Trends in survival of Northern Goshawks (*Accipiter gentilis*) in the Netherlands

Natasha Desai

February 2023

Trends in survival of Northern Goshawks (*Accipiter gentilis*) in the Netherlands

Natasha Desai
MSc Forest and Nature Conservation

REG-80436
February 2023

Supervisors:
Dr. R. Buij (WENR)
Dr. J. Ottenburghs (WEC)

Wildlife Ecology and Conservation group

The author declares 1) that this work is his/her own and 2) that he/she has adhered to The Netherlands Code of Conduct for Academic Practice.

WAGENINGEN
UNIVERSITY & RESEARCH

Abstract

As apex predators, northern goshawks (*Accipiter gentilis*) hold considerable influence over ecosystem health and are an important indicator species for the fragmented woods they occupy. They are, however, quite adaptable and thrive in urban areas. The shift to anthropogenic regions will likely affect their mortality factors, which might impact their survival and population dynamics in turn. The survival of goshawks was examined to understand the relationship between age, sex and survival probabilities. Mark-recapture analysis was carried out on a ringing-recovery dataset with about 35000 records between 1970 to 2022 from EURING using the program MARK, with additional statistical models to test for potential effects of age and sex. Adult goshawks had a significantly higher survival estimate compared to juveniles (0.78 and 0.26 respectively). Causes of death for recovered individuals were grouped and evaluated across decades to check for any peaks or shifts towards specific factors. This analysis revealed a decline in pollution-related deaths and an increase in traffic accidents and collisions with artificial structures over time. The shift in mortality from natural to anthropogenic factors is telling of habitat fragmentation and an increase in human-made structures within their range. Further research using additional variables like body mass and chosen habitat is recommended for more accurate estimates and to develop a solid plan of action to stabilize goshawk numbers in the Netherlands.

Introduction

One of the most important aspects of wildlife conservation research in the 21st century revolves around population declines of threatened species, and the biotic and abiotic factors that influence their distribution and abundance. The Anthropocene (Waters et al. 2016) has seen an exponential increase in the number of endangered species (IUCN 2000), with around 108 bird species going extinct over the last four hundred years (Johnson and Stattersfield, 1990). Recent decades have seen massive shifts from natural areas towards an anthropogenic landscape (Ellis and Ramankutty, 2008). Decreases in species richness and composition, and animal population declines are some of the strongest results of urbanisation largely due to natural habitat loss and degradation (Marzluff and Ewing 2001; Gaston 2010; Gil and Brumm 2014).Devising appropriate conservation strategies for these animals includes identifying important life history stages, and how they are influenced by changing environmental conditions.

Due to their high trophic position, apex predators are particularly sensitive to environmental shifts and contamination. They require a specific habitat for hunting and reproduction, and they often function as useful biotic indicators of ecosystem health (Sergio et al. 2005, 2006, 2008; Lima 2009). They wield considerable influence over lower trophic levels in their systems (Palomares and Caro 1999; Terborgh et al. 2001; Heithaus et al. 2008; Sekercioglu, 2006; O'Bryan et al. 2019) via their direct impact on prey numbers (Burgas 2014, Park et al 2008, Alkama et al. 2005; Sergio & Hiraldo 2008) or their indirect impact on the behaviour of prey species (Thomson et al. 2006, Lima 2009, Michel et al. 2016).

Birds of prey are some of the most endangered species on the planet, with 18% of the existing species facing extinction and 52% showing population declines due to anthropogenic factors (McClure et al. 2018). Populations of birds of prey are mostly influenced by available prey resources and nest site availability, while pollution and persecution can be similarly or more important locally (Newton 1979, 1991). Hunting, forest fragmentation and decreased prey density have led to sharp decreases in bird of prey populations and their available habitats (Bijleveld, 1974; Newton, 1998). While several conservation studies have been conducted on raptors, more information regarding survival statistics and mortality for individual species is required to understand population dynamics in increasingly human-dominated landscapes.

One species that has adapted well to anthropogenic transformation of its forest habitat is the northern goshawk (*Accipiter gentilis*) - an opportunistic generalist raptor (Rutz and Bijlsma 2006) with an extremely wide geographic range across the northern hemisphere – spanning Eurasia and North America (Squires and Kennedy, 2006). *Accipiter gentilis* is a superspecies consisting of four, possibly five allospecies - of which *A. gentilis gentilis* is the most widespread and most extensively studied - and around twelve subspecies depending on the source of taxonomic information (del Hoyo et al; 1994, Squires and Reynolds 1999, Brown and Amadon 1968; Kunz et al, 2019). Goshawks are territorial and traditionally feed on a variety of small to medium-sized mammals and birds that include pigeons and doves, corvids, passerines, hares, and waterfowl (Squires and Reynolds; 1997, Rutz and Bijlsma; 2006; Rutz et al; 2006). Goshawks, much like other species with similar long-life spans, show a strong influence of adult survival rates on overall population gains (Mertz 1971, Stahl & Oli 2006, Sergio et al. 2011). When modelled as a function of age alone, survival peaked at around 9 years. However, goshawks can live around 13-14 years in the wild, with a captive individual reaching 19 years. Previous research has shown that average annual adult survival can vary from 0.70-0.87 depending on the modelled time effect and addition of covariates like prey availability and precipitation (Wiens et al. 2006).

Survival rates for birds are difficult parameters to estimate. Birds of prey, much like other apex predators, naturally have lower densities than most other birds in their distribution range, making sample-size issues a common occurrence (Newton 1979). Studies on the post-fledgling survival of goshawks in relation to territorial, environmental, and individual variation showed that differences in survival rate were best explained by changes in body mass (both at fledging and as adults during the breeding season) and food availability (Wiens et al. 2006, Reynolds et al. 2017). The effect of body mass on survival rates is mainly linked to sex: when modelled as an additive effect, there is a significant association with survival (Todd et al. 2003, Wiens et al. 2006). Northern goshawks show reversed sexual dimorphism, with male body mass averaging around 71% of the female (Reynolds et al. 1994). Sex-associated survival in this species is usually linked to the difference in body mass; studies on survival models which included the sex of goshawks yielded evidence for lower male survival over females (DeStefano et al. 1994; Kenward et al. 1999; Reynolds and Joy 2006, Kruger 2007). Apart from the increased body mass (which provides via internal stores during food shortages) and higher mobility (Kenward et al. 1981; Widen 1985), another reason for lower male survival is the higher foraging risk, especially during the early breeding period when they travel more often and further from the nest than females (Kenward 2010).

Birds of prey tend to have the highest mortality recorded in their first year during the post-fledgling period, where almost half of the fledged chicks die (Newton 1979). Starvation, environmental exposure and predation are the leading causes of death for juveniles (Kenward et al. 1999, Dewey and Kennedy 2001). This is a common pattern in many birds: juveniles will have lower survival estimates than adults since they are mostly defenceless and prone to additional threats, and their survival probability increases with age (Martin 1995; Redmond and Murphy 2012; Reynolds et al. 2017). However, when raptors utilize developed areas for hunting and breeding, different causes of death are found compared to birds with territories in natural habitats.

Research shows that compared to natural causes of death such as age and predation, adult raptor mortality in the 21st century is more closely linked to collisions with anthropogenic structures (Hager S.B, 2009), hunting (Smart et al, 2010, Etheridge et al, 1997), pollution and diseases (Krone et al; 2005, de Chapa et al. 2020). Urban land cover has increased substantially in the last twenty years leading to further fragmentation of their natural habitat. Studies in the late 90s recorded large distribution gaps in goshawk populations that overlapped with agricultural land and cleared forest in Europe (Bijlsma and Sulkava, 1997). The most prominent disease in urban raptors appears to be trichomoniasis, caused by the parasite *Trichomonas gallinae*, commonly found in feral pigeons (Boal 1998, de Chapa et al. 2020). Another problem was the toxic effects of organochlorides like DDT – several raptor species including goshawks across the world saw severe population declines until the usage of these chemicals was banned. (Luzardo et al. 2014, Prestt et al. 1970, Vos et al. 2000, Kenntner et al. 2003). Goshawk hunting has also been shown to have an adverse effect on average lifespans by impacting nesting success (Bijlsma 1993).

Historically, goshawks tended to avoid human disturbance by foraging and breeding in quiet, dense forests (Rutz et al., 2006) where their hunting style - short-stay perch strikes from concealment – is most suitable (Widen 1984). However, with continual human encroachment and habitat loss, several goshawk territories now include fragmented woods and urbanized areas, where they use anthropogenic structures for cover instead (Rutz 2001). While the prey diversity is low in urban areas, feral pigeons are abundant, and the goshawks have adapted to include more of them in their diet (de Chapa et al. 2020). While this does put them at increased risk of contracting disease, the goshawks still thrive and have good reproductive success: goshawks in the Netherlands produced three or more chicks with higher body mass, as compared to the one or two young seen in the forest nests (Visser 2021). Nonetheless, more research is needed to establish the full impact of urbanization on goshawk survival; while the areas might appear suitable for nesting due to food availability, they are prone to additional mortality factors like chemical and air pollution, diseases, increased risk of collisions with anthropogenic structures, and stress (Boal 1997, Rutz 2006).

In this thesis, I aim to examine survival probabilities for northern goshawks in the Netherlands and identify the main causes of mortality from ringing and recovery data. I specifically focus on the effect of age and sex on the survival of the species. In the Netherlands, the goshawk population saw a marked decline until DDT, aldrin and dieldrin was banned in the 1970s, after which the numbers slowly improved and stabilized in the 80s and 90s due to the increasing availability of prey species and the maturation of planted woodlands resulting in more breeding areas (Bijlsma and Sulkava, 1997, Bijlsma et al. 2001). After the main range was saturated in the 1980s, goshawks started occupying the new forests and spreading across the country, particularly westward. However, in the eastern parts, the numbers fell after 1990 following large declines in prey species. (Bijlsma et al. 2001). I expect an overall decrease in survival, particularly over the last twenty years, owing to habitat loss, persecution, and loss of prey availability. I predict that younger goshawks will have lower survival than adults (Reynolds et al. 2017), and females will have higher estimates than males (Reynolds and Joy 2006, Kruger 2007). I also expect a shift in mortality from natural to anthropogenic causes due to human encroachment resulting in fragmented original habitat and more individuals residing in urbanized areas (Hager S.B, 2009; Krone et al; 2005, de Chapa et al. 2020).

