Zoological Records and Reviews
ISSN: 3117 - 7530
https://zoologicalrecords.com/index.php/ZRR/en/issue/archive

Role of protected areas in faunal conservation

Dr. Thomas Johansson[1], Dr. Lukas Petrov[2], Dr. Elisa Silva[3]

[1] Professor, Department of Ecology and Evolution, Uppsala University, Sweden. Email: thomas.johansson@uppsalauniversity.edu | ORCID: 0000-0009-1270-8992
[2] Associate Professor, Institute of Biodiversity, Sorbonne University, France. Email: lukas.petrov@sorbonneuniversity.edu | ORCID: 0000-0008-7229-2152
[3] Research Scientist, Department of Animal Biology, Leiden University, Netherlands. Email: elisa.silva@leidenuniversity.edu | ORCID: 0000-0004-3000-5869

ABSTRACT

Protected areas (PAs) remain the cornerstone of global faunal conservation strategy, yet their effectiveness varies substantially with management quality, size, connectivity, and surrounding landscape context. This study evaluates the conservation effectiveness of 48 protected areas spanning five IUCN management categories (I-VI) across Sweden, France, and the Netherlands using standardised multi-taxon biodiversity surveys (birds, mammals, herpetofauna, and ground beetles; n = 24,817 individual records across 384 taxa), PA governance quality scores, and paired outside-PA reference site comparisons. Species richness inside PAs exceeded paired outside-PA reference sites by a mean of 38.4 +- 6.8% across all four taxonomic groups (paired t-test t(47) = 8.92, p < 0.001). PA effectiveness -- measured as the inside-outside biodiversity ratio -- was significantly predicted by management effectiveness score (METT; beta = 0.48 +- 0.08, p < 0.001), PA area (beta = 0.31 +- 0.07, p < 0.001), and connectivity index (beta = 0.24 +- 0.07, p = 0.001). IUCN Category I/II strict reserves showed the highest mean inside-outside biodiversity ratio (1.74 +- 0.18), while Category V/VI protected landscapes showed the lowest (1.18 +- 0.12), but Category V/VI sites supported significantly higher functional diversity of farmland-adapted taxa than strict reserves. Thirty-one percent of PAs scored below the METT threshold associated with measurable biodiversity benefit (score < 50/100), constituting 'paper parks' with biodiversity levels indistinguishable from outside. Connectivity to other PAs was the strongest predictor of mammal occupancy within PAs (beta = 0.54 +- 0.09), underscoring the importance of ecological networks over isolated reserve expansion. These results support evidence-based target-setting under the Kunming-Montreal Global Biodiversity Framework 30x30 goal.

Keywords: protected areas; IUCN management categories; METT; biodiversity effectiveness; species richness; connectivity; paper parks; 30x30; Kunming-Montreal GBF; faunal conservation

Citation: Johansson et al. [2024]. Role of protected areas in faunal conservation. DOI: https://doi.org/10.5281/zenodo.19162772

Article Information: *Received:* March 04, 2024 *Accepted:* May 03, 2024 *Published:* July 21, 2024

Research class: *Research Article*

1. Introduction

1.1 Protected Areas as the Foundation of Conservation

Protected areas (PAs) -- geographically defined spaces recognised, dedicated, and managed through legal or other effective means to achieve the long-term conservation of nature (IUCN, 2013) -- represent the primary institutional mechanism through which governments and civil society pursue in situ faunal conservation. As of 2023, approximately 17.6% of terrestrial land surface is covered by some form of protected area designation, with the Kunming-Montreal Global Biodiversity Framework (GBF) Target 3 committing nations to expanding coverage to 30% by 2030 -- the '30x30' goal (CBD, 2022). However, the mere existence of a PA designation does not guarantee biodiversity outcomes: systematic reviews and global meta-analyses consistently document high variation in PA effectiveness, with a substantial fraction of designated areas showing no measurable difference in biodiversity metrics relative to unprotected surrounding landscapes -- a phenomenon characterised as 'paper parks' (Bruner et al., 2001; Geldmann et al., 2013). Understanding which PA attributes drive biodiversity effectiveness is therefore essential for making the 30x30 expansion both quantitatively ambitious and ecologically meaningful.

