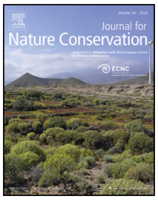
Journal for Nature Conservation 37 (2017) 122–132

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.de/jnc



Putting bryophyte communities in the map: A case study on prioritizing monitoring of human pressure in riverscapes

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ARTICLE INFO

Article history:
Received 3 January 2017
Received in revised form 31 March 2017
Accepted 4 April 2017

Keywords:
Conservation prioritization
Freshwater
Monitoring design
Spatial modelling of biodiversity

ABSTRACT

Freshwater ecosystems support biological communities with high species richness and conservation interest. However, these ecosystems are highly altered by human intervention and threatened worldwide, making them a priority in conservation planning and biodiversity monitoring. Bryophytes, including several conservation-interest taxa, are recognized indicators of ecological status in freshwaters. We aimed to develop a framework for designing monitoring networks to detect trends in aquatic and semi-aquatic bryophyte communities, prioritizing high-conservation interest communities in different contexts of human pressure (specifically, resulting from the intersection of two criteria: (i) protection status and (ii) presence of a potential impact area).

The framework consists of three steps: (1) Spatial modelling of biodiversity; (2) Spatial conservation prioritization; and (3) Model-assisted monitoring network design. Community-level modelling was used to model the distribution of the main bryophyte assemblages in the study area. A conservation prioritization software was utilized to identify areas with high conservation value. The monitoring network was designed using stratified random sampling and unequal-probability sampling techniques to target high conservation value sites distributed across different contexts of human pressure.

We have identified four distinct community types, each characterized both by a small group of common and dominant species, and by small group of rarer, conservation-interest species. This typification of four species assemblages occurring in the study area, also highlighted those with potentially higher conservation-interest. The most valuable areas for the conservation of aquatic and semi-aquatic bryophyte communities coincide with specific environmental zones: mountainous areas in Lusitania, large watercourses in the Mediterranean North and some locations in the Mediterranean Mountains. Finally, we obtained a potential monitoring network consisting of 64 monitoring points, unequally distributed across different contexts of human pressure, privileging locations with higher conservation value.

The framework presented here illustrates the potential of combining biodiversity modelling, spatial conservation prioritization and monitoring design in the development of monitoring networks. Namely, this framework allowed us to counter data deficiencies, to identify high priority areas to monitor and to design a monitoring network considering different scenarios of human pressure at a regional scale.

This framework can also be valuable for conservation efforts as an approach to monitoring conservation-interest biodiversity features in anthropogenically modified riverscapes, which present different degrees of human pressure and the cumulative effects of these different impact elements. Moreover, this approach allows for the comprehensive monitoring of biodiversity values important for management at the national and regional levels. In addition, this framework is one of the first efforts in the development of monitoring networks that target aquatic and semi-aquatic bryophyte communities, a long-neglected plant group of high ecological and conservation importance in freshwater ecosystems.

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http://dx.doi.org/10.1016/j.jnc.2017.04.002
1617-1381/

1. Introduction

Freshwaters ecosystems are biologically diverse ecosystems due to their high spatiotemporal and hydrogeomorphological heterogeneity (Ward, 1998; Wiens, 2002). In the Mediterranean region, a long history of human intervention in freshwater ecosystems has resulted in alteration of: (i) hydrological regime and fluvial connectivity (Nilsson & Berggren, 2000); (ii) river beds and margin substrates (Jones, Swanson, Wemple, & Snyder, 2000); (iii) nutrient input (Woodward et al., 2012); (iv) aquatic and riparian habitats, and consequently the alteration of the structure of biological communities (Bruno et al., 2014; Demars & Britton, 2011). The uniqueness and vulnerability of freshwater ecosystems have rendered freshwater biodiversity among the most threatened worldwide (Sala et al., 2000), and thus they should be considered a priority in biodiversity conservation and monitoring.

Biodiversity monitoring is a key component in management and policy evaluation by generating data on recent and current trends in species or communities' conservation (Honrado, Pereira, & Guisan, 2016). However, biodiversity management and monitoring have to account for human impact, anticipate possible future trends, and simultaneously face challenges related to limited human and financial resources hindering comprehensive surveys (Downes et al., 2002; Levrel et al., 2010). These limitations negatively affect: (i) field data collection and the number of survey sites (Rondinini, Wilson, Boitani, Grantham, & Possingham, 2006); (ii) the development of regional databases on species and communities' distributions (Hortal, Lobo, & Jiménez-Valverde, 2007); (iii) extensive surveys outside protected areas (Margules, Pressey, & Williams, 2002); and, (iv) the implementation of extensive biodiversity monitoring schemes (Watson & Novelly, 2004). In light of the targets for halting biodiversity loss established by the Convention on Biological Diversity (COP10, 2010) and the aforementioned constraints, several methodologies have been developed to surpass technical limitations and applied in biodiversity conservation and management, namely: (i) spatial modelling of biodiversity (Guisan et al., 2013); (ii) spatial conservation prioritization (Hierl, Franklin, Deutschman, Regan, & Johnson, 2008); and, (iii) model-assisted, monitoring network design (Nichols & Williams, 2006).

