Forest fragmentation, ecosystem services, and community value within complex social and natural landscapes

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ABSTRACT
This study assessed how community perceptions and adjacent land uses impact the functioning of forest fragments and their edges. The results showed that edge effects persist beyond 50m into the fragment and that community members of Saratoga are concerned about protecting fragments for their ecosystem services, but are unclear on who has the power to protect them. The authors suggest that conservation of these fragments must be considered both a natural and social landscape issue.

INTRODUCTION

Ecological Perspective

Humans use the land for personal benefit, be it sustenance, enjoyment, or economic. This is particularly true for forests where humans have long depended on the ecosystem services they provide, such as carbon sequestration, habitat, and recreation (Sugden et al. 2008; Chazdon 2008). Further services are less apparent, but equally important, such as pollution filtration and methane sequestration (Bedard and Knowles 1989; Bodelier and Laanbroek 2004). However, increases in human land-use have altered forest coverage in the US and world-wide (Dovciak and Brown 2014**;** Chapman et al. 2015). As a result of land clearing, forests have become more fragmented, with patches remaining in a mosaic of parcels surrounded by different land-use (Weathers et al. 2001). These remaining forest fragments sustain biodiversity within the region by supporting native plants and ecosystems and by acting as refuges for animals that are unable to persist in other landscapes (Chapman et al. 2015). For example, it has also been found that without the presence of forested landscapes adjacent to agricultural lands there is diminished community richness and decreased community stability, especially among birds (Devictor and Jiguet 2006). While these forest patches maintain ecosystem stability, they often have altered and more abrupt edges, which disrupts ecological functioning within the fragment due to the edge effects.

Edge effects are changes in the abiotic conditions along a gradient from the edge into the fragment interior. Changes include increased solar radiation, wind exposure, available colonization space for invasive species, and soil disturbance (Dovciak and Brown 2014; Chapman et al. 2015; Flores-Rentería et al. 2015). Furthermore, the microclimate at forest edges is dependent on aspect and relative input of solar radiation, which contributes to the discrepancy between interior forest composition and edge composition (Gehlhausen 2000; Collinge 1996). Forest interior is thought to begin 50 meters from an edge, so as the forest interior area decreases, the impact of edge effects increase (Malmivaara-Lamsa et al. 2008; Collinge 1996). Shape indexes marry the concepts of edges and interiors, using a perimeter to area ratio, where a larger shape index indicates a forest of decreasing interior space (Ohman and Lamas 2005; Collinge 1996). Under this definition, many fragments globally are comprised of all edges and lack a true forest interior. Thus, when compared to intact forests, forest fragments often are heavily influenced by the adjacent landscape.

As forest fragments are created, soil and plant communities respond to disturbance and changes in environmental conditions; some recover to a pre-disturbance state while some do not. Soil microbial responses are particularly uncertain because little is known about what controls the distribution, abundance, and function of soil microbes (Fierer et al. 2009; Zak et al. 2006). A healthy soil is defined as "a stable soil, with resilience to stress, high biological diversity, and high levels of internal cycling of nutrients" (van Bruggen and Semenov 2000). Increased solar radiation and temperature fluxes impact soil function, but edge effects can be further exacerbated by unintended inputs of nitrogen (N) from surrounding land uses (Malmivaara-Lamsa et al. 2008; Pregitzer et al. 2008; Guadio et al. 2015). It is suspected that the interaction with the adjacent land will lead to a concentration of nutrients at the interface, rather than at the forest interior. In general, excess N increases soil nitrification rates, leaches essential base cations, and increases soil acidity (Guadio et al. 2015). This impacts the structure and activity of soil microbial communities, which, in turn, largely determines the aboveground vegetation (Malmivaara-Lamsa et al. 2008). Furthermore, within 0 to 20 meters of the forest edge, soil has been found to have lower microbial biomass, lower moisture content, and decreased litter decomposition (Malmivaara-Lamsa et al. 2008).

Clearly, N inputs from adjacent land uses are critical to understanding altered functioning at forest edges. Two common sources of N inputs into forest systems are atmospheric deposition and runoff. Forest patches concentrate atmospheric deposition by catching nutrient laden fog and clouds as they move across the landscape (Weathers et al. 2001). Vehicle exhaust and other mobile sources account for approximately 56% of nitrogen oxide (NO_x) deposition and are the second largest producers of nitrous oxide (N_2O) after agriculture (Bettez et al. 2013). N fertilization and agricultural activities can also lead to near-by deposition and ammonium (NH_4^+) volatilization (Asman et al. 1998). Forest edges might accumulate a disproportionate amount of that deposition. Furthermore, increased N deposition inhibits soil methanotrophs from oxidizing methane, a radiatively active atmospheric trace gas (Bedard and Knowles 1989). This results in a reduced atmospheric methane sink and potentially enhancing the greenhouse effect. Furthermore, N fertilizers are the largest source of anthropogenic N globally due to food production demands (Vitousek et al. 1997). Consequently, soil only retains a portion of applied fertilizer, ranging from 19-86%. Therefore, runoff is a common means of nutrient input, but there have been few studies on the impacts of fertilizer runoff on terrestrial ecosystems (Matson et al. 2002). However, given the common use of N fertilizers in agricultural landscapes, increased hydrologic and erosion-based N transport to forest edges is plausible (Adesmoye and Kloepper 2009).

Specific nutrient input rates and the degree of edge effects vary depending on the adjacent land use (Dovciak and Brown 2014). For example, a study of vehicle emissions by Bettez et al. (2013) found that N deposition was highest at the edge of forests adjacent to roads, and total dissolved N rates ranged from 1.2 to 2.5 mg m^{-2} day^{-1} . However, forests and soils near industrial sources experience elevated ammonium (NH_4^+) and nitrate (NO_3^-) that were found to range from 0.7 to 21.0 kg $ha^{-1}yr^{-1}$ (Lajtha et al. 1997) and 0.91 to 13.99 kg ha^{-1} *yr^{-1} (Lilleskov and Fahey 2002).

Community Perspective

Saratoga County, New York exemplifies a mosaic landscape with various land uses abutting forest fragments. The county is rapidly developing, with land uses ranging from conserved forest fragments to new downtown development and suburban housing. The Saratoga "green belt" refers to the town's arrangement and diversity of land-uses; the town has a residential area encased in agricultural land with forested areas interspersed (Figure 1). Understanding the dynamic interplay associated with this mosaic of urban, residential, agricultural, and forested land uses is therefore important for developing forest patch management plans. From the years 1996-2010 Saratoga County has experienced a wide variety of land use changes, mostly due to increases in the levels of development with an increase in population. Over the 14 year span the county has seen a loss of 3.73 sq miles of agricultural land and 10.86 sq miles of total forested area, while experiencing an increase of 9.52 sq miles of development. In terms of the distribution of forest fragments in the area, there has been a gain of 0.8 sq miles of patch, 0.46 sq miles of perforated, and 4.85 sq miles of edge fragments. The only decrease in the level of forest fragments is seen in the core fragments which decreased by 17.72 sq miles (C-Cap Land Cover Atlas).

