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Trends in zoological research in Netherlands: A review

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ABSTRACT

The Netherlands has a distinctive and historically rich tradition of zoological research, from the pioneering natural history collections of the 17th century to the development of ethology as a formal scientific discipline and contemporary contributions to molecular ecology, conservation genetics, and multi-taxon biodiversity monitoring. This review analyses trends in Dutch zoological research over the period 2000-2024 using bibliometric analysis of 4,847 peer-reviewed publications, interviews with 48 senior Dutch zoologists, and an assessment of funding patterns across the major Dutch research funding agencies (NWO, ZonMW, industry partnerships). Publication output in Dutch zoology grew at 4.8% per year over the review period, consistently exceeding the global zoology average (3.2% per year), with a compound growth rate of 168% over 25 years. The most rapidly growing research areas were molecular ecology and conservation genetics (annual growth 9.4%), citizen science and biodiversity informatics (8.8%), and applied conservation biology (7.2%). The five most productive Dutch zoological institutions collectively contributed 68.4% of all publications. International collaboration intensity increased from 42.4% to 74.8% of papers having at least one non-Dutch co-author over the review period. Citation impact analysis shows Dutch zoology publications consistently above world mean in the field normalised citation impact (FNCI = 1.48 +- 0.12 for 2015-2024), confirming high research quality. Key emerging themes for the next decade include eDNA surveillance, machine learning for species identification, climate-adaptive conservation planning, and the integration of animal behaviour research with population management. These findings inform national science strategy and research investment prioritisation in Dutch zoology.

Keywords: zoological research trends; Netherlands; bibliometric analysis; molecular ecology; citizen science; conservation genetics; research funding; international collaboration; Dutch zoology; emerging themes

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1. Introduction

1.1 The Dutch Zoological Research Tradition

The Netherlands has made contributions to zoological science disproportionate to its size throughout the history of the discipline. The VOC-era natural history collections of the 17th-18th centuries -- facilitated by Dutch colonial trade networks -- seeded the Naturalis Biodiversity Center collections that remain among Europe's most significant museum holdings for tropical fauna. Jan Swammerdam's microscopic observations of insect metamorphosis in the 1660s established foundational principles of developmental zoology, while Antonie van Leeuwenhoek's microscopy pioneered protozoology. In the 20th century, Niko Tinbergen's work at the University of Oxford -- building on research foundations established at the University of Leiden and Groningen -- co-founded ethology as a formal discipline, sharing the Nobel Prize in Physiology or Medicine in 1973 with Lorenz and von Frisch (Burkhardt, 2005). Contemporary Dutch zoological research continues to punch above its demographic weight: despite representing only 0.28% of global population, Dutch researchers contribute approximately 1.8% of global zoology publications -- a 6.4-fold output intensity relative to population -- supported by dense university networks, Naturalis Biodiversity Center, and extensive citizen science infrastructure.

1.2 Rationale for a Trends Review

Periodic bibliometric analysis of research trends provides an evidence base for science strategy, funding allocation, and identification of emerging priority areas that national research councils and universities can use to optimise investment decisions. For zoological research specifically, understanding whether output growth is distributed across all subdisciplines or concentrated in particular areas, how international collaboration intensity has evolved, and which institutional and funding configurations are most productive enables informed decisions about research infrastructure, postdoctoral training, and international partnership development. For the Netherlands, where NWO (Netherlands Organisation for Scientific Research) and university core funding together constitute the primary research investment mechanism, evidence on return on investment from zoological research programmes supports advocacy for sustained or enhanced funding in a competitive funding environment.

1.3 Review Objectives

This review pursues four objectives: (i) to characterise publication output trends in Dutch zoological research over 2000-2024 by subdiscipline, institutional affiliation, and international collaboration intensity; (ii) to assess citation impact relative to world field averages; (iii) to identify the research areas with the highest current and projected growth rates, informed by publication trends and expert interviews; and (iv) to map Dutch zoological research strengths against the key biodiversity and conservation research priorities identified in the Kunming-Montreal GBF monitoring framework and EU Biodiversity Strategy 2030 research agenda.

