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Assessing impacts of land abandonment on Mediterranean biodiversity using indicators based on bird and butterfly monitoring data

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SUMMARY

In Europe, and particularly in the Mediterranean Basin, the abandonment of traditional land-use practices has been reported as one of the main causes of decline for open-habitat species. Data from large-scale bird and butterfly monitoring schemes in the north-east Iberian Peninsula were used to evaluate the impact that land abandonment has had on local biodiversity. Species' habitat preferences, along a gradient from open to forest habitats, were significantly related to population trends: for both birds and butterflies, open-habitat species showed the most marked declines while forest species increased moderately. Multi-species indicators for tracking the impact of land abandonment on bird and butterfly populations were developed using habitat preference estimates and population trend indices. The patterns shown by these indicators were in line with the changes occurring in forest cover in the monitoring sites. This study reveals that multi-species indicators based on monitoring data from different taxonomic groups (here, birds and butterflies) may usefully be employed to track impacts of environmental change on biodiversity.

Keywords: driving force impact, habitat shift, land-use change, multi-species index, open habitat loss, population trends, vegetation encroachment

INTRODUCTION

Although reducing the direct pressures on biodiversity and promoting sustainable use is one of the four goals of The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets, habitats of all types continue to be fragmented and degraded (SCBD [Secretariat of the Convention on Biological Diversity] 2014). The conversion of native forests into cultivated and urban land is still causing major losses in biodiversity worldwide (de Chazal & Rounsevell 2009). However, in Europe, the abandonment of traditional land uses, such as low intensity land cultivation and livestock husbandry, is leading to a loss of habitats dominated by sparse vegetation, thereby giving rise to a succession towards forest habitats (Poschlod *et al.* 2005; Strijker 2005; Rounsevell *et al.* 2006). Indeed, afforestation appears to be the main transitional land-cover flow throughout Europe, a process that is particularly notable in Mediterranean countries (Feranec *et al.* 2010). This trend in land-use change is having a strong negative impact on the components of biodiversity that are associated with open habitats (Blondel & Aronson 1999).

Over the past decade, there has been a consistent improvement in the development of indicators that measure shifts in biodiversity related to environmental change (see for example de Heer *et al.* 2005; Gregory *et al.* 2005; van Swaay & van Strien 2005; Gregory *et al.* 2009; Devictor *et al.* 2012). Birds and butterflies are probably the two most widely used taxonomic groups to generate indicators in terrestrial ecosystems (Gregory *et al.* 2008; van Swaay *et al.* 2008). This has been possible thanks to the development of scientifically robust methods for monitoring their populations, the existence of appropriate datasets provided by large-scale and long-term citizen science projects, and a general acceptance of their use as surrogates of other less known groups (Kremen 1992; Furness & Greenwood 1993; Thomas 2005). However, despite the importance of taking into account a wide range of biodiversity components within the framework of essential biodiversity variables (EBV) (Pereira *et al.* 2013), few attempts have been made so far to simultaneously examine the impact of environmental change on these two taxonomic groups.

Thomas *et al.* (2004) analysed trends of butterflies and birds in the UK over the last 20–30 years and showed that the former have declined more severely than the latter. In contrast, Devictor *et al.* (2012) reported a higher climate debt for birds than for butterflies in Europe. These different responses to global environmental pressures were interpreted by the authors as a consequence of some of the particularities of each group, such as the lower dispersal ability of butterflies (making

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them more vulnerable to habitat fragmentation) in the first study, or the higher potential for local adaptation to climate warming for short-lived ectotherms in the second study. In general, contrasting patterns observed between the two groups may also depend on factors such as the spatial scales, habitats and regions taken into consideration (for example Ricketts *et al.* 2002; Tews *et al.* 2004; Fleishman & Murphy 2009).

In the present study, we attempt to match the requirements of the EBV framework by analysing data from bird and butterfly monitoring schemes within the same conceptual and methodological approach. Birds and butterflies have a great potential as indicators of the impact of land abandonment given the wealth of information available from monitoring schemes, and also because both taxa are sufficiently species-rich along the open-forest habitat gradient. In addition, they complement each other owing to their contrasting ecological requirements and life history traits. For instance, differing responses to land-cover change are likely due to the usually narrower range of environmental conditions required by butterflies (for example they require host specificity for larval development) and the fact that both groups are allocated to distinct trophic levels (Hilty & Merenlender 2000). Any approach for measuring impacts on biodiversity based on a single taxonomic group is likely to generate less representative results than an examination of data derived from several groups.

