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ORIGINAL PAPER

Ecology and recovery plans for the four Spanish endangered endemic butterfly species

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Abstract Data compiled during three fieldwork seasons and habitat models provided the tools to produce Species recovery plans for the endangered and endemic butterflies in Spain: *Polyommatus violetae, P. golgus, Agriades zullichi*, and *Euchloe bazae*. The distribution of each species has been updated with new field records. For *E. bazae* and *P. violetae* the known distribution records increased 33% and 8%, respectively. Detailed habitat descriptions, based on fieldwork data, are given for the four species and models show relatively small and fragmented habitat patches for *P. violetae, P. golgus*, and *P. zullichi*. Those areas might be particularly sensitive under a climate change scenario. Habitat of the four species is very specialized and mainly consists of open areas with grassland or scrub vegetation. Population densities are provided for the first time for these species and show low numbers for *E. bazae*, particularly in the area around Baza in SE Spain. 25 to 54% of the populations were apparently not threatened. For the rest, apparent habitat suitability threats were abandonment for *E. bazae* and *P. violetae*, trampling for *A. zullichi*, and overgrazing for *P. golgus*. Recovery plans included aspects on legislation, habitat management, precautionary measures (limit new developments and land use changes), research, and public awareness campaigns. Suggested habitat management actions are: (1) support extensive grazing and prevent overgrazing; (2) reduce the effect of trampling by visitors in mountain areas; and (3) woodland and scrub clearing of abandoned areas and pine plantations to improve the quality of grassland habitats.

Keywords Conservation · Distribution · Habitat models · Threats · Management · Lepidoptera

Introduction

The species in this study were included in the European Red List of Butterfies (van Swaay et al. 2010) as endangered (EN): *Agriades zullichi* Hemming, 1933, or vulnerable (VU): *Polyommatus violetae* (Gómez Bustillo and Expósito and Martínez, 1979), *P. golgus* (Hübner, 1813), and *Euchloe bazae* Fabiano, 1993. The Mediterranean Red List (Numa et al. 2016) also regarded *A. zullichi* as endangered and *P. golgus* as vulnerable. They are also endemic to Spain and have very small occupancy areas. The main reason for their restricted distribution is the specialized habitat upon which they rely. For all species habitat is limited to mountains, except for *E. bazae* that lives in semiarid scrublands at lower elevations (Munguira 1989; Olivares and Jiménez 1996). Concern about the conservation of these species has always been high and they have been widely treated in legislation and conservation studies. Three of the four species are legally protected at the regional level in

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Andalusia (*A. zullichi, P. violetae, P. golgus*), and *P. golgus* is also protected by Spanish law and the European Habitats Directive (Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora). Conservation studies for these species are the Spanish Atlas of Endangered Invertebrates (Verdú and Galante 2009), or at the regional level, the Andalusian Invertebrates Red Data Book (Barea-Azcón et al. 2008a). The main threats in the mentioned conservation studies for each species were wildfires (*P. violetae*), urban development (*P. golgus* and *A. zullichi*), and overgrazing (*E. bazae*). The small size of the populations or the small occupancy areas are cited for the four species, while other threats are overgrazing and urban development for *P. violetae*, waste accumulation and climatic change for *P. golgus*, collecting for *A. zullichi*, and pine plantations for *E. bazae*.

The four species have only been recognized as true species during the last four decades, and were previously regarded as subspecies of more widespread species. The first conservation study to consider these species was that of Viedma and Gómez Bustillo (1974), which in their Red Data Book listed *Polyommatus golgus* and *Agriades zullichi* as endemic species and recommended their strict protection and the study of their biology. Following this seminal study, these two species were thoroughly studied by Munguira (1989) who described for the first time their life cycle and suggested the protection of their habitat in Sierra Nevada as a National Park. *P. golgus* lives at high altitudes in five different sierras of SE Spain and its larvae feed exclusively on *Anthyllis vulneraria* (Munguira 1989). *A. zullichi* is restricted to Sierra Nevada (SE Spain), where it lives at altitudes above 2,300 m and feeds on *Androsace vitaliana* during the larval stage. The habitat of *A. zullichi* is severely fragmented into 39 patches that only cover a total surface of 0.6 km^2 (Barea-Azcón et al. 2014). *Euchloe bazae* was first studied by Olivares and Jiménez (1996) who regarded it as a different species and described its life history. This species is limited to semiarid habitats and is close to the African *Euchloe charlonia* (Donzel, 1842), but morphological and molecular studies performed by Back et al. (2005, 2006), proved that *E. bazae* is a different species. *E. bazae* has two subspecies: *bazae*, occurring near Baza, in southern Spain, where its food plant is *Eruca vesicaria*; and *iberae*, from the Monegros area, in Huesca, Lérida, and Zaragoza provinces, in North-East Spain, that feeds on the shrub *Vella aspera* during the larval stage. *Polyommatus violetae* was regarded as critically endangered (CR) by Gil-T. (2008), because its range was thought to be restricted to a small mountain range in Málaga province. More recent studies (Vila et al. 2010) showed that the populations of the Betic sierras, previously assigned to *P. fabressei*, belong in fact to *P. violetae* and that both species are not sympatric. Recent studies also found the species in Sierra Nevada and extended the previously known range in other areas (Moreno-Benítez et al. 2012). *P. violetae* uses *Onobrychis argentea* as its larval food plant and its habitat is located at medium altitudes (García-Barros et al. 2013).

The information available for the studied species mainly focused on the geographic distribution and biology, and was summarized in red data books (Gil-T. 2008; Munguira et al. 2009a, b; Olivares and Jiménez 2008) or general reference works (García-Barros et al. 2013). Regarding population numbers, these species had never been considered in demography studies. The threats these species are presumed to face (e.g. van Swaay et al. 2012), were often based on circumstantial observations or expert judgments. A more detailed account on the threats that are operating at a given time is necessary in order to suggest sound actions for the recovery of the species. For all these reasons and because of their very restricted distribution and threatened condition, a species recovery plan is urgently needed for each of the four species. Field studies are also necessary to fill the knowledge gaps on the ecology of the species and to provide more objective assessments on the threats the species are facing.

Actions suggested for the recovery plans will help, if they are successful, to protect the species from extinction and greatly improve their conservation status. Recovery plans are vital tools for the conservation of highly threatened animal and plant species. SRPs have traditionally been developed mainly for vertebrate species, at least in the Mediterranean area, where conservation has always received lower attention for invertebrates. As a result, while several recovery plans have already been implemented in Spain for its important vertebrate fauna (Morales and Lizana 2011), only 11 invertebrate species (6.6%) were taken into account from a total of 166 recovery plans that include 72 bird or 26 mammal species (http://www.magrama.gob.es). Of these, three out of 11 correspond to aquatic invertebrates. Although butterflies were taken into consideration since the beginning of the conservation movement (Heath 1981; Viedma and Gómez Bustillo 1974), they have received less attention in Spain. The species listed in the Spanish Endangered Species Act (Catálogo Español de Especies Amenazadas) are requried to have a recovery plan developed under the Spanish law. In Spain, these plans have only been produced for Lepidoptera species within the framework of a wider plan to protect high mountain animal and plant species, which includes three of the species of this study (Plan de Recuperación de Especies de Altas Cumbres, BOJA 2012). This recovery plan is a legal tool that has been issued by the regional government of Andalusia and is indeed a milestone for the protection of invertebrates in the area. However, species recovery plans have never been produced independently for particular Spanish butterfly species and we tried to fill this gap focusing on these four endangered and endemic species.

