Science of the Total Environment 540 (2016) 63–70

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning

Marta Terrado [a,*], Sergi Sabater [a,b], Becky Chaplin-Kramer [c], Lisa Mandle [c], Guy Ziv [d], Vicenç Acuña [a]

[a] Catalan Institute for Water Research (ICRA), Emili Grahit 101, Girona E-17003, Catalonia, Spain
[b] Institute of Aquatic Ecology, University of Girona, Girona E-17071, Catalonia, Spain
[c] The Natural Capital Project, Woods Institute for the Environment, 371 Serra Mall, Stanford University, Stanford, CA 94305-5020, USA
[d] School of Geography, University of Leeds, Leeds LS2 9JT, United Kingdom

HIGHLIGHTS

- We present a model for the simultaneous assessment of land & aquatic habitat quality.
- We assess the reliability of the model as a proxy for biodiversity in river basins.
- We demonstrate the suitability of the model for scenario analysis in river basins.
- We recommend the model to assess biodiversity changes of conservation planning actions.

ARTICLE INFO

Article history:
Received 30 January 2015
Received in revised form 17 March 2015
Accepted 17 March 2015
Available online 30 March 2015

Keywords:
Anthropogenic threats
Biodiversity
Environmental management
Habitat quality
Scenario analysis
River basin

ABSTRACT

There is a growing pressure of human activities on natural habitats, which leads to biodiversity losses. To mitigate the impact of human activities, environmental policies are developed and implemented, but their effects are commonly not well understood because of the lack of tools to predict the effects of conservation policies on habitat quality and/or diversity. We present a straightforward model for the simultaneous assessment of terrestrial and aquatic habitat quality in river basins as a function of land use and anthropogenic threats to habitat that could be applied under different management scenarios to help understand the trade-offs of conservation actions. We modify the InVEST model for the assessment of terrestrial habitat quality and extend it to freshwater habitats. We assess the reliability of the model in a severely impaired basin by comparing modeled results to observed terrestrial and aquatic biodiversity data. Estimated habitat quality is significantly correlated with observed terrestrial vascular plant richness ($R^2 = 0.76$) and diversity of aquatic macroinvertebrates ($R^2 = 0.34$), as well as with ecosystem functions such as in-stream phosphorus retention ($R^2 = 0.45$). After that, we analyze different scenarios to assess the suitability of the model to inform changes in habitat quality under different conservation strategies. We believe that the developed model can be useful to assess potential levels of biodiversity, and to support conservation planning given its capacity to forecast the effects of management actions in river basins.

1. Introduction

Loss and degradation of natural habitats is a primary cause of declining biodiversity (Fuller et al., 2007), yet humans must balance conservation with development needs. It is difficult to strike such a balance with inadequate information about the consequences of our land use and management decisions. Nevertheless, we do know that the main drivers of the decrease in habitat quality are land use and climate change (Sala et al., 2000), which are exacerbated by other anthropogenic threats such as the construction of infrastructure and the introduction of exotic species (Ricciardi and Rasmussen, 1999). Worldwide, species extinction in freshwater environments is estimated to be higher than in terrestrial ecosystems (McAllister et al., 1997; Abell, 2002). Despite their reduced extent, freshwater systems support 10% of all known species (Carrizo et al., 2013). One of the reasons for higher extinction rates in freshwater is the difficulty of conservation efforts. Freshwater systems are susceptible not only to direct impacts but also to indirect impacts from disturbances elsewhere in the basin, all of which can contribute to the loss of biodiversity in rivers. Whereas many terrestrial conservation programs consider only threats adjacent to the site of interest, conservation of freshwater systems needs to take into account the connected nature of rivers, which present a strong directional component (Ward et al., 2002; Moilanen et al., 2008; Linke et al., 2011).

* Corresponding author.
E-mail addresses: mterrado@icra.cat (M. Terrado), ssabater@icra.cat (S. Sabater), bchaplin@stanford.edu (B. Chaplin-Kramer), lmandle@stanford.edu (L. Mandle), g.ziv@leeds.ac.uk (G. Ziv), vicenc.acuna@icra.cat (V. Acuña).

http://dx.doi.org/10.1016/j.scitotenv.2015.03.064
0048-9697/

Maintaining and protecting habitat quality and biodiversity, while still meeting human needs, is an urgent task in ecosystems management. Efforts to preserve biodiversity have resulted in the creation of a variety of environmental policies, like the ambitious new strategy adopted in 2012 by the European Parliament to halt the loss of biodiversity and ecosystem services in the European Union (EU) by year 2020, or the USA Endangered Species Act of 1973, and the Fish and Wildlife Conservation Act of 1980 (Goble et al., 2005; Stoms et al., 2010; EC, 2011). Other laws are oriented to restoring and maintaining the biological integrity of freshwater ecosystems, such as the Water Framework Directive of year 2000 in the EU, or the Clean Water Act of 1965 in the USA (Karr, 1991; Griffiths, 2002). Major conservation efforts also exist in emerging economies such as China, which committed to setting aside 23% of the country as priority conservation areas through the Strategy and Action Plan for Biodiversity Conservation of 2010 (MEPC, 2011). Similarly, some Latin American countries have progressive conservation policies, like Costa Rica's Biodiversity Law of 1998 and Colombia's National System of Protected Areas of 2010 (Solís-Rivera and Madrigal-Cordero, 1999; Vasquez and Serrano, 2009).

