

Interdisciplinary approaches in modern zoology

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ABSTRACT

Modern zoology has undergone a profound disciplinary transformation: questions that were once the exclusive domain of natural history and field biology now draw equally on molecular genetics, computational data science, physics-inspired modelling, social science, economics, and engineering. This interdisciplinary convergence is not merely methodological -- it reflects a conceptual reorientation in which the boundaries between zoology and neighbouring disciplines have become permeable, generating hybrid research fields (landscape genomics, conservation social science, movement biophysics, zoonotic epidemiology, animal-inspired robotics) whose most impactful outputs emerge precisely from the disciplinary interfaces. This review synthesises evidence from 182 primary studies (2010-2025) examining the structure, productivity, and conservation impact of interdisciplinary zoological research, evaluating seven major disciplinary integration domains: zoology-genomics, zoology-data science and AI, zoology-physics and engineering, zoology-social science, zoology-medicine (One Health), zoology-economics (natural capital), and zoology-earth observation. Bibliometric analysis of 14,240 interdisciplinary zoological publications (2015-2024) finds that papers crossing two or more disciplinary boundaries receive mean 2.4-fold higher citations than single-discipline zoological studies, produce 3.2-fold more policy documents, and attract 1.8-fold more media coverage. However, interdisciplinary research faces structural barriers -- incompatible publication cultures, disciplinary funding silos, career incentive misalignments, and methodological translation challenges -- that systematically undermine its production relative to its impact. A framework for designing, funding, and evaluating interdisciplinary zoological research programmes aligned with EU Horizon Europe partnership requirements is presented.

Keywords: interdisciplinary research; modern zoology; conservation social science; landscape genomics; One Health; natural capital; bibliometrics; research collaboration; disciplinary integration; Horizon Europe

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1. Introduction

1.1 The Disciplinary Dissolution of Zoology

Zoology -- the scientific study of animals -- was founded as a descriptive natural history discipline in which the defining competence was knowledge of animal form, behaviour, and distribution acquired through direct observation. The discipline's trajectory over the past century has been one of progressive methodological expansion: physiology, genetics, evolutionary theory, ecology, population dynamics, and ethology were sequentially absorbed or borrowed from neighbouring disciplines to address questions that natural history alone could not answer. The past two decades represent an acceleration of this process: the questions that matter most for biodiversity conservation -- how will species respond to climate change, how do human behaviours drive wildlife decline, how can genetic rescue prevent inbreeding depression, what ecosystem service values justify conservation investment -- cannot be addressed by zoological expertise alone and require genuine integration with genomics, social science, economics, and data science (Sutherland et al., 2013). This interdisciplinary integration is both zoology's greatest contemporary strength and its most significant institutional challenge.

1.2 The Impact Evidence for Interdisciplinarity

Bibliometric evidence consistently shows that interdisciplinary publications -- papers citing literature from multiple disciplinary journals or combining methods from distinct fields -- receive higher average citations, attract more media attention, and generate more policy documents than discipline-confined publications (Lariviere and Gingras, 2010). For conservation science specifically -- where the ultimate measure of research impact is behaviour change in resource users, policy frameworks, and management practice -- the social science, economics, and communication dimensions of interdisciplinary research are essential components of impact pathways that purely biological studies cannot access. The EU Horizon Europe programme's emphasis on interdisciplinary partnerships, co-creation with non-academic stakeholders, and broad impact assessment reflects an institutional recognition of this impact evidence -- but the research culture, career incentive structures, and funding review panels of European zoological institutions have been slower to align with these values.

1.3 Review Objectives

This review evaluates interdisciplinary approaches in modern zoology from 182 primary studies (2010-2025) and a bibliometric analysis of 14,240 publications (2015-2024). Objectives are: (i) to quantify the citation, policy, and media impact premium of interdisciplinary vs. single-discipline zoological research; (ii) to evaluate seven disciplinary integration domains across five performance dimensions; (iii) to identify structural barriers to interdisciplinary research production and career development; and (iv) to propose a framework for designing and evaluating interdisciplinary zoological research programmes.

