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ANNUAL CAPTURES AND BIOMETRICS OF GOLDCRESTS *REGULUS REGULUS* AT A WESTERN HUNGARIAN STOPOVER SITE

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ABSTRACT

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Annual captures and biometric parameters of the Goldcrest (*Regulus regulus*) were studied at Tömörd, western Hungary. We used records of 4,284 individuals trapped and ringed between August and November within the study period (1998–2020). The Goldcrest was determined to be a regular partial migrant species with highly intensive migration in 2000, 2001, 2008, 2014 and 2019. The catching results showed very high number fluctuations at Tömörd, but the smoothed curves were distinctly wave-like in all age and sex classes. There were significant positive correlations between annual captures of age and sex classes. The average proportion of immature Goldcrests was 90%, the average proportion of male individuals was 63% and both proportions were stable between 1998 and 2020. There were similar decreasing trends in the average annual wing length and body mass of males and females from 1998 to 2020. This may indicate that the migration strategies of females may be modified by global climate change.

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INTRODUCTION

The Goldcrest is one of the smallest birds, in terms of body mass, nesting in the Palearctic region. It prefers to nest in coniferous forests of the boreal zone and mountain ranges. In Hungary about 1500-12,000 pairs breed primarily in old growth spruce forests, mixed spruce forests, parks and arboretums of the Alpine Foothills and the Northern Uplands. The Western and Northern European population appears to be decreasing, but in Eastern Europe, including Hungary, its population has recently been increasing (MME 2021). Harsh winter conditions, particularly if they persist for lengthy periods over broad areas of the wintering region, can significantly reduce population levels (Martens and Päckert 2015). Climate change and destruction of spruce forests may also influence the distribution and abundance of Goldcrests in Europe (Krajl *et al.* 2013, Askeyev 2018).

The Goldcrest is considered a partial and short-distance migrant (Cramp 1998). Goldcrests recovered in Hungary originate in Scandinavia, the Baltic region, and north-western Russia, while Hungarian ringed birds have been recovered in Italy and Slovenia (Gyurácz and Csörgő 2009). The migrating part of the population spends the winter mainly in southern Europe, and also in North Africa in small numbers. The proportion of resident birds increases towards the south (Cramp 1998). This diversity in the migratory strategy is remarkable, particularly given that the Goldcrest is the smallest bird in Europe and an original insectivore. Moreover, its closest relative, the more southerly distributed Firecrest (*R. ignicapillus*), is a completely migratory bird in Central Europe in spite of the much milder winters prevailing there, and the more distantly related *Phylloscopus* species are nearly all long-distance migrants (Hildén 1982).

Knowledge of the migratory system of regular migrants is in many cases extensive (Alerstam 1990), but knowledge of the migratory patterns of partial migrants is much more limited (Berthold 2001, Newton 2011). Detailed studies of partial migration of Goldcrests in the Carpathian Basin in autumn are very scarce; only two papers about their autumn migration dynamics have been published (Miklay and Csörgő 1998, Gyurácz *et al*. 2003). In other European countries, there have been studies on feeding ecology during spring migration (Laursen 1976), wintering (Hildén 1982, Hogstadt 1984, Taylor 1984, Scebba and Lövei 1986), fat deposition, stopover strategy in autumn (Busse and Machalska 1969, Frelin and Cornillon 1974, Karlsson 1980, Lifjeld 1982, Kania 1983, Hanssen 1981, Hansson and Petterson 1989, Thorpe 1992, Remisiewicz and Baumanis 1996, Bojarinova *et al*. 2005) and moult-migration (Merila 1997, Norman 1999, Bojarinova *et al.* 2008). However, there is little evidence concerning long-term changes in the size of the migratory population (Busse 1994) or in biometric features. We also know little about the age- and sex-dependence of these changes. Changes in population numbers, individual size, and body mass have been observed in many bird species, and these changes may differ even in sister species (Baillie and Peach 1992, Csörgő *et al*. 2009). Several studies suggest that there may be unidirectional changes in morphology as a response to various environmental factors (e.g. temperature, habitat, food type, prey size, feeding habits, or predation) (Loockwood *et al.* 1998, Dawson 2005, Gardner *et al*. 2011). It should be noted that even age and sex groups may adapt differently (Catry *et al*. 2006, 2007).

