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Annual survival rates of satellite-tracked adult European honey buzzards (*Pernis apivorus*) based on the Kaplan-Meier estimator and its probabilistic extension

Ročná miera prežívania satelitne sledovaných dospelých jedincov včelára lesného (*Pernis apivorus*) s na základe Kaplan-Meierovho odhadu a jeho pravdepodobnostného rozšírenia

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Abstract: The annual survival rate of adult raptors is an important parameter in population dynamics and is needed to derive measures for population stability and conservation management. Here we studied adult European honey buzzards (*Pernis apivorus*), a migratory land bird, using satellite telemetry throughout the year for up to three years. We used the Kaplan-Meier method of survival estimation in combination with the distribution density function for survival. This function describes the number of survivors N as a function of time t, based on the survival rate SR. This probabilistic extension of the Kaplan-Meier estimator results in a simple method that does not require a commercial statistical program to extract survival rates from event time analysis. It can be applied to analysing any event-time data, not only telemetry results but also ring recoveries, as demonstrated using European honey buzzards as an example. The average adult survival rate in our study, based on permanent satellite telemetry monitoring, was 0.44/year (linear correlation factor f = 0.99). This implies an adult mortality rate of 0.56 per year. It seems that particularly unfavourable weather conditions during the crossing of the Sahara and the Mediterranean led to this high mortality rate of our birds during migration from 2001 to 2011, but is likely to vary greatly from year to year. However, the loss rate in the wintering area was also high, at one third of the birds. More honey buzzards need to be tracked throughout the year to assess factors affecting survival and threats to populations adequately.

Abstrakt: Ročná miera prežívania dospelých dravcov je dôležitým parametrom populačnej dynamiky a je poznanie je potrebné na odvodenie opatrení pre stabilitu populácie a manažment ich ochrany. V priebehu jedného až troch rokov sme pomocou satelitnej telemetrie študovali dospelé jedince včelára lesného (*Pernis apivorus*). Použili sme Kaplan-Meierovu metódu odhadu prežitia v kombinácii s funkciou distribučnej hustoty pre prežitie. Táto funkcia opisuje počet prežívajúcich (N) ako funkciu času (t) na základe miery prežitia (SR). Výsledkom tohto pravdepodobnostného rozšírenia Kaplan-Meierovho odhadu je jednoduchá metóda, ktorá nevyžaduje komerčný štatistický program na extrakciu miery prežitia z analýzy časových údajov. Metóda sa môže použiť na analýzu akýchkoľvek časových údajov, nielen výsledkov telemetrie, ale aj metód založených na krúžkovaní, ako bolo demonštrované na včelárovi lesnom. Naša štúdia na základe permanentného satelitného telemetrického monitorovania zaznamenala priemernú mieru prežívania dospelých jedincov 0,44/rok (lineárny korelačný faktor f = 0,99). Miera úmrtnosti dospelých jedincov bola až 0,56 ročne. Zdá sa, že počas prechodu Sahary a Stredozemného mora v rokoch 2001 až roku 2011 prevládali obzvlášť nepriaznivé poveternostné podmienky, ktoré viedli k tejto vysokej miere úmrtnosti vtákov počas migrácie. Je ale pravdepodobné, že medziročne sa budú tieto podmienky značne líšiť. Vysoký úbytok, až jedna tretina jedincov bol však zaznamenaný aj na zimovisku. Pre primerané posúdenie faktorov ovplyvňujúcich prežívanie a ohrozenia populácie je potrebné sledovať väčšie množstvo jedincov včelára lesného.

Key words: year-round monitoring, satellite telemetry, mortality, tagging, biologging, raptors, birds of prey

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Introduction

Survival is a key life history trait in animals. However, most methods of estimating survival require significant human and economic investment over the long term, particularly for species that occur at low densities, which is the case for most threatened species. Estimates from general ring recoveries are mainly based on birds found dead (Newton 1979). Only in recent years has it become possible to track large and medium-sized birds of prey globally over several years using satellite and GSM telemetry, and to determine when and where they die. This allows researchers to study honey buzzard (*Pernis apivorus*) migratory routes much more precisely (see Vansteelant and Agostini 2021), identify the most dangerous phases and areas of the annual cycle, and measure survival rates more accurately than in the past.

