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Modelling land use changes for landscape connectivity: The role of plantation forestry and highways

Soledad Nogués*, Alejandro Cabarga-Varona

GEURBAN Research Group, Dpt. of Geography, Urban and Regional Planning, School of Civil Engineering, University of Cantabria, Av. Los Castros, 44, 39005 Santander, Spain

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ABSTRACT

Landscape connectivity is a key aspect for the maintenance of biodiversity and ecosystem viability. Nowadays, the competition between economic development and nature conservation is intense. In most territories natural vegetation is being replaced by exotic tree plantations, which have a better performance in terms of timber productivity but often, a lower ecological value. We evaluated potential natural forest connectivity improvement in the Cantabria region (Northern Spain) through two main actions: protection of environmentally valuable forest areas, and reforestation with indigenous species of those patches of exotic plantation trees with a particularly important role for the connectivity of the forest network. We established a variety of scenarios to calculate least cost paths, considering the presence or absence of plantation forestry and highways to examine connectivity. Then, we applied two habitat availability indices (integral index of connectivity and probability of connectivity) attending to different dispersal distances. Our analyses show a great potential for improving connectivity using plantation forests in the natural forest network, and a dramatic impact of the highway in the north–south connectivity of the study area. Based on these results, we identified those patches of plantation forest and natural forest that are more important for the maintenance of overall landscape connectivity, and propose their protection or conversion through reforestation. The final proposed network constitutes a larger and better connected natural forested landscape than the existing one.

Introduction

Connectivity can be synthesised as the degree in which landscape facilitates or impedes species movements and other ecological flows (Rubio & Saura, 2012; Taylor et al. 1993), and is one of the key factors maintaining the ecological functions of forests (Liu et al. 2014a). When forests are fragmented, the pattern of spatially structured habitats is modified and the movement of dispersing individuals may be constrained, hampering biodiversity conservation (Laita et al. 2010; Saura & Torné, 2009). This is in fact the case for many forest and ground-dwelling species (Pascual-Hortal & Saura, 2006, 2008), whose habitat availability has been severely altered due primarily to human actions. Indeed, mosaics of landscape patches can have a natural origin, but are mainly caused by anthropogenic activities, such as plantation forestry, agricultural intensification, road network, or urbanization (Di Giulio et al. 2009; Fu et al. 2010; Li et al. 2010; Liu et al. 2008, 2011, 2014b; Szabó et al. 2012; Yu et al. 2012). In highly populated areas, landscape fragmentation limits species survival to the existence of connectivity between spatially separated populations (Fischer & Lindenmayer, 2007; Kramer-Schadt et al. 2004).

Deforestation is one of the activities inflicted by humans which has the most influenced landscape fragmentation (e.g. Fearnside, 2005; Harper et al. 2007; Skole & Tucker, 1993). Clearance has sometimes been aimed at the substitution of native tree species with fast-growing ones, often exotic. These new species contribute significantly to the economic growth of many regions as a result of the derived benefits of timber exploitation and the functions that they provide as forest habitats (see e.g. Brockerhoff et al. 2003, 2005; Carnus et al. 2006; Humphrey et al. 2000). However, they may also induce substantial changes in natural ecosystems and habitat structure (Calviño-Cancela et al. 2012; Fabiao et al. 2002; Poore & Fries, 1985) and it is usually true that natural forests offer

* Corresponding author at: Dpt. Geografía, Urbanismo y Ordenación del Territorio, E.T.S. Ingenieros de Caminos, Canales y Puertos, Universidad de Cantabria, Av. Los Castros 44, 39005 Santander, Spain. Tel.: +34 942201780; fax: +34 942201703.
E-mail addresses: soledad.nogues@unican.es (S. Nogués), alejandrocabarga84@gmail.com, cabargaa@unican.es (A. Cabarga-Varona).
URL: http://grupos.unican.es/geurban/ (A. Cabarga-Varona).

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better quality habitats for native forest species than plantation ones (Brockerhoff et al. 2008).

Plantation forests can enhance indigenous biodiversity by improving connectivity between natural forest remnants (see e.g. Brockerhoff et al. 2008 and references therein). In fact, some plantation forests can be assimilated to natural ones when their management is sustainable, and is allowed to acquire "old-growth" conditions (Humphrey, 2005). On the other hand, when plantation forestry is very intensive, with short rotations and high timber productivity performance, plantation patches with a key role in network connectivity are eventually transformed into autochthonous vegetation forest. Thus, previously existing plantations can benefit the restoration of natural forests, accelerating natural recovery by modifying physical and biological conditions positively (Lamb et al. 2005 and references therein). These management actions however, need to be contemplated in the global perspective of the modified landscapes where they are planned and not as isolated actions, since specific topographical or man-made features may modify their results substantially. Large highways or high speed railway infrastructures, for instance, may pose important barriers to connectivity notwithstanding the effect of plantation patches, and their effect should be included in the connectivity analyses before a reforestation strategy is approved or put in motion.