Research methods

Data collection and area of research

This project specifically looks at survival of Dutch goshawks, and only uses data collected for individuals ringed within Dutch country borders. The goshawk breeding season in the Netherlands runs between March and June – chicks hatch in April-May and fledge in June and July (Reynolds and Wight 1978, Dewey et al. 2003). In these months, active nests are monitored, and the brood and clutch sizes are noted using a standard protocol for goshawks (Bijlsma, 1998). Chicks are ringed between 2,5-4 weeks, and their body mass, wing length, tarsus are measured and recorded (Piersma and Davidson, 1991). These findings are recorded as a ringing entry in EURING format and reported as such. The EURING database is a compilation of avian ringing and recovery data from different species, countries and schemes in Europe. If a ringed individual is resighted or recovered, it is also reported. The dataset uses reported entries from the public as well as researchers, and as such was thoroughly checked for possible human errors, such as misreported ring numbers, sex, ages, or locations.

Data formatting

The data follows EURING convention and consists of 35493 records of ringed goshawks in and around the Netherlands, of which 8164 entries are dead recoveries (EURING 2020). The data consists of multiple fields per recording, in five different character types: alphabetic, alphanumeric, integer, numeric and text. (Table 1, appendix)

The data was cleaned and checked for potential errors and unwanted entries in R 4.1.2. These included:

- A live report after the individual was recovered dead/not returned to the wild
- Erroneous date and age between subsequent records of an individual
- Misreported genders
- Birds ringed outside the Netherlands
- Inaccurate dates (> 6 weeks inaccuracy on date of recovery)
- Manipulated individuals (hand reared/transported/died within two weeks of ringing/euthanized)

The data was then transformed into the encounter histories format required for mark-recapture analysis in R – a binary sequence like the following:

10101010010000000 1 0 0 1 ;

Figure 1: example of a line in encounter history format. The first box represents encounters, the second is age groups, and the third is gender.

Where the first sequence of numbers represents the encounters over the period – since this analysis involves both live and dead encounters, each year is represented by two numbers: the first indicates release or recapture (live) and the second indicates recovery (dead). For example, a 1010 indicates a live recapture and release in period 1 and 2, while a 1011 would indicate that the bird was also recovered dead in period 2 after the live recapture. The following four columns are the attribute groups – young, adult, male and female – with a 1 in the column indicating that the individual does belong to that group. For example, a 1 0 0 1 would indicate that the encounter history is for a female that was first caught during the fledgling phase.

Statistical analysis

Survival estimates per year and group (sex and age) were obtained using mark-recapture analyses. This is best suited to the data according to the size of the dataset and similar to previous studies carried out on goshawks and other animals (Lebreton et al., 1992; Le Gouar et al., 2011, McGrady et al., 2016, Reynolds et al., 2017). Since the data included both live recaptures and dead recoveries, the Burnham survival model was used, which incorporates both kinds of records for more accurate survival estimates than would be obtained by using only one. (Burnham 1993). Compared to a Cormack-Jolly-Seber live recapture analysis, which would involve the estimation of only two parameters (ϕ and p; survival and recapture), Burnham live-dead analysis has four parameters:

Parameter	**Symbol**	**Explanation**
Apparent survival	S	Probability of survival from occasion i to i+1
Recapture	p	Probability that individual is reencountered if alive and in sample at time i
Recovery	r	Probability that individual is found dead and reported between i and i+1
Fidelity	F	Probability of remaining in sampling area between i and i+1

First, models were designed to measure the effect of time, age, and sex on survival separately. Next, those groups were modelled together to test for interaction effects between the factors. These models included both constant and variable survival and recapture probabilities for each group, taking all permutations into account. Notation of the models was taken from Lebreton et al. 1992, and works as follows:

S(t) p(t) r(t) F(t) – full time dependence for all four parameters.

S(t) p(.) r(t) F(t) – recapture probability (p) is constant with time, the other three may vary.

S(g*t) p(t) r(.) F(.) – survival (S) depends on the interaction of the group attribute and time (g*t), recapture (p) varies with time, and recovery (r) and fidelity (F) are constant over time.

In this analysis, the groups involved would be per age and sex – young, adult, male, and female. Since the actual age of a bird is difficult to estimate, avian survival analysis often uses two age categories: young/juveniles (individuals that are approximately less than one year in age) and adults (individuals that are one year or older) (Anderson and Burnham 1999, Harnos et al. 2015).

The program MARK (White and Burnham 1999, Cooch and White 2008) was used to build, calculate, and compare models which address the research questions of survival rate magnitudes and the impact of ecological factors on those rates. (Lebreton et al, 1992; Wiens et al. 2006). Akaike's information criterion (ΔAIC_c) was used to compare models for variation in survival over the years and select the most appropriate approximation (Akaike 1974, Anderson and Burnham 2002). This information-theoretic approach is preferred over likelihood-ratio testing (LRT) when analysing survival for several reasons – LRT in MARK is time-consuming if there are many candidate models and this approach requires the model to contain nested subsets. For example, S(t)p(.) is not a subset of S(.)p(t), although both are subsets of S(t)p(t)). Multi-model inference allows for comparison and weighing of all models simultaneously, as well as retention of information from the "losing" models. The groups were fitted both alone and additively to the models, and structures with constant survival and recapture probabilities were also checked. All estimates were calculated with 95% confidence intervals and standard errors.

For the analysis of causes of death, all dead entries from the dataset (Table 1) were extracted using the Condition column (codes corresponding to live recaptures/recoveries were removed) and the codes from the Circumstances column were matched with the descriptions from the EURING website. Certain causes of death were grouped together for the purposes of this study and broadly split into natural and anthropogenic causes. Deaths caused by human activities still fall under a large spectrum and were therefore further split into categories like traffic casualties (including both road and rail-related deaths), agriculture-related causes, hunting, and pollution.

Results

The changes in apparent survival over time and any apparent effects of age and sex were determined from mark-recapture analysis in program MARK. Separate models were built to test for the effects of age and sex independently, as well as full models. This comparison was carried out to test for any changes in the type of interaction between the grouping variable and time if the other was absent.

Time-dependent survival

Table 1: best fitting models for time-dependent survival of northern goshawks in the Netherlands from 1970-2020.

No.	**Model**	**AICc**	**ΔAICc**	**AICc weight**	**Model likelihood**	**Parameters**
1	S(t) p(t) r(.) F(.)	30499.34	0	0.53745	1	97
2	S(t) p(t) r(.) F(t)	30499.64	0.3002	0.46255	0.8606	107
3	S(t) p(t) r(t) F(.)	30532.93	33.5946	0	0	145
4	S(.) p(t) r(t) F(t)	30557.88	58.5362	0	0	108
5	S(.) p(t) r(t) F(.)	30566.78	67.4436	0	0	99

The best fitting model (S(t) p(t) r(.) F(.)) included both survival and recapture probabilities varying over the studied period as opposed to a constant survival rate (Table 1, Figure 2). Overall, two models (the aforementioned, and the model that includes varying survival, recapture and fidelity probabilities over time) showed a higher AICc weight compared to the other models, but an LR test supported the selection of the model with the highest weight and lowest ΔAICc (Model 1 in Table 1) despite the lower number of parameters (p=0.0309).

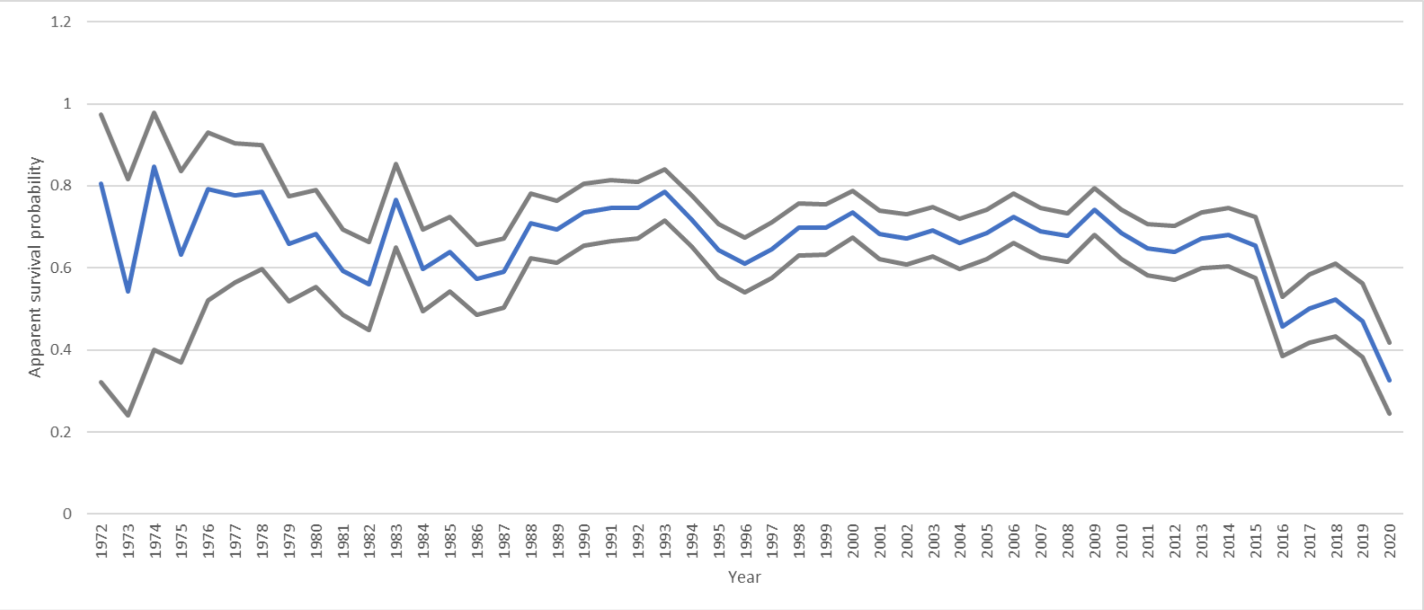

Figure 2: Varying survival probabilities of northern goshawks in the Netherlands from 1970-2020 corresponding to model 1, Table 1. The blue line is the calculated survival estimates per year; grey lines indicate the lower and upper confidence intervals.

Age

Table 2: best-fitting models for time and age-dependent survival of northern goshawks in the Netherlands from 1970-2020.