Overall, understanding and monitoring the annual survival of adult raptors is crucial for effective conservation and population management. Knowledge of survival/mortality rates and reproductive rates is paramount for population modelling and quantitative results on population stability.

To the present day, only a few adult European honey buzzards (hereafter honey buzzard) have been tracked by satellite throughout the year (e.g., nine by Howes 2020), but nothing has been published on their survival rates. Saratosa et al. (2024) have recently reported some mortality events in honey buzzards, but no distinction is made between age classes, in particular between adults, immatures and juveniles. It is generally accepted that mortality, especially natural mortality, is much lower in adults than in juveniles. We only consider adult birds in this paper and are therefore unable to compare the results of Saratosa et al. (2024) with ours.

In a recent paper, we focused on mortality patterns throughout the annual cycle of migrating adult honey buzzards. Of 12 adults tracked by satellite, three died during the autumn migration, four in wintering areas, two during the spring migration and one in breeding areas, while the fate of two remained unclear (Meyburg & Ziesemer 2024). Considering the duration of these different periods, deaths per unit of time were four times higher during migration than during the rest of the year, and relatively more frequent in spring than in autumn, as Newton (2024) summarised.

In the present study, we calculated the survival rate of the satellite-tracked honey buzzards using the Kaplan-Meier estimator (Kaplan & Meier 1958) with a new probabilistic extension, the survival probability density function, which was developed for the evaluation of our tracked birds and any telemetric study.

Methods

Twelve adult honey buzzards (seven males and five females) breeding in northern Germany were monitored with 13 satellite transmitters between 2001 and 2011. Birds were captured in 2001–2011 during the nesting period in the forest near the eyrie using a dho gaza trap technique and live eagle owls (*Bubo bubo*) as decoys.

The breeding sites were checked in subsequent years after the honey buzzards had been tagged. If telemetry contact was lost before the birds arrived at the breeding site and the birds were not found at the old breeding site, this was taken as a good indication that the individual had died.

After 2–3 years, three birds were recaptured in good condition at the breeding site. Bird 13289 was fitted with a new transmitter (40867). Bird 40868 transmitter was removed as it no longer worked and released without. Bird 41504 was accidentally captured and released with a working tag.

Birds were fitted with 18–22 g solar-powered backpack satellite transmitters (PTTs) manufactured by Microwave Telemetry, Inc. (USA) and NorthStar (USA) (Meyburg & Fuller 2007), which used the Argos satellite system to locate and track honey buzzards. At the beginning of our study, only Doppler-shift transmitters were used due to the species' small size. Later, six GPS-enhanced tags were used, which also transmitted data on flight direction and speed (Ziesemer & Meyburg 2024). Four of these also provided altitude data. The GPS/PTTs were programmed to acquire a GPS fix every hour. The weight of the transmitter plus harness was always well below 3% of the 'birds' weight. For more details see Meyburg & Ziesemer (2024). As honey buzzards are very faithful to their breeding site, monitoring the return to the old breeding site allows a relatively good estimate of whether the birds have survived the last return migration and wintering period.

Information reported by Sergio et al. (2018) was taken into account for assessing whether a sudden failure of data collection or an unexpected cessation of movement – e.g., in the Sahara Desert – was due to the death of the bird, a transmitter defect, or transmitter loss while the bird was still alive. In addition to the guidance provided by Sergio et al. (2018), we were able to draw on our own experience in tracking several hundred birds of prey via satellite, from small falcons (e.g., Amur falcon *Falco amurensis*, Eurasian hobby *F. subbuteo*) to extremely large eagles (e.g., Steller's sea eagle *Haliaeetus pelagicus*, white-tailed eagle *H. albicilla*), belonging to 15 different species. Among those were many cases in which transmitters failed or had been dropped, but the birds survived (e.g., Meyburg & Meyburg 2013). For further details on methodology and analysis, see Meyburg & Ziesemer (2024). We assume that (1) the tagged birds were representative of the local population, (2) the tagging process did not affect survival, and (3) our method of distinguishing death from transmitter failure is valid. Unfortunately, we could not tag more than 12 adult honey buzzards, as the official authorisation was limited to this. In addition, occupied nests of the species are difficult to find, and adults are not easy to trap. We tagged our first individuals early since the introduction of satellite telemetry for bird species of this size when there was little experience of its effects.

