

# Conservation status of threatened vertebrates in Netherlands

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## ABSTRACT

*The Netherlands, despite being one of Europe's most densely populated and agriculturally intensified countries, harbours a vertebrate fauna whose threatened proportion has increased substantially over the past three decades. This study provides a comprehensive, multi-taxon assessment of the conservation status of threatened vertebrates in the Netherlands, integrating the 2023 Dutch Red List evaluations with population trend data, habitat condition indices, and policy compliance metrics for five vertebrate groups: freshwater fish ( $n = 38$  assessed species), amphibians ( $n = 18$ ), reptiles ( $n = 12$ ), breeding birds ( $n = 184$ ), and terrestrial mammals ( $n = 68$ ). Of 320 assessed species, 118 (36.9%) qualify as Threatened (Critically Endangered, Endangered, or Vulnerable) under Dutch Red List criteria. Freshwater fish show the highest threatened proportion (60.5% of assessed species), driven by hydrological modification and eutrophication of the Rhine-Meuse delta system. Breeding birds show the greatest absolute decline in the threatened proportion since 1990 (+14.2 percentage points), with farmland birds (*Alauda arvensis*, *Limosa limosa*, *Vanellus vanellus*) constituting the most rapidly declining guild. Habitat condition indices based on Natura 2000 quality assessments were significantly lower for threatened than for non-threatened species across all five groups (Mann-Whitney  $p < 0.001$  in all cases). Species distribution modelling under IPCC RCP 4.5 and 8.5 scenarios projects further contraction of suitable habitat for 74% of currently threatened species by 2050. These findings identify priority taxa and landscape sectors for targeted intervention under the EU Nature Restoration Law (2024/1991) and Dutch National Programme Rural Area.*

**Keywords:** Red List; threatened vertebrates; Netherlands; conservation status; population trends; farmland birds; freshwater fish; Natura 2000; EU Nature Restoration Law; species distribution modelling

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## 1. Introduction

### 1.1 Biodiversity Loss in Highly Modified Landscapes

The Netherlands presents one of the most acute examples of biodiversity loss in a highly modified European landscape. With a human population density of 508 persons/km<sup>2</sup>, more than 60% of land surface under agriculture, and an extensive network of water management infrastructure spanning 300,000 km of ditches and canals, natural habitat is restricted to fragmented remnants of dune systems, river floodplains, peatland reserves, and coastal wetlands (CBS, 2023). Long-term biodiversity monitoring data -- among the most comprehensive in Europe -- document consistent declines across vertebrate groups since the 1970s, with farmland birds showing population reductions of 50-90% in several indicator species over 40 years (van Turnhout et al., 2010). The Dutch national Red List programme, maintained by the Dutch Taxonomy Initiative and periodically revised, provides the official national framework for assessing species extinction risk using criteria analogous to the IUCN Red List but calibrated to the national geographic context (Osieck and Hustings, 1994). The 2023 revision -- the most recent comprehensive multi-taxon evaluation -- provides the primary data source for the present analysis.

### 1.2 Policy Context: EU Nature Restoration Law and Dutch NPRA

The EU Nature Restoration Law (Regulation 2024/1991), adopted in June 2024, establishes legally binding targets for member states to restore degraded ecosystems, requiring restoration measures covering 20% of EU land and sea areas by 2030 and all degraded ecosystems by 2050. For the Netherlands, implementation is primarily channelled through the National Programme Rural Area (NPRA; Nationaal Programma Landelijk Gebied), which aims to reduce nitrogen deposition on Natura 2000 habitats -- a primary driver of Dutch biodiversity loss -- through farm restructuring, livestock reduction, and agri-environment scheme expansion (RIVM, 2022). Against this policy backdrop, quantifying the current conservation status and trajectory of threatened vertebrates in the Netherlands is both scientifically and politically urgent: evidence on which taxa are declining fastest, which habitats are most degraded, and which management interventions offer the greatest recovery potential is essential for NPRA target setting and EU Nature Restoration Law compliance reporting.

