

ANALYSIS OF THE PEREGRINE FALCON'S (*FALCO PEREGRINUS*) DIET IN SOUTHERN SWEDEN IN RELATION TO THE CURRENT THREAT OF AVIAN INFLUENZA



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Abstract

The peregrine falcon (*Falco peregrinus*) has recently recovered from the severe population decline in the 1970s where bioaccumulation of organochlorines caused thinning of their eggshells. In present times, highly pathogenic avian influenza (HPAI) has emerged as the current threat to peregrine populations. Monitoring in Sweden indicates a steady decline of breeding pairs since 2020 as the result of a major outbreak in wild birds. Species risk of being infected varies and therefore the peregrine's level of threat is uncertain depending on their diet composition. In this project, the diets of nesting peregrine falcons in southern Sweden have been examined and compared with data from 1983. This was done by reviewing images taken by camera traps between 2017-2024. The peregrine's risk of being infected by HPAI is discussed based on their diet. A size-dependent extrapolation was conducted to predict unknown prey. Results indicate that the peregrine falcon diet consists mainly of thrushes, gulls and corvids, doves and waders are slightly less common. Starlings and ducks are rare in their diet. Comparison between the performed prey estimate and 1970s display an increase in thrushes, small birds and corvids. Doves, gulls and starlings have decreased. The shift in diet can partly be confirmed by the Swedish Bird Survey. The risk of a peregrine falcon being infected by HPAI is quite indicative since gulls, which are highly affected, are a big part of their diet. Risks are thought to increase during winter, when migrating birds flock in western Europe and the range of prey changes. What causes such a big proportion of peregrines to be infected relative to other birds of prey remains untold and would be of great interest to investigate in further studies.

Keywords: Peregrine falcon, diet, HPAI, diet shift

Sammanfattning

Pilgrimsfalken (*Falco peregrinus*) har under de senaste 40 åren återhämtat sig från den allvarliga populationskraschen som skedde under 1970-talet, då bioackumulering av organiska föreningar orsakade äggskalsförtunning. I dagsläget har högpåtaglig fågelinfluensa (HPAI) spridit sig okontrollerat och blivit det senaste hotet mot populationen. Rapportering från Sverige visar på en stadig minskning av antalet häckande par sedan 2020 till följd av ett omfattande utbrott bland vilda fåglar. Risken för smitta varierar mellan arter vilket innebär att pilgrimsfalkens hotnivå är ovisst och beroende av dess bytesval. I denna studie har födosammansättningen hos häckande pilgrimsfalkar i södra Sverige undersökts och jämförts med data från 1983. Detta genomfördes genom att granska bilder tagna med viltkameror mellan åren 2017–2024. Pilgrimsfalkens risk att smittas av HPAI diskuteras utifrån sammansättningen av föda. En storleksberoende extrapolering utfördes för att uppskatta okända byten som ej gick att identifiera. Resultaten indikerar att pilgrimsfalkens föda huvudsakligen består av trastar, måsfåglar, kråkfåglar, medan duvor och vadare är något mindre vanliga. Starar och änder fångas sällan. I en jämförelse mellan resultatet i denna studie och 1970-talet visar på att trastar, småfåglar och kråkfåglar har ökat i pilgrimsfalkens diet medan duvor, måsfåglar och starar har minskat. Denna förändring i födosammansättningen kan delvis bekräftas av Svensk Fågeltaxering. Risken för att en pilgrimsfalk ska smittas av HPAI framstår som påtaglig eftersom måsfåglar, vilka är hårt drabbade av viruset, utgör en stor del av deras diet. Riskerna bedöms öka under vintern när flyttfåglar flockas i Västeuropa och utbudet av bytesdjur förändras. Vad som orsakar att en så stor andel pilgrimsfalkar smittas i förhållande till andra rovfåglar är fortfarande okänt och vore intressant att undersöka i framtida studier.

1 Introduction

1.1 Persistent pollutants and the historic decline

Populations of peregrine falcons have been severely harmed by environmental pollution during the last century. As an apex predator occupying the highest trophic level of global food webs, the peregrine falcon is vulnerable to biomagnification, which is a process where persistent contaminants concentrate progressively upward through the food chain. Because persistent chemical structures are retained while energy transfers between trophic levels are inefficient, top-tier predators must consume massive amounts of prey biomass over their lifespans. As a result, minor concentrations of contaminants magnify exponentially, traveling through local food webs until they accumulate in hazardous concentrations within the falcon's tissues ((Castagna et al., 2024). Quantifying a predator's dietary proportions is therefore essential to assessing the current status of the species.

Moore and Ratcliffe were one of the first to record insecticide residues in peregrine falcons from Great Britain in 1962. Their hypothesis stated that the extensive use of chlorinated hydrocarbons such as DDT, Dieldrin, and Heptachlor epoxide was the cause of the decline. The examination of an unhatched egg revealed chlorinated hydrocarbon residues. They concluded that these residues could only have been passed down from the parent bird (Moore & Ratcliffe, 1962). Ratcliffe clarified the peregrine's situation in 1963; the British population had decreased by two-fifths since pre-war counts, and only 19% of territories visited reared any chicks. Sterility of birds, infertility and breakage of the eggs were pointed out as the main causes to the event (Ratcliffe, 1963). Similar population trends occurred in North America and the rest of Europe (Sielicki et al., 2009). Investigation of eggshell thickness in several birds of prey, including peregrine falcon, displayed a synchronous and rapid decrease when comparing eggs from 1904-50 to 1951-60 (Ratcliffe, 1967). The correlation between eggshell thinning and presence of chlorinated hydrocarbons became apparent in the 1970s (Anderson & Hickey, 1974; Cade et al., 1971; Lincer, 1975; Olsen & Olsen, 1979). Falk et al. (2025a) compared eggs from the pre-DDT era (1864-1945) with clutches from 1964-2023 in Sweden. Egg shells from the 1960s to 1980s were 16 % thinner on average than the reference period. Between 1980 and 2020 the shell width has increased to 7% thinner below normal. This highlights the long-term persistence of residues in the environment and that the peregrine still is vulnerable to emerging stochastic events (Falk et al., 2025a).

Recovery of the peregrine falcon population has been recognized worldwide since insecticide bans in the 1970s (Ambrose et al., 2016; Holroyd & Bird, 2012; Nygård et al., 2019). Population counts in Sweden were estimated to <15 pairs in 1975 compared to 900-1400 in 1900 (Lindberg, 2007). This initiated the Swedish captive breeding program which yielded 439 young between the years 1974-2007 (Lindberg & Sjöberg, 2009). Estimates from 2007 stated that the population consisted of >150-175 pairs (Lindberg, 2007) and data from 2025 display that number has increased further to 500 pairs (SLU Artdatabanken, 2025).

1.2 Nesting and migration

The majority of the global population are migrating, usually from breeding sites in Alaska, Canada, Scandinavia and Siberia southwards. However, in areas where prey is readily available year-round, some pairs are resident (White et al., 2024). Scandinavian populations migrate to western Europe. Typically, France, Netherlands Germany and Denmark are the destinations

where most Swedish peregrines have been found in winter; the migration period in Sweden begins in late August and the falcons return in March-April (Fransson & Petterson 2001). About half of the individuals from southern Sweden remain in or near their breeding areas throughout the winter (Andersson & Sandberg 2015).

Steep cliffs higher than 8 meters with suitable ledges are common nesting spots for the peregrine, but they can also use the abandoned nests of larger birds such as ravens, eagles and ospreys. In urban areas where steep cliffs are absent, churches, silos, bridges and skyscrapers have been found to operate as alternative nesting spots. The clutch size is between two and five eggs, which are incubated for approximately 30 days until hatching. Chicks are born with their eyes closed and covered in whitish down; the nesting period lasts for 35-42 days (White et al., 2024).

1.3 Diet analysis

To better understand the peregrine falcons' risk of exposure to environmental pollutants and diseases it is vital to examine their diet composition. Although the peregrine falcon is famous for striking down other birds mid-air, they are opportunistic predators and can also prey on bats or rodents. In certain regions where prey diversity is low, they can become specialized on the available prey if it is abundant (White et al., 2024). Studies from south-west England (Dixon & Drewitt, 2018) and Poland (Rejt, 2001) reveal that feral pigeon (*Columba livia*) contributed to one third of the diet in urban peregrines. Prey estimates from Italy highlight corvids (Corvidae) and doves (Columbidae) as the most abundant (Bondi et al., 2016). Diet studies of peregrine falcons in Sweden are sparse and was last conducted by Peter Lindberg in 1983. He wrote his dissertation about how the diet was related to the presence of organochlorines and mercury in peregrine falcons. Results displayed migratory birds such as waders containing the highest amount of pollutants while doves and gulls contained less. The conclusion was that northern subpopulations were exposed to higher amounts of residues since their diet consisted mostly of waders (Lindberg, 1983). Lindberg et al. states in 1985 that accumulation of organochlorines may increase in winter quarters when the diet shifts towards aquatic prey species (Lindberg et al., 1985). This example examines the importance of diet analysis in predatory birds such as the peregrine falcon, showing that annual prey preference is key to understanding the broader ecological picture.