Probabilistic methods can be used to calculate bird mortality or survival by incorporating stochastic factors and environmental variables into population modelling. This method is often applied by simulation but does not provide the measured results needed to justify, for example, regulatory action by government agencies. To quantify measured survival and inferred survival rates from telemetric monitoring, we introduce a new methodology in ornithology. We combine the methodology of the Kaplan-Meier survival estimator (Kaplan & Meier 1958) (see also https://en.wikipedia.org/wiki/Kaplan%E2%80%93Meier estimator), which sorts and censors raw data with incomplete knowledge for further event time analysis, with the equation that calculates the number of survivors N as a function of time t, based on the survival rate SR. The Kaplan-Meier survival estimator has been used in various fields, including statistical and medical research, clinical trials, failure analysis, engineering, economics and actuarial science. It has also sometimes been used in ornithological research (e.g., Panter et al.2021), but has not been used to quantify survival rate. The challenge is that the Kaplan-Meier estimator and the resulting plot alone give no guidance on how to extract a survival rate from it. It plots cumulative survival (not survival rate) against time on a linear vertical axis. Pollock et al. (1989a, b) showed that the extraction of survival rates requires an assumption about the validity of a probability density function for survival. Alternatively, the survival rate is calculated by comparing the proportion of survivors after a discrete period with the proportion of survivors in the previous period. This is also the classical way of generating survival rates from ring recoveries.

The novelty presented here, which makes the Kaplan-Meier estimator now easily applicable to ornithology and especially telemetric studies, is to combine it with the basic mathematical definition of survival rate and use it as a probability density function for survival over time.

The mathematical derivation is as follows:
The survival rate definition equation (1) calculates the number of survivors N as a function of time t ("N(t)"), based on the survival rate SR:

$N(t) = N_0 * SR^t$ (1)

whereby

$N(t)$ = number of survivors at time t after fitting a transmitter

N_0 = number of birds fitted with transmitters

SR = annual survival rate = 1 - annual mortality rate

Equation (1) can be rearranged and differentiated to give

$d\ln (N(t)/N_0) / dt = \ln (SR)$ (2)
(with ln = natural logarithm)

If $\ln(N(t)/N_0)$ is now plotted against t in the KAPLAN-MEIER survival plot, the final result is what we call the

"GRIES-MEYBURG plot". The slope of the resulting linear regression line in the plot is ln(SR), which finally gives access to the desired result for SR (and, therefore, the mortality rate). Note that the vertical axis is no longer linear, as in the usual Kaplan-Meier graphs, but a transformed axis to linearise the probability density function for survival over t. A fundamental advantage of this new method is that it uses a continuous mathematical equation to which the results, based on a continuous time line, are fitted by linear regression. Classical use, e.g., for ring recovery, is based on a discrete comparison from time period to time period (mostly year to year). This classical method cannot take advantage of the daily precision of event detection by telemetry, which is in contrast to the new method, which can handle any broken numbers for t. The classical period-to-period method stems from ring recovery exploitation methods and can only use integers for t if the statistical ensemble is large. Using linear regression, the result is automatically averaged.

The date of death of the last survivor cannot be taken into account for mathematical reasons, since N in equation (2) would become zero. Ln(0) cannot be calculated.

