Biodivers Conserv
DOI 10.1007/s10531-015-0893-9

ORIGINAL PAPER

Population restoration of the nocturnal bird *Athene noctua* in Western Europe: an example of evidence based species conservation

Jan Christian Habel · Julia Braun · Christina Fischer · Wolfgang W. Weisser · Martin M. Gossner

Received: 16 November 2014 / Revised: 13 February 2015 / Accepted: 26 February 2015

Abstract Agricultural intensification is one of the key factors leading to the recent global biodiversity crisis. Especially farmland species are negatively affected by both, agricultural intensification and abandonment. The nocturnal Little Owl *Athene noctua* inhabits low-intensity agricultural landscapes and showed severe population declines over Central Europe during the past decades. In this study we analysed the effects of land-use changes on the Little Owl between 2001 and 2010 across Western Luxembourg. We assessed the occurrence of *A. noctua* and tested for the specieś habitat use and the effects of nesting boxes. In total we analysed 63 occupied and unoccupied study sites over a 20 km × 40 km study region located in Western Luxembourg. Our data indicate a transformation of pastures with single trees into arable land during the past 10 years. As a response to a perceived decline of the species in the region a total of 450 nesting boxes were installed in high stem orchards which are considered potentially suitable habitats, in areas with and without past *A. noctua* occurrence. We tested how nesting boxes and various habitat structures in the surrounding (e.g. percentage of high stem orchards, habitat heterogeneity) affected the occurrence of *A. noctua*. Despite agricultural intensification, the presence of *A. noctua* increased, most likely as a result of the installation of nesting boxes. We found that land-use parameters such as arable land, forests, pastures and pastures with trees had a negligible impact on the occurrence of *A. noctua*. Our findings suggest that the

Communicated by Stuart Pimm.

Electronic supplementary material The online version of this article (doi:10.1007/s10531-015-0893-9) contains supplementary material, which is available to authorized users.

J. C. Habel (✉) · J. Braun · W. W. Weisser · M. M. Gossner
Terrestrial Ecology Research Group, Department of Ecology and Ecosystem Management, School of Life Sciences Weihenstephan, Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany
e-mail: Janchristianhabel@gmx.de

C. Fischer
Restoration Ecology, Department of Ecology and Ecosystem Management, Technische Universität München, 85354 Freising, Germany

Published online: 14 March 2015

conservation of the little owl can be supported with comparatively simple and convenient measures, such as the installation of nesting boxes, even in an intensively used environment, provided that sufficient prey is available.

Keywords European birds directive · Landscape composition · Land-use change · Land-use intensity · Nesting boxes · Nesting space limitation hypothesis · Surrogate habitat

Introduction

The recent global biodiversity crisis is driven by various factors, such as habitat destruction, climate change and the introduction of invasive species (Pereira et al. 2010). The transformation of pristine habitats or of extensively used traditional landscapes into an intensively used agricultural landscape caused the fragmentation and deterioration of remaining habitats (Ricketts 2001; Fahrig 2003). Agricultural modifications are mainly characterised by two processes—agricultural intensification on the one hand, and land abandonment with subsequent reforestation (or urbanization) on the other hand (Gardner 1996; Benton et al. 2003).

Central European cultural landscapes used to be characterized by a mosaic of extensively used meadows, high stem orchards, hedgerows, fields and forests during the past (Robinson and Sutherland 2002). However, most of these former extensively used cultural landscapes became transformed into monocultures recently in the wake of the 'third agricultural revolution' (Benton et al. 2003). This agricultural intensification and homogenization further increased in the past years due to rising demand for plant resources to produce green energy such as biofuel and biogas (Donald et al. 2001, 2006), and heralded a new wave of extinction for many species (Vickery et al. 2004; Kaatz 2011). Thus, the second half of the 20th century is characterised by a revolution in agricultural practice, which surpasses any previous agricultural developments with a prevailing transformation of agricultural environments (Blaxter and Robertson 1995; Van Nieuwenhuyse et al. 2008).

The intensification of farming techniques such as the use of inorganic fertilizers and pesticides or intensive monocultures caused widespread declines, especially in farmland biodiversity, during the past decades. Such declines have been identified for a variety of different animal groups including birds (Donald et al. 2001; Sanderson et al. 2006; Geiger et al. 2010; Fischer et al. 2011), mammals (Flowerdew 1997), arthropods, but also for flowering plants (Sotherton and Self 2000). Among farmland bird species, there are many losers (e.g. *Perdix perdix*, *Streptopelia turtur*, *Motacilla flava*, *Vanellus vanellus* and *Emberiza calandra*) showing severe population declines in Western and Northern Europe (Voríšek et al. 2010). However, there are also a few winners such as *Corvus frugilegus*, *Sylvia communis* and *Lanius collurio*, profiting from increasing agricultural intensification, large monocultures and open land (Voríšek et al. 2010).