1.4 Recent threat

Although Sweden's leading peregrine falcon monitoring group (*Projekt Pilgrimsfalk Sverige*) reports a steady population recovery since the pesticide crash, highly pathogenic avian influenza (HPAI) has emerged as a serious concern that should not be ignored (Falk et al., 2025b). The most severe outbreak occurred in the Netherlands in 2020, which led to global dispersion and mass mortality among wild birds and poultry (SVA, 2026). The Swedish Veterinary Agency (SVA) reports that Sweden's first recorded case of HPAI was detected in a pair of tufted ducks (*Aythya fuligula*) in 2006. Since then, irregular outbreaks of different mutations have continued to return at varying scales. Dead birds collected and sampled by SVA reveal waterfowl and colony-nesting birds to be the main carriers of the disease. Out of all birds of prey, the peregrine falcon has the highest percentage of infected specimens, a highly concerning trend (SVA, 2026). Breeding pairs of peregrine falcons peaked in 2020 in the province of Götaland, with approximately 80 out of 124 territories successfully yielding fledglings; since then, this figure has slightly decreased annually. *Pilgrimsfalk Sverige* mentions that one cannot expect a continuous population increase forever, as the curve must eventually level out. However, it is concerning that former territories which used to yield fledglings annually suddenly host no pairs. They also point

out that while the decrease in breeding territories might seem minor, this is because young peregrines (1–4 years old) quickly fill the vacancies left by dead adults and that this pool of young birds is diminishing. Unfortunately, inexperienced birds almost always have less success in raising chicks into fledglings, resulting in a halting re-establishment of the population (Falk et al., 2025b).

Due to the threat of HPAI, the peregrine falcon was recently upgraded from near threatened (NT) to vulnerable (VU) on Sweden's national red list. SLU Swedish Species Information Centre evaluates that a decrease in the reproductive population will proceed the decline (SLU Artdatabanken, 2025). Because of their apex predator status and global distribution, peregrine falcons serve as vital ecological sentinel species for monitoring both legacy organic pollutants and emerging contaminants (Castagna et al., 2024). Given the peregrine falcon's life history and historical population collapse, it is highly justified to continue monitoring the species and gathering as much information regarding their current population status as possible.

1.5 Aim

The aim of this study is to examine the current diet composition of the peregrine falcon in southern Sweden. Because no comprehensive analysis has been conducted in this region over the past 40 years, it is of great ecological interest to investigate if the diet has shifted. Furthermore, analysing current diet composition will evaluate the population's exposure risk to HPAI, thereby providing critical context regarding the species' ongoing population decline.

2 Material and method

Diet composition was estimated by reviewing pictures captured by camera traps.

2.1 Origin of the image data

The photographic data used in this study were provided by *Pilgrimsfalk Sverige* which included material from 66 nests monitored between 2013-2025, some locations were sampled multiple years. Distribution of the nests were spread across southern Sweden with a bias towards western Sweden. The camera traps had slightly different setups, shutter speeds and distance to the nest. Motion was usually the triggering event that captured a picture. Before analysing the material, a quality check was performed on the material, assigning a number from 1-5 to each nest based on image resolution and camera angle. To ensure high-quality results, nests were randomly selected from the highest-rated groups, with the goal of examining as many nests as possible.

2.2 Sampling

From the original 66 nests, 11 (10 unique ones) were sampled from the years 2017-2024 (Fig. 1), yielding a total of 79088 images. Pictures from each nest were imported into Adobe Lightroom and reviewed, one nest at a time, for systematic review. Every image where a feeding event could be recognized was given a grade from 1-5 depending on what could be distinguished.

Grade

- 1- The prey is out of sight, or the sight is blocked by chicks or parent (Fig 2.1).
- 2- Bloody remnants containing bones and no feathers. Visible size (Fig 2.2)
- 3- Visible feathers/fur and/or legs that may be categorized into a broad group of prey (Fig 2.3)
- 4- Visible feathers/fur/legs/head that define a species, no doubt but may be hard to spot (Fig 2.4)
5. Almost intact prey, species identification possible (Fig 2.5)

The graded images were then reviewed in detail a second time to categorize the prey into broader functional groups. These groups, referred to hereafter as “prey categories”, include thrush, gull, corvid, starling, wader, duck, dove, “unknown bird”, and “bloody lump/bony”.

Feeding events where the view to the prey item was obscured were recorded as “blocked sight”. Each feeding event was logged into an excel spreadsheet where the specific nest, date, time, species, prey category, size (of the prey), number of chicks and the duration spent feeding on the prey was recorded. Prey size was estimated relative to the adult peregrine’s legs and body using five classes: S (small bird e.g. Great tit (*Parus major*)), S/M (thrush e.g. common blackbird (*Turdus merula*)), M (dove e.g. common wood pigeon (*Columba palumbus*)), M/L (e.g. herring gull (*Larus argentatus*)), and L (large waterfowl e.g. greylag goose (*Anser answer*), although unlikely). Due to species diversity within certain groups, some prey categories were distributed across multiple size classes.

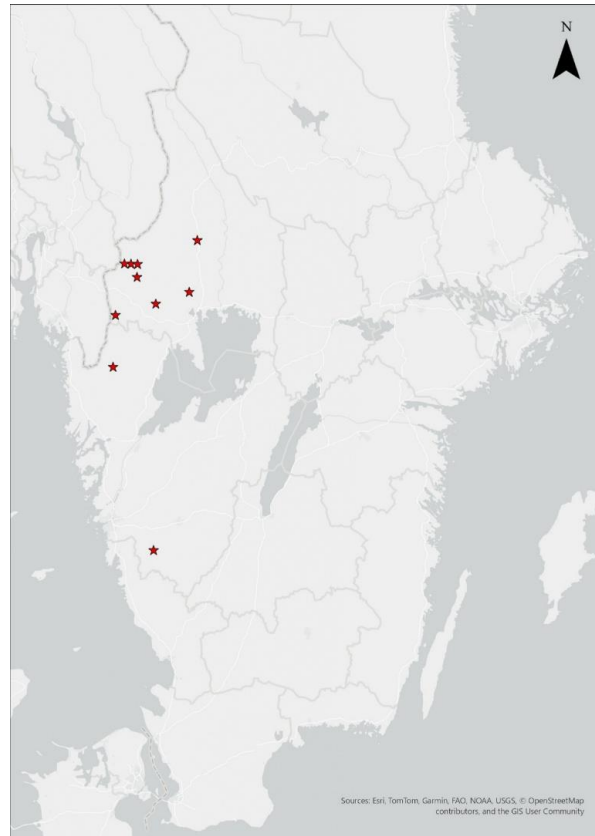


Figure 1. Locations of the nests examined



Figure 2 Graded images of prey observations in Adobe Lightroom. 1: line of sight blocked by chicks. 2: Bloody remnant with no distinguishable trait. 3: Visible plumage and size of a possible thrush. 4: pink/red feet and a coloured ring on each leg can only be a feral (homing) pigeon (*Columba livia domestica*). 5: Intact bird with visible plumage, a Eurasian jay (*Garrulus glandarius*).

2.3 Extrapolation

All statistics were made in R version 4.5.3. Packages used were: tidyverse and ggplot2. Because approximately 80 % of observed feeding events could not be assigned to a “known” prey category (thrush, gull, corvid, starling, wader, duck, dove), an extrapolation was performed. Each observation of the prey categories “unknown bird” and “bloody lump/bony” that had an approximated size were assigned to a known prey category. Observations categorized as “blocked sight” were excluded from the extrapolation.

A proportion was assigned to every bird that had been recorded in each size class. For example, the small-medium size class consisted of 10% starlings, 88% thrushes and 2% waders (Table 4). These are the global size proportions (P_{global}). The same thing was done for each nest separately, creating the nest specific size proportions (P_{nest}). Since peregrine falcons are opportunistic birds of prey, the diet composition will presumably vary between each individual nesting site depending on the available prey in the area. A shrinkage estimator (Datta & Ghosh, 2012) was therefore applied to weight how much of the global- or nest specific proportions should contribute to the target observations of the extrapolation. The weighting factor (ω) was defined as:

$$\omega = \frac{n_{nest\ size}}{n_{nest\ size} + k}$$

Here, $n_{nest\ size}$ represents the total number of identified prey items of a specific size class at a given nest, while k is a constant (set at 50) that dictates the threshold at which nest-specific data begins to outweigh the global average. This model assumes that if a specific prey type is present and identified at a nest, the falcons are likely to continue hunting it; thus, unknown prey of the same size at that site are more accurately represented by the local diet. Conversely, when observations at a nest are sparse, ω decreases, and the model relies more heavily on global probabilities to avoid bias from small local sample sizes. The combined probability for an unidentified prey item with a known size class ($P_{combined}$) was then calculated as:

$$P_{combined} = (\omega * P_{nest}) + ((1 - \omega) * P_{global})$$

The $P_{combined}$ probabilities were normalized within each size class so that they summed up to 1. These proportions were then assigned to all observations of unknown prey with a size. Note that this method assigns decimal values to unidentified prey items. The total count for each prey category is then obtained by summing these fractions. To verify the stability of estimates, a sensitivity analysis was conducted by varying k between 5, 10, 50 and 100. The resulting diet proportions remained stable across this range, indicating that the reconstruction was robust to the choice of the smoothing parameter.

