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Research paper

Impact of habitat management of small game species on bird communities in French Mediterranean scrublands

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Abstract

Impact of habitat management of small game species on bird communities in French Mediterranean scrublands. In the French Mediterranean region, the progressive abandonment of traditional activities has led to the expansion of scrubland and landscape encroachment, thereby driving biodiversity loss. Hunters participate in habitat management mostly by opening scrubland to increase the habitat of small game species. The aim of our study was to evaluate the contribution of such management to the conservation of non-targeted bird species. In three 30-hectare managed (MA) and unmanaged (UMA) areas we monitored birds in spring using the progressive frequency sampling method (EFP). Species richness (a proxy of alpha diversity) and beta diversity indexes were estimated to compare bird communities in MA and UMA neighbouring areas. We also studied the presence of priority species and the response of bird species along a gradient of management. Our results showed that habitat management of small game species was associated with higher bird species richness, including open-habitat specialists. Most of the Mediterranean bird species detected were present in managed areas, with coexistence of bird species from open and closed environments. Hunters' management of scrubland environments can result in areas of high conservation value for non-targeted bird species. This study could support guidelines for opening scrubland in order to preserve bird diversity.

Key words: Avifauna, Scrubland opening, Species richness, Conservation, Southern France

Resumen

Impacto de la gestión del hábitat de especies de caza menor en las comunidades de aves de los matorrales mediterráneos franceses. En la región del Mediterráneo francés, la progresiva disminución de las actividades tradicionales ha dado lugar a la expansión de los matorrales, que han invadido el territorio, lo que induce cierta pérdida de biodiversidad. Los cazadores participan en la gestión del hábitat principalmente mediante la apertura de los matorrales para ampliar el hábitat de las especies de caza menor. El objetivo de nuestro estudio fue evaluar la contribución de dicha gestión a la conservación de especies de aves no objetivo. En tres áreas gestionadas (MA) y no gestionadas (UMA) de 30 hectáreas, las aves fueron monitoreadas en primavera mediante el método de muestreo de frecuencia progresiva (EFP). Se estimaron los índices de riqueza de especies (un indicador de la diversidad alfa) y de diversidad beta para comparar las comunidades de aves entre áreas gestionadas y no gestionadas vecinas. También se estudiaron la presencia de especies prioritarias para la conservación y la respuesta de las especies de aves a lo largo de un gradiente de gestión. Nuestros resultados mostraron que la gestión del hábitat de especies de caza menor se asoció con el aumento de la riqueza de especies de aves, en especial las especialistas en hábitats abiertos. La mayoría de las especies de aves mediterráneas detectadas estaba presente en zonas gestionadas, donde convivían especies de aves de ambientes abiertos y cerrados. La gestión de los ambientes de matorrales por parte de los cazadores puede dar lugar a áreas de alto valor de conservación para especies de aves no objetivo. Este estudio podría respaldar las pautas para la apertura de matorrales con el fin de conservar la diversidad de aves.

Palabras clave: Avifauna, Apertura de matorrales, Riqueza de especies, Conservación, Sur de Francia

Introduction

Contemporary Mediterranean land ecosystems are the heritage of a wide variety of land uses, particularly in southern France (Brotons et al 2006). These ecosystems constitute a 'biodiversity hotspot' whose preservation is a major conservation challenge (Myers et al 2000). However, in recent decades, the strong expansion of scrubland resulting from the progressive abandonment of traditional agricultural practices has changed these landscapes (Blondel and Médail 2009, Sirami et al 2010).

Scrubland expansion is widely recognized as a major driver of biodiversity loss in Mediterranean landscapes (Preiss et al 1997, Sirami et al 2008, Vimal et al 2017, Brotons et al 2018). It is one of the causes of the decline of some emblematic bird species, such as the ortolan bunting *Emberiza hortulana* (Fonderflick et al 2010). It is also a cause of the decline of some insects, such as many Orthoptera (Russo 2007), and also of small game species (Delibes-Mateos et al 2009, 2012) such as the red-legged partridge *Alectoris rufa*, the Iberian hare *Lepus granatensis*, and the European rabbit *Oryctolagus cuniculus* (Delibes-Mateos et al 2008, Ferreira et al 2014, Casas and Garcia 2022). Drastic land use changes from the 1950s to the 1990s affected the distribution and abundance of these species in the Mediterranean area of the Iberian Peninsula (Vargas et al 2007, Delibes-Mateos et al 2009, 2012). Birds are relevant indicators of ecological changes within landscapes (Blondel 1965, Russo 2007, Aebischer et al 2016). Scrubland expansion is highly detrimental to the numerous Mediterranean bird species that favour open garrigues and rocky habitats, particularly priority species for conservation which rely on open habitats and/or depend on human activities (Vimal et al 2017), such as the southern grey shrike *Lanius meridionalis* and the woodchat shrike *Lanius senator* (Sfougaris et al 2014, Moreno-Rueda et al 2016). Their presence is the result of long and constant rural uses despite strong variations in intensity and extent. Owing to the significant changes in Mediterranean landscapes, many species associated with agricultural ecosystems are currently in decline, such as, for example, the vulnerable European goldfinch *Carduelis carduelis* and the European serin *Serinus serinus* (UICN France et al 2016). The significant loss of open landscape species is partly compensated by the expansion of forest species benefiting from the maturation of scrublands (Lindenmayer et al 2000, Laiolo et al 2004, Sirami et al 2007, Brotons et al 2018).

Hunters are concerned by these changes and share an interest in biodiversity with conservationists (Alphandéry and Fortier 2007, Casas et al 2009, Ballon et al 2012, Caro et al 2014, Crétois et al 2020, Gortázar and Fernandez-de-Simon 2022). In France, hunters play an essential political, economic (Schultz et al 2003), social (Stedman and Heberlein 2001) and ecological role in rural areas (Loveridge et al 2007, Ginelli 2009, Gallo and Pejchar 2016). In order to favour the maintenance or increase of small game species populations they release individual partridges and hares, and manage suitable habitats for the target species (Mustin et al 2011). In the Mediterranean region they restore small open areas in scrublands, they fund the plantation of crops for wildlife, they dig out water bodies, and they may also provide additional food seasonally (Borralho et al 1998, Ponce-Boutin et al 2004, Casas et al 2022). These habitat management practices often benefit non-target species (Gallo and Pejchar 2016, Mustin et al 2018). However, such practices are usually restricted to small experimental areas where ecological impacts on non-target species are rarely considered (Arroyo and Beja 2002, Sánchez-García et al 2024). Thus, the effect of scrubland opening by hunters on non-game wildlife in the French Mediterranean region has so far received little attention, despite its possible conservation value (Martinez-Padilla et al 2002). The aim of our study was to evaluate the impact of such habitat management on bird assemblages in three scrublands in southern France by comparing pairs of neighbouring managed (MA) and unmanaged (UMA) areas. We hypothesized that habitat management for small game species should benefit non-targeted bird species through (1) a higher richness and beta diversity, (2) an increased number of priority species for conservation, and (3) differences in occurrence within open habitat species.

