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TESTING THE EFFECT OF PERSECUTION AND PERMANENT DISPERSION OF SUB-ADULT BIRDS IN LONG-TERM SUSTAINABILITY OF WHITE TAILED EAGLES (*HALIAEETUS ALBICILLA* L.) POPULATION AT DIFFERENT MANAGEMENT OPTIONS IN CROATIA

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According to known population parameters, we used software Vortex for simulating long-term population dynamics of white tailed eagles (*Haliaeetus albicilla* L.) on fourteen management options. The main purpose of the study was the assessment of the dispersion rate detection importance (integrating effects of persecution and permanent dispersion) for the long-term viability of the population.
None of the fourteen management scenarios led the population to extinction (P(E)<0.00). Basic scenario, the one that represents the present knowledge about the population in Croatia, was determined with deterministic (r_{det}) and stochastic growth rates r_{stoch} of 0.074 and 0.072 respectively. All the scenarios with assumed dispersion rate of five sub-adult pairs had significantly lower deterministic and stochastic growth rates. Four of them, all characterised with degraded conditions for both breeding and non-breeding parts of the population, resulted in negative stochastic growth rates and led the population to extinction with probabilities ranged from r_{stoch} –0.05 to –0.093. According to the obtained results we gave recommendations for future monitoring program improvements focusing the field work on dispersion rate detection as well as on the non-breeding part of the population in general.

Key words: population, viability, eagle, sustainability, management

INTRODUCTION

Many populations in the wild, once widespread and numerous, today inhabit sparse and limited areas with low number of specimens. For most species, the reasons for declines in spread and number are mainly of deterministic nature, like overhunting and degradation of habitats in the way that no longer fulfil the basic needs for the species (MILLER & LACY 2003). The contamination of the environment with diverse chemical pollutants, as well as recent changes in the climate, has modified environment characteristics under the human performance. Population viability analysis (PVA) is the quantitative evaluation of all factors and their interactions that act on populations and contribute their risks of short and long-term decline or extinction. The method is widely applied in conservation biology for comparing alternative options for species management (BROOK *et al.* 2000). PVA uses population demographics data to project population persistence over given time period and plays an important role in developing conservation strategies for numerous species (NISBET & GURNEY 1982, PATTERSON & MURRAY 2008). There are, also, different types of criticism from numerous authors on problems in using PVA analysis like limited data used to estimate population parameters for rare species (COULSON *et al.* 2001), lack of precision in population parameters (ELLNER *et al.* 2002) and lack of independent model validation (MCCARTHY *et al.* 2001) but for the moment being few alternatives to PVA have been offered.

Drastic decrease in European population of the white tailed eagles lasted until the 1960s (TUCKER & HEATH 1994). In the 1980s the population in Europe was at the lowest (SCHNEIDER-JACOBY *et al.* 2003). After abandonment of DDT and PCB the European population has started to recover (STJERNBERG & SAUROLA 1983). Even until the beginning of the 20th century, the white tailed eagle had been bread on the island of Cres in the northern Adriatic and a small isolated population along Neretva river estuary survived until 1960s (RUCNER 1998). Since then there was no data on breeding attempts in the entire Croatian Adriatic region (RADOVIĆ, D. pers. comm.). At the beginning of the 1990s about 80 pairs lived in Croatia (TUCKER & HEATH 1994) and according to RADOVIĆ *et al.* (2003) in the year 2000 Croatia held 80–90 pairs. RADOVIĆ and MIKUSKA (2009) have confirmed the increase of the population and today this is the second largest population in the neighboring Central European countries (BIRDLIFE INTERNATIONAL 2004).

Recent monitoring program of white tailed eagles in Croatia is based on checking only the territory occupancy and partially breeding success without considering the non-breeding part of the population and as such can postpone the detection of decrease in number of individuals in the population (KENWARD *et al.* 2000). Since the dynamics of non-breeding part can differ from breeding part of the population (PENTERIANI *et al.* 2006) by influencing the stability of the population in the whole (BROWN & KODRIC-BROWN 1977) the simulations are used to emphasize the extent and specific set of negative influences that can affect the populations the most. Fourteen possible scenarios (original scenarios) were prepared as well as their equivalents with assumed dispersion rate of five sub-adult pairs. Two processes are integrated under the dispersion criterion: the persecution of sub-adult birds and permanent occupancy of the territories outside the area model was prepared for. The main aim of this paper was providing proof, by simulations, of the need for the monitoring system improvements of the white tailed eagles in Croatia in order to detect the early negative trends in the population. Special attention was given to the parameter dispersion (integrated effect of permanent hold of territories away from the area for what the model is prepared and illegal persecution of sub-adult birds).

