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The Heat is On: The Global Threat to Owls from Climate Change

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Simple Summary

Utilizing multiple published studies from around the world, we examine the numerous negative effects of climate change has on owls globally. Here, we attempt to identify which species of owls, their habitats and their prey species are most threatened and to what extent the various extreme climatic events caused by climate change negatively impacts specific owl species and their ability to hunt and breed successfully. Drastic owl population declines are usually attributed to multiple sources, such as the global climate change and habitat degradation through excessive logging, inducing decreased food supply. Studies such as this one may help form environmental mitigation strategies for future climate change expansion and indirectly to modern forest management.

Abstract

As the global threat from climate change continues to increase almost unchecked, the negative impacts of climate change on biodiversity are also increasing, and this could result in the loss of numerous species, habitat fragmentation, and phenological change. Here, we look at the global impact climate change poses to one particular group of birds: Owls (Strigiformes). As apex predators inhabiting every continent and in almost every country of the world, with the exception of Antarctica and some small isolated islands, they are an ideal group to study in relation to negative impacts caused by extreme climatic events globally. Examining multiple published studies from around the world, we determine which species are most susceptible to be negatively impacted by one or multiple events caused by climate change: wildfires, unprecedented levels of precipitation and flooding, rising temperatures, drought, melting of ice and snow, storm events, and rising sea levels. In the case of well-studied Tengmalm's Owl (Boreal Owl) Aegolius funereus the principal reason for low productivity may not be the climate change but loss and degradation of mature and old-growth forests due to modern forest management. The Tawny Owl Strix aluco also offers one of the first evidences that recent climate change can alter natural selection in a wild population leading to a micro-evolutionary response, which demonstrates the ability of wild populations to evolve in response to climate change.

Keywords: Owls, Climate Change, Ecosystems, Increasing Temperatures, Microevolution, Wildfires, Precipitation, Flooding, Rising Sea Level, Drought, Snow Structure, Thawing, Habitat Loss, Nestbox Competition, Prey Species

1. Introduction

Climate change is one of the greatest ecological and social challenges of the 21st century, and while opinion polls continue to show that the increasing threat of climate change is at the top of public concern, continuing geopolitical discord and the reluctance of wealthy industrial nations to vastly reduce their reliance on fossil fuels are only increasing those challenges [1]. According to the United Nations (UN) agency, the World Meteorological Organization (WMO), 2024 was the warmest year on record globally, while one WMO report finds that there is a staggering 86% chance that global average temperatures will exceed 1.5°C above pre-industrial levels in at least one of the next five years, and a 1% chance of one of those years exceeding 2°C of warming [2]. Biodiversity and climate are interconnected to each other and, as such, climate change is a continuous threat to wildlife and ecosystems across the world. The basic cause of these climatic changes is human activities. These anthropogenic activities increase the greenhouse gases (such as carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons), which cause the greenhouse effect, where the rising temperature of the atmosphere causes thermal optima to shift towards high altitudes and high latitudes, causing long-term change in weather patterns, including temperature, precipitation, and storm events. Impacts of climate change on biodiversity are continuous, and this could result in the loss of numerous species, habitat fragmentation, and phenological change. Even a slight temperature change will have a complex sequence in terms of species distribution and numbers, affecting behaviour, reproduction, migration, and foraging. Therefore, it is critical to address climate change for biodiversity conservation and ecosystem management [3].

Here, we look at the global threats climate change poses to one particular group of birds: Owls (Strigiformes). Owls are an important study group in terms of the impact climate change has on a wide variety of ecosystems globally. Not only are they apex predators, where their high trophic position allows them to be prime indicators to the health of lower trophic levels and the availability of prey, more importantly, species of owls are found on every continent and in almost every country of the world, with the exception of Antarctica and some small isolated islands, and can thrive in habitats as diverse as frozen tundra, equatorial rainforests, temperate northern forests, and even open grasslands and deserts [4].

Because of their vast geographical range and the incredible diversity of habitats, many owl species are negatively impacted by one or multiple events caused by climate change: wildfires, unprecedented levels of precipitation and flooding, rising temperatures, drought, ice and snow melt, storm events, and rising sea levels. However, it is challenging to separate the impacts of climate change on owl biodiversity from those of other global change drivers such as urbanization, land-use change, and increased long-distance trade [5]. It is also important to remember that avian response to climate change may be species-specific and not all species exhibit changing phenology despite regional climatic changes [6].

Climate change is a global phenomenon, but most of our examples and references are from northern regions. Warming takes place in tropical areas as well but its impact to owls is more difficult to recognize in an environment that is initially warm and with large human populations and human activity. Therefore, in an increasingly anthropized world, alpine tundra and boreal forest ecosystems can be more easily seen to be affected by climate change rather than by human disturbance.

2. Methods

The data examined in this paper was collected from relevant published studies, ranging in date from 1984–2025. Selective keywords were used in online search engines, such as Google Scholar, online databases, such as the Searchable Ornithological Research Archive (SORA), online educational platforms, such as Academia.edu and ResearchGate, and the references from those same published studies. Here, we review more than 100 owl studies representing 35 different owl species facing the global climate change impacts.

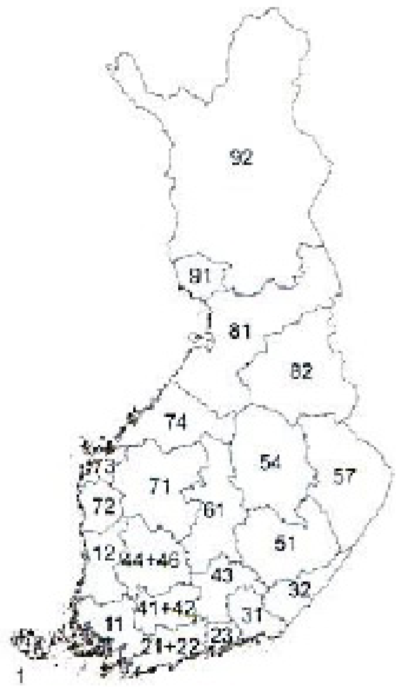
In addition to a world literature search, we have used published active nest and fledged broods of owls' material from Birdlife Finland Year books 1996–2024 in order to see the assumed northward movements of the populations due to climate change [7-35,36]. Two eight-year periods have been compared, 1996–2003 and 2017–2024. South Finland includes BirdLife Finland societies 1,11,12,21-23,31.32,41 and 42; Central Finland includes 43,44,46,51,54,57,61 and 71–74; and North Finland respectively 81,82,91 and 92 (Map 1 [from 35]). Reasoning for the eight-year period is that it should cover two peak vole years and two low vole years in the 3–4-year vole cycle to reduce the cyclic variation in the average period nest numbers (Table 1).

In addition, population trends for each species in South, Central and North Finland were investigated by fitting three generalized linear models to the Birdlife yearbook data. The models included either linear, quadratic or third polynomial year effects as well as their full interaction with area (South, Central and North). For the Tawny Owl *Strix aluco* North Finland with zero observations was excluded. For each species Akaike's Information Criterion (AICc) was used to choose the best fitting model which was then used to predict the number of owl observations and their 95% confidence intervals during 1996-2024 in each part of Finland (Figure 1). The chosen Year effect was linear for the Tengmalm's Owl *Aegolius funereus*, the Short-eared Owl *Asio flammeus*, the Eurasian Eagle Owl *Bubo bubo* and the Great Grey Owl *Strix nebulosa*, quadratic for the Long-eared Owl *Asio otus*, the Eurasian Pygmy Owl *Glaucidium passerinum*, the Ural owl *Strix uralensis* and the Northern Hawk Owl *Surnia ulula*, and third polynomial for the Tawny owl. The main purpose was to see if the owl populations have moved north from the southern and central parts of the country, as the southern part of the country covers mainly the southern coastal areas and Åland archipelago, and the northern parts include north Ostrobothnia and Kainuu, resembling Lapland more than Central Finland. Table 2 summarizes known climate change impacts on owl species, including data collected from global literature and from this study based on BirdLife Finland yearbook material as presented in Table 1.

Owl 1996-2024	Total no of active nests	Minimum of any year	Maximum of any year	Average of 29 years	Trend of the population
Aegolius funereus	S 1217 C 8485 N 2955 T 12657	S 1 C 28 N 3 Tmi 98	S 196 C 981 N 386 Tma 1285	S 42.0 C 292.6 N 101.9 T 436.5	S - 5.5% C - 2.3% N + 7.8% Ttr - 74.1%
Asio flammeus	S 36 C 976 N 302 T 1314	S 0 C 0 N 1 Tmi 1	S 24 C 293 N 49 Tma 305	S 1.2 C 33.7 N 10.4 T 45.3	S + 6.0% C - 21.3% N + 15.3% Ttr - 65.2%
Asio otus	S 3274 C 3424 N 133 T 6831	S 20 C 6 N 0 Tmi 32	S 500 C 633 N 24 Tma 1135	S 112.9 C 118.1 N 4.6 T 235.6	S + 22.2% C - 21.0% N - 1.2% Ttr - 54.9%
Bubo bubo	S 3053 C 2381 N 194 T 5628	S 33 C 20 N 0 Tmi 64	S 220 C 198 N 14 T ma 428	S 105.3 C 82.1 N 6.7 T 194.1	S + 10.5% C - 9.9% N - 0.6% Ttr - 50.0%
Glaucidium passerinum	S 1912 C 7929 N 243 T 10084	S 18 C 37 N 1 Tmi 60	S 167 C 788 N 22 Tma 963	S 65.9 C 273.4 N 8.4 T 347.7	S - 3.9% C + 2.4% N + 1.5% Ttr - 59.2%
Strix aluco	S 8868 C 4942 N 0 T 13810	S 131 C 84 N 0 Tmi 231	S 656 C 370 N 0 Tma 905	S 305.8 C 170.4 N 0 T 476.2	S + 12.4% C - 12.4% N 0 Ttr + 31.1%
Strix nebulosa	S 97 C 1085 N 508 T 1690	S 0 C 0 N 0 Tmi 4	S 9 C 107 N 55 Tma 118	S 3.4 C 37.4 N 17.5 T 58.3	S - 1.9% C + 24.9% N - 23.0% Ttr + 54.0%
Strix uralensis	S 7390 C 17086 N 1162 T 25638	S 68 C 242 N 3 Tmi 391	S 516 C 1229 N 67 Tma 1786	S 254.8 C 589.1 N 40.1 T 884.0	S - 1.5% C - 0.1% N + 1.6% Ttr - 0.3%
Surnia ulula	S 9 C 110 N 600 T 719	S 0 C 0 N 0 Tmi 1	S 3 C 43 N 116 Tma 120	S 0.3 C 3.8 N 20.7 T 24.8	S - 0.7% C - 17.8% N + 18.5% Ttr - 45.2%