Indeed, these infrastructures are a major element in the fragmentation of natural habitats, and pose particular problems to forest dwelling fauna species which often encounter insurmountable barriers in particularly broad or busy highways (Forman & Alexander, 1998; Liu et al. 2014b; Spellerberg, 1998). Forest patches are often severely segregated by roads limiting connectivity between forest-dwelling species. Their impacts can be intensified by the flow of traffic (Langevelde et al. 2009), especially in border areas (see e.g. Forman & Deblinger, 2000), where noise, pollution, luminosity, waste, etc. are more intense (Forman et al. 2002). On the other hand, roads have also been found to attract specific faunal species (Dean & Milton, 2003; Dodd et al. 2007), some being able to disperse through landscapes with major roads or highways (Blanco et al. 2005; Waller & Servheen, 2005). The impact of these infrastructures will also vary depending on the sensitivity of the affected habitats and landscapes, and the tolerance and adaptability of distinct animal and plant species living in the area (Forman et al. 2002; Geneletti, 2006; Rytwinski & Fahrig, 2013). For instance, the dispersal ability of organisms across changing landscapes, which is a fundamental issue for long-term biodiversity conservation (Fahrig, 2007), is a clear limiting factor when considering species abilities to move between preferred habitat patches, or surmount specific obstacles such as roads or highways.

Reforestation schemes aimed at guaranteeing connectivity between forested areas must take all these factors into account and specifically analyse the implications that the presence of a particular barrier, such as a prominent highway or railway, may have for achieving the planned connectivity objectives.

We evaluated the potential connectivity improvement of the forest habitats network in the county of Trasmiera (Cantabria, Spain) for medium and large sized mammals. To achieve this, we analysed the connectivity of natural and plantation forests, under various land use scenarios and considered the specific influence of a major infrastructure barrier: a highway, by applying the integral index of connectivity (IIC), and the probability of connectivity (PC) index. We identified those patches of plantation forest with the best connectivity performance to include them in the natural forest network and analysed their restoration possibilities through reforestation. Finally, we proposed two main courses of action: (1) protection of environmentally valuable forest areas; and (2) reforestation of relevant patches of exotic plantation trees previously identified as pertinent for forest network connectivity, with native species.

Material and methods

Study area

The county of Trasmiera, is a ca. 600 km^2 historic and natural district located in the region of Cantabria (N of Spain), in the coastal plain (Fig. 1). Trasmiera is limited to the north by the Atlantic Ocean, and is constrained to the east and west by two bays, respectively, limiting its connection with the rest of the territory to the southern stretch, which is bordered by the A-8 national highway (Fig. 1). In the past, at least 50% of the area was occupied by *Quercus robur*, *Quercus ilex* and bushes, while crops and pastures occupied a smaller area than present (García-Martino, 1862). Various preindustrial activities contributed to the deforestation of the area, mainly from the 18th to the 19th century (ship construction, cannon and conventional foundries, mining, etc.), but the cellulose industry was the decisive landscape change agent in the 20th century, replacing native forest and agricultural-grassland/pastures patches mainly with *Eucalyptus* sp., but also with plantation pines (*P. radiata* and *P. pinaster*) in a smaller proportion and in specific areas. In relation to this industry, the reforestation policy throughout the 20th century did not include reforestation with native species and focused on the planting of these high-yield species.

The populations inhabiting natural forest patches are thus currently severely segregated from southern populations by the highway, which is devoid of fauna crossings and has only three main viaducts under which communication with the other side of the highway is facilitated.

Approach to connectivity analysis

Landscape connectivity is currently viewed either structurally, where connectivity is entirely based on landscape pattern (e.g. size, shape, etc.), or functionally, where behavioural responses to landscape elements are considered together with the spatial structure of the landscape (Tischendorf & Fahrig, 2000; Ziólkowska et al. 2012). The assessment of functional connectivity usually requires more resources, since it entails monitoring species movements in the area. Conversely, structural connectivity can be evaluated directly from the spatial configuration of the landscape mosaic (Taylor et al. 2006).

Among the different methods proposed to evaluate connectivity (Ziólkowska et al. 2012), there are two complementary approaches (Rubio et al. 2012), that have significantly contributed to an improved and operational forest landscape connectivity analysis: graph theory and habitat availability (reachability) metrics (for an overview see Galpern et al. 2011; Urban & Keitt, 2001). Graph theory models the relationships among nodes of a network. It can be applied to "patch-based graphs", where the nodes are the habitat patches and the links suggest the potential connections for the species (Galpern et al. 2011). Conversely, habitat availability metrics consider a patch as a space where connectivity occurs (the larger the patch, the larger the connected area), integrating habitat patch area (or other patch attributes) and connections between different patches in a single measure (Pascual-Hortal & Saura, 2006). Graph theory has given rise to many connectivity measures, some of them specifically designed for the evaluation of landscape connectivity (Laita et al. 2011). We used the integral index of connectivity (IIC) and the probability of connectivity (PC), which are based both on graph theory and on the habitat availability concept (Pascual-Hortal & Saura, 2006, 2008; Saura & Pascual-Hortal, 2007). Both indices provide a reasonably detailed picture of potential