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Ecological Indicators xxx (2005) xxx–xxx

ECOLOGICAL INDICATORS

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Bird communities as bioindicators: The focal species concept in agricultural landscapes

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Abstract

The use of bioindicators as a tool in conservation and landscape ecology projects is becoming more widespread. We suggest objective criteria for selecting suitable focal species to identify important semi-natural elements in agricultural landscapes and provide quality indications at two different spatial scales. At a broad scale, focal species can indicate overall landscape quality, and species abundance data allow an environment suitability map to be drawn. At a local scale, focal species abundances can be related to structural characteristics of landscape elements, thus, providing valuable indications of the most effective locations for restoration projects.

Keywords: Focal species; Landscape planning; Hedgerows; Birds; Conservation biology; Landscape ecology

1. Introduction

Research in landscape ecology often addresses the use of bioindicators (Meffe et al., 2002; Storch and Bissonette, 2003) for landscape planning (Hobbs and Lambeck, 2002). An indicator should have a number of qualities including high data synthesis value, user benefit, and relevancy for both political choices and management purposes. Bioindicators have often been used in ecology to test specific circumstances and quantify degradation and restoration processes (Ellenberg, 1974; Landolt, 1977; Schubert, 1991; Meffe et al., 2002). Their use may often allow quick synthetic data collection and provide data otherwise requiring too complex or costly analyses (in terms of time, energy, and money). In conservation biology and landscape ecology, different bioindicator concepts, such as flag, umbrella, keystone, and focal species, have been defined (Meffe et al., 2002).

Birds have been used as bioindicators for many reasons, including: (1) their ecology is well understood; (2) the links among bird communities, vegetal associations, and territory has been clearly demonstrated (Keast, 1990; Petty and Avery, 1990); (3) they cover different levels of the ecological pyramid in every environment (Bunce et al., 1981; Burrough,

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1470-160X/$ – see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.ecolind.2005.08.006

1986); (4) they are easily detected, thus, allowing rapid data collection not only on presence/absence but also on abundance (Holling, 1978; Haila, 1985; Wiens, 1989).

The mere abundance of one or more birds species can be an important parameter to estimate the environmental quality of an area. This statement, without doubt, is not valid for all the species and for each kind of landscape or ecosystem: anyway the review of Bock and Jones (2004) about the effective usefulness of considering the abundance of birds as an indirect measure of environmental quality confirms this method suitability.

Together with the abundance, the breeding success, the production characteristic (sensu Van Horne, 1983) and the species survival could be taken into account in order to obtain a clearer insight and an added value of a given area analysis (as Van Horne, 1983); although those approaches require much more time and efforts to realize the analysis. Moreover, carrying out this kind of analysis in a subregional or regional scale is a much difficult task and demands a strong investment of resources. These two elements make the use of breeding success, production characteristic and survival of species not effective as wide-scale bioindicators.

The focal species concept (Lambeck, 1997) means a species or group of species, having spatial and functional requirements effectively defining environmental limits for the protection of other species present in the area. This concept fits quite well with bird communities and has been used in numerous studies (Carroll et al., 2001; Lambeck, 2002; Noss et al., 2002; Massa et al., 2003) as a tool to plan faunal conservation at various spatial scales from provincial to continental.

Therefore, considering: (a) the paper of Bock and Jones (2004), (b) the definition of focal species proposed by Lambeck (1997), and (c) a practical application that use focal species as a planning tool (Bani et al., 2002), we accept the statement that the abundance is related to the environmental quality, therefore, with focal species selection, we want to characterize some groups of species linked to different habitats in agricultural landscapes.

In particular, the work follows these steps:

(1) Indication of the most objective criterion (as possible) to define the focal species inside the study area: we are aware that the first paper on focal species selection (Lambeck, 1997) does not indicate objective selection criteria. However, our attempt is to indicate criteria *before* carrying out the analysis and that may contribute to determine the species rarity.
(2) Indication about how focal species can be used at different scales: in local context, the focal species abundance is related with the structural characteristics of habitat, in a wider context the focal species abundance is related with the environmental variables of the landscape.
(3) The results obtained in point (2) can be used to supply some practical suggestions for landscape management.

