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Population Viability Analysis of the Egyptian Vulture *Neophron percnopterus* in Macedonia and Implications for Its Conservation

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Abstract: We used VORTEX 9.99 to run 21 simulations on the viability of the population of the Egyptian Vulture *Neophron percnopterus* in Macedonia. Our baseline scenario indicated that there is a high probability of total extinction of the Egyptian Vulture from Macedonia within 50 years, with mean and median time periods to first extinctions being 26 and 25 years, respectively. Productivity rates have little influence on the persistence of the population, and conservation actions should be focused on reduction in the mortality rate not only in the breeding regions but also along the migration routes and in the wintering quarters. The possible supplementation of population would be justified only if the programme is accomplished together with some *in-situ* conservation measures. The number of the released juveniles in such a programme will have a clear effect on the viability of the population. Further research is urgently needed in order to identify the migration routes and wintering areas of the birds that breed or fledge in Macedonia, as well as to determine the actual mortality rates among the different age classes, since our results have indicated that the numbers used in this study may be considered too optimistic. Great care in planning of the future infrastructural and touristic development of the country and more efforts to control the illegal use of poison are also needed in order to protect the Egyptian Vulture from extinction in Macedonia. Currently, the species should be considered as Critically Endangered at national level.

Key words: decline, extinction, population dynamics, Vortex

Introduction

The aim of the Population Viability Analyses (PVAs) is to estimate the probability of survival of a population for a certain time interval by considering factors such as demographic parameters (age-specific rates of survival and reproduction, and their variances), variability of the environment, catastrophes, accidental genetic events, demographic stochasticity and others (Boyce 1992, Boyce *et al*. 2007). That type of analyses is particularly useful in determining the most important demographic parameters that have an impact on population survival (Beissinger, McCullough 2002). PVA is often used to provide recommendations for management of rare, threatened or harvested populations of various species from diverse taxonomic groups (an overview in Akçakaya 2000). The debate over the risks that PVA may carry (e.g. Ellner *et al*. 2002), seems to be settling (Brook *et al*. 2002), since, notwithstanding the uncertainty of the results (which is mostly associated with the need of gathering huge amount of data about the species lifestyle), PVA really offer a possibility of ranking different management practices (Akçakaya, Sjögren-Gulve 2000, Ellner, Fieberg 2003). On the other hand, Patterson, Murray (2008) noted that a

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wider philosophical approach to the realization and accurate and objective interpretation of those analyses was yet to be expected.

At present the most reputed PVA software is the VORTEX (Lacy *et al.* 2009), that enables creation of different scenarios with various input parameters for a population. This software performs individual-based simulations (creation and tracking of the representations of individuals and recording their sex, origin and age), which are grounded on events from the typical lifestyle of a diploid organism with sexual reproduction. VORTEX takes into account the effects of the demographic and deterministic factors, as well as the stochastic events that arise from the genetics and environmental variability in order to predict the most likely viability of a population for a given time period. The software has originally been developed to model bird and mammal populations and then upgraded to be used in other taxonomic groups (Miller, Lacy 2005). It has been frequently used to assess the viability of vulture populations (Bustamante 1996, 1998, Pavokovic, Susic 2006, Grande 2006, Carrete *et al.* 2009, García-Ripollés, López-López 2011).

In the present study, we have used VORTEX to assess the extinction probability of the endangered Egyptian Vulture *Neophron percnopterus* in Macedonia. The vulture is a long-lived (up to 25 years, Grande 2006) opportunistic scavenger with generation time of 13 years (Grange 2006, Grande *et al.* 2009, Agudo *et al.* 2011), which starts its reproduction at age 6-7 years (Grande 2006, Carrete *et al.* 2009), and shows a trade-off between the age of recruitment into the breeding population and the territory quality (Grande *et al.* 2009). The reproduction is long-term monogamy (Donázar 1993), and high turnover rates for adults (annual survival rate of 0.9) have been found (Agudo *et al.* 2011). Productivity (number of fledglings/number of monitored pairs) has been found to vary between 0.48 and 1.10, with fledgling rates (number of fledglings/successful pairs) being between 1.09 and 1.75 (see Liberatori, Penteriani 2001, García-Ripollés, López-López 2006, Kurtev *et al.* 2007, Iñigo *et al.* 2008). The average values of those two indices recorded recently in Macedonia were 0.84 and 1.19, respectively (Grubač *et al.* 2014). Different survival rates have been reported for different age classes and for territorial and non-territorial adults (Grande *et al.* 2009). The same study reveals importance of the territory quality for survival of the fledglings. Direct man-induced mortality is known to affect the species on the breeding grounds (Carrete *et al.* 2007, Hernández, Margalida 2009). Environmental factors, such as changes in primary productivity, degradation of habitats, livestock carcass availability and decrease in numbers of wild ungulates, as well as persecution and electrocution have been suggested or confirmed to have impact on the species in its wintering regions (Rondeau, Thiollay 2004, Thiollay 2006b, 2007b, Angelov *et al.* 2012, Carrete *et al.* 2013).

The Egyptian Vulture has been declining range-wide, on long term in the European part of the range (Iñigo *et al.* 2008), and rapidly in India (Cuthbert *et al.* 2006) and Africa (Rondeau, Thiollay 2004, Thiollay 2006b, 2007b). The decline on the Balkans has started also decades ago (at least since 1970s in Macedonia, Grubač *et al.* 2014), and the present population is estimated at 60-70 pairs, grouped within 4-5 core areas (S. Nikolov, L. Sidiropoulos, B. Hallmann, pers. comm.; authors' unpublished data). Designation of protected areas in some regions where the species lives, along with some soft conservation measures (incl. supplementary feeding on one permanent and three more irregular feeding places, as well as education and capacity building in order to prevent poisoning), which were implemented in the last decade in Macedonia, do not appear to have succeed in stopping the population crash. It has been found that the Egyptian Vulture populations in Spain are more sensitive to some threats, such as poisoning, wind turbines, disturbance, in comparison with other ones (e.g., livestock reduction and closure of predictable food sources) (Carrete *et al.* 2007, 2009, Zuberogoitia *et al.* 2008, Donázar *et al.* 2010, García-Ripollés, López-López 2011). However, there is a significant and critical difference between the Spanish populations subjected to PVA, and the Macedonian one (or more general, the Balkan one): the size of the latter remained after the long period of decrease on the Balkans. In fact, on the grounds of our long-term monitoring (Grubač *et al.* 2014), we are convinced that our present study should not seek an answer to whether the Macedonian population of this endangered vulture will become extinct, but how much time is left for urgent conservation actions, and which management strategies and activities are most likely to change the population viability.

