

Diversity, ecological structure, and conservation of the landbird community of Dadia reserve, Greece

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ABSTRACT

Birds are integral to many environmental monitoring schemes. However, there has been little research on the ecological basis of utilizing bird species as indicators of their respective communities and habitats. We used point counts to survey 72 landbird species, 16 of conservation concern, in the Dadia Nature Reserve, Greece, in order to understand the ecology of bird diversity patterns, analyse community composition, identify species characteristic of major vegetation types, and improve long-term management and monitoring protocols. We sampled 36 sites representing 21 vegetation types. Highly heterogeneous sites were the most species rich and rural mosaics (small fields and pastures of low intensity land use, separated by thick hedgerows and tree lines) were twice as rich as intensified crop monocultures. Using multivariate analysis, we found that vegetation cover and height affected the composition of the avifauna. Twenty-one predefined vegetation categories clustered into eight distinct bird habitat types: field crops, rural mosaics, mosaic sites, poplar trees, broadleaved woods, pinewoods, shrubs, and heaths. Ten bird species were highly characteristic of the main bird habitat types in the study area. Our results emphasize the importance of conserving rural mosaics, hedgerows, and openings within forests for landbird conservation in the Mediterranean countryside. We also provide evidence in support of maintaining horizontal heterogeneity at a local scale. Finally, we suggest that monitoring populations of certain indicator bird species can be a cost-effective and efficient way to monitor the state and habitat quality of the entire landbird community, thereby integrating the knowledge of community structure into conservation decision-making.

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Keywords

Agricultural policy, biodiversity monitoring, habitat heterogeneity, indicator species, landscape ecology, protected area management

INTRODUCTION

Since the conservation status, distributions, and population trends of European birds are particularly well-known (Heath *et al.*, 2000; BirdLife International, 2004), birds are widely used in European conservation planning (Council of Europe, 1979) and population trends of farmland bird species are one of the 15 'Quality of Life' indicators used by the UK government (BirdLife International, 2004; Gregory *et al.*, 2004). Given the significance of birds for conservation planning and environmental assessments, there is a need for a better ecological understanding of the role of bird diversity patterns and avian community structure in conservation decision-making.

Small landbirds in particular have often been proposed as potential indicators for the presence of other unrelated taxa (Prendergast *et al.*, 1993; Lombard, 1995; Howard *et al.*, 1998;

Kati *et al.*, 2004a) or as environmental change indicators to be integrated into broader monitoring schemes (Gregory *et al.*, 2004). They are also frequently included in evaluation studies for overall biodiversity conservation (Dobson *et al.*, 1997; Lawton *et al.*, 1998; Vessby *et al.*, 2002; Kati *et al.*, 2004b).

This study took place in the Dadia forest reserve (Greece), which was designed particularly for the protection of Eurasian black vultures (*Aegypius monachus*), a globally endangered species that is officially 'vulnerable' in Europe (Poirazidis *et al.*, 2004). The reserve has high conservation value for the birds of prey, as 36 of the 38 European species of raptors have been observed there. A special management plan (Adamakopoulos *et al.*, 1995) and a pilot monitoring project (Poirazidis *et al.*, 2002) are currently in practice in the Dadia reserve, targeting the biodiversity conservation of the reserve and particularly focused on raptor species of conservation concern. Our study explores

the ornithological value of the reserve for the landbird community, highlighting an easy-to-survey component of local biological diversity as an important parameter to be taken into consideration in reserve management. We define landbirds as the species belonging to the orders Passeriformes, Piciformes, Coraciiformes, and Columbiformes.

The aims of this study were: (1) to assess the importance of different habitats for landbird diversity, (2) to analyse the ecological structure of this community, (3) to identify indicator species, defined as typical species for the main habitat types, and (4) to integrate these findings into the conservation management and long-term monitoring protocols of the reserve.

METHODS

Study area

The study area is situated in north-eastern Greece (40°59'–41°15' N, 26°00'–26°19' E). It covers 430 km², almost all of which belongs to the Dadia Nature Reserve. It is a hilly area with elevation ranging from 10 to 650 m. The climate is submediterranean. Temperature ranges from –19° to 40 °C and the mean annual rainfall varies between 556 mm and 916 mm (Adamakopoulos *et al.*, 1995). Forests are dominated by Aegean pine (*Pinus brutia*) and black pine (*Pinus nigra*), oaks or a mixture cover 75% of the reserve, followed by agricultural land (16%), shrubs and mosaics (5%), and open areas consisting of grasslands and heaths (4%). The reserve was declared in 1980 and consists of two strictly protected zones (72.9 km²), which, in combination, have 85% cover of pinewoods and mixed pine–oak woods and are of great importance as nesting sites for Eurasian black vultures (Poirazidis *et al.*, 2004). The buffer zone of the reserve (351.7 km²) has 72% forest cover and has more open or semi-open areas. A detailed map of the vegetation types in the study area is presented in Kati *et al.* (2004c).