Fig. 1 outlines the path of the research, the spatial scales of different analyses and the main results obtained: focal species selection, and therefore the management prescription.

2. Materials and methods

2.1. Study area

Our study area was a Lombardy regional park, the Parco Agricolo Sud Milano, a 46,300 ha area south of Milan, this was an agricultural area (rice, maize, wheat) at least from XII Century. The area is characterized by an extended network of draining ditches, fed by resurgences, and partly encircled by hedgerows. The resurgences have implemented the agricultural vocation of the whole area during the centuries. The park was founded in 1990 to safeguard traditional farming activities, protect natural sites (wetlands and residual woods), develop the historical and architectural heritage, restore the environment and landscape, and check the rapid development resulting from uncontrolled urbanization (Fig. 2). To carry out detailed analysis at local scale, we decided to study three areas within the park boundaries, legally defined as natural reserves with their surrounding areas (20 km^2 for every detailed area). The reserves are widespread: the first one in the western, the second in the southern, and the third in the eastern part of the park (Fig. 2).

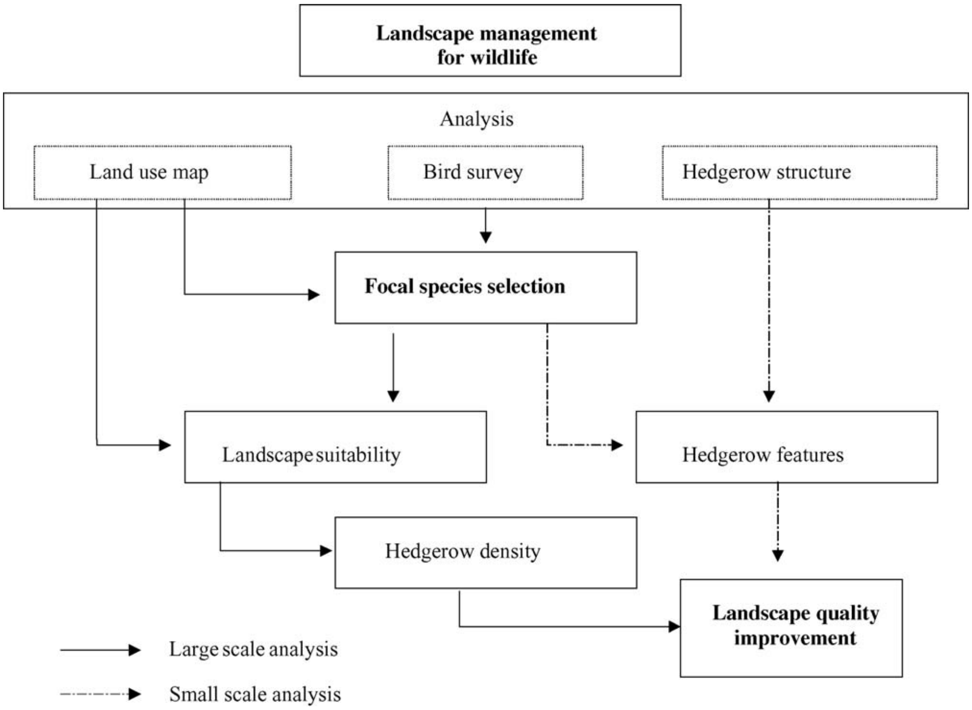

Fig. 1. Flow chart of our project.

