Nitrogen Cycling and Dynamics in Upland Managed and Preserved Watersheds of the Adirondack Mountains, New York.

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ABSTRACT

This study investigated nitrogen cycling differences between management systems in the Adirondacks. The definition of managed site was that there had been active logging within the past twenty-five years and the sites fit into the preserve category because they had no active logging within the past eighty-five years. The soil nitrogen cycle is complex and can be disturbed in many ways, including timber harvesting management practices. These disturbances were investigated over the summer of 2005 when logged and preserve forested watershed soil nitrogen was examined. Five soil cores were taken from each of two managed and two preserved watersheds over a two-day period. These four adjacent watersheds have identical temperature, precipitation, and climate so this eliminates outside influence. Chemical and physical parameters including organic matter content, nitrate, ammonium and total Kjeldahl nitrogen (TKN) were compared between watershed management practices. No significant differences were found between organic matter, nitrates, or ammonium, but there was a significant difference in TKN. Managed sites contained higher concentrations of TKN. These differences are most likely not due to direct influences by the timber harvesting that has taken place in the last twenty-five years. The explanation possibly lies in the composition of the forest since the site with less deciduous trees had a higher nitrogen concentration in the soil. This could be due to a lower carbon to nitrogen (C:N) ratio in the forest litter resulting in litter that is broken down more easily.

Key Words: Adirondack Upland streams, nitrogen, land use .

INTRODUCTION

Nitrogen is the most common limiting factor in most terrestrial ecosystems. A limiting factor is “the one component to which the application of a given amount of effort will pay the greatest returns” in the ecosystem (National Geographic, 2005). Nitrogen is a key component in amino acids, peptides, nucleic acids, and proteins. The majority of nitrogen, around 90% found on Earth, is an inert gas existing as two triple-bonded nitrogen atoms (N_2) that is unusable to most organisms. (Cunningham, Cunningham, et al., 2003).

Inert nitrogen has to be fixed, or oxidized to form nitrate NO_3^- or bonded to hydrogen to form ammonium (NH_4^+) which is readily available to plants. Fixation is the result of extremely high temperatures, such as near a lightning strike, or it can occur as a result of microbial enzymes. Microbes live in the soil of terrestrial ecosystems and are responsible for the majority of nitrogen fixation for terrestrial ecosystems. Nitrogen fixing microbes are found either free living in the soil or living in the nodules of legumes and other specialized plants in a symbiotic relationship. The nitrogen fixing bacteria get the benefit of sugars, starches, nutrients and water in the plant’s rhizosphere and the plant gets the benefit of having a steady supply of fixed nitrogen from the atmosphere. Nitrogen fixation can only take place in the soil where there is air penetration. If the microbe has no source of atmospheric nitrogen, it cannot produce the fixed product. Fixation of N_2 to NH_4^+ makes the nitrogen readily available for some plant forms which can then be taken up into their plant mass (Columbia Electronic Encyclopedia, 2005). NH_4^+ is a cation, which means it has a positively charged ion and can be adsorbed to the surface of negatively charged soil particles. This prevents ammonium from leaching out of the system. Ammonium is often present in sparingly small amounts, though, because all available ammonium is usually converted to nitrite then nitrate almost immediately upon introduction.

Soil ammonium is converted by a specialized group of bacteria called the nitrifiers (*Nitrosomonas*) to nitrite (NO_2^-), which is quickly converted, by another specialized group (*Nitrobacter*) of bacteria to nitrate (NO_3^-). Nitrite is the intermediate phase between ammonium and nitrate and usually does not have detectable levels in forest soils because they are quickly taken up by nitrifying bacteria to form nitrate. Nitrate are also readily take up by plants and assimilated into biomass from the soil. Nitrate, however, is an anion and has a negative charge. It is not adsorbed to the negative soil particle surface, and therefore can be leached. If nitrate is leached from the soil, it can acidify the stream in a watershed if there is excess in the soil (Brady, et al. 1999.)

