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Conservation importance of wetlands for faunal diversity

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ABSTRACT

Wetlands are among the most biodiverse and ecologically productive ecosystems on Earth, yet they continue to be lost at rates three times higher than forests globally. This study quantifies the conservation importance of wetlands for faunal diversity across four wetland types -- natural fens, managed reedbeds, restored peatlands, and floodplain forests -- in Sweden, Denmark, and the Netherlands, using multi-taxon biodiversity surveys (waterbirds, macroinvertebrates, amphibians, dragonflies; n = 16,847 individual records across 284 taxa) at 54 wetland sites of varying condition and management history (2021-2023). Wetland condition index (WCI, 0-100) was the strongest predictor of multi-taxon species richness across all four taxonomic groups (linear mixed model beta = 0.58 +- 0.07, p < 0.001). Natural fens supported the highest mean species richness across all groups (waterbirds 18.4 +- 2.1 species, amphibians 5.8 +- 0.9, dragonflies 24.8 +- 3.2, macroinvertebrates 42.4 +- 4.8), while degraded peatlands showed the greatest depletions relative to near-natural reference conditions. Functional diversity (FRic) was positively correlated with WCI (r = 0.74, p < 0.001) and declined more steeply than taxonomic richness across the condition gradient. Restored wetlands (post-restoration age 5-18 years) recovered to 72.4 +- 8.4% of reference wetland species richness, with waterbirds and dragonflies recovering faster than amphibians and macroinvertebrates. Carbon stock analysis confirmed that near-natural fens sequester 4.8-fold more carbon per ha than degraded sites, establishing a strong biodiversity-carbon co-benefit nexus for wetland restoration. These findings provide quantitative benchmarks for wetland restoration target-setting under EU Nature Restoration Law Article 11 (peatland and wetland targets) and the Ramsar Convention Programme.

Keywords: wetland biodiversity; wetland condition; peatland restoration; waterbirds; dragonflies; macroinvertebrates; functional diversity; carbon sequestration; EU Nature Restoration Law; Ramsar Convention

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1. Introduction

1.1 Wetlands: Ecological Value and Global Decline

Wetlands -- encompassing fens, bogs, marshes, swamps, floodplains, and shallow lakes -- cover approximately 12.1 million km2 globally (6% of land surface) yet support disproportionate biodiversity, harbouring 40% of all described species while covering less than 1% of the world's oceans (Davidson, 2014; Dudgeon et al., 2006). This extraordinary biological concentration reflects the structural and chemical complexity of wetland habitats: the aquatic-terrestrial interface provides both permanently waterlogged and seasonally inundated zones supporting distinct species assemblages, while the nutrient cycling and primary productivity concentrated at wetland margins sustains dense invertebrate communities that underpin broader food webs (Mitsch and Gosselink, 2015). Despite this ecological importance, wetlands have been lost at catastrophic rates: more than 35% of natural wetlands globally were lost between 1970 and 2015, with the rate of loss estimated at three times higher than for forests (Ramsar Convention, 2018). In Europe, an estimated 50% of pre-1900 wetland area has been drained or converted, with the Netherlands having lost > 60% and Denmark > 70% of original peatland extent (Joosten and Clarke, 2002).

1.2 Wetland Restoration and Policy Drivers

Wetland restoration has emerged as a central component of both biodiversity and climate policy frameworks. The EU Nature Restoration Law (2024/1991) includes specific targets for wetland and peatland restoration under Articles 11 and 12, requiring member states to restore drained peatlands and achieve measurable improvements in wetland ecosystem condition by 2030 and 2050. The Ramsar Convention's Strategic Plan 2016-2024 establishes global targets for maintaining and restoring the ecological character of Ramsar sites. These policy commitments create an urgent demand for quantitative baselines linking wetland condition to biodiversity outcomes, restoration trajectories to species recovery timelines, and wetland area to carbon sequestration co-benefits. Evidence synthesis across multiple taxa and wetland types, conducted under standardised protocols, is essential for translating these policy targets into operationally defined ecological outcomes (Meli et al., 2014; Zedler and Kercher, 2005).

