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PROTECTING BIODIVERSITY OUTSIDE PROTECTED AREAS: CAN AGRICULTURAL LANDSCAPES CONTRIBUTE TO BIRD CONSERVATION ON NATURA 2000 IN ITALY?

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Abstract. Even when a Protected Area (PA) is adequately managed within its boundaries, its ecological functioning may be influenced by human activities in the surrounding landscape through a number of mechanisms. This paper investigates how conservation outcomes are affected by land use change in neighboring areas on a cross-section of protected sites, the Italian portion of the EU's Natura 2000 network. We exploit variation in space to relate indicators of success of conservation efforts to measures of landscape structure. We focus on features of the landscape that pertain to agriculture because this is the dominant form of land use in many areas of the country, and the major ongoing trends in land use dynamics involve farmland. Our results suggest that the patterns and rates of land use change currently observed in Italy have the potential to result in non-negligible adverse consequences for wildlife.

Keywords: landscape management, protected areas, agricultural landscapes, land use change, Natura 2000.

Introduction

Ever since concerns began to emerge over the loss of biodiversity, protected areas (PAs) have represented the cornerstone of conservation strategies throughout the world. Over the past three decades, about 26,000 PAs – which are now collectively known as the Natura 2000 network – have come into existence in the European Union, covering about 20% of its territory (European Commission 2008).

The designation of a site as a PA typically implies restricting the acceptable types of land use in order to preserve species or habitats that are deemed of particular interest. Especially in regions with a long history of habitat conversion, a significant proportion of the species of conservation concern are dependent on PAs for their survival. In Britain, for example, it is estimated that more than a half of such species occur largely or entirely within PAs (Jackson, Gaston 2008).

Even adequate management of a PA within its borders may not be enough to ensure that valuable species and habitats will continue to exist. In general, the outcome of conservation efforts within PAs will depend also on influences coming from the surrounding landscapes, where human activities are not subjected to special regimes of protection. A number of ecological mechanisms have been proposed through which biodiversity within a PA may be affected by land use change in the neighboring areas (Dunning *et al.* 1992; Hansen, DeFries 2007). For instance, if the effective size of the ecosystem is larger than the PA, loss of habitats in its unprotected portions will generally result in smaller populations and higher risk of extinction. It is likely that, as the effective size of the ecosystem shrinks, it is large predators that disappear first, which in turns impacts the trophic structure of the ecosystem. Also, habitats that are seasonally important may be located outside the PA's boundaries. Furthermore, different uses of the lands surrounding a PA entail different levels of water and air pollution, different regimes of fire and flood disturbance, and different levels of exposure to humans.

The effects of processes occurring off-site can be unexpectedly strong on a PA's conservation status. For example, the extinction rates of large mammals in national parks of the western United States correlate more strongly with the density of human population in the surrounding area than they do with park size (Park, Harcourt 2002).

Indeed, conservationists have long recognized the importance of managing not only PAs but also the neighboring lands (Schonewald-Cox *et al.* 1992; Shafer 1999). To a significant extent, the literature on ecological networks and habitat fragmentation is inspired by similar concerns (Harrison, Bruna 1999; Jongman *et al.* 2004; Fischer, Lindenmayer 2007).

Even so, there has been relatively little empirical research on how conservation efforts within PAs are affected by land use change in the surroundings, especially in Europe. Most existing research focuses on individual large reserves located in North America (Hansen, Rotella 2002; Gude *et al.* 2007) or in developing countries (Vester *et al.* 2007; Viña *et al.* 2007). At a much coarser scale, some recent studies have called attention to the threats posed to conservation by the current trends in residential development around PAs in the United States (Wade,

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Theobald 2010), Europe (Di Giulio *et al.* 2009) and other regions of the world (Macdonald *et al.* 2008).

In this paper we use a spatially explicit dataset assembled from a variety of sources to investigate the relationship between the conservation status of Italy's Natura 2000 sites and the structure of the landscapes in which they are situated. Because they typically have small surface areas (the median in our sample is 11 km^2), these PAs are potentially highly vulnerable to pressures arising in their surroundings. Indeed, it has been argued that Italy's Natura 2000 network is not sufficient to preserve many of the species for which it was designed, and that attaining the conservation goals will not be possible unless the surrounding matrix is managed as a functional part of the system (Maiorano *et al.* 2007). Furthermore, even though PAs in Italy have generally been effective at protecting the ecosystems within their borders from land use change, in many cases there is significant and widespread land use pressure in the neighboring areas (Maiorano *et al.* 2008).