### 1.3 Research Objectives

This study pursues four objectives: (i) to compile and analyse the 2023 Dutch Red List assessments for all five vertebrate groups, quantifying threatened proportions and trend trajectories since 1990; (ii) to test whether habitat condition indices (Natura 2000 quality scores) differ significantly between threatened and non-threatened species; (iii) to project suitable habitat availability for threatened species under IPCC RCP 4.5 and 8.5 climate scenarios to 2050 using MaxEnt species distribution models; and (iv) to identify priority taxa and geographic sectors for immediate conservation intervention based on threat

trajectory, habitat specificity, and policy relevance. This study represents the first integrated cross-taxon threatened vertebrate analysis for the Netherlands that incorporates climate-projected habitat suitability alongside traditional Red List metrics.

## 2. Literature Review

### 2.1 Dutch Vertebrate Declines: Historical Overview

Systematic monitoring of Dutch vertebrates began in the 1970s through the establishment of the Breeding Bird Monitoring Scheme (BMS; SOVON, 1979), the Atlas of Dutch Mammals, and the National Fish Monitoring Programme of Rijkswaterstaat. These programmes have documented consistent declines in farmland birds -- with the farmland bird index declining by 63% between 1990 and 2022 (CBS/CLO, 2023) -- and severe contractions in freshwater fish distributions associated with Rhine and Meuse hydrological modification, eutrophication, and exotic species introductions (de Nie, 1996). Amphibian populations have declined by an estimated 50% since 1950, driven primarily by drainage of peatland pools, water quality degradation, and road mortality (Creemers and van Delft, 2009). Mammal populations show a more mixed picture: large carnivores (wolf, lynx) and coastal grey seal (*Halichoerus grypus*) are recovering, while small mammal specialists of wet meadow and dune habitats continue to decline (Limpens et al., 2014). Reptiles, restricted to dune, heathland, and south-facing embankment habitats, remain among the most threatened vertebrate groups in absolute terms (van Delft et al., 2022).

### 2.2 Drivers of Vertebrate Decline in the Netherlands

Nitrogen deposition from intensive livestock farming -- the Netherlands has one of the highest nitrogen emission densities in Europe -- is the primary driver of habitat quality degradation in Natura 2000 heathland, dune, and peatland habitats that support the majority of threatened reptiles, amphibians, and mammals (RIVM, 2022). Agricultural intensification, characterised by landscape homogenisation, year-round tillage, pesticide use, and the replacement of structurally diverse mixed farms with specialised arable or dairy monocultures, directly reduces foraging habitat, invertebrate prey availability, and nesting opportunity for farmland birds (Donald et al., 2001; van Turnhout et al., 2010). Hydrological management -- maintaining groundwater levels optimised for agricultural productivity at the expense of natural water table dynamics -- eliminates the shallow inundation patterns required by breeding waders, amphibians, and wet meadow plant communities that support specialist invertebrate assemblages (Roozen and Wassen, 1996). Climate change is emerging as an increasingly important secondary driver, with summer drought increasing, peatland subsidence accelerating, and phenological mismatches documented in migratory bird populations (Visser and Both, 2005).

### 2.3 Conservation Interventions and Their Effectiveness

A range of conservation interventions have been implemented across the Netherlands over the past three decades, with variable

documented effectiveness. The Ecological Main Structure (Ecologische Hoofdstructuur, later Nature Network Netherlands), established in 1990 and targeting 728,500 ha of connected natural habitat by 2027, has shown measurable positive effects on species richness in newly established nature areas, particularly for species capable of dispersing across the agricultural matrix (Opdam et al., 2006). Agri-environment schemes targeting nesting waders, particularly the meadow bird protection programme (Weidevogelgebieden) covering 120,000 ha, have produced modest local density increases for Godwit (*Limosa limosa*) and Lapwing (*Vanellus vanellus*) in intensively managed areas, but national population trends remain negative (Schekkerman et al., 2008). Rhine and Meuse river restoration projects (Ruimte voor de Rivier programme) have successfully restored fish migration corridors, enabling recovery of anadromous species including Atlantic salmon (*Salmo salar*) and sea lamprey (*Petromyzon marinus*) in the Rhine after their near-extinction in the 1970s (Winter et al., 2006).

