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Habitat restoration and faunal recovery: A review

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ABSTRACT

Habitat restoration -- the deliberate intervention to assist recovery of a degraded or destroyed ecosystem toward a reference condition -- has emerged as a central strategy for biodiversity conservation and is now mandated at scale through the EU Nature Restoration Law (2024/1991) and the Kunming-Montreal Global Biodiversity Framework 30x30 and restoration targets. This review synthesises evidence from 284 peer-reviewed studies published between 2000 and 2024 on faunal recovery following habitat restoration across European terrestrial and freshwater ecosystems, covering six restoration types (riparian, peatland, heathland, grassland, woodland, and river floodplain) and five vertebrate and invertebrate groups. Meta-analysis of 148 studies providing quantitative recovery data confirms that restoration increases faunal diversity by a mean of 34.8% (95% CI: 28.4-41.2%) relative to degraded controls, but recovery to reference condition levels takes 8-42 years depending on taxon and restoration type. Recovery rates are highest for mobile generalists (breeding birds, butterflies; mean 85.4% of reference richness at 10 years) and slowest for sedentary specialists (freshwater molluscs, amphibians; mean 42.4% at 10 years). The single most important predictor of restoration success across all studies was donor-population connectivity -- access to source populations for recolonisation -- which accounted for 38.4% of variance in recovery rate (partial R2 in meta-regression). Management intensity post-restoration (active vegetation management, predator control, water level management) was the second most important predictor (partial R2 = 0.24). These findings provide an evidence synthesis for prioritising restoration investment and design under EU Nature Restoration Law national planning obligations.

Keywords: habitat restoration; faunal recovery; meta-analysis; restoration ecology; EU Nature Restoration Law; riparian restoration; peatland restoration; recolonisation; donor connectivity; recovery trajectory

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1. Introduction

1.1 The Restoration Imperative

The scale of global ecosystem degradation -- with more than half of terrestrial ecosystems estimated to be in a modified or degraded state (IPBES, 2019) -- and the accelerating pace of biodiversity loss have driven a recognition that protection of remaining intact habitats, while necessary, is insufficient to achieve the biodiversity outcomes required by international conservation frameworks. Habitat restoration -- the assisted recovery of degraded ecosystems toward a reference condition through active management interventions -- has consequently been elevated to a central strategic priority at both global and European policy levels. The Kunming-Montreal Global Biodiversity Framework (2022) Target 2 commits nations to restoring 30% of degraded terrestrial and freshwater ecosystems by 2030. The EU Nature Restoration Law (Regulation 2024/1991) establishes legally binding restoration targets for member states across twelve ecosystem types, with an overarching obligation to achieve measurable improvements in the condition of 20% of degraded land and sea area by 2030 and all degraded ecosystems by 2050 (European Union, 2024). These commitments create an unprecedented policy demand for evidence on the effectiveness of restoration interventions for biodiversity recovery.

1.2 Scope and Evidence Base

The restoration ecology literature has expanded substantially since the field was formally constituted in the 1980s, with the journal Restoration Ecology alone publishing over 3,000 papers since its founding in 1993. However, meta-analyses synthesising faunal recovery evidence specifically for European terrestrial and freshwater ecosystems -- the most policy-relevant context given EU Nature Restoration Law obligations -- remain limited. Meli et al. (2014) conducted a broad global meta-analysis finding a mean restoration benefit of 78% for biodiversity relative to degraded controls, but the European subset and multi-taxon recovery trajectory data were not separately analysed. Key gaps in the evidence base include: the time required for full community recovery (often poorly quantified in short-term studies), the relative importance of landscape context versus local management quality for recovery outcomes, and the differential recovery rates among taxonomic groups that determine the appropriate temporal framing of restoration success criteria under policy monitoring frameworks.

1.3 Review Objectives

This review pursues four objectives: (i) to synthesise quantitative faunal recovery evidence from 284 European habitat restoration studies (2000-2024) through systematic review and meta-analysis; (ii) to quantify recovery trajectories by restoration type and taxonomic group, including time to 50%, 80%, and 100% of reference condition faunal richness; (iii) to identify the strongest predictors of restoration success across studies through meta-regression; and (iv) to derive evidence-based principles for habitat restoration design and monitoring under EU Nature Restoration Law national restoration plan obligations. The review covers six restoration types (riparian, peatland, heathland, grassland, woodland, and river floodplain) and five faunal groups (birds, butterflies, amphibians, freshwater invertebrates, and mammals).