To combat the decline of farmland birds due to intensification and abandonment, a variety of management actions are being implemented, such as local conservation actions (e.g. the provision of nesting sites), country specific or European-wide agri-environmental schemes and legislative procedures (e.g. limitations of the usage of pesticides) which are proposed to enhance farmland (bird) diversity (Newton 2004). Recent research has shown that for successful conservation, measures need to affect not only the local but also the landscape scale and may include actions like hedgerow provision in simple landscapes to improve the feeding and the breeding habitat of farmland birds (Batáry et al. 2010). However, management options vary between species. Hence, for effective species conservation management we have to consider species specific habitat demands which have to be studied in advance (Newton 2004).

The nocturnal raptor bird, the Little Owl *Athene noctua*, is a Turcmenic-Mediterranean faunal element (Vogus 1962). Its core distribution is located in the temperate steppes and deserts of the Mediterranean region, including North and Northeast Africa, and to a lesser extent in Asia Minor (Schönn et al. 1991; Mebs and Scherzinger 2000). The bird uses open habitats such as meadows, grasslands and fields as hunting grounds. Nesting takes place in trees which are further important as raised stands (Framis et al. 2011). The clearance of forest and its transformation into open agricultural land provided new surrogate habitats for *A. noctua* over major parts of Central Europe (Scherzinger 1981). Today, the bird species often breeds in old trees of high stem orchards, as well as in buildings and quarries with suitable cavities (Mebs and Scherzinger 2000; Van Nieuwenhuyse et al. 2008). However, *A. noctua* severely declined in major part of Europe during the past decades and is now listed in the red lists of several European countries (Sálek and Schröpfer 2008; Zmihorski et al. 2009). Very simple conservation measures might have helped to support the population restoration of *A. noctua*, as artificial nesting boxes, which were frequently accepted as surrogate breeding places. Thus, frequent local conservation measures were the installation of nesting boxes in potential suitable habitats, preferable in high stem orchards. However, further information about the species' habitat requirements is needed for efficient conservation measures, covering both the breeding and the foraging habitat.

In this study we analyse the population structure and habitat demands of *A. noctua* for a 20 km × 40 km study area in western Luxembourg, Central Europe. In this region, *A. noctua* was previously a common bird, but its population density declined severely during the past decades (Lorgé and Biver 2010). Study sites were selected randomly from available high stem orchards, of which some were occupied by *A. noctua* during the past. Nesting boxes were installed in the year 1999 and 2000 in occupied and unoccupied sites by the Syndicat Intercommunal de l'Ouest pour la Conservation de la Nature (SICONA) Luxembourg. We assessed landscape structures within a radius of 300 m around the nesting boxes and observed the presence/absence of the bird species using a standardised playback approach. Specifically, we analysed (i) whether land-use changed in our study region between the years 2001 and 2010, and tested (ii) how habitat properties influence the occurrence of *A. noctua*.

Materials and methods

Study region and site selection

The selected study region is located in Southwest and Central Luxembourg (Fig. 1). This area is part of the Western Palaearctic distribution range of *A. noctua*. In Luxembourg the species is classified as close to extinction (Lorgé and Biver 2010). The landscape of Luxembourg is dominated by agriculture and forest occupying as much as 85 % of the land surface (Statec 2012), and has experienced a strong increase of agricultural intensification, livestock and expanding urban areas during the past decades (Schneider 2011; Freymann and Schaich 2012; Statec 2012). The increasing demand for green energy crops (such as maize for biogas) caused a transformation from small parcelled meadows and grasslands and high stem orchards into large maize fields. These landscape changes have led to the disappearance of vertical structures such as shrubs and trees (Kaatz 2011). Hence,