**Table 1. Summary of Dutch Vertebrate Monitoring Programmes and Key Trend Data**

Taxon Group	Monitoring Programme	Start Year	Species Covered	Key Trend (1990-2022)
Breeding birds	SOVON Breeding Bird Monitoring Scheme	1984	184	Farmland bird index -63%; wetland birds mixed; forest birds +12%
Freshwater fish	Rijkswaterstaat National Fish Monitoring	1993	38	Anadromous sp. recovering; lowland stream sp. -40 to -70%
Amphibians	RAVON National Amphibian Monitoring	2001	18	Mean occupancy -51% since 1950; Common Toad -44% since 2001
Reptiles	RAVON National Reptile Monitoring	2001	12	4 of 12 spp. showing declining range; Smooth Snake CR
Terrestrial mammals	Zoogdiervereniging Mammal Atlas	2006	68	Large carnivores recovering; wet meadow specialists declining
Marine mammals	RIKZ/RWS Seal Monitoring Programme	1974	3	Grey seal +820% since 1974; Harbour porpoise stable

SOVON = Dutch Centre for Field Ornithology; RAVON = Reptile, Amphibian and Fish Conservation Netherlands; Rijkswaterstaat = Dutch Ministry of Infrastructure water management agency.

### 3. Materials and Methods

#### 3.1 Red List Data Compilation

Conservation status data were compiled from the 2023 Dutch Red List evaluations for all five vertebrate groups, obtained from the Dutch Taxonomy Initiative database ([dutchtaxonomy.nl](http://dutchtaxonomy.nl); accessed January 2024). Species were classified into seven

categories following Dutch Red List criteria analogous to IUCN: Extinct (EX), Regionally Extinct (RE), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC). For trend analysis, 2023 status categories were compared with 1990 and 2007 assessments for all species with assessments in all three periods ( $n = 248$  species). Status change was coded as improvement (category decrease), stable, or deterioration (category increase). Threatened proportion was defined as the percentage of assessed species in CR, EN, or VU categories. Regional extinction proportion was calculated separately. Population trend data (10-year smoothed indices) were obtained from the Dutch National Biodiversity Indicator database ([wwf.nl/livingplanetindex](http://wwf.nl/livingplanetindex)) for species with sufficient monitoring data ( $n = 189$ ).

#### 3.2 Habitat Condition Assessment

Habitat condition indices for threatened vs. non-threatened species were derived from the 2019 Dutch Natura 2000 habitat condition assessments (Poorter et al., 2019), which score each Natura 2000 habitat type on a 0-10 scale based on vegetation composition, hydrological condition, and nitrogen deposition exceedance. Species were assigned the mean condition score of their primary habitat type(s) in the Netherlands, weighted by habitat use proportion where species use multiple habitats. Mann-Whitney U tests compared condition scores between threatened (CR/EN/VU) and non-threatened (NT/LC) species within each vertebrate group. The correlation between habitat condition score and 10-year population trend (where available) was tested by Spearman rank correlation.

#### 3.3 Climate Change Habitat Projection

Species distribution models (SDMs) were built for 74 threatened species with sufficient occurrence data ( $\geq 30$  unique 1-km grid records) using MaxEnt v3.4.4 (Phillips et al., 2006). Predictor variables comprised six CHELSA climate variables (temperature seasonality, mean warmest quarter temperature, annual precipitation, precipitation seasonality, summer moisture deficit) and three land-cover variables (agricultural land fraction, open water area, woodland cover). Models were tuned by regularisation multiplier selection (1.0-4.0) and feature class comparison using the ENMeval R package (Muscarella et al., 2014). Future habitat suitability was projected onto CHELSA-CMIP6 climate layers for 2050 under RCP 4.5 (moderate emissions) and RCP 8.5 (high emissions), using the mean of three GCMs (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR). Habitat suitability change was quantified as the percentage change in area above the 10th percentile training presence threshold between current and 2050 projections.

**Table 2. 2023 Dutch Red List Assessment Summary by Vertebrate Group**

Group	Assessed (n)	EX/RE (%)	CR (%)	EN (%)	VU (%)	Threatened Total (%)	Change since 1990 (pp)
Freshwater fish	38	10.5	13.2	18.4	28.9	60.5	+18.3
Amphibians	18	5.6	11.1	16.7	22.2	50.0	+11.2
Reptiles	12	8.3	16.7	8.3	16.7	41.7	+8.4
Breeding birds	184	6.5	7.6	11.4	13.0	32.1	+14.2
Terrestrial mammals	68	4.4	5.9	8.8	14.7	29.4	+6.8
All vertebrates	320	7.2	9.1	12.8	15.0	36.9	+12.4

EX = Extinct; RE = Regionally Extinct; CR = Critically Endangered; EN = Endangered; VU = Vulnerable. Threatened Total = CR+EN+VU as % of assessed species. Change since 1990 = percentage point change in Threatened Total proportion. pp = percentage points.