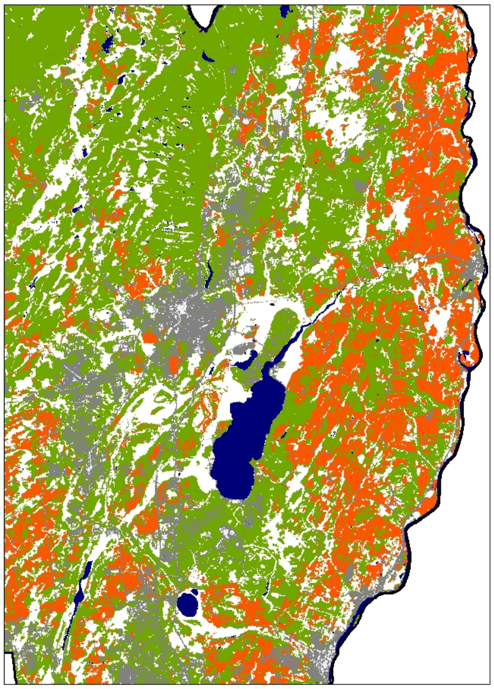

Figure 1. Saratoga County’s land use. Green indicates forested areas, orange indicates agriculture and pastoral land, and grey indicates developed land. Image processed with ArcGIS (Version 10.3.1).

Local community support for forests, parks, and recreational sites seem to be based upon the costs and benefits of a variety of social, cultural, economic and political considerations. Ite (1996) found an increased level of community awareness for the conservation of the Cross-River National Park in south-east Nigeria. However, there still remains a low level of physical, local support. This lack of support is likely due low levels of socio-economic development, the slow pace of project implementation, and the lack of relationship between the community and the park officials (Ite 1996). These factors can be related directly to community prioritization for the conservation of local forests within Saratoga County, which already suffer from fragmentation and may be negatively affected in the future. A lack of socio-economic development has the potential to prevent them from being able to finance conservation projects and to go without utilizing specific ecological resources within a given area like food and fuel. Even if there are funds put in place for the conservation of national forests, like Cross-River National Park, there tends to be a disconnect between project planning and implementation. This disconnect may be a result of a poor relationship between members of the community and park officials which need to come to an agreement about the allocation of resources and the various ways in which the land will remain protected.

On the other hand, it is imperative to view the management and conservation of local forests as a community-based issue. In order to benefit from the conservation of forests there are many social interactions that need to take place; community based forest management has the potential to simultaneously meet the needs of both local and global environmental development interests (Klooster and Masera 2000). Under acceptable social conditions, forest conservation has the ability to prevent deforestation and mitigate carbon emissions. In underdeveloped countries like Nigeria, and Mexico, forest dwelling communities often highly value the future productivity of the forest and have strong social ties that bind them to a specific piece of land. People in Saratoga often use these forest fragments for recreation and may feel a personal connection to the well-being of these sites. In order for productive conservation to occur in this community, conservation efforts need to include the participation of locals to provide mechanisms and incentives for conservation. Not only would this provide motivation for the future protection of fragmented forest parcels, it could also provide jobs and revenue for the community and contribute to the health of the local ecology (Klooster and Masera 2000).

Purpose

The purpose of this study was to assess how various surrounding land uses and disturbances influence forest fragment health and function, particularly with respect to nutrient cycling and soil processes expected to be most sensitive to many land use impacts (Bettez et al. 2013). We wanted to know if there are differences in atmospheric deposition and soil disturbance in forest patches depending on the interface type. Furthermore, we wanted to know if people's attitudes toward the conservation of these patches influences the fragment conservation and health. In order to answer these questions, we collected soil along a gradient from forest edge to interior in relation to three major land use interfaces (residential, agricultural, and roads). The soils were assessed for nutrient dynamics and microbial activity as metrics of land use impacts. This study was supplemented with surveys of community members to understand their attitudes toward the value of forest fragments, disturbance effects on fragments, and the need for fragment conservation and management. We hypothesized that forest edges have higher levels of atmospheric deposition and diminished soil health (i.e. lower methane oxidation and greater leachable nitrate concentrations) when compared to interior forest soil. Furthermore, we expected that different adjacent land uses impact the forest soils differently due to different mechanisms of inputs, such as fertilizer application on agricultural lands. Lastly, we hypothesized that community members exhibit positive attitudes toward conservation of these lands.

METHODS

Study Sites

We selected public land parcels containing forest fragments in Saratoga County, New York using ArcGIS (Version 10.3.1) and Google Earth (Google, 2016) (Figure 2; Table

1). These primarily hardwood forest fragments are adjacent to agricultural lands, residential areas, and/or roadways and at least 100 m^2 so the fragment has an interior component not influenced by edge effects (Collinge 1996; Malmivaara-Lämsä 2008). The vegetation comprised mixed hardwoods species, such as oak, maple and pine species. We sampled the sites once in mid-January and mid-April 2016.

Within each forest patch, we established two transects running from the adjacent land use to the forest interior; measuring from the edge to the interior we sampled at -10, 0, 10, 25, and 50 m. Control gradients were established at forest edges along power lines, where there is no development or disturbance, to determine deposition patterns with only vegetation removal disturbance.

