Edge Effects and Nitrogen Cycling along Roads

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ABSTRACT

As humans mobilize more nitrogen, it is causing a number of changes in the environment. Nitrogen saturation has been found to have certain effects on forests. Increased traffic on roads was studied for possible edge effects in nearby forests using nitrogen cycling as an indicator of how much of an effect road my have. The study was conducted using 5 sites on Route 28 and Route 151 in Mashpee, MA and Falmouth, MA. Some patterns in individual species was measured, but was not significant. No patterns in soil respiration were found. The ammonia and net nitrogen mineralization rate were greater within the first 20m from the road while inconsistent nitrate and nitrification was measured at any distance from the road. The C:N ratio increased within the first 20m from 31.04 to 39.79 before plateauing around 39, also indicating the increased nitrogen near the road.

Key Words: nitrogen saturation, edge effect, roads, local pollution.

INTRODUCTION

Nitrogen fixation and mobilization by humans has become one of a number of growing environmental issues today. Humans mobilize more nitrogen today through burning fossil fuels, fertilizer production and growing legumes than natural systems (Galloway 1996). As nitrogen moves and accumulates in the biosphere, it causes changes in the ecosystem. Aber et al. (1989) proposed that as forest ecosystems were pushed toward nitrogen saturation through fertilization, NH4 and NO3 increased in soils as well as rates of mineralization and nitrification. Because NO3 is very labile and water soluble, it then leaches out of the forest into groundwater and eventually into rivers, lakes and estuaries where it can cause eutrophication. Wedin and Tilman (1996) found that long-term nitrogen fertilization in grasslands could even cause a decrease in species diversity and also found a lower C:N ratio in plant biomass, something also mentioned in Aber et al. (1989). Lastly, soil respiration can be suppressed in areas with nitrogen fertilization because plants reduce the amount of sugars they secrete to feed soil microbes and mycorrhizae, which in turn reduces populations of these microbes (Aber et al. 1989; Bowden et al. 2004).

While long-distance atmospheric nitrogen deposition has not drastically changed in the past century (Figure 1, Bowen & Valiela 2001), local sources can also increase nitrogen loads in the forest. Cars act as a source of many different compounds and pollutants, one of which is fixed nitrogen in the form of NO2 and NH4 (Perrino et al. 2002). NO2 gas can travel long distances and deposit into ecosystems as NO3 in rainfall while NH4 does not travel very far (Kirchner et al. 2005). At the same time, forest edges, as shown by Weathers et al. (2001), can capture and concentrate pollutants and compounds from the air, reducing the amount of these compounds that reach the interior of the forest.

There are two aspects of this edge effect that I propose to study using nitrogen: the magnitude or gradient of the effect and the long-term change. While not to nearly the same degree as some of the previous studies on nitrogen fertilization and saturation, roadside forests have the potential to be loaded with nitrogen in excess of the background deposition rate, which would push the system towards nitrogen saturation. If there is nitrogen saturation along roadsides, I expect to find results similar to those found by Aber et al. (1989), Wedin & Tilman (1996) and Bowden et al. (2004): lower species diversity, increased nitrogen cycling, lower C:N ratio and lower soil respiration. Additionally, I expect tree wood to record the C:N ratio over time and for it to decrease near the road as traffic increases.

METHODS

Site and Transect Selection

Five sites along two busy roads in Falmouth, MA and Mashpee, MA were chosen for study. Sites 1 and 2 were on the west side of Route 28 near the Falmouth/Mashpee town line while sites 3, 4 and 5 were on the north side of Route 151 between Sam Turner Road and Sandwich Road (Figure 3). At each site one 100m transect was selected starting from the first forest vegetation on the roadside (i.e. Not the grassy strip). Each transect had 6 sample points determined by distance from the edge at 0m, 5m, 10m, 20m, 50m and 100m. All field work was completed in mid-November 2007.

Vegetation

I characterized the vegetation at each site to determine if the sites could be called replicates, as they were intended. I looked at both tree species and understory vegetation. For trees, I measured and recorded the diameter at breast height (DBH) of trees greater than 5cm in diameter within 1m of the transect. This represents a 200m^2 sample area of forest at each site. At each of the sample points mentioned above, I recorded understory plant species and their percent cover within a 1m radius. The 0m sample point was actually centered at 1m to get a full circle within the forest.

Soils

Soil was collected on two days, 3 days apart. At each sample point, 3 soil cores were taken using a tulip bulb planter and combined into one composite sample to average out soil heterogeneity. Each composite soil sample was then brought back to the lab for a suite of nutrient analyses. NH4 and NO3 were extracted from 15g of wet soil using KCl over 24 hours and NH4 was measured using a modification of Solarzano's phenol-hypochlorite method while NO3 was measured on a Lachat flow injection analyzer. Approximately 10g of fresh soil was dried at 60°C to calculate moisture content and later samples from 0m, 5m, 20m and 100m were analyzed for carbon and nitrogen content using a PerkinElmer Series II CHNS/O Analyzer.

Sixty grams of fresh soil from all soil composites was also incubated for two weeks[1] in 4cm diameter PVC tubes covered loosely in tin foil. Soil respiration was measured on a LiCor 6200 after 2 days and at the end of the incubation. Because the soils appeared dried out, I added 5 mL of DI to each tube on November 26 (about 1 week) and covered tightly with parafilm for the remainder of the incubation. At the end of the incubation, the soil was analyzed for NH4 and NO3 using the same methods as before. From this, I calculated net nitrogen mineralization and net nitrification.

Change Over Time

Presuming that tree wood would be a record of C:N ratio over time, I took 2 tree cores at each site; one from a Quercus coccinea nearest to each end of the transect (referred to as "near" and "far" trees for their relation to the road). I sampled 3 annual rings of growth every 15 years from the present to create a history of C:N ratio. This was compared to traffic counts on Route 28 and Route 151 from the Cape Cod Commission.