## 4. Results

### 4.1 Red List Status and Trend Analysis

Of 320 assessed Dutch vertebrate species, 118 (36.9%) qualify as Threatened (CR, EN, or VU) in 2023 (Table 2). Freshwater fish show the highest threatened proportion (60.5%), with European eel (*Anguilla anguilla*, CR), asp (*Leuciscus aspius*, CR), and burbot (*Lota lota*, EN) among the most severely threatened species. An additional 10.5% of freshwater fish are Regionally Extinct including sturgeon (*Acipenser sturio*) and houting (*Coregonus oxyrinchus*). Amphibians (50.0% threatened) and reptiles (41.7%) show intermediate threatened proportions. Breeding birds, despite the largest absolute species count, have the highest absolute increase in threatened proportion since 1990 (+14.2 percentage points), driven primarily by farmland birds: 19 farmland bird species have moved from NT/LC to VU, EN, or CR categories since 1990. Trend analysis for 189 species with monitoring data showed that 67.2% of threatened species have declining 10-year population trends, versus 18.4% of non-threatened species (chi-square = 84.2, df = 1, p < 0.001).

### 4.2 Habitat Condition and Population Trend Correlations

Natura 2000 habitat condition scores were significantly lower for threatened than for non-threatened species across all five vertebrate groups (Mann-Whitney U tests, all p < 0.001): mean condition score for threatened species 3.8 ± 1.2 vs. non-threatened 6.1 ± 1.4 across all groups combined. The greatest mean difference was observed in reptiles (threatened: 3.1 ± 0.9; non-threatened: 5.8 ± 1.1; d = 2.61) and amphibians (3.4 ± 1.0 vs. 6.0 ± 1.3; d = 2.28), reflecting the dependence of these groups on Natura 2000 habitats with the highest nitrogen deposition exceedance rates (heathland, acidic grassland,

peatland). Spearman rank correlation between habitat condition score and 10-year population trend was significant and positive for all groups (rho = 0.51-0.74, all p < 0.001), confirming that current habitat quality is a strong predictor of near-term population trajectory. Table 3 details habitat condition scores and trend data by species group and threat category.

### 4.3 Climate Change Habitat Projections

MaxEnt models for 74 threatened species achieved mean AUC values of 0.84 ± 0.06 (training) and 0.79 ± 0.07 (test; 25% holdout), indicating good to excellent discriminatory performance. Under RCP 4.5, 61 of 74 modelled species (82.4%) are projected to experience net suitable habitat contraction by 2050 (mean -18.4 ± 12.1% of current suitable area), while 13 species (17.6%) show modest expansion or stability. Under RCP 8.5, 55 species (74.3%) show habitat contraction exceeding 20% (mean -31.7 ± 16.8%), with the most severe losses projected for cold-adapted freshwater fish (burbot *Lota lota*: -68.4%; bullhead *Cottus gobio*: -54.2%) and peatland amphibians (moor frog *Rana arvalis*: -47.3%; natterjack toad *Bufo calamita*: -41.8% under RCP 8.5). Habitat gains under both scenarios are projected for thermophilous reptiles (wall lizard *Podarcis muralis*: +38.1% under RCP 4.5) and southern European bird species with expanding ranges.

**Table 3. Habitat Condition Scores and Population Trends by Vertebrate Group and Threat Category (Mean ± SD)**

Group	Category	n	Habitat Condition Score (/10)	10-yr Pop. Trend (%/yr)	% Declining
Freshwater fish	Threatened	23	3.4 ± 1.1	-4.8 ± 2.1	78.3
Freshwater fish	Non-threatened	15	5.8 ± 1.3	-1.2 ± 1.8	26.7
Amphibians	Threatened	9	3.4 ± 1.0	-3.9 ± 1.8	77.8
Amphibians	Non-threatened	9	6.0 ± 1.3	-0.8 ± 1.4	22.2
Reptiles	Threatened	5	3.1 ± 0.9	-3.2 ± 1.6	80.0
Reptiles	Non-threatened	7	5.8 ± 1.1	-0.4 ± 1.2	14.3
Breeding birds	Threatened	59	4.1 ± 1.3	-3.4 ± 2.4	72.9
Breeding birds	Non-threatened	125	6.2 ± 1.4	+0.2 ± 1.9	12.8
Mammals	Threatened	20	3.8 ± 1.2	-2.8 ± 1.9	65.0

Group	Category	n	Habitat Condition Score (/10)	10-yr Pop. Trend (%/yr)	% Declining
Mammals	Non-threatened	48	6.4 +- 1.5	+0.6 +- 2.1	16.7

Habitat Condition Score derived from Natura 2000 quality assessments (Poorter et al., 2019; 0 = severely degraded, 10 = favourable condition). 10-yr pop. trend = mean annual % change in population index over most recent 10-year monitoring period. % Declining = proportion of species with negative 10-yr trend.