Table 1: Changes in the active nest and fledged broods of owls in Finland

from recorded observations in the Year books of Birdlife Finland 1996–2024 [7–35]. S = South Finland, C = Central Finland and N = Northern Finland. T = Total number of nests in all areas; Tmi = Minimum of any particular year totals of that species in all areas; Tma= Maximum of any particular year totals of that species in all areas; Tav = Average total of that species in all areas, and Total trend calculated by comparing the area nest number percentage difference during the first eight and last eight years between 1996–2024 and Ttr = total nest number difference in the country per species as a percentage from the larger eight year period sum, - = decreasing and + = increasing



Map 1: BirdLife Finland Observation Areas [35]

3.1. Results

Tables 1&2 and Figure 1 show that in Finland, all owl species except Tawny Owls and Great Grey Owls have declining populations based on these two 8-year periods from 1996–2003 and 2017–24, as well as the trend estimates in Figure 1. Tawny and Great Grey Owls have increased 31 and 54 per cent, while the Ural Owl has kept its population stable (-0.3%). Two smallest owls, Tengmalm's Owl and Eurasian Pygmy Owl have seen the great declines (74% and 59% correspondingly). Both *Asio* owls also have declined markedly, Long-eared Owl 55% and Short-eared Owl 65%. Clear declines have taken place in Eurasian Eagle Owls and Northern Hawk Owls (50% and 45% respectively). Figure 1 also suggests non-linear trends for Short-eared Owl, Eurasian Pygmy Owl, Ural owl and Northern Hawk Owl with somewhat increasing numbers for the early years, ca. 1996-2009, but decreasing trends thereafter. Also the increase in Tawny Owls has mainly occurred during 2015-2024 (Figure 1). Decreasing populations make it difficult to see clearly how much owl populations would have moved northwards in direct relation to climate change, especially with the boreal forest owls. The clearest move to the north has taken place with the Northern Hawk Owl (+ 18.5%).

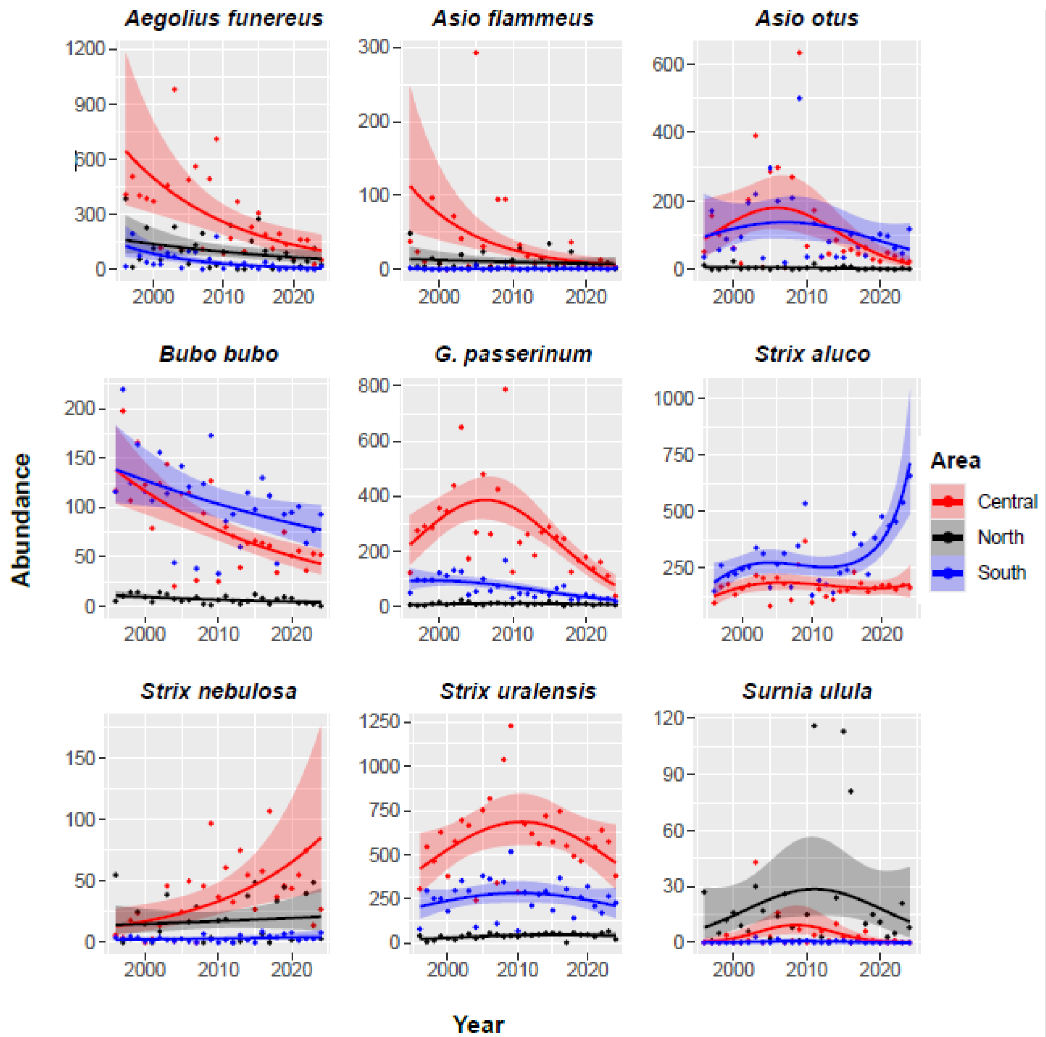


Figure 1: Owl population trend estimates for central (red), north (black) and south (blue) Finland in 1996-2024. The lines depict the predicted number of owl observations (abundance) across years and the shaded areas are the 95% confidence intervals for the predictions, based on the best models for each species (see Methods for details). Differences are significant if the prediction line for a time point (or area) does not overlap with the 95% confidence interval of the prediction for another time point (or area).

It seems that also the Short-eared Owl and Tengmalm's Owl, have seen little increase in their nesting in the north (+15 and +8% respectively). Southern species, Eurasian Eagle Owl, Tawny Owl and Long-eared Owl, have increased their population share in the south, and climate change has not yet assisted them in moving further north in Finland. The Eurasian Pygmy Owl and the Ural Owl have shown only minor shifts between south, central, and north (Table 1). Figure 1 suggests that for several species the decline has been stronger in central Finland than in the other parts, especially in the last 15 years. Exceptions are Tawny owl with strong increase in south but no change in central, and Great Grey Owl with increase in central but no change in north or south Finland (Figure 1).

Climate change is taking place more severely in the Arctic, rapidly affecting Arctic ecosystems [72]. Long-term Arctic breeding surveys suggest that the world population of Snowy Owls is much lower than estimated earlier. The breeding range is 12 million km2, but only 1.3 million of that has a high probability for breeding, i.e. breeding at no more than 3–9-year intervals.

Population size (previously 50,000–290,000 individuals) is now calculated to be only 14,000–28,000 mature individuals, making the owl vulnerable [73,47]. Roughly half the remaining population lives in the Canadian Arctic. In many countries, like Finland, the owl is already seen as Critically Endangered (Figure 2). Table 2 estimation of population decrease in Finland is 88%

[46]. Global temperatures have risen dramatically in recent years, with the frequency and duration of extreme heat events expected to continue increasing. The Snowy Owl has less and less thermal refugia, which could allow it to escape the extreme heat and adapt more readily to temperature shift [74]. In the Russian Arctic, the increasing June temperatures are already being seen to be responsible for the long-term decline in the breeding effort of Snowy Owls [75].

Owl species	**Climate change impact(s)**	**Reference(s)**
Aegolius acadicus	Predicted to lose 60% of its current breeding habitats in the Southwestern US (hereafter SW US)	37
Aegolius funereus	In Finland, a drastic habitat related decrease (- 74%) in population but the reduced numbers have shifted northwards (+ 7.8%) In SW US projected to experience the steepest climate change related habitat loss, up to 85% Interestingly, in Central Europe one of range increasing owls even in commercially used forests and in Scots pine *Pinus sylvestris* and not Spruce *Picea* sp: a keystone species (namely Norway Spruce *Picea abies*) for the owl in Finland	This study 37 38 and 39
Asio flammeus	In Finland, second largest loss of the population (65%) and the second largest shift northwards (+15.3%) Loss, fragmentation, and degradation of grass- and wetlands causing a range-wide long term decline in North America Sea level rising reduces winter habitats	This study 40 41
Asio otus	In Finland, sizeable population loss (55%) and many owls have shifted to south (+ 22%) In SW US predicted to lose 70% of its current breeding habitats	This study 37
Asio stygius	In Colombia, up to 22% habitat loss due to climate change	42
Athene cunicularia	One well studied population in central New Mexico declined from 52 pairs to 1 pair in 16 years due to increasing air temperature and extreme multiyear drought conditions Changes in phenology linked to climate change in N-America. Delays in breeding are due to food limitation caused by drought. Drought during migration also constrains energetic requirements, forcing owls to stop more frequently and for longer periods at stopover sites, resulting in delayed arrival on breeding grounds	43 44 44
Bubo bubo	In Finland, 50% decrease in population and 10.5% shift to south	This study
Bubo magellanicus	In central Chile, a climatic period defined as Mega-Drought forced normally mammal eating Magellanic Horned Owls to eat 98 % of arthropods. Breeding impacts not studied, but drastic effects on their populations and reproduction possible as above in Athene cunicularia [44]	45
Bubo scandiacus	In Finland, Snowy Owls breeds irregularly , average 2 nests per year (min 0 and max 10) ; the population change – 88% calculated by comparing the average during the first four and last four years between 2007–2024 Global decline, however, is only 30% over the past three generations Milder and wetter climate in the Arctic has been fading lemming population cycles and increasing the risk for detrimental black fly (Simulidae) attacks on nestlings and breeding females	46 47 48,49 and 50
Bubo virginianus	Predicted to lose 35% of its current breeding habitats in SW US	37
Glaucidium jardinii	Up to 43% habitat loss due to climate change in Colombia	42
Glaucidium minutissimum	Climate change will have a negative impact in Brazil	51
Glaucidium gnoma	Predicted to lose 75% of its current breeding habitats in SW US	37
Glaucidium passerinum	In Finland, 59% population decline but no clear region shifts Climate change lowers food store quality when autumn rains and mild winters rot food hoards	This study 52 and 53
Megascops albogularis	Up to 41% habitat loss due to climate change in Colombia	42
Megascops atricapilla	Climate change will have a negative impact in Brazil	51