Land abandonment is a complex process affecting different habitat types. Herrando *et al.* (2014) found that farmland abandonment (which produces a shift from cultivated land to open semi-natural habitats) had a smaller impact on bird populations than the encroachment of natural vegetation (which produces a shift from open natural or semi-natural habitats to forests) in the north-west Mediterranean Basin. Consequently, our study focused on the second environmental process and had two main objectives. First, we aimed to determine the preferences of bird and butterfly species along an ecological gradient from open habitats to forests and then use this information to test whether recent population trends in species could be predicted from their position along this gradient. Second, we developed multi-species indicators to evaluate whether bird and butterfly population trends were in line with changes in land-cover occurring at the study sites. These objectives are particularly relevant, given the extensive network of bird and butterfly monitoring schemes in Europe (PECBMS [Pan-European Common Bird Monitoring Scheme] 2013; Munguira *et al.* 2014) and the current need to generate policy-relevant biodiversity indicators (Butchart *et al.* 2010; Pereira *et al.* 2013).

METHODS

Study area

We carried out this study in Catalonia, a region of *c.* 32000 km^2 situated in the north-east Iberian Peninsula. It is an environmentally highly diverse area that encloses four out

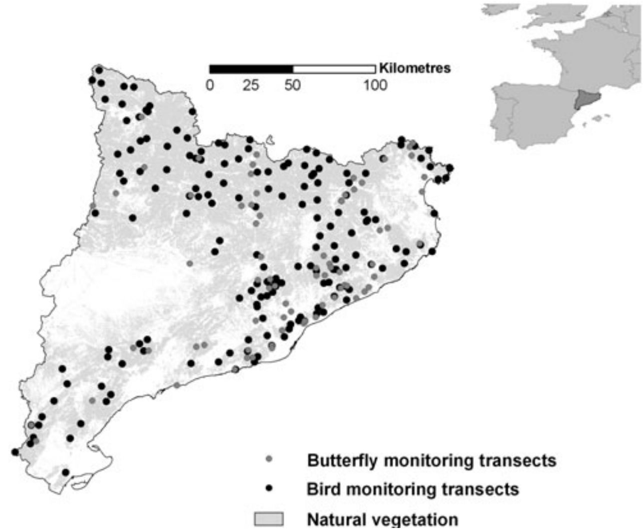

Figure 1 Locations of natural habitats (grassland, shrubland and forest) in Catalonia and of the 174 bird and 74 butterfly monitoring transects used in this study.

of the 13 main European Environmental Zones (Metzger *et al.* 2005). Roughly half of Catalonia is covered by farmland and urban areas, and half is covered by natural or semi-natural vegetation that includes many types of forests, shrublands and grasslands (Fig. 1). As a result of socioeconomic changes that occurred during the second half of the twentieth century, these later habitats are being affected by progressive land abandonment.

Bird and butterfly data

Bird data were derived from the Catalan Common Bird Survey (CCBS). This monitoring scheme started in spring 2002 and currently consists of *c.* 300 itineraries scattered throughout Catalonia (Herrando *et al.* 2014). The field methodology is based on linear transects of *c.* 3 km (mean = 3127 m, range = 1885–4625 m) that are walked twice a year during the breeding period (15 April–15 June). For each breeding bird species and each year, the maximum count recorded during these two censuses is retained as the best estimation of its annual abundance and is thereafter used to calculate population trends over time. In case of missing counts for one of the two annual visits to a site, we set the annual abundance for this combination site/year as a missing value and omitted the data from the analyses to avoid bias in abundance estimation.

Butterfly data were provided by the Catalan Butterfly Monitoring Scheme (CBMS), which began in 1994 and currently consists of *c.* 70 recording sites throughout the region (www.catalanbms.org). The CBMS is also based on line transects, and observers count the butterflies detected within a counting band of 2.5 m on both sides of the transect (Pollard 1977). Transects vary in length (mean = 1674 m, range = 727–4908 m) and are divided into a variable number of sections (mean = 8.9, range = 5–17) representing different kinds of habitats. Butterfly censuses are carried out on 30 consecutive weeks from March to September, and the sum of the individuals recorded during the surveys for a species (including estimated values for missing weeks) is retained as the estimate of its annual abundance.

There is growing evidence suggesting detection probability is a relevant issue for the analyses of bird and butterfly monitoring data (see Kéry *et al.* 2005; Kéry & Plattner 2007). However, available methods to account for potential changes in detectability over time are complex and data demanding, and they have not been implemented so far for the computation of trends and population indices in European bird monitoring programmes (Voříšek & Klvaňová 2012). In addition, habitat selection in both birds and butterflies is generally so strong (Estrada *et al.* 2004; Suggitt *et al.* 2012) that field counts are expected to be more strongly related to actual variations in species abundance associated to habitat features than to variations in detectability (see for example Isaac *et al.* 2011). Hence, we did not take into account changes in species detectability over time in this study.