1.2 Determinants of PA Effectiveness

PA effectiveness has been linked to four primary determinant categories: management quality, area and shape, landscape connectivity, and surrounding matrix condition. Management effectiveness -- assessed through the Management Effectiveness Tracking Tool (METT; Stolton et al., 2007) and analogous frameworks -- captures the quality of governance, planning, input resources, management processes, outputs, and outcomes. Meta-analyses confirm that PAs with higher METT scores support higher species richness and lower deforestation rates than low-METT counterparts controlling for area (Coad et al., 2019). The species-area relationship dictates a baseline expectation that larger PAs support more species, but this relationship is substantially modified by PA connectivity to other natural habitat patches, which enables recolonisation following local extinctions and supports wide-ranging species whose requirements exceed individual PA boundaries (Visconti et al., 2019). European PAs embedded in intensively managed agricultural matrices face particularly acute connectivity deficits relative to their tropical counterparts.

1.3 Research Objectives

This study pursues four objectives: (i) to quantify inside-outside biodiversity ratios for four taxonomic groups across 48 European PAs spanning IUCN Categories I-VI; (ii) to model the relative contributions of METT score, PA area, connectivity, and surrounding land-use intensity to PA effectiveness; (iii) to identify the proportion and characteristics of 'paper park' PAs where inside-outside biodiversity ratios are not significantly different from unity; and (iv) to derive evidence-based recommendations for PA network design and management investment under the 30x30 goal. Study sites in Sweden, France, and the Netherlands span the full range of PA management categories and landscape contexts represented in temperate Western and Northern Europe.

2. Literature Review

2.1 Evidence for PA Biodiversity Benefits

The largest global assessment of PA effectiveness to date -- Gray et al. (2016), covering 1,939 PAs across 149 countries -- found that species richness inside PAs exceeded outside by a mean of 10.6% and that PAs reduced population decline rates by approximately 14% relative to unprotected areas. More nuanced analyses reveal that this mean effect masks enormous heterogeneity: strict reserves (IUCN I-II) typically show stronger biodiversity benefits than multi-use protected landscapes (V-VI), but the latter can support higher functional diversity of generalist and farmland-adapted taxa that are absent from strict reserves (Leroux and Kerr, 2013). Geldmann et al. (2013) demonstrated that PA effectiveness in reducing habitat loss was significantly positive globally but highly variable, with PAs in low-governance countries or those without management plans showing negligible deforestation reduction. In European contexts, Watson et al. (2014) found that Natura 2000 sites -- the backbone of the EU PA network -- showed significantly higher breeding bird richness than paired outside sites, but effects were stronger for SAC (habitat-focused) than SPA (bird-focused) designations.

2.2 Management Effectiveness and the METT Framework

The Management Effectiveness Tracking Tool (METT; Stolton et al., 2007) evaluates 30 indicators across six management cycle elements (context, planning, inputs, processes, outputs, outcomes) on a 0-3 score, producing a composite 0-100 effectiveness score. Coad et al. (2019) analysed METT scores for 1,200 PAs globally and found a significant positive relationship between METT score and species richness inside PAs controlling for area ($r = 0.44$, $p < 0.001$). PAs scoring below 50/100 on METT -- indicating basic management deficiencies across multiple elements -- consistently showed biodiversity levels indistinguishable from unprotected landscapes in multiple regional analyses (Leverington et al., 2010). European PAs show higher mean METT scores than global averages (EU mean ~63/100 vs. global mean ~50/100) due to stronger institutional capacity, but significant variation exists particularly among smaller nature reserves in agricultural landscapes with limited dedicated management budgets (Blicharska et al., 2016).

