Surviving urbanisation and agricultural intensification: A review of the threats for farmland and urban birds in human-modified landscapes in the Netherlands

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ABSTRACT

(1) Birds hold a key place in the functioning of ecosystems worldwide; they play vital roles in controlling pests, act as plant pollinators, spread seeds, contribute to nutrient cycling and soil formation, and provide important opportunities for people to connect with nature. Unfortunately, increasing urbanization, agricultural intensification and industrialization by the ever-expanding human population is now taking a heavy toll on bird populations. Dwindling bird numbers and varieties can negatively impact human health, economy and food production, so conserving the avian community is of key importance. Understanding how birds are impacted by human-induced rapid environment changes (HIREC) can help policymakers, urban planners and farmers to better protect birds to maintain the beneficial ecosystem services they provide.

(2) In this literature thesis, we provided an in-depth overview of the current knowledge regarding the ways in which urbanisation and agricultural intensification can impact the breeding success and adult survival of avian wildlife inhabiting human-modified habitats, focussing on the case example of the Netherlands; the most densely populated country in the European Union and the second-largest agricultural exporter in the world.

(3) We found that human impacts, such as land-use change (drainage, ploughing, intensive mechanical grass cutting, reseeding with grass monocultures), the use of chemical pesticides and fertilizers, the introduction of invasive plant and predator species, plastic pollution, and the increase in man-made structures can have clear negative effects on a birds' reproductive success and survival through many different direct and indirect processes that are intertwined. Taken together, these effects are a prime suspect as to why more and more Dutch breeding birds are classified on the IUCN red list of threatened species.

(4) After a series of unsuccessful conservation measures, the Dutch government recently adopted the 'grutto aanvalsplan' [godwit battle plan] which aims at restoring biodiversity in the agricultural environment by transitioning to a nature-inclusive approach. Hopefully other countries can learn from the mistakes that the Netherlands made, which are outlined in this essay, and also the solutions it is now trying out by governing the transformation towards 'nature-inclusive' agriculture early on.

Key-words: conservation biology, agricultural intensification, urbanisation, the Netherlands, HIREC, environmental pollution, predation, habitat fragmentation, insect decline, farmland birds, urban birds

CONTENTS

1. INTRODUCTION 3

2. HOW DO URBANISATION AND AGRICULTURAL INTENSIFICATION AFFECT BIRD BREEDING SUCCESS AND SURVIVAL?.. 5

I. The loss of suitable nest sites in the agricultural and urban environment 5

a. Homogenisation of farmland.. 5

b. Low-diversity of vegetation layers in urban environments 5

c. Building modernisation.. 6

II. The mechanisation of grass cutting and advancement of mowing 6

a. Nest destruction by mowing machinery 6

b. Direct adult mortality and skewed sex-ratios 7

III. The decline in food availability and accessibility 7

a. Food declines for farmland birds.. 7

b. Food declines for urban birds... 8

IV. The pollution of habitats.. 8

a. Pesticides 8

b. Plastic waste 9

c. Artificial light at night 9

d. Noise pollution 10

V. The impact of man-made structures 10

a. Lethal collision events 10

b. Lower predator visibility... 11

VI. The fragmentation of suitable habitat 12

a. Limited food resources... 12

b. Increased predation risks 12

VII. Changes in the mammalian predator community 13

a. Native predatory species... 13

b. Invasive predatory species 14

3. THE WAY FORWARD.. 15

4. BIBLIOGRAPHY.. 17

1. INTRODUCTION

For millions of years birds were thriving, they survived an asteroid strike, multiple ice ages and numerous natural disasters. But increasing urbanization, agricultural intensification and industrialization by the ever-expanding human population is now taking a heavy toll over a, in geological terms, very short time. The question is whether bird species can adapt to such human-induced rapid environment changes (HIREC) and what measures can be taken to preserve biodiversity? A key case example of a country undergoing major landscape and ecological changes is the Netherlands. Especially since the second world war, as the Netherlands has industrialized and the Dutch population increased from 9.4 to more than 17.4 million people, the landscapes have changed drastically (Herzog et al. 2006, CBS Statline 2021). Across the whole country, vast areas of native vegetation have been cleared to be replaced by cities, farms and infrastructure. Large continuous habitats became divided into many small fragments isolated from each other by pavement, buildings, cropland, waterbodies or pasture. The expansion of cities and infrastructures resulted in a 30% decrease in grassland from 1.32 million ha in 1950 to 0.93 million ha in 2013 (Roodbergen and Teunissen, 2014). Moreover, there has been an eightfold increase in the proportion of non-permanent grassland since 1950 (Roodbergen and Teunissen, 2014). Agricultural practices have also experienced a major revolution: livestock densities increased, grass is mowed earlier and more frequently, groundwater levels are lowered and soils are injected with chemical fertilisers and sprayed with pesticides to increase the productivity of cultivated crops (Herzog et al., 2006; Silva-Monteiro et al., 2021). Nowadays, the Netherlands has become the second-largest agriculture exporter in the world (Jukema et al., 2020). Taken together, these human activities are putting the survival of birds depending on these habitats at risk.

In the early 1960s, when the intensity of farmers' activities was still low in the Netherlands and urban areas just started to expand, many birds were surprisingly successful in adapting to the anthropogenic landscape changes and some population numbers increased as a cause of it. Hole-nesting species such as the house sparrow *(Passer domesticus)* and common starling *(Sturnus vulgaris)* started occupying novel nest sites in eaves of houses and the widespread availability of nest sites on roofs resulted in dramatic population increases of urban gulls (Soldatini et al., 2008; Mainwaring, 2015). In agricultural landscapes, farmers started removing bushes and trees and they put cattle on the land for grazing. The resulting openness of landscapes and shorter pasture turned out to be beneficial for ground-nesting species and over the first half of the twentieth-century population sizes of many meadow birds increased (Silva-Monteiro et al., 2021). But as the years went by, the Dutch landscape became more and more urbanized and agricultural practices intensified to such an extent that birds could no longer keep up with the rapid changes (Van Der Vliet et al., 2010). To date, eleven out of twenty breeding bird species typically found in Dutch urban environments are declining. The crested lark (*Galerida cristata)* and European serin *(Serinus serinus)* are particularly at risk as they are placed on the 'IUCN red list of threatened species' under respectively 'critically endangered' and 'endangered' (IUCN, 2016). Farmland birds are doing even worse; 21 out of the 27 representative Dutch farmland species are showing significant population declines (CBS statline, 2021b). Among them, the black-tailed godwit (*Limosa l. limosa),* grey partridge (*Perdix perdix)* and the Eurasian tree sparrow (*Passer montanus)* are showing the most substantial population decreases (CBS statline, 2021b). Since the year 2000, the overall meadow bird population in the Netherlands declined by a third making it one of the steepest declines on the whole European continent (Silva-Monteiro et al., 2021).

