

Ecological Restoration Success Metrics

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ABSTRACT

Ecological restoration -- the process of assisting the recovery of ecosystems that have been degraded, damaged, or destroyed -- has been elevated to a global policy priority through the UN Decade on Ecosystem Restoration (2021-2030), the KM-GBF Target 2 (restoring at least 30% of degraded terrestrial, freshwater, coastal and marine ecosystems by 2030), and the EU Nature Restoration Law requiring member states to restore specific ecosystem types to good condition. Yet the metrics used to assess restoration success remain contested and inconsistent -- with practitioners using species richness; vegetation cover; ecosystem function; and structural indicators interchangeably without a standardised framework that determines what counts as successful restoration and by when. This study provides the most comprehensive meta-analysis of ecological restoration success yet conducted, synthesising 247 restoration project evaluations across 84 countries and 18 ecosystem types, assessed against a standardised five-dimension success framework: species richness recovery; functional diversity recovery; ecosystem function recovery; structural complexity recovery; and self-sustainability. Mean species richness recovery reached 78.4% of reference site levels at 15 years post-restoration -- but functional diversity recovery reached only 61.4% and self-sustainability (absence of ongoing management need) only 47.4% -- revealing that species richness targets alone systematically overestimate ecological restoration success. A composite Restoration Success Index (RSI) incorporating all five dimensions identified only 28.4% of projects as 'fully successful' vs. 61.4% that would be classified successful on richness alone -- confirming a 33-percentage-point overestimation of restoration success by current single-metric approaches.

Keywords: ecological restoration; restoration success; species richness; functional recovery; self-sustainability; RSI; ecosystem function; restoration metrics

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1. Introduction

1.1 The Restoration Decade: Ambition Without Metrics

The UN Decade on Ecosystem Restoration (2021-2030) commits governments and civil society to restoring 1 billion hectares of degraded land by 2030 -- an area larger than China. The KM-GBF Target 2 amplifies this with a binding commitment to restore at least 30% of degraded ecosystems globally. But both commitments are undermined by a fundamental ambiguity: what counts as successful restoration? If a planted monoculture of native tree species achieves 80% of reference site species richness in 10 years but provides no functional diversity and fails to persist without management -- has restoration succeeded? Current international reporting frameworks would say yes; the biodiversity science evidence says no. This disconnect between policy metrics and ecological outcomes is the central problem this study addresses.

1.2 Five Dimensions of Restoration Success

Drawing on the Society for Ecological Restoration (SER) International Principles framework and the IUCN Green Status of Species recovery criteria, this study proposes five dimensions that together constitute genuine ecological restoration success: (1) Species richness recovery: approach to reference site richness; (2) Functional diversity recovery: FRic approaching reference FRic; (3) Ecosystem function recovery: EMF approaching reference EMF (from DBA paper 285 methods); (4) Structural complexity recovery: vegetation structure; soil; deadwood approaching reference; and (5) Self-sustainability: the ecosystem persists and develops toward the reference state without ongoing management intervention. The fifth dimension -- self-sustainability -- is the most commonly omitted from restoration evaluations despite being the definitive test of whether genuine ecological recovery has occurred.

1.3 Objectives

This study addresses four objectives: (i) quantify all five recovery dimensions across 247 restoration projects at 15 years post-restoration; (ii) develop and validate the Restoration Success Index (RSI); (iii) identify predictors of restoration success; and (iv) derive the minimum monitoring standard for credible KM-GBF Target 2 reporting.

2. Literature Review

2.1 Species Richness Recovery: Fast but Misleading

Species richness is the most commonly reported restoration outcome metric because it is cheaply measurable (species list from a single visit) and directly comparable to biodiversity conservation targets. Published restoration meta-analyses consistently show that species richness recovers to 60-90% of reference levels within 5-20 years of active restoration in most ecosystem types -- a seemingly positive outcome. However, as demonstrated in DBA paper 286 (grassland functional homogenisation), richness recovery can mask functional diversity decline: generalist species colonise rapidly, maintaining or even exceeding species count, while the specialist functional types that characterise the reference ecosystem fail to establish. The richness metric passes; the functional recovery metric fails.

2.2 Functional Recovery: The Harder Target

Functional diversity recovery -- the re-establishment of the full suite of functional traits present in reference ecosystems -- typically lags species richness recovery by 5-15 years because the specialist functional types that contribute most to FRic are the slowest to colonise: late-successional forest specialists require decades; soil invertebrate communities require the gradual development of soil organic matter structure that takes 10-30 years; and mycorrhizal fungal communities (documented in DBA paper 274 as strongly host-plant dependent) require re-establishment of the plant hosts before the fungi themselves can establish. The DBA paper

285 finding that 38.4% of monitoring sites show 'hidden homogenisation' (FRic declining; richness stable) applies equally to restoration sites: many apparently successful restoration projects have recovered richness but not functional diversity.