Material and methods

Study sites

We sampled three sites in the French Mediterranean region, all with a landscape structure dominated by scrubland (fig. 1). These three sites have the characteristic local Mediterranean climate, namely, hot and dry summers (average summer temperature: 24.0-25.5 °C; average summer rainfall: 12-23 mm) and mild and wet winters (average winter temperature: 6.5-8.0 °C; average winter rainfall: 38-50 mm; 15-25 days of frost): (1) Bourg-Saint-Andéol (BSA, 44° 22' 24'' N, 4° 38' 39'' E, Ardèche, Auvergne-Rhône-Alpes) is located in the vicinity of the Ardèche canyon and the Rhône valley. This area is covered by vegetation varying from the meso-Mediterranean to lower supra-Mediterranean levels, including holm oak *Quercus ilex*, downy oak *Quercus pubescens* and boxwood coppice *Buxus sempervirens*; (2) Lançon-Provence (LP, 43° 35' 36'' N, 5° 07' 43'' E, Bouches du Rhône, Provence-Alpes-Côte-d'Azur) is located near the brackish water lagoon 'Etang de Berre' on the Fare Mountain range near the Dura valley. The xeric landscape is made up of scrubland with kermes oaks *Quercus coccifera* and rosemary bushes *Salvia rosmarinus*, Ibero-Mediterranean limestone cliffs, and rocky escarpments; and (3) Montpeyroux (MP, 43° 41' 46'' N, 3° 30' 25'' E, Hérault, Occitanie) is located at the foothills of the Cevennes, below Mont Saint-Baudille, at the extreme south-west of the southern slope of the Seranne mountain. It includes vast limestone hills, and is covered by scrubland with holm oak and xeric species of bushes. LP and MP are part of the Natura 2000 network.

Habitat management types

Each studied site included an area which was managed for small game species. Three main types of habitat management were identified (fig. 2):

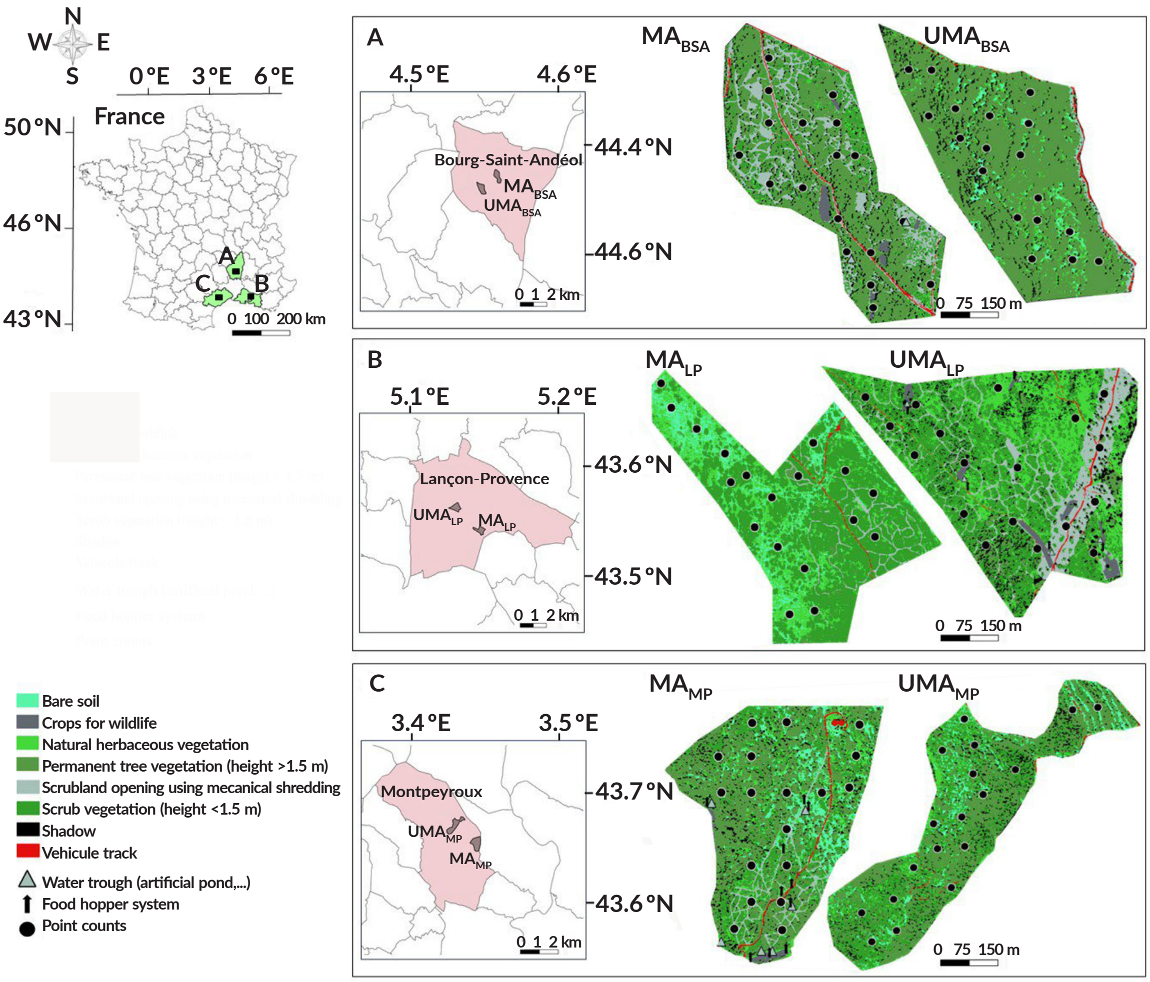

Fig. 1. Location and landscape structure of the three study sites (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence, MP, Montpeyroux), in southern France, including managed (MA) and unmanaged (UMA) areas for small game species, and the 108 bird count points. (Source: IGN, production IMPCF 2024).

Fig. 1. *Ubicación y estructura del territorio de los tres sitios de estudio (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux) en el sur de Francia, incluidas las áreas gestionadas (MA) y no gestionadas (UMA) para especies de caza menor y los 108 puntos de conteo de aves. (Fuente: IGN, producción IMPCF 2024).*

(1) Scrubland opening/clearance: corridors and open spaces of 20 to 100 hectares named alveolar openings, created within the scrubland using mechanical shredding. These openings are regularly created in autumn or winter, and some can evolve to dry grasslands after years.

(2) Crops for wildlife: small and closed natural areas of scrubland are converted or rehabilitated into game crops. Each plot is sown with subterranean clover *Trifolium subterraneum*, white lupin *Lupinus albus*, or orchard grass *Dactylis glomerata*, and cultivated without chemical input.

(3) Food and water supplementation: food hopper systems built from recycled materials and set on openings, corridors, or alongside crops. Each local hunting society maintains them on a daily basis (table 1s in supplementary material). Ponds or permanent water bodies are created to mitigate summer drought.

Vegetation maps of each studied area were produced using remote sensing technology. Eight variables were derived from remote sensing data to describe composition, vertical vegetation structure and heights opening alveolar, road or forest trail, crops, bare soil, low scrubs (< 1.50 m), high scrubs (> 1.50 m), trees, and herb layer in each MA or UMA. All steps were performed with QGIS 3.22.6 and the Orfeo ToolBox application (OTB 8.0.1) (Grizonnet et al 2017).

Description of bird assemblages

Bird assemblages were described using a fixed-radius count point method, the progressive frequency sampling (EFP) defined by Blondel (1975) to study the composition and structure of bird communities in various landscapes with minimal sampling effort (Archaux 2004). The radius, the time, the duration of the count points, and the distance between two neighbouring points was further developed by other authors (Hutto et al 1986, Ralph et al 1995). This frequential sampling method enables the study of the composition and structure of bird communities in various landscapes.