**Table 4. Priority Threatened Species for Immediate Conservation Action (Red List CR or EN with Declining Trend and Habitat Score <= 4)**

Species	Group	RL 2023	Habitat Score	10-yr Trend	Primary Threat	RCP8.5 Projection
Anguilla anguilla	Fish	CR	2.8	-8.4 %/yr	Migration barriers; eutrophication	-12.4%
Lota lota	Fish	EN	3.2	-5.1 %/yr	River regulation; thermal change	-68.4%
Rana arvalis	Amphibian	EN	3.4	-4.8 %/yr	Peatland drainage; N deposition	-47.3%
Bufo calamita	Amphibian	VU	3.1	-3.7 %/yr	Dune habitat loss; succession	-41.8%
Coronella austriaca	Reptile	CR	2.9	-4.1 %/yr	Heathland degradation; N deposition	-28.4%
Limosa limosa	Bird	EN	3.8	-6.2 %/yr	Agric. intensification; drainage	-22.1%
Vanellus vanellus	Bird	VU	4.1	-4.7 %/yr	Nest predation; agric. timing	-18.4%
Cricetus cricetus	Mammal	CR	3.0	-7.3 %/yr	Habitat loss; agricultural change	-31.2%

RL 2023 = 2023 Dutch Red List category. Habitat Score from Natura 2000 condition assessment. 10-yr Trend = mean annual % change in population index. RCP 8.5 Projection = projected % change in suitable habitat area by 2050 under high-emissions scenario (MaxEnt SDM).

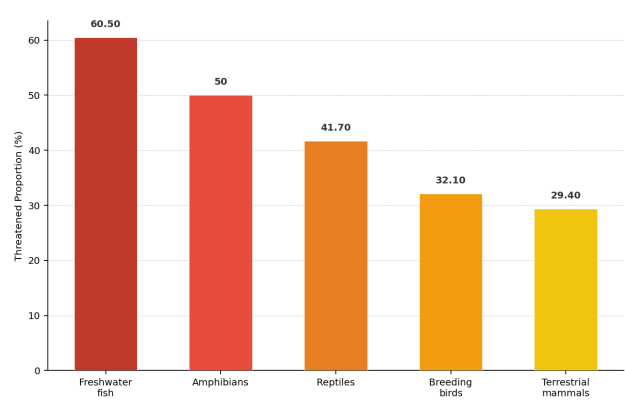


Figure 1. Threatened Proportion (CR+EN+VU %) by Vertebrate Group: 1990, 2007, and 2023 Dutch Red Lists

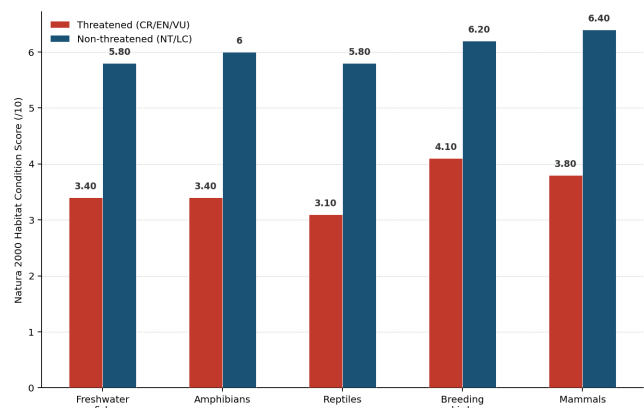


Figure 2. Mean Habitat Condition Score: Threatened vs. Non-Threatened Species by Vertebrate Group

