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Assessing the importance of High Nature Value farmlands for the conservation of Lesser Kestrels *Falco naumanni*

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ABSTRACT

Agricultural areas, such as cereal cultivations, that support species of European and/or national conservation concern are considered as 'High Nature Value' farmlands (HNVf) and are very important for the preservation of biodiversity in Europe. The lesser kestrel *Falco naumanni* is a migratory falcon breeding largely in the HNVf of the Mediterranean basin. The main cause of its decline in Europe has been habitat loss and degradation as a result of agricultural intensification driven largely by the EU Common Agricultural Policies (CAP). In Greece, its population dropped by about 50% since the 1970s and its preferred habitats have shrunk. The aim of this study was to assess habitat preferences of breeding Lesser Kestrels in agro-ecosystems of Greece and relate these habitats to HNVf for conservation purposes. The study area is located in the plain of Thessaly, Central Greece, holding the main lesser kestrel breeding populations in the country, where dry cereal crops have been significantly depleted over the past decades. Species distribution models were developed with generalised additive models for the analyses. Predicted probability of lesser kestrel occurrence was found to be positively associated with farmed landscapes of dry cereal cultivations. Other important predictors were cultivated irrigated farmland and landscape heterogeneity. Main results of the statistical models agree with the findings of other habitat-based studies that highlight the importance of low-input farming systems, that is, HNVf, for safeguarding vital Lesser Kestrels habitats in their breeding grounds in the Mediterranean. A key conservation priority for conserving species dependant on HNVf is the maintenance of those low-input farming systems and the implementation of a greener CAP that would promote environmental-friendly farming practices to preserve and enhance biodiversity in the agro-ecosystems of Europe.

KEYWORDS

Falco naumanni, Generalised additive models, Common Agricultural Policy, High Nature Value farmlands, umbrella species, conservation, Greece

INTRODUCTION

Agriculture has shaped much of Europe's landscape and biodiversity, creating important habitats such as semi-natural grasslands and traditional low-input farming systems that support a rich flora and fauna (Bignal & McCracken 1996; Pain & Dixon 1997; Delbaere 2005). Agro-ecosystems that rich in biodiversity, such as cereal crops and pastures, sustain the species of European and/or national conservation concern are considered as 'High Nature Value' farmlands (HNVf) (EEA 2004). HNVf are very important for the preservation of biodiversity in the agro-ecosystems of Europe.

However, production-oriented management of agriculture in Europe, implemented through the Common Agricultural Policies (CAP) of the European Union, has intensified farming since the mid 1960s (Young et al. 2005) and caused either deterioration or altered agro-ecosystems, leading to the collapse of many bird populations that depend on these habitats for their survival (Donald et al. 2000; Donald et al. 2006; Poláková et al. 2011). In particular, raptors, being top avian predators, are some of the most vulnerable species in agricultural changes suffering dramatic losses (Krebs et al. 1999; Newton 2004). Raptors occurring in agricultural areas are considered suitable bioindicators of the health of European farmland ecosystems and wildlife as a whole because they are umbrella species (Lambeck 1997; Roberge & Angelstam 2004; Caro 2010), and as top predators, their distribution can be used to reflect hotspots of biodiversity (Sergio et al. 2006, 2008).

The lesser kestrel *Falco naumanni* is a migratory colonial falcon that, within its European range, breeds in steppe-like grasslands and cultivated landscapes with short vegetation and extensive crops and feeds mainly on invertebrates (Iñigo & Barov 2010). A collapse of its European population since the 1950s was affected largely by urbanisation of open areas and intensification of agricultural practices (Biber 1996). Recently, lesser kestrel populations have become stable or increased in southwest Europe to due conservation efforts and the species was down-listed to 'Least Concern' in the International Union for Conservation of Nature Red List in 2011 (Deinet et al. 2013). Greece's populations declined by about 50% since the 1970s, whilst breeding and foraging habitats also shrank (Legakis & Maragou 2009); however, it has recently recovered, with current estimates of over 6,000 breeding pairs (Deinet et al. 2013).

The lesser kestrel is an Annex I species of the EU Wild Birds Directive (2009/147/EEC) and its important breeding habitats, including different agro-ecosystems, have been designated as Special Protection Areas (SPAs) of the Natura 2000 Network in Spain, Portugal, Italy and Greece (Gallo-Orsi 2001; HMEE 2010). Moreover, according to BirdLife International habitat classification, the lesser kestrel is a priority species in 'steppic habitats, arable land and improved grasslands', including cereal pseudo-steppes (Tucker & Evans 1997).