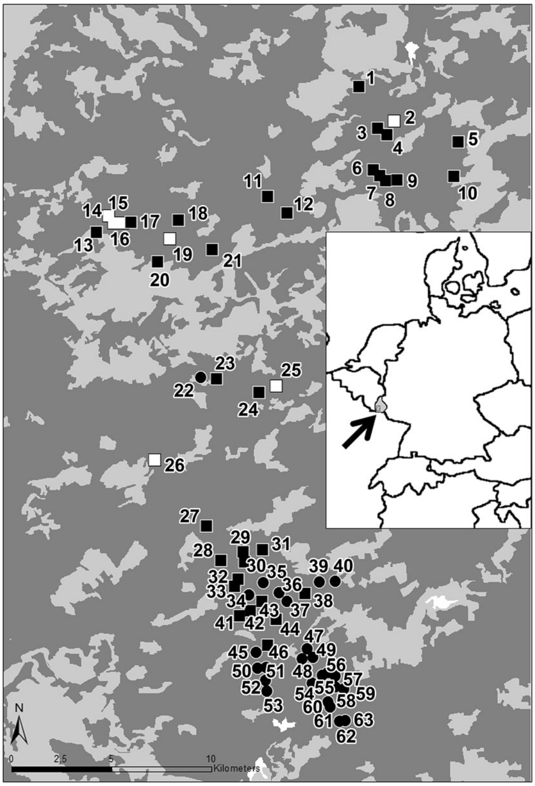

Fig. 1 Locations of all 63 study sites. The map is based on data from the Pan-European project CORINE Land Cover (CLC) (CORINE 2006). *Dark grey* open land, *light grey*: forest; white: urban area. Running numbers coincide with Supplementary Material Electronic Appendix S1. Presence of *A. noctua* is indicated as *circle*, absence of *A. noctua* as *square*. Study sites which were assessed in 1999/2000 are shaded in *black*, study sites which were assessed in 2010/2012 only are *white*

landscape diversity (parcelling), habitat diversity and consequently the composition of arthropods and small mammals, the main food of *A. noctua*, changed in this area (Augenstein et al. 2012; Freymann and Schaich 2012). Counts and estimates of breeding pairs in Luxembourg during the past decades show an alarming population decline, with still 4200 breeding pairs estimated in 1960 (Hulten and Wassenich 1960), but only 15–20 in 2002, according to the red list of birds of Luxembourg (Lorgé and Biver 2010). To impede this severe population collapse, 450 nesting boxes were installed since 1999 in major parts of Luxembourg. This conservation measure is thought to have had positive effects on the population size of *A. noctua* (Junck and Schoos, personal communication).

In our study we randomly selected 63 study sites located in high stem orchards, an important habitat type for the species, in the south-western part of Luxembourg. Some of the study sites were occupied by *A. noctua* in the past, whereas others did not have any Little Owls (based on the assessment in 1999/2000; 38 of the 63 sites were occupied). In both types (occupied/unoccupied) nesting boxes were installed at a subset of sites. Further details about each study site are given in Supplementary Material Electronic Appendix S1.

Land use and land-use change

We investigated the land-use cover for the years 2001 and 2010 using high resolution arial images (Land Registry Office Luxembourg, www.geoportail.lu, accessed 2 July 2014). We set habitat circles with a 300 m diameter for each selected study point. This size of the radius was selected according to the home-range size of the species (Martinez and Zuberogoitia 2004). The aerial images from both time cohorts were digitized with the programme ArcGIS vers. 10.2.1. (1999–2010 ESRI Inc.), classifying the following landscape features: arable land, forest, garden, meadow, high stem orchards, pastures without trees, pastures with single trees, sealed land and shrubs. Additionally we estimated habitat heterogeneity by calculating the Shannon diversity index. Finally we measured the distance to the next settlement and assessed the presence/absence of nesting boxes for each study point.

Occurrence of *A. noctua*

The occurrence of *A. noctua* was assessed for all 63 study sites during the mating season in March and April of 2012. During this time period, vocal activity has been observed to be highest in *A. noctua* (Finck 1990). Birds were detected using playback of male territory calls (Exo and Hennes 1980) with the following standardised conditions: 15 s attracting, 1 min break, 30 s attracting, 1 min break, 1 min attracting, 3 min break. Playback was immediately stopped when an individual responded. As lower responsiveness was observed for regions where individuals occur in lower densities (Schönn et al. 1991), the assessment of the study sites was conducted up to 10 times at sites where *A. noctua* did not respond immediately. To detect possible relationships between *A. noctua* occurrence and the distance to the next individual i.e. breeding pair on a landscape scale, minimum geographical distance between occupied study sites was calculated using the R package *vegan* version 2.0-10 based on a euclidian dissimilarity index (Oksanen et al. 2013).

Statistics

We analysed land-cover changes between the years 2001 and 2010 for all habitat circles. We assessed the occurrence of *A. noctua* over our study region in the year 2012. Due to non-normality of landscape parameters, Wilcoxon rank sum test statistics were applied and land-cover of each landscape parameter was compared between the 2 years. Subsequently, we modelled the occurrence probability of *A. noctua* depending on the presence and absence of nesting boxes. This analysis could exclusively be calculated for the year 2012, as *A. noctua* was not yet present at most sites in the year 2001. We used generalized linear models (GLM) for binary data (presence/absence of *A. noctua*) with a logit link (Zuur et al. 2009). To avoid multicollinearity between landscape variables (see Supplementary Material Electronic Appendix S2), we performed Spearman's rank correlation analysis (Dormann et al. 2013). In case of variables showing a significant correlation among each other ($r_s > 0.5$; following Binzenhöfer et al. 2005), the variable with longer gradient length was considered for further modeling procedures. Variables which covered only very short gradients (gradient length < 10 %) were excluded from the full model (Supplementary Material Electronic Appendix S2). Therefore the full model was confined to the following parameters: presence/absence of nesting boxes, percentages of high stem orchards, arable land, pastures without trees, pastures with trees, and forests, habitat heterogeneity (here Shannon diversity index) (all analysed within the 300 m habitat circles), the distance to the next *A. noctua* occurrence, and distance to the next settlement. Model simplification was conducted by stepwise backward model selection by AIC using the *step* command. To measure the goodness-of-fit of the minimal adequate model pseudo R^2 values were calculated after Nagelkerke (1991) using the R package *fmsb* version 0.4.5 (Nakazawa 2014). For all analyses, R version 3.0.2 (R Core Team 2013) was used. As all landscape variables did not differ between sites with and without nesting boxes (except habitat heterogeneity) we included the interaction between nesting box occurrence and habitat heterogeneity in the reduced model to test if effects of nesting boxes on the occurrence of *A. noctua* depend on habitat heterogeneity. No significant interaction was observed and therefore interactions were not further considered.

