

# Lesser Spotted Eagle *Clanga pomarina* Brehm, 1831 (Aves: Accipitridae) in Dadia-Lefkimi-Soufli National Park, Greece: Population Trends and Spatial Use in Respect to Continuous Landscape Changes during the Last 35 Years

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**Abstract:** Lesser Spotted Eagle is a medium sized raptor with a stable population within its breeding range. Nonetheless, its favourable habitats (a mosaic of forest and low-vegetation forest-openings, often with water elements such as small ponds and flowing streams), are suffering from land abandonment as a result of abrupt socio-economic changes related to rural depopulation and the decline of traditional agro-silvo-pastoral practices. The species' breeding population in Dadia National Park (Dadia NP) of approximately 20 pairs, is an important stronghold at the southern fringe of its European breeding range. The breeding territories and their spatial distribution trends were studied in Dadia NP for 35 years (1979 to 2012). The overall interannual trend was not statistically significant for the population, with a minimum value of 17 pairs (2001 and 2012) to a maximum of 22 (2005). Despite this long-term stability though, territories' distribution in Dadia NP has changed remarkably. During the 1970s, a more uniform and clearly territorial distribution had been observed in the western part of Dadia NP, the stronghold of the species. It was an area characterized predominantly by forests, mixed with small-extension open landscapes, an optimal foraging and breeding landscape for the species. In contrast, in the 21st Century the population has shifted progressively to the eastern forest lowlands of Dadia NP adjacent to agricultural land, demonstrating a clustered distribution with reduced territory distances in an agro-forest area, not considered optimal for Lesser Spotted Eagle. This noticeable spatial change could be related to a decline in forest openings and habitat mosaics to the western part, as a result of land abandonment. Thus, the most suitable region for the species, decreased from 66% in 1979 to 54% in recent years, and specifically in Zone A of the National Park the most radical change was observed (from 80% to 53%). In conclusion, increased landscape homogeneity and reforestation of open areas could be major threats to the viability of Lesser Spotted Eagle. This has forced the species to shift its breeding territories already towards more humanized areas, in a more clustered distribution and expose them to human induced risks. Conservation policies should strive to increase heterogeneity at the landscape level and decrease the ecological impact of land abandonment.

**Key words:** *Clanga pomarina*, Dadia, Greece, landscape change, Maxent, niche shift, space use change

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## Introduction

Lesser Spotted Eagle *Clanga pomarina* Brehm, 1831 is a medium sized raptor with a stable population in most of its breeding range. Although it is a species of Least Concern according to IUCN (BIRDLIFE INTERNATIONAL 2016), the Lesser Spotted Eagle is a priority species for conservation in the EU. During recent decades a negative trend has been observed in many parts of its EU range (BIRDLIFE INTERNATIONAL 2015) and a large-scale action was drafted in a respective European Action Plan (MEYBURG et al. 2001). Greece is forming the southern limit of the species' western Palaearctic breeding range, and is estimated to host a small population of about 70-90 breeding pairs with negative trend. It is considered an endangered eagle according to the Red Book of the Threatened Animals of Greece (LEGAKIS & MARAGOU 2009). Dadia-Lefkimi-Soufli National Park (Dadia NP hereafter), a Natura 2000 area located in north-eastern Greece and renown as a major European biodiversity hotspot for raptors, holds the biggest population of this species in the country (POIRAZIDIS et al. 2010a).