Megascops ingens	In Colombia, significant habitat loss due to climate change but no percentage given	42
Megascops kennicottii	Predicted to lose 55% of its current breeding habitats in SW US	37
Megascops sanctaecatarinae	Climate change will have a negative impact in Brazil	51
Megascops trichopsis	Predicted to lose up to 60% of its current breeding habitats in SW US	37
Otus scops	Northward moving population in Britain and Europe	54
Psiloscops flammeolus	As cavity nester associated with large diameter trees, climate change would most likely be through disturbance processes that remove large trees. Shifts to denser forest structure would be a concern, but this is unlikely because drought and wildfire are projected to increase throughout the Northern Rockies In SW US projected to experience the steepest climate change related habitat loss, up to 85%	55 37
Pulsatrix koeniswaldiana	In Brazil, climate change will have a negative impact but no percentage given	51
Pulsatrix melanota	Up to 44% habitat loss due to climate change in Colombia	42
Strix albitarsis		42
Strix aluco	Dampening vole cycles may drive this owl towards extinction from Northern England In Finland, advance in breeding dates have been noted Second owl species in Finland with clearly increased population (31%) but this far no northward expansion happening, rather opposite 12.4% increase in the south and similar loss in central Finland In Israel, climate change, which would increase spring temperatures and decrease rainfall, is a larger threat to this owl than rural development.	56 57 This study 58
Strix hylophila	In Brazil, climate change will have a negative impact	51
Strix occidentalis	In SW US negative associations between warm, dry conditions and seemingly less heat-tolerant	59
Strix nebulosa	In Europe, population moving southward and westward against the climate change expectations In Finland, the number one owl species with a clear population increase (+ 54%) and this material would indicate population move between Central and North Finland (C + 24.9% and N – 23%) and slight decrease in the south (- 1.9%).	60–68 This study
Strix uralensis	In Finland, no visible population decrease (only -0.3%) and only very slight sift to north (+ 1.6%). Climate change may advance the breeding in Finland– deep snow depth has delayed breeding In Slovakia, a positive population and range trend (from the east to the west), but reason may not be climate related	57 69 and 70 This study
Surnia ulula	In Finland, 45 % reduction in breeding population, and remaining owls moving clearly further north (+18.5%)	This study
Tyto alba	Snowrich winters are part of non-linear climate change and can be dramatic to adult and juvenile barn owls in Switzerland	71

Table 2: Known climate change impacts on owls species. Data collected from global literature and from this study based on Birdlife Finland Year Book material as summarized in Table 1 [7-35]

Figure 2: In Finland, the Snowy Owl *Bubo scandiacus* is already as Critically Endangered.
Figure 2: The Snowy Owl *Bubo scandiacus*. Photo: Esko Rajala

3.2. Microevolution

In many species, markedly different colour morphs exist, and the frequency of these is sometimes climate-related, the pheomelanic reddish-brown morph (hereafter rufous or brown morph) predominates in warm climates while less melanic grey morph dominates in a less humid and colder environment [76]. One polymorphic example is the Eastern Screech Owl *Megascops asio*, individuals of which exhibit rufous, intermediate, or grey coloration (Figure 3). This species exhibits clinal variation in morph prevalence; rufous Eastern Screech Owls are relatively scarce in northern areas because it appears that they suffer greater mortality than grey ones do during severe winter cold snaps. It has also been noted that rufous females are likely to survive cold spells better than rufous-coloured males [77]. In Europe, skin collections of Eurasian Scops Owls *Otus scops*, spanning a 137-year period, show a significant increase in the rufous morph corresponding to an increase in rainfall, humidity and temperature over that time [78].

Figure 3: Eastern Screech Owl *Megascops asio* has clear rufous and grey morphs pairing freely with each other. Photo: Dick Daniels/ Creative Commons

In Finland, numbers of brown and grey morphs of Tawny Owls are also climate-related, as the grey morphs have a denser and more insulative plumage, enabling them to survive better in a cold climate compared to a brown phase [79]. The brown morph consistently moults more primary flight feathers than the grey morph [80]. This is interesting when we know that the plumage moult is a costly and crucial somatic maintenance function in owls [81]. The two morphs differ also in several life-history aspects related to immune defence against parasites and somatic maintenance costs, possibly explaining their different sensitivity to winter conditions [82]. Over the last three decades, the warming of the winter climate has produced a microevolutionary response in morph frequency: the brown morph has increased in number at the expense of the grey [83]. Thus, colour polymorphism in owls is an adaptive character likely maintained by the selective advantage of camouflage under different light regimes or in terms of physiological adaptation to environmental conditions via disruptive selection mechanisms. Under this hypothesis, climate change could bring about a dramatic change in the colour polymorphism of some northern species [83, 84]. It has already been noted with Tawny Owls in Finland that in winter the grey phase helps avoid avian mobbing and predators more efficiently than the brown morph and therefore has a higher survival rate in snowy environments [85]. However, as winters are getting milder and shorter in this species range due to climate change, the selection periods promoting grey colouration may eventually disappear or shift northward [82,85]. However, the Tawny Owl in Finland offers one of the first evidences that recent climate change can alter natural selection in a wild population leading to a microevolutionary response, which demonstrates the ability of wild populations to evolve in response to climate change.

Plumage traits of Barn Owls have been proven to be strongly heritable and on a continental scale, climatic factors are associated with plumage traits [86]. Western Barn Owls in continental Europe and in the British Isles have larger spots in the colder north-east regions and smaller spots in the warmer southern regions. American Barn Owls *Tyto furcata* are also displaying larger black feather spots in regions where ambient temperatures were colder. Female spottiness is shown to signal parasite resistance [87]. However, climate related body coloration change is a complex matter because dark plumage can also support animals in thermoregulation in cold environments, and this is especially the case for birds with thermal melanism [88]. It is well documented that Tawny Owl plumage is darkening over time in regions where a concurrent increase both tempeture and precipitation occurrs but data on populations living in climates that became warmer and drier are still lacking [83,88]. It is still debated if historical changes in bird phenotypes related to climate warming are phenotypically or genetically determined, often concluding that melanin-based colour changes are the consequence of phenotypic plasticity. However, plasticity and microevolution can act together in the same population, so further research is needed with populations living in regions where the climate has changed the most [83,88– 90].

3.3. Wild Fires

Climate change creates warmer and drier conditions globally, lengthening fire seasons and increasing the frequency and severity of wildfires. The severity of forest fires is measured in terms of low-density, mid-density, and high-density, with especially severe high-density fires now being classed as megafires. Global forests are key ecosystem indicators, used to monitor a wide range of ecological factors from climate regulation to biodiversity habitat. Today, forests are under increasing pressure from the combined impacts of climate and land use change. In 2024, global forest fires burned a record-breaking 13.5 million hectares of forest worldwide, surpassing the loss of forests to agricultural use globally for the first time [91].

The immediate effect of a high-density forest fire on forest-dwelling owls is devastating, with the initial loss of habitat, nesting sites, and prey species. However, studies have shown that any long-term negative effect varies from species to species, depending on which ecological niches they occupy within the forest area and on the severity of the fire [92]. In the USA, one species, the Northern Spotted Owl *Strix occidentalis caurina,* already endangered by past commercial logging and competition from the much larger Barred Owl *Strix varia,* relies on closed canopy old growth forests and is especially vulnerable to forest fires, with one recent study showing that Spotted Owls avoid high-severity burned sites for up to two decades after a fire [93,92].

Recent studies have also shown that, amongst other forest owl species, the Northern Saw-whet Owl *Aegolius acadicus* also appears to avoid nearly all burned areas. However, Barred Owls and Great Horned Owls *Bubo virginianus* have been found to use unburned and low-severity burned areas compared to areas that burned more severely, whereas Northern Pygmy Owls *Glaucidium gnoma* and Western Screech Owls *Megascops kennicottii* have shown high use of high-severity burned areas [92,94].

While some owl species, like the Spotted Owl, are extremely vulnerable to both immediate and long-term negative effects from forest fires, some species, such as the Great Grey Owl, although impacted by the immediate effect of loss of nesting habitat and prey species, are showing some short-term resilience. A study has shown that after one megafire in California's Sierra Nevada, many Great Grey Owls remained within the burned area and continued to nest in the newly created snags and open meadows. As Great Grey Owls typically nest in dead trees, fire would kill off large trees, potentially creating new nesting sites, while the newly created meadows would help in the recovery of their meadow-dwelling rodent prey [95].

3.4. Precipitation & Flooding

Global rainfall in 2025 has shown regional variation, with forecasts of above-normal precipitation in the Indian subcontinent, parts of eastern Asia, the Maritime Continent (Southeast Asia), eastern Australia, northwestern South America, northwestern North

America, and interior eastern equatorial Africa [2]. The rise in global average temperatures is a key driver of changes in rainfall patterns as a hotter planet leads to more intense rainfall events and a higher risk of flooding [96].

Continuous heavy rainfall is a serious threat to owls, especially to species such as the Western Barn Owl *Tyto alba,* as their soft, lightly oiled feathers can quickly become waterlogged, making their silent flight extremely difficult and making their ability to hunt by hearing impossible. This inability to hunt effectively can lead to the starvation of both adult owls and chicks, ultimately impacting their ability to breed successfully [97].

Long periods of torrential rain can also lead to flooding in certain circumstances, thus causing additional problems, such as fast-rising river levels bursting their banks and flooding low-lying areas, negatively impacting the habitat of small mammal assemblages and further reducing the food availability for the owl and forcing them to find alternative prey [98]. On the other hand, regular rainfall may increase rodent activity, improving their catchability [99].

Ground nesting species, such as the Short-eared Owl, are, of course, vulnerable to extreme rainfall events, with one species in particular, the Burrowing Owl *Athene cunicularia,* being especially vulnerable. A recent study from Canada recorded that within the study area, Burrowing Owl nest and owlet survival markedly declined due to extreme precipitation and burrow flooding. As the heavy rainfall occurred late in the season, giving the owls little chance of re-nesting, the extreme precipitation resulted in a complete loss of annual reproductive output for the pairs that failed [100].

3.5. Rising sea level

Sea levels rise due to climate change. This will reduce coastal wintering habitats of Short-eared Owl as some wintering locations will be lost to the sea and saltification may affect some of the remaining habitats. This would increase competition and reduce the suitability of coastal wintering grounds, reducing owls' wintering survival and breeding condition upon return from migration [41].