Results

Land-cover change (2001–2010)

The overall land cover changed only marginally between the years 2001 and 2010 (Supplementary Material Electronic Appendix S3). The percentage of pastures with single trees decreased (d.f. = 54, W = 1080, $p < 0.001$), while the percentage of meadows increased (d.f. = 54, W = -2072.5; $p < 0.001$) between these two time cohorts. The percentages of arable land, forests, gardens, high stem orchards, pastures, sealed areas, shrubs and trees, as well as habitat heterogeneity (Shannon diversity index) did not change significantly between 2001 and 2010 (Supplementary Material Electronic Appendix S2 and S4).

Population structure and habitat use

In total 28 of the 63 study sites (44 %) (i.e. 27 of the 38 sites with nesting boxes, 71 %) were occupied by *A. noctua* in 2012. Nesting boxes were available in 11 unoccupied and 27 occupied study sites. Occurrence probability of *A. noctua* was much higher in study sites with nesting boxes compared to study sites without nesting boxes (Fig. 2, Table 1).

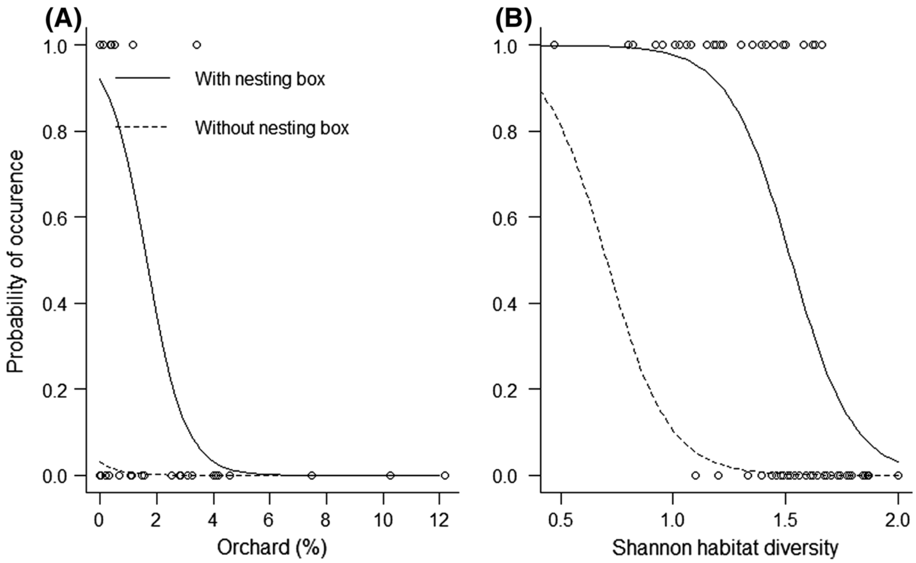

Fig. 2 Probability of the occurrence of *A. noctua* in relation to **A** the percentage of orchards and **B** habitat heterogeneity (Shannon diversity index) within a 300 m radius of study sites with and without nesting boxes. Regression lines represent predictions (with other explanatory variables held at mean values) from generalised linear models (GLM)

Table 1 Results from the minimal adequate GLM model

Variable	Estimate ± SE	*z*	***p***
Intercept	12.47 ± 5.53	2.26	0.024
Nesting box (absence)[a]	−5.92 ± 1.78	−3.34	<0.001
Orchard	−1.47 ± 0.62	−2.37	0.018
Habitat heterogeneity	−7.23 ± 3.60	−2.01	0.044
Pastures with trees	0.13 ± 0.10	1.32	0.186

Given are potential effects from nesting boxes (sites with and without nesting boxes), percentage of orchards, habitat heterogeneity (Shannon diversity index) and the percentage of pastures with trees on the probability of *A. noctua* occurrence in 2012. Parameter estimates with standard error (SE), z-values and levels of significance are given. Bold values indicate predictor variables, which affect *A. noctua* occurrence significantly

