

Population Dynamics of the Eastern Imperial Eagle (*Aquila heliaca*) in Hungary between 2001 and 2009

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Abstract: The Eastern Imperial Eagle (*Aquila heliaca* SAVIGNY 1809) reaches the western border of its range in the Carpathian Basin, which is the largest known population outside Russia and Kazakhstan. An increasing trend of this population in Hungary and also in the nearby areas of Slovakia has been reported since the 1980's, when the number of breeding pairs supposedly reached the historical minimum. In this study we evaluated the dynamics of the Hungarian Imperial Eagle population between 2001 and 2009. As a result of the continuous increase of the population the monitoring program revealed 105 nesting pairs by 2009. While an expansion of the breeding area towards lowland agricultural habitats was observed, the ratio of pairs inhabiting the historical mountainous breeding habitats decreased from 50 % to only 15 % during the study period. The frequency of the two- and three-chick broods in respect to single-chick broods increased in comparison to the 1980-2000 period showing a higher average annual productivity of the population (1.15 fledglings per nesting pair). Besides the favourable changes in population trend and productivity, the area expansion in the recently occupied lowland habitats also raised several new threats to the population, such as the increased number of illegal poisoning incidents and more frequent collisions with vehicles.

Key words: population dynamics, breeding success, agriculture, raptor, Hungary

Introduction

The Eastern Imperial Eagle inhabits a large area of the Palearctic region along the forest-steppe belt, although its distribution is highly scattered (DEL HOYO *et al.* 1995). World population consists of a few thousand breeding pairs only, and the species is classified as 'Vulnerable' by the IUCN Red List of Threatened Species (BIRDLIFE 2009). In spite of the high conservation priority of this species, only a fraction of the populations is monitored regularly (HORVÁTH *et al.* 2002), although the quality of available data increased considerably during the last decade, especially for the largest eastern populations (e.g. BELIK *et al.* 2002, KARYAKIN *et al.* 2008). Long-term monitoring of Eastern Imperial Eagle populations, which would enable us to evaluate changes in the population size, distribution, breeding success or mortality (FERRER 2001), are extremely rare and probably only two significant populations have been monitored continuously over the decades. One of these populations in the Naurzum Reserve in North-Kazakhstan remained stable since 1978 (BRAGIN 1999, KATZNER *et al.* 2006), while the other population in the Carpathian Basin in Central Europe increased significantly since 1977 (DANKO, CHAVKO

1996, HARASZTHY *et al.* 1996, BAGYURA *et al.* 2002).

The Carpathian Basin's population of Eastern Imperial Eagles is the most western population in its distribution area (DANKO, HARASZTHY 1997), where Imperial Eagles have continuously occurred and bred since written information was available. The first proved data is from as early as 1811, when an adult pair was collected near Vienna, East-Austria (NATURAL HISTORY MUSEUM OF VIENNA, unpubl. data). Later during the 19th century the Imperial Eagle was reported as a breeding species mainly from the southernmost parts of the Carpathian Basin, as Vojvodina (North-Serbia) and Slavonia (Northeast-Croatia) (VASVÁRI 1938). Nevertheless, we cannot exclude that this species was already present in other regions of the Basin as well, since reliable data were only available in exceptional cases from these early periods. The first published data from the present territory of Hungary is from the Bakony Mountains, where Imperial Eagles were observed during the breeding season in 1889. The first localised nest sites were reported from the beginning of the 20th century from the Vértes (1912), Zemplén (1913) and Bükk Mountains (1929) (VASVÁRI 1938, VÁSÁRHELYI 1964). After World War II, nesting of the Eastern Imperial Eagle was also recorded in almost all other mountainous regions in Hungary, such as the Buda (1950), Mecsek (1951), Gerecse (1954), Börzsöny (1957), Bakony (1959) and Pilis Mountains (1968), most probably as the result of an improved data collection, and not because of the expansion of the species (BÉCSY 1972, CSERESNYÉS 1960, PÁTKAI 1951, SÁGHY 1968, SOMOGYI 1971, TAPFER 1973, HUNGARIAN BIRD RINGING CENTRE unpubl. data, NÁDAI unpubl. data). Since no specific national surveys were performed until the late 1970's, we are not able to estimate the population size exactly in Hungary prior to these years. Nevertheless, we can conclude that in the middle of the 20th century the Eastern Imperial Eagle was a rare, but a characteristic breeding species in the Hungarian mountains, while the lack of observations and data on breeding from the Hungarian Plain suggest that the species probably did not breed regularly in open lowland areas (VASVÁRI 1938).