No.	Model	AICc	ΔAICc	AICc weight	Model likelihood	Parameters
1	S(y./. a.) p. r(y./. a.) F(y./. a.)	29511.15	0	1	1	7
2	S(age*t) p(age) r(age) F(age)	30349.8	838.6503	0	0	85
3	S(age) p(age) r(age) F(age)	30375.5	864.352	0	0	7
4	S(age+t) p(age+t) r(age+t) Fage+t)	30396.47	885.3216	0	0	214
5	S(age*t) p(t) r(.) F(.)	30414.64	903.4908	0	0	125

To investigate the effect of age on survival, 18 models with different interactions of age and time on survival were compared with each other (Table 2). When modelled alongside time, a constant survival rate for juveniles and adults was supported over any type of interaction of age and time. Since birds ringed as chicks will move into the "adult" class after a year elapses, the parameter index matrix for the "young" group is changed to match the adults after a year for models testing for constant survival rates. In the model with the highest weight, juveniles had a significantly lower survival estimate than adults – the former at 0.2630667 (95% CI, [0.2134383, 0.3195466]) and the latter at 0.788278 ((95% CI, [0.7753945, 0.8006116]) (two sample t-test: p=0.0007, t=-71.647, Figure 3).

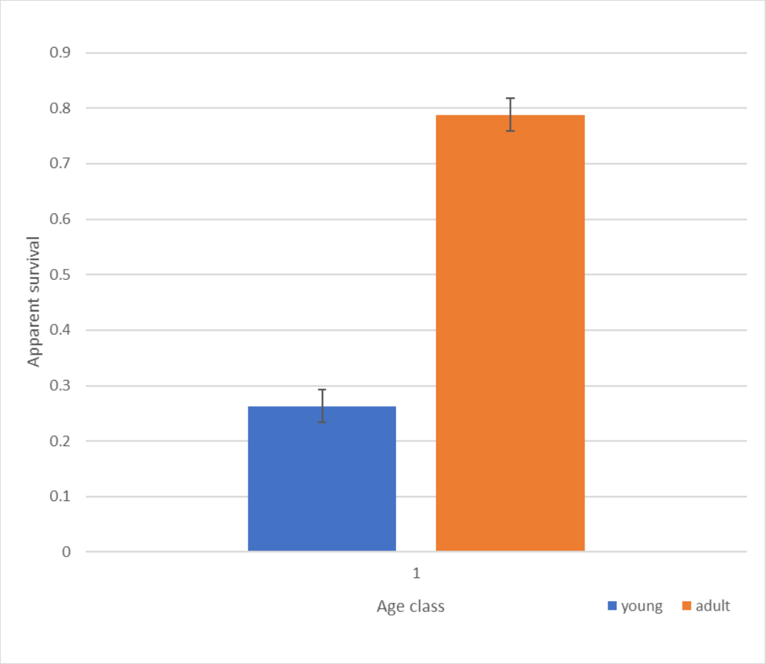

Figure 3: Apparent survival probabilities for juvenile and adult northern goshawks in the Netherlands from 1970-2020. Birds classified as adults in this study are one year or older.

Sex

Table 3: Best-fitting models for time and sex-dependent survival of northern goshawks in the Netherlands from 1970-2022.

No.	Model	AICc	ΔAICc	AICc weight	Model likelihood	Parameters
1	S(sex*t) p(t) r(.) F(.)	30537.59	0	0.98401	1	143
2	S(sex*t) p(g*t) r(.) F(.)	30545.85	8.2567	0.01585	0.0161	179
3	S(sex*t) p(t) r(t) F(t)	30555.57	17.9828	0.00012	0.0001	196
4	S(sex+t) p(sex+t) r(sex+t) F(sex+t)	30560.14	22.5506	0.00001	0	160
5	S(sex*t) p(sex*t) r(sex*t) F(sex*t)	30607.21	69.6186		0	283

18 models were built to test for any effect of sex on survival. The five models with the highest likelihood all showed an interaction between sex and time having an influence on survival, indicating that time does affect male and female survival differently (Table 3, Figure 4).

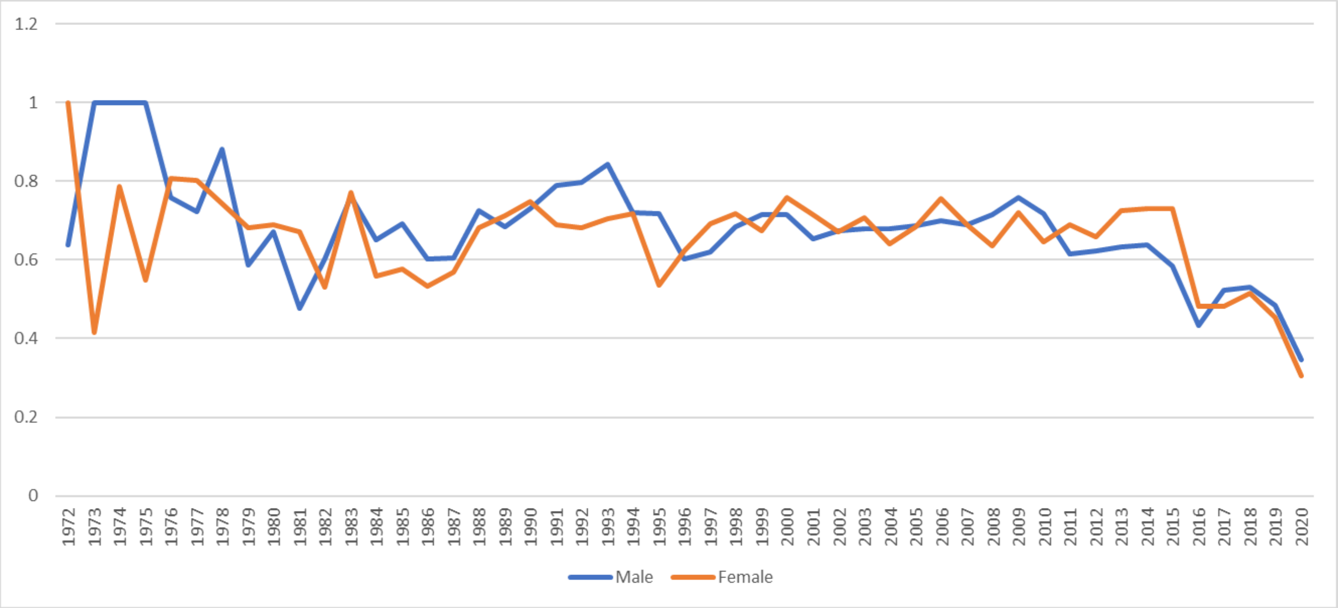

Figure 4: Varying survival probabilities for both sexes of northern goshawks in the Netherlands from 1970-2020 corresponding to model 1, Table 3.

Full model

When age and sex are both included as grouping attributes (for a total of four groups in analysis), the best supported model still shows an interaction of sex and time, but no interaction of age and time – which correspond to when each of those attributes was modelled separately (Table 4, Figure 6). The apparent survival of the age classes is still significantly different (young = 0.2630668 (95%CI, [0.2134385, 0.3195465]), adult = 0.7882776 (95%CI, [0.7753946, 0.8006117])) (two sample t-test: t = -18.933, p = 0.0007).

Table 4: best-fitting models for time, age and sex-dependent survival of northern goshawks in the Netherlands from 1970-2020.

No.	**Model**	**AICc**	**ΔAICc**	**AICc weight**	**Model likelihood**	**Parameters**
1	S(y./. a. sex*t) p(sex*t) r(y./. a. sex*t) F(y./. a. sex*t)	60119.8786	0.00	1.00	1.00	292
2	S(y./. a. m. f.) p(. m. f.) r(y./. a. m. f.) F(y./. a. m. f.)	60184.7386	64.8582	0.00	0.00	14
3	S(age+sex+t) p(age+sex+t) r(age+sex+t) F(age+sex+t)	60563.4456	443.5670	0.00	0.00	85
4	S(t) p(age*sex*t) r. F.	60667.3388	547.4602	0.00	0.00	202
5	S. p(age*sex*t) r(t) F(age*sex)	60782.4656	662.5870	0.00	0.00	205
6	S(age*sex*t) p(age*sex*t) r. F.	60803.2554	683.3768	0.00	0.00	327

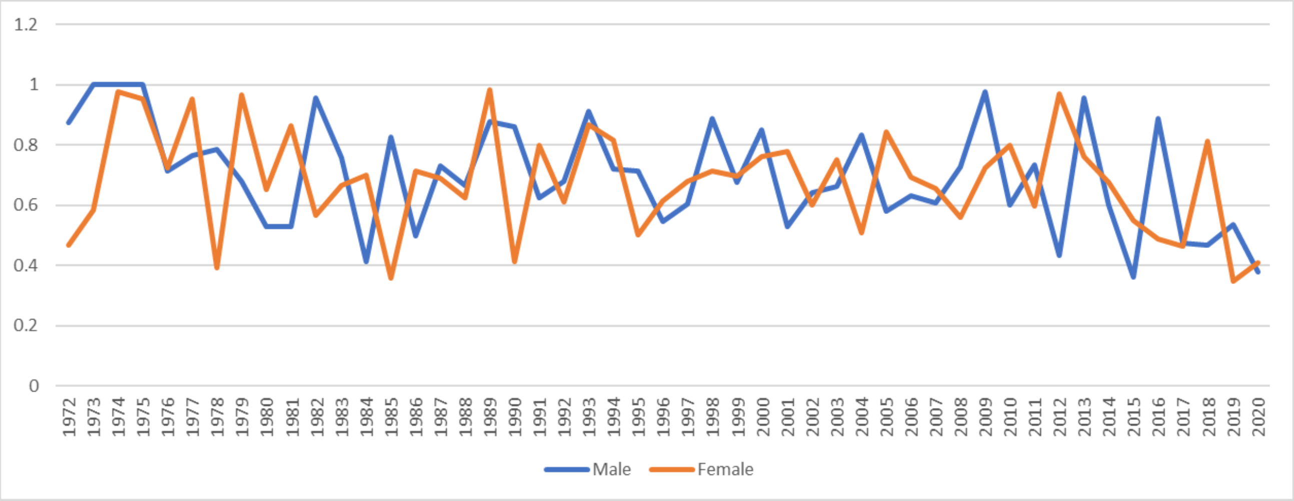

Figure 5: Varying survival probabilities of northern goshawks in the Netherlands from 1970-2020 corresponding to model 1, table 4.

It is important to note that the global model incorporates the most information about the goshawks and is the most accurate representation of survival estimates over the study period. When comparing Figure 5 and Figure 6, the effect of the difference in survival for age classes is noticeable in Figure 6. In general, goshawk survival fluctuated between 0.5 – 0.8 from 1991-2011, and has seen a marked decline in the following years.

Mortality factors

I focused on specific causes of death based on existing literature, largest sample sizes and noticeable peaks in certain years and analysed further - namely pollution, traffic casualties and collisions with artificial structures. There were 39 different causes of death across 1620 recovery records, which were categorized as Urban, Natural, Agricultural, Illness, Traffic, Shot and Other. The proportion of deaths per category was plotted per year (Figure 7) and per decade (Figure 8).