Within each of the 30 ha MAs and UMAs spaced 1 to 1.5 km apart at each site according to Balent and Courtiade (1992), we established 18 fixed point-counts spaced 300 m apart to avoid overlap and ensure the independence of records. At each site and each day, we sampled the same number of point counts in MA and UMA. Bird species seen or heard, in flight or landed, were recorded within a 100-m radius surrounding the observer for 20 minutes, following Petit et al (1995) and Sirami et al (2007). Two Mediterranean bird experts conducted the field surveys simultaneously. They visited each MA and UMA several times, alternatively from 6:00 to 11:00 am between April 27 and June 3 in 2021 and 2022. Due to weather conditions, they sampled 42 point-counts per area at BSA, 48 point-counts per area at LP, and 57 point-counts per area at MP.

Species richness

Indices to estimate biodiversity are numerous but species richness is widely used in ecology (Scott et al 1987, Purvis and Hector 2000, Gotelli and Colwell 2001, Magurran 2021). We identified species richness as the number of species detected at a point count. We plotted the cumulative number of bird species as a function of the cumulative number of point count samples surveyed in MAs and UMAs and for each site using 'iNEXT' R package (Hsieh et al 2016), and contrasted species richness values using 84% confidence intervals (Payton et al 2003), after equalizing the sample sizes by extrapolation. An exhaustivity index of the species richness was calculated for MA and UMA at each study site using the Monod formula, adapted from the Michaelis-Menten formula (Lauga and Joachim 1987).

Beta diversity

Beta diversity evaluates the difference in species composition between two sites (Koleff et al 2003, Baselga 2010). The Sørensen index (Sørensen 1948) was used to compare species assemblages between MA and UMA at each site, and to check whether the recorded differences were due to additional species, or if areas were occupied by different communities. The values of the index vary from 0 (no similarity) to 1 (total similarity). The formula is as follows:

$$\beta_{s\phi r} = 2 * A / 2 * A + X_{MA} + X_{UMA}$$

where A is the number of species recorded in both MAs and UMAs; X_{MA} is the number of species recorded only in the MA; X_{UMA} is the number of species recorded only in the UMA.

Priority species

We defined priority species according to their conservation and legal status (Cheylan 1995, Fonderflick 2007). These included species listed as vulnerable (VU) or endangered (EN) in the French IUCN Red list (UICN France et al 2016) and species listed in Annex I of the European Union Birds Directive (European Commission 2009) (table 2s in supplementary material). Species observed in flight and nocturnal birds were excluded from subsequent analyses because they cannot be considered direct users of the sampled area. We compared the prevalence (number of count points with record) of priority species between MAs and UMAs using chi-square-tests.

Effect of managed surface on bird ecological profile

It would be inadequate to evaluate the potential impact of MAs solely on the basis of species richness (Fusco et al 2021). It was thus important to consider the specific responses of the species according to their habitat preference listed in the *Inventaire National du Patrimoine Naturel* website (https://inpn.mnhn.fr). A species is considered generalist if it occurs in several types of habitats, and specialist if it occurs in only one type of habitat.

We therefore studied the occurrence of the 68 species recorded at the 147 point counts in MAs along a management gradient ranging from 0 to 49% of the surface. An occurrence frequency was calculated as the ratio between the number of point counts for which a species was present and the total number of point counts. Following Sirami (2006), we then considered a buffer zone of 100 m around each point count using remote sensing. Land use within each buffer was quantified in terms of managed surface and natural surface, before discretizing the managed surface into five classes that included the same amount of bird species data (0-4%, 4-13%, 13-18%, 18-27%, 27-49%).

Results

A total of 3,320 bird records were collected at the three sites over the two years of sampling. According to the study requirements, 2,322 records were kept, summarizing the occurrence of 71 bird species. The 998 records excluded from the analyses were: i) 958 records of flying birds, and ii), 40 records of landed raptors and nocturnal bird species.

Species richness and beta diversity

At the site level, species richness was 48 in BSA, 55 in LP and 55 in MP (fig. 3A). Species richness was significantly higher in MAs (68.00 ± 4.00 calculated species) than in UMAs (55.00 ± 3.15 calculated species; fig. 3B). This was confirmed at the study site level, with MA having significantly more bird species than UMA (BSA = MA: 49.16 ± 4.33, UMA: 39.07 ± 3.27 calculated species; LP = MA: 55.81 ± 4.29, UMA: 43.02 ± 3.73 calculated species; MP = MA: 52.5 ± 3; UMA: 43.39 ± 2.83 calculated species).

According to the accumulation curves and exhaustivity indices, around 90% of the estimated number of species were recorded in each area type of the three study sites (fig. 1s in supplementary material).

Sørensen indices showed that beta diversity was similar in the three study sites (table 1). However, the greater number of records in MAs was associated with a greater number of exclusive species (16 *vs* 3 in UMAs of the three sites).

