dry seasons separately. Internal data checks were conducted, such as regressions and correlations between standard parameters (e.g.: TN, TN versus TKN).

Total nitrogen (TN) loads were calculated for each neighborhood based on published mean annual runoff coefficients for the land use and soil type (Harper & Baker, 2007), actual measured stormwater TN concentration data, and site-specific annual rainfall using the standard formula (load = runoff volume × EMC [event mean concentration] × conversion factor × treatment reduction). Runoff volume was calculated from annual rainfall, runoff coefficient (C value), and area (Table 10). The runoff coefficients defined by Harper and Baker (2007) correspond to drainage areas classified as single-family residential with 40% impervious area, located in Meteorological Zone Cluster 4, and the site-specific soil hydrologic group. US Department of Agriculture soil type information was obtained in spatial format for every community (provided in Table 10) and used as ancillary data to select the appropriate runoff coefficient per community. Study sites varied in terms of soil hydrologic group, percent impervious and total drainage area; thus, runoff coefficients also differed between communities. Once the runoff volume is calculated based on the coefficient, total drainage area, and total measured annual rainfall at each site, loads can be calculated based on measured concentration data. This is the method typically used to develop Total Maximum Daily Loads (TMDLs) within the State of Florida.

Since the neighborhood drainage basin areas differed, load values were normalized by basin area in kg per hectare. We assumed for the purposes of the load estimation that the area was being treated with retention ponds (reduction of 30% for TN loads and 50% for TP loads).

Additionally, power analyses were done to provide recommendations of future sampling needs to detect a significant reduction in mean water quality parameters. We assumed the need to have 0.9 statistical power in detecting a minimum of 20% reduction in TN and inorganic N for both pond water and stormwater. The minimum sampling size was obtained for each neighborhood and sample type (pond water versus storm runoff) based on one-sample T-tests.

3. Results

3.1. County telephone survey

Telephone survey data were compared with Census data to understand the representativeness of the survey population relative to the overall county populations (Table 2). The survey population differed from the county population in terms of gender (more female), age (older), and race (more Caucasian). For final interpretation, data were weighted to be representative of county population in terms of gender, age, and race.

3.1.1. Lawn fertilizer practices

In the three counties, most homeowners (60%) fertilized their lawns and those who did typically relied on a professional lawn service (63%). More Manatee County residents (64%) fertilized their lawns than residents of Hillsborough (61%) or Pinellas (55%), although the differences were not significant. It is also the case that more Manatee County residents relied on a professional company to apply fertilizer to their lawn (43%) than residents in Hillsborough (38%) or Pinellas (32%), although these differences were not significant. Residents in the three counties applied fertilizer to their lawns an average of 2.14 times per year, with Hillsborough County residents applying fertilizer significantly more frequently than Pinellas County residents (Table 3). A majority of the lawns were reported as being fertilized in the summer months (67%) and many of these were being fertilized by professionals (63%). Interviewed homeowners were unaware of the fertilizer contents that professionals apply, consistent with other findings (Souto & Listopad, 2013).

Table 3
County lawn fertilizer frequency.

County	n	Fertilizer Frequency	Standard Deviation (SD)
Hillsborough	253	2.46^{a}	3.47
Pinellas	223	1.73^{b}	2.50
Manatee	252	$2.17^{a,b}$	2.72
Total	728	2.14	2.95

Note: “How many times was fertilizer applied to the lawn in the past 12 months?”
Column values followed by different letters are significantly different at $p < 0.05$.

Table 4
Respondents knowledge of when not to fertilize the lawn (frequency %).

Situation	Hillsborough	Pinellas	Manatee
During a drought	16	15	18
Right before a hard rain*	14^{a}	30^{b}	15^{a}
Summer*	13^{a}	26^{b}	16^{a}
After a hard rain	11	11	8
Winter	7	10	7
Fall	1	1	1
Spring	0	0	0
Not sure*	52^{a}	35^{b}	50^{a}

Note: n = 474, “Are there times or situations when you should NOT fertilize your lawn? If so, when?”
*$p < 0.01$, Row values followed by different letters are significantly different at $p < 0.05$.

