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Research Paper

Measuring forest fragmentation using multitemporal forest cover maps: Forest loss and spatial pattern analysis in the Gran Chaco, central Argentina

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HIGHLIGHTS

- Forest loss and spatial pattern changes by sampling multi-temporal land cover maps.
- Pattern metrics show index-specific relationships with forest cover.
- Significant forest loss occurs along with significant changes in pattern metrics.
- Useful information for land management and fragmentation-prevention issues.

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ABSTRACT

Forest fragmentation is a landscape-level process that consists of two interdependent components: forest loss and spatial pattern changes to which species respond differently. Efficient programs to conserve native biodiversity require a sound understanding of the relation between forest cover and the spatial pattern of forest fragments, but these issues remain almost unknown for subtropical ecosystems. We examine the forest fragmentation of the Gran Chaco in central Argentina over the last 30 years. In particular, we quantify forest loss and spatial pattern changes using random sampling techniques on multi-temporal forest cover maps (1979, 1999 and 2010). We analyzed forest fragmentation according to the following steps: (i) selection of fragmentation pattern indices (PIs), (ii) sampling on forest cover maps and PIs calculation, (iii) statistical comparison by bootstrapping, and (iv) trajectory analysis. During the last three decades, forest cover declined dramatically (~90%) and the selected pattern metrics (MPS, PD, ED) varied significantly ($p < 0.05$). The results depict a devastating situation of Gran Chaco forests with a progressive reduction to few small fragments during the last decades. Furthermore when forest loss exceeded the ~50% of the total land area, the temporal trajectories of the selected PIs underwent an abrupt change. Distinguishing habitat spatial pattern changes from forest loss over time supports the identification of specific conservation actions and provide the basis to establish the lower threshold of forest cover and the more effective arrangement of fragments necessary to mitigate the fragmentation effects.

1. Introduction

Forest ecosystems have played a major role in human history, and forest fragmentation has accompanied population growth and development throughout the world for thousands of years (Food and Agricultural Organization of the United Nations, 2012). The extent of fragmentation, which has affected many natural forests

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worldwide, constitutes one of the most serious causes of biodiversity loss, which in turn greatly influences ecosystem structure and function. Recent studies have indicated that fragmentation has several negative (Trombulak et al., 2004) and long-lasting (Flaspohler et al., 2010; Turner, 1996) environmental and ecological consequences: it affects ecosystem functions, such as hydrological cycles and soil dynamics (Rudel et al., 2005), climate regulation (Houghton et al., 2000; Nabuurs, Schelhaas, Mohren, & Field, 2003) and biodiversity (see Fahrig, 2003 for a review).

According to the patch-corridor-matrix model (Forman, 1995), forest fragmentation can be seen as a landscape-level process in which a large, intact area of a single forest type is progressively subdivided into smaller, geometrically altered and isolated patches (Fahrig, 2003; Forman & Godron, 1986; McGarigal, Cushman, & Regan, 2005). Forest fragmentation consists of two components: forest loss and changes in the spatial pattern (i.e. pattern metrics) (Fahrig, 2003; Long, Nelson, & Wulder, 2010; Neel, McGarigal, & Cushman, 2004). Forest loss and spatial pattern changes are the two most important factors in the current species extinction event at global scale (Fahrig, 1997; McGarigal et al., 2005). In response, there is a growing mandate among natural resource managers to evaluate the impacts of proposed management actions on habitat fragmentation (Long et al., 2010; Wang, Blanchet, & Koper, 2014). Thus, new guidelines to help managers to understand the many complex issues involved in the assessment of habitat fragmentation are urgently needed. For instance, if in a given landscape forest loss results in a constant number of smaller patches, then fragmentation effects on biodiversity are due to forest loss alone. Only when the number of patches increases by the breaking apart of forests do we find that both forest loss and spatial pattern (decreasing size and increasing isolation of forest patches) are involved. On the other hand, when forest amount is constant over time, changes in spatial pattern generally has either no effect or a negative effect on forest species survival (Fahrig, 1997; Gavish, Ziv, & Rosenzweig, 2012).