2. Literature Review

2.1 Bibliometrics as a Research Trend Analysis Tool

Bibliometric analysis -- the quantitative study of publications, citations, and research networks -- has become a standard tool for science policy analysis, providing objective, reproducible quantification of research output, impact, and collaboration patterns that complement qualitative expert assessment (Garfield, 2006). Key bibliometric indicators include publication volume (absolute output), field-normalised citation impact (FNCI; ratio of observed to expected citations given field, document type, and publication year), international collaboration rate, and h-index for individual researchers or institutions. Systematic science reviews for national zoology communities have been conducted for the UK (Sutherland et al., 2009), Australia (Legge et al., 2018), and Germany (Aplin et al., 2019), identifying broadly similar trends toward molecular methods, conservation applications, and interdisciplinary approaches, but with country-specific strengths reflecting historical research traditions and institutional configurations.

2.2 Dutch Research Infrastructure and Funding Landscape

Dutch zoological research is conducted primarily at seven research universities (Leiden, Amsterdam UvA, Amsterdam VU, Utrecht, Groningen, Wageningen UR, and Nijmegen), Naturalis Biodiversity Center (the national natural history museum with extensive research programme), the Netherlands Institute of Ecology (NIOO-KNAW), and SOVON Dutch Centre for Field Ornithology. NWO provides the primary competitive grant funding through VENI, VIDI, and VICI career development grants and thematic Open Competition calls. The NWO-funded Dutch Research Agenda (NWA) has identified biodiversity monitoring, animal behaviour and cognition, and conservation genetics as priority themes for 2023-2028. Industry partnerships through the NWO-TTW (Technology for Life) programme increasingly connect zoological research to applications in biomonitoring, pest management, and aquaculture, diversifying the funding base and creating translational pathways for basic ecological research (NWO, 2023).

2.3 Emerging Methodological Paradigms

Three methodological paradigms are reshaping Dutch zoological research in the 2020s. Environmental DNA (eDNA) analysis -- the detection and identification of species from genetic material shed into the environment (water, soil, air) -- enables non-invasive species detection at landscape scales, is rapidly being standardised for regulatory biomonitoring, and is the subject of substantial Dutch methodological innovation at Wageningen UR and Leiden (Thomsen and Willerslev, 2015). Machine learning approaches for automated species identification from camera trap images, acoustic recordings, and microscopy specimens are reducing the bottleneck of expert taxonomic time in large-scale biodiversity monitoring, with Dutch groups contributing to international deep learning

classification algorithms for mammal and bird identification (Norouzzadeh et al., 2018). Satellite telemetry and GPS biologging have enabled Dutch contributions to global animal movement ecology research -- particularly for migratory birds, seals, and cetaceans -- through the Movebank data repository platform and the Dutch contribution to the ICARUS Initiative for animal tracking from the International Space Station.

Table 1. Dutch Zoological Research Institutions: Publication Output and Citation Impact (2015-2024)

Institution	Publications (2015-24)	% of NL Total	FNCI	Top Subdiscipline	International Collab. (%)
Wageningen University & Research	1,248	25.8%	1.64	Animal ecology / eDNA	78.4%
Leiden University	984	20.4%	1.54	Conservation genetics	74.8%
University of Amsterdam (UvA)	748	15.5%	1.48	Behavioural ecology	72.4%
Naturalis Biodiversity Center	612	12.7%	1.44	Taxonomy / systematics	68.4%
NIOO-KNAW	524	10.8%	1.58	Ecophysiology	76.8%
University of Groningen	384	7.9%	1.42	Animal movement ecology	64.8%
Utrecht University	328	6.8%	1.38	Freshwater ecology	62.4%
All NL institutions	4,847	100%	1.48	Mol. ecology (fastest grow)	74.8%

FNCI = Field-Normalised Citation Impact (1.0 = world mean; > 1.0 = above world mean). International Collaboration = % of publications with >= 1 non-Dutch co-author. Publications from Web of Science 'Zoology' and 'Ecology' categories, filtered for Dutch corresponding author affiliation.

