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# Rewilding Strategies and Ecological Restoration

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## ABSTRACT

*Rewilding -- the large-scale restoration of self-regulating ecosystems through reintroduction of keystone species, removal of human interventions, and reconnection of landscape fragments -- has emerged as one of the most ambitious and scientifically contested approaches to ecological restoration. This study conducted a systematic meta-analysis of 147 rewilding and large-scale ecological restoration projects across five continents (1985-2024), quantifying outcomes across biodiversity, ecological process, carbon sequestration, and socioeconomic dimensions using a standardised multi-outcome framework. Rewilding projects showed significant mean positive effects on species richness (+34.7% +- 8.4% relative to degraded reference sites), trophic chain length (+1.24 +- 0.38 trophic levels), ecosystem carbon stocks (+47.4% +- 12.4%), and visitor numbers (+284% +- 84%), but with substantial heterogeneity (I2 = 74.8%) explained by project design factors. Apex predator reintroduction delivered the largest biodiversity co-benefits (mean cascading richness increase: +28.4% across prey and vegetation communities), but only when prey recovery had been established as a prerequisite (OR for success with vs. without prey recovery: 4.84, p < 0.001). Passive rewilding -- cessation of agricultural or grazing pressure without active species reintroduction -- achieved 61.4% of the biodiversity gain of active rewilding at 12.4% of the cost over a 15-year period, suggesting substantial cost-effectiveness advantages in landscapes with source populations of native species within dispersal range. Human-wildlife conflict events increased significantly in rewilding zones (mean +187% in adjacent agricultural areas), and conflict mitigation infrastructure (electric fencing, livestock protection dogs, compensation schemes) was the strongest predictor of maintained social licence for rewilding projects. These results provide the first quantitative evidence synthesis on which to base evidence-informed rewilding programme design at the scale required by the EU Nature Restoration Law and GBF Targets 2 and 3.*

**Keywords:** rewilding; trophic cascade; apex predator reintroduction; passive rewilding; ecological restoration; social licence; human-wildlife conflict; EU Nature Restoration Law

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# 1. Introduction

## 1.1 Rewilding: Concept and Controversy

Rewilding -- broadly defined as the restoration of natural processes and self-regulating ecosystems through reduction of human management interventions and/or reintroduction of previously extirpated species -- has emerged over the past three decades from a conceptual proposal (Soule and Noss, 1998) to one of the most widely discussed and contested approaches to conservation and ecological restoration (Svenning et al., 2016; Navarro and Pereira, 2015). Multiple rewilding definitions coexist in the literature, ranging from the '3Cs' framework of cores, corridors, and carnivores (Soule and Noss, 1998) to the broader ecological process approach emphasising trophic complexity, stochastic dynamics, and reduced human control (Rewilding Europe, 2022; Perino et al., 2019). Key areas of scientific debate include: whether apex predator reintroduction produces the transformative 'trophic cascades' seen in Yellowstone (Ripple and Beschta, 2012) or more modest and context-dependent effects (Ordiz et al., 2013); whether Pleistocene rewilding with ecological surrogates for extinct megafauna is ecologically meaningful (Donlan et al., 2006); and how rewilding projects can be designed to maintain social licence in landscapes shared with farming communities (Chapron et al., 2014).

## 1.2 Policy Context: EU Nature Restoration Law and GBF

The European Union's Nature Restoration Law -- adopted in June 2024 -- requires member states to restore at least 20% of the EU's land and sea areas by 2030 and all degraded ecosystems by 2050, including specific targets for forests, agricultural land, rivers, and coastal habitats. The law explicitly references natural processes and biodiversity as restoration objectives, making rewilding principles directly relevant to national implementation planning. At the global level, GBF Targets 2 (restoring 30% of degraded ecosystems by 2030) and 3 (effectively conserving 30% of land and sea) create ambitious restoration mandates for all 196 CBD signatories that require evidence-based restoration strategy design to be achievable at the required scale and pace (CBD, 2022). The policy demand for evidence-based rewilding and restoration guidance has never been greater, yet comprehensive quantitative outcome synthesis from implemented projects has been lacking.

## 1.3 Objectives

This study provides the most comprehensive quantitative synthesis of rewilding and large-scale ecological restoration outcomes yet assembled, addressing five objectives: (i) estimate pooled effect sizes for biodiversity, ecosystem process, carbon, and socioeconomic outcomes from 147 rewilding projects; (ii) identify project design features predicting biodiversity and social success through meta-regression; (iii) compare active versus passive rewilding cost-effectiveness for biodiversity outcomes; (iv) quantify human-wildlife conflict escalation and identify mitigation effectiveness; and (v) derive evidence-based rewilding design recommendations for EU Nature Restoration Law implementation. The resulting evidence synthesis represents the most rigorous quantitative basis yet available for rewilding policy design.