Species recovery plans (SRPs) are documents which bring together relevant information about a given endangered species, present an overview of the threats that a given species is facing, and list the actions needed to reverse these threatening factors (Pullin 2002). We followed these three steps to provide for the first time recovery plans for four Spanish endemic species. First, previous data from the four species was collated in order to have a framework for further work. Second, fieldwork was planned to visit representative localities covering the different habitats of the four species and recording information on their threats and ecology. In order to draw distribution maps we gathered previously published records for each species and added new field records. Finally, following the results of field studies and habitat modelling, we discussed possible conservation actions with conservation experts and landscape managers during a workshop in 2013. We also visited Sierra Nevada National Park and the Natural Parks of Sierras de Cazorla, Segura y las Villas and Sierras de Tejeda, Almijara y Alhama in which we developed management action plans with technicians from the parks. The resulting recovery plans are available from the Butterfly Conservation Europe webpage (Munguira et al. 2015a, b, c, d), in four extensive documents which have English and Spanish versions.

The objective of this paper is to design recovery plans for *Polyommatus violetae, P. golgus, Agriades zullichi*, and *Euchloe bazae*. The goal of these plans is to improve the status of the four species. We also present habitat models for the species and a compilation of the information gathered during field studies carried out in 2012–2014. These studies are planned to assess if the species have restricted distribution ranges, their populations show low numbers, the variables result in a specialized habitat, or the observed threats are similar to those reported in published accounts.

Methods

Basic information on the biology, ecology and threats was gathered for each species as a background for further analysis. These were compiled from scientific papers, distribution records and chapters of Red Data Books or reports. Particular attention was paid to distribution records that served to complete distribution maps and to plan the fieldwork campaign in a set of locations that represented the whole distribution of each species.

Fieldwork took place during the years 2012–2014 with the aim of providing a better knowledge of the species ecology and the threats taking place in each site, and covered most of the known distribution range of the four species, with visits to potential new places that could host unknown populations. These new places were selected for having the larval food plants of the species and sharing habitat features with already known habitats. The number of studied locations was 56: 23 for *Polyommatus violetae*, seven for *P. golgus*, five for *Agriades zullichi*, 17 for *Euchloe bazae*, three shared by *P. golgus* and *A. zullichi*, and one for *P. golgus* and *P. violetae*. Most locations were visited at least twice in subsequent years (2013–2014 for *E. bazae* and 2012–2013 for the rest of the species).The following data were recorded for each population of the species: name of the locality, date, geographic coordinates, altitude, geological substrate, number of adults on transect counts, larval food plant density, threats for the survival of the species, and vegetation type. Latitude-longitude coordinates and altitude were noted precisely with the aid of a GPS. Geological substrate was described with the type of rock that was predominant in the area. When necessary rock samples were collected and identified by one of the authors (J. Olivares). Larval food plant density was estimated for each species by counting the number of plants in one randomly selected 10×10 m square. The following observed threats were registered: abandonment, when a previous grazing area was covered by more than 50% of invading shrubs; trampling if shortcuts or occasional paths crossed the species habitat or livestock trampling was evident; pine plantations when alien pine species were planted substantially reducing the open habitats; overgrazing when high densities of livestock produced a depletion of natural vegetation; agriculture where crops had reduced by >25% of the total extension of the suitable habitat for the species in the site; urban development if housing, tourist facilities, or roads invaded suitable sites; and fire where signs of recent wildfires were detected during fieldwork. Where no threats were evident during the visit we registered the threats as "none". Vegetation was recorded by noting the predominant vegetation type, following Rivas-Martínez (1987), and structure, and the shrubs or relevant plant species that dominated the habitat. Special attention was paid to the presence of the different larval food plant species that are needed for a suitable habitat.

Distribution maps were prepared using published records and fieldwork data. Records were georeferenced to squares of 10×10 km of the Military Grid Reference System (MGRS) and represented with the aid of MapInfo Professional software 10.0 (MapInfo 2008). A complete list of the locations in which each species had been recorded during fieldwork or taken from literature records is given in Supplementary Material. The percentage of squares falling within the limits of protected areas was estimated by reference to the networks of Natura 2000 (http://www.natura2000.eea.europa.eu) and Spanish Protected Areas (http://www.europarc.org). Following Romo et al. (2014), squares with 15% or more of the surface within the limits of a protected area were included within the limits of protected areas.

For the production of habitat models, independent localities were obtained from field data on the distribution range of each target species. To avoid spatial correlation between locations (Kühn 2007; Legendre et al. 2002) we established a minimum distance threshold between locations of 100 m. This was based on previous knowledge about the ecology of the species (for example Barea-Azcón et al. 2014), which rarely move distances larger than 100 m. It can therefore be assumed that this distance guarantees independence between points. As a result we obtained 28 independent locations for *P. violetae*, 111 for *P. golgus*, 138 for *A. zullichi*, and 24 for *E. bazae*. From this presence data set, potential distribution was modelled using Maxent software (Phillips et al. 2006). Maxent is a niche-based model from presence-only data with the general-purpose method for making predictions or inferences from incomplete information. This software estimates a target probability distribution by finding the maximum entropy probability distribution, subject to a set of constraints that represent our incomplete information about the target distribution. As environmental predictors we used a set of 27 variables from three main conceptual groups: climate, land use, and topography. Climate variables were taken from WorldClim database (http://www.worldclim.org, Hijmans et al. 2005), and the rest from the EDIT Geoplatform (Sastre et al. 2009), at a 30 arc-seconds resolution. We considered default Maxent parameters and a subset of 10% of presence points was used to test the models. Once the model was generated, we classified each grid cell as present (holding potential butterfly habitats), or absent based on the suitability threshold associated with the presence record that occurs at the 10 percentile of presence records (i.e. the 10 Percentile Training Presence Logistic Threshold value showed on the Maxent report). These thresholds were used to transform the continuous maps into binary maps and showed values of 0.51 for *P.violetae*, 0.41 for *P. golgus*, 0.43 for *A. zullichi*, and 0.67 for *E. bazae*. AUC scores (Area Under the Receiver Operating Characteristic Curve) were used as reference parameter in order to evaluate the predictive capacity of the models. This value was 0.997 in the case of *P. violetae*, 0.999 in *P. golgus*, 0.998 in *A. zullichi*, and 0.998 in *E. bazae*. Values higher than 0.8 show that the models have a high predictive capacity (Fielding and Bell 1997).

Adult populations were estimated along fixed 1-km transect routes for each site, and according to criteria from Butterfly Monitoring Schemes across Europe. Weather and other sampling conditions followed the protocol described in Pollard and Yates (1993). Transects crossed the centre of the population, went through areas where adequate habitat and adults were previously spotted, and were selected on accessible areas, particularly where mountains prevented random selection. Figures for this estimate were given in number of adults per m^2. In the case of *P. golgus* data were completed with a temporal series of transect counts, available from the monitoring scheme taking place in the Sierra Nevada National Park, whose records started in 2008. These transects took place in the location of Hoya de la Mora, which has 2250 m of length and an altitude of 2520–2570 m, and crosses one of the studied populations of the species.

Data are presented for each species in the "Results" section: distribution records, habitat and habitat models, adult densities and threats. A summary of the resulting species recovery plans is also given individually.