Land abandonment at monitoring sites

We used available land-cover maps for Catalonia from 1993 and 2009 (http://www.creaf.uab.es/mcsc/) to assess the change in the proportion of forest habitats versus the total amount of natural habitats (namely habitats with natural or semi-natural vegetation and low intensity of human intervention) in the bird and butterfly monitoring sites. The period elapsed between the two land-cover maps roughly matches the time frame of the butterfly monitoring scheme (1994–2013) and to a lesser extent that of the bird monitoring scheme (2002–2013). Original land-cover categories were reclassified into either 'open' (grasslands and shrublands) or 'forest' (open and dense forests) habitats. Then, percentage of forest cover versus the total amount of natural habitats was calculated in a buffer of 1 km surrounding each monitoring site. We tested the significance of the difference in the proportion of forest/(open+forest) area between 1993 and 2009 using a repeated measures ANOVA approach with site as within-subject factor. Although this was done for the whole dataset, we included in the analysis the two types of monitoring sites (CCBS and CBMS) and their interaction with the difference in the proportion of forest/(open+forest) between 1993 and 2009 to test whether land-cover changes differed according to the monitoring scheme.

Habitat preferences of birds and butterflies along an open–forest gradient

Birds and butterflies differ in terms of the spatial scale at which biological processes occur (Seto *et al.* 2004). Therefore, we used data at different spatial resolutions to analyse habitat preferences in these two groups: abundance data along the whole CCBS transect for birds, but at the CBMS section level for butterflies. In the first case, habitat types were assessed along 100-m wide buffers of the CCBS transects using the Catalan Habitat Cartography 1999–2010 (www.ub.edu/geoveg/en/mapes.php), while butterfly habitat types were recorded by a botanist in the 5-m buffer area occurring along the CBMS transect routes. Both habitat descriptions employed the same CORINE land-cover categories (www.eea.europa.eu/publications/COR0-landcover), although the original categories were reclassified as 'open' or 'forest' in the subsequent analyses.

Along every bird monitoring transect and section of the butterfly monitoring transects, we assessed the percentage cover of these two main habitat categories (open and forest). In order to focus on this ecological environmental gradient, we only selected CCBS transects and CBMS sections in which the sum of the coverage of habitats of interest (grasslands, shrublands and forests) was at least 75% (Fig. 1).

We carried out generalized linear models (GLMs) with a Poisson error distribution and a log-link function to quantify the species' habitat preference along the open–forest gradient. The mean abundance of a species along a transect (for CCBS) or in a section (for CBMS) within the monitoring time frame was the dependent variable and the proportion forest/(forest+open) was the independent variable. In both cases, we selected species with significant models ($p < 0.05$) and used the parameter estimate of the slope of the linear model as an indication of the preferred position of the species along the open–forest gradient: species with a high positive or negative parameter estimates had greater affinities for the forest or open habitats, respectively. Generalist species were thus excluded. Significant habitat preferences were less likely in rare species (simply because of insufficient data) and hence the selection was focused on relatively common and well monitored species. Although the linear approach used did not allow defining species whose habitat preference was placed at intermediate positions along the open–forest gradient, we preferred to keep the procedure as simple as possible to facilitate interpretation of the results, which is essential from a policy support perspective.

In general, butterflies are more commonly associated with open habitat than birds. This ecological difference was taken into account in the analytical procedure; we considered that in order to establish comparable indicators for both taxa it was desirable to have a similar number of species positively and negatively associated with open or forest habitats in birds and in butterflies. Therefore, open habitat was defined in a slightly different way for birds and butterflies using a combination of expert assessment on species ecology and preliminary analyses with varying vegetation height thresholds between open and forest habitats. Thus, for birds, open habitats were defined as those vegetation types with a maximum vegetation height below 150 cm, whilst for butterflies this threshold was set at 60 cm.

Prediction of population trends from species' habitat preferences

We tested whether habitat preferences along the open-forest gradient played a role in determining the temporal trends of bird and butterfly species over the period covered by the two monitoring schemes. To do so, we first calculated population trends from the bird and butterfly monitoring transects (CCBS and CBMS, respectively) using log-linear Poisson regression models with TRIM [TRends and Indices for Monitoring Data]. TRIM is a user-friendly computer program developed to analyse time series of count data (van Strien *et al.* 2000). The method produces annual indices and trend estimates, and can also deal with several difficulties inherent to monitoring data, especially missing values, over- and under-sampling of particular strata, serial correlation and deviations from Poisson distribution. More specifically, we used time-effect models, and the overall multiplicative slopes were considered as the most reliable estimates of the magnitude of the population trends over the studied period (van Strien *et al.* 2000). Since our aim was to test whether habitat preferences along the open-forest gradient have played a role in determining recent population trends, we selected only monitoring transects covered by natural vegetation potentially affected by land abandonment. Together with our previous criteria, this led to the selection of 174 bird and 74 butterfly monitoring transects (Fig. 1). The number of transects increased during the study period. In the case of CCBS, there were 67 transects at the beginning of the time series and 115 at the end, whereas, in the case of CBMS, the initial value was 10 and the value at the end was 40. It is important to emphasize that TRIM allowed us to estimate counts for the missing years for each transect based on trends modelled using available data. Rare species present in fewer than 10 transects over the monitoring timeframe were not included in the final analyses to minimize stochastic effects inherent to their low sample sizes.

