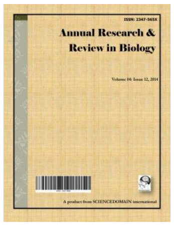

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Population Trends and Multi-Scale Breeding Habitat Analysis for the Black Stork (*Ciconia nigra*) in Dadia-Lefkimi-Soufli National Park, North-Eastern Greece

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Authors' contributions

Both authors designed the study, performed the statistical analysis, wrote the manuscript, read and approved the final manuscript.

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ABSTRACT

Aims: The aim of the study was to assess Black stork (*Ciconia nigra*) population trends and breeding habitat preferences in two habitat scales, in the National Park of Dadia-Lefkimi-Soufli (Dadia NP), in north-eastern Greece. Dadia NP is a renowned European biodiversity hot-spot (N 40° 59' to N 41° 15', E 26° 19' to E 26° 36').
Study Design: The Black stork breeding population was monitored under the Systematic Raptor Monitoring Scheme (SRM), which was established in the area by World Wildlife Fund (WWF) Greece.
Place and Duration of Study: The study was conducted in Dadia NP with annual monitoring efforts from 2001 until 2006, and once again in 2012.
Methodology: Twenty-four vantage points and ten road transects were selected throughout the entire study area. All Black stork individuals were surveyed and mapped during five months (March

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to July), for each monitoring year. Nesting habitat was measured in two scales. To assess the microhabitat, nesting-trees and vegetation variables were measured in a circular area of 0.1 ha (radius 17.85 m) around each nest. For the macro-habitat scale, a total of ten environmental variables were analyzed to model habitat suitability. MaxEnt software was used using high spatial resolution satellite data for each monitoring year.

Results: Black stork territories increased in Dadia NP from 24 pairs in 2001 to 33 pairs in 2012 demonstrating a total of 34.7% relative increase. According to Man Kendal tests, the species had a positive MK slope (1.7) which although not significant (tau = 0.69, P = 0.08), denoted a continuous increase. Increasing trends were corroborated by GAM models. The Black stork generally used large mature trees for nesting in sparse forests patches. The variable “elevation” demonstrated the most useful information for habitat modeling. During all monitoring years, Black stork showed a clear preference for the lowlands close to arable fields and wetlands which were used for foraging. Following the positive trend of Black stork population, the species’ suitable nesting habitat also extended from 48% in 2001 to 72% in 2012.

Keywords: Black stork; Ciconia nigra, Dadia; Greece; population trends; habitat suitability.

1. INTRODUCTION

Human population overgrowth has resulted in an unsustainable exploitation of Earth’s biological diversity, which was exacerbated by climate change, and other anthropogenic impacts [1]. Effective biodiversity conservation though, is essential for human survival, and thus, successful conservation approaches need to be reinforced [1]. In respect to wildlife specifically, human pressure has a major impact on wildlife populations by influencing habitat structure, resource availability and population interactions [2]. As far as forest dwelling species are concerned, deforestation and intensive forest exploitation, although less obvious in temperate zones, threaten specialists which depend on healthy forest ecosystems to breed [3]. Within the forest landscape context, habitat diversity and connectivity are crucial elements for wildlife populations, since they define resource partitioning in respect to food, nesting, cover, roost, and both intra and inter-guild interactions [4]. Therefore, forest management must be based on up-to-the date scientific evidence, in order not to threaten sensitive and specialist species [5].

In that context, long–term monitoring schemes are essential tools for effective nature conservation. More specific, long-term avian populations monitoring, can offer insights by: (i) estimating current population status, and (ii) accurately assess long-term population trends [6]. In the present study, we propose a multi-scale framework for effective monitoring as a conservation tool, as it is analytically explained in Poirazidis [6]. We apply this approach using Black stork (*Ciconia nigra*) monitoring data from Dadia-Lefkimi-Soufli National Park (Dadia NP hereafter). Since 2001 a Systematic Raptor Monitoring Scheme (SRM) has been established by World Wildlife Fund (WWF) Greece in Dadia NP, in order to evaluate the status of protected avian species at regular temporal intervals [6]. Furthermore, the area’s importance as a biodiversity hot-spot is renowned in the European Union (EU) [6,7], along with the region’s importance for the Black stork [8,9].