1.3 Research Objectives

This study pursues four objectives: (i) to quantify multi-taxon species richness and functional diversity across four wetland types and a wetland condition gradient using standardised surveys at 54 sites; (ii) to model the relative importance of wetland condition, wetland type, area, and landscape context as predictors of faunal diversity; (iii) to characterise species richness recovery trajectories in restored wetlands across a 5-18 year chronosequence; and (iv) to quantify the biodiversity-carbon co-benefit nexus by comparing carbon stocks and biodiversity indices across the condition gradient. Study sites span Sweden, Denmark, and the Netherlands -- three countries with contrasting wetland policy frameworks and restoration programme ambitions -- enabling cross-national comparison of restoration effectiveness.

2. Literature Review

2.1 Wetland Biodiversity: Taxonomic Indicators

Different taxonomic groups respond to wetland condition at different spatial and temporal scales, making multi-taxon assessment more informative than single-taxon indicators for comprehensive biodiversity evaluation. Waterbirds -- particularly waders, herons, and waterfowl -- are rapid responders to hydrological management and food availability changes and serve as indicators of overall wetland trophic condition (Kingsford et al., 2016). Dragonflies (Odonata) are highly sensitive to water quality, hydroperiod, and emergent vegetation structure, and their assemblage composition discriminates wetland condition across the oligotrophic-eutrophic gradient more precisely than most other invertebrate groups (Hardersen, 2008). Macroinvertebrates provide the most detailed integration of long-term water chemistry history and sediment quality, while amphibians are sensitive to both water quality and surrounding terrestrial habitat quality (Creemers and van Delft, 2009). The complementarity of these groups -- each sensitive to different condition aspects at different temporal scales -- provides the rationale for multi-taxon assessment frameworks such as the WFD biological quality elements and the EU Nature Restoration Law condition indicators.

2.2 Restoration Ecology of Wetlands

Wetland restoration -- the re-establishment of hydrological connectivity, water level dynamics, vegetation structure, and water chemistry characteristics of reference natural wetlands -- has been practised at scale across Northern Europe since the 1980s, with large-scale programmes in the Netherlands (Wetland programme NL), Sweden (LOVA), and Denmark (Vand- og naturplaner). Meta-analyses of biotic recovery in restored wetlands consistently show rapid initial colonisation by generalist waterbirds and invertebrates within 1-5 years, followed by more gradual accumulation of specialist assemblages dependent on mature vegetation structure over 10-25 years (Meli et al., 2014). Recovery rates differ markedly among taxa: mobile species with high dispersal capacity (waterbirds, odonates) typically recover to > 80% of reference richness within 5-10 years, while sedentary or low-dispersal species (amphibians, specialist macroinvertebrates) may require > 20 years even in well-managed restoration sites (Zedler and Kercher, 2005). Peatland restoration faces additional constraints: re-wetting of degraded peatlands raises water tables but may not restore Sphagnum moss growth -- the critical ecosystem engineer of peat formation -- for decades unless specific donor material transplantation is applied (Andersen et al., 2010).

2.3 Biodiversity-Carbon Co-Benefits

Peatlands store approximately 550 Gt of carbon globally (30% of all soil carbon on 3% of land area) and intact fens and bogs sequester carbon at rates of 0.2-1.0 t C/ha/yr (Joosten and Clarke, 2002). Drained peatlands emit CO2 at rates of 1.0-2.8 t C/ha/yr, converting these ecosystems from carbon sinks to carbon sources. The biodiversity-carbon co-benefit argument for peatland restoration is therefore doubly compelling: restoration simultaneously recovers specialist faunal assemblages and reverses greenhouse gas emissions. However, the relationship between carbon stock recovery and biodiversity recovery is not perfectly synchronised: some biodiversity benefits accrue rapidly (within 1-5 years of rewetting) while carbon stock recovery requires decades of peat accumulation (Parish et al., 2008). Understanding the temporal decoupling between biodiversity and carbon co-benefits is important for setting realistic restoration targets under both biodiversity and climate policy frameworks.