Sampling

We distinguished 21 vegetation types in the study area, using the Corine typology database (Devillers & Devillers-Terschuren, 1996) as a reference system (19 Corine habitat types present in the study area). In two cases (Corine codes 41.733 and 4285A) we further distinguished two vegetation subcategories, on the basis of vegetation physiognomy (bushy undergrowth or not). One site or usually two sites (indicated with 'a' or 'b' next to the site code) were randomly selected to represent each one of the 21 vegetation types of the study area. We sampled 36 sites with 310 point counts (Blondel *et al.*, 1970; Bibby *et al.*, 1992). In a point count, the territorial-breeding song of a male represents a future breeding pair and is therefore counted as two individuals (Bibby *et al.*, 1992). Every call different from the male breeding song is counted as one individual. We recorded all bird species seen or heard within a circle of 100-m radius. Each count lasted for 10 min and took place between 30 min before sunrise and 4 h after sunrise. In order to sample both sedentary and late migrant species, we conducted two sets of 155 point counts between 15

April to 15 May and 15 May to 15 June, 1999. Because of the differences in area extent sampled, we could not have the same sampling effort at all sites and adjusted the sampling effort based on the site's area. We sampled 25 sites of 20 ha with five point counts, and 11 smaller sites with two to four point counts (Table 2). Sampling stations were at least 200 m away from each other and 100 m away from the site edge.

Each point count was located at the centre of a quadrat of 50 × 50 m, within which we estimated the overall vegetation cover of trees and bushes (> 0.5 m), in order to describe the general vegetation physiognomy of the site sampled (Table 1). The vegetation cover is defined as the total vertical projection of the crown area of trees and bushes, using the Braun–Blanquet scale for cover estimation: 1 = 1–5%, 2 = 6–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100%. Based on Kent & Coker (1994), we characterized the four main vegetation layers as follows: (1) trees > 7 m, (2) low trees (4–7 m), (3) high bushes (2–4 m), and (4) bushes (0.5–2 m). We defined the dominant vegetation layers as the ones contributing more than 25% to the overall vegetation cover (Table 1).

Data analysis

The species diversity of sites was estimated in terms of species richness (*S*), weighted species richness (*WS*), and Shannon–Weiner index (*H*) (Magurran, 2004). Weighted species richness is the species richness of the site, with each species having a different weight based on its conservation status (SPEC category) (BirdLife International, 2004). We gave a standard weight (*w* = 1) to the species of SPEC 4 category, which are concentrated in Europe and have either a favourable conservation status or are not covered by any SPEC category. We gave double weight (*w* = 2) to the species of SPEC 3 category, which are not concentrated in Europe but have an unfavourable conservation status. Finally we gave quadruple weight (*w* = 4) to the species of SPEC 2 category, which are concentrated in Europe and have an unfavourable conservation status and to the species of Annex I of the European Directive 79/409 EU, which includes all bird species subject to special conservation measures in Europe. We calculated *H* of each site using as relative abundance of bird species the maximum abundance of the two values recorded in the two sampling seasons.

Using the *r3* software package (Legendre & Vaudor, 1991), we analysed the bird community composition by creating a similarity matrix of the samples on the basis of relative abundance data (Steinhaus coefficient of similarity — *S17*). A distance matrix was produced from the similarity matrix, and it was used as an input into the spatial visualization in the Euclidian space, using Principal Coordinate Analysis with corrected eigenvalues (DistPCoA), a method that resolves the problem of 'non-Euclideanarity' (Legendre & Anderson, 1998). We used the samples' coordinates of DistPCoA as an input into the *k*-means partitioning procedure, using the *FASTCLUS* procedure (SAS, 1985). We applied the above procedure for *k* algorithm computation, *k* being the final number of clusters produced. Computation was repeated 1000 times, randomly reallocating samples as initial seeds at each

Table 1 Vegetation types in the study area based on the Corine typology system (Devillers & Devillers-Terschuren, 1996) and descriptions of the sites sampled