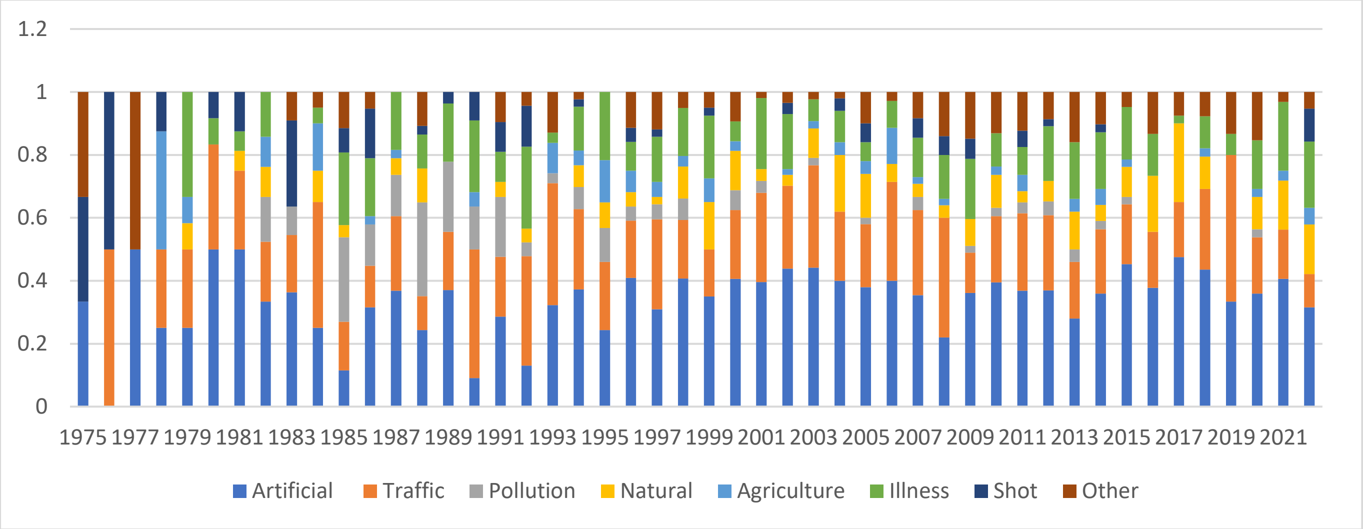

Figure 6: proportions of causes of death of northern goshawks from 1970-2022 in the Netherlands.

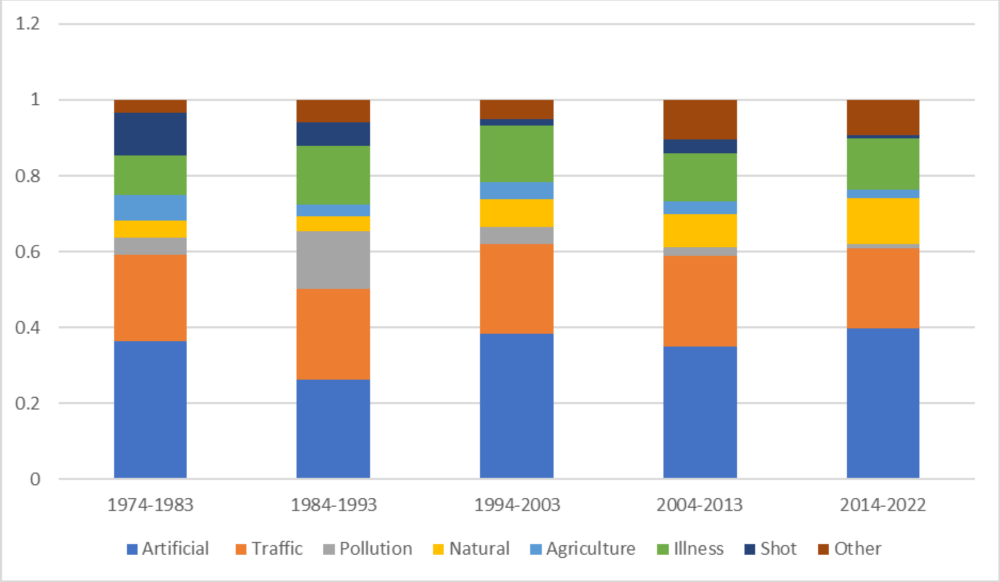

Figure 7: proportions of causes of death of northern goshawks per decade in the Netherlands.

The graphs show which certain factors hold greater sway than others, and in which years a certain factor had a stronger influence (such as Pollution from 1984-1993). The Urban category, which includes death by colliding with glass, wires, and buildings, has consistently been the largest contribution to ringed recoveries (25-50%). It is followed by deaths to cars and trains. Chi-square tests (Appendix, Table 5) only showed significant differences with the Shot category. Specific causes of death were selected and analysed based on existing literature – which point to pollution and collisions with buildings and vehicles as leading causes of mortality for birds of prey (Hager 2009; Krone et al. 2005, de Chapa et al. 2020).

Chemical pollution

The years between 1980-1990 listed chemical pollution as the cause of death for most recovered goshawks. Noticeably, no pollution-related deaths were reported prior to 1982. (Appendix figure 11). A linear regression model shows a decline of chemical-related deaths between 1980 and 2020 ($R^2 = 0.48$, $p < 0.001$)

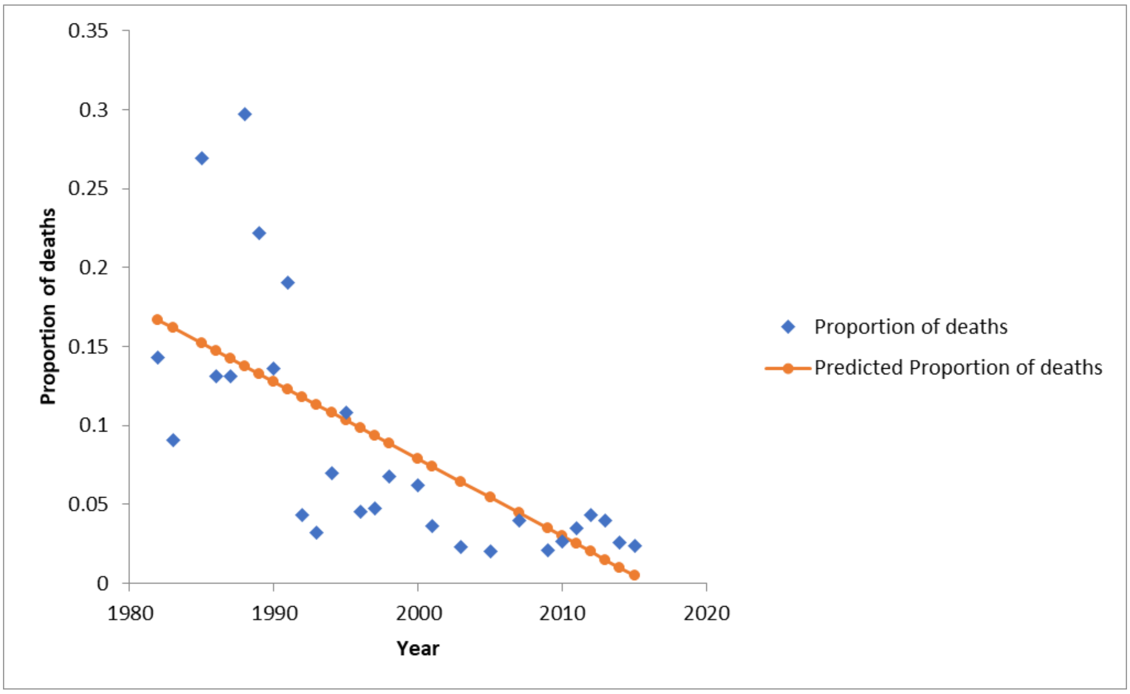

Figure 8: linear regression model for northern goshawk deaths by chemical pollution from 1970-2022 in the Netherlands.

Collisions with artificial structures

The number of deaths due to a goshawk flying into glass have increased significantly over the time of data collection, and it is still the factor contributing the most to deaths at present (Appendix, figure 13). The linear regression model also shows a positive relationship of collision-related deaths with time ($R^2 = 0.4226$, $p = 0.0005$)

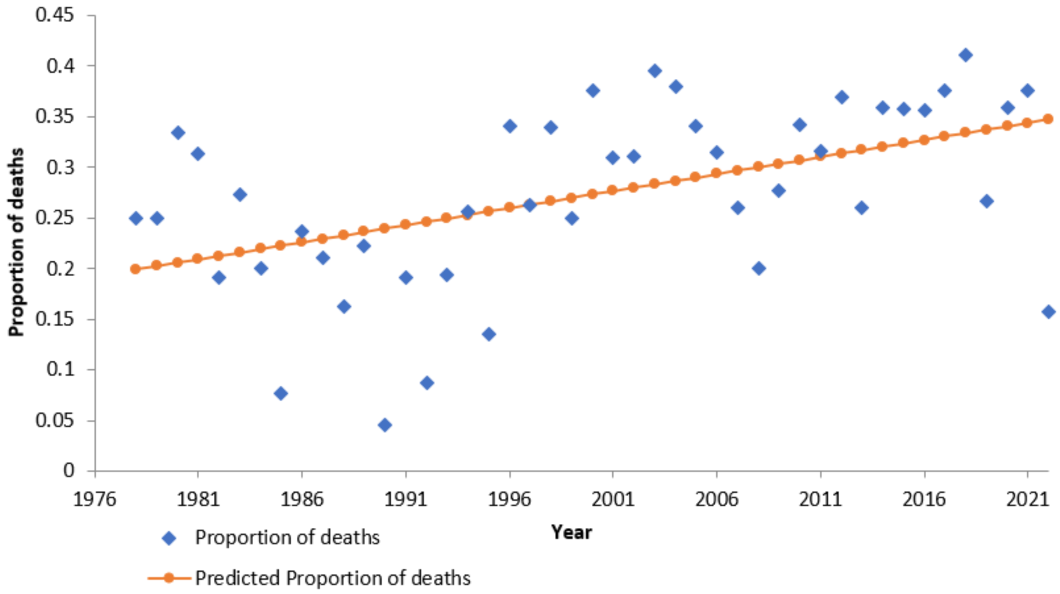

Figure 10: linear regression model for northern goshawk deaths by collision with artificial structures from 1970-2022 in the Netherlands.

Discussion

As more goshawks choose territories in and around urban areas, there is a pressing need for the current and future status of the species to be evaluated. The results show a decline in survival estimates in the Netherlands over the time of study, with a marked difference between age classes. Causes of death in ringed individuals have shifted from natural to anthropogenic factors, with the highest numbers attributed to hitting man-made structures.