Materials and Methods

We used Vortex 9.99 (Lacy *et al.* 2009) to model the viability of the Egyptian Vulture's population in Macedonia. We developed the baseline scenario on the grounds of the population size (the number of known pairs – 21) for 2012. In the initial population size we also included the most likely number

Table 1. Input parameters for the baseline and additional scenarios for the population viability analyses of the Egyptian Vulture in Macedonia

Scenario name	% Adult females breeding (SD = 9.00, except when marked with *, = 4.5)	0 Broods	1 Brood	1 Offspring	2 Offspring	Mortality age 0 to 1 (SD = 2)	Mortality age 1 to 2 (SD=2)	Morality age 2 to 3 (SD=3)	Morality age 3 to 4 (SD=3)	Mortality age 4 to 5 (SD=5)	Mortality age 5 to 6 (SD=2)	Mortality after age 6 (SD=2)	Supplementation (juvs)
Baseline	70.00%	23.00%	77.00%	81.86%	18.14%	27	27	22	22	40	25	17	No
+ 10% productivity	77.00%	20.70%	79.30%	80.05%	19.95%	As in baseline scenario							
+ 30% productivity	91.00%*	16.10%	83.90%	76.42%	23.58%								
- 10% productivity	63.00%	25.30%	74.70%	83.67%	16.33%								
- 30% productivity	49.00%	29.90%	70.10%	87.30%	12.70%								
- 10% all age classes mortality	As in baseline scenario					24.3	24.3	19.8	19.8	36	22.5	15.3	As in baseline scenario
- 10% mortality subadults and adults						As in baseline scenario				36	22.5	15.3	
- 30% mortality all classes						18.9	18.9	15.4	15.4	28	17.5	11.9	
- 30% mortality subadults and adults						As in baseline scenario				28	17.5	11.9	
+ 10% mortality all age classes						29.7	29.7	24.2	24.2	44	27.5	18.7	
+ 30% mortality all age classes						35.1	35.1	28.6	28.6	52	32.5	22.1	
- 10% mortality all age classes productivity +10%	77.00%	20.70%	79.30%	80.05%	19.95%	24.3	24.3	19.8	19.8	36	22.5	15.3	
- 30% mortality all age classes +30% productivity	91.00%*	16.10%	83.90%	76.42%	23.58%	18.9	18.9	15.4	15.4	28	17.5	11.9	
Supplementation with 4 juveniles	As in baseline scenario												4
+10% mortality all age classes and supplementation with 4 juveniles	As in baseline scenario					29.7	29.7	24.2	24.2	44	27.5	18.7	4
+30% mortality all age classes and supplementation with 4 juveniles						35.1	35.1	28.6	28.6	52	32.5	22.1	4
-10% mortality all age classes +10% productivity and supplementation with 4 juveniles	77.00%	20.70%	79.30%	80.05%	19.95%	24.3	24.3	19.8	19.8	36	22.5	15.3	4
Supplementation with 8 juveniles	As in baseline scenario												8
+10% mortality all age classes and supplementation with 8 juveniles	As in baseline scenario					29.7	29.7	24.2	24.2	44	27.5	18.7	8
+30% mortality all age classes and supplementation with 8 juveniles						35.1	35.1	28.6	28.6	52	32.5	22.1	8
-10% mortality all age classes +10% productivity and supplementation with 8 juveniles	77.00%	20.70%	79.30%	80.05%	19.95%	24.3	24.3	19.8	19.8	36	22.5	15.3	8

of individuals in each of the age classes from 1 to 6 years (Grande 2006, Carrete *et al*. 2009), based on calculations using the fledgling rates from the period 2003-2011 (Grubač *et al*. 2014). In absence of empirical data on mortality from the study area or the Balkans in general, for both the mortality rates in the baseline scenario and the estimation of the initial population size we used the survival rates from Spain (Grande 2006, Grande *et al*. 2009). As we have never observed non-territorial adults, and in order to avoid double counting, we excluded the estimated number of birds at age of 6 years (4 individuals) from the initial population size, assuming that those birds are immediately recruited in the breeding pool. After adjustment for equal number of males and females, the initial population size was set to 82 birds. We specified the exact age distribution for the non-adults, and used another VORTEX file to generate stable age – class distribution for the adults (using the number of adult birds in 2012 as an initial population size). We set the age of first offspring at 6 years, and maximum reproductive age at 25 years (Carrete *et al*. 2009). The maximum number of progeny was set to 2, while the sex ratio at birth was assumed to be 1:1. We assumed availability of males for every female, and no density dependant reproduction. We set up the carrying capacity K to 650 individuals, a value derived from breeding population estimate for 1983 (137 pairs, Grubač *et al*. 2014), which also includes estimation of the probable number of non-adults. Although this number is probably an overestimate of the real situation, this was of no importance for the simulations, as in none of the simulated populations the carrying capacity was approached (see Results). We did not account for environmental variables in the K, because they were not measures in the field, and the number of lethal equivalents was left to 3.14, with percent due to recessive lethals set at 50 (in absence of data and as recommended by Miller, Lacy (2005). We have not considered genetic management.

Having in mind the high natal philopatry of the Egyptian Vulture (Grande 2006, Carrete *et al*. 2007, Elorriaga *et al*. 2009), and the recent disintegration of its Balkan population into core areas .distanced apart for about the maximal usual dispersal range recorded (150 km, Grande *et al*. 2009), we considered the Macedonian population as isolated one, although it is likely that some emigration and immigration events are possible, as it has been shown for the population of the Canary Islands (Agudo *et al*. 2011).

Detailed input parameters for the baseline and the derived scenarios are presented in Table 1.

We developed additional 20 scenarios based on the baseline scenario. Parameters in most of them were changed within two scales – low effect (changes of 10% from the baseline scenario), and high effect (changes of 30%) (Pavokovic, Susic 2005, García-Ripollés, López-López 2011). Because of the low number of individuals and continued population decline in the last four decades, we did not consider density dependence in our models (Grande 2006, Carrete *et al*. 2009, García-Ripollés, López-López 2011).

The first group of scenarios tested the increase and decrease in the breeding parameters by changing simultaneously the percentage of population breeding, percentage of successful pairs and percentage of females with two offspring.