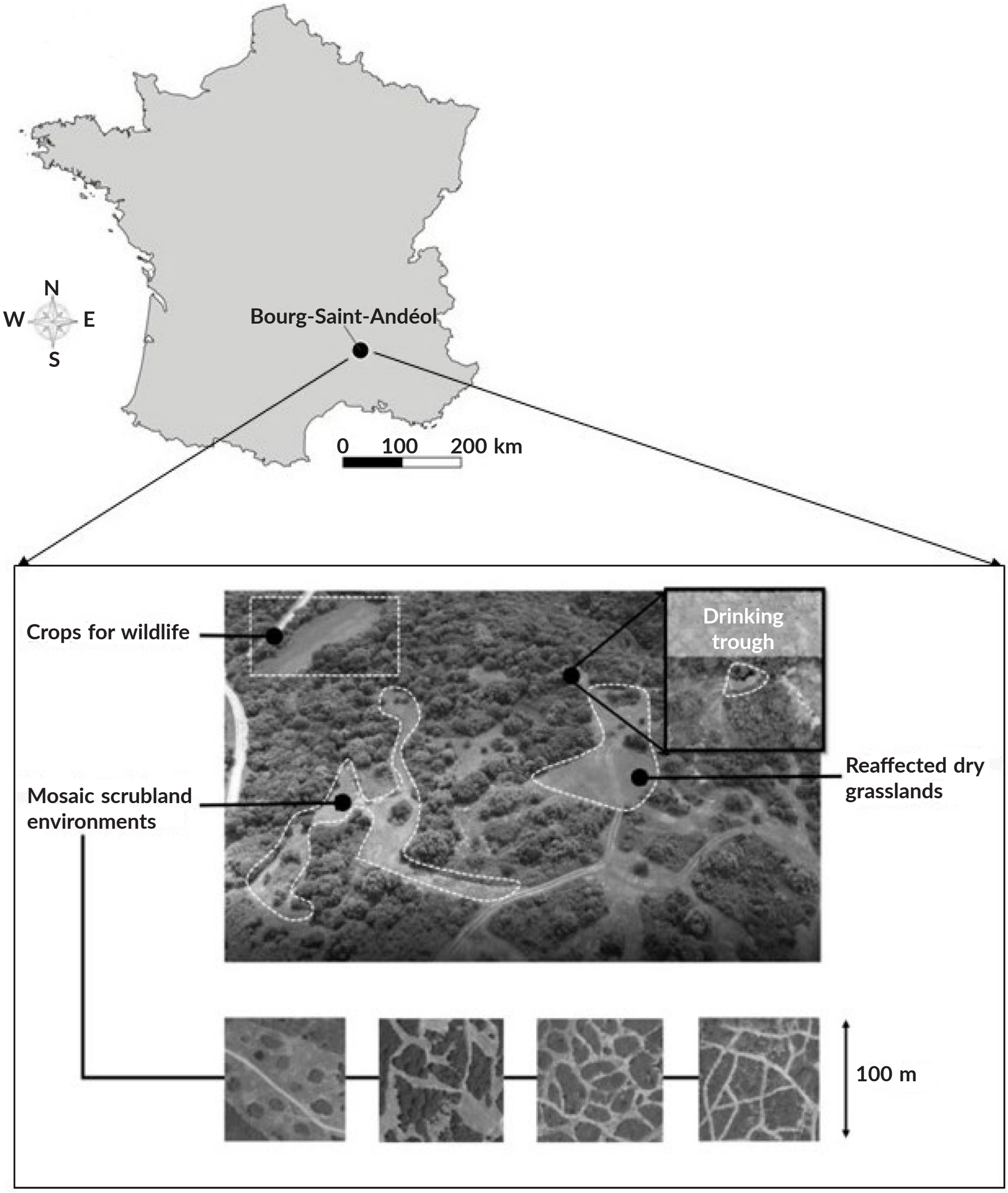

Fig. 2. Drone shot illustrating a habitat managed for small game species in Bourg-Saint-Andéol (44° 22' 24'' N, 4° 38' 39'' E). Each type of improvement is presented.

Fig. 2. *Toma de dron que ilustra un hábitat gestionado para especies de caza menor en Bourg-Saint-Andéol (44° 22' 24" N, 4° 38' 39'' E). Se presentan todos los tipos de mejora de hábitat.*

Priority species

Among the 71 bird species, 17 were considered priority species, either because of their French IUCN status (4 as 'Endangered', 9 as 'Vulnerable') or because they were listed in Annex I of the European Birds Directive (table 2). They included mainly the European turtle-dove *Streptopelia turtur*, the Dartford warbler *Sylvia undata* and the European serin. Priority species were more prevalent in MA (fig. 4) and the difference was significant at BSA ($\chi^2 = 6.39$, $p < 0.05$), LP ($\chi^2 = 5.04$, $p < 0.05$) and MP ($\chi^2 = 10.6$, $p < 0.01$). On average, an observer had a 14.2 % chance of observing a priority species when conducting a survey in MAs, compared to a 10.6 % chance in UMAs.

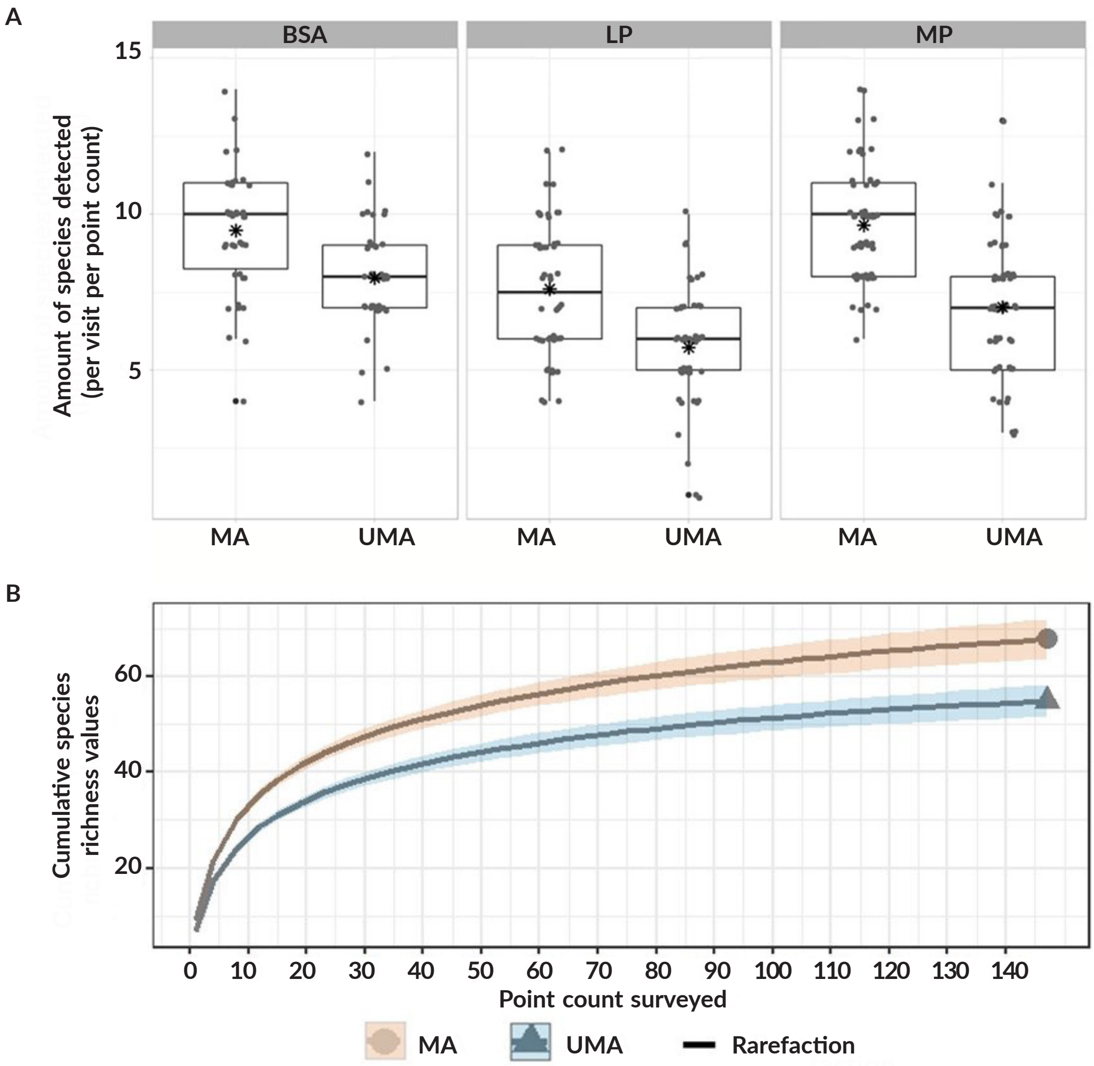

Fig. 3. A, bird species richness in managed (MA) and unmanaged (UMA) areas of the three study sites in southern France (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux). Each point corresponds to the number of species detected at a point count during a visit. Stars correspond to mean values. B, accumulation curves of bird species richness (y-axis) with 84 % confidence intervals estimated on 147 point counts (x-axis) in MAs and UMAs using the R package 'iNEXT'.