Once nitrogen is fixed, it usually stays within the system as biomass as proteins, amino acids, and nucleotides. Nitrogen reenters the system various ways. The obvious way of reentry is through death and decay of an organism's biomass. The rate of decay depends on the carbon: nitrogen ratio, the higher the ratio, the slower the decomposition rate. Nitrogen is also reintroduced to soil though plants shedding leaves, needles, flowers, fruits and cones. A smaller input is animals shedding fur, feathers, skin, exoskeletons, and waste products. (Cunningham et al. 2003).

Background Information

There is a complex biogeochemical cycle that cycles organic nitrogen through a complex food web including microbes and metazoans, such as nematodes. The excess nitrogen from this cycle is released into the soil matrix. Waste products are broken down into smaller organic components or plant-available mineral forms that are rapidly absorbed through roots and cell membranes.

Leaf litter and decomposition in an undisturbed watershed mainly determine available nitrogen in soil. Subsequent release of nitrogen as a result of the decomposition into the environment is the limiting factor in plant growth (Davidson et al., 1992). Forest management can affect nitrogen availability and nitrogen cycling in forest by removing vegetation or altering growth amounts and rates within the watershed (Vitousek and Melillo, 1979). Forest age and type could have an influence on how much nitrate per hectare is exported from the watershed each year (Gardner et al., 2005).

Forests are an important indicator of forest health and more research needs to be done on logging effects. Although the ocean takes up more than six times the area of the Earth's surface, approximately 92% of the Earth's plant biomass and 46% of its yearly NPP occurs in forested watersheds (Likens and Bormann, 1995). This shows that in less than ten percent of the Earths' surface, almost half of the productivity is occurring. This makes forested watersheds an essential indicator of the planet's health. The purpose of this study was to monitor the changes and ascertain if there is a difference in soil nitrogen cycling steps (nitrate, ammonium and total nitrogen) between managed and preserved watersheds. This investigation was conducted in a half-managed/half-preserved forest, which consisted of first and second order streams located in Jay, New York that all flow directly into the Ausable River.