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[1] Sites 1, 2 and 3 for 17 days and Sites 4 and 5 for 14 days. They differ due to different collection days but the same end date.

RESULTS

Vegetation.

The five transects contained a similar composition of 4 common tree species greater than 5 cm in diameter (Figure 4) with several rarer species found only at one or two sites. The two most common species were *Pinus rigida* and *Quercus coccinea* accounting for between 63% and 87% of the basal area of all trees at all sites. Additionally, a plot of tree diameter at breast height showed little pattern of where individual species grew in relation to the road (Figure 5). The data shows a higher tree density near the road (Figure 6), but this is most likely an artifact of a 7-8 meter wide dirt road towards the back of the forest at sites 3, 4 and 5.

The study of understory species cover also showed that the 5 sites had similar composition (Figure 7). The four most common species; *Gaultheria procumbens*, *Gaylussacia baccata*, *Pteridium aquilina* and *Vaccinium angustifolium* accounted for over ⅔ of the understory species cover found at any site. Other species found were also *Vibernum nudum*, Quercus seedlings and *Pinus* seedlings. The variation in these other species accounts for some of the larger variation in the overall species cover. Of the 4 most common species, *G. procumbens* and *G. baccata* showed slight trends with distance from the road while *P. aquilina* and *V. angustifolium* did not show any trend (Figure 8). *G. procumbens* showed the strongest trend (R^2 = 0.8504)with distance from the road decreasing from 13% cover at 0m to 2.4% at 50m before increasing slightly to 5% cover at 100m. *G. baccata* showed a slight upward trend away from the road, increasing from a mean cover of 9.2% at 0m from the road to 23% at 100m from the road, but it is not a strong trend (R^2 = 0.3863). Average species richness declines slightly with distance from the road with about 1 more species at 0m than at 100m (Figure 9).

Soil Analyses

Some soil analyses showed strong trends while others did not show any at all. Soil respiration showed no overall trend with distance from the road (Figure 10, Figure 11). Some measurements that were lower early in the incubation doubled or tripled after 2 weeks while others dropped dramatically during the incubation. Extractable ammonia showed a decreasing trend away from the road (Figure 12). Twice as much NH4 was found in soils near the road than at 100m. While extremely variable at 0m, the average net N mineralization decreased within the first 20m from 17.49µg N/g dry soil/day to 8.76µg N/g dry soil/day and then was fairly consistent from 20m to 100m (Figure 13). Nitrate and Nitrification were found only at a few sample points overall, but nitrate was only found within the first 10m of the road (Figure 14). Nitrification was low at nearly every point where it occurred, ranging from 0.01µg N/g dry soil/day to 0.02µg N/g dry soil/day. 0m and 10m both had larger net nitrification/denitrification values but they represent finding nitrate at only one site either in the initial soil or the post-incubation soil. The average carbon to nitrogen molar ratio across the five sites increased in the first 20m from 31.04 to 39.79 (Figure 15). The 20m and 100m averages were similar, though the 100m average was slightly lower at 38.66.

Change Over Time

In tree cores, I presumed that I would find a record of the woody C:N ratio over time that I could compare with traffic trends and perhaps find a correlation between the two. The average C:N ratio over all 5 sites both near and far trees declines over time

(Figure 16). Until the last sample year, the trees near the road had a lower C:N ratio by 100 or more. There is a particularly large drop in the last sample year where the far trees have a much lower C:N ratio than the near trees. During this entire time, long-distance deposition has minimally increased and even steadied in the past 20 years (Figure 2). In the past 20 years, the traffic increased by 30% on Route 28 and almost doubled on Route 151 (Figure 16).

DISCUSSION

Vegetation

Overall, the vegetation showed little difference between sites and little significant difference over distance from the road, generally supporting my assertion that the five sites are replicates. It is important to characterize the vegetation and determine that it is consistent from site to site because of the effects that even the herbaceous layer can have on nutrient cycling in a forest (Gilliam 2007). The 5 sites have generally the same mix of tree species based on basal area and the same mix of understory species in roughly the same proportions at each site (Figure 4, Figure 7). *P. rigida* varies the most in trees while *G. baccata* tended to vary the most in the understory, but both were still prevalent at each site. I believe that the sites are similar enough to call them replicate sites, allowing me to average them together to determine edge effects.

With the five sites established as replicates, I combined the DBH data with distance and found no pattern in either tree size or species location with distance from the road indicating that there is not enough of an edge effect to affect where trees grow or how large they have grown (Figure 5). Additionally, there were no significant trends in individual understory species, though *G. procumbens* and *G. baccata* showed slight trends with distance from the road (Figure 8). The trends in these two species could be related to the edge, but if it is connected with the nitrogen cycling is unknown. The increased species richness near the road, though small, does not support my hypothesis of increased nitrogen loading (Figure 9). Increased nitrogen has been shown to decrease diversity, not increase it (Wedin & Tilman 1996). Other factors like light and the chronic disturbance of the grassy area of the road may be overwhelming the effect of nitrogen loading. Light and disturbance may also have some effect on *G. procumbens* and *G. baccata*, accounting for their decreasing and increasing trends with distance from the road.

Soil Analyses

The soil analyses either supported my hypothesis or were inconclusive. The lack of any rhyme or reason to the soil respiration is puzzling (Figure 10, Figure 11). Two weeks apart, soils doubled or cut in half their respiration rate with no apparent pattern. Handling of the soils could be a partial cause, but great care was taken not to disturb the soil when connecting it to the LiCor 6200. From what I personally observed, but did not quantify, chronic sanding and road salting in the winter may affect the first couple meters of soil along the forest edge.

The increase in NH4 and net mineralization do support my hypothesis of increased nitrogen loading (Figure 12, Figure 13). Increased rates of mineralization converting organic nitrogen into NH4 and NO3 are apparent in the first 20m. The very edge at 0m is likely highly variable because of the previously mentioned observed differences in soil composition. The lack of consistent NO3 or nitrification across sites indicates that there may not be as much nitrogen entering the system as I had believed (Figure 14). Nitrogen loading could still be occurring, but the effect is not strong enough to trigger nitrification across all sites.