2.4 Nonparametric resampling

Statistical uncertainty was assessed using non-parametric bootstrap resampling (1000 iterations). In each iteration, the dataset was resampled with replacement, and the weighted probabilities were recalculated to redistribute “unknown” observations based on the specific prey composition of that sample. This procedure allowed for the calculation of confidence intervals, accounting for variance in both the initial identification of prey and the subsequent imputation of unidentified items.

2.5 Supporting data

Peter Lindberg's survey from 1983 is used for the comparative analysis. In his study he visited 4 nests from southern Sweden between the years 1971-1979 in which he systematically collected feathers, bones and pellets to create diet proportions of prey. He also sampled nests from northern Sweden, but they are excluded in this comparison (Lindberg, 1983). SVA were contacted, and they provided this study with an excel spreadsheet covering all birds sampled for HPAI between the years 2020-2026 in Sweden. Specimens are reported and sent into SVA by the public. Far from every infected bird is registered. Data can also be found on their webpage (SVA, 2026).

These datasets have been visualized in R. The prey categories in both SVA's and Lindberg's data have been grouped in a similar way as the current diet estimations to simplify the examination.

3 Results

Out of the 79088 images reviewed in Adobe Lightroom, a total of 948 feeding events were recorded. Of these events, 191 could be categorized into a broader taxon or known prey group, resulting in an identification rate of 20.15% for the observed feeding events. The contribution to the total number of prey items was uneven among nests. Nest SVM_24 accounted for the highest number of observed preys with 149 items, whereas nest TGV_18 accounted for the lowest with 40 items (Table 1). Out of the 191 identified prey items, 89 individuals could be defined at the species level. The top three most abundant species identified were the Eurasian woodcock (*Scolopax rusticola*), the black-headed gull (*Chroicocephalus ridibundus*), and the feral pigeon (*Columba livia domestica*) (Table 2). The estimated size of the prey for each observation is detailed in Table 3, which shows that the majority of the prey items fell into the small-to-medium category with 374 observations and the medium category with 360 observations. Additionally, 94 observed prey items were categorized as small, and only 21 items were classified as medium-to-large. For the remaining 99 observations, no size estimation could be determined because the line of sight was obstructed by either a parent bird or a chick (Table 3).

Table 1. Each nests contribution to the total 948 observed feeding events.

<i>Nest ID</i>	<i>Identified prey</i>	<i>Unidentified prey</i>	<i>Total nr of prey</i>	<i>% identified</i>	<i>Obs.period (days)</i>	<i>Images examined</i>	<i>First day of observed prey</i>
DAM_21	17	29	46	36,96	31	6227	2021-06-16
HUG_19	32	52	84	38,10	22	8733	2019-05-23
HÅL_22	38	66	104	36,54	33	9346	2022-05-12
ING2_17	5	73	78	6,41	18	4898	2017-06-01
JSG_23	8	65	73	10,96	12	3402	2023-05-25
PD_22	5	71	76	6,58	10	8027	2022-06-14
PD_23	25	86	111	22,52	30	7953	2023-05-28
SAB_20	32	62	94	34,04	35	5933	2020-06-11
STB2_22	11	82	93	11,83	29	12689	2022-05-21
SVM_24	6	143	149	4,03	27	7488	2024-05-25
TGV_18	12	28	40	30,00	19	4392	2018-05-28
Total	191	757	948	20,15	266	79088	

Table 2. Identified observations of species level and their size.

Species	Nr	Size	Prey category
common gull (<i>Larus canus</i>)	1	M	gull
black-headed gull (<i>Chroicocephalus ridibundus</i>)	19	M	gull
European herring gull (<i>Larus argentatus</i>)	1	M/L	gull
Eurasian blackbird (<i>Turdus merula</i>)	3	S/M	thrush
fieldfare (<i>Turdus pilaris</i>)	1	S/M	thrush
mistle thrush (<i>Turdus viscivorus</i>)	1	M	thrush
song thrush (<i>Turdus philomelos</i>)	1	S/M	thrush
song/mistle thrush	8	S/M	thrush
starling (<i>Sturnus vulgaris</i>)	6	S/M	starling
common wood-pigeon (<i>Columba palumbus</i>)	3	M	dove
feral (homing) pigeon (<i>Columba livia domestica</i>)	11	M	dove
Eurasian jay (<i>Garrulus glandarius</i>)	1	S/M	corvid
hooded crow (<i>Corvus cornix</i>)	2	M/L	corvid
Eurasian jackdaw (<i>Corvus monedula</i>)	10	M	corvid
Eurasian woodcock (<i>Scolopax rusticola</i>)	21	M	wader
Total	89		

Table 3. Size distribution of known and unknown prey observations.

Size	Known prey	Unknown prey	Nr
L	0	0	0
M/L	10	11	21
M	124	236	360
S/M	57	317	374
S	0	94	94
NO size	-	99	99

Table 4. Distribution of known prey categories among size classes

Size	Prey category	Nr
M	corvid	34
M	dove	21
M	duck	1
M	gull	45
M	thrush	1
M	wader	22
M/L	corvid	3
M/L	dove	2
M/L	gull	5
S/M	starling	6
S/M	thrush	50
S/M	wader	1
tot		191

3.1 Current diet estimate

Results of the 11 nests sampled between 2017-2024 indicate that the Peregrine diet in southern Sweden consists mainly of thrushes, gulls and corvids. Doves and waders are slightly less common. Starlings and ducks seem rare in their diet (Fig. 3).

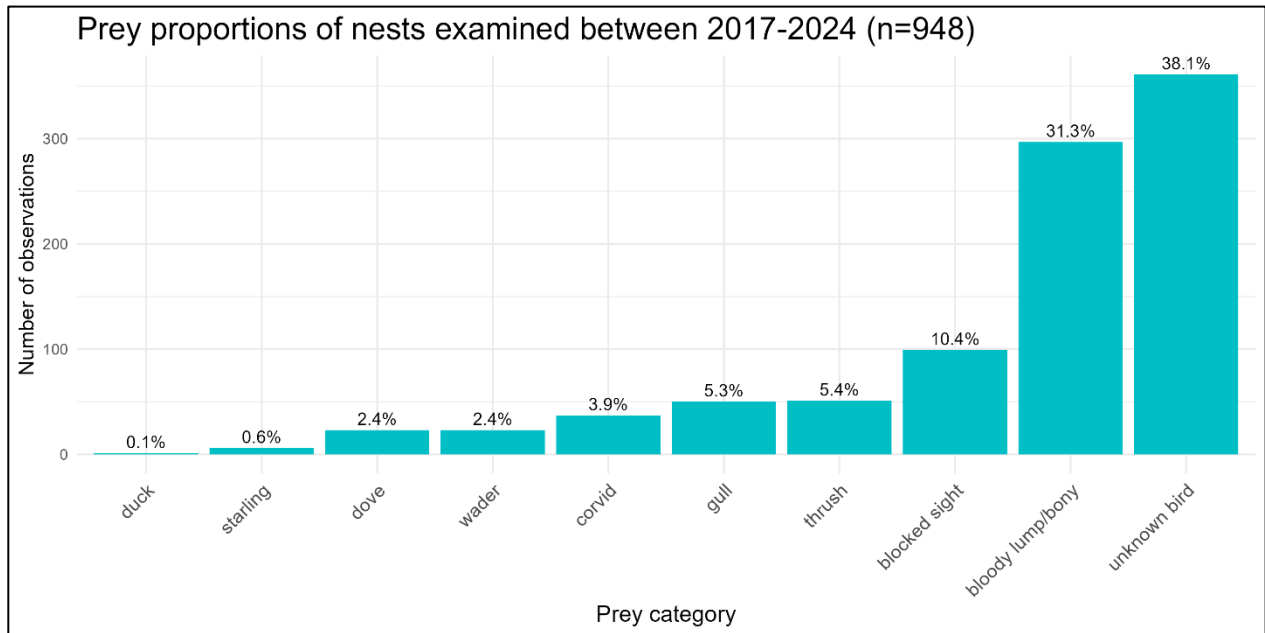


Figure 3. Data gathered from photographic data between 2017-2024. Observed percentages for each prey category including unknown feeding events. n=948

3.2 Comparison between 2017-2024 and 1971-1979

Diet composition from 1971-1979 in southern Sweden consisted mostly of gulls and doves, followed by an approximately equal number of thrushes, starlings, corvids and waders. A comparison with the 2017-2024 analysis (excluding unknown prey) displays a considerable increase in thrushes and corvids, and a decrease in doves, starlings and gulls. In waders and ducks, no outstanding change could be observed. No sightings of small birds or other birds were recorded in the current analysis which limits a comparison (Fig. 4).