The Lesser Spotted Eagle is a forest dwelling raptor with a preference for forest edges, which offer rich food resources at a remarkable distance from human presence and settlements (VÄLI et al. 2004, MIRSKI 2009). Throughout its breeding range, it prefers mainly broadleaved forests (TREINYS 2004, DOMBROVSKI & IVANOVSKI 2005, MIRSKI 2009) and during its foraging activity the species mainly preys in forest openings, natural grasslands, small open valleys, low-height riparian vegetation, wetlands and agricultural areas (TREINYS 2004, MEYBURG et al. 2004, VALI et al. 2017, MIRSKI et al. 2010, ZUB et al. 2010). In Dadia NP, it is considered a raptor with a narrow ecological niche, specialized in pine forest ecosystems, adjacent to forest openings, usually with ponds and flowing streams, which provide an adequate and preferable foraging habitat (POIRAZIDIS et al. 2007). In Slovakia, the Balkans and the Carpathians Lesser Spotted Eagle breeds in completely dry mountain woods at middle altitude (300-800 m, over 500 m on average) (MEYBURG 1971, DEMERDZHEV et al. 2019). In contrast, in Dadia NP, it mainly breeds in forests lower than 300 m of altitude, characterized by mosaic habitats dominated by forest edges, small portions of mature forests and local streams, while it avoids pure broadleaved forests (POIRAZIDIS et al. 2007).

Nest adjacency to local streams reflects its preference for this particular foraging habitat, as indicated by the large proportion of Grass Snakes

(*Natrix natrix* Linnaeus, 1758) in its diet (42.3%, VLACHOS & PAPAGEORGIOU 1996). In Dadia NP, the eagle avoids north-facing slopes for nesting, although such sites provide protection from high summer temperatures during the breeding season, which extends into July–August (POIRAZIDIS et al. 2007). A general deduction may be that this is an optimization mechanism to avoid cold weather conditions that sometimes occur in the early breeding season (KOSTRZEWA & KOSTRZEWA 1990). Genetic analyses showed that the most common Baltic haplotype was present also in the Dadia population of Lesser Spotted Eagle, indicating that the Balkan Peninsula acted as a refugium for the European population during the last ice age, constituting Dadia population a source population for the other European populations; the northern regions were re-colonized after the deglaciation 8000±1500 years ago (VÄLI 2004).

In respect to social and economic changes that have both direct and indirect effects on the environment, the abandonment of traditional rural and agricultural practices and professions as well as the depopulation of rural areas have often been indicated to produce landscape homogenization with negative impacts on biodiversity (ZAKKAK et al. 2014). In specific, radical socio-economic changes that took place in the 1960's all over Greece, e.g. rural depopulation, development of the tourist industry (XYSTRAKIS et al. 2017), along with European agricultural policies (RENWICK et al. 2013), played an important role in fostering land abandonment throughout the rural areas in the country. That fact produced a number of ecological consequences at various spatial scales, with land abandonment of rural areas being the first, removing the element of traditional human actions, which shaped habitat mosaics rich in biodiversity. Abandonment was also associated with landscape homogenization and densification adjacent to extended patches of dense scrublands and forests (ROURA-PASCUAL et al. 2005). Within that context, the 35-year study in Dadia NP also hypothesized that land abandonment created a non-optimal habitat for the Lesser Spotted Eagle.

The present work examines the species' spatial use in the light of continuous landscape changes in Dadia NP, which affect many raptor species in the region (POIRAZIDIS 2017). We analyzed the long-term adaptation of the breeding territories of Lesser Spotted Eagle to the increasing homogenization of forest landscape in Dadia NP for the period 1979–2012, and our work had three main aims: **a)** assess long-term population variability of the species and

explore population trends, **b**) assess spatial changes of suitable habitat based mainly on vegetation characteristics and forest density, **c**) describe the ecological tolerance of the species during this period in respect to landscape changes through environmental niche models (ENMs hereafter).