The Black stork, is recently considered both by International Union for Conservation of Nature (IUCN) as well as Birdlife [10], as a species of Least Concern. It is a species with a Eurasian distribution range mainly, which has undergone sharp declines in the past, mainly due to: (i) habitat loss, especially of important foraging habitats which are wetlands, and (ii) due to the use of pesticides in Africa which holds the main wintering grounds for the species [10]. Although the species is listed as Least Concern in its global evaluation, according to the Greek Red Data Book [8], the Black Stork in Greece has undergone serious declines in most of its distribution range. Today, Black storks breeding range is restricted to specific nucleus in Thrace, Macedonia, Epirus, north-eastern Thessaly, and the island of Lesvos. The total breeding population in Greece is estimated at 70-100 pairs [8], whereas in Dadia NP lies the stronghold area for the species in the country, with a breeding population of 32-35 pairs [9].

Main target of the present study is to assess the species’ conservation status, using data systematically collected from Dadia SRM. Specific aims are: (i) explore Black stork long-term population trends and habitat suitability in regional scale, (ii) recognize specific habitat needs for nesting sites in order to define optimal breeding habitats in micro-habitat scale, and (iii) pinpoint essential elements of that habitat. Ultimate goal is to channel all resulting knowledge into sound management programs. Concrete management decisions function towards effective protection of biological diversity in the area, reduce conflicts between management and nature conservation, and can formulate effective conservation strategies [11, 12].

Nesting habitat quality is essential for the conservation of any species. In respect to Black stork, it is a species that needs high, old mature trees with generally large breast height diameters [9]. It generally inhabits old undisturbed forest areas, interspersed with shallow lakes, marshes, ponds and streams [9].

To the best of our knowledge, previous Black stork studies in the region [9,13], have not encompassed such a large time-series dataset as the one included in our study, and they have not presented so far population trends for the species, whereas we also focus on habitat suitability in the region from both a macro and micro landscape perspective.

2. METHODOLOGY

2.1 Study Area

Dadia NP is located in northeastern Greece in Evros Prefecture (N 40° 59' to N 41° 15', E 26° 19' to E 26° 36'). It forms part of the south-eastern Rhodope Mountains, bordering with Turkey in the east. The total area is approximately 43.000 hectares and it includes two strictly protected core areas, which encompass a total of 7.290 ha. The altitude ranges between 10m and 654 m, and the topography is characterized by hilly slopes with small and large valleys and a diverse habitat-mosaic landscape. The main land cover is dominated by coniferous stands of Corsican pine (*Pinus nigra*) and Calabrian pine (*P. halepensis subsp. Brutia*), pure oak (*Quercus* sp.) stands, mixed stands of pines and oaks and in lesser extent there are also evergreen broadleaves and open areas. The agricultural areas and settlements are concentrated mainly at the lowland eastern part of the Dadia NP (for a detailed habitat analysis see Poirazidis [6]).

2.2 Field Work and Statistical Analysis

Black stork breeding population was monitored for six years (on an annual basis from 2001 till 2005 and once more in 2012), under the framework of SRM, which was established by WWF Greece in Dadia NP. Twenty-four vantage points and 10 road transects were selected throughout the entire study area and all individuals were surveyed and mapped for a five-month period (March to July), during each monitoring year [6]. Field work observation data were entered in seven different ArcGIS layers: general flights, territorial observations, landings, synchronous observations, nest areas, meeting points and meeting point flights. GIS analysis was applied in three consecutive stages to estimate total territories for the species [6]. Breeding territories were classified as “confirmed” or “possible.” The classification “possible” was used when it was not possible to confirm with absolute certainty that the observations were obtained from separate individuals, which maintained a separate territory. At the end, the final number of territories for each species was calculated by adding 50% of possible territories to the confirmed values (for a detailed field work methodology see Poirazidis [6]).