The sharp population declines, in increasingly urbanized and agriculturally intensified areas such as the case example here of the Netherlands, are alarming as birds play an essential role in the functioning of all ecosystems in the world and they have a direct impact on our health, economy and food production (Sekercioglu, 2006; Whelan et al., 2008). Birds can provide regulating services such as the dispersal of seeds and the pollination of plants, and insectivorous birds can play a key role in the provisioning of natural pest control services (Milligan et al., 2016; García et al., 2018). In the Netherlands, the infestation of the harmful oak processionary caterpillars was locally reduced by 85% in four municipalities that had adopted biological pest control services by birds (Hellingman and van Vliet, 2020). Besides these regulating services, birds also contribute to nutrient cycling, ecosystem engineering and soil formation (supporting services)(Whelan et al., 2008). Finally, birds provide important opportunities for people to connect with nature and they play prominent roles in art, culture, religion and leisure activities; Drawings of birds are depicted on traditional Delft blue porcelain, and Dutch folklore tells tales of how one clever wren became king of the birds after winning a flying contest by secretly sitting on the back of an eagle (Sinninghe, 1978; Sekercioglu, 2006; Soga and Gaston, 2016).

Understanding how human development can impact bird populations and ultimately avian biodiversity and composition can help policymakers, urban planners and farmers to better protect birds to promote the beneficial ecosystem services they provide. In this literature thesis, we will provide an in-depth overview of the current knowledge regarding the ways in which urbanisation and agricultural intensification can impact the breeding success and survival of avian wildlife inhabiting human-modified habitats, focussing on the case example of the Netherlands. Figure 1 provides a schematic overview of the main human-driven processes that will be discussed in this review. The focus of this essay lies on birds inhabiting agricultural and (sub)urban areas specifically because the largest part of the land surface of the Netherlands consists of these heavily-modified habitats. After reviewing the threats, we discuss the currently available management strategies of the Dutch government for addressing these issues and suggest some affordable conservation measures that can be easily implied by both farmers and citizens to promote their local bird biodiversity.

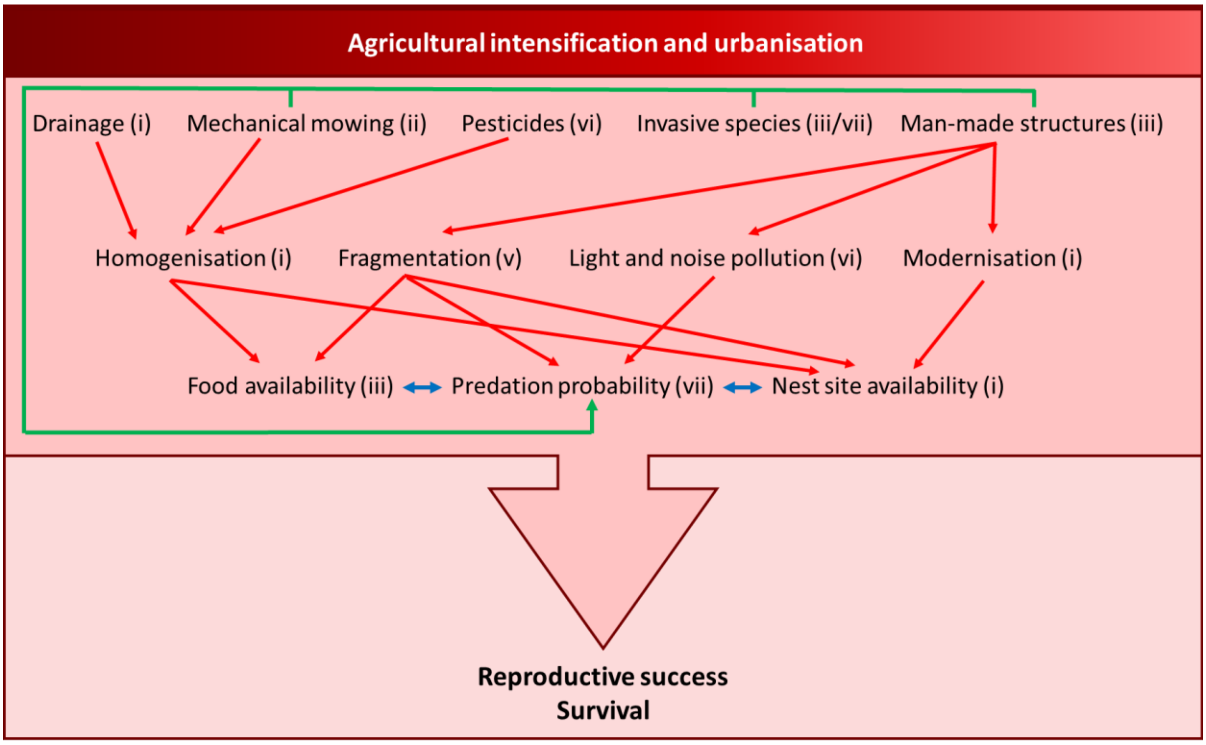

Figure 1. Schematic overview of the human-driven processes in agricultural and (sub)urban habitats discussed in this literature review. The Latin numbers between the brackets refer to the corresponding chapters. The processes that are depicted in the first row can impact food availability, predation probability and nest-site availability both directly (→) and indirectly (→), and the processes in the last row can also interact (→). Cumulatively, the processes can ultimately impact a birds' reproductive success and survival.