## Materials and Methods

In respect to the population monitoring of the species realized between 1979 and 2000, the population estimations of the Lesser Spotted Eagle were based on the works of HALLMAN (1979), VLACHOS (1989), ADAMAKOPOULOS et al. (1995) and after 2000, the Systematic Raptor Monitoring scheme (SRM hereafter), which was established in Dadia NP by WWF Greece (POIRAZIDIS et al. 2001) and set the basis for continuous and detailed monitoring of all raptors in the region, which continues until today (see POIRAZIDIS 2017 for a detailed analysis of monitoring results). To explore the population trends of Lesser Spotted Eagle, we implemented the non-parametric and distribution-free test of Mann-Kendall (MK). The test was applied to the number of annual territories to statistically determine whether there was a monotonic upward or downward (increases/decreases) trend over time (BALDWIN et al. 2012). MK tau and p values were calculated, using Kendall package (MCLEOD 2015) in R programming language (R CORE TEAM 2017).

We used the MaxEnt software (PHILLIPS et al. 2006) to create models of a potential suitable habitat based mainly on vegetation characteristics. MaxEnt is a general-purpose machine learning technique estimating the target species probability distribution (statistical model) of maximum entropy (closest to uniform) based on constant restrictions (constraints) that are placed by the processed data and by using presence-only data as a function of explanatory variables (PHILLIPS et al. 2006). In the present study, the entire landscape was represented by 10.000 random points with a random seed that were used as pseudo-absences points. The MaxEnt parameterization (e.g. convergence threshold, regularization parameter  $\lambda$ ) was set at default values (PHILLIPS & DUDIK 2008, ELITH et al. 2011).

The geometric centre of each estimated territory for the Lesser Spotted Eagle was used as independent presence for the years 1979 and 2012 to explore long-term spatial changes of the suitable habitat in Dadia NP. The explanatory variables were based on Landsat images of the closest available date to the population survey (satellite images of August for the years 1985 and 2011). The following

thematic foci were derived from each Landsat satellite image: **a**) thematic variable of vegetation density in three classes: dense forest (80–100%), loose forest (40–80%), open forest (0–40%), based on a hybrid method using vegetation index (Normalized Difference Bare Soil Index) and unsupervised classification (ISO-Data) to determine forest densification. Normalized Difference Bare Soil Index was calculated as:  $NDBSI = ((S1 - N) / ((S1 + N)))$ , where S1 is the shortwave infrared band, with a wavelength between 1.55 and 1.75  $\mu\text{m}$ , and N is near infrared band with wave length between 0.76 and 0.90  $\mu\text{m}$ . For each thematic class, the percentage of cover was calculated in four different spatial scales (500, 1000, 1500, 2000 m) using a circular moving window, **b**) four vegetation indices were used: NDVI, MSAVI, EVI, NDMI, all calculated in the four spatial scales above, and **c**) a digital elevation model (<https://asterweb.jpl.nasa.gov/gdem.asp>) was also applied including topographical characteristics like terrain roughness, inclination and aspect affecting vegetation characteristics and fundamental nesting and foraging factors. All variables were calculated in a 30 m spatial analysis.

Preliminary modelling was performed for each multiscale variable, in order to choose the optimal scale based on maximum univariate gain among the four scales per variable. The initial full model, using all variables (at the optimal scale for multiscale variables), was pruned by selecting a subset of uncorrelated variables based both on Variance Inflation Factor (VIF) criterion ( $VIF < 10$ ) and pairwise correlation ( $r < 0.8$ ) using “usdm” package in R environment (NAIMI 2015). Response curves of univariate models were created for each variable participating in the prune model, in order to examine how each one of them affects the species habitat selection. The suitability map with a scale that was firstly continuous between 0 and 1, was transformed into a binary file (presence – absence) according to the threshold “Minimum training presence”. According to the threshold, all training locations (centre of territories) would be correctly classified, as our goal was to predict the suitable area based on all estimated territories, indicating the least-suitable environmental conditions (RADOSAVLJEVIC & ANDERSON 2014).