The increasing and then consistent C:N ratio is the most encouraging data in regards to nitrogen loading near the road. The logarithmic increase and then plateau of the C:N ratio in the first 20m indicates how confined the effect is to the first 20m of forest (Figure 15). As more nitrogen is deposited in the soil, the carbon content doesn't change to the same degree, decreasing the ratio. However, with distance from the road, less nitrogen is deposited further into the forest, decreasing the amount of nitrogen while carbon does not change, increasing the ratio. At about 20m, the C:N ratio stabilizes near 39, indicating that the local source of nitrogen loading (cars) is no longer affecting the forest.

Change Over Time

My study of the tree cores turned up some interesting results. The C:N ratio does decrease with time, indicating the proportional increase in nitrogen that I expected (Figure 16). For 3 of the 4 time points, the average C:N ratio near the road is lower than in the far trees, showing the increased nitrogen near the road and supporting my hypothesis. Unexpectedly, both near and far trees decrease with time, especially in the past 15 years. Long-distance atmospheric nitrogen deposition in the area has been relatively constant or decreasing during that time period (Figure 1), but traffic has been increasing during that time period (Figure 16). It is unclear if the decrease over time is entirely because of the increase in traffic, though they correlate well. Perhaps trees absorb the nitrogen more readily than the soils, showing the effect first. Another possibility is that tree wood generally just loses nitrogen over time, increasing the C:N ratio in the oldest wood. This could be part of the explanation because of the similar decline in trees both near and far from the road.

It appears that forest edges along roads are being pushed towards nitrogen saturation but are not at the saturation point yet. The edge effect also appears to be concentrated in the first 20m from the forest edge.

ACKNOWLEDGEMENTS

This work would not have been possible without either of my advisors: Dr. Chris Neill, who was invaluable in both the field and analysis, and Neil Bettez, who is working on this topic as well. Thank you as well to all the TAs in the program who assisted day and night in the lab.

WORKS CITED

Aber, J.D., Nadelhoffer, K.J., Steudler, P., Melillo, J.M., (1989). Nitrogen saturation in northern forest ecosystems—hypotheses and implications. *BioScience* 39, 378-386.

Bowden, R. D., Davidson, E., Savage, K., Arabia, C., Steudler, P. (2004). Chronic nitrogen additions reduce total soil respiration and microbial respiration in temperate forest soils at the Harvard Forest. *Forest Ecology and Management* 196, 43–56.

Bowen J. L. and Valiela, I. (2001). The ecological effects of urbanization of coastal watersheds: historical increases in nitrogen loads and eutrophication of Waquoit Bay estuaries. *Can. J. Fish. Aquat. Sci.* 58, 1489–1500

Galloway J. N. (1996). Anthropogenic Mobilization of Sulphur and Nitrogen: Immediate and Delayed Consequences. *Annual Review of Energy and the Environment* 21, 261–92.

Gilliam, F. S. (2007). The Ecological Significance of the Herbaceous Layer in Temperate Forest Ecosystems. *Bioscience* 57 (10), 845-858.

Kirchner, M., Jakobi, G., Felcht, E., Bernhardt, M., & Fischer, A. (2005). Elevated NH3 and NO2 air concentrations and nitrogen deposition rates in the vicinity of a highway in Southern Bavaria. *Atmospheric Environment*, 39(25): 4531-4542.

Perrino, C., Catrambone, M., Di Menno Di Bucchianico, A., Allegrini, I. (2002). Gaseous ammonia in the urban area of Rome,Italy and its relationship with traffic emissions. *Atmospheric Environment* 36, 5385–5394.

Weathers, K. C., Cadenasso, M. L., & Pickett, S. T. (2001). Forest edges as nutrient and pollutant concentrators: Potential synergisms between fragmentation, forest canopies, and the atmosphere. *Conservation Biology*, 15(6), 1506-1514.

Wedin, D. A., and Tilman, D. (1996). Influence of Nitrogen Loading and Species Composition on the Carbon Balance of Grasslands. *Science* 274, 1720-1723.

APPENDIX

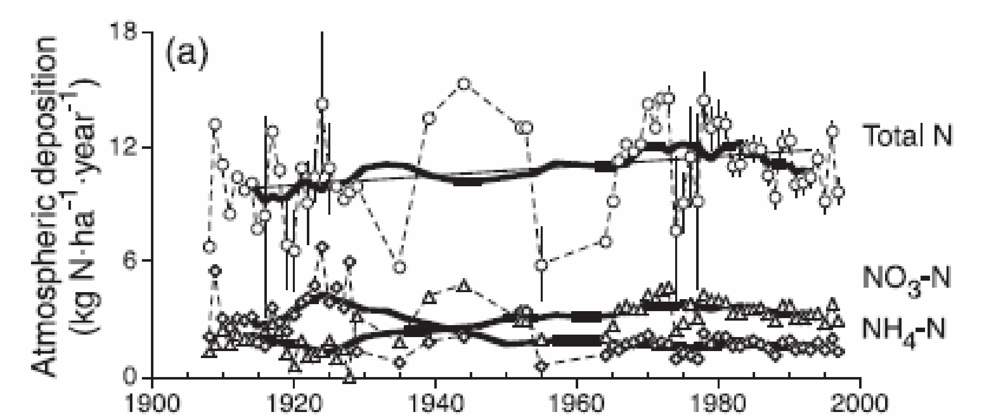

Figure 1. The long-term trend of atmospheric nitrogen deposition on Cape Cod is slightly increasing, but constant or decreasing in the past 20 years (Bowen & Valiela, 2001)