[a] Nesting box (presence) was the reference category

Increasing percentage of high stem orchards as well as increasing habitat heterogeneity (Shannon diversity index) within the 300 m radius caused a decrease in the probability of *A. nocta* occurrence (Fig. 2, Table 1). The probability of *A. noctua* occurrence was not influenced by the percentages of arable land, forests, or pastures, distance to the next *A. noctua* occurrence, or distance to the next settlement (excluded from the minimal adequate model). Furthermore, *A. noctua* occurrence was not significantly influenced by the percentage of pastures with single trees, although this variable remained in the final model (Table 1). The overall model performance was very good with $R^2 = 0.89$.

Discussion

Marginal land-use change

We detected marginal changes in land use for our study region between the years 2001 and 2010, but a significant decrease in the proportion of pastures with trees. Transformations of meadows and pastures into arable land (mainly maize and oilseed rape) could be observed all over Luxembourg during the past years (Statec 2012). Furthermore, the landscape structure across Luxembourg is characterised by a decreasing heterogeneity, with an increase in the size of land parcels, a reduction in small scale farming and a reduction in the proportion of pastures (Statec 2012). This transformation toward intensification observed for our study region, and Luxembourg in general, is a trend found all over Europe (Robinson and Sutherland 2002; Newton 2004; Gregory et al. 2005), with mostly negative impact on various farmland bird species (Donald et al. 2001; Chylarecki and Jawinska 2007).

In contrast to this rather negative picture of land-use intensification, the population density of *A. noctua* increased in Luxembourg, most probably as a result of the installation of 450 nesting boxes. This increase was consistent across our study region, without increased occurrence probability if other *A. noctua* pairs are in close geographic proximity. Latter is in contrast to other studies showing that *A. noctua* populations often occur clustered. Such biased distribution patterns (depending on the occurrence of other pairs or individuals) could be observed for other regions, where even low quality habitats became colonised if other *A. noctua* breeding pairs were present in close geographic proximity

(Van Nieuwenhuyse and Bekaert 2002; Blache 2004; Martinez and Zuberogoitia 2004). This observed biased distribution might also result from limited dispersal of the fledglings, which mostly colonise new habitats within a distance of less than 10 km to their parental territory (Peter 1999; Kaatz 2011).

Key habitat resources: open land and nest site availability

Most of our study sites with nesting boxes (74 %) were occupied by *A. noctua*, while areas without nesting boxes remained frequently unoccupied (only one of 25 sites, i.e. 4 % was occupied), and this was independent of habitat structure (no significant interaction effect). The presence of nesting boxes was the most important predictor of *A. noctua* occurrence in the generalized linear models which suggests nesting site limitation for this species. The high conservation relevance of nesting boxes is further underlined by studies in Germany by Peter (1999), who showed that about 90 % of all pairs were breeding in artificial nesting boxes. Similar to our findings in Luxembourg, studies in other areas showed that the density of *A. noctua* increased despite the transformation of extensively used meadows and pastures into arable land, as long as nesting sites (provided by nesting boxes) and sufficient feeding sites were available (Taux 2009; Kaatz 2011). Originally, old trees in high stem orchards (Schönn et al. 1991; Martinez and Zuberogoitia 2004; Loske 2007; Van Nieuwenhuyse et al. 2008), but also old buildings provide important breeding structures (Martinez and Zuberogoitia 2004; Kasprzykowski and Golawski 2006). Such structures, however, have largely vanished in today's landscapes. The high relevance of nesting site availability for sustaining viable populations has been shown for many species and was described as the 'nesting space limitation hypothesis' (Fonseca 1999).

In comparison to the availability of nesting sites, which seems to be the limiting factor for the occurrence and population density of *A. noctua*, land-use parameters play a rather negligible role. In our study, sites with *A. noctua* were characterised by a high percentage of open land. This is in line with other studies focussing on the habitat demands of *A. noctua*, indicating positive effects from open land (Dalbeck et al. 1999; Kasprzykowski and Golawski 2006; Loske 2007; Sálek and Schröpfer 2008), and from the presence of pastures (Dalbeck et al. 1999; Mebs and Scherzinger 2000; Sálek and Schröpfer 2008) and grasslands (Sálek and Schröpfer 2008). The high relevance of open land might be due to the hunting behaviour of *A. noctua*: the bird typically feeds where crops have been recently harvested and/or replanted or where meadows were cut (Framis et al. 2011; Tomé et al. 2011). This condition simplifies visual recognition of prey and hunting (Schönn et al. 1991). In contrast to meadows and pastures, arable land is only suitable as long as the crop is still short, but becomes unsuitable if high standing crops avoid visual recognition of prey (Van Nieuwenhuyse et al. 2008). This is further supported by negative trends between an increase of arable land and the population density of *A. noctua* in some areas in Europe (Loske 2007).