The aim of our study was to analyse annual variation in the numbers of Goldcrests captured at a stopover site in western Hungary and to identify changes in biometric parameters. We assumed that in some years, many Goldcrests belonging to populations of partially migrant species leave their breeding areas to appear at other sites as irruptive or invasive species. We used wing length and body mass to examine how these biometrics have changed during the last 23 years. These biometric changes may represent changes in the composition of populations passing through the stopover area, thus indirectly showing the possible effects of climate change.

STUDY AREA AND METHODS

Study site and field work

The study was carried out at the Tömörd Bird Ringing Station in western Hungary (47°21'N, 16°40'E), located 15 kilometres from Szombathely. The study site has a typical continental climate, with cold winters and warm summers. There are four natural habitat types around the station of Tömörd:

– Scrubland: bushes and herbaceous plants make up compact, dense vegetation, which is dissected by small grass patches. Its characteristic plant is the Blackthorn (*Prunus spinosa*).
– Forest edge: broadleaf trees and bushes form a compact, dense edge, constituting an ecotone community with the Turkey oak (*Quercus cerris*) as the characteristic plant. There is considerable felling and normal forestry management in the forest.
– Grassland with shrubs: this habitat type represents a transition between the wet habitats of the swamp and the steppe communities that used to cover the agricultural land around the marsh. There are a few bushes in the grassland, with two small patches of Dwarf elder (*Sambucus ebulus*). The grassland is not managed.
– Marsh: a small (6 ha) permanent and isolated wetland. The characteristic plant is the Reedmace (*Typha latifolia*).

The birds were captured and ringed from 1998 to 2020. Bird ringing took place during the post-fledging period (dispersal and migration), between the last weekend of July and the first weekend of November. We used 28 numbered Ecotone mist-nets (12 metres long and 2.5 metres high, with 5 shelves and a mesh size of 16 mm) for trapping. The nets were evenly distributed among the four habitat types. Throughout the study period the number of nets and their location remained unchanged. Birds were captured from dawn to dusk, except on rainy and stormy days, when the nets were closed. All birds were ringed, sexed and aged according to Svensson (1992). First-year birds that hatched in the year of ringing were defined as immatures, while all older birds were defined as adults. Flattened maximum wing length was measured to the nearest millimetre using a graded wing ruler, and birds were weighed to the nearest 0.1 g (using a digital balance). Fat reserves (fat score) were estimated visually according to the SE European Bird Migration Network protocol (Busse 2000), using a scale from 0 (no fat) to 8 (bulging fat). As the dates of the fieldwork differed slightly between years, a reference period was defined from 1 August to 5 November. This period covered 90% of Goldcrest dispersion and migration within the region, and the main migration waves were in the second half of October (Gyurácz and Bánhidi 2008, Gyurácz *et al*. 2017).

Data processing and statistical analysis

To study the catching dynamics over the years, raw catching results and running five-year averages were presented (see Fig. 1) to enable compatibility with similar data from the Baltic area (Busse 1994), and the population chain index was calculated as well (Greenwood *et al.* 1993). Spearman's rank-order correlation was used to check for differences between age and sex classes in the distribution of annual captures.

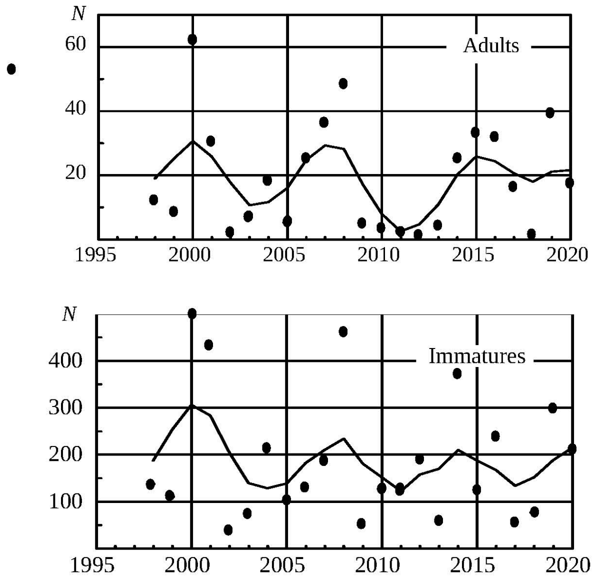

Fig. 1. Population dynamics of adult and immature Goldcrests at the study site in 1998-2020 expressed as numbers of individuals caught (*N* – dots) and smoothed five-year values (lines).