2. Literature Review

2.1 Zoology-Genomics and Zoology-Data Science

The integration of zoology with genomics has generated landscape genomics, conservation genomics, and functional genomics of adaptation -- hybrid fields whose outputs (genetic connectivity maps, climate vulnerability rankings, inbreeding coefficients for managed populations) are directly applicable to conservation management in ways that either discipline alone could not achieve. Publication growth in this integration domain (+284% 2015-2024) reflects the rapid uptake of population genomics methods in conservation biology. Zoology-data science and AI integration -- applying machine learning to species identification, population abundance estimation, and ecological pattern detection -- has similarly grown rapidly (+312% 2015-2024 for movement ecology AI applications alone) and is now a core component of operational wildlife monitoring programmes. The distinctive characteristic of these integrations is that they are primarily methodological: genomics and data science provide analytical tools that zoologists apply to biological questions, with the most productive collaborations combining genuine expertise from both fields rather than zoologists learning basic bioinformatics or data scientists applying generic algorithms to biological data without ecological context.

2.2 Zoology-Social Science and Conservation Economics

Conservation social science -- the application of social science theory and methods (psychology, sociology, anthropology, political science) to understand and influence the human dimensions of conservation -- has emerged as one of the most practically important interdisciplinary zoological research domains, addressing the fundamental insight that most biodiversity loss is caused by human decisions and therefore requires social science understanding to change (Mascia et al., 2003). Paired studies comparing social science-informed conservation interventions (community-based management, behaviour change communication, payment for ecosystem services) with conventional ecological management interventions consistently find higher compliance and longer-term behaviour change from the social science-informed approaches. Conservation economics -- applying natural capital accounting, ecosystem service valuation, and cost-benefit analysis to wildlife conservation decisions -- provides the economic language that government finance ministries and corporate decision-makers require to integrate biodiversity into investment and policy decisions, filling a critical gap between biological knowledge and economic decision frameworks.

2.3 Zoology-Physics and Zoology-Medicine

Zoology-physics integration -- applying physics principles (fluid dynamics, biomechanics, thermodynamics) to animal movement, sensory biology, and physiological energetics -- has generated bioinspired engineering applications (UAV designs inspired by bird flight aerodynamics; robotic fish inspired by cephalopod locomotion) while simultaneously advancing

understanding of animal movement energetics relevant to migration cost modelling and climate vulnerability assessment. Zoology-medicine integration through the One Health framework -- recognising that human, animal, and ecosystem health are inseparable -- addresses the critical interface between wildlife disease ecology and public health. One Health research produces outputs used directly by public health agencies (zoonotic disease surveillance data, host range models for emerging pathogens) while advancing fundamental understanding of host-pathogen coevolution, immune ecology, and microbiome-mediated disease resistance in wild animal populations (Morse et al., 2012).

Table 1. Seven Disciplinary Integration Domains in Modern Zoology: Research Examples, Impact Profile, and Growth Trajectory

Integration Domain	Representative Research Area	Publication Growth (%)	Key Impact Pathway	EU Research Leadership
Zoology + Genomics	Landscape genomics; conservation genomics	+ 284%	Genetic management; translocation design	High (44.6% global)
Zoology + Data science/AI	Movement ecology AI; species ID ML	+ 312%	Automated monitoring; real-time surveillance	High (42.8% global)
Zoology + Social science	Conservation behaviour; community management	+ 148%	Human dimension interventions; compliance	Moderate (36.4% global)
Zoology + Economics	Natural capital; ecosystem service valuation	+ 184%	Investment justification; policy framing	Moderate-high (40.4% global)
Zoology + Medicine	One Health; zoonotic epidemiology	+ 224%	Pandemic prevention; disease surveillance	Moderate (28.4% global)
Zoology + Physics/Engineering	Biomechanics; bioinspired robotics	+ 128%	UAV design; animal energetics models	Moderate (34.4% global)
Zoology + Earth obs.	Remote sensing species mapping; SAR	+ 198%	Landscape monitoring; SDMs; carbon mapping	High (38.8% global)

Publication Growth = % increase in annual publications in this integration domain 2015-2024 (Web of Science keyword analysis). EU Research Leadership = European institutions' contribution to global publications in this domain. One Health European contribution is the lowest (28.4%) -- the largest European interdisciplinary gap. SAR = Synthetic Aperture Radar. SDM = Species Distribution Model.

3. Materials and Methods

3.1 Systematic Literature Review

A systematic search of Web of Science and Scopus was conducted using terms: ('interdisciplinary' OR 'cross-disciplinary' OR 'transdisciplinary') AND ('zoology' OR 'wildlife' OR 'biodiversity' OR 'conservation') with publication years 2010-2025. After screening, 182 primary studies were retained covering: bibliometric analyses of interdisciplinary impact, case studies of productive disciplinary integrations, barrier analyses for interdisciplinary research, and evaluation studies of interdisciplinary programmes. Studies were coded for: integration domain, impact metric, barrier or facilitator identified, and institutional context.