We used the Kaplan-Meier estimator methodology to refine the raw data from telemetry studies. Birds with an unknown date of death or with an unclear reason for loss of tracking contact, e.g., due to transmitter failure, are 'censored' according to the Kaplan-Meier entry design, i.e., they are not included in the analysis. Birds proven to be alive after the last recorded mortality event increase the number for $N(t)/N_0$.

To refine the raw data, the time span between deployment of the transmitter and the mortality event is calculated precisely in days, but later, it has been used in terms of broken years (t is given in years, as we want to determine survival rate in years). It is also possible to determine the survival rate per day if t is left in "days"). Second, the raw data are sorted according to the time between tagging and death.

Thirdly, $N(t)/N_0$ is calculated for each mortality event, whereby at $t = 0$ the value for N is N_0. Fourthly, $Ln(N(t)/N_0)$ is plotted against t, the regression line is calculated or manually drawn, and its slope is determined. The fourth step was done in a spreadsheet, which also gives access to the linear correlation factor f and can generate a plot. It is advisable to generate the plot before the data range for linear regression is selected, as the survival rate may change over time.

N(t) is normalised to N_0, as it is being done in Kaplan-Meier survival plots. Mathematically, it is not necessary to do so, but due to the normalisation, different statistic samples can be compared in the same plot.

Following the Kaplan-Meier methodology, 2 of the 12 birds needed to be censored (see Meyburg & Ziesemer (2024) for details about the fate of these birds). As the data of the last death of 10 bird cannot be made use of, there are 9 deaths whose dates could be evaluated.

We have also tested the robustness of the new method regarding the impact of the last bird having died after a very long lifetime (5.1 years after tagging). This bird (13289–40867) could not be included for the mathematical reason mentioned above, but as a test, we assumed that a hypothetical survivor lived longer and reassessed the survival rate.

Assuming that the ring recovery results represent the age class distribution and that the statistical sample is large enough, the methodology presented can also be applied, allowing published results to be re-checked and re-used if the raw data are available. In this case, it is sufficient to know the fraction of rings recovered for each age class out of all rings recovered. The Kaplan-Meier entry design is obsolete here, provided the ring recaptures stem from dead and not from birds alive. We have revisited an older ring recovery study from Sweden (Tjernberg & Ryttman (1994), only birds found dead, N = 53) to get second source numbers for survival rate by the applied new method. This source gives the number of rings for each age class. For the same purpose, we have revisited ring recovery data published by Cösters et al. (2000) (N = 5) which were published with exact ringing and recovery dates. The birds were adult when they were found. No survival rate had been determined from these data up to now.

Results

Ten of the birds disappeared and were presumed to have died during the tracking period, of which three disappeared during the autumn migration, two during the spring migration, four during the winter and only one in the breeding area (Meyburg & Ziesemer 2024).

Figure 1 shows that survival, and therefore mortality, is relatively constant over time, as the results are well represented by a straight regression line over time. The average adult survival rate derived from the slope of the regression line was 0.44 per year. This gives an adult mortality rate of 0.56 per year (linear correlation factor $f = 0.99$). Note that the slope of the regression line is not the survival rate itself, but its logarithm.

The assumption of a hypothetical survivor increases the survival rate to 0.62/year ($f = 0.97$), respectively decreases the mortality rate to 0.38/year (Fig. 2), but the scatter