Wing length and body mass data were normally distributed (PPCC > 0.95), so we used parametric statistical methods (*t*-test and one-way ANOVA) to compare the mean wing lengths and mean body masses of immature males and females captured in the years of the study. Body mass and fat score were correlated (Gyurácz *et al.* 2003), so only body mass was included in the statistical analyses. There was insufficient data for biometric study of adults. General linear models (GLM) were used to determine the relationships between the dependent biometric variables and the year covariate (Fowler and Cohen 1986). We only analysed the first capture data of every individual, and thus, as arriving migrants are predominantly captured shortly after arrival (Kovács *et al.* 2010), our biometrics represent the condition of newly arrived birds. We used the records of 4,284 individuals trapped and ringed between August and November within the study period (1998–2020) (Table 1). The PAST computer program was used for the statistical analysis (Hammer *et al.* 2001).

Table 1
Number of birds caught during post-breeding season at Tömörd Bird Ringing Station in Western Hungary in 1998–2020

	Adults		Immatures		Total
	♂♂	♀♀	♂♂	♀♀	
1998	6	6	73	51	136
1999	5	3	60	41	109
2000	40	22	262	176	500
2001	17	13	247	155	432
2002	2	0	27	8	37
2003	3	4	33	33	73
2004	8	10	124	73	215
2005	2	3	66	30	101
2006	10	15	68	37	130
2007	22	14	86	64	186
2008	34	14	277	137	462
2009	3	2	31	12	48
2010	1	2	90	33	126
2011	1	1	69	51	122
2012	0	1	118	71	190
2013	2	2	31	21	56
2014	12	13	235	109	369
2015	24	9	63	27	123
2016	16	16	130	74	236
2017	10	6	25	13	54
2018	0	1	42	32	75
2019	25	14	176	82	297
2020	9	8	131	59	207
Total	252	179	2464	1389	4284

RESULTS

The five years with the most catches at the study site were 2000, 2001, 2008, 2014 and 2019. Figure 1 shows the catching dynamics of both age and sex classes. There were significant positive correlations between annual captures of age and sex classes ($r_{sp} > 0.63$, $p < 0.01$; Figure 2). The average proportion of immature Goldcrests was 90% (min. 71% in 2017, max. 99 % in 2012), the average proportion of male individuals was 63% (min. 50% in 2003, max. 75% in 2002), and both proportions were stable between 1998 and 2020 (multivariate linear regression, immature: $r = -0.17$, $p = 0.44$, male: $r = 0.23$, $p = 0.29$).

The total average wing lengths and body masses of age and sex classes were highly varied in Tömörd (Table 2), which is unsurprising. However, the annual mean wing lengths ($F = 11.34$; $df = 22, 2418$; $p = 0.001$) and body masses ($F = 5.34$; $df = 22, 2398$;

p = 0.001) of immature males were also significantly varied. They showed a negative trend between 1998 and 2020, but at a non-significant level (Table 3). The annual mean wing lengths (F = 4.9; df = 22, 1348; p = 0.001) and body masses (F = 3.25; df = 22, 1341; p = 0.001) of immature females were also significantly varied, while showing a significant negative trend between 1998 and 2020. The slopes for wing length and body mass were not significantly different between sexes.

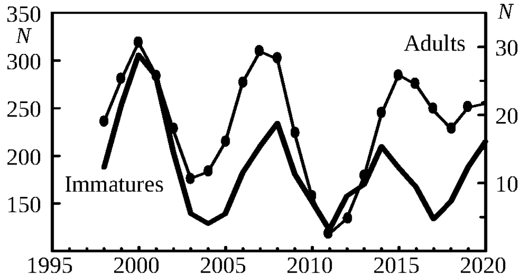

Fig. 2. Comparison of smoothed number dynamics curves of adult and immature Goldcrests caught at the study site in 1998–2020

Table 2
Comparison of biometric parameters of age/sex groups at Tömörd

			♂♂	♀♀	*t*	*p*
Wing length	*Adults*	*N*	252	172		
		Mean	54.52	51.99	17.08	0.001
		SD	1.41	1.55		
	Immatures	*N*	2440	1372		
		Mean	54.21	52.02	45.79	0.001
		SD	1.43	1.39		
		t	3.26	0.26		
		p	0.001	0.797		
Body mass	*Adults*	*N*	251	171		
		Mean	5.62	5.40	5.52	0.001
		SD	0.40	0.40		
	Immatures	*N*	2421	1364		
		Mean	5.64	5.46	12.88	0.001
		SD	0.41	0.40		
		t	0.77	1.91		
		p	0.443	0.058		

Table 3
Results of GLM (multivariate) test for the regression slope of biometric parameters of immature Goldcrests within the period of 1998-2020.
SE – standard error of the slope. Statistically significant values are given in bold.