2.2. Landscape and single-element analysis

Landscape classification was made by means of a land use map created from three satellite images acquired in May 23, July 26, and October 6, 1999; the first two from a Landsat TM 5 scan and the last from a Landsat TM 7 scan. Satellite images were processed with *ENVI 2.7 Research System Software Inc*. and classified with the *Supervised Maximum Likelihood System* (Lillesand and Kiefer, 1987). Aerial digital photographs (taken by Compagnia Generale Riprese Aeree during 2000) were used to identify the main linear elements (hydrological networks, roads, and hedgerows), which might not be detected in Landsat satellite images having a spatial resolution of 30 m at ground level. Hedgerows were analysed extensively in the three reserves because of their importance for avifauna in an agricultural landscape. Some structural characteristics of the hedgerows (width, proportion of tree and shrub coverage – sensu phytosociological, Pignatti (1994) – lateral density, i.e. of the percentage of landscape covered by hedgerow) were measured directly in the field.

2.3. Focal species selection

Avifauna data were collected by bird point counts at unlimited distance (Blondel et al., 1970; Massa, 1993). We carried out the landscape-scale analysis by drawing a 1 km square grid in the larger area, than we selected with a random sampling 188 squares: in each one we realized a single point count. For the local-scale analysis, 500 m square grids were drawn in the three reserves, here we carried out a systematic sampling (Scherrer, 1984) and 270 point counts were obtained.

To include these points in landscape analysis, and at the same time, obtain homogeneous data, we grouped together the 188 point counts with 68 out of 270 point counts randomly chosen, for a total of 256 point counts. In this way, all point counts considered were distributed in a 1 km square grid.

Focal species selection used several criteria. Both common (frequency exceeding 30%) and rare (frequency under 2%) species were excluded (see Massa et al., 2003, for further information), common species because of their generally lower habitat