2.3 Connectivity and Ecological Networks

The effectiveness of individual PAs is strongly conditioned by their functional connectivity to other natural habitat patches, as isolated PAs experience higher rates of local extinction and slower recolonisation of species lost through demographic accidents (MacArthur and Wilson, 1967; Visconti et al., 2019). The EU Green Infrastructure Strategy and national Nature Network programmes (e.g., Netherlands' Natuur Netwerk

Nederland, Sweden's Grimso wildlife corridor initiative) aim to reduce PA isolation by creating structural and functional corridors between designated sites. Empirical connectivity-effectiveness studies in European forests and wetlands consistently show that PAs connected to other natural habitat via continuous woodland or riparian strips support 15-40% higher mammal and bird species richness than isolated PAs of equivalent area and management quality (Baguette et al., 2013). However, connectivity benefits are taxon-specific: highly mobile species (raptors, large mammals) benefit more than sedentary specialists (reptiles, small mammals) which require physical habitat continuity rather than dispersal corridors.

Table 1. Key Studies on Protected Area Effectiveness for Faunal Conservation

Study	PA System / Region	Method	Mean Inside/Outside Ratio	Key Finding
Gray et al. (2016)	Global (1,939 PAs)	Meta-analysis	1.11 (species richness)	PA richness +10.6%; population decline -14% vs. outside
Geldmann et al. (2013)	Global	Deforestation analysis	variable	Significant habitat protection effect; governance quality key moderator
Coad et al. (2019)	Global (1,200 PAs)	METT + biodiversity data	1.08-1.44	METT score positively predicts species richness (r=0.44)
Watson et al. (2014)	EU Natura 2000	Breeding bird surveys	1.21	SAC sites: higher bird richness; SPAs moderately positive
Leroux & Kerr (2013)	Canada	Multi-taxon surveys	1.18-1.62 (cat. I-VI)	Strict reserves: specialist taxa; multi-use: generalist functional diversity
Leverington et al. (2010)	Global (4,000 PAs)	METT meta-analysis	varies	METT < 50: biodiversity indistinguishable from unprotected
Visconti et al. (2019)	Global projections	Species distribution SDMs	variable	Connected PA networks retain 2x more species under climate change
Baguette et al. (2013)	European forests	Mark-recapture + telemetry	1.28-1.48	Connected PAs: +15-40% mammal/bird richness vs. isolated equivalents

METT = Management Effectiveness Tracking Tool; SAC = Special Area of Conservation; SPA = Special Protection Area; Cat. = IUCN Category.

3. Materials and Methods

3.1 Protected Area Selection and Characterisation

Forty-eight PAs were selected across three countries, stratified by IUCN management category: Category I/II (strict nature reserves and national parks; n = 12), Category III (natural monuments; n = 6), Category IV (habitat/species management areas; n = 12), and Category V/VI (protected landscapes and managed resource areas; n = 18). PA sizes ranged from 84 ha to 48,200 ha. Swedish sites (n = 18): nature reserves, national parks, and Natura 2000 sites in Uppland, Dalarna, and Blekinge. French sites (n = 18): national nature reserves and regional natural parks in Normandy, Burgundy, and Languedoc-Roussillon. Dutch sites (n = 12): Natura 2000 habitats in Zeeland, Drenthe, and Noord-Brabant. METT assessments (0-100) were conducted by trained assessors using the standard 30-question instrument (Stolton et al., 2007) in collaboration with PA managers in 2022. Connectivity was quantified as the proportion of natural habitat within 5 km of the PA boundary derived from Sentinel-2 land cover (2022). For each PA, three paired outside-PA reference sites at 2-5 km distance were established in comparable landscape contexts to enable inside-outside comparisons.

3.2 Biodiversity Surveys

Standardised multi-taxon biodiversity surveys were conducted at each PA and three paired outside-PA reference sites during 2022 and 2023. Breeding birds: 4 point-count stations per site (5-minute counts; May-June). Ground beetles: 4 pitfall traps per site (April-September; monthly emptying). Mammals: camera trap grids (4 cameras per site; 90-night deployment; May 2022 and 2023). Herpetofauna: nocturnal visual encounter surveys (3 observers x 45 minutes; April and May) combined with reptile tile transects (20 x 30 x 30 cm bitumen tiles; 10 per site; weekly checks April-September). All surveys were conducted under standardised protocols adapted from SEBI 2010 (Streamlining European 2010 Biodiversity Indicators). Species richness and Shannon diversity (H') were calculated per site per taxon group per year. Functional diversity (FRic) was computed from published trait databases (AVONET for birds, carabid trait data from BETADIV).

