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Research article

Navigating protected areas networks for improving diffusion of conservation practices

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ABSTRACT

The Natura 2000 protected area network is the cornerstone of European Union's biodiversity conservation strategy. These protected areas range across multiple biogeographic regions, and they include a diversity of species assemblages along with a diversity of managing organizations, altogether making difficult to pool relevant sites to facilitate the flow of knowledge significant to their management. Here we introduce an approach to navigating protected area networks that has the potential to foster systematic identification of key sites for facilitating the exchange of knowledge and diffusion of information within the network. To demonstrate our approach, we abstractly represented Romanian Natura 2000 network as a co-occurrence network, with individual sites as nodes and shared species as edges, further combining into our analysis network topology, community detection, and network reduction methods. We identified most representative Natura 2000 sites that may increase the transfer of information within the national network of protected areas, detected clusters of sites and key sites for maintaining network cohesiveness, and highlighted the subsample of sites that retain the characteristics of the entire network. Our analysis provides implications for protected area prioritization by proposing a network perspective approach to collaboration rooted in ecological principles.

1. Introduction

Protected areas are established to safeguard biodiversity in the long-term by implementing conservation measures on well-defined territories (Watson et al., 2014). Protected areas are considered as 'networks' when they are under the same jurisdictions and governed by similar principles and regulations (Evans, 2012; Lemos and Agrawal, 2006). The Natura 2000 protected areas network of the European Union (EU) is a cornerstone of the EU's biodiversity conservation strategy. EU Member States are required to designate Special Protection Areas (SPAs, for species covered by Birds Directive) and Sites of Community Importance (SCIs, for habitat and species covered by Habitats Directive) as part of EUs "Natura 2000 network" (Evans, 2012). To fully implement the Birds and Habitats Directives, Member States must take appropriate conservation measures to ensure a Favorable Conservation Status of protected habitats and species at the national and EUs biogeographical region levels (European Commission, 2011). These measures require collaborative approaches to conservation of species and habitats in Natura 2000 sites and sharing of best management and conservation practices (European Commision, 2015).

The high number of Natura 2000 sites (over 27000 in the EU), their distribution across multiple biogeographic regions, and the diversity of their species assemblages, coupled with diverse managing organizations, makes difficult the flow of knowledge and expertise relevant to species and habitat management across Natura 2000 sites (Battisti and Fanelli, 2015; Hoffmann et al., 2018; Rozylowicz et al., 2017).

Research plays a pivotal role in advancing best management practices with the intent of sustaining species and ecosystem services provided by protected areas (Blicharska et al., 2016). Key aspects addressed by Natura 2000 research includes conservation status of species and habitats (Maiorano et al., 2007), spatial connectivity of protected areas (Pereira et al., 2017), identification of the most representative sites for protecting particular taxa (Dimitrakopoulos et al., 2004; Popescu et al., 2013), ecosystem services (Bastian, 2013), governance and societal engagement (Manolache et al., 2018; Nita et al., 2018). Heavily influenced by the multiscale approach of EU biodiversity po-

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licies (Battisti and Fanelli, 2015), existing research on Natura 2000 has been performed from the local (i.e., group of sites within a country's borders) to a continental scale, however, the local approach still dominates (Hoffmann et al., 2018; Nita et al., 2016; Orlikowska et al., 2016; Popescu et al., 2014). Furthermore, studies addressing the potential of collective action and sharing of knowledge among Natura 2000 sites to achieve EU Biodiversity Strategy to 2020 targets are lacking.

To fill this knowledge gap, we employ a well-established analytical tool – network analysis – to identify biological and ecological (i.e., species-based) prospects for cooperation among Natura 2000 sites. Within the framework of network theory, protected areas may be abstractly represented as *nodes* (individual sites), while shared species can be considered *edges* (common species linking two sites). By protecting species occurring in two or more sites (i.e., same resource), the managers of these sites should have motivation for building a collaborative network for conservation management grounded on common species (Bodin, 2017).

The approach has the potential to expand the use of systematic conservation planning, including gap analysis (Margules and Pressey, 2000) by improving the representativeness and effectiveness of protected areas for conserving biodiversity. Furthermore, the adoption of novel approaches to management, the avoidance of ineffective or disruptive practices, the stimulation of co-learning and co-production knowledge, are dependent on information flow within governance networks (Alexander et al., 2016; Alexander and Armitage, 2015; Berardo and Scholz, 2010; Bodin, 2017; Vance-Borland and Holley, 2011).

