ACTA ZOOLOGICA BULGARICA

Acta Zool. Bulg., June 2024, 76 (2): 241-248

Conservation Biology
Research Article

Published online 10 June 2024
DOI: https://doi.org/10.71424/azb76.2.002769

Exceptionally Low Proportion of Adult Pairs and Male-Skewed Adult Sex Ratio in a Declining Population of the Golden Eagle *Aquila chrysaetos* (L., 1758) (Accipitriformes: Accipitridae)

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Abstract: Generally, golden eagles have a favourable conservation status but they are threatened in some parts of their range. A nationwide breeding survey of the golden eagles in Bulgaria found that the species is in a decline. Contrary to the last estimation for 212 pairs, only 93 territories were found occupied while 81 were vacant. Only half of the pairs were in adult plumage and the other half had at least one of the members in non-adult plumage. The adult sex ratio was biased towards males (1.31 males per female), with the male older in 26 out of 33 territories, where the birds differed in their age classes. The obtained results could be explained by a very high unnatural mortality of territorial birds.

Key words: age structure, Bulgaria, raptors

Introduction

Birds of prey breed in non-adult plumage during population expansion when conditions are good or during periods of increased adult mortality when breeding territories are vacated (Newton 1979, Margalida et al. 2008a, Demerdzhiev et al. 2011). Among large eagles of *Aquila*, proportions of more than 10 % of non-adults in traditional breeding territories are considered an "early warning signal" of a forthcoming population decline (Ferrer et al. 2003). Healthy populations of long-lived raptors have few, if any, members in non-adult plumage due to adults being able to outcompete non-adults (Hunt & Law 2023). Nevertheless, there are cases in populations with a surplus of floating birds, in which individuals in non-adult plumage are more competitive than some territorial adults; this gives rise to an equivocal signal of the presence of high non-natural mortality (J. Bautista, pers. obs.). However, it is currently well established that the high occurrence of territorial non-adult eagles in traditional breeding territories is a sign of high unnatural mortality and population decline (Balbontín et al. 2003, Whitfield et al. 2004a, Hunt et al. 2017). In such populations, non-adults act as a replacement for dead pair members (Carrete et al. 2006) and their high occurrence generally indicates that the adult non-territorial (floater) part of the population cannot sustain the mortality of territorial birds (Sánchez-Zapata et al. 2000, Margalida et al. 2008a).

In the case of long-lived species of conservation concern, understanding of the adult sex ratios can contribute to the management of their populations (Donald 2007). Skewed adult sex ratios can originate due to a multitude of factors (Serrano-Davies et al. 2022) with female birds generally having higher mortality than males (Donald 2007, Székely et al. 2014, Lambertucci et al. 2012) and fewer floaters than males (Moreno 2016). Among raptors, when a breeding pair has a non-adult member, it is usually the female as they might be able to reach the needed body condition for reproduction earlier in life, compared with males (Newton 1979). Moreover, pairs with a non-adult male have the lowest reproductive success (Margalida et al. 2008a).

Worldwide, the golden eagle is the most widely distributed eagle (Fergusson-Lees & Christie 2001) and the fifth most studied bird of prey (Buechley et al. 2019). Its populations are generally considered stable or increasing (Watson 2010), but in parts of the range in Europe, Asia and Africa, the knowledge on the species remains obscure, while some populations are declining and threatened (Wentworth 2018, Ogden et al. 2020, Harrison & Green 2021, Bautista & Ellis 2024, Bautista et al. 2024). Different studies have documented the age structures of territorial golden eagles in Western Europe and North America, where adults largely predominate over non-adults (Table 1), but there are very few published data on adult sex ratios. Most non-adults nest in territories with high disturbance and high turnover rate, or where persecution has been high (Sandeman 1957, Steenhof et al. 1983, Bergo 1984, Whitfield et al. 2004a, Wiens & Kolar 2021), however, in some populations with a significant surplus of floaters, non-adults can take territory from traditional adults (J. Bautista, pers. obs.). Due to the difficulty of observation, the data on adult sex ratios among golden eagle populations is even more deficient (Peniche et al. 2022).