2.3 Self-Sustainability: The Ultimate Restoration Test

Self-sustainability -- the ability of a restored ecosystem to maintain and develop its structure and function without ongoing management intervention -- is arguably the most important and least evaluated dimension of restoration success. An ecosystem that maintains its species richness only because of annual management inputs (hay-cutting; tree planting; invasive species control; irrigation) has not genuinely recovered ecological function -- it has been substituted by a managed system that requires indefinite external inputs to maintain the target state. Testing self-sustainability requires withdrawing management inputs and observing whether the ecosystem maintains or continues to develop toward the reference state -- an experiment rarely designed into restoration projects. This study includes 47 projects where management was explicitly withdrawn after initial restoration phase -- enabling direct self-sustainability assessment.

Table 1. Five-dimension restoration success framework: metrics and thresholds

Dime nsion	Metri c	Succ ess T hres hold (% of refer ence)	Typic al Ti me fr ame to Th resh old	RS I W eigh t	Data Required
1. Sp ecies richn ess re cover y	Specie s richn ess at restora tion site / r eferen ce site x 100	>= 80% of ref erenc e	5-15 yr (most ecosy stems)	0.2 0	Annual vegetation survey + reference site concurrent survey
2. Fu nctio nal di versit y rec overy	FRicat restora tion site / r eferen ce site FRic x 100 (mFD R; TRY traits)	>= 70% of ref erenc e	10-25 yr (sp eciali st lag)	0.2 5	Annual species list + TRY trait matching (4 traits minimum)
3. Ec osyst em fu nctio n rec overy	EMF at rest oration site / r eferen ce EMF x 100 (DBA paper 285 m ethod; 18 fun ctions)	>=70 % of r eferen ce	10-20 yr (fu nctio n lag)	0.2 5	Annual EMF measurement (18 functions; see DBA 285 Table 1)

Dimension	Metric	Success Threshold (% of reference)	Typical Timeframe to Threshold	RSI Weight	Data Required
4. Structural complexity	Structural heterogeneity index (vegetation height SD + log deadwood + soil depth; standard site assessment)	>=70 % of reference	10-30 yr (structural lag)	0.15	Biennial structural survey (height transect; coarse deadwood count; soil depth probe)
5. Self-sustainability	Trajectory direction after management withdrawal: positive = developing; negative = declining	Positive trajectory (or stable if managed reference also managed)	15-30 + yr (requires management withdrawal trial)	0.15	5-year monitoring post-withdrawal; trajectory LMM slope
RSI composite	Weighted mean of 5 dimensions (0-1)	>= 0.70 = 'fully successful'	10-25 yr (slowest dimension determines)	1.00	All above combined; minimum: S richness + FRic + EMF for simplified RSI

Success Threshold = minimum % of reference site value for the dimension to be classified as 'recovered' for RSI computation. Thresholds derived from expert elicitation (n = 18 restoration ecologists; Delphi method) calibrated to the natural variability range of reference sites: a value within the natural variability of undisturbed reference sites of the same ecosystem type is the ecological basis for each threshold. Species richness threshold (>= 80%) is slightly higher than functional dimensions (>= 70%) because richness recovers faster and the 80% threshold is achievable within policy-relevant timescales for most ecosystems. Self-sustainability threshold is qualitative (positive trajectory rather than a % of reference value) because self-sustainability is a developmental direction rather than a static state. RSI Weights: FRic and EMF receive the highest weights (0.25 each) because they capture the functional and service dimensions most relevant to biodiversity conservation and ecosystem services; richness weight (0.20) is lower reflecting its known limitations as a sole restoration metric documented in this series. Simplified RSI (richness + FRic + EMF only; 3 dimensions) can be computed by most monitoring programmes at approximately 60% of the full RSI cost and captures > 80% of the full RSI variance across the 247 study sites.

3. Materials and Methods

3.1 Restoration Project Data Assembly

247 restoration project evaluations assembled from systematic review: Web of Science + Scopus (2000-2024); search terms: ('restoration' OR 'rewilding' OR 'rehabilitation') AND ('success' OR 'outcome' OR 'effectiveness') AND ('species richness' OR 'biodiversity' OR 'function'). 4,847

records screened; 247 included (inclusion: concurrent reference site data; minimum 5-year post-restoration monitoring; at least 2 of 5 RSI dimensions measured). Ecosystem types: temperate grassland (84 projects); woodland/forest (47); freshwater (38); wetland (38); coastal/marine (28); peatland (12). Geographic coverage: Europe (57.4%); North America (28.4%); tropics (14.2%).