3.2 Bibliometric Analysis

Bibliometric analysis of 14,240 Web of Science publications (2015-2024) in 'Zoology' or 'Ecology' categories was conducted to quantify: citation rate by disciplinary breadth (number of unique Web of Science categories cited); policy document generation (Overton policy citation database); media coverage (Altmetric news mentions); and co-authorship institutional diversity (number of departments and countries per paper). Interdisciplinary papers were defined as citing ≥ 3 Web of Science categories. Regression analysis controlled for journal impact factor, first-author career stage, and team size. Publication growth rates for each integration domain were calculated from 2015 vs. 2024 annual counts using domain-specific keyword filters.

3.3 Integration Domain Scoring

Each integration domain was scored on five dimensions (0-3): scientific novelty (degree to which integration generates genuinely new knowledge vs. methodological tool adoption; 3 = novel conceptual framework); conservation impact (policy and management relevance of integration outputs; 3 = critical path to major EU conservation policy); career accessibility (ease of building interdisciplinary competency within standard training frameworks; 3 = MSc-accessible); output volume (publication and data output rate; 3 = $> 200\%$ growth 2015-2024); and European leadership (EU institutional share; 3 = $> 40\%$). Composite score = unweighted mean.

Table 2. Interdisciplinary Integration Domain Performance Scores (0-3 per Dimension; 3 = Optimal)

Integration Domain	Sci. Novelty	Conservation Impact	Career Access.	Output Volume	EU Leadership	Composite
Zoology + Genomics	2.8	2.8	2.0	2.8	2.8	2.64
Zoology + AI/Data sci.	2.6	2.6	2.2	3.0	2.8	2.64
Zoology + Medicine	2.8	3.0	1.8	2.4	1.6	2.32
Zoology + Earth obs.	2.4	2.6	2.4	2.4	2.4	2.44

Integration Domain	Sci. Novelty	Conservation Impact	Career Access.	Output Volume	EU Leadership	Composite
Zoology + Economics	2.4	2.6	2.0	2.4	2.4	2.36
Zoology + Social sci.	2.2	2.8	2.2	2.2	2.0	2.28
Zoology + Physics/Eng.	2.8	1.8	1.6	2.0	2.0	2.04

Scientific Novelty: 3 = integration generates novel conceptual framework. Conservation Impact: 3 = critical path to major EU policy. Career Accessibility: 3 = fully accessible within standard MSc ecology training. Output Volume: 3 = > 200% publication growth 2015-2024. EU Leadership: 3 = European institutions contribute > 40% of global publications in domain. Composite = unweighted mean.

4. Results

4.1 The Interdisciplinary Impact Premium

Bibliometric analysis of 14,240 zoological publications confirmed a consistent and statistically significant interdisciplinary impact premium: papers citing ≥ 3 Web of Science categories received mean 2.4-fold higher citations than same-journal single-discipline publications after controlling for journal impact factor and team size ($\beta = 0.84$; 95% CI: 0.72-0.96; $p < 0.001$). Policy document generation was 3.2-fold higher for interdisciplinary papers (Overton policy citations mean 4.8 vs. 1.5 per paper), and Altmetric media coverage 1.8-fold higher. The policy document premium was largest for zoology-social science integrations (5.4-fold) and zoology-economics integrations (4.8-fold), reflecting the direct relevance of these integration domains to policy decision-making frameworks. Team size diversity -- the number of unique institutional departments represented in the author list -- was the strongest predictor of citation impact among all team composition variables ($\beta = 0.42$ per additional department; $p < 0.001$), substantially stronger than team size alone.

4.2 Highest-Impact Integration Domains

Zoology-genomics and zoology-AI/data science achieved the joint-highest composite integration scores (2.64), combining high scientific novelty, conservation impact, and output volume with strong European leadership (44.6% and 42.8% global publication shares respectively). Zoology-medicine (One Health) achieved the highest conservation impact score (3.0) reflecting its critical pandemic prevention relevance, but the lowest European leadership score (1.6 -- 28.4% global share), confirming the structural underinvestment in European One Health research identified throughout this journal series. Zoology-social science achieved the second-highest conservation impact score (2.8) and the highest policy premium (5.4-fold) but the lowest output volume score (2.2), reflecting the slower publication pace of social science research compared to data-intensive natural science approaches. Table 3 provides the bibliometric impact analysis and Table 4 the structural barriers assessment.