3.3 Extrapolation

Diet counts including extrapolated unknown prey items display a substantial amount of thrushes in the peregrine falcon diet, followed by gulls, corvids, small birds, waders, doves and starlings. Ducks seem rare in their diet. Since no birds with size small (S) could be identified to a known prey category, all the unknown prey of size small have been extrapolated into small birds (Fig. 5).

3.4 Comparison between resampled extrapolation and 1971-1979

By resampling the extrapolated diet model and subtracting the extracted proportion of each prey category from its respective proportion in the 1970s, I found that thrushes increased by over 20%, while small birds and corvids showed a minor increase. Conversely, doves and gulls decreased by at least 10%, and starlings experienced a slight decline. Ducks, waders, and other birds displayed no significant change (Fig. 6).

3.5 HPAI in wild birds

Visualized data from SVA reveal that gulls, terns, waterfowl, pelagic birds and waders exhibit high percentages of being infected by HPAI. Terrestrial birds show little evidence of being infected by HPAI with the exception being the common pheasant (*Phasianus colchicus*). Out of all the birds of prey, the peregrine falcon has the highest percentage of infected birds at 47.4%, 57 specimens tested (Fig. 7).

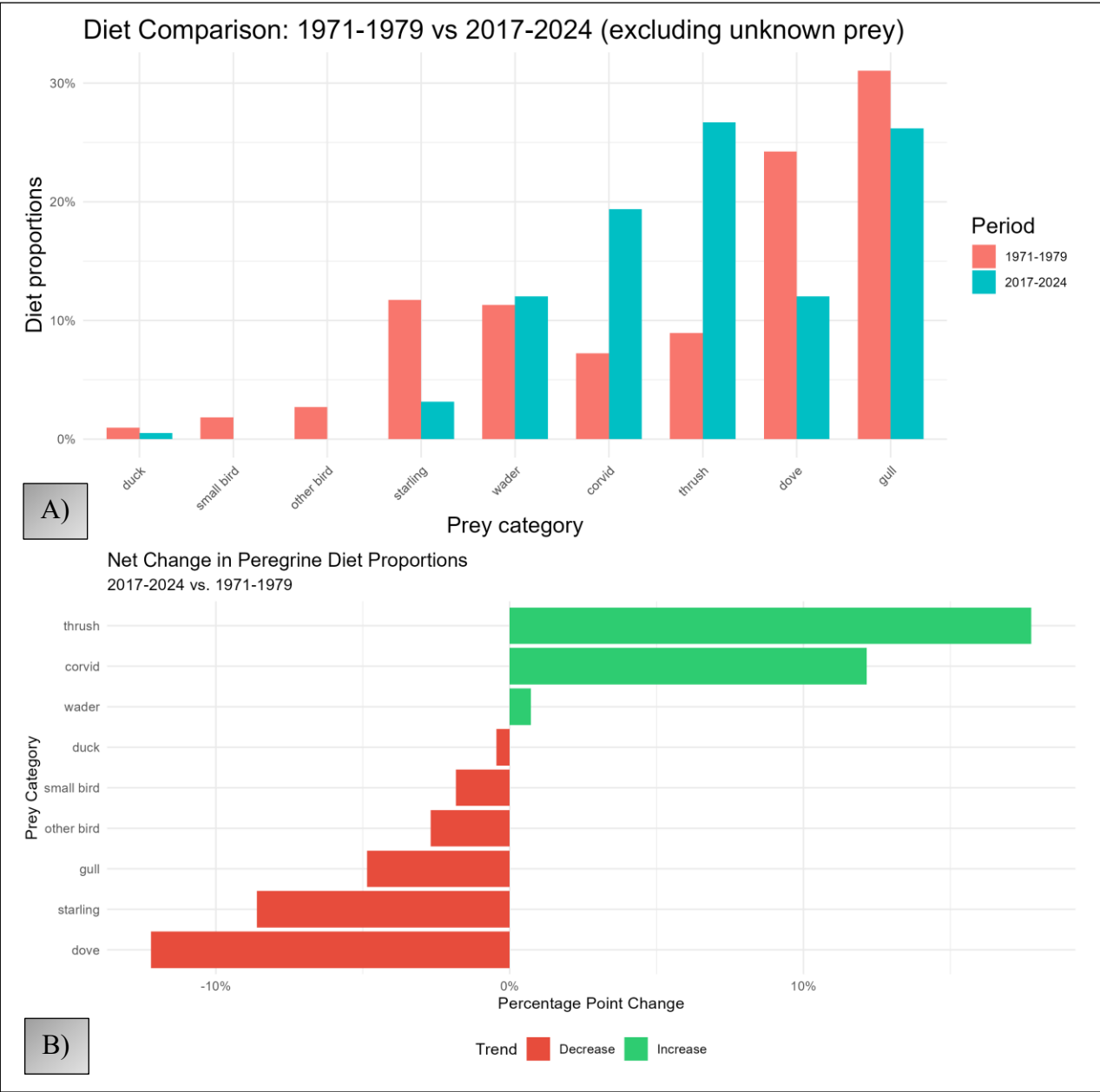


Figure 4. A) Diet proportions in 1971-1979 (red, n=842) compared to 2017-2024 (blue, excluding unknown prey) in southern Sweden. B) The proportional net change in each prey category between 1971-1979 and 2017-2024.

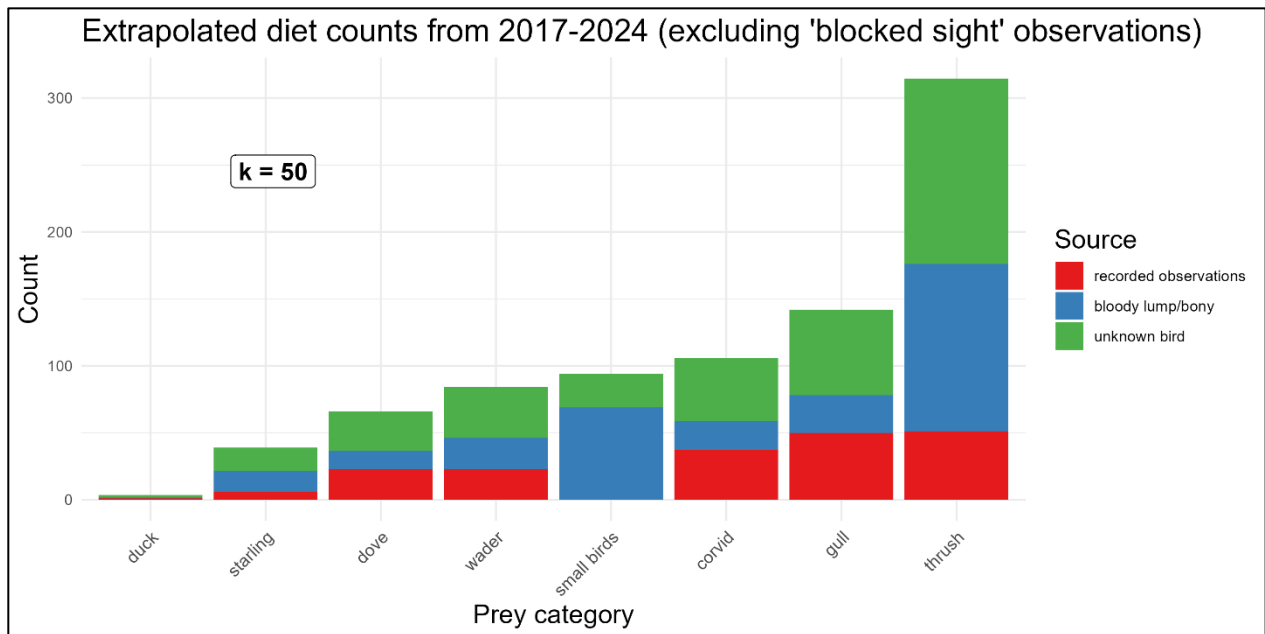


Figure 5. Unknown bird and bloody lump/bony observations have been assigned to a known prey category and summed with known prey counts to create a total diet estimation of peregrine falcons in southern Sweden. 99 observations of blocked sight have been excluded. k=50.