The effects of age and sex on apparent survival

As predicted, apparent survival estimates for northern goshawks in the Netherlands have decreased over the last fifty years. The age of the ringed individual had a substantial effect on the estimated survival probabilities of goshawks – goshawks are at greater risk of death in their first year compared to the rest of their lifespans. These results are in accordance with existing literature on survival of goshawks and other birds of prey, where the individual has a higher likelihood of survival once it makes it past the fledgling phase (Wiens et al. 2006). Goshawk chicks are especially prone to predation from larger raptors like owls, and most recorded predation-related deaths are nestlings and juveniles (Reynolds et al. 2006). The inability to hunt and exposure to weather are also detrimental to birds that are unable to fend for themselves yet (Kenward et al. 1999, Dewey and Kennedy 2001). In line with those findings, most deaths recorded under “Predation” in the dataset were indeed chicks or juveniles.

The observed difference between sexes in this analysis is minimal. Some previous studies have also reported no significant difference in survival based on sexes. This is likely due to absence of body mass as a variable – any studies that have used sex as a variable in survival analyses of goshawks have either seen no effect or heightened female survival only if body mass is also an included factor. Females are generally heavier and hence have more energy reserves than males, aiding their survival (Wiens et al. 2006). This implies that linking gender to survival might be possible with the addition of other variables, such as body mass and size.

Prominent causes of mortality

With survival being so closely linked to population dynamics, the results from the full model (Figure 6) correspond to what we know about Dutch goshawks: numbers increased and stabilized during the late 80s-90s. The model also indicates a decrease in goshawks in the Netherlands over the last ten years. This decline can be linked to increasing mortality from anthropogenic sources, as more goshawks take up territory in urbanized areas due to habitat fragmentation and feral prey abundance (Chace and Walsh, 2006; Visser et al. 2021). It is important to note a slight lowering effect due to the fluctuating number of ringing and recovery records for goshawks between 2011 and 2022 compared to previous decades. Multiple years between 1994 and 2005 have over a thousand records, while later numbers have slowly dropped into the 650-750 range. The years 2021 and 2022 were left out of the analysis as they have much lower numbers compared to the other years (less than 500) – which can be attributed to the coronavirus pandemic and subsequent difficulties in collecting and recording data (Baloch et al. 2020). Nonetheless, the resulting temporal patterns show clear trends that provide important insights into the survival and mortality of Dutch goshawks.

The apparent survival probabilities show a clear dip in the first two decades of the study – survival seems to have declined sharply between 1978-1986, after which it improved towards a relatively stable value until 2012. In the 20th century, global declines in animal populations were strongly linked to the usage of organochlorine pesticides like DDT (dichlorodiphenyltrichloroethane), dieldrin and aldrin that were eventually banned for their toxic effects on humans and the environment alike. The ecological problem was especially prominent in birds of prey due to DDE (the main metabolic product from DDT) causing severe thinning of eggshells and consequent death of chicks (Vos et al. 2000, Newton 1979, Newton and Wyllie 1992).

DDT was banned in the Netherlands in 1972 and across other countries in Europe between 1970-1980. Raptor populations in the continent saw definite improvements after this policy change (Opdam et al. 1987; Wyllie & Newton 1991; Newton & Wyllie 1992; Bijlsma 1994). However, my study shows lowered survival estimates between 1980 – 1987, with over half of the recorded deaths in that period attributed solely to chemical pollution. This lag effect can be explained by the fact that the usage of DDT was gradually petered out in the years following 1972. DDT and associated pesticides probably persisted in soil and groundwater (Koeman et al. 1969, Silva et al. 2019, Van Maanen et al. 2001). Similar effects have been observed in several raptor species following pesticide bans (Wallin 1984; Burgers et al. 1986) It is thus likely that the recorded pollution-related deaths were connected to the bioaccumulation of residual organochlorine pesticides. In addition, illegal usage and poisoning might also have played a role. Moving onwards from the late 80s, deaths to chemical pollution are no longer the highest contributing factor – which ties in with the decrease and eventual halt of usage of toxic agricultural materials (Bouwman et al. 2013).

The largest factor contributing to human-related goshawk deaths in the data is colliding with glass, followed by entanglement with wires and hitting buildings (Figure 8). Collisions with artificial structures are the largest cause of human-related avian death across the planet, competing directly with habitat loss (Klem 2006; Manville and Albert 2005; Manville 2009). Collisions with electric wires, telephone poles and buildings are important mortality causes for birds, both when the structure is covered by vegetation (Summers and Dugan 2001) or protruding into open airspace (Manville and Albert 2005, Drewitt and Langston 2008). The inability to distinguish transparent panes obstructing a flight pathway or simply reflecting open habitat is the major mechanism behind birds hitting glass panels, and it is heightened by proximity to vegetation and prey (Hager et al. 2008; Klem et al. 2009, Klem 2006; Borden et al. 2010). Goshawks also have a particular style of flight when hunting that makes them especially prone to impacts with large structures like wind turbines, skyscrapers, vehicles and bridges (de Chapa et al. 2020). In terms of conservation strategies, one-way films and patterns on glass panes have been extremely effective in deterring bird strikes (Klem 2009) and their implementation is strongly recommended.

Traffic also plays a role in the recorded mortality in this study, which is in line with studies that report it as one of the major causes of death for animals in anthropogenic areas (Forman and Alexander, 1998; Trombulak and Frissell 2000, Forman et al. 2003). The chances of an avian death via vehicle increases with the volume of traffic and obstruction of sight by passing traffic (Clevenger et al. 2003). Raptors that eat carrion are prominent victims of road accidents, as are those that hunt prey found in roadside ditches (Meunier et al. 2000). The regression analysis shows a decrease in traffic collision-related deaths until 2010, beyond which there is a slight increase. While there are insufficient studies about goshawk deaths on road networks, the vehicle-related mortality of other raptors like the golden eagle and tawny owl has been recorded and directly linked to traffic volume and visibility loss (Franson et al. 1995; Harmata 2002). There are existing mechanisms that reduce accidents for larger vertebrate species, like building ecoducts and fences (Jackson and Griffin, 1998). However, they do not work as well for animals capable of flight. The seasonal closing of roads and implementation of limits on traffic volume and speed are better potential options to reduce the chances of avian vehicular collisions, but more research is required to confirm their efficacy.

Conclusions and future research

This study provides insight into the state of the northern goshawk population in the Netherlands over the last fifty years and highlights the pressing need for heightened conservation measures due to declining estimates. It also demonstrates a definite influence of age on their survival, indicating the necessity of leaving known nesting territories undisturbed and free of anthropogenic disturbances so more chicks can reach the age of independence. The strong shift in mortality causes from natural to artificial factors such as collisions with man-made structures and vehicles is also a pressing issue and raises several questions for the future of goshawk conservation in the country.

Mark-recapture analyses greatly benefit from the addition of environmental variables in models. While specific causes of death like hunting and pollution will have a large impact locally, raptor densities are largely affected by the amount of available prey, movement and foraging distances, precipitation and suitable breeding area (Newton 1991, Reynolds et al. 2006). Habitat type as a covariate could answer more detailed questions about territory selection and changing preferences. The goshawk is a versatile bird, and some research does support its ability to successfully forage and breed in urbanized areas (de Chapa et al. 2020, Visser 2021). Habitat as a covariate in mark-recapture analysis will further clarify the trade-off between prey availability in urban areas and heightened mortality due to anthropogenic factors. GPS data from tagged individuals can be used to study breeding pairs and chicks that fledge in urban and rural areas and can be compared for possible differences in pre- and post-fledgling survival probabilities between the two categories.

Another variable to consider is the amount of prey in the area. The trade-off between prey availability and increased risk to goshawks - especially in urban areas - has already been widely studied. While pigeons are numerous, there is an added risk of parasitic diseases and other contaminated prey (Kenntner et al. 2003, de Chapa et al. 2020). For breeding birds, lack of food before eggs are laid could prevent females from reaching body conditions required for producing and sustaining a clutch, which pushes males to hunt more and restricts mating opportunities (Rutz 2003). If the food scarcity persists, females will abandon incubation to hunt instead (Reynolds et al. 2017). Studies have shown a high likelihood for models with a positive relationship between survival and prey density (Reynolds et al. 2006). Collection and modelling of prey availability and density data would be a strong addition to further mark-recapture studies on the goshawk population.

Body mass is an important covariate for raptor survival analyses, especially when trying to investigate for possible effects of gender. Higher energy reserves are proportional to increased survival (Wiens et al. 2006) and female birds of prey, including goshawks, are usually bulkier than males as an adaptation to different functions performed during the nesting and brooding phase (Widen 1985). Some studies on goshawks have already shown a direct link between sex, body mass and survival, with males having lower estimates than the females (Reynolds and Joy 2006, Kruger 2007). Including size and/or weight in future studies will boost model accuracy regardless of whether it shows a stronger interaction of sex with goshawk survival. More mark-recapture analyses in the coming years involving complex models will help produce a highly accurate estimate of the goshawk population in the Netherlands. In combination with limiting the number of deaths due to anthropogenic factors, it lays the base for stabilization of the species in the country.

Appendix

Column	Type	Description
Scheme Code	Alphabetic	Indicates country and choice of ringing method
Ring Number	Alphanumeric	Unique sequence of 10 characters that are printed on the ring itself
Species Reported	Integer	Series of codes assigned by EURING: corresponds to species of bird reported by the entry maker. Can contain human errors due to misidentification
Species Concluded	Integer	Same codes as above field, but this is the corrected code as per ring number
Metal Ring Information	Integer	Indicates if this was the first (ringing) encounter or a recapture
Status	Alphabetic	Indicates if bird was moulting/roosting/wintering/breeding, if observed by recorder
Other marks code	Alphabetic	Other markings on bird, like GPS tags or dye marks
Age	Integer	Age code as per EURING scheme. Actual age is never estimated directly
Pullus Age	Integer	If applicable, indicates age of pullus
Gender	Alphabetic	Sex of bird
Brood size	Integer	Number of live young in nest, if applicable
Date	Integer	Date of ringing/recovery
Accuracy of date	Integer	Accuracy of above field
Manipulated	Alphabetic	Additional information if bird was altered in any way
Moved before recovery	Integer	Indicates if the bird was relocated from original site
Location	Alphanumeric	Location of ringing/recovery
Latitude	Numeric	Coordinates of site
Longitude	Numeric	Coordinates of site
Accuracy of coordinates	Integer	Accuracy of recorded latitude/longitude
Catching method	Alphabetic	Type of trap used if any
Catching Lures	Alphabetic	Type of bait used if any
Condition	Integer	Indicates if the bird is alive or dead, and if it is sick, or how long it has been dead
Circumstances	Integer	Indicates the health of the bird, or the cause of death if it is a dead recovery

Table 1: Description of fields in northern goshawk EURING dataset.