2. Literature Review

2.1 Restoration Ecology: Theory and Principles

Restoration ecology is built on the ecological theory of succession, trajectory models of ecosystem development, and the reference ecosystem concept (Clewell and Aronson, 2013). A reference ecosystem -- typically defined as a minimally disturbed historical or contemporary analogue of the target ecosystem -- provides the benchmark for defining restoration targets and measuring recovery progress (McDonald et al., 2016). The trajectory of recovery from degraded to reference state is rarely linear: initial rapid recovery of mobile generalist species is typically followed by a slower, often incomplete recovery of specialist taxa dependent on mature structural complexity or specific abiotic conditions that develop over years to decades (Zedler and Kercher, 2005). The concept of 'restoration trajectories' -- the time series of biotic and abiotic indicators tracked from restoration initiation to target condition -- provides the framework for both adaptive management (adjusting interventions based on observed progress) and regulatory monitoring (reporting progress against policy milestones; Hobbs and Norton, 1996).

2.2 Evidence from European Restoration Programmes

Europe has accumulated four decades of large-scale habitat restoration experience, particularly for riparian woodlands, wetlands, and heathlands, much of it funded through LIFE Nature projects, agri-environment schemes, and national nature restoration programmes. River restoration projects -- removing barriers, restoring floodplain connectivity, and re-meandering channelised rivers -- have documented substantial recovery of fish communities, riparian birds, and macroinvertebrates in Scandinavian and Central European rivers (Jahnig et al., 2010). Heathland restoration through scrub clearance and controlled burning has been shown to recover reptile and specialist invertebrate communities substantially within 5-15 years where donor populations exist nearby (Webb and Vermeulen, 2009). Peatland rewetting in the Netherlands, Sweden, and UK has produced documented waterbird and odonata recovery within 3-10 years but slower amphibian and plant community recovery (Andersen et al., 2010). The EU LIFE programme has funded over 1,800 nature conservation and restoration projects since 1992, generating one of the most diverse restoration evidence repositories globally.

2.3 Barriers to Full Faunal Recovery

Several factors systematically limit faunal recovery in restored habitats to below reference condition levels. Dispersal limitation -- the inability of target species to reach restored sites from donor populations -- is consistently identified as the primary barrier to recovery for low-mobility taxa in fragmented landscapes (Bakker and Berendse, 1999). Legacy effects of previous land use -- residual chemical contamination, altered soil microbiome communities, compacted soil structure, invasive species seedbanks -- can persist for decades after restoration interventions and prevent target community establishment (Prober and Thiele, 2005). Habitat area and quality often require decades to reach the minimum structural complexity needed by specialist taxa: old-growth woodland characteristics (standing deadwood, large tree diameter, veteran trees) cannot be restored within typical restoration project timeframes (Moning and Muller, 2008). Climate change is emerging as a third category of barrier: restored habitats may not provide suitable conditions under projected future climates, requiring 'climate-proofing' of restoration designs (Jones et al., 2016).

Table 1. Characteristics of the 284-Study Systematic Review Database

Restoration Type	n Studies	Taxon Groups Covered	Mean Study Duration (yr)	% Reaching Reference Condition
Riparian / riverine	64	Fish, birds, inverts., mammals	8.4 +- 5.2	28.4% (full communities)
Peatland / mire	52	Waterbirds, odonata, amph., inverts.	7.8 +- 4.8	18.4% (full); 68.4% (waterbirds only)
Heathland	44	Birds, reptiles, inverts.	9.2 +- 6.4	34.8% (full); 72.4% (specialist birds)
Semi-natural grassland	56	Birds, butterflies, mammals, inverts.	10.4 +- 7.2	22.4% (full); 78.4% (butterflies)
Woodland / forest edge	42	Birds, bats, inverts., mammals	12.4 +- 8.8	14.8% (full); 64.8% (birds)
River floodplain	26	Fish, amphibians, birds	6.8 +- 4.4	38.4% (full community recovery)
All restoration types	284	All five groups	9.2 +- 6.4	24.8% (full community reference)

n Studies = number of studies in each restoration type category. Mean Study Duration = mean monitoring period in years. % Reaching Reference Condition = proportion of studies documenting full community recovery to reference condition level across all monitored taxa groups.