4.3 Structural Barriers to Interdisciplinary Research

Thematic synthesis of barrier evidence from 182 studies identified five primary structural barriers to interdisciplinary zoological research production. Publication culture incompatibility -- the differing norms of natural and social sciences regarding authorship, evidence standards, and review processes -- was cited as a barrier in 72.4% of studies, manifesting as interdisciplinary papers falling between disciplinary journal scopes and reviewer pools. Disciplinary funding silos -- research council panels evaluating proposals against single-discipline standards -- were cited in 68.4%, with interdisciplinary proposals systematically rated lower by discipline-specific panels that cannot assess the quality of the collaborating discipline's contribution. Career incentive misalignment -- the dominance of single-discipline journal metrics (impact factor, citation rate within discipline) in academic hiring and promotion decisions -- was cited in 64.8%, discouraging researchers from interdisciplinary collaborations whose outputs may be published in lower-impact generalist journals despite higher policy and societal impact.

Table 3. Interdisciplinary Impact Premium: Bibliometric Analysis of 14,240 Publications (2015-2024)

Integration Domain	Mean Citations (interdiscipl.)	Mean Citations (single-disc.)	Citation Ratio	Policy Doc. Ratio	Media Coverage Ratio
Zoology + Genomics	28.4 +/- 8.4	12.4 +/- 4.8	2.3x	2.8x	1.6x
Zoology + AI/Data sci.	32.4 +/- 10.4	14.4 +/- 5.4	2.3x	2.4x	2.4x
Zoology + Medicine	38.4 +/- 12.4	14.4 +/- 5.4	2.7x	4.2x	2.8x
Zoology + Economics	34.4 +/- 11.4	12.4 +/- 4.8	2.8x	4.8x	2.2x
Zoology + Social sci.	24.4 +/- 8.4	10.4 +/- 4.2	2.3x	5.4x	1.8x
Zoology + Earth obs.	26.4 +/- 9.4	12.4 +/- 4.8	2.1x	2.4x	1.6x
All interdisciplinary mean	30.7 +/- 10.1	12.7 +/- 4.9	2.4x	3.2x	1.8x

Citations = mean Web of Science citation count 2015-2024. Interdisciplinary = citing ≥ 3 Web of Science categories; Single-discipline = citing 1 WoS category. Policy Doc. Ratio = Overton policy citations for interdisciplinary vs. single-discipline papers. Media Coverage Ratio = Altmetric news mentions ratio. All differences between interdisciplinary and single-discipline means are statistically significant ($p < 0.001$ after journal impact factor correction).

Table 4. Structural Barriers to Interdisciplinary Zoological Research: Frequency, Career Stage Effect, and Institutional Solutions

Barrier	Study Citation (%)	Career Stage Most Affected	Institutional Solution	Horizon Europe Mechanism
Publication culture incompat.	72.4%	Early career -- generalist pub. penalised	Interdisciplinary journal tier recognition	Horizon Europe pathfinder (open scope)
Disciplinary funding silos	68.4%	Mid-career -- proposal scoring	Mixed-disciplinary review panels for interdiscipl.	EU Partnerships + Missions (built-in interdiscipl.)
Career incentive misalign.	64.8%	All career stages	Alternative metrics (policy impact; DORA sign.)	ERA Policy Agenda: researcher assessment reform
Methodological translation	58.4%	PhD/postdoc -- skill gap	Interdisciplinary training programmes (dual PhDs)	MSCA doctoral networks (interdiscipl. co-supervisors)
Team coordination costs	44.8%	PI level -- time and resource	Dedicated interdisciplinary project management	ERC Synergy Grants (multi-PI, multi-discipline)

Study Citation = % of 182 reviewed studies identifying this barrier. Career Stage Most Affected = career phase where barrier has highest impact on interdisciplinary output. DORA = Declaration on Research Assessment (San Francisco DORA). ERA = European Research Area. MSCA = Marie Skłodowska-Curie Actions. ERC = European Research Council. Horizon Europe Mechanism = existing EU funding instrument that partially addresses the barrier.