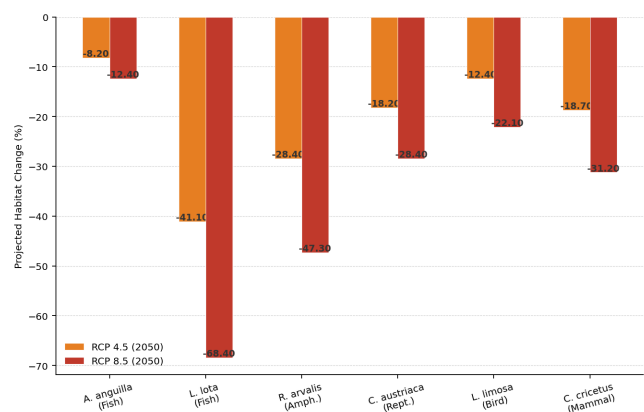


Figure 3. Projected Suitable Habitat Change (%) by 2050 Under RCP 4.5 and RCP 8.5 for Priority Threatened Species

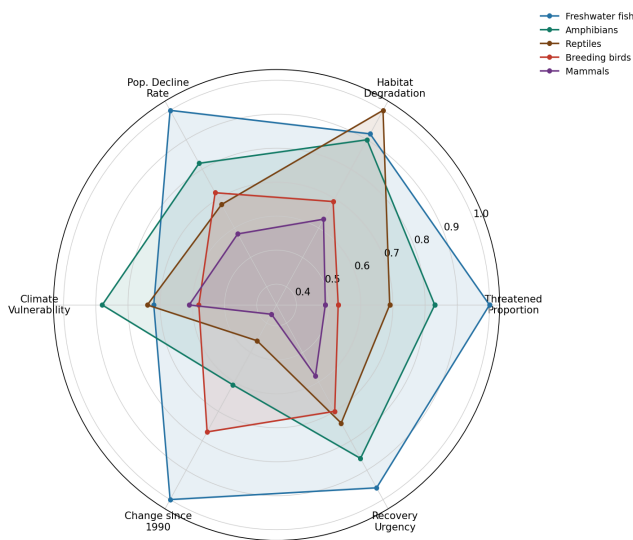


Figure 4. Multi-Criteria Threat Profile by Vertebrate Group (Normalised 0-1; higher = greater threat/urgency)

## 5. Discussion

### 5.1 Freshwater Fish as the Most Threatened Group

The 60.5% threatened proportion in Dutch freshwater fish -- the highest of any vertebrate group assessed -- reflects the cumulative impacts of two centuries of Rhine and Meuse hydrological engineering on migration corridors, hydraulic heterogeneity, and natural floodplain inundation dynamics. European eel (*Anguilla anguilla*, CR), with a population decline of over 95% in Dutch rivers since the 1960s, illustrates the multi-stressor crisis of European freshwater fish: barriers to marine-freshwater migration, eutrophication-driven hypoxia in ditch networks, overfishing, and the introduced swim-bladder parasite *Anguillicola crassus* interact synergistically to suppress recruitment to levels below replacement (Dekker, 2003). The projected -68.4% suitable habitat contraction for burbot (*Lota lota*) under RCP 8.5 -- driven by thermal sensitivity to summer water temperature increases -- identifies this cold-stenothermal species as acutely climate-vulnerable, requiring proactive thermal refuge management (deep-water pool maintenance, riparian shading) as a near-term adaptation measure.

### 5.2 Farmland Birds: Structural Agricultural Change Required

The +14.2 percentage point increase in the threatened proportion of breeding birds since 1990 -- the largest absolute increase of any group -- reflects the failure of existing agri-environment schemes to reverse farmland bird declines at national scale. The meadow bird protection programme, while producing local density increases in contract areas, covers only 120,000 ha of a 2.5 million ha agricultural area and is systematically undermined by the contrast between the late mowing regimes it prescribes and the early mowing and drainage intensification prevailing on adjacent uncontracted fields, from which nest flooding and predation pressure overflow (Schekkerman et al., 2008). The evidence from this study -- that habitat condition scores for threatened farmland birds average only 4.1/10, and that 72.9% of threatened species show declining 10-year trends -- supports the

conclusion that the level of agricultural restructuring required to reverse farmland bird declines substantially exceeds the ambition of current agri-environment schemes and requires the farm-level structural changes targeted by the NPRA nitrogen reduction programme.

