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The extent of edge effects in fragmented landscapes: Insights from satellite measurements of tree cover

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ABSTRACT

Due to deforestation, intact tropical forest areas are increasingly transformed into a mixture of remaining forest patches and human modified areas. These forest fragments suffer from edge effects, which cause changes in ecological and ecosystem processes, undermining habitat quality and the offer of ecosystem services. Even though detailed and long term studies were developed on the topic of edge effects at local scale, understanding edge effect characteristics in fragmented forests on larger scales and finding indicators for its impact is crucial for predicting habitat loss and developing management options. Here we evaluate the spatial and temporal dimensions of edge effects in large areas using remote sensing. First we executed a neighborhood pixel analysis in 11 LANDSAT Tree Cover (LTC) scenes (180 × 185 km each, 8 in the tropics and 3 in temperate forested areas) using tree cover as an indicator of habitat quality and in relation to edge distance. Second, we executed a temporal analysis of LTC in a smaller area in the Brazilian Amazon forest where one larger forest fragment (25,890 ha) became completely fragmented in 5 years. Our results show that for all 11 scenes pixel neighborhood variation of LTC is much higher in the vicinity of forest edges, becoming lower towards the forest interior. This analysis suggests a maximum distance for edge effects and can indicate the location of unaffected core areas. However, LTC patterns in relation to fragment edge distance vary according to the analyzed region, and maximum edge distance may differ according to local conditions. Our temporal analysis illustrates the change in tree cover patterns after 5 years of fragmentation, becoming on average lower close to the edge (between 50 and 100 m). Although it is still unclear which are the main causes of LTC edge variability within and between regions, LANDSAT Tree Cover could be used as an accessible and efficient discriminator of edge and interior forest habitats in fragmented landscapes, and become invaluable for deriving qualitative spatial and temporal information of ecological and ecosystem processes.

1. Introduction

In tropical fragmented forests, a rich amount of research has focused on the ecological process changes that occur in the edges of forest fragments (Haddad et al., 2015; Ibáñez et al., 2014; Laurance et al., 2011, 2006; Wade et al., 2003). Due to microclimatic changes such as higher light incidence, reduced humidity and higher temperatures (Camargo and Kapos, 1995), the forest structure in edges is remarkably different from interior forest (Oliveira et al., 2008). Edge tree communities are more similar to early successional stages, with larger abundance of pioneer species, and low recruitment of large-seeded shade tolerant groups (Tabarelli and Lopes, 2008). Trees in these areas suffer from increased mortality, especially in the emergent stratum (Oliveira et al., 2008), resulting in lower aboveground carbon stocks in edges (Dantas de Paula et al., 2011). The continuing degradation of edges in recently fragmented forests presents a challenge for the control of carbon emissions (Chaplin-Kramer et al., 2015; Pütz et al., 2014). Even though global forest emissions have decreased by over 25% between the period 2001–2010 and 2011–2015 due to decline in deforestation rates, emissions due to forest degradation have more than doubled, and now represent one-quarter of total forest emissions (FAO, 2015), persisting especially in poor tropical countries (Sloan and Sayer, 2015). This means strategies to monitor forest degradation will become more relevant as deforestation rates decrease.

The spatial scale in which edge effects occurs vary from 10 m, in case of reduced density of fungus fruiting bodies, to more than 1000 m in the case of changes in plant phenology, increased fire

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frequency and weed invasion, although most changes happen up to the 200 m distance range (Broadbent et al., 2008; Laurance et al., 2002). The temporal scale has also been observed, and the transition from an interior into an edge community at least 5 years (Laurance et al., 2002), although simulations suggests changes in stem number and biomass content can take up to 100 years (Dantas de Paula et al., 2015). The temporal dimension of fragmentation is important to note, because changes can take several years to manifest (Ibáñez et al., 2014). Therefore, three “debts” of recently fragmented forests have been identified (Haddad et al., 2015): the “extinction debt”, where loss of forest species takes more than 10 years to reach 50% of previous pristine areas; the “immigration lag”, where fewer species arrive in remote areas; and “ecosystem function debt”, described as delayed changes in nutrient cycling and to plant and consumer biomass.

However, these debts still predict that edges will become degraded in relation to core areas. Therefore, specific observations have been reported for several biotic and abiotic variables—for example, edges have up to 36% less biomass than interior forests (Laurance, 1997). In spite of this, when samples, not average values are considered, some forest edge areas measurements show great variation and retain in some cases core area conditions (Ibáñez et al., 2014; Pinto et al., 2010), as can be seen with aboveground carbon content in Fig. 1.