3.1.2. Fertilizer ordinance awareness & knowledge

To measure homeowner awareness of the fertilizer ordinance and prescribed fertilizing practices, respondents were asked about times or situations when it is inappropriate to apply fertilizer. Pinellas County residents had significantly fewer “Not sure” responses than those in Hillsborough or Manatee Counties and more often identified times or situations when it’s inappropriate to fertilize lawns (Table 4). Additionally, Pinellas County residents were significantly more likely to indicate that fertilizer should not be applied right before a hard rain or during the summer.

Pinellas County residents were also significantly more likely than Hillsborough or Manatee County residents to have heard about government regulations concerning residential fertilizer use (Table 5). Those who had heard about the ordinance (n = 230) were probed further for details about what they had heard. Pinellas County residents were significantly more likely than Hillsborough or Manatee County residents to know that local ordinances restricted the sale of lawn fertilizer during certain months.

3.2. Neighborhood resident interviews

All of the interviewed Hillsborough neighborhood (H101) residents applied fertilizer to the lawn in the past 12 months (100%), while only half (50%) of the Manatee neighborhood (M101) residents; and about three-quarters (71%) of Pinellas neighborhood (P201) and Pinellas neighborhood (P202) residents (75%) applied fertilizer. There were similarities and differences in the neighborhood residents and the surveyed county residents. Generally, neighborhood residents applied fertilizer more frequently than the county resident average, except in Manatee County, where they were identical (2.17 times/year).

Consistent with the findings of the telephone survey, the (H101) residents applied fertilizer significantly more frequently than the residents in the Pinellas (P201 & P202). H101 residents also applied fertilizer significantly more frequently than Manatee (M101) neighborhood residents (Table 6).

3.3. Neighborhood environmental sampling

3.3.1. Soil

There were significant differences among the four communities in mean soil organic matter, TKN, EC, and pH values (One-Way ANOVA, $p < 0.001$) (Table 7). Tukey HSD tests indicated that P201 had significantly higher organic matter, TKN, EC and pH than the other communities. Lowest values were found in P202 (Organic matter, EC, and PH) or M101 (TKN).

3.3.2. Water quality

The retention ponds in this study were designed to provide stormwater treatment over time. We expected nutrient concentrations to be lower in the pond water than in the untreated stormwater, and this was the case in all locations. Annual stormwater Total Nitrogen (TN) concentrations were significantly higher than pond water concentrations ($p = 0.007$) overall, but there were interesting seasonal variations (Table 8). Pond water nitrogen (TKN) concentrations were significantly higher in the wet season than the dry season ($p = 0.02$, One-way ANOVA) although ammonia (NH_3-N) and nitrite/nitrate (NO_2/NO_3-N) were not significantly different. In contrast, stormwater nitrogen concentrations were significantly higher in the dry season than the wet season for all parameters (TN, $p = 0.0018$, TKN, $p = 0.0018$, NO_2/NO_3-N, $p = 0.018$ and NH_3-N, $p < 0.001$; One-Way ANOVA).

The Manatee neighborhood (M101) pond had significantly higher TN; TKN; and NO_2/NO_3-N concentrations than the Hillsborough neighborhood (H101) and Pinellas neighborhood (P201). P201 pond NH_3-N concentrations were significantly higher than the three other communities (Table 9).

The load calculations in Tables 10 and 11 show that Hillsborough (H101) had the highest total nitrogen load followed by Manatee (M101), Pinellas (P202), and Pinellas (P201). The normalized values by hectare showed highest nitrogen loads in H101, followed by P202, P201, and finally M101.

3.3.3. Detecting significant changes over time

Using observed means and standard deviations for the collected parameters, we estimated the number of samples required to detect a mean reduction of 20% Total Nitrogen (TN) with a detection power of 0.9 for the four communities. Specific sample sizes based on a power of 90% for a 20% or greater reduction in mean concentrations are provided in Table 12.

The required sample size to detect a significant reduction in TN pond concentration would be 22–32 samples or 2–3 years of monthly sampling. Of the four neighborhoods, P202 had the smallest range of N concentration variability, requiring the fewest samples to detect a significant difference in pond water TN. M101 pond water had the greatest observed variability, requiring the highest number of samples to be collected to be able to detect a mean reduction in TN.