MATERIALS AND METHODS

Basic model is representing our present knowledge of the white-tailed eagle population in Croatia. Some of the parameters used in simulations are the result of author's prior research on species but for those missing we used the assessed values for some other European population with observed similar recovery during last decades. Population of white tailed eagles in Croatia was monitored during 1980s and 1990s but occasionally and on restricted part of the population. According to preliminary results of marked young white tailed eagles (HAM *et al.* 1990) they were recorded as far as 178 km apart of hatching place so it is realistic to assume that some of the pairs estblish their permanent territories outside Croatia. All simulations were performed with Vortex 9.94 (© Copyright 2009 Zoological Society of Chicago).

Population productivity – Data on productivity (Table 1) for the part of the population from Nature Park Kopački rit for the period 1986–1989 (unpubl. data) and 2005–2007 (RADOVIĆ & MIKUSKA 2009) were applied to the whole population since authors did not manage to prove the difference in breeding success for the part of the population inside and outside the borders of protected areas (RADOVIĆ & MIKUSKA 2009). Simulations were made with the assumption that population comprises of approximately 130 breeding pairs (RADOVIĆ & MIKUSKA 2009). Exact number of individuals was calculated by Vortex providing it with assessed mortality rates for specific age classes.

Longevity and maximal age of reproduction – Precise monitoring of survival and longevity is known for a handful of species (KOHLER *et al.* 2006). Longevity of *Haliaeetus albicilla* in the wild was assessed with several authors STRUWE-JUHL (2003) at 17, NEWTON and OLSEN (1990 cited from KOHLER 2006) at 21.1 and DELHOYO *et al.* (1992) at 27 years. We assumed the breeding performance during animal's lifetime assessed at 20 years.

Mortality rates for age classes – According to KOHLER *et al.* (2006) there are no differences in mortality rates for female and male birds. Analysis of re-sight of marked white tailed eagles from Sweden for the period 1991–1999 revealed that the minimal survival rate from first till fourth year ranged from 86–96% (SAUROLA *et al.* 2003). Annual survival rate for the first two years of young white tailed eagles from Norway was 90–95% (NYGÅRD *et al.* 2000). Reintroduced population from Scotland revealed the annual survival rate for the birds before the retrieval of permanent territories was assessed at 73–75% and 94–97% for adult birds (GREEN *et al.* 1996). For closely related species *H. leucocephalus* BOWMAN *et al.* (1995) detected annual survival rate during first year at 71% and 90% after first year. In contrast to all stated BROWN (1997) found high mortality rate of young *H. leucocephalus* at even 95%. The survival rate for adult (6–21 years old) white tailed eagles from Sweden was estimated according re-sighting of individuals to 91–98% (HELANDER *et al.* 2002). Similar results can be assumed for Croatian population since from data on re-sighting of marked birds on the territory of former Yugoslavia (HAM *et al.* 1990) revealed the high survival rate. Estimated mortality

Table 1. Productivity parameters for the part of population from Nature Park Kopački Rit for the period 1986–1989 and 2005–2007.

	1986	1987	1988	1989	2005	2006	2007
Successful	5	12	14	8	9	18	19
No. of fledglings	7	18	18	13	12	32	34
No. of fledglings / Successful	1.40	1.50	1.30	1.63	1.33	1.78	1.79

No. of fledglings / No. of successful pairs: Mean±SD 1.56±0.21

Percentage of successful pairs (according to RADOVIC & MIKUSKA 2009): 77%

rates for particular age class were derived from literature data on white tailed eagles research from Europe and are all presented in Table 2.

Dispersion is the movement of organisms away from their parent source and within Vortex dispersion is assumed when individuals from some population permanently occupy territories outside the range for what model is prepared. The effect of illegal hunting was integrated into the model through setting dispersion parameter to five sub-adult pairs per year.