3.6. Drought

Climate change intensifies droughts, making them more frequent, longer, and more severe. As average temperatures have risen because of climate change, higher temperatures dry out soils and vegetation, strain water supplies, and reduce snowpack. Historically dry areas are more likely to see reduced precipitation, and total land area subject to drought is projected to increase.

Relationship between weather and reproduction of the Western Barn Owl was studied a 13-year period in a semi-arid environment in Israel [101]. A prolonged heatwave reaching over 40ºC killed 78 Barn Owl nestlings in 2002 indicating more problems in the future as the heat waves are predicted to become more frequent due to the climate change [102].

The effect of drought on prey selection of the Eastern Barn Owl *Tyto javanica* was studied in north-eastern South Australia. Prolonged dry periods have made Barn Owls predominantly prey on Geckos and other reptiles when small mammals became less available [103]. The owl being able to switch to a primarily reptilian diet may explain why Barn Owls sometimes remain faithful to a single area, and even a single roost/breeding site, for generations.

Owls often have a particularly difficult time during periods of drought. Many owls, like the Barking Owl *Ninox connivens* in Australia, are very territorial and don't move to new locations easily. Some breeding pairs seem to stay and defend their patch at all costs; therefore, the combination of both drought and bushfires has become a 'double whammy' for this species [104].

The effects of increasing air temperature and aridity on a Burrowing Owl population has been studied from 1998-2013 in central New Mexico, US [43]. Decreased precipitation and rapid warming caused a multiyear drought, and over a period of 16 years, the owl population declined from 52 pairs to 1 pair. Nest success and productivity declined after an unexpected delay in breeding phenology, most likely causing a mismatch with food resources. Significant changes in body mass in both breeders and nestlings reflect poor breeding as well as wintering habitat quality [43]. Further studies indicated that delays are due to food limitation caused by drought. Drought during migration may also constrain energetic requirements, forcing Burrowing Owls to stop more frequently and for longer periods at stopover sites, resulting in delayed arrival on breeding grounds [44].

3.7. Winter and Snow

Northern Europe has been suffering increasingly warm and wet winters associated with long-term changes in the North Atlantic Oscillation [105]. Shifts in precipitation frequency, intensity, and quantity serve as significant indicators of climate change. There has been a decrease in the frequency alongside an increase in intensity of precipitation [106]. Insects that undergo winter dormancy in soil are directly influenced by concurrent rainfall. Essentially, heavy rainfall can cause flooding and prolonged water stagnation, posing a threat to insect survival and potentially disrupting their dormancy patterns. Also, insect eggs and larvae may be washed away due to heavy rains and flooding [106].

In the case of owl species sensitive to coldness, such as the Western Barn Owl, these can expect a positive future with fewer harsh winters due to climate change [102], where many individuals can die when snow cover remains over a long period [107]. Weather conditions prevailing in winter and during reproduction has a negative influence on breeding population and clutch size of the Western Barn Owl [99]. Interestingly, Tawny Owl breeding performance and diet were strongly associated with Western Barn Owl laying dates and breeding population and as an indicator of the effect of winter severity on Barn Owl reproduction [108].

The warming climate in Fennoscandia has induced the reduction and duration of the subnivean space, which has had a negative impact on the survival and reproductive performance of northern rodents, consequently altering their population cycles [109]. When available, the subnivean space provides thermal insulation, access to food plants, and protection from owls and raptors, and other generalist predators. Extension of the available subnivean space has been shown to increase winter survival of the Root Vole *Microtus oeconomus* [110]. Increasingly warm late winter/early spring and snow conditions are seen as a reason to observe the absence of rodent peak years since 1994. This has led to dramatic declines in northern owls, also noted in this study (Table 1) [111].

Climate change impairs owls' foraging and thus decreases local overwinter survival. The Eurasian Pygmy Owl normally hoards food (small mammals and birds) in nest-boxes for winter, but now this hoarding behaviour is highly susceptible to global warming. In several northern areas, autumns have become warmer and winters milder and wetter. This is likely to continue, ultimately decreasing the length of winter. The more days with persistent rainfall there are between mid-October and mid-December, the more likely it is that the food hoards of the owl go rotten. Especially during the poor vole years, owls are forced to use rotten food, meaning that the owl either dies or is forced to leave the area [112]. The future will show if the Pygmy Owls are able to adapt to climate change by delaying food hoarding or, more likely, they will suffer further due to the changes caused by the autumn/winter warming.

During the winter, it is normal for Great Grey Owls to move south in search of food (Figure 4). Although literature gives the impression that this is mainly a forest owl, it is by no means confined to the forest when it wanders south in winter. Lately, every winter, Great Grey Owls have entered the capital city, Helsinki, where BirdLife Finland decided to ban publishing the photos, as so many birdwatchers approached the owl, giving it no peace to feed itself [113]. Despite apparently unfavourable climate changes for boreal species, the Great Grey Owl has been expanding its range in Europe to the south and west. Especially in Sweden and Norway, the southward shift in recent decades has been almost total, coupled with drastic declines in the north of their range. For a number of years, no Great Grey Owl nests were found in Norwegian Lapland, but these days as many as 140 nests have been found annually in Hedmark county, SE Norway, below 62°N. In Sweden, most southern nests occur even below 58°N. In Europe, the most southern nests are in Ukraine and Poland around 51°N, while in North America, it breeds as far south as 37-38°N, which in Europe would take it down to Sicily [114]. It is interesting to note that during the Pleistocene Period (3 million to 10,000 years ago), the Great Grey Owl inhabited areas as far south as Bulgaria and Romania according to fossil findings [115]. Table 1 shows that between1996 and 2025 the Great Grey Owl population in Finland has increased by some 54%. It seems that the North Finland population has moved to Central Finland (C + 24.9% and N –23.0). South Finland has lost 1.9% of breeding Great Grey Owls, so no similar population movement to the south has been noted as in Norway and Sweden [67,68].

Figure 4: Great Grey Owl *Strix nebulosa* is mainly a forest owl but may move to urban areas in search of food. Photo: Esko Rajala

A recently published study in the US tracked the movement of Great Grey Owls in relation to variable snow/melt conditions. The study quantified the movement of 42 owls using global positioning system (GPS) data within the Greater Yellowstone Ecosystem, USA, during 2017–2022 and employed a novel ecological application of Snow Model, a snow evolution modeling system, to estimate fine-scale, physical snow properties likely to influence access to prey [116]. These variables included snow depth, snow crusts produced by wind, and ice crusts produced by melt-freeze and rain-on-snow events. It was found that the owls avoided heterogeneously distributed wind crusts via local shifts in habitat selection, while more homogenous ice crusts elicited long-distance movements away from affected home ranges. It was also found that the owls employed both proximate shifts in habitat selection and long-distance movements to avoid deeper snow. Ultimately, the owls exhibited behavioral flexibility in response to limiting snow conditions that can vary in terms of severity, spatial extent, and duration. Such behavioral responses determine species distribution, with implications for population and community dynamics in spatiotemporally variable systems. Understanding the effects of, and responses to, environmental controls is increasingly important given the scope of on-going global change [116].

3.8. Snow Structure

Boreal owl species, wintering in Fennoscandia, are dependent in their winter hunting not only on snow depth, but of the hardness and ice structures in the snow carpet as well [117]. Several abiotic processes can make significant changes to a snow cover, affecting owl hunting success. One important factor might be sudden melting periods or rain episodes followed by cold weather, forming crusts. Repeated cycles of freezing and thawing, named as "frost seesaw effect", create through the winter several ice layers which are buried into the snow layer by new snowfalls [118,119]. Cold wind alone often hardens the snow cover, especially in higher elevations, making wind the most significant abiotic factor imposing extreme hardness on snow covers in alpine and arctic areas of Fennoscandia [117]. How vulnerable boreal owl species are to snow hardness is not well known, but climate change definitely has changed wind regimes, increasing the frost seesaw effect [118]. This effect is expected to be more significant in the cold and continental areas, lacking more frequent fluxes from maritime influence. Mild winters at least allow the Ural Owl to breed earlier [57]. Also, the Tawny Owl benefits from increasing late winter or early spring temperatures, advancing its breeding at least as much as does high autumn abundance of voles. However, breeding too early or too late may decrease reproductive output if the timing of breeding does not meet the food peak [120].

A dramatic Western Barn Owl population decline has been projected in Switzerland under a scenario of non-linear relationships between climate change and population vital rates [71]. Adult and juvenile owl survival plummeted due to the extended snow cover duration, recorded only twice in a 58-year study period. Under the scenario of non-linear climate change, the extreme snow-rich winters can increase, reducing small mammal prey availability and owls' long-term growth rates [71].

3.9. Habitat Loss

Forest management is not directly a climate change issue, but the growth of the pulp industry has caused large-scale impacts on forest landscapes globally, causing severe habitat loss and indirect climate change affecting the forest dwelling owls [121]. The modern forestry harvesting method is intensive logging, which has made old-growth forests less and less common. Forest dwelling owls depend on large trees for breeding in natural cavities. Clear-cutting of trees also results in loss of coverage of prime habitat for main (Bank Voles *Myodes glareolus*) and alternative prey (small birds) of owls, inducing a lack of food, and refuges against predators of Tengmalm's Owls [122]. The best known old-growth forest associated species is the Northern Spotted Owl but old-growth forest species also include Great Grey, Tawny and Ural Owls [123]. Changes in the numbers of these owls can be an effect of climate change but it is accepted that this is mainly due to human activities.

Climate change habitat models forecast severe, region-wide breeding habitat losses for most montane owls in the Southwestern US by 2090 [37]. The steepest rates of habitat loss were predicted for the *Aegolius funereus* habitat distribution, which will only consist of isolated areas, perhaps too small to sustain the regional persistence of the species. The near-complete loss of current breeding habitats is also projected for known Flammulated Owl *Psiloscops flammeolus* populations in Western New Mexico. However, restoration of more open stands of ponderosa pine and mixed conifer forest through reduction of stand densities would benefit the Flammulated Owl [55].

Three more species, the Long-eared Owl, Northern Pygmy Owl, and Northern Saw-Whet Owl, were predicted to lose at least 60% of their current breeding habitats. The Whiskered Screech Owl *Megascops trichopsis* was forecasted to lose all its current habitat and would only persist in the region if it could track areas that become suitable to the north of its current range. More uncertainty exists for the Great Horned Owl and the Western Screech Owl, both with distributions that extend down to lower elevations [37].