The lesser kestrel is known for its sensitivity to agriculture intensification (Iñigo & Barov 2010) and could serve as a biodiversity surrogate (Caro & O'Doherty 1999; Caro 2010) and as an umbrella species, expected to offer protection for other natural co-occurring species (Lambeck 1997; Roberge & Angelstam 2004) and to monitor or solve conservation problems in its breeding grounds in the agro-ecosystems of Greece. It has been identified as a species indicator for HNVf and a baseline indicator for assessing the integration of environmental policies in the Rural Development Programmes (RDP) in the EU member states (EEA 2004; IEEP 2007, Beaufoy et al. 2009; Keenleyside et al. 2014). Bird species used as bioindicators of HNVf areas and as proxy of HNVf quality for conservation purposes include passerine birds in montados in Portugal (Catarino et al. 2014) and also passerines and shrubland bird species in traditional farmlands in Italy (Morelli et al. 2014).

Understanding factors that determine the spatial distribution of biodiversity surrogates is essential for designating protected areas, developing effective conservation programmes, projecting future potential range changes and identifying potential areas for reintroductions and recovery plans (Ferrier 2002; Araujo et al. 2005; Boyce et al. 2007). The spatial distributions of biodiversity surrogates and umbrella species can be integrated with environmental information through predictive models to identify priority sites in conservation planning, particularly across large spatial scales (Guisan & Thuiller 2005). In recent decades, lesser kestrel habitat studies have related its occurrence with low-input farming systems and heterogeneous landscapes with cereals, uncultivated patches, fallow land and pastures, that is, typical HNVf, also revealing the negative impact of CAP on those agricultural areas and the species' survival in its breeding areas (Bustamante 1997; Franco & Sutherland 2004; De Frutos et al. 2007, 2010; Rodríguez et al. 2014).

The aim of this study was to assess habitat preferences of breeding Lesser Kestrels in the agro-ecosystems of Central Greece using the presence/absence species distribution models. The study also evaluated the importance of the selected habitats, relating them to the HNVf in Greece for conservation purposes in order to preserve and enhance biodiversity in the agro-ecosystems.

Model outcomes could be a useful means for effective management planning of Natura 2000 sites within agricultural areas through the implementation of realistic, targeted Agri-Environment Measures (AEMs) under the RDP of Greece, using the lesser kestrel as a biodiversity surrogate and an umbrella species for safeguarding vital habitats such as HNVf areas in its breeding grounds.

1. MATERIALS AND METHODS

1.1. Study Area

The study area lies within the largest plain in the country, in the Region of Thessaly in Central Greece (Larissa: 39°38.21N, 22°25.05E; Fig. 1). Nearly half (46.2%) of the Region of Thessaly is farmland (Liarikos et al. 2012). The plain is dominated by intensive cultivations of irrigated cotton and other industrial crops (tobacco, maize) that occupy flat areas in the lowlands and non-intensive dry cereal cultivations (mostly wheat) located in both lowland and hilly areas. Pastures are close to urban areas and on hilly slopes, supporting the traditional livestock rotational system. The plain is surrounded by high mountains covered with natural grasslands, Mediterranean sclerophyllous short vegetation with open areas (garrigue), Mediterranean sclerophyllous evergreen vegetation of dense impenetrable thickets (maquis) and mixed deciduous forests, according to Corine Land Cover 2000 (EEA 2000). The climate is typical of the continental Mediterranean region, characterised by wet, cold winters and dry, hot summers. Five areas within the stronghold of lesser kestrel population in Thessaly are designated as SPAs by the Hellenic Ministry of Environment and Energy (HMEE 2010, 2012). Two SPAs (GR142011 and GR142012) lie within the study area and three SPAs (GR1420006, GR14200007, GR1420013) are partially contained in it (Fig. 1), including urban areas with lesser kestrel colonies. The elevation in the study area ranges from 0 to 2,005 m.

1.2. Bird data

Because Lesser Kestrels breeding in Thessaly plain are mainly urban nesters, villages and towns were surveyed twice, during the years 2006 and 2007, for bird colonies in the study area. Regions with elevations >1,000 m were excluded from surveys, as there were no records of colonies in those altitudes in Thessaly (Hallmann 1996). Data were collected in June, during the period of chick rearing (Negro et al. 1993). Colony surveys were carried out from sunrise until sunset and the time spent at each site ranged from a few minutes – when breeding birds were directly detected at the site – up to 1 h in sites without any birds. Sites where birds had been observed were considered breeding colonies locations and used as 'presences' in the model development, whilst places without observations were considered 'absences'. All places with absences were visited twice.