Inter-annual variation of Black stork territories was firstly explored through relative variation. The initial monitoring year 2001 was used as a baseline threshold for territory numbers, which was appointed the value of 1. For all subsequent monitoring years, the relative difference between occupied territories in respect to the baseline value was calculated [14]. In order to further explore Black stork population trends, the non-parametric test of Mann-Kendall (MK) was applied to the annual SRM values. With the MK test, a monotonic upward/downward trend is produced which depicts if the variable under question, consistently increases or decreases through time [15]. All MK tests were applied with the “Kendall” package [16] in R programming language [17]. In order to locate the best fitting model and explain Black stork territories trends since 2000, we evaluated alternative models based on the criterion of AIC and BIC [18], namely Generalised Linear Models (GLMs) with Poisson and Negative Binomial distributions and Generalised Additive Models (GAMs), with and without smoothing terms (cubic and cyclic cubic regression splines). The latter ones fitted best to the variables under question. The packages “mgcv” and “AICcmodavg” were applied to perform aforementioned analyses in R programming language [19].

Suitable nesting habitat was measured in two scales, both from the micro and macro perspective. At the finer scale, nest-tree and vegetation variables were measured in-situ, while at the macro-scale habitat, suitability models were formulated using variables at the landscape level. In 2001, 16 active nests were found in occupied territories and they were used to analyze nesting micro-habitat. Nest-tree variables included diameter breast height (DBH), nest-tree height (m), height of tree canopy (m), and nest height from the ground (m), while vegetation variables were estimated in a circular plot of 0.1 ha (radius 17.85 m) around each nest, in order to characterize the nesting micro-habitat for Black stork breeding grounds. Mean canopy cover and canopy height were estimated by averaging the measurements of four quartiles (facing to north, east, south and west). To maintain variables' independence and avoid pseudo-replication, only nests which were found active in 2001 were used for the micro-habitat analysis [20]. Nest variables were calculated by the end of the breeding season in order to avoid nestlings' disturbance. A random sampling was also conducted in 2001 throughout the suitable area as estimated by habitat modeling, in order to evaluate available habitat. Regions where the mean Diameter of Breast Height (DBH) of surrounding forest stand was less than 20 cm were excluded (sites with very young forests stands), as it is unusual to be adopted by the Black stork as potential nesting sites. To stabilize the variance, a minimum number of 70 samples were estimated to achieve accuracy ± 20% and a significance level of $p = 0.05$. All datasets were tested for normality with Kolmogorov-Smirnov test. The canopy-cover variables were arcsine transformed. After data normalization, trees with diameter classes 36 - 48 and 48 - 80 where combined in one category.

At the macro level, macro-habitat suitability (HS hereafter) was evaluated for the six monitoring years by assessing 10 environmental variables, as extracted from GIS layers (Table 1). The center of confirmed territories was used to indicate species' breeding presence, from each year dataset. Land cover variables were calculated with an integrated classification, using very high spatial resolution satellite-data for years 2001 and 2011. The 2001 classification was used for the analysis of 2001, 2002, 2003, 2004 and 2005 territory data and the 2011 classification for 2012 data.

Habitat suitability for the Black stork in Dadia NP was predicted with the maximum entropy models (MaxEnt). MaxEnt is a machine learning technique, which processes iteratively the probability distribution of studied species by using presence data as a function for the independent variables' dataset [21]. The initiation point for MaxEnt is the uniform probability distribution in the study area. All included features in the model, along with their relative weights are updated through a consecutive and continuous process, as the gain exponentially explores all possible suitable areas [21, 22]. In the present study, the entire landscape was represented by 10.000 random points with random seeding which were used as pseudo-absences points. The results for each year model were averaged after 10 replications, using the method of cross-validation and the rest of MaxEnt's parameterization (e.g. convergence threshold, regularization parameter λ) was set at default values [23,24]. The Area Under Curve (AUC) was used as a "goodness of fit" indicator for each produced model, in order to evaluate predictive accuracy. We considered an excellent model performance above 0.90 threshold (0.90 - 1), and likewise, a good performance at 0.80 - 0.90, average at 0.7 - 0.8 and poor at 0.6 - 0.7. Models below 0.5 were considered insufficient [25]. Response curves of univariate models were also created to examine how each environmental variable affects the prediction per year. The output of MaxEnt suitability map ranged in a logistic scale of 0 – 1, and it was reclassified into a binary map (presence/ absence) using the threshold "minimum training presence (MTP)", which determines the minimum predicted value for any presence location, predicting marginal and core regions.

