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

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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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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 (α = 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 the existence of a nested pattern in the community, a matrix A was constructed in which each row and each column correspond to a species and a pole, respectively. So $A_{ij} = 1$ when the species i was detected electrocuted in the post j and 0 otherwise. For this purpose, we used ANINHADO software (Guimarães and Guimarães, 2006). This program uses a metric called NODF (Nestedness overlap and decreasing fills) to quantify nestedness (Almeida-Neto et al., 2008). The NODF index is related to the proportion of overlap in the distribution of the species that occurs in a nested way. This metric ranges between 0 and 100, being 100 for highly nested networks, while random matrices show intermediate NODF values. The significance of the nestedness is calculated by comparing the nestedness of the empirical matrix with the nestedness of random matrices generated by a null model. ANINHADO uses a null model where the presence of i species in the j pylon is the arithmetic average of the probability of presence in the j pylon (ratio of presence in line j) and i species (ratio of presences in the column i). We calculated 1000 matrices for the null model using Monte-Carlo simulations. Finally, we compared the NODF of our matrix with the distribution of NODF values in the simulated matrices to test pattern signification. When the NODF in the observed matrix was located within the range of variation of any of the null models, the pattern was not considered nested.

To assess the co-occurrence of each species in the community we used the degree index (Freeman, 1979). This metric has previously been used for the identification of indicator species (Jordán et al., 2003, 2007). The degree index indicates the number of co-occurrences in the same power pylon of each species with the other species of the network. In addition, we calculated the standardized degree, which is the ratio between the degree of each species and the maximum degree of the network (Borgatti and Everett, 2006). High degree scores indicate species that co-occur with more species than others, and therefore can be used as an indicator of the potential presence of other community's species. Both indices were calculated using UCINET 6.4 for Windows (Borgatti et al., 2002). To illustrate the structure of the network we used NetDraw 2.1 program (Borgatti, 2006).

3. Results

A total of 335 electrocuted birds of 29 species were collected in a total of 190 power pylons. Raptors were the largest group, both in number of species (14 sps) as in records (75.5%), followed by pigeons and doves (11.3% of the records), and corvids (7.2%).

AICc scores indicated that the best models explaining the sensitivity of the bird species to electrocution included the variables "Wingspan" and "Status" (ΔAICc = 0.00) and "Wingspan", "Status" and "Breeding Population" (ΔAICc = 0.81) (Table 1). Thus, according to these sensitivity models and the morphological and biological characteristics of the raptor species (Table 2), large and resident species with large breeding populations such as eagle owl or common buzzard (*Buteo buteo*), could be selected as indicator species of electrocution. The DCA indicated a strong gradient in species composition electrocuted in power pylons (length of gradient = 6.7). This implies a low similarity between the electrocuted species and power pylons where they appear along the environmental gradients. The CCA included 5 environmental variables, with a significant impact on the community ordination reaching a total inertia of 8.8%. The first two axes achieved explained inertia percentage of 3.4% and 5.8% for the species and 39.4% and 68.6% for the species–environmental variables relationship. The first axis was related positively with percentage of pine forest and the second axis positively with elevation and negatively with percentage of pine forest and irrigation crops (see Table A1 in Appendices). The organization chart showed how the bird community was pooled and revealed a low influence of the habitat variable. The species located near the intersection of the axes, as eagle owl or common kestrel (*Falco tinnunculus*), showed greater habitat independence (Fig. 1).

The community of electrocuted birds studied had a significantly nested pattern, so that the species found in power pylons with low species richness was a subset of the electrocuted bird community found in higher species richness pylons ($NODF_{pylons} = 11.1$, $NODF_{sps} = 3.17$ and $NODF_{null} = 6.41$; $p < 0.001$). The analysis of co-occurrences showed that 29.6% of the species were recorded in pylons where no other species were detected. The network showed a mean degree of 2.81 ± 3.67 species per pylon, whereas the normalized mean degree was $10.83 \pm 12.30\%$. The highest normalized degree was reached by eagle owl that co-occurred with 50% of all species found (Fig. 2), followed by common kestrel with 34.6% and common buzzard with 30.7%. Raptors showed marginally higher

Table 1
Results of the model selection procedure for the raptor's electrocution in the study area in relation to status, size and population variables. Models were ranked according to AICc values and Akaike weights (AICc Wi); k, number of parameters in the model. Variables: 'Stat' status, 'Wing' wingspan, 'Float' floating population and 'Breed' breeding population.