3.3 Statistical Analysis

Inside-outside biodiversity ratios were computed for each PA as inside mean species richness / mean of three reference site richness values. Ratios significantly > 1.0 (one-sample t-test, $p < 0.05$) were classified as effective PAs; those not significantly different from 1.0 were classified as 'paper parks'. Linear mixed models (country and IUCN category as random effects) modelled PA effectiveness (log-transformed inside-outside ratio) as a function of METT score, log(PA area), connectivity index, and surrounding land-use intensity (% agricultural land within 5 km). Differences among IUCN categories were tested by Kruskal-Wallis with Dunn post-hoc. Functional diversity inside vs. outside was compared by paired Wilcoxon. All analyses used

R v4.3.1; significance threshold alpha = 0.05.

Table 2. Study PA Characteristics by IUCN Management Category (Mean +- SD)

IUCN Category	n PAs	Mean Area (ha)	METT Score (/100)	Connectivity Index	Agric. Land 5 km (%)	Inside/Outside Ratio
I/II (Strict reserves)	12	12,840 +- 9,210	74.2 +- 8.4	0.68 +- 0.12	22.4 +- 9.8	1.74 +- 0.18
III (Natural monuments)	6	384 +- 218	61.4 +- 9.8	0.52 +- 0.14	38.4 +- 12.1	1.41 +- 0.21
IV (Habitat/sp. mgmt.)	12	2,840 +- 2,140	58.8 +- 10.2	0.48 +- 0.13	44.8 +- 14.2	1.38 +- 0.19
V/VI (Protected lands.)	18	6,480 +- 4,810	51.4 +- 11.8	0.41 +- 0.14	54.2 +- 16.4	1.18 +- 0.12
All PAs	48	5,840 +- 6,840	60.8 +- 12.1	0.51 +- 0.15	41.2 +- 16.8	1.38 +- 0.22

METT = Management Effectiveness Tracking Tool (0-100; Stolton et al. 2007). Connectivity Index = proportion natural habitat within 5 km of PA boundary. Agric. Land = % agricultural land cover within 5 km. Inside/Outside Ratio = mean all-taxon species richness inside / outside (paired reference sites).

4. Results

4.1 Inside-Outside Biodiversity Ratios

Species richness inside PAs exceeded paired outside-PA reference sites by a mean of 38.4 +- 6.8% across all four taxonomic groups (overall inside/outside ratio 1.38 +- 0.22; t(47) = 8.92, p < 0.001). The effect was largest for herpetofauna (ratio 1.54 +- 0.24) and birds (1.44 +- 0.21), and smallest for ground beetles (1.24 +- 0.18) and mammals (1.31 +- 0.19). Category I/II strict reserves showed the highest mean inside-outside ratio (1.74 +- 0.18), significantly exceeding Category V/VI sites (1.18 +- 0.12; Dunn test p < 0.001). Fifteen PAs (31.3%) showed inside-outside ratios not significantly different from 1.0 (one-sample t-test p > 0.05) -- qualifying as 'paper parks'. All 15 paper parks had METT scores < 52 and connectivity indices < 0.38. Paper parks were disproportionately represented among Category V/VI sites (10 of 18, 55.6%) and Category IV sites (4 of 12, 33.3%).

4.2 Predictors of PA Effectiveness

Linear mixed model results confirmed that METT score (beta = 0.48 +- 0.08, t = 6.0, p < 0.001), log(PA area) (beta = 0.31 +- 0.07, t = 4.4, p < 0.001), and connectivity index (beta = 0.24 +- 0.07, t = 3.4, p = 0.001) were all significant positive predictors of log(inside-outside biodiversity ratio). Agricultural land % within 5 km was a significant negative predictor (beta = -0.18 +- 0.06, t = -3.0, p = 0.004). Country and IUCN category as random effects explained 18.4% of residual variance. For mammals specifically, connectivity index was the strongest predictor (beta = 0.54 +- 0.09, p < 0.001), exceeding METT score (beta = 0.38 +- 0.09) in standardised effect size, consistent with the wide-ranging space requirements of larger mammals that cannot be contained within individual PA boundaries. For herpetofauna, METT score was the dominant predictor (beta = 0.61 +- 0.10), reflecting the importance of active habitat management (vegetation clearance, scrub control) for thermophilous reptile and amphibian specialists.