3. RESULTS AND DISCUSSION

3.1 Population Trends

Black stork territories increased in Dadia NP from 24 pairs in 2001 to 33 pairs in 2012 (Table 2), demonstrating a total of 34.7% relative increase (Fig. 1). That relative increase depicts the variation of Black stork throughout the monitoring years, in respect to the first year value.

According to Man Kendal tests, the species had a positive MK slope (1.7) which although not significant (tau= 0.69, P=0.08), denoted a continuous stable increase. Additionally, General Additive Models (GAM) indicated as well a significant variation over time ($t = 24.702$, $P < 0.001$), as demonstrated in Fig. 2.

Table 1. Habitat variables for the Black stork macro-habitat modelling of breeding site preferences in Dadia NP

Variables used in macro-habitat analysis, coding and description	
elevation	Altitude over sea (m)
slope	Slope of the hills (%)
land cover (thematic)	Land cover of 13 (14) different types
dst_urban	Distance to nearest village
dst_settlements	Distance to nearest other settlement
dst_paved	Distance to nearest paved road
dst_unpaved	Distance to nearest unpaved road
dst_mainriver	Distance to nearest main river
dst_cultivations	Distance to nearest agriculture field
dst_openings	Distance to nearest open habitat
Land cover types included in macro-habitat analysis, coding and description	
1	Broadleaved Forest Patches
2	Arable land
3	Conifer_Forest_Patches
4	Coniferous
5	Evergreen
6	Mixed
7	Openings
8	Psp/Qsp
9	Qsp/Psp
10	Quercus
11	Roads
12	Settlements
13	Water
14	Burned area (only in 2011)

Table 2. Number of Black stork territories per monitoring year, during the period 2001-2012

	2001	**2002**	**2003**	**2004**	**2005**	**2012**
Confirmed	20	24	29	26	28	31
Possible	8	2	8	6	6	4
Total territories	**24**	**25**	**33**	**29**	**31**	**33**

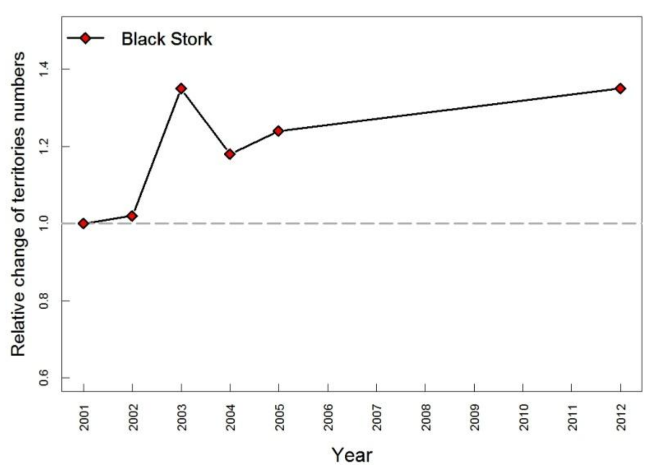

Fig. 1. Relative variation of Black stork territory numbers Dadia NP during the six Systematic Monitoring surveys (March to August: 2001–2005 and 2012)

3.2 Nesting Habitat Assessment from the Micro-Habitat Perspective

The Black stork used large trees for nesting, both in the horizontal and vertical concept. The mean DBH of nesting trees was formed at 55.7 ± 10.3 cm, which, apart from being significantly bigger than in random samples (26.9 ± 9.6 cm), indicates as well the importance of DBH parameter for Black stork nest-site selection ($p < 0.001$). Additionally, the height of nesting trees differentiated significantly and was higher from random selected trees ($p < 0.01$). The Black stork preference on high trees with the greatest DBH, and the location of nests at the middle of the trunk (distance from the ground of 8.4 ± 2.2 m), most probably reflects the species' need for mature trees, in order to support a heavy nest construction. Biggest trees are also significantly more selected for nesting within the 0.1ha area. The total number of trees in class diameter of 8 - 20 cm, were significantly fewer than at the random sites ($p < 0.01$), while more bigger trees were found at nesting sites ($p < 0.05$), reaching to 6.7 ± 2.7 trees with a class diameter of 36 - 80 cm, whereas at the random points a total of 4.4 ± 4.4 trees were found. Although the canopy cover was insignificantly different in the nesting areas compared to the random samples ($p > 0.05$), around nesting sites a higher canopy cover was estimated (74.3% ± 19.6) than at random sites (57.9% ± 21.6). The presence of mature forest, probably enables Black storks to choose and construct nests on different mature trees each following year, as it has already been noted in other studies [26-28]. Loose forests with nests positioned at a great height from the ground, are likely to facilitate nest access, offer vantage points for locating predators, and concealment [28].