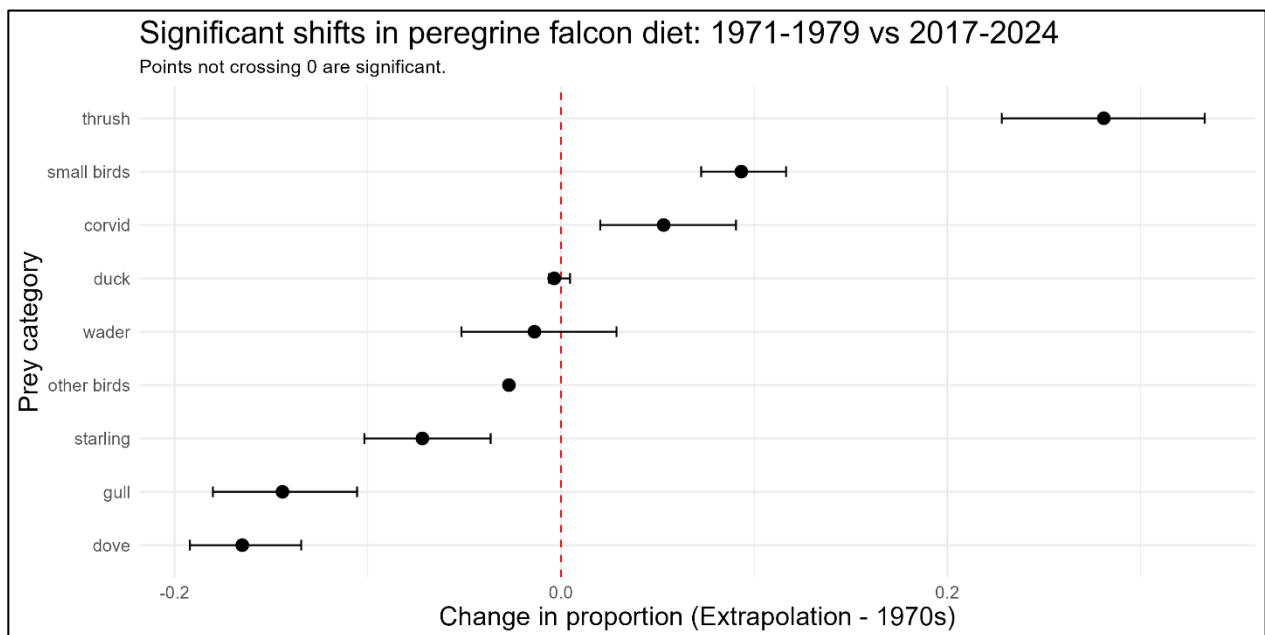


Figure 6. 95 % confidence intervals displaying the change in diet proportion between the resampled extrapolation (1000 iterations) and 1970s proportions. Intervals not crossing 0 are significant.

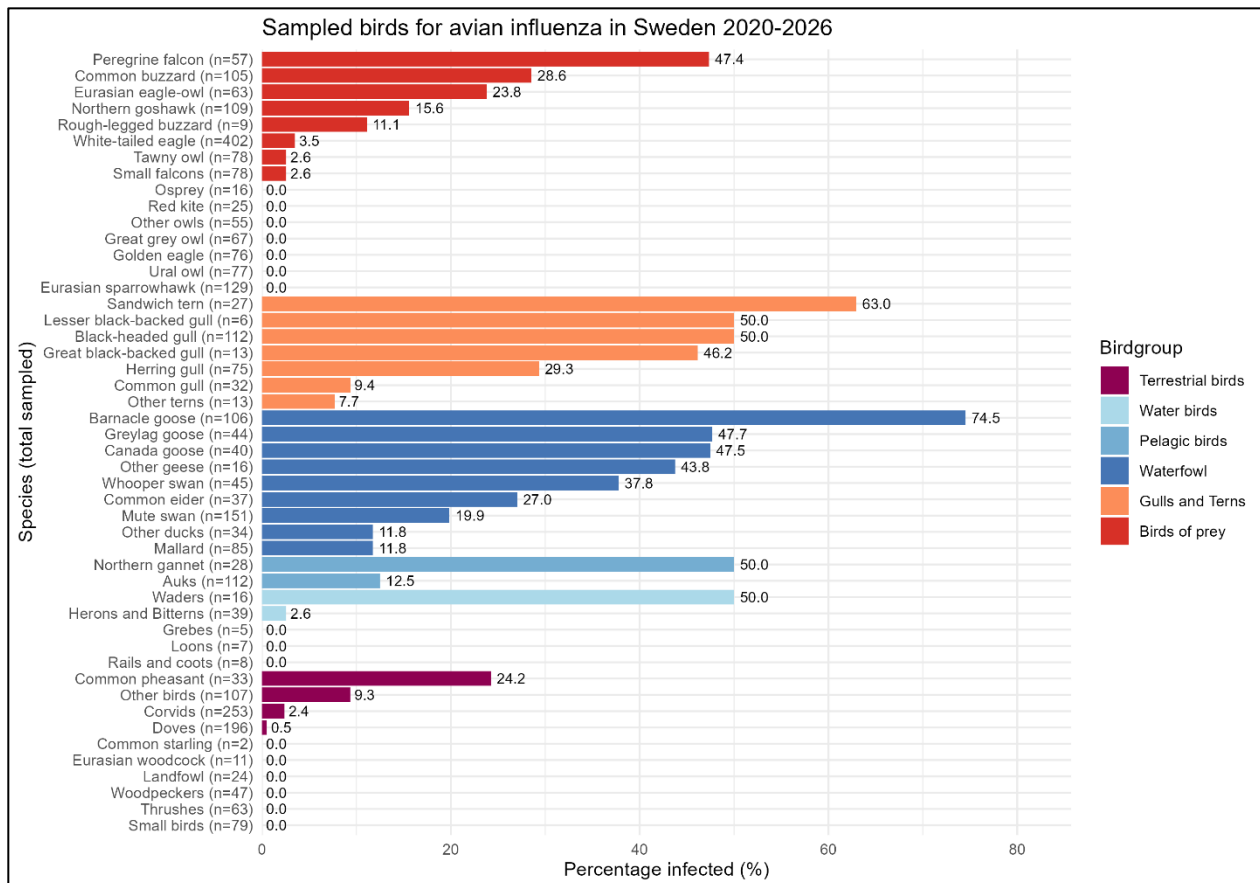


Figure 7. Sampled birds for HPAI in Sweden 2020-2026 measured in percent. Number for each species or group sampled in parentheses.

4 Discussion

The current diet estimate (Fig 3) suggest that prey such as thrushes, gulls and corvids account for a majority of the peregrine falcon's diet in southern Sweden. When excluding observations of unknown prey items, the net change in proportions between current data and 1970s displays a >10% increase of thrushes and corvids, while doves and starlings have decreased with approximately 10 %. Gulls have decreased by 5%. The percentual change in ducks and waders are minor and categories' small birds and other birds were not identified in the current data, therefore they appear as decreasing (Fig. 4). By extrapolating observations of unknown birds and bloody lump/bony the proportions change notably since many of those observations are classified as small and small/medium (Table 3.). Therefore, a major part of the target extrapolated prey is assigned to thrushes, small birds and starlings which increase their change in proportion compared to Fig. 4A. (Fig. 6). By examining the locations of sampled nests (Fig. 1), one can draw the conclusion that peregrines in this study possibly have access to more terrestrial prey compared to coastal territories.

4.1 The risk for HPAI

According to prey proportions registered in the current analysis (Fig. 3.), peregrine falcons in southern Sweden probably get infected by gulls during nesting (Fig. 7). It is unlikely that corvids, doves, thrushes and small birds are the driving factor since they have a low proportion of infected birds (Fig. 7). Ducks have a significant proportion infected (Fig. 7) but are not that common in

the peregrine's diet (Fig. 3). Waders, which overall have a high percentage of infected birds (Fig. 7), were represented almost exclusively by the terrestrial wader Eurasian woodcock (*Scolopax rusticola*) (Table 2). Because these woodcocks showed no signs of infection (Fig. 7), they are unlikely to be the source of HPAI in peregrine falcons. However, since the major part of HPAI infected peregrines was found outside of nesting season, especially in January-March (Fig. A2), indicates that the risk increases during winter. This is the time of migration when large flocks of wild birds accumulate in western parts of Europe and the virus spreads rapidly. Comparing outbreaks in wild birds (Fig. A3) with recoveries of ringed peregrines from Sweden during September-October (Fig. A4) one can draw the conclusion that the infection risk of HPAI increases during winter season. Caliendo et al. (2025) confirms this by sequencing for virus genes in infected peregrine individuals and prey in the Netherlands, revealing waterfowl (Anseriformes) and gulls (Laridae) to be the most likely reason for HPAI infection in peregrine falcons. They also mention that the inland population seems to increase, preying on pigeons (Caliendo et al., 2025). Diet shifts in winter have been recorded in Norway and Italy where migratory birds are essential prey in autumn but get replaced in winter by abundant prey (Serra et al., 2024; Time, 2016). Southern populations of peregrine falcons which winter close to their nesting area in Sweden might be less exposed to infection than northern populations migrating to Denmark and western Europe. However, findings of infected peregrines suggest that the risk is still severe in western Sweden where most dead peregrines have been found (Falk et al., 2025b). During nesting season when a great quantity of waders has migrated northwards the risk for infection of HPAI might increase further for northern populations of peregrine falcons since wetland-waders constitute a major proportion in their diet (Lindberg, 1983).