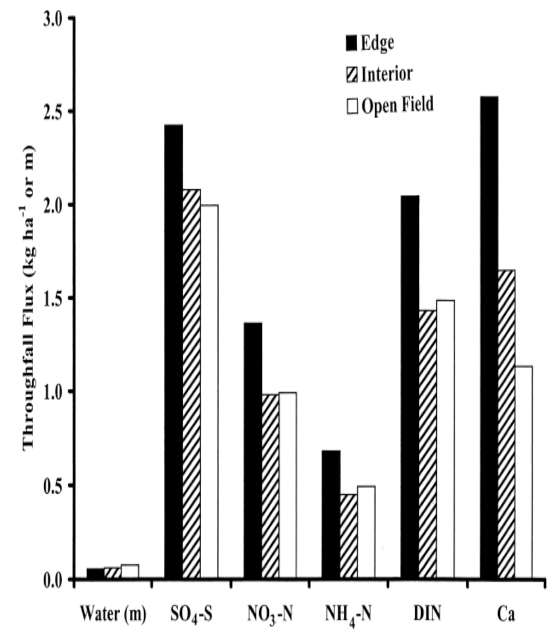

Figure 1. Average throughfall fluxes of sulfate-sulfur (SO_4^{-}-S), nitrate-nitrogen (NO_3^{-}-N), ammonium nitrogen (NH_4^{+}-N), dissolved inorganic nitrogen (DIN), and calcium (Ca^{++}) for two deciduous-forest edges and interior zones. Also shown is the bulk rain deposition in an adjacent field. Total fluxes are kilograms per hectare per season (measured from July to September 1995), and water is in meters calculated from volume measurements divided by sample area.

Figure 2. The edges of forests along an agricultural area concentrate and capture more deposition through throughfall than either the open field or the interior of the forest (Weathers et al. 2001).

Figure 3. I sampled from 5 sites on Cape Cod. Going counter clockwise: Site 1, 2, 3, 4 and 5. Site 1 and 2 are on Route 28 while sites 3, 4 and 5 are on Route 151. Photo courtesy of Google Earth.

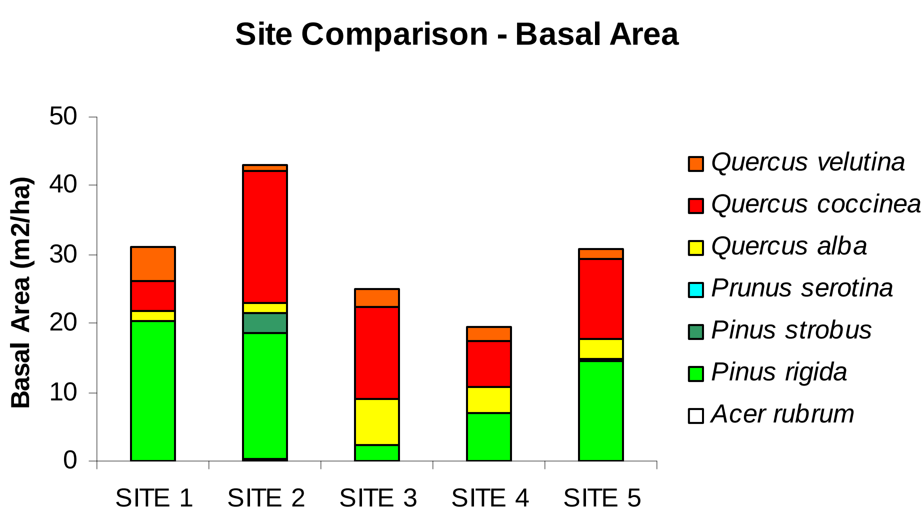

Figure 4. A comparison of tree species basal areas across the 5 sites I sampled. They all contain a mixture of *P. rigida* and various *Quercus* species with a few other rarer species. *P. rigida* varied the most between sites and *Q. coccinea* was the most common *Quercus* species.

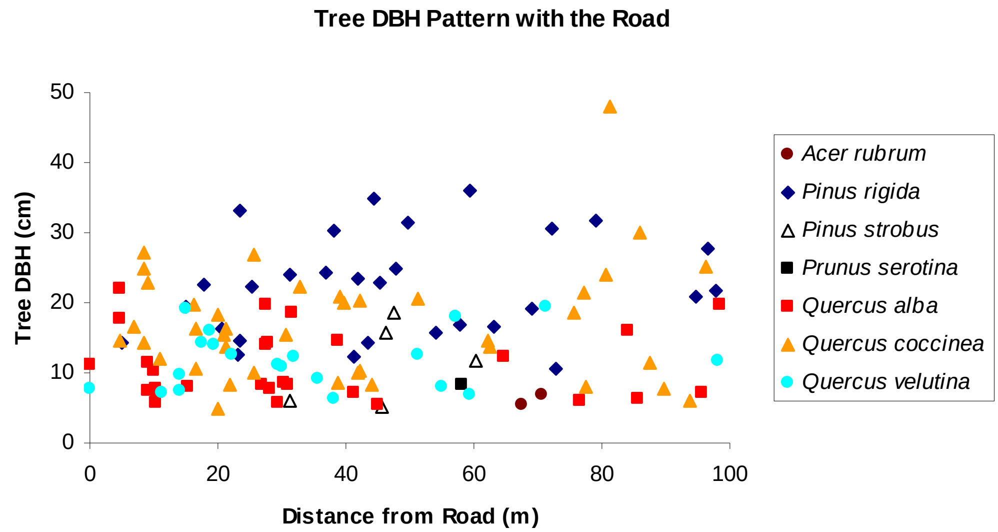

Figure 5. Overall there appears to be no pattern between either the size of trees or the species of tree with distance from the road. The most abundant species (*P. rigida*, *Q. alba*, *Q. coccinea* and *Q. velutina*) show no preference for close or far from the road.