Stormwater sample concentrations varied greatly across neighborhoods, requiring a greater sample size to detect a similar reduction in

Table 5
Awareness of fertilizer ordinance details (frequency %).

Question	Hillsborough	Pinellas	Manatee
Have you heard about local fertilizer regulations?*	26^{a}	44^{b}	24^{a}
If yes, do the ordinances…			
Restrict the use of lawn fertilizer during the rainy season?	75	75	66
Restrict the sale of lawn fertilizer during certain months?	62^{a}	79^{b}	51^{a}
Reduce the amount of phosphorous (“P”) allowed in lawn fertilizer?	65	77	69
Reduce the amount of nitrogen (“N”) allowed in lawn fertilizer?	58	62	66
Require training for professional landscape maintenance companies?	57	52	4

Note: n = 750, *“Have you heard anything about government regulations concerning residential landscape fertilizer?
“Yes maybe” and “Yes definitely” are reported.
Row values followed by different letters are significantly different at $p < 0.05$.

Table 6
Comparing county and neighborhood resident fertilizer frequency (μ).

County name (n)	County Fertilizer Frequency	Neighborhood Fertilizer Frequency	Neighborhood code (n)
Hillsborough (253)	2.46^{a}	5.96^{a}	H101 (23)
Pinellas (223)	1.73^{b}	3.82^{b}	P201 (11)
		3.67^{b}	P202 (15)
Manatee (252)	2.17^{a,b}	2.17^{b}	M101(12)

Note: Column values with different letters are significantly different at $p < 0.05$.

Table 7
Soil mean results by neighborhood (n = 40).

Analyte	H101	P201	P202	M101
NO_2/NO_3 (mg/kg)	9.13 (2.56)	11.94 (5.78)	6.20 (2.93)	5.91 (2.44)
NH4 (mg/kg)	2.45 (1.41)	2.76 (0.95)	2.151 (0.68)	2.50 (1.41)
*Org. Matter (%)	4.54 (1.12)^{a}	6.46 (2.22)^{b}	4.311 (0.93)^{a}	2.616 (0.56)^{c}
*TKN (mg/kg)	1296.24 (356.04)^{a}	1657.28 (499.91)^{a}	1395.66 (251.81)^{a}	793.60 (181.71)^{b}
*EC (ds/m)	0.09 (0.01)^{a}	0.15 (0.03)^{b}	0.07 (0.03)^{a}	0.09 (0.03)^{a}
*pH	6.50 (0.48)^{a}	7.44 (0.32)^{b}	6.30 (0.57)^{a}	6.67 (0.65)^{a}

Note: n = 40, Row values followed by different letters are significantly different at $p < 0.05$ (SD).
*$p < 0.05$, median.

Table 8
Seasonal variations in pond and storm water nitrogen concentrations ($mg\,L^{-1}$).

Analyte	Pondwater Sample Concentrations		Stormwater Sample Concentrations	
	Dry Season	Wet Season	Dry Season	Wet Season
TN	1.10	1.29	2.13*	1.25
TKN	0.97	1.19*	1.81*	1.04
NO_2/NO_3-N	0.12	0.11	0.32*	0.21
NH_3-N	0.13	0.17	0.24*	0.13

Note: n = 224, *Seasonal differences are significantly different at $p < 0.05$.

Table 9
Neighborhood pondwater nitrogen mean concentrations ($mg\,L^{-1}$).

Analyte	H101	M101	P201	P202
Total N	0.993^{a}	1.398^{b}	0.935^{a}	1.173^{a,b}
TKN	0.976^{a}	1.251^{b}	0.783^{a}	1.042^{a,b}
NO_2/NO_3-N	0.027^{a}	0.147^{b}	0.145^{a}	0.133^{a,b}
NH_3-N	0.055^{a}	0.125^{a}	0.183^{b}	0.169^{a}

Note: n = 40, Row values followed by different letters are significantly different at $p < 0.05$.

Table 10
Neighborhood load calculation variables.