4.2 Sampling method

Sampling with camera traps is a common way to monitor wildlife ecology and has been done in peregrine falcons before to estimate prey proportions (Robinson et al., 2015; Time, 2025). However, the method yields a large proportion of unidentified prey items and underestimates small prey but compared to collecting prey remains, camera traps register more prey items due to longer monitoring (García-Salgado et al., 2015). In addition, peregrine falcons can pluck their prey before delivery to the nest at plucking sites or consume large prey direct from the ground (White et al., 2024). This could explain why a large proportion of prey are small-medium size and may indicate that medium and large prey are underestimated since their remains are unrecognizable at delivery.

The proportion of unidentified prey items in my data is relatively high compared to that of García-Salgado et al. (2015); This discrepancy is likely driven by differences in camera trap configuration, as their setup was optimized specifically for diet monitoring (García-Salgado et al., 2015). When reviewing the Swedish images, a prey item could appear out of nowhere with no parent bird in sight or an image could start in the middle of a feeding event. This indicates that some prey observations might have been missed since the camera registered motion right before the delivery of the prey and the timer delayed capturing of the event.

4.3 Extrapolation

The extrapolated diet displays that thrushes contribute to a major proportion of the peregrine diet. This number of thrushes should be taken with caution due to the large amount of unidentified small-medium prey that almost exclusively assigns to thrushes since that is the most abundant prey in that size class (Table 4). The same should be considered with small birds as that is a

created prey category assuming that some of the small unidentified preys are small birds, which have been recorded in 1983 (Lindberg, 1983).

Due to uneven contribution between the nests to the total number of feeding events (Table 1) the global diet could be biased by peregrine pairs specializing on abundant prey. This concern was managed by weighting each nest specific proportions to the global proportions, relying on the prey's abundance. However, if a prey category has never been recorded in the global proportions due to difficulties in identification, the extrapolation will fail to assign unknown prey since there is no proportion to rely on. This results in overestimation of recognized prey. Furthermore, several nests had very low identification rates (Table 1) and will rely entirely on global proportions. This is concerning because a given nest might be specialized on a specific prey type, but this specialization would be overlooked due to identification errors.

4.4 Diet shift

A comparison between diet estimates from the 1970s and the current analysis (Fig 6) suggests that thrushes and corvids have increased, while doves, gulls, and starlings have decreased. By examining which species contribute to each prey category (Table 2) and comparing them to data from the Swedish Bird Survey (Lindström & Green, 2026), one can draw the following conclusions: the song thrush (*Turdus philomelos*), mistle thrush (*Turdus viscivorus*) and Eurasian jackdaw (*Corvus monedula*) are the most abundant species within their respective prey categories (Table 2) and have displayed a steady population increase since the 1970s (Svensk fågeltaxering, 2026); meanwhile, the black-headed gull (*Chroicocephalus ridibundus*) and starling (*Sturnus vulgaris*) are the most abundant species within their categories (Table 2) and have displayed a steady decrease since the 1970s (Svensk fågeltaxering, 2026). Waders, which consisted mostly of the terrestrial wader, Eurasian woodcock (*Scolopax rusticola*) (Table 2), exhibited no significant shift in either the diet comparison (Fig 6) or the long-term trend (Svensk fågeltaxering, 2026). These findings strengthen the results of the diet shifts documented in this study (Fig 6), as it correlates with observations of wild bird population changes. However, doves displayed a decrease in the current analysis (Fig 6) despite the fact that wild populations of the observed species, the feral pigeon (*Columba livia domestica*) and common wood-pigeon (*Columba palumbus*), have both increased since the 1970s (Svensk fågeltaxering, 2026). The reasons for this discrepancy remain speculative. Doves may be difficult to identify accurately on camera trap images because they are predominantly grey and lack highly distinguishing visual features compared to other groups, such as gulls. Alternatively, doves might be plucked to a greater extent than other prey prior to being brought to the nest, or the local peregrines may simply prefer hunting abundant thrushes and corvids. Although this final scenario contradicts the view of the peregrine falcon as an opportunistic specialist that focuses on specific prey items when they become highly abundant, it highlights a potential gap between prey availability and actual consumption. However, many of the feral pigeons were homing pigeons since they were ringed with several coloured rings. To what extent these are accounted for in the Swedish bird survey is uncertain.

4.5 Future studies

There are multiple different aspects to consider in future studies to increase the quality of diet estimates and better understand the peregrine falcons' risk of being exposed to HPAI. First, since the diet of peregrine falcons is in constant shift throughout the year, the annual diet is key to understanding their exposure to HPAI. By tagging some individuals in Sweden during nesting

and following them throughout migration, examining their diet regularly would increase the knowledge of the Swedish population. However, this cannot be done with camera traps since consumption of the prey is not stationary as in nesting season. Studies utilizing DNA metabarcoding have been performed in sharp-shinned hawks (*Accipiter striatus*) and merlins (*Falco columbarius*) during migration. Specimens have been captured and swabbed on their beaks and talons for prey residues. Results displayed that merlins preyed upon 3,3 $\pm$ 1,6 prey species/individual, almost exclusively on migrating songbirds (Bourbour et al., 2021). Sharp-shinned hawks took the most abundant prey in most cases however some species thought to be preyed upon because they were energetically rewarding (DeLong et al., 2013). This type of information would be of great interest to investigate in the peregrine falcon's diet and could be performed during the standard ringing process.

Another concern that is still disguised is the fact that the peregrine falcon is the most infected bird of prey out of all birds tested (Fig 7). Why is the infection risk in white tailed eagle (*Haliaeetus albicilla*) significantly lower with 3,5% of 402 birds tested when their diet comprises a large proportion of large waterfowl and seabirds (Reid et al., 2023; Valero, 2008)? A report from North America found that 23 % of birds tested carried antibodies against HPAI, and 70 % of them had the specific antibodies to the H5N1 variant that has caused mass deaths in wild birds lately. The bald eagle (*Haliaeetus leucocephalus*) was the species that exhibited the most antibodies out of the birds tested, with 54% carrying antibodies to H5N1 (Tang, 2026). This suggests that eagles may have developed a high resistance to HPAI while peregrines have not, though the precise reason remains uncertain. Is it possible that historical population declines and persistent organic pollutants still compromise the peregrines' immune systems, or are there other unexplored toxins at play?

5 Conclusion

This study demonstrates that the peregrine falcons' diet composition in southern Sweden consists of thrushes, gulls, corvids, waders, doves, starlings and to some extent small birds and ducks. Collecting data with camera traps is an efficient sampling method, but reviewing the images is time consuming. Suggestions for future studies are therefore to apply swabbing methods performed in other birds of prey for a more precise result. A diet shift compared to 40 years ago could be recognized and partly confirmed by the Swedish Bird Survey.

The risk for HPAI in Swedish peregrines is high due to their consumption of gulls in nesting season. However, the probability of infection varies depending on season and location of individual nests.

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References

- Ambrose, S., Florian, C., Ritchie, R. J., Payer, D., & O'Brien, R. M. (2016). Recovery of American peregrine falcons along the upper Yukon River, Alaska. *The Journal of Wildlife Management*, 80(4), 609–620. <https://doi.org/10.1002/jwmg.1058>
- Anderson, D. W., & Hickey, J. J. (1974). Eggshell Changes in Raptors from the Baltic Region. *Oikos*, 25(3), 395–401. <https://doi.org/10.2307/3543962>
- Bondì, S., Guzzo, E., Vitale, E., Baragona, A., Grancagnolo, D., & Sarà, M. (2016). Factors affecting the diet of Peregrine Falcon in Italy. *Avocetta*, 40(1). <https://doi.org/10.30456/avo.2016105>
- Bourbour, R. P., Aylward, C. M., Tyson, C. W., Martinico, B. L., Goodbla, A. M., Ely, T. E., Fish, A. M., Hull, A. C., & Hull, J. M. (2021). Falcon fuel: Metabarcoding reveals songbird prey species in the diet of juvenile Merlins (*Falco columbarius*) migrating along the Pacific Coast of western North America. *Ibis*, 163(4), 1282–1293. <https://doi.org/10.1111/ibi.12963>
- Cade, T. J., Lincer, J. L., White, C. M., Roseneau, D. G., & Swartz, L. G. (1971). DDE Residues and Eggshell Changes in Alaskan Falcons and Hawks. *Science*, 172(3986), 955–957. <https://doi.org/10.1126/science.172.3986.955>
- Caliendo, V., Bellido Martin, B., Fouchier, R. A. M., Verdaat, H., Engelsma, M., Beerens, N., & Slaterus, R. (2025). Highly Pathogenic Avian Influenza Contributes to the Population Decline of the Peregrine Falcon (*Falco peregrinus*) in The Netherlands. *Viruses*, 17(1), 24. <https://doi.org/10.3390/v17010024>
- Castagna, F., Montano, L., Lombardi, R., Pagano, A., Gigliotti, A., Bava, R., Lupia, C., Costagliola, A., Giordano, A., Palma, E., Britti, D., & Liguori, G. (2024). Understanding Environmental Contamination Through the Lens of the Peregrine Falcon (*Falco peregrinus*). *Environments*, 11(12), 264. <https://doi.org/10.3390/environments11120264>
- Datta, G., & Ghosh, M. (2012). Small Area Shrinkage Estimation. *Statistical Science*, 27(1). <https://doi.org/10.1214/11-STS374>
- Delong, J. P., Cox, N. S., Cox, S. W., Hurst, Z. M., & Smith, J. P. (2013). DNA Sequencing Reveals Patterns of Prey Selection in Migrating Sharp-Shinned Hawks: Las Secuencias de ADN Revelan Patrones de Selección de Presas por Individuos Migratorios de *Accipiter striatus*. *The Condor: Ornithological Applications*, 115(1), 40–46. <https://doi.org/10.1525/cond.2012.120016>
- Dixon, N., & Drewitt, E. (2018). A 20-year study investigating the diet of Peregrines, *Falco peregrinus*, at an urban site in south-west England (1997–2017). *Ornis Hungarica*, 26, 177–187. <https://doi.org/10.1515/orhu-2018-0027>
- Falk, K., Järås, T., Lindberg, P., Andersson, L.-Å., & Nilsson, L. (2025a). Hur drabbas pilgrimsfalken av fågelinfluensan? *Vår Fågelvärld*, (1).
- Falk, K., Lindberg, P., Andersson, L.-Å., Järås, T., Leksén, L., Lindström, B.-O., Nilsson, P., & Olofsson, F. (2025b). Long-term changes in eggshell thickness in the Peregrine Falcon *Falco peregrinus* in Sweden. *Ornis Svecica*, 35, 50. <https://doi.org/10.34080/OS.V35.26042>