We pay particular attention to landscape characteristics related to agriculture, as in most cases farming is the dominant form of land use around PAs. On average, about half the land within 20 km of a site in our sample is used for agriculture. In 42% of sample PAs, indeed, managers report concerns that conservation may be negatively affected by changes in agriculture occurring off-site. Furthermore, agriculture is involved in two important long-term trends in land use dynamics. Firstly, as the profitability of farming deteriorated, woodlands have gradually been replacing pastures and extensively cultivated lands in many marginal areas. In several mountainous or hilly parts of the country, this phenomenon has continued for decades (Falcucci *et al.* 2007). Secondly, on the plains and along the coasts significant portions of land have been switching from farming to urban development, as common throughout Europe (e.g. Bauža 2007). For example, it has been calculated that, between 1999 and 2005, 2.3% of Lombardy's agricultural land was converted to artificial uses (Anon 2009). As is clear from Fig. 1, there is a widespread tendency for the proportion of Italian landscapes used for agriculture to shrink, albeit at differing rates. Based on Corine Land Cover data, we compute that between 1990 and 2000, agricultural surface area declined in about 39% of Italy's 8,101 municipalities (the smallest administrative units). Increases only appear to have taken place in less than 4% of municipalities. This is a cause of concern because changes in farming systems have been shown to produce potentially dramatic effects on biodiversity. On the one hand, the widespread declines in wildlife observed in Europe over the past few decades have been widely blamed on the intensification of farming (Robinson, Sutherland 2002; Wickramasinghe *et al.* 2003; Báldi, Faragó 2007; Hanley *et al.* 2009), and a number of common farming practices have been linked with adverse effects on various components of biodiversity (see, for example, Tilman 1984; Freemark, Boutin 1995; McLaughlin, Mineau 1995; De Snoo 1999; Kladivko 2001). Indeed, intensively farmed land temporarily set-aside from production – as mandated by the European Commission schemes – has been unequivocally shown to enhance biodiversity (Van Buskirk, Willi 2004). The negative implications of intensifying farming are particularly well documented in the case of birds (Chamberlain *et al.* 2000; Donald *et al.* 2001; Benton *et al.* 2002). Yet, reductions in agricultural area should not be expected to unambiguously benefit wildlife. For a start, in several parts of Italy there has been a conversion of farmed land into uses, such as urban development, that are at best no more beneficial to wildlife than agriculture. In addition, low intensity agriculture and traditional farming practices often support high levels of bird (Farina 1997; Fox 2004; Laiolo *et al.* 2004; Verhulst *et al.* 2004), plant (Fischer, Wipf 2002; Luoto *et al.* 2003; Sendžikaite, Pakalnis 2006) and other (e.g. Zervas 1998; Giupponi *et al.* 2006) biodiversity. European landscapes have been shaped by agriculture over centuries and it has been speculated that at least 50% of Europe's most valuable biotopes are found on farmland that is managed extensively (Bignal, McCracken 1996). In the Mediterranean basin, where only 4.7% of the primary vegetation remains, high environmental diversity is the result of anthropogenic disturbances over millennia (Falcucci *et al.* 2007). Abandoning farming could therefore place the local survival of many species at risk.

In fact, not only is land abandonment widespread in Europe and typically associated with negative consequences for the environment (MacDonald *et al.* 2000), but there also seems to be more of it ahead. Deteriorating farm profitability as a result of Common Agricultural Policy reform is likely to result in more land being abandoned in areas of high significance for wildlife but low agricultural productivity (Oñate *et al.* 2007). Demography, international trade and technological change are also expected to contribute to this trend (Verburg *et al.* 2006).

The conservation implications of land use trends in Italy's landscapes feature as an important issue in the ongoing debate on the definition of a national biodiversity strategy for the next decade (Ministero dell'Ambiente 2010). While a substantial proportion of the residual area of valuable habitats in the country is probably already under protection, this does not make it immune from the influence of land use change in the vicinity. This paper attempts to assess to what extent the existence of a buffer zone around valuable natural sites contributes to maintaining that nature in good conservation status and how important agricultural forms of land use around Natura 2000 PAs are in providing support for wildlife. Our analysis exploits spatial variation across PAs to relate indicators of success of conservation efforts to site characteristics and measures of the structure of the surrounding landscape. We show that valuable natural habitats inside a PA generally have a better conservation status when the PA includes some kind of internal buffer area within its borders. Focusing on birds, we also find that – controlling for a variety of confounding factors – wildlife is richer on PAs situated in landscapes that are largely used for low-intensity agriculture.