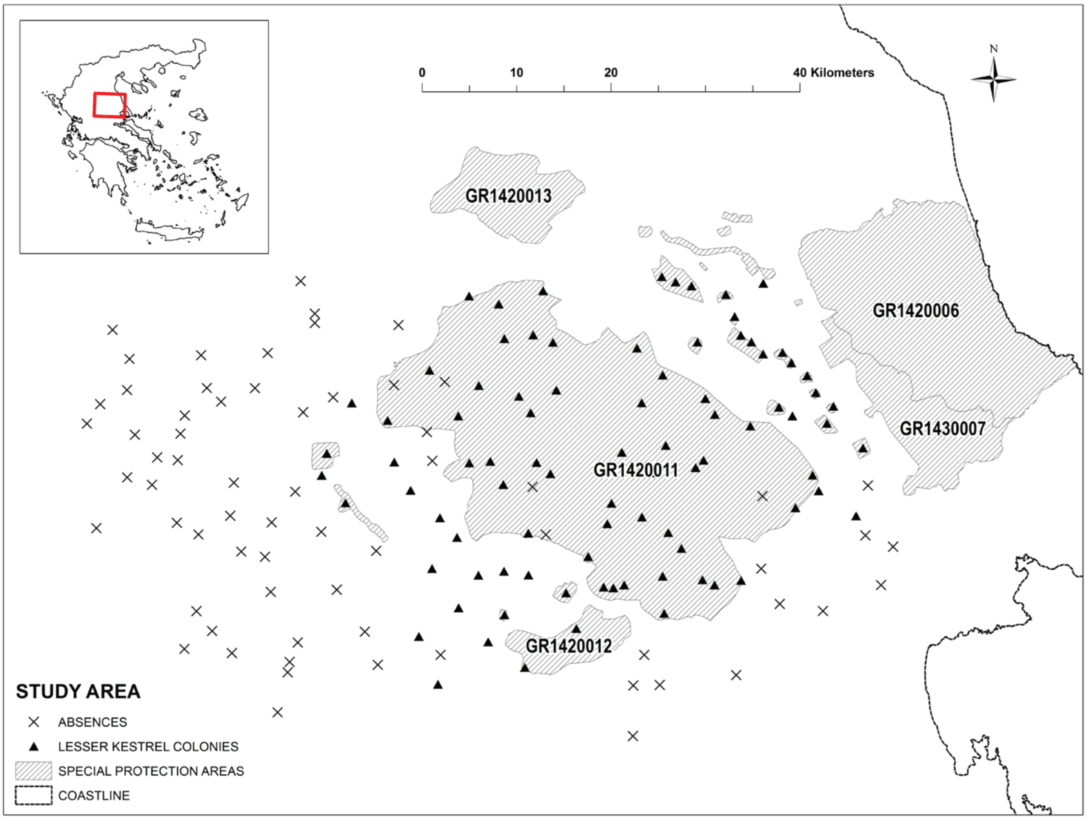

Figure 1. Map of the study area in the Region of Thessaly, Central Greece. Triangles represent the 87 colonies (in towns and villages) recorded during the years 2006 and 2007 and the '×' symbols represent the absences. Cross-hatched areas show the five Special Protection Areas (SPAs) in Thessaly; SPA GR1420011 (comprised of a larger and many smaller areas) and GR1420012 lie within the study area, whilst the SPAs GR1420006, GR1420007 and GR1420013 are in the periphery of the study area. The lesser kestrel is a species triggering SPAs' classification.

Birds at colonies were not counted, as population estimation was beyond the scope of this study. The centre of all sites was marked using a Global Positioning System receiver.

1.3. Predictor variables

Habitat data were derived by satellite image processing. A cloud-free Landsat Thematic Mapper image (30-m resolution) of seven spectral bands, obtained from the US Geological Survey (http://eros.usgs.gov/), was used to generate a land cover map for the year 2006. Acquisition date was from late summer (08 August 2006), which enables better discrimination between the main types of agricultural land cover in the study area, that is, irrigated cotton crops and dry cereal fields, the most significant habitat types for the purposes of this study. Cereals are, generally, harvested in June and fields are left fallow until the following November and the soil remains bare or covered with sparse short, dry herbaceous vegetation, whilst cotton plants are in full growth in mid August (Toulios & Sileos 1994). The image was radiometrically and geometrically corrected and geo-referenced (USGS 2006). A supervised image classification analysis (Campbell 2002) was performed using MultiSpec (v.3.1) (Purdue Research Foundation 2007). Seven broad land cover classes, following the Corine Land Cover classification (EEA 2000), were identified: urban and built-up areas, irrigated, non-irrigated farmland, grassland, scrubland, woodland and areas with tall vegetation (e.g. tree plantations and orchards) and water cover. Land cover classes were expressed as percentages. Maximum likelihood classification (Campbell 2002) was used for image classification. The Kappa statistic and the 'leave-one-out' re-sampling method were used to calculate producer's accuracy and user's accuracy (Lillesand & Kiefer 1999). Training areas were selected based on the information on land cover collected during field visits. Land cover data were imported in a Geographical Information System (GIS) as a raster thematic map (30 m pixel size).

For data retrieval, sampling plots of a 4-km radius were selected, based on foraging dispersal distances of radio-tracked birds from colonies in the Iberian Peninsula (Tella et al. 1998; Franco et al. 2004) and observational studies in Greece (Lucking 2006; Galanaki 2011).