- Fransson, T., & Pettersson, J. (with Larsson, P., Naturhistoriska riksmuseet, & Sveriges ornitologiska förening). (2001). *Svensk ringmärkningsatlas. Vol. 1, Lommar-rovfåglar = Divers-raptors*. Naturhistoriska riksmuseet : Sveriges ornitologiska fören.
- García-Salgado, G., Rebollo, S., Pérez-Camacho, L., Martínez-Hesterkamp, S., Navarro, A., & Fernández-Pereira, J.-M. (2015). Evaluation of Trail-Cameras for Analyzing the Diet of Nesting Raptors Using the Northern Goshawk as a Model. *PLOS ONE*, 10(5), e0127585. <https://doi.org/10.1371/journal.pone.0127585>
- Gargallo, G., Davies, J. G., Faverjon, C., Kampichler, C., Baillie, S. R., Cameron, A., Robinson, R. A., & Sierdsema, H. (2022). Development of a prototype early warning system for avian influenza in the EU based on risk-mapping. *EFSA Supporting Publications*, 19(12). <https://doi.org/10.2903/sp.efsa.2022.EN-7762>
- Holroyd, G. L., & Bird, D. M. (2012). Lessons learned during the recovery of the peregrine falcon in Canada. *Canadian Wildlife Biology & Management*, 1(1), 3–20.
- Lincer, J. L. (1975). DDE-Induced Eggshell-Thinning in the American Kestrel: A Comparison of the Field Situation and Laboratory Results. *Journal of Applied Ecology*, 12(3), 781–793. <https://doi.org/10.2307/2402090>
- Lindberg, P. (1983). *Relations between the diet of Fennoscandian peregrines Falco peregrinus and organochlorines and mercury in their eggs and feathers, with a comparison to the gyrfalcon Falco rusticolus*. [Dissertation]. (University of Gothenburg). <http://hdl.handle.net/2077/12621>
- Lindberg, P. (2007). The fall and the rise of the Swedish Peregrine Falcon population. J. Sielicki & T. Mizera (Eds). *Peregrine Falcon Populations – status and perspectives in the 21st Century* (p. 125-132). Turul Publishing & Poznan University of Life Sciences Press, Warsaw-Poznan. https://www.researchgate.net/profile/Peter-Lindberg-2/publication/270902791_The_fall_and_the_rise_of_the_Swedish_Peregrine_Falcon_population/links/54b948c60cf253b50e2931c9/The-fall-and-the-rise-of-the-Swedish-Peregrine-Falcon-population.pdf
- Lindberg, P., Odsjö, T., & Reutergårdh, L. (1985). Residue levels of polychlorobiphenyls, ΣDDT, and mercury in bird species commonly preyed upon by the peregrine falcon (*Falco peregrinus* Tunst.) in Sweden. *Archives of Environmental Contamination and Toxicology*, 14(2), 203–212. <https://doi.org/10.1007/BF01055613>
- Lindberg, P., & Sjöberg, U. (2009). Captive breeding and restocking of the Peregrine Falcon in Sweden. J. Sielicki & T. Mizera (Eds). *Peregrine Falcon Populations: Status and Perspectives in the 21st Century* (p.677-694). Turul Publishing & Poznan University of Life Sciences Press, Warsaw-Poznan. https://www.researchgate.net/profile/Peter-Lindberg-2/publication/270903016_Captive_breeding_and_restocking_of_the_Peregrine_Falcon_in_Sweden/links/54b94a6f0cf2d11571a34f6b/Captive-breeding-and-restocking-of-the-Peregrine-Falcon-in-Sweden.pdf
- Moore, N. W., & Ratcliffe, D. A. (1962). Chlorinated hydrocarbon residues in the egg of a Peregrine Falcon (*Falco peregrinus*) from Perthshire. *Bird Study*, 9(4), 242–244. <https://doi.org/10.1080/00063656209476032>
- Nygård, T., Sandercock, B. K., Reinsborg, T., & Einvik, K. (2019). Population recovery of peregrine falcons in central Norway in the 4 decades since the DDT-ban. *Ecotoxicology*, 28(10), 1160–1168. <https://doi.org/10.1007/s10646-019-02111-4>

- Olsen, P., & Olsen, J. (1979). Eggshell Thinning in the Peregrine, *Falco Peregrinus* (Aves: Falconidae), in Australia. *Wildlife Research*, 6, 217–226.
<https://doi.org/10.1071/WR9790217>
- Ratcliffe, D. A. (1963). The status of the Peregrine in Great Britain. *Bird Study*, 10(2), 56–90.
<https://doi.org/10.1080/00063656309476042>
- Ratcliffe, D. A. (1967). Decrease in Eggshell Weight in Certain Birds of Prey. *Nature*, 215(5097), 208–210. <https://doi.org/10.1038/215208a0>
- Reid, R., Grant, J., Broad, R., Carss, D., & Marquiss, M. (2023). *The breeding season diet of White-tailed Eagles in Scotland*. 43, 305–318.
https://www.researchgate.net/profile/David-Carss/publication/376191616_The_breeding_season_diet_of_White-tailed_Eagles_in_Scotland/links/656dba71ce88b8703131c5b2/The-breeding-season-diet-of-White-tailed-Eagles-in-Scotland.pdf?origin=publication_detail&_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uRG93bm9vYXQpLCJwcmV2aW91c1BhZ2UiOiJwdWJsZW9hdGlvbiJ9fQ
- Rejt, Ł. (2001). Feeding Activity and Seasonal Changes in Prey Composition of urban Peregrine Falcons (*Falco peregrinus*). *Acta Ornithologica*, 36(2), 165–169.
<https://doi.org/10.3161/068.036.0201>
- Robinson, B. G., Franke, A., & Derocher, A. E. (2015). Estimating nestling diet with cameras: Quantifying uncertainty from unidentified food items. *Wildlife Biology*, 21(5), 277–282.
<https://doi.org/10.2981/wlb.00114>
- Serra, G., Lucentini, M., & Romano, S. (2024). Diet and Prey Selection of Nonbreeding Peregrine Falcons in an Urban Habitat of Italy. *Journal of Raptor Research*, 35(1).
<https://digitalcommons.usf.edu/jrr/vol35/iss1/11>
- Sielicki, J., Mizera, T., European Peregrine Falcon Working Group, & Society for the Protection of Wild Animals ‘Falcon’ (Poland) (Eds). (2009). *Peregrine falcon populations: Status and perspectives in the 21st century*. Turul Publishing. International Peregrine Conference.
- SLU Artdatabanken. (2025). *Pilgrimsfalk-Rödlista 2025-Artfakta från SLU Artdatabanken*.
<https://artfakta.se/>
- SVA. (2026). *Fågelinfluensa — smittläge med karta*. SVA.
<https://www.sva.se/djurhaelsa/djursjukdomar-a-oe/sjukdomar/faagelinfluensa/faagelinfluensa-smittlaege-med-karta/>
- Svensk fågeltaxering. (2026). *Populationstrender för enskilda arter | Svensk fågeltaxering*. Biologiska institutionen, Lunds universitet.
<https://www.fageltaxering.lu.se/resultat/populationstrender-enskilda-arter>
- Tang, A. (2026, March 23). Antibodies Suggest Some Raptors May Be Developing Resistance to Avian Influenza. *All About Birds*. <https://www.allaboutbirds.org/news/antibodies-avian-influenza-raptors-resistance/>
- Time, B. E. (2016). Hunting activity by urban Peregrine Falcons (*Falco peregrinus*) during autumn and winter in south-west Norway. *Ornis Norvegica*, 39, 39–44.
<https://doi.org/10.15845/on.v39i0.1048>