Results

Polyommatus violetae

According to literature references and our own field data the species is restricted to SE Spain and is found in the sierras of Tejeda, Almijara, Nevada, and Gádor (subspecies *violetae*) and in Cazorla, Segura, Alcaraz, La Sagra, Las Cabras, and Los Álamos (subspecies *subbaeticus*). The total number of recorded 10×10 km squares was 26, from which 13 were studied in detail (Fig. 1a; Table 1). Two new squares (7.7%) from the Sierra de Segura are added by our data to previously known records. In the studied squares 23 sites were visited during fieldwork. The altitude range of the visited locations is 733–2104 m (Table 1). In these locations the habitat consists of grassy areas usually surrounded by natural or planted woodlands. Only two (9%) out of 23 localities visited are open grassland areas with no tree cover, a habitat restricted to the highest locations of the eastern part of Sierra Nevada. Natural and planted pines are present in 74% (Fig. 2a) and holly oak (*Quercus ilex*) in 48% of the sites. Almost half of the sites have a high proportion of shrubs as part of the habitat (usually *Erinacea anthyllis*), that are mixed with grassland patches. Some of the sites dominated by grasslands are being invaded by *Genista scorpius*, a frequent invading plant in calcareous Mediterranean areas. The substrate of the species habitat is predominantly calcareous, with 36% of the sites on limestone, 3% on marble, and 45% on marl and limestone. However, the sites in Sierra Nevada (16%) have schist substrate, an interesting finding, because the species has always been regarded to live on calcareous habitats (García-Barros et al. 2013). The larval food plant confirmed in the sierras of Tejeda, Almijara, Nevada, and Cazorla is *Onobrychis argentea*, but in the Sierra de Alcaraz (Albacete Province) a new food plant was recorded during fieldwork: *O. matritensis*,

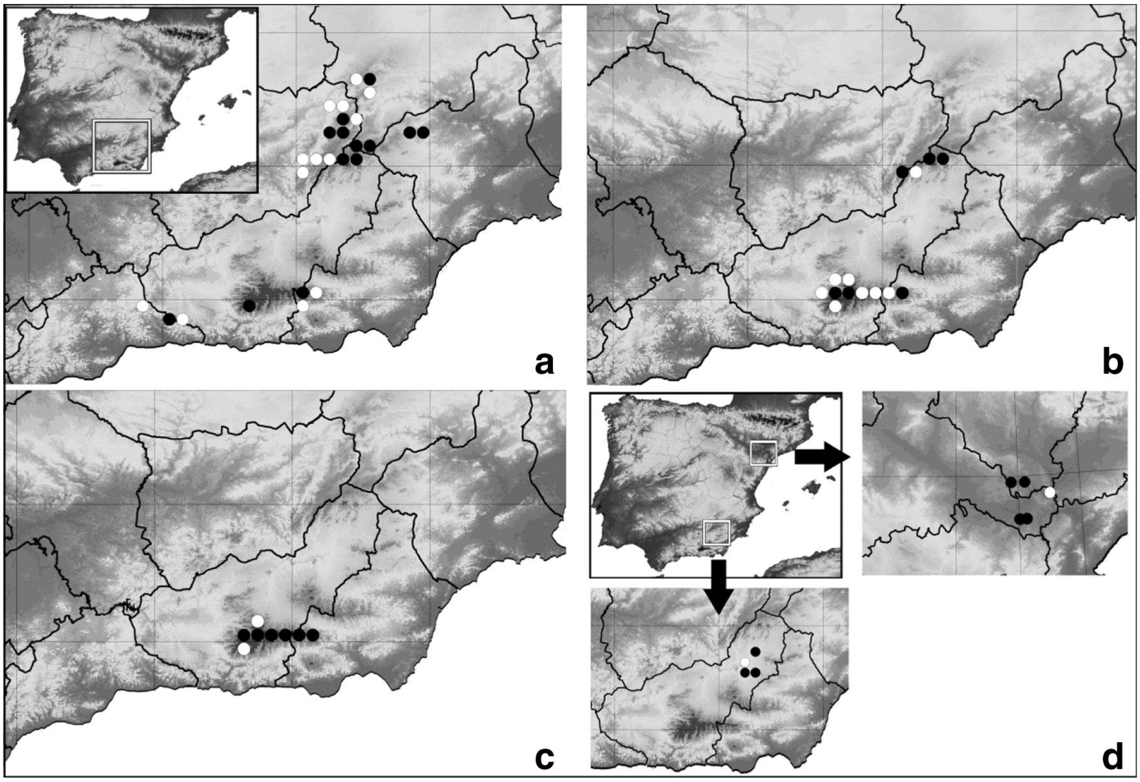

Fig. 1 Distribution maps of *Polyommatus violetae* (**a**), *P. golgus* (**b**), *Agriades zullichi* (**c**), and *Euchloe bazae* (**d**). *Black circles* represent the presence of each species in 10×10 km squares of the Military Grid Reference System (MGRS) from visited locations during fieldwork and *white circles* from bibliography records. Provincial limits are shown with *black lines*

Table 1 Habitat and ecological preferences of the four endangered endemic butterflies in Spain (see Methods)

	Polyommatus violetae	*P. golgus*	*Agriades zullichi*	*Euchloe bazae* Monegros/Baza
Altitude range (m)	733–2104	1817–2726	2376–2779	804–958/109–331
Altitude (m), average ± SD	1460 ± 326 N = 31	2377 ± 301 N = 22	2622 ± 136 N = 15	872 ± 36/226 ± 59 N = 19 / 18
Substrate	Limestone, marble, marl-limestone, schist	Schist, limestone, marl-limestone, dolomite	Schist	Marl, marl-limestone/ marl-limestone, marl-sandstone
Distribution 10 × 10 km squares	13 (26)	6 (14)	6 (8)	4 (5)/3 (4)
Larval food plants	*Onobrychis argentea, O. matritensis*	*Anthyllis vulneraria*	*Androsace vitaliana*	*Vella asperal Eruca vesicaria*
Population density (adults/ m^2), average ± SD	0.0043 ± 0.0056 N = 20	0.0041 ± 0.0028 N = 19	0.0066 ± 0.0041 N = 9	0.0017 ± 0.0013/0.0004 ± 0.0003 N = 11/16
Food plants/m^2, average ± SD	2.67 ± 1.98 N = 13	1.79 ± 2.18 N = 9	1.68 ± 1.58 N = 10	0.46 ± 1.81/1.40 ± 0.311 N = 16/3
% Protected areas	92	100	100	80/0

Distribution range is expressed in 10×10 km squares of the Military Grid Reference System (MGRS) and the number of squares visited during fieldwork is given with the total number of known distribution squares (fieldwork and relevant literature) expressed in brackets. % Protected Areas represents the percentage of locations that are within a protected area of the Natura 2000 network. For *Euchloe bazae* data are separated (by a /) into the two areas where the species lives: Monegros and Baza