Rank	Models	k	AICc	ΔAICc	AICc Wi
1	Wing + Stat	5	127.38	0	0.30
2	Stat + Wing + Breed	6	128.19	0.81	0.20
3	Float	2	129.61	2.23	0.10
4	Wing + Breed	3	129.63	2.25	0.10
5	Stat + Wing + Float	6	129.69	2.30	0.09
6	Breed	2	129.85	2.47	0.09
7	Wing + Float	3	130.09	2.71	0.08
8	Stat + Breed	5	132.75	5.37	0.02
9	Stat	4	133.41	6.03	0.01
10	Stat + Float	5	134.06	6.68	0.01
11	Wing	2	134.29	6.90	0.01

Table 2
Morphological and biological characteristics of the raptor species recorded in the study area between 2000 and 2013. Species were ranked by mortality and wingspan. We show the maximum wingspan, status, maximum number of breeding pairs (Max. breed.), maximum number of floating individuals (Max. float.), number of electrocuted individuals (indvs.) and number of power pylons with any electrocution (pylons). Status was sorted in Resident (R), Summer (S), Winter (W) and Migrant (M). If a smaller fraction of the population had another status, this was shown in parentheses.

Species	Wingspan (cm)	Status	Max. breed.	Max. float.	Electrocutions	
					Indvs.	Pylons
Bubo bubo	168	R	70(2)	450(2)	100	79
Buteo buteo	118	R (w)	27(3)	110(3)	37	31
Falco tinnunculus	82	R (w)	40(4)	240(5)	30	25
Aquila fasciata	180	W (r)	0(4)	30(4)	27	22
Aquila pennata	132	W (r)	1(3)	35(3)	17	16
Circaetus gallicus	195	S (w)	2(3)	5(3)	9	7
Accipiter gentilis	127	W (r)	1(3)	10(3)	7	6
Aquila chrysaetos	220	W (r)	0(4)	20(4)	6	6
Gyps fulvus	280	M	0(4)	0(5)	3	3
Athene noctua	59	R	60(1)	480(1)	2	2
Pandion haliaetus	170	W	0(5)	2(5)	1	1
Falco peregrinus	117	R	0(4)	5(5)	1	1
Falco subbuteo	84	S (m)	1(1)	5(5)	1	1
Accipiter nisus	80	R (m)	8(3)	40(3)	1	1
Milvus migrans	150	M (s)	1(3)	3(5)	0	0
Circus aeruginosus	130	M (w)	0(4)	5(5)	0	0
Circus cyaneus	122	M	0(4)	8(5)	0	0
Circus pygargus	115	M (s)	0(4)	2(5)	0	0
Asio otus	100	R	10(1)	50(1)	0	0
Tyto alba	99	R	6(1)	24(1)	0	0
Elanus caeruleus	95	S	1(5)	3(5)	0	0
Otus scops	64	S	30(1)	120(1)	0	0

References: (1) Navarro et al. (2003); (2) Pérez-García et al. (2012); (3) Pérez-García et al. (2009); (4) Sánchez-Zapata et al. (2003); (5) own data.