We analysed the potential association between habitat preference estimate and population trend using linear regression models. Habitat preference estimate was taken as predictor and the overall multiplicative imputed slope as the response variable. We also analysed whether the relationship between habitat preferences and population trends differed between butterflies and birds by evaluating the significance of the interaction between habitat preference estimates and the taxonomic group.

Indicators of the impact of land abandonment on birds and butterflies

We calculated two indicators of the impact of land abandonment, one for birds and one for butterflies. These indicators were generated using the methodological framework developed in Gregory *et al.* (2009) to measure the impact of climate change on birds, and later adapted by Herrando *et al.* (2014) to generate indicators of the impact of land-use change. This approach is based on the quantitative assessment of species responses to a particular environmental pressure according to their ecological traits, and the subsequent incorporation of these assessments in the statistical analysis of impact by means of multi-species indicators. This approach fulfils the necessary mathematical properties for indicators of biodiversity change (van Strien *et al.* 2012).

In a first step, a composite index was created separately for those species that were significantly and positively associated with forest habitats along the open-forest gradient (+), and for those that were significantly and negatively related with this type of habitat (-). For each species we used the annual index obtained by TRIM (van Strien *et al.* 2000) as the population index for year a (I_a). Then, we obtained a value of change (X_{ab}) between years a and b, where $b = a + 1$, using the formula $X_{ab} = \log (I_b / I_a)$. Subsequently, we calculated the sum of $W_i \times X_{ab}$ for i species, where Wi is the weight of each species (ratio between the habitat preference estimate for i species and the sum of all estimates for species of the subgroup). We then applied an exponential transformation to obtain interannual change values. By establishing an initial reference value at 100 for the first year of the monitoring, we used these interannual changes to calculate the annual values of the composite indices (+) and (-).

In a second step, an overall multi-species indicator of the impact of land abandonment for each taxonomic group was generated as the ratio between the composite index of species affected positively (+) and that of species affected negatively (-). Following Gregory *et al.* (2009), these indicators were also set at an initial value of 100 for the first study year of each monitoring scheme, and we established the 90% confidence intervals using a bootstrap method. To do that we took the natural logarithm of the indicator and then expressed it as a deviation from the mean of the bootstrap log(indicator) across all years. From each of these annual values we then subtracted the difference between log(indicator) for the initial year and the mean of log(indicator) for the whole study period for the original observed series to give (Δlog(indicator)). We then repeated this bootstrap sampling and estimation procedure 10000 times. The 90% confidence limits of Δlog(indicator) were taken to be defined by the central 9000 of the ranked bootstrap set of estimates for a given year. The bounds of the confidence interval were then back-transformed.

In order to obtain the statistical significance of the trends in the indicators a randomization test was performed. To do this we first calculated ordinary least squares linear regression between the log of the indicator and calendar year. We then shuffled the estimates values (Wi) for all species and reallocated them at random to the population data for a given species. We then calculated the indicator from the randomized data, fitted the regression on calendar year and recorded whether the value of the regression coefficient was as positive or more positive than that obtained from the non-randomized real data. We repeated this randomization procedure 10000 times and took the proportion of repetitions

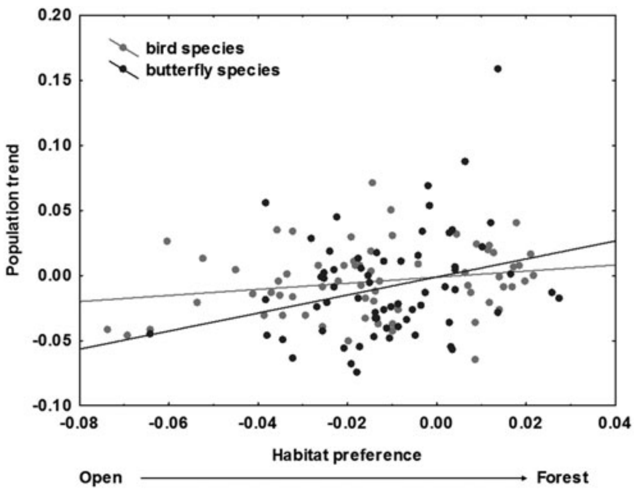

Figure 2 Plot of population trends (1994–2013 for butterflies and 2002–2013 for birds) against habitat preference estimates for species along the open-forest gradient.

where the regression coefficient was as positive as or more positive than that observed from the real data as the probability that the observed trend of the indicator with calendar year having occurred by chance.

We also analysed whether the indicators of the impact of land abandonment differed between butterflies and birds in terms of the magnitude of the change (slope) during the study period. To do so, we built a regression model with the annual values of the multi-species indicators as dependent variables, time (calendar years) as the independent variable, and taxonomic group (bird or butterfly) as a covariate, and then evaluated the presence of an interaction between time and taxonomic group.