A national species-specific survey was initiated by MME Birdlife Hungary in 1977, and its results revealed that the species disappeared from several previously known breeding areas (i.e. Pilis, Buda

and Mecsek Mountains) and also became scarce in the remaining ones (HARASZTHY *et al.* 1996). From the available nesting records the Hungarian population seems to have reached its historical minimum by the late 1970's and early 1980's, when probably not more than 15-25 breeding pairs remained in mountainous forests (BAGYURA *et al.* 2002). From 1980 onwards due to favourable environmental changes, changes in human behaviour, and to the continuous population monitoring and conservation programme of MME and national park directorates of the Hungarian Ministry of Environment and Water, the known Imperial Eagle population size was increasing continuously. In the first decade of the programme (1980-1989) it was proven already that on the most intensively surveyed regions (Bükk, Zemplén and Mátra mountains) several new pairs of immature birds occupied territories. Anyhow during this period the increasing trend of the known population size could be biased also by the increased monitoring efforts. From 1990 onwards the monitoring has regularly covered the great majority of potential breeding habitats, therefore the changes in the number of known nesting pairs have presumably reflected the real changes of the population. In parallel with the increasing population size the breeding distribution of the species expanded from the mountain forests to the open plain habitats, where the first two breeding pairs were recorded in 1989. By 2000 the Hungarian population consisted of 54 known territorial pairs, from which 50 % occupied lowland agricultural habitats (BAGYURA *et al.* 2002).

In the present study our aim was to follow the dynamics of the Hungarian Eastern Imperial Eagle population between 2001 and 2009 and to compare recent population trends with the previously studied period of 1980-2000.

Material and Methods

Study area

The core breeding area of the Eastern Imperial Eagle in Hungary located in the central part of the Great Hungarian Plain (Jászság, Heves, Borsod, Nagykunság and Békés Plains) and the adjacent North Hungarian Mountains (Mátra, Bükk and Zemplén Mts.). Scattered breeding pairs can also be

found in the western regions of the country, namely in the Dunántúl Mountains (Vértes and Gerecse Mts.) and most recently in the Little Hungarian Plain at the north-western corner of Hungary (see detailed list and location of regions in Fig. 1).

In forested mountainous habitats (200-700 m a.s.l.) Imperial Eagles breed in Sessile Oak (*Quercus petraea* LIEBL.), Downy Oak (*Quercus pubescens* WILLD.) and Turkey oak (*Quercus cerris* L.), beech (*Fagus sylvatica* L.) and introduced pine (*Pinus nigra* J.F.ARNOLD, *Pinus sylvestris* L., *Larix decidua* MILL.) forests (KOVÁCS *et al.* 2005), sometimes more than ten kilometres from the nearest open foraging habitats. Recently a tendency shows that an increasing number of pairs are moving from the inner parts of the mountains toward the edges of the mountain ranges, and some of these pairs already occupied nest sites in the foothill foraging areas. In the lowland plain habitats (80-120 m a.s.l.) the Eastern Imperial Eagle breeds in small groups of poplars (*Populus*

sp. L.) and black locust trees (*Robinia pseudoacacia* L.). A complex of intensive agricultural fields and remaining grassland areas are the most preferred foraging habitats, usually within a 3-8 km radius around the breeding sites. In contrast, some of the mountainous pairs regularly forage even in a 10-15 km distance from their nests.

Population survey

The active and potential breeding territories of Eastern Imperial Eagles in Hungary were monitored within the framework of the Hungarian Imperial Eagle Working Group during the study period, as a continuation of the comprehensive species-specific survey started in 1980 (HARASZTHY *et al.* 1996, BAGYURA *et al.* 2002). The volunteers and employees of the MME BirdLife Hungary, the rangers of national park directorates and the amateur bird-watchers formed a well-trained national network of approximately 500 observers covering the majority of the potential breeding area of the Imperial Eagle

