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Selective logging of lowland evergreen rainforests in Chiloé Island, Chile: Effects of changing tree species composition on soil nitrogen transformations

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ABSTRACT

Lowland evergreen rainforests in southern Chile growing on highly productive soils and accessible sites have been subjected to traditional and industrial logging of valuable timber trees. Old-growth rain forests in this area are characterized by highly conservative N cycles, which results in an efficient N use of ecosystems. We hypothesize that different logging practices, by changing forest structure and species composition, can alter the quantity and quality (i.e. C/N ratio) of litterfall and soil organic matter and soil microbial processes that determine N storage and availability. To test this hypothesis we investigated chemical properties, microbial N transformations, N fluxes and N storage in soils of lowland evergreen rainforests of Chiloé Island after 10 years since industrial selective logging (ISL) and in stands subjected to traditional selective logging (TSL) by landowners in small properties. We compared them to reference unlogged old-growth stands (OG) in the same area. Tree basal area was more reduced in the stands subjected to ISL than to TSL. Litterfall inputs were similar in both logging treatments as in OG stands. This was due to greater biomass of understory species after logging. In TSL understory tree species determined a higher litterfall C/N ratio than ISL. We found higher soil N availability and content of base cations in surface soils of logged forests than in OG. The litter horizon of OG forest had significantly higher rates of non-symbiotic N fixation than logged forests. In the ISL treatment there was a trend toward increasing soil denitrification and significantly higher NO_3–N/N_t ratio in spring waters, which led to a stronger $\delta^{15}N$ signal in surface and deep soils. We conclude that massive understory occupation by the shade-intolerant native bamboo *Chusquea quila* in ISL led to enhanced litter quality (lower C/N ratios) relaxing the tightness of the N cycle, which increased soil N availability leading to a higher proportion of nitrate in spring waters and higher gaseous N losses. In contrast, under TSL a higher litterfall C/N ratio slowed decomposition and net N mineralization rates thus reducing the chances for N losses, and enhancing C and N storage in soil. We suggest that sustainable logging practices in these rain forests should be based on lower rates of canopy removal to enhance colonization of the understory by shade-tolerant trees, which are associated with a more efficient N cycle.

1. Introduction

Old-growth temperate rainforests of southern South America are strongly nitrogen-limited. The nutrients are efficiently retained in soils and above ground biomass reflecting that theses ecosystems are very conservative in nutrient use (Hedin et al., 1995; Pérez et al., 1998; Vann et al., 2002; Perakis and Hedin, 2001; Satti et al., 2003; Diehl et al., 2008). Limited nitrogen (N) inputs to these southern forest ecosystems derive primarily from non-symbiotic nitrogen fixation in forest soils, at the same time low rates of internal nitrogen cycling and denitrification have also been reported (Pérez et al., 2003a).

Logging practices that alter forest structure and tree species composition can be detrimental to ecosystem functions, especially those that depend on the chemical quality (e.g. C/N ratio) and quantity of organic matter entering the soil. Processes that are highly sensitive to the chemical quality and quantity of litter are those controlled by heterotrophic soil bacteria, responsible for N inputs and transformations in soils; e.g. non-symbiotic N fixation, denitrification, and net N mineralization and nitrification. In fact, more than 99.9% of total nitrification came from soil organic matter in a Chilean Andisol (Rütting et al., 2008). In northern temperate and boreal forests, logging often increases net N mineralization rates, soil N availability (Reynolds et al., 2000; Thibodeau et al., 2000; Hope et al., 2003; Lindo and Visser, 2003; Inagaki et al., 2008) and litter decomposition rates (Prescott, 1997; Brais et al., 2002). Such effects are generally associated with increases in soil temperature and enhanced soil moisture as a result of tree

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removal (Reynolds et al., 2000; Thibodeau et al., 2000; Heithecker and Halpern, 2006). However, other studies have found limited or no effects of selective logging on soil N transformations and litter decomposition (Berg and Edmonds, 1999; Brais et al., 2002; Kranabetter and Coates, 2004; Westbrook et al., 2006; Idol et al., 2006; Jerabkova et al., 2006) and no effects of logging on soil carbon and nitrogen storage (Johnson and Curtis, 2001). These conflictive results may be due to differences in site factors among the studied ecosystems, such as climate, vegetation, time since logging disturbance, type of machinery used in the selective logging and land use history. Changes in N availability following disturbance can alter other microbial processes in ecosystems such as non-symbiotic N fixation and denitrification, but there is less documentation of the effect of logging on these ecosystems processes (but see Shaffer et al., 2000; Ballard, 2000; Griffiths and Swanson, 2001).

Most studies of biogeochemistry in southern Chilean temperate forests have been conducted in montane rain forests. Lowland primary rain forests developed on highly productive, glacial soils are disappearing much faster than higher elevation forests, however, due to logging, fire and land use changes, especially in the last decades (Wilson and Armesto, 1996; Echeverría et al., 2007). Nowadays lowland primary rain forests in Chiloé Island occupy less than one-third of its original distribution. Chile belongs to the group of countries that have increased its overall deforestation rate from 1.02% during 1980s to 1.76% during the 1990s (Jha and Bawa, 2006), which has greatly altered the landscape of this temperate forest region. It has been estimated that only 5% of logging of native forests is based on controlled silvicultural practices (Lara, 1996). Depending on logging intensity, selective logging scenarios can substantially alter forest structure and tree species composition (Rüger et al., 2007), mainly because of the broad diversity of light requirements of different timber species (Donoso et al., 1999; Gutierrez et al., 2004; Figueroa and Lusk, 2001).