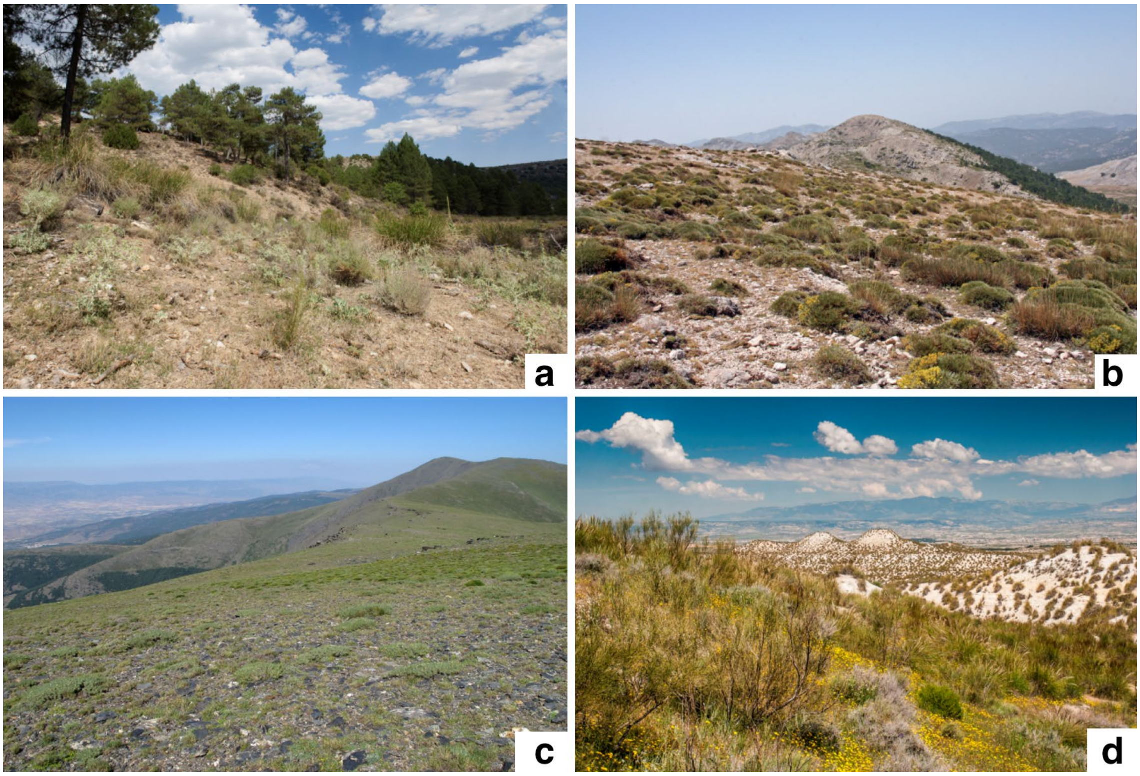

Fig. 2 Representative habitats of *Polyommatus violetae* (**a**, Santiago de la Espada, Albacete), *P. golgus* (**b**, Sierra de Cazorla, Jaén), *Agriades zullichi* (**c**, Sierra Nevada, Granada), and *Euchloe bazae* (**d**, Cúllar, Granada). Photos ML Munguira (**a, b**), JM Barea-Azcón (**c**), and J Olivares (**d**)

an endemic plant from central and southern Spain. The habitat model (Fig. 3a) shows a potential distribution area for the species which is larger than the observed distribution. The variables that have the highest contribution to the model performance are altitude and the annual range of temperature (Table 2). Potential areas where the species have not been recorded include the sierras of Filabres and María in Almería Province, and a larger area than observed in the sierras of Alcaraz, Segura and Cazorla. The potential area in the type locality of the species in Sierra Almijara is comparably small, in accordance with the restricted distribution of the species in this area.

Average estimates of adults per m^2 are given in Table 1 and were 0.0054 adults/ m^2 in 2012 and 0.0032 in 2013. 25% of the visited populations showed no evident threats (Fig. 4). This fact is due to the predominant mountain or marginal nature of the habitat in which the species lives. The main threat, on those sites with evident threats, is abandonment (38% of visited sites), followed by pine plantations (25%). Overgrazing incidence is relatively low (13% of the sites). Abandonment has been mentioned as a threat for this species by Beaufoy et al. (2015) and overgrazing by Gil-T. (2008). *P. violetae* is the species of our study facing the widest range of threatening factors (six).

The recovery plan for this species includes the following actions:

- Protection of the populations in La Sagra is a priority. Populations are threatened by abandonment, overgrazing, and the extension of crops. This area is already a Natura 2000 site, but we propose declare it as a Natural Park. La Sagra also hosts a rich butterfly fauna (114 recorded butterfly species, Tarrier 1993). Extending the limits of the Parque Natural Sierra de Castril to enclose La Sagra, is probably the most efficient way to upgrade the conservation status of this mountain range.
- Habitat management for the species needs keeping the livestock pressure under control in overgrazed areas and enhancing active but controlled grazing in abandoned areas. The High Peaks Recovery and Conservation Plan in Andalusia (Plan de Recuperación y Conservación de Especies de Altas Cumbres de Andalucía: BOJA 2012) can act as a legal framework, because it deals with the negative effect of overgrazing and natural herbivores, and supports sustainable extensive grazing for *P. violetae*. To increase the extension of grassland habitats for the species we suggest clearing up pine plantations. Local conservation authorities have planned to imple-