Simulated scenarios

- 1) Basic scenario – parameters of the model are estimated on the basis of the research of breeding success during 2003–2006 (RADOVIĆ & MIKUSKA 2009); young bird markings (1986–1990 and 2005–2007); unpublished data on breeding success of the part of the population from the Nature Park Kopački Rit) and with the published data on white tailed eagle population from other populations from the region (all cited before in this section). The basic scenario is describing most probable state of the population and it is used for comparison of relative impact on population of other simulated scenarios.
- 2) Improved conditions during breeding season (sufficient food supply and lower disturbance rate) that reflect improved productivity and decrease of adult and sub-adult mortality.
- 3) The best scenario – improved conditions for breeding part of the population, lower mortality of sub-adult birds as well as permanent increase in carrying capacity (for example with building new carp fish ponds or improving the forest structure in the area where the limiting factor for the population growth is lack of adequate breeding ground).
- 4) Small degradation of temporal territories that reflects in the increased mortality of sub-adult birds without permanent territories without any influence on breeding success of the population.
- 5) Larger degradation of temporal territories that reflects in the increased mortality of sub-adult birds without permanent territories.
- 6) Reduction in food supplies for the breeding part of the population that reflects in the decrease of productivity and increase of adult birds mortality rate.
- 7) Decrease of food supplies with degradation of temporal territories of sub-adult birds. This can be caused with increase of contamination of environment with chemical substances that for some longer time period decrease the productivity of the population. Similar effects will be achieved with increased disturbance rate for breeding and non-breeding part of the population that reflects in the decreased productivity and increased mortality rate for sub-adult birds.
- 8) Lighter degradation of temporal territories that reflects in the increase of mortality rate of non territorial birds with the simultaneous appearance of catastrophic years that periodically decrease productivity of the population and increase mortality of the adults. Example for this kind of catastrophes would be the acute (short term) environmental pollution that affects population only during one year.
- 9) Heavier degradation of the temporal territories quality with more frequent catastrophic events that result in higher increased mortality rate of non territorial birds and with more often and stronger periodical decrease of productivity.
- 10) Permanent decrease of food supply for breeding and non-breeding (non territorial) part of the population that reflects on decreased productivity, increased mortality rates for adults and non territorial birds.

Table 2. Estimated parameters used in preparation of the basic model.

Parameter	Value
Iterations	500
Years	200
Extinction definition	Only 1 sex remains
Number of populations	1
Inbreeding depression	Included into mortality rates for young birds from 0–1 year
Lethal equivalents	3.14 (RALLS *et al.* 1988)
Percent due to lethal alleles	50
EV concordance	Yes
Number and types of catastrophes	1 – extreme weather conditions
Reproductive system	Long – term monogamy
Age of the first reproduction for female and males	5 (STUWE-JUHL 2003, EVANS *et al.* 2003)
Maximal age of reproduction	21 – individuals breed in characteristic way during lifetime
Maximal number of young per year	3 (WILLGOHS 1961, HELANDER 1985, YOUNG 1994)
Ratio of the sexes at birth – expressed as % of males	50
Percentage of adult females that breeds	60–80
Productivity	Normal approximation
Mean±SD	1.56±0.21
Presence of the difference of % in breeding females in relation to density of breeding pairs (density dependant breeding)	Yes
Environmental stochastic variation in % of breeding pairs	10
0–1 year estimated mortality rate	8% (SD 2%)
1–2 year estimated mortality rate	8% (SD 2%)
2–3 year estimated mortality rate	8% (SD 2%)
3–4 year estimated mortality rate	8% (SD 2%)
4–5 year estimated mortality rate	8% (SD 2%)
Adult birds estimated mortality rate	5 (SD 2%)
Population number estimate	480 start with specified age distribution
Carrying capacity	576 (arbitrary set to 30% increase from most recent estimation)
Standard deviation in carrying capacity caused by environmental variability	50
Future changes in K	NO (tested through scenarios)
Harvest	Yes (2 adult females and 2 adult males yearly, start at 1st year)
Supplementation	No

Table 3. Percentage changes in parameters used in simulations of described scenarios given in relation to the basic scenario.

Scenario	Reproductive rate	Carrying capacity (K)	Survival rate – non-territorial birds	Survival rate – adult birds
1	0	0	0	0
2	30	–	20	20
3	–	15	20	–
4	–	–	–30	–
5	–	–	–45	–
6	–20	–	–	–15
7	–30	–	–30	–
8	–40 – short-term (frequency 5)	–	–30	–30 – short-term (frequency 5)
9	–40 – short-term (frequency 10)	–	–30	–30 – short-term (frequency 10)
10	–15	–	–15	–15
11	–15	–15	–15	–15
12	–	(basic value the same – SD 20% of basic value)	–	–
13	–15	–	–	–
14	–50	–	–	–

– 11) Simultaneous effects of several relatively small negative influences.

– 12) Long-term fluctuation in relatively high carrying capacity that can be caused by change and/or decreased production of fresh water fish. Similar effect can be produced by changes in the climate that can have as its result the irregular floods of the alluvial forests highly important for white tailed eagles.

– 13) Degradation of high quality breeding habitats that can result in small but long-term decrease in breeding success because of increased distance from the breeding to feeding place.

