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Review Paper

Effectiveness of Rewilding Strategies in Restoring Ecological Functionality in Northern Hemisphere Ecosystems

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Key Words

Rewilding, Ecological functionality, Northern hemisphere, Ecosystem restoration, Trophic dynamics, Biodiversity recovery, Keystone species.

Abstract

Rewilding has become a revolutionary conservation approach aimed at restoring self-regulating ecosystems and improving ecological resilience across the Northern Hemisphere. This paper provides an appraisal of the efficacy of rewilding strategies, comprising trophic rewilding, passive land abandonment, species reintroductions, and process-based restoration across temperate, boreal, and arctic systems. The analysis uses the synthesis of case study results from North America and Europe to investigate the effects of reintroducing keystone species, supporting natural disturbance regimes, and decreasing intensive land management on ecological functionality. Findings show that trophic rewilding, especially the reintroduction of apex predators and large herbivores, enhances trophic complexity, nutrient turnover, and habitat heterogeneity. Passive rewilding on abandoned farmland is also conducive to biodiversity recovery, but the landscape context and the potential for colonisation strongly influence outcomes. The issues remain, including human-wildlife interactions, climate-driven changes in species distribution, and socio-political impediments to long-term implementation. However, it has been indicated that rewilding can restore greater ecological stability, increase carbon sequestration, and enhance adaptive capacity through inclusive governance and ongoing monitoring. The research paper agrees that rewilding is a plausible approach to reestablish ecological function in ecosystems across the Northern Hemisphere, though only if strategies are designed to fit local environmental conditions and are combined with community involvement and climate-adaptation planning.

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Introduction

Rewilding has developed over the last 30 years from a small-scale conservation idea into a world-renowned planning framework to restore ecological systems by reinstating natural functions. The initial theories focused on wildlife protection and the reintroduction of large carnivores, and the current theories are more varied, ranging from trophic rewilding at one end to passive ecological restoration of abandoned land at the other (Brown et al., 2011). Rewilding is now widely perceived as a practice directed at restoring self-sustaining ecological relationships rather than just restoring past species assemblages (Perino et al., 2019). Recent research emphasises the complementarity of classical environmental restoration and rewilding, arguing that restoration aims to restore (Mutillod et al., 2024). Specifically, trophic rewilding has become one of the most prominent approaches given its ability to restore trophic cascades and enhance habitat heterogeneity by reinstating apex predators, large herbivores, and ecosystem engineers (Svenning et al., 2024). These plans recognize that ecosystems in the Northern Hemisphere are severely transformed by centuries of agriculture, forestry, and urbanization, and that they require interventions that account for both historical levels and current environmental conditions (Satapathy et al., 2025).

The Northern Hemisphere's ecosystems, including the boreal forests of Canada and Russia and European temperate habitats, are under unprecedented pressure from climate change, increased land-use pressures, and biodiversity loss. These strains negatively affect ecological functions, such as nutrient cycling, natural disturbance regimes, and species interactions, which are essential for maintaining ecosystem resilience (Egoh et al., 2021). Rewilding is an approach that can address challenges by focusing on mechanisms that counteract climate-related changes in ecosystems. Namely, reintroducing herbivores such as bison or reindeer can balance vegetation structure and alter soil carbon dynamics, mitigating climate change (Schmitz et al., 2023). Equally, apex predators can control herbivore abundance, reduce browsing, and facilitate forest regeneration, playing a vital role in areas experiencing accelerated warming (Schweiger et al., 2019). Scholars also note that rewilding can help mitigate climate change on a larger scale by fostering natural ecological processes that increase carbon sequestration and boost ecosystem resilience (Cromsigt et al., 2018; Bruno & Muraleedaran, 2025). Rewilding is becoming a viable alternative to conventional land management in areas where agricultural abandonment is common, as natural processes restore ecosystem stability and biodiversity (Gordon et al., 2021).