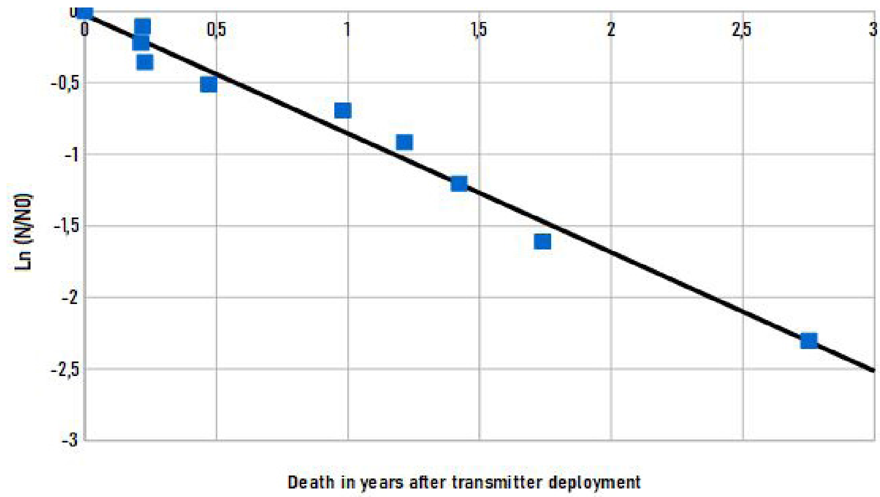

Fig. 1. Fatalities after tagging. GRIES-MEYBURG plot for quantitative determination of survival of adult honey buzzards tagged as adults. Black: straight line of calculated linear regression with f = 0.990 and adult survival rate 0.44/year. Each data point represents one of nine mortalities with known date of death. The slope of the line is not the survival rate but its logarithm. The slope of the line is not the survival rate but its logarithm. Ln(N/N_0) is the log-transformed normalised survival.

Obr. 1. Úmrtia po označení. GRIES-MEYBURGOV graf na kvantitatívne stanovenie prežívania dospelých jedincov včelára lesného, ktoré boli označených ako dospelé. Čierna: priamka vypočítanej lineárnej regresie s f = 0,990 a mierou prežitia dospelých jedincov 0,44/rok. Každý údajový bod predstavuje jednu z deviatich úmrtí so známym dátumom smrti. Sklon čiary nie je miera prežitia, ale jej logaritmus. Ln(N/N_0) je logaritmicky transformácia normalizovanej hodnoty prežívania.

Fig. 2. Fatalities after tagging. GRIES-MEYBURG plot for quantitative determination of survival of adult Honey Buzzards, tagged as adults. Black: straight line of calculated linear regression with f = 0.974 and adult survival rate 0.62/year. The slope of the line is not the survival rate but its logarithm. Ln(N/N_0) is the log-transformed normalised survival.

Obr. 2. Úmrtia po označení. GRIES-MEYBURGOV graf na kvantitatívne stanovenie prežívania dospelých jedincov včelára lesného, ktoré boli označených ako dospelé. Čierna: priamka vypočítanej lineárnej regresie s f = 0,974 a mierou prežitia dospelých 0,62/rok. Sklon čiary nie je miera prežitia, ale jej logaritmus. Ln(N/N_0) je logaritmicky transformovaná normalizovanej hodnota prežívania.

around the regression line becomes larger, systematic deviations become obvious, and f becomes smaller.

We also analysed our telemetry results in the conventional way by periods (year ends). The cumulative survival at the end of years 1 to 3 was 50, 30 and 10%, respectively. Therefore, the resulting survival rates for these years are 50, 60 and 33%/year, respectively, so the resulting mortality rates are 50, 40 and 67%/year, respectively.

The average of these last figures is 0.52/year, which compares well with the 0.56/year obtained by the new method.

Figure 3 shows that the survival rate of honey buzzards ringed as nestlings in Sweden is not constant over time. Two regression curves were necessary because there are two life phases with different survival rates (two lines with different slopes). Survival rates are 0.883/year for the years 8 to 24 and 0.838/year for the years 2 to 5 (f = 0.925 and 0.975, respectively), so the mortality rate is 0.117 and 0.162/year, respectively. This means that it decreases with age. The survival rate for the first year was calculated using the classical method (N_1/N_0) = 0.53/year). The average of both life phases is 0.860/year, respectively 0.140/year for mortality rate.

The few ring recovery data from Cösters et al. (2000) resulted in a survival rate of 0.860/year (f = 0.995), so the adult mortality rate was 0.140/year (Fig. 4).

Discussion

To date, only a few adult honey buzzards have been tracked by satellite throughout the year, but nothing has been published on the resulting survival rates. Meyburg & Ziesemer (2024) have already described our findings on where and when birds disappeared and the challenges researchers face in identifying mortality events throughout the year and interpreting such data (Meyburg & Ziesemer 2024).