3.3 Habitat Modeling and the Macro-Habitat Perspective

Model performance was quite similar among different years. High AUC values > 0.8 were produced for the first five years, but dropped at less than 0.8 during the last monitoring year. Most of the variables, when analyzed in isolation demonstrated a poor discriminative power by receiving an AUC value < 0.6, but there was not a clear pattern among years (Table 3). The variable elevation offered the most useful information both in AUC values but also for its permutation importance (Table 4). As derived from the analyses, the Black stork shows a clear preference in lowlands for breeding (the suitability is maximized in the region of 100-200 m a.s.l.) and this pattern has also been increasing with time (Fig. 3).

In terms of habitat suitability and human settlements, it maximized at a distance of 2000 m from the nearest village. That distance appeared as a constant pattern on time. An interesting difference was also apparent between the relative uses of different land covers in a temporal basis. During the first monitoring years (2001- 2005), water land-types were not selected by the Black stork, whereas in 2012 the land

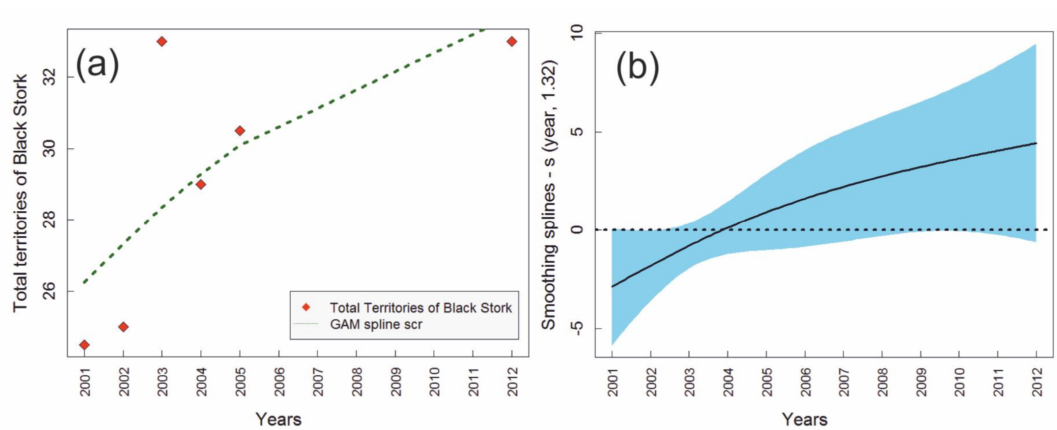

Fig. 2. Inter-annual variation in Black stork territory numbers in Dadia NP: (a) Trends fitted in a Generalized Additive Models analysis, and (b) predictive population trends fitting a cubic regression (cr) spline as a smoothing term

Table 3. Inter-annual gain value for full model and AUC values both for full model and per variable

Year	2001	2002	2003	2004	2005	2012
GAIN model	0.64	0.51	0.49	0.60	0.69	0.29
AUC model	0.89	0.81	0.84	0.86	0.87	0.77
			AUC value with only one variable			
elevation	0.66	0.65	0.65	0.59	0.72	0.62
land cover	0.54	0.65	0.57	0.60	0.48	0.56
dst_urban	0.61	0.58	0.60	0.56	0.70	0.54
slope	0.27	0.46	0.55	0.61	0.54	0.53
dst_cultivations	0.50	0.70	0.54	0.52	0.62	0.52
dst_paved	0.51	0.51	0.48	0.45	0.57	0.49
dst_mainriver	0.46	0.63	0.55	0.55	0.54	0.47
dst_openings	0.72	0.52	0.50	0.61	0.49	0.41
dst_settlements	0.50	0.55	0.56	0.49	0.52	0.28
dst_unpaved	0.50	0.50	0.56	0.52	0.45	0.22