Neighborhood	Soil Hydrogroup[1]	Runoff Coefficient	Basin Area (hectares)	Annual Rainfall (cm)
H101	C (some A and D)	0.31	16.32	142.70
M101	D (B/D)	0.35	13.75	140.64
P201	D (B/D and D)	0.35	7.40	110.95
P202	A (minor D)	0.23	5.35	146.53

[1] Obtained from USGS Soil Classification spatial layer.

TN concentrations. P201 had the greatest variability in stormwater nitrogen concentrations and would require the greatest sample size (85 samples) and M101 would require the least number of samples (56 samples).

4. Discussion

This applied research project presents an evidence-based approach to examine linkages between a social institutional driver (landscape fertilizer ordinances) and ecological processes at the household and neighborhood scale. A theoretical framework based on program evaluation establishes a logical flow of change required to get from public awareness of a new legal requirement to associated behavior change to improved water quality. The study illuminated important findings but many limitations and confounding influences prevent confident final conclusions to be drawn, primarily due to time and budget constraints. The study demonstrates the need for long-term sampling to confidently conclude a change in water quality resulting from a change in landscape behavior at the community level.

4.1. Fertilizer ordinance as mechanism for behavior change

Larson and Brumand (2014) found that informal institutions were the strongest forces influencing residential landscape management decisions and that formal rules are often unknown, unenforced, and limited in influence. Before a formal rule can be associated with changes in landscape management practices, it must be determined that the targeted residents are aware of the ordinance and understand the prescribed behavior. The telephone and neighborhood surveys conducted in our study demonstrated that where fertilizer ordinances were in place, the residents were aware of the ordinances. In Pinellas County, where the most restrictive fertilizer ordinance included a summer ban on fertilizer sales and an extensive ordinance awareness campaign had been conducted, homeowner ordinance awareness, knowledge, and implementation were significantly higher than in the other two counties. This was evident in our findings that Pinellas County residents were significantly more aware of the existence of a county fertilizer ordinance and they were more likely to recount details of the ordinance. Specifically, Pinellas County residents were significantly more likely to know they should not apply fertilizer during the rainy season, one of the key differences between Pinellas and Hillsborough County ordinances.

The awareness of the ordinance and its requirements may be effecting a change in behavior. Pinellas County residents applied significantly less fertilizer to their lawns than Hillsborough County residents, although a direct causal effect cannot be confidently established by the current study. A pre- and post- intervention design was impossible in our study and there are many well-established influences on landscape maintenance behaviors that confound a causal explanation such as property values, social norms, home age, and landscape management responsible party (Boyer et al., 2002; Fraser

Table 11
Annual estimated total nitrogen loads per neighborhood basin area (kgs/hectare).

Neighborhood	Number of rain events (N)	Mean TN (mg/l)	Runoff Volume (1000 m^3/yr)	TN Load (kgs/yr)	TN Load by Area (kgs/hectare)
H101	11	1.76	72.60	69.59	4.26
M101	9	1.39	67.05	53.43	3.89
P201	10	1.45	28.48	30.11	4.07
P202	10	1.76	17.79	22.31	4.17

Table 12
Minimum sample sizes to detect a 20% reduction in TN concentrations.

	H101	M101	P201	P202
Pond water	23	32	28	22
Storm water	64	54	85	56

Note: Estimates based on a one-sample T-test and not a seasonal trend test.

et al., 2013; Hope et al., 2003; Robbins et al., 2001; Robbins & Sharp, 2003; Souto & Listopad, 2013).

Income and property value may partially explain the different fertilizer frequency rates in Hillsborough and Pinellas Counties. The Hillsborough County population had the highest average annual household income and the highest fertilizer frequency, however, at the neighborhood level this relationship eroded. The Pinellas County neighborhood (P201) had the highest property values by far, nearly double the average property value in Hillsborough County neighborhood (H101), and yet P201 residents applied fertilizer significantly less frequently than H101 residents. The Manatee County neighborhood had the lowest property values and the lowest fertilizer frequency of the investigated neighborhoods, reinforcing previous findings that relate socio-economics with fertilizer use. This may explain why Manatee County, which has the second strongest fertilizer ordinance (a seasonal restriction without a sale ban), had the lowest fertilizer frequency.