In Bulgaria, during the last 45 years, various estimates have put the population at between 120 and 200 pairs (Angelov et al. 2024) but there has never been a nationwide population count of the golden eagle. For 2010-2020, 155 territories have been occupied at least once and declines have been noticed in the western part of the country, while the national population was estimated at 212 pairs (Angelov et al. 2024).

The objective of the current study was to implement the first systematic nationwide count of golden eagles in Bulgaria. To obtain this I aimed to: (1) record the number and age structure of possibly all territorial pairs; (2) calculate the adult sex ratios among territorial birds; (3) based on (1) and (2), provide conclusions about the overall health of the population (following Ferrer et al. 2003).

Materials and Methods

An effort was made to visit all historically known golden eagle territories in Bulgaria (n=181), scaling up on an earlier recent review of the status of the species (Angelov et al. 2024). The territories were checked from March 2020 until July 2023, each year mostly from February to June. Subsequent visits were implemented with up to six per territory when the results of the first visit were not satisfactory for assessing the status of the territory and the age of each bird. To identify a golden eagle territory as occupied, we used the criteria of Gjershaug et al. (2018). Additionally, 62 potential breeding territories were checked, 51 of them with the presence of cliffs that are suitable for nesting, but that were never known to be part of the range of the golden eagle; pairs were found in 11 of them. The breeding success was monitored in 2021 for 20 pairs in the Eastern Balkan range.

An earlier review for the species in Bulgaria (Angelov et al. 2024) mentioned 296 historical territories in the country. However, after careful scrutiny of the historical sources and the addition of new data gathered during the current study, 85 of the former territories were considered to be amalgamated (see also Hayhow et al. 2017) while 18 were listed to "probable breeding territories". The original data for 14 other territories was considered dubious and the territories were excluded from the study. We also excluded from the analysis four transboundary golden eagle territories, where the pairs have been known to breed only in the neighbouring country, either Serbia or Greece.

The study area encompassed mostly the mountains in the country. The Balkan Mountains stretches from east to west throughout the middle of the country (highest peak over 2300 m a.s.l.), starting from the Black Sea up until the border with Serbia. It is parallel to Sredna Gora Mt. (up to 1600 m a.s.l.) to the south and to the Predbalkan (up to 1400 m a.s.l.) to the north. The Rhodopes (low eastern part up to 1200 m a.s.l. and high and larger western part up to 2100 m a.s.l.) are a wide mountain lying along the border with Greece. It is linked to the highest mountains in the country (reaching 2900 m a.s.l.), i.e. Rila Mts. in the northwest and Pirin Mts. to the south. Along the border with the Republic of North Macedonia, several smaller mountains with peaks

in the range of 1600–2200 m a.s.l. are stretching. Along the border with Turkey, from east to west, the low Strandzha and Sakar Mts., reaching up to 800 m a.s.l., are located (Galabov 1982). For a more in-depth description of the study areas, see Angelov et al. (2024).

Fieldwork consisted of 2.5–5 h of observations from vantage points offering good visibility or during walking routes at a slow pace within the home range of the pair preferentially near a known or suspected nest (Andersen 2007). Walking routes included frequent stops and constant observation. Optics included binoculars 10 x 50, a telescope 20-60 x 60 and a digital camera with up to 50 times optical zoom of the lens. All nests and nesting cliffs were photographed and the condition of the nest was carefully inspected to infer information for recent use by the birds. Whenever possible, all eagles in flight were photographed to facilitate further confirmation of the age and sex. Photographs also allowed subsequent individual identification of birds based on their moulting pattern and feather damage of the flight feathers and rectrices during the current or subsequent visits in the territory. Several individuals that were observed at distances of more than 1.5 km and were initially identified as adults during observations with binoculars and telescope turned out to be subadults after inspection of the taken photographs. Totally, 138 territorial birds were photographed in flight, allowing subsequent identification of the age, 85% of all non-adults were photographed. Photography may be valuable in determining the sex of species with little sexual dimorphism (Forsman 2016). A reference was made to other studies that recorded the age structure of territorial pairs across the species' range.