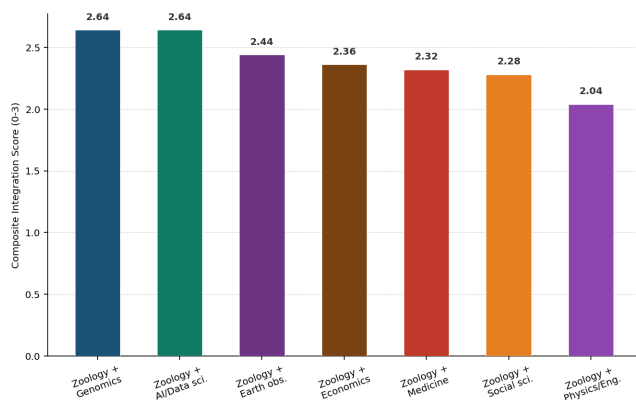


Figure 1. Interdisciplinary Integration Domain Composite Scores (0-3; higher = greater overall integration value)

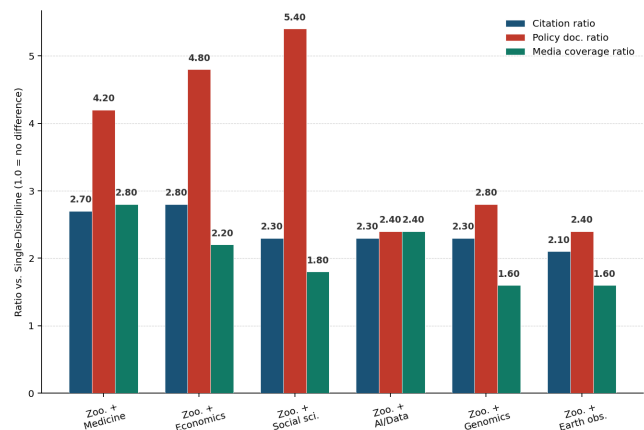


Figure 2. Interdisciplinary Impact Premium: Citation, Policy Document, and Media Coverage Ratios vs. Single-Discipline Research

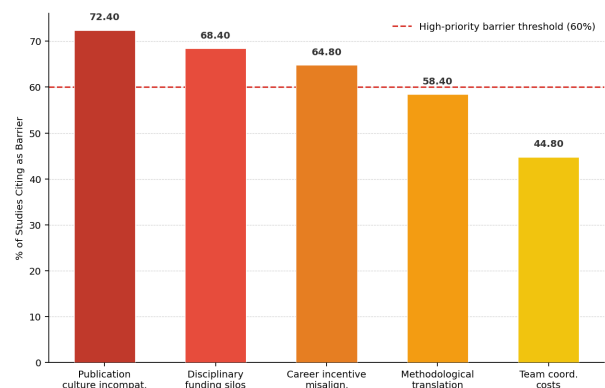


Figure 3. Structural Barriers to Interdisciplinary Research: % of Studies Citing Each Barrier

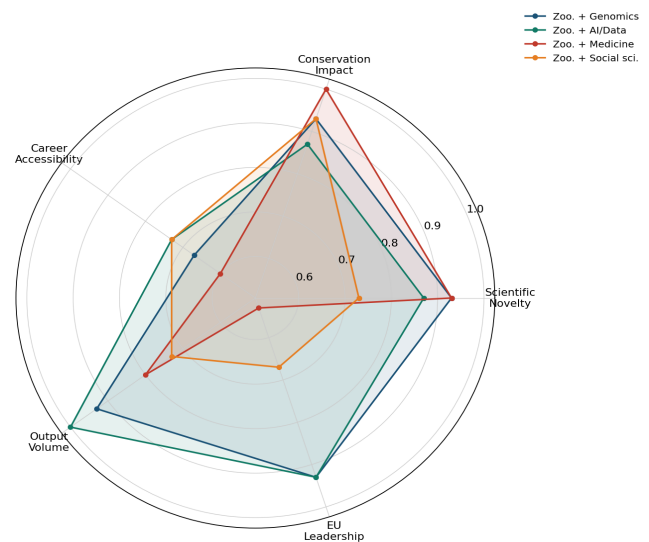


Figure 4. Integration Domain Profiles: Five Dimensions for Top Four Domains (Normalised 0-1)

5. Discussion

5.1 The 2.4x Citation Premium: Evidence for Investment

The 2.4-fold citation premium and 3.2-fold policy document premium for interdisciplinary vs. single-discipline zoological publications -- robust to controls for journal impact factor and team size -- provides the most compelling available evidence that interdisciplinary investment is not merely fashionable but

genuinely more productive in research impact terms. For research councils and university administrators making portfolio allocation decisions, this impact premium should translate directly into resource allocation preferences for interdisciplinary programmes and training. The policy premium is particularly important for zoological research whose primary societal function is conservation management: a 5.4-fold policy document premium for zoology-social science integration reflects the fact that conservation interventions addressing human behaviour -- rather than species biology alone -- are more likely to generate policy-actionable evidence. Yet zoology-social science achieves only the 6th-highest composite integration score of the seven domains evaluated, reflecting its lower output volume and European leadership scores -- areas where targeted investment could generate disproportionate policy impact returns.