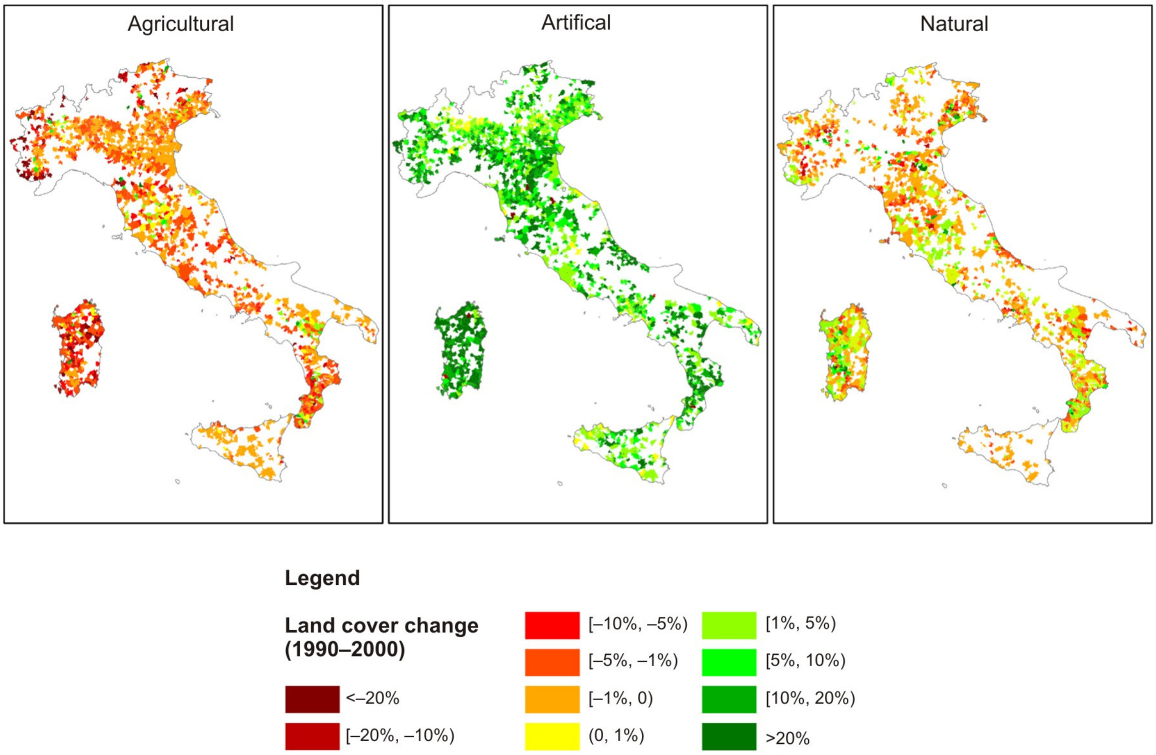

Fig. 1. Percent land cover change by municipality (1990–2000); smoothed rates using locally weighted estimator with 5-km radius; areas represented in white experienced no change

1. Methods

1.1. Methodological framework

The studied PAs are located throughout Italy and belong to the Natura 2000 network established in compliance with EU Directives 79/409/EEC ('Bird Directive') and 92/43/EEC ('Habitat Directive'). Using the cross-sectional dataset described in section 2.2, we exploit variation across sites to perform two types of statistical analysis.

1.1.1. Buffer zones and habitat conservation status

As a first step, we examine the relationship between the conservation status of the habitats a PA is designed to protect and the amount of additional 'buffer' zones that are included within the PA's boundaries. The conservation indicator that we use as the dependent variable is the share of valuable habitat surface whose conservation status is reported by PA managers as not compromised. Using ordinary least squares (OLS) regression, we relate that indicator to a number of bio-geographic site characteristics and a variable measuring the share of PA surface that is not occupied by habitats of conservation concern (MARGIN). We take this variable to indicate the extent to which a PA may include within its boundaries some kind of buffer zone around its most valuable areas, and attempt to evaluate its statistical and practical significance for PA conservation.

1.1.2. Bird species richness and landscape structure

The conservation status of a PA, we postulate, depends on both its local features and the structure of the surrounding landscape matrix. In the second step of the analysis, a linear regression model is estimated in which (the natural logarithm of) bird species richness is explained as a function of characteristics of both the PA and the landscape beyond its boundaries. Our aim is to assess the consequences for biodiversity of different types of land use and different levels of human disturbance in the surroundings of a PA, while controlling for the presence of potentially confounding factors.

1.1.3. Site selection

All the analyses focus on birds and on those Natura 2000 areas – known as Special Protection Areas (SPAs) – that were designed with an explicit emphasis on their conservation. Because birds perceive the landscape at a broader spatial scale than less vagile taxa, the issue of offsite influences on conservation outcomes within PAs appears both particularly relevant and easier to assess at the coarse spatial scale that we use. Even though in general it has proved difficult to identify taxa that can be used as predictors of general biodiversity patterns (Billeter *et al.* 2008), there is some evidence that bird indicators can provide a useful surrogate for information on other elements of biodiversity in agricultural landscapes (Gregory *et al.* 2005). In some countries, indeed, the government routinely uses indicators based on bird populations to monitor environmental quality in the countryside (e.g. Anon 2007). Irrespective of their relevance as a proxy for broader biodiversity, from an economic standpoint birds are associated with non-negligible cultural and recreational benefits, a classic example being bird-watching (e.g. Woodward, Wui 2001).