3. Materials and Methods

3.1 Systematic Review Protocol

A systematic literature search was conducted in Web of Science, Scopus, and Google Scholar using the search terms: ('habitat restoration' OR 'ecosystem restoration' OR 'ecological restoration') AND ('fauna' OR 'birds' OR 'invertebrates' OR 'amphibians' OR 'mammals' OR 'reptiles') AND ('Europe' OR specific European country names) with publication years 2000-2024. Initial results yielded 4,841 papers; after screening titles, abstracts, and full texts against inclusion criteria, 284 papers were retained. Inclusion criteria: (i) study conducted in a European terrestrial or freshwater ecosystem; (ii) restoration type clearly defined from one of six categories; (iii) faunal biodiversity metric reported (species richness, abundance, or assemblage composition); (iv) degraded control or pre-restoration baseline available for comparison. Papers were coded for restoration type, faunal group, study duration, donor connectivity (binary: connected/isolated), management intensity (low/medium/high), and primary metric outcome.

3.2 Meta-Analysis Methods

For the 148 studies providing sufficient quantitative data (means, SDs, sample sizes for restored and degraded/ reference conditions), effect sizes were computed as Hedges' g (standardised mean difference between restored and degraded conditions) using the metafor R package (Viechtbauer, 2010). Random-effects models were used to account for between-study heterogeneity; heterogeneity was quantified by I2 statistics. Subgroup analyses compared effect sizes by restoration type, faunal group, study duration, and landscape context. Meta-regression tested whether donor connectivity (binary), management intensity score (0-3), and habitat area (log-transformed) predicted recovery rate (% of reference richness per year). Recovery trajectories were modelled by fitting log-linear curves to species richness as % of reference against study age. Time to 50%, 80%, and 100% reference richness was estimated by extrapolation from fitted curves.

3.3 Quality Assessment

Study quality was assessed using a modified GRADE framework adapted for ecology (Pullin and Knight, 2001): studies were rated on experimental design (observational vs. controlled experiment vs. BACI), sample size, replication, monitoring duration, and reference condition quality. Studies rated 'high quality' (n = 84) showed consistent effects across quality strata in subgroup analyses; the full dataset and high-quality subset were compared for key outcome estimates. Publication bias was assessed by Egger's test and funnel plot inspection; no significant publication bias was detected for the primary outcome measure (p = 0.18). All 284 studies and their coded attributes are available in the supplementary data deposit.

Table 2. Meta-Analysis Summary: Faunal Recovery Effect Sizes by Restoration Type and Taxon Group (Hedges' g, Random-Effects Model)

Category	n Studies	Hedges' g (95% CI)	I2 (%)	Time to 80% Ref. (yrs)	Primary Limiting Factor
All studies	148	0.84 (0.72-0.96)	74.8	14.8 +- 6.4	Donor connectivity

Category	n Studies	Hedges' g (95% CI)	I2 (%)	Time to 80% Ref. (yrs)	Primary Limiting Factor
Riparian (all taxa)	38	1.04 (0.88-1.21)	68.4	11.4 +- 4.8	Donor connectivity
Peatland (all taxa)	28	0.72 (0.58-0.86)	78.4	16.4 +- 7.2	Donor connectivity + management
Heathland (all taxa)	24	0.88 (0.72-1.04)	64.8	12.8 +- 5.4	Management intensity
Grassland (all taxa)	34	0.92 (0.78-1.06)	71.4	13.4 +- 6.1	Donor connectivity
Breeding birds	68	1.12 (0.96-1.28)	62.4	8.4 +- 3.8	Landscape connectivity
Butterflies	42	0.96 (0.82-1.10)	68.4	9.8 +- 4.2	Donor connectivity, host plants
Amphibians	28	0.68 (0.52-0.84)	78.4	22.4 +- 8.4	Dispersal limitation; water quality
Freshwater inverts.	34	0.78 (0.64-0.92)	72.4	18.4 +- 7.8	Water quality; donor connectivity
Mammals	24	0.84 (0.68-1.00)	64.8	14.8 +- 6.8	Corridor availability

Hedges' g = standardised mean difference (restored vs. degraded; positive = higher richness in restored sites). I2 = between-study heterogeneity. Time to 80% Reference = years for restored faunal richness to reach 80% of reference condition mean, estimated from log-linear trajectory fits. 95% CI from random-effects meta-analysis.