The main hypothesis of this work was that the removal of tree biomass by logging practices, generally consisting of selectively removing valuable timber species, should alter N transformations mediated by soil heterotrophic bacteria, which are highly dependent of organic matter quality in unpolluted forests. To test this hypothesis, we compared nitrogen cycling in a forest stand affected by industrial selective logging of trees for timber production (65% of the canopy removed 10 years ago), with a stand subjected to traditional selective logging by local people (continuously harvested at lower rate) and a reference unlogged, old-growth stand under similar climate and soils. For this purpose, we measured the following responses to logging treatments: (1) tree species composition and cover, (2) chemical quality (e.g. C/N ratio) and quantity of litterfall, (3) N return via litterfall from vegetation to soil, (4) chemical properties of soils and spring waters, (5) soil microbial N transformations (e.g. non-symbiotic nitrogen fixation, net N mineralization and denitrification), (6) litter decomposition rates, and (7) microclimate.

2. Materials and methods

2.1. Study sites

Study sites were located in Melleico (42°37′08″S, 73°46′06″W), 12 km west from Chonchi, Isla Grande de Chiloé, Chile (Fig. 1). Forest type in the study area is evergreen Valdivian rain forest dominated by broad-leaved tree species, such as *Laureliopsis philippiana* (Monimiaceae) and different Myrtaceae species (Armesto and Figueroa, 1987). Prevailing climate is wet-temperate with a strong oceanic influence (Di Castri and Hajek, 1976). Meteorological records (4 years) at Senda Darwin Biological Station, located about 100 km north of the study site, indicate an annual rainfall of 2090 mm and a mean annual temperature of 12 °C. Maximum monthly temperatures (January) are 16 °C and minimum monthly temperatures (July–August) are 5 °C. Rainfall occurs throughout the year, but 64% of the precipitation falls between April (austral fall) and September (austral spring). The forests studied are situated at the foothills of the Coastal Range at ca. 100–200 m above sea level. A full description of the flora, vegetation structure and dynamics is provided by Gutierrez et al. (2009) and Pérez et al. (in press).

Within an area of 2 km^2 (Fig. 1), relatively homogeneous regarding topography and soils, we selected forest stands subjected to two logging treatments: (1) forests continuously logged by small landowners for limited timber extraction and

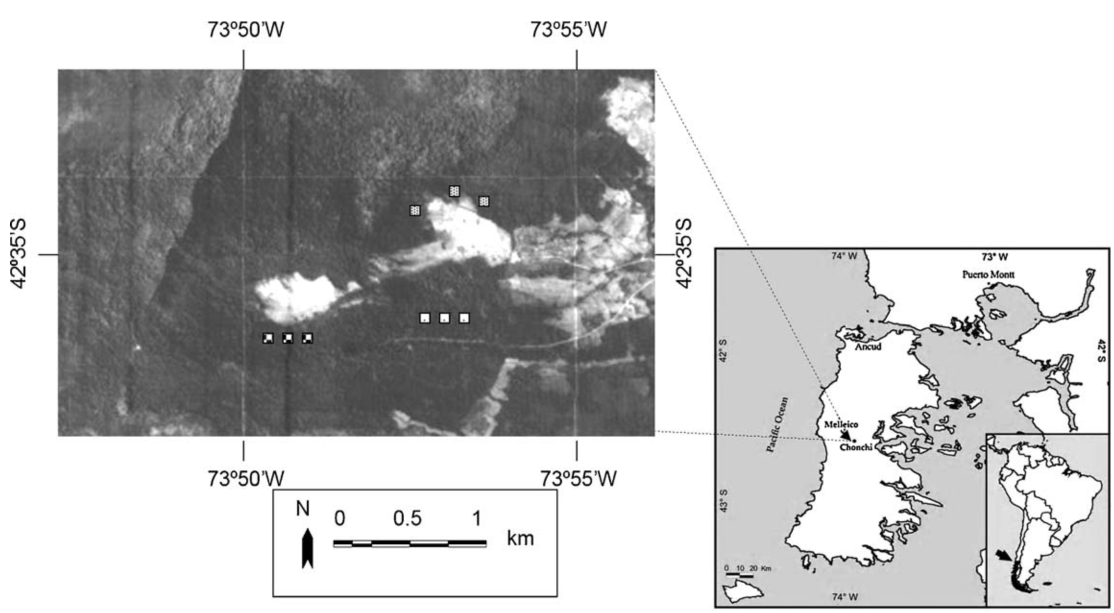

Fig. 1. Map of the study area in central Chiloé Island. Three reference spring waters in the OG forest: bottom left, three reference spring waters in ISL: bottom right, and three reference spring waters and plots in the TSL in the top. The orthophoto was taken in year 1993, so the ISL was still not applied.