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Spatio-temporal analysis of the human footprint in South Ecuador: Influence of human pressure on ecosystems and effectiveness of protected areas

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A B S T R A C T

Human influence and its impacts are perceptible in all ecosystems resulting in land transformation, changes in global biogeochemistry, climate change, and loss of biological diversity. Mapping the spatial and temporal patterns of human influence is essential to address land use management and conservation programs. In this study, we tailored the Human Footprint index (HF) developed at global level to evaluate the spatial and temporal patterns of human pressure in South Ecuador for 1982, 1990 and 2008. Landscape and ecosystem levels were analyzed to identify the contribution of different human proxies to the HF. We also used the HF to evaluate the effectiveness of protected areas to reduce human pressure in the surrounding landscape. We found that levels of human pressure increased and the wildest areas decreased since 1982. We identified important "hotspots of changes" in the seasonally dry forests in the western part and the premontane evergreen forest in the eastern part of the study area. Our results show that each human proxy contributes in a different way to the observed values of HF in the studied ecosystems. Finally, we found that Podocarpus NP, the most important protected area in our study region, seems to be partially effective in reducing human pressure inside and in the buffer zones where only a low increase in HF was detected. However, the HF values observed in the surrounding landscape were higher than those observed in the buffer zone and inside the protected area. We demonstrated that HF could be a useful regional evaluation tool to facilitate conservation planning.

1. Introduction

Human influence and its impacts are perceptible in all terrestrial and marine ecosystems (Halpern et al., 2008; Sanderson et al., 2002) resulting in land transformation, changes in global biogeochemistry, climate change, and loss of wilderness areas and biological diversity (Vitousek, 1994; Watson et al., 2016). Human pressure is caused by the synergistic interaction of demographic, politic, physic, and socioeconomic factors. For instance, a higher demand of resources is related to population growth and also to the affluence levels (Dietz, Rosa, & York, 2007; Goudie, 2013; McKee, 2004; Weinzettel, Hertwich, Peters, Steen-Olsen, & Galli, 2013; York, Rosa, & Dietz, 2003). Land transformation is strongly associated with trade dynamics at national and international levels and with land disparities (Venter et al., 2016). Mapping the spatial and temporal patterns of human pressure is essential to address land use management and conservation programs (Woolmer et al., 2008).

The Human Footprint index (HF) proposed by Sanderson et al. (2002) is a tool that maps the spatial dimension of human influence showing the extent and intensity of human presence and its actions. The HF shows not only the levels of anthropogenic stress that an area is exposed to but also the wildest, still untouched, zones which could be included under protection. According to Haines, Leu, Svancara, Scott, and Reese (2008) the HF is also a good approach to assessing the success of landscape conservation efforts (e.g. if anthropogenic influence was mitigated or reduced after the implementation of a conservation strategy, the strategy could be

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considered as successful). The temporal analysis of the HF also allows the understanding of changing human influence and the identification of "hotspots of change" as well as the description of the human proxies which contribute most to the observed values of HF (Woolmer et al., 2008). The level of disturbances present in buffer zones is also directly related to the effectiveness of protected areas (DeFries, Hansen, Newton, & Hansen, 2005).

The dynamic nature of human threats makes it essential for conservation planners to consider the spatially explicit changes in threats and the fact that threats (e.g. increase in human population) do not have a uniform behavior across the landscape (Pressey, Cabeza, Watts, Cowling, & Wilson, 2007). Ellis and Ramankutty (2008) demonstrated that human proxies exhibit particular patterns in different ecosystems and therefore contribute differently to human impact levels. In this context, the HF can help us understand these differences, especially in areas with a high heterogeneity of biophysical, climatic, socio-economic, and cultural factors as tropical landscapes (Tosi & Voertman, 1964).

The HF needs to be interpreted carefully when it is applied to understand local patterns. Woolmer et al. (2008) rescaled the HF at an ecoregional level and concluded that although at global and ecoregional level the same general patterns of human influence were observed, the ecoregional analysis revealed a higher level of spatial heterogeneity, supporting the importance of local studies.

The objective of this study is to demonstrate how geospatial tools developed at local scale could be used to provide information about the level of human pressure that an area is exposed to and how this information can be used for land managers and decision makers to prioritize areas taking into account the local realities. Specifically, this study aims to tailor the HF proposed by Sanderson et al. (2002) to South Ecuador, an area with substantial and unique biodiversity and endemism, in order 1) to evaluate the spatial changes in the HF values for two different periods (1982–1990 and 1990–2008), and to localize the principal "hotspots of change" and the wildest areas, 2) to understand how human pressure levels vary between different ecosystems, 3) to define which is the contribution of the analyzed human proxies to the HF and 4) to evaluate the effectiveness of the most important protected area in reducing human pressure.