In addition, most SPAs were created earlier than other sites in the Natura 2000 network and more reliable data are typically available for them. As opposed to PAs of more recent creation, SPAs have a longer history of being managed to preserve or restore valuable habitats, and the effects should be visible. Thus the risk of mistaking the effect of deteriorated local habitat for negative influences arising in the surrounding landscape is small. In fact, there is a substantial amount of overlap between SPAs and the remaining Natura 2000 sites.

1.1.4. Covariates

For convenience, the explanatory variables that appear in the various stages of the analysis are divided into two groups: 'site characteristics' that describe the local features of the PA (either pertaining to its natural environment or to the way it is managed); and 'landscape characteristics' that describe aspects of the landscape beyond the PA boundaries (its structure and the intensity of land use) that represent the main object of our interest.

While its actual content varies among the different analyses, the vector of general site characteristics is composed of the following variables: latitude, longitude, elevation above sea level, site area, share of PA surface used for agriculture, and a set of binary indicators for wetland, coastal area, location in the Po Valley, and biogeographic region (Alpine, continental, Mediterranean). A dummy variable for national park or reserve is also included in order to control for the higher level of protection granted to some sites and their longer history.

Potentially, biodiversity and conservation outcomes at a given location can be affected by a number of other factors that cannot be accounted for here (temperatures, rainfall, moisture, and so forth; see, for an example, Okzan *et al.* 2009). In practice, however, many of the environmental factors that influence biodiversity are often highly collinear (Gaston, Williams 1996). At a sufficiently large scale, a substantial proportion of spatial variation in species richness can be explained statistically in terms of a few environmental variables (Gaston 2000).

Landscape characteristic variables are meant to account for the composition of the landscape in a buffer area around the PA and the intensity of land use or other disturbance by humans. For the purpose of this analysis, we distinguish three classes of land use/land cover: agricultural, artificial, and a residual class that includes woodlands and other natural areas, which is labeled 'natural' for convenience.

In addition to the proportion of buffer area used for agriculture (FARM) and artificial purposes (URBAN), our vector of landscape variables includes the natural logarithm of the distance to the nearest highway (HIGHWAY). Inclusion of this explanatory variable is meant both to account for the potential adverse effects of closeness to road networks (Csereklye 2010) and to serve as a proxy for the intensity of disturbance from human presence. Also, in order to allow the effect of agriculture to depend on the intensiveness of farming, a term is also included that is the interaction of FARM with an indicator of pesticide use (FARM×PEST).

An important issue in our analysis is how far from a PA's boundaries can land use change affect conservation. This question appears to have no general answer, as the appropriate buffering distance seems to vary substantially across locations and taxonomic groups. For instance, Park and Harcourt (2002) use zones of influence that are 50- and 100-km wide to study large mammals. An investigation by Bolger *et al.* (1997) of the relative influence on bird abundance of local versus landscape factors works with buffering distances between 250 m and 3 km, but sensitivity to landscape characteristics appears to vary significantly even among bird species (Flather, Sauer 1996). We consider a 5-km buffer around each PA, but all the analyses were also performed for longer distances (10, 15, and 20 km) to verify the sensitivity of the results to this assumption.

1.2. Data

The data used in the analysis were collected from a variety of administrative sources. Information about Italy's Natura 2000 areas was obtained from a database maintained by the Ministry of the Environment. The data were submitted by PA managers over the course of some years, but mostly between 2004 and 2007. They include digital maps and information on general site characteristics, the presence and conservation status of protected species and types of habitat, land use within the site, human activities and natural processes that may influence the site's ecological functioning. More detailed information about the data collection process for Natura 2000 – including the questionnaire – is available from the European Commission (Commission Decision No. 97/266/EEC, O.J. L 107/1).

PA managers were required to report what types of habitats protected under EU legislation were present on the site and what surface area each of them occupied, and to rate the conservation status of each on a three-point scale ('excellent', 'good', 'average or reduced'). We used that information to compute for each PA the proportion of valuable habitat surface whose conservation status is not compromised (i.e. that did not receive the lowest grade), which represents the dependent variable in our first analysis. The natural logarithm of bird species richness – the dependent variable in our second analysis – was calculated as the total count of protected bird species that are found on the PA. Most information about site characteristics (geographical coordinates, elevation a.s.l., and so forth) was also obtained from this dataset.