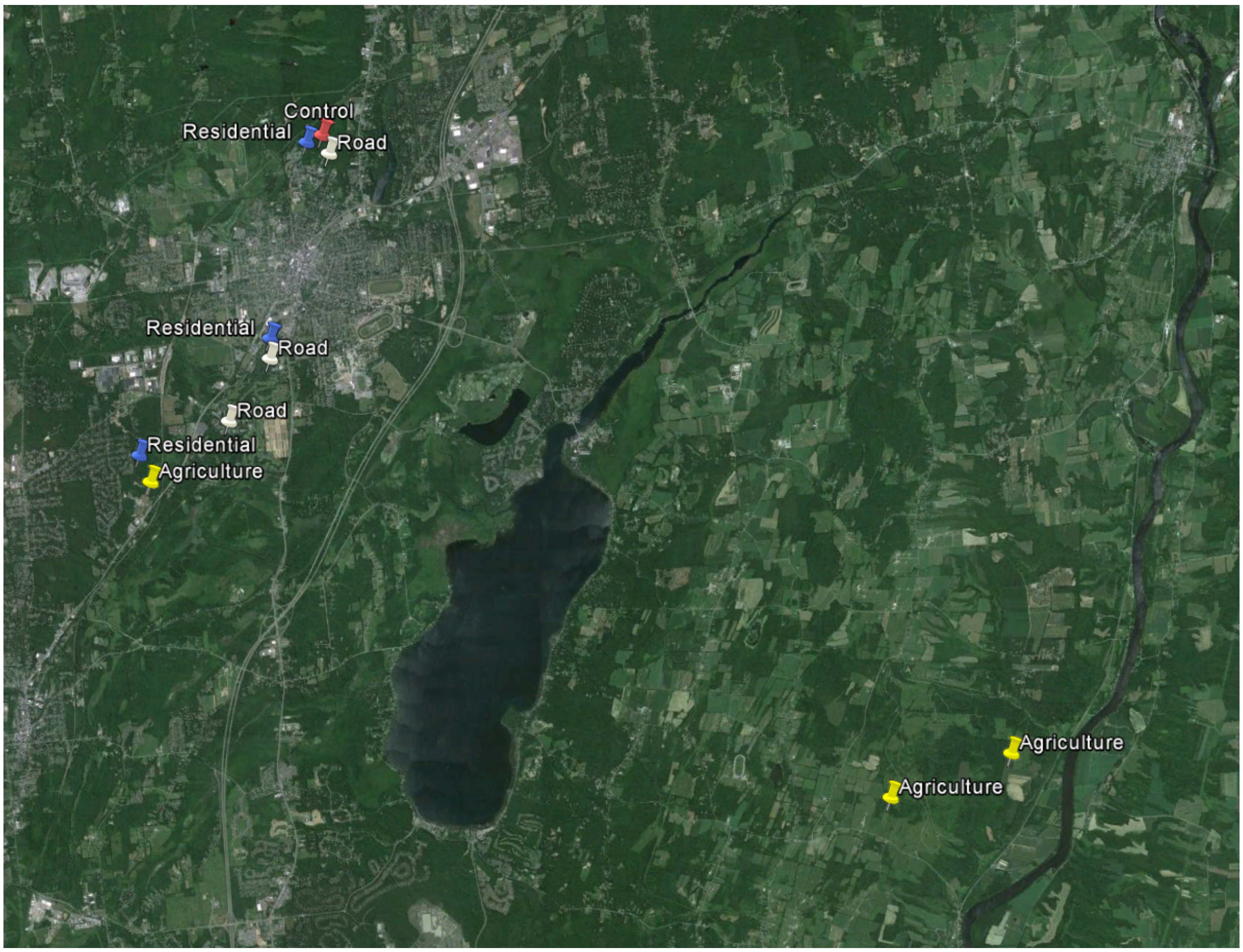

Figure 2. Study sites in Saratoga County, NY. Fragments are contained within Skidmore's Northwoods, Saratoga Spa State Park, and Saratoga Battlefield. Map sourced from Google Earth (Google, 2016).

Table 1. The forest fragment locations and adjacent land use.

Site	Coordinates	Land Use
Skidmore's Northwoods	43º05'54.81" N, 73º46'49.07" W	Road
Skidmore's Northwoods	43º06'1.52" N, 73º47'7.98" W	Residential
Skidmore's Northwoods	43º06'6.06" N, 73º46'54.74" W	Control
Saratoga Spa State Park	43º04'1.85" N, 73º47'38.35" W	Residential
Saratoga Spa State Park	43º03'49.63" N, 73º47'38.27" W	Road
Saratoga Spa State Park	43º03'11.39" N, 73º48'12.45" W	Road
Saratoga Spa State Park	43º02'50.44" N, 73º49'27.58" W	Residential
Saratoga Spa State Park	43º02'34.37" N, 73º49'17.84" W	Agriculture
Saratoga Battlefield	42º59'49.03" N, 73º37'19.29" W	Agriculture
Saratoga Battlefield	42º59'22.09" N, 73º39'0.06" W	Agriculture

Population and Setting

The 2014 population estimates for the County of Saratoga was 224,921 people (U.S. Census Bureau 2014). The per capita income level was $35,176, while the median household income was $69,826 (U.S. Census Bureau 2014). The total land area in 2010 for Saratoga County was 809.98 square miles and persons per square mile were 271.1 (U.S. Census Bureau 2013). The major industries within Saratoga are both public and private; education, healthcare, hospitality, and Stewart's Company, are the main sources of employment for its citizens. Saratoga Springs provides an interesting dynamic of a popular city center with high end shops and restaurants located within a landscape of rural farmlands (City of Saratoga Springs 2010). Saratoga County is also made up of many different forests, parks, and recreational sites, such as Saratoga Spa State Park, Northwoods at Skidmore College, Saratoga National Historical Battlefield, Woodcock Preserve, Malta Ecological Park, Wilton Wildlife Preserve & Park and many others.

Atmospheric Deposition

Ion exchange resin (IER) collectors were used to quantify total N deposition from the forest edge and interior sample locations at each of our study sites (Fenn and Poth 2014). Collectors consisted of IER collectors fitted with 18 inch snow tubes and 8 inch diameter funnels attached to a 2 meter piece of rebar inserted into the ground. Collectors were placed at least 0.5 m away from tree trunks to avoid interference of overstory on throughfall (Weathers et al. 2001). Two IER collectors were established along each transect in February 2016 and collected in April 2016, for a total deployment of 69 days, as IER collectors provide accurate readings when left in the field for up to one year (Fenn and Poth 2014).

After collection from the field, resin from each collector was extracted four times, with 100 mL of 2 *M* KCl to collect ions, creating one composite sample (Bettez and Groffman 2013; Fenn and Poth 2014). Nitrate (NO_3^-) and ammonium (NH_4^+) were analyzed colorimetrically in 96 well-plate format following methods detailed by DeForest and Scott (2010). Background N deposition was determined using the control collectors (power lines); the contribution of land-use to deposition was determined by subtracting the background level from the observed level.

Soil Analysis

We collected three soil cores (5 cm diameter x 10 cm depth) at each point along the transect and transported them to the lab for processing. The cores from each sampling point were then composited, passed through a 2 mm mesh sieve to homogenize, and coarse fragments removed. These were stored for less than 48 hrs at 4 °C. A subsample was dried to determine moisture content. To assess inorganic N and PO_4^{3-}, 20 g of soil was extracted with 50 mL of 1 *M* KCl, shaken for one minute at 0 hours and again 24 hours. Extraction solution was filtered and analyzed colorimetrically in 96 well-plate format following methods detailed by DeForest and Scott (2010).

Microbial Activity

We estimated potential CH_4 oxidation rates using an adaptation of the methods described by Smemo and Yavitt (2006). 30 g of field moist soil was placed in sterile 460 mL mason jars. Mason jars were capped and headspace was sampled through a butyl rubber septa using a needle and syringe. After each jar was sealed, we removed 1 mL of headspace and replaced it with 1 mL of pure CH_4 to create an ~1% CH_4 headspace concentration. Headspace CH_4 concentration was sampled and measured at 12, 24, and 36 hours using an Agilent 7890 Gas Chromatograph equipped with a Flame Ionization Detector. For each sample taken, an equal amount of room air was injected to equalize pressure and maintain oxic conditions.