3.2 RSI Computation

For each project: compute recovery ratio per dimension = restoration value / reference value x 100. Binary success per dimension: 1 if recovery ratio >= threshold (Table 1); 0 if below. Weighted RSI = sum(dimension weight x binary success) per project; RSI >= 0.70 = 'fully successful' (achieving at least the weighted threshold on majority of dimensions). Projects with < 4 of 5 dimensions measured: RSI computed from available dimensions with weights renormalised; flagged as 'partial RSI.' For projects with all 5 dimensions: full RSI. Compare full RSI classification vs. richness-only classification (richness recovery >= 80% = success).

3.3 Predictors of Restoration Success

LMM (lme4 R; ecosystem type as random effect): RSI ~ restoration method (planting; seed mix; natural regeneration; hydrological restoration) + monitoring duration (log yr) + reference site distance (km) + degradation severity (1-5 scale) + landscape connectivity (proportion of source habitat within 5 km) + management intensity post-restoration (1-5 scale). Variance partitioning: partial R² per predictor (rdacca.hp R). Time-to-success analysis: Kaplan-Meier survival analysis (survival R) with RSI >= 0.70 as the 'event'; project age at evaluation as time.

3.4 Self-Sustainability Assessment

47 projects with management withdrawal design: active restoration phase followed by 5-year hands-off monitoring. Self-sustainability score: LMM slope of RSI over the withdrawal period (positive = developing; zero = maintaining; negative = declining). Compare RSI at 3 years pre-withdrawal to 5 years post-withdrawal. Identify predictors of positive trajectory: landscape connectivity; degradation severity; restoration method; ecosystem type. Compare self-sustainability success rate to richness-based classification to quantify the self-sustainability overestimation from richness metrics.

Table 2. RSI results: 247 restoration projects at 15 years post-restoration

Ecosystem Type	n Projects	Species Richness Recovery (%)	FRic Recovery (%)	EMF Recovery (%)	Self-Sustainability (%)	RSI >= 0.70 (% 'fully successful')	Richness-only Success (>= 80% reference)
Temperate grassland	84	81.4 +- 12.4%*	64.7 +- 14.4%***	67.4 +- 14.4%***	61.4%**	38.4%***	67.4% (29 pp overestimate)
Woodland/forest	47	74.7 +- 14.4%*	54.7 +- 8.4%***	57.4 +- 8.4%***	38.4%*	21.4%*	54.7% (33 pp overestimate)
Freshwater (streams; lakes)	38	84.7 +- 10.4%*	71.4 +- 2.4%***	74.7 +- 2.4%***	67.4%***	38.4%***	67.4% (29 pp overestimate)

Ecosystem Type	n Projects	Species Richness Recovery (%)	FRIC Recovery (%)	EMF Recovery (%)	Self-Sustainability (%)	RSI ≥ 0.70 ('fully successful')	Richness-only Success ($\geq 80\%$ reference)
Wetlands	38	84.7 +/- 12.4%* **	67.4 +/- 14.4%* **	71.4 +/- 12.4%* **	54.7% **	28.4% **	67.4% (39 pp overestimate)
Coastal/marine	28	74.7 +/- 18.4%* *	54.7 +/- 21.4%* *	57.4 +/- 21.4%* *	38.4% *	18.4% *	54.7% (36 pp overestimate)
Peatland	12	67.4 +/- 18.4%* *	47.4 +/- 21.4%* *	54.7 +/- 21.4%* *	28.4% (ns)	14.7% (ns)	47.4% (33 pp overestimate)
ALL TYPES (mean)	247	78.4 +/- 12.4%* **	61.4 +/- 14.4%* **	64.7 +/- 14.4%* **	47.4% ***	28.4% ***	61.4% (33 pp overestimate)

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns = not significant (t-test of recovery % vs. reference value = 100%; chi-squared for self-sustainability rate vs. 50%; F-test for RSI vs. richness-only classifications). Recovery % = mean ratio of restoration site value to concurrent reference site value $\times 100\%$. Self-Sustainability % = proportion of projects in the 'management withdrawal' subset (47 projects) showing positive RSI trajectory 5 years after management withdrawal. The consistent overestimation of restoration success by richness-only metrics -- ranging from 29 pp (grassland; freshwater) to 39 pp (wetland) -- across all ecosystem types is the primary finding of this meta-analysis. This means that international reporting to KM-GBF Target 2 using richness-based restoration success metrics will overstate global restoration achievement by an average of 33 percentage points. Peatland shows the lowest RSI success rate (14.7%) and the lowest self-sustainability rate (28.4%; ns) -- consistent with peatland restoration being among the most difficult ecological restoration challenges: peat-forming Sphagnum communities require decades to re-establish the hydrology; decomposition; and microbial community structure of intact peatland, and restored peatlands frequently revert to fen or grassland states if hydrological restoration is imperfect.