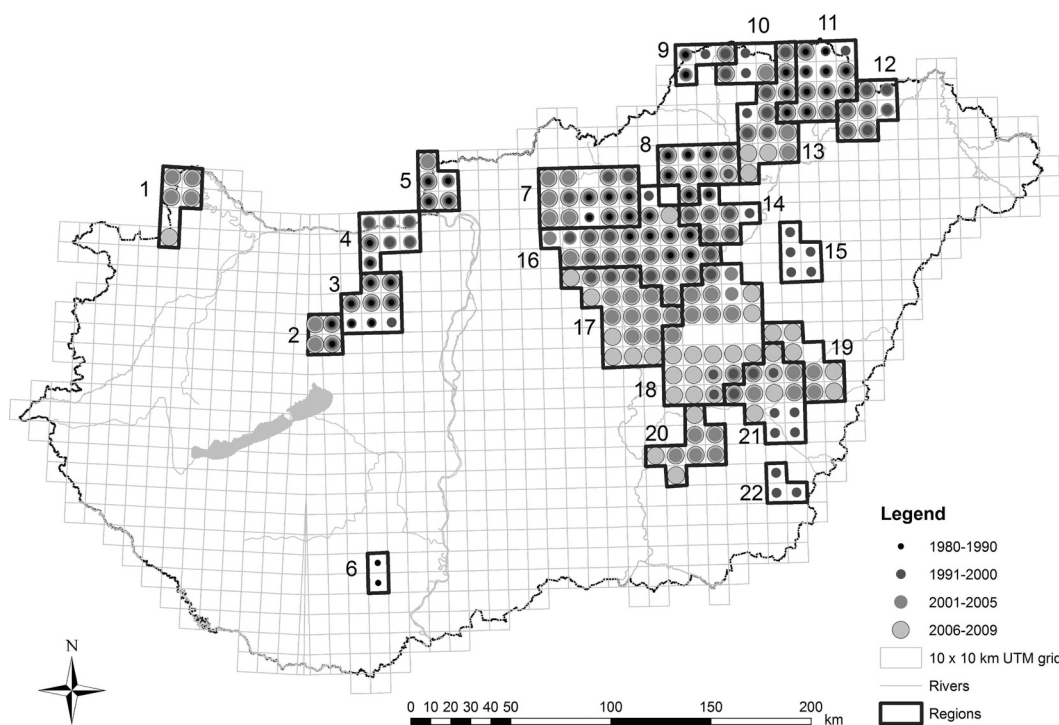


Fig. 1. Expansion of the breeding range of Eastern Imperial Eagles in Hungary between 1980 and 2009. Data are presented in a 10 km x 10 km UTM grid. GIS processed data derived from BAGYURA *et al.* (2002) represent the situation prior to 2001. Regions: (1) Little Hungarian Plain, (2) Bakony Mts., (3) Vértes Mts., (4) Gerecse Mts., (5) Börzsöny Mts., (6) Mecsek Mts., (7) Mátra Mts., (8) Bükk Mts., (9) Aggtelek Karst Mts., (10) Cserhát Hills, (11) Zemplén Mts., (12) Bodrogek Plain, (13) Hernád-valley and Taktaköz Plains, (14) Borsodi Mezőség Plain, (15) Hortobágy Plain, (16) Heves Plain, (17) Jászság Plain, (18) Nagykunság Plain, (19) Bihar Plain, (20) Cserebökény Plain, (21) Dévaványa Plain, (22) Kígyós Plain

in Hungary. We estimate that less than 5 % of the breeding Imperial Eagle pairs could have gone unnoticed, and the distribution and size of the population was reliably revealed within the study period.

We assigned territory coordinators for each breeding pair, who were responsible for the regular check of the given territories according to the suggested monitoring protocol. This included a thorough search for active nesting sites in potential territories at the beginning of the breeding seasons, during the time of displaying and nest building, but before leaving (February-March). Areas were handled as potential Imperial Eagle territories, if (1) an active nest was localised within a 10 km radius after 1980, or (2) more than one observations of adult or subadult birds were reported during the breeding season. In open lowland areas nest searching was executed by checking all of the potential trees or forest patches. However, in forested mountainous habitats typically daylong observations of the territorial birds' behaviour from vantage points were usually needed to locate the nest or to clarify the status of the territory. Identified nesting sites were checked at least once a month during the breeding period (from April to August) to determine breeding success. Nest observations were carried out with spotting scopes (20-60 X) from large distance (0.5-1.5 km) to avoid disturbance of the birds (GONZALEZ *et al.* 2006). However, in June at each nest we ringed the chicks in almost all of the nests and fixed the coordinates of the nests by GPS.