# 2. Literature Review

## 2.1 Trophic Cascades and Apex Predator Effects

The reintroduction of wolves (Canis lupus) to Yellowstone National Park in 1995-1996 produced the most widely studied trophic cascade in a large mammal system: wolf predation reduced elk (Cervus canadensis) browsing intensity in riparian zones, enabling willow (Salix spp.), aspen (Populus tremuloides), and cottonwood recovery that in turn supported beaver (Castor canadensis) populations, altered stream hydrology, and increased songbird diversity (Ripple and Beschta, 2012; Beschta and Ripple, 2009). However, subsequent analyses have challenged the magnitude of vegetation recovery attributable to wolves versus other factors including climate variability and fire history (Winnie, 2012; Kauffman et al., 2010), and cross-system meta-analyses have found that trophic cascades vary substantially in strength across ecosystems and predator-prey systems -- strongest in aquatic and island systems, more variable in terrestrial continental systems (Estes et al., 2011; Terborgh and Estes, 2010). Understanding the conditions under which apex predator reintroduction produces strong cascading effects is essential for predicting rewilding outcomes.

## 2.2 Passive Rewilding and Natural Regeneration

Passive rewilding -- achieving ecosystem recovery through cessation of human management disturbances (grazing, tillage, drainage, burning) without active species reintroduction -- is increasingly recognised as a cost-effective complement to active restoration in landscapes where native species source populations exist within dispersal distance of the target area (Prach and Hobbs, 2008; Benayas et al., 2009). Passive rewilding has documented recovery trajectories across multiple ecosystem types: European agricultural abandonment areas show spontaneous woodland succession with associated increases in forest bird diversity within 20-30 years (Navarro and Pereira, 2015); former arable fields in the UK that are simply fenced from grazing and allowed to succeed show plant diversity recovery within 5-10 years (Elsen et al., 2018). The Knepp Estate in West Sussex, UK, is the most extensively documented passive rewilding project in Europe, showing 15-year trajectories of woodland and scrub succession, population recoveries of turtle doves, nightingales, and purple emperor butterflies, and establishment of free-roaming cattle, pigs, and horses as ecological proxies for aurochs and wild boar (Tree, 2018).

## 2.3 Social Dimensions and Human-Wildlife Conflict

Rewilding projects occur in human-dominated landscapes where ecological recovery inevitably creates interactions -- sometimes positive (wildlife tourism, ecosystem services), often negative (predator attacks on livestock, crop damage, competition for grazing) -- with adjacent farming and pastoral communities (Chapron et al., 2014; Gangaas et al., 2013). Human-wildlife conflict is consistently identified as the most common social challenge to rewilding social licence in European and African contexts: the expansion of wolf populations across central and western Europe following passive recovery and reintroduction has been accompanied by intense political conflict in shepherd and farming communities (Kaczensky et al., 2013). Conflict mitigation interventions -- livestock protection dogs, electric fencing, night penning, and rapid compensation payment systems -- have varying effectiveness depending on implementation quality and community trust (Treves and Karanth, 2003; Lescureux and Linnell, 2014). Understanding which conflict mitigation measures most effectively maintain social licence for rewilding is essential for scaling up programmes under the EU Nature Restoration Law.

**Table 1. Rewilding project dataset: geographic distribution, rewilding type, duration, and primary outcome metrics assessed**

| Region | n Projects | Rewilding Type | Mean Duration (yr) | Primary Biodiversity Target | Carbon Assessed | Social Conflict Data |
|---|---|---|---|---|---|---|
| Europe | 68 | Active (54%) + Passive (46%) | 12.4 +- 6.8 | Multi-taxon vertebrates | 54 projects | 64 projects |
| North America | 34 | Active (79%) + Passive (21%) | 14.7 +- 8.4 | Predator-prey communities | 28 projects | 31 projects |
| Sub-Saharan Africa | 24 | Active (88%) + Passive (12%) | 11.2 +- 5.7 | Large mammal assemblages | 18 projects | 22 projects |
| South America | 12 | Active (67%) + Passive (33%) | 8.4 +- 4.2 | Forest biodiversity | 10 projects | 8 projects |
| Australasia | 9 | Active (78%) + Passive (22%) | 9.8 +- 4.8 | Endemic fauna recovery | 7 projects | 8 projects |
| TOTAL | 147 | Active (64%) + Passive (36%) | 12.1 +- 6.8 | Variable | 117 projects | 133 projects |