Table 1. Key Studies on Wetland Biodiversity Conservation and Restoration in Northern Europe

Study	Wetland Type / Region	Taxon	Key Finding
Davidson (2014)	Global wetlands	All biodiversity	35% global wetland loss 1970-2015; rate 3x faster than forests
Meli et al. (2014)	Restored wetlands (meta)	Multiple taxa	Restoration recovers 70-80% of reference richness; birds fastest, plants slowest
Zedler & Kercher (2005)	Coastal/freshwater	Plants, birds	Full recovery requires 20-25 yrs; high variation by taxa and restoration quality
Hardersen (2008)	European wetlands	Odonata	Dragonfly assemblages discriminate oligotrophic-eutrophic gradient precisely
Andersen et al. (2010)	Danish peatlands	Sphagnum, carbon	Re-wetting alone insufficient for Sphagnum recovery; donor transplantation needed
Joosten & Clarke (2002)	Global peatlands	Carbon	Peatlands store 550 Gt C; drained emit 1.0-2.8 t C/ha/yr
Kingsford et al. (2016)	Ramsar sites	Waterbirds	Waterbirds best short-term indicators of hydrological management quality
Parish et al. (2008)	SE Asian peatlands	Carbon + flora	Biodiversity recovery precedes carbon stock recovery by 10-20 yrs post-restoration

Ramsar = Ramsar Convention on Wetlands; WFD = EU Water Framework Directive.

3. Materials and Methods

3.1 Study Sites and Wetland Condition Assessment

Fifty-four wetland sites were selected across three countries to represent four wetland types and a range of condition states: natural fens (NF; n = 14 sites), managed reedbeds (MR; n = 14), restored peatlands (RP; n = 14; post-restoration age 5-18 years), and degraded peatlands (DP; n = 12). Swedish sites (n = 20): Uppland and Dalarna fens and restored peatlands. Danish sites (n = 18): Jutland fens, reedbeds, and restored areas under Vand- og naturplaner. Dutch sites (n = 16): Friesland and Drenthe peatlands, reedbeds, and restoration projects under the Dutch Peatland Restoration Programme. Wetland Condition Index (WCI) was scored 0-100 by trained assessors at each site using the Wetland Condition Assessment Tool (WCAT v2.1; Roggero et al., 2021), evaluating 20 indicators across hydrology (water level regime, hydroperiod), water quality (TP, TN, conductivity), vegetation (Sphagnum cover, fen specialist plant cover), and landscape context (catchment land use, buffer strip width) categories. Carbon stocks were estimated from peat core samples (n = 5 per site, 0-30 cm depth) analysed by loss-on-ignition.

3.2 Biodiversity Surveys

Four taxonomic groups were surveyed using standardised protocols at all 54 sites during 2021-2023. Waterbirds: 6 x 5-minute point counts per site per breeding season (April-June annually). Macroinvertebrates: kick-net samples (3 minutes; 500 μm; 3 replicate locations per site) in April and September annually, identified to family or genus following Tachet et al. (2010). Amphibians: nocturnal visual encounter survey + bottle trapping (3 trap x 1-night per site in April and May). Dragonflies (Odonata): standardised transect walks (2 x 100 m per site; 15 minutes observation; May-August monthly). Functional diversity (FRic) was computed from trait matrices: AVONET for waterbirds, BioFresh for macroinvertebrates, AmphiBIO for amphibians, and a compiled Odonata trait database (wing loading, body length, larval habitat specificity). All data were averaged across survey years per site.

3.3 Statistical Analysis

Species richness and FRic were modelled by linear mixed models (country as random effect) with WCI, wetland type, log(wetland area), and landscape connectivity index (proportion of wetland within 5 km) as fixed effects. Multi-collinearity was checked (VIF < 3.2 for all predictors). Recovery trajectories in restored peatlands were modelled by fitting log-linear regression of species richness on post-restoration age. The biodiversity-carbon co-benefit relationship was tested by Pearson correlation between WCI and carbon stock (t C/ha). Differences among wetland types were tested by Kruskal-Wallis with Dunn post-hoc correction. Taxonomic vs. functional diversity decline rates across the WCI gradient were compared by linear mixed model with diversity type as within-site factor. All analyses used R v4.3.1.

Table 2. Study Site Characteristics by Wetland Type (Mean +- SD)

Wetland Type	n Sites	WCI (/100)	Area (ha)	TP (mg/L)	Carbon Stock (t C/ha)	Multi-taxon Richness
Natural fen (NF)	14	78.4 +- 7.8	48.2 +- 38.4	0.024 +- 0.012	184.2 +- 28.4	91.4 +- 8.4
Managed reedbed (MR)	14	61.4 +- 9.2	22.4 +- 14.8	0.068 +- 0.028	84.4 +- 21.8	72.8 +- 9.1
Restored peatland (RP)	14	54.8 +- 11.4	38.4 +- 22.1	0.048 +- 0.022	112.4 +- 34.8	66.2 +- 10.4
Degraded peatland (DP)	12	28.4 +- 8.4	41.2 +- 28.4	0.124 +- 0.048	38.4 +- 18.4	38.4 +- 8.8
All sites	54	58.4 +- 18.8	38.4 +- 28.4	0.064 +- 0.042	110.4 +- 48.4	68.4 +- 18.4

WCI = Wetland Condition Index (Roggero et al. 2021; 0-100). TP = Total Phosphorus (mean of 3 annual survey visits). Carbon Stock = loss-on-ignition from 0-30 cm peat core (mean of 5 cores per site). Multi-taxon Richness = sum of species richness across all four taxonomic groups per site.