Fig. 3. *A, riqueza de especies de aves en áreas gestionadas (MA) y no gestionadas (UMA) de los tres sitios de estudio en el sur de Francia (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux). Cada punto corresponde al número de especies detectadas en un punto de conteo durante una visita. Las estrellas corresponden a valores medios. B, curvas de acumulación de riqueza de especies (eje y) con intervalos de confianza del 84 % estimados a partir de 147 puntos de conteo (eje x) en áreas gestionadas y no gestionadas utilizando el paquete "iNEXT" de R.*

Ecological profiles of bird species

Sixty-eight species were grouped according to the average managed surface in the 100-m buffer zone of MA count points where they were detected (fig. 5). Three main ecological profiles were identified. Most species were present whatever the managed surface and can be considered generalist (45 species). These were priority species such as the European turtle-dove and the European greenfinch *Chloris chloris*, or common species such as the Eurasian magpie *Pica pica* and the common chaffinch *Fringilla coelebs*. The frequency of close habitat specialists (seven species), such as the endangered spectacled warbler *Sylvia conspicillata* and the Dartford warbler, decreased with the managed surface of the scrubland in the buffer. In contrast, the open habitat specialists (16 species), such as the red-legged partridge *Alectoris rufa* and the common pheasant *Phasianus colchicus*, benefited from larger scrubland openings.

Discussion

Here we evaluated the outcome of small game habitat managed by hunters on non-targeted bird species in three French Mediterranean scrubland sites. With an overall occurrence of 71 species, the exhaustiveness of species richness close to 90 % for each area type indicates that we recorded representative samplings

Table 1. Beta diversity indexes comparing bird communities recorded during count points in managed (MA) and unmanaged areas (UMA) for each study site of southern France: BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux.

Tabla 1. *Índices de diversidad beta que permiten comparar las comunidades de aves registradas durante los puntos de conteo entre áreas gestionadas (MA) y no gestionadas (UMA) para cada sitio de estudio en el sur de Francia: BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux.*

	Study sites					
	BSA		LP		MP	
Area	MA	UMA	MA	UMA	MA	UMA
Count points	42	42	48	48	57	57
Records	398	334	365	275	550	400
Species	46	37	53	41	52	43
Exclusive species	11	2	14	2	12	3
Sørensen index	0.843		0.830		0.842	

of the bird assemblages. Observability within the study sites was not an obstacle to detect the species in either MAs or UMAs because 97 % of our records were obtained by acoustic detection. Progressive frequency sampling (Blondel 1975) has been used previously in numerous studies in the Mediterranean region (e.g., Blondel et al 1978, Martin 1983, Fonderflick et al 2001). However, the relative abundance of each species was not estimated at each point count. This may be a limitation of our study in addition to the somewhat different management at the three sites (table 1s in supplementary material). Another recording method such as the index of point abundance may be required (Blondel et al 1970).

Effect of habitat management on bird richness and beta diversity

Our results support the former hypothesis, as habitats managed by hunters for small game species were more attractive for non-targeted bird species than unmanaged habitats, with both a higher species richness and a greater number of exclusive species. We observed a clear relationship between the diversity of bird species and the structural diversity of the sampled areas. Indeed, it has long been recognized that the structure of vegetation is the main ecological factor conditioning variability and differentiation of bird communities in the Mediterranean region (Prodon and Lebreton 1981). Nevertheless, our data lack an evaluation of bird species abundance in order to more accurately evaluate the influence of vegetation structure (Fonderflick 2007). The number of breeding pairs should be compared between MAs and UMAs in a future study as suggested previously.

Within each study site, we were unable to identify the relative impact of each specific management practice on the non-targeted bird species at both local and landscape scales. We only considered scrubland opening for defining MAs, and punctual improvements such as feeders and trough were neglected. As no information was available about the area impacted by such improvements they could not be integrated into the managed surface of the point count buffers. However, providing food and water to game species could also benefit non-targeted species (Gaudioso-Lacasa et al 2010, Arroyo et al 2013, Armenteros et al 2021), and even predators by increasing the number of prey (Beja et al 2009).

Benefit of habitat management on priority species

Our results also support the second hypothesis as we found MAs showed a positive effect on some priority species for conservation. This result is consistent with their selection of heterogeneous habitat at the landscape scale (Preiss et al 1997, Suárez-Seoane et al 2002). This is the case for threatened species inhabiting agroecosystems, such as the European goldfinch, the European serin, the European turtle-dove, and the European greenfinch, all of which were more frequently recorded in MAs than in UMAs. Surprisingly, the endangered southern grey shrike, which also inhabits agroecosystems, did not benefit from habitat opening as did the open habitat specialist meadow pipit *Anthus pratensis*. On the other hand, the habitat management did not affect the occurrence of scrubland specialists such as the spectacled warbler or the Dartford warbler. This suggests that in the Mediterranean landscape, the role of habitat heterogeneity through MAs could be a key factor for conserving a number of threatened species.

Occurrence of open habitat specialists

Some of the bird species recorded in MAs do not belong to traditional Mediterranean bird communities of scrublands. This is due to a secondary colonization by species of open and human managed environments, including some priority species for conservation. This observation is consistent with previous studies carried out in the French Mediterranean region where most bird species with an unfavourable conservation status are linked to open and semi-open habitats (Fonderflick 2007, Vimal et al 2017, Brotons et al 2018). At a larger scale, in Europe, most priority species for conservation need a mixture of woodland,

Table 2. Occurrence of the 71 bird species recorded during count points in both the managed (MA) and unmanaged (UMA) area of the three study sites in southern France (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux). Species are listed according to their IUCN conservation status in France: EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern (IUCN France et al 2016). Species whose IUCN status is followed by (*) are listed in Annex I of the European Bird Directive (European Commission 2009). Species flagged with (**) are not scrubland specialists.

Tabla 2. Avistamientos de las 71 especies de aves registradas durante los puntos de conteo tanto en las áreas gestionadas (MA) como en las no gestionadas (UMA) de los tres sitios de estudio en el sur de Francia (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux). Las especies se enumeran según el estado de conservación de la UICN en Francia: EN, en peligro; VU, vulnerable; NT, casi amenazado; LC, preocupación menor. Las especies cuyo estatus en la UICN va seguido de (*) se enumeran en el Anexo I de la Directiva Europea de Aves (Comisión Europea 2009). Las especies marcadas con (**) no son especialistas en matorraless.