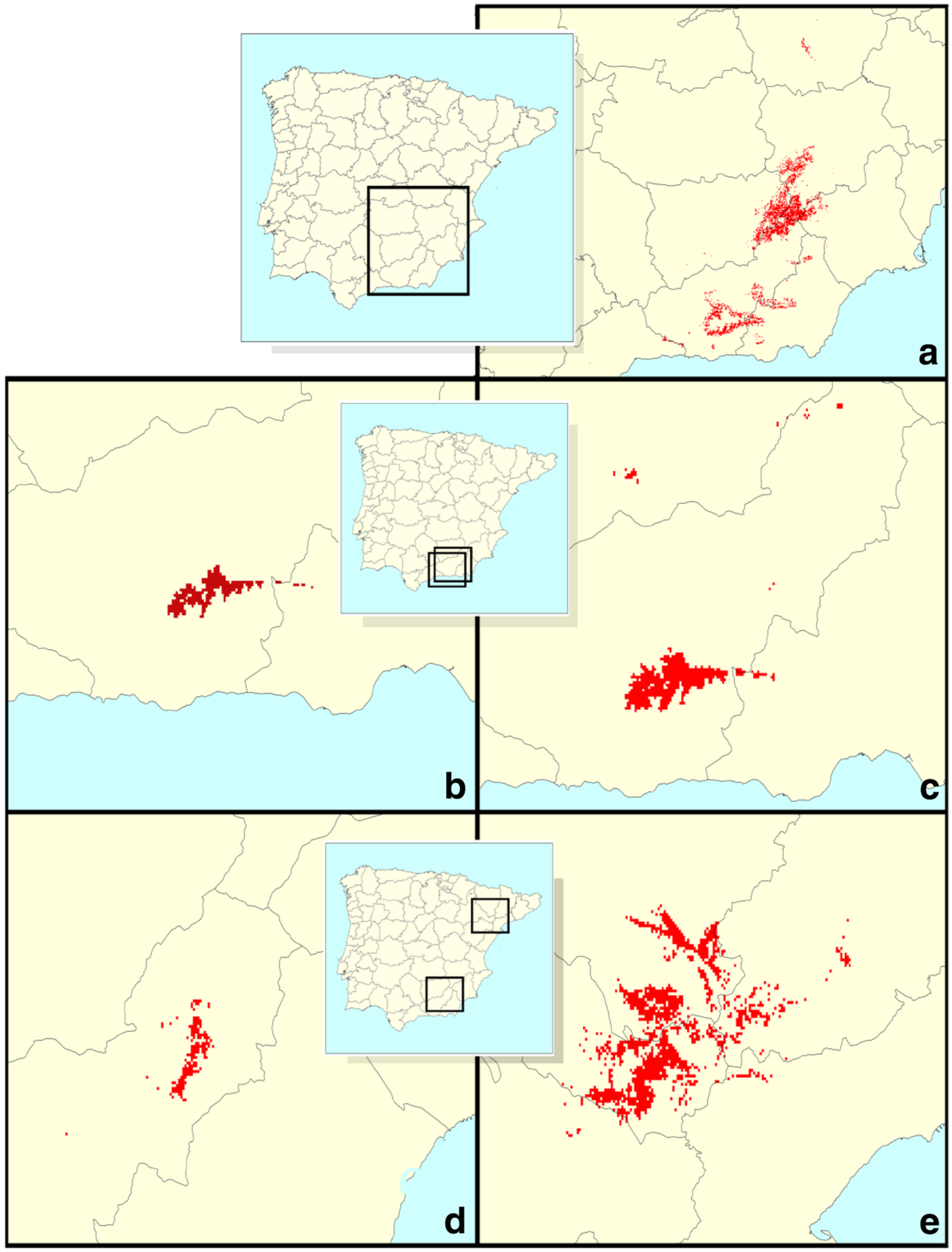

Fig. 3 Habitat models of *Polyommatus violetae* (**a**), *Agriades zullichi* (**b**), *P. golgus* (**c**), and *Euchloe bazae* (**d, e**) obtained with Maxent software. The potential distribution of each species is shown with a resolution of 30 arc-seconds

ment these measures in Sierra Nevada National Park and the Natural Parks of Sierra de Cazorla, Segura y las Villas and Sierra de Tejeda, Almijara y Alhama. These clearings could also be planted with seeds or saplings of the larval food plant, produced by the Andalusian network of botanic gardens.

- Precautionary measures should prevent land use changes such as new crops on wild areas and developments of roads and tourist infrastructures.
- Research actions needed are monitoring the trends in adult populations with regular censuses and searching for new populations, because the species lives on areas that have not been thoroughly explored.
- A public awareness campaign included media releases, leaflets with data for the species delivered to visitor centres of the Natural and National Parks with presence of the butterfly, information in webpages (e.g. Butterfly Conservation Europe, http://www.bc-europe.eu), and information panels displayed in protected areas where the species lives.

Polyommatus golgus

According to literature and our own observations, *P. golgus* has a restricted distribution range and is found in 14 squares (10 × 10 km) from the sierras Nevada, La Sagra,

Table 2 Percent contribution of the climatic, land use, and topography variables to the Maxent habitat model performance of the four study species

	Polyommatus violetae	*P. golgus*	*Agriades zullichi*	*Euchloe bazae*
Altitude	**43.6**	**68.9**	**65**	0.4
Mean temperature of driest quarter	0.7	0.5	4.8	3.9
Mean temperature of wettest quarter	1	0.2	**23.2**	
Mean temperature of warmest quarter		1.4	1.6	6.7
Temperature annual range	**31.5**	0.5	1.4	0.1
Temperature seasonality (standard deviation × 100)	4.5	**18.2**	1.1	3.9
Mean temperature of coldest quarter	0.4	0.9	0.8	**12.7**
Min temperature of coldest month	0.7	1.9	0.4	2.2
Precipitation of wettest quarter			0.1	3.3
Land cover	6	0.3	0.1	6.2
Mean diurnal range	5	4.4		0.2
Max temperature of warmest month		0.6		5.6
Annual precipitation		0.1		**13.7**
Precipitation of wettest month				**19**
Precipitation of coldest quarter	0.1			**17.9**
Roughness	1.7			0.7
Topographic position	1.4			

Only variables with contributions higher than 1% for any of the models are presented and those with contribution >10% are highlighted with bold characters.

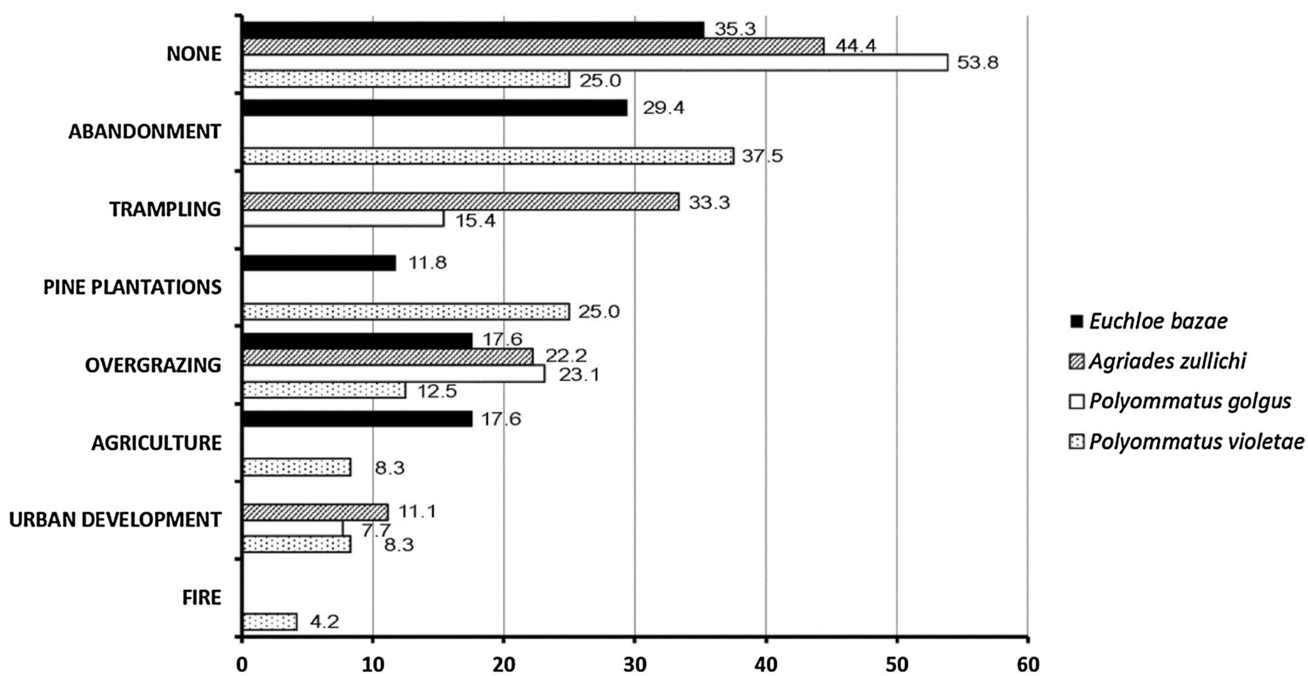

Fig. 4 Percentage of the threats recorded during fieldwork for the four species of the study. Percentages for each species do not add 100%, because one given site can have several threatening factors. A percentage of the sites showed no evident threatening factors and were classified as "none"

Cazorla, Guillimona, and Seca from Eastern Andalusia (SE Spain, Fig. 1b). The two subspecies of *P. golgus* live in rather different habitats. Our records show that subspecies *golgus* lives in Sierra Nevada at altitudes ranging from 2152 to 2726 m (Table 1), although it has been found at altitudes of 3200 m (Barea-Azcón et al. 2008b).