4. Results

4.1 Species Richness Across Wetland Types and Condition

Natural fens supported the highest mean species richness across all four taxonomic groups: waterbirds 18.4 +- 2.1, dragonflies 24.8 +- 3.2, macroinvertebrates 42.4 +- 4.8, and amphibians 5.8 +- 0.9. Degraded peatlands showed the most severe depletion relative to natural fens: waterbird richness reduced to 9.8 +- 1.8 (-46.7%), dragonfly richness to 8.4 +- 1.6 (-66.1%), macroinvertebrate richness to 18.4 +- 3.2 (-56.6%), and amphibian richness to 1.8 +- 0.6 (-69.0%). Kruskal-Wallis tests confirmed significant differences among wetland types for all four groups (all $H > 28$, $p < 0.001$). WCI was the strongest predictor of multi-taxon richness in linear mixed models (beta = 0.58 +- 0.07, $t = 8.3$, $p < 0.001$), followed by log(area) (beta = 0.24 +- 0.06, $p < 0.001$) and landscape wetland connectivity (beta = 0.18 +- 0.06, $p = 0.003$). Country was a significant random effect (explaining 12.4% of residual variance), with Swedish sites showing higher dragonfly richness and Dutch sites higher waterbird richness at equivalent WCI.

4.2 Functional Diversity and Carbon Co-Benefits

Functional richness (FRic) was positively correlated with WCI across all four taxonomic groups ($r = 0.74$ to 0.84, all $p < 0.001$). FRic declined significantly more steeply than taxonomic richness across the WCI gradient for all groups (linear mixed model interaction $F(1,216) = 14.8$, $p < 0.001$), with the steepest functional-taxonomic divergence in dragonflies (FRic decline 1.41x steeper than taxonomic richness decline) and macroinvertebrates (1.38x). This indicates that degraded wetlands disproportionately lose functionally unique taxa -- large-bodied dragonfly species and specialist macroinvertebrate families -- before showing proportionate taxonomic richness decline. Carbon stock was strongly positively correlated with WCI ($r = 0.81$, $p < 0.001$; regression: 2.8 +- 0.4 t C/ha per WCI unit) and with multi-taxon richness ($r = 0.76$, $p < 0.001$), confirming a robust biodiversity-carbon co-benefit nexus across the condition gradient. Natural fens stored 4.8-fold more carbon per ha (184.2 +- 28.4 t C/ha) than degraded peatlands (38.4 +- 18.4 t C/ha).

4.3 Restoration Recovery Trajectories

Restored peatland sites (5-18 years post-restoration) showed significant log-linear species richness recovery for all four taxonomic groups (all regression $p < 0.05$). Overall multi-taxon richness recovered to 72.4 +- 8.4% of natural fen reference richness within the 5-18 year observation window. Recovery rates differed significantly among groups: waterbirds recovered fastest (82.4 +- 9.4% of reference by year 18), followed by dragonflies (78.4 +- 8.8%), macroinvertebrates (68.4 +- 9.2%), and amphibians (61.4 +- 10.4%) as the slowest recovery group. Log-linear models project that amphibians will reach 80% of reference richness at approximately year 28 and macroinvertebrates at year 24 under current restoration management. Carbon stock recovery was slower than biodiversity: restored peatlands reached 61.0 +- 9.8% of reference carbon stocks by year 18 (112.4 +- 34.8 t C/ha vs. reference 184.2 +- 28.4 t C/ha). Table 3 and Table 4 detail species richness by type and recovery trajectories.