- Time, B. E. (2025). Hunting success and efficiency of an urban Peregrine Falcon (*Falco peregrinus*) during the low light season in south-west Norway. *Ornis Norvegica*, 48, 1–6. <https://doi.org/10.15845/on.v48.3625>
- Valero, S. O. P. (2008). White-tailed Eagle hunting behaviour and food choice in Kvismaren. *Sveriges Ornitologiska Förening*. https://www.researchgate.net/profile/Sergio-Ovidio-Pinedo/publication/337720620_White-tailed_Eagle_hunting_behaviour_and_food_choice_in_Kvismaren/links/6890886d58199117bcaa2d3a/White-tailed-Eagle-hunting-behaviour-and-food-choice-in-Kvismaren.pdf
- White, C. M., Clum, N. J., Cade, T. J., & Hunt, W. G. (2024). Peregrine Falcon (*Falco peregrinus*), version 1.1. *Birds of the World*. <https://doi.org/10.2173/bow.perfal.01.1>

Appendix 1

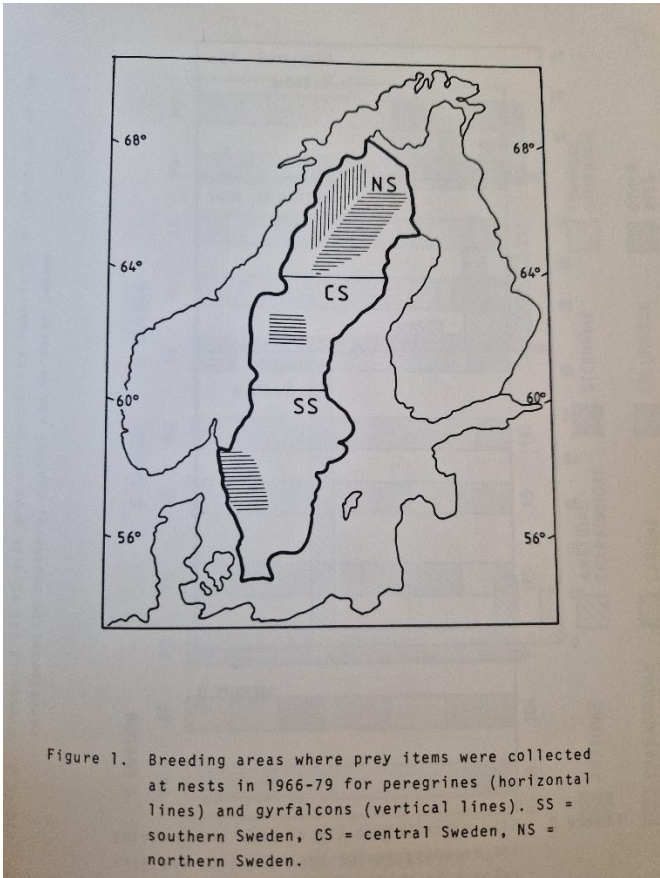


Figure A1. Areas of sampled nests in Peter Lindbergs diet study (Lindberg, 1983)

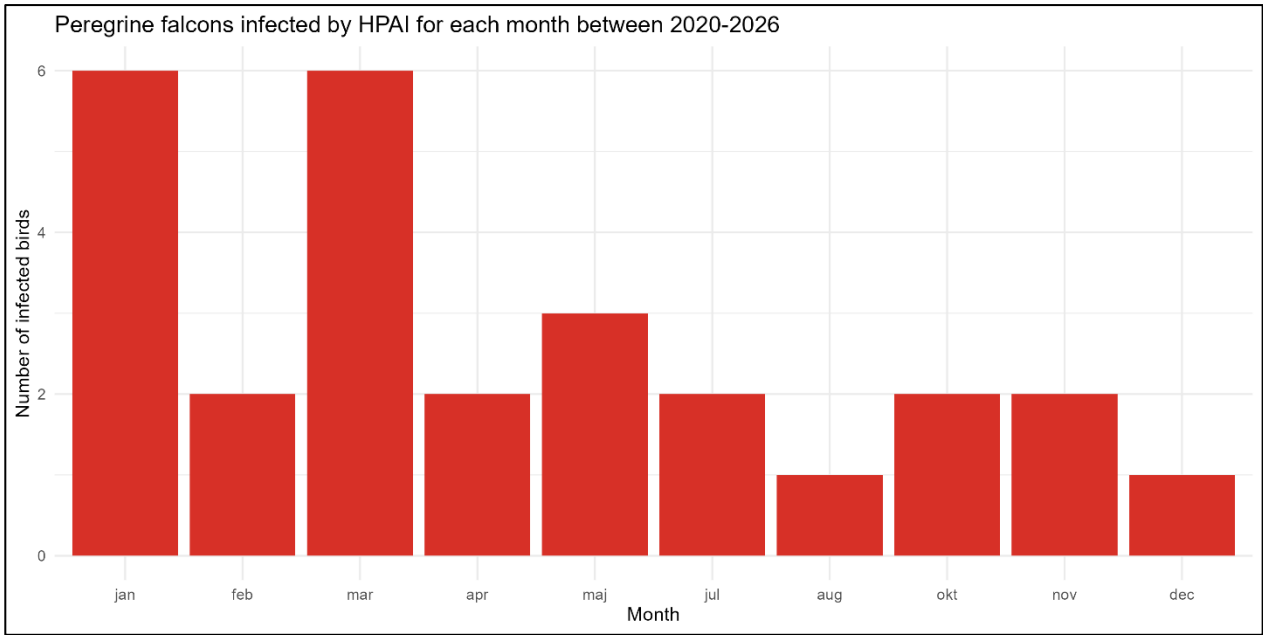


Figure A2. Infected peregrine falcons in Sweden by month between 2020-2026 (SVA, 2026)

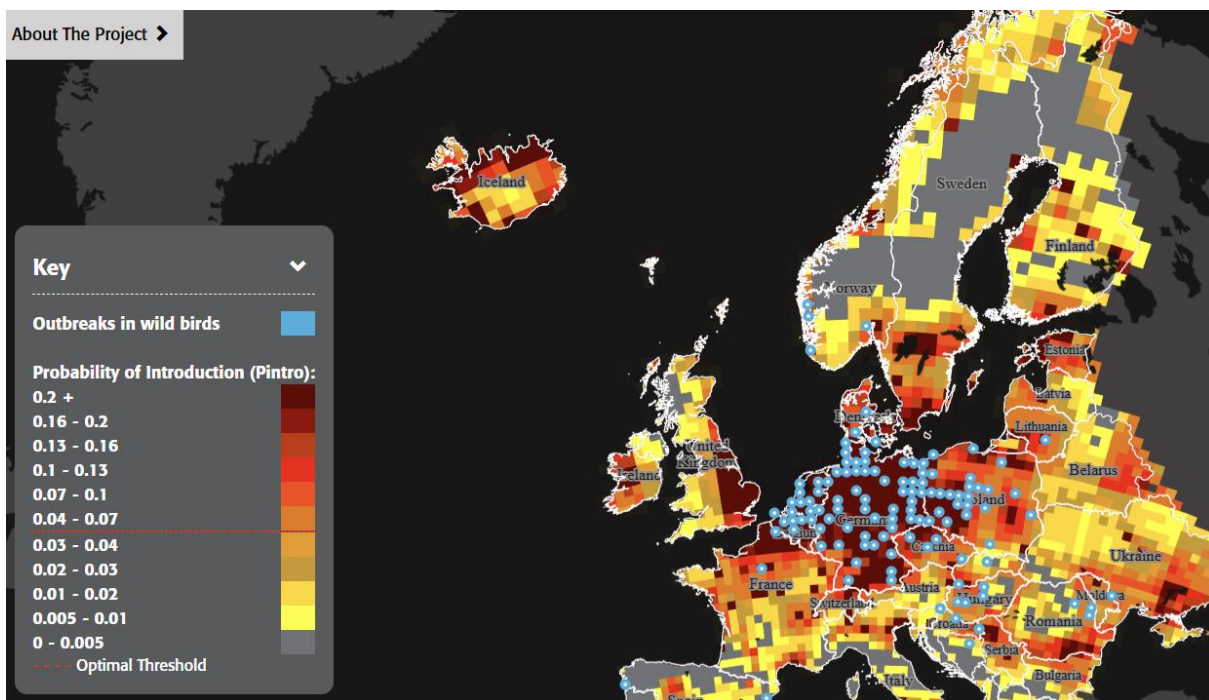


Figure A3. Outbreaks of HPAI in wild birds and the probability of introduction between 26/1 to 1/2 in 2026 (Gargallo et al., 2022)



Figure A4. Recoveries of peregrine falcons ringed in Sweden between September and October, 1911-2001 (Fransson & Petterson, 2001).