– 14) Increased disturbance rate on breeding place that can affect the breeding performance for longer period. Similar effect can be the result of higher level of environmental contamination

All described scenarios were simulated also in its equivalent with the assumption that five sub-adult pairs exit the population (supposed dispersion and illegal hunting) (Table 3). All scenarios were simulated 500 times as suggested by HARRIS *et al.* (1987) for the 200 year period since ARMBRUSTER *et al.* (1999) shown that simulation models for the long-lived species that were projected for 100 years underestimated the probability of extinction.

RESULTS

None of the fourteen basic scenarios had led the researched population to extinction. For the basic scenario exponential rate of growth $r = 0.1$ and finite growth rate $\lambda = 1.106$ were obtained. Table 4 represents the results of the simulations according to described management scenarios in the form of stochastic growth rates of the population as well as with related standard deviations. The numbers of individuals in the populations are high even at worst scenarios numbered 7, 8 and 9. Much worse results are obtained for the same scenarios with assumed dispersion rate of five sub-adult pairs. Scenarios with lower stochastic growth rates are also characterised by high values of standard deviations (Table 4). Comparison test of the mean difference revealed statistically important difference in absolute values of the stochastic growth rates among scenarios without and with assumed dispersion ($t = 2.6$; $p < 0.01$; $df = 26$).

Total numbers of the individuals in all simulated scenarios with assumed dispersion are significantly lower when comparing with its equivalents without dispersion (Table 4). All scenarios numbered 4–13 showed significant sensitivity for assumed dispersion rate that is seen by more pronounced variations in the mean number of the individuals and lower stochastic growth rates. Four of the scenarios with assumed dispersion lead population to extinction with probabilities (P(E)) ranging from 0.502–0.996 (Table 4). More than 50% of simulated populations for scenarios 9d and 14d went extinct giving median time to extinction (median TE) 142 and 54 years respectively.

The best scenario (scenario no. 3) that assumes improvement of the conditions for both breeding and non-breeding parts of the population (among other through permanent increase of carrying capacity), supposed dispersion rate of five sub-adult pairs, significantly influence the mean number of the survived individuals but it still remains very high with low fluctuation in number over the years. For most of the scenarios (coded from 5 to 14) the assumed dispersion significantly affected the standard deviations of survived individuals from simulated scenarios.

DISCUSSION

Unavailability of good quality data is one of the main obstacles for usage of population viability analysis and results presented through this paper should be regarded as rough indicator in which direction future research of population should be focused as well as for the relative comparison of appropriateness of management options (AKÇAKAYA *et al.* 1999, YOCCOZ *et al*. 2001). Beside attempt of de-

Table 4. Results of simulations. Nonparametric comparison (paired Wilcox test) of the mean number of the individuals from simulated population without and with assumed dispersion of five sub-adult pair. Coding: deterministic r (det-r), stochastic r (stoch-r), difference in deterministic and stochastic growth rates (DIFF), mean number of the survived populations (N-all) – original 14 scenarios (org), scenarios with assumed dispersion

	r_{stoch}	r_{stoch}			SD(r)			P(E)			N-all			
Scenario	Orig/DISP	orig	DISP	DIFF	orig	DISP	DIFF	orig	DISP	DIFF	orig	DISP	Wilcox-Z	p-value
Basic	0.074	0.072	0.052		0.06	0.07		0.000	0.000		541	531	3.91	0.00
2	0.115	0.112	0.094		0.07	0.07		0.000	0.000		558	551	3.90	0.00
3	0.082	0.083	0.066		0.06	0.07		0.000	0.000		637	628	3.38	0.00
4	0.060	0.059	0.038		0.07	0.07		0.000	0.000		539	517	3.92	0.00
5	0.065	0.064	0.043		0.07	0.07		0.000	0.000		538	521	5.03	0.00
6	0.023	0.023	**–0.050**		0.06	0.14		0.002	**0.996**		491	0	5.13	0.00
7	0.026	0.026	**–0.038**		0.06	0.13		0.000	**0.952**		504	11	5.50	0.00
8	0.056	0.051	0.014		0.11	0.13		0.006	**0.502**		499	217	5.50	0.00
9	0.039	0.025	**–0.044**		0.14	0.20		0.194	**0.978**		337	7	4.77	0.00
10	0.051	0.050	0.027		0.06	0.07		0.000	0.032		531	481	5.03	0.00
11	0.051	0.048	0.013		0.06	0.08		0.000	0.266		440	274	5.15	0.00
12	0.074	0.072	0.052		0.06	0.07		0.000	0.000		533	514	5.50	0.00
13	0.057	0.057	0.036		0.06	0.06		0.000	0.002		536	510	5.40	0.00
14	0.008	0.006	**–0.093**		0.06	0.17		0.078	**1.000**		367	0	5.40	0.00

