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A stand of trees does not a forest make: Tree plantations and forest transitions

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ABSTRACT

Global programs are calling to increase tree cover, including plantations, which supply global pulp and wood demand, energy, food, and carbon markets. Tree plantations that replace native forests, cultivated agriculture, or previously cleared land are essentially commodity crops with global market drivers, and do not provide the same ecosystem services as native forests. Nonetheless, they are counted as "forest" by global programs. We test whether 1) the forest transitions framework (FTF), which typically explains reforestation, adequately describes the socio-economic drivers of plantation establishment and 2) descriptions of the effects of land cover change on ecological processes are obscured when tree plantation and native forest classes are aggregated. We used longitudinal multi-temporal satellite imagery (1985–2001) to map and analyze plantation systems across a 35,853 km^2 area in southern Chile at the plantation frontier. As predicted by the FTF, plantations were established in foothills of predominantly agricultural watersheds rather than in watersheds dominated by native forests or in flat, agriculturally productive areas. Half of the plantations were planted on agricultural or cleared lands that were deforested years ago. Counter to predictions of the FTF, the other half of the plantations replaced native forests. Tree plantations were not associated with rural population loss; instead their establishment was related to the amount of potential usable land. We find that when native forests and tree plantation classes are disaggregated, land in coastal catchments that were converted to tree plantation is related to lower quality nearshore resources; analyses that aggregate plantations with native forests obscure this effect.

1. Introduction

Relatively new programs such as the Reducing Deforestation and Forest Degradation (REDD+) program of the United Nations Framework Convention on Climate Change (UNFCCC), and the clean development mechanism (CDM) of the Kyoto Protocol call for the increase in tree cover that includes both native forests and plantations (Gullison et al., 2007). Conservation scientists call for landscape change frameworks to direct these efforts (Angelsen and Rudel, 2013) and careful attention to the tree species and planting strategies that comprise these mitigation strategies because maximum rates of carbon sequestration may lead to unanticipated conservation outcomes (Putz and Redford, 2009). Tree plantations have become a major land use globally (Rudel, 2009; Lambin and Meyfroidt, 2010). Since 1989, wood products supplied from native forests have been declining, with plantations filling the gap of roundwood supply (Warman, 2014). According to higher projection estimates by the FAO, tree plantations, excluding palms, will account for ~7% of global forests by 2030, (Penna, 2010). Tree plantations increasingly meet the market demand for global pulp, energy, wood, food, and carbon storage (Sedjo, 1999; Berndes et al., 2003; Gullison et al., 2007; Gutierrez-Velez et al., 2011; Popp et al., 2011). Government subsidies have lead Brazil, Chile, China, India, and Russia to become important tree-plantation regions for wood pulp production (Sedjo, 1999; Barr and Cossalter, 2004; Bull et al., 2006; Zhang and Song, 2006). Since the late 1970′s, the global area of wood-pulp plantations has steadily increased, especially in the southern hemisphere (Sedjo, 1999) and tree plantations have expanded dramatically in Asian countries (Barbier et al., 2010). Pine (*Pinus* spp.) and eucalyptus (*Eucalyptus* spp.) plantations are the most commonly planted trees for wood and pulp (Sedjo, 1999), although people may also plant teak, poplar, acacia, and other trees such as palm and rubber (Gutierrez-Velez et al., 2011). Often these plantations are comprised of trees that are not native to the area

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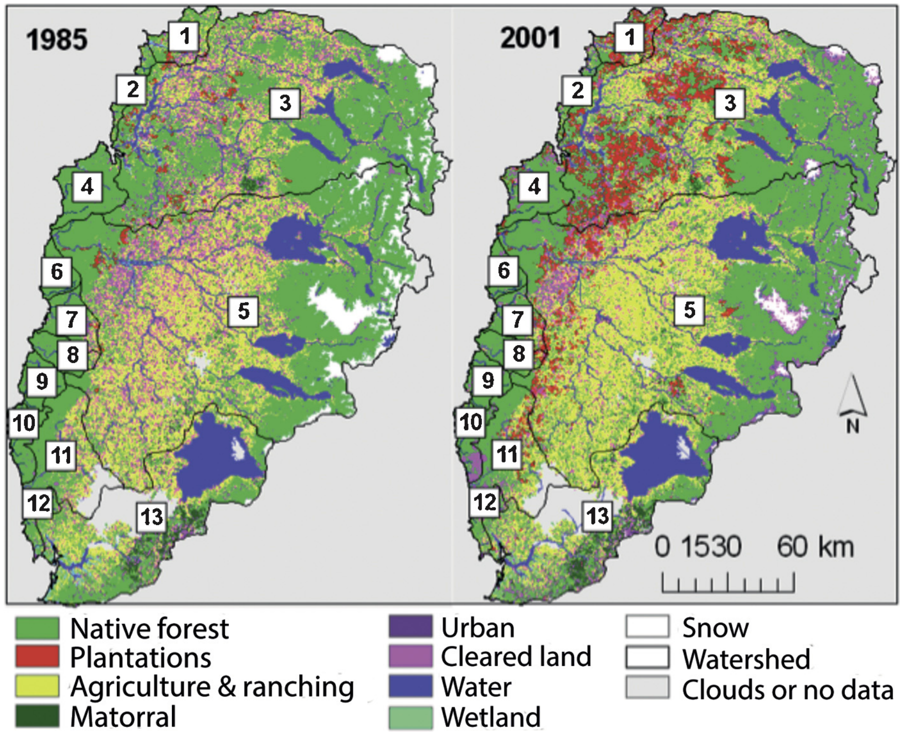