Data on human population size, which serves as a surrogate measure of urban areas extent, were obtained from the National Statistical Service of Greece (NSSG; http://www.statistics.gr). Data on elevation and slope were extracted from a 90-m pixel resolution digital elevation model derived from Shuttle Radar Topography Mission (USGS 2004). Standard deviations of elevation and slope were calculated as measures of topographic complexity (Luoto et al. 2002). Total river lengths and their distance to colonies were generated in ArcView3. 2 with the Nearest Features tool (v.3.8a) (Jenness 2004). Four landscape metrics of habitat structure were also calculated at the landscape level from the thematic map using FRAGSTATS (v.3.3-5) (McGarical & Marks 1994): largest patch index (LPI), landscape shape index (LSI), total edge (TE) and Shannon's diversity index (SHDI). Habitat associations based on landscape patterns can influence the distribution of species and, hence, improve the accuracy and ease of use of models (McGarical & McComb 1995; Lawler & Edwards 2002). Also, landscape metrics are useful in order to identify HNVf (Šímová 2017). In total, 22 predictor variables were used for the analyses (Table 1).

1.4. Data analyses

Descriptive statistics were calculated for predictor variables. Variables with many zeros were omitted from the analyses. Predictive distribution models were developed using generalised additive models (GAMs) (Hastie & Tibshirani 1990). Because GAMs may be affected by multicollinearity amongst predictors, although the overall model is significant and its predictive reliability is not reduced, some or even all of the predictors might have not significant regression coefficients (Graham 2003). Thus, before model development, variables were tested for multicollinearity and a threshold value of r = 0.8 was applied to omit the highly correlated ones. From intercorrelated predictors, those ones that were more informative and had an ecological meaning were retained for further analysis.

Univariate GAMs were fitted using a logit link function, first with a default smoothing level of three and then with a stepwise selection from a range of increasingly complex smoothing functions, to identify the appropriate smoothing level for the development of the final GAM model. Predictors with the Bonferroni corrected p-value of >0.05 were excluded from the analysis (Pearce & Ferrier 2000). Analyses were performed using the gam package (v.1.0) (Hastie 2008) in R (v.2.8.1) (R Development Core Team 2008).

Residual deviance was calculated to measure the goodness of fit for the GAM, and the Akaike's information criterion (AIC) was also used, which determines the model that best fits the data; in general, the smaller the AIC, the better is the fit (Crawley 2007). Effect plots that describe the partial prediction for each predictor variable (after removing the effect of all other predictors) (Xiang 2002; Fielding 2007) were also constructed.

GAM model performance was assessed using receiver operating characteristic (ROC) curves with their associated area under the curve (AUC) statistics (Fielding 2007) using the PresenceAbsence package (v. 1.1.2) (Freeman 2007) in R. Classification tables with percentages of the accurate predictions (i.e. percentages of correctly classified cases, PCC) and misclassified cases [false positives (FP) and false negatives (FN)] were created, and outliers were determined for the training and testing data. Moreover, four threshold optimisation criteria were used to assess the effect of threshold allocation: (a) Sens=Spec, the threshold in which sensitivity equals specificity; (b) maxSens=Spec, the threshold that maximises the sum of sensitivity and specificity; (c) MaxKappa, the threshold that gives the maximum value of Kappa; and (d) MinROCdist, the threshold that minimises the distance between the ROC curve and the upper left corner of the unit square (Freeman & Moisen 2008).

2. RESULTS

2.1. Colony surveys – Univariate analysis

Eighty-seven lesser kestrel colonies were found within the study area (Fig. 1). On the basis of the data collected, presences were selected to be equal to absences in the training set, that is, 66 presences and 66 absences were used for model building (N = 132). For model testing, 50 cases of presences and absences were used (N = 50).

Percentages of land cover classes from the supervised image classification analysis were 24.7% for irrigated land, 22.7% for scrubland, 14.1% for woodland and other tall vegetation, 13.7% for nonirrigated land, 11.8% for urban and built-up areas, 8.8% for grassland and 4.2% for water (Appendix 1). Overall image classification accuracy was 97.3%, and the Kappa statistic (*x*100) was 96.2% (Appendix 1).

The descriptive statistics for the 22 predictor variables in the plots of presences and absences are shown in Appendix 2. Two variables 'water' and 'slopemin' were excluded in the first step of data analysis because of many zeros. When checked for multicollinearity, the more informative ones from the highly correlated variables were retained for further analysis, that is, 'elevation' and 'slope mean' and the 'LPI' and 'SHDI', whilst seven predictors ('elevmin', 'elevmax', 'elevstd', 'slopmax' 'slopestd', 'LPI' and 'TE') were omitted. Finally, 13 predictors were retained for further analysis.

2.2. Model performance

Results from the fitted stepwise GAMs for the 13 individual predictors and the smoothing levels for the development of the final models are presented in Table 2**.** Three predictors (nonirrigated, irrigated land and SHDI) were significant in the final GAM developed (Tables 3 and 4). The effect plots that reveal the non-linear relationships between the probability of lesser kestrel occurrence and the predictors are presented in Fig. 2. Irrigated farmland is positively associated with colonies, but as the coverage increases, its effect becomes negative, whilst the probability of species occurrence in relation to nonirrigated farmland is, initially, positive and then becomes relatively stable in higher cover percentages. Lesser kestrel presence is negatively associated with landscape heterogeneity (represented by large SHDI values) above a certain threshold value.