2. HOW DO URBANISATION AND AGRICULTURAL INTENSIFICATION AFFECT BIRD BREEDING SUCCESS AND SURVIVAL?

I. The loss of suitable nest sites in the agricultural and urban environment

In order to successfully reproduce within the breeding season, birds need to complete three phases: egg-laying, incubation and chick-rearing. For this, they need a suitable breeding site which offers everything they need. Over the past years, anthropogenic landscape changes have resulted in a decline of suitable nest sites for birds that breed in human-dominated ecosystems. Understanding how human activities are impacting nest-site availability of various bird species is important to formulate management guidelines.

a. Homogenisation of farmland

For birds that breed in agricultural landscapes, the structure of the vegetation is an important habitat requirement for nest-site selection as most farmland birds build their nest on the ground. In the first half of the 20th century, the Dutch agricultural landscapes consisted mainly of large, open wetlands with a rich mixture of grasses and flowers which were the product of traditional, low-intensity farming (Bos et al., 2013; Kentie et al., 2015). These flower-rich hay meadows provided important nesting habitats for ground-nesting species such as the black-tailed godwit, northern lapwing (*Vanellus vanellus)*, and Eurasian skylark (*Alauda arvensis),* and they also provided food for seed-eating and insectivorous birds in the spring-summer season (Newton, 2017). However, to improve the productivity of the grasslands, farmers started to intensify their agricultural practices (Onrust et al., 2019). They did so by lowering the groundwater tables of their fields through landscape-level drainage, ploughing and reseeding the parcels with more productive grasses and injecting the fields with slit and slurry to increase nutrient supply (Schekkerman and Beintema, 2007; Kleijn et al., 2010; Onrust et al., 2019). The wide variety of wild plants and flowers that were once present on these meadows could not compete with the fast-growing grasses and as a consequence, the species-rich wetlands were being replaced by monocultures with high-yielding grasses (Verhulst et al., 2007). These grassland transformations resulted in massive habitat losses for meadow bird species as the tall, dense and homogenous vegetation swards made many sites unsuitable for nesting (Chamberlain et al., 1999; Wilson et al., 2005; Verhulst et al., 2007).

b. Low-diversity of vegetation layers in urban environments

Besides the loss of nest sites in agricultural landscapes, urban birds increasingly also face a landscape with few nest sites to choose from. In urban landscapes, most people tend to prefer well-maintained and ordered green parks with plants and trees which are arranged in recognizable patterns (Carlson and Lintott, 2008; Page, 2016). To fulfil these wishes, dead or damaged trees are cut down, branches and shrubs are trimmed and ground cover is simplified (Marzluff and Ewing, 2001). What remains is a sterile habitat with a low diversity of horizontal and vertical vegetation layers (herb, shrub, understory, canopy). These non-diverse vegetation layers provide little nest coverage and offer a low availability of nest sites compared to habitats with a more diverse vegetative structure (Tilghman, 1987; Wohner et al., 2021). Moreover, the selective removal of standing dead trees reduces the nesting opportunities of cavity-breeders as natural cavities formed by decay or damage processes are usually found more abundantly in older, larger trees (van der Hoek et al., 2017).

c. Building modernisation

To adapt to the low vegetation diversity in cities, some bird species started to successfully exploit urban environments by nesting in or on buildings and other man-made structures. These new nesting opportunities resulted in the population increases of many so-called 'urban exploiters' (Blair, 1996; Marzluff, 2001). However, over the past three decades, building modernization and renovation have eliminated many potential nest sites for building-nesting birds (Dulisz et al., 2021). Suitable cavities in walls and roofs are closed, and, to reduce the nuisance of birds, ledges and overhangs are equipped with plastic fascia boards or anti-roosting spikes to limit access by undesirable feral pigeons *(Columba livia domestica)*(Dulisz et al., 2021). A recent study conducted by a team of researchers from Poland looked into the relationship between the number of birds and the level of building modernization in 104 Polish villages (Rosin et al., 2020). The results of their study revealed that population sizes of building-nesting bird species in modernized villages were almost half the size compared to population sizes of birds breeding in villages with mainly old houses (Rosin et al., 2020). In the Netherlands, almost all urban areas are heavily modernized and populations of most urban exploiters have therefore been undergoing dramatic population declines. The most extreme example is the population decline of the formerly common house sparrow. Its population decreased by more than half since 1990, and house sparrows are currently placed on the Dutch IUCN red list of threatened species (Klok et al., 2006; IUCN, 2016).

Besides the direct loss of suitable nesting sites in the urban and agricultural environment, there are many processes by which nesting sites, though still available, have degraded. In the remaining sections below we will dive into several of these changes in the breeding habitat of birds and their impact on bird populations.

II. The mechanisation of grass cutting and advancement of mowing

a. Nest destruction by mowing machinery

A potentially destructive form of habitat change in the agricultural context specifically is the intensification of mowing. In the past, grass was cut mostly by hand or with horse-drawn mowing machines (Newton, 2017). This grass cutting process was slow and allowed most birds that were breeding on the meadows to escape in time before their nests were getting destroyed. But with the mechanisation of grass cutting around the 1960s, the average mowing date advanced as farmers could now mow more efficiently and faster (Schekkerman and Beintema, 2007; Newton, 2017). In addition, the increasingly warmer spring temperatures, a result of climate change, and the use of fertilisers resulted in even earlier mowing dates because both factors improve grass growth (Schroeder et al., 2012b). Studies have shown that many meadow bird species, among which the black-tailed godwit, have not been able to advance their breeding dates in accordance with the earlier mowing times (Kleijn et al., 2010; Kentie et al., 2015). The changes in mowing phenology are therefore threatening the nest survival of ground-nesting breeders as the dates of the breeding cycle and mowing start to overlap. The resulting mortality by agricultural losses is estimated to contribute to around a fifth of the total brood losses in areas where no nest protection takes place (Teunissen et al., 2008; Schekkerman et al., 2009).

b. Direct adult mortality and skewed sex-ratios

Agricultural changes in grassland management do not only affect brood fate but can also lead to direct adult mortality and adult sex-ratio distortion in bird species where only females incubate the eggs. Incubating birds usually stay on the nest for as long as possible and only leave the nest seconds before the mowing machinery destroys their nests (Grüebler et al., 2008). Mowing during the incubation phases of birds is therefore tricky as some birds may fail to leave the nest in time resulting in lethal causalities or immediate death. Grüebler et al. (2008) studied anthropogenic sex-specific mortality in a population of Alpine whinchats *(Saxicola rubetra),* a ground-nesting grassland bird species with female-only incubation. The results of their study revealed that adult survival was reduced significantly during the mowing period, and female survival was more than 12% lower compared to male survival (Grüebler et al., 2008). This female-biased mortality leads to more unmated males which in turn could accelerate population declines of birds through fewer mating opportunities.