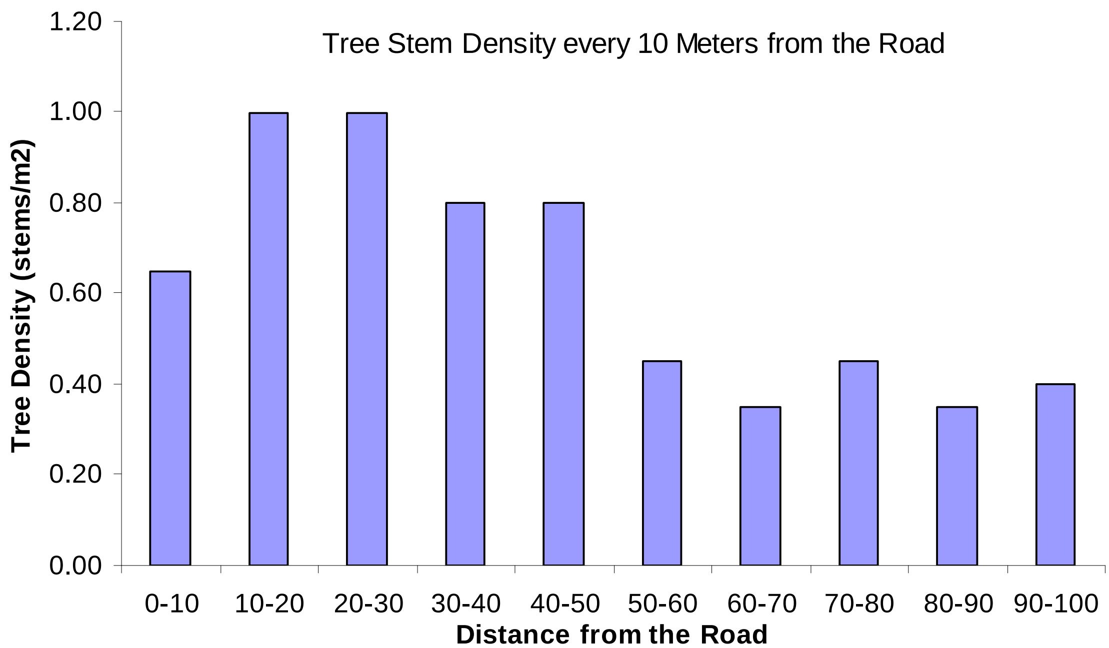

Figure 6. Stem density appears to decline with distance from the road, but this is most likely an artifact of a small dirt road (7-8 meters across) at sites 3, 4 and 5. Nothing conclusive can be said about tree density because of this.

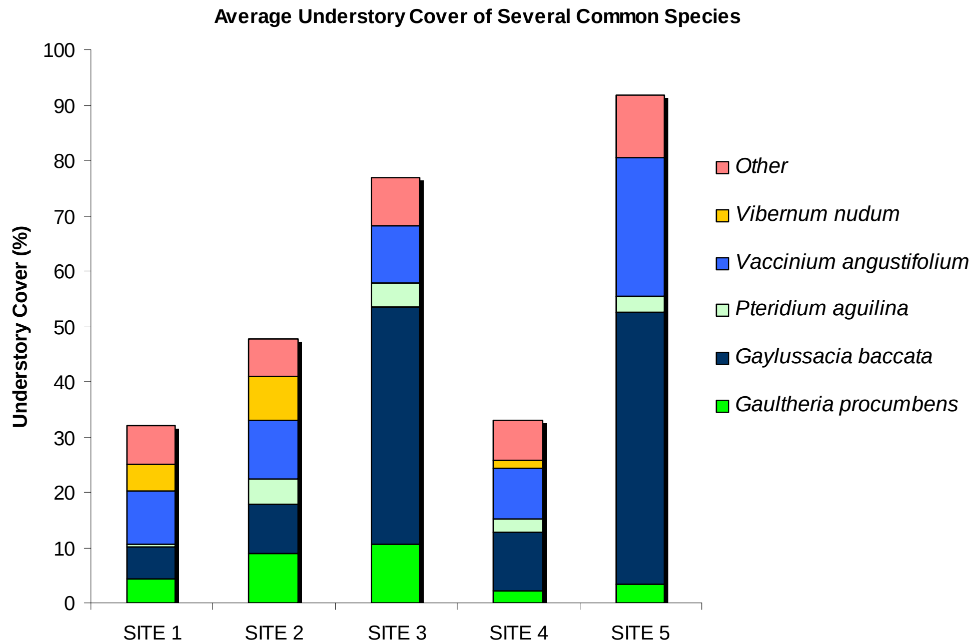

Figure 7. A comparison of understory plant species across the 5 sites I sampled. Species are averaged across the whole site to see the picture of the forest as a whole.