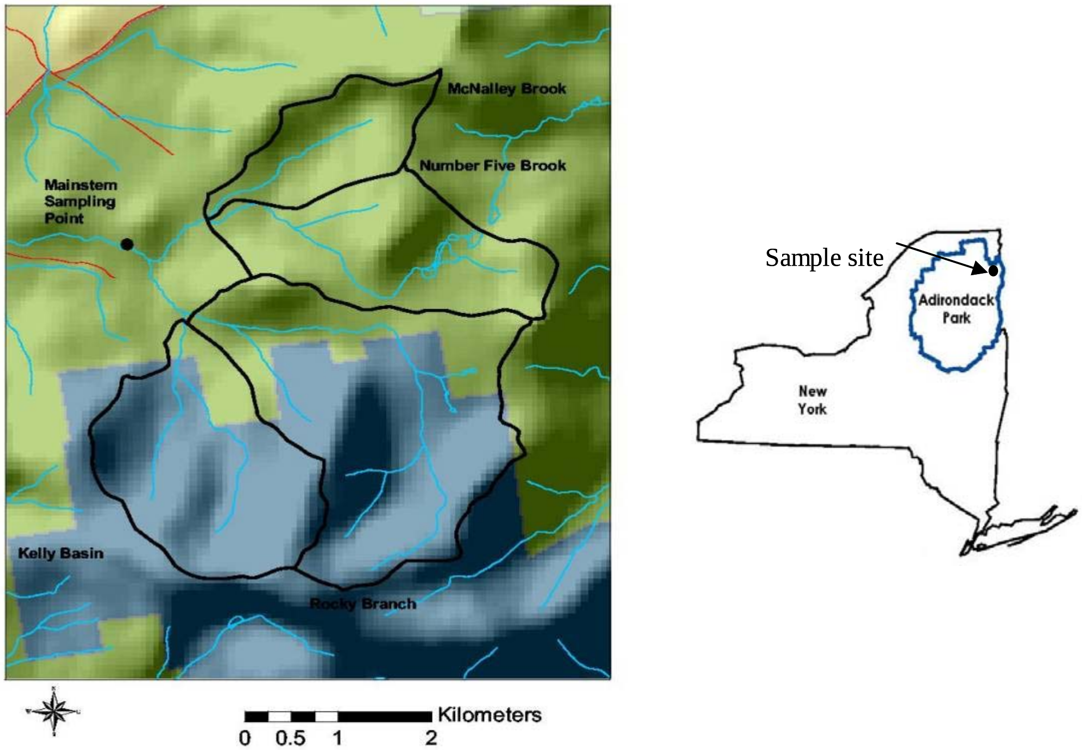

Figure 1 – Location of the four study watersheds and mainsteam confluence sampling location found within Adirondack Park. Areas shown in green are managed for forestry, including two study watersheds (Number Five Brook and McNalley Brook). Areas shown in gray are located in the NYS forest Preserve including two study watersheds (Kelly Basin and Rocky Branch).

Of the four sites studies, two were managed; McNally Brook and #5 Brook and the other two were preserved streams, Kelly Basin and Rocky Branch. The definition of managed was that there had been active logging within the past twenty-five years. Sites located in the NYS forest Preserve had no active logging within the past eighty-five years. Jay, NY is located in the northeastern portion of the Adirondack Park. The forests near the sampling sites in McNalley, Kelly Basin, and Rocky tributary were dominated by hemlock (*Tsuga Canadensis*) and were overwhelmingly coniferous. Watershed #5 had a heterogeneous forest with dominance displayed by deciduous trees, especially eastern red oak (*Quercus rubra*). Average daily temperatures for this area is 4.8°C and average precipitation is 964.4-mm/year (World Climate, 2005). The amount of available nitrogen in the soil in these watersheds should have a direct correlation to the amount of plant growth occurring, the amount of subsurface storm flow, the amount of dead organic material decaying, and many other complex factors (Rita, 2005).

Not only is the managed forest negatively impacted by the direct removal of biomass and the nitrogen contained within, but also because of the organic matter disturbance. Much of the soil nitrogen pool is in the organic layer, and if this is disturbed, so is nitrogen cycling. Forest removal guidelines state that leaving 10 to 125 megagrams of coarse woody debris per hectare could lessen the impact of loss of woody materials during the timber harvest. Upwards of 500 kg of nitrogen per hectare can be lost when harvesting operations are in operation. It may take anywhere from 10 to 275 years to replace this nitrogen through biological nitrogen fixation or atmospheric deposition. All of these factors depend on the severity of the operation and the responsibility with which the procedure was carried out. Davidson, Hart, and Firestone (1992) also point out that forest harvesting results in the direct removal of nitrogen in forest biomass, alters mineralization and nitrification rates, and increases nitrates in stream water. They also reiterate that the degree of these impacts depend on the severity and intensity of the harvest.

Another factor affecting nitrogen cycle in management areas is the newly formed gaps where pioneer species can take over. Pioneer species such as striped maple (*Acer pensylvanicum*), trembling aspen (*Populus tremuloides*), and white birch (*Betula papyrifera*) take over a site and grow very quickly due to decreased competition. Nitrogen is taken up very quickly by these young and actively growing plants in the light and space vacated by the extracted timber, which reduces the amount of available nitrogen in the soil and the amount of nitrates leaching off into the stream because of the increased biotic demand (Ohrui and Michell, 1996; Likens and Borhman 1995). This has a cascade effect because of the increased terrestrial demand, there are less nutrients running off into the stream, and this strains the aquatic communities and may even change the composition of the macroinvertebrate populations. During this first regeneration, the leaf area matures quickly and assimilates a large amount of nitrogen in the process. Nitrogen uptake in the forest slows when the ecosystem reaches a steady equilibrium state (Schlesinger et al., 1997) such as our “preserved” watersheds have. These findings support the hypothesis that there would be a difference in the soil nitrogen levels between managed and preserved watersheds.