Data about the structure of the landscapes surrounding the PAs were extracted using GIS software (ESRI ArcInfo) from the land cover maps produced by the Corine Land Cover (CLC) project for the year 2000. Our definitions of the land-use types 'artificial' and 'agricultural' match CLC classes 1 and 2, respectively. The residual type 'natural' includes all remaining CLC classes. Additional information was obtained from Italy's bureau of statistics (ISTAT), institute of agricultural economics (INEA), and environmental protection agency (APAT). In particular, cereal yields (YIELD) and land prices (LLANDVAL) in the surroundings of the PAs were estimated from official statistics aggregated at the province level. Table 1 reports a brief description of all the variables that are used at some point in the empirical analysis, along with summary statistics and the source of the data.

Table 1. Descriptive statistics (N. Obs = 300; only 289 obs. on HABCONS)

Variable	Description	Mean	Std. Dev.	Source
Conservation indicators				
LBIRD	Log bird species richness	3.40	1.03	N2000
HABCONS	Proportion of protected habitat surface in good conservation status	0.93	0.13	N2000
Site characteristics				
LAREA	Log PA surface (ha)	6.84	1.59	N2000
ELEV	Mean site elevation (100 m a.s.l.)	2.36	2.78	N2000
LAT	Latitude (degr. north)	43.5	2.30	N2000
LON	Longitude (degr. east)	11.6	2.20	N2000
MARGIN	Proportion of site area not occupied by valuable habitats	0.55	0.31	N2000
MEDIT	=1 if Mediterranean biog. region	0.42	0.49	N2000
ALPINE	=1 if Alpine biog. region	0.07	0.25	N2000
PO	=1 if in Po watershed	0.33	0.47	APAT
WET	=1 if wetland	0.30	0.46	N2000
PARK	=1 if national park or reserve	0.45	0.50	N2000
Landscape characteristics				
FARM	Share of 5-km buffer surface occupied by agricultural areas	0.50	0.29	CLC2000
URBAN	Share of 5-km buffer surface occupied by artificial surfaces	0.08	0.09	CLC2000
HIGHWAY	Log distance to nearest highway (km)	2.59	1.23	APAT
LPEST	Log pesticide use (kg a.i./ha ag. land)	1.62	0.82	ISTAT
Other variables				
YIELD	Average cereal yield (100 kg/ ha, avg. 2000–2004)	55.6	25.0	ISTAT
LLANDVAL	Log land price (1,000/ha, avg. 1992–2000)	2.61	0.61	INEA

As mentioned in previous sections, we focus on SPAs, the PAs in Natura 2000 designated for bird conservation. PAs that are located at very high elevation (>1000 m a.s.l.), purely marine areas, and sites with extremely large or extremely small surfaces were excluded from the analysis. The resulting sample is comprised of 300 observations out of 588 SPAs.

All statistical computations were performed in Stata (StataCorp 2007), except for the spatial analyses that were conducted using R (R Development Core Team 2009) and the routines described in Bivand *et al.* (2008).

2. Results

2.1. Buffer zones and habitat conservation status

The first step of the analysis is concerned with the health status within PAs of the habitats of conservation interest. Using ordinary least squares (OLS), we studied its relationship with a measure of the extent to which PA design allows for a buffer area around those habitats (MARGIN). Table 2 reports two sets of results which only differ by whether or not MARGIN is included in the model. While it appears that there is a substantial amount of variation in conservation outcomes which our model is not able to able to account for, the covariates we use are jointly highly significant in either specification ($F_{6.282} = 4.18$ and $F_{7.281} = 4.38$, respectively). When MARGIN is added to the model (column 2), its coefficient is positive and highly significant, and the overall fit of the model improves remarkably. Including the landscape characteristics FARM, URBAN and HIGHWAY (column 3) further improves fit, but these variables – although signed consistently with the results of subsequent analyses – are not significant either individually or jointly ($F_{3.278} = 2.04$).

From a methodological standpoint, a potential issue with the estimates in Table 2 is the presence of spatial correlation. To the extent that nearby PAs resemble one another more than PAs located farther away with respect to unobserved factors, OLS estimation may not be the most satisfying option. We tested for the presence of spatial autocorrelation using Moran's I statistic for regression residuals and found little evidence of it ($p = .212$).

As expected, we observed that the share of PA valuable habitat area that is in satisfactory conditions of conservation tends to be larger on PAs that also include additional ‘buffer’ zones within their boundaries. This observation is consistent with the notion that the areas surrounding valuable natural sites can have an important influence on their conservation, and that allocating those areas to more nature-friendly types of land use can contribute to the viability of a PA. In fact, the effect of MARGIN seems modest: the results in column 2 imply that, at the median of the data, adding 100 hectares of buffer zone to a PA – which represents 9% and 15% increases in total area and in buffer zone, respectively – is associated with an average increase of about .4 percentage points in HABCONS.