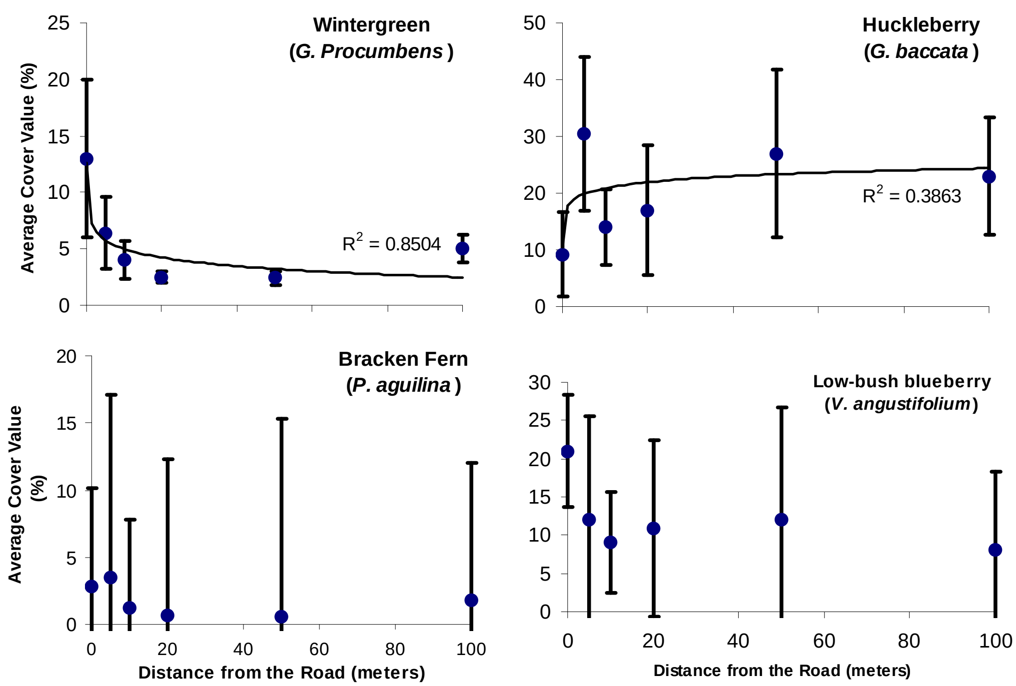

Figure 8. Four of the most common individual species and their average cover value across the sites at each distance from the road. *G. procumbens* and *G. baccata* show weak trends with distance ($p>0.05$) while *P. aguilina* and *V. angustifolium* varied wildly to the point that no pattern can be distinguished.

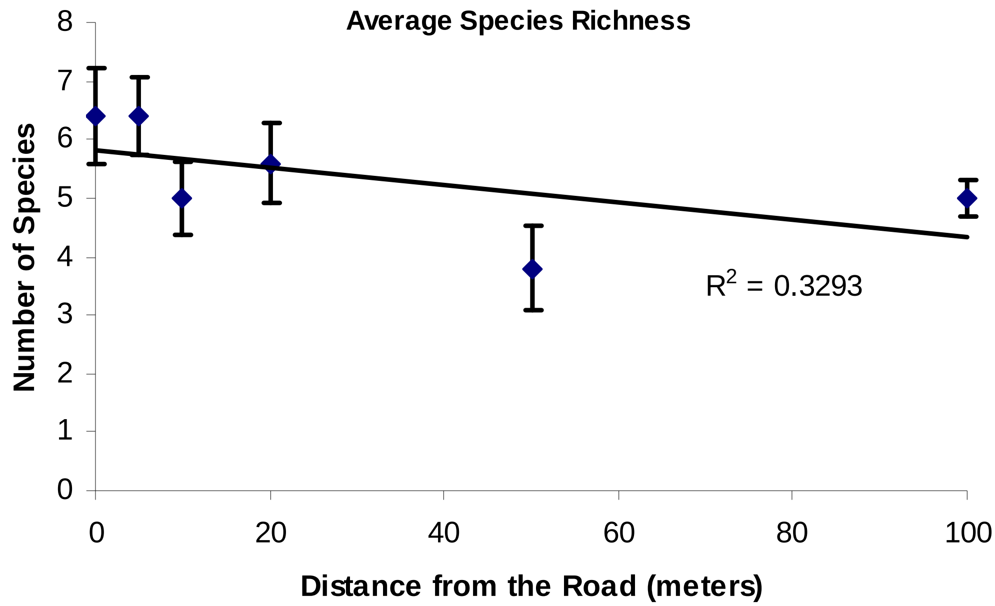

Figure 9. Average species richness across the 5 sites decreased slightly away from the road.

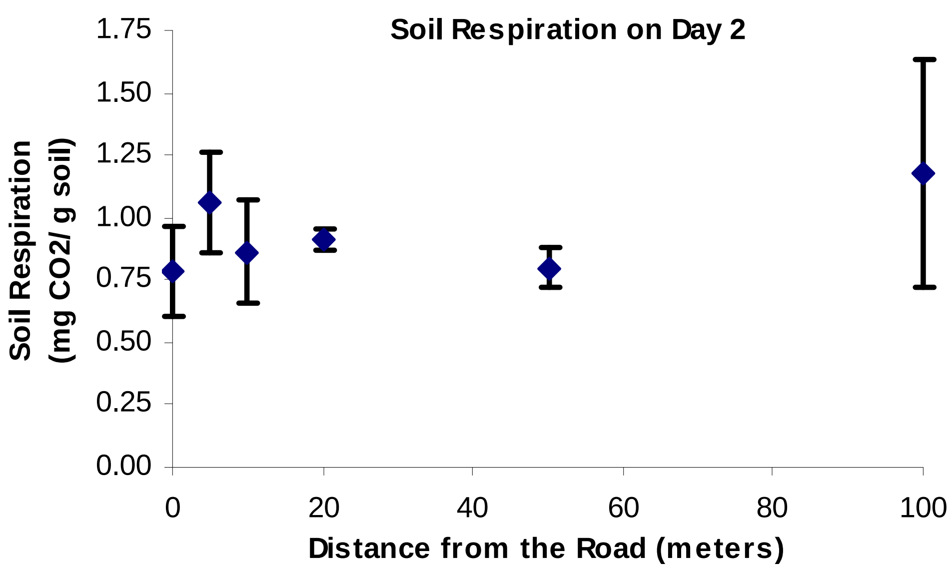

Figure 10. Average soil respiration across all 5 sites showed little pattern with distance from the road.