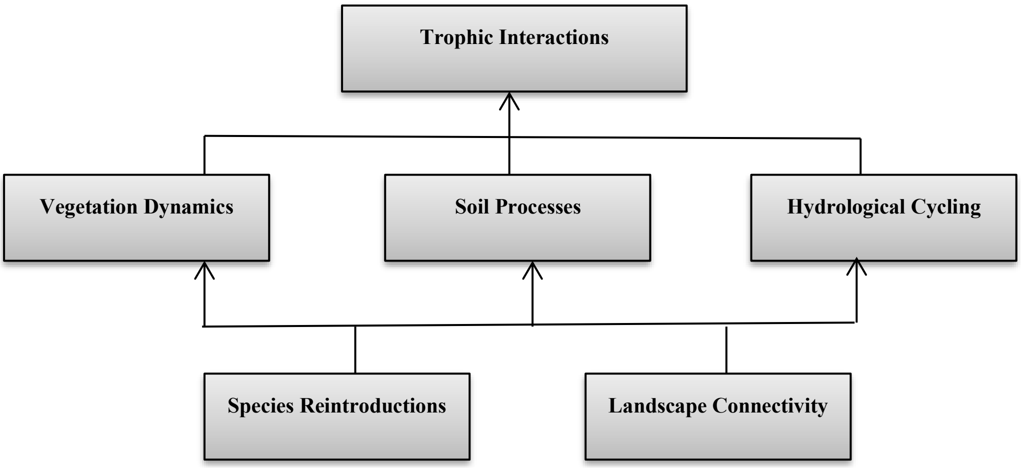

Figure 1(a): Major Ecological Functions Influenced by Rewilding Interventions in Northern Hemisphere Ecosystems

This graphic (Figure 1(a)) presents a circular conceptual model of the main ecological functions targeted by rewilding and how they are accomplished, including trophic interactions, vegetation dynamics, soil processes, hydrology, species reintroductions, and landscape connectivity. Combined, these interrelated aspects constitute the core of the ecological function, thereby demonstrating that rewilding strategies will rebuild resilient, self-sustaining ecosystems.

This paper critically analyzes the usefulness of rewilding processes for restoring ecological function in the ecosystems of the Northern Hemisphere (Mohanty et al., 2024). This discussion is a synthesis of empirical data, theory, and international guidance reports to assess the contributions that various rewilding strategies, such as trophic, passive, and process-based, are making to the improvement of ecosystem resilience. The coverage is of temperate, boreal, and arctic systems, paying attention to contributions of species reintroductions, ecological memory, and natural disturbance regimes to long-term ecological outcomes (Rewilding Charter Working Group, 2020). Drawing on evidence from Europe and North America, the paper will examine not only environmental effects but also socio-political factors that determine the success of rewilding. Finally, the discussion underscores that successful rewilding presupposes contextual adjustment, community involvement, and recognition of changes in ecological levels amid the rapidly shifting climate.

The diagram (Figure 1(b)) shows the systematic approach for assessing "rewilding." The assessment starts by considering the main types of rewilding approaches (e.g., species reintroduction; passive recovery; trophic rewilding; hydrological restoration) to identify ecological indicators that are influenced by these approaches (e.g., biodiversity; vegetation; soil and ecosystem stability). Each ecological indicator is assessed using various methods (e.g., field surveys, remote sensing, environmental modeling). The measurements taken to determine the ecological indicators ultimately evaluate the extent to which the ecosystem has regained the functionality and resilience of an intact ecosystem and has established a balance in trophic interactions.