## Results

For 34 years, since the late 1970's, when Lesser Spotted Eagle monitoring was actually initiated in Dadia NP, the species' numbers appear to be generally stable. Since the first estimation, eagle breeding

numbers were successively estimated by different researchers: HALLMAN (1979) recorded 19 territories, VLACHOS (1989) recorded a range of 16–20 territories, ADAMAKOPOULOS et al. (1995) estimated a range of 14–17 territories and, since 2000 until recent years, the long-term SRM has been producing reliable indices about the species breeding population at similar levels for the years 2001–2005 and 2012, ranged from 17 to 22 territories (POIRAZIDIS 2017). The change in the territories' numbers may demonstrate certain irregular fluctuations (Fig. 1); nonetheless, according to Mann Kendal test, which includes a total of eight years of estimation (1979, 1989, 2001, 2002, 2003, 2004, 2005, 2012) it overall indicates a stable population ( $\tau = 0.046$ , 2-sided  $p$  value = 0.92786).

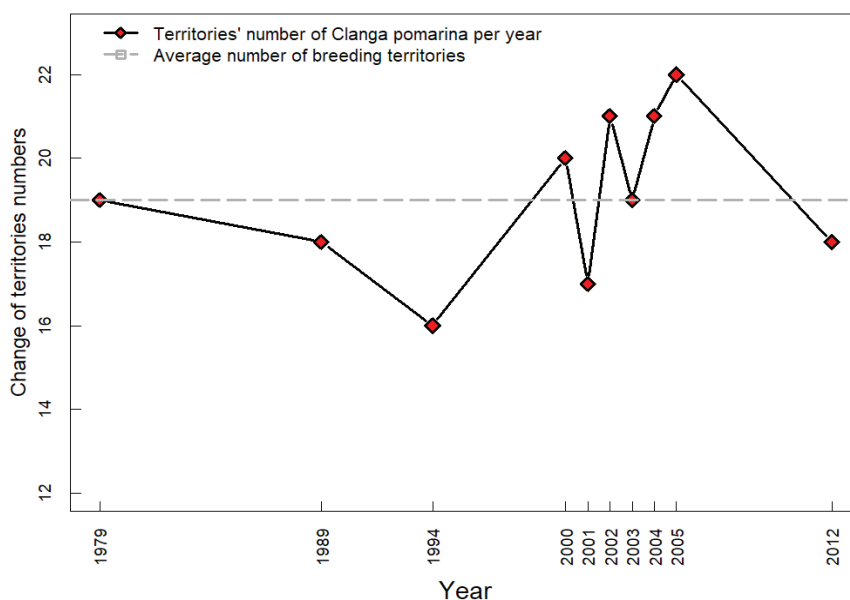
Apart from the arithmetic estimations for the Lesser Spotted Eagle in Dadia NP during the last 25 years, which indicate population stability, there is a notable spatial change both in horizontal and vertical landscape use. It has been found that while only 50% of the pairs bred in elevations below 100 m in the 1970's, this number has progressively increased since 2001. In addition, the horizontal spatial use by the Lesser Spotted Eagle with regard to its breeding habitats was uniformly distributed in Dadia NP in the 1970's. Since 2000, though the population has shifted to breed predominantly in the lowlands and at the eastern part of Dadia NP (Fig. 2).

The habitat parameters which created a suitable landscape for the Lesser Spotted Eagles breeding in the western part of Dadia NP decreased overall

from 66% in 1979 to 54% in recent years, whereas into Zone A, which is the strictly protected core of the Natura 2000 area in Dadia NP, the most radical change was demonstrated (reduction from 80% in 1979 to 53% in 2011) (Fig. 2). ENMs also indicate that the current breeding habitat of the eagle in Dadia NP has lower elevation than in 1979, whereas less adjacent dense forest appears in the species' surroundings in 2012, even within large radius of 2 km (Fig. 3). In that context, it is also noted that the species had a clearly narrower ecological niche in 1979 with a diverse mosaic of suitable habitat according to MSAVI, whereas in 2012, within even larger radius, much more open areas appeared in its territories, while the species no longer occupied dense forest (Fig. 3).