Altogether 673 nesting events in 127 different territories were followed in Hungary between 2001 and 2009. Data on breeding attempts were processed in a GIS database. In order to compare recent data with those previously reported by BAGYURA *et al.* (2002), we also processed historical data of 473 breeding attempts from the period of 1980 and 2000, and incorporated them in the same GIS database. Breeding success was described by three variables, such as the frequency of breeding attempts with at least one fledged chick (referred to as *success rate*), the mean number of young fledged per successful pair (referred to as *fledging success*), and the mean number of young fledged per nesting pair (referred to as *productivity*). When the exact sizes of the failed broods could not be determined (in case of 72 broods with eggs and 10 with chicks) the number of unhatched eggs or dead chicks per brood was de-

fined as two, as this is the most typical brood size in Hungary (authors own data).

Distribution of the territories was visualized in a 10 km x 10 km UTM grid by using ArcMap© software (ESRI Inc., version 9.0). Grid cells were considered as occupied if they were overlapped with an active breeding territory during the study periods. Hypothetical territory boundaries were defined as a 3.5 km buffer zones around the active nests. This size is approximately equal to the half of the average nearest neighbour distance in Hungary (KOVÁCS *et al.* 2005). It is notable, that for the closely related species, the Spanish Imperial Eagle (*Aquila adalberti* BREHM 1861), almost the same value, 3.25 km was defined and applied in a similar study (GONZALEZ *et al.* 1992).

Results

Changes in the breeding area

The breeding area of Eastern Imperial Eagles expanded significantly in the Great Hungarian Plain during the study period (Fig. 1). This species also occupied the Little Hungarian Plain as a result of the expansion of the West-Slovakian and East-Austrian populations (VÁCZI 2008). On the other hand the shrinking of the breeding range was observed in the western mountainous breeding pairs in the Bakony, Vértes, Gerecse and Börzsöny Mountains (only three pairs remained by 2009 out of the eight in 2001). Similarly, the single breeding pair of the Aggtelek Karst Mountains at the north-eastern part of the country disappeared in 2003.

Population trend

In Hungary the increasing trend of the Eastern Imperial Eagles' breeding population, which started in the 1980's, continued between 2001 and 2009, and with the 10 % mean annual increase it has become more intensive than ever since 1980 (Fig. 2a). The trend of the population differed relevantly between the two main breeding habitat types, as the number of mountainous breeding pairs slowly decreased (annually by -5 % in average), while lowland populations increased remarkably (annually by 15 % in average). Altogether, the Hungarian population almost doubled during the nine years of study and reached 105 breeding pairs by 2009, of which as many as 85 % bred in lowland agricultural habitats.

Breeding success

A total of 783 Imperial Eagle chicks fledged from 452 successful breeding attempts in Hungary between 2001 and 2009. Brood mortality was accurately surveyed between 2003 and 2009, meanwhile 142 breeding failures and further 60 cases of partial loss of broods caused the mortality of approximately 239 eggs and 81 chicks (Table 1).

Similarly to the trend of the population size, the number of fledglings also increased significantly in lowland habitats (Fig. 2b).

Annual success rate of breeding attempts ranged between 59 and 75 %, fledging success was between 1.54 and 1.93 fledgling per successful pair, and overall annual productivity was between 0.91 and 1.30 fledgling per nesting pair (Fig. 3).

In the study period the mean annual success rate was similar to the rate of the previous 20-year period

(1980-2000: 69 % vs. 2001-2009: 67 %). The mean proportion of two-chicks brood was slightly higher in the recent study period than in the previous one (1980-2000: 41 % vs. 2001-2009: 48 %); the difference was more prominent in the frequency of three-chicks broods (1980-2000: 5% vs. 2001-2009: 14%), and in parallel the frequency of one-chick broods decreased (1980-2000: 54% vs. 2001-2009: 40%). The higher frequency of larger broods resulted in a higher mean of fledging success (1980-2000: 1.48 vs. 2001-2009: 1.72) and also a higher overall productivity (1980-2000: 1.03 vs. 2001-2009: 1.15) (Fig. 4).