All recorded populations of this subspecies are on north facing slopes or in the summits, suggesting a preference for more humid and/or cooler habitats. The distribution of this species becomes isolated to the eastern side of the mountain range, where conditions are drier. The vegetation formations are dominated by dwarf junipers, *Genista* shrubs and grasses. Rock substrate consists of schist that locally can show a high proportion of quartz. The oro- and crio-romediterranean habitats where the species lives are listed under the Habitats Directive Annex 1 (92/43/CEE) as Habitats of Community Interest: Oro-Iberian *Festuca indigesta* grasslands (code 6160) and Mountain *Cytisus purgans* formations (code 5120). The northern populations of the subspecies *sagratrox* live in four nearby sierras within the oromediterranean stage, on clearings of *Pinus nigra* woodlands, and at higher elevation on cushion shrub communities with *Erinacea anthyllis* (Fig. 2b). Altitudes in our samples are between 1817 and 2381 m in La Sagra, at an average of 1847 m in Sierra Guillimona, and at 2041 m in Sierra de Cazorla. The habitat model (Fig. 3c) shows coincidence of predicted areas with the observed distribution with the exception of Sierra Mágina in the province of Jaén, where the species has not been recorded. The two variables that contribute to the model performance with highest values (Table 2) are altitude and temperature seasonality. The small potential area in the NE of the province of Granada is in accordance with the limited distribution of the species there and also shows a highly fragmented habitat. These latter facts, together with the presence of the species always in the proximity of the peaks of the mountains, points out the vulnerability of the species in the area, particularly in relation to the changing ranges forced by climate warming.

The two years in which population densities were estimated show different values: 0.0035 adults/m^2 for 2012 and 0.0055 for 2013. The differences between estimates in 2012 and 2013 are probably an effect of different climatic conditions. The very dry and extremely hot 2012 spring was probably negative for larval survival and consequently might have reduced adult numbers. In the population of Hoya de la Mora in Sierra Nevada, the Butterfly Monitoring Scheme of the National Park has been recording numbers since 2008 (Fig. 5). Although trend estimates would need longer time series, it is evident from these data that the population shows strong fluctuations. 54% of the studied populations showed no evident threats. As for the other species, this fact is due to the predominant mountain or marginal nature of the habitat in which the species lives. The main threat, on those sites where threats are evident, is overgrazing (23% of the visited sites, Fig. 4), which was also considered a threat for the species and its habitat by Barea-Azcón et al. (2008b) and Blanca (2002). Trampling (15% of the studied populations) is caused by footpaths crossing the species habitat or by grazing animals (Fig. 6).

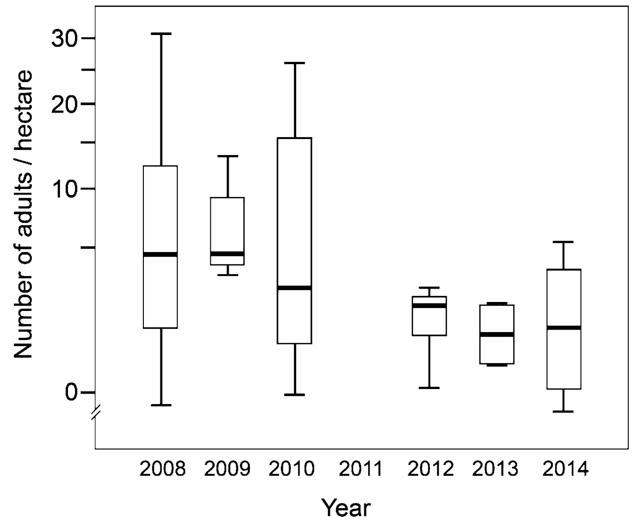

Fig. 5 Box plots of the estimates of adult numbers of *Polyommatus golgus* from Sierra Nevada Butterfly Monitoring Scheme in the location of Hoya de la Mora. Adult numbers per hectare are given for average values, range and standard deviation in each year of the scheme. In the year 2011 the population was not recorded

Fig. 6 Roads, footpaths, and shortcuts showing that trampling considerably reduces the suitable habitat of *Polyommatus golgus* and *Agriades zullichi* in the slopes of Pico Veleta, Sierra Nevada (SE Spain)

Actions for the recovery plan of *P. golgus* include the following:

- We suggest the protection of La Sagra as a Natural Park. This area hosts *P. violetae* and *P. golgus* and has a rich fauna and flora, which are values in accordance with the Natural Park status.
- In Sierra Nevada, eight exclusion fences in some well-known populations (100 m^2 each) are being planned as an experimental action for the protection of the habitat. The habitat of *P. golgus* has been damaged to a small extent (15% of the sites) by the trampling effect

of livestock and by footpaths shortcutting for access to the mountain summits (Fig. 6). Trampling causes the destruction of natural vegetation at high altitude mountains on the narrow strips or small areas where it occurs and can limit a certain amount of the total extension of suitable habitat for the species by damaging the larval food plants. Reducing the impact of trampling can be partially achieved by exclusion fences, but for the whole distribution range of the species, more widespread actions would be needed such as trying to direct visitors through marked footpaths.

- Among precautionary measures to protect suitable habitat from potential damage, new developments such as roads and tourist infrastructures related with the ski resort in Sierra Nevada should be avoided.
- The main research action needed is monitoring the adult population changes. Captive breeding and reintroduction programs would be an interesting research topic that would secure, if successful, live specimens for increases in population numbers. Strengthening of plant populations could be beneficial for the species and the botanical gardens placed in Sierra Nevada National Park and Sierra de Cazorla, Segura y las Villas Natural Park could play an important role growing plants for further plantations. Finally, genetic studies are still needed so that the genetic distance between the populations from the two areas in which the species lives can be definitively ascertained.
- Public awareness campaigns with media releases, leaflets, information in webpages, and information panels have been developed for the species as described above for *P. violetae*.

Agriades zullichi

This is the most restricted species, only present in Sierra Nevada (SE Spain) and recorded in literature and own records from eight 10 × 10 km squares (Fig. 1c). The studied localities are mainly at elevated spots where the vegetation grows interspersed with schist screes, which represent the substrate of these habitats (Fig. 2c). It is always found on wind-exposed ridges that, in the visited locations, had a northern aspect, with only one exception that has eastern aspect. The areas where the butterfly lives exhibit less vegetation cover than surrounding areas, and have scattered grasses (e.g. *F. clementei, Festuca indigesta* and *F. pseudoeskia*), shrubs (*Genista versicolor, Cytisus galianoi, Astragalus nevadensis* and *Arenaria pungens*), and junipers (*Juniperus sabina* and *J. communis*). The habitat is part of the Oro-Iberian *Festuca indigesta* grasslands habitat type (Annex I of the EU Habitats Directive, code 6160), a habitat of Community Interest. The larval food plants, *Androsace vitaliana*, grow in populations of a highly variable density, ranging from 0.36 to 5.72 plants/ m^2 (Table 1). The habitat model (Fig. 3b) is consistent with the distribution restricted to Sierra Nevada and shows small potential areas in the eastern limits of the range. Altitude and the mean temperature of wettest quarter are the variables with higher contribution to the performance of the model (Table 2), a fact that supports the vulnerable condition of the eastern populations, particularly under climate change scenarios. These populations have the lowest altitudes recorded for the species and are also fragmented into small habitat patches.

Adult estimates were only possible for 2013 and show maximum values of 0.0133 and minimum of 0.0012 adults/m^2. The percentage of visited populations with no evident threats is 44%. The main threat, on those sites where there are threats, is trampling (33% of the studied localities, Fig. 4). It is caused by footpaths crossing the species habitat or by grazing animals. Trampling threatens the populations of *A. zullichi* because it reduces the suitable habitat, which is very fragile in these high altitude mountains, and changes the vegetation cover and plant richness (Jägerbrand and Alatalo 2015). Aerial photographs of the habitat of *A. zullichi* and *P. golgus* (Fig. 6) showed the effect of this threat on the habitat for these two species. Overgrazing was detected in 22% of the sites and urban development, limited to the Veleta ski resort, in 11%. Overgrazing was considered a threat for the species and its habitat by Travesí et al. (2008) and Blanca (2002).