The second group of scenarios considered changes in the mortality rates either simultaneously for all age classes or only for subadults and adults. We noted that there was significant difference among the birds under three years old with regard to the distribution and territory ranges. Part of those birds usually stay in Africa throughout the year (Donázar 1993, but see Yosef, Alon 1997), while the birds of older age return to the breeding regions, which results in difference between the effectiveness of implementation of conservation measures in the breeding and wintering ranges of the species. This might lead to uneven changes in the survival rates, considered already in some earlier analyses (Grande 2006). However, having in mind the recent increase in knowledge on the ecology and threats of the Egyptian Vultures (and other raptors) in Sahel region in Africa, along with development of conservation actions that aim at improving the survival of non-breeding populations, we assumed that possible changes in the survival rates might be achieved among all age classes. We further checked the effect on the increase of survival rate for subadult and adult birds only. In absence of mortality rates from from the Balkan region, these scenarios also tested the possible response of the population to the mortality rates that are potentially higher than those recorded in the population from the Ebro River valley (Grande 2006; Grande *et al*. 2009).

The third group of scenarios combined the changes in the productivity and mortality rates, using the same input parameters as in the previous two scenario groups.

Finally, the fourth group of scenarios considered restocking activities by means of supplementing the population with 4 (2 male and 2 female) and 8 (4 male and 4 female) juveniles (Grande 2006), without changes in the mortality or productivity rates, productivity rates, and with minor positive changes. We set the restocking process to begin 10 years after the scenario starts, as we believe this is realistic time to finish the needed preparatory activities for such a programme in Macedonia. We assumed that the restocking programme lasts 20 years, in order to be able to control how viable the population is after the programme has ended. We did not consider taking of birds from nature (harvest) to found the breeding stock.

Post-hoc, we decided not to introduce catastrophes in our models, as many of the simulations showed negative trend (see Results), and as catastrophes are unlikely to happen in Macedonia (e.g., there are no gathering sites in Macedonia where in case of poisoning incident large number of adult individuals will be lost). Thus, we probably underestimated the risk of catastrophes along the migration routes or in the wintering regions.

Based on the different input parameters for productivity and mortality, we proposed the most likely circumstances under which they can occur. In the end, we discussed management possibilities for conservation of the Egyptian Vulture at national and regional level, in light of the biodiversity conservation programmes and national strategies.

Results

The baseline scenario affirms with high probability the extinction of the Egyptian Vulture population in Macedonia within 50 year period (PE=1, SE=0.0005), with median time to first extinction of 25 years. According to this scenario, 1999 out of 2000 simulated populations are extinct. The negative stochastic growth rate (stoc-r = -0.127) is consistent with the observed long-term decline of the population.

In the all 21 scenarios tested, we have never obtained positive average stoc-*r* values (Table 2, Fig. 1). In 15 of the scenarios there is a high probability

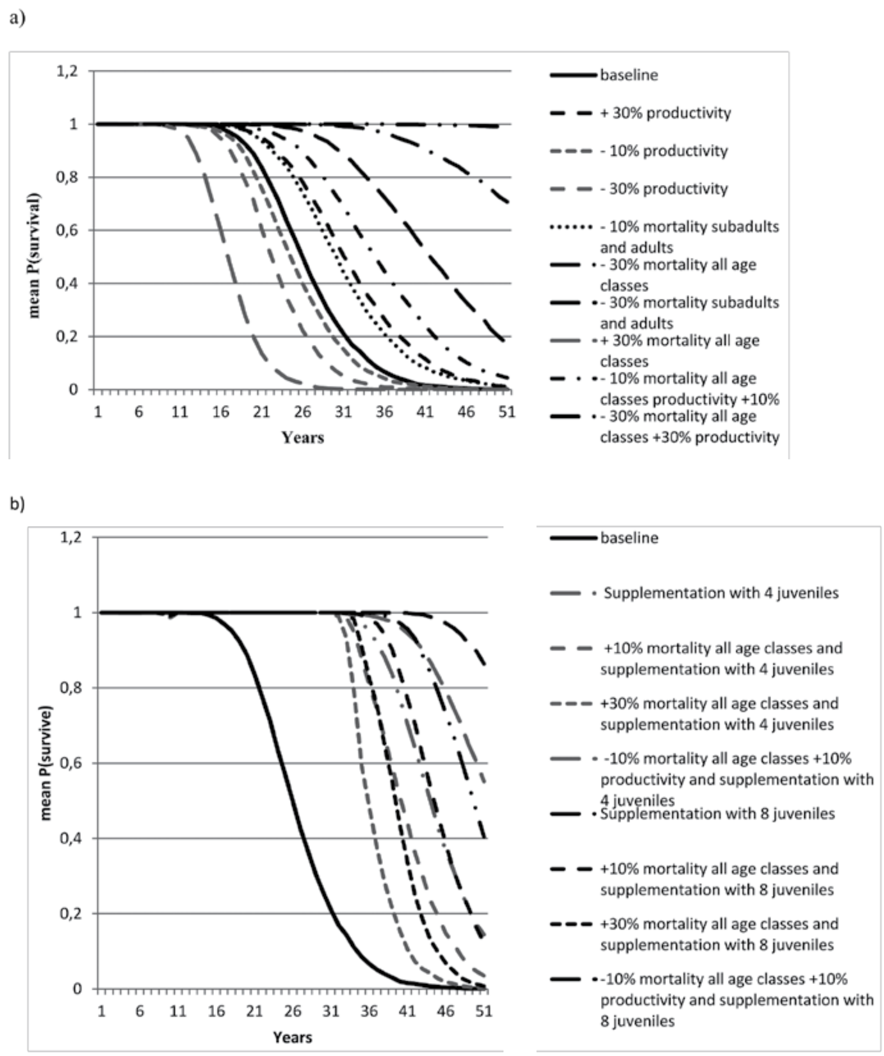

Fig. 1. Probability for survival (mean values) of the population of Egyptian Vulture in Macedonia for 50 years period for selected scenarios, without (a) and with (b) supplementation

(>80%) of population extinction within 50 years, and in only 3 scenarios this probability is under 20.

Population sizes show continuous decline in 17 of the analyzed scenarios (Fig. 2). In the remaining four scenarios, which are scenarios that include supplementation of the population with 8 juveniles annually, a positive population growth rate is observed only during the supplementation programme.