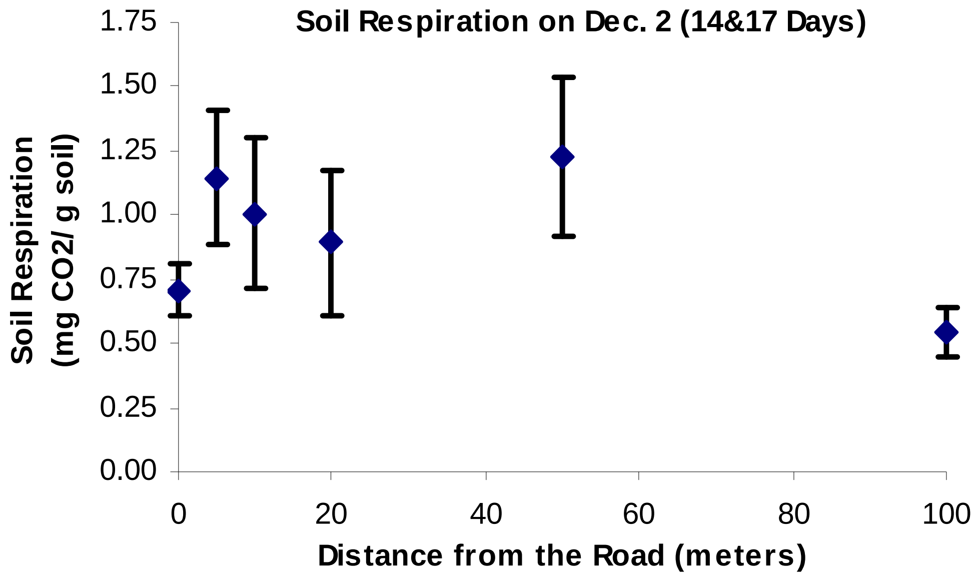

Figure 11. Average soil respiration across all 5 sites showed little pattern with distance from the road.

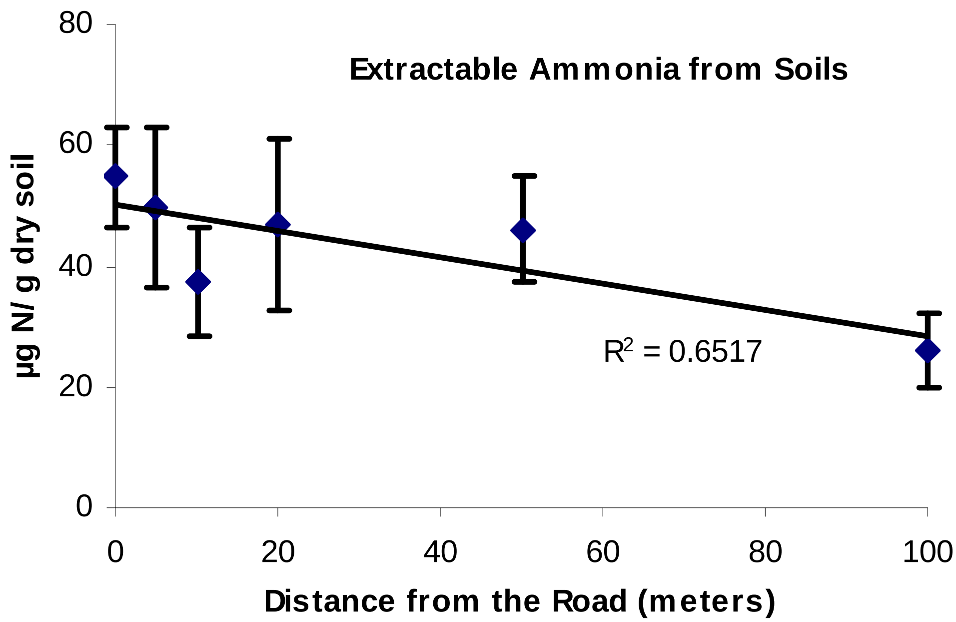

Figure 12. Average extractable ammonia across all 5 sites decreased with distance from the road, but tended to be variable as well.

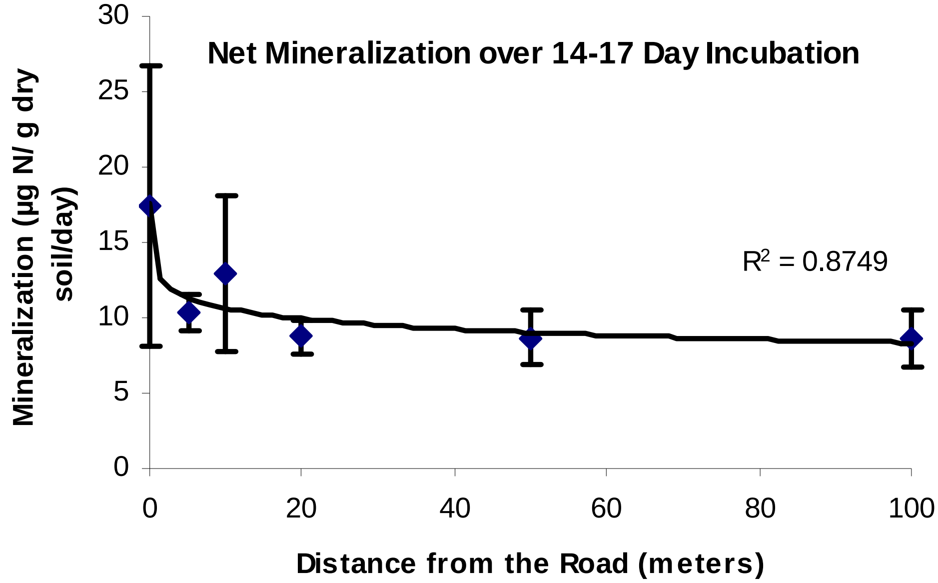

Figure 13. Average net nitrogen mineralization across all 5 sites decreased in the first 20m before remaining relatively consistent out to 100m. Soil types may be the cause of the wide variation at 0m.