Spatial modelling of biodiversity has partly overcome the limitations of biological data gathering and the lack of distribution databases on species and/or communities by enabling the extrapolation of distributions across large regions. Community-level modelling, has allowed the extrapolation of community distributions by combining large datasets, numerical classification and statistical modelling (Arponen, Moilanen, & Ferrier, 2008; Leathwick, Moilanen, Ferrier, & Julian, 2010; Olden, 2003). Spatial conservation prioritization allows the prioritization of sites according to conservation value combining several biodiversity features across large scales, accounting for complementarity, connectivity and priority given to each biodiversity feature (Leathwick et al., 2010; Lehtomäki & Moilanen, 2013; Moilanen, Leathwick, & Elith, 2008). Finally, model-assisted monitoring networks provide a feasible way of assessing ecological resources and enable monitoring for large, heterogeneous areas (Carvalho, Gonçalves, Guisan, & Honrado, 2016; Convertino, Muñoz-Carpena, Kiker, & Perz, 2015; Metzger, Bunce, Jongman, Mücher, & Watkins, 2005).

Building upon existing databases and combining current techniques it becomes possible to design monitoring schemes for freshwater biodiversity that are not restricted to protected areas or individual Environmental Impact Assessment studies (Beger et al., 2015; Hierl et al., 2008; Micheli et al., 2013), and that maximize cost-efficiency by allocating monitoring sites to the most informative areas (Amorim, Carvalho, Honrado, & Rebelo, 2014; Carvalho et al., 2016).

Bryophytes, as one of the most common groups of macrophytes in mountainous riverscapes, are recognized indicators of human impact, microhabitat heterogeneity and fluvial integrity, which in turn are reflected in the structure and composition of their communities (Abati, Minciardi, Ciadamidaro, Fattorini, & Ceschin, 2016; Ceschin, Bisceglie, & Aleffi, 2012; Fritz, Glime, Hribljan, & Greenwood, 2009; Scarlett & O'Hare, 2006; Vieira, Séneca, Ferreira, & Sérgio, 2012; Zechmeister, Grodzinska, & Szarek-Lukazewska, 2003). In Portugal, these distinctive communities comprise some rare, endemic species with conservation interest (Vieira, Séneca, & Sérgio, 2012; Vieira, Séneca, Sérgio, & Ferreira, 2012; Vieira, Sérgio, & Séneca, 2005), and are associated with priority aquatic and semi-aquatic European habitats (Council of the European Communities, 1992).

To this day, the difficulties associated with identifying certain bryophyte taxa or incomplete knowledge of species distributions hinder their inclusion in management and monitoring plans in most countries (Tremp, Kampmann, & Schulz, 2012). Nevertheless, bryophytes are effectively used as mandatory biological elements for monitoring water quality and catchment environmental quality, for example, in the European Water Framework Directive (WFD, Directive 2000/60/EC) (Ceschin, Aleffi, Bisceglie, Savo, & Zuccarello, 2012; Gecheva & Yurukova, 2013; Luís, Hughes, & Sim-Sim, 2013; Vieira, Aguiar, & Ferreira, 2014).

In this work, we propose a framework using multiple techniques – spatial modelling of biodiversity, conservation planning, and model-assisted monitoring network design – to design monitoring networks for bryophyte conservation and management in freshwater ecosystems.

We aimed to design a monitoring network to detect trends in aquatic and semi-aquatic bryophyte communities that: (i) prioritized sites with potentially high conservation value; (ii) allowed a regional assessment of human pressure by considering the influence of several impacting factors in protected and non-protected areas; (iii) remained flexible to alterations in the face of financial constraints and/or changing goals.

Our approach aims to design monitoring networks at the regional level in different contexts of human pressure as opposed to the current tendency of designing monitoring schemes restricted to protected areas or individual Environmental Impact Assessment studies. We illustrated this framework in the Northern Portugal region using aquatic and semi-aquatic bryophyte communities. This is an often-neglected plant group despite its ecological and conservation importance in freshwater ecosystems. Furthermore, this is, to our knowledge, one of the first efforts (Averis, Genney, Hodgetts, Rothero, & Bainbridge, 2012) in the development of a community-level framework to design monitoring networks to detect trends in high-conservation interest aquatic and semi-aquatic bryophyte communities at a regional scale.

2. Material and methods

2.1. Study area and bryophyte diversity

Northern Portugal (Fig. 1(a)) is characterized by a temperate climate, with mean annual temperatures of 13 °C and an average total annual precipitation of 1013 mm. However, the study area presents a west-east climatic differentiation that results from the decreasing influence of the Atlantic climate and the interaction of the Atlantic and Mediterranean climates with land relief (Metzger et al., 2005).

A European climatic stratification by Metzger et al. (2005) divided the study area into three environmental zones (Fig. 1(b)) that reflect the above-mentioned differentiation. The Lusitanian area is influenced by the proximity to the Atlantic Ocean and has