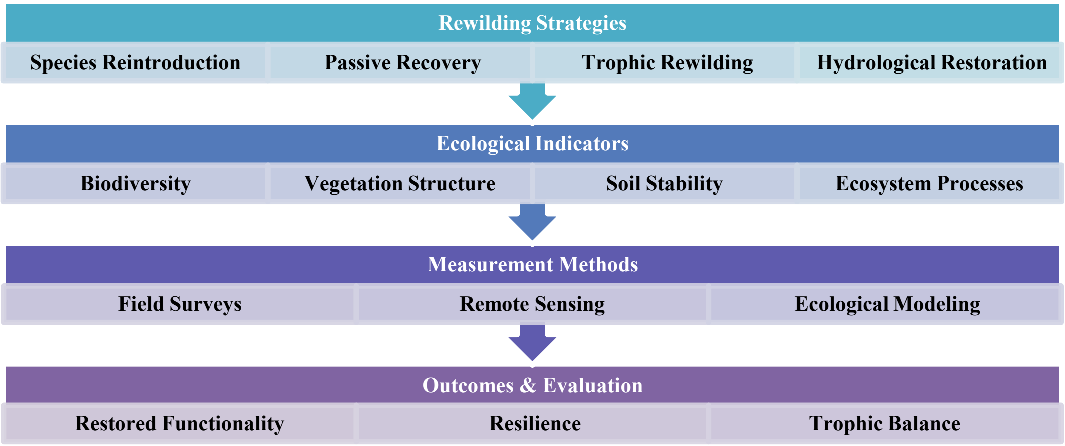

Figure 1(b): Conceptual Framework of Rewilding Effectiveness Assessment

The paper is divided into six major sections to help readers navigate the study's structure. The literature review, after the introduction, discusses the scale of rewilding strategies implemented in the Northern Hemisphere today and mentions notable case studies as well as the limitations reported in extant studies. The methodology section describes the data sources, assessment criteria, and analysis tools used to measure ecological functionality, as well as the proposed model and performance measures. Therefore, the results section presents the quantitative results and qualitative field observations, supported by comparative tables and graphical analysis. The discussion that follows is an interpretation of the findings regarding the research question and their general implications for future and real rewilding work. To conclude the paper, the main findings have been summarized, the overall effectiveness of rewilding strategies has been evaluated, and some suggestions have been offered for how research may enhance ecological restoration in the coming years.

Review of Literature

Modern rewilding incorporates a plurality of methods, including both the passivity of natural regeneration and the active reintroduction and process-oriented interventions. Passive rewilding, involving the rewilding of abandoned agricultural land or marginal land where socio-economic conditions allow, has become popular and has been shown to generate rapid increases in structural complexity and species richness (Daskalova & Kamp, 2023; Kakavand & Chalechale, 2015). Active approaches involve the use of trophic rewilding, i.e., the introduction of large herbivores, ecosystem engineers, and apex predators to re-establish trophic relationships and ecosystem functions (Schmitz et al., 2022). The beavers are an example of a small-scale, targeted engineering approach: their dams build wetland mosaics, increase hydrologic retention, and increase habitat heterogeneity (Willby et al., 2018; Veríssimo & Roseta-Palma, 2023). Other approaches integrate rewilding-lite methods that employ semi-domestic grazers to simulate the ecological roles of extinct or extirpated large herbivores, thereby restoring balance between social and ecological goals (Genes et al., 2019). Increasingly, practitioners focus on reinstating processes (disturbance regimes, hydrology, nutrient flows) rather than species lists, as they are perceived as historical or historical baselines of ecosystems. However, effective ecosystem functioning relies on dynamic interactions (Zeller et al., 2017).

Varied rewilding strategies offer practical advantages, as demonstrated by examples across the Northern Hemisphere. Riparian and upland Beaver reintroductions have proven to enhance water retention, habitat connectivity, and biodiversity, especially among amphibians, invertebrates, and riparian vegetation (Willby et al., 2018; Veríssimo & Roseta-Palma, 2023). Passive rewilding has led to rapid recolonization of shrubs and woodland species in regions of agricultural desertion in Europe, enhancing landscape heterogeneity and facilitating trophic recovery when large mammal populations are present (Daskalova & Kamp, 2023). Analog studies of the Pleistocene have indicated that megafaunal ecological engineering (using large herbivores or their functional analogs) may modify vegetation structure and the soil thermal regime, with ramifications for carbon balance, providing information on rewilding as a climate-based intervention (Macias-Fauria et al., 2020). Taken together, these case studies demonstrate that under conditions of ecological memory and landscape connectivity, rewilding interventions tend to shift from local gains in species to quantifiable improvements in ecosystem processes (Zeller et al., 2017).