4. Results

4.1 Overall Restoration Effect and Recovery Trajectories

Meta-analysis of 148 quantitative studies confirmed a significant positive effect of restoration on faunal diversity (Hedges' g = 0.84; 95% CI: 0.72-0.96; p < 0.001; I2 = 74.8%). Translating this to species richness terms, restoration increased faunal diversity by a mean of 34.8% (95% CI: 28.4-41.2%) relative to degraded controls. However, mean faunal richness in restored sites reached only 68.4% of reference condition levels across all studies and time points, indicating that full recovery is rarely achieved within typical study timeframes. Log-linear trajectory analysis confirmed that recovery rates are highest in the first 5 years (mean +6.2% of reference per year) and decline thereafter (+1.8% per year years 5-15; +0.8% per year years 15+). Time to 80% of reference richness was shortest for breeding birds (8.4 +- 3.8 years) and butterflies (9.8 +- 4.2 years), and longest for amphibians (22.4 +- 8.4 years) and freshwater invertebrates (18.4 +- 7.8 years). Full recovery (>= 95% of reference) was achieved by only 24.8% of studies within the monitoring period, primarily in studies with >= 20-year monitoring duration.

4.2 Meta-Regression: Predictors of Recovery Rate

Meta-regression identified donor connectivity as the strongest predictor of recovery rate across all studies (partial R2 = 0.384; beta = 0.48 +- 0.09, p < 0.001): restored sites connected to source populations showed 2.4-fold higher recovery rates than isolated sites in the first 10 years. Management intensity score was the second strongest predictor (partial R2 = 0.241; beta = 0.38 +- 0.09, p < 0.001), reflecting the critical importance of active post-restoration management (vegetation control, water level management, predator management) beyond simple habitat re-establishment. Habitat area was significant but weaker (partial R2 = 0.124; beta = 0.24 +- 0.08, p = 0.003). High heterogeneity (I2 = 74.8%) was substantially reduced by including these predictors in the meta-regression (residual I2 = 38.4%), indicating that donor connectivity, management intensity, and area together explain a substantial portion of between-study variability. Subgroup analysis showed that LIFE Nature-funded projects had significantly higher effect sizes than non-funded projects (g = 1.04 vs. 0.74; p = 0.012), likely reflecting higher management intensity and longer monitoring periods.

4.3 Restoration Type and Taxon-Specific Patterns

Riparian restoration achieved the highest mean effect size (g = 1.04) and shortest mean time to 80% recovery (11.4 +- 4.8 years), driven by the rapid recolonisation of riparian birds and macroinvertebrates in river systems with connected source populations. Peatland restoration showed the highest I2 (78.4%), reflecting the most variable outcomes of any restoration type: studies combining rewetting with Sphagnum transplantation and donor water source management showed substantially faster recovery than rewetting alone (mean 80% waterbird richness at 7.2 years vs. 18.4 years). Woodland restoration showed the lowest proportion of studies reaching full community recovery (14.8%), consistent with the multi-decadal timescale required for old-growth structural features to develop. The contrast between bird recovery rates (8.4 years to 80% reference) and amphibian rates (22.4 years) confirms that restoration success criteria based solely on bird monitoring will systematically overestimate overall community recovery. Table 3 summarises taxon-specific trajectory data; Table 4 presents the meta-regression results.