Ringing results for honey buzzards can provide data on survival rates, but little information on where mortality is occurring. Most ring recoveries have come from the area north of the Sahara. Since 1945, 2196 honey buzzards ringed in Germany have led to only three recoveries in West Africa. The recovery rate (long-distance detections over 10 km and more) is only 3.3% (Bairlein et al. 2014). A large dataset of ring recovery records (31,269 records) spanning more than 100 years suggests that the mortality of six large migratory birds of prey, including the honey buzzard, has declined dramatically since the late 1970s. After 1979, indirect anthropogenic factors increased while direct factors decreased (De Pascalis et al. 2020).

Survival rates of breeding adult raptors may be highly dependent on habitat quality. For example, in a study of sparrowhawks (*Accipiter nisus*) by Newton et al. (2008), the survival of breeding females was negatively related to the number of rainy days. Annual survival was estimated using a capture-recapture method in three different areas of southern Scotland and east-central England. The three study areas differed at 59%, 66% and 72%. Under certain conditions, the survival of long-lived territorial birds can be estimated using age ratios or turnover rates (Hernández-Matías 2011).

Honey buzzard populations are generally stable (BirdLife International 2004). However, there is increasing evidence that the species is declining in most parts of its European breeding range (Tjernberg & Ryttman 1994, Cösters et al. 2000, Bijlsma 2006, Kjellén 2006, Björklund et al. 2008, Mammen & Stubbe 2009a, b), while counts of migrants in southern Italy by Agostini et al. (2007) suggest that the breeding population of this species in the Balkans may have increased in recent decades. In the Schleswig-Holstein (northern Germany) area, where we tagged most birds, Ziesemer (2024) observed no population decline or increase during a long observation period.

According to Bijlsma et al. (2012), the mortality rate of adult honey buzzards is higher than that of other raptor species in Europe, which is consistent with the observed declines in much of northern and western Europe. Survival results from Bijlsma et al. (2012) are based on recoveries of honey buzzards ringed across Europe (collected by EURING and individual ringing stations between 1957 and 2005). Using the Seber recovery model, survival results ranged from 0.82 to 0.808/year for years 4 to 7 (average: 0.812/year), resulting in an average adult mortality of 0.188/year (average calculated by the authors of this article).

The survival rates of Tjernberg & Ryttman (1994) (0.851 to 0.917/year) in Sweden are higher than the result reported by Bijlsma (2012). We calculated a survival rate of 0.883 for the adult Swedish birds found dead, which is slightly lower than the published 0.917/year.

Cösters et al. (2000) published some raw data for ring recoveries (N = 5) of honey buzzards from North Rhine-Westphalia (Germany) from 1972 to 1998. Using these data, the new method applied here gives a mortality rate of 0.140/year, which is in the same range as the result reported by Tjernberg & Ryttman (1994) for birds shot and found dead together (0.14/year) and our results for birds found dead from the same source (0.14/year averaged over all adult life phases). Both sources of ringing data from Sweden and Germany are historical and do not necessarily reflect the current situation, but give comparable figures for mortality. It can therefore be assumed that both studies represent the situation at that time very well, and that Bijlsma et al. (2012) found already a trend to lower survival rates.

The large discrepancy between the obtained survival rate of 0.44/year and the published results cannot be due to the probabilistic extension of the Kaplan-Meier estimator,