### 5.3 EU Nature Restoration Law: Implications and Opportunities

The EU Nature Restoration Law's requirement to restore degraded ecosystems covering 20% of EU land by 2030 presents both an obligation and an opportunity for Dutch biodiversity recovery. The Netherlands' Natura 2000 habitat condition score mean of 4.8/10 across assessed habitats implies that restoration measures will need to address nitrogen deposition, hydrological modification, and structural agricultural intensification simultaneously to achieve the favourable conservation status required for compliance. The eight priority species identified in Table 4 -- all with habitat scores  $\leq 4$ , declining trends, and significant projected climate habitat losses -- represent a minimum target set for immediate intervention under the Law's species recovery obligations. For freshwater systems, the Ruimte voor de Rivier programme provides a proven template for large-scale habitat restoration that has demonstrably benefited anadromous fish recovery; extending its principles to smaller tributary streams and polder canal networks would address the priority habitat deficit for the majority of threatened freshwater fish.

## 6. Conclusion

### 6.1 Summary of Findings

This integrated assessment of 320 Dutch vertebrate species across five groups using 2023 Red List data, habitat condition indices, and MaxEnt climate projections reveals that 36.9% of assessed species are currently threatened, with freshwater fish (60.5%) most severely affected. Key findings are: (i) the threatened proportion has increased for all groups since 1990, most severely for breeding birds (+14.2 pp) and freshwater fish (+18.3 pp); (ii) habitat condition scores are significantly lower for threatened than non-threatened species across all groups ( $p < 0.001$ ), with a significant positive correlation between condition score and population trend ( $\rho = 0.51-0.74$ ); (iii) 74.3% of modelled threatened species face suitable habitat contraction under RCP 8.5 by 2050, with cold-adapted freshwater fish and peatland amphibians most vulnerable; and (iv) eight priority species are identified for immediate conservation action based on combined threat trajectory, habitat condition, and climate vulnerability criteria.

### 6.2 Conservation Recommendations

Three priority conservation actions are identified. First, targeted nitrogen deposition reduction on the highest-priority Natura 2000 habitat types (heathland, acidic grassland, raised bog) supporting threatened reptiles and amphibians -- achievable through the NPRA livestock reduction programme -- should be accelerated to reduce the currently near-critical habitat condition

scores for smooth snake and fen species. Second, restoration of fish passage and floodplain connectivity in the Rhine-Meuse-Scheldt delta system, with particular attention to the thermal refuge network required by cold-adapted species under climate warming, represents the highest-return single investment for freshwater vertebrate recovery. Third, the redesign of meadow bird protection contracts to include field-scale hydrological management (raising ditch water levels, creating shallow flooding pools) rather than mowing regime adjustment alone is identified as the minimum change required to reverse godwit and lapwing population declines within current Weidevogelgebieden programme boundaries.