Carbon mineralization was determined using 30 g of field moist soil in sterile 460 mL mason jars. The headspace samples were extracted through a butyl rubber septa using a needle and syringe. 20 mL of headspace CO_2 was extracted and measured at 0, 2, 4, and 6 hours using a Q-S151 Infrared Gas Analyzer.

Statistics

Mixed models were conducted in JMP (Version 11.2; SAS, 2014) using distance into the fragment, adjacent land use, and transect as random and fixed effects. A p-value of <0.05 was used to determine statistical significance. Transects were not significantly different than one another and were removed from the model. When a mixed model was not appropriate, given low AIC values, a two-way ANOVA was used to assess the effects of landuse and distance.

Surveys

A survey, available online and physically, was created using Skidmore Qualtrics survey tool. Postcards encouraging people to participate in the survey were distributed on cars and to people. The Director of Wilton Wildlife Preserve & Park and Saratoga PLAN's Stewardship Coordinator were both contacted and asked to advertise the survey in their newsletters. An email was also sent out to the entire community of Skidmore College including students, faculty, and professors asking them to participate in the survey.

The goal of the survey was to determine whether or not the county places both societal and ecological value on our local forests, to assess people's preferences for undeveloped land use within the county, and to analyze community prioritization and concern for the conservation and preservation of these altered natural landscapes. The survey consisted of a series of questions that aimed to gain a more comprehensive understanding of how people use the various land in Saratoga Springs and how it is affecting forest fragmentation locally. Other questions were directed towards alternative properties that suffer from forest fragmentation and how they can be restored in the future.

RESULTS

Atmospheric Deposition

It was hypothesized that a trend of higher deposition for all atmospheric nutrients would be found at the edge of the forest fragment. It was also hypothesized that adjacent land uses would have a significant effect on deposition.

Atmospheric deposition of NH_4^+ was not significantly correlated with distance into the fragment or with land use (Table 1). There was, however, high deposition of NH_4^+ across all land uses and across the transects (Figure 7). Atmospheric deposition of NO_3^- was found to be significantly correlated with distance, but not with land use. This trend was opposite of what was expected, with a larger deposition of NO_3^- at the core of the forest (Figure 8). Though not significant, forests adjacent to roads exhibited a higher deposition of NO_3^- at the edge of the forest (p=0.2284). However, atmospheric deposition of total inorganic nitrogen (TIN), which is a composite of NO_3^- and NH_4^+, was not significantly correlated with land use or with distance (Table 1).

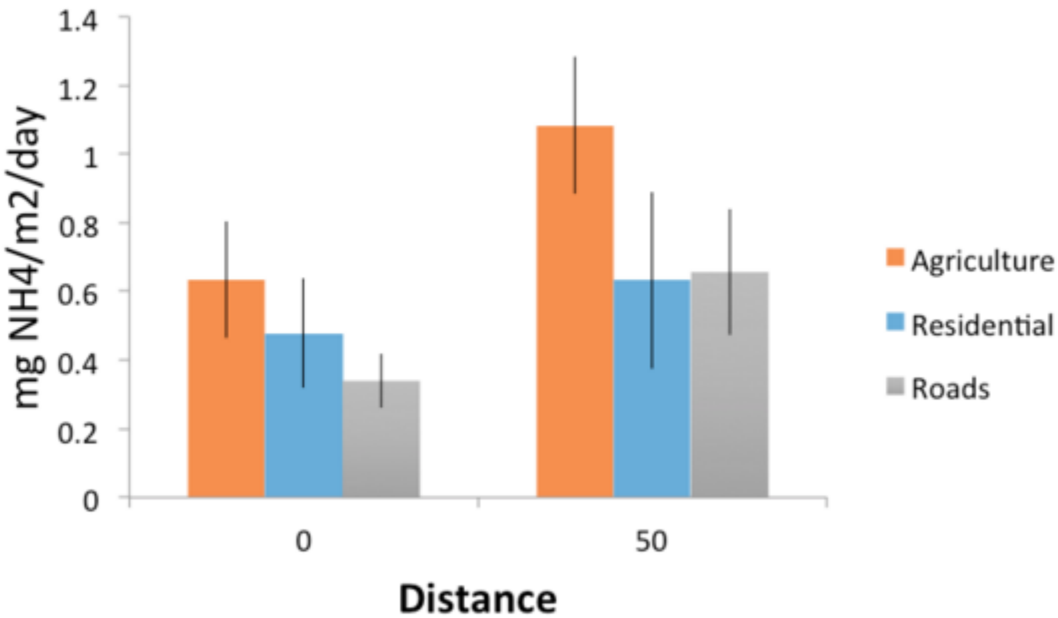

Figure 7. Atmospheric deposition of NH_4^+ (mean±SE), with no significant relationship between deposition and land use (p=0.1149) or deposition and distance (p=0.1117).

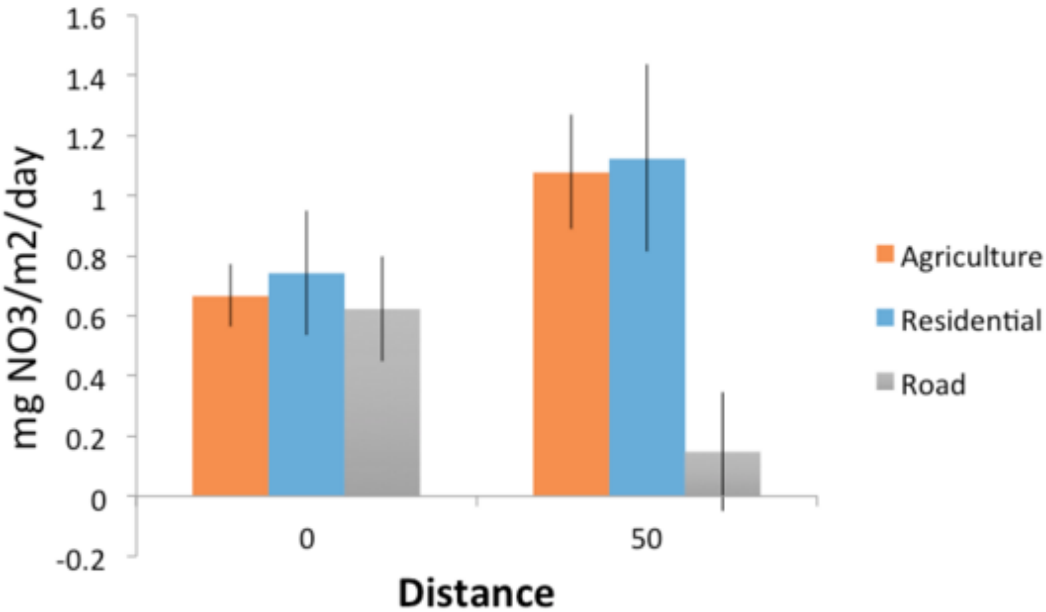

Figure 8. Atmospheric deposition of NO_3^- (mean±SE), with a significant relationship between deposition and distance (p=0.0444) and no significant relationship between deposition and land use (p=0.7197).