Our simulations indicate that the population productivity has a negligible impact on the population size. A slight increase in the productivity (by 10%) does not result in substantial changes in the mean number of the survived individuals either within the 30 or within the 50 year period. However, if the productivity substantially increases (by 30%), then the probability of total extinction will decrease drastically for the period of 30 years and the median time period to first extinction will be prolonged with

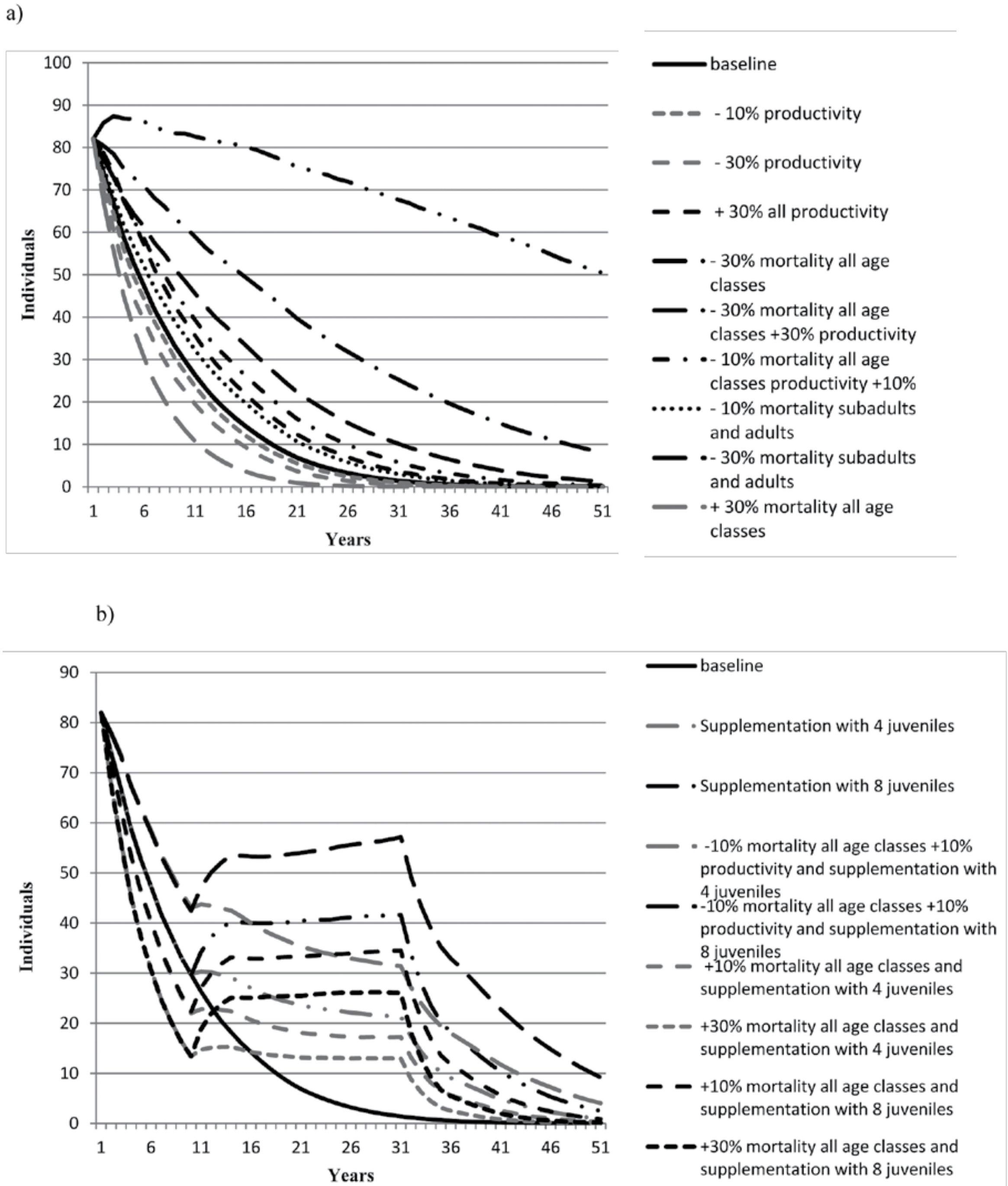

Fig. 2. Mean number of surviving individuals in the Macedonian population of the Egyptian Vultures under selected scenario settings, for 50 years period, without (a) or with (b) supplementations

Table 2. Basic demographic parameters of the simulated scenarios of Egyptian Vulture populations in Macedonia at the end of the 50 year simulation period

	Scenario	det-r	stoc-r	SD(r)	MedianTE	MeanTE
1	baseline	-0.113	-0.127	0.168	25	26.1
2	+ 10% productivity	-0.103	-0.119	0.166	27	27.5
3	+ 30% productivity	-0.082	-0.104	0.164	31	31.1
4	- 10% productivity	-0.125	-0.135	0.17	24	24.7
5	- 30% productivity	-0.15	-0.151	0.168	22	22.2
6	- 10% all age classes mortality	-0.083	-0.1	0.16	32	32.2
7	- 10% mortality subadults and adults	-0.093	-0.108	0.162	30	30
8	- 30% mortality all classes	-0.031	-0.052	0.119	0	42.8
9	- 30% mortality subadults and adults	-0.061	-0.078	0.148	41	38.7
10	+ 10% mortality all age classes	-0.145	-0.155	0.178	21	21.5
11	+ 30% mortality all age classes	-0.204	-0.204	0.191	16	16.7
12	- 10% mortality all age classes productivity +10%	-0.073	-0.093	0.156	34	34.1
13	- 30% mortality all age classes +30% productivity	0.001	-0.014	0.076	0	45.3
14	Supplementation with 4 juveniles	-0.113	-0.074	0.159	44	42.4
15	+10% mortality all age classes and supplementation with 4 juveniles	-0.145	-0.081	0.176	40	39.8
16	+30% mortality all age classes and supplementation with 4 juveniles	-0.204	-0.091	0.209	35	35.8
17	-10% mortality all age classes +10% productivity and supplementation with 4 juveniles	-0.073	-0.06	0.135	0	45.2
18	Supplementation with 8 juveniles	-0.113	-0.065	0.154	49	45.6
19	+10% mortality all age classes and supplementation with 8 juveniles	-0.145	-0.073	0.175	44	43.2
20	+30% mortality all age classes and supplementation with 8 juveniles	-0.204	-0.084	0.217	39	39
21	-10% mortality all age classes +10% productivity and supplementation with 8 juveniles	-0.073	-0.047	0.122	0	47.4

Abbreviations: det-r: deterministic growth rates; stoc-r – stochastic growth rates; SD(r) – Standard deviation of the stochastic growth rates; Median TE – median time to first extinction (years); Mean TE – mean time to first extinction (years)

6 years (Tables 2 and 3). Similarly, a decrease by 10% in the productivity does not cause a substantial change in the population size, but a decrease by 30% shortens the time to first extinction with 3-4 years.

