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Forest transition in developed agricultural regions needs efficient regulatory policy

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ABSTRACT

The shift from net forest loss to gain—*forest transition*—has been associated variously with economic development, market-driven reforestation, forest policy, and globalization. Evidence shows that governments can expedite forest transition, although economic and institutional failures can distort policy incentives. This study addresses the paucity of spatially explicit empirical research on the robustness of the forest transition hypothesis in a developed country context and identifies factors that may hasten, delay, or even reverse forest transition. We applied spatial-econometric analysis to high-resolution forest cover, climatic, socioeconomic, physiographic, and State-jurisdiction data for the Australian intensive agricultural zone from 1988 to 2014. While environmental and physiographic factors explained the spatial distribution of forests, net forest cover change was significantly associated with trends in farm-output prices inducing deforestation in Queensland, the State with less effective land clearance regulations. Changes in land clearing regulations in Queensland were significantly associated with the national forest cover trends that resulted in forest transition in Australia around 2008. Yet when land clearing regulations and their enforcement were subsequently relaxed in 2012, significant forest cover loss was once again observed in that State, particularly in remnant forests. We conclude that if forest regulatory protection is not effective, net forest loss could resume or increase, even in developed countries, in response to growing incentives for forest conversion to agriculture.

1. Introduction

Agricultural expansion in recent decades has resulted in a significant net loss of forest cover in tropical and sub-tropical regions (Gibbs et al., 2010; Hansen et al., 2010). Over the same period, net gains in forest cover have occurred in boreal and temperate forests, tropical savannahs, and shrublands (Liu et al., 2015). Although some of those gains have been attributed to carbon dioxide fertilization and climate change (Zhu et al., 2016), market and governmental incentives are also important drivers of net forest expansion (Mather, 2007). The switch from net forest loss to gain is called *forest transition* (Mather, 1992). This process has been documented in both developed (Mather, 1992; Rudel et al., 2005) and developing countries (Mather, 2007; Redo et al., 2012), allowing the identification of multiple non-exclusive and often overlapping pathways to forest transition. For instance, the *economic development pathway* relates rural to urban migration, increasing agricultural input productivity and efficient land governance with land-sparing resulting in net forest gain (Mather, 1992; Redo et al., 2012; Rudel et al., 2005). The *forest scarcity pathway* is associated with market-driven expansion of forest plantations and forest conservation and expansion policy to address growing social preferences and pressures for increased provision of forest ecosystem services (Lambin and Meyfroidt, 2010; Mather, 2007; Rudel et al., 2005). The *State-led pathway* involves forest policy to address issues unrelated to the forestry sector (e.g., protection of aboriginal tribes living in forested regions, or promotion of eco-tourism) (Lambin and Meyfroidt, 2010). Net forest gains achieved by the displacement of deforestation to other countries through international trade or by reduced land pressures due to

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international remittances to rural regions represents the *globalization pathway* (Lambin and Meyfroidt, 2010; Meyfroidt et al., 2010). The institutional, socioeconomic, and environmental conditions associated with these pathways are usually complementary, yet their presence does not guarantee forest transition. Market, policy, and institutional failures can delay transition (Barbier et al., 2010)—e.g., some States in the USA lagged behind others, not reaching forest transition until the early 2000s (Kauppi et al., 2006). In recent decades, parts of North America, Europe and Australia—affluent regions with strong land-use governance—have experienced substantial net forest cover loss at rates comparable to those observed in the tropical forests of developing nations (Hansen et al., 2013; Hansen et al., 2010; Kauppi et al., 2006). Emerging evidence portends net forest reductions—potentially even in regions where forest cover has until recently remained stable or increased (Ceddia et al., 2013; Hansen et al., 2010)—as global population grows and becomes more affluent, diets change, and demand for food and biofuel production intensifies (Laurance et al., 2014).

In this paper, we examined factors that may hasten, delay, or even reverse forest transition in a developed country experiencing overlapping processes associated with the multiple pathways to forest transition. First, we assembled a unique, high-resolution spatiotemporal dataset of forest cover, and human and environmental variables influencing forest cover change in Australia's intensive agricultural region (Fig. 1) during the period 1988–2014. We then investigated the occurrence of forest transition and, by applying spatial panel econometric methods, quantified the influence of various biophysical, socioeconomic, and institutional factors on pixel-level forest cover dynamics. Additionally, we discuss the implications of the results for forest transition processes, and the relevance of high-resolution data and the joint analysis of forest cover gains and losses to better inform forest policy and forest conservation strategies at multiple scales.