Table 1. Predictor variables used in the model building with the GAM.

Variable	Description and units
Urban	Urban areas, other artificial surfaces such as roads and airports, within each plot (%)
Irrigated	Irrigated agricultural land dominated by cotton fields and other industrial plants (maize, tobacco) within each plot (%)
Nonirrigated	Non-irrigated agricultural land dominated by dry cereals (mainly wheat) within each plot (%)
Grassland	Grasslands, pastures and fallow land within each plot (%)
Scrubland	Sclerophyllous vegetation (garrigue and low maquis) within each plot (%)
Woodland	Forest, tall maquis and areas of woody crop plantations and tree groves within each plot (%)
Water	Areas covered with water (sea, lakes, water bodies, etc.) within each plot (%)
humanpop	Human population size in each village/town of all presence/absence sites (counts)
elevmin	Minimum value of elevation within each plot (metres)
elevmax	Maximum value of elevation within each plot (metres)
elevmean	Mean value of elevation within each plot (metres)
elevstd	Standard deviation of elevation; measure of topographic complexity (metres)
slopemin	Minimum value of slope within each plot (º)
slopemax	Maximum value of slope within each plot (º)
slopemean	Mean value of slope within each plot (º)
slopestd	Standard deviation of slope; measure of topographic complexity (º)
riverdistance	Distance of the nearest-to-each-colony river (metres)
riverlength	Total length of rivers within each plot (metres)
LPI	Largest patch index, percentage of the largest patch in the landscape (%)
TE	Total edge, sum of the lengths of all edge segments in the landscape (metres)
LSI	Landscape shape index, describes the landscape shape complexity (no units)
SHDI	Shannon's diversity index; describes the landscape heterogeneity (no units)

The value of the AUC for the final GAM was 0.99 (Table 4). Threshold values for the four threshold optimisation criteria that were used to measure the classification accuracy in GAM with training data are shown in Appendix 3. The percentage of correctly classified cases for the model developed with the training data (with a threshold = 0.5) is higher than that for the model developed with the testing data as shown in the classification table in Appendix 4. The model with the training data misclassified four cases and with the testing data in nine cases (Appendix 4).

3. DISCUSSION

3.1. Lesser kestrel colonies – habitat associations

Nonirrigated land dominated by dry cereals, that is, typical HNVf areas, was a significant habitat predictor for breeding lesser kestrel distribution in the study area. Large colonies in the plain lie within areas cultivated with dry cereals (Hallmann 1996) and high numbers of birds have been recorded to forage in this habitat type (Galanaki et al. in press). Cereals have little demand for pesticides and are, mostly, nonirrigated in Greece (EEC 2007). The results agree with the findings of other lesser kestrel studies in the Iberian Peninsula where the species occurrence is associated with extensive cereals, a habitat related with the abundance of preferred prey, mainly during chick-rearing period that is crucial for the species reproductive success (Doňazar et al. 1993; Parr et al. 1995; Bustamante 1997; Tella et al. 1998; Franco et al. 2004; Rodríguez et al. 2006; De Frutos & Olea 2008; Catry et al. 2013; Rodríguez et al. 2014; Hernández-Pliego et al. 2017). Thus, Lesser Kestrels could stand as a biodiversity surrogate and as an umbrella species for delivering farmland biodiversity conservation in the agro-ecosystems of Greece.

Intensively cultivated irrigated land, mainly cotton, was also an important predictor of lesser kestrel colonies. How-

Table 2. Results from (a) the descriptive statistics with mean values for the 13 predictor variables in the plots (see also standard deviations in Appendix 2) and (b) the fitted stepwise GAMs for the retained 13 individual predictors with the smoothing levels (s.l.) for the development of the final GAM and the significant predictors. The six significant predictors after the Bonferroni correction are highlighted in bold.

Predictor	Presences (mean values)	Absences (mean values)	AIC	Residual deviance	d.f.	s.l.	Chi-squ-are	P(chi)	Predictor significance*
Urban	11.2	12.3	184.99	182.99	131	1	-	-	NS
Irrigated	35.3	39.7	170.73	156.73	125	6	22.476	0.000	S
Nonirrigated	22.8	11.1	139.88	125.88	125	6	23.107	0.000	S
Grassland	10.5	9.0	176.18	168.18	128	3	10.838	0.004	NS
Scrubland	11.8	22.3	145.31	135.31	127	4	17.499	0.000	S
Woodland	2.2	5.4	156.02	142.02	125	6	12.817	0.025	NS
humanpop	682.0	838.1	177.56	169.56	128	3	10.304	0.005	NS
elevmean	155.5	164.7	171.39	157.39	125	6	21.990	0.000	S
slopemean	2.9	3.0	164.19	150.19	125	6	25.551	0.000	S
riverdistance	1,139.3	918.0	184.99	182.99	131	1	-	-	NS
riverlength	10,841.5	16,257.1	176.17	170.17	129	2	0.814	0.367	NS
LSI	20.4	23.5	174.77	164.77	127	4	10.152	0.017	NS
SHDI	1.4	1.3	175.75	161.75	125	6	19.442	0.001	S

* NS, not significant predictor; S, significant predictor (after the Bonferroni correction to the significance level of the chi-square test).