	Traffic	Artificial	Natural	Illness	Shot	Agriculture	Other	Pollution
Traffic		0.534	0.432	0.122	0.435	0.869	0.32	0.995
Artificial			0.184	0.079	**0.014**	0.634	0.845	0.179
Natural				0.066	0.565	0.164	0.122	0.976
Illness					0.593	0.051	0.406	0.598
Shot						0.863	0.063	**0.03**
Agriculture							0.975	0.531
Other								0.711

Table 5: chi-square test results for northern goshawk mortality categories (at 95% level of confidence)

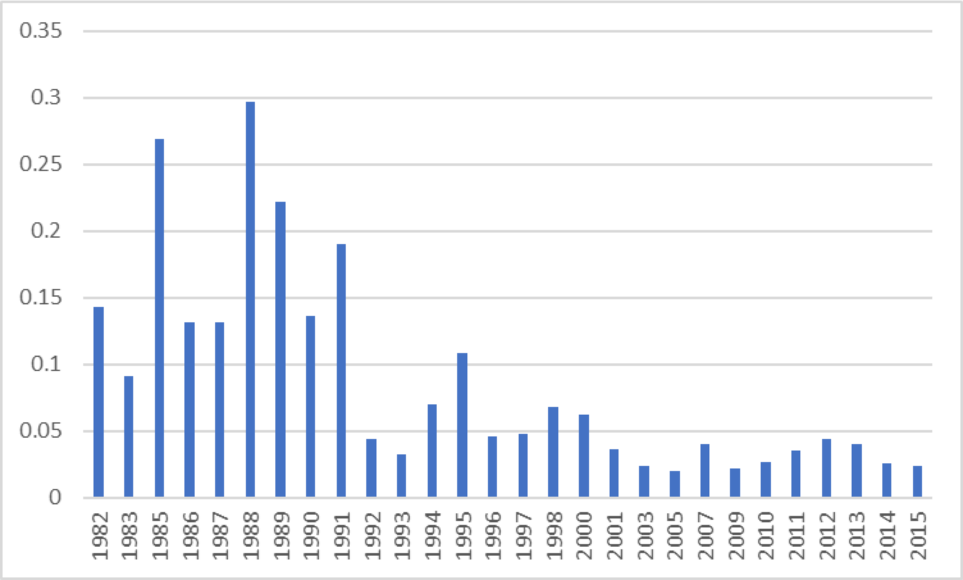

Figure 11: proportion of northern goshawk deaths by chemical pollution from 1970-2022 in the Netherlands.

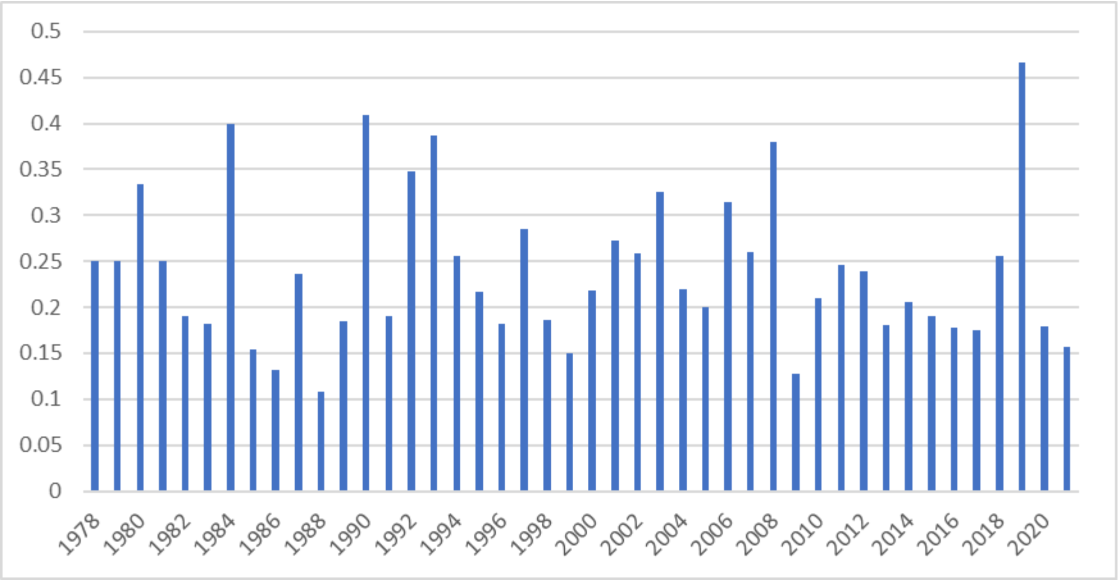

Figure 12: proportion of northern goshawk deaths by traffic collisions from 1970-2022 in the Netherlands.

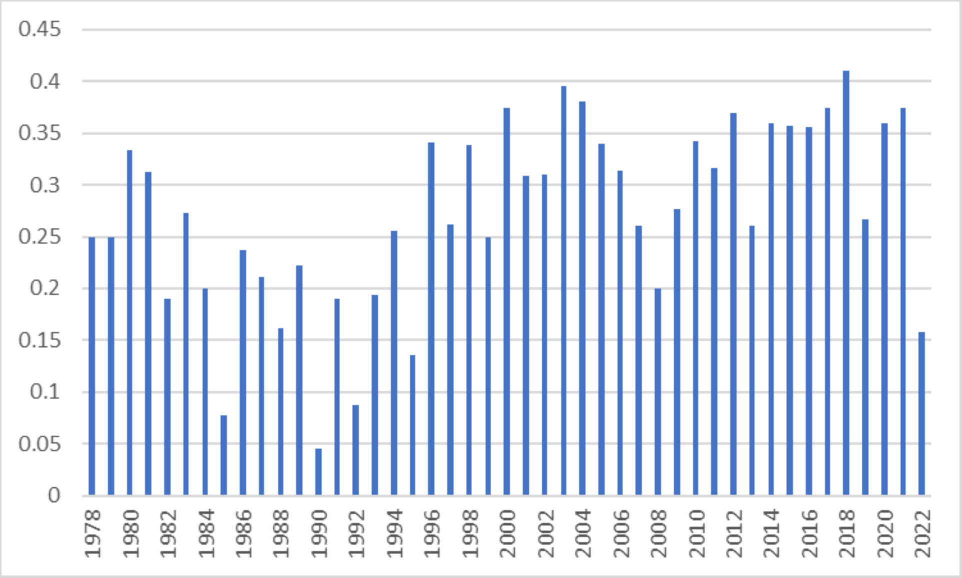

Figure 13: proportion of northern goshawk deaths by collision with artificial structures from 1970–2022 in the Netherlands.

References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE transactions on automatic control*, *19*(6), 716-723.

Alkama, J., Korpimäki, E., Arroyo, B., Beja, P., Bretagnolle, V., Bro, E., Kenward, R., Mañosa, S., Redpath, S.M., Thirgood, S. & Viñuela, J. (2005). Birds of prey as limiting factors of gamebird populations in Europe: a review. *Biological Reviews*, *80*(2), 171-203.

Baloch, S., Baloch, M. A., Zheng, T., & Pei, X. (2020). The coronavirus disease 2019 (COVID-19) pandemic. *The Tohoku journal of experimental medicine*, *250*(4), 271-278. doi:10.1620/tjem.250.271

Bateman, P. W., & Fleming, P. A. (2012). Big city life: carnivores in urban environments. *Journal of Zoology*, *287*(1), 1-23.

Bijleveld, M. (1974). The systematic persecution: A review of historical and more recent examples of the destruction of birds of prey in Europe. *Birds of Prey in Europe*, 1-43.

Bijlsma, R.G. & Sulkava, S. 1997: Accipiter gentilis Goshawk. — In EBCC atlas of European breeding birds: their distribution and abundance (ed. Hagemeijer, W.J.M. & Blair, M.J.): 154–155. Poyser, London.

Bijlsma, R.G. (1994). Recente roofvogelliteratuur (1993). *De Takkeling*, *2*(2), 44–50.

Boal, C. W. (1997). *An urban environment as an ecological trap for Cooper's hawks* (Doctoral dissertation, The University of Arizona).

Boal, C. W., Mannan, R. W., & Hudelson, K. S. (1998). Trichomoniasis in Cooper's hawks from Arizona. *Journal of Wildlife Diseases*, *34*(3), 590-593.

Borden, W. C., Lockhart, O. M., Jones, A. W., & Lyons, M. S. (2010). Seasonal, taxonomic, and local habitat components of bird-window collisions on an urban university campus in Cleveland, OH. The Ohio Journal of Science, v110, 44-52.

Brown, L., & Amadon, D. (1968). Eagles, hawks and falcons of the world.

Burgas, D., Byholm, P., & Parkkima, T. (2014). Raptors as surrogates of biodiversity along a landscape gradient. *Journal of Applied Ecology*, *51*(3), 786-794.

Burgers, J., Opdam, P., Müskens, G., & De Ruiter, E. (1986). Residue levels of DDE in eggs of Dutch Sparrowhawks Accipiter nisus Following the ban on DDT. *Environmental Pollution Series B, Chemical and Physical*, *11*(1), 29-40.

Burnham, K. P. (1993). A theory for combined analysis of ring recovery and recapture data. *Marked individuals in the study of bird population*, 199-213.

Chace, J. F., & Walsh, J. J. (2006). Urban effects on native avifauna: a review. *Landscape and urban planning*, *74*(1), 46-69.

Clevenger, A. P., Chruszcz, B., & Gunson, K. E. (2003). Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. *Biological conservation*, *109*(1), 15-26.

Cooch, Evan and White, Gary (2008). Program MARK: A Gentle Introduction (19th edition). *http://www. phidot.org/software/mark/docs/book/*.

David R. Anderson & Kenneth P. Burnham (1999). General strategies for the analysis of ringing data, Bird Study, 46: S261-S270.

Del Hoyo, J., Elliott, A., & Sargatal, J. (1992). *Handbook of the birds of the world* (Vol. 1, No. 8). Barcelona: Lynx editions.

DeStefano, S., Woodbridge, B. R. I. A. N., & Detrich, P. J. (1994). Survival of northern goshawks in the southern Cascades of California. *Studies in Avian Biology*, *16*, 133-136.

Dewey, S. R., & Kennedy, P. L. (2001). Effects of supplemental food on parental-care strategies and juvenile survival of Northern Goshawks. *The Auk*, *118*(2), 352-365.