Table 2. Results from mixed model and ANOVA tests for atmospheric deposition of nutrients.

Atmospheric Deposition	Land use (Prob>F)	Distance (Prob>F)
NO_3	0.7197	0.0444*
NH_4	0.1149	0.1117
TIN	0.3907	0.0572

Soil Nutrients

It was expected that soil nutrients would be concentrated in the edge of the forest fragment due to input mechanisms, such as atmospheric deposition and runoff. Furthermore, it was hypothesized that the concentrations of nutrients would vary based on the adjacent land use. It was also expected that soil TIN would reflect atmospheric deposition of TIN.

Soil concentrations of PO_4^{3-} were not significantly different at varying distance into a fragment, nor were they different between land uses (Table 3). Soil TIN was found to be significantly different based on land use, but not across distance into the forest, with forests adjacent to residential areas having the highest plant available nitrogen (Figure 9; Table 2). Furthermore, soil NO_3^- was significantly different depending on land use, but not with distance and soil NH_4^+ was no significantly different with land use or with distance (Table 2).

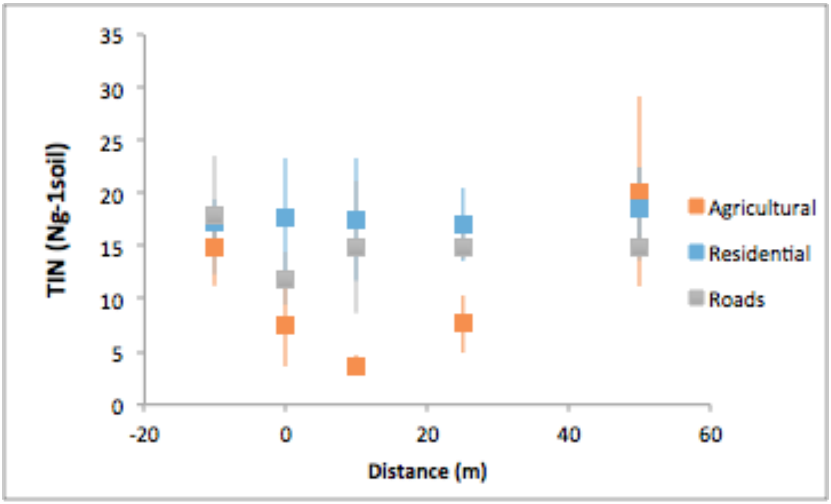

Figure 9. Total inorganic nitrogen (TIN)(mean±SE) found in forest soils adjacent to different land uses (p-value=0.0153). Distance was not a significant predictor of TIN (p-value=0.3928).

Table 3. Results from mixed model and ANOVA tests for soil nutrient metrics.

Soil Nutrient	Land use (Prob>F)	Distance (Prob>F)
NO_3	<0.0001*	0.7234
NH_4	0.0508	0.4412
TIN	0.0153*	0.3928
PO_4	0.631	0.224

Microbial Activity

Based on the expectation that excess nutrients would be most abundant at the forest edge, it was hypothesized that microbial responses would be most altered there, as well. The microbial responses were also expected to vary with land use.

Methane oxidation rates were not significantly different across distance into a fragment, or among land uses (Table 3). However, rates were consistently high in each fragment sampled. Carbon mineralization, a proxy of soil microbial activity, was not significantly predicted by distance, but rates were different in fragments abutting different land uses (Table 4). When next to agriculture and residential areas, fragments exhibited higher rates of carbon mineralization (agriculture: p=0.001; residential: p=0.055; roads: p=0.5659) (Figure 10; Table 4).

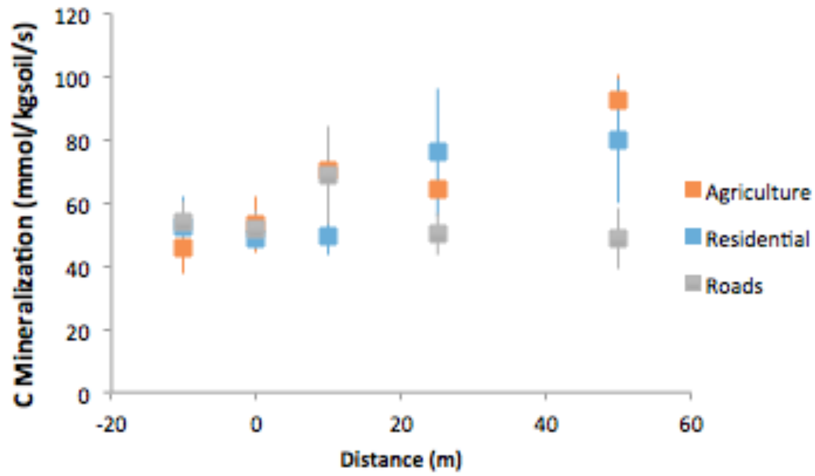

Figure 10. Carbon mineralization (mean±SE) is significantly higher in fragments next to agriculture and residences (agriculture: p=0.001; residential: p=0.055; roads: p=0.5659).

Table 4. Results from mixed model and ANOVA tests for soil microbial activity metrics.

Microbial Activity	Land use (Prob>F)	Distance (Prob>F)
CH_4 Oxidation	0.665	0.608
Carbon Mineralization	See text*	0.115

Surveys

The survey received a total of 178 responses from various members of the Saratoga County community including farmers, doctors, lawyers, professors, students, engineers, chefs, and politicians. Out of the 178 total, the bulk of the responses were from people aged 50-59 (26%) and 40-49 (22%). Almost three quarters of the respondents who took the survey reported as being female, while only 29% reported as being male. In terms of highest education level completed, the majority of the respondents had a Master's Degree (33%) or a Doctorate Degree (22%).

The activities that the community most frequently participates in local forests is hiking/running (85%) and nature appreciation (72%). The majority (68%) of people strongly agree that our local forests, parks, and recreational sites should be fully protected in their current state; they also strongly agree that more of the remaining forest fragments should be protected or preserved.

Saratoga Spa State Park was visited the most frequently with 58 out of the 175 respondents claiming that they have been there more than ten times annually followed by Skidmore's Northwoods and Wilton Wildlife Preserve & Park. The least popular sites were the Woodcock Preserve, Orra Phelps Nature Preserve, and Malta Ecological Park with zero respondents stating that they have been to these sites more than ten times annually.