A small decrease in mortality in all age classes leads to a higher probability of survival (0.59) for the 30 year period, and prolongs substantially the median time to first extinction (with 7 years). At the same time, the average estimated number of survived individuals at the end of the 50 year period remains very low (only 4 individuals). If the mortality is reduced only in the subadult and adult classes (i.e, for individuals that can be subject to management in the breeding areas), then the probability of population survival during the first 30 years will decrease to 0.44.

More optimistic results are obtained when mortality is reduced by 30% in all age classes. Such scenario shows only 70% probability of survival within 50 years. Again, if mortality is reduced only in the subadult and adult classes, then the extinction probability will be 17% for the 50 year period, and at the end of this period there will be only one survived individual. However, in both cases, the median time to the first extinction is much longer (41 years with 10% reduction in the mortality) or the extinction does not occur in the first 50 years of the simulation (with 30% reduction of the mortality) compared to the baseline scenario.

If the survival rates of the different age classes are indeed underestimated, or the threats that cause higher mortality, increase in the future, then the sim-

Table 3. Changes in the mean population sizes and mean probabilities of survival of the Egyptian Vulture in Macedonia for the different simulated scenarios

	Year 10 (=2022)		Year 20 (=2032)		Year 30 (=2042)		Year 40 (=2052)		Year 50 (=2062)	
Scenario	N (all)	P(sur)	N (all)	Psur	N (all)	Psur	N (all)	Psur	N (all)	Psur
baseline	26.34	1	6.87	0.8365	1.42	0.2105	0.19	0.016	0.02	0.0005
+ 10% productivity	29.06	1	8.43	0.8815	1.92	0.295	0.28	0.029	0.03	0.001
+ 30% productivity	35.63	1	12.37	0.9495	3.63	0.504	0.79	0.1155	0.11	0.01
- 10% productivity	23.64	0.9995	5.54	0.758	0.98	0.1515	0.12	0.0115	0.01	0.0005
- 30% productivity	19.44	0.9985	3.69	0.605	0.48	0.0505	0.04	0.0015	0	0.0005
- 10% all age classes mortality	35.5	1	13.37	0.9705	4.21	0.59	0.99	0.144	0.18	0.026
- 10% mortality subadults and adults	32.19	1	10.69	0.938	2.96	0.441	0.64	0.083	0.11	0.0135
- 30% mortality all age classes	58.93	1	39.71	1	25.21	0.992	14.89	0.906	7.94	0.707
- 30% mortality subadults and adults	45.54	1	22.39	0.997	10.12	0.8875	3.87	0.5235	1.24	0.171
+ 10% mortality all age classes	19.11	0.997	3.39	0.55	0.4	0.049	0.03	0.002	0	0
+ 30% mortality all age classes	10.72	0.978	0.91	0.136	0.05	0.0015	0	0	0	0
- 10% mortality all age classes productivity +10%	39.3	1	16.03	0.9785	5.74	0.692	1.63	0.2405	0.35	0.0445
- 30% mortality all age classes +30% productivity	82.59	1	75.5	1	67.66	1	58.99	0.998	50.41	0.9885
Supplementation with 4 juveniles	30.35	1	23.59	1	21.38	1	4.86	0.7035	0.97	0.1445
+10% mortality all age classes and supplementation with 4 juveniles	22.81	1	18.08	1	17.22	1	2.58	0.4405	0.35	0.035
+30% mortality all age classes and supplementation with 4 juveniles	14.74	1	13.13	1	12.92	1	0.82	0.1055	0.06	0.0025
-10% mortality all age classes +10% productivity and supple-mentation with 4 juveniles	43.73	1	35.27	1	31.41	1	11.76	0.945	4.05	0.5515
Supplementation with 8 juveniles	34.23	1	40.45	1	41.6	1	10.36	0.9565	2.48	0.4045
+10% mortality all age classes and supplementation with 8 juveniles	27.09	1	33.28	1	34.49	1	5.65	0.771	0.89	0.1235
+30% mortality all age classes and supplementation with 8 juveniles	18.84	1	25.47	1	26.08	1	1.97	0.337	0.15	0.0075
-10% mortality all age classes +10% productivity and supple-mentation with 8 juveniles	47.18	1	54.03	1	57.14	1	22.78	0.999	9.16	0.864

Abbreviations: N(all) – total number of individuals surviving in the given simulation year. P(sur) – probability for population survival in the given scenario year ulations will show a reduction in the median time to the first extinction by 4 years (with 10% decrease in the survival rates), or as much as by 9 years (with 30% decrease).

The combination of a small increase in fecundity and a decrease in mortality (by 10%) for all age classes again leads to a high probability of extinction for the period of 50 years (96%). Only if these values are dramatically improved (by 30% each), then the results will show survival of a relatively high number of individuals for both periods of 30 and 50 years (68 and 50 individuals), but the population will still undergo an overall decrease.

Scenarios that include supplementation of the populations show that the population continues to persist for the duration of the supplementation programme (the first 30 years), even if only a small number of juveniles is released, and mortality rates are significantly higher than those in the baseline scenario. The average number of estimated individuals that survived in this period, however, ranges almost two-fold between the number in the scenarios with high (+30%) mortality rates and that in the scenario, in which the natural fecundity increases (by 10%) and simultaneously the mortality throughout all age classes (by 10%) decreases. Although in all cases, after the termination of the supplementation programme, the population at the end of the 50-year period becomes extinct or reaches very low numbers, there is very big difference in the mean number of survived individuals at the end of the 30-year period between scenarios that consider restocking, and scenarios that simulate increased mortality rates.