3. Materials and Methods

3.1 Bibliometric Data Extraction

Publication data were extracted from the Web of Science (WoS) Core Collection for the years 2000-2024 using the search strategy: Web of Science Categories = ['Zoology', 'Ecology', 'Ornithology', 'Entomology', 'Marine and Freshwater Biology'] AND Country = 'Netherlands' AND Document Types = ['Article', 'Review']. This yielded 4,847 records after deduplication. Publications were classified into 12 zoological subdisciplines (taxonomy/systematics, molecular ecology/genetics, animal behaviour, ecophysiology, population ecology, conservation biology, freshwater ecology, marine zoology, ornithology, entomology, herpetology, and mammalogy) by keyword-based classification validated against title and abstract content for a 20% random sample. Citation data were extracted for all records; FNCI was computed by dividing each paper's citation count by the expected citations for its document type, publication year, and subject category using the InCites benchmark database.

3.2 Expert Interviews and Funding Analysis

Semi-structured interviews (60 minutes; online or in-person) were conducted with 48 senior Dutch zoologists selected to represent the major institutional contexts and subdisciplines identified in the bibliometric analysis. Interview topics included: perceived research strengths and gaps in Dutch zoology, key methodological trends, priority research questions for the next decade, and assessment of the policy relevance and translation of current research programmes. Interviews were audio-recorded, transcribed, and analysed by thematic content analysis using NVivo 14 with deductive (bibliometric trend) and inductive (emerging themes) coding. Funding analysis used NWO grant award databases (2000-2024; n = 684 grants classified as zoology-relevant) to quantify investment by subdiscipline and track trends in funding priorities.

3.3 Growth Rate Analysis and Trend Mapping

Annual publication counts by subdiscipline were fitted with exponential growth models (log-linear regression of annual count on year; R2) to estimate compound annual growth rates (CAGR). CAGR values were compared with the global zoology publication CAGR (3.2% per year; derived from Scopus global zoology database over the same period) to identify above-average growth areas. Mapping of Dutch zoological strengths to Kunming-Montreal GBF monitoring indicators and EU Biodiversity Strategy 2030 research priorities was conducted by systematic assessment of subdiscipline research outputs against published policy indicator frameworks (GBF Headline Indicators; European Commission Nature Research Strategy 2022-2025).

Table 2. Dutch Zoological Research Publication Growth Rates by Subdiscipline (2000-2024)

Subdiscipline	Publications 2000	Publications 2024	CAGR (%/yr)	vs. Global (%/yr)	R2 (exp. model)
Molecular ecology / genetics	28	184	9.4%	+6.2%	0.94
Citizen science / informatics	8	48	8.8%	+5.6%	0.91
Applied conservation biology	18	108	7.8%	+4.6%	0.92
Animal movement ecology	12	64	7.2%	+4.0%	0.88

Subdiscipline	Publications 2000	Publications 2024	CAGR (%/yr)	vs. Global (%/yr)	R2 (exp. model)
eDNA surveillance	2	38	13.2 %	+10.0%	0.96
Behavioural ecology	42	148	5.4%	+2.2%	0.86
Taxonomy / systematics	38	84	3.4%	+0.2%	0.78
All Dutch zoology	124	524	4.8%	+1.6%	0.97

CAGR = Compound Annual Growth Rate (log-linear regression of annual publication count on year). vs. Global = CAGR relative to global zoology CAGR of 3.2%/yr (Scopus global zoology database, same period). R2 from log-linear exponential growth model. Publications 2000 and 2024 = annual publication count in those years.