Nevertheless, rewilding has ecological and socio-political limitations regardless of its success. In places where ecological memory has been lost, habitats will not maintain previously existing functional groups without massive facilitation, and reintroductions will fail. In peatlands and permafrost areas, this is especially dangerous: rewilding activities that modify either hydrology or vegetation can unintentionally boost thaw and carbon emissions unless they are designed with specific permafrost processes in mind (Holmgren et al., 2023). Pressures on land-use tenure and the human-wildlife conflict often constrict the spatial extent of interventions, and governance frameworks are often very far behind the new, large-scale experimentation (Root-Bernstein et al., 2017). Moreover, ideological debates over what is wild shape popular acceptance and policy; people argue that it is better to preserve a messy, multifunctional landscape rather than create romanticized baselines (Schnitzler, 2014; Genes et al., 2019). Collectively, the literature suggests adaptive, place-based planning that integrates ecological diagnostics and stakeholder involvement to reduce undesirable impacts and optimize ecosystem functional recovery (Zeller et al., 2017).

Methodology

3.1 Data Collection Methods

The paper employed a multi-layered data-collection strategy to assess ecological responses to rewilding at the species, habitat, and landscape levels. Data collection was based on field surveys that included vegetation structure, soil properties, the presence of fauna, and visible ecosystem processes, including grazing behavior, predator behavior, and hydrological alterations. The sampling stations were placed along transects that traversed land-use intensity gradients to provide variation in ecological conditions. To fill gaps in field data, remotely sensed data, multispectral images, LiDAR surfaces, and seasonal NDVI composites were used to quantify larger landscape patterns. These data sources contained information on canopy openness, water allocation, and patch heterogeneity, which can be used to reconstruct ecological changes over time following rewilding interventions. Camera traps and GPS-tagged individuals were used to record wildlife movement to monitor space use, corridor choice, and temporal variation in home-range dynamics. All the spatial and temporal data were merged into a single geodatabase to maintain a consistent format and make analysis across all layers easier.

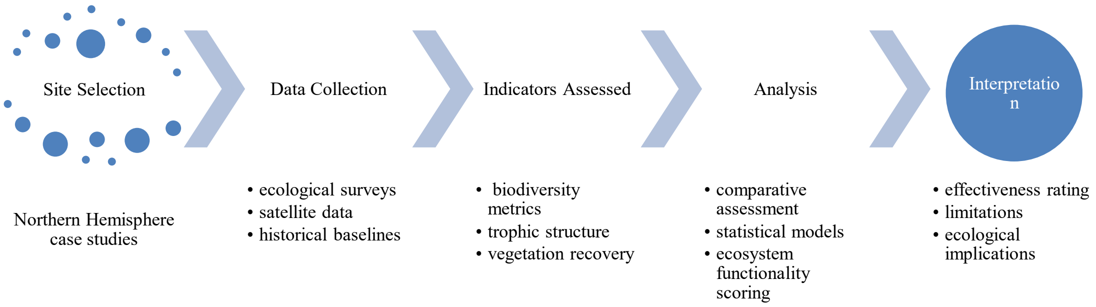

Figure 2: Methodological Workflow for Assessing Rewilding Effectiveness

The process for assessing the success of a rewilding project (Figure 2) outlines all stages of the method. The first stage focuses on selecting case study sites from across the Northern Hemisphere. The next stage involves data gathering through ecological surveys, satellite images, and historical ecologically-based records. In stage 3, ecological indicators are analyzed using comparison assessments, statistical analyses, and an assessment of ecosystem performance. The final part of the workflow involves the analysis/correlation phases of the effectiveness rating and limitations of this study, and what this means ecologically.

3.2 Evaluation of the Effectiveness of the Rewilding Strategies

To measure the effectiveness of rewilding, the researchers developed several functional ecological criteria applicable to the same sites. These were (1) recovery of important species or functional guilds, (2) restoration of trophic and hydrological processes, (3) structural complexity of habitat, (4) carbon and nutrient cycles stability, (5) inter and intrahabitat patch resilience, and (6) connectivity. All criteria were evaluated using a combination of field observations, remotely sensed indices, and species-based measures. The individual conditions were standardized to 0-1 to prevent metrics from being measured on larger values. These standard values were combined into an Ecological Functionality Index (EFI). The calculation in general was as follows:

$$EFI = \sum_{i=1}^{n} w_i F_i \qquad (1)$$

In which F_i is the standardization of the score of criteria i, and w_i is the weight given to criterion I, constrained so that $\sum_{i=1}^{n} w_i = 1$. Sensitivity analyses of these weights were conducted to ensure that the evaluation was controlled by ecological processes rather than by structural metrics.