III. The decline in food availability and accessibility

The previous sections have demonstrated that agricultural intensification and urbanisation can result in significant losses of suitable nesting habitat and increased risks of anthropogenic nest destruction. But the rapid human-induced habitat changes can also negatively impact the breeding success of birds further by reducing the availability of breeding habitats with sufficient food abundance, food diversity and food accessibility for foraging chicks.

a. Food declines for farmland birds

Surface-dwelling and above-ground insects and invertebrates form a major dietary component of many farmland birds and their offspring (Beintema et al., 1995). The availability of those arthropods is therefore crucial for the breeding success of birds. Following the drainage of grasslands, invertebrates that were commonly present in the wet top-soil layers of grasslands are now retraining to the deeper layers of the soil which makes them inaccessible for foraging birds (Onrust et al., 2019). On top of that, the dry topsoil layers of the drained grasslands make it harder or even impossible for birds to probe the soil in search for prey, resulting in lower food intakes (Mccracken and Tallowin, 2004; Onrust et al., 2019). The elimination of plant biodiversity, caused by monoculture farming and heavy nitrogen use, also affects the biodiversity of the arthropod community feeding on those plants (Morris, 2000). Larger-bodied arthropods with longer life cycles are diminishing from heavily managed fields as they have no time to develop between the successive grass cuts and the remaining small arthropods are often too small to be utilized by birds (Mccracken and Tallowin, 2004). The frequent cutting of the grass also influences the arthropod abundance, as several studies have shown that arthropod numbers crash directly after mowing (Morris, 2000; Newton, 2017). Finally, the accessibility of arthropod prey of meadow bird chicks is very low in the uniform and dense vegetation swards that dominate the intensively managed grass fields (Butler and Gillings, 2004; Kleijn et al., 2010). To confirm the hypothesis that birds consume fewer prey items in heavily managed fields, Schekkerman and Beintema (2007) performed a foraging experiment in which they let captive black-tailed godwit chicks forage in a cut agricultural grassland plot and a plot located in an uncut sward in a nature reserve. In line with the expectations, the results of their experiment showed that chicks foraging in the cut agricultural grassland ingested around a third fewer prey items per unit time compared to chicks foraging in the uncut reserve fields, a difference large enough to reduce chick growth and survival (Schekkerman and Beintema, 2007).

For granivorous species, such as the common starling *(Sturnus vulgaris),* house sparrow and Eurasian skylark, food abundance and diversity in agricultural areas also declined as the frequent and earlier mowing of parcels allowed little capacity for plants to set seed (Mccracken and Tallowin, 2004). Moreover, the defoliation caused by ploughing of the fields severely reduced the possibility of seed production (Mccracken and Tallowin, 2004; Newton, 2017). For a more in-depth overview of the effects of agricultural intensification on seed availability, we refer the interested reader to pages [383-388] of Ian Newton's book 'Farming and Birds' (2017).

b. Food declines for urban birds

Urban habitats differ immensely from more natural habitats in terms of food types and food abundance (Meillère et al., 2017). Because of the high human population densities in urban areas, birds have greater access to human-derived food sources through supplementary feeding (e.g. birdseed, sugar mixtures) or by consuming human food waste (e.g. bread, biscuits, beans, rice, vegetables)(Jones and Reynolds, 2008; Ottoni et al., 2009). Although some urban birds could, in theory, survive by only consuming the many available anthropogenic food sources during their adult life, most would not be able to reproduce as more than 90% of all terrestrial bird species rear their young on insects (Tallamy and Shriver, 2021). The availability of insects is thus a determining factor in the survival of bird populations (Tallamy and Shriver, 2021). In urban areas, vegetation density is usually low and areas of native vegetation are scarce which results in a low insect availability (Shaw et al., 2008). In addition, vast areas of native vegetation have been progressively removed and replaced by non-native vegetation which generally supports a lower food base for nestlings than native plants do (Southwood, 1961; Ortega et al., 2006). This insect scarcity in urban habitats can lead to population declines of wild birds as parents may not be able to provide their offspring with sufficient food (Peach et al., 2008; Seress et al., 2012; Tallamy and Shriver, 2021).

Habitat deterioration has thus led to significant declines in the food abundance, food diversity and food accessibility of birds across human-modified agricultural and urban landscapes. Besides the direct negative effects on birds' survival and reproductive success, these changes in the food supply may also affect birds indirectly through increased predation risks (Evans, 2004). A reduction in local food availability could force birds to forage in more dangerous places, and increases their foraging time which may make them and their offspring more vulnerable to predation as this extra time spent foraging cannot be used for guarding or defending their young (Martin, 1992; Evans, 2004).

IV. The pollution of habitats

a. Pesticides

With agricultural intensification came also an increased use of chemical pesticides. Since the 1960s, pesticides are commonly used by farmers to control crop pests, weeds and pathogens (Newton, 1998). Although beneficial for crop production, the use of pesticides can have deleterious or even deadly side effects on birds. Insecticide use has for example been shown to reduce the food supplies of birds as these synthetic toxins are non-specific and kill a wide range of insects and arthropods (Newton, 2017). Most pesticides are applied during the crop growing season which falls simultaneously with the nesting phase of birds. As a result, nestlings or adult birds are sometimes directly exposed to chemical pesticides. Depending on the type of chemical used, direct contact with pesticides can result in acute dermal toxicity (Driver et al., 1991; Sánchez-Bayo, 2011). If birds ingest contaminated plants and insects, the chemical compounds of pesticides can accumulate in the body after which birds may experience chronic toxicity, sub-lethal effects or even acute death if a sufficient amount of pesticides are consumed (Sánchez-Bayo, 2011). Fortunately, many of the traditional toxic pesticides are no longer approved for use today and most modern pesticides are readily metabolized and thus do not accumulate in the body anymore (Canters and de Snoo, 1993; Sánchez-Bayo, 2011). Nonetheless, even today there still exist several commonly used pesticides that are suspected to negatively impact wild birds, for example through egg-shell thinning. For a more detailed summary of the effects of modern-day pesticides on bird populations, we would recommend Arya et al. (2019) and Li et al. (2020) for detailed analyses on this topic.