Recent advances in remote sensing have been particularly useful for conservation biology, providing access to large amounts of data in short time, and permitting researchers to work in large scale with detail (Kerr and Ostrovsky, 2003). A particularly interesting dataset is the LANDSAT Tree Cover, a global 30 m resolution rescaling of the MODIS (Moderate Resolution Imaging Spectroradiometer) vegetation continuous fields (VCF) product (Sexton et al., 2013). The original MODIS VCF, with 250 m resolution, is a classification of annual global tree cover (each pixel having a value of 0–100%), and now is in its 5th version with yearly data from 2000 to 2010. It was developed in order to substitute conventional methods of categorical land classifications, which suffer from the imposition of arbitrary thresholds between classes (DeFries et al., 1995). The resulting tree cover pixel values, represent light penetration to the ground, as opposed to simple “crown” cover (Townshend et al., 2011). Several global and regional studies exist evaluating vegetation patterns of the MODIS VCF product (Hansen et al., 2005; Montesano et al., 2009; Ranson et al., 2011), its advantages and limitations (Hansen et al., 2005), and applicability in monitoring using ground validation data (Hansen et al., 2008a,b). Higher errors for MODIS VCF estimation of tree cover can be expected for values of tree cover lower than 20% (Jeganathan et al., 2009) The 30 m LANDSAT VCF dataset is a further improvement of the original MODIS product, and was created using 2000–2005 LANDSAT images and MODIS’ own Cropland Layer in order to increase the accuracy of agricultural areas. Also, validation with high resolution LIDAR data was used, having a post-calibration RMSE of 9.4% compared to 13.5% in MODIS VCF estimates. (Sexton et al., 2013).

Tree cover is considered to be an important forest descriptor—it is has been used for calculations of absorbed photosynthetically active radiation (FPAR), albedo, canopy conductance, roughness, photosynthesis and transpiration, net primary production, and carbon and nutrient dynamics (DeFries et al., 1995). Furthermore, tree cover affects patterns of animal diversity (Harvey et al., 2006), large predator habitat preference (Conde et al., 2010), bird foraging dynamics (Trainor et al., 2013), and soil water balance (Joffre and Rambal, 1993). Also, tree cover influences human property value (Sander et al., 2010), and may help to indicate areas rich in the offer of environmental services (Huang et al., 2009). Finally, in regard to fragmented forests, tree cover has been identified as one of the most significant variables driving the microclimatic patterns of forest edges (Pinto et al., 2010).

One of additional goals of having large-scale information on the environment in fragmented forests is identification of areas for conservation (Groves et al., 2002; Poiani et al., 2000; Sanderson et al., 2002). Since the main focus for conservation biology is the preservation of endangered species, their occurrence, or of indicator species that signal preserved habitats, is the main pointer that an area should be protected. In the absence of those (or if indicator species are large area ranging carnivores), forest fragment size is used as criteria (Poiani et al., 2001), being larger fragments preferred. This makes sense because larger fragments have larger interior to edge ratios (less prone to edge effects) (Metzger and Décamps, 1997), can meet more species requirements in terms of area and heterogeneity(Martensen et al., 2012) and have more area isolated from human disturbances (Tabarelli et al., 2004; Veríssimo et al., 1995). However, several studies have pointed out the importance of very small (<100 ha) fragments in large-scale conservation schemes, due to their role in the increase of connectivity, use as stepping stones, and simply because in many cases a very large part of the remaining forest area is contained in the small fragment category (Hernandez-Ruedas et al., 2014; Ribeiro et al., 2009). Most approaches to conservation areas identification however, are limited due to the fact that no information on habitat quality within forest patches is included. In those cases fragment delimitations can include secondary and degraded forests, or patches occurring in poor soil types which are of suboptimal conservation value (Ribeiro et al., 2009).

In this work, we aim to observe how tree cover fraction changes in relation to forest edge distance, a measurement that is crucial to understand the ability of fragmented landscapes to retain biodiversity and ecosystem services. We use as an indicator of forest conditions LANDSAT Tree Cover (LTC) (Sexton et al., 2013), which although is indirect, can provide much more data and in a larger scale than field measurements of biotic variables. For this we analyzed 11 LTC images from different fragmented forest regions around the world in order to answer the question: How does LTC vary in relation to edge distance? It is crucial to use for this analysis the highest resolution sensors available, since edge effects are known to occur in the 100 m range (Laurance et al., 2002), and many sensors used for large scale studies have 300, 500 or 1000 m resolution (Chaplin-Kramer et al., 2015; Loveland et al., 2010; Pérez-Hoyos et al., 2012; Saatchi et al., 2011). Also, since many studies on edge effects (e.g. carbon loss in fragments) define a fixed distance for forest edges e.g. (Pütz et al., 2014), it is important to investigate the distance threshold beyond which edge effects do not affect our measured variable.

2. Materials and methods

2.1. Analysis of edge effects on LANDSAT Tree Cover

We selected 11 complete LANDSAT Tree Cover (LTC) scenes (each 170 × 185 km, with 30 m resolution) from several fragmented forests around the world (Fig. 2) using the Global Land Cover Facility (http://glcf.umd.edu/data/) website, for the year 2000. The 11 scenes are home to 3 different forest types: Closed broadleaved deciduous forest, Closed to open broadleaved evergreen or semi-deciduous forest, Closed to open mixed broadleaved and needleleaved forest, as categorized by the GLOBCOVER 2009 v2.3 map (http://due.esrin.esa.int/page_globcover.php). We calculated statistical information for each fragmented landscape and present them in Table 1. This illustrates the diverse conditions of our selected scenes (Forest extent varying from 1.86% in scene 7 (Northeastern Brazil) to 56.89% in scene 11, Northern Brazil 2). As an example, in Fig. 3 LTC values for two sites in Brazil are shown. In each selected scene, we defined forest fragments, using a >30%