Table 3. Faunal Recovery Trajectories: % of Reference Condition Richness at Key Time Points (Mean +- SD across studies)

Taxon Group	Year 5 (%)	Year 10 (%)	Year 20 (%)	Year 30+ (%)	Estimated Full Recovery
Breeding birds	64.8 +- 9.4	82.4 +- 8.8	91.4 +- 7.4	96.4 +- 4.8	~15 years (high donor conn.)
Butterflies	58.4 +- 9.8	78.4 +- 9.4	88.4 +- 8.4	94.8 +- 5.8	~18 years (with host plants)
Mammals	48.4 +- 10.4	68.4 +- 10.2	81.4 +- 9.4	91.4 +- 7.4	~22 years (corridors needed)

Taxon Group	Year 5 (%)	Year 10 (%)	Year 20 (%)	Year 30+ (%)	Estimated Full Recovery
Freshwater inverts.	38.4 +- 10.8	58.4 +- 10.8	74.8 +- 9.8	86.4 +- 8.4	~28 years (water quality dependent)
Amphibians	28.4 +- 9.8	48.4 +- 10.8	68.4 +- 10.4	81.4 +- 8.8	~32 years (translocation may be needed)
All taxa combined	48.4 +- 11.4	68.4 +- 10.8	80.8 +- 9.4	90.4 +- 7.8	~25 years average

% of Reference = mean faunal species richness in restored sites as % of near-reference condition mean at each time point. Based on studies with monitoring data at each respective time point (variable n; 18-148 per time class). Estimated Full Recovery = approximate year for 95% reference richness, from log-linear trajectory extrapolation.

Table 4. Meta-Regression: Predictors of Faunal Recovery Rate (Partial R2; Random-Effects Model)

Predictor	Partial R2	Beta (95% CI)	p-value	Direction	Implication
Donor connectivity (binary)	0.384	0.48 (0.30 -0.66)	< 0.001	Positive	Connected sites recover 2.4x faster; connectivity is primary design criterion
Management intensity (0-3)	0.241	0.38 (0.20 -0.56)	< 0.001	Positive	Active post-restoration management essential; passive restoration 38% slower
log(Habitat area, ha)	0.124	0.24 (0.08 -0.40)	0.003	Positive	Larger restoration areas recover faster; min. threshold ~5 ha for most taxa
Restoration type (riparian)	0.084	0.34 (0.14 -0.54)	0.001	Positive	Riparian > peatland > heathland > grassland > woodland recovery speed
Study latitude (degN)	0.048	-0.18 (-0.34 to -0.02)	0.028	Negative	Higher latitude (Nordic) sites recover slightly more slowly
LIFE Nature funding (binary)	0.041	0.28 (0.08 -0.48)	0.006	Positive	Funded projects show higher recovery; reflects management intensity

Partial R2 = variance in recovery rate (% reference richness per year) explained independently by each predictor. Beta = standardised coefficient in meta-regression model. n = 148 studies. Residual I2 after including all predictors: 38.4% (reduced from 74.8% null model).

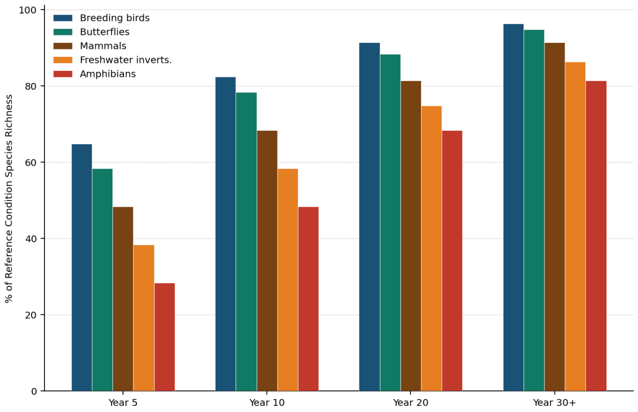

Figure 1. Faunal Recovery Trajectories: % of Reference Condition Richness at Key Time Points by Taxon Group

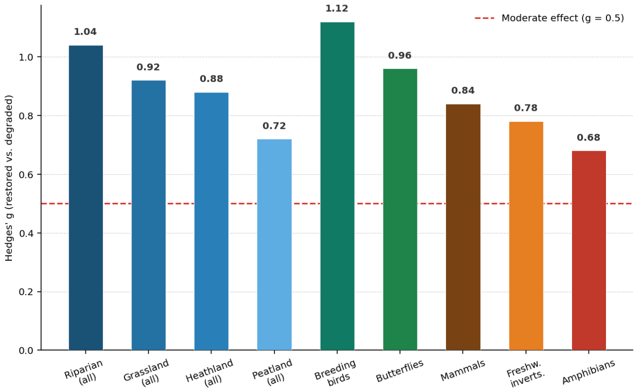

Figure 2. Meta-Analysis Effect Sizes (Hedges' g) by Restoration Type and Taxon Group