b. Plastic waste

Besides pesticides, an increasingly-important pollution threat to bird communities is the accumulation of plastic waste in the environment. Most data regarding birds and plastic comes from studies on marine organisms (Barnes et al., 2009). But terrestrial birds, especially those living in close proximity to human-modified landscapes, are also exposed to huge amounts of plastic waste. As mentioned earlier, the availability of natural nest material in urban areas is generally low due to the reduced native vegetation density (Reynolds et al., 2019). As a response, birds from many different taxa have been found to replace the unavailable natural nest materials with anthropogenic waste which, in contrast to natural elements, is abundantly available in urban areas (Wang et al., 2009; Radhamany et al., 2016; Jagiello et al., 2019; Hiemstra et al., 2021). Not surprisingly, the incorporation of plastic debris in nest construction is associated with increasing urbanisation (Wang et al., 2009; Radhamany et al., 2016; Jagiello et al., 2019). The use of anthropogenic materials can reduce the duration of the nest-building phase, but it can also have negative consequences for birds' survival. Nestlings can for example become entangled in plastic debris, leading to injuries or even mortality (Blem et al., 2002; Townsend and Barker, 2014). Besides entanglement risk, nestlings can also accidentally ingest plastic waste material which can result in immediate death when sharp plastics puncture their organs, or they may starve to death when they feel full from consuming plastic but receive no nutritional benefits (Theodosopoulos and Gotanda, 2018). Finally, long-term exposure to the toxic chemicals that coat plastics, causes damage to the chromosomal material of birds' blood cells which could result in changes in mortality or reproduction (Tanaka et al., 2013; Lavers et al., 2014; Wang et al., 2021).

c. Artificial light at night

In addition to pollutant substances, there also exist human-generated sensory sources that can impact living organisms. One example of such an anthropogenic pollutant source is artificial light at night (ALAN). Where artificial light at night may benefit humans through increased opportunities for economically productive activities, leisure and social interactions, it negatively impacts the behaviour, physiology, reproductive success and survival of birds inhabiting those areas (Gaston et al., 2015). Bird species that breed in temperate zones such as the Netherlands use the length of the photoperiod to predict the optimal onset of reproduction (Dawson et al., 2001). Light stimulation at night could however alter the perceived day length period of birds (Kumar et al., 2018). An experimental field study on a population of European blackbirds *(Turdus merula)* demonstrated that the reproductive system of birds exposed to ALAN developed up to one month earlier than birds that were kept under dark conditions (Dominoni et al., 2013). Most strikingly, their results revealed that the differences in reproductive timing were already significant under very low artificial light intensities (Dominoni et al., 2013). Earlier onset of breeding may result in a lack of synchrony between chick hatch and food availability peaks which could potentially decrease the growth rates of nestlings (Visser et al., 2006). However, strong empirical evidence for a correlation between fitness declines and changes in reproductive timing due to ALAN is currently lacking and needs further studying (Dominoni et al., 2013; 2019). Another well-studied effect of night-time light pollution on birds is the disruption of the natural circadian rhythms. Several wild-bird studies indicated that white light causes sleep deprivation, evokes stress responses and negatively impacts the immune functioning of birds (Ouyang et al., 2017; Alaasam et al., 2018; Kumar et al., 2018; Dominoni et al., 2020).

d. Noise pollution

Another sensory stressor for birds inhabiting areas with high concentrations of human activities is the noise pollution by cars, planes and other machinery. Several studies have indicated a negative relationship between the fitness levels of breeding birds and the amount of anthropogenic noise. First of all, noise pollution can mask begging calls of nestlings which impairs parent-offspring communication resulting in lower feeding frequencies and impeding chick development (Schroeder et al., 2012a; Meillère et al., 2015b). Anthropogenic noise could also impair mate choice as females may not be able to assess male quality based on their sexual song (Habib et al., 2007; Halfwerk et al., 2011). A study on great tits (*Parus major)* in Leiden reported that great tit males at noisy locations adjust their sexual signal calls by singing with a higher minimum frequency, to prevent their songs from being masked (Slabbekoorn and Peet, 2003). However, these higher frequency calls have been linked to reduced male attractiveness and could hence lead to lower female investment and reduced pairing success (Habib et al., 2007; Halfwerk et al., 2011). Thirdly, high noise levels may also mask the alarm calls of birds and change their vigilance behaviour, which could in turn increase their predation risk (Meillère et al., 2015a; Templeton et al., 2016). Finally, the drowning out of begging calls, alarm songs and sexual calls, forces birds to expend more energy on communication (Francis et al., 2009; Ciach and Fröhlich, 2017).

V. The impact of man-made structures

In recent years, the increasing need for urbanisation has led to a further deterioration of the quality of the remaining breeding habitat of birds; New roads and train rails are built to transport the growing human population, high-rise flats are constructed to accommodate the housing shortage, and communication towers, wind turbines and electricity towers are built to provide humans with enough energy and electricity. These man-made structures cause disturbances in the landscapes of birds. On the one hand indirectly through the decrease of safe breeding grounds, on the other hand, also through direct mortality.

a. Lethal collision events

Collisions with man-made structures can be an important cause of direct avian mortality. In North America, bird strikes are even thought to rank among the top two threats to birds (Loss et al., 2014a;

