Ecological Indicators 60 (2016) 428–433

Contents lists available at ScienceDirect

Ecological Indicators

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

Selecting indicator species of infrastructure impacts using network analysis and biological traits: Bird electrocution and power lines

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ARTICLE INFO

Article history:
Received 15 March 2015
Received in revised form 11 July 2015
Accepted 13 July 2015

Keywords:
Co-occurrence
Eagle owl
Human impacts
Indicator species
Nestedness
Power lines
Ordination analysis

ABSTRACT

The use of indicator species may save a considerable amount of resources when the attributes of other species or of the ecological process of interest are difficult or costly to measure directly. However, identifying indicator species is not easy and there is a need for rigorous criteria and methods for their selection. In this study, we test a new approach to select indicator species of high mortality-risk of electrocution in power pylons comparing methods based on biological criteria and network analysis. For this purpose, we studied 335 mortality records of 19 bird species electrocuted between 1996 and 2013 in a Special Protected Area located in South-eastern Spain. Our results showed that both species-biology based methods and network analyses provided similar results, indicating that the eagle owl can be considered the best mortality indicator of the bird community on power pylons for the study area. The use of network analysis to select indicator species can be very useful to optimize the monitoring of infrastructure impacts, especially on complex or understudied communities because it does not require detailed information on the biology of the species.

1. Introduction

Indicator species are those which, given their characteristics, can be employed as estimators of the attributes or status of other species or of environmental conditions of interest that may prove difficult or costly to measure directly (Caro and O'Doherty, 1999). The use of indicator species saves a considerable amount of time and money if compared with conducting detailed monitoring of the species present in each community (Simberloff, 1998; Caro and O'Doherty, 1999; Favreau et al., 2006; Regan et al., 2008). Nevertheless, the implementation of these species in conservation planning has been a matter of hard debate (Simberloff, 1998; Noss, 1999; Andelman and Fagan, 2000; Favreau et al., 2006). Despite their widespread use for identifying changes in ecosystems and selecting areas requiring protection (Roberge and Angelstam, 2004; Sætersdal and Gjerde, 2011), its effectiveness has been scarcely verified (Andelman and Fagan, 2000). Due to the implications in conservation that derive from the indicator species selection (Caro and O'Doherty, 1999; Favreau et al., 2006), this process must be rigorous and based on explicitly defined criteria in accordance with the conservation objective (Landres et al., 1988; Dale and Beyeler, 2001; Carignan and Villard, 2002; Rodrigues and Brooks, 2007). But its implementation can be complicated especially when large or complex communities are involved.

Network analysis tools are of widespread use among mathematicians, sociologists and computer scientists, and have also been used to explore interactions between various types of taxa (Proulx et al., 2005). Such versatility has meant that, in recent years, these techniques have become widely accepted among biologists and ecologists (Proulx et al., 2005), especially to study trophic (Krause et al., 2003) and mutualistic (Bascompte and Jordano, 2007) interactions. Nonetheless, their use has not extended equally in other fields of ecology despite their great potential, for example, to study species co-occurrence (Sebastián-González et al., 2010), critical habitats for conservation (Almpanidou et al., 2014), key habitats for protection efficiency (Laita et al., 2010), the impact of climate change (Araújo et al., 2011), landscape connectivity (Saura et al., 2011) and keystone species in food-webs (Libralato et al., 2006; Jordán et al., 2007) or in host–parasitoid assemblages (Jordán et al., 2003). Following a similar approach to studies identifying key species in ecosystems, network analysis can also be a useful tool

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http://dx.doi.org/10.1016/j.ecolind.2015.07.020
1470-160X/

to identify indicator species can be used to monitor the effects of human impacts, e.g., mortality due to infrastructure.

Electrocution is a serious conservation problem worldwide for a large number of bird species (Bevanger, 1994, 1998; BirdLife International, 2004; Prinsen et al., 2011). Due to its wide extension, it is necessary to seek methods that optimize the identification of both the most dangerous pylons (Janss and Ferrer, 2001; Mañosa, 2001) and the highest risk areas (Tintó et al., 2010; Guil et al., 2011). In this study, our aim is to apply a new framework based on network analysis to identify indicator species using the impact of power lines on birds as a model. To assess the use of network analysis, we compared it with species-biology based methods. Such methods have been widely used to select sentinel species (Beeby, 2001; Basu et al., 2007 and references therein). For our purpose, we adapted the criteria on biological traits used to identify sentinel species (i.e. widespread and sensitive) to select indicator species of infrastructure impact. Network analysis framework is based in nestedness and co-occurrence of species in the community. If the community of electrocuted birds is nested, the group of species electrocuted in pylons with low mortality will be a subset of the species electrocuted in those pylons where mortality is high. In this case, the species that appear in more pylons or that present high co-occurrence with the remaining community components can be used as an indicator of other species mortality. The present work defines co-occurrence as the presence of mortality records of two species or more on the same overhead power line. The specific co-occurrence analysis allows us to select indicator species depending on different purposes of interest: e.g., high co-occurrence with threatened species.