Causes of mortality

Identified mortality causes of full-grown Imperial Eagles are summarized in Table 2. Before 2005 electrocution was the main mortality cause, but poisoning incidents increased significantly between 2005

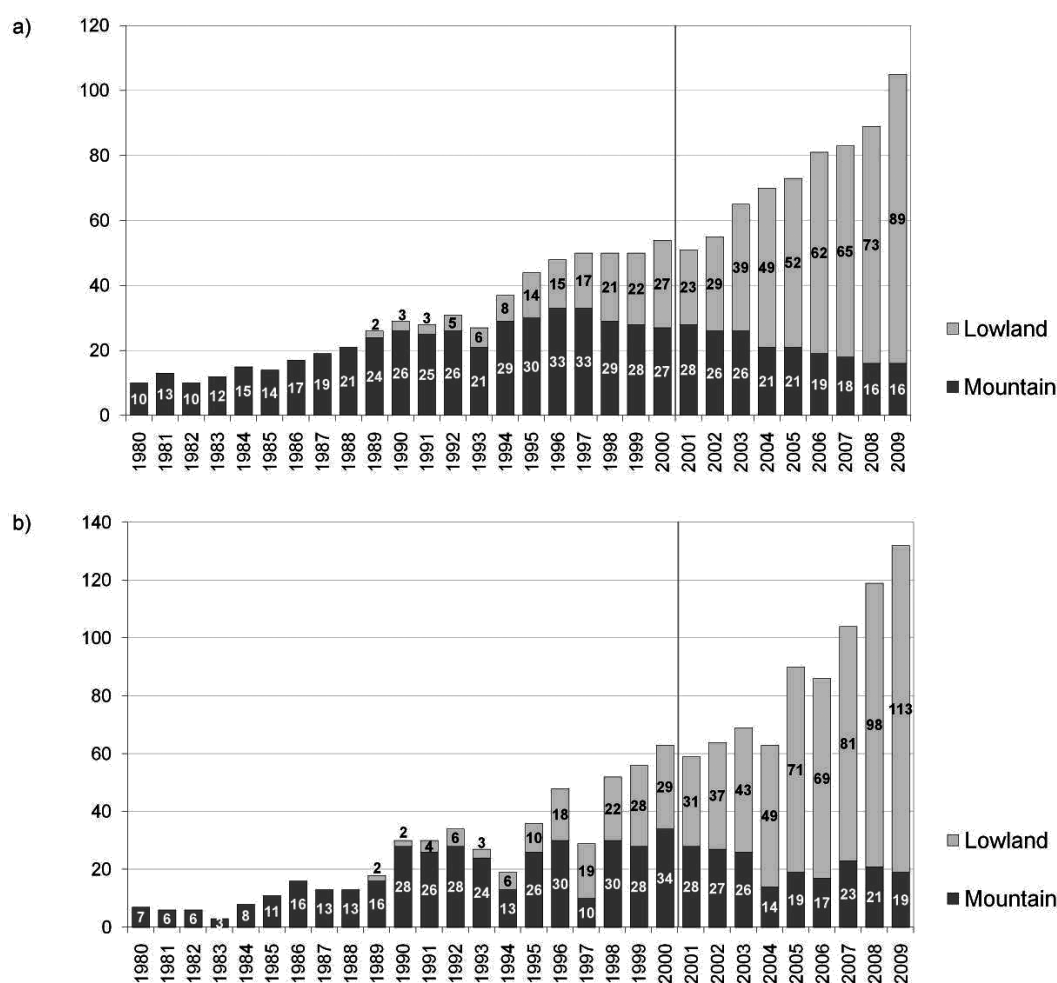


Fig. 2. Number of known nesting pairs (a) and fledglings (b) of Eastern Imperial Eagles in Hungary between 1980 and 2009. Data prior to 2001 were taken from BAGYURA *et al.* (2002)

Table 1. Causes of breeding failures, mortality of eggs and chicks of Imperial Eagles in Hungary between 2003 and 2009. Mortality data includes complete failures of 142 broods and also those 60 cases when the incident affected only a part of the brood. The number of failed breeding attempts and the estimated number of dead offsprings are followed by their relative frequencies in brackets

Cause	Breeding failure			Mortality		
	Incubation	Chick-rearing	Total	Egg	Chick	Total
Storm	18 (16 %)	15 (54 %)	33 (23 %)	37 (15 %)	34 (42 %)	71 (22 %)
Disturbance	15 (13 %)	2 (7 %)	17 (12 %)	27 (11 %)	3 (4 %)	30 (9 %)
Unfertilized eggs	7 (6 %)		7 (5 %)	23 (10 %)		23 (7 %)
Poisoning	2 (2 %)	1 (4 %)	3 (2 %)	4 (2 %)	3 (4 %)	7 (2 %)
Cainism					3 (4 %)	3 (1 %)
Shooting to the nest	2 (2 %)		2 (1 %)	3 (1 %)		3 (1 %)
Mortality of parents	1 (1 %)		1 (1 %)	2 (1 %)		2 (1 %)
Illegal logging	1 (1 %)		1 (1 %)	2 (1 %)		2 (1 %)
Abnormal embryo				1 (0 %)		1 (0 %)
Haywire coiled on chick					1 (1 %)	1 (0 %)
Nest-robbing					1 (1 %)	1 (0 %)
Unknown	68 (60 %)	10 (36 %)	78 (55 %)	139 (58 %)	36 (44 %)	175 (55 %)
Total	114 (100 %)	28 (100 %)	142 (100 %)	239 (100 %)	81 (100 %)	320 (100 %)