Other research demonstrates significant differences in fertilizer application by homeowners and professionals (Law et al., 2004; Souto & Listopad, 2013). Souto and Listopad (2013) found that in Wekiva, FL, USA, homeowners applied fertilizer significantly less frequently than professionals, they were more likely to apply fertilizer as needed, they spent more time doing yard work than homeowners that hired professionals, and they were significantly more likely to be motivated by community pressure to have a nice yard. Further exploration of the Tampa Bay Residential Survey data will examine differences in awareness, knowledge, and practices among residents who apply fertilizer themselves and those that hire professionals.

In the current study, we were unsuccessful at confidently determining a difference in the numbers of households applying fertilizer during the rainy season. We found that residents who applied fertilizer themselves were more likely to apply it in spring or fall, not the summer rainy season. This is consistent with other behavioral studies conducted in southwest Florida prior to the fertilizer ordinances (Martin, 2009; Mitchell, 2009) and thus may have little to do with the new ordinances. Among the interviewed homeowners who hired yard and landscape maintenance professionals, we found that fertilizer was applied according to an agreed upon contract and that homeowners didn't know what was being applied. This too was consistent with previous studies (Mitchell, 2009; Souto & Listopad, 2013). Professionals can apply fertilizer that doesn't contain N to the lawn in the rainy season, so homeowners indicating that professionals are applying fertilizer during the restricted season does not mean professionals are not complying with ordinances.

It is likely that ordinance awareness and knowledge of best management practices differ between residents who don't fertilize their lawn at all, those who apply fertilizer themselves and those who hire professionals. Additional analyses can be conducted to better understand which target audience is most receptive to current messages and methods.

4.2. Linking behavioral change to environmental change

We were unable to confidently establish a linkage between fertilizer behaviors and neighborhood level water quality within the short timeframe of our research but we expected that there would be a lag between the change in fertilizer behavior and resulting water quality. Researchers have described the complexity of multi-scalar, socio-ecological interactions and how the linkages are confounded by legacy effects of nutrients leaching or fluxing into the environment over an extended period of time, (Cook et al., 2012; King et al., 2012; Lehman et al., 2009, 2011; Sebilo, Mayer, Nicolardot, Pinay, & Mariotti, 2013). There are many source-sink dynamics and meteorological conditions that influence the timing of nutrient releases (Compton, Hooker, & Perakis, 2007; Engelsjord, Branham, & Horgan, 2004; Frank, O'Reilly, Crum, & Calhoun, 2006; Raciti et al., 2008; Zhu, Dillard, & Grimm, 2004). Due to the large variability in meteorological conditions and annual and seasonal nitrogen concentrations in our study, a minimum of 5–7 years and preferably 10 years of data collection is needed to confidently measure a 20% reduction of TN in stormwater. It might be possible to observe a reduction in TN pond water concentrations in less time, but extreme weather events and drought years increased the measured variability used as basis for the sample size estimates. An alternative would be to sample for 2 years prior to implementing behavioral changes and again 5–10 years later comparing communities with or without significant interventions.

Even within the time and budget constraints of this project, mean load calculations, based on environmental data, partially corroborate the behavioral data. In the Hillsborough County neighborhood (H101) where homeowners' yards were fertilized most frequently, the normalized TN load/hectare was highest and in the in the Manatee neighborhood (M101), where fertilizer frequency was lowest, the TN load/hectare was the lowest. The lack of pre-ordinance data prevents us from establishing a causative link between a change in behavior spurred by the implementation of the ordinance and local water quality impact.

We found significant differences in neighborhood soil characteristics that can influence nutrient dynamics. Carbon content and organic matter enable the soils to act more as a sink or source of N over time, holding nutrients until a capacity threshold is reached (Vitousek & Reiners, 1975). For example, the Pinellas neighborhood P201 had much higher organic content, which can act as a sink for N inputs or a continued source of N leaching and runoff over time. Selecting communities based on socio-demographic and ecological conditions, or having greater replication of different types of conditions would be ideal.