RESULTS

Changes in land cover in bird and butterfly transects showed a significant (4%) increase in the proportion forest/(open+forest) between 1993 and 2009 ($F_{1,236} = 5.43$, $p = 0.021$). No significant interaction was found between this land-cover change and the type of monitoring site (CBMS or CCBS; $F_{1,\,236} = 0.20$, $p = 0.656$).

The number of bird and butterfly species significantly associated with the studied open-forest gradient was very similar. In total, 66 bird species showed a significant association with the gradient ranging from open to forest habitats: the association with forests was negative for 44 species and positive for 22 species (Table 1). For butterflies, we found significant associations in 65 species, 48 negatively and 17 positively associated with forests (Table 1).

The direction and magnitude of the habitat preference estimates of the species constituted a significant predictor of their population trends in the area for both birds and butterflies (Fig. 2): for each taxonomic group, there was a significant positive relationship between the species population trend and the habitat preference estimates (birds, period 2002–2013: $F_{1,64} = 4.17$; $p = 0.045$; butterflies, period 1994–2013: $F_{1,63} = 5.33$, $p = 0.024$). No significant difference ($F_{1,127} = 1.86$, $p = 0.175$) was found in regression slopes between birds and butterflies.

The impact of this land-cover change on biodiversity was evaluated using multi-species indicators (Table 1). Both for birds and butterflies, two composite indexes were calculated, one for the subgroup of species positively associated with forests and one for the subgroup of species negatively associated with this habitat type (Fig. 3). In both taxonomic groups, a divergence in the trends was detected between these two subgroups, with species positively associated with forests showing more positive trends than species negatively associated with forests. As a result, the indicators calculated as the ratio between these two indexes showed a clear increase during the study periods (Fig. 4). For birds, the randomization test indicated a probability of 0.025 of obtaining as positive or more positive linear trend by chance over the whole period, whereas for butterflies this probability was 0.008. These values denoted, for both taxonomic groups, a gradual turnover in species assemblages, with open habitat species being progressively replaced with forest species. There was no significant difference between birds and butterflies in the direction and magnitude of this trend ($F_{1,28} = 0.30$, $p = 0.586$).

DISCUSSION

To our knowledge, this is one of the first formal attempts to study the impact of the same environmental driving force on biodiversity using large-scale datasets from two taxonomic groups with very different life histories and ecological requirements. Interestingly, we found that, although population trends greatly varied among species, in our study region both birds and butterflies exhibited very similar overall responses to the same environmental pressures.

Bird monitoring projects are being undertaken throughout most of the European Mediterranean basin as part of several national or regionally implemented schemes. For butterflies, the situation is generally less well developed, but coverage is progressively increasing. We believe that the approach presented in this study could be implemented easily across the Mediterranean region, in order to determine the consistency of the impact of land abandonment across this biodiversity hotspot (Myers *et al.* 2000).

Birds and butterflies track the impact of land abandonment

We found that species associated with open habitats had more negative trends than forest species. This pattern was observed in both birds and butterflies and, as in other studies in the north-west Mediterranean Basin (see Preiss *et al.* 1997; Suárez-Seoane *et al.* 2002; Sirami *et al.* 2008; Stefanescu *et al.* 2009), this indicates that land abandonment constitutes an

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Table 1 Habitat preferences of butterfly and bird species along the open-forest gradient (positive estimates indicate species associated with forests and negative estimates species associated with open habitats). For butterflies, < 60-cm-high habitats were classified as open habitats; for birds this threshold was set at 150 cm. Values correspond to the estimates of a GLM using species abundance as the response variable and the percentage of forest along the monitoring sites as the independent factor (see text for details). Models were generated using data from the Catalan Butterfly Monitoring Scheme (CBMS) and the Catalan Common Bird Survey (CCBS), respectively. Only estimates for significant models ($p < 0.05$) are shown.