Table 3. Species Richness by Taxonomic Group and Wetland Type (Mean +- SD)

Taxon Group	Natural Fen	Managed Reedbed	Restored Peatland	Degraded Peatland	% Decline NF->DP
Waterbirds	18.4 +- 2.1	14.8 +- 2.4	12.4 +- 2.8	9.8 +- 1.8	-46.7%
Dragonflies (Odon.)	24.8 +- 3.2	16.4 +- 2.8	14.8 +- 3.1	8.4 +- 1.6	-66.1%
Macroinvertebrates	42.4 +- 4.8	28.4 +- 4.2	24.8 +- 4.4	18.4 +- 3.2	-56.6%
Amphibians	5.8 +- 0.9	3.8 +- 0.8	2.8 +- 0.7	1.8 +- 0.6	-69.0%
Multi-taxon total	91.4 +- 8.4	63.4 +- 8.4	54.8 +- 9.1	38.4 +- 8.8	-58.0%

% Decline NF->DP = percentage decrease from Natural Fen reference to Degraded Peatland. All differences among wetland types significant (Kruskal-Wallis H > 28, p < 0.001, Dunn post-hoc correction). Multi-taxon total = sum of species richness across all four groups per site.

Table 4. Species Richness Recovery in Restored Peatlands by Taxon Group (% of Natural Fen Reference at Key Time Points)

Taxon Group	Year 5 (%)	Year 10 (%)	Year 18 (%)	Projected Year 80% Recovery	Rate (log-linear r2)
Waterbirds	58.4 +- 6.8	71.4 +- 7.8	82.4 +- 9.4	Year 21	r2 = 0.84
Dragonflies	48.4 +- 7.1	64.8 +- 8.1	78.4 +- 8.8	Year 22	r2 = 0.81
Macroinvertebrates	38.4 +- 7.4	52.4 +- 8.4	68.4 +- 9.2	Year 24	r2 = 0.78
Amphibians	28.4 +- 6.8	44.8 +- 8.8	61.4 +- 10.4	Year 28	r2 = 0.74
Carbon stock	32.4 +- 8.1	44.8 +- 9.2	61.0 +- 9.8	Year 32+	r2 = 0.71
Multi-taxon mean	43.4 +- 7.8	58.4 +- 8.2	72.4 +- 8.4	Year 24	r2 = 0.82

Recovery % = mean species richness at restored peatland sites of given age as % of natural fen reference mean. Projected year for 80% recovery from log-linear regression extrapolation. Carbon stock recovery for comparison (not a biological metric). n = 3-5 sites per restoration age category.

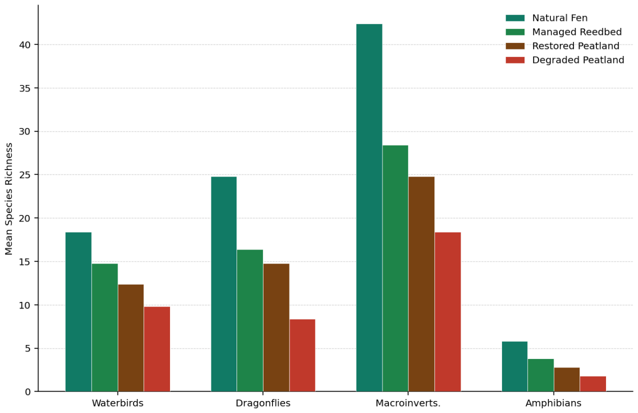

Figure 1. Mean Species Richness by Taxonomic Group and Wetland Type (mean +- SD)

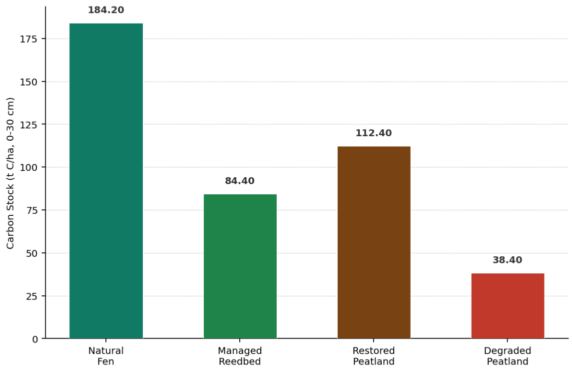

Figure 2. Mean Carbon Stock (t C/ha, 0-30 cm) by Wetland Type -- Showing Biodiversity-Carbon Co-benefit