Table 2. Share of habitat area with conservation status not compromised: OLS estimates (robust standard errors in brackets). Legend: * $p < .1$; ** $p < .05$; *** $p < .01$

	(1)	(2)	(3)
LAREA	0.009*	0.010**	0.009*
	(0.005)	(0.005)	(0.005)
ELEV	0.008**	0.009**	0.010**
	(0.004)	(0.004)	(0.004)
MEDIT	–0.031	–0.016	–0.020
	(0.022)	(0.022)	(0.023)
ALPINE	–0.092**	–0.081**	–0.071*
	(0.042)	(0.039)	(0.040)
WET	0.034*	0.037*	0.038**
	(0.019)	(0.019)	(0.019)
PO	0.063***	0.045**	0.044**
	(0.022)	(0.020)	(0.019)
MARGIN		0.101***	0.105***
		(0.029)	(0.032)
FARM			0.039
			(0.034)
URBAN			–0.036
			(0.126)
HIGHWAY			0.012
			(0.007)
Intercept	0.841***	0.770***	0.728***
	(0.044)	(0.053)	(0.070)
R^2	0.096	0.136	0.153
N	289	289	289

2.2. Bird species richness and landscape structure

As a second step, we examined how a site's bird species richness relates to the features of the site itself and the landscape in which it is situated. The estimates from OLS regression of the natural logarithm of bird species richness on site and landscape characteristics are displayed in the first two columns of Table 3.

In the first specification (column 1), landscape characteristics are excluded from the model. All coefficients have plausible signs and the overall fit is acceptable. When included in the model (column 2), FARM, FARM×PEST, URBAN and HIGHWAY turn out significant both jointly ($F_{4,287} = 7.15$) and individually, and improve the model fit considerably. Species richness on PAs appears to be positively associated with the proportion of the surrounding landscape that is used for agriculture. As expected, landscapes where farming is more intensive appear less welcoming to wildlife than those farmed at lower intensities. Also, species richness tends to be greater away from highways. On the other hand, the sign on URBAN is disturbingly positive and significant.

As in the previous section, we tested for the presence of spatial autocorrelation among PAs using Moran's I. Because in this case independence of the observations is rejected ($p < .001$), an alternative specification of the model is estimated which allows for spatial correlation. Column 3 in Table 3 reports the estimates from a spatial autoregressive error model (SAR) that uses an inverse-distance weight matrix (Anselin 1988). While the results remain qualitatively unchanged, the newly estimated coefficients on landscape characteristics have generally smaller magnitudes. This is especially true of URBAN, which indeed is no longer significant. Statistical significance is also lost for FARM×PEST, which however retains the appropriate sign.

Table 3. Log bird species richness: estimates from alternative specifications (Legend: * $p < .1$; ** $p < .05$; *** $p < .01$; standard errors in brackets)

	OLS (1)	OLS (2)	SAR (3)	2SLS (4)
LAREA	0.225***	0.224***	0.233***	0.227***
	(0.031)	(0.030)	(0.026)	(0.030)
ELEV	–0.093***	–0.053**	–0.074***	–0.050**
	(0.020)	(0.023)	(0.022)	(0.023)
LAT	–0.077**	–0.083**	–0.010	–0.141**
	(0.035)	(0.035)	(0.053)	(0.057)
PARK	0.211**	0.263***	0.406***	0.270***
	(0.096)	(0.095)	(0.083)	(0.094)
MEDIT	–0.636***	0.783***	–0.460*	0.691***
	(0.163)	(0.164)	(0.239)	(0.178)
ALPINE	0.723***	0.814***	0.736***	0.886***
	(0.205)	(0.213)	(0.227)	(0.218)
WET	0.612***	0.608***	0.570***	0.589***
	(0.113)	(0.109)	(0.098)	(0.109)
PO	0.814***	0.733***	0.686***	0.672***
	(0.127)	(0.124)	(0.165)	(0.131)
FARM		1.254***	0.719**	1.168***
		(0.307)	(0.331)	(0.311)
URBAN		1.485**	0.912	1.014
		(0.593)	(0.593)	(0.695)
HIGHWAY		0.132***	0.121**	0.138***
		(0.043)	(0.050)	(0.043)
FARM×LPEST		–0.245**	–0.120	–0.265**
		(0.120)	(0.134)	(0.119)
YIELD (indicator)				0.010
				(0.008)
Intercept	5.113***	4.474***	1.366	6.443***
	(1.582)	(1.567)	(2.388)	(2.202)
lambda			0.497***	
log-likelihood			–305.4	
R^2	0.433	0.484		0.475
N	300	300	300	300