Fig. 1. Plantations were established predominantly on the foothills of agricultural watersheds, rather than watersheds dominated by native forest or flat agricultural lands. The supervised classification of October 5, 1985 (Landsat TM, path 233, rows 87–89) and November 29, 2001 (Landsat ETM, path 233, rows 87–89) images shows native forest, plantation, matorral (shrubland), agriculture, cleared land, sand, water, urban, snow, and wetland land cover/uses. The numbers in white boxes correspond to watersheds in Fig. 2. Overall accuracy in 2001 is 90% with a 0.90 kappa coefficient; average 1985 classification accuracy is 91% with a 0.90 kappa coefficient (see Appendix A for full accuracy assessment). The plantation watersheds are numbers 1, 3, 5, 7, and 11.

where they are established and likely do not represent the same drivers as reforestation of native forests.

1.1. Can the forest transition framework explain plantation establishment?

Forest-transitions research focuses on explaining natural, native forest regeneration (Rudel et al., 2005), although planted trees are included in some forest-transition studies (Mather, 1992; Mather, 2007; Farley, 2007; Grau et al., 2008; Meyfroidt and Lambin, 2008; Rudel et al., 2009; Lambin and Meyfroidt, 2010; Aide et al., 2012). This study contributes an analysis of an important case study to the growing research on tree plantations and forest transitions. The Forest Transitions Framework (FTF) explains many observed temporal and spatial patterns of native forest regrowth despite continued deforestation at the global level. According to the FTF, less-productive land becomes reforested as rural populations abandon their fields and migrate to urban areas where economic opportunities have grown (Mather, 1992; Rudel et al., 2005; Lambin and Meyfroidt, 2010). The FTF suggests that agriculture plays a role in tree-plantation establishment because tree-cover increases commonly occur on land previously cleared for agriculture as agricultural regions are concentrated and intensified on optimal lands (Mather, 1992; Rudel et al., 2005; Lambin and Meyfroidt, 2010). If the FTF explains tree plantation patterns, then we would expect tree plantations to develop in areas where rural farmers have moved to urban areas and abandoned their fields that regrow. We would also expect that tree plantation crops replace other agricultural crops or marginal agricultural lands, rather than native forests. Within the forest-transitions literature, Chile is often cited as a case in which tree plantations are established (Rudel, 2009). Chile was the world's sixth largest wood pulp exporting country by 1992 (Sedjo, 1999). In 2005, plantations comprised 2.1 million hectares or 13.4% of the total tree cover (INFOR, 2006). Using satellite image analysis, Echeverria et al. (2006) and Aguayo et al. (2009) concluded that mainly substitution – of native forests for plantation is occurring in central Chile. In contrast, Clapp concludes from interviews with small landholders that plantations in central Chile were a result of planting trees on lands that were previously agricultural areas (Clapp, 1995, 2001). Using geomorphology, soil characteristics, and road networks, Wilson et al. (2005) identified sites in southern Chile that would be vulnerable to plantation establishment; they assumed that most tree plantations were a result of direct substitution of native forest for tree crops.

1.2. Will aggregating tree-plantation and native-forest classes mask the conclusions drawn from land cover change analyses?

Tree plantations and native forests are different ecologically, so how does treating them as one class confound analyses and conclusions? In comparison to native forest, tree plantations are associated with lower biodiversity (Munoz et al., 1987; Vergara and Simonetti, 2004; Saavedra and Simonetti, 2005; Carnus et al., 2006) and biodiversity potential (Hall et al., 2012). Carbon sequestered in tree plantations established through substitution usually decreases (Fearnside, 1995; Glenday, 2006; Nosetto et al., 2006; Betts et al., 2007) and plantations were associated with lower carbon sequestration potential (Hall et al., 2012). Watershed hydrology changes when plantations are established because typically tree plantations have higher evapotranspiration rates than native forests or grasslands/cultivated lands, resulting in less water flow to catchment streams (Farley et al., 2005; Huber et al., 2008). Erosion and consequent sediment loading in streams are high at the onset of plantation establishment and after harvesting (Stevens et al., 1994; Oyarzun and Pena, 1995; Farley and Kelly, 2004; Oyarzun et al., 2007) and trees planted on higher slopes lead to higher erosion