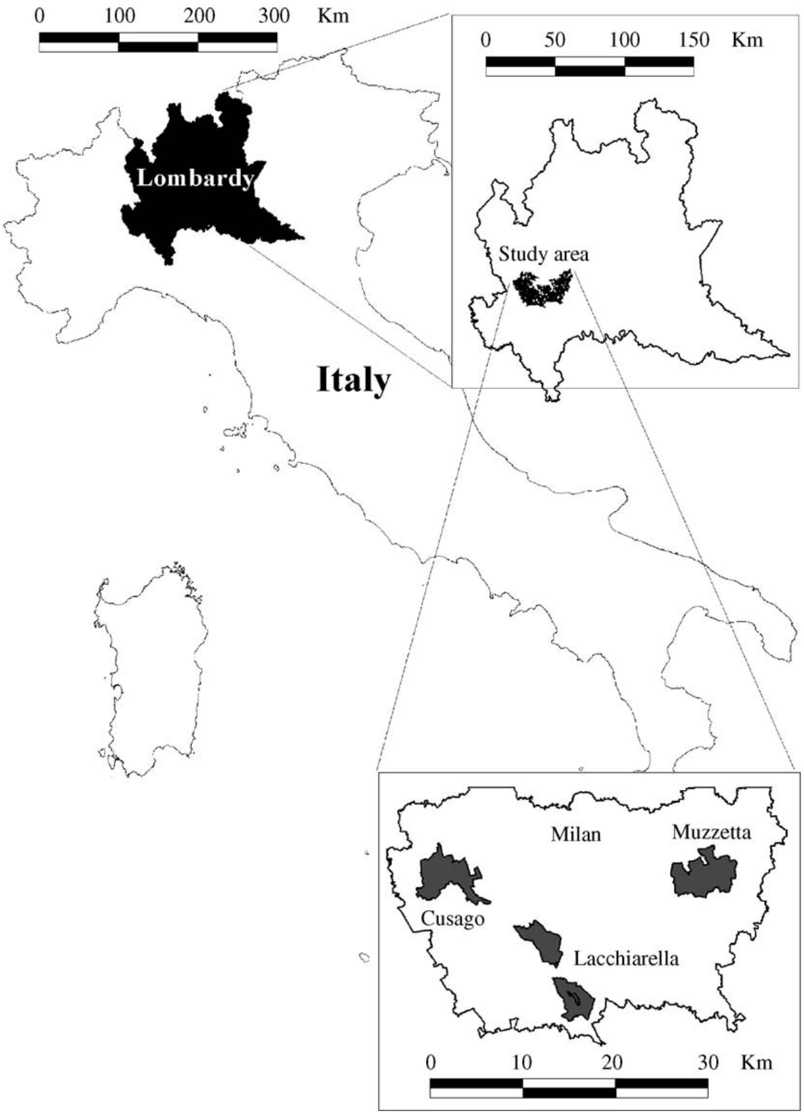

Fig. 2. Study area and reserves.

selectivity and rare species to reduce random contacts. The next step was to exclude social species (those with a mean abundance greater than two individuals per point count), because of their non-linear abundance variation pattern with environmental variables. Because these species are typically quite abundant in optimal patches and completely absent in the remaining areas, their abundance peaks could bias the analysis. Species detected in flight (raptors and water fowl) were also excluded because of their potential remoteness from breeding habitat. Similarly, introduced game birds, whose abundances are dependent upon human intervention, were not included. The final criterion was the choice of urban barycentre lower than 10% to identify species sensitive to urbanization. We define a barycentre with this formula:

$$B_{\mathrm{s}} = \frac{\sum_i n_i \cdot x_i}{N}$$

where B_s is the barycentre of the species S, n_i the number of individuals in the ith counts, x_i the value of the environmental variable x considered in the ith count, and N is the total number of individuals (Massa et al., 1998).

Using these criteria, a set of species was selected for analysis.

For each of these species, environmental barycentres were derived from land use data, and cluster analyses were run using five different methods: complete linkage with Pearson's correlation coefficient; complete linkage with quadratic Euclidean distance; mean linkage among groups; mean linkage within groups; and Ward's distance. Selected species were split into different clusters according to environmental typologies. A two-tailed Spearman's test evaluated the correlations between these species clusters and environmental variables.

2.4. Statistical analysis.

Multiple steps regression analysis was run to assess landscape suitability (the landscape capacity to sustain a population or a group of populations and its probability to be selected by them) for focal species. Hedgerow focal species were included as dependent variables by means of 0.05 maximum insertion probability and 0.01 removal probability (Jongman et al., 1995), while environmental factors were used as independent variables. For local-scale analysis, land use percentages were evaluated at different distances from point counts (100, 250, and 500 m) to account for varying environment perception among species. Only minimum distances from point counts were considered for linear elements.

Hedgerows were put into three classes according to their width: narrow (<5 m width), medium (5–25 m width), and wide (>25 m width). Environmental variables were logarithmically transformed to obtain an equation. This equation was applied in a GIS by means of *Spatial Analyst* extension (ArcView) to draw a suitability map. A cross-validation procedure, the leave-more-out method, was performed to validate the model. We maximized the cross-validated R^2 (Q^2), subdividing the data set into six groups and leaving out one group at each step, according to the method of Todeschini (1998). To examine local-scale relationships between avifauna and hedgerow structure, 500 m diameter circles were drawn around every point count location and only hedgerows within these circles were considered. A Mann–Whitney U-test was run to assess the significance of results.

3. Results

3.1. Land use and environmental mosaic

Land use data (Fig. 3) show a landscape with a strongly agricultural matrix (more then 80% of the study area), where natural woodland remnants currently represent only a minor component (3%). Residual elements, such as hedgerows, even if not widespread (only 1.4% of the study area), seem to be