In consequence, transition zones between high stem orchards and open land are more suitable than orchards alone (Van Nieuwenhuyse and Bekaert 2002), because nesting opportunities can only be evaluated as minimum factor as long as food supply is guaranteed (cf. Thorup et al. 2010). A combination of (i) open land to hunt (e.g. fields), and (ii) nesting sites to breed (e.g. high stem orchards, or surrogate nesting places like nesting boxes, or old buildings) is likely to be the most successful conservation measure for *A. noctua*.

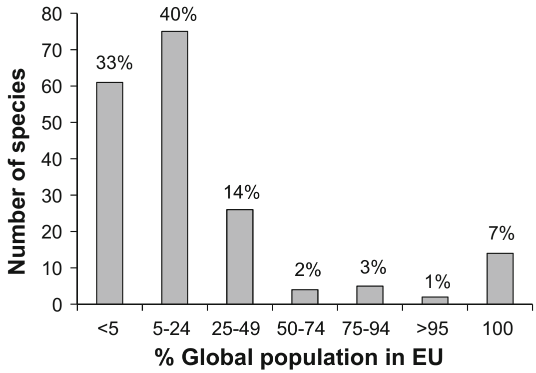

Fig. 3 Proportion of the entire distribution range extending across Europe analysed for 187 bird species protected by the European Birds Directive (2009/147/EC) listed in Annex I. For these species Special Protection Areas have to be designated. The numbers on *top of the bars* indicate the percentage of species in each category relative to all analyzed species. Three species were excluded due to missing information. Distribution data are taken from BirdLifeInternational (2004)

Final critical statement

Our study species, *A. noctua* colonised Central Europe in the wake of traditional farming practices. However, this species is a Eurasian and Mediterranean steppe species. In consequence, the question arises whether species with its biogeographical core distribution mainly located outside of Central Europe should be handled as target species for nature conservation management in countries of Central Europe. Directing conservation action to relict species or species which are found in surrogate habitats should be reflected critically. For example more than 70 % (136 species) of all birds listed in the Appendix I of the European Birds Directive have their core distribution outside of Europe (populations in Europe comprise less than 25 % of global populations; Fig. 3). The European directive, however, demands expensive investments for the designation of protected areas for these species. The demand for evidence based conservation strategies (Sutherland et al. 2004; Sutherland 2006) has to consider the biogeographical background of each target species: focusing on species with their core distribution in Central Europe would be of higher conservation value and should be the main responsibility of European countries.

Acknowledgments We thank the Land-Registry Office Luxembourg for providing data and aerial imageries. We thank Simone Schneider, Marc Olinger, Claudine Junck and Fernand Schoos (Biological station SICONA, Luxembourg) for providing occurrence data of *A. noctua*, the information on nesting boxes, and for valuable comments on a draft version of this article. We thank Mike Teucher (Trier, Germany) for producing Fig. 1, as well as Martin Husemann (MLU, Halle, Germany) and Dries Van Nieuwenhuyse (Netherlands) for their critical comments and linguistic improvement of an earlier version of this article.

References

Augenstein B, Ulrich W, Habel JC (2012) Directional temporal shifts in community structure of butterflies and ground beetles in fragmented oligotrophic grasslands of Central Europe. J Basic Appl Ecol 8:715–724

Batáry P, Matthiesen T, Tscharntke T (2010) Landscape-moderated importance of hedges in conserving farmland bird diversity of organic vs. conventional croplands and grasslands. Biol Conserv 143:2020–2027

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol Evol 18:182–188

Binzenhöfer B, Schröder B, Strauss B, Biedermann R, Settele J (2005) Habitat models and habitat connectivity analysis for butterflies and burnet moths—the example of *Zygaena carniolica* and *Coenonympha arcania*. Biol Conserv 126:247–259

BirdLifeInternational (2004) Birds in the European Union: a status assessment. BirdLife International, Wageningen

Blache S (2004) La Chevêche (*Athene noctua*) en zone d'agriculture intensive (plaine de Valnece; Drôme): habitat, alimentation, reproduction. Ecole Pratique des Hautes Etudes. Sciences de la Vie et de la Terre. Laboratoire Biogéographie et Ecologies des Vertebrés. Montpeiller

Blaxter K, Robertson N (1995) From death to plenty: The second agricultural revolution. Cambridge University Press, Cambridge, p 278

Chylarecki P, Jawińska D (2007) Common breeding bird monitoring in Poland: Annual report 2005–2006. Polish Society for the Protection of Birds, Warszawa. (in Polish with English summary)

CORINE (2006) Pan-European project CORINE land cover (CLC). Available at http://www.eea.europa.eu/data-and-maps. Accessed August 2014