4.3. Lawn as a nitrogen sink

Whether a lawn acts as a source or sink of N is influenced by biological and meteorological conditions that are challenging to hold constant in the field. There are source/sink dynamics that sequester excess N in biomass, soils, and pore space water for long periods of time and release the N when the lawn reaches carrying capacity, (Engelsjord et al., 2004; Fissore et al., 2012; Frank et al., 2006; Law et al., 2004; Raciti et al., 2008; Vitousek & Reiners, 1975; Zhu et al., 2004). Sebilo et al. (2013) showed that three years after fertilizer was applied to abandoned agricultural land, 32–37% of labeled fertilizer was still in the soil organic matter and twenty-five years later, 12–15% was still there. They concluded that restoration measures must consider the delay resulting from legacies of past applications of synthetic fertilizers in agricultural systems. We expect that similar lag times can occur in fertilized residential lands that have received high inputs of nitrogenous fertilizers. Future research that attempts to compare in-situ neighborhood N dynamics should invest more in soil research to better understand the lag-time of N source-sink dynamics.

Rainfall timing and amount influences the potential for N runoff by filling soil pore spaces, dissolving nutrients and carrying dissolved and particulate nutrients into the storm system. We found that stormwater N concentrations were greater during the first rain events of the season than those later in the year. Particularly, we found higher stormwater concentrations of organic nitrogen (TKN) and lower concentrations of dissolved and inorganic N after a long period of no rain. This may be indicative of particulate organic matter that accumulated between rain events and flushed into the storm system with the first storm.

Stormwater nutrient concentrations must be considered within the larger pattern of rainfall to understand the flushing potential. In both Pinellas communities (P201 and P202) stormwater N concentrations peaked at the end of the dry season and then dropped over the wet season samples, peaking again at the beginning of the dry season. Rainfall patterns that are critical to nutrient fate and transport at the neighborhood level were impossible to hold constant in our study. The first-flush dynamics confounding any seasonal relationship between fertilizer application timing in the dry and rainy seasons and stormwater quality in the short timeframe of this applied research.

Differences in the stormwater systems of the four communities also contributed to variability in our results. The H101 stormwater pipe where the autosampler was installed was compromised during the study. There was an apparent rupture of the line, or a clog, where the line broke and washed away the soil outside the pipe, undermining the culvert. It was uncertain what the cause of this break was or when it was repaired. Initial flows when establishing the pacing at this site were difficult. The M101 stormwater system had little gradient and remained full of water all of the time. P201 system discharged to a skimmer that outflowed to a wetland. Considering these structural differences, it is difficult to compare water quality concentrations between communities and a more robust, long-term study would be needed to confidently portray a difference in nitrogen loads.

5. Conclusion

Understanding the linkages between human behaviors, ecological outcomes and ecosystem response must be considered within the framework of neighborhood management strategies and interventions (Cook et al., 2012) as well as meteorological and biological conditions. Our research contributes to a critical missing gap of inter-disciplinary research that links socio-political drivers of human behaviors with environmental effects at the fine-scale, neighborhood level. We demonstrate the complexity of holding constant the myriad of ecological, socio-economic, and meteorological variables when working in the applied research realm. Fissore et al. (2011, 2012) conclude that any change in behavior among high input fertilizers will have a significant impact on water quality. We established relevant linkages between county fertilizer ordinances, resident ordinance awareness and neighborhood behaviors that can contribute to reduced residential fertilizer nitrogen inputs, but we were unable to confidently conclude that load reductions were associated with behavior change in the short timeframe of the study. Linking residential lawn fertilizer use with N concentrations in receiving storm and ponds waters is complicated by seasonal variations in rainfall that cause high variability in stormwater N concentrations. Long-term trend analysis over multiple seasons is needed to cover the extent of meteorological conditions that contribute to variability in N source/sink dynamics. Based on the power analysis conducted in our study, we recommend ten years of stormwater monitoring to confidently measure a concomitant reduction in N concentrations. From our results and the results of others that demonstrate the temporal variability of N source/sink dynamics (Fissore et al., 2011, 2012; Lehman et al., 2009, 2011), the timing of fertilizer application may not be as important to reaching long-term water quality improvement goals as reducing the amount of nitrogen applied overall. A comprehensive approach to examining regional, neighborhood, household drivers of nitrogen inputs and system response may be accomplished when adequate time is dedicated to long-term system monitoring.

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