Environmental policies should go along with further understanding of the necessary actions to preserve habitats and species (Strayer and Dudgeon, 2010). Scenario analysis has proved useful for assessing the effects of specific management actions on biodiversity (Kass et al., 2011; Nelson et al., 2011; Carwardine et al., 2012), identifying vulnerability to global change (Pereira et al., 2010; Domisch et al., 2013), and guiding conservation planning (Dauwalter and Rahel, 2008; Hermoso et al., 2011; Moilanen et al., 2011). Thus, central to any conservation strategy throughout the world has been the establishment of protected areas, which has led to the evolvement of systematic conservation planning. Regarding this, systematic conservation tools have been designed to help planners decide on the location and configuration of conservation areas, so that the biodiversity value of each area can be maximized. Among these tools we find models like Marxan (Ball et al., 2009), Zonation (Moilanen et al., 2009), C-Plan (Pressey et al., 2009) or ConsNet (Sarkar et al., 2006). Recent conservation efforts have also used species distribution models to deliver insights into the relationship between biodiversity and the environment (Elith and Leathwick, 2009; Vander Laan et al., 2013; Kuemmerlen et al., 2014). These models usually relate known occurrences of a species with environmental conditions and predict occurrences in areas where suitable environmental conditions are known but no occurrence data are available. More recently, focus has shifted towards understanding and incorporating the distribution of threats (Allan et al., 2013; Tulloch et al., 2015). Approaches to threat mapping range from mapping the distribution of a single threat to additive scoring approaches for multiple threats that incorporate ecosystem vulnerability (Evans et al., 2011; Coll et al., 2012; Auerbach et al., 2014). Models that predict the status of biodiversity as a function of anthropogenic threats using biodiversity proxies are useful to inform management. Such models include GLOBIO (Alkemade et al., 2009) and InVEST (*Integrated Valuation of Environmental Services and Tradeoffs*; Tallis et al., 2011; Sharp et al., 2014), that are based on the mean species abundance (MSA) and on estimates of habitat quality respectively. However, proxy effectiveness as an adequate indicator of biodiversity has not been fully tested (Eigenbrod et al., 2010), and this can only be achieved by rigorous comparison of biodiversity proxies such as habitat quality to different indicators of biodiversity (either species richness, taxa, rarity, etc.) over space and time. Unlike GLOBIO, that uses a biodiversity index related to a baseline corresponding to the similarity to the natural situation, InVEST requires assessing which habitat type reflects natural conditions the best. The InVEST habitat quality model has successfully been applied to estimate the impact of different scenarios of land use/land cover (LU/LC) change or conservation policies on terrestrial habitat for biodiversity (Polasky et al., 2011; Bai et al., 2011; Nelson et al., 2011; Leh et al., 2013; Baral et al., 2014). Since InVEST is by now exclusively estimating the habitat quality of terrestrial ecosystems, developing tools that include the aquatic compartment together with the terrestrial is highly advisable given the increasing concern for freshwater biota and the interrelation of the two compartments. Both terrestrial and aquatic components play an important role in environmental management for habitat protection (Palmer et al., 2008).

In this study, we adapt the deterministic spatially-explicit habitat quality module of the InVEST suite of models for the assessment of habitat quality in river basins, considering the effects of anthropogenic threats on terrestrial and aquatic habitat. The extension of the module to assess aquatic ecosystems is one of the improvements presented in this work. Our goal is to provide a simple model that can be used to reliably assess the effects of ongoing threats and environmental management actions on habitat quality and current levels of biodiversity, and that allows for scenario analysis in order to forecast the effects of future management actions. We select the InVEST model because it proceeds with data on LU/LC, anthropogenic threats and expert knowledge, to obtain reliable indicators about the current and future response of biodiversity to threats, and because unlike other approaches used in biodiversity conservation, it does not require prior information about the distribution or presence of species. To illustrate the performance of the model, we apply it to the case study of a severely impaired basin in the Mediterranean region (Llobregat River basin, NE Iberian Peninsula). We test the reliability of the model by comparing the estimated habitat quality values with observed terrestrial and aquatic biodiversity data. We also check the response of the model for the assessment of changes in habitat quality under different scenarios that may occur with the future development of the region or under management actions that could be adopted to fulfill environmental conservation policies.

2. Methods

2.1. Case study site

The Llobregat River basin is an example of a highly populated and severely exploited and impacted area in the Mediterranean region. The basin has 4950 km^2 and the Llobregat River, which flows from the Pyrenees Mountains to the Mediterranean Sea, is one of the main water sources for the city of Barcelona and its metropolitan area, with a population of 3 million people. Population and industry mainly concentrate in the lower basin, whereas forest and grassland are more predominant in the upper part of the basin (Fig. 1a). The basin is affected by many disturbances, ranging from diffuse agricultural pollution to obstacles to connectivity such as dams or weirs, or important water abstractions for industrial and domestic purposes, among others (Fig. 1b–j).

2.2. Description of the habitat quality model

We apply the habitat quality module of InVEST (v.2.4.4; Kareiva et al., 2011; Tallis et al., 2011), which combines information on LU/LC suitability and threats to biodiversity to produce habitat quality maps. This approach generates information on the relative extent and degradation of different habitat types in a region which can be useful for making an initial assessment of conservation needs and for projecting changes across time. The model is based on the hypothesis that areas with higher habitat quality support higher richness of native species, and that decreases in habitat extent and quality lead to a decline in species persistence.

Habitat quality in the InVEST model is estimated as a function of: (1) the suitability of each LU/LC type for providing habitat for biodiversity, (2) the different anthropogenic threats likely impairing habitat quality, and (3) the sensitivity of each LU/LC type to each threat. A LU/LC map from the study area based on data from Landsat-TM was obtained from the Catalan Government for year 2002, and land uses were aggregated in 10 different categories corresponding to habitat types (Fig. 1a). A relative habitat suitability score H_j from 0 to 1, where 1 indicates the highest suitability for species, was assigned to each habitat