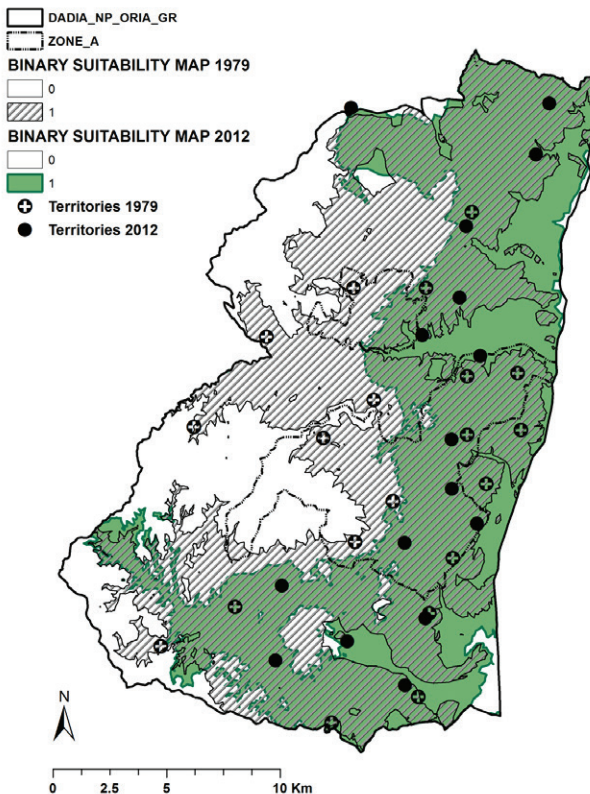
## Discussion

Major changes have occurred during the last decades in the landscape of Dadia NP (TRIANTAKOSTANTIS et al. 2006, XOFIS & POIRAZIDIS 2018), including intensification of agriculture, increased forest exploitation, abandonment of traditional agricultural practices and reduction of forest openings. It could be argued that these habitat changes affecting the foraging areas of Lesser Spotted Eagle would have affected the species' population as well. Nonetheless, the breeding population appears stable during the last 25 years. On the other hand, an apparent change has been noted on the spatial distribution of its territories. An abandonment of "in-forest" breeding territories has been recorded since the first monitoring



**Fig. 1.** Breeding densities of Lesser Spotted Eagle in Dadia NP since 1970's expressed in numbers of occupied territories.

Lesser Spotted Eagle - Spatial changes of Suitable Habitat 1979 - 2012



**Fig. 2.** Binary habitat-suitability map demonstrating Lesser Spotted Eagle spatial changes between 1970's and 2000's.

results of 1979 (HALLMANN 1979), where half of the eagle population bred within “interior” forest sites. In 1979, the Lesser Spotted Eagle population was recorded to breed in rich ecotones, which were formed of numerous forest openings that could support a forest-edge raptor dweller. Nowadays, all breeding pairs have established their territories on the periphery of the Dadia NP at altitudes exclusively lower than 100 m, where the breeding habitats are now dominated by more humanized landscapes with less availability of forest openings, but an adjacency to agricultural areas.

That spatial change may also function as increasing pressure on the abundance of the Lesser Spotted Eagle, in a future of further reduction of suitable habitats, which may push the population to limit down (VÄLI et al. 2004). According to LOHMUS & VÄLI (1999), semi-natural forest openings offer better feeding conditions than agricultural arable lands, and function as optimal habitats under stress for the species. On the other hand, if the stress factors cease but optimal habitats decrease, the birds will gradually move to alternative habitats. Even though Lesser Spotted Eagle is a species with notable preference for forest edges to nest (TREINYS

2004, TREINYS & MOZGERIS 2010, MIRSKI 2009, ZUB et al. 2010), it must be stressed that after 2000 the species was slowly “pushed” to completely translocate all its breeding attempts exclusively in the eastern lowlands of Dadia NP, denoting prior existence of available habitats within the core of Dadia NP.