Table 4. Inter-annual permutation importance per variable

	2001	2002	2003	2004	2005	2012
elevation	48.55	25.90	45.38	1.53	52.42	38.13
dst_urban	8.78	0.09	15.47	22.33	11.13	19.85
land cover	6.66	10.27	8.58	37.12	11.31	17.24
dst_cultivations	3.03	20.75	3.23	3.83	3.17	9.06
dst_unpaved	0.15	2.70	0.34	6.68	0.01	4.55
slope	1.93	1.18	4.88	10.11	4.71	4.20
dst_settlements	0.03	6.71	1.75	1.90	0.79	2.97
dst_paved	12.88	1.73	4.16	0.97	10.94	1.82
dst_mainriver	0.21	28.09	8.95	6.80	5.43	1.51
dst_openings	17.80	2.59	7.25	8.72	0.08	0.63

class "water" was the highest selected type (Fig. 3). A possible explanation for that shift, may be the construction of two big dams in the region during the period 2001-2012, which increased water surface areas in Dadia NP from 0.03% to 0.08%. That increase, although small in numbers, may have offered a significant addition to wetland foraging areas which are of main importance for the Black stork.

Black stork used mainly arable fields and wetlands for foraging which are actually limited in the study area [29]. As of consequence, the establishment of nesting sites was close to all aforementioned habitats. It is quite probable, that the species is reducing intraspecific competition by best exploiting preferred habitats, through these nesting patterns of choice. In that context though, Black stork preference towards nesting in low altitudes, could be a function of not only their vicinity to main foraging areas (cultivations, open water areas with streams) but rather to their absence from higher altitudes [29,30]. In that sense, nesting patterns may not necessarily reflect an adaptation of nesting near human settlements, but it could be a side effect, since human settlements occur more in low altitudes. It remains though, to be further quantified in the future, up to which point cultivations' irrigation near human settlements also function periodically as "human-induced" plots for foraging near water, which could potentially attract Black storks near human settlements.

Slope is another important factor affecting nest site selection for avian species. Nonetheless, it was not selected by the Black stork possibly due to limited availability of steep areas. Furthermore, the lack of statistical relationships between nesting sites' distance from forest openings is probably due to increased availability of forest openings in the lowlands of Dadia NP [30]. As such, forest openings and streams are hosts to high densities of reptiles, amphibians and small fishes, which are primary prey types for the Black stork. In the same context nonetheless, a lack of significant relationships to forest openings may also be an effect of studied scale. In specific,