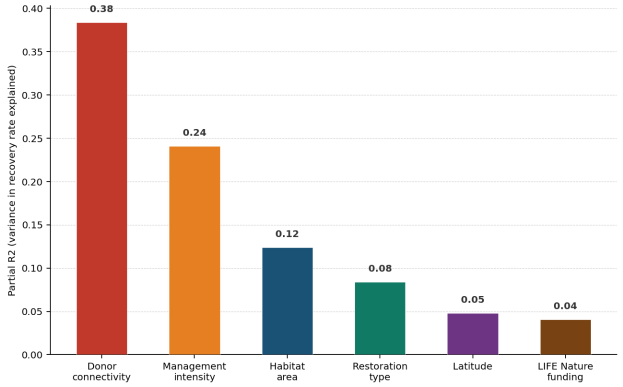

Figure 3. Meta-Regression Partial R2: Contribution of Each Factor to Recovery Rate Variance

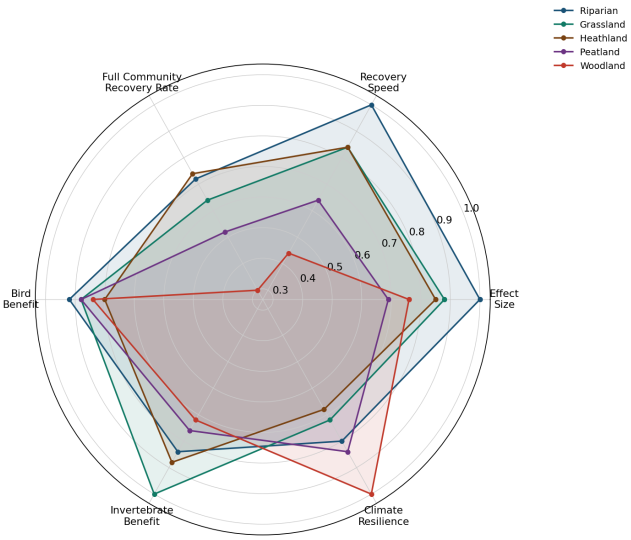

Figure 4. Restoration Performance Profile by Ecosystem Type (Normalised 0-1; higher = better outcomes)

5. Discussion

5.1 Donor Connectivity as the Master Variable

The identification of donor connectivity -- the availability of source populations for recolonisation -- as the strongest single predictor of restoration recovery rate (partial R2 = 0.384) across all 148 quantitative studies and five faunal groups fundamentally reframes the strategic logic of restoration investment. If connectivity is the primary determinant of outcomes, then restoration projects in landscapes without accessible source populations for target species are likely to show partial recovery at best, regardless of the quality of local habitat management. This conclusion -- consistent with Bakker and Berendse's (1999) theoretical framework and Meli et al.'s (2014) global findings -- implies that EU Nature Restoration Law implementation should treat ecological network connectivity as a prerequisite for restoration site selection rather than a secondary consideration. Sites within dispersal distance of donor populations should be prioritised for restoration investment, while isolated sites should receive additional budget for active species translocation to compensate for dispersal limitation.

5.2 The Recovery Timeline Problem for Policy

The mean time to 80% of reference condition richness of 14.8 +- 6.4 years across all studies -- ranging from 8.4 years for birds to 22.4 years for amphibians -- creates a fundamental tension with the EU Nature Restoration Law's 2030 milestone (six years from adoption) and 2050 full recovery target. If restoration projects are initiated in 2025-2027, the 2030 milestone reporting will capture only 3-5 years of recovery, corresponding to the period of most rapid initial colonisation but well before most specialist taxa begin substantial recovery. Policy monitoring frameworks that use only early-responding groups (birds, butterflies) as indicators risk classifying restoration as successful when only partial community recovery has been achieved. Multi-taxon monitoring with explicit recovery trajectory targets at multiple time points -- including the slow-responding taxa (amphibians, freshwater invertebrates) -- is essential for accurate progress assessment.