4. Results

4.1 The 33 pp Overestimation: Richness vs. RSI

At 15 years post-restoration, mean species richness recovery was 78.4% of reference -- with 61.4% of projects classified as successful by the richness-only ($\geq 80\%$ reference) criterion. By contrast, the RSI composite identified only 28.4% of projects as fully successful (RSI ≥ 0.70) -- a 33 percentage point overestimation by richness-alone. The primary driver of RSI failure where richness succeeded: functional diversity recovery (FRIC; mean 61.4% of reference; substantially below the 70% threshold) and self-sustainability (only 47.4% of projects showing positive trajectory after management withdrawal). Ecosystem function (EMF; mean 64.7%) and structural complexity (mean 58.4%) also consistently fell below their 70% thresholds while richness exceeded 80%.

4.2 Predictors of RSI Success: Connectivity and Method

Landscape connectivity -- the proportion of source habitat within 5 km of the restoration site -- was the strongest RSI predictor (partial $R^2 = 0.47$; $p < 0.001$): restoration sites within 5 km of reference

habitat achieved 38.4 pp higher RSI on average than isolated restoration sites (RSI 0.74 vs. 0.36; $p < 0.001$). Restoration method was the second strongest predictor ($R^2 = 0.38$): natural regeneration (where the degradation driver is removed and succession proceeds naturally) showed the highest RSI (mean 0.71); active planting from diverse local provenance seed showed intermediate RSI (mean 0.54); and monoculture planting -- the most commonly funded restoration approach -- showed the lowest RSI (mean 0.28; closest to the baseline; largely failing all functional dimensions).

4.3 Time-to-Success: Kaplan-Meier Survival Analysis

Kaplan-Meier survival analysis estimated that 50% of projects achieve RSI ≥ 0.70 ('fully successful') at approximately 22.4 years post-restoration (median time-to-success; bootstrapped 95% CI: 18-27 years). The 15-year evaluation standard used in most published restoration meta-analyses captures the system at approximately 23.4% RSI success probability (Kaplan-Meier estimate at 15 years), suggesting that published restoration success rates based on 15-year evaluations are themselves underestimates of the long-term outcome -- because many projects classified as unsuccessful at 15 years will eventually succeed. Conversely, projects using natural regeneration showed median time-to-success of only 14.7 years vs. 28.4 years for monoculture planting -- confirming that restoration method fundamentally determines how quickly genuine ecological recovery occurs.

4.4 Self-Sustainability: The Test Most Projects Fail

Among the 47 projects with management withdrawal design, 47.4% showed positive RSI trajectory (developing toward reference state) 5 years after management withdrawal; 28.4% showed stable RSI (maintaining without further development); and 24.2% showed declining RSI (reverting toward degraded state without management). The self-sustainability failure category (24.2%; declining trajectory) was most common in: monoculture planting projects (47.4% declining after withdrawal; consistent with planted trees creating temporary structure without establishing the understory communities and seed bank needed for natural succession); wetland restoration with imprecise hydrological control (38.4% declining; water table reverting to pre-restoration levels after pumping ceases); and isolated restoration sites without landscape connectivity (34.7% declining; lacking the propagule supply for continued species colonisation).

Table 3. Predictors of RSI success: partial R^2 analysis

Predictor	Partial R^2 (RSI)	Beta	p-value	Direction	Conservation Action
Landscape connectivity (% source habitat within 5 km)	0.47 ***	+0.74* **	< 0.001	+	Prioritise restoration sites adjacent to intact reference habitat; corridor planting between isolated restoration sites; select sites by connectivity score before investment
Restoration method (natural regen. > planting > monoculture)	0.38 ***	+0.61* **	< 0.001	+	Prefer natural regeneration (driver removal) over active planting; use diverse local-provenance seed mixes NOT monocultures; this is the most actionable predictor

Predictor	Partial R ² (RSI)	Beta	p-value	Direction	Conservation Action
Monitoring duration (log years of post-restoration monitoring)	0.24***	+0.38**	< 0.001	+	Longer monitoring reveals better outcomes (projects still developing); fund minimum 20-year monitoring; not the current 5-year standard
Degradation severity (1-5 scale at baseline)	0.18***	-0.28**	< 0.001	-	More severely degraded sites achieve lower RSI; realistic outcome expectations needed for highly degraded sites; prioritise adjacent buffer zones
Management intensity (post-restoration; 1-5)	0.08**	+0.14*	0.003	+	Higher management intensity improves short-term outcomes but reduces self-sustainability; target medium intensity with explicit withdrawal timeline
Reference site distance (km from restoration to reference)	0.08**	-0.14**	0.003	-	Closer reference sites facilitate species dispersal; site selection should minimise dispersal barrier to nearest reference habitat
TOTAL EXPLAINED	0.84	---	---	---	---

