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Atlantic Forest replacement by non-native tree plantations: Comparing aboveground necromass between native forest and pine plantation ecosystems

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ABSTRACT

Necromass is a critical structural and functional component of forest ecosystems that represents an important and relatively long-lived aboveground forest carbon pool. In the Atlantic Forest of Northern Argentina, a large area of native forest has been replaced by commercial, non-native tree plantations. We hypothesized that total aboveground necromass would be affected by forest conversion. Specifically, we expected a general decrease in necromass with conversion to non-native pine plantations. In five different *Pinus taeda* plantations (PP) and five native forests (NF) sites in Misiones, Argentina, we quantified the fallen coarse woody debris (CWD: >2 cm diameter) and litter layer (LL: <2 cm diameter) biomass. We compared NF and PP ecosystems with respect to biomass, CWD size classes, decomposition levels, mass moisture content and water volume retained. Coarse woody debris was greatly reduced in PP (1.7 ± 0.5 Mg ha^{-1}) compared to NF (7.5 ± 3.5 Mg ha^{-1}). However, LL biomass in pine plantations increased by 180%, such that similar amounts of total fallen necromass (CWD + LL) were observed in NF (13.5 ± 1.1 Mg ha^{-1}) and PP (14.1 ± 3 Mg ha^{-1}). The CWD size class with the highest biomass was CWD > 10 cm in NF (5.4 ± 3.7 Mg ha^{-1}), and 2–5 cm in PP (1 ± 0.2 Mg ha^{-1}). Coarse woody debris in NF was principally composed of detritus in intermediate to advanced states of decomposition (5.1 ± 3 Mg ha^{-1}; 68% of total CWD), while in PP recently dead material accounted for the majority of CWD (0.8 ± 0.5 Mg ha^{-1}; 49% of total CWD). Necromass moisture content was similar in both forest ecosystems, and increased as the level of decomposition increased. However, because CWD was more abundant in NF, the water volume retained in NF was four times higher than in PP (6.38 ± 1.3 vs. 1.68 ± 0.5 m^3 ha^{-1}, respectively). The observed differences in necromass can be explained by the stand characteristics of PP, which are monospecific young systems of short harvest cycles and low quality litter where all aboveground biomass is removed during harvesting. Our findings suggest that NF replacement by PP could have large effects on ecosystem function due to changes in the amount and composition of necromass. Specifically, the predominance of fine detritus in PP likely lowers the residence time of carbon and water storage in detritus, as well as ecosystem biodiversity, while also increasing the risk of natural fires. Management strategies that would increase coarse necromass, such as not removing harvest residues and extending tree harvest age, should be considered.

1. Introduction

An important feature of native forests is that they possess high quantities of dead material in all stages of decay, as well as high proportions of old, live trees with dead components (Harmon et al., 1986). As this necromass decomposes relatively slowly, it represents an important long-lived aboveground forest carbon (C) pool (Liu et al., 2006) that plays an important role in biogeochemical cycles (Krankina and Harmon, 1995; Zhou et al., 2014) and links the above and belowground biota (Bardgett and Wardle, 2010). Necromass is also a critical structural and functional component of forest ecosystems (Franklin et al., 1987). It provides habitat for a large variety of organisms (Sefidi and Marvie Mohadjer, 2010) and it is a key component for both tree regeneration and the maintenance of environmental heterogeneity

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and biological diversity (Harmon et al., 1986; Stevens, 1997). Moreover, in tree plantations, accumulated aboveground debris is an important source of nutrients and organic matter that has a strong impact on nutrient cycling, especially in short-rotation forest plantations (Tiarks et al., 1998). Previous studies have suggested that necromass regulates hydrologic processes (Lindenmayer and Noss, 2006) and influences the probability of wildfires (Uhl and Kauffman, 1990). However, the effect of forest management and the replacement of native forests with tree plantations on necromass stocks, and the dynamics of these stocks in forest ecosystems, is still poorly understood.

Aboveground necromass stocks consist of litter layer (LL) that includes all necromass with a diameter less than 2 cm (forest floor, fine debris or O horizon), and coarse woody debris (CWD), the fallen plant detritus larger than 2 cm (Palace et al., 2012; Binkley and Fisher, 2013). In tropical and temperate forests, the dead organic material typically comprises a substantial proportion of the total aboveground C stocks, accounting for 14–40% of carbon storage (USDA, 2004; Rice et al., 2004; Palace et al., 2007; Iwashita et al., 2013).

Studies concerning the role of necromass, its characteristics, quantity and quality have increased in recent years, in part because climate change can alter ecosystem C balance through changes in the dynamics of this pool (Chambers et al., 2000; Woodall and Liknes, 2008; Weedon et al., 2009). In the Amazonian Forest, dry periods have reportedly increased the tree mortality rate (Phillips et al., 2009) producing a pulse of CWD into the necromass pool that raises the carbon storage in this stock (Rice et al., 2004). In tropical montane wet forests, both the CWD decomposition rate and the CWD production rate increase with the mean annual temperature, though the increase in decomposition rate is faster, resulting in net CO_2 emissions from CWD to the atmosphere with warming (Iwashita et al., 2013). Consequently, necromass stocks could become a carbon source or a carbon sink depending on several variables that change in space and time. Knowledge of these patterns is needed to improve carbon storage and stability in ecosystems (Chambers et al., 2000; Rice et al., 2004; Radtke et al., 2009).

