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Soil texture and chemical characteristics along an elevation range in the coastal Atlantic Forest of Southeast Brazil

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ABSTRACT

We analyzed soils under forest across an elevation range (100 m, Lowland Forest, 400 m, Submontane Forest, and 1000 m, Montane Forest) in the Atlantic Rainforest of São Paulo State, Brazil. We hypothesized that soil nutrient content would increase with elevation in the surface mineral soil as a result of higher organic matter stocks, and the observation that both above and below ground biomass increase with elevation in the Atlantic Forest. This hypothesis was partially confirmed. Percent silt, carbon (C) and nitrogen (N) increased with elevation. Base cation concentrations, pH (<4), and extractable phosphorus (P) concentration were low across the sites and did not differ among elevations. Extractable aluminum (Al) was highest at 1000 m, but there was no trend with elevation. The sharp decrease in P and cation concentration with soil depth and the low concentration of these elements in the parent material, suggest that the vegetation of the Atlantic Forest is dependent on recycling of these nutrients or atmospheric deposition to maintain productivity.

1. Introduction

Montane tropical forests and adjacent lowlands (hereafter MTFs) provide a variety of ecosystem services, including hosting high levels of plant biodiversity (Brummitt and Lughadha, 2003; Murray-Smith et al., 2009), storing carbon (Spracklen and Righelato, 2014), and capturing and storing rain and fog water (Bruijnzeel, 2001). All of these functions are threatened by the rapid destruction of these forests, which has implications for local, regional and global climate (Oliveira et al., 2014). This problem is particularly acute in Brazil's Atlantic Forest, where over 85% of the existing forest has been cleared during centuries of use (Ribeiro et al., 2009). Despite hosting over 60% of Brazil's population, the forests that once dominated the Atlantic coast remain relatively unstudied. Thus while their high biological diversity has been documented, the drivers of this diversity, and the diversity of ecosystem functions provided by differ portions of the Atlantic Rainforest landscape remain poorly understood.

We hypothesized that contrasts in elevation and topography drive diversity of soil nutrients and biomass across the Atlantic Forest (Edwards, 1977; Eisenlohr et al., 2013; Sanchez et al., 2013). Tree height and aboveground biomass (AGB) tend to decrease with elevation in MTFs (Weaver and Murphy, 1990; Kitayama and Aiba, 2002; Leuschner et al., 2007; Moser et al., 2011; Scaranello et al., 2012; Spracklen and Righelato, 2014), although this pattern is not universal (Raich et al., 1997; Unger et al., 2012; Culmsee et al., 2010; Alves et al., 2010). Soil characteristics also commonly vary with elevation. Upland soils often have higher carbon (C) and nitrogen (N) stocks in upland soils (Marrs et al., 1988; Townsend et al., 1995; Raich et al., 2006; Zimmermann et al., 2009; Moser et al., 2011; Vieira et al., 2011), in part because of lower temperature and thus litter decomposition rates (Kitayama and Aiba, 2002; Raich et al., 2006). Although the soil N stocks increase with elevation, N availability declines as a result of slower decomposition (Marrs et al., 1988; Tanner et al., 1998; Corre et al., 2010; Wolf et al., 2011). This pattern has been observed in the MTFs in Ecuador (Arnold et al., 2009; Unger et al., 2012), Borneo (Kitayama and Aiba., 2002) and though not in Puerto Rico (Silver et al., 2011).

Changes in soil characteristics with elevation are not restricted to C and N (Sanchez et al., 2013). In some MTF soils extractable pH decreases and aluminum (Al) concentrations increase with elevation (Marrs et al., 1988; Tanner et al., 1998; Schawe et al., 2007). High Al concentrations may be toxic to some plants species; consequently, this phytotoxicity may decrease plant growth at higher elevations (Rehmus et al., 2014). Several studies have documented decreasing soil cation content with elevation in the Bolivian Andes and Ecuadorian tropical forests (Grieve