Logging patches of forest was assumed to provide Great Grey Owl foraging areas by creating meadows, but a new study shows that relatively dry openings created by clearings and regeneration harvests are unlikely to provide preferred, long-term foraging habitat [124]. As for many other species, conserving mature forests, including riparian forests, is critical [125,126].

3.10. Climate-Related Nestbox Competition

Climate change is altering the strength of interspecific interactions as rising temperatures are encouraging nest box competition. In southern Hungary, there are sympatric breeding populations of Western Barn Owls and Tawny Owls co-occurring in the same nest box during the same breeding season [127]. The onset of Tawny Owl breeding has not changed during the study period, but that of Barn Owl advanced by two weeks in parallel with rising temperatures. Thus, the breeding season has shifted closer to the breeding season of the Tawny Owl. When using the same nest box, the breeding of Barn Owls was delayed by a month, and second clutches were practically absent. Climate change heightens competition for nest-sites between Barn and Tawny Owls [127]. As the preferred nest boxes are limited, the Barn Owl faces greater disadvantages in this competition with the heavier and more aggressive Tawny Owl; able to kill Barn Owls, at least the young ones [128]. A significant decline in reproductive success of Barn Owls happens due to the absence of second broods [127]. Barn Owls can also exert negative effects on the Tawny Owls by killing their chicks [129].

3.11. The Effect of Climate Change on Prey Species

Small mammals such as rodents and shrews predominate as food items for the majority of larger owls, and insects and other arthropods for the smaller ones. Many species supplement their diet by eating other birds, reptiles, amphibians, fish, crabs, and earthworms. Of the world's 273 owl species, 40% are mainly insectivorous, 31% are carnivorous, and 3% are piscivorous. The diet and hunting behaviour of the remaining 26% are still unknown [123].

3.11.1. Amphibians and Reptiles

Ambhibians are the most threatened vertebrates to climate change and a 4ºC global temperature increase would create a step change in impact severity, pushing 7.5% of species beyond their physiological limits [118]. This far decline of amphibians in any owl's diet has not been documented, which is not surprising given the fact that owls capture amphibians relatively infrequently; Western Barn Owl only 0.54% out of 3.32 million prey items [131].

It is certain that climate change will affect reptiles around the world due synergic effects with other abiotic and biotic conditions [132]. The well-studied Western Barn Owl ate only 0.08 per cent of reptiles out of 3.07 million prey items, and no decline of reptiles was shown in that material, yet [133].

3.11.2. Birds

Between 1990 and 2023, the index of 168 common birds in Europe decreased by 15 per cent and the decline in common farmland birds was 42% and significant decreases had already occurred before this 1990 baseline [134]. Agricultural intensification and climate change explain mostly this long-term decline, habitat alteration strengthens the negative effects of climate change. Studies over the last 150 years has shown that the Western Barn Owl consumes fewer birds nowadays than before, making it useful indicator for studying the decline of farmland birds at the scale of the continent [135]. However, suburban and urban owls often eat many more birds than their rural counterparts [136].

3.11.3. Fish

Semi-aquatic fish-eating owls use their talons to seize fish from the surface of rivers, or they hunt crabs on shores and in river shallows. Eastern Screech Owls hunting both early and late in the evening tended to hunt for crayfish in the evening (18–23h) and small mammals later at night (23–03h). In global terms, there are only nine mainly piscivorous species, 14 species have been recorded to eat occasionally fish, or crustaceans, 11 species, or both, 17 species [123]. Extreme climatic events include unpredictable rainfall patterns causing both droughts and floods, which impact fish-eating owls. Serious drought can force owls to seek new areas with water in ponds and rivers, and flooding makes it difficult for owls to locate fish in deep, muddy waters.

3.11.4. Insects

Climate change is dramatically affecting insects in a wide variety of ways all over the world. It impacts insects by altering habitats, shifting suitable climatic areas, and increasing extreme weather events like heatwaves and droughts, which can increase population mortality, species range shifts, and changes in community composition. Many species are relocating to poleward places with lower temperatures or to higher altitudes. It has been estimated that up to 49% of insects will lose more than half of their historical geographical distribution [137].

A strong decline in the consumption of invertebrates has been noted in the diet of Western Barn Owls in Europe between 1860 and 2012 [138]. The use of insecticides and habitat loss seen as possible reasons, i.e, negative impact of human activities on biodiversity if not directly the climate change.

In Norway, the number of insects has decreased by 14 per cent over the past four years, from 2020 to 2023. The weather change seems to affect them, and understandably, insects thrive in warm and not too dry summers. More surprising is that cold winters with lots of snow have a positive effect on insects. A thick snow cover insulates well, but climate change brings more dry and mild winters with less snow, and therefore has negative effects on insects in the future [139]. Early spring can cause insects to become active too early, as the return to more winter-like conditions impacts their survival badly.

3.11.5. Small Mammals

The impact of climate change on small mammals can be significant, affecting them directly as well as indirectly. Extreme weather events like droughts and heatwaves can lead to population decline. The low dispersal ability and small body size make them particularly vulnerable. Very few species are able to relocate to areas with more favourable, cooler temperatures and face challenges in highly fragmented landscapes, often resulting from human activities, to find new suitable habitats. Changes in species distribution and population dynamics lead to new inter-specific interactions, including increased competition and changes in community composition [140–142].

Many owl species are known to have high site tenacity with limited ability to migrate to new areas if their existing habitat becomes unsuitable or after their regular food supply has disappeared. Stochastic demographic modeling predicted that already visible dampening vole cycles could be driving the Northern England Tawny Owl population towards extinction [56]. Western Barn Owl diet analysis in multiple locations in Italy demonstrated a consistent increase of xerothermophilic species (living in hot and dry places) in the small mammal communities since 70s [143]. Also, in Spain, the small mammal diversity has declined with time due to climate change [144]. Such a reduction in diversity and abundance of small mammals is alarming for place faithful owl species like *Tyto alba*, among others, whose diet, breeding success, and other ecological parameters depend on small mammals' abundance [144].

There has been a significant decrease in the consumption of bats from 1860 to the present day, also, shrews and moles all insectivorous mammals, suggesting that during the last century human activities have had a continuous negative impact on invertebrate communities and on their predators such as bats, moles and shrews. The diet of Western Barn Owl has changed accordingly during the last 150 years [145,146].

Predators that feed upon declining species may decline themselves, modify their diet or move to regions where their stable prey is still abundant [135]. Nomadic and migratory owls have better chances to relocate to cooler temperatures, but unfortunately, their main prey animals, small mammals, are less able to move to new cooler areas at higher altitudes or poleward.

4. Discussion

Drastic owl population declines are usually attributed to multiple sources, such as the global climate change and habitat loss and degradation, inducing decreased food supply [147]. However, only in the case of relatively few owl species has the interactive effects of fluctuations in abundance of main foods and weather conditions on population densities and reproductive success been well studied. In the case of Tengmalm's Owl, milder and more humid spring and early summer temperatures due to global warming are not able to compensate for the lowered offspring production of owls [122]. The main reason for low productivity is probably loss and degradation of mature and old-growth forests due to modern forest management [121]. The most common harvesting method has been clear-felling, which results in loss of coverage of prime habitat for main and alternative prey (small birds) of owls, inducing a lack of food, and refuges against predators of Tengmalm's Owls [121,122].

Some birds have advanced their breeding or migration phenology, and northward density shifts have been observed in Fennoscandian species, but not so much in the case of owls. Contrary to this, the Great Grey Owl has moved rather to the south and southwest in Norway and Sweden [148,67,68]. Only the southern Eurasian Scops Owl has shown an opposite tendency to expand its distribution to the north [54].

In Finland, there are some indications that Short-eared and Tengmalm's Owls, have increased their nesting in the north. However, climate change has not yet assisted southern species, such as Eurasian Eagle, Tawny and Long-eared Owls, in moving further north in Finland. Eurasian Pygmy and Ural Owls show only minor shifts between south, central, and north. Only the Northern Hawk Owl has moved clearly towards north (Table 1). So, the response of one species to climate change can hardly be used to predict the response of another [149].

Therefore, studying survival and distribution in an apex predator, like the Great Grey owl, requires individual-based data from long-term studies and is complicated by the integration of climatic effects on prey species at lower trophic levels [64,65]. According to Mysterud, not only are field studies of raptor distribution extensions that take into account the food factor needed, but simultaneous snow-cover studies are very much needed as well. Among the most important ecological winter factors might be the frost seesaw, that is, alternating thaw and freezing cycles and related ice formations blocking hunting and decreasing the food factor [117,118].

Tawny Owl and Barn Owl studies have shown that climate change can alter natural selection in a wild population leading to a microevolutionary response. This demonstrates the ability of wild populations to evolve in response to climate change. Even if a species could be able to adapt slowly to climate change, the speed of change has been so fast that a negative impact is unavoidable. This assumption disregards the owl species' capacity to persist through plasticity or shift their distribution to other regions when confronted with novel environmental conditions. It is also possible that climate change itself could take a new direction at least in the northern hemisphere should the Gulf Stream collapse. There are signs that rotating ocean currents south of Greenland have been losing stability since the1950s. This would bring harsh, freezing cold winters back to Europe and North America, but could it bring Snowy Owls back remains to be seen [150-152].

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References

1. Dietz, T., Shwom, R. L., & Whitley, C. T. (2020). Climate change and society. *Annual Review of Sociology, 46*(1), 135-158.
2. WMO: https://wmo.int
3. Sattar, Q., Maqbool, M. E., Ehsan, R., & Akhtar, S. (2021). Review on climate change and its effect on wildlife and ecosystem. *Open J Environ Biol, 6*(1), 008-014.
4. Sieradzki, A. (2022). Designed for darkness: The unique physiology and anatomy of owls. In Owls-Clever Survivors. IntechOpen.
5. Pautasso, M. (2012). Observed impacts of climate change on terrestrial birds in Europe: an overview. *Italian Journal of Zoology, 79*(2), 296-314.
6. Vegvari, Z., Bokony, V., Barta, Z., & Kovacs, G. (2010). Life history predicts advancement of avian spring migration in response to climate change. *Global Change Biology, 16*(1), 1-11.