Discussion

Although we kept the ecological parameters of the species (productivity and mortality) within the limits of the observed values and proposed reasonable management actions, we were not able to find a scenario that would lead to the population growth of the Egyptian Vulture in Macedonia. The conservation measures implemented in the period 2003-2011, if continued with the same intensity, will be far from sufficient to stop the extinction of the species in Macedonia. According to the basic scenario, the population of the Egyptian Vulture will certainly disappear in 50 years, but actually the median and mean time of first extinctions indicate that it might become extinct in half of that time. Similar scenarios with negative trend for the Egyptian Vulture were found in Ebro Valley (Grande 2006), three out of five regions in Spain (García-Ripollés, López-López 2011) and Italy (Andreotti, Leonardi 2009), all of the mentioned authors used the mortality rates from Ebro Valley (Grande *et al*. 2009). We should note, however, that the values for survival rates given by García-Ripollés, López-López (2011) (Table 1 in their paper) do not correspond (i.e, are lower) to the values given by the source they provide (Grande *et al*. 2009). If this inconsistency is more than a technical mistake, it may lead to unreliable results regarding the trends in the remaining two Spanish sub-populations. The time period, in which the Macedonian population decreases by 40% (about 10 years), is much shorter than the period of similar population decrease in Ebro Valley, Spain (25 years, Grande 2006). In that case, the author suggested possible immigration of adults from other regions to contribute to the population persistence. Such rescue effect is very unlikely for the Macedonian population, as the entire Balkan population is in steep decline. As the general productivity rates of the Macedonian population are similar to those found in Spain (Grande 2006, García-Ripollés, López-López 2006, Cortés-Avizanda *et al*. 2009), such steep decrease in the Macedonian population presumably owes to higher mortality rates, and therefore, the baseline scenario that uses mortality data from Spain might well be considered optimistic. We should further note that if mortality rates are indeed higher than in Spain, then our initial population size should be smaller than the one we used in our simulations (since it was derived on the basis of observed numbers of fledged juveniles in the period 2006-2011 and the survival rates found in Spain), this will inevitably lead to even shorter time period to first extinctions.

Our findings are in accordance with the studies of Grande (2006) and García-Ripollés, López-López (2011) who showed that the mortality is much more significant factor in the population dynamics of the Egyptian Vulture than the productivity. Our results further show that it will be probably not sufficient to slow down the population decline with management actions which only aim at improving survival in adults and subadults. Although poison is believed to be the main reason for the losses in the breeding range in Macedonia, losses during migration and/or wintering are also suspected to be significant (Grubač *et al*. 2014). Several factors may lead to such increased mortality rates in the Egyptian Vultures in Macedonia:

Risks along migration routes. Exceptionally high risk of poisoning incidents may occur at some gathering sites along the migration route, such as the rubbish dumps (known in Turkey, I. Angelov, pers. comm., Vaassen 2003, Vaassen, Aykurt 2003), or at other, still unknown sites that cause high continuous mortality. Such site is the power line in Sudan, which since probably the 1950s has killed large numbers of Egyptian Vultures (Angelov *et al*. 2013). So far there are no studies that offer any evidence in this direction. An additional problem of particular relevance to the inexperienced juvenile birds may be the selection of migration route. Although most of the juveniles from the eastern part of the Balkan range choose safe route via the Dardanelles and Bosporus (Meyburg *et al*. 2004, www.lifeneophron.eu), the only two satellite-tracked juveniles from the central part of the Balkans (one from Macedonia and another one from Greece) unsuccessfully attempted to cross the Mediterranean via Peloponnesus (unpublished data of the Bulgarian Society for Protection of Birds, the Hellenic Ornithological Society and the Macedonian Ecological Society). It is known that the juvenile Egyptian Vultures, which migrate from Sicily to Africa, follow the adult birds during their first migration and choose the safer route via the island of Marettimo instead of crossing directly to Africa; presumably they learn this migration route from the adults (Agostini *et al*. 2004). Although there are only preliminary information on migration of the Egyptian Vulture in the central-eastern Mediterranean available (Lucia *et al*. 2011), it seems that the juvenile Egyptian Vultures, which try to cross the Mediterranean Sea via Crete and smaller islands, are more numerous than the adults (8 juveniles vs. 2 adults in 2008 and 4 juveniles vs. 1 adult in 2009), which presumably take the safer circuitous route, and thus are exposed to higher risk of unsuccessful sea crossing. The possibility of juvenile birds fledged in Macedonia to follow migrating adults has probably been drastically reduced after the loss of pre-migration gathering site at the dumping place near Negotino (Grubač *et al*. 2014). It was shown that the high mortality rates in wintering and dispersal areas among the non-breeders can significantly contribute to population decrease due to the impossible recruitment of new birds in the breeding pool (Penteriani 2005). Therefore, in order to increase the survival of non-breeders ("role" of the *muladares* in Spain, Donázar *et al*. 1996) and to enable the gatherings before migration, it might be beneficial to facilitate the formation of roost(s) (the best in the vicinity of the former pre-migratory gathering site) by regular provision of large quantities of food, and to perform regular monitoring in order to avoid catastrophic poisoning events.

Negative impact on the wintering territories, e.g. the general deterioration of the environment in West Africa induced by about triple increase in human population in the last three decades has affected many raptors and other large birds, and their decline has been relatively well documented (Rondeau, Thiollay 2004, Thiollay 2006c, 2007a, Anadón *et al*. 2010). The factors that cause population decrease most likely include the reduced food availability (general decrease of mammals and improved veterinary practices), poisoning and direct persecution, as well as the use of vultures in human diet and religious rituals. The Egyptian Vultures in Western Africa have apparently decreased by 86% (Rondeau, Thiollay 2004, Thiollay 2006a), although the authors could not distinguish between resident and migrant populations. In general, the trans-Saharan migrants have experienced less pronounced decrease (Anadón *et al*. 2010) which is explained by a shorter period of exposure to the threats in the wintering regions. Furthermore, large birds and raptors have experienced a less pronounced decrease in the protected areas (Thiollay 2006a, 2007a) (however, no Egyptian Vultures have been found in the protected areas, Thiollay 2006a, 2007b) and in areas, which are less modified and have small human population (Thiollay 2007a, Anadón *et al*. 2010). That decrease was explained with the increased hunting pressure for bush meat (Thiollay 2006a), which is found to be significantly lower in the protected areas (Brashares *et al*. 2001). The wintering regions of the Egyptian Vultures breeding in Macedonia are not known, although they are probably not very different from those of the birds in Bulgaria and Greece, which have currently been better understood by means of satellite-tracking (www.lifeneophron.eu). Those regions are found further east than the wintering areas of the birds from France, Spain and Italy (Meyburg *et al*. 2004, Ceccolini *et al*. 2009, García-Ripollés *et al*. 2010, Carrete *et al*. 2013). The decrease of the Egyptian Vultures has been documented in the central part of the Sahel region as well (Thiollay 2001, 2007b). Based on available data, we can conclude that the eastern parts of Sub-Saharan Africa (possible wintering regions of the Egyptian Vultures from the Balkans) are not very safe as well. There are reports about negative effects on the population of *Gyps africanus* vultures in Kenya as a result of the use of carbofuran (Otieno *et al.* 2010), and about a general decrease by 40% in the numbers of raptors in the period 2001-2003, with a decrease in the number of vultures by 70% (Ogada, Keesing 2010), as well as reports about a general decline of the Hooded Vulture *Necrosyrtes monachus* in eastern Africa (Ogada, Buij 2011). As present, the protected areas, which are roughly the wintering regions of the Egyptian Vultures, appear to have very low coverage and poor implementation of the protection measures