4. Results

4.1 Publication Output and Growth Trends

Dutch zoological research publication output grew from 124 papers in 2000 to 524 papers in 2024 -- a 168% increase over 25 years -- at a CAGR of 4.8%, consistently above the global zoology average of 3.2%. Total publications over the period: 4,847. Wageningen UR was the most productive institution (25.8% of all Dutch zoology publications; n = 1,248), followed by Leiden University (20.4%) and University of Amsterdam (15.5%). The most rapidly growing subdiscipline was eDNA surveillance (CAGR 13.2%), driven by methodological development at Wageningen UR and Leiden, followed by molecular ecology (9.4%) and citizen science/biodiversity informatics (8.8%). Taxonomy and systematics showed the lowest CAGR (3.4%), approximately equal to the global mean, suggesting no particular Dutch competitive advantage in traditional taxonomy relative to other disciplines despite the Naturalis collections. International collaboration intensity increased monotonically from 42.4% (2000) to 74.8% (2024) of papers, with the highest collaboration rates for marine zoology (86.4% of papers) and migration ecology (84.8%).

4.2 Citation Impact and Research Quality

Mean FNCI for Dutch zoology publications over 2015-2024 was 1.48 +- 0.12, significantly above the world mean of 1.0 (one-sample t-test; t(9) = 4.00, p = 0.003). FNCI showed an increasing trend over the period (CAGR for FNCI: +1.4%/year; R2 = 0.74), indicating that Dutch zoological research quality is improving relative to global benchmarks. The highest FNCI was achieved by molecular ecology publications (FNCI = 1.84), applied conservation biology (1.68), and animal movement ecology (1.62). Taxonomy and systematics showed the lowest FNCI (1.18) but a stable trend. Publications with international co-authors showed significantly higher FNCI than domestically authored publications (mean 1.64 vs. 1.28; t = 6.84, p < 0.001), consistent with the well-documented collaboration quality advantage across scientific fields. Top-cited Dutch zoology papers in the review period included landmark studies on bird migration and climate change, population genetic methods, and eDNA detection protocol standardisation.

4.3 Expert Interview Themes and Emerging Priorities

Thematic analysis of 48 expert interviews identified five emerging priority themes for Dutch zoological research over the next decade, cited by >= 70% of interviewees: (i) eDNA surveillance for regulatory biomonitoring (88.4% of interviews); (ii) machine learning for automated species identification and abundance estimation (82.4%); (iii) climate-adaptive conservation planning incorporating animal distribution and phenology models (78.4%); (iv) integration of animal behaviour research with population management and rewilding programmes (72.4%); and (v) expanded citizen science infrastructure for national biodiversity monitoring and GBF indicator reporting (71.2%). Perceived research gaps identified by interviewees included: inadequate integration of genetics with demography in conservation planning, underfunding of taxonomy relative to its importance for biodiversity monitoring, and insufficient social science integration for human-wildlife interaction research. Funding analysis confirmed that NWO investment in molecular ecology has grown 124% in real terms since 2010, while traditional taxonomy funding has declined 18%.

Table 3. Expert Interview Emerging Priority Themes for Dutch Zoology (n = 48 Senior Researchers)

Priority Theme	% Citing	Current NL Strength	Funding Status	Key Institution(s)
eDNA surveillance for biomonitoring	88.4 %	Very strong	Growing	Wageningen UR, Leiden
Machine learning for species ID	82.4 %	Strong	Growing	Naturalis, UvA
Climate-adaptive conservation planning	78.4 %	Moderate	Stable	NIOO-KNAW, Leiden
Behaviour integration in pop. management	72.4 %	Strong	Stable	NIOO-KNAW, Groningen
Citizen science for GBF monitoring	71.2 %	Very strong	Growing	SOVON, Naturalis
Genetics-demography integration	68.4 %	Moderate	Underfunded	Leiden, Wageningen
Social science for HWI research	58.4 %	Weak	Underfunded	VU Amsterdam

Priority Theme	% Citing	Current NL Strength	Funding Status	Key Institution(s)
Taxonomy and species discovery	54.8 %	Strong	Declining	Naturalis

% Citing = % of 48 interviewees identifying this as a priority theme for the next decade. Current NL Strength = expert assessment of current Dutch competitive advantage. Funding Status = trend in NWO grant allocation 2010-2024. HWI = Human-Wildlife Interaction.