7. Haapala, J., Korhonen, J., & Saurola, P. (1997). Breeding and population trends ofcommon raptors and owls in Finland in 1996. Linnut-vuosikirja 1, 41-53. Finnish with English summary (hereafter F w E s.)
8. Haapala, J., Korhonen, J., & Saurola, P. (1998). Breeding and population trends ofcommon raptors and owls in Finland in 1997. Linnut-vuosikirja 2, 39-54. F w E s.
9. Taivalmäki, 3,., Haapala, J., & Saurola, P. (1999). Breeding and population trends ofcommon raptors and owls in Finland in 1998. Linnut-vuosikirja 3, 38-53. F w E s.
10. Taivalmäki, J-P., Haapala, J., & Saurola, P. (2000). Breeding and population trends ofcommon raptors and owls in Finland in 1999. Linnut-vuosikirja 4, 25-39. F w E s.
11. Taivalmäki, J-P., Haapala, J., & Saurola, P. (2001). Breeding and population trends ofcommon raptors and owls in Finland in 2000. Linnut-vuosikirja 5, 44-54. F w E s.
12. Hannula, H., Haapala, J., & Saurola, P. (2002). Breeding and population trends of common raptors and owls in Finland in 2001 –a year with rodents almost absent. Linnut-vuosikirja 6, 15-25. F w E s.
13. Björklund, H., Saurola, P. & Haapala, J. (2003). Breeding and population trends of common raptors and owls in Finland in 2002. - Linnut-vuosikirja 7, 28-40. F w E s.
14. Björklund, H. & Saurola, P. (2004). Breeding and population trends of common raptors and owls in Finland in 2003 – a good vole year in Western Finland. Linnut-vuosikirja 8, 58-72. F w E s.
15. Honkala, J., Björklund, H. & Saurola, P. (2005). Breeding and population trends of common raptors and owls in Finland in 2004. Linnut-vuosikirja 9, 44-56. F w E s.
16. Honkala, J. & Saurola, P. (2006). Breeding and population trends of common raptors and owls in Finland in 2005. Linnut- vuosikirja 10, 9-22. F w E s.
17. Honkala, J. & Saurola, P. (2007). Breeding and population trends of common raptors and owls in Finland in 2006. Linnut-vuosikirja 11, 55-67. F w E s.
18. Honkala, J. & Saurola, P. (2008). Breeding and population trends of common raptors and owls in Finland in 2007. Linnut-vuosikirja 12, 36-51. F w E s.
19. Björklund, H., Honkala, J. & Saurola, P. (2009). Breeding and population trends of common raptors and owls in Finland in 2008. Linnut-vuosikirja 13, 52-67. F w E s.
20. Honkala, J., Björklund, H. & Saurola, P. (2010). Breeding and population trends of common raptors and owls in Finland in 2009. Linnut-vuosikirja 14, 78-89. F w E s.
21. Honkala, J., Saurola, P. & Valkama, J. (2011). Breeding and population trends of common raptors and owls in Finland in 2010. Linnut-vuosikirja 15, 52-63. F w E s.
22. Honkala, J., Saurola, P. & Valkama, J. (2012). Breeding and population trends of common raptors and owls in Finland in 2011. Linnut-vuosikirja 16, 58-69. F w E s. (2008).
23. Honkala, J., Saurola, P. & Valkama, J. (2013). Breeding and population trends of common raptors and owls in Finland in 2012. Linnut-vuosikirja 17, 50-61. F w E s.
24. Honkala, J.,Valkama, J. & Saurola, P. (2014). Breeding and population trends of common raptors and owls in Finland in 2013. Linnut-vuosikirja 18, 55-65. F w E s.
25. Björklund, H., Honkala, J., Saurola, P. & Valkama, J. (2015). Breeding and population trends of common raptors and owls in Finland in 2014. Linnut-vuosikirja 19, 42-57. F w E s.
26. Björklund, H., Saurola, P. & Valkama, J. (2016). Breeding and population trends of common raptors and owls in Finland in 2015. Linnut-vuosikirja 20, 40-53. F w E s.
27. Meller, K., Björklund, H., Saurola, P. & Valkama, J. (2017). Breeding and population trends of common raptors and owls in Finland in 2016. Linnut-vuosikirja 21, 16-31. F w E s.
28. Björklund, H., Saurola, P. & Valkama, J. (2018). Breeding and population trends of common raptors and owls in Finland in 2017. Linnut-vuosikirja 22, 56-69. F w E s.
29. Meller, K., Björklund, H., Saurola, P. & Valkama, J. (2019). Breeding and population trends of common raptors and owls in Finland in 2018. Linnut-vuosikirja 23, 80-95. F w E s.
30. Björklund, H., Saurola, P. & Valkama, J. (2020). Breeding and population trends of common raptors and owls in Finland in 2019. Linnut-vuosikirja 24, 44-59. F w E s.
31. Honkala, J., Piha, M., Saurola, P. & Valkama, J. (2021). Breeding and population trends of common raptors and owls in Finland in 2020. Linnut-vuosikirja 25, 70-85. F w E s.
32. Honkala, J., Lehikoinen, P., Saurola, P. & Valkama, J. (2022). Breeding and population trends of common raptors and owls in Finland in 2021. Linnut-vuosikirja 26, 62-77. F w E s.
33. Honkala, J., Lehikoinen, P., Saurola, P. & Valkama, J. (2023). Breeding and population trends of common raptors and owls in Finland in 2022. Linnut-vuosikirja 27, 70-83. F w E s.
34. Honkala, J., Lehikoinen, P., Saurola, P. & Valkama, J. (2024). Breeding and population trends of common raptors and owls in Finland in 2023. Linnut-vuosikirja 28, 66-77. F w E s.
35. Honkala, J., Lehikoinen, P., Saurola, P. & Valkama, J. (2025). Breeding and population trends of common raptors and owls in Finland in 2024. Linnut-vuosikirja 29, 64-79. F w E s.
36. Virkkala, R., Heikkinen, R. K., Leikola, N., & Luoto, M. (2008). Projected large-scale range reductions of northern-boreal land bird species due to climate change. *Biological Conservation, 141*(5), 1343-1353.
37. Cartron, J. L. E., Triepke, F. J., Stahlecker, D. W., Arsenault, D. P., Ganey, J. L., Hathcock, C. D., ... & Calhoun, K. C. (2023). Climate change habitat model forecasts for eight owl species in the southwestern US. Animals, 13(24), 3770.
38. Kopij, G. (2011). Population and range expansion of forest boreal owls (Glaucidium passerinum, Aegolius funereus, Strix uralensis, Strix nebulosa) in East-Central Europe. *Vogelwelt, 132*(4), 207-214.
39. Kasprzyk, K. A., & Frątczak, W. (2025). Diet of solitary males Boreal Owls Aegolius funereus in the lowlands of the Bydgoszcz Forest (northern Poland). *Ecological Questions, 36*(2), 1-15.
40. Booms, T. L., Holroyd, G. L., Gahbauer, M. A., Trefry, H. E., Wiggins, D. A., Holt, D. W., ... & Swengel, S. (2014).

Assessing the status and conservation priorities of the short-eared owl in North America. *The Journal of Wildlife Management, 78*(5), 772-778.
41. Peak District National Park Authority (2025). Feature Assessment: Wildlife/Short-eared Owl. Reports.peakdistrict.gov.uk/cova/docs/assessment/wildlife/owl.html Accessed 18.09.2025.
42. Penagos-López, A.P. & Esquivel Melo (2025). Impact of climate change on Andean owls in Colombia. Ornitologia Colombiana 27(i):49.
43. Cruz-McDonnell, K. (2015). Negative effects of rapid warming and drought on reproductive dynamics and population size of an avian predator in the arid southwest. The University of New Mexico, Albuquerque.
44. Porro, C. M., Desmond, M. J., Savidge, J. A., Abadi, F., Cruz-McDonnell, K. K., Davis, J. L., ... & Rodríguez, N. H. (2020). Burrowing Owl (Athene cunicularia) nest phenology influenced by drought on nonbreeding grounds. The Auk, 137(2), ukaa008.
45. Ahumada, S. C., Suárez, L. C., & Rivera, R. (2023). Could an event of extreme drought (2019-2020) affect the feeding ecology of Bubo magellanicus (Gmelin 1788)(Strigiformes: Strigidae) in a Mediterranean region of Chile?. PeerJ, 11, e15020.
46. Lehtiniemi, T. (2025). The occurrence of some threatened and fairly rare bird species in Finland in 2024. Linnut vuosikirja 29, 80-89. F w E s.
47. McCabe, R. A., Aarvak, T., Aebischer, A., Bates, K., Bety, J., Bollache, L., ... & Therrien, J. F. (2024). Status assessment and conservation priorities for a circumpolar raptor: the Snowy Owl Bubo scandiacus. Bird Conservation International, 34, e41.
48. Domine, F., Gauthier, G., Vionnet, V., Fauteux, D., Dumont, M., & Barrere, M. (2018). Snow physical properties may be a significant determinant of lemming population dynamics in the high Arctic. Arctic Science, 4(4), 813-826.
49. Lamarre, V., Legagneux, P., Franke, A., Casajus, N., Currie,D. C., Berteaux, D., & Bêty, J. (2018). Precipitation and ectoparatism reduce reproductive success in an arctic-nesting top predator. *Scientific Reports, 8*(1), 8530
50. Solheim, R., Jacobsen, K. O., Øien, I. J., Aarvak, T., & Polojärvi, P. (2013). Snowy Owl nest failures caused by blackfly attacks on incubating females. Ornis Norvegica, 36, 1-5.
51. Penagos-López, A.P., Jiménez García, D. & Carlos, C.J. (2025). Protected areas as key to identifying and prioritizing climate refugia for the conservation of endemic Atlantic Forest owls. Ornitologia Colombiana 27(i): 53.
52. Masoero, G. (2020). Food hoarding of an avian predator under food limitation and climate change. University of Turku.
53. Class, B., Masoero, G., Terraube, J., & Korpimäki, E. (2021). Estimating the long-term repeatability of food-hoarding behaviours in an avian predator. *Biology Letters, 17*(7), 20210286.
54. Martin, J.R. & Mikkola, H. (2019). Distribution trends of the Scops Owl in Britain and northern Europe. Scottish Birds 39(2): 168-172.
55. McKelvey, K. S., & Buotte, P. C. (2017). Effects of climate change on wildlife in the Northern Rockies. In *Climate change and Rocky Mountain ecosystems* (pp. 143-167). Cham: Springer International Publishing.
56. Millon, A., Petty, S. J., Little, B., Gimenez, O., Cornulier, T., & Lambin, X. (2014). Dampening prey cycle overrides the impact of climate change on predator population dynamics: A long-term demographic study on tawny owls. *Global change biology, 20*(6), 1770-1781.
57. Lehikoinen, A., Ranta, E., Pietiäinen, H., Byholm, P., Saurola, P., Valkama, J., ... & Korpimäki, E. (2011). The impact of climate and cyclic food abundance on the timing of breeding and brood size in four boreal owl species. *Oecologia, 165*(2), 349-355.
58. Comay, O., Ezov, E., Yom-Tov, Y., & Dayan, T. (2022). In its southern edge of distribution, the tawny owl (Strix aluco) is more sensitive to extreme temperatures than to rural development. *Animals, 12*(5), 641.
59. Peery, M. Z., Gutiérrez, R. J., Kirby, R., LeDee, O. E., & LaHaye, W. (2012). Climate change and spotted owls: potentially contrasting responses in the S outhwestern U nited S tates. *Global Change Biology, 18*(3), 865-880.
60. Berg, T., Solheim, R., Wernberg, T. & Østby, E. (2011). Lappuglene kom! [Great Grey Owls come!]. Vår Fuglefauna 34(3): 108–115. (in Norwegian)
61. Keller, M., Chodkiewicz, T., & Woźniak, B. (2011). Great Grey Owl Strix nebulosa–a new breeding species in Poland. Ornis Pol, 52, 150-158. (In Polish, English summary)
62. Ławicki, Ł., Abramčuk, A. V., Domashevsky, S. V., Paal, U., Solheim, R., Chodkiewicz, T., & Woźniak, B. (2013). Range extension of Great Grey owl in Europe. Dutch Birding, 35, 145-154.
63. Mikkola, H. (2010). Most Southern Great Grey Owl. Tyto; The International Owl Society XIII (4):8–9.
64. Mikkola, H. (2014a). Global Warming and Great Grey Owls. Tyto, The International Owl Society March 2014: 7-8.
65. Mikkola, V. H. Der Einfluss der Erderwärmung auf die Ausbreitung von Bartkäuzen. Kauzbrief 26, 22-23 (in German)
66. Mirski, P., Ivanov, A., Kitel, D., & Tumiel, T. (2021). The ranging behaviour of the Great Grey Owl *Strix nebulosa*: A pilot study using GPS tracking on a nocturnal species. Bird Study, 68(1), 129-134.
67. Solheim, R. (2009). Lappugla–en klimaflyktning på vei sydover? Vår Fuglefauna, 32(4), 164-169. (in Norwegian).
68. Solheim, R. (2014). Lappugglan på frammarsch. Vår Fågelvärld, 73(6), 46-50. (in Swedish).
69. Vermouzek, Z., Krenek,D., Czerneková, B. (2005): Increase in numbers of Ural Owls (*Strix uralensis*) in the Beskydy Mts. (NE Czech Republic). Sylvia 40: 151-155.
70. Šotnár, K. (2005): Nesting, diet and expansion of the Ural Owl (*Strix uralensis*) in the area of Horné Ponitrie (Central

