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The drivers of tree cover expansion: Global, temperate, and tropical zone analyses

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ABSTRACT

This paper uses new, high resolution satellite-derived data to explore recent cross-national differences in expanding tree cover. Increases in tree cover have concentrated in nations with recent histories of extensive deforestation, humid climates, high crop yields, and small numbers of farm workers. The associations of expanded tree cover with high yields for cereal crops and small populations of cultivators suggests a dynamic, sometimes referred to as a forest transition, in which urbanization and industrialization promote a long-term expansion in tree cover on certain types of land. The association of tree cover gains with tree cover losses and humid climates suggests a second dynamic, a churning, treadmill-like production of wood products from lands subjected to recurring harvests of wood products followed by tree cover gains in the recently harvested areas. The forest transition dynamic suggests that many smallholders would allow tree cover to expand on their lands if payments for environmental services were available. The salience of the treadmill dynamic of tree cover losses followed by tree cover gains underscores the importance of questions about the implications of commercial tree monocultures for biodiversity, carbon sequestration, and social justice.

1. Introduction and rationale

As the destruction of tropical rain forests has proceeded over the past four decades, the significance of forest regeneration for global environmental change has increased. In places where forests regenerated, they protected watersheds, sequestered carbon, and restored some biological diversity to disturbed landscapes (Wright and Muller-Landau, 2006; Asquith et al., 2008; Grau et al., 2008; Meyfroidt and Lambin, 2011; Chazdon, 2014; Putz and Romero, 2014). The carbon sequestering capacity of regenerating forests, in particular, attracted the attention of policymakers because, by reducing CO_2 levels in the atmosphere, it would counter climate change. A better understanding of the forces that drive forest regeneration would facilitate the design of policies to accelerate forest regrowth. With this end in mind, this paper uses new remote sensing data to analyse the global and regional-scale drivers of tree-cover expansion.

Efforts to understand the dynamics that have driven tree cover expansion have been seriously handicapped during the past three decades by definitional and assessment issues (Chazdon et al., 2016). For example, increases in tree cover in a place can signal either natural forest regeneration or the establishment of tree plantation monocultures. While satellite observations of increases in tree cover have long been possible with early satellite imagery, as well as at increasingly larger scales since the advent of moderate-resolution MODIS imagery in 2000 (Hansen et al., 2002), the coarse resolution and/or limited spatial coverage of the satellite imagery made it difficult to detect regrowth reliably over time at large scales (Lucas et al., 1994; Lucas et al., 2000a,b; Sloan, 2012). These impediments to global-scale analyses of secondary forest cover were substantially reduced in 2013 when a team lead by Matthew Hansen (Hansen et al., 2013) released a global-scale data set of tree cover dynamics (loss and gain) derived from higher resolution Landsat images for 2000–2012.

In Hansen's maps a tree cover gain occurs when a satellite detects a canopy of >50% tree cover in a 30-m pixel that did not contain >50% tree cover in the previous year. As with other remotely-sensed definitions of tree cover gain, this definition lumps together a wide range of changes in tree cover. Increases

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in tree cover could involve either species rich, spontaneously-generated secondary forests on abandoned agricultural lands, agro-biodiverse forest gardens, recovering heavily logged forests, or commercial tree plantation monocultures. We refer to all such forests detected by the Hansen data as 'new tree covers'. We draw a further distinction between new tree covers subject to frequent perturbation and recovery such as cyclically logged forests and new tree covers that naturally regenerate on abandoned agricultural lands and represent longer-term increases in tree cover. The Hansen data do not permit the distinction between newly planted trees and spontaneously regenerated trees, but circumstantial evidence like the size of the commercial forestry sector in a nation or the locations of oil palm or short-rotation forestry concessions can be used to strongly infer whether or not planted trees or spontaneously regenerated trees make up most of the new tree cover in a country.[1]

The environmental services provided by the different types of new tree cover vary dramatically (Tropek et al., 2014). Particularly in the tropics, spontaneously generated second-growth forests support more diverse biota than tree plantation monocultures (Poorter et al., 2016). The effects of these trees on watersheds varies with the species composition and structural complexity of the new tree cover. *Eucalyptus* plantations, for example, reduce runoff from precipitation while spontaneously regenerated secondary forests may reduce fluctuations in the volume of runoff during rainy seasons (Samra et al., 2001). Trees, in spontaneous natural regeneration and even more so in high yield plantations, sequester carbon (Kirby and Potvin, 2007), so, in an era of climate change, they all provide at least one valuable environmental service. Regenerating forests sequester carbon at higher rates than do old growth forests, and the amounts of carbon sequestered in regenerating tropical forests are sufficient to offset most of the greenhouse gas emissions associated with tropical deforestation (Pan et al., 2011; Reich, 2011; Bongers et al., 2015). Particularly in steep topographies, the new tree cover improves watershed conservation by reducing soil erosion. The beneficial ecological effects of second-growth forests and agro-forests make it important to understand the mix of social and ecological forces that foster expansions of tree cover. This understanding should aid policymakers in drafting policies to promote tree cover expansion.