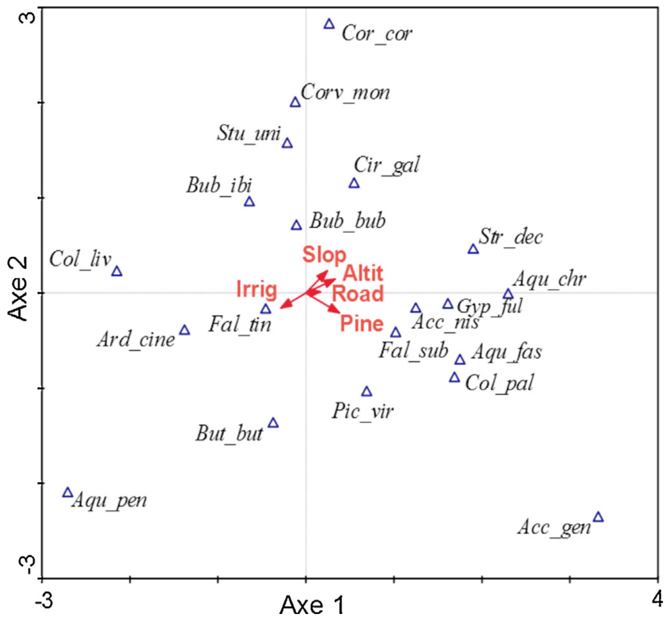

Fig. 1. Scatter plot of canonical correlation analysis CCA between environmental variables and electrocuted bird community on power lines. Canonical values of species and habitat variables on the two principal axes. Landscape variables: Slop: mean slope in a 100 m buffer (%); Road: distance to the nearest road (m); Pine: percentage of pine forest in a 100 m buffer (%); Altit: mean altitude in a 100 m buffer (m); Irrig: percentage of irrigated crops in a 100 m buffer (%). Species name code specified in Table A2 of Appendices.

degree than non-raptors (Kruskal–Wallis, $X_1^2 = 2.97$, $p = 0.08$). In fact, 7 of the 10 species with the highest degrees were raptors (see Table A2 in Appendices).

4. Discussion

Despite the interest shown in correcting the impact of power lines on avian mortality (Janss and Ferrer, 1999; López-López et al., 2011), very few studies have dealt with this problem from the animal communities' viewpoint (Lehman et al., 2007; Moleón et al., 2007). Our work compared detailed information about species' biology and community structure to identify an indicator species that can be used to detect dangerous pylons where management actions should be applied. In the first assessment, we confirmed that large-sized resident species with an abundant breeding population are highly sensitive to electrocution and could be good candidates for indicator species. Species-habitat analyses revealed that even though some habitat characteristics were related with the patterns of mortality displayed by the community, this relationship was, in general, very weak. Therefore, the best candidate indicator species were birds located close to axes intersection, which suggests electrocution independence to the habitat variables.

The network analysis methods allowed assessing candidates to indicator species from a community structure viewpoint. The use of nestedness analysis ensured that the most frequent species (those that generally appear electrocuted on the power pylons and with several victims) are representative of most of the species encountered. So, they can be used as surrogates of the whole community. On the other hand, the co-occurrence analysis allowed us to evaluate which species could better perform this role from a quantitative perspective.

The two methods used were consistent in the identification of potential indicator species for bird mortality on power pylons for the study area: eagle owl, common buzzard and common kestrel. Eagle owl seems to be the best mortality indicator in our system because its biological traits (size, abundance, status) and other characteristics, such as hunting behavior, confer this species a high sensitivity to electrocution (Janss, 2000; Rubolini et al., 2001; Sergio et al., 2004; Martínez et al., 2006; Schaub et al., 2010). Moreover, other features may justify its selection as indicator species: e.g., it is easy to detect during field samplings due to its large size and reduced carcasses lost by scavenging (Bevanger, 1998; Ponce et al., 2010), and its population is undergoing large-scale recovery process throughout the Iberian Peninsula (Penteriani and Delgado, 2010). Thus, it can be employed in areas where other potential indicator species are absent or scarce (i.e. *A. fasciata* in Moleón et al., 2007).

In some studies, indicator species fail in fulfilling the objectives for which they were selected mainly because they were used in