*Active rewilding = projects involving at least one species reintroduction component (predators, herbivores, ecosystem engineers). Passive rewilding = projects based primarily on cessation of management disturbance (agricultural abandonment, removal of grazing, drainage restoration) without formal reintroduction. Duration = years from project initiation to most recent outcome assessment included in this meta-analysis. Social Conflict Data = number of projects for which human-wildlife conflict metrics were recorded and available.*

## 3. Materials and Methods

### 3.1 Literature Search and Eligibility

A systematic literature search following PRISMA 2020 guidelines was conducted in Web of Science, Scopus, and Google Scholar using search terms: (rewilding OR ecological restoration OR trophic restoration OR species reintroduction) AND (biodiversity OR species richness OR trophic cascade OR ecosystem function) AND (outcome OR effect OR result OR monitoring). Grey literature was searched through Rewilding Europe project database, IUCN Conservation Success database, and European LIFE programme project reports. After deduplication, title/abstract screening, and full-text assessment by two reviewers (ICC = 0.88), 147 projects met all eligibility criteria: (i) minimum 5 years active management plus 3 years post-initiation monitoring; (ii) quantitative biodiversity baseline and post-project data; and (iii) matched control or degraded reference site data enabling effect size computation.

### 3.2 Effect Size Computation and Meta-Analysis

Effect sizes were computed as log-response ratios (lnRR = ln(rewilding/reference)) for species richness, abundance, trophic chain length, carbon stock, and visitor numbers; or as Hedges' g for normally distributed outcomes. Variance of effect sizes was computed from standard errors of means reported in primary studies; where SEs were not reported, variance was imputed from published regression of SE on sample size for each outcome type. Random-effects meta-analysis used REML estimation in metafor R package; heterogeneity was quantified by I2 and tau2. Meta-regression examined nine pre-specified moderators: rewilding type (active/passive), apex predator presence, prey recovery status, project area (ha), project duration, conflict mitigation investment, governance type, biome, and income group. Publication bias was assessed using Egger's test and Rosenthal's fail-safe N.

### 3.3 Cost-Effectiveness and Conflict Analysis

Cost-effectiveness was assessed from 47 projects with complete financial records, computing biodiversity gain per EUR 1,000 invested as the primary metric. Active versus passive rewilding cost-effectiveness was compared using mixed-effects linear models with project area, duration, and biome as covariates. Human-wildlife conflict data from 133 projects with conflict monitoring records were analysed using negative binomial regression to assess conflict incident rate change relative to pre-rewilding baselines, with conflict mitigation investment as the primary predictor. Social licence was operationalised as the absence of sustained community-led opposition causing project modification or abandonment within the monitoring period; logistic regression identified predictors of social licence maintenance.

### 3.4 Active vs. Passive Cost-Effectiveness Comparison

A direct comparison of active versus passive rewilding cost-effectiveness was conducted for 38 project pairs matched by biome, project area, and duration -- where at least one active and one passive project existed in comparable landscape contexts. For each matched pair, species richness response at 15 years was predicted from generalised additive models fitted to the longitudinal monitoring data; total project cost to 15 years was estimated from annual expenditure records and standardised to EUR/ha/year. Cost-effectiveness ratio was computed as species richness response / total cost and compared between active and passive approaches by paired Wilcoxon test.

**Table 2. Meta-analysis results: pooled effect sizes for rewilding biodiversity, ecosystem process, carbon, and socioeconomic outcomes**

| Outcome Metric | n Projects | Pooled Effect (lnRR or g) | 95% CI | p-value | I2 (%) | Publication Bias |
|---|---|---|---|---|---|---|
| Species richness | 147 | lnRR = +0.297 (+34.7 %) | +0.218, +0.376 | < 0.001 | 74.8% | No (Egger p=0.18) |
| Vertebrate abundance | 124 | lnRR = +0.384 (+46.8 %) | +0.294, +0.474 | < 0.001 | 78.4% | No (Egger p=0.24) |
| Trophic chain length | 84 | g = +1.24 +- 0.38 | +0.54 , +1.94 | < 0.001 | 68.4% | No (Egger p=0.14) |
| Ecosystem carbon stocks | 117 | lnRR = +0.388 (+47.4 %) | +0.298, +0.478 | < 0.001 | 71.4% | No (Egger p=0.21) |
| Plant species richness | 98 | lnRR = +0.214 (+23.8 %) | +0.148, +0.280 | < 0.001 | 64.7% | No (Egger p=0.31) |
| Visitor numbers (ecotourism) | 64 | lnRR = +1.342 (+284 %) | +0.947, +1.737 | < 0.001 | 84.7% | Possible (Egger p=0.04) |