			Number of occurrences					
			BSA		LP		MP	
Species	Valence	IUCN status	MA	UMA	MA	UMA	MA	UMA
Acrocephalus melanopogon	Specialist (**)	EN	0	0	1	0	0	0
Lanius meridionalis	Generalist	EN	0	0	1	2	2	2
Sylvia conspicillata	Specialist	EN	2	0	0	0	0	0
Sylvia undata	Specialist	EN	8	3	28	24	10	16
Anthus pratensis	Specialist	VU	0	0	1	0	0	1
Carduelis carduelis	Generalist	VU	3	0	6	1	4	1
Chloris chloris	Generalist	VU	3	1	0	0	3	2
Lanius senator	Generalist	VU	0	0	0	0	2	0
Linaria cannabina	Generalist	VU	1	0	1	0	3	3
Pyrrhula pyrrhula	Specialist (**)	VU	1	0	0	0	0	0
Saxicola rubetra	Specialist (**)	VU	0	0	1	0	0	0
Serinus serinus	Generalist	VU	0	0	3	1	26	6
Streptopelia turtur	Generalist	VU	27	20	13	4	36	15
Coracias garrulus	Generalist	NT (*)	0	0	1	1	0	0
Lanius collurio	Generalist	NT (*)	0	0	2	0	0	0
Locustella naevia	Generalist	NT	2	0	0	0	1	1
Phylloscopus trochilus	Generalist	NT	9	2	5	2	3	5
Saxicola rubicola	Generalist	NT	0	0	2	2	1	0
Sylvia borin	Generalist	NT	3	3	0	0	0	0
Sylvia melanocephala	Generalist	NT	26	25	45	40	48	53
Acrocephalus scirpaceus	Specialist (*)	LC	0	0	0	0	1	0
Aegithalos caudatus	Generalist (*)	LC	5	6	3	0	6	2
Alectoris rufa	Generalist	LC	10	3	13	14	22	6
Anthus campestris	Generalist	LC (*)	0	0	1	4	0	0
Anthus trivialis	Generalist	LC	0	0	0	0	1	0
Caprimulgus europaeus	Generalist	LC (*)	0	0	0	0	0	1
Certhia brachydactyla	Generalist	LC	3	4	2	0	5	2
Certhia familiaris	Specialist	LC	0	0	0	0	1	0
Columba palumbus	Generalist	LC	19	15	6	3	13	11
Corvus corax	Generalist	LC	3	0	0	0	0	0
Corvus corone	Generalist	LC	3	0	4	2	4	1
Corvus monedula	Generalist	LC	0	0	3	2	0	0
Cuculus canorus	Generalist	LC	1	3	4	1	18	11
Cyanistes caeruleus	Generallst	LC	9	16	8	3	8	6
Dendrocopos major	Specialist (**)	LC	1	0	0	0	0	0
Emberiza calandra	Specialist (**)	LC	2	0	3	2	6	0
Emberiza cia	Specialist (**)	LC	0	0	0	1	0	0
Emberiza cirlus	Generalist	LC	4	2	6	3	8	2
Erithacus rubecula	Generalist	LC	9	28	4	2	4	5
Fringilla coelebs	Generalist	LC	33	27	26	15	48	48
Galerida cristata	Generalist	LC	0	0	1	0	1	0
Garrulus glandarius	Generalist	LC	12	14	4	7	3	9

Table 2. (Cont.)

			Number of occurrences					
			BSA		LP		MP	
Species	**Valence**	**IUCN status**	**MA**	**UMA**	**MA**	**UMA**	**MA**	**UMA**
Hippolais polyglotta	Generalist	LC	3	0	6	5	12	8
Lophophanes cristatus	Generalist	LC	0	0	4	0	1	0
Lulula arborea	Generalist	LC	7	6	10	12	17	3
Luscinia megarhynchos	Generalist	LC	38	21	34	27	45	43
Merops apiaster	Generalist	LC	1	1	2	1	2	0
Motacilla alba	Generalist	LC	0	0	2	0	0	0
Oriolus oriolus	Generalist	LC	5	0	2	1	7	2
Parus major	Generalist	LC	19	20	12	9	21	14
Passer domesticus	Generalist	LC	0	0	0	0	1	0
Phasianus colchicus	Generalist	LC	2	2	21	21	3	3
Phoenicurus ochruros	Specialist (**)	LC	1	1	1	5	2	1
Phoenicurus phoenicurus	Specialist (**)	LC	12	2	7	4	15	11
Phylloscopus bonelli	Generalist	LC	6	3	3	0	5	3
Phylloscopus collybita	Specialist	LC	1	2	1	1	3	2
Pica pica	Generalist	LC	1	3	8	13	2	3
Picus viridis	Generalist	LC	3	8	3	1	1	0
Prunella modularis	Specialist	LC	1	1	0	0	0	0
Regulus ignicapilla	Generalist	LC	8	2	2	0	10	3
Sitta europaea	Generalist	LC	0	0	0	0	3	0
Streptopelia decaocto	Generalist	LC	5	5	1	4	1	1
Sturnus vulgaris	Generalist	LC	4	1	1	0	0	0
Sylvia atricapilla	Specialist	LC	21	25	7	4	17	15
Sylvia cantillans	Specialist	LC	22	19	20	14	17	13
Sylvia communis	Specialist	LC	0	0	1	0	0	1
Sylvia hortensis	Generalist	LC	0	1	3	2	12	18
Troglodytes troglodytes	Specialist	LC	0	1	0	0	5	3
Turdus merula	Generalist	LC	35	34	6	8	28	36
Turdus philomelos	Generalist	LC	0	0	0	1	0	0
Upupa epops	Generalist	LC	4	4	10	6	32	8
Number of point counts			42	42	48	48	57	57

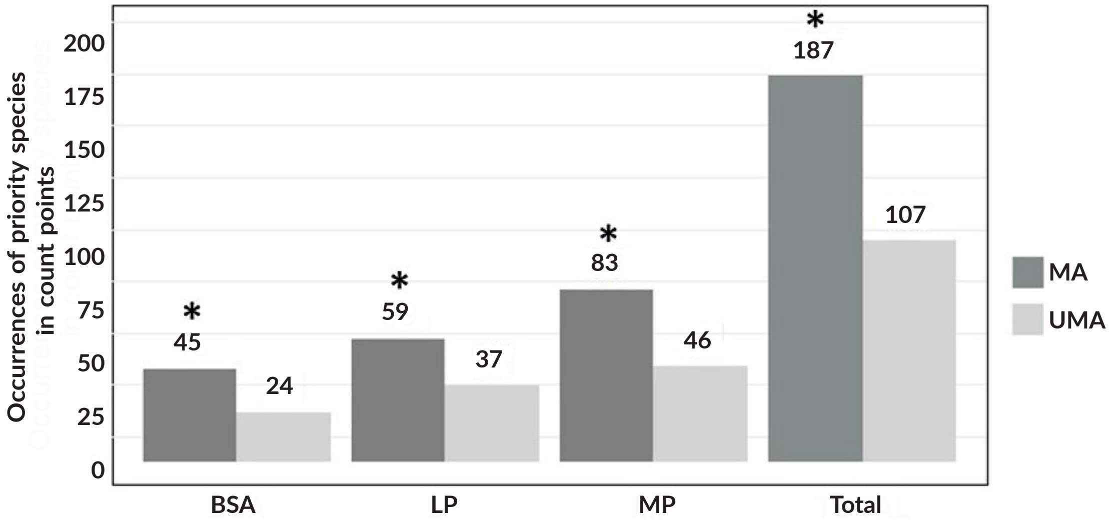

Fig. 4. Occurrences of priority species in count points surveyed in managed (MA) and unmanaged (UMA) areas of the three study sites in southern France: BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux. Stars indicate significant differences (chi-squared tests, $p < 0.05$).

Fig. 4. *Avistamientos de especies prioritarias para la conservación en puntos de conteo estudiados en áreas gestionadas (MA) y no gestionadas (UMA) de los tres sitios de estudio en el sur de Francia: BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux. Las estrellas indican una diferencia significativa (pruebas chi-cuadrado,* p *< 0,05).*

scrubland and rocky habitat within their foraging area (Tucker and Evans 1997). Nevertheless, most species exclusive to MAs are anthropophilic, with variable ecological amplitudes, and they occurred in managed habitats, either as to substitute or complement their preferred habitat. Described in a more general context, the sensitivity of bird species to environmental changes was shown to be linked to a sensory pattern whose main proxies are the scale of perception and the nature of the perceived elements (Sirami 2006). In our study, scrubland management has structured an agro-forestry bird assemblage in MAs. However, the ecological profile of most species living in the three scrublands identified them as generalists, known to be favoured by landscape opening (Dunning et al 1992, Brotons et al 2006, Caplat and Fonderflick 2009). Finally, we note that scrubland habitat management for small game species can fulfil biological requirements of many non-targeted bird species, and may be considered necessary to maintain habitat heterogeneity after agricultural abandonment.