At the median of the data, the estimates in Table 3 suggest that, when 1% of the landscape area surrounding a PA (roughly 160 ha) is converted away from agriculture, bird species richness declines on average by a non-negligible .5% to .9%, (depending on which set of estimates is used). In other words, it would be sufficient that 4% to 6.5% of the buffer zone is withdrawn from agriculture for the change to result in the local disappearance of 1 species. It might be tempting to compare the estimated effects of changes in the landscape matrix to the coefficient on PARK, a binary indicator of the site's status as national park or reserve, which is typically associated with both a longer history of habitat protection and stricter management rules. On average, sites granted protection at the national level appear to enjoy approximately 50% more bird species. As this result is due to better local habitat conditions resulting from longer and more effective conservation efforts, it suggests that, although appropriate interventions in the landscape matrix may contribute to conservation, careful management of the lands within PA boundaries is likely to produce more conspicuous effects. In fact, the large coefficient on PARK is likely to reflect not only the biodiversity consequences of better local habitats, but also the principles that informed the selection of national parks: higher protection was presumably given to richer sites in the first place (as in Paiders 2008).

An analysis very similar to the one presented in this section was also performed on a measure of bird conservation status analogous to the indicator used for habitats in section 2.1. In this case, the dependent variable of the regression model is the proportion of protected bird species whose conservation status is described as not compromised. Because the data on bird conservation status from which our indicator is computed were often incomplete, estimates from the analysis are not presented here. Yet, the results are consistent with those in Table 3.

2.3. Estimation issues

A potentially serious issue with the results of the previous section is the possibility that some of the site and landscape characteristics that we examined are correlated with unobserved determinants of biodiversity. Suppose, for example, that whatever makes an area welcoming to biodiversity also causes it to be attractive to humans. On the one hand, an area that is comparatively more attractive in this sense would support relatively high levels of wildlife, and would perhaps be more resistant or resilient in the face of human disturbance. On the other hand, such an area would tend to have a larger anthropic component: because land is more valuable, smaller portions of the landscape would be set aside for conservation, and larger portions would be farmed or developed. If there is some factor – which, for concreteness, we call 'resources' – that influences both our biodiversity and land use indicators, it is important that our analyses control for it, lest the associations we observe be spurious.

There are reasons to be concerned that a mechanism of this type might be at work. A significant body of literature has documented positive correlations between human population density and species richness in several taxa (McKinney 2002; Araújo 2003; Chown *et al.* 2003; Evans *et al.* 2006) including birds (Gaston, Evans 2004), with the strength of those associations increasing as the spatial scale of the analysis becomes coarser (Pautasso 2007). There is indeed agreement that the main reason why such positive species-human relationships arise is that both species richness and human population respond similarly to environmental energy availability. Also, the data analysis of the previous sections provides a warning sign that bias from ignoring 'resources' may be an issue: the counterintuitive sign on URBAN in the bird species richness equation.

With regard to the analysis of section 2.1, it should be noted that neglecting to control for 'resources' should not invalidate the main conclusion, namely that the conservation status of valuable habitats can be improved through appropriate management of the surrounding lands. As long as long-term planning choices at the landscape level to some extent reflect the relative costs and benefits of different types of land use, LAREA and MARGIN will tend to be smaller in areas with greater availability of resources. Reasonably, such negative correlations would result in the coefficients on LAREA and MARGIN being biased downwards rather than upwards.

On the other hand, the issue looks more serious for the bird species richness equation of section 2.2. In theory, indeed, it is possible that the observed positive association of biodiversity with human-related types of land use (e.g. with FARM) are entirely due to the latter being positively correlated with lurking 'resources'.

Plausibly, including a variety of control variables in the model should be enough, if not to address, at least to mitigate the problem. As we argued above, it is likely that the effect of many unobserved factors influencing biodiversity can be captured by relatively few environmental macro-descriptors.

In principle it is possible, using instrumental variable (IV) procedures, to test – and correct, if need be – for correlation between landscape characteristics and the unobservables that are dumped in the error term of the equation. Doing so would require identifying the (potentially) endogenous regressors that are correlated with 'resources' and coming up with at least as many instrumental variables that have explanatory power for the endogenous regressors, while being uncorrelated with 'resources'. In our application, however, IV estimation looks impractical, because the list of potentially endogenous regressors is long and data are in short supply on variables that would make for defensible instruments. Therefore, we used a variation of this approach that is sometimes referred to as the multiple indicator solution. The procedure, which requires no assumptions as to which regressors are potentially endogenous, makes use of two indicators of 'resources', one to be included in the equation of interest, the other to be used as an instrument for the first in order to carry out two-stage least squares (2SLS) estimation. Readers are referred to Wooldridge (2002) for a detailed description of the procedure.

The two indicators that we used are average cereal yields (YIELD) and the log of average land prices (LLANDVAL) in the surroundings of PAs. The estimates from multiple indicator estimation are reported in the fourth column of Table 3. Remarkably, all coefficients are left substantially unaffected, with the notable exception of that on URBAN which drops remarkably in magnitude and loses statistical significance. The coefficient on LPOP, the resource indicator, while positive, also falls short of statistical significance, but that should not be too surprising given that two-stage estimation typically produces large standard errors. As appropriate, the key results remain essentially unaffected when the roles of LLANDVAL and YIELD are reversed in the estimation.