	Corine vegetation type	Vegetation type description	Site code	Site area (ha)	Dominant vegetation layer	Vegetation cover estimation
Shrubs (S)	32.313	High dense maquis (<i>Arbutus</i> sp.) without undergrowth	S1a	20	3	5
			S1b	20	3	5
	32.161	Deciduous oak matorral (<i>Quercus pubescens</i>) with <i>Phillyrea latifolia</i> undergrowth	S2	20	3	3–4
	32.21A4 × 34.53	Bushes (<i>Phillyrea latifolia</i>) with grassy undergrowth	S3	10	3	2
Heaths (H)	32.32	Low (< 0.5) ericaceous maquis (<i>Erica arborea</i>) with sparse oak trees	Ha	10	3	1
			Hb	10	3	1
Grasslands (G)	37.4 (× 41.8221)	Humid grasslands with sporadic broadleaved trees and <i>Juniperus</i> bushes	G1a	10	1,3	2
			G1b	5	3	2
	34.53	Xeric grasslands with sporadic low pine trees	G2a	5	2	1
			G2b	10	2	1
34.2	Serpentine grasslands with sporadic pines	G3	5	3	2	
Mosaics (M)	32.71 × 38.1	Mosaic of pseudomaquis × pastures	M1a	20	1,3,4	1–3
			M1b	20	1,3,4	2–3
	32.71 × 38.1 37.1 × 44.12 × 41.733	Mosaic of pseudomaquis × pastures × humid grassland × willow shrubs × oakwoods	M2	10	1,3	2–3
Forests (F)	41.1B × 41.19311	Mediterraneo–Moesian beech forests	F1a	20	1	5
			F1b	20	1	5
	41.76	Oakwoods (<i>Quercus frainetto/cerris</i>)	F2a	20	1	5
			F2b	20	1	5
			F3a	20	2	4
	41.733	Oakwoods (<i>Quercus pubescens</i>)	F3b	20	2	4
			F4a	20	2,4	3
	43.7	Oakwoods (<i>Quercus pubescens</i>) with bush undergrowth	F4b	20	2,4	3
			F5a	20	1	5
	42.661(C)	Mixed pine–oak woods	F5b	20	1	5
			F6	5	1	4
	42.85 A	Pinewoods (<i>Pinus nigra</i>)	F7	20	1	5
			F8a	10	1,4	4
	44.514	Pinewoods (<i>Pinus brutia</i>) with bush undergrowth	F8b	5	1,4	4
			F9a	20	1	5
44.615	Riparian vegetation — tree line along streams of <i>Alnus glutinosa</i>	F9b	20	1	5	
		F10a	20	1	5	
Agricultural land (A)	84.4	Riparian vegetation — tree line along streams of <i>Populus</i> sp.	F10b	20	1	5
			A1a	20	3	2
82.11	Rural mosaics. Small agricultural plots separated by hedges and tree lines	A1b	20	3	2	
		A2a	20	4	0–1	
Total	21	Field crops. Agricultural land without bush cover	A2b	20	4	0–1
			36	575		

Dominant vegetation layer: 1, trees > 7 m; 2, low trees (4–7 m); 3, high bush (2–4); 4, bush: (0.5–2 m).

Vegetation cover estimation of trees and bushes: 1 = (1–5)%, 2 = (6–25)%, 3 = (26–50)%, 4 = (51–75)%, 5 = (76–100)%.

run. From the n dimensions of samples' coordinates we used the first ordination axes capturing a standard percentage of 85% of data variance, avoiding thus the noise of the last axes. The final output was the non-hierarchical up-to-down robust dendrogram with k clusters, including only samples with a level of

persistence > 75%. These k clusters are also shown as 80% confidence ellipses in the ordination of point counts (SAS, 1985). Finally, we used the indicator value procedure (Dufrêne & Legendre, 1997) in order to find out the typical species that characterize each of the clusters. The indicator value of each species

Table 2 Bird diversity and sampling effort at each site. Sites are ranked by descending species richness (S), then by descending weighted species richness (WS)

Site		S	WS	H'	Mean S	Mean WS	No. point counts
M1a	Mosaic	37	59	3.26	22.00	35.60	5
A1b	Rural mosaic	35	65	3.17	17.80	35.40	5
A1a	Rural mosaic	35	60	3.11	17.60	29.80	5
M2	Mosaic	34	53	2.96	15.80	22.40	5
M1b	Mosaic	32	48	2.99	15.80	21.00	5
F9a	Alder vegetation	29	36	2.94	15.40	19.40	5
F4b	Oakwood with bush undergrowth	28	52	2.89	14.40	24.40	5
S2	Oak matorral	28	42	2.96	16.40	23.80	5
F10b	Poplar vegetation	28	41	2.85	11.40	14.00	5
G1a	Humid grassland	27	49	2.94	15.25	26.75	4
F4a	Oakwood with bush undergrowth	26	43	2.81	14.60	24.80	5
F1a	Beech wood	25	37	2.79	13.40	17.80	5
F2b	Oakwood	24	40	2.75	11.60	19.00	5
F5b	Mixed pine–oakwood	24	39	2.83	15.60	21.60	5
S1b	High maquis	24	38	2.67	13.20	22.00	5
S1a	High maquis	24	35	2.74	13.60	20.20	5
S3	<i>Phillyrea</i> bushes	23	36	2.91	17.00	24.00	3
F10a	Poplar vegetation	23	36	2.87	11.80	15.40	5
F2a	Oakwood	22	38	2.69	11.20	16.60	5
Ha	Heath	22	37	2.70	12.67	23.67	3
G3	Serpentine grassland	22	32	2.78	16.50	25.00	2
G2b	Xeric grassland	22	30	2.83	16.00	19.50	2
F1b	Beech wood	22	29	2.67	12.00	13.40	5
G2a	Xeric grassland	21	40	2.65	16.00	22.00	2
F8a	Pinewood with bush undergrowth	21	31	2.65	9.75	15.25	4
F9b	Alder vegetation	21	28	2.75	11.00	13.40	5
F5a	Mixed pine–oakwood	20	27	2.67	12.80	16.40	5
A2b	Field crops	19	48	2.29	8.00	21.40	5
F3b	Oakwood	19	35	2.31	8.80	15.40	5
F7	Pinewood	19	29	2.30	9.00	10.60	5
Hb	Heath	18	36	2.38	10.33	24.67	3
F3a	Oakwood	17	34	2.29	8.20	15.80	5
F6	Black pinewood	16	22	2.22	10.50	13.50	2
A2a	Field crops	15	35	2.05	8.20	19.40	5
F8b	Pinewood with bush undergrowth	15	14	2.48	12.50	12.00	2
G1b	Humid grassland	13	22	2.38	9.33	15.33	3