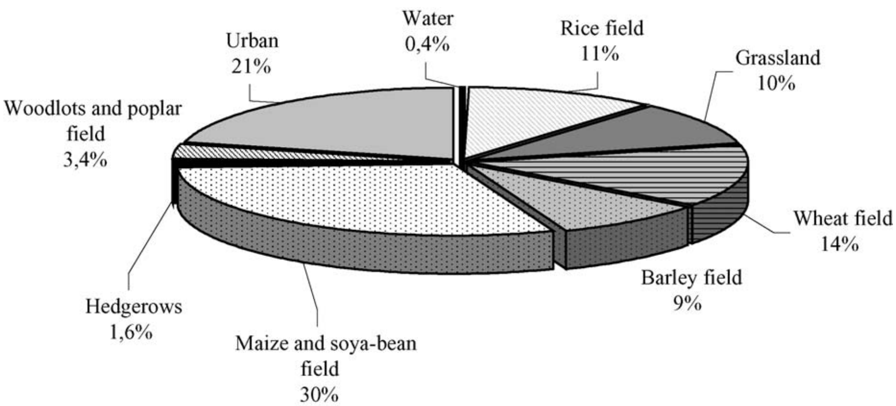

Fig. 3. Land use percentage in Parco Agricolo Sud Milano.

very important, as their presence can dramatically increase landscape quality for fauna (Snow and Snow, 1988; Baudry et al., 2000).

3.2. Avifauna analysis and focal species output

Eighty bird species were detected in the 458 point counts. Focal species selected according to the above criteria were quail (*Coturnix coturnix*), moorhen (*Gallinula chloropus*), woodpigeon (*Columba palumbus*), turtle dove (*Streptopelia turtur*), great spotted woodpecker (*Dendrocopos major*), yellow wagtail (*Motacilla flava*), white wagtail (*Motacilla alba*), stonechat (*Saxicola torquata*), Cetti's warbler (*Cettia cetti*), melodious warbler (*Hippolais polyglotta*), spotted flycatcher (*Muscicapa striata*), blue tit (*Parus caeruleus*), golden oriole (*Oriolus oriolus*), and red-backed shrike (*Lanius collurio*). Cluster analysis rendered five subsets: species mainly associated with woodlands (represented only by blue tit); species associated with wide hedgerows (great spotted woodpecker, golden oriole); species associated with medium-width hedgerows (wood pigeon, turtle dove, melodious warbler, spotted flycatcher, red-backed shrike); open field species (yellow wagtail, stonechat, quail); species associated with stream environments (moorhen, white wagtail, and Cetti's warbler). Table 1 shows correlations among species groups and environmental variables.

3.3. Landscape-scale analysis: suitability map for hedgerow species and hedgerow density

We decided to focus on hedgerow focal species group because hedgerows are an endangered element in our countryside (Fabbri, 1997) that has a great role in maintaining biodiversity (Hinsley and Bellamy, 2000). Furthermore, as more than 1000 farms are still active in this area, only a hedgerow restoration program seems realistic to be suggested.

Our hedgerow species suitability map (Fig. 4) assigns a suitability value to each cell (expressed as species abundance). These values were divided into four suitability classes: null (for negative suitability), low, medium, and high. Using the leave-more-out method, we obtained values of $R^2 = 0.162$ and $Q^2 = 0.161$; the similarity of R^2 and Q^2 indicates a valid model (Todeschini, 1998).

Although the study area shows numerous medium and high suitable patches for hedgerow species (accounting for 26.5% of the whole territory), their distribution is not uniform. While the western sector is rich in sizeable suitable areas, suitable areas in the eastern sector show smaller mean dimensions. Southern and northern sectors score low suitability values for two different reasons: huge rice fields without hedgerows are found in the southern sector, while in the north the metropolitan area of Milan lowers suitability to null values.