Dewey, S. R., Kennedy, P. L., & Stephens, R. M. (2003). Are dawn vocalization surveys effective for monitoring goshawk nest-area occupancy? *The Journal of wildlife management*, 390-397.

Drewitt, A. L., & Langston, R. H. (2008). Collision effects of wind-power generators and other obstacles on birds. *Annals of the New York Academy of Sciences*, *1134*(1), 233-266.

du Feu, C.R., Clark, J.A., Baillie, S.R., Fiedler, W., Laesser, J. and Moss, D. (2020). EURING Exchange Code 2020 v201.

Ellis, E. C., & Ramankutty, N. (2008). Putting people in the map: Anthropogenic biomes of the world. Frontiers in Ecology and the Environment, 6(8), 439-447. doi:10.1890/070062

Etheridge, B., Summers, R. W., & Green, R. E. (1997). The effects of illegal killing and destruction of nests by humans on the population dynamics of the hen harrier Circus cyaneus in Scotland. *Journal of Applied Ecology*, 1081-1105.

EURING (2022). https://euring.org/data-and-codes/euring-databank

Forman, R. T., & Alexander, L. E. (1998). Roads and their major ecological effects. *Annual review of ecology and systematics*, *29*(1), 207-231.

Forman, R. T., Sperling, D., Bissonette, J. A., Clevenger, A. P., Cutshall, C. D., Dale, V. H., Fahrig, L., France, R.L., Goldman, C.R., Heanue, K., & Winter, T. C. (2003). *Road ecology: science and solutions*. Island press.

Franklin, A. B., Anderson, D. R., & Burnham, K. P. (2002). Estimation of long-term trends and variation in avian survival probabilities using random effects models. *Journal of Applied Statistics*, *29*(1-4), 267-287.

Franson, J., Sileo, L., & Thomas, N. J. (1995). Causes of golden eagle deaths. *Our Living Resources. A report to the nation on the distribution, abundance and health of US plants, animals and ecosystems. US Department of the Interior-National Biological Service., Washington, DC, US*.

G Bijlsma, R. (1998). Effect van boswerkzaamheden in het broedseizoen op broedvogels. *Drentse vogels*, *11*(1), 1-6.

G Bijlsma, R., Schipperijn, J., van Swieten, R., & Zoun, P. (2002). Vervolging van roofvogels in Nederland in 2001. *De Takkeling*, *10*(1), 49-55.

Gaston, K. J. (2010). Valuing common species. *Science*, *327*(5962), 154-155.

Gil, D., & Brumm, H. (2014). Acoustic communication in the urban environment: patterns, mechanisms, and potential consequences of avian song adjustments. *Avian urban ecology*, 69-83. doi:10.1093/acprof:osobl/9780199661572.003.0006

Gregoire, A., Faivre, B., Heeb, P., & Cezilly, F. (2002). A comparison of infestation patterns by Ixodes ticks in urban and rural populations of the Common Blackbird Turdus merula. *Ibis*, *144*(4), 640-645.

Hager, S. B. (2009). Human-related threats to urban raptors. *Journal of Raptor Research*, *43*(3), 210-226.

Hager, S. B., Trudell, H., McKay, K. J., Crandall, S. M., & Mayer, L. (2008). Bird density and mortality at windows. *The Wilson Journal of Ornithology*, *120*(3), 550-564.

Harmata, A. R. (2002). Encounters of golden eagles banded in the Rocky Mountain West. *Journal of Field Ornithology*, *73*(1), 23-32.

Harnos, A., Fehérvári, P., & Csörgő, T. (2015). Hitchhikers’ guide to analysing bird ringing data.

Hegglin, D., Bontadina, F., Contesse, P., Gloor, S., & Deplazes, P. (2007). Plasticity of predation behaviour as a putative driving force for parasite life-cycle dynamics: the case of urban foxes and Echinococcus multilocularis tapeworm. *Functional Ecology*, *21*(3), 552-560.

Heithaus, M. R., Frid, A., Wirsing, A. J., & Worm, B. (2008). Predicting ecological consequences of marine top predator declines. *Trends in ecology & evolution*, *23*(4), 202-210.

Henk Bouwman, Riana Bornman, Henk van den Berg and Henrik Kylin. (2013). Late lessons from early warnings: science, precaution, innovation. Chapter 11: DDT: fifty years since Silent Spring.

Hilton-Taylor, C., & Brackett, D. (2000). IUCN red list of threatened species.

Jackson, S. D., & Griffin, C. R. (1998). Toward a practical strategy for mitigating highway impacts on wildlife. In *International Conference on Wildlife Ecology and Transportation (ICOWET 1998).*

Johnson, T. H., & Stattersfield, A. J. (1990). A global review of island endemic birds. Ibis, 132(2), 167-180. doi:10.1111/j.1474-919X.1990.tb01036.x

Kenntner, N., Krone, O., Altenkamp, R., & Tataruch, F. (2003). Environmental contaminants in liver and kidney of free-ranging northern goshawks (Accipiter gentilis) from three regions of Germany. *Archives of Environmental Contamination and Toxicology*, *45*(1), 0128-0135.

Kenward, R.E., Marcstrom, V. & Karlbom, M. (1981). Goshawk winter ecology in Swedish pheasant habitats. – J. Wildlife Management 45: 397 – 408.

Kenward, R. E., Marcstrom, V & Karlbom, M. (1999) .Demographic estimates from radio-tagging: models of age-specific survival and breeding in the goshawk. – J. Animal Ecology 68: 1020 – 1033.

Klem Jr, D. (2006). Glass: a deadly conservation issue for birds. *Bird Observer*, *34*(2), 73-81.

Klem, D., Farmer, C. J., Delacretaz, N., Gelb, Y., & Saenger, P. G. (2009). Architectural and landscape risk factors associated with bird–glass collisions in an urban environment. *The Wilson Journal of Ornithology*, *121*(1), 126-134.

Koeman, J. H., Ten Noever De Brauw, M. C., & De Vos, R. H. (1969). Chlorinated biphenyls in fish, mussels and birds from the river Rhine and the Netherlands coastal area. *Nature*, *221*(5186), 1126-1128. doi:10.1038/2211126a0

Krone, Oliver, Altenkamp, Rainer, and Kenntner, Norbert (2005). Prevalence of *Trichomonas gallinae* in northern goshawks from the Berlin area of northeastern Germany. Journal of Wildlife Diseases, 41(2): 304-309. doi:10.7589/0090-3558-41.2.304

Krüger, O. (2007). Long-term demographic analysis in goshawk Accipiter gentilis: the role of density dependence and stochasticity. *Oecologia*, *152*(3), 459-471.

Kunz, F., Gamauf, A., Zachos, F. E., & Haring, E. (2019). Mitochondrial phylogenetics of the goshawk accipiter [gentilis] superspecies. Journal of Zoological Systematics and Evolutionary Research, 57(4), 942-958. doi:10.1111/jzs.12285

Le Gouar, P. J., Schekkerman, H., van Der Jeugd, H. P., Boele, A., van Harxen, R., Fuchs, P., Stroeken, P., & van Noordwijk, A. J. (2011). Long-term trends in survival of a declining population: the case of the little owl (Athene noctua) in the Netherlands. *Oecologia*, *166*, 369-379.

Lebreton, J. D., Burnham, K. P., Clobert, J., & Anderson, D. R. (1992). Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecological monographs*, *62*(1), 67-118.

Lima, S. L. (2009). Predators and the breeding bird: behavioral and reproductive flexibility under the risk of predation. *Biological reviews*, *84*(3), 485-513.

Luzardo, O. P., Ruiz-Suárez, N., Henríquez-Hernández, L. A., Valerón, P. F., Camacho, M., Zumbado, M., & Boada, L. D. (2014). Assessment of the exposure to organochlorine pesticides, PCBs and PAHs in six species of predatory birds of the Canary Islands, Spain. *Science of the total environment*, *472*, 146-153.

Manville, A. M. (2009, February). Towers, turbines, power lines, and buildings–steps being taken by the US Fish and Wildlife Service to avoid or minimize take of migratory birds at these structures. In *Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics* (Vol. 262272).

Manville, A. M., & Albert, M. (2005). Bird strikes and electrocutions at power lines, communication towers, and wind turbines: state of the art and state of the science–next steps toward mitigation. *USDA Forest Service General Technical Report PSW-GTR-191*, 1051-1064.

Martin, K. (1995). Patterns and mechanisms for age-dependent reproduction and survival in birds. *American Zoologist*, *35*(4), 340-348.

Marzluff, J. M., & Ewing, K. (2001). Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. Restoration Ecology, 9(3), 280-292. doi:10.1046/j.1526-100X.2001.009003280.x

McClure, C. J., Westrip, J. R., Johnson, J. A., Schulwitz, S. E., Virani, M. Z., Davies, R., Symes, A., Wheatley, H., Thorstrom, R., Amar, A., Buij, R., Jones, V., Williams, N., Buechley, E., & Butchart, S. H. (2018). State of the world's raptors: Distributions, threats, and conservation recommendations. *Biological Conservation*, *227*, 390-402.

McFadzen, M. E., & Marzluff, J. M. (1996). Mortality of Prairie Falcons during the fledging-dependence period. *The Condor, 98*(4), 791-800.

McGrady, M. J., Al Fazari, W. A., Al Jahdhami, M. H., Hines, J. E., & Oli, M. K. (2016). Survival of Sooty Falcons (Falco concolor) breeding in Oman. *Journal of Ornithology*, *157*, 427-437.

Merling de Chapa, M., Courtiol, A., Engler, M., Giese, L., Rutz, C., Lakermann, M., ... & Krone, O. (2020). Phantom of the forest or successful citizen? Analysing how Northern Goshawks (Accipiter gentilis) cope with the urban environment. *Royal Society Open Science*, *7*(12), 201356.

Mertz, D. B. (1971). The mathematical demography of the California Condor population. *The American Naturalist*, *105*(945), 437-453.

Meunier, F. D., Verheyden, C., & Jouventin, P. (2000). Use of roadsides by diurnal raptors in agricultural landscapes. *Biological Conservation*, *92*(3), 291-298.

Michel, V. T., Jiménez-Franco, M. V., Naef-Daenzer, B., & Grüebler, M. U. (2016). Intraguild predator drives forest edge avoidance of a mesopredator. *Ecosphere*, *7*(3), e01229.

Newton, I. (1991). Habitat variation and population regulation in Sparrowhawks. *Ibis*, *133*, 76-88.

Newton, I. (1998). *Population limitation in birds*. Academic press.

Newton, I. & Wyllie, I. (1992). Recovery of a Sparrowhawk population in relation to declining pesticide contamination. *J. Appl. Ecol.* **29**: 476–484.