Most of the studies on this subject have been performed in the tropics (Melillo et al., 1993; Potter et al., 1993; Grace et al., 1995; Malhi et al., 1998; Phillips et al., 1998; Martius et al., 2004), while studies in the subtropical forests of Neotropical regions, many of which have been subject to forest replacement in recent decades (Eclesia et al., 2012), are lacking. The Atlantic Forest is one of the most diverse forests of the world, but also among the most threatened. Approximately 84–93% of its original area has been lost and the remnants are highly fragmented (Ribeiro et al., 2009). In Misiones Province, Argentina, only 40% of native forest cover remains, and this fraction represents one of the larger portions of continuous Atlantic Forest in the region (Ribeiro et al., 2009). Forest fragmentation and loss in this area have been caused by the conversion of forest to crop and cattle fields and extensive non-native tree plantations for fiber production (Eclesia, 2004; Izquierdo et al., 2008; Ribeiro et al., 2009). Ecological modeling has recently shown that changes in land use and forest fragmentation have greatly decreased carbon storage in aboveground live biomass (Pütz et al., 2014). However, little is known about the effects of changes in land use on necromass stocks.

Tree plantations in tropical and subtropical ecosystems accumulate a significant amount of C in their aboveground biomass in a short period of time (Hoen and Solberg, 1994; Harmon and Sexton, 1995). Thus, afforestations and the use of forestry products for bioenergy have been proposed as a clean development mechanism to reduce greenhouse gas emissions (UNFCCC, 1992). However, more recent studies have found that afforestation decreases soil organic carbon by ~20% in plantations under 40 years old (Guo and Gifford, 2002; Eclesia et al., 2012). In South America the total area planted with different species of the *Pinus* genus exceeded 4,250,000 ha in 2009 (Simberloff et al., 2010). In Argentina, the afforested area grew rapidly during the last 30 years, today accounting for 1,024,277 ha with many sites already undergoing their second or third rotation after the native forest replacement. Fast growing plantations in this country are monospecific, and afforestation usually uses the non-native genus *Pinus*. These plantations occupy 64% of the total afforested area in the country. In Misiones Province (northeastern Argentina, Atlantic Forest biome), *Pinus* plantations occupy 10% of the provincial area, accounting for 306,592 ha (MAGyP, 2015). The most common species is *Pinus taeda*. In this region, the pine plantations effect on carbon and nutrient cycling has been associated with the harvest system. Soil loss and nutrient instability are moderate with the conventional practice of harvesting only the trunk (the remains of branches, leaves and fruits are left decomposing on the ground; Martiarena, 2008), but they are increased substantially with the system that harvests the whole tree (Goya et al., 2003). Despite the importance of necromass for the nutrient cycling within these productive systems (Tiarks et al., 1998), few studies have analyzed this issue and none have focused on the Atlantic Forest (Ranius and Kindvall, 2004; Radtke et al., 2009).

In this context, we developed the present study with the main objective of quantifying the effects of native forest replacement with non-native *P. taeda* plantations on necromass stocks. We formulated the following questions: (1) Does the total necromass volume change when non-native tree plantations replace native forest? and (2) Are the different necromass categories equally affected in the pine plantation systems? We hypothesized that necromass would be affected by native forest replacement with *P. taeda* plantations. We expected to find that total necromass, and in particular CWD, would decrease in commercial non-native tree plantations when compared to native forests. To test this hypothesis we quantified and characterized necromass stocks, diameter size classes, decomposition levels and water content in native forests and non-native *P. taeda* plantations in the Semideciduous Atlantic Forest of North eastern Argentina.

2. Materials and methods

2.1. Study site

This study was carried out over a one-year period (2013–2014), in a private, protected forest area, adjacent to the Iguazú National Park, Misiones province, Argentina (25°48′56.25″S, 54°32′17.28″W, Fig. 1). The region has a subtropical humid climate with no dry season. The mean annual rainfall is 2000 mm and the mean annual temperature is 20 °C; the relief is rolling and soils are mostly ultisols derived from basaltic rocks and contain high concentrations of Fe, Al and Si (Ligier et al., 1990). During the sampling period the mean monthly precipitation was 182 mm and ranged from 74 mm to 514 mm (annual total: 2187 mm; TRMM, 2014) and the mean annual temperature was 21 °C with a minimum of 15 °C (winter) and a maximum of 25 °C (summer) (MODIS, 2014).

The Semideciduous Atlantic Forest in Misiones constitutes the southern portion of the Atlantic Forest, which extends along the coast of Brazil up to Paraguay and Argentina, but it is also included within a broad group of neotropical seasonally dry forests (Prado and Gibbs, 1993). The tree structure is uneven-aged and includes more than 70 tree species (Chediack, 2008) usually covered with lianas and epiphytes, mixed with shrubs, bamboos and grasses (Parodi, 1964). At the study sites, tree density is 1200 ind/ha, the basal area of trees larger than 10 cm DBH (diameter at breast height) is 28.74 $m^2\ ha^{-1}$ and the tree canopy height is about 30 m (Chediack, 2008). The canopy vegetation is dominated by