Table 1
Correlation analysis for focal species groups (in bold we highlighted the significant correlations)

Group		Correlation coefficient and significance (*P*)	% Woods	Distance from large hedgerow (25–50 m)	Distance from medium hedgerow (5–25 m)	Distance from small hedgerow (2–5 m)	% Maize	Distance from water
1	Woodland		**0.120**	−0.088	−0.069	0.009	−0.113	0.017
		P	**0.050***	0.160	0.271	0.882	0.071	0.790
2	Large hedgerows		**0.224**	**−0.290**	0.069	0.057	−0.052	−0.017
		P	**0.000****	**0.050***	0.273	0.367	0.410	0.786
3	Medium hedgerows		0.080	**−0.218**	**−0.245**	−0.082	0.069	−0.054
		P	0.203	**0.000****	**0.000****	0.193	0.272	0.389
4	Open field		**−0.296**	0.047	0.111	−0.079	**0.298**	−0.064
		P	**0.000****	0.454	0.076	0.209	**0.000****	0.311
5	Stream		**−0.244**	**−0.198**	−0.120	**−0.313**	0.102	**−0.303**
		P	**0.000****	**0.001****	0.056	**0.000****	0.102	**0.000****

*(<0.05); **(<0.01).

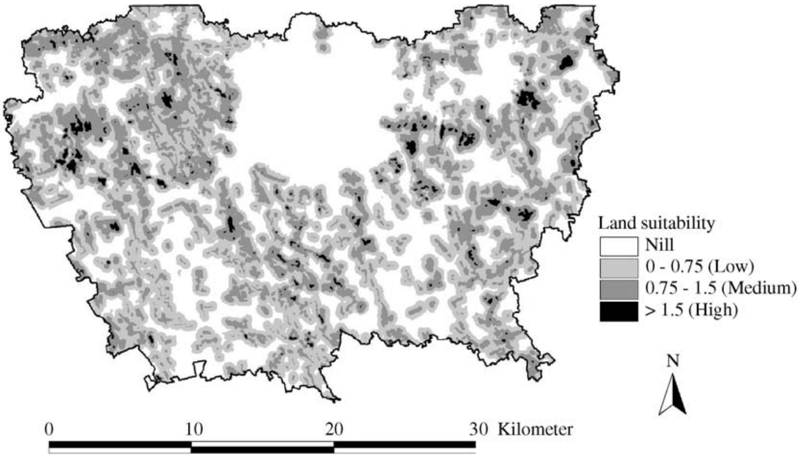

Fig. 4. Suitability map for hedgerow focal species.

Because hedgerows appear to play an important role among elements capable of raising landscape matrix quality; hence, suitability for focal species, we estimated the hedgerow threshold density goal for a prospective landscape restoration project within the park. As hedgerow density increases, an increase in hedgerow focal species abundance is evident (Fig. 5a). A Mann–Whitney *U*-test confirmed a significant difference in focal species mean abundances between areas with hedgerow densities lower than 0.04 km^2/km^2 and areas with higher densities; also an optimal threshold may be determined 'at a density higher than 0.075 km^2/km^2 (Table 2).

3.4. Analysis in reserve areas: hedgerow features

Our reserve area analyses are also focused on focal species found in hedgerows. We surveyed 900 hedgerows in the three local-scale analysis areas; 11% were dominated by shrubs, 21% were arboreal, and 68% were mixed. Hedgerow structural features (width, tree and shrub coverage, and lateral density) influence focal species abundances, which increase with hedgerow width (Fig. 5b), tree and shrub coverage, and lateral density (Fig. 5c). The Mann–Whitney *U*-tests showed significant differences between focal species mean abundances in hedgerows less than 15 m wide and those greater than 15 m, and

Table 2
Relationships between hedgerow features and focal species

Structural feature	Value 1	Value 2	N1	N2	Mann–Whitney *U*-test	Significance
Large scale						
Hedgerow density	<0.04 km^2/km^2	Between 0.04 and 0.075 km^2/km^2	212	159	0.000	0.000**
	Between 0.04 and 0.075 km^2/km^2	>0.075 km^2/km^2	159	110	0.000	0.000**
Small scale						
Hedgerow width	<15 m	>15 m	127	57	2371	0.000**
Tree coverage	<50%	>50%	65	119	2877	0.001**
Shrub coverage	<50%	>50%	76	104	2723.5	0.000**
Lateral density	<50%	>50%	69	115	2707.5	0.000**

We evaluated the abundance of hedgerows at the broad scale and hedgerow structure at the local scale. Density is expressed as hedgerow area for land area (km^2/km^2); width is in meters; tree coverage, shrub coverage and lateral density are evaluated, and then reported as percentages (0 = 0–10%; 1 = 11–25%; 2 = 26–50%; 3 = 51–75%; 4 = 76–100%).
*(<0.05); **(<0.01).