Dalbeck L, Bergerhausen W, Hachtel M (1999) Habitatpräferenzen des Steinkauzes (*Athene noctua*) im ortsnahen Grünland. Eulen-Rundblick 48(49):3–15

Donald PF, Green RE, Heath MF (2001) Agricultural intensification and the collapse of Europés farmland bird populations. Proc R Soc Lond B 268:25–29

Donald PF, Sanderson FJ, Burfield IJ, van Bommel FPJ (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. Agric Ecosyst Environ 116:189–196

Dormann CF, Elith J, Bacher S, Buchmann C, Carl G, Carré G, Marquéz JRG, Gruber B, Lafourcade B, Leitao PJ, Münkemüller T, McClean C, Osborne PE, Reineking B, Schröder B, Skidmore AK, Zurell A, Lautenbach S (2013) Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36:27–46

Exo KM, Hennes R (1980) Beitrag zur Populationsökologie des Steinkauzes – eine Analyse deutscher und niederländischer Ringfunde. Vogelwarte 30:162–179

Fahrig L (2003) Effects of habitat fragmentation on biodiversity. Ann Rev Ecol Evol Syst 34:487–515

Finck P (1990) Seasonal variation of territory size with the Little Owl (*Athene noctua*). Oecologia 83:68–75

Fischer C, Flohre A, Clement LW, Batáry P, Weisser WW, Tscharntke T, Thies C (2011) Mixed effects of landscape structure and farming practice on bird diversity. Agric Ecosyst Environ 141:119–125

Flowerdew JR (1997) Mammal biodiversity in agricultural habitats. In: Kikwood RC (ed) Biodiversity and conservation in agriculture. British Crop Protection Council, Hampshire, pp 25–40

Fonseca CR (1999) Amazonian ant-plant interactions and the nesting space limitation hypothesis. J Trop Ecol 15:807–825

Framis H, Holroyd GL, Mañosa S (2011) Home range and habitat use of the Little Owl (*Athene noctua*) in an agricultural landscape in coastal Catalonia, Spain. Anim Biodiv Conserv 34:369–378

Freymann E, Schaich H (2012) Landnutzungsentwicklung und Kulturrelikte in der Region Müllerthal (Luxemburg). Bull Soc Nat Lux 113:49–66

Gardner B (1996) European agriculture: policies, production and trade. Routledge, London

Geiger F, Bengtsson J, Berendse F, Weisser WW, Emmerson M, Morales MB, Ceryngier P, Liira J, Tscharntke T, Winqvist C, Eggers S, Bommarco R, Pärt T, Bretagnolle V, Plantegenest M, Clement LM, Dennis C, Palmer C, Oñate JJ, Guerrero I, Hawro V, Aavik T, Thies C, Flohre A, Hänke S, Fischer C, Goedhart PW, Inchausti P (2010) Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl Ecol 11:97–105

Gregory RD, van Strien AJ, Vorisek P, Gmelig Meyling AW, Noble DG, Foppen RPB, Gibbons DW (2005) Developing indicators for European birds. Phil Trans R Soc B Lond 360:269–288

Hulten M, Wassenich V (1960) Die Vogelfauna Luxembourgs. Inst Gr-D Lux. 27:285–422

Kaatz G (2011) Entwicklung des Steinkauzbestandes *Athene noctua* auf einer 300 km^2 großen Bearbeitungsfläche des Landkreis Dithmarschen/Schleswig-Holstein. Eulen-Rundblick 61:91–97

Kasprzykowski Z, Golawski A (2006) Habitat use of the Barn Owl *Tyto alba* and the Little Owl *Athene noctua* in Central-Eastern Poland. Biol Lett 43:33–39

Lorgé P, Biver G (2010) Die Rote Liste der Brutvögel Luxemburgs—2009. Regulus Wissenschaftliche Berichte 25:67–72

Loske K-H (2007) Erfassung des Steinkauzes (*Athene noctua)* in Krefeld: Ein Beispiel für die Berücksichtigung geschützter Arten in der Bauleitplanung. Natur in NRW 3:2–8

Martinez JA, Zuberogoitia I (2004) Habitat preferences for Long-eared Owls *Asio otus* and Little Owls *Athene noctua* in semi-arid environments at three spatial scales. Bird Study 51:163–169

Mebs T, Scherzinger W (2000) Die Eulen Europas: Biologie, Kennzeichen. Bestände. Franchkh-Kosmos Verlags-GnbH & Cl, Stuttgart