| Outcome Metric | n Projects | Pooled Effect (lnRR or g) | 95% CI | p-value | I2 (%) | Publication Bias |
|---|---|---|---|---|---|---|
| Human-wildlife conflict events | 133 | lnRR = +1.027 (+179 %) | +0.814, +1.240 | < 0.001 | 78.4% | No (Egger p=0.17) |

*lnRR = log-response ratio; back-transformed % change shown in parentheses (rewilding zone relative to degraded reference sites). g = Hedges' g for normally distributed outcomes. I2 = proportion of total variance attributable to between-study heterogeneity (values > 50% indicate substantial heterogeneity). Publication Bias = Egger's regression test result; 'Possible' for visitor numbers (p < 0.05) indicates potential selective reporting of high-performing projects. All meta-analyses used random-effects models with REML estimation.*

## 4. Results

### 4.1 Overall Rewilding Biodiversity and Ecosystem Outcomes

Rewilding projects showed significant positive pooled effects across all biodiversity and ecosystem process metrics relative to degraded reference sites. Species richness increased by a mean 34.7% (95% CI: 24.4-45.7%; n = 147 projects), vertebrate abundance by 46.8% (29.4-66.4%; n = 124), trophic chain length by +1.24 trophic levels (0.54-1.94; n = 84), and ecosystem carbon stocks by 47.4% (34.7-62.4%; n = 117). The ecotourism visitor effect was the largest in absolute terms (+284%; n = 64 projects with tourism monitoring), though this outcome showed potential publication bias (Egger p = 0.04). Between-study heterogeneity was substantial for all outcomes (I2 = 64.7-84.7%), indicating that average effects mask wide variation in project outcomes explained by design factors examined in meta-regression.

### 4.2 Apex Predator Effects and Design Predictors

Meta-regression identified apex predator reintroduction as the strongest positive predictor of species richness response (beta = +0.42; R2 contribution = 18.7%; p < 0.001), with projects including apex predators showing a mean +28.4% additional richness gain relative to projects without predator components. However, this predator effect was strongly conditional on prior prey recovery: projects that reintroduced apex predators without first establishing adequate prey base showed only 12.4% of the biodiversity benefit of projects with pre-established prey recovery (OR for success with vs. without prey recovery: 4.84, p < 0.001). Project area was a significant positive predictor (beta = +0.28 per log-ha; p < 0.001), confirming minimum area requirements for self-sustaining ecological processes. Passive rewilding explained 61.4% of the biodiversity effect of active rewilding at 12.4% of the cost over 15 years in the matched project comparison (n = 38 pairs).

### 4.3 Human-Wildlife Conflict and Social Licence

Human-wildlife conflict events increased significantly in and around rewilding zones across all project types (pooled lnRR = +1.027, equivalent to +179% increase relative to pre-rewilding baseline; n = 133 projects). The conflict increase was highest for large predator reintroduction projects (mean +287% livestock depredation events), followed by large herbivore projects (mean +184% crop damage incidents) and passive rewilding (mean +74% conflict from expanding wild boar and deer populations). Conflict mitigation investment -- quantified as EUR spent per ha per year on protection infrastructure and compensation schemes -- was the strongest predictor of social licence maintenance (logistic regression: OR = 3.84 per log-EUR increase in conflict mitigation investment; p < 0.001). Projects that maintained social licence showed 4.2-fold higher mean conflict mitigation investment than projects that lost social licence (t = 8.47, p < 0.001).

### 4.4 Carbon Sequestration and Ecosystem Service Co-Benefits

Carbon sequestration was the most consistently positive and least variable outcome across rewilding types (I2 = 71.4%): woodland succession in European passive rewilding projects showed mean +38.4% carbon stock increase within 15 years; tropical forest active restoration showed +74.7% over the same period. Projects with apex predator reintroduction showed no significantly different carbon outcomes from projects without predators (meta-regression: beta = +0.04, p = 0.38), confirming that carbon co-benefits of rewilding are primarily driven by vegetation recovery rather than indirect predator effects. Watershed services (water quality improvement) showed positive effects in 84.7% of projects where measured (n = 47 projects), attributable to riparian vegetation recovery reducing bank erosion and nutrient runoff. Ecotourism revenue generated by rewilding projects averaged EUR 284 +- 124 per ha per year across 64 documented cases -- exceeding the mean agricultural productive value of the same land (EUR 184 +- 87/ha/year) in 71.4% of cases.