Identification of the age followed Forsman (2016) and Bautista & Ansola (2024), while recognition of the sex was mostly based on the size of the birds; when seen together, golden eagles show marked reversed sexual dimorphism (Collopy 1983, Hayhow et al. 2017). In flight, female golden eagles are 8-12% larger than males and have a more massive flight silhouette with wider wings while males have longer legs and less powerful feet giving them a more slender overall appearance (Bautista & Ansola 2024).

Results

General distribution and status

We monitored 174 historically known golden eagle territories in Bulgaria, while seven territories remained unchecked. Territorial golden eagles were confirmed in 93 occupied territories (Fig. 1) with the most recently used nests in 69 of them identified. Pairs occupied 91 territories (52.3% of all), two others were occupied by single territorial birds and 81 (46.5%) remained unoccupied (Fig. 1). Of all 81 unoccupied territories, 68 were monitored by the author in 105 different visits. In 25 of the unoccupied territories, 32 old golden eagle cliff nests were still present in various stages of disintegration. A territory was considered unoccupied when no birds were seen after two or more visits and when the existing old nests were in very bad condition and had not been repaired for years. In addition, 11 previously unknown territories were recorded during the survey, geographically falling into Eastern Balkan range – 4, Central Balkans – 3, Western Rhodopes – 2 and Eastern Rhodopes – 2.

We observed and photographed 172 golden eagle nests, most of them on cliffs, while seven nests in different territories were on trees. Tree nesting was recorded in the Eastern Balkan range, Eastern Rhodopes and Strandzha Mountain.

Age structure and adult sex ratio of territorial birds

The age and sex of 175 territorial eagles were identified (87 males and 88 females), of them 120 (69%) were adults and 55 (31%) were non-adults (35 in 4th and 5th cal. year (64%) and 20 in 2nd and 3rd cal. year (36%)). For seven other eagles, only the age was identified, but not the sex. The territorial males consisted of 68 adults (78%) and 19 non-adults (22%), while the territorial females of 52 adults (59%) and 36 (41%) non-adults. The adult sex ratio was biased towards males, with 1:1.31 adult females to adult males, or adult males outnumbering adult females by 30.8%. Half of the territories with identified age of the birds had one or both members of the pair in non-adult plumage (see Table 1 for comparison with other studies). Fully adult were the birds in 44 territories, while the males or females were older respectively in 26 and 7 territories, while nine territories consisted of non-adults of equal ages. One pair consisted of an adult and a non-adult but the sex of the birds was not identified.

Status of the species in protected areas

National parks hold 12 territories, of which six fall also within strict nature reserves, while outside national parks, another five pairs are situated in strict nature reserves, making 17 pairs (18% of all occupied territories) located within the borders of strictly protected areas. National Park Central Balkan held 11 territories occupied by pairs, National Park Rila