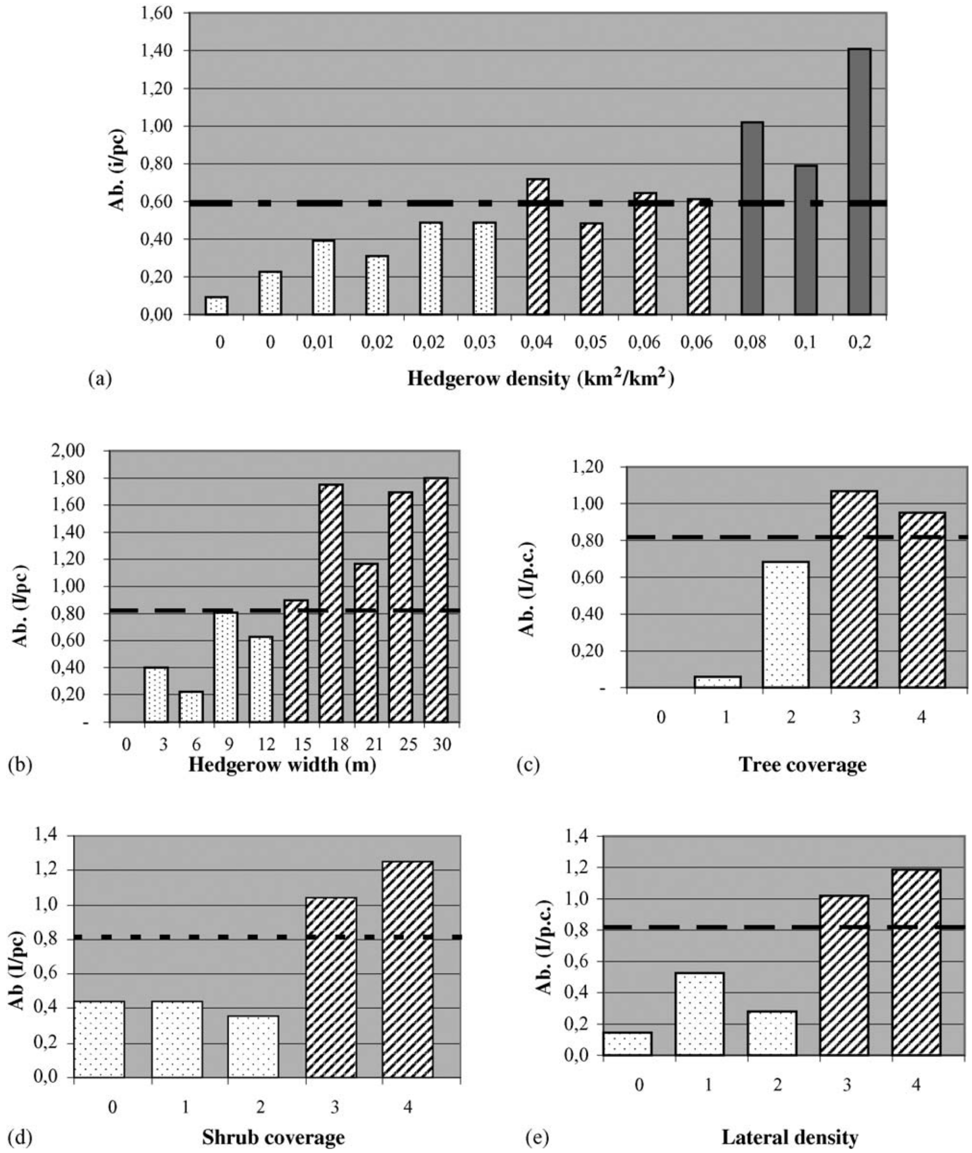

Fig. 5. Main results: hedgerow density (a) at large scale; hedgerow width (b), tree coverage (c), shrub coverage (d), and lateral density (e) at local scale. The dotted line represents the mean abundance of hedgerow focal species (always expressed as number of individuals/point count).