mographic research of the population during 1980s (HAM *et al.* 1990), almost all recent activities of monitoring of the white tailed eagles in Croatia were focused on determination of number of produced fledgling per breeding pair as well as on the detection of number of breeding pairs in the area that poorly reflects population size growth and are not informative on severe changes in the population size (KENWARD *et al.* 2000, KATZNER *et al.* 2007). It is unrealistic to expect that in the near future field work would extend to all demographics parameters but simulations presented emphasized the importance of incorporating some parameters through direct research or detection through highly correlated surrogates whose main task is to narrow future field research (e.g. MORRISON & POLLOCK 1997, FERRER *et al.* 2004). Simulations results obtained on the basis of known population parameters together with some estimation based on knowledge from some other European populations, revealed the combination of factors that greatly influence the future population dynamics.

Neither of fourteen simulated scenarios without assumed dispersion leads the population to extinction. Much poorer results were obtained for the scenarios with assumed sub-adult disperse from the population. The worst results are obtained for the scenarios where we assumed degradation of conditions for both, breeding and non-breeding parts of the population (Table 4). Four simulated scenarios with assumed dispersion (7d, 8d, 9d and 14d) bringing population to extinction emphasising the importance of more precise assessment of the dispersion rate of the population. These results are in concordance with the statements of PENTERIANI *et al.* (2005*a*) that emphasized potentially large influence of simultaneous impact of several negative effects on viability of the population in whole. Simulated scenarios show the model sensitiveness for parameters adult mortalities as well as the long-term changes in reproductive rate (Table 4). Scenarios with those parameters simultaneously detrained in some extent parameters like deterministic, stochastic growth rate total number of individuals in population which had significantly lower values while standard deviations from the mean value increased. The worst scenario (9) is associated with several simultaneous effects that influence both breeding and non-breeding parts of the population in conjunction with catastrophic years. This is in concordance with the statement of PENTERIANI *et al.* (2005*a*) that environmental stochasticity influences greatly the population dynamics when it acts synchronously among breeding area and temporary territories of sub-adult birds. The specific breeding characteristic, e.g. low reproductive rate with high survival of fledglings makes the species vulnerable to adult mortality rates as well as to long-term decrease in productivity rate (GREEN & HIRONS 1991, WOOTTON & BELL 1999). Even though the population of white tailed eagles in Croatia has been increasing for the past two decades we must not forget that in recent past the species was at the edge of extinction proclaimed globally threatened (TUCKER & HEATH 1994) mostly due to decreased productivity (FALANDYSZ 1994, HELANDER *et al.* 2002) and persecution where the latest remains the main obstacle for the population recovery in South Europe (HELANDER & STJERNBERG 2002, HELANDER *et al.* 2002). The dramatic decrease of white tailed eagle reproduction due to the influence of DDT and PCBs, and the subsequent rise following their ban, illustrates the usefulness of raptors like sea eagles as sentinels for environmental pollutants (HELANDER *et al.* 2008).

All scenarios that assume the periodical impact of catastrophic years yielded poor results (Table 4). One of the reasons for considering those kind of scenarios likely to occur is the high dependence of the regarded population on semi-natural food source like carp fishponds (RADOVIĆ & MIKUSKA 2009) and possible future changes in climate. Construction of new carp fishponds are the main reason for enlargement of the breeding area in the central part of the country, in the first place. This production is subjected to diverse problems that can result in abandonment or significant reduction of the production as already noticed in some areas (SCHNEIDER-JACOBY 2003).

The changes in white tailed eagle habitats in Croatia are already detected (report in preparation) along the entire breeding area as well as along the area used by non-territorial (sub-adult) birds. Sustainability of non-breeding part of the population, as subpart of the whole population, depends on local dynamics and probability that non territorial birds survive vagrancy every year and are successfully integrated into reproductive part of the population. In the same way that dynamics of the breeding part influence the non-breeding part of the population, vice versa holds also (MURRELL *et al.* 2002). This is the reason why we need to monitor the dynamics of the non territorial part of the population when modelling the breeding part. Since our knowledge of areas where non territorial bird settle before finding its permanent territory are scarce the little attention is given for their protection (PENTERIANI *et al.* 2005*b*). The research on it should be the one of the tasks in years that follow. A lot of species use highly anthropogenic area for their temporal territories which results in high mortality rates (sink areas) with significant biological consequences (FERRER *et al.* 2003). As all equivalent pairs of simulated scenarios revealed a great difference in both mean and standard deviations of stochastic growth rates as well as for the total number of individuals, the presence and quantity of emigration as well as potential immigration should be one of the main tasks for future field research.

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