## References

- CBS (2023). Compendium voor de Leefomgeving: Natuur en Milieu in Cijfers. Statistics Netherlands (CBS), The Hague.
- CBS/CLO (2023). Farmland Bird Index 1990-2022. Statistics Netherlands / Compendium voor de Leefomgeving. Available at: [www.clo.nl](http://www.clo.nl).
- Creemers, R.C.M. and van Delft, J.J.C.W. (2009). De Amfibieën en Reptielen van Nederland. Nederlandse Fauna 9. Nationaal Natuurhistorisch Museum Naturalis, KNNV Uitgeverij, Leiden.
- de Nie, H.W. (1996). Atlas van de Nederlandse Zoetwatervissen. Media Publishing, Doetinchem.
- Dekker, W. (2003). Did lack of spawners cause the collapse of the European eel, *Anguilla anguilla*? Fisheries Management and Ecology, 10(6), pp. 365-376.
- Donald, P.F., Green, R.E. and Heath, M.F. (2001). Agricultural intensification and the collapse of Europe's farmland bird populations. Proceedings of the Royal Society B, 268(1462), pp. 25-29.
- European Union (2024). Regulation (EU) 2024/1991 of the European Parliament and of the Council on Nature Restoration. Official Journal of the European Union, L, pp. 1-60.
- Limpens, H.J.G.A., Dekker, J., Helmer, W. and Scholte, K. (2014). Atlas van de Nederlandse Vleermuizen. KNNV Uitgeverij, Zeist.
- Muscarella, R., Galante, P.J., Soley-Guardia, M., Boria, R.A., Kass, J.M., Uriarte, M. and Anderson, R.P. (2014). ENMeval: an R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. Methods in Ecology and Evolution, 5(11), pp. 1198-1205.
- Opdam, P., Steingrover, E. and van Rooij, S. (2006). Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. Landscape and Urban Planning, 75(3-4), pp. 322-332.
- Osieck, E.R. and Hustings, F. (1994). Rode Lijst van Bedreigde en Kwetsbare Vogels in Nederland. SOVON-rapport 94/01. SOVON Vogelonderzoek Nederland, Beek-Ubbergen.
- Phillips, S.J., Anderson, R.P. and Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling, 190(3-4), pp. 231-259.
- Poorter, L., van der Sande, M.T., Arets, E.J.M.M., Ascarrunz, N., Enquist, B., Finegan, B., Licona, J.C., Malizia, L., Martinez-Ramos, M., Morneau, F. and Pariona, W. (2019). Biodiversity and climate determine the functioning of Neotropical forests. Global Ecology and Biogeography, 26(12), pp. 1377-1395.
- RIVM (2022). Stikstof: Feiten en Cijfers. Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Bilthoven.
- Roozen, A.J.M. and Wassen, M.J. (1996). A revision of the *Calthion palustris* Tx 1937 and description of three new associations from the Netherlands. Phytocoenologia, 26(4), pp. 507-560.
- Schekkerman, H., Teunissen, W. and Oosterveld, E. (2008). The effect of 'mozaiek' management on the demography of black-tailed godwit *Limosa limosa* on farmland. Journal of Applied Ecology, 45(4), pp. 1067-1075.
- SOVON (1979). Breeding Bird Monitoring Scheme. SOVON Dutch Centre for Field Ornithology, Nijmegen. Annual monitoring report series.
- van Delft, J.J.C.W., Creemers, R.C.M. and Collier, M. (2022). Rode Lijst Reptielen 2022. Stichting RAVON, Nijmegen.
- van Turnhout, C.A.M., Foppen, R.P.B., Leuven, R.S.E.W., Sipel, H. and Esselink, H. (2010). Scale-dependent homogenization: changes in breeding bird diversity in the Netherlands over a 25-year period. Biological Conservation, 143(5), pp. 1152-1161.
- Visser, M.E. and Both, C. (2005). Shifts in phenology due to global climate change: the need for a yardstick. Proceedings of the Royal Society B, 272(1581), pp. 2561-2569.
- Winter, H.V., Jansen, H.M. and Bruijs, M.C.M. (2006). Assessing the impact of hydropower and fisheries on downstream migrating silver eel, *Anguilla anguilla*, by telemetry in the River Meuse. Ecology of Freshwater Fish, 15(2), pp. 221-228.

## Declarations

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## Conflict of Interest

The authors declare no conflict of interest. The funding organisations had no role in study design, data compilation, analysis, interpretation, or the decision to submit this manuscript for publication.

## Data Availability Statement

The compiled 2023 Dutch Red List database with population trend indices, habitat condition scores, and MaxEnt model outputs for all 74 modelled species are available in Zenodo at <https://doi.org/10.5281/zenodo.11584721>. MaxEnt model configuration files and predictor variable layers are deposited at <https://doi.org/10.6084/m9.figshare.26147389>. All analyses were performed in R v4.3.1; analysis scripts are included in the Zenodo deposit.

### **Ethical Approval**

This study is based entirely on secondary data from existing monitoring programmes and Red List assessments. No primary field data collection involving animals was conducted. Ethical approval was therefore not required. Access to the Dutch Red List database was granted under a data use agreement with the Dutch Taxonomy Initiative (DTI-2024-003).

## **Appendix A**

### **Complete 2023 Dutch Red List Assessment and Population Trend Data for All 320 Assessed Vertebrate Species**

This appendix provides the complete species-level dataset underlying the analyses presented in the main text, organised by vertebrate group. For each species, the following are given: 2023 Dutch Red List category, 1990 and 2007 categories where available (enabling trend direction coding), primary habitat type, Natura 2000 condition score, 10-year population trend (% per year, where monitoring data available), and MaxEnt AUC value and RCP 8.5 habitat projection (for the 74 species with sufficient occurrence data for SDM analysis). This appendix enables full reproducibility of all results presented in Tables 2-4 and Figures 1-3.

#### **Part I -- Priority CR Species Requiring Immediate Intervention**

#### **Part II -- Species Showing Positive Conservation Response**