Table 3. Model deviance statistics for the final GAM developed with the six variables (enter method). The three significant predictors of the final GAM analysis based on p-values are highlighted in bold.

Predictor and selected s.l.	d.f.	Chi-square	P(Chi)
(Intercept)			
s(irrigated, 6)	5	11.920	0.036*
s(nonirrigated, 6)	5	33.424	0.000***
s(scrubland, 4)	3	3.362	0.339
s(elevmean, 6)	5	10.453	0.063
s(slopemean, 6)	5	7.629	0.178
s(SHDI, 6)	5	17.650	0.003**

ever, abundance of foraging Lesser Kestrels was negatively associated with irrigated land at a finer scale analysis (Galanaki et al. in press). Cotton is identified as a poor habitat for wildlife because of the use of toxic agrochemicals (EEC 2007) and prey density is lower in cotton fields than in other habitats such as cereals and field margins (Rodríguez & Bustamante 2008). Philopatry of birds for building colonies in areas previously covered by suitable habitats could explain the selection of this habitat despite its low foraging quality (Bustamante 1997). As birds do not have territorial restrictions, they can fly long distances to forage when there are no suitable habitats close to colonies or food is insufficient (Negro et al. 1993; García et al. 2006; Bonal & Aparicio 2008; Catry et al. 2013). Other studies show, however, that birds are negatively associated with irrigated crops such as maize (Ursúa et al. 2005; De Frutos & Olea 2008; De Frutos et al. 2010; De Frutos et al. 2015).

Selection of cotton could also be explained by birds association with linear habitat features, such as field margins, that is, important elements of HNVf, interspersed in cotton fields used for foraging (pers.obs., Ursúa et al. 2005). Field margins were not included in model development, because they could not be detected by the image classification analysis because of the coarseness of the thematic map resolution (30 m pixel). This habitat is commonly reported to be preferred for foraging by Lesser Kestrels (Parr et al. 1997; Tella et al. 1998; Rodríguez et al. 2006; Rodríguez & Bustamante 2008; Rodríguez et al. 2014).

Landscape heterogeneity was also an important predictor of Lesser Kestrels in the study area. Lesser kestrel colonies were negatively associated with heterogeneous landscapes (represented by large SHDI values), explained by the fact that are uncommon in the study area that is composed of extensive, fairly homogeneous cotton and cereal fields, lacking complexity and tall vegetation (e.g. trees), which gets usually burnt at fires set for burning cereal stubbles in the summer. Use of landscape metrics related to lesser kestrel habitat structure by De Frutos et al. (2007) made no significant contribution to their model performance. However, researchers argue that habitat associations based on landscape patterns could influence the distribution of species, improve the accuracy and ease the use of models (McGarical & McComb 1995; Lawler & Edwards 2002).

Table 4. Summary of results on predictors' significance; only the three significant predictors of Table 3 are shown here. The model residual deviance statistics, AIC, AUC, threshold and Kappa values and percentages of correctly classified cases (PCC) for training and testing data are presented. Null deviance was 182.991 with 131 d.f.

Model	Significant predictor	Residual deviance and d.f.	AIC	AUC	Threshold	Kappa	PCC training data	PCC testing data
GAM	Irrigated, nonirrigated, SHDI	34.79 (97)	104.79	0.99	0.515	0.939	96.96	82.00