The Gran Chaco, which is among the largest seasonally dry subtropical forests in the world, (ca. 1,200,000 km^2), occurs in Argentina, Paraguay and Bolivia (Bucher, 1982; Zak, Cabido, Cáceres, & Diaz, 2008). It comprises one of the few areas worldwide where the transition between the tropics and the temperate belt does not occur in the form of a desert but as semi-arid forests and woodlands (Morello & Adamoli, 1974; Prado, 1993). These subtropical seasonally dry forests are characterized by a specific vegetation and fauna that determines consistent biodiversity values (Cagnolo, Cabido, & Valladares, 2006; Molina, Valladares, Gardner, & Cabido, 1999; Torrella, Ginzburg, Adámoli, & Galetto, 2013). Moreover, these forests provide numerous ecosystem services (Conti & Díaz, 2013) that are necessary for the subsistence of local communities and the regional economy (Cáceres, 2014; Zak et al., 2008). Despite many outstanding features that make these complex ecosystems worthy of protection, the Chaco forest is a poorly represented ecoregion in the Argentinean and South American protected area systems (Izquierdo & Grau, 2008; Matteucci & Camino, 2012). Furthermore, the current legal regulation for the region, which is crucial for generating practices to mitigate the impacts of forest fragmentation, is liberal and permissive, thereby promoting deforestation (Mastrangelo & Gavin, 2012; Torrella et al., 2013). The generalized expansion of agriculture, driven by global trends in technology and soybean markets (Grau, Gasparri, & Aide, 2005) and by global changes in precipitation regimes (Hoyos et al., 2013; Zak et al., 2008), has promoted the clearing of approximately 6 million ha of native forest over the last three decades (Grau & Aide, 2008; Torrella et al., 2013). In particular, the generalized expansion of anthropic land uses are related to the sharp drop of the Gran Chaco natural ecosystems which lead the exiting protected areas to a worrying ecological isolation (Matteucci & Camino, 2012). Although efficient programs to conserve forest biodiversity in fragmented landscapes require a sound understanding of the evolution and spatial distribution of the size of forest fragments over time (Zuidema, Sayer, & Dijkman, 1996), these issues remain almost unknown for the Gran Chaco forests. Regional patterns of forest fragmentation have been recently described in different sectors of the Gran Chaco (e.g., Grau et al., 2005; Hoyos et al., 2013; Zak et al., 2008) but fragmentation studies accounting of the relation of forest loss and spatial pattern changes over time are still necessary.

Thus, the purpose of this paper is to examine the forest fragmentation of the Gran Chaco over the last 30 years accounting for the interdependencies between forest loss and spatial pattern changes. The research, based on multi-temporal land cover maps (1979, 1999 and 2010) of central Argentina addressed the following questions: (i) How did forest cover change? (ii) How did forest spatial pattern vary? (iii) Which is the relative importance of forest loss and spatial pattern on the fragmentation process?

In particular, we quantify forest loss and spatial pattern changes using random sampling techniques on multi-temporal maps followed by a bootstrapping significance test (Fortin, Jacquez, & Shipley, 2012; Manly, 2006). In order to investigate the relationship between forest loss and spatial pattern changes over time we built specific bidimensional 'relationship spaces' (*sensu* Long et al., 2010) in which the variation of spatial pattern metrics (e.g. mean patch size, patch density, edge density) were plotted against different levels of forest cover. We assumed that the relative importance of forest loss and spatial pattern varies through space and time. By identifying the role of forest cover and configuration changes, we contribute to the in-depth description of the process of fragmentation of the Gran Chaco over the last 30 years and we provide the basis for the formulation of a scientifically sound hypothesis about their effects on biodiversity. For instance, specific thresholds of forest cover could be crucial in determining temporal changes on pattern metrics, which might promote irretrievable losses on forest biodiversity and functionality. By interpreting the observed forest cover and spatial pattern changes, and their non linear relationships we contribute to stress the ecological value of the remaining forest patches in order to prioritize conservation efforts in this fragile and highly vulnerable ecosystem.

2. Material and methods

2.1. Study area

The study area is located at the southern extreme of the dry Chaco, to the northeast and northwest of Cordoba Province, in central Argentina (Fig. 1), and it belongs to the Chaco Phytogeographical Province (Cabrera, 1976). Its lowlands were formerly dominated by *Aspidosperma quebracho-blanco* Schlecht and *Schinopsis lorentzii* (Cris.) Engl. subtropical seasonally dry forests (Bonino & Araujo, 2005; Zak & Cabido, 2002). At present, the non-cultivated area is covered mostly with secondary semi-deciduous forests and shrub lands, alternating with patches of old-growth forests and open shrub lands. The plant communities in the arid and semi-arid Chaco of Cordoba are known in detail from the works of Cabido, Acosta, Carranza, and Diaz (1992), Cabido, González Albarracín, Acosta, and Díaz (1993), Cabido, Manzur, Carranza, and González Albarracín (1994), Carranza, Cabido, Acosta, and Páez (1992) and Zak and Cabido (2002). While forest loss and conversion have affected the species richness of both plants and animals (Cabido et al., 1994; Gardner, Cabido, Valladares, & Diaz, 1995), well-conserved forest patches have been reported to comprise the highest alpha diversity in the area (Cagnolo, Valladares, Salvo,