S, species richness; WS, weighted species richness; H', Shannon diversity index; Mean S, mean species richness of point counts; Mean WS, mean weighted species richness of point counts.

for a given cluster is calculated as: $\text{IndVal} = A \times B \times 100$, where $A = \text{mean number of the individuals across the sites of the cluster}$, which is the sum of mean number of the individuals in all clusters, and $B = \text{number of sites in the cluster where the species is present}$, which is the total number of sites in that cluster.

IndVal is a percentage that ranges between 0 and 100 and takes its maximum value when the species is present only in one cluster and in all sites of this cluster. All calculations were carried out using INDVAL software (Dufrêne, 1999). A species is considered to be a 'symmetrical indicator' ($\text{IndVal} > 50\%$) for one cluster when it is present in $> 70\%$ of the sites of the cluster and when $> 70\%$ of its individuals occur in the cluster. A random reallocation procedure (1000 iterations) of sites among site groups was

used to test the significance level of IndVal ($\alpha = 0.05$). In order to represent all the bird species in the study area, we drew a complementary network of sites starting with the most important site in terms of conservation and, using a stepwise procedure, added the sites that contributed new species to the network, giving priority to species with high conservation value (criteria WS and then S).

RESULTS

During our point count sampling, we counted 9305 individuals of 72 bird species (Appendix I), distributed among the orders of Passeriformes (61), Piciformes (6), Coraciiformes (3), and

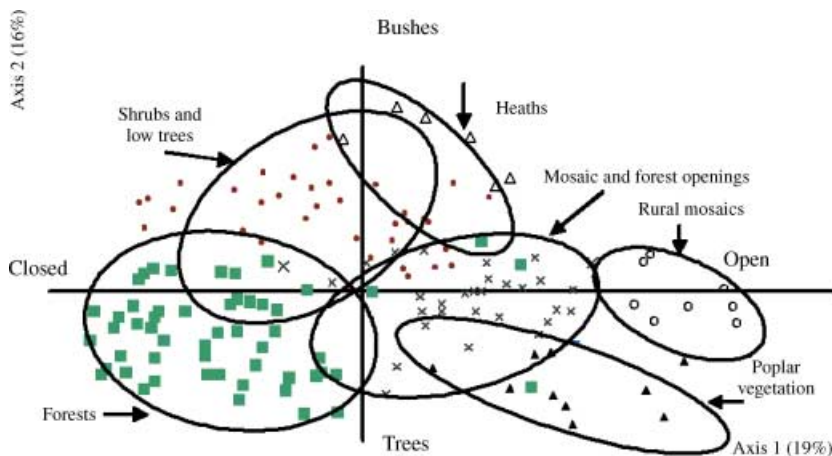


Figure 1 Ordination of 145 point counts using Principal Coordinate Analysis (DistPCoA) in two axes explaining 19% and 16% of the data set variability. Different shape spots refer to the point counts of the different clusters, which are shown as 80% confidence ellipses.

Columbiformes (2 species). Sixteen species were of special conservation concern since they belonged to SPEC 2 category or to the Annex I of the Bird Directive 79/409 EU. Thirteen more species belonged to SPEC 3 category.

Diversity

The most important sites for bird conservation were highly heterogeneous sites, combining grassy openings, hedges, and wood plots, such as rural mosaic (A1) and mosaic sites (M1, M2), because they hosted the greatest number of species (*S*) and the greatest number of species of concern (*WS*) (Table 2). These mosaic character sites are proven also to be the most diverse, based on the Shannon's diversity index as a ranking criterion (M1a, A1b, A1a, M1b, M2).