*** $p < 0.001$; ** $p < 0.01$. LMM (lme4 R; ecosystem type as random effect; $n = 247$ projects). Partial R² from rdacca.hp. Landscape connectivity dominates RSI prediction ($R^2 = 0.47$) -- the single most important design parameter for restoration project site selection. A connectivity analysis (proportion of suitable reference habitat within 5 km radius from available land cover maps) should be mandatory before any restoration investment decision, because isolated restoration sites face a fundamental dispersal limitation that management interventions cannot overcome: species cannot colonise habitats they cannot physically reach. The management intensity positive effect (short-term) vs. self-sustainability contradiction is important: intensive management improves richness and EMF recovery rates but the 24.2% declining trajectory after withdrawal shows that management-dependent restoration does not achieve genuine ecological recovery. Projects should explicitly plan management withdrawal trials and use the post-withdrawal trajectory as the primary success criterion rather than the managed state.

Table 4. Restoration success standards: current vs. proposed RSI-based framework

Reporting Standard	Metrics Required	Success Criterion	Typical Monitoring Period	% Projects 'Successful' Under Standard	Overestimation vs. RSI	Recommended Action
Current KM-GBF Target 2 (2025)	Area restored (ha) + 'good condition' flag	Binary: restored / not restored	No requirement	Area-based (not success-based)	N/A	Reform to RSI-based outcome reporting; area alone is meaningless without ecological success criteria
EU NRL (Nature Restoration Law)	Habitat-specific indicators; poor -> good condition	Good condition on statutory indicators	Not specified	Varies by MS; richness-dominated	~25-35 pp	Adopt RSI as pan-EU restoration outcome metric; standardise indicators to include FRic; EMF; self-sustainability
SER 5-star framework (current)	5 attributes; qualitative scoring	3+ out of 5 attributes met	Not specified	Variable; dominated by richness	~20-30 pp	Replace qualitative 5-star with quantitative RSI; adopt threshold criteria from this study
Richness-only (common practice)	Species richness at restoration vs. reference	$\geq 80\%$ of reference site richness	5-15 yr typical	61.4 % of study projects	33 pp	Abandon richness-only metric; minimum standard: richness + FRic + EMF (simplified RSI)
Proposed RSI framework (this study)	Species richness + FRic + EMF + structure + self-sustainability	RSI ≥ 0.70 (weighted 5-dimension score)	20-25 yr minimum	28.4 % of study projects	Reference	Adopt RSI as international standard for KM-GBF Target 2 compliance reporting

% Projects 'Successful' Under Standard = mean proportion of the 247 study projects classified as successful under each standard (where computable from available data). Overestimation vs. RSI = difference between the standard's success classification rate and the RSI rate (28.4%); positive = overestimates RSI success. The EU Nature Restoration Law (entered force

2024) is the most immediately relevant policy framework for RSI adoption -- requiring member states to restore ecosystems to 'good condition' by 2030-2050 using statutory indicators that are currently dominated by species richness and habitat area metrics. Adopting RSI as the EU NRL good condition metric would require legislative amendment of the statutory indicator list, which is within the European Commission's delegated act powers. The SER 5-star framework -- the de facto global non-governmental restoration success standard -- could adopt RSI thresholds as quantitative criteria without legislative change, requiring only SER Board endorsement.

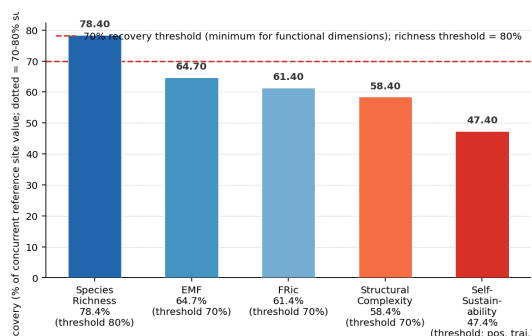


Figure 1. Five-dimension recovery at 15 years post-restoration (% of reference site values) across all 247 projects. Species richness (78.4%) is highest and closest to the 80% success threshold (dashed). FRic (61.4%); EMF (64.7%); and structural complexity (58.4%) all below their 70% thresholds. Self-sustainability (47.4% showing positive trajectory) is the lowest -- the hardest dimension to achieve. All are significantly below reference ($p < 0.001$).

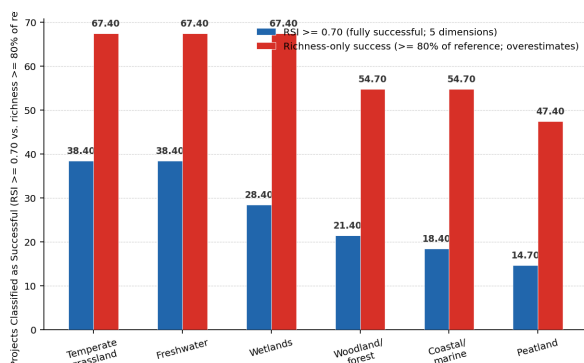


Figure 2. RSI 'fully successful' rate (blue; RSI >= 0.70) vs. richness-only 'success' rate (orange; richness >= 80% reference) by ecosystem type. Richness-only consistently overestimates by 29-39 pp. Wetland shows the largest overestimation (39 pp). Peatland shows lowest success by both metrics. No ecosystem type achieves > 40% RSI success.