Habitat heterogeneity has been recognized as one of the main landscape characteristics determining biodiversity patterns (TUANMU & JETZ 2015), and the richness in forest openings and diversity in forest composition throughout the entire extent of Dadia NP, is the major characteristic which creates a unique landscape formation that supports high levels of biodiversity (POIRAZIDIS et al. 2010b).

Already in 2001, many areas in the southwestern parts of Dadia NP showed low levels of forest diversity (SCHINDLER et al. 2008) but in the next decade general transition from open to forest land, in most of Dadia NP parts, has led to increased forest ecosystem homogeneity (XOFIS & POIRAZIDIS 2018). That is most possibly the main driver behind the allocation of Lesser Spotted Eagle's breeding territories exclusively in the eastern lowlands. Although a thorough analysis of environmental parameters to assess other possible drivers behind this differentiated spatial use has not been realized, surrogate factors corroborate the hypothesis. For instance, a significant increase has been noted in forest dwelling raptor species of Dadia NP such as the Northern Goshawk *Accipiter gentilis* Linnaeus, 1758, probably due to environmental factors such as forest homogenization (POIRAZIDIS et al. 2007, POIRAZIDIS 2017).

In recent years, a notable decline of the eagle's population due to the loss of suitable habitats has been observed in other countries such as Lithuania (TREINYS et al. 2007) and Germany (MEYBURG et al. 2004). In respect to Dadia NP, the reduction of the suitable habitat has forced the species to translocate its breeding in the eastern non-optimal landscapes but still no decline of the population has been observed. The decline in open and semi-open habitats in the interior of the forest since the 1950s (TRANTAKONSTANTIS et al. 2006) has caused a heterogeneity loss that may have also caused a decline in the abundance of reptiles and amphibians, which represent an important food source for the Lesser Spotted Eagle in Dadia NP (VLACHOS & PAPAGEORGIOU 1996) and strongly depend on landscape heterogeneity at scales ranging from 50 to 500 ha (SCHINDLER et al. 2013). In comparison, though with the Short-toed Eagle *Circaetus gallicus* Gmelin, 1788, a species which also relies on forest openings to capture its prey, the latter appears