To better compare the site species richness regardless of the variations in site area and the sampling effort, we also used the mean species richness of point counts as the main ranking criterion. Mosaic (M1a) and rural mosaics (A1a, A1b) again emerged as the three most important sites, followed by smaller sites such as grasslands with *Phillyrea* bushes (S3), serpentine grasslands (G3), or xeric grasslands (G2). These sites are openings within the expanded pine forest zone (Table 2). Oak matorral with shrubs (S2) also ranked as one of the most species-rich sites. Pinewoods hosted few species, including only two breeding species of conservation concern (*Streptopelia turtur*, *Picus viridis*), which also bred in the broadleaved woods of the study area.

Ecological structure

Considering all the 155 point counts together, the ordination procedure (DistPCoA) clustered the 10 point counts in field crops (A2), positioning them on the right part of the horizontal axis that explained 23% of the variation. Therefore, agricultural land with almost no tree or bush cover is clearly distinguished from the remaining sites. We then excluded these point counts and re-analysed our data set, in order to discern the environmental gradients within the remaining 145 point counts. Shaded sites with high vegetation cover were positioned on the left of the

horizontal axis which explained 19% of the variation, semi-open sites in the centre, and open sites on the right. On the other hand, the vertical axis that explained 16% of the variation separated sites with tall trees from those with shrubs (Fig. 1). Hence, two major environmental gradients affect bird distribution in the study area: vegetation cover and vegetation height.

The first cluster set apart in the clustering procedure encompassed all point counts conducted in the field crops (A2). We recorded three bird species exclusively in the field crops: *Melanocorypha calandra*, *Calandrella brachydactyla*, and *Anthus campestris* (IndVal = 20%, 20% and 10%, respectively).

Figure 2 shows the main habitat types defined by their bird communities and the typical species for each cluster, using the 145 point counts analysed with the k-means and IndVal procedures. Some bird species are generalists and they are common throughout the study area, having no indicator value for a precise vegetation type (i.e. *Fringilla coelebs*, *Turdus merula*, *Luscinia megarinchos*, *Erithacus rubecula*, *Garrulus glandarius*, *Oriolus oriolus*, *Parus major*, *Carduelis chloris*, *S. turtur*, and *Upupa epops*). Combining the results from ordination and clustering procedures (Figs 1 & 2), seven different bird habitat types can be distinguished: heaths, shrubs and low trees, pinewoods, broadleaved woods, mosaic sites and forest openings, rural mosaics, and poplar vegetation. *Lullula arborea* characterizes heaths, while *Certhia brachydactyla* is a typical species of the broadleaved woods. *Emberiza cirrus* characterizes the mosaic sites and the grassy openings inside forest areas. Five species are typical of agricultural fields separated by hedges and trees: *Emberiza melanocephala*, *Galerida cristata*, *Hippolais pallida*, *Miliaria calandra*, and *Sylvia communis*. *Emberiza hortulana* characterizes areas with low trees, shrubs, and heaths, while *Parus caeruleus* characterizes forest habitats. No characteristic species exist for shrubs and low trees, pinewoods, and poplar habitats.

Species representation

All bird species found in the study area can be represented in a network of 10 sites. This network includes one site from each bird habitat type (Fig. 2), with the exception of rural mosaics that contribute two sites in the network. The network sites are