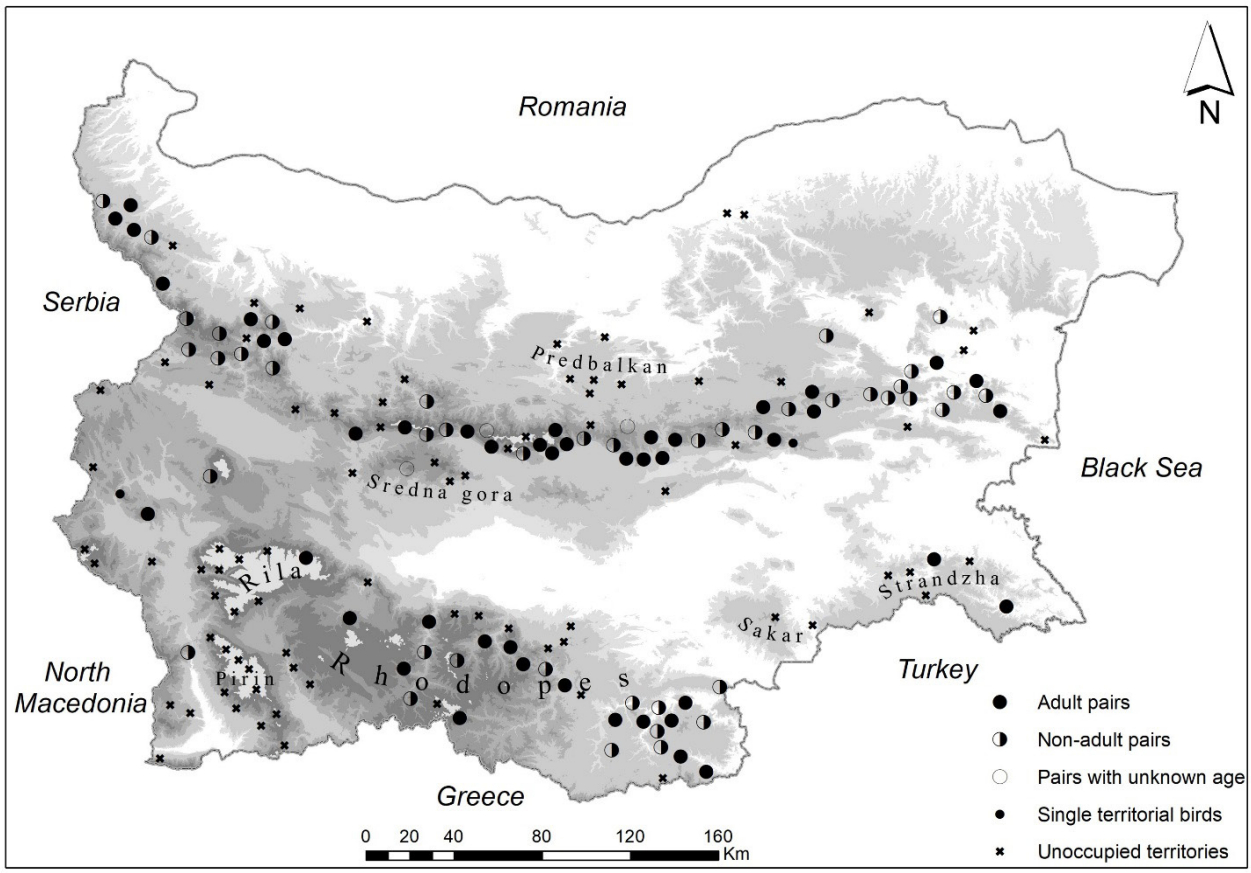

Fig. 1. Distribution of the golden eagles according to the age of pairs: adult pairs (black circles), non-adult pairs with one or both birds in non-adult plumage (black and white circles), pairs of unknown age (empty circles), single territorial birds (small black dots), unoccupied territories ("x").

had one pair, while the golden eagle is probably extinct as a breeder from Pirin National Park. Special Protected Areas according to the Birds' Directive held 65 pairs or 70% of the occupied territories in the country. Of all unoccupied territories, 13 were within national parks (seven in Rila, four in Pirin and two in Central Balkan National Parks), of which five territories fell within strict nature reserves, while another two territories were in strict nature reserves that were outside national parks. Thus, 15 territories were situated within strictly protected areas, or 18.5% of all unoccupied territories. In relation to SPAs, 53% of all unoccupied territories were within SPAs.

Discussion

The striking decline of the golden eagle in large areas in Bulgaria has been going on unnoticed. Only very recently, data were published about declines in parts of the country (Milchev 2022, Angelov et al. 2024). In the case of Rila and Pirin National Parks, ornithologists have been expressing concerns about the lack of pairs of golden eagles but, in the absence of a dedicated survey for the species, it was assumed that some pairs probably exist in more remote parts of the mountains but remain unnoticed. The range in Bulgaria has substantially shrunk towards the higher parts of the mountains. The decline is most pronounced in the southwest, where only several scattered territories remain occupied among vast areas of suitable mountainous habitat. Notable more recent declines are in Strandzha Mountain (see also Milchev 2022), along the north slope of the Rhodopes, Sredna Gora Mountain and Strazhata Plateau in Central Predbalkan.