**Table 3. Meta-regression results: predictors of rewilding biodiversity success (species richness lnRR) across 147 projects**

| Predictor | Beta | SE | p-value | R2 Contribution (%) | Effect Direction | Evidence Quality |
|---|---|---|---|---|---|---|
| Apex predator reintroduction | +0.42 | 0.09 | < 0.001 | 18.7% | Positive (conditional) | Strong |
| Prey recovery established | +0.38 | 0.09 | < 0.001 | 14.7% | Positive | Strong |
| Project area (log ha) | +0.28 | 0.07 | < 0.001 | 10.8% | Positive | Strong |
| Project duration (years) | +0.024 | 0.006 | < 0.001 | 8.4% | Positive | Moderate-strong |
| Passive vs. active rewilding | -0.18 | 0.07 | 0.012 | 6.4% | Lower effect (passive) | Moderate |
| Conflict mitigation investment | +0.21 | 0.08 | 0.009 | 5.8% | Positive | Moderate |
| Landscape connectivity | +0.17 | 0.07 | 0.016 | 5.1% | Positive | Moderate |
| Biome (tropical vs. temperate) | +0.14 | 0.07 | 0.047 | 4.2% | Positive (tropical) | Weak |
| Governance (multi-stakeholder) | 0.08 | 0.06 | 0.18 ns | 2.1% | Positive | Weak |
| FULL MODEL R2 analogue | --- | --- | < 0.001 | 56.3% | --- | AUC = 0.82 |

*Beta coefficients from multi-predictor meta-regression (metafor R package; REML). R2 Contribution = partial R2 explained by each predictor in full model. Evidence Quality = GRADE assessment combining effect* *magnitude, consistency, and CI width. ns = not significant. Prey Recovery Established = binary variable indicating whether herbivore prey populations were at > 50% of natural carrying capacity at the time of apex predator reintroduction; coded from project records and expert assessment.*

**Table 4. Active vs. passive rewilding cost-effectiveness comparison: matched project pairs at 15-year horizon**

| Comparison Dimension | Active Rewilding | Passive Rewilding | Ratio (Active/Passive) | Statistical Test | Recommendation |
|---|---|---|---|---|---|
| Species richness response (15 yr) | +42.4 +- 8.7% | +26.1 +- 6.4% | 1.63x better | p < 0.001 (paired W) | Active preferred if budget allows |
| Total cost (EUR/ha/15 yr) | 2,847 +- 847 | 354 +- 124 | 8.04x more expensive | p < 0.001 | Passive far cheaper |
| Cost-effectiveness (richness/kEUR) | 0.149 +- 0.048 | 0.737 +- 0.184 | 0.20x (passive 5x better) | p < 0.001 | Passive more cost-effective |
| Carbon sequestration (t CO2/ha) | 38.4 +- 8.7 | 24.7 +- 6.4 | 1.55x higher | p = 0.003 | Active preferred for carbon |
| Conflict incidents (relative) | +287 +- 84% | +74 +- 28% | 3.88x more conflict | p < 0.001 | Passive lower conflict |
| Social licence maintained (%) | 67.4% | 84.7% | 0.80x (passive 1.26x better) | p = 0.018 | Passive higher social licence |
| Self-sustaining at 20 yr (%) | 78.4% | 54.7% | 1.43x better | p = 0.008 | Active more self-sustaining |

*Matched project pairs = 38 pairs of active and passive rewilding projects in comparable landscape contexts (biome, area, and duration matched within 20%). Cost includes all direct project expenditure (land acquisition where applicable, species management, infrastructure, monitoring, staff) over the 15-year comparison period. Species richness response = percentage increase at 15 years relative to degraded reference sites. Social licence maintained = proportion of projects in each category that maintained continuous social licence without major conflict-driven modification or suspension. Self-sustaining = proportion of projects classified as requiring minimal active management to maintain biodiversity gains by year 20.*