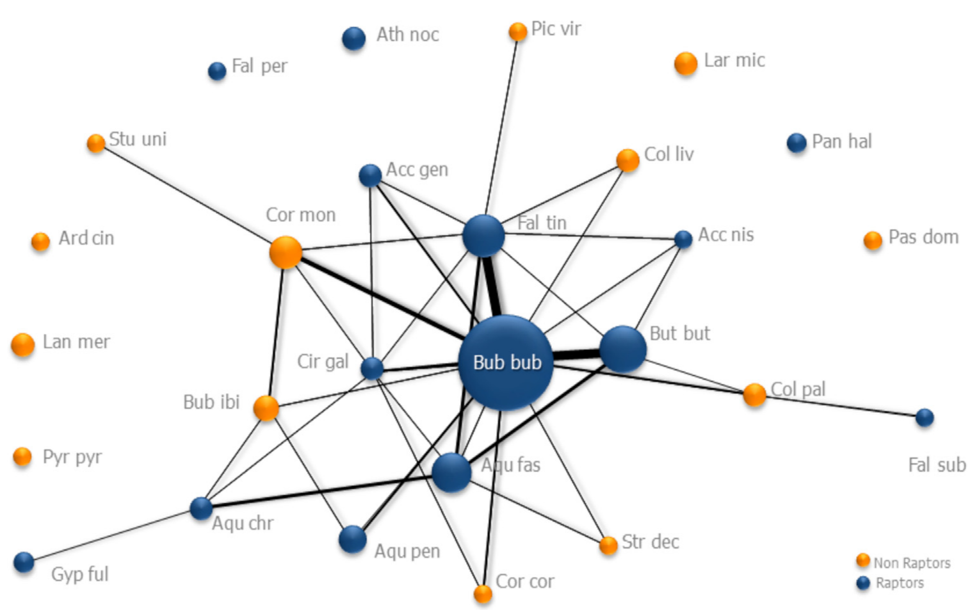

Fig. 2. Graphical representation of the co-occurrence pattern of species mortality in power pylons. The size of the node representing the number of dead individuals and the width of the connectors is proportional to the number of cases of co-occurrence. Species that have no connectors were detected alone. Species name code specified in Table A2 of Appendices.

different spatio-temporal scales or habitats for which they were not chosen (Favreau et al., 2006). Some studies have shown that selected indicator species did not correctly show the occurrence of rare, endemic or threatened species (Reyers et al., 2000), mainly due to the poor habitat selection overlap between them. While indicators are generalist species, rare and endemic species usually select highly specific habitats (Lindenmayer et al., 2002; Ricketts et al., 2002). This is likely to be the reason why the selected indicator species in our study did not achieve 100% co-occurrence with all the species detected. Indeed, the species that did not co-occur with the indicator species are those that select highly specific habitats (e.g., osprey or grey heron), rare species, or species whose distribution in the study area is very restricted (e.g., peregrine falcon, red-billed chough or griffon vulture). A more appropriate management could be to complement the approach proposed with high-risk electrocution predictive models for rare and specialist species. Therefore, the optimized strategy that include indicator species approach and specific risk electrocution models according to the conservation needs of each location, could obtain high success rates.

The method proposed to select indicator species depends on particular spatio-temporal conditions of the studied process; therefore extrapolating the species selected to other areas should be previously verified by validation. The indicator species can respond differently to a new habitat structure or to a distinct bird community composition as occurs in wetlands or coastal areas. By way of example, the eagle owl is unusually abundant in the study area (Pérez-García et al., 2012), which might not be the case in other areas. Thus, it is important to emphasize that we are not claiming that the eagle owl can be used as indicator species for electrocution mortality everywhere. The main take-home message of this study is that the combination of species biological information and network analysis seems appropriate to detect indicator species. Moreover, the methodology described in this work has proven to be a simple method that helps to optimize the monitoring of the impact that infrastructures have on the bird community, and could be applied to other systems such as in wind turbines or road collisions. Besides, the use of network analysis to select indicator species can be of particular interest in complex communities, where the details on the biology of all the species are not fully known and there is an urgent need for efficient and easy to perform management strategies.

5. Conclusions

As far as we know, this is the first use of the network analysis framework for the selection of indicator species. Network analysis is a useful tool to evaluate community structure and to identify which species show a greater surrogating with the process to assess. This approach allows an objective assessment on which species is best placed to be selected as indicator. The use of network analysis to select indicator species can be particularly recommended to optimize the monitoring of infrastructure impacts on wildlife communities in areas where the information on the biological characteristics of the impacted species is scarce, or in complex communities. This approach will allow solving some of the common pitfalls on the selection of indicator species, improving their effectiveness.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2015.07.020

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