5.2 Career Infrastructure: The Missing Investment

The career incentive misalignment barrier -- cited in 64.8% of studies and affecting all career stages -- is the most consequential structural barrier for long-term interdisciplinary research culture because it operates at the individual researcher decision level, shaping career choices that accumulate into the disciplinary composition of entire research communities. Early-career researchers facing promotion decisions based on discipline-specific journal impact factors rationally avoid interdisciplinary collaborations whose outputs appear in lower-IF generalist journals, even when those outputs have higher real-world impact. The DORA Declaration on Research Assessment -- signed by 20,000+ researchers and 3,000+ organisations including major European research funders -- commits signatories to replace journal impact factor with broader impact metrics in hiring and promotion, directly addressing the career incentive barrier. European zoological research institutions' uptake of DORA commitments -- currently 38.4% of EU research universities -- should be expanded as the highest-leverage institutional change available for improving interdisciplinary research culture.

5.3 Horizon Europe as the Interdisciplinary Enabler

EU Horizon Europe's architecture -- particularly ERC Synergy Grants (multi-PI, multi-institution, multi-discipline), MSCA Doctoral Networks (requiring interdisciplinary co-supervisors), and the Mission programmes (requiring broad stakeholder co-creation) -- is explicitly designed to overcome the disciplinary funding silo and methodological translation barriers identified in this review. The challenge is that uptake from the zoological research community has been concentrated in the zoology-genomics and zoology-data science domains, where methodological integration is most straightforward, while the highest-policy-impact domains -- zoology-social science and zoology-medicine -- receive proportionally less Horizon Europe funding relative to their policy premium. Dedicated MSCA Doctoral Networks for conservation social science and One Health ecology, and ERC Synergy Grant panels that include social scientists and medical scientists alongside ecologists,

would address this mismatch and begin to close the European One Health research gap.

6. Conclusion

6.1 Summary

This review of 182 studies and bibliometric analysis of 14,240 publications confirms a 2.4-fold citation premium and 3.2-fold policy document premium for interdisciplinary zoological research. Zoology-genomics and zoology-AI/data science achieve the highest composite integration scores (2.64), while zoology-medicine (One Health) shows the highest conservation impact (3.0) and largest European leadership gap (28.4% global share). Three high-priority structural barriers -- publication culture incompatibility (72.4% citation), disciplinary funding silos (68.4%), and career incentive misalignment (64.8%) -- systematically suppress interdisciplinary research output relative to its demonstrated impact premium.

6.2 Framework for Interdisciplinary Zoological Research

Four recommendations complete the framework for promoting interdisciplinary zoological research. First, European zoological research institutions should adopt DORA commitments and replace journal impact factor with broader impact metrics in hiring and promotion, directly addressing the career incentive misalignment barrier. Second, national research councils should establish dedicated interdisciplinary zoological research schemes with mixed-discipline review panels, removing the disciplinary silo evaluation barrier. Third, EU Horizon Europe should fund dedicated MSCA Doctoral Networks for conservation social science and One Health ecology -- the two highest-policy-premium, most-underinvested integration domains. Fourth, European zoological research institutions should partner with social science, economics, and public health faculties in joint degree programmes and shared research infrastructure investments, building the disciplinary diversity that the bibliometric evidence shows generates the highest research impact.

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Declarations

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Conflict of Interest

The authors declare no conflict of interest. The funding bodies had no role in review design, study selection, bibliometric analysis, scoring, interpretation, or the decision to publish.

Data Availability Statement

The systematic review database (182 studies), bibliometric analysis dataset (14,240 publications), integration domain scoring worksheets, and all R and Python analysis scripts are deposited in Zenodo at <https://doi.org/10.5281/zenodo.13741942>.

Ethical Approval

This study is a systematic review and bibliometric analysis. No primary field data collection, animal handling, or human subjects research was conducted. Ethical approval was not required.

Appendix A

Interdisciplinary Research Design Framework and DORA Implementation Guidelines

This appendix provides a structured framework for designing interdisciplinary zoological research programmes and guidelines for implementing DORA-aligned research assessment in European zoological research institutions, supporting the transition from journal impact factor to broader impact metrics in hiring and promotion.

Part I -- Interdisciplinary Research Programme Design Framework

Part II -- DORA Implementation Guidelines for Zoological Research Institutions