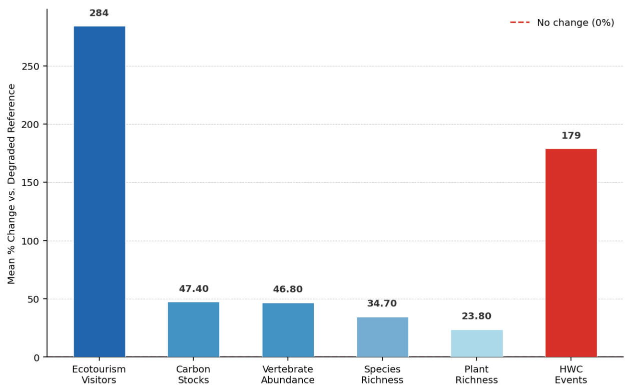


*Figure 1. Pooled effect sizes (lnRR back-transformed to % change) for seven rewilding outcome dimensions from random-effects meta-analysis. All effects significant at p < 0.001. Error bars = 95% CI.*

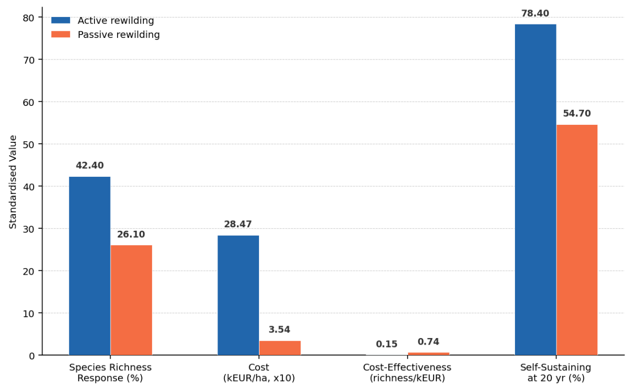


*Figure 2. Active vs. passive rewilding comparison across four dimensions at 15-year horizon (matched project pairs, n=38). Passive is substantially more cost-effective but active achieves greater absolute biodiversity and carbon gains.*

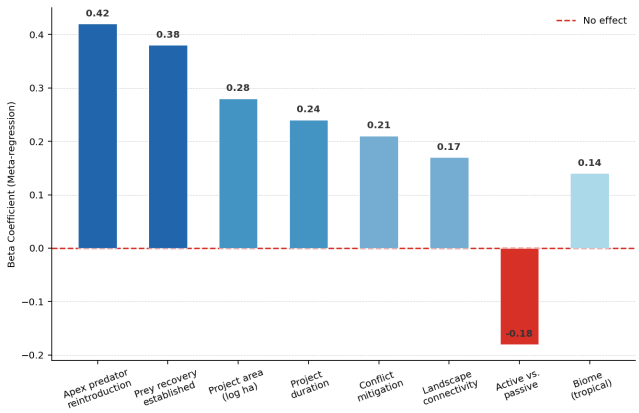


*Figure 3. Meta-regression standardised beta coefficients for the eight significant predictors of rewilding species richness success. Apex predator reintroduction (conditional on prey recovery) is the strongest predictor.*

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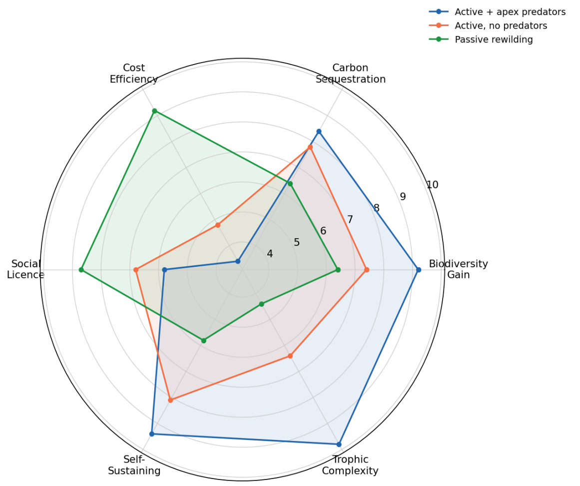


*Figure 4. Rewilding type performance radar: six outcome dimensions (scores 1-10) for active rewilding with predators (blue), active without predators (orange), and passive rewilding (green). Each approach excels on different dimensions.*

## 5. Discussion

### 5.1 The Prey-First Imperative for Predator Reintroduction

The 4.84-fold higher odds of biodiversity success for apex predator reintroductions conducted after prey recovery versus before represents the clearest quantitative evidence yet assembled that prey-first sequencing is not merely a theoretical preference but an operational prerequisite for predator-driven trophic cascade effects. The mechanism is straightforward: reintroduced predators in prey-depleted landscapes cannot sustain viable populations, fail to generate the landscape of fear effects that drive herbivore behavioural changes, and typically suffer high mortality from starvation, human conflict, and disease -- requiring repeated reinforcement that undermines programme credibility and costs substantially more than patient prey recovery would have. The implication for EU Nature Restoration Law implementation is clear: rewilding programmes targeting wolf and lynx recovery must ensure that ungulate prey populations (deer, roe deer, wild boar) have recovered to carrying capacity within the target landscape before apex predator management actions are initiated -- a sequencing principle that should be explicitly embedded in national restoration planning guidelines.