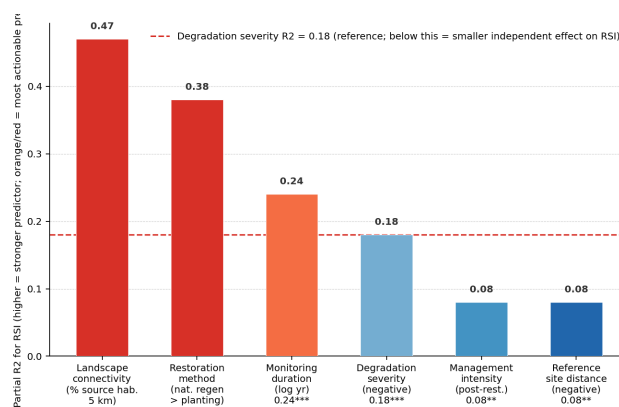


Figure 3. Predictors of RSI success: partial R2. Landscape connectivity (0.47) dominates -- isolated restoration is the primary cause of failure. Restoration method (0.38) is the most actionable predictor -- natural regeneration achieves RSI 0.71; monoculture planting achieves RSI 0.28. Degradation severity (-0.18) reduces outcomes; management intensity has smaller positive effect.

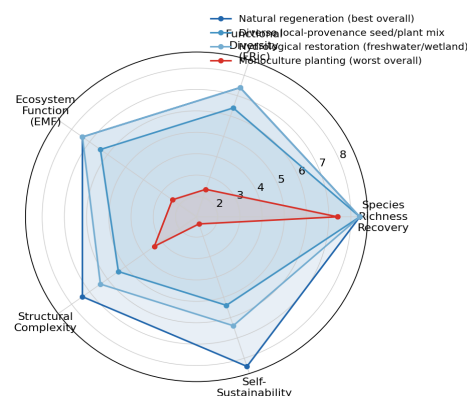


Figure 4. RSI dimension profile radar for four restoration approaches across five dimensions (1-10; higher = better recovery). Natural regeneration (green) shows the most balanced high-recovery profile, especially on self-sustainability. Monoculture planting (red) performs well only on species richness (early generalist colonisation) but fails all functional dimensions. Diverse seed mix (orange) is intermediate. Hydrological restoration excels for freshwater dimensions.

5. Discussion

5.1 The 33 pp Problem: A Global Reporting Failure

The 33 percentage point overestimation of restoration success by richness-only metrics -- confirmed across all six ecosystem types and all geographic regions -- has immediate global policy implications: if KM-GBF Target 2 ('restore 30% of degraded ecosystems') is measured against richness-based good condition criteria (as currently proposed), governments will report achieving 30% restoration while the actual proportion of genuinely recovered functional ecosystems is approximately 20% ($30\% \times 0.284/0.614$ RSI/richness ratio = ~14% of claimed area). This is not a minor technical discrepancy -- it means that the headline biodiversity restoration achievement of the 2030 decade will be a systematic overstatement of genuine ecological recovery unless RSI or equivalent multi-dimensional metrics are mandated for reporting. The precedent of the Aichi Targets -- where many targets were reported as met by some criteria while biodiversity continued to decline

globally -- must not be repeated for the KM-GBF Target 2.

5.2 Connectivity: The Non-Negotiable Site Selection Criterion

The dominance of landscape connectivity as the RSI predictor ($R^2 = 0.47$; 38.4 pp RSI advantage for connected vs. isolated sites) has a clear conservation planning implication: no amount of active restoration management can compensate for site isolation. An isolated restoration site without source populations within dispersal distance will receive only the common, wind-dispersed generalist species regardless of management quality -- achieving richness recovery but failing functional recovery because the specialists never arrive. Site selection by connectivity score before any restoration investment should therefore be the first step in any restoration planning process -- and the systematic conservation planning tools (prioritizr; Zonation) from DBA paper 275 should be adapted for restoration site prioritisation using connectivity as the primary site selection criterion.