Slovakia). Buteo 14: 67–68.
71. Jenouvrier, S. (2013). Impacts of climate change on avian populations. Global Change Biology, 19(7), 2036-2057.
72. Gilg, O., Kovacs, K. M., Aars, J., Fort, J., Gauthier, G., Grémillet, D., ... & Bollache, L. (2012). Climate change and the ecology and evolution of Arctic vertebrates. *Annals of the New York Academy of Sciences, 1249*(1), 166-190.
73. Solheim, R., Jacobsen, K. O., & Øien, I. J. (2008). Snøuglenes vandringer. Ett år, tre ugler og ny kunnskap. Vår Fuglefauna, 31(3), 102-109. (In Norwegian)
74. Mikkola, H. (2022a). Gufo delle nevi *Bubo scandiacus*. Pp. 192-203, 391. In: Cauli, F., Galeotti, P. & Genero, F. (Eds.) Rapaci d'Italia e d'Europa. Edizioni Belvedere, Latina. (in Italian)
75. Morozov, V. V., Rosenfeld, S. B., Rogova, N. V., Golovnyuk, V. V., Kirtaev, G. V., & Kharitonov, S. P. (2020). What is the number of snowy owls in the Russian Arctic? Ornithologia 44, 18-25. Russian, English summary.
76. Gasparini, J., Bize, P., Piault, R., Wakamatsu, K., Blount, J. D., Ducrest, A. L., & Roulin, A. (2009). Strength and cost of an induced immune response are associated with a heritable melanin-based colour trait in female tawny owls. *Journal of Animal Ecology, 78*, 608-616.
77. Gehlbach, F. R. (2012). Eastern screech-owl responses to suburban sprawl, warmer climate, and additional avian food in Central Texas. *The Wilson Journal of Ornithology, 124*(3), 630-633.
78. Galeotti, P., Rubolini, D., Sacchi, R., & Fasola, M. (2009). Global changes and animal phenotypic responses: melanin-based plumage redness of scops owls increased with temperature and rainfall during the last century. *Biology Letters, 5*(4), 532-534.
79. Koskenpato, K., Ahola, K., Karstinen, T., & Karell, P. (2016). Is the denser contour feather structure in pale grey than in pheomelanic brown tawny owls Strix aluco an adaptation to cold environments? *Journal of Avian Biology, 47*(1), 1-6.
80. Karell, P., Brommer, J. E., Ahola, K., & Karstinen, T. (2013). Brown tawny owls moult more flight feathers than grey ones. *Journal of Avian Biology, 44*(3), 235-244.
81. Mikkola, H., & Lamminmäki, J. (2014). Moult, ageing and sexing of Finnich owls. Saarijärvi, Finland: Suomenselän Lintutieteellinen Yhdistys. F w E s.
82. Karell, P., Bensch, S., Ahola, K., & Asghar, M. (2017). Pale and dark morphs of tawny owls show different patterns of telomere dynamics in relation to disease status. *Proceedings of the Royal Society B: Biological Sciences, 284*(1859), 20171127.
83. Karell, P., Ahola, K., Karstinen, T., Valkama, J., & Brommer, J. E. (2011). Climate change drives microevolution in a wild bird. *Nature communications, 2*(1), 208.
84. Brommer, J. E., Ahola, K., & Karstinen, T. (2005). The colour of fitness: plumage coloration and lifetime reproductive success in the tawny owl. *Proceedings of the Royal Society B: Biological Sciences, 272*(1566), 935-940.
85. Koskenpato, K., Lehikoinen, A., Lindstedt, C., & Karell, P. (2020). Gray plumage color is more cryptic than brown in snowy landscapes in a resident color polymorphic bird. *Ecology and Evolution, 10*(4), 1751-1761.
86. Roulin, A. (2014). Melanin-based colour polymorphism responding to climate change. *Global Change Biology, 20*(11), 3344-3350.
87. Roulin, A., Riols, C., Dijkstra, C., & Ducrest, A. L. (2001). Female plumage spottiness signals parasite resistance in the barn owl (*Tyto alba*). Behavioral Ecology, 12(1), 103-110.
88. Romano, A., Florent, G., Novelli, A., Séchaud, R., & Roulin, (2024). Spatio-temporal shift in body size and plumage coloration is associated with the magnitude of climate change in a cosmopolitan owl. *Journal of Biogeography, 51*(10), 1921-1932.
89. Dreiss, A. N., Séchaud, R., Béziers, P., Villain, N., Genoud, M., Almasi, B., ... & Roulin, A. (2016). Social huddling and physiological thermoregulation are related to melanism in the nocturnal barn owl. Oecologia, 180(2), 371-381.
90. Cumer, T., Machado, A. P., Siverio, F., Cherkaoui, S. I., Roque, I., Lourenço, R., ... & Goudet, J. (2022). Genomic basis of insularity and ecological divergence in barn owls (*Tyto alba*) of the Canary Islands. *Heredity, 129*(5), 281-294.
91. Potapov, P., Tyukavina, A., Turubanova, S., Hansen, M. C., Giglio, L., Hernandez-Serna, A., ... & Stolle, F. (2025). Unprecedentedly high global forest disturbance due to fire in 2023 and 2024. Proceedings of the National Academy of Sciences, 122(30), e2505418122.
92. McGinn, K., Zuckerberg, B., Jones, G. M., Wood, C. M., Kahl, S., Kelly, K. G., ... & Peery, M. Z. (2025). Frequent, heterogenous fire supports a forest owl assemblage. *Ecological Applications, 35*(1), e3080.
93. Lesmeister, D. B., Davis, R. J., Sovern, S. G., & Yang, Z. (2021). Northern spotted owl nesting forests as fire refugia: A 30-year synthesis of large wildfires. Fire Ecology, 17(1), 1-18.
94. Duchac, L. S., Lesmeister, D. B., Dugger, K. M., & Davis, R. J. (2021). Differential landscape use by forest owls two years after a mixed-severity wildfire. *Ecosphere, 12*(10), e03770.
95. Siegel, R. B., Eyes, S. A., Tingley, M. W., Wu, J. X., Stock, S. L., Medley, J. R., ... & Rich, A. C. (2019). Short-term resilience of Great Gray Owls to a megafire in California, USA. The Condor: Ornithological Applications, 121(1), duy019.
96. metoffice.gov.uk
97. Barn Owl Trust: www.barnowltrust.org.uk/
98. Avotins, A., Avotins Sr, A., Ķerus, V., & Aunins, A. (2023). Numerical response of owls to the dampening of small mammal population cycles in Latvia. *Life, 13*(2), 572.
99. Chausson, A., Henry, I., Almasi, B., & Roulin, A. (2014). Barn Owl (*Tyto alba*) breeding biology in relation to breeding season climate. *Journal of Ornithology, 155*(1), 273-281.
100. Fisher, R. J., Wellicome, T. I., Bayne, E. M., Poulin, R. G., Todd, L. D., & Ford, A. T. (2015). Extreme precipitation reduces reproductive output of an endangered raptor. *Journal of Applied Ecology, 52*(6), 1500-1508.