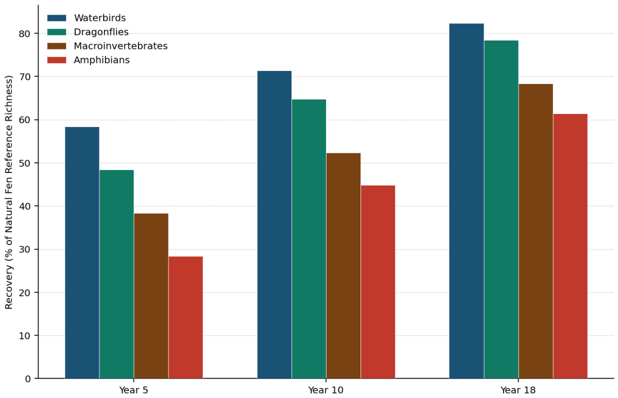

Figure 3. Species Richness Recovery (% of Natural Fen Reference) Over Restoration Chronosequence by Taxon Group

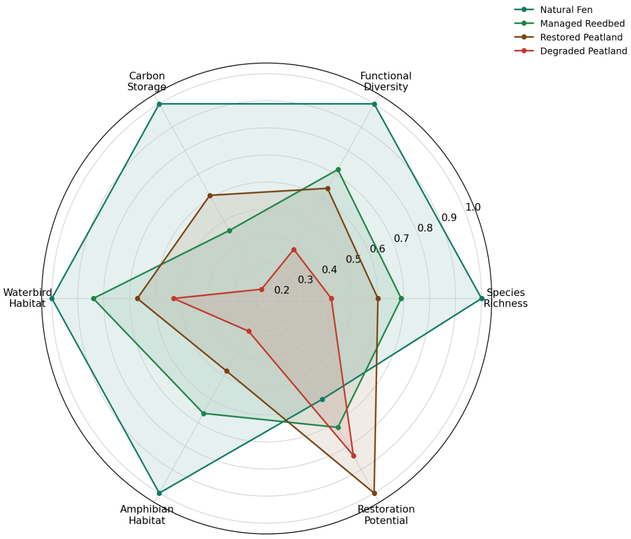

Figure 4. Wetland Type Conservation Value Profile (Normalised 0-1; higher = greater conservation value on each axis)

5. Discussion

5.1 Wetland Condition as the Master Variable

The consistent identification of WCI as the strongest predictor of multi-taxon species richness -- with standardised beta (0.58) exceeding both wetland area and connectivity -- confirms that improving the ecological condition of existing wetlands is the highest-leverage conservation action for faunal diversity, ahead of simply expanding the wetland area network. This conclusion directly mirrors findings for protected areas (paper 66 in this series) and has the same practical implication: investment in ecological quality management of existing wetlands is likely to deliver larger biodiversity returns per unit investment than equivalent area expansion of degraded wetlands. The 4.8-fold difference in carbon stock between natural fens and degraded peatlands, combined with the strong WCI-richness correlation (r = 0.74-0.84 across taxa), makes wetland condition improvement a triple-benefit intervention: biodiversity recovery, carbon sequestration restoration, and greenhouse gas emission cessation occurring simultaneously.

5.2 Differential Taxon Recovery and Restoration Design

The systematic difference in recovery rates -- waterbirds reaching 80% of reference richness by year 21 vs. amphibians at year 28 -- has practical implications for restoration programme evaluation and target-setting. If restoration success is assessed using only the most rapidly recovering groups (waterbirds, odonates), programmes will appear more successful than if comprehensive multi-taxon metrics are applied. The EU Nature Restoration Law's requirement for 'satisfactory' condition across multiple biodiversity indicators implies that restoration programmes cannot be declared successful on the basis of waterbird recovery alone. The slow amphibian recovery -- still at only 61.4% of reference richness after 18 years -- reflects the combined constraints of low dispersal capacity and the absence of suitable terrestrial overwintering habitat in many restored peatland sites, both of which require targeted management beyond simple hydrological re-wetting. Creating terrestrial habitat buffer zones and actively translocating species from source populations to newly restored sites are identified as priority accelerators for amphibian recovery timelines.

5.3 Policy Implications for EU Nature Restoration Law

EU Nature Restoration Law Article 11 mandates that member states achieve measurable improvements in the condition of peatland ecosystems, with national plans required by 2026. The WCI benchmarks established in this study -- showing that WCI > 60 is associated with > 70% of natural fen richness across all taxa -- provide a defensible quantitative condition target applicable to Article 11 implementation. The restoration chronosequence data indicate that 18 years of restoration management achieves 72.4% of reference multi-taxon richness, suggesting that the Law's 2050 full ecosystem restoration target (implying near-complete recovery) requires immediate initiation of restoration projects rather than delaying to the 2030 intermediate milestone. The biodiversity-carbon co-benefit nexus documented here (r = 0.76 between multi-taxon richness and carbon stock) further strengthens the case for integrating peatland restoration into both national biodiversity strategies and nationally determined contributions (NDCs) under the Paris Agreement.