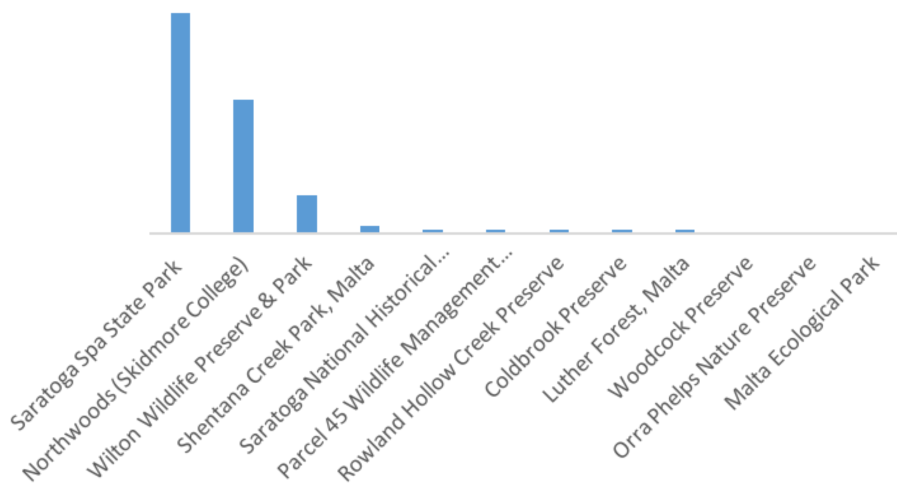

Figure 3: Frequency of visits to the following forests, parks, and recreational sites

Only 13% of the respondents claimed that they do not know what forest fragmentation was, leaving 87% of the total respondents aware of the term. According to the community, the most important service provided by forests was habitat for wildlife with 43%, followed by carbon storage with 18%, and biological diversity with 17% of respondents. Some of the services that this study tested as metrics of fragmentation impacts, like nutrient cycling and pollution control were only viewed as moderately important services by the community (8% and 6%, respectively).

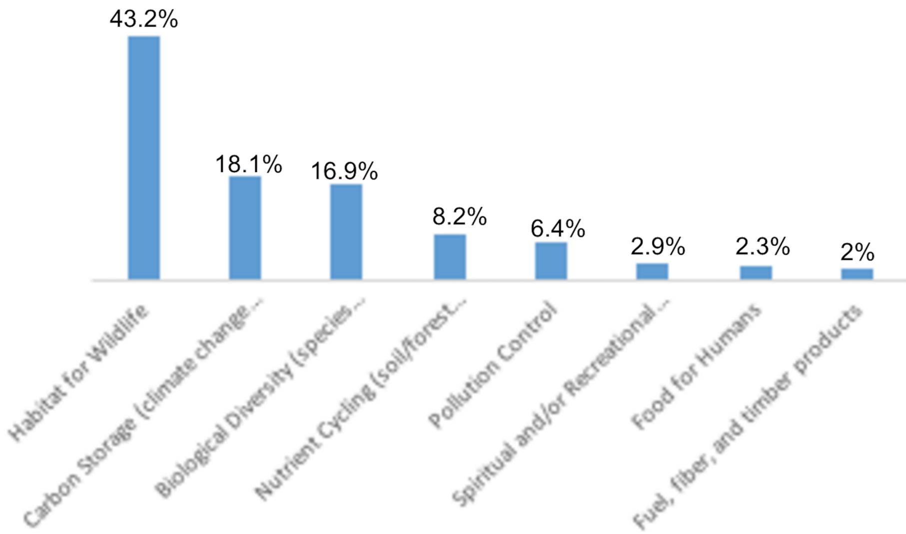

Figure 4: Importance of Ecosystem Services Provided by Forests

In relation for how the population thinks undeveloped land in Saratoga should be used, the most popular response was forest conservation/wildlife (73%), followed by agricultural (13.5%) and recreational (10.5%) land uses. Residential land use received only (3%) of the votes, followed transportation, and, lastly, industrial with no responses.

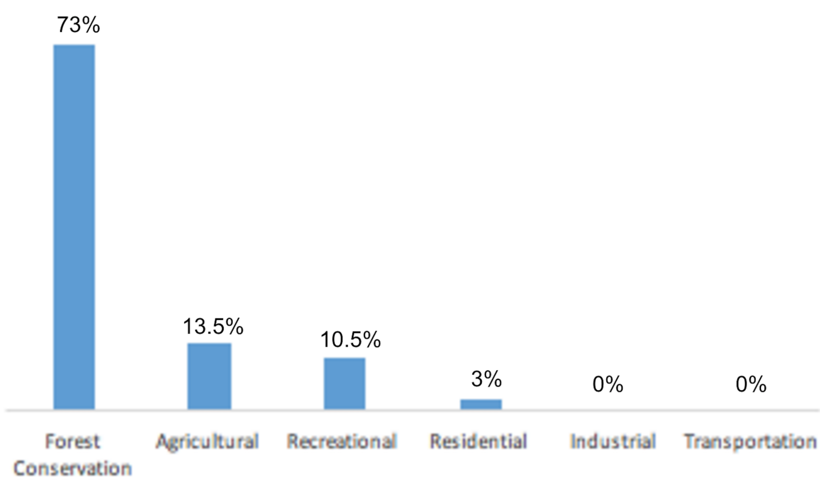

Figure 5: Preferences for undeveloped land use within Saratoga County.

Lastly, the survey assessed societal perceptions of who in the community has the most power to reduce future forest fragmentation and manage existing parcels. The most popular response was the NY State Department of Environmental Conservation (20%) followed by the US Environmental Protection Agency (18.7%) and conservation organizations (16%). None of the respondents felt as though the city and town courts are actually able to influence the reduction of future fragmentation.

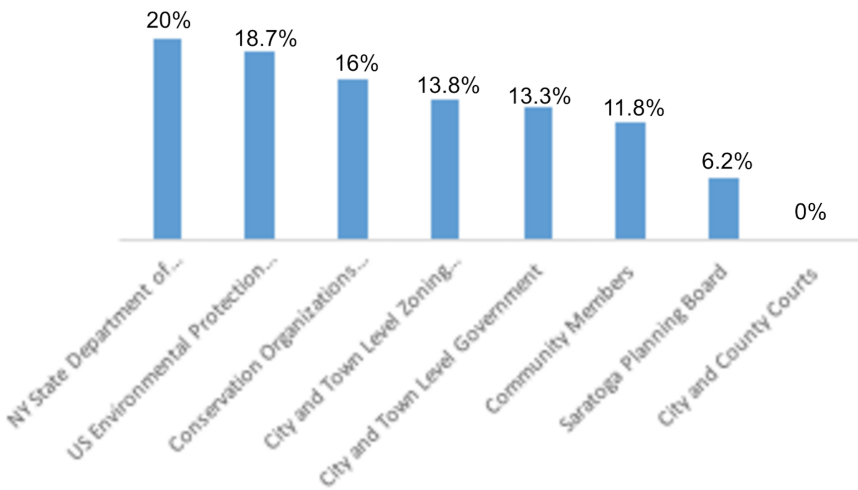

Figure 6: Community perceptions of those in charge of forest fragmentation.