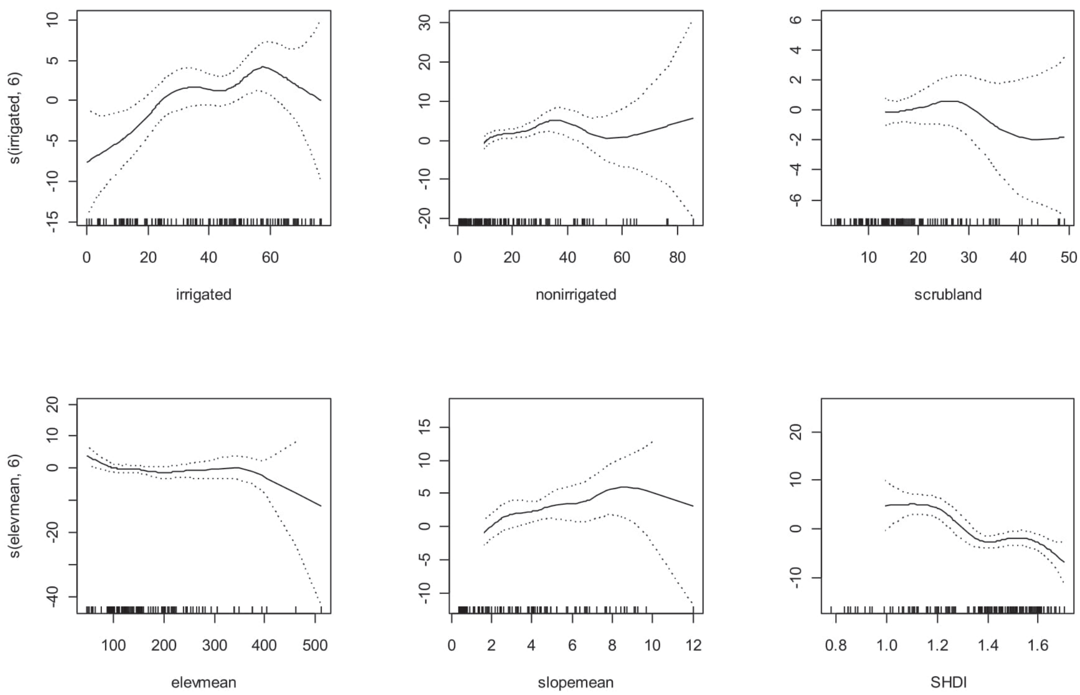

Figure 2. Partial effect plots with standard errors of the predictors for the final GAM analysis. Confidence intervals (95%) are indicated with the dashed lines. The rug-plot on the x-axis indicates range of values for each predictor.

Typical HNVf such as grasslands and fallow land when located in the vicinity of lesser kestrel colonies are considered as important foraging habitats for the species, being rich in prey availability (Doňazar et al. 1993; Parr et al. 1997; Franco et al. 2004; García et al. 2006; De Frutos et al. 2010; Catry et al. 2012, 2013). However, they were not identified as significant predictors in this analysis. Yet, foraging Lesser Kestrels were positively associated with grasslands at a finer scale analysis in the study area (Galanaki et al. in press).

3.2. Model evaluation

The final GAM over-fitted the data [i.e. their accuracy with testing data is less than that with training data (MacNally 2000; Fielding 2007)], but overall, the reduction in accuracy was relatively small, suggesting that the model is robust. Occurrence of more false negatives (i.e. models fail to detect the species' presence, whilst birds breed there) than false positives in testing data is probably because some areas in presence sites have similar attributes (irrigated land) with some others in places with absences.

The value of AUC indicates that they can incorporate non-linear relationships between the response and the predictor variables. However, the very high value of AUC should be treated with caution; researchers question the AUC as a measure of the performance of predictive models, arguing that it can be misleading, as the AUC could be biased and overestimate the goodness of fit of models (Lobo et al. 2008). Regarding threshold optimisation, there was no need for threshold adjusting because the differences in their values are small between models. Adjustment of the threshold must be based on the aim for which models are developed (Fielding 2007). Incorporation of predictors related to fine-scale habitat features such as linear field margins might be useful in a future analysis to refine models.

3.3. Conservation planning for Lesser Kestrels

In this study, typical HNVf such as dry cereals were a significant predictor of lesser kestrel colonies in Thessaly. The results could be used to lobby for maintaining and promoting this cultivation type and other low-input arable crops in Natura 2000 sites in agro-ecosystems, to safeguard vital Lesser Kestrels habitats in their breeding grounds. The relation of Lesser Kestrels with HNVf could also be used as an additional tool for promoting farmland biodiversity conservation for other priority species and outside protected areas, acting as an umbrella species (Lambeck 1997; Roberge & Angelstam 2004; Caro 2010).

An essential step for lesser kestrel conservation in Greece would be the planning and promotion of realistic, targeted AEMs under the RDP of Greece and the conservation of HNVf, based on the EU proposals for species and habitats conservation (EEC 2011), with strong technical support to secure their implementation and effectiveness. Targeted AEMs in the Pillar 2 of CAP could yield biodiversity benefits in agricultural ecosystems and support the maintenance of HNVf (Poláková et al. 2011; Whittingham 2011; Batáry et al. 2015). Such measures would ensure continuation of extensive agricultural practices and maintenance of low-input farming systems (e.g. dry cereals, other low-input arable crops, grasslands and other HNVf that support Lesser Kestrels), creation of wildlife refuges and corridors (field margins, uncultivated land strips and field borders used as foraging sites), preservation and planting of tree stands (used as perches by birds) and maintenance of all structural landscape elements in intensive arable cultivations (Marshall & Moonen 2002). They could enhance the creation of habitat heterogeneity (Rodríguez & Bustamante 2008; Catry et al. 2012; Rodríguez et al. 2014) and support a high variety in density and species composition of both wild flora and fauna in farmland areas (Suárez et al. 1997; Oňate et al. 2007). Moreover, maintenance of traditional cereal fields that retain scattered non-cropped areas of fallow land at different age level, semi-natural and edge habitats would be beneficial for Lesser Kestrels and other species in the agro-ecosystems of Greece.