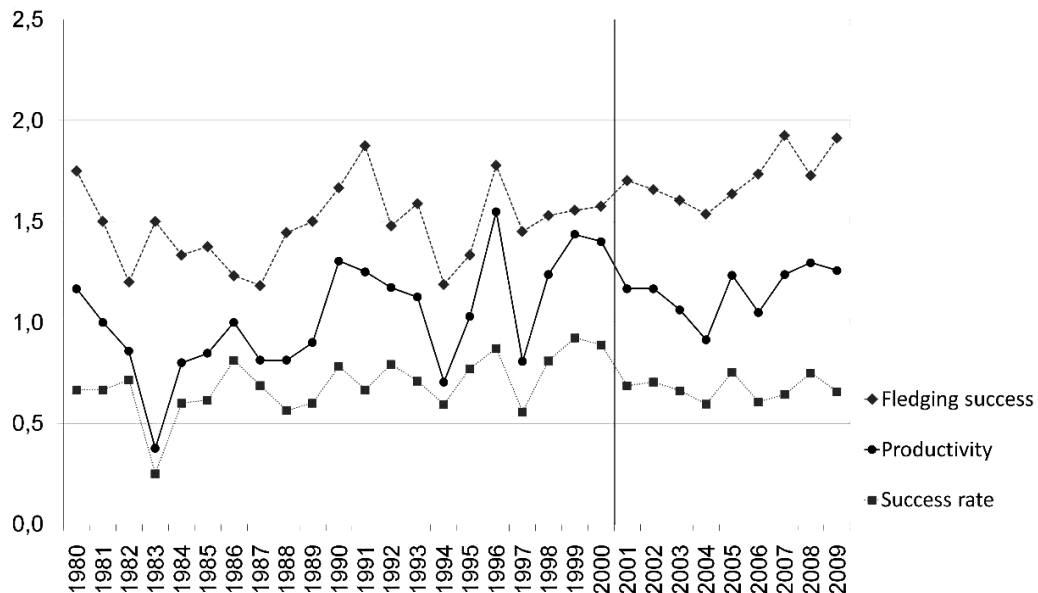


Fig. 3. Mean annual productivity (no. of fledglings/no. of nesting pairs), success rate (no. of successful pairs/no. of nesting pairs) and fledgling success (no. of fledglings/no. of successful pairs) of Imperial Eagles in Hungary between 1980 and 2009. Data prior to 2001 were taken from BAGYURA *et al.* (2002)

and 2008, and by now poisoning became the most important human-induced threat to Eastern Imperial Eagles in Hungary. Collision with vehicles has become an important mortality factor, too, which proved to be highly dangerous especially for juvenile eagles fledged from shelterbelts along railways, as already three fatal accidents were reported, out of nine such breeding attempts.

Discussion

Population dynamics

In parallel with the increase of the Hungarian Eastern Imperial Eagle population the numbers of Imperial Eagle breeding pairs in the neighbouring South-Slovakian, East-Austrian, and Southeast-Czech re-