Another explanation for the difference in nitrogen levels may be the forest composition within the sampling sites. Coniferous forests mineralize nitrogen much slower than hardwood dominated stands (Reich et al. 1997). This would mean if given the same amount of organic nitrogen pool, the deciduous forest would mineralize the nitrogen much more quickly because the carbon to nitrogen ratio is much lower and can be readily decomposed for reuse. Carbon to Nitrogen ratios explain leaf litter quality. The lower the ratio, the higher quality litter being produced. As found by Satti et al. (2003), conifers have a much higher C:N ratio that is more variable than broad leafed deciduous trees. It has also been found that nitrogen availability could be seven to twenty times greater in clear-cut sites than preserved or unmanaged sites (Binkely, 1984). Many coniferous trees also have more recalcitrant litter containing higher levels of lignin which resists decomposition and slows nitrogen release.

METHODS

Soil samples were collected in the watersheds on June 2^{nd} and 3^{rd}, 2005. The sites began at the pour point of the study watershed and taken every twenty-five meters upstream to sample the water characteristics. The core sites were situated approximately fifteen meters from the stream bank to void any riparian influences on the chemical parameters. The pits were hand dug to minimize soil disturbance as close to the fifteen-meter mark as possible, but moved as a result of rocks, poor soil depth, or trees and roots. Hand digging ensured proper collection of exclusively B-horizon soil with no outside inputs. On the twenty-five meter transects between the soil collection sites, a tree inventory was taken on all trees greater than or equal to five cm in DBH (diameter at breast height). This gives an idea of the immediate litter input into the soil, which may be the most important source of nitrogen in the watershed. At each soil pit, elevation above the stream, ground cover flora, canopy cover, and GIS coordinates were taken, all to have a better understanding of any differences in the chemical analysis. Approximately 250 grams of B-horizon mineral illuvial soil were collected for analysis, which varied in depth from five to sixty one centimeters below the surface. The samples were immediately stored on ice to slow or stop biological processes and were air dried within 12 hours to completely stop these biological alterations. Once dry, the soil was passed through a 2 mm sieve to remove stones, roots, and other large debris. Prepared samples were stored at 4°C until analysis to avoid any further mineralization.

Chemical analysis of organic matter, nitrate, ammonium, and total nitrogen were done in the Lake Champlain Research Institute (LCRI) laboratory at SUNY Plattsburgh. Organic matter was determined by a loss on ignition procedure. Soil samples were dried for 24 hours at 105°C and then combusted at 450°C for 24 hours. Organic matter was obtained by difference of weights. Nitrate and nitrite were extracted from the soil by shaking five grams with 50 mL of deionized water and filtering through a 0.45-micron glass fiber filter. The filtered samples were then passed through an Onguard P filter and analyzed by using ion chromatography (Dionex Series 200i/SP). Ammonium was extracted by shaking five grams of soil with one molar potassium chloride (1 M KCl) for one hour and filtering through a 0.45-micron glass fiber filter. The extracts were analyzed using the Bran Luebbe split flow auto-analyzer (Bran Luebbe, 1999). Total nitrogen was extracted using the Kjeldahl method (U.S. EPA, 1984) and analyzed for ammonium on the auto analyzer.

RESULTS

The four-chemical/physical properties varied markedly among the sites. For organic matter (figure 2), one logged and one preserve site averaged about eight percent and one logged and one preserved site averaged around 3.4 percent. There was no significant difference in the level of organic matter between the two management styles. Organic matter in the four soils averaged from 1.07% to 15.6%.