Although AEMs for biodiversity have been put in practice in Greece since the 2000s, they have not been successful. AEMs were implemented for the first time in 2004, under the 2000–2006 RDP by the Hellenic Ministry of Rural Development and Food, including a measure for Lesser Kestrels and other birds of agro-ecosystems (Galanaki 2004). They accounted for about 1.5% of the national rural development budget during the years 2000–2006 RDP (DG AGRI 2011), with very limited participation of farmers, putting such measures very low in the Greek agenda. Under the 2007–2013 RDP, one AEM for arable crop management was designed, aiming at preserving farmland bird populations, but it was never implemented (HMRDF pers.com.), whilst no AEM targeting HNVf was designed. Under the 2014–2020 RDP, one AEM on HNVf has been designed, but it has not been into practice yet, whilst there are no measures for targeted priority bird species in farmlands (HMRDF 2017). Based on the above, although many options for concerning biodiversity under a greener CAP occur, a lot of effort is still needed to preserve and enhance farmland biodiversity, including breeding Lesser Kestrels, through the implementation of targeted AEMs for the EU priority species and habitats in the agro-ecosystems and the HNVf in Greece.

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APPENDIX 1
CLASSIFICATION TABLE OBTAINED WITH THE LEAVE-ONE-OUT METHOD FOR THE TRAINING DATA.

Land-cover class	Reference Accuracy (%)*	Samples	Urban	Irrigated	Nonirrigated	Grassland	Scrubland	Woodland	Water
Urban	96.7	3191	3087	0	33	7	64	0	0
Irrigated	98.2	11351	24	11151	0	0	26	150	0
Nonirrigated	90.0	46072	1022	2	41001	3779	197	70	1
Grassland	93.5	14355	46	0	588	13427	294	0	0
Scrubland	95.1	5589	85	2	48	108	5316	30	0
Woodland	95.2	32766	236	328	2	2	989	31209	0
Water	99.3	48887	11	0	0	0	1	332	48543
Total		162211	4539	11483	41672	17324	6887	31791	48544
Reliability Accuracy**			68	97.1	98.4	77.5	77.2	98.2	100

*(100 – percent omission error), also called producer's accuracy.
**(100 – percent commission error), also called user's accuracy.

APPENDIX 2
DESCRIPTIVE STATISTICS WITH MEAN VALUES AND STANDARD DEVIATIONS (STD. DEV) FOR THE PREDICTOR VARIABLES IN THE PLOTS

Predictor (units)	Presence sites (n=66)		Absence sites (n=66)	
	Mean	Std. Dev.	Mean	Std. Dev.
Urban (%)	11.2	3.8	12.3	5.2
Irrigated (%)	35.3	19.7	39.7	23.7
Nonirrigated (%)	26.8	20.2	11.1	12.1
Grassland (%)	10.5	7.5	9.0	10.9
Scrubland (%)	13.8	8.6	22.3	9.8
Woodland (%)	2.2	1.7	5.4	5.5
Water (%)	0.004	0.3	0.003	0.02
humanpop (%)	682.0	1432.8	838.1	949.7
elevmin (m)	108.6	45.0	111.6	48.9
elevmax (m)	281.5	152.6	299.1	226.2
elevmean (m)	155.5	73.0	164.7	102.2
elevstd (m)	35.0	30.8	36.9	43.9
slopemin (º)	0.02	0.06	0.01	0.05
slopemax (º)	16.4	10.5	17.9	15.5
slopemean (º)	2.9	2.2	3.0	3.2
slopestd (º)	2.5	1.9	2.7	2.7
riverdistance (m)	1,139.3	846.9	918.0	629.1
riverlength (m)	10,841.5	7,259.0	16,257.1	10,421.7
LPI (%)	21.1	13.2	22.3	11.9
TE (m)	479,186.0	181,555.6	592,920.8	262,521.2
LSI (no units)	20.4	5.5	23.5	7.6
SHDI (no units)	1.4	0.2	1.3	0.2

APPENDIX 3
SELECTED THRESHOLD VALUES FOR THE FOUR OPTIMISATION CRITERIA TO ASSESS THE EFFECT OF THRESHOLD ALLOCATION

Model	Optimisation Method	Threshold value	PCC*	Sensitivity	Specificity	Kappa
GAM	Sens=Spec	**0.515**	0.970	0.970	0.970	0.939
	MaxSens+Spec	**0.540**	0.977	0.970	0.985	0.955
	PredPrev=Obs	**0.515**	0.970	0.970	0.970	0.939
	MinROCdist	**0.540**	0.977	0.970	0.985	0.955

* PCC is the percentage of correctly classified cases.

APPENDIX 4
CLASSIFICATION TABLE WITH THE PERCENTAGES OF CORRECTLY CLASSIFIED CASES (THRESHOLD = 0.5) FOR ALL MODELS DEVELOPED WITH TRAINING DATA (N = 132) AND TESTING DATA (N = 50). THE THRESHOLD VALUE APPLIED WAS 0.5.

Model	TP	FP	TN	FN	PCC (%)
GAM (training data N = 132)	64	2	64	2	96.96
GAM (testing data N = 50)	12	4	29	5	82.00

TP, true positives; FP, false positives; TN, true negatives; FN, false negatives.