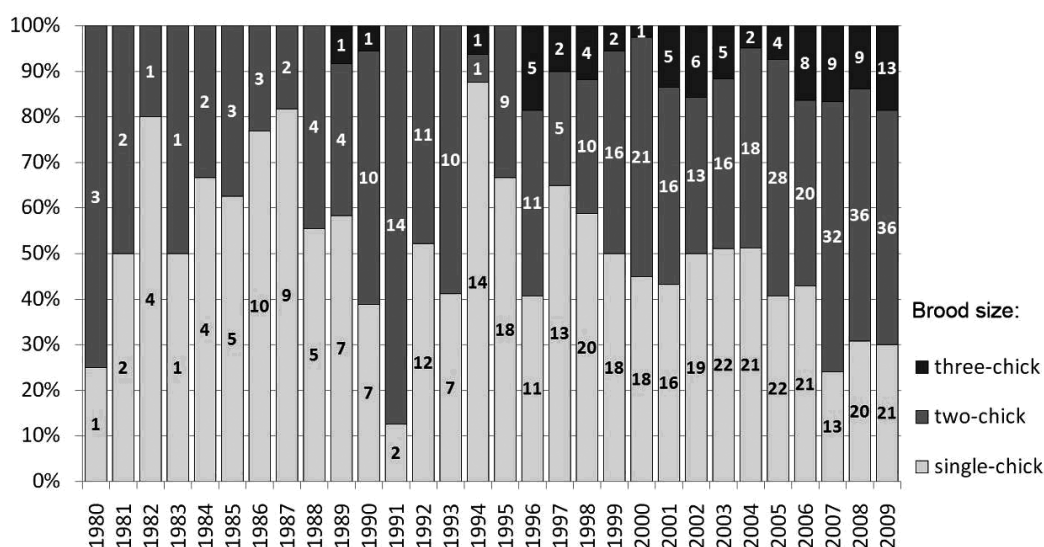


Fig. 4. Frequency of single-, two- and three-chick broods among successful Imperial Eagle breeding attempts in Hungary between 1980 and 2009. Columns represent the relative frequencies of the different brood sizes by years. The exact numbers of different sized broods are written in the columns. Data prior to 2001 were taken from BAGYURA *et al.* (2002)

Table 2. Mortality factors of full-grown Imperial Eagles found in Hungary between 1980 and 2009. Data prior 2001 were taken from the database of the Hungarian Bird Ringing Centre, the Raptor Rehabilitation Centre of Hortobágy National Park and from BAGYURA & SZITTA (unpubl. data). The numbers of specimens are followed by their relative frequency during the given period in brackets. Other causes including single cases of accidental trapping by a pheasant farm's net and by a poacher's loop, drowning in flood just after fledging and a fungal lung infection

Cause	1980-2000	2001-2009	Total
Poisoning		29 (32%)	29 (26%)
Electrocution	4 (17%)	20 (22%)	24 (21%)
Collision with vehicle		8 (9%)	8 (7%)
Starving		6 (7%)	6 (5%)
Shooting	1 (4%)	4 (4%)	5 (4%)
Collision with electric cable	1 (4%)	1 (1%)	2 (2%)
Other		4 (4%)	4 (4%)
Unknown	17 (74%)	18 (20%)	35 (31%)
Total	23 (100%)	90 (100%)	113 (100%)

gions of the Carpathian Basin also increased (CHAVKO, WICHMANN unpubl. data). By 2009 the population of the Carpathian Basin consisted altogether more than 150 known breeding pairs, therefore recently it seems to be the biggest unified population of the Eastern Imperial Eagle outside Russia and Kazakhstan.

In parallel with the increasing population size the decrease of the breeding success could be predicted because of density-dependent population regulation (FERRER 2001, FERRER, PENTERIANI 2008). Anyhow our data showed an opposite trend, as the breeding success also increased with the population

size, which could be explained by two reasons.

The first reason is that the population still inhabits only a fraction of suitable lowland habitats of Hungary, therefore the population is most probably still under-saturated and density dependent regulation did not affect significantly the population parameters yet. If the expansion of the population could continue during the next decade we predict the decrease of breeding success parameters due to the higher and higher density dependent effects.

On the other hand the population shifted to lowland habitats, which habitats provided better

foraging possibilities than mountains (HORVÁTH *et al.* 2010), therefore the increasing ratio of lowland pairs within the population resulted in an increased overall breeding success. The reason that these high quality lowland habitats were most probably not inhabited by the species for at least a century, could be that eagles in these open and highly populated landscapes directly faced the effects of extremely high human persecution (shooting and poisoning) of raptors during the first three quarters of the 20th century. Meanwhile the remote mountainous forests could serve as a refuge for Imperial Eagles and several other raptor species, which populations could have been the base for the expansion to the lowlands during the 80's and 90's, when persecution of raptors significantly decreased.