The goal of this study is to explore the potential of network analysis to facilitate systematic identification of protected areas that are pivotal in fostering the exchange of ecological knowledge and diffusion of information within a network of protected areas. We focused on terrestrial Natura 2000 Sites of Community Importance in Romania (hereafter, Natura 2000 sites), having high ecosystem diversity, and a large number of Natura 2000 sites and protected species (Manolache et al., 2017). These features make the identification of the key sites of interest for various conservation activities a challenge.

In our approach, we combine analysis of network topology, community detection, and network reduction to (1) identify key Natura 2000 sites in terms of their potential to increase the transfer of information within the Romanian network of protected areas, (2) identify groups of closely connected Natura 2000 sites based on species co-occurrence, as well as sites of high conservation value (rich biodiversity and hubs for knowledge transfer), and (3) identify the backbone of Natura 2000 network, a subsample of protected areas which retain characteristics of the entire network but includes sites whose species similarity is larger than random.

2. Methods

2.1. Network data

This study focuses on terrestrial Natura 2000 Sites of Community Importance in Romania. From this initial list of 435 Natura 2000 sites and 166 species (EIONET, 2017), we excluded 9 marine sites, 37 terrestrial sites designated only for habitats protection (i.e., no Natura 2000 species protected), and 2 marine species (the common bottlenose dolphin - *Tursiops truncatus,* and the harbour porpoise - *Phoecena phoecena*). The final list of Natura 2000 protected areas analyzed in this study included 389 sites and 164 protected species (Supplementary Table S1, Box 1).

Box 1

Short characterization of the Romanian Natura 2000 area network (Sites of Community Importance) used in this study.

> The analyzed Romanian Natura 2000 network for the protection of species listed by Habitats Directive includes 389 Sites of Community Importance and cover 40275.72 km^2. The size of protected areas varies between 0.03 km^2 and 4536.45 km^2 (average = 103.54, stdev = 307.43). The Natura 2000 network protects 164 species of EU interest, i.e., 46 plants, 54 invertebrates, 26 mammals, 26 fishes, 6 reptiles, and 6 amphibians. The number of species protected within a Natura 2000 site varies between 1 and 64 (median = 6, IQR = 3–12), and as expected, is moderately correlated with the area, the larger sites protecting more species (Kendall tau = 0.49, $p < 0.001$). The top sites in terms of number of protected species (> 40 species) are Iron Gates (Portile de Fier), Domogled Valea Cernei, Calimani Gurghiu, Cheile Nerei Beusnita, Fagaras Mountains and Tur River and by surface (> 1200 km^2) Danube Delta, Fagaras Mountains, Frumoasa, Calimani Gurghiu, Iron Gates.

Based on the map of natural vegetation (Evans, 2012), Romanian Natura 2000 sites are grouped into five biogeographical regions, i.e., Alpine, Continental, Pannonian, Steppic and Black Sea (Iojă et al., 2010). Because we analyzed only the terrestrial sites and species, we considered the neighborhood Steppic and Black Sea regions as one biogeographical region. When a Natura 2000 site overlaps two biogeographical regions, we assigned the respective site to the region with the highest coverage.

We represented Natura 2000 network as a weighted one-mode undirected graph, where two Natura 2000 sites (*nodes* in the network) are considered connected if they share at least one common species (*edges* or *links* in the network) (Wasserman and Faust, 1994). If the two sites are linked by more than a species (i.e., *edge weight* > 1), the similarity of these sites increases which then increases the potential and need for collaboration (Fig. 1).

2.2. Network metrics

The Natura 2000 network-level structure was described employing the following metrics: *network density*, *network transitivity*, *average step length*, and *network diameter*. The centrality of Natura 2000 sites was analyzed using: *degree*, *eigenvector* and *betweennesses* metrics (Bodin and Prell, 2011; Nita et al., 2016; Vance-Borland and Holley, 2011). A detailed description of network terms and metrics is provided in Supplementary Note.

Considering two sites as connected if they share at least a species, network *density* represents the number of connections in the network divided by the total possible connections (Borgatti et al., 2018). Network *transitivity* is a clustering index and represents the ratio between the number of triangles (three connected sites, e.g., sites 1, 2, and 3 directly connected as follow: site 1—site 2, site 2—site 3, and site 3—site 1) and maximum possible triangles in the network. Networks with a transitivity index close to 1 are highly clustered (Wasserman and Faust, 1994). The *average step length* of a network represents the average