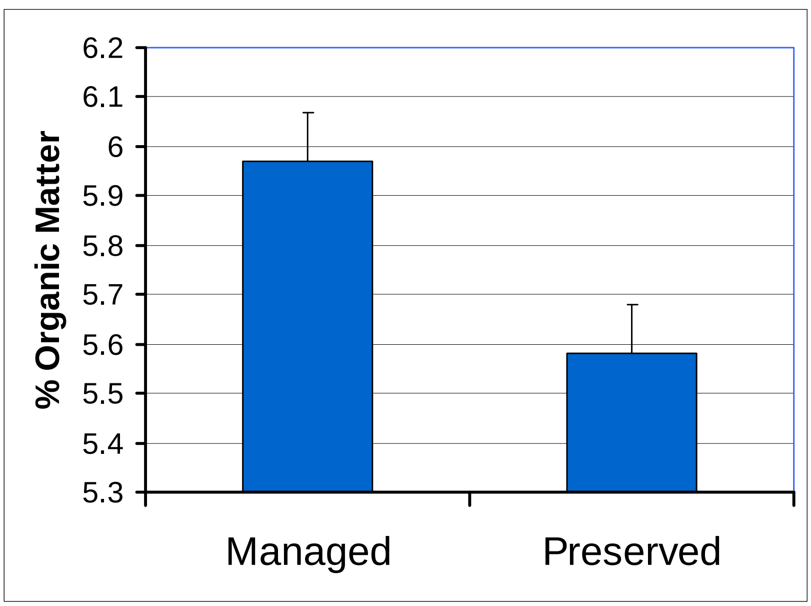

Figure 2. Average amounts of organic matter in managed and preserved sites

Nitrate ranges in the B-horizon mineral soil were from undetectable limits to .902 milligrams per gram of soil (Figure 3). Nitrates were similar in this respect, where each managed and preserved had a high and low value. The preserve site average was 0.707 mg/L and the managed sites had an average of 0.527 mg/L.

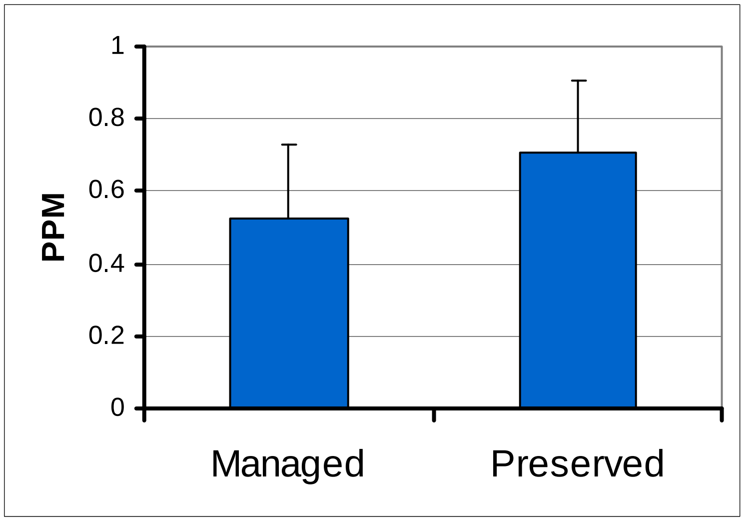

Figure 3. Average amounts of nitrates (ppm) in managed and preserved sites.

Ammonium values (figure 4) were consistent for preserved sites, but the managed sites had the highest and lowest value. The average value for ammonium in the preserve site was 3.52 mg NH_4^+/g soil and there was 4.34 mg NH_4^+/g soil in the managed site.