between shrub coverage classes and lateral density ratings less than four and greater than four.

4. Discussion

Our selection procedure for focal species distinguished five groups, each characterizing one type of environment in the study area. Other studies (Tucker and Heath, 1994; Lefranc, 1995; Faivre and Ferry, 1997; Jarry, 1997) have shown that the focal species we analysed are strongly associated with environments characterized by the groups we found. Our suitability map, based on multiple regression, allows us to delineate the most important areas for these focal species; moreover, the map enables us to identify prospective restoration areas for improving overall landscape quality.

Our analysis of the relationship between focal species and hedgerow density indicates a goal of 0.04 km^2/km^2 hedgerow network density for the entire territory of the park. If we assume 15 m to be an optimal width, we obtain an optimal density of 2.6 km of hedgerow/km^2. This result is similar to Lütz and Bastian (2002). Operational parameters for focal species mean abundances can be extrapolated from our local-scale analyses: focal species abundances in hedgerows wider than 15 m are always greater than mean abundances found in reserves (Fig. 5). This width should be the minimum recommended in an environmental restoration plan for the park.

Unlike studies in other areas (Hinsley and Bellamy, 2000; Fuller et al., 2001), the ratio of hedgerow density and focal species abundances in our study area do not appear to peak, and then decline. This may be because there are very few large hedgerows in our study area. However, the criteria we used to find a reference width is consistent with criteria proposed by other authors for different study areas; the same is true for all other variables we considered. At the local scale, we noted that the same hedgerow structural features important to our hedgerow focal species seem to influence other bird species abundances positively (i.e. blackcap, great spotted woodpecker, blackbird, blue tit; Padoa Schioppa, 2002). Studies of species groups other than birds have also found hedgerow width and tree and shrub coverage to be major factors contributing to diversity increase (Lasserre, 1982; Osborne, 1984; Parish et al., 1994, 1995). Those findings may be regarded as an indirect confirmation of the value of our approach.

5. Conclusion

Our analysis demonstrates how the focal species concept can be applied productively and with great flexibility at different spatial scales. Highly suitable indicators can be adopted for the area of interest on the basis of quantitative faunal surveys. Whereas other indicator groups (i.e. vulnerable species) are inferred on the basis of national or continental surveys and keystone species are mainly associated with only one type of ecosystem, focal species analysis can help to identify ecological complexes needing protection or restoration in each specific study area.

We focused our analyses on hedgerow species because in our study area conservation can be accomplished by enhancing hedgerows rather than by restoring original woodlands. The high human impact of the area (>1200 farms within the park boundaries), urbanization (30% increase of urban area), and many bird declining trends (Baietto, 2002) suggest the need to concentrate conservation efforts on those elements that could most increase overall landscape quality mostly. This observation is consistent with results from similar studies in other countries (Gillings and Fuller, 1998; Chamberlain and Fuller, 2001). Landscape suitability analysis is the first step in planning conservation actions and priorities. Using these methods, we have identified some optimal landscape elements useful in the future to plan an ecological network in this area (see also Baietto, 2002; Padoa Schioppa, 2002).

Acknowledgments

The research was supported by Parco Agricolo Sud Milano, through Ph.D. fellowship to Marco Baietto and Emilio Padoa-Schioppa. The comments of Jürgen Ott, Ken Vance-Borland, and two anonymous referees greatly improved an earlier draft of the manuscript.

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