Newton, I. (1979). *Population Ecology of Raptors*. Berkhamsted: T. and A.D. Poyser.

Newton, I., & Moss, D. (1986). Post-fledging survival of sparrowhawks accipiter nisus in relation to mass, brood size and brood composition at fledging. Ibis, 128(1), 73-80. doi:10.1111/j.1474-919X.1986.tb02094.x

O'Bryan, C. J., Holden, M. H., & Watson, J. E. (2019). The mesoscavenger release hypothesis and implications for ecosystem and human well-being. *Ecology Letters*, *22*(9), 1340-1348.

Opdam, P., Burgers, J., & Müskens, G. J. D. M. (1987). Population trend, reproduction, and pesticides in Dutch sparrowhawks following the ban on DDT. *Ardea*, *75*(2), 205212.

Palomares, F., & Caro, T. M. (1999). Interspecific killing among mammalian carnivores. *The American Naturalist*, *153*(5), 492-508.

Park, K. J., Graham, K. E., Calladine, J., & Wernham, C. W. (2008). Impacts of birds of prey on gamebirds in the UK: a review. *Ibis*, *150*, 9-26.

Piersma, T., & Davidson, N. C. (1991). Confusions of Mass and Size. *The Auk*, *108*(2), 441–443.

Prestt, I., Jefferies, D. J., & Moore, N. W. (1970). Polychlorinated biphenyls in wild birds in Britain and their avian toxicity. *Environmental Pollution (1970)*, *1*(1), 3-26.

Redmond, L.J. and Murphy, M.T. (2012), Using complementary approaches to estimate survival of juvenile and adult Eastern Kingbirds. Journal of Field Ornithology, 83: 247-259. https://doi.org/10.1111/j.1557-9263.2012.00373.x

Reynolds, R. T., & Wight, H. M. (1978). Distribution, density, and productivity of accipiter hawks breeding in Oregon. *The Wilson Bulletin*, 182-196.

Reynolds, R. T., Joy, S. M., & Leslie, D. G. (1994). Nest productivity, fidelity, and spacing of northern goshawks in Arizona. *Studies in Avian Biology*, *16*, 106-113.

Reynolds, R. T., Lambert, J. S., Flather, C. H., White, G. C., Bird, B. J., Baggett, L. S., Lambert, C., & Bayard De Volo, S. (2017). Long-term demography of the Northern Goshawk in a variable environment. *Wildlife Monographs*, *197*(1), 1-40.

Reynolds, R. T., Wiens, J. D., & Salafsky, S. (2006). A review and evaluation of factors limiting northern goshawk populations. *Studies in Avian Biology. 31: 260-273.*, *31*, 260-273.

Reynolds, Richard T.; Joy, Suzanne M. 2006. Demography of Northern goshawks in northern Arizona, 1991-1996. Studies in Avian Biology. 31: 63-74.

Riley, S. P., Sauvajot, R. M., Fuller, T. K., York, E. C., Kamradt, D. A., Bromley, C., & Wayne, R. K. (2003). Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. *Conservation Biology*, *17*(2), 566-576.

Rutz, C. (2003). Assessing the breeding season diet of goshawks accipiter gentilis: Biases of plucking analysis quantified by means of continuous radio-monitoring. Journal of Zoology, 259(2), 209-217. doi:10.1017/S0952836902003175

Rutz, C. (2006). Home range size, habitat use, activity patterns and hunting behaviour of urban-breeding Northern Goshawks Accipiter gentilis. *ARDEA-WAGENINGEN-*, *94*(2), 185.

Rutz, C. (2012). Predator fitness increases with selectivity for odd prey. *Current Biology*, *22*(9), 820-824.

Rutz, C., & Bijlsma, R. G. (2006). Food-limitation in a generalist predator. *Proceedings of the Royal Society B: Biological Sciences*, *273*(1597), 2069-2076. doi:10.1098/rspb.2006.3507

Rutz, C., Loretto, MC., Bates, A.E.. . COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. *Nat Ecol Evol* **4**, 1156–1159 (2020).

Rutz, C., Whittingham, M. J., & Newton, I. (2006). Age-dependent diet choice in an avian top predator. *Proceedings of the Royal Society B: Biological Sciences*, *273*(1586), 579-586. doi:10.1098/rspb.2005.3353

Sekercioglu, C. H. (2006). Increasing awareness of avian ecological function. *Trends in ecology & evolution*, *21*(8), 464-471.

Sergio, F., & Hiraldo, F. (2008). Intraguild predation in raptor assemblages: a review. *Ibis*, *150*, 132-145.

Sergio, F., Caro, T., Brown, D., Clucas, B., Hunter, J., Ketchum, J., McHugh, K., & Hiraldo, F. (2008). Top predators as conservation tools: ecological rationale, assumptions, and efficacy. *Annual review of ecology, evolution, and systematics*, 1-19.

Sergio, F., Newton, I. A. N., Marchesi, L., & Pedrini, P. (2006). Ecologically justified charisma: preservation of top predators delivers biodiversity conservation. *Journal of Applied Ecology*, *43*(6), 1049-1055.

Sergio, F., Newton, I., & Marchesi, L. (2005). Top predators and biodiversity. *Nature*, *436*(7048), 192-192.

Sergio, F., Tavecchia, G., Blas, J., López, L., Tanferna, A., & Hiraldo, F. (2011). Variation in age-structured vital rates of a long-lived raptor: implications for population growth. *Basic and Applied Ecology*, *12*(2), 107-115. doi:10.1016/j.baae.2010.11.004

Silva, V., Mol, H. G., Zomer, P., Tienstra, M., Ritsema, C. J., & Geissen, V. (2019). Pesticide residues in European agricultural soils–A hidden reality unfolded. *Science of the Total Environment*, *653*, 1532-1545.

Smart, J., Amar, A., Sim, I. M., Etheridge, B., Cameron, D., Christie, G., & Wilson, J. D. (2010). Illegal killing slows population recovery of a re-introduced raptor of high conservation concern–the red kite Milvus milvus. *Biological conservation*, *143*(5), 1278-1286.

Squires, J. R., & Kennedy, P. L. (2006). Northern Goshawk ecology: an assessment of current knowledge and information needs for conservation and management. *Studies in Avian Biology. 31: 8-62.*, *31*, 8-62

Squires, J.R. & Reynolds, R.T. (1997). Northern Goshawk (Accipiter gentilis). In Poole, A. & Gill, F. (eds) The Birds of North America., no. 298: 1–32. Philadelphia, PA: The Academy of Natural Sciences, and Washington, DC: The American Ornithologists' Union

Stahl, J. T., & Oli, M. K. (2006). Relative importance of avian life-history variables to population growth rate. *Ecological modelling*, *198*(1-2), 23-39. doi:10.1016/j.ecolmodel.2006.04.001

Summers, R. W., & Dugan, D. (2001). An assessment of methods used to mark fences to reduce bird collisions in pinewoods. *Scottish Forestry*, *55*(1), 23-29.

Terborgh, J., Lopez, L., Nuñez, P., Rao, M., Shahabuddin, G., Orihuela, G., Riveros, M., Ascanio, R., Adler, G.H., Lambert, T.D. and & Balbas, L. (2001). Ecological meltdown in predator-free forest fragments. *Science*, *294*(5548), 1923-1926.

Thomson, R. L., Forsman, J. T., Mönkkönen, M., Hukkanen, M., Koivula, K., Rytkönen, S., & Orell, M. (2006). Predation risk effects on fitness related measures in a resident bird. *Oikos*, *113*(2), 325-333.

Todd, L. D., Poulin, R. G., Wellicome, T. I., & Brigham, R. M. (2003). Post-fledging survival of burrowing owls in Saskatchewan. *The Journal of wildlife management*, 512-519.

Trombulak, S. C., & Frissell, C. A. (2000). Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation biology*, *14*(1), 18-30.

van Langevelde, F., van Dooremalen, C., & Jaarsma, C. F. (2009). Traffic mortality and the role of minor roads. *Journal of Environmental Management*, *90*(1), 660-667.

Van Maanen, J. M. S., De Vaan, M. A. J., Veldstra, A. W. F., & Hendrix, W. P. A. M. (2001). Pesticides and nitrate in groundwater and rainwater in the province of Limburg in the Netherlands. *Environmental monitoring and assessment*, *72*, 95-114.

Visser, A.F (2021). The reproductive rate of Northern goshawks (Accipiter gentilis) benefits from urbanisation. Wageningen University and Research.

Vos, J. G., Dybing, E., Greim, H. A., Ladefoged, O., Lambré, C., Tarazona, J. V., Brandt, I. & Vethaak, A. D. (2000). Health effects of endocrine-disrupting chemicals on wildlife, with special reference to the European situation. *Critical reviews in toxicology*, *30*(1), 71-133.

Wallin, K. (1984). Decrease and recovery patterns of some raptors in relation to the introduction and ban of alkyl-mercury and DDT in Sweden. *Ambio*, 263-265.

Waters, C. N., Zalasiewicz, J., Summerhayes, C., Barnosky, A. D., Poirier, C., Gałuszka, A., Cearreta, A., Edgeworth, M., Ellis, E.C., Ellis, M., & Wolfe, A. P. (2016). The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science*, *351*(6269), aad2622.

White, G. C., & Burnham, K. P. (1999). Program MARK: Survival estimation from populations of marked animals. Bird Study, 46, S120-S139. doi:10.1080/00063659909477239

Widén, P. (1984). Reversed sexual size dimorphism in birds of prey: revival of an old hypothesis. *Oikos*, 259-263.

Widén, P. (1985). Breeding and movements of goshawks in boreal forests in Sweden. *Ecography*, *8*(4), 273-279.

Wiens, J. D., Noon, B. R., & Reynolds, R. T. (2006). Post-fledging survival of northern goshawks: The importance of prey abundance, weather, and dispersal. *Ecological Applications*, *16*(1), 406-418.

Wyllie, I. & Newton, I. (1991). Demography of an increasing population of Sparrowhawks. *J. Anim. Ecol.* **60**: 749–766.

Xie, W., Chen, K., Zhu, X., Nie, X., Zheng, G., Pan, D., & Wang, S. (2010). Evaluation of heavy metal contents in water and fishes collected from the waterway in Pearl River Delta in south China. *Journal of Agro-Environment Science*, *29*(10), 1917-1923.

Yasin, Y. J., Grivna, M., & Abu-Zidan, F. M. (2021). Global impact of COVID-19 pandemic on road traffic collisions. World Journal of Emergency Surgery, 16(1) doi:10.1186/s13017-021-00395-8