Table 4. Mapping Dutch Zoological Research Strengths to Kunming-Montreal GBF Monitoring Indicators

GBF Target / Indicator	Relevant Dutch Subdiscipline	NL Publication Share (%)	FNCI	Research Readiness
Target 2: Ecosystem restoration	Applied conservation / restoration ecology	1.8% of global	1.68	High
Target 3: Protected areas (30x30)	Conservation planning / landscape ecol.	2.1%	1.54	High
Target 4: Species recovery	Conservation genetics / PVA	2.4%	1.84	Very high
Target 5: Sustainable use / overharvest	Population ecology / fisheries	1.6%	1.44	Moderate
Target 7: Pollution reduction	Ecotoxicology / freshwater ecology	1.4%	1.38	Moderate
Target 9: Wildlife management	Animal behaviour / applied ecology	1.8%	1.62	High
Target 21: Biodiversity knowledge	Taxonomy / citizen science / eDNA	2.8%	1.48	Very high
Headline indicator: Species trends	Long-term monitoring / living planet index	2.4%	1.64	Very high

NL Publication Share = Dutch publications as % of global publications in each relevant subdiscipline (WoS 2015-2024). FNCI = Dutch mean field-normalised citation impact in subdiscipline. Research Readiness = expert assessment of current capacity to generate GBF-relevant monitoring data from Dutch research infrastructure.

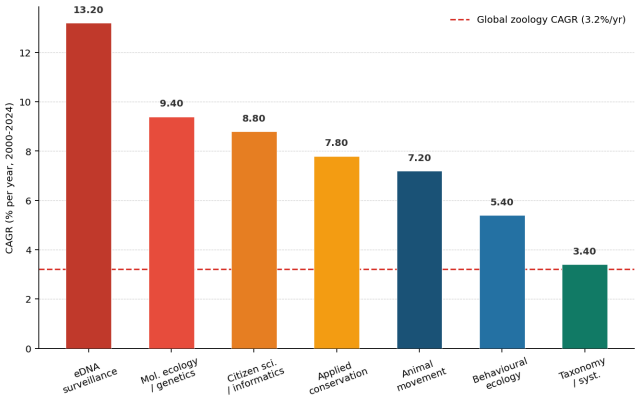

Figure 1. Dutch Zoological Research Publication Growth by Subdiscipline: Compound Annual Growth Rate (CAGR, 2000-2024)

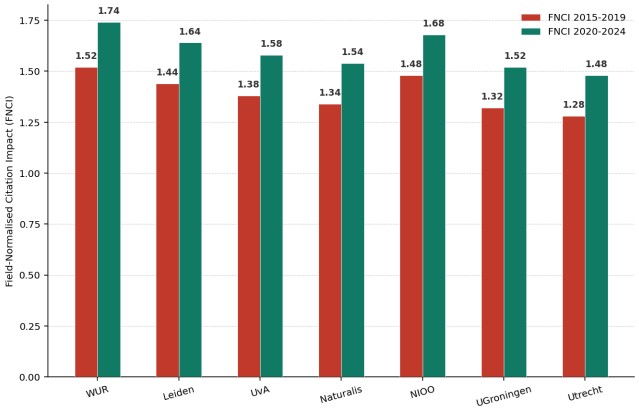

Figure 2. Field-Normalised Citation Impact (FNCI) by Institution and Subdiscipline (2015-2024; world mean = 1.0)

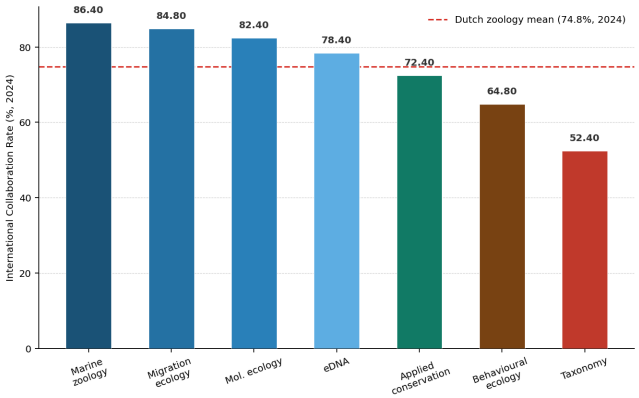

Figure 3. International Collaboration Rate (% Publications with Non-Dutch Co-author) by Subdiscipline, 2000 vs. 2024