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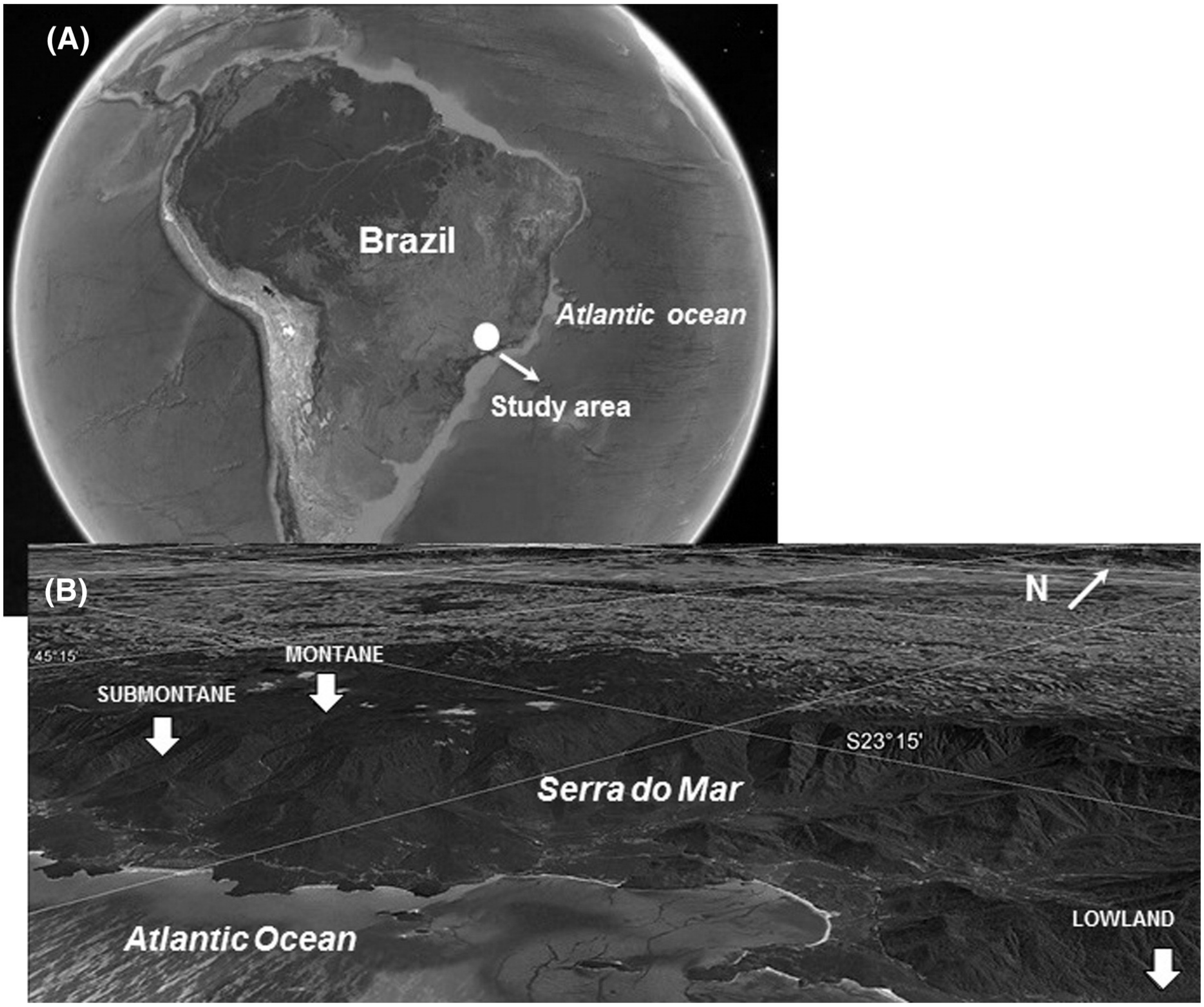

Fig. 1. Brazil map highlighting the State of São Paulo. The gray area in the State of São Paulo represents the *Serra do Mar* State Park. The circle represents the study area, and below the elevation range of soil sampling sites.

et al., 1990; Schawe et al., 2007; Wilcke et al., 2008; Soethe et al., 2008) perhaps as a result of rapid soil weathering and ferrolysis under high precipitation. However, as with nitrogen, this pattern is not universal, and some studies have found increasing soil cation contents with elevation. Fertile soils as high as 2500 m elevation in New Guinea have been cited as promoting high tree heights (Grubb and Edwards, 1982), some forested mountains in Ecuador show increasing concentration of soil cations and phosphorus (P) at higher elevations (Unger et al., 2010), and others have postulated that there is a general trend towards increasing nutrient capital with elevation (Marrs et al., 1988).

In light of these disparate trends, we described changes in soil characteristics along a 1000 m elevation gradient in the Serra do Mar, a large fragment of Atlantic Rainforest on the coast of São Paulo State, Brazil. In Serra do Mar, both above and below ground biomass (AGB and BGB) increase with elevation (Vieira et al., 2011; Alves et al., 2010). We hypothesized that soil nutrient content would increase with elevation in the surface mineral soil as a result of higher organic matter stocks, and the observation that both above and below ground biomass increase with elevation in the Atlantic Forest (Vieira et al., 2011).

Table 1
Basic information on the three sampling sites.

Site parameter	Forest type		
	Lowland	Submontane	Montane
Plot code	B, E	G, J	K, N
Topography	Gentle (10–30°)	Steep (>30°)	Steep (>30°)
Air temperature[b]	20 °C	19 °C	16 °C
Soil temperature[b]	20 °C	19 °C	15 °C
Precipitation	3050 mm		2300 mm
Forest type	Lowlands	Submontane	Montane
Forest biomass[a]	209 $Mg \cdot ha^{-1}$	254 $Mg \cdot ha^{-1}$	283 $Mg \cdot ha^{-1}$
Litter fall[b]	8.4 $Mg \cdot ha^{-1} \cdot yr^{-1}$	7.7 $Mg \cdot ha^{-1} \cdot yr^{-1}$	5.5 $Mg \cdot ha^{-1} \cdot yr^{-1}$
Rock type	Granite/gneisses	Granite/gneisses	Granite/gneisses

[a] Alves et al. (2010).
[b] Sousa Neto (2008).

Table 2
Components of variance (express in percent) attributed to difference between plots and elevation (forest types). Error is defined as the percentage of the variance that could not be explained by these two variables.

	H	P	Al	Ca	Mg	K	C	N	Sand	Silt	Clay
Plot	6.9	2.0	6.9	27.8	1.1	8.2	11.2	10.2	10.2	31.6	20.9
Elevation	28.9	16.0	28.9	9.3	59.0	0	6.1	6.3	6.3	39.1	30.8
Error	64.2	82.0	64.2	62.9	39.8	91.8	82.7	83.5	83.5	68.4	48.3