Wing length	Slope	*SE*	*p*
♂♂	-0.026	0.013	0.06
♀♀	-0.028	0.012	**0.02**
Body mass	Slope	*SE*	*p*
♂♂	-0.005	0.003	0.14
♀♀	-0.008	0.003	**0.01**

DISCUSSION

The Goldcrest was a dominant songbird and a regular partial migrant species with highly intensive migration in the study area in 2000, 2001, 2008, 2014 and 2019, and we identified highly diversified migratory patterns. Similar periodic wave-like long-term migration dynamics were observed in the Baltic area between 1961 and 1990 (Busse 1994). In some years, large portions of the populations of many partially migrating bird species left their breeding grounds to appear in other areas as invasive species (Nilsson *et al*. 2006). In the southern Baltic region, similarly to the results obtained in Tömörd, the annual number of birds captured during autumn migration showed considerable variation, which could be connected with changes in the size of breeding populations. Two birds ringed in Russia were recovered in Tömöröd (Gyurácz *et al*. 2017), so we can assume that the intensive migration (e.g. 2000, 2001, 2014, 2019) in the study area may be linked to the higher number of Goldcrests breeding in eastern European Russia. The changes in Goldcrest abundance between years depended on winter and summer temperatures and other climatic conditions in early winter. In 2000, 2001 and 2008, the mean temperature was also significantly higher than in previous years (Askeyev *et al*. 2018). However, the yearly fluctuation in the number of birds captured in autumn may be associated with occasional changes in migration routes as well as in stopover and feeding sites (Remisiewicz and Baumanis 1996). This could have been the reason for the significant variation in the average wing length and the average body mass of migratory birds captured in different years. In our view, this phenomenon is explained by the annual change in the migration distance and the morphology of the birds from different breeding areas which stopped over in the study area.

Many definitions have been proposed to describe partial migration, among which the most widely accepted includes both individuals that migrate and those that do not migrate from the same breeding population (Terrill and Able 1988, Berthold 2001). Another interesting phenomenon is differential migration, i.e. variations in the length of migration period among individuals following the same route. Usually, this pattern results in segregation between age and sex groups at their stopover sites and wintering grounds (Cristol *et al*. 1999). Juveniles and females generally predominate among the migrants (Smith and Nilsson 1987, Nyquist 2007), but the proportion of Goldcrest males was higher than that of females at the study site. Two major hypotheses have been proposed to explain the difference in migratory behaviour between age and sex classes: the body-size hypothesis and the dominance hypothesis. According to the former, small individuals, such as juveniles and/or females, are more likely to migrate than large ones (adults and/or males) due to their different abilities to tolerate hunger. Larger individuals should have greater reserves relative to their basic metabolic rate, and if energy stores are proportional to body size, they would survive temporary food shortages better than small individuals. According to the other hypothesis, dominant members of a population, usually the male individuals, force the less dominant conspecifics to migrate through competition (Smith and Nilsson 1987, Nyquist 2007). Observations of the sex ratio in different parts of Europe during the autumn migration season reveal that the further south we go along the migration route, the larger is the proportion of males (Lifjeld 1982, Scebba and Lövei 1986, Miklay and Csörgő 1998). This could be explained by strong competition within the species even during migration (Hansson and Pettersson 1989). The larger and more aggressive males acquire more food, so their mortality may be lower than that of the females, in resident populations as well as in autumn-migrant and overwintering populations. The data from the Tömörd observations fit this pattern. Pronounced heterogeneity of sex ratios even over very short time scales indicates that Goldcrests may tend to migrate in small groups in which the proportion of one sex is significantly higher (Hansson and Pettersson 1989, Miklay and Csörgő 1998). Overall migration numbers suggest that for each potential breeding pair in spring, approximately five first-year birds set out during the autumn migration (Thorpe and Sapsford 1986).

The decreasing trends with similar slopes in the average annual wing length and body mass of males and females during the study period may indicate that the migration strategies of Goldcrests may be modified by global climate change. Due to warmer winters, the habitats are becoming more favourable, which may increase the chance of survival of short-distance migrants or residents. Based on Helbig (2003) and Pulido and Berthold (2003), we predict that the migratory part of the partially migratory populations and the intensive October migration at Tömörd will decline as a response to global warming.

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Ethical approval

All procedures performed in the study involving animals were in compliance with the ethical standards and practices of BirdLife Hungary and Savaria Campus.

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