Nagelkerke NJD (1991) A note on general definition of the coefficient of determination. Biometrica 133:225–245
Nakazawa M (2014) Fmsb: Functions for medical statistics book with some demographic data. R package version 0.4.5
Newton I (2004) The recent declines of farmland bird populations in Britain: an appraisal of causal factors and conservation actions. Ibis 146:579–600
Oksanen J, Blanchet GF, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Wagner H (2013) vegan: Community Ecology Package. R package version 2.0-10
Pereira HM, Leadley PW, Proenca V, Alkemade R, Schlemann JPW, Fernandez-Manjarrés JF, Araújo MB, Balvanera P, Biggs R, Cheung WWL, Chini L, Cooper HD, Gilman EL, Guénette S, Hurtt GC, Huntington HP, Mace GM, Oberdorff T, Revenga C, Rodrigues P, Scholes RJ, Sumaila UR, Walpole M (2010) Scenarios for global biodiversity in the 21st Century. Science 330:1496–1501
Peter W (1999) Schutzmaßnahmen für den Steinkauz (*Athene noctua*) und dessen Bestandsentwicklung im Main-Kinzig-Kreis. Eulen-Rundblick 48/49:S.24–25
R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/
Ricketts T (2001) The matrix matters: effective isolation in fragmented landscapes. Am Nat 158:87–99
Robinson R, Sutherland WJ (2002) Post-war changes in arable farming and biodiversity in Great Britain. J Appl Ecol 39:157–176
Sálek M, Schröpfer L (2008) Population decline of the Little Owl *Athene noctua* scop in the Czech Republic. Polish J Ecol 56:527–534
Sanderon FJ, Donald PF, Burfield IJ (2006) Farmland birds in Europe: from policy change to population decline and back again. In: Bota G, Camprodon J, Manosa S, Morales MB (eds) Ecology and conservation of steppe island birds. Lynx Edicions, Barcelona, pp 209–234
Scherzinger W (1981) Vorkommen und Gefährdung der vier kleinen Eulenarten in Mitteleuropa. Ökologie der Vögel 3:283–292
Schneider S (2011) Die Graslandgesellschaften Luxemburgs. Ferrantia 66, Luxemburg
Schönn S, Scherzinger W, Exo KM, Ille R (1991) Der Steinkauz. Urania Verlagsgesellschaft mbH, Leipzig
Sotherton NW, Self MJ (2000) Changes in plant and arthropod diversity on lowland farmland: an overview: in the ecology and conservation of lowland farmland birds, British Ornithologistś Union, pp 26–35
Statec (2012) Luxemburg in Zahlen. Institut national de la statistique et des études économiques
Sutherland WJ (2006) Evidence-based conservation—Discrepancy between practice and evidence led to the development of evidence-based medicine. Do we need a similar revolution for conservation? Conserv Prac 4:39–42
Sutherland WJ, Pullin AS, Dolman PM, Knight TM (2004) The need for evidence-based conservation. Trends Ecol Evol 19:305–308
Taux K (2009) Das Steinkauzprojekt im Landkreis Oldenburg und Randgebiet. Vortrag bei der 24. Jahrestagung der AG Eulen, Freiburg. Eulen-Rundblick 59:22
Thorup K, Sunde P, Jacobsen LB, Rahbek C (2010) Breeding season food limitation drives population decline of the Little Owl *Athene noctua* in Denmark. Ibis 152:803–814
Tomé R, Dias MP, Chumbinho AC, Bloise C (2011) Influence of perch height and vegetation structure on the foraging behaviour of Little Owls *Athene noctua*: how to achieve the same success in two distinct habitats. Ardea 99:17–26
Van Nieuwenhuyse D, Bekaert M (2002) An (auto)logistic regression model for prediction of Little Owl (*Athene noctua*) suitability of landscapes in East Flanders. Evidence for socially induced distribution patterns of Little Owl, Raptors in the new millenium. In Yosef R (ed.) Proceedings of the world conference on Birds of Prey and Owl Eilat, Israel 2–8 April 2000. International Birding and Research Center. Eilat 80–90
Van Nieuwenhuyse D, Génot JC, Johnson DH (2008) The Little Owl, conservation, ecology and behaviour of *Athene nocuta*. Cambridge University Press, Cambridge
Vickery JA, Bradbury RB, Henderson IG, Eaton MA, Grice PV (2004) The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England. Biol Conserv 119:19–39
Vogus KH (1962) Die Vogelwelt Europas und ihre Verbreitung. Hamburg, Berlin
Voríšek P, Jiguet F, van Strien A, Škorpilová J, Klvanová A, Gregory RD (2010) European trends in farmland birds, BOU Proceedings: Lowland Farmland Birds III, www.bou.org.uk/bouproc-net/lfb3/vorisek-etal.pdf
Zmihorski M, Romanowski J, Osojaca G (2009) Habitat preferences of a declining population of the little owl, *Athene noctua* in Central Poland. Folia Zool 58:207–215
Zuur A, Ieno EN, Walker N, Saveliev AA, Smith GM (2009) Mixed effects models and extensions in ecology with R. Springer, New York