2. Methods

2.1. Study site

The target area covers the provinces of Loja and Zamora Chinchipe in South Ecuador that cover a total area of 21631 km^2 (Fig. 1). In this region elevation ranges from 105 to 3866 m a.s.l. (Farr et al., 2007). The mean annual temperature ranges from 7 °C to 25 °C, and the precipitation ranges from 500 mm to 8000 mm annuals (Bendix & Lauer, 1992; Emck, 2007). Soil conditions are highly variable, depending on elevation, bedrock, slope position and climate (e.g. Wolf, Veldkamp, Homeier, & Martinson, 2011).

South Ecuador is characterized by five principal vegetation types (more details are provided in Tapia-Armijos, Homeier, Espinosa, Leuschner, & de la Cruz, 2015). The montane evergreen forest (MEF) (occupies 45% of the surface area) and the premontane evergreen forest (PMEF; 23%), both are located mainly on the eastern and more humid escarpment of the Andes. The páramo (Pa) occupies only 4% of the surface and is present at lower altitudes than in the rest of the country. The shrubland (Sl; 17%) and the seasonally dry forest (SDF; 23%) are more characteristic of the western escarpment of the Andes under more arid conditions.

The high heterogeneity of landscape and climate and the location of South Ecuador in the Amotape - Huancabamba Andean depression are reasons for the observed high levels of biodiversity and endemism in the area and for this South Ecuador has been recognized as an important center of floristic diversity (Homeier, Breckle, Günter, Rollenbeck, & Leuschner, 2010; Richter, Diertl, Emck, Peters, & Beck, 2009; Weigend, 2002). Nevertheless, the area is highly threatened as consequence of human actions, Tapia-Armijos et al. (2015) registered an increase of fragmentation with an annual deforestation rate of 2.01% for the last three decades (1976–2008), where the largest surface of native forest was principally degraded or converted to pastures.

2.2. Human footprint map

Human Footprints maps were obtained for years 1982, 1990 and 2008. This temporal series was defined according to the availability and quality of geographical data (Table 1). To map the human pressure levels for South Ecuador we rescaled and adapted the Human Footprint (HF) method proposed by Sanderson et al. (2002) who combined human population density, land transformation, power infrastructure distribution and human access as proxies to evaluate the spatial distribution of human pressure.

These four variables were derived from the combination of the data described in Table 1, some of this data had to be preprocessed and rescaled to considering the geographical characteristics of the studied area as well as the available geographic data (for more details see Appendix). The four variables were expressed as overlaying grids at a resolution of 100 × 100 m and coded with scores from 0 to 10 according to their contribution (0 for low human influence to 10 for high human influence). The sum of the four variables resulted in the Human Influence Index (HII) for each year.

The human influence interacts in different ways depending on the ecological attributes of the landscape and its response to transformation (Sanderson et al., 2002). Accordingly, we normalized the HII for each year by using the main vegetation types described for South Ecuador (Fig. 1, see details in Tapia-Armijos et al., 2015) to obtain a more detailed explanation of the spatial variation of human pressure. In this way, we assigned a score of 0 to the grid cell with the minimum HII value and a score of 100 to the cell with the maximum value in each vegetation type, stretching intermediate values linearly between these extremes. The result of this normalization was the Human Footprint (HF), calculated for each study year (1982, 1990 and 2008) separately.

2.3. Human footprint change analysis

We evaluated how HF and thereby human pressure changed temporally and spatially from 1982 to 2008 identifying a human influence gradient from the wildest areas to the most influenced areas. For this, we reclassified the HF values (0–100) in 4 classes: Wildest areas (HF = 0), low impacted areas (HF: 1–15), medium impacted areas (HF: 16–60) and high impacted areas (HF: 61–100). This evaluation was done at the regional level but also for each of the different vegetation types.

To locate areas considered as "hotspots of change", we calculated a single mean change rate (Eq. (1)) for each pixel, where $\Delta y/\Delta x$ is the mean change rate of HF and $f(x2)$ and $f(x1)$ are the HF values in the second $(x2)$ and first $(x1)$ study year, respectively. The change analysis allowed us to detect the pixels where the changes of HF were stronger.

$$\Delta y_{/\Delta x} = f(x2) - f(x1)_{/x2 - x1} \quad (1)$$

The resulting change maps were reclassified, those pixels with negative mean variation rates ($\Delta y/\Delta x < 0$), indicating a decrease of HF values between the last and first year, where included within the category "Decreased". The pixels where the HF values were the