Consequences for conservation

The sharp increase of illegal poisoning incidents in the recent past bewares us that the favourable conservation status of the species is still vulnerable. The species is highly exposed to poisoning, since wandering immature individuals, but also territorial adult pairs frequently take carcasses, especially wintertime (DEL HOYO *et al.* 1995). Intentional illegal poisoning against carnivores and corvids started to spread in Hungary after 2005, probably due to changes in authorised hunting methods (HORVÁTH 2008). A good example of this threat is that in a four-year period 29 poisoned Imperial Eagles have been found. It was shown for the Spanish Imperial Eagle that such a sudden increase in the mortality due to poisoning could negatively influence population dynamics, and even reverse the increasing trend of eagle populations locally (FERRER, PENTERIANI 2008). Probably the increased mortality of Eastern Imperial Eagles in Hungary due to poisoning was the cause that the overall annual increase of the population was smaller in 2007 and 2008 (only 4 % in average), just after the peak of the reported poisoning incidents than in other years of the study period (12 % annual increase in average). MME BirdLife Hungary started an anti-poisoning campaign in 2007, which should be maintained in the future even if the number of incidents decreased. Fortunately, during the winter of 2008/2009 relatively few poisoning incidents were reported and the previous increasing trend of the population continued with

16 new nest building pairs in 2009 (equal to 19% increase in one year).

Besides poisoning, the other main direct threat to the Eastern Imperial Eagle is electrocution, similarly to the Spanish Imperial Eagle (FERRER, HIRALDO 1991, GONZÁLEZ *et al.* 2007). In spite of the almost 20-year effort for bird-friendly modification of electric pylons in Hungary (BAGYURA *et al.* 2004), electrocution is still among the most important mortality factors of several raptor species, including the Imperial Eagle. Although the presumably most dangerous power lines have been located, and the most effective methodology for bird-friendly modifications is known, we may have to wait further decades for a satisfactory solution to the problem because of financial considerations (HORVÁTH *et al.* 2008).

The third most frequent cause of mortality affecting fledged Imperial Eagles was collision with cars and trains. As it was also reported by DANKO, BALLA (2007), some Imperial Eagle pairs in the Carpathian Basin are able to tolerate the immediate vicinity of roads and railways when they choose nesting trees. This adaptability to the more disturbed lowland areas increased significantly the available habitats for the species, but these new type of habitats can also affect the mortality rate of eagles, e.g. by increased incidents of collisions with vehicles.

Storms destroying nesting trees were the most common cause of the breeding failures recorded in Hungary. The shortage of suitable nesting trees in many parts of the Hungarian Plain forces the eagles to nest on suboptimal trees as well (e.g. on weaker black locust trees), which are exposed to the damage of windstorms. A similar problem was reported in a Spanish Imperial Eagle population, where the alien eucalyptus (*Eucalyptus* sp. L'HER.) tree became the main nesting tree species, and these nests were more frequently damaged by windstorms than those on native tree species (CALDERON *et al.* 1987).

Summarizing our results, we suppose that the Hungarian population of Eastern Imperial Eagles is in a favourable conservation status, nevertheless the changes in the main breeding habitat types raised several new threats for the population. Nature conservation organizations should be able to address these new problems to promote the further expan-

sion of this globally threatened species, for which the Hungarian Plain still provides suitable unoccupied habitats.

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Популационна динамика на Източния Царски орел (*Aquila heliaca*) в Унгария в периода 2001-2009

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(Резюме)

Западната граница на ареала на Източния Царски орел (*Aquila heliaca* SAVIGNY 1809) се простира до Карпатския басейн – най-голямата известна популация на вида извън Русия и Казахстан. След 1980-те, когато се предполага, че броят на размножаващите се двойки достига своя исторически минимум, се наблюдава тенденция към увеличаване на популацията в Унгария, а също и в съседните територии на Словакия. Настоящото изследване представя оценка на динамиката на унгарската популация на Царския орел в периода 2001-2009 г. В резултат от продължаващото увеличение на популацията, мониторинговата програма идентифицира 105 гнездящи двойки към 2009 г. Макар че се наблюдава разширяване на гнездовия ареал в равнинни земеделски местообитания, през периода на изследване броят на двойките, обитаващи историческите планински гнездови територии намалява от 50% на едва 15%. Случаите на люпила от две и три малки се увеличават в сравнение с периода 1980-2000, разкривайки по-висока средна годишна продуктивност на популацията (1.15 излетели малки на гнездяща двойка). Въпреки благоприятните промени в популационните тенденции и продуктивност, експанзията в наскоро заетите равнинни местообитания поражда също някои нови заплахи за популацията, като увеличаване броя на случаите на незаконно отравяне и сблъсък с превозни средства.