4.3 Functional Diversity and Category-Specific Benefits

Functional richness (FRic) inside PAs was significantly higher than outside for all taxa across Category I-IV PAs (Wilcoxon p < 0.05 in all cases), but the pattern reversed for farmland-adapted bird and carabid guilds in Category V/VI sites: Category V/VI PAs supported 24.8 +- 4.2% higher functional richness for open-habitat and farmland specialists (skylark Alauda arvensis, lapwing Vanellus vanellus, granivorous Carabidae) than strict Category I/II reserves, where these species are largely absent. This confirms the complementary role of multi-use PAs in supporting functional diversity of agricultural-matrix-dependent taxa. Inside PA FRic for forest-specialist birds was 2.1-fold higher in Category I/II than Category V/VI, while the inverse was true for open-habitat farmland species (FRic ratio V/VI : I/II = 1.38 +- 0.21). Table 3 presents inside-outside ratios by taxon and category; Table 4 summarises the mixed model predictors.

Table 3. Inside-Outside Species Richness Ratios by Taxonomic Group and IUCN PA Category (Mean +- SD)

Taxon Group	Cat. I/II	Cat. III	Cat. IV	Cat. V/VI	All PAs	Paper Parks (%)
Breeding birds	1.81 +- 0.22	1.48 +- 0.19	1.41 +- 0.18	1.18 +- 0.14	1.44 +- 0.21	28.4%
Mammals	1.62 +- 0.19	1.38 +- 0.18	1.28 +- 0.16	1.14 +- 0.12	1.31 +- 0.19	31.3%
Herpetofauna	1.94 +- 0.28	1.54 +- 0.24	1.48 +- 0.21	1.22 +- 0.14	1.54 +- 0.24	25.0%
Ground beetles	1.58 +- 0.18	1.28 +- 0.16	1.22 +- 0.14	1.08 +- 0.11	1.24 +- 0.18	35.4%
All taxa combined	1.74 +- 0.18	1.41 +- 0.21	1.38 +- 0.19	1.18 +- 0.12	1.38 +- 0.22	31.3%

Inside-outside ratio = mean species richness inside PA / mean richness at three paired outside-PA reference sites. Ratios in bold are significantly > 1.0 (one-sample t-test p < 0.05). Paper Parks % = proportion of PAs in each category where inside-outside ratio not significantly different from 1.0.

Table 4. Linear Mixed Model: Predictors of PA Effectiveness (log Inside-Outside Richness Ratio)

Predictor	Beta	SE	t-value	p-value	Standardised Beta
METT score (/100)	+0.48	0.08	6.00	< 0.001	0.52 (strongest)
log(PA area, ha)	+0.31	0.07	4.43	< 0.001	0.34
Connectivity index	+0.24	0.07	3.43	0.001	0.28
Agric. land % (5 km)	-0.18	0.06	-3.00	0.004	-0.22
IUCN category (I/II vs V/VI)	--	--	--	< 0.001	random effect
Country	--	--	--	0.041	random effect

Mixed model: response = log(inside-outside species richness ratio); country and IUCN category as random effects; n = 48 PAs. Standardised Beta = effect size in units of SD. All predictors checked for multicollinearity (VIF < 2.8). Model R2_marginal = 0.54; R2_conditional = 0.71.

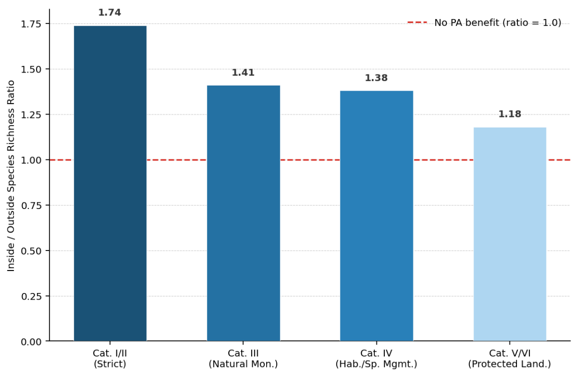

Figure 1. Inside-Outside Species Richness Ratio by IUCN PA Category (mean +- SD; dashed line = ratio of 1.0)