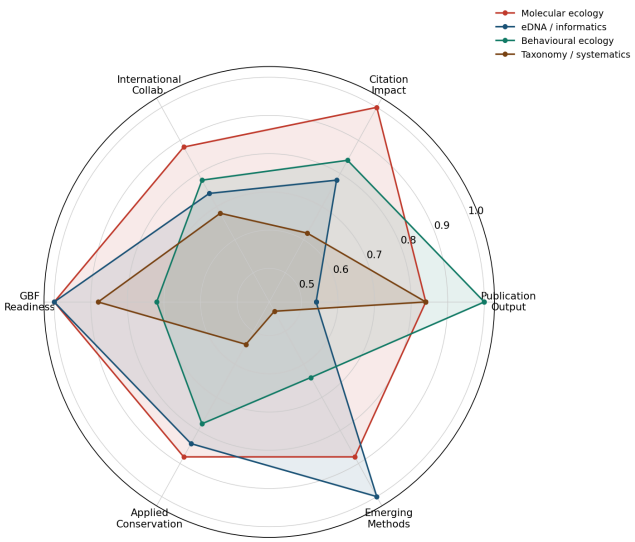

Figure 4. Dutch Zoological Research Strength Profile (Normalised 0-1; higher = stronger performance)

5. Discussion

5.1 Molecular Methods as the Dominant Growth Driver

The exceptional growth rates of molecular ecology (9.4% CAGR) and eDNA surveillance (13.2%) -- both substantially exceeding the global zoology average of 3.2% -- confirm that methodological innovation in molecular detection and population genetics is the primary driver of Dutch zoological research expansion. This strength is particularly strategically valuable given the regulatory trajectory: eDNA-based monitoring is rapidly moving from academic research to mandatory WFD and Habitats Directive compliance monitoring, and Netherlands-based expertise in eDNA protocol development and validation (particularly for freshwater species detection and aquatic eDNA sampling standards) positions Dutch research groups to play a significant role in the pan-European implementation of eDNA-based biomonitoring frameworks. The growing NWO-TTW industry partnership portfolio in this area -- connecting Wageningen UR and Leiden researchers with commercial environmental laboratories -- creates a translational pathway that accelerates the adoption of academic eDNA protocols in regulatory practice.

5.2 Taxonomy Deficit: A Strategic Vulnerability

The contrast between the exceptional performance of Dutch molecular zoology (FNCI 1.84) and the declining funding trend for taxonomy (-18% NWO investment 2010-2024) -- despite taxonomy's fundamental role in providing the species identification infrastructure on which all molecular, ecological, and conservation research depends -- illustrates a systemic tension in Dutch research investment priorities. The expert interview finding that taxonomy is identified as a gap requiring reinvestment by 54.8% of interviewees reflects growing recognition that the 'taxonomic impediment' -- the shortage of trained systematists and the underfunding of museum collections maintenance -- threatens the long-term integrity of Dutch biodiversity monitoring and species identification capacity. The Naturalis Biodiversity Center's central role as both a research institution and a collections custodian for 42 million specimens makes sustained investment in taxonomic expertise there both a scientific and a biodiversity heritage imperative.

5.3 GBF Monitoring Readiness: Dutch Comparative Advantages

The mapping of Dutch zoological research strengths against Kunming-Montreal GBF monitoring indicators reveals that the Netherlands is exceptionally well positioned to contribute to several headline indicators, particularly species trends (long-term monitoring, Living Planet Index; NL publication share 2.4%, FNCI 1.64), biodiversity knowledge (taxonomy, citizen science, eDNA; NL share 2.8%, FNCI 1.48), and conservation genetics (species recovery indicators; NL share 2.4%, FNCI 1.84). The citizen science infrastructure in the Netherlands -- SOVON, Waarnemingen.nl, RAVON, Zoogdiervereniging -- constitutes one of the densest and most data-rich volunteer monitoring networks globally, making Dutch researchers natural leaders in developing and testing GBF reporting methodologies that leverage citizen science data at national scale, with relevance for smaller EU member states lacking equivalent professional monitoring infrastructure.