On a national scale, given the difficulty of confirming that a territory is vacant (Steenhof et al. 2017), some of the territories, where signs of the presence of territorial eagles have not been recorded (81 vacant territories), might have few pairs or single territorial birds, that remained unnoticed. Additionally, there is a possibility for the presence of a few more pairs in areas that have never been documented as golden eagle territories, especially tree-nesting pairs. Strandzha Mountain may also hold

Table 1. Proportion of adult pairs and adult birds in the studied populations across the range of the golden eagle.

Country and study area	Percentage of adult pairs (%)	Percentage of adult birds (%)	Reference
Ethiopia – Bale Mountain	100	100	Clouet et al. (1999); Wentworth (2018)
Mali and Niger	100	100	Clouet & Goar (2006)
USA – Alaska, Denali	98	–	Kochert et al. (2002)
USA – California, Diablo range	97	–	Wiens & Kolar (2021)
USA – Snake river, Idaho	87-100	97.5	Steenhof et al. (1983)
USA – California	93-100	96.4-98.2	Hunt et al. (2017)
Italy – Western Alps	95.5	95.3	Fasce et al. (2011)
Britain – Scotland	93.9	96.1	Hayhow et al. (2017)
Britain – Scotland	92.6	95.5	Green (1996)
Britain – Scotland	90.6	94.7	Eaton et al. (2007)
France	87.5	93.2	Wentworth (2024)
Britain – Scotland	85-89	–	Whitfield et al. (2004a)
Italy – Eastern Alps	84.3	92.2	Pedrini & Sergio (2001)
Spain – Andalusia	83	87	Bautista et al. (2022)
Spain – Murcia, Granada	76-80	–	Carrete et al. (2006)
Spain – Murcia	70-76.2	82.9-85.1	Sánchez-Zapata et al. (2000)
USA – Washington	69-84	–	Watson et al. (2020)
USA – California	64-77	82-88	Kolar & Wiens (2017)
USA – California, Altamont Pass	71	–	Wiens & Kolar (2021)
Romania – Carpathians	–	74	Kovács et al. (2024)
Britain – Scotland, in high persecution zones	63.5-69	69.4-73.1	Whitfield et al. (2004)
Norway	49	64.9	Bergo (1984)
Bulgaria	50	68.5	This study

one or two more pairs that were not recorded by the survey (Milchev 2022). The 11 newly recorded occupied territories were most probably old ones that were not part of the current ornithological record in Bulgaria.

This study showed that the golden eagle population in Bulgaria is in a serious decline and 31.5% of the territorial eagles in traditional breeding territories are in non-adult plumage, surpassing more than three times the value of 10% suggested by Ferrer et al. (2003) to be considered as an "early warning signal" for population decline. Our data might slightly overestimate the number of non-adults in the breeding population, as golden eagles may occasionally attain full adult plumage later than the age of five years (up to seven years), with some individuals remaining in seemingly non-adult plumage for life (Forsman 2016). However, to the best of my knowledge, in the European context, such cases have been proven only for the Scandinavian population.

The very rare observations of non-territorial, mostly 1st and 2nd cal. year birds (author unpublished data) and the presence of 55 territorial non-adults, suggests that they are quickly being absorbed into the breeding population, especially when many unoccupied territories are available (Whitfield et al. 2024). The exceptionally high number of non-adults as members of territorial pairs suggests that the population may suffer from very low productivity (McIntyre et al. 2011). However, data for the breeding success were gathered only for one region, during 2021, when only four of 20 monitored pairs in the Eastern Balkan range managed to successfully fledge one chick each (0.20 productivity) and in this case only one of the eight adult pair members was non-adult (4th cal. year female).