2015). Recent quantitative reviews have estimated that buildings collisions in the United States kill between 365 to 988 million birds every year (Loss et al., 2014a), communication masts lead to an additional death of around 6,6 million birds (Longcore et al., 2012) and roughly 80 to 340 million birds are killed annually in the US by vehicle collisions (Loss et al., 2014b). These figures demonstrate the huge impact bird strikes can have on population numbers. Very few recent peer-reviewed studies of this topic have been conducted in the Netherlands so the estimated mortality rates of bird collisions in the Dutch landscapes remain largely unknown. However, an old study conducted in 1977 estimated that wildlife-vehicles collisions killed around 653.000 birds annually in the Netherlands (Erritzoe et al., 2003). Considering the rapid fleet expansion and infrastructure improvements of the past forty years, bird traffic mortality has most likely increased exponentially. Wind turbines are other man-made structures that have become an indispensable part of the Dutch landscape. A study conducted in the western part of the Netherlands calculated that an average of 28 birds were killed per wind turbine per year, with the highest proportion of victims being local and diurnally active birds among which the northern lapwing (Krijgsveld et al., 2009). With more than 3.500 on-shore wind turbines currently in the Netherlands, a rough back-of-the-envelope calculation suggests that this could add up to around 100.000 victims a year. The likelihood of a structure causing a collision event can be influenced by many factors, such as the location of a structure. Not surprisingly, a greater number of collisions have been observed at man-made structures that are located on migratory and local flyways (e.g. between foraging and nesting areas) or that are situated close to feeding or breeding areas of birds (Everaert and Stienen, 2007; Drewitt and Langston, 2008; Tellería, 2009). The correct placement of man-made structures could thus dramatically decrease the collision risk of breeding adults.

b. Lower predator visibility

Next to the fact that buildings and other man-made structures can directly kill birds, these structures may also affect the perceived level of predation risk by birds and thereby deteriorate their environment. The openness of a landscape is an important habitat characteristic for ground-nesting meadow bird species as this allows them to detect potential danger earlier (Melman et al., 2008; van der Vliet et al., 2008). Meadow birds trust their instinct to scare away predators from their territory, but to do so they need to have the ability to quickly detect an approaching predator. The more open a landscape, the faster they can detect potential predators (van der Vliet et al., 2008). However, the increase of disturbing elements in the Dutch landscapes hampers the visibility for breeding birds and hence can result in a decrease in safe breeding areas. Besides the reduced visibility, raptor species can also utilize man-made objects as artificial perching sites, thereby improving their hunting efficiency resulting in even less safe breeding areas (Meunier et al., 2000). Measuring the effect of an increase in disturbing elements on predation levels is difficult as the predation rate depends on many non-exclusive factors. However, the presence of view-obstructing elements could create a so-called landscape of fear in which breeding birds may avoid areas of high perceived predation risk (Laundré et al., 2001; Van Der Vliet et al., 2010). To test this hypothesis, van der Vliet et al. (2010) studied the effect of different landscape elements on the nest-site selection of three meadow bird species (black-tailed godwit, Eurasian oystercatcher and the northern lapwing) breeding in the Netherlands. In their review paper, they distinguished between view-obstructing elements (houses, wind turbines, electricity cables, bridges, trees) and flat elements (roads, canals, railway)(Van Der Vliet et al., 2010). The results of their study revealed that birds keep up to one kilometre distance from village edges and highways. Moreover, they found a significant positive correlation between the intensity of traffic and the disturbance distance of birds (Van Der Vliet et al., 2010). Although the results clearly show that meadow birds keep a distance from anthropogenic disturbance elements, it is not sure if these responses are caused by a fear of predation or if this behaviour may at least be partially driven by other urban-related stressors, such as traffic noise or light pollution [as described in section IV].

VI. The fragmentation of suitable habitat

Human development (converting land to agricultural, industrial, and urban uses) and the presence of man-made structures in the Dutch landscape have reduced the quality of the remaining suitable breeding habitats of birds through accelerated habitat fragmentation (Franklin et al., 2002). Habitat fragmentation or habitat sub-division is the process in which large continuous mosaics of native vegetation become divided into many small fragments surrounded by a matrix of cement, grass, crops, and degraded lands (Franklin et al., 2002; Fischer and Lindenmayer, 2007). When habitats become fragmented, the size of habitat patches decreases (area effect), the ratio of edge to interior habitats increases (edge effect), and the distance between occupied patches increases (dispersal effect) (Batáry and Báldi, 2004; Fischer and Lindenmayer, 2007). These three processes can negatively affect the breeding success and survival of birds in various ways, as will be discussed in more detail below.

a. Limited food resources

Smaller isolated habitat patches can cause population declines, for example because food resources could become limited. Several studies have demonstrated that invertebrate biomass and foraging efficiency is significantly lower in small fragments of native habitat than in large continuous habitats (Burke and Nol, 1998; Zanette et al., 2000), similar results have been found in grassland patches of varying sizes (Kruess and Tscharntke, 1994; Steffan-Dewenter and Tscharntke, 2002; Piessens et al., 2009). The lack of habitat connectivity could also decrease the ability of insect populations to resist and recover from environmental disturbances, making them more susceptible to extinction (Piessens et al., 2009). Evidence from several studies has shown that increased distance between habitat fragments decreases patch colonization rates and increases the insect extinction probability (Kruess and Tscharntke, 1994; Steffan-Dewenter and Tscharntke, 2002).

b. Increased predation risks

A number of studies have reported elevated predation rates in fragmented landscapes with high ratios of edge to interior area (Winter et al., 2000; Marzluff and Ewing, 2001; Batáry and Báldi, 2004). Most predatory species are adapted to, and more abundantly present in edge habitats (Winter et al., 2000; Marzluff and Ewing, 2001). Moreover, most mammalian predators use the edges of fragmented habitats as travel or forage lanes (Chalfoun et al., 2002). Thus, increases in the amount of edge habitat make breeding birds inhabiting fragmented habitat patches more subjected to influences from their surroundings (Fagan et al., 1999). To better understand the mechanisms underlying the increase of predation in fragmented landscapes, Chalfoun et al (2002) performed a meta-analysis in which they evaluated whether predator responses to fragmentation depend on landscape type. The results of their study revealed that predator effects (e.g. predator abundance, predator activity and species-richness) were most prevalent in landscapes that are divided by agricultural development or surrounded by urban settlement than in predominantly forested landscapes (Chalfoun et al., 2002).