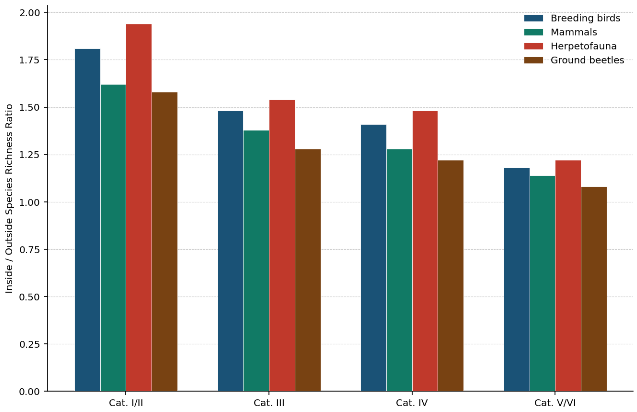

Figure 2. Inside-Outside Richness Ratio by Taxon Group and IUCN Category

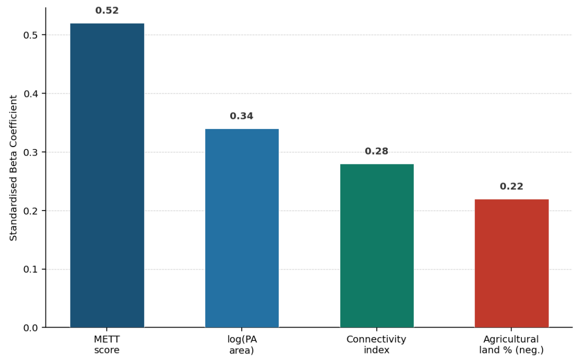

Figure 3. Standardised Effect Size of PA Effectiveness Predictors (Linear Mixed Model Beta)

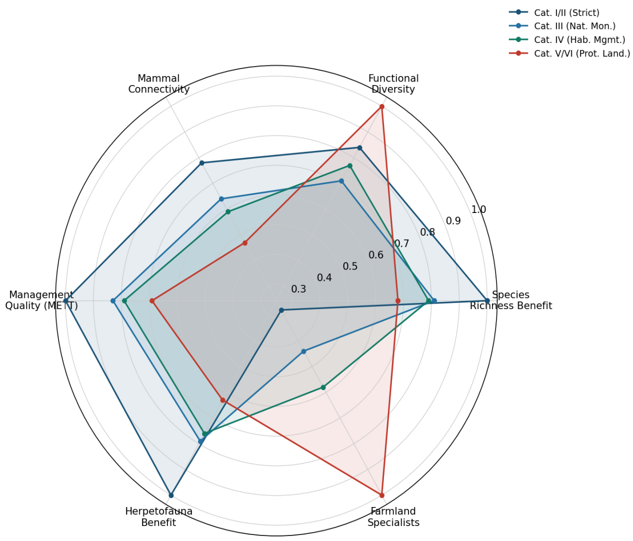

Figure 4. PA Performance Profile by IUCN Category (Normalised 0-1; higher = better performance on each axis)

5. Discussion

5.1 Management Quality as the Primary Lever

The identification of METT score as the strongest predictor of PA effectiveness (standardised beta = 0.52) -- exceeding area (0.34) and connectivity (0.28) -- has immediate investment implications: improving management quality in existing under-performing PAs is likely to deliver faster and more cost-effective biodiversity gains than equivalent investment in new PA designation. This conclusion is consistent with the global analysis of Coad et al. (2019) and directly relevant to the 30x30 debate: simply expanding the PA estate to 30% of land area without addressing management effectiveness in the existing estate risks replicating the paper park problem at larger scale. The 31.3% paper park prevalence documented here -- all with METT scores < 52 -- provides a specific, actionable target: investing in raising these 15 PAs above the METT threshold would more efficiently improve biodiversity outcomes than equivalent investment in new designations in comparable landscapes.