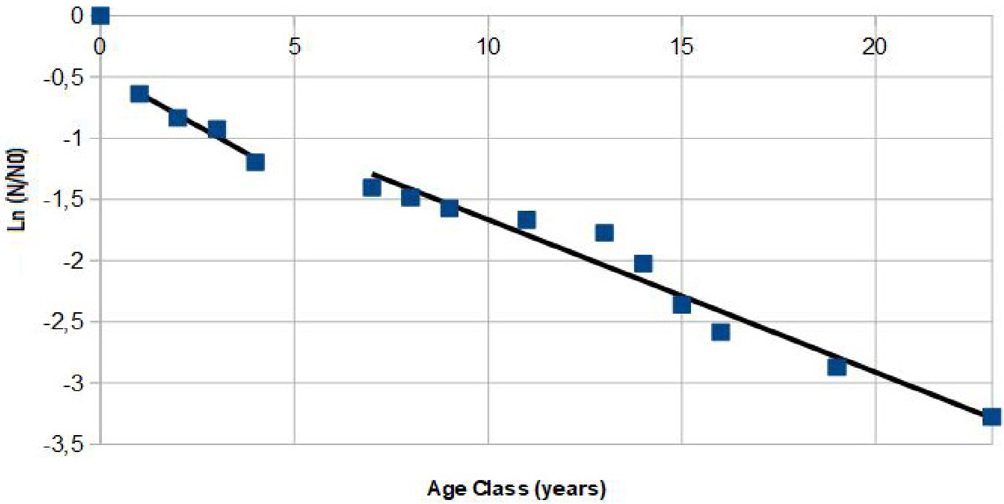

Fig. 3. GRIES-MEYBURG plot for quantitative determination of survival of honey buzzards found dead and ringed as nestlings in Sweden (N = 15). Raw data taken from Tjerrnberg& Ryttman (1994). Black: calculated linear regression lines. The gap is because no rings were recovered from these age classes. Survival rates are 0.838 and 0.883 for subadults/ younger adults and adults, respectively. Both curves together give a survival rate of 0.86/year. The slope of the line is not the survival rate but its logarithm. $Ln(N/N_0)$ is the log-transformed normalised survival.

Obr. 3. GRIES-MEYBURGOV graf na kvantitatívne stanovenie prežívania jedincov včelára lesného nájdených uhynutých a krúžkovaných ako mláďatá vo Švédsku (N = 15). Nespracované údaje prevzaté z Tjerrnberg & Ryttman (1994). Čierna: čiara lineárnej regresie. Medzera je spôsobená absenciou záznamov v príslušnej vekovej kategórií. Miera prežívania subdospelých/mladších dospelých jedincov bola 0,838 a 0,883 pre dospelé jedince. Obe krivky spolu dávajú mieru prežitia 0,86/rok. Sklon čiary nie je miera prežitia, ale jej logaritmus. $Ln(N/N_0)$ je logaritmicky transformovaná normalizovaná hodnota prežívania.