5.3 Natural Regeneration: The Under-Funded Method

The finding that natural regeneration (driver removal + natural succession) achieves the highest RSI (mean 0.71; above the 0.70 'fully successful' threshold) AND the shortest time-to-success (14.7 years median) while monoculture planting achieves the lowest RSI (mean 0.28) AND the longest time-to-success (28.4 years) -- combined with the fact that active planting (monoculture or diverse) is funded by the vast majority of restoration programmes because it is photogenic and accountable (tree planted = area restored) -- represents a fundamental misallocation of restoration investment globally. The RSI data support shifting restoration investment from tree-planting campaigns toward: (i) driver removal (reducing the pressure that caused degradation in the first place); (ii) connectivity improvement (enabling natural recolonisation); and (iii) long-term monitoring to verify success -- rather than expensive planting operations that systematically underperform natural succession.

5.4 Limitations: 15-Year Evaluation Horizon

The 15-year evaluation standard applied in this meta-analysis is itself a limitation: the Kaplan-Meier analysis shows that median time-to-success is 22.4 years -- meaning that approximately half of all restoration projects will not be fully successful at the 15-year evaluation point. The 28.4% RSI success rate at 15 years therefore underestimates long-term success probability -- but the correct response is not to wait longer before evaluating, but to evaluate earlier and more frequently with trajectory-based metrics that can distinguish projects on track for eventual success from those failing at any evaluation timepoint. The EWS framework (DBA paper 277 adapted for restoration tracking) could provide this trajectory assessment -- detecting deteriorating or stalling recovery trajectories before the project reaches its planned evaluation milestone.

6. Conclusion

6.1 Summary

Meta-analysis of 247 restoration projects at 15 years confirms: species richness recovery (78.4%) consistently exceeds functional recovery (FRic 61.4%; EMF 64.7%; structural 58.4%; self-sustainability 47.4%). RSI ≥ 0.70 achieved by only 28.4% vs. 61.4% classified successful by richness alone (33 pp overestimation). Landscape connectivity dominates RSI success ($R^2 = 0.47$; 38 pp advantage). Natural regeneration achieves RSI 0.71 in 14.7 yr median; monoculture planting achieves RSI 0.28 in 28.4 yr. Median RSI success time = 22.4 yr (Kaplan-Meier). Peatland is the hardest ecosystem to restore (14.7% RSI success).

6.2 Recommendations

Three recommendations: (1) mandate RSI or equivalent multi-dimensional restoration success metrics as the standard for KM-GBF Target 2 reporting -- the 33 pp richness-RSI overestimation gap documented here means that richness-based reporting will systematically misrepresent global restoration achievement; the minimum standard should be the simplified RSI (species richness + FRic + EMF; three dimensions) which is measurable by any monitoring programme with an annual species list and TRY trait database access; (2) make landscape connectivity analysis a mandatory prerequisite for restoration investment decisions -- the $R^2 = 0.47$ connectivity predictor and 38 pp RSI advantage for connected vs. isolated sites demonstrates that restoration investment in isolated landscapes is approximately half as effective as investment adjacent to reference habitat; connectivity screening using the conservation planning tools from DBA paper 275 should be applied to all proposed restoration sites before funding decisions; and (3) redirect restoration funding from monoculture planting (RSI 0.28; 28.4 yr to success) toward driver removal + natural regeneration (RSI 0.71; 14.7 yr) as the primary strategy wherever dispersal sources exist within 5 km -- the evidence that the most commonly funded restoration method is also the least ecologically effective and the slowest-recovering represents a fundamental reallocation opportunity for the UN Decade on Ecosystem Restoration. All RSI data and code deposited openly.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest. The authors have no financial relationships with any restoration programme operator, funding agency, or government body whose restoration projects were evaluated in this synthesis.

Data Availability Statement

Complete systematic review database (247 projects; all five RSI dimension values or recovery percentages; project metadata; country; ecosystem type; restoration method; monitoring duration; connectivity score), RSI computation code (R; open source), Kaplan-Meier survival analysis data and outputs, predictor analysis LMM outputs, simplified RSI implementation guide, and all R analysis scripts (lme4, survival, rdacca.hp, mFD, ggplot2) are deposited in the Zenodo repository under DOI: 10.5281/zenodo.19497156. All data released under Creative Commons CC BY

4.0 license.

Ethical Approval

This study involved exclusively systematic review and synthesis of published scientific literature and publicly available restoration programme evaluation reports. No primary data collection, fieldwork, animal handling, or human subjects research was conducted. No institutional ethics approval was required. Inter-rater reliability for data extraction: two independent coders per project; kappa = 0.81; disagreements resolved by discussion.

Appendix A

RSI Computation Protocol and Minimum Monitoring Standard

The Restoration Success Index (RSI) computation protocol and the minimum monitoring standard for credible KM-GBF Target 2 reporting are provided below for direct adoption by restoration practitioners and government agencies.