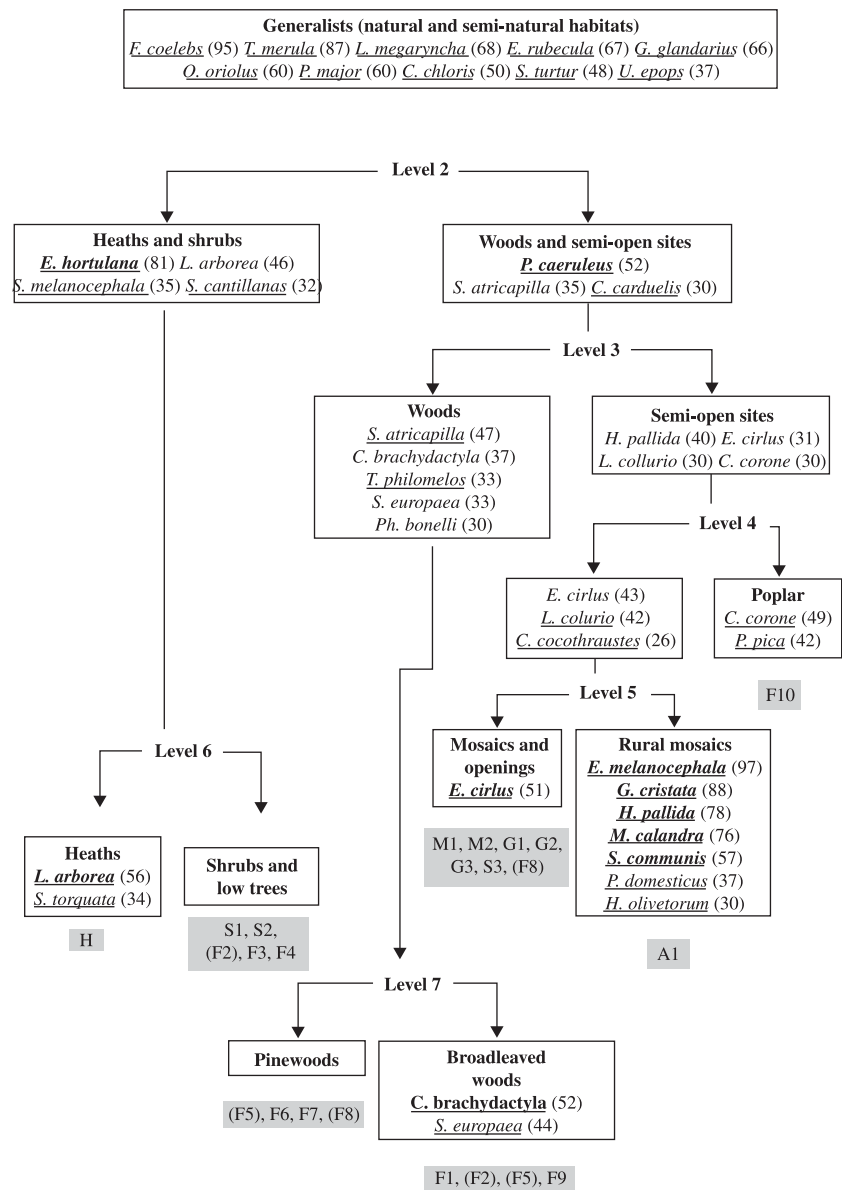


Figure 2 Habitat types as defined by birds and the indicator values of bird species (in parentheses) for the hierarchy produced by k-means clustering procedure. Species names in bold are symmetrical indicators with IndVal > 50% and underlined species names have their maximum IndVal in that habitat. Vegetation codes are from Table 1. Vegetation types that belong to more than one cluster are given in parentheses.

prioritized as follows, with complementary weighted species richness of each site and complementary species richness (number of new species contributed to the network) given in parentheses: rural mosaic A1b (65, 35), mixed pine–oak wood F5b (21, 9), field crops A2b (17, 6), poplar tree line F10a (11, 8), xeric grassland G1b (5, 4), heath Ha (5, 4), high maquis S1a (4, 1), rural mosaic A1a (3, 2), beech wood F1a or F1b (2, 2), and mosaic M1b (2, 2).

DISCUSSION

Ecological structure

Vegetation cover and height determine the composition of the avifauna in our study area, which is in agreement with other studies in the Mediterranean region (Blondel *et al.*, 1970; Prodon & Lebreton, 1981; Catsadorakis, 1997). The height gradient

mainly corresponds to vegetation successional stage and the vegetation cover to disturbance intensity, caused either by humans (agriculture, logging, livestock grazing) or by natural processes (fire, native herbivore grazing).

Birds discriminate landscape features at a coarse scale, perceiving the 21 vegetation types of the study area as eight distinct bird habitat types: field crops, rural mosaics, semi-open mosaics and grasslands, poplar vegetation, broadleaved woods, pinewoods, shrubs, and heaths. The habitat typology as revealed by the landbird community does not necessarily correspond to the predefined vegetation classifications (Fig. 2), thus emphasizing the importance of planning habitat conservation from the perspective of the taxon of interest. Each of these bird habitat types is also represented in the complementary network constructed to include all bird species, with rural mosaics being represented twice. Kati *et al.* (2004b) also found that for various taxonomic groups, including landbirds, any number of sites selected at random with the

condition that each site belonged to a different cluster, conserves more species than an equal number of sites selected at random from different vegetation types defined after Corine typology. Hence, bird typology provides us with a guideline for specific habitats to be maintained for avifauna conservation.

Even though some of the species recorded are generalists, there are 10 specialist species that are highly characteristic and strongly dependent on the habitat types they are found in, as they are found in almost all sites of that habitat type and rarely in others. Monitoring the populations of such 'indicator' bird species may be a cost-effective and efficient way to monitor the overall landbird community and their habitats.