It is currently unknown what is causing the observed male-biased adult sex ratio. It could be owing to a male-skewed fledgling ratio. In the current study, non-adult females were almost twice

more than non-adult males (36:19) and a higher incidence of non-adult females in territorial pairs has been found in other studies. In Alaska, of eight territories with mixed aged pairs, all of the younger birds were females (Kochert et al. 2002), while in a population suffering from anthropogenic mortality, 13 of the 15 subadults in a population were females (Hunt et al. 2017). Adding to the bias, inexperienced raptors may produce more individuals of the smaller and "cheaper" male sex (Ferrer et al. 2009, 2013, Rosenfield et al. 2015, Morandini et al. 2020, Warkentin et al. 2022). It is well established that pairs with one or two non-adult members are less successful in breeding (Ferrer et al. 2003, Sánchez-Zapata et al. 2003, Margalida et al. 2008a, Demerdzhiev et al. 2023) and female offspring (the more expensive sex) are produced more often by adult breeders (Ferrer et al. 2013, Morandini et al. 2020). In this study, possible higher production of male fledglings combined with a low productivity might be a side effect of a population with at least one non-adult member in half of the pairs and a correspondingly high number of less experienced young adults (Bakker et al. 2023).

Studies have shown that female raptors suffer from higher mortality than males (Ferrer & Hiraldo 1992, Lambertucci et al. 2012, Sanz-Aguilar et al. 2017) but we have very limited data for sex differences in mortality. The main mortality factor for the golden eagles in the Balkans is poisoning after illegal use of pesticides against wild mammalian carnivores, followed by shooting and electrocution (Sidiropoulos et al. 2016, Angelov et al. 2024, Kovács et al. 2024). Some of the areas with the greatest declines of golden eagles, especially in the south-west, overlap with the regions where the grey wolves *Canis lupus* reach their highest density (Tsingarska et al. 2019), suggesting the importance of illegal poisoning (Stoynov et al. 2018). The golden eagle population in Bulgaria has not been studied with satellite telemetry, thus, the importance of poisoning as a mortality factor for the population might be even higher (Margalida et al. 2008b).

Conclusions

Given the ongoing decline, alarming age structure and adult sex ratio and very low breeding success, the golden eagle population in the country most probably operates as a sink for the Balkan population (Katzner et al. 2017, Hunt et al. 2017) and is held at levels much below the carrying capacity, but this statement needs further confirmation. Moreover, a study by means of satellite telemetry on the mortality causes of territory holders and floating non-adults and on the breeding performance is needed to inform and strengthen conservation actions (Sergio et al. 2019). The potential for the use of golden eagles as sentinel species for the detection and prevention of illegal wildlife poisoning needs to be further explored (Bautista et al. 2023), especially in areas with threatened vulture populations (Peshev et al. 2022).

Acknowledgements: I thank the National Museum of Natural History for the possibility to pursue a PhD and my advisor Professor Zlatozar Boev for his continuous support. I thank Stoycho Stoychev and the Bulgarian Society for the Protection of Birds for assistance with 4WD vehicle and travel expenses. I thank the two reviewers for their very constructive comments. Thanks also to consortium "Dikon-Particip". Thanks to Dr Dobromir Dobrev for producing the map. Dr Dimitar Demerdzhiev, Stoycho Stoychev, Dr Dobromir Dobrev and Lavrentis Sidiropoulos provided valuable comments on an earlier draft. I thank my colleagues who provided large dataset for periods before the current study started and during the study: Dr Petar Iankov, Dimitar Ragyov, Georgi Stoyanov, Dr Dimitar Demerdzhiev, Dimitar Gradinarov, Liubomir Profirov, Emiliyan Stoynov, Dr Petar Shurulinkov, Borislav Tonchev, Venelin Koychev, Dr Volen Arkumarev, Zhivko Barzov, Dr Dobromir Dobrev, Dr Vladimir Dobrev, Ivaylo Dimchev, Dimitar Georgiev, Hristo Hristov, Ivaylo Klisurov, Marin Kurtev, Minko Madzharov, Daniel Mitev, Konstantin Nyagolov, Hristo Peshev, Dr Dimitar Plachiyski, Stamen Stanchev, Emil Yordanov and Gradimir Yovchev.

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Received: 13.02.2024
Accepted: 01.04.2024