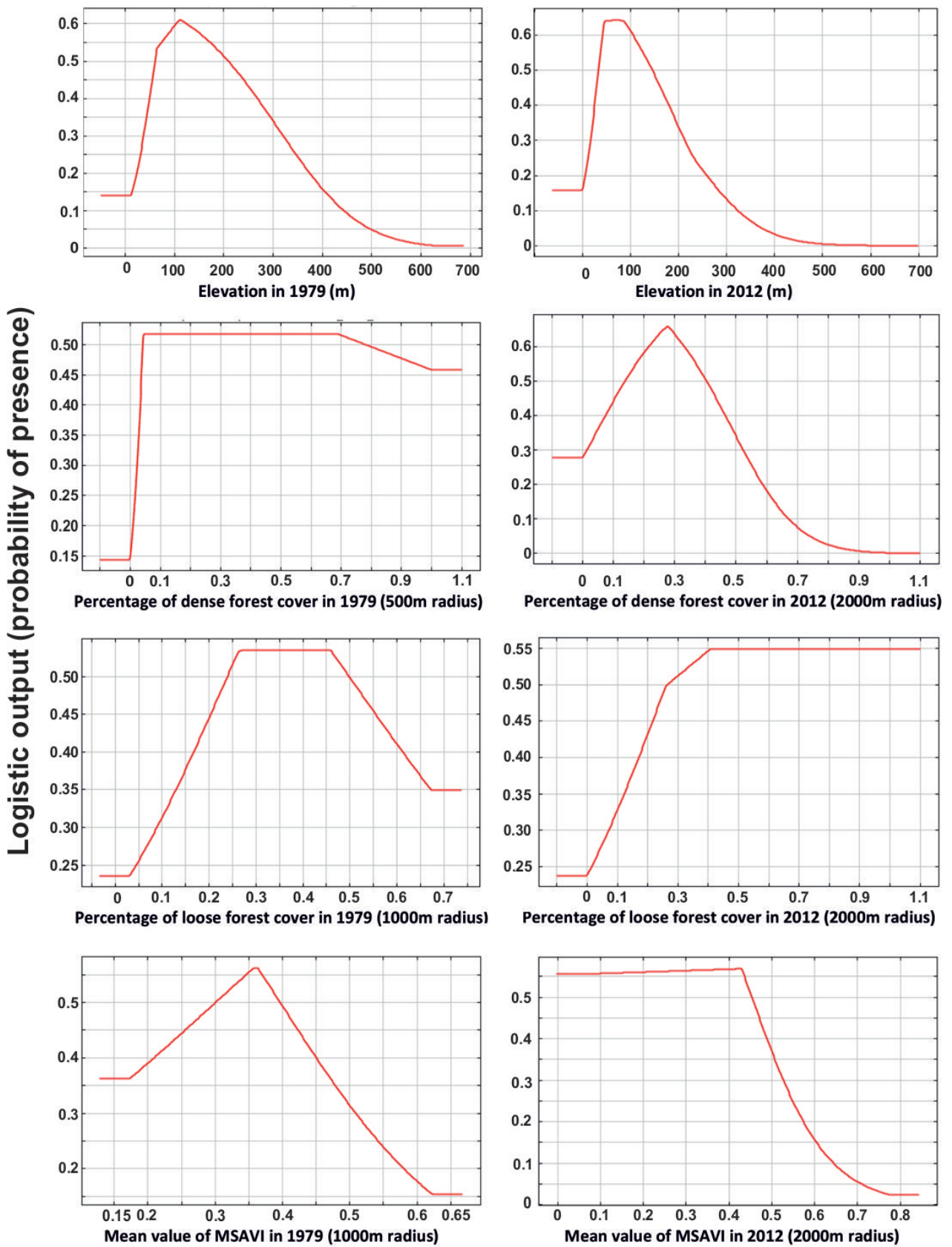


Fig. 3. Environmental niche model results with regard to Lesser Spotted Eagle spatial preferences in respect to elevation, MSAVI index, forest density and forest openings in 1979 and 2012 in Dadia NP.

to be increasing in the region (POIRAZIDIS 2017). Nonetheless, it is possible that the tolerance threshold differs between the two eagle species with Lesser Spotted Eagle being more sensitive and susceptible to forest homogenization, whereas the existing tertiary road and fire-break network in Dadia NP may be a sufficient ecotone habitat for the foraging requirements of Short-toed Eagle (POIRAZIDIS 2017).

Among the reasons behind this slow transformation of the forest into a more homogeneous form, is also the abandonment of traditional and open livestock farming, also recorded in other regions (ZAKKAK et al. 2014). An additional possible threat to the Lesser Spotted Eagle population in Dadia NP within the context of landscape homogenization, may also be the increase of *Helianthus* farming, which further decreases agricultural openings towards massif crop types that reduce farmland biodiversity and the diversity of prey species (BENTON et al. 2003, VÄLI et al. 2017).

Quite controversially, as also debated in POIRAZIDIS (2017), while deforestation is a major problem in many countries (CARRARA et al. 2015), the ecosystem of Dadia NP relies on the co-existence of man, forest, land use and livestock farming through a traditional practice that maintains forest clearings, in order to support a highly diverse landscape and biodiversity. Consequently, the present study and its conclusions denote on one hand the importance of raptor monitoring in a systematic pattern, which offers deep insights in population trends and can be further enhanced, when combined with spatial analyses including environmental parameters. In the case of Lesser Spotted Eagle in Dadia NP specifically, although its numbers remain stable for almost 4 decades, the species spatial translocation may pinpoint the beginning of a “stress” period for Lesser Spotted Eagle in the region, which may require further research and concrete conservation actions.

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