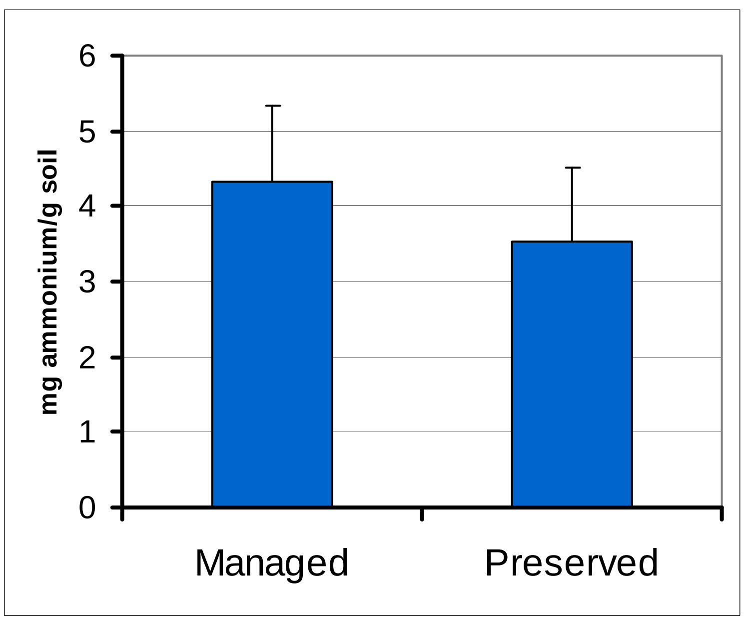

Figure 4. Average amounts of ammonium in managed and preserved sites

Total Kjeldahl nitrogen (Figure 5) proved to be the only test that did not vary a great deal across sites. TKN was the only parameter to be significantly different between management practices. Preserve's average was 0.90 mg N/g soil and managed had 2.96 mg N/g soil. Overall, the managed sites had a much higher level of TKN than the preserve sites.

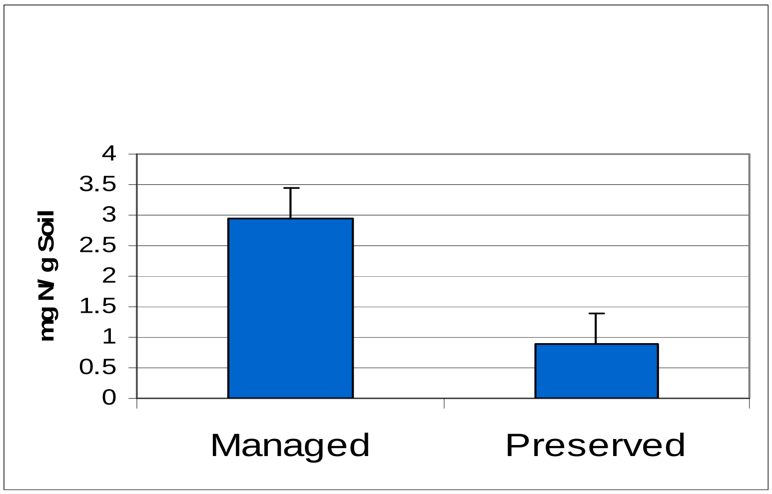

Figure 5. Average amounts of total Kjeldahl Nitrogen in managed and preserved sites

Carbon:nitrogen ratios (figure 6) show that there is different organic parent material. The R-squared values and equation of the regression lines show that there is different carbon:nitrogen ratios in soil between managed and preserve sites, with a higher C/N ratio in the Preserve sites.