Conservation of landbird diversity

The rural mosaics were the most diverse and important sites for conserving the breeding bird fauna in our study area. Cultivated areas are generally known to play a fundamental role in maintaining breeding bird diversity in the Mediterranean region (e.g. Farina, 1997; Suarez-Seoane *et al.*, 2002). Not only human-dominated habitats can support a substantial proportion of native bird diversity (Hughes *et al.*, 2002; Sodhi *et al.*, 2005) but these birds in return also provide key ecosystem services such as seed dispersal and pest control (Sekercioglu *et al.*, 2004). However, agricultural intensification has led to a dramatic decline in farmland bird diversity in many European countries (Pain & Pienkowski, 1997; Chamberlain *et al.*, 2000; Donald *et al.*, 2001), although not all of them (Fox, 2004). In Greece, the policy followed by the Ministry of Agriculture during the last 50 years aimed at the unification of small agricultural properties into expanded agricultural land in order to permit the use of large machinery and the intensification of crop production. Small properties were exchanged through a procedure of land reallocation, simultaneously removing 'living fences' and tree and bush vegetation that comprised the natural borders of former small-scale properties. Our results show that rural mosaics, defined as small fields and pastures separated by natural vegetation of thick hedgerows and tree lines were twice as rich in bird species number than intensified crop monocultures. Removing hedges and lines of trees, even exotic conifer species (Pithon *et al.*, 2005), can have negative effects on farmland birds. Our study provides additional evidence supporting the European common agricultural policy (CAP) towards the maintenance of the rural mosaic landscape as a habitat of great importance for farmland breeding birds in the Mediterranean region.

We found that semi-open mosaic sites and forest openings are also among the most species-rich sites in our study area and host species of conservation concern. Mosaics are heterogeneous sites combining patches of woodland, shrubs, and pastures in a small area, whereas openings in forest enhance landscape heterogeneity. Spatial heterogeneity is often the main factor that increases avian species diversity within habitat and landscape scales (Roth, 1976; Huston, 1994; Bohning-Gaese, 1997; Farina, 1997; Sekercioglu, 2002).

Forest openings are also important habitats for other taxonomic groups in the study area, such as insects (Grill & Cleary, 2003; Kati *et al.*, 2004c) and several raptor species that use them for

hunting (Adamakopoulos *et al.*, 1995; Poirazidis *et al.*, 2004). The forested zone includes fewer landbird species, but large areas of core habitat may be important to maintain viable populations of certain specialized forest-dwelling species. There is a need for research in the Mediterranean region to determine the threshold size of forest openings that will not harm forest-dependent bird species and hinder forest regeneration (Sekercioglu, 2002).

We found that all bird species sampled in the year 1999 can be represented in a complementary network of 10 sites. Reserve designers usually target to maximize protected biodiversity while minimizing reserve size (Cabeza & Moilanen, 2001). One of the best practices to do so is to pick up complementary areas with the maximum combined species richness (Pressey *et al.*, 1993; Margules & Pressey, 2000), rather than species-rich areas, or areas representative of the vegetation types that are found at local (e.g. Kati *et al.*, 2004b) or regional scales (e.g. Lombard, 1995; Howard *et al.*, 1998). In the current study, our network of 10 selected sites is not intended as a proposal for a new subnetwork within the existing protected area of the Dadia Nature Reserve. These 10 sites by themselves are unlikely to maintain viable populations of the bird species of the reserve as units isolated from their landscape context. This network, however, highlights habitats that are important for local bird conservation. The network also confirms the importance of monitoring and conserving different bird habitat types represented in the clustering procedure, given that at least one site from the different clusters is represented in the network.

Interestingly, most species-rich habitats are located in the buffer zone, which is less forested, than in the strictly protected zone, which is covered mostly by pinewoods (85% cover). The high value of the buffer zone has also been shown for other biological groups studied in the reserve (e.g. Grill & Cleary, 2003; Kati *et al.*, 2004c). The main conservation value of pinewoods is for the maintenance of the Eurasian black vulture population (Poirazidis *et al.*, 2004) as well as for some forest-dwelling raptor species, rather than for the landbird community. It is encouraging that the management plan of the reserve (Adamakopoulos *et al.*, 1995), which targets mainly the conservation of its birds of prey, is also compatible with the conservation of the landbird community in general. The management plan proposes to conserve rural mosaics with hedges and woodland patches and to maintain forest openings in the core area through livestock grazing, wood-cutting, and the reintroduction of natural herbivore populations. Hence, there is no conservation conflict in the reserve as far as management practices are concerned.

Conservation proposals

The current study implies the importance of horizontal heterogeneity for bird conservation at the local and landscape scales, as shown by the high species richness of mosaic character sites and of openings in the forested zone, respectively. We also provide evidence against land reallocation and agricultural intensification and emphasize the importance, for breeding birds, of conserving rural mosaics in the Mediterranean landscape. Our findings also indicate that the knowledge of bird community structure should

be integrated into conservation decision-making focused on landbird communities.