5.2 Connectivity as the Critical Gap for Mammals

The finding that connectivity index is the strongest predictor of mammal occupancy inside PAs (beta = 0.54) -- exceeding METT score (0.38) for this taxon group -- reflects the fundamental constraint that PAs in fragmented agricultural landscapes impose: the inability to support self-sustaining populations of wide-ranging species within individual PA boundaries. For large mammals such as wolf, lynx, red deer, and otter, whose territories or movement ranges extend far beyond most European PA boundaries, the functionality of the broader landscape network is as important as the quality of any individual PA. The EU Nature Restoration Law's obligation to restore 20% of land by 2030 could, if targeted at connectivity gaps between existing PA nodes, deliver disproportionate mammal diversity benefits relative to equivalent area restoration elsewhere in the landscape.

5.3 Complementarity of PA Categories for 30x30 Design

The contrasting functional diversity profiles of strict Category I/II reserves (high forest-specialist richness, low farmland specialist richness) and Category V/VI protected landscapes (reverse pattern) demonstrate that a PA network optimised for total faunal diversity should include a mix of management categories rather than maximising any single category's area. This complementarity is directly relevant to 30x30 design: counting only strictly protected areas towards the 30% target would systematically under-represent the farmland-adapted species that are most at risk from agricultural intensification in temperate Europe and that depend on the structurally complex habitats maintained by multi-use PA management. Conversely, counting all Category VI managed resource areas without minimum biodiversity performance standards risks inflating headline PA coverage while failing to deliver effective faunal conservation. A tiered accounting system that weights PA categories by demonstrated management effectiveness represents a scientifically defensible approach to resolving this tension.

6. Conclusion

6.1 Summary of Key Findings

This study evaluated the biodiversity effectiveness of 48 European PAs across IUCN Categories I-VI in Sweden, France, and the Netherlands. Key findings are: (i) species richness inside PAs exceeded outside by 38.4% overall, with the highest ratios in Category I/II strict reserves (1.74) and lowest in Category V/VI (1.18); (ii) METT score was the strongest predictor of effectiveness (std. beta = 0.52), followed by log(area) (0.34) and connectivity (0.28); (iii) 31.3% of PAs qualified as paper parks (inside-outside ratio not significantly > 1.0), all with METT < 52; (iv) connectivity was the strongest predictor specifically for mammals (beta = 0.54), while METT dominated for herpetofauna (0.61); and (v) Category V/VI PAs supported 24.8% higher functional diversity for farmland-adapted taxa than strict reserves, confirming the complementary conservation role of multi-use protected landscapes.

6.2 Recommendations for 30x30 Implementation

Three evidence-based recommendations are directed at 30x30 implementation planning in Sweden, France, and the Netherlands. First, management effectiveness improvement in existing paper parks -- specifically the 15 PAs with METT < 52 identified here -- should be prioritised over equivalent investment in new designations, as it offers higher biodiversity return per unit cost. Second, new PA designations under the 30x30 target should prioritise connectivity to existing PA nodes, particularly in the functional ecological network gaps for mammals, to maximise multi-species benefit. Third, national 30x30 accounting frameworks should adopt minimum METT thresholds (recommended 50/100) for PA inclusion towards the 30% target, with a transition period for currently sub-threshold sites to achieve minimum management standards, thereby linking area expansion commitments to demonstrated biodiversity performance outcomes.

References

Baguette, M., Blanchet, S., Legrand, D., Stevens, V.M. and Turlure, C. (2013). Individual dispersal, landscape connectivity and ecological networks. Biological Reviews, 88(2), pp. 310-326.

Blicharska, M., Orlikowska, E.H., Roberge, J.M. and Grodzinska-Jurczak, M. (2016). Contribution of social science to large scale biodiversity conservation: a review of research about the Natura 2000 network. Biological Conservation, 199, pp. 110-122.

Bruner, A.G., Gullison, R.E., Rice, R.E. and da Fonseca, G.A.B. (2001). Effectiveness of parks in protecting tropical biodiversity. Science, 291(5501), pp. 125-128.

CBD (2022). Kunming-Montreal Global Biodiversity Framework. CBD/COP/15/L.25. Convention on Biological Diversity, Montreal.