Butterflies		***Birds***	
Scientific name	***Estimate***	***Scientific name***	***Estimate***
Aglais urticae	–0.064	*Oenanthe hispanica*	–0.074
Polyommatus coridon	–0.038	*Lanius meridionalis*	–0.069
Cupido argiades	–0.038	*Anthus spinoletta*	–0.064
Coenonympha pamphilus	–0.038	*Oenanthe oenanthe*	–0.060
Argynnis aglaja	–0.034	*Sylvia communis*	–0.053
Melitaea cinxia	–0.032	*Galerida theklae*	–0.052
Melitaea didyma	–0.028	*Emberiza hortulana*	–0.045
Polyommatus icarus	–0.027	*Alectoris rufa*	–0.041
Aporia crataegi	–0.026	*Carduelis cannabina*	–0.039
Colias alfacariensis	–0.026	*Alauda arvensis*	–0.037
Argynnis adippe	–0.025	*Monticola solitarius*	–0.036
Polyommatus bellargus	–0.025	*Anthus campestris*	–0.035
Colias crocea	–0.025	*Sylvia undata*	–0.035
Cupido alcetas	–0.024	*Saxicola rubicola*	–0.034
Pyrgus malvoides	–0.023	*Lanius senator*	–0.033
Hipparchia semele	–0.023	*Corvus corax*	–0.032
Brintesia circe	–0.022	*Emberiza calandra*	–0.032
Pyronia cecilia	–0.021	*Monticola saxatilis*	–0.029
Polyommatus escheri	–0.019	*Passer montanus*	–0.026
Erynnis tages	–0.018	*Lanius collurio*	–0.026
Melitaea phoebe	–0.017	*Merops apiaster*	–0.025
Melanargia lachesis	–0.017	*Sylvia hortensis*	–0.022
Vanessa cardui	–0.017	*Lullula arborea*	–0.021
Issoria lathonia	–0.017	*Petronia petronia*	–0.020
Boloria dia	–0.015	*Emberiza citrinella*	–0.019
Pyronia tithonus	–0.015	*Sylvia melanocephala*	–0.018
Aricia cramera	–0.014	*Falco tinnunculus*	–0.018
Glaucopsyche alexis	–0.014	*Hippolais polyglotta*	–0.017
Pseudophilotes panoptes	–0.014	*Pica pica*	–0.017
Melitaea deione	–0.013	*Upupa epops*	–0.016
Coenonympha arcania	–0.013	*Emberiza cia*	–0.016
Hipparchia statilinus	–0.012	*Sylvia cantillans*	–0.015
Maniola jurtina	–0.012	*Phoenicurus ochruros*	–0.015
Euphydryas aurinia	–0.011	*Pyrrhocorax pyrrhocorax*	–0.014
Pontia daplidice	–0.010	*Prunella modularis*	–0.014
Iphiclides podalirius	–0.010	*Jynx torquilla*	–0.014
Papilio machaon	–0.009	*Carduelis chloris*	–0.013
Thymelicus acteon	–0.008	*Ptyonoprogne rupestris*	–0.013
Thymelicus sylvestris	–0.008	*Sylvia borin*	–0.010
Lycaena phlaeas	–0.007	*Corvus corone corone*	–0.010
Euchloe crameri	–0.005	*Passer domesticus*	–0.010
Leptidea sinapis	–0.005	*Carduelis carduelis*	–0.010
Pieris rapae	–0.004	*Serinus serinus*	–0.008
Anthocharis euphenoides	–0.003	*Luscinia megarhynchos*	–0.004
Satyrium esculi	–0.003	*Phylloscopus bonelli*	0.005
Lampides boeticus	–0.002	*Parus major*	0.007
Gonepteryx cleopatra	–0.002	*Turdus merula*	0.007
Gonepteryx rhamni	–0.001	*Streptopelia turtur*	0.008
Limenitis reducta	0.002	*Pyrrhula pyrrhula*	0.009
Argynnis paphia	0.003	*Loxia curvirostra*	0.009

Table 1 Continued

Butterflies		*Birds*	
Scientific name	*Estimate*	*Scientific name*	*Estimate*
Pyronia bathseba	0.003	*Fringilla coelebs*	0.009
Glaucopsyche melanops	0.003	*Sylvia atricapilla*	0.012
Inachis io	0.004	*Parus ater*	0.012
Lycaena alciphron	0.004	*Troglodytes troglodytes*	0.012
Pieris napi	0.004	*Columba palumbus*	0.013
Vanessa atalanta	0.004	*Garrulus glandarius*	0.014
Anthocharis cardamines	0.004	*Regulus regulus*	0.014
Nymphalis antiopa	0.007	*Parus cristatus*	0.015
Polygonia c–album	0.010	*Aegithalos caudatus*	0.017
Neozephyrus quercus	0.012	*Turdus philomelos*	0.017
Libythea celtis	0.014	*Dendrocopos major*	0.018
Callophrys rubi	0.014	*Parus caeruleus*	0.018
Celastrina argiolus	0.017	*Certhia brachydactyla*	0.020
Charaxes jasius	0.026	*Regulus ignicapilla*	0.021
Pararge aegeria	0.028	*Erithacus rubecula*	0.022
		Sitta europaea	0.027