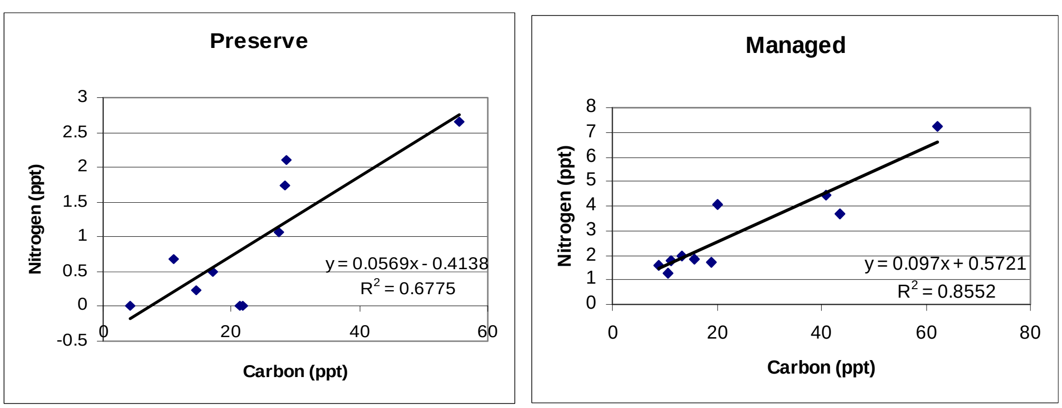

Figure 6: Carbon Nitrogen ratios in preserved and managed watersheds.
Watershed #5 has much higher values in the managed watersheds on the left.

DISCUSSION

Our results showed that three out of the four soil characteristics measured did not differ between management regimes. Organic matter (P=0.821), nitrates (P=0.370), and ammonium (P=0.410) showed no significant difference between managed and preserved sites (T-test P> 0.05). Total Kjeldahl nitrogen (P=0.007), did show a significant difference between managed and preserved regimens, although it was skewed in the opposite direction of what was expected.

Total nitrogen differences could be due to the intensity of the management that occurred less than ten years ago. If the timber extraction was severe enough to disturb soil horizons, then mineralization may not occur at the correct rate. Soil compaction from timber harvesting equipment could also negatively impact nitrogen mineralization rates.

The more likely reason for this differences in nitrogen in managed areas is the litter inputs into the soil. The main inputs into these soils are the leaf litter from immediately surrounding trees. The carbon to nitrogen (C:N) ratio explains this very well. In managed sites, there is more total nitrogen and there is also more nitrogen per unit of carbon. In these managed sites, there is more demand for the nitrogen so as soon as it is mineralized the plants take it up. Stream nitrate levels are higher in the preserve streams than in the managed sites because the managed sites are actively taking up nitrates and this prevents them from being leached out of the soil and into the stream. In both preserve sites and one managed site (McNalley), the forest is dominated (>64%) by coniferous forests. Coniferous litter has higher lignin content and they have a higher C:N ratio, which makes it much more recalcitrant to decay (Hobbie, 2000). The higher quality leaf litter in the second managed site (#5) increases the amount of available nitrogen because of the less resistance to decay. #5 watershed only has 30% coniferous forest, making the majority of the litter easy to break down. Deciduous litter is broken down much more quickly and is leached downward resulting in higher concentrations in the B-Horizon.

This was shown with organic matter when each managed and preserved had a value near three and each had a value close to eight. In further investigations, more samples would need to be taken because it is difficult to characterize an entire watershed between two and eight hectares with only one kilogram of sample. More extensive sampling may be correlated with the forest plots from this project to ascertain a larger and more all-encompassing sample of the soils.

Conclusion

In this study, it cannot be concluded that nitrogen cycling or nitrogen levels are significantly different between management practices. It can be concluded from this study, however, that immediate area forest composition can greatly influence the nitrogen cycle in the soil. This is shown because the only watershed that is dominated by deciduous trees has a much lower C:N ratio than the other three watersheds that are dominated by coniferous species. This means that the trees in the area are the dominating force in the nitrogen cycle after timber harvesting management plan. Small differences are still found in the nitrates, which would be expected, but differences in TKN are most likely explained by forest composition. With an equal nitrogen pool in the area, the managed sites had lower TKN most likely due to litter from deciduous trees in #5 watershed being mineralized much more quickly and being utilized by the forest almost immediately. Future studies should consider the selective management and which types of trees are taken out of the forest as they influence nitrogen cycling. If management takes deciduous trees, this could impact the forest soil by increasing the amount of organic matter and TKN.

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