To understand how social changes, coupled with ecological forces, produce global scale landscape transformations, data sets must contain measures of both ecological and social variables at the same scale that, when combined, suggest socio-ecological dynamics that play out at regional and global scales. The ecological data in this instance come from Hansen's global scale remote sensing of tree cover gains and losses, with the changes in tree cover broken down into aggregates for each country. Comparable social data for countries comes from censuses of human activities conducted and reported by national governments. Variations from nation to nation in these social aggregates may suggest, when analysed alongside changes in forest cover, how social forces have spurred tree cover expansion in different sets of countries.

Using this mix of data, we describe the extent of new tree cover and assess explanations for the differential prevalence of these new forests across the global landscape. Given the importance of tropical forests in the provision of environmental services and the sharp declines in tropical forest cover over the past half century (Sloan and Sayer, 2015), it would be important to capture differences, if any, between the dynamics of tree cover expansion in tropical and temperate biomes. For this reason we carried out additional analyses of countries in each of these biomes. The paper begins with a discussion of theoretical approaches to understanding expansions in tree cover. Then we discuss measures for the variables and methods for analysing the data. We subsequently present the results from our analyses of new tree cover globally as well as in temperate zones and tropical zones. Finally, we discuss the implications of these findings for understanding and promoting tree cover expansion.

2. New tree cover: theoretical expectations

Global patterns of new tree cover reflect large scale changes in the shape and scale of human activities during the past two centuries. The morphology of human societies began to change during the 19th century when people began to reorganize themselves around industrial activities in cities. The scale of human activities also increased. Both the human population and the private enterprises that organized capitalist production grew tremendously in size, a change that observers have recently begun to refer to as 'the great acceleration' (Steffen et al., 2015). In this context new tree cover occurs across a range of situations that can be construed as a continuum that stretches from spontaneously regenerating forests without human intervention to planted forests that only spread through extensive human intervention. As outlined below, spontaneous regeneration has occurred in many fields in places experiencing urbanization, industrialization, and a decline in the extent of agricultural lands. These associated processes of land cover change are referred to as the forest transition (Mather, 1992; Mather and Needle, 1998). Human engineered forest plantations have become more common during the past forty years, particularly in the tropics, as logging firms have shifted from extracting old growth trees from a diminishing number of unexploited frontier forests to growing timber in forest plantations (Boyd et al., 2001; Marchak, 1995). The corporate leadership of these companies have designed these tree farms to produce an unending stream of forest products, so the metaphor of an out-of-doors assembly line operating like a treadmill captures the essential features of this productive process. Between the transitions with little human intervention and the treadmills with extensive human intervention, there are intermediate forms of new tree cover. For an example, many forest owners in the American South sell timber from their lands to pulp and paper companies, but they do not consider the income from timber sales to be the primary reason for owning forested lands and do not manage their forests for the sole purpose of generating revenue from timber sales (Butler, 2008). To define the end points of the continuum between forest transitions and the forest product treadmill, we outline below the dynamics that drive the transitions and the treadmills.

2.1. New tree cover in old agricultural zones: a forest transition

In some situations landscapes undergo historical transitions in which forests first decline and then expand in extent when agriculture contracts to selected, relatively fertile lands. Sometimes referred to as 'the forest transition' (Mather, 1992; Mather and Needle, 1998), this historical process has entailed, at first, the rapid destruction of forests and expansion of agricultural lands. Landless peasants from densely settled regions of Southeast Asia or Latin America, often with state sponsorship, moved during the 1970s and 1980s into predominantly forested regions and laid claim to land by clearing the forests (Rudel, 2005). A large fraction of these recently cleared lands reverted to forest because, as in the eastern Brazilian Amazon (Moran et al., 2000; Vieira et al., 2014), their new owners discovered that the lands did not produce as well as anticipated

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[1] Globally, naturally regenerated forests are approximately ten times greater in extent than planted forests. Only in the Far East do planted forests begin to approach naturally regenerated forests in extent. See Table 2.9 in the FRA 2010 report (FAO, 2010). .