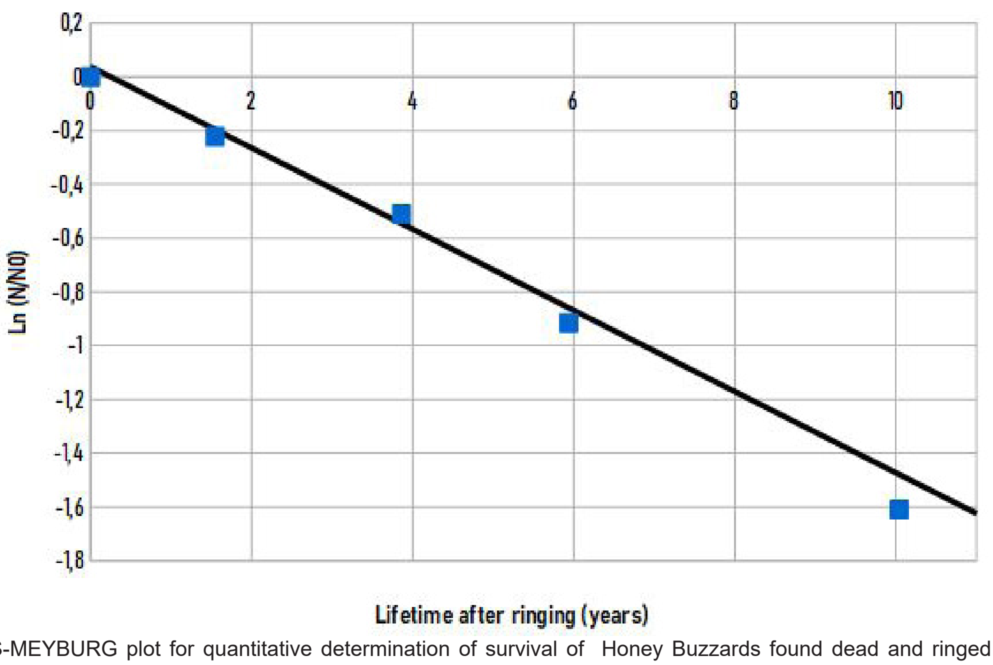

Fig. 4. GRIES-MEYBURG plot for quantitative determination of survival of Honey Buzzards found dead and ringed as nestlings in Germany (N = 5). Raw data from Cösters et al. (2000). Black: calculated linear regression line. The survival rate is 0.86 (f = 0.995). The slope of the line is not the survival rate but its logarithm. $Ln(N/N_0)$ is the log-transformed normalised survival.

Obr. 4. GRIES-MEYBURGOV graf na kvantitatívne stanovenie prežívania jedincov včelára lesného nájdených uhynutých a krúžkovaných ako mláďatá v Nemecku (N = 5). Nespracované daje od Cösters et al. (2000). Čierna: čiara lineárnej regresie. Miera prežitia bola 0,86 (f = 0,995). Sklon čiary nie je miera prežitia, ale jej logaritmus. Ln(N/N0) je logaritmicky transformovaná normalizovaná hodnota prežívania.

since the classical evaluation produces almost the same number (see “Results”).

According to Bijlsma et al. (2012), the decline in Scandinavia and parts of Western Europe seems beyond doubt. Regardless of the difference in data evaluation, the change to lower survival rates over decades is evident from the literature and may reflect rapidly changing conditions (habitat quality) on the breeding grounds, the African wintering grounds or both. Unfavourable wind and drought conditions partly due to climate change and weather fluctuations in the areas overflown during migration may also play a role. Cösters et al. (2000) also described a negative trend in the population from 1978 to 1998 in the Münsterland area in Germany.

In West and Central Africa, there has been a significant reduction and degradation of wooded savannahs, gallery forests and rainforests (Justice et al. 2001, Duveiller et al. 2008, Zwarts et al. 2009). These landscapes are the main wintering areas for honey buzzards (Bijlsma 2002, Hake et al. 2003, Gamauf & Friedl 2011, Strandberg et al. 2012), and these habitat impacts are likely to affect the survival and fecundity of the k-selected food specialist. This is supported by Howes et al. (2019, 2020), who predicted that continued forest loss in Africa would negatively impact the honey buzzard population, and in accordance with this 1/3 of our tracked individuals were lost in the wintering area.

It seems that particularly unfavourable weather conditions during the crossing of the Sahara and the Mediterranean led to the high mortality of our birds during migration, and these conditions are likely to vary greatly from year to year. Klaassen et al. (2013) also reported significantly increased mortality for three raptor species using the same migratory flyway. Based on 32 published papers on different species, Newton (2024) concluded that most studies showed that mortality was higher during migration than at other times.

Weather conditions during migration have been found to influence the annual survival of large raptors, e.g., studies of peregrine falcons (*Falco peregrinus*) breeding in the Arctic showed that climatic conditions during migration, particularly autumn NAO indices, were correlated with apparent annual survival rates (Franke et al. 2011).

Newton (2007) found that most migratory bird mortalities were attributed to adverse weather conditions, such as losses in flight due to storms and other unfavourable conditions en route. Most mortalities tend to occur over water. Records of in-flight weather-related mortality, involving hundreds or thousands of birds at a time, have mainly affected small passerines, but also larger birds, including eagles and swans.

The numbers of adult honey buzzards tracked here were too small, and the time period too short to adequately assess the many negative factors affecting long-term averaged survival rates. As many other questions about the species’ biology could be answered by satellite tracking, further studies using more technologically advanced transmitters are recommended.

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