(Rondeau, Thiollay 2004, Thiollay 2006a). The establishment of new protected areas and the implementation of active conservation in the wintering regions of the birds that originate from the Balkans should be beneficial for the Egyptian Vulture survival. However, as survival of the Egyptian Vultures in the wintering areas also depends on the primary productivity (Grande 2006, Grande *et al*. 2009), the effective conservation actions may not be easy to implement. Still, there is an urgent need to understand the migration routes and to determine the wintering regions of the birds breeding in Macedonia.

Four major trends/groups can be distinguished among the results of our population simulations:

1. We found a "time buying" scenario (30% reduction in all mortality rates) that allows for approximately half of the present population to survive in the next 25 years. This scenario requires significant efforts to control the direct threats that cause un-natural mortality at the breeding grounds, as well as in the wintering regions and along migration routes. Given the ecology of the species (trans-Saharan migrant), such reduction of mortality will require substantial international coordination, efforts and resources. If the conservation measures aiming at reduction of mortality are focused only on the sub-adult and adult portion of the population during the breeding period (i.e, on the birds that breed or search for territories in Macedonia), the population remaining at the end of the 25 year period will be further reduced to half. Based on the current experience of countries that implement more intensive conservation measures, the negative trend can be locally stopped (e.g., in the Italian Peninsula, primarily owing to the absence of poisoning and after the establishment of feeding places, Liberatori, Penteriani 2001), or even reverted (e.g., in Sicily, due to decreased disturbance and persecution, but also probably because of improved survival in wintering regions, Sarà, Di Vittorio 2003). We should note, however, that after a period of stabilization and/or increase, the Italian population recently continued to decline both on the Peninsula and in Sicily (Andreotti, Leonardi 2009). Similar cases of population increase have been observed in some regions of Spain: in the Cantabrian Mountains, a region characterized by low number of poisoning incidents, where the increase might also be due at least partially to improved census (Mateo-Tomás *et al*. 2010); and in the Bardenas National Park, where neither poisoning nor persecution have been recorded (Cortés-Avizanda *et al*. 2009). The establishment of protected areas without the implementation of specific species-oriented conservation measures, such as prevention of poison use, disturbance and supplementary food provision, has not been sufficient to stop the decline of the Egyptian Vulture neither in Macedonia (Grubač *et al.* 2014), nor in Bulgaria and Greece, where the Natura 2000 network of protected sites under the EU Birds and Habitats directives has been established (unpublished data of the Bulgarian Society for Protection of Birds and the Hellenic Ornithological Society).

2. Our simulations clearly show that the best results are obtained by combination of the measures from the previous scenario aiming at mortality reduction and the measures aiming at increase of the productivity of the Egyptian Vultures by 30%. Some of the measures needed to achieve the effects of the previous scenario, notably the supplementary feeding, are also expected to contribute to the increase in the fecundity of the Egyptian Vulture, as has been observed in other obligatory or facultative scavengers (González *et al*. 2006, Oro *et al*. 2008). However, evidence for direct positive impact of those measures on the Egyptian Vulture reproduction is still missing (Vlachos 1998). Such supplementary feeding should preferably be aimed at individual pairs instead of at formation of large feeding places, which were reported to bring long-term risks to the populations (Carrete *et al*. 2006, Lemus *et al*. 2008) and to facilitate gathering of large number of birds at one place (Oro *et al*. 2008). Thus, the risk of mass poisoning using the food provided at the feeding places as bait (as happened in Macedonia in 2011 and led to the death of three adult Egyptian Vultures) will also decrease. As the majority of the breeding Egyptian Vulture population in Macedonia is outside the national network of protected areas (Velevski *et al.* 2010), an establishment of new protected areas for the species is needed in order to stop the further habitat loss and to reduce the disturbance at the breeding sites, both factors considered of importance to the territory persistence (Carrete *et al*. 2007) and to the breeding failure (Zuberogoitia *et al*. 2008). Active measures to reduce the poisoning risks will be also necessary.

3. We have paid special attention in developing scenarios that consider captive breeding programme. Restocking in fact means an artificial increase in the productivity of the population. Our results show that restocking has low impact on the population persistence. The main difference from the natural productivity in our scenarios is that the number of released juveniles is not dependent on the population size once it becomes very small, and thus it has a stronger positive effect on the population size. We found that restocking activities without *in-situ* actions for the reduction of mortality and increase of

productivity do not bring any results. Our results clearly show that the population cannot achieve viability if the threats are not mitigated, this fact should be taken into account before every restocking or reintroduction programme starts (Griffith *et al*. 1989). Actually, in our supplementation scenarios that do not include in-situ conservation measures once the restocking programme stops the population will drop to numbers almost equal to the scenarios, which do not include supplementation of the population. If the restocking programme is implemented together with measures aiming at only a slight reduction of mortality and an increase in productivity, then the programme will ensure population increase for as long as it continues. Thus the programme will allow for the implementation of more successful conservation actions *in-situ* and will provide a longer time-period for general improvement of the environmental factors. The number of released juveniles (8 versus 4) substantially influence on the final results. However, the captivity breeding programmes are expensive to implement (in Europe, estimations are available only for the Bearded Vulture, Frey 1998). In the case of the Egyptian Vultures, we are facing a situation of relatively small European breeding stock (a total of 73 individuals of the nominotypical subspecies, *Neophron percnopterus percnopterus*, are kept in European zoos with very low breeding rates, Pithart 2010) and a lack of funding, knowledge and experience for the implementation of such programmes. Currently, except a pair in the zoo of Subotica (Serbia), which successfully reproduces in captivity (S. Marinković, pers. comm.), and one bird in the Sofia zoo (Bulgaria, S. Nikolov pers. comm.), no other birds of Balkan origin are known and can potentially enter a founder stock for such a breeding programme. Paired adult Egyptian Vultures seems to accept easily foster juveniles (Donazar, Ceballos 1990, Di Vittorio *et al*. 2006), and a hacking technique appeared to provide good results (Ceccolini, Cenerini 2005) if a release of juveniles is considered. Such juveniles can start and finish successfully the migration even if they originate from parents of different geographic origin (Ceccolini, Cenerini 2005, Ceccolini *et al*. 2009), most likely by learning the migration routes from the adults they follow (Agostini *et al*. 2004). Although we do not consider harvesting of juveniles from a wild population for the establishment of a breeding stock, rescued individuals, which are unfit for survival in nature, should become a part of the breeding stock. Such a restocking programme should also plan measures such as a release of adult instead of juvenile individuals, or a release of individuals from different age-classes, because those measures are expected to give better results in long-lived species (Sarrazin, Legendre 2008).