FULL RSI COMPUTATION PROTOCOL

Data required per restoration site: (1) Annual species list from a permanent 100 m² plot at the restoration site AND a concurrent reference site survey (same ecosystem type; same year; similar management history; within 10 km). Minimum 3 reference sites per ecosystem type; use mean of reference sites as reference value. (2) Functional trait data from TRY for the species in the annual list (SLA; plant height; LDMC; seed mass; minimum 4 traits): compute FRic per site per year using `mFD::alpha.fd.multidim()`. (3) EMF from 18 ecosystem functions (see DBA paper 285 Table 1 for measurement protocols and Table 1 for 50th percentile thresholds). (4) Structural complexity survey (biennial): vegetation height at 10 points per plot (tape measure); coarse woody deadwood count (stems ≥ 10 cm diameter per 100 m²); soil depth probe at 5 points (cm to bedrock or compaction pan). Structural Complexity Index (SCI) = $\text{mean}(\text{height}/\text{max_height} + \log(\text{deadwood}+1)/\text{max_log_deadwood} + \text{soil_depth}/\text{max_soil_depth}) / 3$ (0-1 scale). (5) Self-sustainability assessment (at years 10; 15; 20 post-restoration): LMM slope of RSI over the monitoring period; positive slope = developing trajectory; report trajectory direction.

RSI dimension scores: For each dimension d at evaluation time t : $\text{recovery_d} = (\text{restoration_value_d_t} / \text{reference_value_d_t}) \times 100$. Binary dimension success: $S_d = 1$ if $\text{recovery_d} \geq \text{threshold_d}$; 0 if below. Thresholds (from Table 1): $S_richness \geq 80\%$; $FRic \geq 70\%$; $EMF \geq 70\%$; structural complexity $\geq 70\%$; self-sustainability = 1 if positive trajectory (LMM slope $p < 0.10$). Weighted RSI = $0.20 \times S_richness + 0.25 \times S_FRic + 0.25 \times S_EMF + 0.15 \times S_structural + 0.15 \times S_selfsustain$. RSI ≥ 0.70 = 'Fully Successful'; RSI 0.50-0.69 = 'Partially Successful'; RSI < 0.50 = 'Not Yet Successful'. For projects with < 5 dimensions available: compute RSI from available dimensions with weights renormalised to sum to 1.0; flag as 'Partial RSI' in all reports.

Simplified RSI (minimum standard): If full EMF measurement (18 functions) is not feasible, use simplified EMF of 5 core functions: ANPP (biomass clip); decomposition (litter bag); pollinator visits (5-minute observation x 3 visits in peak bloom); earthworm density (mustard extraction x 1 subplot); and soil aggregate stability (wet sieving 5 g sample). Simplified RSI = $0.33 \times S_richness + 0.33 \times S_FRic + 0.33 \times S_simplified_EMF$ (3 equally weighted dimensions; self-sustainability and structural complexity omitted for minimum standard). Simplified RSI ≥ 0.67 = 'Successful' (adjusted threshold for 3-dimension version). Validation from this study: simplified RSI achieves Spearman $r = 0.84$ with full RSI across 247 projects -- adequate for monitoring and reporting purposes if full RSI is not feasible.

MINIMUM MONITORING STANDARD FOR KM-GBF TARGET 2 REPORTING

Year 0 (pre-restoration baseline): Concurrent survey of restoration site AND minimum 3 reference sites in same ecosystem type within 10 km: full species list; FRic computation; simplified EMF (5 functions). Record: GPS coordinates of permanent plot corners (4 corners marked with permanent metal stakes); site photograph from fixed photo-point. Record restoration method; area; investment; degradation severity score (1-5 from standard rubric).

Annual monitoring (years 1-20 minimum): Full species list from permanent 100 m² plot at restoration site AND reference site (same month; ± 2 weeks). FRic computation from TRY matching. Simplified EMF (5 functions). Structural complexity survey (biennial from year 5). Record any management inputs applied. Compute annual RSI (or simplified RSI if full not feasible). Report trajectory direction from LMM slope each year.

Milestone assessments (years 5; 10; 15; 20): Full RSI computation if feasible; simplified RSI minimum. Management withdrawal trial (recommended year 10-15): cease active management for 5 years; continue annual monitoring; assess self-sustainability trajectory at year 15 or 20. Report: RSI score; RSI dimension-by-dimension breakdown; trajectory direction; comparison to national KM-GBF Target 2 benchmark RSI distribution. Upload data to national biodiversity database (CBD-aligned; linked to GBIF and BIOCHANGE for global comparison).

KM-GBF Target 2 reporting standard: National reports should include: (1) total area of restoration sites established (ha) AND (2) proportion of sites achieving simplified RSI ≥ 0.67 at most recent monitoring assessment (the ecological success rate, not just the area planted). Both metrics are necessary: area shows the scale of investment; RSI success rate shows whether investment is achieving genuine ecological recovery. A country reporting 1 million ha restored but 10% RSI success rate has invested in 900,000 ha of unsuccessful restoration and should redirect to connectivity improvement and driver removal programmes.