An ecological analysis of bird community structure resulted in the identification of eight distinct bird habitat types and 10 indicator bird species that are highly dependent on the habitat types they breed in. We propose the landbird community to be integrated as a monitoring parameter in the ongoing pilot monitoring project of the reserve and we provide a list of indicator bird species to monitor. Monitoring these indicator species is an efficient method to monitor the ecological state of the landbird community in the reserve and it gives a more direct insight into bird habitat quality, than surveying all vegetation types defined after standard habitat typologies such as Corine. Finally, reserve authorities should be aware of the importance of the buffer zone for local landbird diversity and consider the high conservation value of rural mosaics, mosaic character sites, and forest openings, especially when putting the reserve management plan into practice. Our conclusions have broader implications, both for the conservation of landscape heterogeneity in the European countryside and for the use of birds as indicator species worldwide.

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Appendix I Inventory of bird species sampled and weighted index (*w*) according to their conservation status (SPEC category 2004)

Species	SPEC	w	Species	SPEC	w	Species	SPEC	w
Columbiformes			<i>Troglodytes troglodytes</i>		1	<i>Parus lugubris</i>	4	1
<i>Streptopelia decaocto</i>		1	<i>Eriothacus rubecula</i>	4	1	<i>Parus caeruleus</i>	4	1
<i>Streptopelia turtur</i>	3	2	<i>Luscinia megarhynchos</i>	4	1	<i>Parus major</i>		1
Coraciiformes			<i>Phoenicurus phoenicurus</i>	2	4	<i>Sitta europaea</i>		1
<i>Alcedo atthis</i>	3*	4	<i>Saxicola rubetra</i>	4	1	<i>Certhia familiaris</i>		1
<i>Merops apiaster</i>	3	2	<i>Saxicola torquata</i>		1	<i>Certhia brachydactyla</i>	4	1
<i>Upupa epops epops</i>	3	2	<i>Oenathe oenathe</i>	3	2	<i>Remiz pendulinus</i>		1
Piciformes			<i>Turdus merula</i>	4	1	<i>Oriolus oriolus</i>		1
<i>Picus viridis</i>	2	4	<i>Turdus philomelos</i>	4	1	<i>Lanius collurio</i>	3*	4
<i>Dryocopus martius</i>		1	<i>Turdus viscivorus</i>	4	1	<i>Lanius senator</i>	2	4
<i>Dendrocopos major</i>		1	<i>Cettia cetti</i>		1	<i>Garrulus glandarius</i>		1
<i>Dendrocopos syriacus</i>	4*	4	<i>Hippolais olivetorum</i>	4*	4	<i>Pica pica pica</i>		1
<i>Dendrocopos medius</i>	4*	4	<i>Sylvia cantillans</i>	4	1	<i>Corvus corone</i>		1
<i>Dendrocopos minor</i>		1	<i>Sylvia melanocephala</i>	4	1	<i>Corvus corax</i>		1
Passeriformes		1	<i>Sylvia hortensis</i>	3	2	<i>Sturnus vulgaris vulgaris</i>		1
<i>Melanocorypha calandra</i>	3*	4	<i>Sylvia curruca</i>		1	<i>Passer domesticus</i>	3	2
<i>Calandrella brachydactyla</i>	3*	4	<i>Sylvia communis</i>	4	1	<i>Fringilla coelebs coelebs</i>	4	1
<i>Galerida cristata</i>	3	2	<i>Sylvia atricapilla</i>	4	1	<i>Serinus serinus</i>	4	1
<i>Lullula arborea</i>	2	4	<i>Phylloscopus bonelli</i>	2	4	<i>Carduelis chloris</i>	4	1
<i>Alauda arvensis</i>	3	2	<i>Phylloscopus collybita</i>		1	<i>Carduelis carduelis</i>		1
<i>Riparia riparia</i>	3	2	<i>Regulus ignicapillus</i>	4	1	<i>Coccothraustes coccothraustes</i>		1
<i>Hirundo rustica</i>	3	2	<i>Hippolais olivetorum</i>	4*	4	<i>Emberiza cirrus</i>	4	1
<i>Delichon urbica</i>	3	2	<i>Muscicapa striata</i>	3	2	<i>Emberiza hortulana</i>	2*	4
<i>Anthus campestris</i>	3*	4	<i>Aegithalos caudatus</i>		1	<i>Emberiza melanocephala</i>	2	4
<i>Motacilla cinerea</i>		1	<i>Parus palustris</i>		1	<i>Miliaria calandra</i>	2	4
<i>Motacilla alba</i>		1						

*species in Annex I of 79/409EU. SPEC2: \concentrated in Europe and with unfavourable conservation status. SPEC3: not concentrated in Europe but with unfavourable conservation status. SPEC4: concentrated in Europe and with favourable conservation status.