Profit and loss of habitat management

Our results agree with findings in Spain (Caro et al 2014) and elsewhere in Europe (Preiss et al 1997, Stoate and Szczur 2001, Arroyo and Beja 2002, Stoate et al 2003, Sage et al 2005, Parish and Sotherton 2008, Santana et al 2017) where low-intensity management actions for small game had positive effects on non-targeted bird species. Several authors consider management practices that closely mimic ecological processes to be of added value for small game species (small agricultural plots, mosaic landscape or fire and mechanical shredding of scrubland cover) and have positive effects on bird communities adapted to natural disturbance regimes (Smith et al 2001, Moreira et al 2001, Tapper 2005, Arroyo et al 2013, Aebischer et al 2016, Newey et al 2016). However, these studies have been conducted on farmlands and differ from our framework of analyses, making comparisons with our study difficult. Moreover, the effects of a particular type of management on non-targeted bird species are often paradoxical, inducing both positive and negative effects (Gallo and Pejchar 2016, Mustin et al 2018).

Although mechanical shredding may be important for fire prevention (Legrand et al 1994), its impact on Mediterranean vegetation and wildlife is not yet fully understood. The treatment periods could have a negative impact on the breeding success of ground-nesting birds, on the flowering cycle of plants, and subsequently on the abundance of invertebrates. Moreover, food and water supplementation can easily become ecological traps for some species users. However, the consequences on non-targeted bird species have yet to be fully explored.

Conclusion

Besides preventing fires, which are common in the region, the opening of scrublands appears to be of value for several bird species of high conservation priority.

In the present study, we were unable to identify an optimal threshold of management to support non-targeted bird species. Carrying out a study on a larger set of MAs for a longer period of time could provide more precise responses of non-targeted bird species to each management practice. Moreover, estimating the relative abundance of bird species in MAs based on

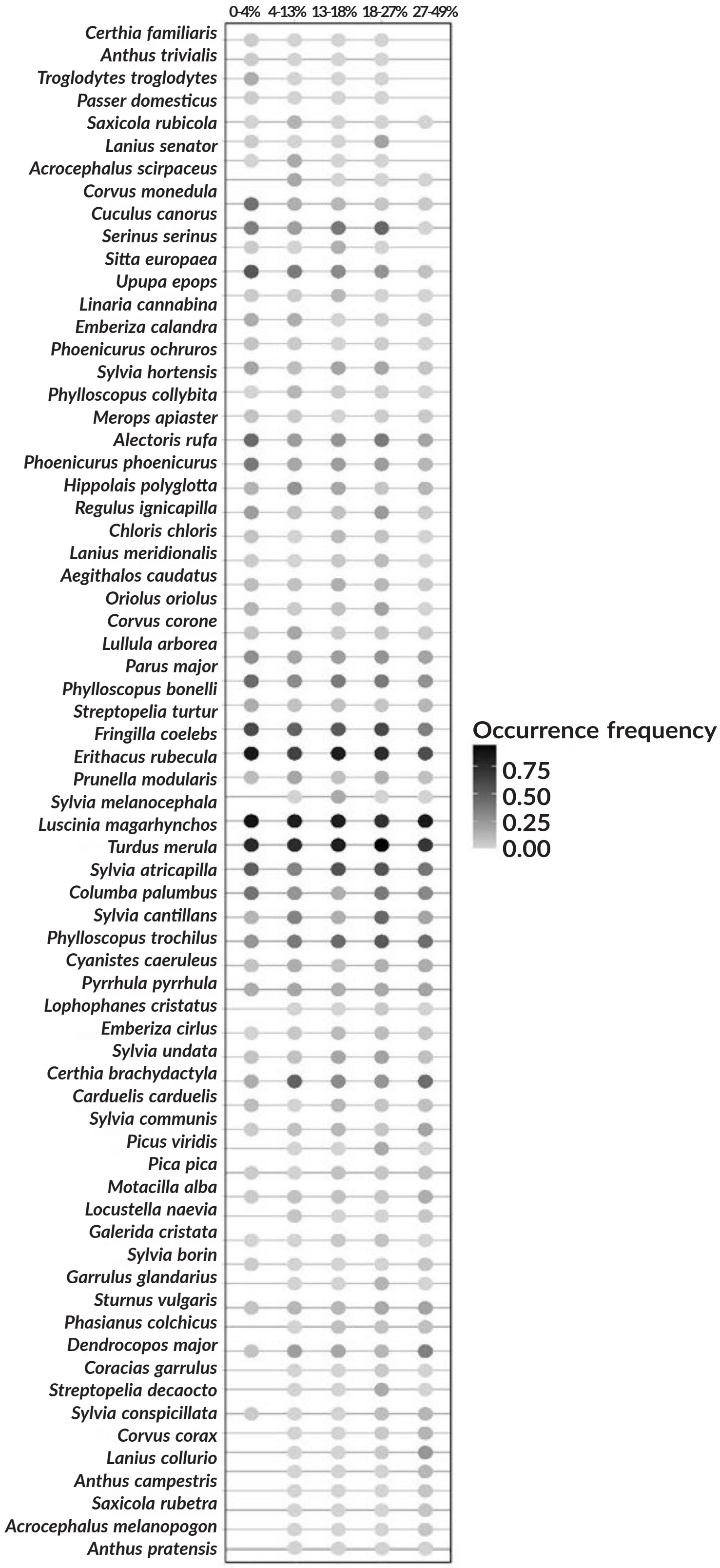

Fig. 5. Frequency of occurrence of the 68 bird species recorded in the 147 point counts classified in five equal frequency classes of managed surface in the three study sites in southern France. Species are ranked in ascending order according to the average of managed surface within a 100-m buffer around the count points where they were detected.

Fig. 5. *Frecuencia de avistamientos de las 68 especies de aves registradas en los 147 puntos de conteo clasificada en cinco clases iguales de frecuencia de superficie gestionada en los tres sitios de estudio en el sur de Francia. Las especies están ordenadas de menor a mayor según el promedio de superficie gestionada dentro de los 100 metros alrededor de los puntos de conteo en los que fueran detectadas.*

breeding pair census would further support the role of MAs for the conservation of non-targeted bird species. Nevertheless, until such results are available, habitat management of small game species in scrublands by hunters at a local scale can benefit the conservation of several bird species. Agricultural or forest management, including food and water provision, should be a further step (Sánchez-García et al 2024).

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N Froustey, **JC Ricci**, **L Pelozuelo** and **S Aulagnier** conceived the original idea of the presented study. **N Froustey**, **Q Gaulé** and **P Dahler** conducted the fieldwork. **N Froustey**, **M Guyot** and **M Crétet** conducted the data analysis. **N Froustey** and **S Aulagnier** wrote the first draft of this publication. All these authors provided critical feedback and helped to shape the research, analysis and approved the final manuscript.

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No conflicts declared

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Supplementary material

Table 1s. Habitat management made by hunters at the three study sites in southern France.