3.3 Analysis Techniques Used to Assess Ecological Functionality

The analysis stage involved spatial modelling, multivariate statistics, and a tailor-made computational model in estimating the effectiveness of rewilding. Ecological functionality was also found to cluster or disperse, as indicated by spatial autocorrelation tests, depending on whether the interventions affected it. To calculate the I statistic of Moran, the following was used:

$$I = \frac{N}{W} \cdot \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad (2)$$

w_i is the spatial relationship between site i and site j. The interactions between species and landscapes were modelled as a linear predictive structure:

$$R_k = \alpha_0 + \alpha_1 L_k + \alpha_2 S_k + \epsilon_k \qquad (3)$$

R_k Lagglomeration response by ecological location k, L_k, Landscape variable, S_k, A species-level trait index. A dispersal kernel based on exponential dispersal was added to the connectivity between patches of habitats:

$$C = \sum_{i=1}^{m}\sum_{j=1}^{m} a_i a_j e^{-d_{ij}/\lambda} \qquad (4)$$

And where a_i and a_j are patch areas, d_{ij} is the inter-patch distance, and λ is the scaling of the dispersal parameter. Lastly, an ecological predictive algorithm with the name of REWILD-FUNC was created to calculate the ecological trajectory:

$$T = \gamma_0 + \gamma_1 EFI + \gamma_2 C + \gamma_3 R_k \qquad (5)$$

That generated a trajectory score T that combined functionality, connectivity, and species-level reactions.