DISCUSSION

Many of the impacts tested in fragments were more likely to vary with land-use than distance. Furthermore, ammonium, which was significantly predicted by distance, was higher in the core. Traditional edge effects that measure changes in vegetation communities and abiotic conditions within forests cite the first 50m as being a crucial buffer zone against outside impacts (Gehlhausen et al. 2000; Dovciak and Brown 2014; Chapman et al. 2015). However, high rates of nitrate and ammonium deposition throughout this study's forest fragments provides an unsettling example of metrics that impact forest fragments in ways that contradict previous preconceptions of fragment edges. Furthermore, the community is concerned about the conservation of local forests, parks, and recreational sites. As mentioned before, the majority of respondents stated that they knew what forest fragmentation was and were worried about the potential loss of important ecosystem services as a result.

Atmospheric Deposition

The two nutrients of concern that were deposited via atmospheric processes were NO_3^- and NH_4^+. Nitrate, an oxidized form of N, is derived from fossil fuel combustion and is a component of acid rain, whereas ammonium, a reduced form of N, is volatilized from fertilizer application and animal operations (Paerl et al. 2002). Deposition of N is known to alter forest functioning, in terms of nutrient cycling and forest biodiversity (Gaudio et al. 2014). Atmospheric deposition of nutrients was expected to be heightened next to certain land uses, especially agriculture and roadways, and at the edge of the forest fragments. However, this trend was not observed.

Overall, deposition of atmospheric NO_3^- was found to be significantly higher at the core of the fragments. However, though not significant, roads followed the opposite, hypothesized trend. The behavior of nutrients from roads seen here is consistent with Bettez et al. (2013), which found that deposition of NO_3^- was highest at the edge of the forest fragment when adjacent to a roadway, likely due to fossil fuel combustion along the roadway. For forests adjacent to residential and agricultural areas, the high deposition at the core of the fragment could be explained by the denser interior tree cover acting as a funnel, despite efforts to place collectors 0.5 m away from tree bases; branches may concentrate deposition down into the collector, resulting in higher values at the forest interior. Another mechanism could be that the interaction with the leaves and branches will alter the amount of NO_3^- and NH_4^+ measured in the throughfall, as ion exchange, leaching, and microbial conversions occurs on leaves and branches (Bettez et al. 2013; Lovett and Lindberg 1984). However, it is important to keep in mind that these findings are from the winter season, where leaves, aside from evergreens, probably provided minimal alteration and exchange. It is also likely that higher deposition was seen at the core due to an influence of prevailing winds, where air masses and precipitation were carried across the fragment in the opposite direction, reaching the edge last.

There was no significant interaction between land use or distance and NH_4^+ deposition, but it was consistently high across all sites. It was expected that since NH_4^+ is mainly derived from fertilizer volatilization there would be an effect of land use, specifically with agricultural and residential. The lack of significance for land use and distance on NH_4^+ deposition may be due to the seasonality, with little volatilization happening with frozen ground and lack of fertilizer applications. However, the consistently high deposition could be due to the high retention rates of NH_4^+ in forest canopies, with a large amount coming from dry deposition (Lovett 1994). Dry deposition of NH_4^+ is thought of as a landscape phenomena, where it originates far away from its point of deposition; the atmospheric deposition of NH_4^+ in these fragments may be the result of the larger landscape, rather than being attributed to the adjacent land use (Lovett 1994).

These rates of deposition may be of concern because when a system has reached N saturation, N will be leached into the greater environment, leading to local and coastal eutrophication, and N_2O emissions will increase, contributing to global warming (Aber et al. 1989; Lawrence et al. 1999). Paerl et al. (2002) noted that anywhere between 10% and 40% of N supplied to coastal systems is from atmospheric origin. Furthermore, Lovett (1994) noted that rainwater in North America should have a pH of 5.6, if it was in equilibrium with atmospheric CO_2, but instead has a pH of 5.0, showing that NO_3^- and sulfate play substantial roles in altering forest functioning through landscape scale deposition. These findings illustrate how the consequences of deposition of nutrients is beyond the influence of just the adjacent landscape, reflecting broader landscape impacts.

Soil Nutrients

Soil nutrients were expected to be more available on the edge of the forest because of the expected increased amount of nutrients from adjacent land uses.

Soil phosphate, found in fertilizers and biosolids, was not significantly different across land-uses or distance. This is most likely due to the season in which data was collected. During the winter months, no farming or gardening activities were taking place that would account for inputs of PO_4^{3-}; per gram of soil, across the sites, the concentrations of phosphate ranged from 0.01 to 6 μg. Therefore, the lack of significance different across both distance and land-use was not surprising.

It was expected that soil N would reflect atmospheric N deposition. Total inorganic N (TIN) in the soil, the composite of soil NO_3^- and NH_4^+, were found to be significantly predicted by land use, but not by distance. Additionally, trends of soil NO_3^- and NH_4^+ with land use and distance reflected the same pattern seen with TIN. It was expected and found that different land uses result in differing amounts of TIN, as N inputs are mainly derived from fertilizer application. This effect might have been suppressed because data was gathered in the winter season when there is no fertilizer application. Furthermore, the insignificance of distance and TIN shows that the effect of the adjacent land use is persisting more than 50 m into the forest.

There are many negative effects that excess N loading can have on these fragments and on a larger scale. One implication of increased N loading in these fragments is the potential for coastal eutrophication, where high levels of N loading within the fragment, especially from an atmospheric origin, will cause NO_3^- to be leached (Paerl et al. 2002; Lawrence et al. 1999). As a result of high nitrate and ammonium inputs within forest fragments, it is probable that these can drive the system towards N saturation, whereby leaching becomes a concern. Another implication of increased N deposition is an increase in plant available nitrogen, which alters the nutrient dynamics and vegetation communities in the systems (Malmivaara-Lamsa et al. 2008). These alterations in deposition rates and available N are further exacerbated by climate (Gaudio et al. 2014).

Microbial Activity

Increases in nitrogen can have negative implications on soil microbial functioning (Bedard and Knowles 1989; Malmivaara-Lamsa et al 2008). Based on the expectations that these excess nutrients would be most abundant along the edge of fragments and at different concentrations based on land use, altered microbial responses were expected to be greatest at fragment edges.

Methane uptake by methanotrophs is an important ecosystem service that aids in greenhouse gas mitigation and climate change control. However, studies have found that excess concentrations of nitrogen, especially NH_4^+, limits the microbes' ability to process methane (Bedard and Knowles 1989). It is surprising, therefore, that despite the high levels of ammonium across the fragments, the methane uptake rates were also consistently high across all fragments and comparable to the rates exhibited at the powerlines. This suggests that the methanotrophs are benefitting from the current concentration of NH_4^+ present in the soils. Bodelier and Laanbroek (2004) cite several mechanisms for increases in methane uptake with high concentrations of ammonium. One explanation is that ammonium tolerant methanotrophs may be dominant in these fragments due to shifts overtime in response to land use impacts (Bodelier and Laanbroek 2004). An important thing to consider is that nitrogen, specifically minimal concentrations of NH_4^+, is necessary for the process of methane oxidation. The second explanation is that the inputs of ammonium in these fragments are stimulating methane uptake rates more than depressing them (Bedard and Knowles 1989; Bodelier and Laanbroek 2004). Additional information is needed about the nitrogen limitation within these sites, as well as the specific microbial groups present in each fragment to fully understand which mechanism is most influencing methane oxidation. Regardless of why this is occurring, it is clear that the fragments, as they exist, are continuing to process methane and perform an important ecosystem service.