The recovery plan for this species could involve comparable actions as to *Polyommatus golgus*, because both species live in the same habitat network of Sierra Nevada. Thus exclusion fences, precautionary measures, research actions, and public awareness campaigns are similar to those mentioned for the previous species. Legal actions are not needed for this species because it is a protected species in Andalusia and its habitat is covered by a National Park (Table 1). To avoid the negative effects of overgrazing it would be important to keep the livestock pressure under control in the future. The High Peaks Recovery and Conservation Plan in Andalusia (BOJA 2012) can favour actions regulating this threat, because it deals with the negative effect of overgrazing. The species habitat has been damaged to a small extent by the trampling of livestock and by footpath shortcuts (see above, Fig. 6). Limiting footpaths and controlling livestock pressure on the species habitat can be partially achieved by exclusion fences, but for all the range of the species widespread actions would be needed. In the Sierra Nevada National Park managers are already trying to direct visitors through marked footpaths to prevent the negative effect of trampling.

Euchloe bazae

The species was recorded from the literature and our data in nine 10 × 10 km^2 squares. During fieldwork all the previously known populations of the species were studied and three new squares were discovered (33.3% distribution increase). The population of one of the previously known locations (La Granja d'Escarp in Catalonia, the easternmost population of the species, Fig. 1d) is considered to be extinct. Four visits by two different recorders (R Vila and ML Munguira) to La Granja d'Escarp in Catalonia, during the months of March and April of the years 2013 and 2014, produced no adult sightings, supporting the idea that this population has become extinct since its discovery in 1994. The habitat consists of sub-steppe grasslands or scrublands with a continental climate-type. Plant communities are characterized by the presence of *Quercus coccifera* (kermes oak). Predominant shrubs and grasses in these communities are *Rosmarinus officinalis* and *Lygeum spartum*, with *Stipa tenacissima, Retama sphaerocarpa*, and *Ononis tridentata* in the Hoya de Baza; and *Genista scorpius, Vella aspera*, and *Pistacia lentiscus* in the Monegros area. Some areas also have pines (*Pinus halepensis*) and junipers (*Juniperus phoenicea*). Populations were found at non-overlapping altitudes in the lowland Monegros and the highland Baza areas (Table 1). The species habitat is characterised by a high percentage cover of bare ground (Fig. 2d). The habitat model shows a restricted potential area for the southern populations, but a much wider area than recorded for the northern range of the species (Fig. 3d). Four climatic variables show the highest contribution to the model performance (Table 2): precipitation of wettest month, precipitation of coldest quarter, annual precipitation, and precipitation of wettest month. This result is a consequence of the semiarid character of the species habitat (see above).

Adult densities are very low, particularly in the Hoya de Baza, where numbers have already been reported to decline (Olivares and Jiménez 2008). Average numbers were significantly lower for the Hoya de Baza (0.0004 adults/ m^2, no. sites = 16) than for the Monegros area (0.0017 adults/ m^2, no. sites = 11) (Table 1; Fig. 7, Student t= −3.516, p = 0.0017, df = 25). The percentage of the populations that show no evident threats is 35%, in this case as a result of the marginal nature of the sub-steppe habitat in which the species lives. The main threat, on those sites where there are threats, is abandonment of land (29% of the sites). New crops, developed within the habitat of the species, and overgrazing affected 18% of the sites in both cases and were mentioned as threats by Olivares and Jiménez (2008). In recent times, native scrublands and gypsum vegetation at the Hoya de Baza populations have been transformed by almond tree cultures and, to a lesser extent, by irrigated crops.

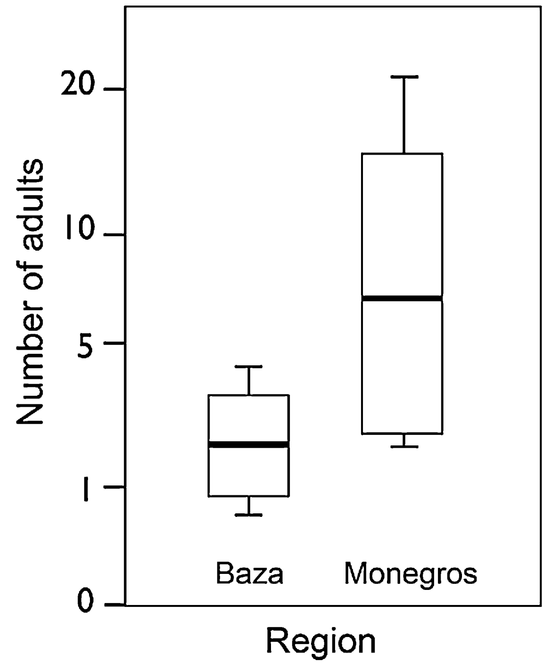

Fig. 7 Box plots of the adult counts of *Euchloe bazae* in Hoya de Baza, Andalusia (N = 16), and Monegros, Aragon (N = 11). Counts for the years 2013 and 2014 were grouped in the graph for both regions. Values represent the number of adults on 1 km long transects and are represented with a square root of density values scale

Recovery plan actions contain the following:

- The restricted range and low population densities of the species supports the need of protection by the local governments of the regions in which it lives: Aragon and Andalusia. The Spanish Environment Office is considering the species as a candidate to be added to the Spanish Endangered Species List (Catálogo Español de Especies Amenazadas). Protecting some of the most relevant populations of *E. bazae* is urgently needed. The areas of Barranco del Espartal (Hoya de Baza, Andalusia) and Barranco de Valcuerna (Monegros, Aragon) are suggested as the best locations for this action because they host some of the strongest populations of the species. The Barranco de Valcuerna is part of a Natura 2000 site, but the protection of *E. bazae* populations is not among its objectives and taking into account the needs of the butterfly is a top priority. Extensive grazing must be enhanced in abandoned areas to preserve a good quality habitat in the populations of Monegros area in Aragon (NE Spain).
- Preventing land use changes within the species habitat such as cultivation of previously wild areas is important for the future of the species.
- Necessary research actions include regular transect counts to monitor the trends of adult populations in the

future and the search for new unrecorded populations because the distribution area of the species is not yet thoroughly explored.
- The public awareness campaign planned for this species comprised media releases in coincidence with the workshops in which the results and recovery plans were presented, leaflets delivered to tourist information offices whose contents showed the values of the species involved and the main conservation actions suggested, and information available in webpages.

Discussion

Although butterfly conservation studies have a long tradition in Spain (e.g. Viedma and Gómez Bustillo 1974), the preparation of species recovery plans has not been commonplace. Generally, invertebrate recovery plans have focused on freshwater or marine species (Anonymous 2008). Gathering the available information for a given species and producing recovery plans based on field studies is a costly-task, especially in countries like Spain, which have diverse fauna and flora, and faces a variety of threats (Morales and Lizana 2011). We tried to fill this gap for the four endangered species (van Swaay et al. 2010) endemic to Spain.

The taxonomy of the four species is well established (García-Barros et al. 2013) at the species level after years of contrasting opinions concerning these four taxa. Only further studies are required to establish the subspecific status of some allopatric populations. This is indeed favourable for the conservation of these endemic species, as discussion will now focus on how to preserve the species rather than ascertaining their taxonomic status.