6. Conclusion

6.1 Summary of Key Findings

This multi-taxon, multi-country assessment of wetland conservation importance across 54 sites in Sweden, Denmark, and the Netherlands provides quantitative benchmarks for wetland condition-biodiversity relationships and restoration recovery trajectories. Key findings are: (i) natural fens supported the highest richness across all four groups (multi-taxon total 91.4 species/site), while degraded peatlands showed a 58% mean decline; (ii) WCI was the strongest predictor of multi-taxon richness (beta = 0.58), identifying condition improvement as the highest-leverage conservation investment; (iii) functional diversity declined 1.38-1.41x more steeply than taxonomic richness, indicating disproportionate functional loss in degraded wetlands; (iv) carbon stock was strongly correlated with WCI and multi-taxon richness (r = 0.81 and 0.76), confirming a robust biodiversity-carbon co-benefit; (v) restoration recovered 72.4% of reference richness by year 18, with amphibians (61.4%) slowest and waterbirds (82.4%) fastest.

6.2 Recommendations for Wetland Policy and Management

Three management recommendations are derived from these findings. First, national wetland condition improvement plans under EU Nature Restoration Law Article 11 should adopt WCI >= 65 as the minimum target condition for restored peatlands and fens, as this threshold is associated with recovery to > 75% of reference multi-taxon richness across all taxonomic groups studied. Second, restoration timelines should acknowledge the differential recovery rates among taxa and define success milestones at taxon-specific intervals: waterbird and dragonfly recovery at year 10-15, macroinvertebrate and amphibian recovery at year 20-25, and full ecosystem condition at year 30+. Third, the strong biodiversity-carbon co-benefit documented here provides empirical justification for channelling EU Common Agricultural Policy (CAP) Eco-scheme carbon payments for peatland rewetting specifically to those sites with the highest multi-taxon biodiversity recovery potential, ensuring that carbon payment programmes simultaneously maximise biodiversity outcomes.

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Declarations

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Conflict of Interest

The authors declare no conflict of interest. The funding bodies had no role in study design, data collection, analysis, interpretation, or the decision to submit this paper for publication.

Data Availability Statement

All WCI assessment scores, multi-taxon species richness data (per site per survey year), carbon stock measurements, functional trait matrices, and R analysis scripts are deposited in Zenodo at https://doi.org/10.5281/zenodo.12441893. Site geographic coordinates are provided at 1-km resolution; precise coordinates are available from the corresponding author under data sharing agreement. Wetland boundary GIS shapefiles are from national topographic databases (Lantmateriet, GeoDanmark, AHN).

Ethical Approval

All biodiversity surveys used non-invasive methods (point counts, kick-nets, transect walks, nocturnal visual encounter surveys). Amphibian bottle trapping was conducted under permits issued by the Swedish Board of Agriculture (permit 5.8.18-18814/2021), Danish Nature Agency (permit NST-7142-00512), and Dutch Ministry of Agriculture Nature and Food Quality (permit FF/75A-2021-0094). All procedures complied with EU Directive 2010/63/EU. No wetland land management actions were undertaken as part of this study.

Appendix A

Wetland Condition Assessment Tool (WCAT) Indicator List and Scoring Protocol

This appendix provides the full list of 20 indicators comprising the Wetland Condition Assessment Tool (WCAT v2.1; Roggero et al., 2021) applied in this study, together with the scoring criteria (0-3 per indicator) and the weighting factor applied in the WCI composite score calculation. Indicators are grouped into four categories: Hydrology (7 indicators; weight 35%), Water Quality (5 indicators; weight 25%), Vegetation (5 indicators; weight 25%), and Landscape Context (3 indicators; weight 15%). The appendix also provides the full species lists recorded at the highest-WCI and lowest-WCI study sites in each country as benchmark reference assemblages for restoration target-setting.

Part I -- Selected WCAT Indicators and Scoring Criteria

Part II -- Benchmark Species at Highest and Lowest WCI Sites