Taken together, these results do provide some evidence of a confounding effect of 'resources'. When no attempt is made to account for the effect of resources, that effect appears to be largely picked up by the coefficient on URBAN, which consequently turns out positive and large; once 'resources' are controlled for, the coefficient on URBAN drops in magnitude dramatically. By contrast, our conclusions on the importance of the surrounding landscape matrix – and more specifically of its agricultural component – for PA conservation hold up across model specifications, and do not appear to merely result from neglecting to control for differences in resource availability.

3. Discussion

The network of PAs known as Natura 2000 represents the cornerstone of Europe's biodiversity conservation strategy. In Italy, N2000 sites are often small and situated in landscapes dominated by human presence. In many cases, especially along the coasts and on the plains, the areas around the PAs are undergoing substantial land use change (Maiorano *et al.* 2008). Against this backdrop, it has been proposed that, because small PAs are heavily influenced by what goes on outside their boundaries, for those PAs to be viable in the long run, it is necessary to manage the surrounding landscape matrix as a part of the system (Maiorano *et al.* 2007).

In this paper, we have observed that, when a PA includes within its boundaries some buffer zones in addition to the habitats of conservation interest that motivated its creation, those valuable habitats are generally in a better status of conservation. Also, we have found that, controlling for a variety of potentially confounding factors, the richness of protected bird species is significantly associated with the characteristics of the surrounding landscape. In particular, our measure of bird species richness is positively related to the share of the landscape matrix that is used as agricultural land, the more so the less intensive farming appears to be.

As there is a sizable literature linking expansions of agricultural land use and biodiversity loss, the observed positive associations between birds and farmland require an explanation. One possible interpretation of our results is that, because agriculture has dominated Italy's landscapes for centuries – so that species either adapted or disappeared – many of the remaining species require at least some level of farming activity for their survival (Kleijn, Baldi 2005). On the other hand, it is possible that the observed positive association between birds and agriculture is merely the result of neglecting to control for some factor – such as 'resources' – that simultaneously influences both the level of biodiversity and extent of farmland in a landscape. While it is difficult, given the limited availability of data, to devise an unquestionable statistical setup to control for this possibility, our analysis has attempted to do so in a 2SLS framework.

Assessing at what distance land use change around a PA ceases to have an influence on conservation efforts is difficult. Based on the findings of previous research, a 5-km buffering distance was chosen for the analysis reported in this paper. At this distance, bird species richness is associated with landscape characteristics, whereas the conservation status of protected habitats is not (after allowing for the presence within PA boundaries of an internal buffer zone). Repeating the analyses using longer distances (10, 15 or 20 km) leaves these results qualitatively unaffected. In fact, given the resolution of the data, landscape composition remains relatively stable as the buffering distance increases. Ultimately, how far offsite influences will affect conservation outcomes will vary across locations and taxa.

By and large, this paper has been concerned with birds, vagile organisms for which the issue of changing land use around protected areas seems especially relevant. Focusing on PAs that were designed primarily for bird protection (SPAs) ensured better data availability, and it is a natural choice to use bird indicators to evaluate the conservation outcomes of those PAs. In fact, although it has been proposed that bird indicators may also provide useful information about other components of biodiversity, evidence that those components respond to the landscape around the PAs in similar ways is relatively thin.

With all these caveats, however, the results presented in this paper show that the relationship between N2000 PAs and their surroundings deserves some consideration on behalf of landscape managers and researchers. Our estimates indicate that the effects of changes in agricultural landscapes on bird species richness are non-negligible – especially at very low intensity of farming – and suggest that the patterns and rates of land use change observed in the recent past in many parts of the country have the potential to result in significant adverse consequences for wildlife.

Conclusions

1. Changes in land use in the surroundings of a protected area have an influence on the protected area's conservation status. Allowing for a 'buffer area' around the habitats of conservation concern is found to increase the chances that those habitats are preserved in good conditions.

2. In particular, the presence of agricultural landscapes around a protected area appears to affect positively some components of biodiversity, namely the richness of birds. This effect tapers off as farming becomes more intensive.

3. The magnitude of the landscape effects that we observed for birds suggests that the changes in land use that are taking place in many parts of Italy represent a non-negligible threat to the long-term viability of many small protected areas of the Natura 2000 network. In this case, adoption of specific zoning rules for the lands neighboring with protected areas may be justified.

4. To the extent that other taxonomic groups are found to be affected in a similar way as birds, preserving agricultural landscapes farmed at low intensity may even, under some circumstances, contribute to the preservation of wildlife in a more cost effective way than expanding protected areas.

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