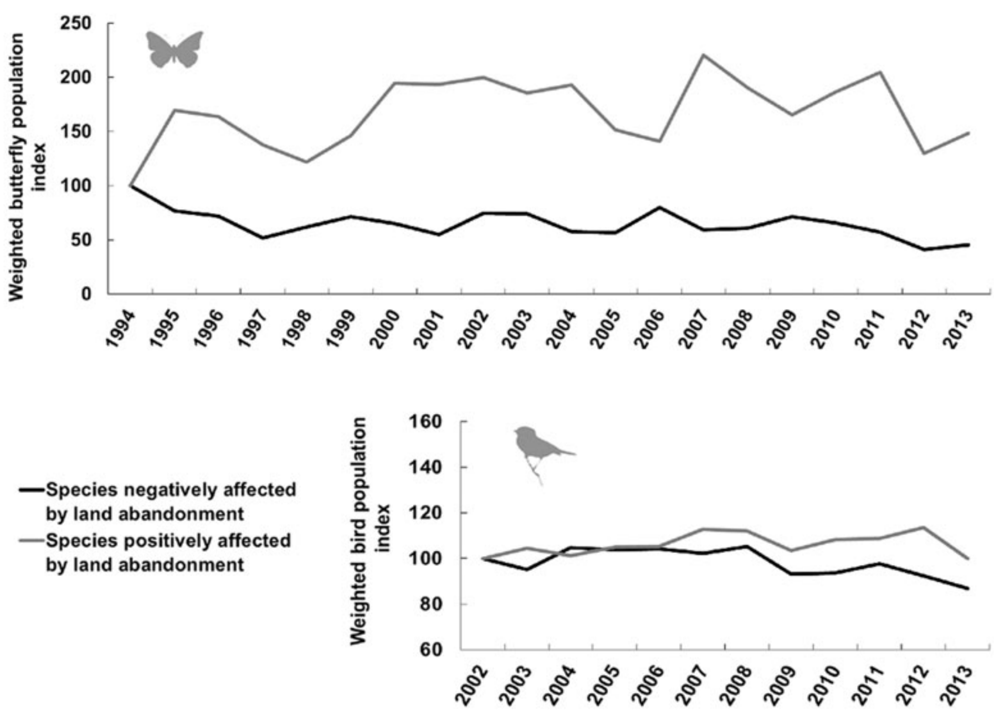

Figure 3 Temporal changes in composite indices for the set of species affected positively and negatively by land abandonment. Butterflies (top) and birds (bottom). Each species' contribution to the indices is weighted according to its estimated response to this process (see Table 1).

important environmental pressure driving general changes in vertebrate and invertebrate communities.

Moreover, the patterns shown by multi-species indicators over the study period (Fig. 3) are in line with the observed changes in land-cover maps at the monitoring sites over a similar time span. Importantly, our selected monitoring sites experienced similar degrees of afforestation over the last two decades to that occurring in the study region as a whole (http://www.creaf.uab.es/mcsc/), which suggests that our results reveal trends at work over the entire region. This is particularly important because afforestation is among the most scale-dependent drivers of change in Europe (Tzanopoulos *et al.* 2013) and such indicators should ideally reflect broad trends in biodiversity if they are to be understood by the general public and used by policy makers (Gregory *et al.* 2008).

One of the most relevant issues concerning the impact of driving forces on biodiversity is the potential interaction between the different environmental pressures acting at the same time on the organisms (Brook *et al.* 2008; Mantyka-Pringle *et al.* 2012). Although land abandonment and subsequent afforestation is one of the main drivers of landscape change in the Mediterranean region, many other drivers are also likely to affect biodiversity under global change (Tzanopoulos *et al.* 2013). A very common environmental

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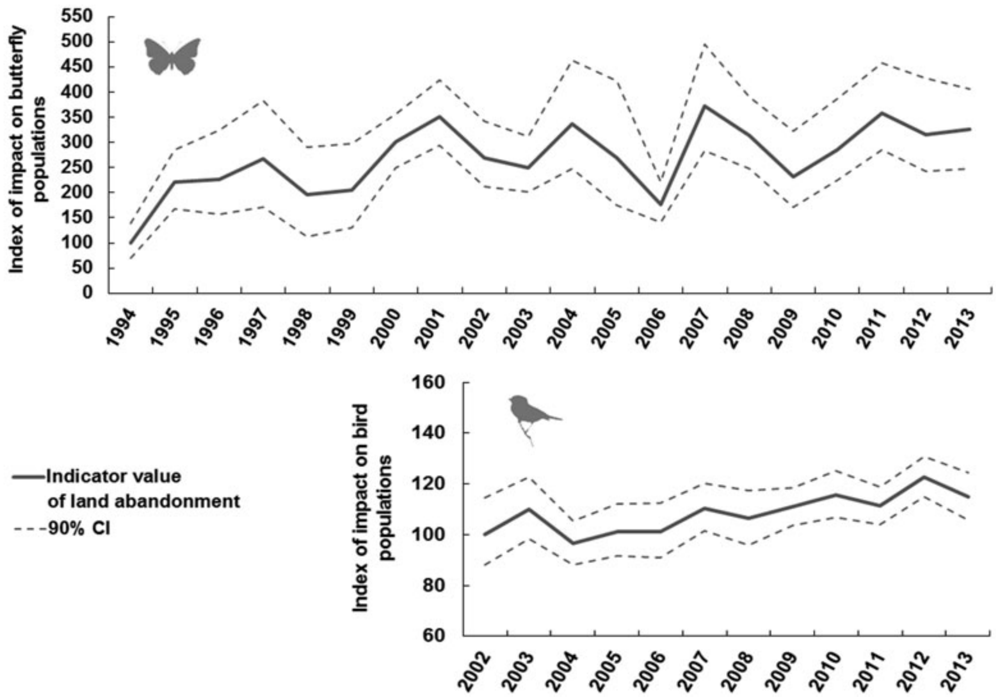