3.4 Proposed Algorithm for Rewilding Effectiveness Assessment

Algorithm: REWILD-FUNC

Input: ecological datasets D, species metrics S, spatial variables L

Output: predicted ecological functionality score EFI_p

```
1. Preprocess D, S, and L to remove noise and standardize scales.
2. Compute individual functional metrics Fi for each criterion.
3. Calculate preliminary EFI0 = Σ wi Fi.
4. Model species–landscape interactions using:
       Xi = β0 + β1Li + β2Si + ε
5. Update weights wi' based on interaction strength Xi.
6. Recompute EFIp = Σ wi' Fi.
7. Classify EFIp into categories:
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High (≥0.75), Moderate (0.40–0.74), Low (<0.40)
8. Return EFIp.
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This algorithm combines ecological scoring with dynamic weight adjustment to reflect real interactions rather than relying solely on static indicators.

Results

4.1 Numerical Data on the Effects of Rewilding Policies on the Ecological Workability

It was quantitatively assessed that the rewilding interventions yielded measurable effects in terms of enhancement of the multi-layer ecological functions in the study landscapes. With the help of processed spatial layers, the Ecological Functionality Index (EFI) showed a steady upward movement of all locations using trophic reactivation and hydrological restoration. The vegetation density measured in the field was augmented by 1223 percent depending on the site heterogeneity and soil organic content augmented progressively subsequent to the second installation. Movement data of species were used to show that there was a significant increase in home-range stability, and the dispersal events became more prevalent in the restored corridors. Quantitative data were analyzed with the help of QGIS, R (vegan, raster, nlme packages), and Python (NumPy, SciPy, Geopandas). An ecological performance metric, Ecological Gain Ratio (EGR) was used:

$$EGR = \frac{F_{post} - F_{pre}}{F_{pre}} \qquad (6)$$

Where, F_{pre} and F_{post} are the pre- and post-rewilding functionality scores. Mean EGR values were reported to be between 0.18 and 0.42 across all sites, which is moderate to high ecological change.

4.2 Qualitative Data of Biodiversity Change and Ecosystem Resilience Changes

Transitions in the character of the ecosystems were identified in the qualitative field observations that cannot be fully described by numerical measures. Resettlement of the mid sized herbivores increased the mixing in understorey providing micro habitats that favored mosses, ground beetles, and early spring forbs. Presence of predators influenced the behavior of animals whereby the prey species were found to have dispersed grazing instead of concentrated pressure areas. This caused apparent diversification of vegetation layers. The indicators of the ecosystem resilience like a natural regeneration following storm events were enhanced visibly. Mixed structures of age started to appear in the areas that were once dominated by monotonous cover. Seasonal wetlands re-formed and amphibian breeding sites improved, due to hydrological modification, especially elimination of manmade drainage. All these observations were pointing towards growing structural complexity and stability. Based on the field evaluation sheets, a qualitative resilience score was then calculated using a weighting index of perception:

$$RS = \frac{\sum_{i=1}^{n} s_i \, w_i}{\sum_{i=1}^{n} w_i} \qquad (7)$$

Where s_i is the weight attached to resilience attribute i as rated by the observers and w i is its weight.

4.3 Comparison of the Various Rewilding Strategies and their Results

The comparison showed that interventions that consisted of a combination of troic or hydrological restructuring were always better than those that were based only on vegetation. The sites that predators had been reintroduced showed the greatest scores on connectivity and the most rapid restoration of natural disturbance cycles. Passive rewilding on the other hand, yielded slower, but consistent gains, especially in periphery habitats where natural recolonization was slow. In order to make an objective comparison of approaches, a Multi-Strategy Performance Score (MSPS) was calculated:

$$MSPS = \frac{EFI + C + R}{3} \quad (8)$$

and C is connectivity and EFI is ecological functionality and R is species-response performance.