Carbon mineralization was expected to be highest at the edge where increased nutrients were available for microbial activity. Our findings illustrated that fragments next to residential and agricultural areas have significantly higher rates of respiration throughout the 50m from the edge when compared to powerlines and roads, which was not a significant land use factor; these rates match the findings that available nitrogen in the soil is significant across land-use rather than distance. Past literature has found that carbon mineralization varies in response to N inputs (Nadelhoffer et al. 1999; Bowden et al. 2004). However, in a study of nitrogen inputs in hardwood forests, Bowden et al. (2004) found that respiration rates increased during the first few years after N additions. Furthermore, at relatively low nitrogen input sites high rates of microbial respiration are sustained for as much as a decade (Bowden et al. 2004). It is evident that more needs to be known on the history of these fragments and over time to understand their functional responses to inputs.

The findings of nitrogen deposition are based on winter months where inputs from inactive agricultural fields would be due to nitrogen off-gassing. Furthermore, inputs from residential areas may also be low since no fertilizers or gardening occurs. Therefore, mineralization may be sustained during these seasons where minimal, beneficial concentrations of nitrogen are present. Roads adjacent to fragments did not have any significant effect on respiration rates. This may be due to variations in traffic along roads selected. However, we cannot control for nearby highways that may have accounted for variations in nutrient deposition and therefore, soil carbon mineralization. Furthermore, it is important to consider that, although rates of respiration are still high within certain fragments, these rates may be significantly different than if the forest was contiguous (Fannin and Bertrand 2016).

Social Values

In terms of the relative importance of ecosystem services provided by forests, the community of Saratoga County placed great emphasis on habitat for wildlife, carbon storage, and the protection of biological diversity. Metrics of adjacent land use impacts used in this study, such as pollution control and nutrient cycling, were only deemed as moderately important ecosystem services by the county. The community may not understand the implications that fragmentation has on the services that they deem most important, as well as ones viewed as relatively unimportant. Interestingly, more anthropogenic ecosystem services that are heavily subsidized by the government, such as food for humans, fuel, fiber, and timber products, were valued the least by the community. There is a possibility for bias in the answers because only eight services were provided as answer options, rather than leaving space to list which service they found to be most important.

The county of Saratoga drastically prefers for their undeveloped land to be utilized for things like forest conservation, agriculture, and recreation. Although land uses like industry, transportation, and residences are vastly important to society because they provide shelter and various other resources, the community does not want their land to be developed for these purposes. It was of particular interest that the community preferred land use types that seem to get the least amount of financial support within the county and viewed land uses that often receive government subsidies as undesirable, such as industry and transportation. Perhaps, by informing the respondents before taking the survey that it was meant to assess community prioritization for conservation, it potentially swayed people's choices for the question about undeveloped land use.

Based on our survey findings, perceptions of power to reduce fragmentation were fairly evenly distributed across all governmental levels. Although there is definitely community support for the conservation and preservation of these local forests, the public is generally uncertain about who has the ability to manage them from being fragmented. This could partially explain why fragmentation of forests within the county remains a pressing issue and continues to occur. The threats to fragments are growing, especially with the rise of population and an increase of development within the county (C-CAP Atlas). Additional semi-structured interviews with some government officials and local conservation organizations are necessary to further evaluate their perceptions of community motivation to become involved in conservation efforts.

CONCLUSIONS

These results have implications for the management and further preservation of forest fragments in developed landscapes. Although many studies have assessed forest-wide nitrogen inputs and subsequent effects, few have considered the implications of these within a fragmented system where nutrient inputs are further exacerbated by traditional edge effects (Nadelhoffer et al. 1999; Bowden et al. 2004).

The fragment-wide impacts to N availability and subsequent alterations to soil microbial communities are a result of the adjacent landscape, but also in relation to the landscape in which these fragments reside. Atmospheric deposition of ammonium and nitrate is the primary mechanism N entering these systems (Bettez et al. 2013). The source of the N deposition can be nearby, like an abutting agricultural field, or it can be a large highway or factory miles away (Gaudio et al. 2014). While some of the impacts in the fragments were significantly linked with land use, additional sources could also be influencing the health and functioning of the forests.

Though forest fragments are impacted by the adjacent land use and, ultimately, the larger landscape, humans still rely on them for their traditional ecosystem services, such as carbon sequestration, recreation, and habitat (Sugden et al. 2008; Chazdon 2008). These forests fragments also serve many other roles, such as methane sequestration, nutrient cycling, and pollutant filtration, as shown by this study's findings. It was found that fragments are still able to sequester methane, which, aside from source reduction, is an important regulator of the amount of this potent greenhouse gas. Furthermore, it was found that, dependent on land use, fragments were able to cycle nutrients, such as N and P, which would otherwise degrade ecosystems if leached (Paerl et al. 2002; Lawrence et al. 1999). This was shown through microbial respiration rates. So while fragmentation and adjacent land uses alter the microbial communities, some integrity is upheld. Collectively, these results show that, while forest fragment functioning is influenced by adjacent land use, they are still able to uphold important ecosystem services. Recognition of these services and preservation of fragments will become increasingly important in the face of climate change and urbanization.

There is public value and ecological support for these local fragments. The community of Saratoga has emphasized their desires for the conservation of undeveloped forested land within the county. People are aware that forest fragmentation is occurring and appreciate natural landscapes, however they remain uninformed about who has the ability to manage existing parcels and prevent future fragmentation. Most likely, this is due to a lack of education about the impact on forest fragmentation of development in the landscape. Although local forest conservation was the main preference for future land use changes within the county, we continue to see an increase in development coinciding with a decrease in forested, agricultural, and recreational lands.

Based on the above conclusions, it is clear that additional considerations are necessary for conserving and protecting these forest fragments. Impacts from land uses, such as nutrient additions, are powerful and persistent throughout fragments. More importantly, the inputs occur on a local and landscape level. While gaining community support for forest conservation is necessary, the concerned community members of Saratoga do not feel that they have much agency or awareness of their role in the conservation process. This group of stakeholders may be essential within the social landscape for creating a plan that further connects and maintains these fragments in the face of increasing development. Ultimately, these fragments are impacted from both the social and natural landscape and conservation plans should address the issues on a local, regional, and global scale.

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