Figure 4 Multi-species indicators of the impact of land abandonment on butterflies (top) and birds (bottom). For each taxon, annual values correspond to the ratios of the indices positively and negatively affected by this driving force (see Fig. 3). Thin discontinuous lines show 90% bootstrap confidence intervals for annual values from 10000 bootstrap replicates.

pressure in this region is fire (Blondel & Aronson 1999). Wildfires could affect biodiversity exactly in the opposite direction to land abandonment by creating new suitable habitats for open habitat species (Moreira & Russo 2007). This is particularly relevant because our indicator, which is based on the species response to changes in habitat structure may also simultaneously evaluate the potential impact of wildfires (for example, open habitat species negatively affected by the vegetation encroachment caused by land abandonment are usually positively affected by the occurrence of burnt areas). Interestingly, the results of our indicators rather suggest that in the study region wildfires have not reversed the general impact of afforestation, most probably because their effect is more strongly marked at local than at regional scale (see Zozaya *et al.* 2010). Another force affecting bird and butterfly population trends that may interact with land abandonment is climate change (Devictor *et al.* 2012). For birds, Herrando *et al.* (2014) found that population responses to land abandonment in the study region were uncorrelated to those associated with climate change reported by Gregory *et al.* (2009). Although further studies are warranted to clarify potential interactions among driving forces, the patterns that we found clearly indicate a general footprint of land abandonment.

Although our study revealed very consistent responses to land abandonment both for birds and butterflies, is it possible to generalize these results to other taxa, thereby widening the scope of our conclusions? Would open habitat species and forest species show the same patterns in other groups? This question could be particularly critical if we consider that according to a recent global review, both bird and butterfly species could have experienced fewer population decreases than other vertebrates and invertebrates (Dirzo *et al.* 2014). The answer to this question is a challenge, since good-quality large-scale monitoring data are lacking for many taxonomic groups, and policy-relevant indicators of annual change are restricted to few taxonomic groups. According to monitoring schemes in Europe, mammals and beetles might, for vertebrates and invertebrates, respectively, be the next candidates for delivering indicators of impact (EuMon 2015). Unfortunately, monitoring schemes based on groups other than birds or butterflies are often geographically less widespread. Consequently, the representativeness of the patterns depicted by birds and butterflies can probably be only investigated at more local scales. In this context, the existence of protected areas in which various taxonomic groups are simultaneously monitored (such as the European Long-term Ecological Research Network; www.lter-europe.net/) may offer pertinent possibilities for evaluating the consistency of the patterns reflected in our multi-species indicators.

Contextualization and interpretation of the indicators

The Strategic Plan for Biodiversity 2011–2020 (SCBD 2014) calls for effective and urgent action to halt biodiversity loss, which includes a series of 20 'Aichi Biodiversity Targets' that have to be evaluated using indicators of 'states' of, 'pressures' upon, 'benefits' from biodiversity and 'responses' to the biodiversity crisis (SCBD 2014). The indicators presented in this study lie within the context of indicators of 'pressure' upon biodiversity (Butchart *et al.* 2010). However, they do not track the magnitude of a driving force in itself, but its direct impact on biodiversity (population response to land abandonment), thus being more directly linked to the ultimate

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aim of biodiversity conservation than measures of land cover change. This constitutes a particularly important issue since a close alignment between conservation targets and biodiversity indicators is expected to be much more informative than loose relationships based on implicit assumptions linking environmental pressures and their impact on biodiversity (Collen & Nicholson 2014).

Our multi-species indicators quantify the impact of a driving force on biodiversity but do not provide any direct judgement on the fact that the observed pattern is good or bad for biodiversity conservation purposes, which depends on conservation targets. However, if we aim to conserve Mediterranean open habitat species, then the indicator shows that the direction of travel is incorrect and policies to halt the afforestation process should be implemented. This should probably be the case from the perspective of birds and butterflies in the study region, with many threatened open habitat species (Stefanescu *et al.* 2011; Herrando *et al.* 2014).

On-going large-scale bird and butterfly monitoring projects yield valuable datasets for generating policy-relevant indicators. We believe that approaches that allow an evaluation of information such as that presented in this study may have the potential for providing more comprehensive measures of the biodiversity change occurring as a consequence of the impact of environmental change.

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