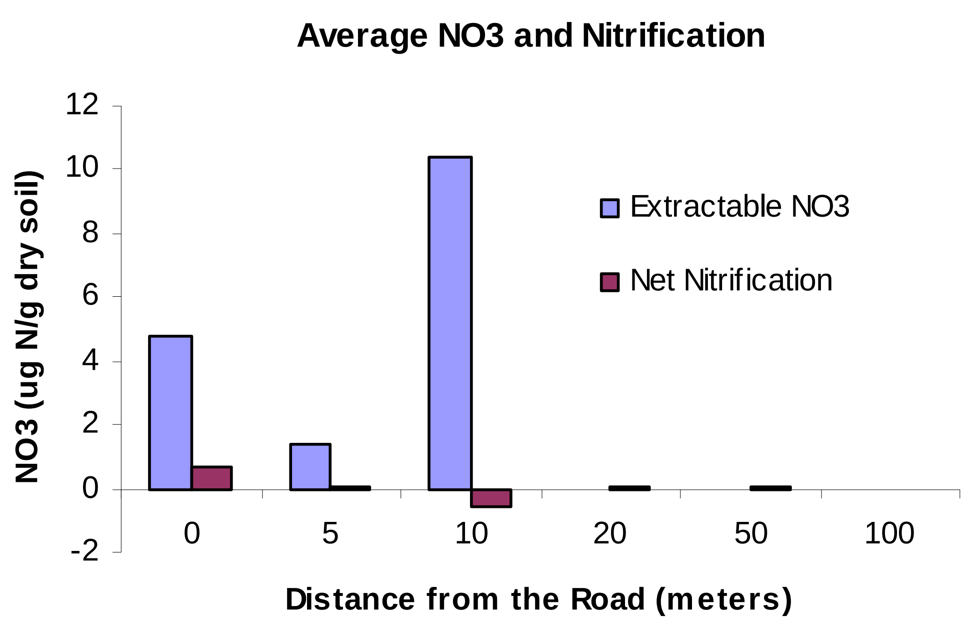

Figure 14. Average nitrate and net nitrification were minimal or random at most distances. Note: error bars not shown, but all are plus/minus the entire height of the bar. This is because NO3 was only found at one or two sites at each distance, but was undectable at most.

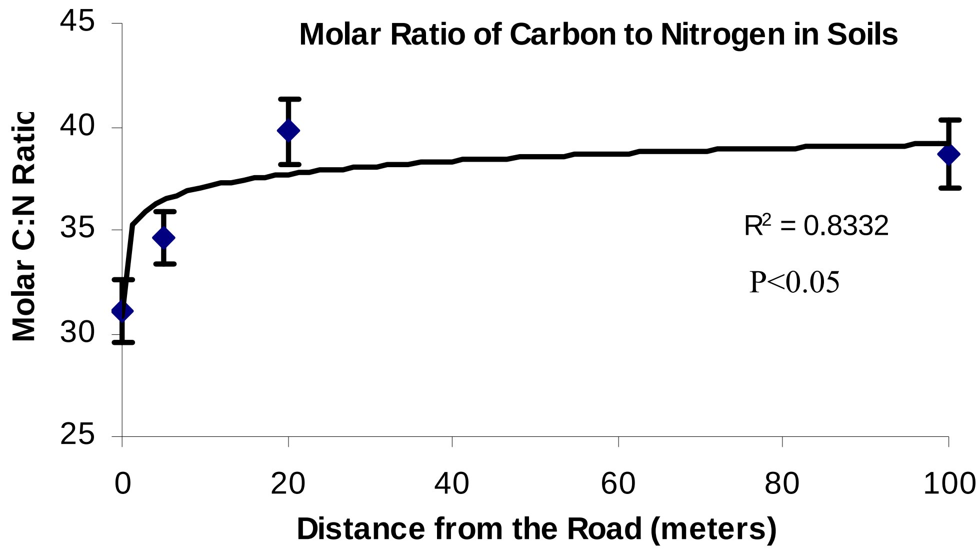

Figure 15. The average molar ratio of carbon to nitrogen across all 5 sites showed a significant trend with distance from the road, increasing in the first 20m and remaining relatively constant out to 100m

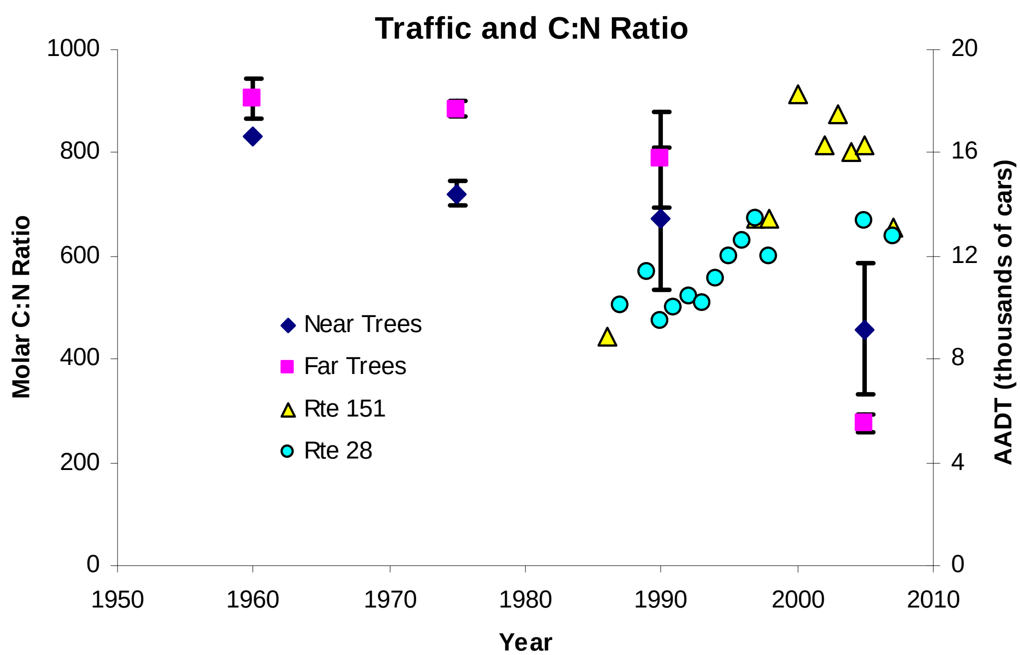

Figure 16. Average woody C:N ratio across all sites for both near and far trees decreased over time. Note the greatest decrease when traffic on both Route 151 and Route 28 increase in the past 20 years. Atmospheric deposition has remained constant over this time period (Figure 1). AADT = Annual Average Daily Traffic. Traffic count courtesy of the Cape Cod Commission.