4. Finally, in four of the scenarios we simulated a further deterioration of the situation, by an increase in the mortality in all age classes (in two scenarios) and by a reduction in the productivity. An increase in the mortality will be a possible outcome if the infrastructural development projects are implemented in Macedonia without careful consideration of their environmental impact and the implementation of precise mitigation measures. Such projects include investments in the energy sector (wind farms, hydro-electric power plants, coal mines) and the infrastructure (motorways and railways). Wind-farms were reported to have negative effects on the population growth rates of the Egyptian Vultures in Spain (Carrete *et al*. 2009, García-Ripollés, López-López 2011) by causing extra-adult mortality. At least four of the planned wind farms in Macedonia are in the foraging (and former breeding) areas of the Egyptian Vultures, but none of them is in the 15 km risk-radius from the known breeding pair (as determined by Carrete *et al*. 2009). Other land-use changes, such as habitat homogeneity, intensive agriculture, fragmentation and urbanization, may further deteriorate the territory quality, and influence negatively on the territory selection of the Egyptian Vultures (Liberatori, Penteriani 2001, Sarà, Di Vittorio 2003, Carrete *et al*. 2007). Apart from the direct loss of breeding and foraging habitats, the infrastructural development and the uncontrolled development of alternative tourism may increase the disturbance rates and influence the territory abandonment and productivity (Zuberogoitia *et al*. 2008). Better enforcement of the sanitary regulation in Macedonia (presently many of the dead animals are not collected from the field) may result in decreased availability of livestock remains, which were reported to impact negatively on the vulture populations in general (Margalida *et al*. 2007, 2010, 2012, Margalida, Colomer 2012). Similar risk arises from the termination of the ongoing conservation measures (operation of feeding places) due to the financial challenges. Furthermore, the ongoing changes in the management of the hunting grounds in Macedonia (concessions on the hunting grounds are also issued to private companies, instead of only to local hunting associations and the public enterprise "Macedonian Forests") in combination with the current poor law enforcement regarding the prevention of poison use may lead to a higher risk of predator control by the poisonous baits. It may result in a shift in the current peak of poison use or, more likely, in the introduction of a second peak from the present February-early April

(author's unpublished data) to April-May-June (similar to Spain, Hernández, Margalida 2009), and may cause mortalities that will affect the survival of the adults, as well as the productivity of the population (Margalida *et al*. 2012). García-Ripollés, López-López (2011) also reported that even a small increase in the poisoning incidents have a significant effect on the population trend. Although there is a lack of regional data on the contamination with pollutants, we should also consider in future their potential impact on the fecundity rates (Lemus *et al*. 2008, 2009) of the Egyptian Vulture.

All these factors can cause rapid extinctions of the species, and may also compromise the expensive conservation measures of a possible restocking programme.

Presently the national Law on protection of Nature (Official Gazette of RM 67/2004, 14/2006, 84/2007, 35/2010, 47/2011, 148/2011, 59/2012) does not foresee a basis for the development of a species action plan on national level that will impose obligatory conservation targets for the Egyptian Vulture (and any other endangered species in Macedonia). Furthermore, in absence of a national red data book and even a national red list, national funding is unlikely to be available for imminent conservation measures. Based on our previous results (Grubač *et al*. 2014) on the reduction of the species range (extend of occurrence and area of occurrence), the period, in which the population decreased, the remaining population size, as well as the most likely survival of the species at national level in three generations (probability of survival in 39 years = 2%), and taking into account the decreasing trend in the Balkans, the Egyptian Vultures should be considered as Critically Endangered in Macedonia (CR A2a+4a;C1+2a(i);E) (IUCN 2012; IUCN Standards and Petitions Subcommittee 2013).

We mentioned that the predictions derived from the PVAs need to be considered as conservative ones, as one of the key parameters used – the mortality rate – was taken from a population that decreases at significantly slower rate. Under one plausible scenario (in which the mortality rates used in our simulations were 30% higher than those observed in the Ebro Valley in Spain), the population became extinct for mean time of 17 years, a period too short for the implementation of efficient restocking programme given the overall circumstances in Macedonia. For this reason, there is an urgent need to collect data on national or regional mortality rates of different age-classes in the Egyptian Vultures. As the current ringing programmes that are undergoing in Macedonia, Bulgaria and Greece focus mostly on ringing of (limited number of) juvenile birds, important time may be lost until those individuals are incorporated in the breeding population, and their turn-over is followed. Non-invasive DNA-fingerprinting technique has been developed (Rudnick *et al*. 2005). That technique makes possible the individual identification of each bird in the breeding population and allows monitoring replacements in the pairs for much shorter period of time. Given the high risk of imminent extinction of the Egyptian Vultures in Macedonia, an immediate implementation of such activity is highly desirable. These actions should also give insight in the spatial dynamics of the Balkan Egyptian Vulture population. Consequently, this PVA exercise should be repeated when data on survival rates and dispersal rates will become available from the Balkans, based on the combination of initiated ringing, satellite tracking (mostly on birds from Bulgaria and Greece, which might also provide additional information on the threats) and DNA-fingerprinting.

Given the similar steep decline of the Egyptian Vulture throughout the Balkan Peninsula, our findings probably also have regional validity. Further studies should also seek to find out whether there are some dispersal movements between the remaining Balkan subpopulations and the population in Turkey, which is also in decline (Iñigo *et al*. 2008), and eventually incorporate them in refined PVAs.

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