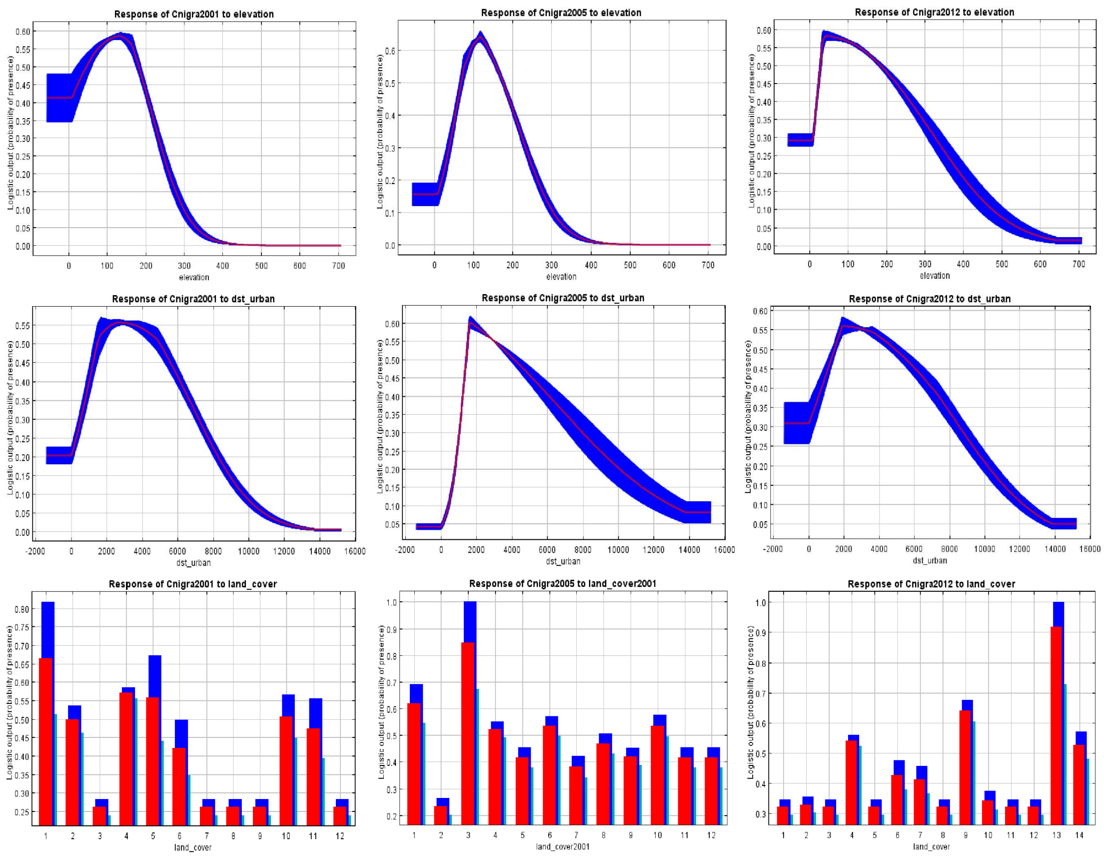

Fig. 3. Univariate models' response curves in respect to the variables: (i) elevation, (ii) dst_urban, and (iii) land-cover types for three monitoring years, first monitoring year, mid-year and final monitoring year

Black storks can fly considerable distances to forage in the late stages of their nestlings' growth, when water ponds are significantly reduced in the region [31].

In terms of spatial positioning of Black stork nests, the species is mainly characterized as a forest-interior bird, nesting at a certain distance from edges [32]. That fact could probably indicate a trade-off between foraging sites' distance and disturbance at edges, along with predation risks [32]. Nonetheless, in Dadia NP the Black stork nested relatively close to human structures, which are potentially disturbance sources. Consequently, in contrast to other European breeding areas where the species preferred undisturbed forest [32], in Dadia NP nesting near anthropogenic edges apparently offers foraging opportunities.

Black stork breeding populations increased in Dadia NP, by establishing new territories each year adjacent to already established ones. Still, the core breeding habitat remained spatially constant during the 12 years of monitoring (Fig. 4).

Despite the stability of the core breeding habitat, when including both marginal and core habitats (using binary presence/absence maps with minimum training presence threshold), an interannual increase of suitable habitat was mapped in this region. The increase started from a 37.03% of suitable area in 2001 and reached to a 71.81% in 2012. Although this trend was not significant (MK tau test = 0.2, $p >> 0.05$), a significant variation over time was detected using GAM ($t = 4.872$, $P < 0.01$), which followed a similar trend with the increase of breeding territories in the region (Fig. 5).

The constant increase of Black stork population in the region, according to Alexandrou et al. [9] has been enhanced by the intensification of agriculture at a small scale, which produced additional foraging areas. Furthermore, (i) a very high reproduction rate for the species, (ii) high hatching percentages, and (iii) high rates of successfully fledged nestlings according to Alexandrou et al. [9], are also additional factors for this population increase. That fact, may probably also be an adaptation to the increase of foraging and food resources. Overall, Black stork nesting habitat in Dadia NP was mainly segregated by distance to foraging areas, and it was further defined by microhabitat characteristics by choosing forest structures and nest-tree characteristics that maximize breeding success. During the period 2001-2012, land use change is clearly benefitting the species though, by giving space to more suitable habitats (Fig. 4).