The general distribution of the four species is now well known, except perhaps for *Polyommatus violetae* and *Euchloe bazae*, for which our study provided new records. The range of *P. violetae* has increased, since the Atlas of García-Barros et al. (2004), from 13 to 26 squares (Fig. 1), presumably as a result of a greater sampling effort. New records come from areas without previous studies or poorly recorded (Romo and García-Barros 2005). The last compilation of records was made by Moreno-Benítez et al. (2012), to which we added two new locations from the Sierra de Segura (7.7% increase). All four species have a very limited distribution range, which is itself a cause of concern regarding the conservation status. Ranges comprising from eight to twenty-six 10×10 km^2 squares (Fig. 1) represent a very fragile situation and are in all cases within the threshold of vulnerable species (2000 km^2, IUCN 2012), with the exception of *P. violetae*. In the case of *Agriades zullichi*, the presence in only one mountain range (Sierra Nevada) adds conservation concern for the species, although in this case, the almost complete representation of the species habitat within a National Park makes the implementation of conservation measures easier. Other priority species in the park do not show conflicting needs with this butterfly.

The habitats of the four species are highly specialized, and in the case of *P. golgus* and *A. zullichi* are classified as Habitats of Community Interest in the European Union (Oro-Iberian *Festuca indigesta* grasslands, code 6160), a fact that adds relevance to the protection of the species. The Habitats Directive requires the designation of Special Areas of Conservation (SACs) for the habitat of *P. golgus*, a fact that was fulfilled by the inclusion of this habitat and by the designation of Sierra Nevada as SAC in 2012. However, in 2014, the Spanish Government reported to the EU that the "overall assessment of conservation status" is bad (U2) for this habitat, because threatening factors are not completely reversed and showing that it should receive more attention in further management actions inside the protected areas. On the other hand, the percentage of the habitats of the four species that fall within the limit of protected areas is considerable (Table 1), except for *E. bazae* for which new reserves are urgently needed as we have already suggested (see also Gil-T. 2008). In the case of *A. zullichi* and *P. golgus* the habitats can be preserved by reducing the human impacts to a minimum, as is suggested by van Swaay et al. (2012) for *P. golgus*. *P. violetae* has been found during our study in habitats over siliceous substrate, which contradicts the current evidence describing the species as calcicole-associate (García-Barros et al. 2013). One possible explanation to this new finding is that warmer climate conditions in southern areas may allow the typically calcicole larval food plant (species of the genus *Onobrychis*) to live on the usually poorer soils resulting from acid substrates.

Classical habitat models were used to detect the most relevant habitat characteristics for these four species. The most influential variables were altitude for three species, and temperature of the wettest quarter for *A. zullichi*, temperature seasonality for *P. golgus*, and annual range temperature for *P. violetae*. *E. bazae* which appears in more semiarid habitats presented a negative relationship with the precipitation of the wettest month and a positive one with the precipitation of the coldest quarter variables in the model performance. The models show small potentially favourable areas (except from *E. bazae*) in the surroundings of the known presence records where the species have not been reported. These are priority locations for future surveys. The fragmented habitats inhabited by these species are also highlighted by these models. Climate change will possibly affect in a negative way the mountain species, although *E. bazae* perhaps has a chance to expand its boundaries.

Population numbers, obtained for the first time for these species in transect counts, were remarkably similar for *P. violetae, P. golgus* and *A. zullichi*. These population densities are also typical to Iberian mountain species (Munguira, personal observations). On the other hand, the estimates obtained for *E. bazae* (Table 1; Fig. 7) were clearly lower, particularly for populations in the Hoya de Baza (Olivares and Jiménez 2008), where such low numbers can make the species extremely vulnerable to other threats. *P. golgus* is the only species for which we have a rather long series of data, and in this case quite strong fluctuations take place over the years. A longer time series is needed to confirm this trend, which would highlight the vulnerability of populations living in western Sierra Nevada.

The knowledge of threats that the four species are facing has notably increased during our study. Previous accounts tended to overestimate threats taking place in a single population such as urbanization or fires (Gil-T. 2008; Munguira et al. 2009b). Besides, we detected threats that were not recorded previously such as trampling (the most frequent threat for *A. zullichi*) or abandonment (the main threat for *P. violetae* and *E. bazae*). Overgrazing has resulted to be the only threatening factor shared by the four species. This was already mentioned by Barea-Azcón et al. (2008b), Gil-T. (2008), and Travesí et al. (2008), which shows that livestock grazing pressure has a very relevant effect in the mountain ranges of southern Spain and stresses the need to regulate grazing regimes, at least in protected areas.

Species recovery plans have been developed in agreement with land management and conservation managers. During the project, public awareness campaigns were planned to raise the interest of stakeholders and target audience on the four species, and this part of the plans has already been implemented. Legal actions are being formalised between regional conservation authorities and butterfly experts, and in the near future at least the conservation of *E. bazae* and the declaration of La Sagra as part of a Natural Park can possibly be achieved. Active management actions will probably take longer to be implemented, but the three protected areas that have collaborated with the project are already planning to develop some of the measures described within the plans (Munguira et al. 2015a, b, c, d). Besides, the proposed precautionary measures will probably be successful once the general public and managers responsible for the conservation of nature are aware of the threats the species are facing.

In the literature (Barea et al. 2014; Munguira et al. 2009b) climate change is considered to be one of the main threats for *P. golgus* and *A. zullichi* in the long term. Effects of global change in Sierra Nevada have been recently updated (Zamora et al. 2015), showing that average minimum temperatures will increase 1.81–4.38 °C from now to the end of the century, while maximum average temperatures will increase 2.56–6.22 °C. These climate changes would displace populations to higher elevations in mountain areas (Wilson et al. 2007). The main consequence of this threat would be a reduction of climatic suitable areas where the species live. For these two species this can be especially dramatic because some populations in Sierra Nevada, La Sagra, Guillimona, and Cazorla already live on the summit of the mountains, have a fragmented distribution, and are isolated from the core distribution of the species (Fig. 3). A similar scenario has been evidenced by habitat models for *P. violetae* which has a fragmented and local distribution in the western limit of its distribution range. Climate change would eventually cause the extinction of these populations. Management measures in specific localities (such as planting larval food plants and adult population reinforcements) should contribute to improved resilience of habitats and populations in a global warming scenario. This aspect is quite important for species living in Mediterranean mountains, where the impacts of climate change are expected to be higher than in the surrounding lowlands. This adaptive management strategy must be based upon monitoring data and contrasted with field actions in order to evaluate treatment effects. It is therefore necessary to define objectives, methodological procedures, and analytic tools in order to monitor the action effects in the long term and at different spatial scales. Finally, it is very important to design these Plans under multidisciplinary and integrative approaches. That is, incorporating collaborative networks between researchers and managers, and taking into account perspectives from different interest groups through a participative process. In this way, the point of view and knowledge of stakeholders such as local businessmen, stockbreeders, farmers, and local politicians cannot be underestimated, because governance based approaches will be key in biodiversity conservation at the Mediterranean hotspot.

Overall we have developed species recovery plans for four Spanish endangered endemic butterflies, based on field studies in which distribution data, habitat features and models, population estimates, and threats were recorded. Three of these species live in mountains and are facing threats mainly related to grazing abandonment, overgrazing, and trampling effects, while the fourth lowland species is also threatened with abandonment. The actions proposed in the plans are already being implemented or can realistically be developed in the near future, a fact that will secure the survival of these four butterfly species if the interest raised during this project is prolonged in the following years.

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Compliance with ethical standards

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Conflict of interest The authors declare that they have no conflict of interest.

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