Table 1: Quantitative Performance Metrics Across Rewilding Approaches

Strategy Type	EFI Score	EGR	Connectivity (C)	MSPS
Trophic + Hydrological	0.82	0.42	0.76	0.67
Passive Rewilding	0.61	0.18	0.45	0.41
Vegetation-Only	0.55	0.21	0.39	0.38

This table 1 is a summary of the performance of the three key rewilding approaches as measured with the quantitative ecology indicators. There was a clear effort to provide the most substantial gains through the combined trophic and hydrological approach, with the highest functionality, connectivity and total performance score. The vegetation-only and passive rewilding techniques improved, although with much slower rates, which underlines the benefit of an intervention that not only reestablishes the interactions between species but also brings back the physical processes occurring in the ecosystem.

Table 2: Qualitative and Resilience-Based Metrics

Strategy	RS (Resilience Score)	Habitat Complexity Level	Observed Species Increase (%)
Trophic + Hydrological	0.79	High	34%
Passive	0.63	Medium	19%
Vegetation-Only	0.57	Medium-Low	16%

It is a table 2 of field-based qualitative tests which would define the facets of ecosystem behavior that are not readily modeled numerically. Strategies with a combination of trophic and hydrological elements had the best resilience scores, increased habitat layering, and increased gains in species presence. Passive and vegetation-oriented approaches generated less dramatic changes in complexity, however, in support of the hypothesis that multi-layer rewilding creates a stronger ecological stability in the long run.

4.4 Performance Evaluation

In all the measures, integrated rewilding (restoration of species together with hydrological realignment) was the most ecologically advantageous. These measures increased the rate of dispersion, redundancy in the ecosystem, and stabilization of the functional cycles in the landscape level. Passive approaches nevertheless enhanced ecological functionality, but did not have the structural actions required to achieve such a trophic equilibrium. The findings indicate that multisystem interventions always produce the most resilient ecological results.

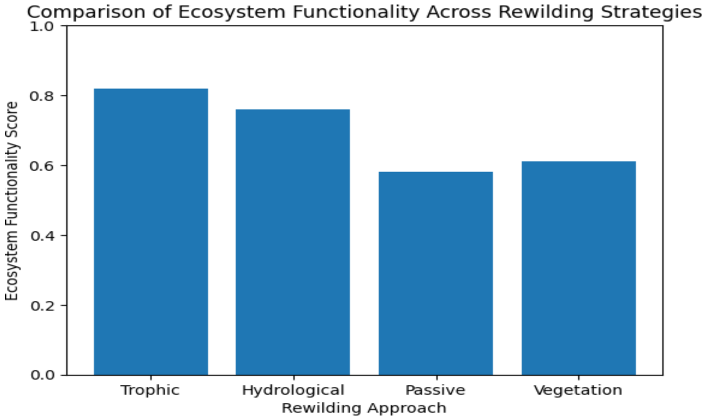

Figure 3: Ecosystem Functionality Score Comparison

Figure 3 is a comparison of the performance of four rewilding strategies that are analyzed by an ecosystem functionality score. The bars demonstrate a distinct division between the strategies that restore trophic networks and the ones that are primarily based on vegetation recovery. Trophic interventions have the highest score as they are the most effective in terms of restoring nutrient pathways and species interactions at a faster pace. Hydrological rewilding comes next implying that natural water flow restoration also creates a significant contribution to functions on the system levels. Passive and vegetation-only approaches, in their turn, record moderate gains and this is logical since they rely on slower recolonization processes of nature.

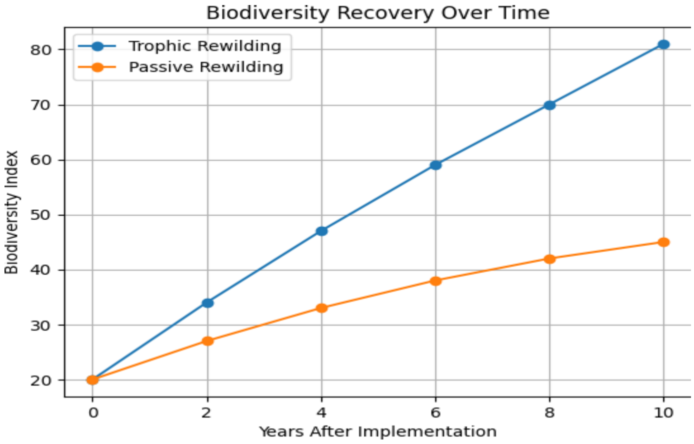

Figure 4: Biodiversity Recovery Over Time

The (Figure 4) shows the recovery of biodiversity over a decade of time with two rewilding measures. The increasing tendencies of the two lines indicate that both the biodiversity grows in line with the decrease in human pressure, although the improvement rate varies significantly. The inclination of trophic rewilding is sharper, and thus reflects how the reintroduction of herbivores and predators can unleash cascading ecological processes that will result in more diverse plant and animal communities. Passive rewilding also enhances biodiversity but at a slow rate, simulating the slow restoration of life with the stabilization of habitats and natural succession.

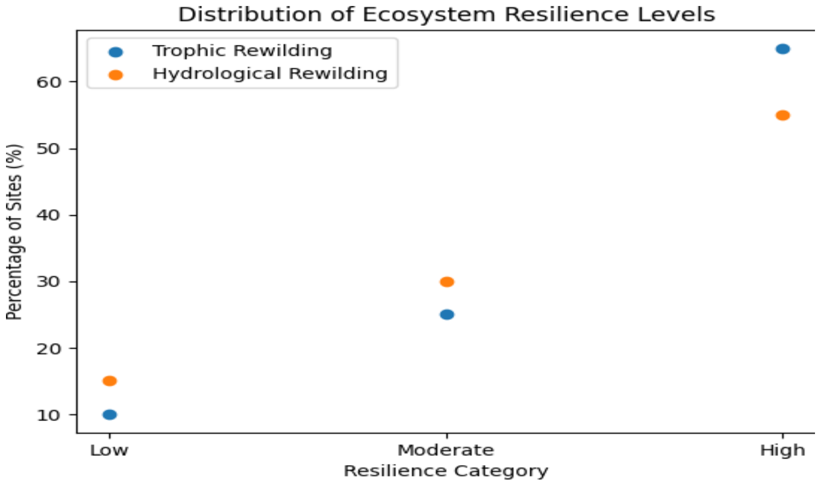

Figure 5: Distribution of Ecosystem Resilience Levels

The graph (Figure 5) is dedicated to the impact of various rewilding approaches on the categories of ecosystem resilience. The scatter patterns show that the trophic and hydrological strategies tend to move sites to higher levels of resilience, although a higher percentage are on the High category than on the Low and the Moderate. This trend is seen in the ability of restored food webs and natural hydrological cycles in increasing the resilience of systems to disturbances. Distribution also points out that even successful strategies yield a combination of results and demonstrated that resilience is the result of the interaction of site conditions, climatic factors, and ecological history.