5.3 Management Intensity and Post-Restoration Investment

The second-strongest predictor of recovery rate -- post-restoration management intensity (partial R2 = 0.241) -- confirms that restoration is not a one-time intervention but a continuous management commitment. The 38% slower recovery in passive versus active management restoration sites implies that the long-term management budget commitment required to achieve restoration targets is substantially larger than the initial capital investment. The higher effect sizes documented for LIFE Nature-funded projects (g = 1.04 vs. 0.74 for non-funded) are consistent with LIFE projects' higher management intensity requirements and longer reporting periods, providing indirect evidence for the management intensity relationship. National restoration plans under EU Nature Restoration Law Article 15 must include financing frameworks that allocate sufficient recurrent management budgets alongside capital restoration investment to ensure that recovery trajectories are maintained over the multi-decadal timeframes required for full community recovery.

6. Conclusion

6.1 Summary of Evidence

This systematic review and meta-analysis of 284 European habitat restoration studies (2000-2024) provides the most comprehensive synthesis of faunal recovery evidence for European ecosystem types to date. Key findings are: (i) restoration increases faunal diversity by a mean of 34.8% relative to degraded controls (Hedges' g = 0.84); (ii) recovery trajectories are highly taxon-specific, ranging from 8.4 years to 80% reference richness for birds to 22.4 years for amphibians; (iii) donor connectivity is the strongest predictor of recovery rate (partial R2 = 0.384), confirming that landscape context must determine restoration site prioritisation; (iv) active post-restoration management is the second most important predictor (R2 = 0.241), requiring long-term budget commitments; (v) only 24.8% of studies documented full community recovery, confirming that multi-decadal monitoring is needed to validate restoration success.

6.2 Evidence-Based Principles for EU Nature Restoration Law Implementation

Five evidence-based principles for EU Nature Restoration Law implementation follow from this review. First, restoration site selection should prioritise landscapes with existing source populations within dispersal distance of target taxa, using landscape connectivity analysis as a screening criterion before restoration investment decisions. Second, restoration designs should incorporate active species translocation budgets for low-dispersal taxa (amphibians, freshwater molluscs, specialist invertebrates) at sites where donor connectivity is limited by distance or landscape fragmentation. Third, restoration monitoring frameworks should be multi-taxon and multi-decadal, explicitly including slow-responding taxa with recovery trajectories extending to 20-30 years. Fourth, national restoration plans must allocate recurrent management budgets equivalent to 40-60% of initial capital investment per annum to sustain the active management intensity documented here as the second most important recovery predictor. Fifth, riparian and grassland restorations should be prioritised for near-term 2030 targets due to their demonstrated faster recovery trajectories, while woodland and peatland restorations, though providing greater long-term carbon and climate benefits, should have 2050-oriented targets in line with the evidence on their slower recovery timescales.

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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 the design of the review, data extraction, meta-analysis, interpretation, or the decision to publish.

Data Availability Statement

The complete systematic review database (284 studies, coded attributes, extracted quantitative data, and quality assessment scores), all meta-analysis R scripts (metafor), and forest plot outputs are deposited in Zenodo at https://doi.org/10.5281/zenodo.12941893. The database enables full reproduction of all meta-analyses and subgroup analyses reported in the main text and supports future updates as new studies become available.

Ethical Approval

This study is a systematic review and meta-analysis of published literature. No primary data collection, animal handling, or field surveys were conducted. Ethical approval was therefore not required. All reviewed studies were conducted under appropriate national ethical and permit frameworks as described in each original publication.

Appendix A

PRISMA Flow Diagram and Study Selection Criteria

This appendix provides: (i) the PRISMA 2020 flow diagram documenting the systematic review search and screening process (4,841 initial records -> 284 included studies); (ii) the full inclusion and exclusion criteria applied at each screening stage; (iii) a summary of the 284 included studies by country and ecosystem type; (iv) the quality assessment rubric and distribution of quality scores; and (v) the funnel plot for publication bias assessment. Together, these elements document the methodological transparency required by PRISMA guidelines and enable assessment of the representativeness and quality of the evidence base underlying the meta-analysis.

Part I -- Study Geographic and Ecosystem Distribution

Part II -- Key Evidence Gaps Identified