101. Charter, M., Izhaki, I., Meyrom, K., Aviel, S., Leshem, Y., & Roulin, A. (2017). The relationship between weather and reproduction of the barn owl *Tyto alba* in a semi-arid agricultural landscape in Israel. *Avian Biology Research, 10*(4), 253-258.
102. Easterling, D. R., Meehl, G. A., Parmesan, C., Changnon, S. A., Karl, T. R., & Mearns, L. O. (2000). Climate extremes: observations, modeling, and impacts. Science, 289(5487), 2068-2074.
103. McDowell, M. C., & Medlin, G. C. (2009). The effects of drought on prey selection of the barn owl (*Tyto alba*) in the Strzelecki Regional Reserve, north-eastern South Australia. Australian Mammalogy, 31(1), 47-55.
104. Beemster, M. (2004). Drought and fires threaten the Barking Owls. https://science-health.csu.edu.au/herbarium/woodland-web/barking-owl Accessed18.09.2025.
105. Stenseth, N. C., Mysterud, A., Ottersen, G., Hurrell, J. W., Chan, K. S., & Lima, M. (2002). Ecological effects of climate fluctuations. *Science, 297*(5585), 1292-1296.
106. John, A., Riat, A. K., Bhat, K. A., Ganie, S. A., Nugroho, C., Handoko, H., & Wani, A. K. (2024). Adapting to climate extremes: Implications for insect populations and sustainable solutions. *Journal for nature conservation, 79*, 126602.
107. Altwegg, R., Roulin, A., Kestenholz, M., & Jenni, L. (2006). Demographic effects of extreme winter weather in the barn owl. Oecologia, 149(1), 44-51.
108. Chausson, A., Henry, I., Ducret, B., Almasi, B., & Roulin, A. (2014). Tawny *Owl Strix aluco* as an indicator of Barn Owl *Tyto alba* breeding biology and the effect of winter severity on Barn Owl reproduction. *Ibis, 156*(2), 433-441.
109. Kausrud, K. L., Mysterud, A., Steen, H., Vik, J. O., Østbye, E., Cazelles, B., ... & Stenseth, N. C. (2008). Linking climate change to lemming cycles. *Nature, 456*(7218), 93-97.
110. Korslund, L., & Steen, H. (2006). Small rodent winter survival: snow conditions limit access to food resources. *Journal of Animal ecology, 75,* 156-166.
111. Ims, R. A., Henden, J. A., & Killengreen, S. T. (2008). Collapsing population cycles. Trends of Ecological Evolution, 23, 79-86.
112. Armarego-Marriott, T. (2020). Owls' hoards rot. Nature Climate Change, 10(9), 802-802.
113. Marttinen, V. (2024). Lapinpöllö lensi Helsinkiin ja someraivo räjähti liekkeihin – lintujärjestö joutui kieltämään pöllökuvien julkaisemisen. https:yle.fi/a/74-20078977?utm_medium=social&utm_source=ema… Accessed 14.03.2024. (in Finnish)
114. Mikkola, H. (2022b). Allocco di Lapponia *Strix nebulosa*. Pp. 240-251, 395-396. In: Cauli, F., Galeotti, P. & Genero, F. (Eds.) Rapaci d'Italia e d'Europa. Edizione Belvedere, Latina. (in Italian).
115. Boev, Z., & Mikkola, H. (2022, May). First Pleistocene record of Great Grey Owl (Strix nebulosa Forster, 1772) in Bulgaria. In *Proceedings of the Bulgarian Academy of Sciences, 75*(5), 680-685.
116. Gura, K. B., Liston, G. E., Reinking, A. K., Bedrosian, B., Elder, K., & Chalfoun, A. D. (2025). Heterogeneity of Locked-Pasture Snow Conditions Modulate Habitat and Movement Choices of a Facultative Migrant. *Ecology and Evolution, 15*(2), e70925.
117. Mysterud, I. (2016). Range extensions of some boreal owl species: comments on snow cover, ice crusts, and climate change. *Arctic, Antarctic, and Alpine Research, 48*(1), 213-219.
118. Solonen, T. (2006). Overwinter population change of small mammals in southern Finland. *Annales Zoologici Fennici 43*, 295-302).
119. Marsh, P., & Woo, M. K. (1984). Wetting front advance and freezing of meltwater within a snow cover: 1. Observations in the Canadian Arctic. *Water Resources Research, 20*(12), 1853-1864.
120. Visser, M. E., Both, C., & Lambrechts, M. M. (2004). Global climate change leads to mistimed avian reproduction. *Advances in ecological research, 35*, 89-110.
121. Korpimäki, E., & Hakkarainen, H. (2012). The boreal owl: ecology, behaviour, and conservation of a forest-dwelling predator. Cambridge University Press.
122. Kouba, M., Bartoš, L., Bartošová, J., Hongisto, K., & Korpimäki, E. (2020). Interactive influences of fluctuations of main food resources and climate change on long-term population decline of Tengmalm's owls in the boreal forest. *Scientific Reports, 10*(1), 20429.
123. Mikkola, H. (2026). Owls of the World. A Photographic Guide. 3rd Revised Edition. Bloomsbury/Christopher Helm, London.
124. Gura, K. B., Bedrosian, B., Patla, S., & Chalfoun, A. D. (2025). Variation in habitat selection by male *Strix nebulosa* (Great Gray Owls) across the diel cycle. Ornithology, 142(2).
125. Bateman, B. L., Wilsey, C., Taylor, L., Wu, J., LeBaron, G. S., & Langham, G. (2020). North American birds require mitigation and adaptation to reduce vulnerability to climate change. *Conservation Science and Practice, 2*(8), e242.
126. Bateman, B. L., Taylor, L., Wilsey, C., Wu, J., LeBaron, G. S., & Langham, G. (2020). Risk to North American birds from climate change-related threats. *Conservation Science and Practice, 2*(8), e243.
127. Schneider, Z., Mátics, E., Hoffmann, G., Laczi, M., Herczeg, G., & Mátics, R. (2025). The potential for climate change to intensify nest-site competition between two sympatric owl species. Ibis. Ibi.13455.
128. Mikkola, H. (1983). Owls of Europe. 397 p. A.D. & T. Poyser, Calton.
129. Matics, R., Bank, L., Varga, S., Klein, A., & Hoffmann, G. (2008). Interspecific offspring killing in owls. *Biological Journal of the Linnean Society, 95*(3), 488-494.
130. Pottier, P., Kearney, M. R., Wu, N. C., Gunderson, A. R., Rej, J. E., Rivera-Villanueva, A. N., ... & Nakagawa, S. (2025). Vulnerability of amphibians to global warming. *Nature 639,* 954-961.

131. Roulin, A., & Dubey, S. (2013). Amphibians in the diet of European Barn Owls. *Bird Study, 60*(2), 264-269.
132. López-Alcaide, S., & Macip-Ríos, R. (2011). Effects of climate change in amphibians and reptiles. Biodiversity loss in a changing planet, 163-184. InTechOpen, Rijeka.
133. Roulin, A., & Dubey, S. (2012). The occurrence of reptiles in barn owl diet in Europe. Bird Study, 59(4), 504-508.
134. European Environment Agency (2025). Common bird index in Europe. https://www.eea.europa.eu/en/analysis/indicators/common-bird-ind… Accessed 10.11.2025
135. Roulin, A. (2015). Spatial variation in the decline of European birds as shown by the Barn Owl *Tyto alba* diet. Bird Study, 62(2), 271-275.
136. Mikkola, H. & Sieradzki, A. (2025). Adaptation of Owls to Urban Life: A Review of Owls' Dietary and Behavioural Responses to Worldwide Anthropogenic Challenges and Environmental Change. Research Perspective on Biological Science, 9(3), 32-78.
137. Wudu, K., Abegaz, A., Ayele, L., & Ybabe, M. (2023). The impacts of climate change on biodiversity loss and its remedial measures using nature based conservation approach: a global perspective. *Biodiversity and Conservation, 32*(12), 3681-3701.
138. Roulin, A. (2016). Strong decline in the consumption of invertebrates by Barn Owls from 1860 to 2012 in Europe. *Bird Study, 63*(1), 146-147.
139. Setsaas, T.H. (2024). Insects prefer cold winters with lots of snow. https://partner.sciencenorway.no/climate-change-insects-natural-sci… Accessed 23.9.2025
140. Hansson, L., & Henttonen, H. (1988). Rodent dynamics as community processes. *Trends in Ecology & Evolution, 3*(8), 195-200.
141. Previtali, M. A., Lima, M., Meserve, P. L., Kelt, D. A., & Gutiérrez, J. R. (2009). Population dynamics of two sympatric rodents in a variable environment: rainfall, resource availability, and predation. *Ecology, 90*(7), 1996-2006.
142. Krebs, C. J., Boonstra, R., Gilbert, B. S., Kenney, A. J., & Boutin, S. (2019). Impact of climate change on the small mammal community of the Yukon boreal forest. *Integrative Zoology, 14*(6), 528-541.
143. Szpunar, G., Aloise, G., Mazzotti, S., Nieder, L., & Cristaldi, M. (2008). Effects of global climate change on terrestrial small mammal communities in Italy. *Fresenius Environmental Bulletin, 17*(9b), 1526-1533.
144. Santoro, S., Sanchez-Suarez, C., Rouco, C., Palomo, L. J., Fernández, M. C., Kufner, M. B., & Moreno, S. (2017). Long-term data from a small mammal community reveal loss of diversity and potential effects of local climate change. *Current Zoology, 63*(5), 515-523.
145. Roulin, A., & Christe, P. (2013). Geographic and temporal variation in the consumption of bats by European Barn Owls. *Bird Study, 60*(4), 561-569.
146. Roulin, A. (2016). Shrews and moles are less often captured by European Barn Owls *Tyto alba* nowadays than 150 years ago. Bird Study, 63(4), 559-563.
147. Sharikov, A. V., Volkov, S. V., Sviridova, T. V., & Buslakov, V. V. (2019). Cumulative effect of trophic and weather–climatic factors on the population dynamics of the vole-eating birds of prey in their breeding habitats. Biology Bulletin, 46(9), 1097-1107.
148. Lehikoinen, A., & Virkkala, R. (2016). North by north-west: Climate change and directions of density shifts in birds. Global Change Biology, 22(3), 1121-1129.
149. Bretagnolle, V., & Gillis, H. (2010). Predator–prey interactions and climate change.In Effects of climate change on birds, 227-248. Oxford University Press.
150. Chadwick, J. (2025). Key North Atlantic current is on the brink of collapsing – plunging Europe into the Ice Age, scientists warn. https://www.dailymail.co.uk/sciencetech/article-15165637/Key-No… Accessed 6.10.1605.
151. Arellano Nava, B., Halloran, P. R., Boulton, C. A., & Lenton, T. M. (2024, April). Clams reveal the North Atlantic subpolar gyre has destabilised over recent decades. In EGU General Assembly Conference Abstracts (p. 20891).
152. Arellano-Nava, B., Lenton, T. M., Boulton, C. A., Holmes, S., Scourse, J., Butler, P. G., ... & Halloran, P. R. (2025). Recent and early 20th century destabilization of the subpolar North Atlantic recorded in bivalves. Science Advances, 11(40), eadw3468.