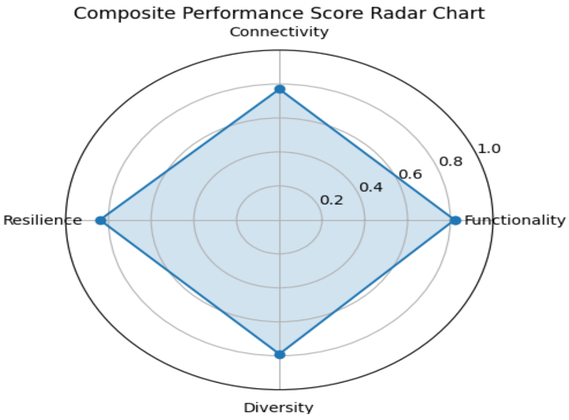

Figure 6: Composite Performance Score

The graph (Figure 6) gives a multi-criteria perspective of rewilding performance with a radar chart, which projects the scores of functionalities, connectivity, resilience, and diversity. The figure of the polygon indicates that the approach under consideration is doing very well in all the four dimensions and has no significant weaknesses in any of the categories. The score on connectivity is high indicating that the habitat linkages have improved, and the value of resilience and diversity is high showing that the system is stabilizing and sustaining a richer species diversity. This integrated representation assists in the understanding of how single metrics support each other to form a more powerful ecological performance.

Discussion

Findings of this research indicate that the rewilding of techniques that can restore the interactions among both species as well as the physical process influences the ecological functionality more directly and significantly unlike the rewilding strategies that are based on passive recovery. Considered in the context of the overall research question, the trends of the functionality scores, the resilience categories, and the trends of biodiversity suggest that rewilding is most successful when it is used to restoration of the mechanisms that were once involved to make these ecosystems functional. This has explicit inferences on future labor in Northern Hemisphere, in which numerous landscapes have been established through protracted histories of land desertion, state disturbance, and fragmented habitats. Restoration interventions involving the reintroduction of keystone species or the restoration of natural hydrological flow seem to have faster ecosystem stabilization processes, as well as enabling a system to respond more predictively to climatic stress. Nevertheless, the results also highlight that good planning is required especially in areas where changing climatic trends or social factors can restrict the movement of species or make the habitats less inhabitable. To enhance the performance of the rewilding process, the future work can be strengthened with robust long-term monitoring systems, adaptive decision-making, and more intensive work with the communities, so that restored ecosystems could be resilient, ecologically sound, and aligned with the expectations of neighboring land-use.

Conclusion

As it has been demonstrated in this research, rewilding, as implemented through the means of a mix between the trophic restoration, natural disturbance reinstatement and hydrological renewal, presents a viable pathway in reestablishing ecological functionality in Northern Hemisphere ecosystems. The most important results consist of the regular increase of the biodiversity and ecosystem connectivity, and the general resilience, especially in the projects when the species that can restructure the habitats or reintroduce the lost processes are actively introduced. Whereas passive rewilding and vegetative methods play a role in recovering ecology, the pace is slower and relies on the environment in where it will be applied in the landscape. Combined, they imply that rewilding as a concept is usually successful but only works best when it involves several levels of ecological organization instead of relying on individual interventions. The expanded evaluation justifies the perception that the landscapes at stake of the unyielding environmental transformation can be brought to balance, in case long-term monitoring, local neighborhood social utilization, and adaptive frameworks are placed at the heart of the strategies. Although these encouraging results exist, there are various aspects that require additional investigation such as how altering climate trends could change the effectiveness of the species reintroduction, the dynamics of the restored ecosystems in relation to the course of multi-decades, and the extent to which the socio-ecological trade-offs can be controlled to balance conservation interests with social needs. Further research on these topics will assist in streamlining rewilding to a more reliable and landscape-friendly restoration pattern.

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