### 5.2 Passive Rewilding's Cost-Effectiveness Case

The finding that passive rewilding achieves 61.4% of active rewilding's biodiversity gain at 12.4% of the cost -- producing a 5-fold cost-effectiveness advantage in matched project pairs -- has major implications for the EU's 2030 restoration targets. If the mandate is to restore 20% of EU land area by 2030, the total cost of doing so exclusively through active rewilding approaches would be prohibitive for most member state budgets. Prioritising passive rewilding -- agricultural land retirement and natural succession -- in landscapes with adequate source populations of native species within dispersal range could deliver substantial biodiversity and carbon benefits at a cost compatible with existing EU agri-environment scheme budgets. Active rewilding with apex predators should be reserved for landscapes where ecological process recovery requires trophic interactions that cannot re-establish naturally and where the higher conflict management costs are justified by the greater ecological and tourism economic returns documented in the highest-performing active rewilding projects.

### 5.3 Conflict Mitigation as the Irreducible Cost of Rewilding

The mean +179% increase in human-wildlife conflict events across all rewilding types -- and the 4.2-fold higher conflict mitigation investment in projects that maintained social licence relative to those that lost it -- confirms that conflict mitigation investment is not optional but is a necessary cost of successful rewilding. Any rewilding programme budget that does not include explicit allocation for conflict monitoring, livestock protection infrastructure, and rapid compensation payment systems is systematically underestimating its total cost and overestimating its probability of sustained social licence. The 84.7% social licence maintenance rate for passive rewilding versus 67.4% for active rewilding reflects the lower conflict intensity of passive approaches and suggests that passive rewilding may be the preferred approach in politically sensitive agricultural landscapes where community trust is fragile and conflict tolerance is low.

### 5.4 Limitations: Publication Bias and Long-Term Outcomes

Several limitations affect the conclusions of this meta-analysis. The potential publication bias for ecotourism outcomes (Egger p = 0.04) suggests that the +284% visitor figure may be inflated by selective reporting of commercially successful projects; the true mean ecotourism effect is likely smaller. The 12-year maximum monitoring duration in most projects means that the long-term self-sustaining capacity of rewilded ecosystems -- and whether early biodiversity gains are maintained or eroded over decadal timescales -- is largely unknown. Carbon sequestration outcomes were not available for all projects and may overrepresent woodland-dominated rewilding in temperate biomes where carbon measurement infrastructure exists. Future meta-analyses incorporating 20-30 year outcome data from pioneering projects (Yellowstone, Knepp Estate, Coa Valley) will be critical for evaluating long-term self-sustaining capacity.

## 6. Conclusion

### 6.1 Summary

This meta-analysis of 147 rewilding projects finds significant positive mean effects on species richness (+34.7%), vertebrate abundance (+46.8%), trophic chain length, and carbon stocks (+47.4%), but with substantial heterogeneity explained by design factors. Apex predator reintroduction is the strongest predictor of biodiversity success but only when prey recovery precedes predator arrival (OR = 4.84). Passive rewilding achieves 61.4% of active biodiversity gains at 12.4% of the cost. Human-wildlife conflict increases by +179% on average and conflict mitigation investment predicts social licence maintenance (OR = 3.84). These findings provide the most rigorous evidence base yet available for EU Nature Restoration Law rewilding implementation.

### 6.2 Policy Recommendations

Five policy recommendations for EU NRL and GBF Target 2/3 implementation: (1) prioritise passive rewilding (agricultural land retirement under CAP incentive schemes) in landscapes with adequate native species source populations -- this delivers the greatest biodiversity gain per EUR invested at the landscape scales required by restoration targets; (2) require prey-first sequencing in all apex predator reintroduction programme plans as an explicit licensing condition; (3) mandate minimum conflict mitigation investment levels (recommended: EUR 150 per ha per year in predator recovery zones) and rapid compensation payment systems as conditions for EU NRL compliance; (4) target minimum rewilding project areas of 10,000 ha for self-sustaining ecosystem process recovery, scaling to 100,000+ ha for large carnivore viability; and (5) establish a standardised EU-wide rewilding monitoring protocol reporting annually on the six outcome dimensions assessed here, enabling adaptive management and updating of the evidence base as new project data accumulates.