2. Materials and methods

2.1. Australian forests

Consistent with the Australian definition of forest (National Forest Inventory, 1998), we defined forest cover as land with at least 20% of canopy cover—either primary or secondary vegetation—with potential to reach at least two meters in height (Lehmann et al., 2013). Under this definition land that has temporarily lost tree cover is still considered as part of the forest estate even if the vegetation has not reached the height threshold during the time of data collection (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2013). Australia has approximately 125 million - hectares (Mha) of forest, comprising approximately 3% of the world's forests and ranking seventh in terms of forested area by country (Australian National Greenhouse Accounts, 2013). Most of this forest cover is native, with only 2 Mha of industrial plantations (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2013). Around 55% of the Australian native forests are managed under long-term leased or privately owned land, 35% are publicly owned and managed and around 10% are owned and managed by indigenous groups (Kanowski, 2017). Around one-third of the privately managed forests are located in the intensive agricultural region. Forest loss and fragmentation has had large negative effects on bird, small mammal, reptile, and plant diversity in Australia (Bradshaw, 2012). Deforestation has also constituted an important source of greenhouse gas emissions accounting for around 22% of Australia's emissions in 1990 and 7% in recent years (Australian National Greenhouse Accounts, 2013; Bradshaw, 2012).

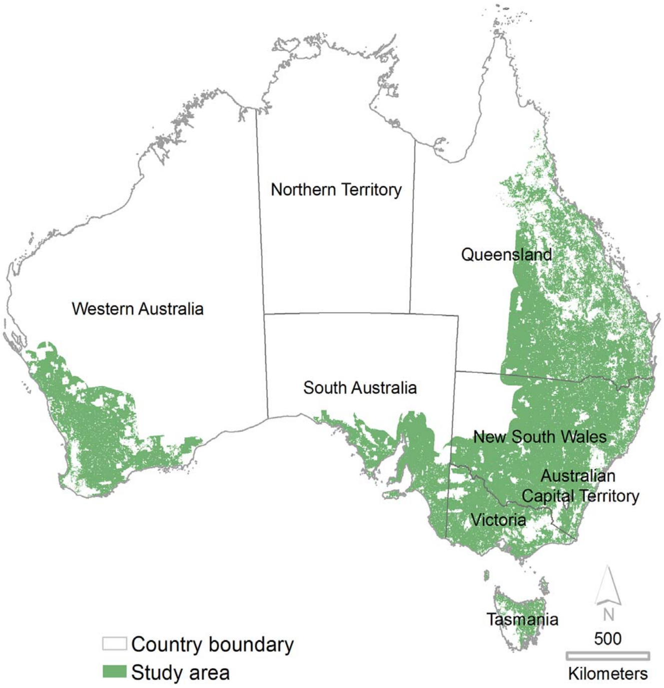

Fig. 1. Study area. The study area is net of protected land, hydrological features, urban areas, fire scars and other land types not influenced by landowners' decisions.

2.2. Forest cover index data

We used data from the Australian National Carbon Accounting System – Land Cover Change Program (NCAS-LCCP) which consists of a forest/non-forest classification at 25-m resolution for 19 epochs (1988, 1989, 1991, 1992, 1995, 1998, 2000, 2002, 2004, and annually from 2005 to 2014). This forest cover mapping was based on the supervised classification of > 7000 Landsat MSS, TM and ETM + images and validated using around 800 historical aerial photographs, 1000 IKONOS images, expert knowledge, ground-based surveys and forest plantation information (Caccetta et al., 2012). Global errors were around 3% for observations identified as *definite* forest or non-forest, and 12% including *not well-identified* observations (Caccetta et al., 2012). To further increase the accuracy of the data we applied transition rules to identify and remove temporary (one and two period) forest cover change that deviated from long-term forest cover dynamics at the pixel level which were illogical on both economic and tree-physiology grounds (Marcos Martinez and Baerenklau, 2015).

We focused our analysis on Australia's intensive agricultural region which accounts for > 99% and 92% of the national gross value of crops and livestock, respectively (Marcos-Martinez et al., 2017). Protected areas, hydrologic features (e.g., rivers, lakes), and other non-agriculture/forest land (e.g., urban areas, roads) within such region were removed from the forest cover dataset along with forest cover change caused by wildfires using fire-scar mapping (Fig. 1). The binary 25 m resolution forest/non-forest data was used to compute 1.1 km grid cell resolution forest cover index layers that represents the proportion of land in forest status during each observation year. The resulting dataset consists of 1.38 million observations per epoch, totaling > 26 million data points. This forest cover index value was used as the dependent variable for our study of net forest cover change and forest transition.

2.3. Explanatory variables

Spatiotemporal data were assembled on a wide range of biophysical, socio-economic, and institutional factors that literature shows influence forest cover change (Ferretti-Gallon and Busch, 2014) (Supplementary material, *SM*, Table S1). We grouped those variables into four categories: 1) temporally invariant, spatial (e.g., soils, land tenure); 2) spatially and temporally varying (e.g., climate); 3) spatially invariant, temporal (e.g., market prices); and 4) binary indicators and interaction