These land use changes though, must be taken into account under a holistic, conceptual and

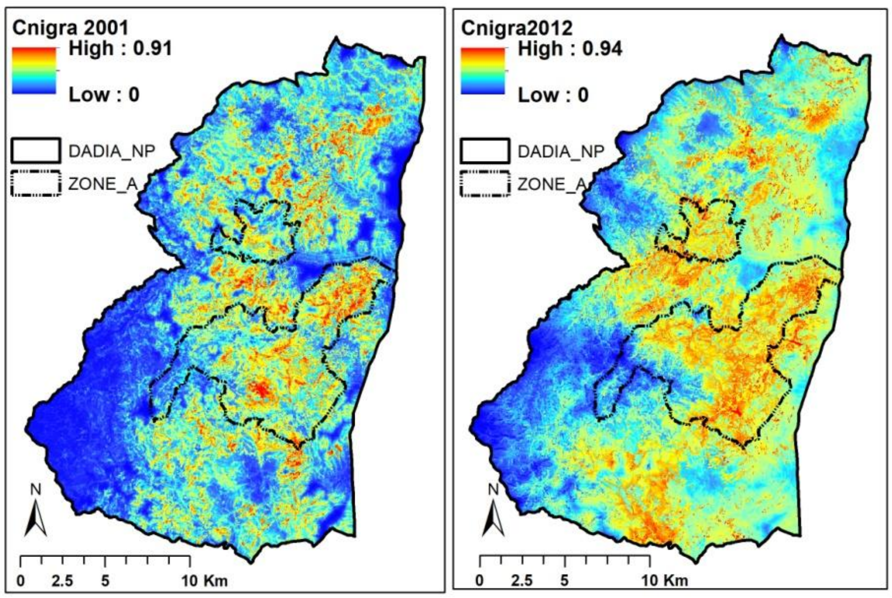

Fig. 4. Habitat suitability for the Black stork in Dadia NP as produced for the first and last monitoring year (2001 and 2012 respectively) in a logarithmic scale 0-1

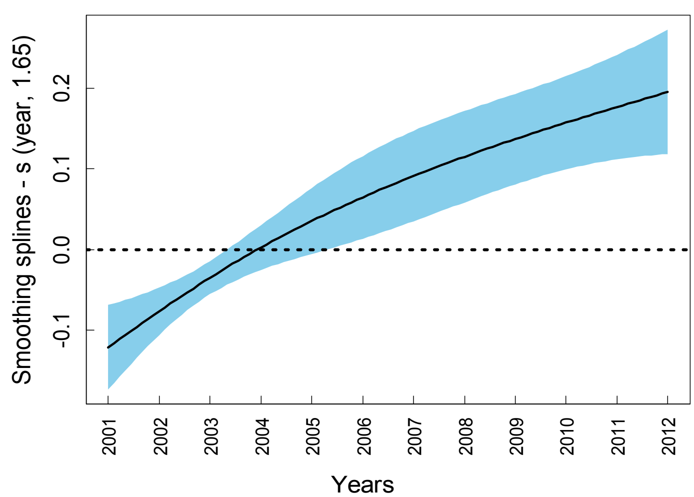

Fig. 5. Inter-annual variation of predictive suitable areas in Black stork in Dadia NP as produced by GAM models with smoothing splines

pragmatic framework, since Dadia NP hosts the most diverse assemblage of raptors in the EU [6]. Thus, thorough management processes need to be initiated in the region, which in respect to Black stork at least, could encompass: (i) maintaining small groups of mature forest with loose density and sparse intermediate canopy. Logging small tree groups can create similar aged forest classes. (ii) In respect to DBH, Black storks nests on forest patches of 50 to 60 years of age. Forest management, must preserve such management stands. (iii) Trees above 80 years must be preserved since they include most important characteristics. (iv) Dispersion of suitable nesting habitats for attracting newcomers, and (v) Increase wetland plots.

4. CONCLUSIONS

The Black stork mainly selects high trees with a large diameter (DBH), in order to establish its nests. Average DBH of nesting trees was calculated at 56 cm. Trees are selected within sparse forest patches, whereas the large tree height along with the large DBH, are most probably preferred by the Black stork because they can sustain heavy nest constructions. Nesting areas are confined in low altitudes, and are located to a certain vicinity to human settlements. The Black stork mainly foraged in agricultural plots of arable land, as well as in streams and wetlands. In respect to the species' population trends, according to SRM data in Dadia NP, the Black stork has demonstrated a constant and significant increase since 2001. An increase was also clearly noted in adequate habitat. According to MaxEnt models, habitat suitability increased significantly since 2001 in the area for the Black stork. That recorded land-use change which takes place in Dadia NP, allows the area to host gradually new breeding attempts each forthcoming year, due to the increasing rate of suitable nesting habitats.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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