Tabla 1s. *Intervenciones de gestión del hábitat realizadas por los cazadores en los tres lugares de estudio del sur de Francia.*

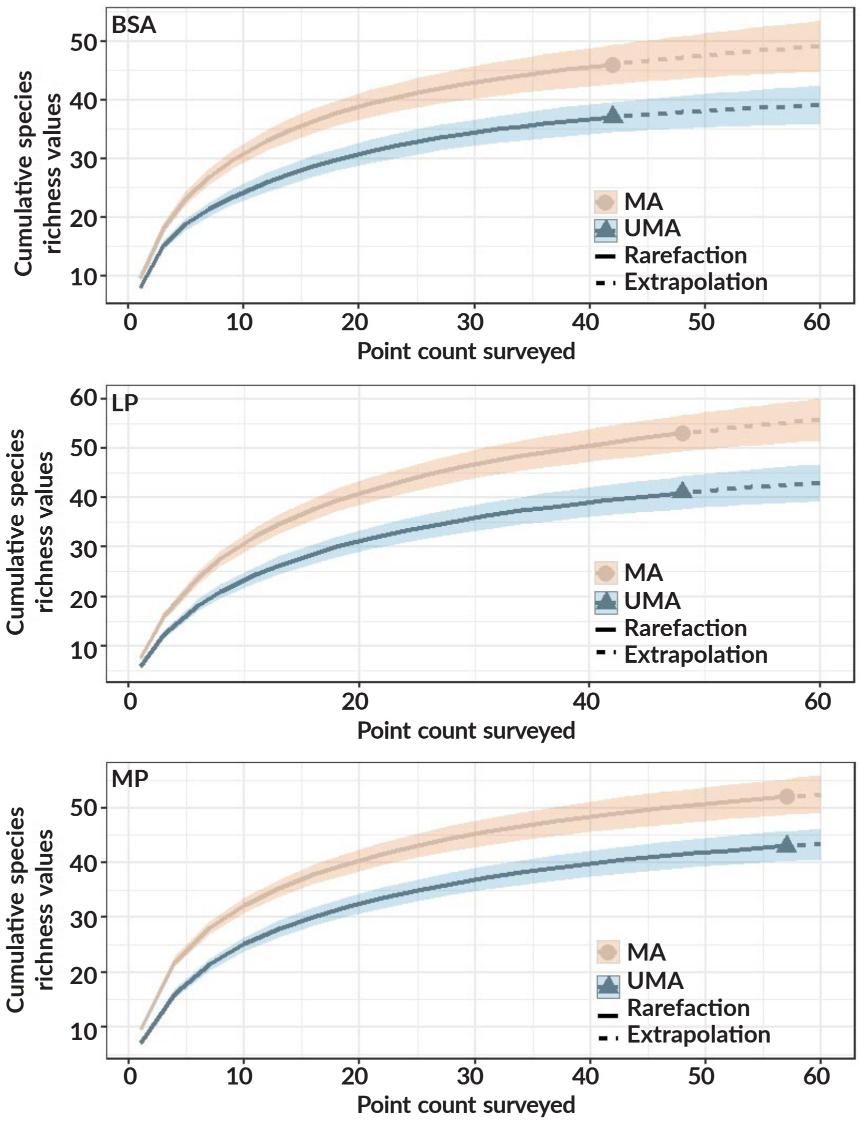
	Bourg-Saint-Andéol	Lançon-Provence	Montpeyroux
Openings of scrubland			
Lines (km)	8	12	2
Period of existence	15 years	8 years	3 years
Maintenance frequency	15 ans	3 à 4 ans	3 à 4 ans
Logistic tools	Mechanical shredding + pastoralism	Mechanical shredding	Mechanical shredding
Artisanal feed hoppers			
Unit	0	5	10
Period of existence	-	> 20 years	20 years
Filling frequency (outside of hunting season)	-	Twice to thrice per week	> once per month
Drinking trough			
Unit	2	5	6
Period of existence	> 15 years	> 20 years	> 20 years
Maintenance frequency		Summer: drought event	
Crops for wildlife			
Unit	5	6	1
Area (acre)	0.65	0.75	0.25
Crop rotation	*Onobrychis sativa* *Medicago sativa* *Triticum aestivum* *Lolium perenne*	*Medicago sativa* *Triticum aestivum*	*Onobrychis sativa* *Medicago sativa* *Triticum aestivum* *Hordeum vulgare hexastichum* × *Triticosecale*
Land cover (in percent of managed area, 30 ha)			
Openings	20 %	16 %	4 %
Forest trail	2 %	1 %	1 %
Crops	2 %	2 %	1 %
Bare soil	0 %	0 %	9 %
Herb layer	18 %	40 %	20 %
Low scrubland (< 1.5 m)	2 %	25 %	10 %
High scrubland (> 1.5 m)	56 %	16 %	55 %

Table 2s. List of the 17 bird species considered priority species, ordered according to their conservation status in France (UICN France et al 2016): EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern. (The table also includes the status in annex I of the European Bird Directive and the species main habitat).

Tabla 2s. *Lista de las 17 especies de aves consideradas como prioritarias para la conservación ordenadas según el estado de conservación en Francia (UICN Francia, et al 2016): EN, en peligro de extinción; VU, vulnerable; NT, casi amenazada; LC, preocupación menor. (En la tabla también se indica el estatus de conservación según en el anexo I de la Directiva Europea de Aves y el hábitat principal de la especie).*

Species	IUCN French status	Listed in Annex I of the European Birds Directive	Habitat
Acrocephalus melanopogon	EN	No	Wetlands
Lanius meridionalis	EN	No	Scrubland, maquis, vine yards
Sylvia conspicillata	EN	No	Mediterranean shrub vegetation
Sylvia undata	EN	No	Mediterranean shrub vegetation
Anthus pratensis	VU	No	Wet grasslands
Carduelis carduelis	VU	No	Heterogenous rural environments
Chloris chloris	VU	No	Heterogenous rural environments
Lanius senator	VU	No	Scrubland, maquis, orchards, dry grasslands
Linaria cannabina	VU	No	Mosaic of agricultural habitat, scrubland, maquis, vineyards
Pyrrhula pyrrhula	VU	No	Temperate forests, groves, parks and gardens
Saxicola rubetra	VU	No	Wet grasslands
Serinus serinus	VU	No	Heterogenous rural environments
Streptopelia turtur	VU	No	Heterogenous rural environments
Coracias garrulus	NT	Yes	Heterogenous rural environments
Lanius collurio	NT	Yes	Semi-open environments with meadows and bushy pastures
Anthus campestris	LC	Yes	Dry grasslands
Caprimulgus europaeus	LC	Yes	Temperate shrubby vegetation

A



B

	Bourg-Saint-Andéol		Lançon-Provence		Montpeyroux	
Area	MA	UMA	MA	UMA	MA	UMA
Recorded species richness	46	37	53	41	52	43
Estimated species richness	50	41	58	47	56	47
Exhaustivity index (%)	91	90	91	88	93	91

Fig. 1s. A, species accumulation curves for bird species detected at point counts in each managed (MA) and unmanaged (UMA) area of the three study sites in southern France (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux) using the R package 'iNEXT'. B, exhaustivity index for point counts surveys in each area of the three study sites (according to Lauga et Joachim 1987).

__Fig. 1s.__ A, curvas de acumulación de las especies de aves detectadas en los puntos de conteo en cada área gestionada (MA) y no gestionada (UMA) de los tres sitios de estudio en el sur de Francia (BSA, Bourg-Saint-Andéol; LP, Lançon-Provence; MP, Montpeyroux), utilizando el paquete "iNEXT" de R. B, indicador de exhaustividad para los puntos de conteo en cada área de los tres sitios de estudio (según Lauga y Joachim, 1987).