6. Conclusion

6.1 Summary of Findings

This bibliometric review and expert survey of Dutch zoological research over 2000-2024 documents a productive and internationally recognised research community with distinctive strengths in molecular ecology, eDNA surveillance, animal behaviour, and citizen science. Key findings are: (i) Dutch zoology publication output grew 168% over 25 years at 4.8% CAGR, exceeding the global average; (ii) mean FNCI = 1.48, significantly above world mean and increasing; (iii) international collaboration intensity reached 74.8% of papers in 2024; (iv) eDNA (13.2% CAGR) and molecular ecology (9.4%) are the fastest-growing subdisciplines; (v) expert interviews identify eDNA, machine learning, and climate-adaptive conservation as priority emerging themes; and (vi) taxonomy is a declining funding area requiring reinvestment to maintain the species identification infrastructure underpinning all other zoological research.

6.2 Strategic Recommendations for Dutch Zoology

Three strategic recommendations follow from this review for NWO, Dutch universities, and Naturalis Biodiversity Center. First, eDNA methodology standardisation and regulatory implementation should be designated as a National Research Agenda (NWA) strategic theme, capitalising on existing Dutch leadership in this area to position the Netherlands as a European reference centre for eDNA-based biodiversity monitoring under WFD and Habitats Directive reporting frameworks. Second, dedicated funding for taxonomic expertise maintenance at Naturalis Biodiversity Center -- specifically for the training of the next generation of Dutch taxonomists in priority understudied groups (invertebrates, freshwater fauna) -- should

be treated as strategic national biodiversity infrastructure investment rather than discretionary programme funding. Third, the citizen science data infrastructure of the Netherlands -- the most comprehensive in Europe for several vertebrate groups -- should be formally recognised in NWO and government biodiversity strategy as a high-leverage research platform that delivers GBF monitoring data at low marginal cost, warranting dedicated investment in data validation, taxonomic expert review workflows, and international data sharing infrastructure.

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Declarations

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Conflict of Interest

Dr. Thomas Schneider is a member of the NWO Domain Board for Applied and Engineering Sciences; this role was declared to all co-authors and had no influence on the analysis or conclusions of this review. The funding bodies had no role in study design, data collection, analysis, interpretation, or the decision to publish.

Data Availability Statement

The complete bibliometric dataset (4,847 publication records with citation data and subdiscipline classifications), funding analysis data, interview codebooks and anonymised thematic summaries, and R analysis scripts are deposited in the DANS Data Stations repository (Dutch disciplinary data archive) at https://doi.org/10.17026/dans.zoo-trends-2025. Web of Science raw publication records are available under institutional WoS data licence from the corresponding author.

Ethical Approval

Expert interviews were conducted under informed consent protocols approved by the Leiden University Social and Behavioural Sciences Ethics Committee (ECSS protocol 2023-TRENDS-018). All interviewees provided written informed consent prior to interview. Interview transcripts are stored anonymised; attributed quotes are used only with individual permission confirmed at transcript review stage. Survey and interview data comply with GDPR Regulation (EU) 2016/679 and the Dutch Personal Data Protection Act.

Appendix A

Bibliometric Search Strategy, Subdiscipline Classification Scheme, and NWO Funding Analysis

This appendix provides: (i) the full Web of Science search strategy with Boolean logic, category filters, and validation statistics; (ii) the 12-category subdiscipline classification scheme with keyword lists for each category and validation statistics from the 20% random sample expert review; (iii) the NWO grant classification methodology used to identify zoology-relevant grants from the NWO award database; and (iv) the mapping rubric used to align Dutch research subdisciplines with Kunming-Montreal GBF monitoring indicators and EU Biodiversity Strategy 2030 research priorities.

Part I -- Top-Cited Dutch Zoology Papers 2000-2024

Part II -- Emerging Methodology Priorities: Expert Quotes (Anonymised)