VII. Changes in the mammalian predator community

In the above sections, it became apparent that changes in the landscape due to agricultural intensification and urbanisation can, in many ways, lead to an increased predation risk for birds and their broods. Besides such effects, anthropogenic changes to the landscape have also resulted in changes in the predator community itself which in turn can have an effect on the success of bird populations. Below we specify these changes focusing on native and invasive mammalian predator species.

a. Native predatory species

During the last decades, the impact of generalist native predatory species in the Netherlands appears to have increased. In 2020, the Dutch government published a revised Red List of threatened species and the Central Bureau of Statistics (CBS) compared the population trends since 1995 (van Norren et al., 2020). The results of their comparison revealed that the average level of threat to mammalian species in the Netherlands has decreased by 35% (Thissen and van Norren, 2020). In contrast, birds have shown no sign of recovery since 1995 (Thissen and van Norren, 2020). The red list data shows that large and medium-sized mammals, in particular, have increased in number. Some examples of predators that have been showing population increases over the last years are the red fox, *(Vulpes vulpes)*, beech marten *(Martes foina),* pine marten *(Martes martes)* and badger *(meles meles)*(van Norren et al., 2020). Important factors in the return of large predators are the bans on hunting, land-use changes, and increases in ambient temperature which – in most cases – favours the large mammals as many landscapes now offer plenty of food all year round and the mild winters increase their survival probability (Deinet et al., 2013).

The recovery of large-bodied mammalian predator species is considered to be a major conservation success. However, their population recoveries and the consequent increases in predation pressure hampers the conservation of breeding birds in the Netherlands. Over the last twenty years, predation in the egg stage of meadow birds has increased by 40% and researchers have determined that 70-85% of the deaths of lapwing and black-tailed godwit chicks are due to predation (Schekkerman et al., 2009). However, there is a large variation in the amount of predation between different types of landscapes. According to several studies, the increase in predation of meadow bird nests appears to be only a problem in poor quality breeding areas (Kentie et al., 2015). In herbaceous grasslands, the success rate of, for example, black-tailed godwit nests was still comparable to the late 1980s, when there were far fewer predators roaming around (Kentie et al., 2015).

A study on a population of northern lapwings indicated that reduced surface flooding and removal of tall vegetation resulted in significant increases in nest predation rates (Laidlaw et al., 2017). If the vegetation is too short, birds and their nests have less shelter and are thus more likely to be detected by potential enemies. Surface flooding on the other hand may create barriers that impact the movement patterns of predators in wet grasslands (Harri et al., 1999). However, strong empirical evidence for this hypothesis is currently lacking. Additionally, intensification of land use also results in population declines of small mammalian species such as the tundra vole (*Alexandromys oeconomus Arenicola),* bi-coloured shrew (*Crocidura leucodon leucodon)*, rabbit (*Oryctolagus cuniculus)*, and brown hare *(Lepus europaeus europaeus)*(van Norren et al., 2020). Small mammals are the main prey species of most generalist predators such as the red fox or beech marten, so a decrease in the number of alternative prey species increases the relative predation pressure on birds nests and chicks (Laidlaw et al., 2017). These examples show that the increase in predator species alone does not necessarily result in higher predation risks. However, it is the combination of a high predator abundance alongside the degradation of habitats that is threatening many wild bird populations (Roos et al., 2018).

b. Invasive predatory species

Besides an increase in nest and chick predation by native predators, many breeding birds are now also commonly exposed to invasive predators which can cause a multitude of problems with native wildlife. According to the definition published by the Dutch government (see Mulder 2013 and references within), an invasive species is; 'an organism which arrives from elsewhere with the aid of humans (by transport or infrastructure) and which is a successful coloniser (by reproduction and population growth)'. According to two Dutch professors, the main invasive predator of birds in the Netherlands is the domestic cat which poses a serious threat to around 367 bird species (Trouwborst and Somsen, 2021). The domestic cat descends from wildcats (*Felis silvestris)* and was domesticated in the Near East around 7500 BC (Ottoni et al., 2017). Nowadays, cats are among the most popular pets of humans and populations have been increasing rapidly since the 1970s. In the Netherlands, the total cat population in 2020 amounts to more than 3 million, that is around one cat for every sixth Dutch citizen (Trouwborst and Somsen, 2021).

A technical report estimated that the direct impact of cats in the Netherlands results in the death of nearly 5 million grassland and meadow birds annually, this is around a quarter of the total breeding population (Knol, 2015). No exact data is available on the number of urban birds that are killed by cats, but a citizen survey under Dutch cat owners reported that each free-ranging cat kills on average 40 to 80 small animals (birds, mammals, reptiles and amphibians) on a yearly basis (Knol, 2015). In addition to predation mortality, the indirect disturbance of cats could also lead to sub-lethal effects. Measuring the impact of indirect disturbance by domestic cats is more difficult as it will not result in immediate death. However, fear or intimidation effects, which are caused by the mere appearance, scent or presence of cats, can impact birds' welfare and reproductive success indirectly by evoking stress responses and influencing the feeding and defence behaviours of birds (Trouwborst and Somsen, 2021). If cats come in close contact with birds, they can also transmit diseases or parasites. One of these cat-transmitted diseases is toxoplasmosis which could lead to death in highly susceptible species, such as the grey partridge which is one of the Dutch red list species (Sedlák et al., 2000). A final way in which cats could negatively impact avian wildlife is through increased competition with other native predators (Trouwborst and Somsen, 2021).

Another important invasive alien predator species to mention in the context of the Dutch landscape is the raccoon dog *(Nyctereutes procyonoides)* (Mulder, 2013). The raccoon dog was introduced to the former soviet union around 1928 for its valuable fur but became feral after deliberate releases and escapes from fur farms (Kauhala and Kowalczyk, 2011). Since then, raccoon dogs have bred exponentially and expanded their range across the European continent. Raccoon dogs have been observed in the Netherlands since the 90s, but their reproduction has only been confirmed recently (Vergoossen and Backbier, 1993; Mulder, 2013). Raccoon dogs can impact avian wildlife directly through the predation of eggs and chicks, but they can also spread diseases and compete for food with other native predators such as the red fox (Kauhala and Kowalczyk, 2011; Mulder, 2013; Krüger et al., 2018).