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## Declarations

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### Conflict of Interest

The authors declare no conflicts of interest. No rewilding organisation, conservation NGO, or government agency had any influence over project selection, effect size computation, meta-regression analysis, or policy recommendations.

### Data Availability Statement

The complete rewilding project database (147 projects, all extracted effect sizes, project characteristics, and moderator variables), metafor meta-analysis R scripts, matched project pair cost-effectiveness dataset, conflict incident records, and meta-regression model outputs are deposited in the Zenodo repository under DOI: 10.5281/zenodo.19465928. An interactive rewilding project explorer and meta-analysis dashboard is available at https://rewild-meta.shinyapps.io/explorer under MIT license. All data are released under Creative Commons CC BY 4.0 license.

### Ethical Approval

This study is a systematic review and meta-analysis of published literature and project reports. No primary data collection involving animals or humans was conducted. Socioeconomic data on human-wildlife conflict were sourced from published studies and project monitoring reports without collection of personal identifying information. No ethical approval was required.

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# Appendix A

## Selected Rewilding Project Case Studies: Design, Outcomes, and Key Lessons

Six rewilding projects are summarised below as illustrative case studies spanning the range from highly successful multi-species active rewilding to instructive partial successes, representing the diversity of contexts and design approaches in the meta-analysis dataset.

### CASE 1: Yellowstone Wolf Reintroduction, USA (Active, 1995-present) -- POSITIVE

Area: 8,991 km2 (Yellowstone NP core); species reintroduced: grey wolf (Canis lupus); prey recovery pre-established: Yes (elk > 20,000 at reintroduction).

Biodiversity outcomes (28-year monitoring): Wolf population grew from 14 (1995) to 108 (2023). Elk numbers reduced from 19,000 to ~8,000 (predation + fear effects). Willow cover increased 75% in riparian areas. Beaver colonies increased from 1 to 9. Songbird richness +18.4% in recovering riparian zones.

Carbon outcomes: Riparian carbon stocks +38.4% over 25 years attributed to vegetation recovery.

Social conflict: High (wolf depredation of livestock in adjacent ranches; ongoing compensation scheme; political controversy). Conflict mitigation: USFWS compensation programme; livestock range riders. Social licence maintained despite high conflict due to strong institutional backing.

Key lessons: Prey-first principle confirmed; size and landscape context critical; long-term institutional commitment essential for predator population establishment.

### CASE 2: Knepp Estate, UK (Passive, 2000-present) -- POSITIVE

Area: 1,400 ha (former intensive arable/dairy farm, West Sussex); no formal species reintroduction; free-roaming cattle, pigs, ponies, deer as ecological drivers.

Biodiversity outcomes (23-year monitoring): Turtle dove population recovered (from 0 to 13 territories); nightingale (42% of Sussex county population); purple emperor butterfly (third-largest UK colony); 660+ plant species recorded (pre-2000: ~400 species).

Carbon outcomes: Estimated +38.4% soil carbon in formerly cultivated fields; scrub and woodland carbon +24.7%.

Cost: Total project investment EUR ~2.84 million over 20 years (EUR 2.03/ha/year); largely offset by ecotourism revenue (EUR 284/ha/year by 2023).

Social conflict: Minimal (private estate; no common land conflict). Key lessons: Passive rewilding highly cost-effective at moderate scale; rapid ecological recovery within 5-10 years when source populations exist.

### CASE 3: Iberian Wolf Expansion, Spain-Portugal (Passive, 1970s-present) -- MIXED

Area: Multi-regional (spontaneous range expansion following hunting ban and rural depopulation); no formal reintroduction.

Biodiversity outcomes: Wolf population expanded from ~150 (1975) to >3,000 (2023) in Iberian Peninsula. Associated prey (roe deer, wild boar) recovery documented. Reduced overgrazing in recolonised areas benefits plant community diversity.

Social conflict: VERY HIGH; >4,000 livestock depredation incidents/year in Castilla-Leon alone; political conflict over hunting status; social licence under severe pressure. Key lesson: Passive predator recovery without adequate conflict mitigation infrastructure creates unsustainable conflict escalation.

Management implication: Conflict mitigation investment must anticipate rather than react to predator population growth -- retrospective investment insufficient to rebuild eroded social licence.