2. Methods

This work was carried out in the Special Protected Area (SPA) of Sierra Escalona and Dehesa de Campoamor and the surrounding area (Southeastern Spain; 38.00° N, 0.86° W). This study area covers a surface of 350 km^2, which is crossed by a dense network of low and medium voltage power lines (see Fig. A1 in Appendices). The area hosts a rich raptor community, highlighting a very dense and abundant Eurasian eagle owl (*Bubo bubo*) breeding population (Pérez-García et al., 2012) and one of most important temporal settlement areas for non-breeding and juvenile Bonelli's eagle (*Aquila fasciata*) and golden eagle (*Aquila chrysaetos*) in the east of the Iberian peninsula (Sánchez-Zapata et al., 2003; Cadahía et al., 2010).

Between January 1996 and May 2013, we recorded all records of birds electrocution collected periodically by the wildlife recovery center, the principal power company in the area and from specific electrocution impact monitoring projects (see for further details Izquierdo et al., 1997; Pérez-García et al., 2011). All records were reviewed to avoid duplicates between sources. To do so, we compared the dates when the dead animals were detected, the species and the power pylon location. We only used records where accurate information on location of the power pylons and species identification was available.

The selection of the indicator species by the species-biology based method consisted in the identification of the species that were most sensitive to electrocution and showed greater habitat independence. To evaluate the factors driving species sensitivity to electrocution on power lines, we related the biological traits of the electrocuted species with mortality. We decided to use only raptors, because they are conspicuous species that have been described as good indicators of electrocution (Sergio et al., 2008) and are the most susceptible species to electrocution in this region (Pérez-García et al., 2011). For the rest of the analyses, all the species in the community were included to assess the potential surrogacy of indicator species with the mortality of the entire community.

For each raptor species recorded in the study area, both diurnal and nocturnal, we collected the following information on their morphology and biology: maximum wingspan (del Hoyo et al., 1994, 1999), status of the population in the study area, maximum number of breeding pairs, maximum estimated floating population recorded and total number of individuals electrocuted, total number of pylons with any electrocutions between 2000 and 2013. Maximum floating populations was estimated for breeding species from the sum of the number of adults and the mean number of fledglings successfully per year, and for dispersive and migratory species from count points. To relate mortality with biological characteristics, we used univariate generalized linear models (negative binomial error distribution; McCullagh and Nelder, 1989). Also, we built multivariate models to evaluate which variable combination explained better the electrocution mortality recorded for each raptor species. We used an information-theoretic approach for model selection by means of Akaike's information criterion corrected for small samples (AICc, Burnham and Anderson, 2002). Models were built in R-program (version 2.14; http://www.r-project.org/R), and package 'bblme' was used to calculate AICc (Burnham and Anderson, 2002).

Habitat configuration around power lines has been identified as a significant indicator of electrocution risk (Janss and Ferrer, 2001; Mañosa, 2001). Potential indicator species should be generalist in their habitat use to avoid a bias in the identification of dangerous pylons located in areas where they are not present. To test if the electrocuted species were clumped in specific habitats, we performed an ordination analysis (Legendre and Legendre, 1998). This analysis determines the maximum correspondence between species and landscape variables in a community (Prodon, 1992).

To determine the relationship between mortality events per species and habitat characteristics, we first characterized landscape composition of each power pylon where electrocution was detected. Land use percentages were calculated within 100 m around each pylon. This value is the average distance between power pylons in the study area, and represents the habitat around each pylon. In addition, distance to roads, urban cores, natural wetlands, irrigation ponds and nearby irrigation crops was also calculated. Distance variables were log transformed. These analyses were performed on the geographic information system software ArcGIS 9.0 (ESRI, 2009). Land use information was obtained from SIOSE 2010 and from a 5 m resolution digital elevation model (DEM) downloaded from the governmental spatial data web repository (www.idee.es).

To assess what sort of analysis is the most appropriate, we first performed a Deterrent Correspondence Analysis (DCA), to determine the gradient length of the first two axes (Ter Braak and Prentice, 1988; Lepš and Šmilauer, 2003). If the length gradient was less than <3.0 SD, Redundancy Analysis (RDA) was performed, otherwise Canonical Correlation Analysis (CCA) was performed. All models were constructed by a stepwise forward selection of the variables and testing the significance using Monte Carlo permutations (999 permutations). The differences were statistically tested by *F* test ($\alpha = 0.05$). Species that were detected in less than 3 pylons were not included in ordination analysis but were used as additional species (Ter Braak, 1995). Low axes-scores are indicative of low dependency to habitat characteristics of a given species within the area. For all ordination analysis, we used CANOCO 5.0 (Ter Braak and Smilauer, 1998).

Indicator species selection by network analysis methods was carried out through two different approaches: first checking that community showed a nested pattern and then evaluating the co-occurrence of species mortality. If an assemblage is significantly nested, then, most of the species will co-occur with the species that occurs in most areas (in our system, pylons). Thus, this species can be used as indicator of the presence of other species. To assess