3. THE WAY FORWARD

The aim of the present research was to examine how birds inhabiting (sub)urban and agricultural habitats are impacted by human-induced rapid environment changes, focussing on the Netherlands as a case study. The large body of evidence reviewed above indicates that human impacts such as land-use change (drainage, ploughing, intensive mechanical grass cutting, reseeding with grass monocultures), the use of chemical pesticides and fertilizers, the introduction of invasive plant and predator species, plastic pollution, and the increase in man-made structures can have clear negative effects on a birds' reproductive success and survival through many different direct and indirect processes that are intertwined. Such effects are a prime suspect as to why more and more Dutch breeding birds are classified on the IUCN red list of threatened (Thissen and van Norren, 2020). Although the fate of many species thus seems dire, it must be noted from a biodiversity point of view that there are also still some opportunistic bird species that are performing surprisingly well in human-modified habitats. Some gull species have for example been steadily increasing in urban environments because they can utilize the rooftops of buildings for nesting, and anthropogenic food sources are easily and abundantly available to them (Auman et al., 2008; Soldatini et al., 2008). However, when considered on the whole, more species are disappearing and declining than thriving in the Netherlands and from a biodiversity perspective action needs to be taken. Over the years, some efforts have been made to restore the downward trend of breeding birds, for example in the agricultural environment by implementing agri-environmental schemes (AES) in 1981 that focus mainly on nest protection and postponed mowing (Kleijn et al., 2001). But, to date, AES have unfortunately proven to be ineffective (Kleijn et al., 2001). The current policy, therefore, needs to change otherwise some bird species are expected to disappear completely from the Netherlands.

In 2020, several scientists, a handful of nature, wildlife and agricultural organizations, and the former Dutch minister Pieter Winsemius joined forces and drafted the 'black-tailed godwit battle plan' ('grutto aanvalsplan'; Winsemius et al., 2020). The aim of this project is to improve the habitat quality on agricultural lands and to restore bird biodiversity by creating multiple large open habitats, the so-called opportunity areas. To improve the habitat quality of these opportunity areas, the water levels on these fields will be raised, livestock densities will be decreased, slurry injections will be replaced by rough farmyard manure and predators will be actively managed (Winsemius et al., 2020). The idea is that the combination of rough farmyard applications together with the raising of water tables will create herb-rich meadows with a high insect availability (Onrust and Piersma, 2019). Moreover, the removal of bushes and trees will create open landscapes that improve predator visibility and the high water tables will hinder the access of mammalian predators (van der Vliet et al., 2008). As the funding for this project has only been recently approved, the effectiveness of this project cannot be assessed yet. However, in 2011, Heinrich Belting set up a similar project in Lower Saxony, Germany and a recent evaluation of this project has shown extremely promising results. In this project named 'LIFE IP', 623 ha of private land was purchased and on these grasslands they created large, open re-wetted areas with extensive grassland management (Belting, 2020). After ten years, eleven breeding species that had completely disappeared from the area have returned and population numbers of the threatened lapwing and black-tailed godwit have more than tripled since the start of the project (Belting, 2020). This success story demonstrates that these large restoration projects have the potential to successfully turn around the current population declines of meadow bird species by transitioning to a more nature-inclusive approach.

Besides the large-scale 'black-tailed godwit battle plan' aimed at restoring biodiversity in the agricultural environment, there also exist some small and inexpensive conservation measures that can be implemented almost instantly by citizens, farmers or municipalities. Although these measures will not turn the population declines of breeding birds around, they could at least partly contribute to the protection of birds in urban and agricultural habitats. First of all, farmers could change their mowing patterns by mowing from the centre outwards. This practice allows adult birds and nestlings to escape to the field edges and prevents them from getting trapped in an ever decreasing circle (Green et al., 1997; Tyler et al., 1998). As mentioned in section V, around 100.000 birds are killed annually through wind turbine collisions. To reduce the collision risk of birds with wind turbines, the visibility of the rotating blades could be increased by painting them (Drewitt and Langston, 2008). A recent experimental study published in ecology and evolution demonstrated that the annual fatality rate of birds at painted wind turbines was reduced by more than 70% compared to unpainted turbines (May et al., 2020). To compensate for the loss of cavities in trees and old buildings, nature organizations, municipalities and citizens have been attaching many nest boxes to trees and buildings. Although the use of nest boxes is an effective conservation measure, more effort could be put into selecting the right nest box design and placement to optimize the effectiveness of these boxes [see Dulisz et al., 2021 for a review]. To reduce the risk of bird predation by domestic cats, cat owners could equip their free-roaming cats with special anti-predation devices (Trouwborst and Somsen, 2021). A recent experimental study tested the effectiveness of a bright cat collar and the results of their trial showed that predation rates of cats wearing the collar were reduced by 78% (Pemberton and Ruxton, 2020). Finally, citizens could be encouraged to plant more native trees in their gardens. Native plants do not only offer more nesting, sheltering and feeding opportunities for birds, they also need less pesticides and fertilizer because they are already well adapted to the local climate and pest species (Southwood, 1961).

On a final note, this review set out to investigate human impacts on birds with the Netherlands as a case example. But is the case example of the Netherlands representative for the rest of the world? The Netherlands is unique in the sense that it is a small country with many inhabitants per square meter and a highly productive agricultural system. While the intense agricultural practices in the Netherlands have yielded high results, the country now also shows the steepest decline of farmland birds across the entire European region. Unfortunately, the steep declines of migrating meadow birds in the Netherlands also impacts the population numbers of these species at their wintering areas in Spain, Portugal and West Africa. Vice versa, Dutch breeding birds are negatively impacted during their non-breeding season by deteriorating habitats and reduced food supplies at their wintering and stopover grounds (Hooijmeijer et al., 2021). Although the current review focused mainly on the effects of agricultural intensification and urbanisation on birds' reproductive success and survival during the breeding season, we should not neglect the importance of studying the impact of human-induced rapid environment changes on birds across their entire flyway. To conclude, we hope that other countries can learn from the mistakes that the Netherlands made and also the solutions it is now trying out by governing the transformation towards 'nature-inclusive' agriculture early on.

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