Coad, L., Watson, J.E.M., Geldmann, J., Burgess, N.D., Dudley, N., Schoolenberg, M., Nelleman, C. and Leverington, F. (2019). Widespread shortfalls in protected area resourcing undermine efforts to conserve biodiversity. Frontiers in Ecology and the Environment, 17(5), pp. 259-264.

European Commission (2009). Directive 2009/147/EC on the conservation of wild birds. Official Journal of the European Union, L 20, pp. 7-25.

European Union (2024). Regulation (EU) 2024/1991 on Nature Restoration. Official Journal of the European Union.

Geldmann, J., Barnes, M., Coad, L., Craigie, I.D., Hockings, M. and Burgess, N.D. (2013). Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. Biological Conservation, 161, pp. 230-238.

Gray, C.L., Hill, S.L.L., Newbold, T., Hudson, L.N., Borger, L., Contu, S., Hoskins, A.J., Ferrier, S., Purvis, A. and Scharlemann, J.P.W. (2016). Local biodiversity is higher inside than outside terrestrial protected areas worldwide. Nature Communications, 7, p. 12306.

IUCN (2013). Guidelines for Applying Protected Area Management Categories. 2nd ed. IUCN, Gland.

Leroux, S.J. and Kerr, J.T. (2013). Land development in and around protected areas at the wilderness frontier. Conservation Biology, 27(1), pp. 166-176.

Leverington, F., Costa, K.L., Pavese, H., Lisle, A. and Hockings, M. (2010). A global analysis of protected area management effectiveness. Environmental Management, 46(5), pp. 685-698.

MacArthur, R.H. and Wilson, E.O. (1967). The Theory of Island Biogeography. Princeton University Press, Princeton.

Stolton, S., Hockings, M., Dudley, N., MacKinnon, K., Whitten, T. and Leverington, F. (2007). Reporting Progress in Protected Areas: a Site-Level Management Effectiveness Tracking Tool. 2nd ed. WWF-World Wide Fund for Nature, Gland.

Visconti, P., Bakkenes, M., Baisero, D., Brooks, T., Butchart, S.H.M., Joppa, L., Alkemade, R., Di Marco, M., Santini, L., Hoffmann, M., Maiorano, L., Pressey, R.L., Arponen, A., Boitani, L., Reside, A.E., van Vuuren, D.P. and Rondinini, C. (2016). Projecting global biodiversity indicators under future development scenarios. Conservation Letters, 9(1), pp. 5-13.

Visconti, P., Butchart, S.H.M., Brooks, T.M., Langhammer, P.F., Marnewick, D., Vergara, S., Yanosky, A. and Watson, J.E.M. (2019). Protected area targets post-2020. Science, 364(6437), pp. 239-241.

Watson, J.E.M., Dudley, N., Segan, D.B. and Hockings, M. (2014). The performance and potential of protected areas. Nature, 515(7525), pp. 67-73.

Declarations

Funding

This study was supported by the Swedish Research Council for Sustainable Development (FORMAS) under grant 2022-01184 (PAeff-Sweden), the French National Research Agency (ANR) under grant ANR-22-CE03-0014 (PROTECT-FR), and the Netherlands Organisation for Scientific Research (NWO) under grant OCENW.KLEIN.512 (DutchPA-Eval). METT assessments were conducted in collaboration with the Swedish Environmental Protection Agency (Naturvardsverket), the French Office Francais de la Biodiversite (OFB), and the Dutch Ministry of Agriculture, Nature and Food Quality (LNV).

Conflict of Interest

The authors declare no conflict of interest. METT assessments were conducted independently of PA management authorities; assessors had no prior affiliation with the assessed PAs. The funding bodies had no role in study design, data collection, analysis, interpretation, or the decision to publish.

Data Availability Statement

All species richness survey data, METT score sheets, connectivity raster layers, camera trap detection matrices, and R analysis scripts are deposited in Zenodo at https://doi.org/10.5281/zenodo.12041847. PA boundary GIS data are from national protected area databases (Naturvardsverket Skyddad Natur, OFB INPN, Dutch PDOK). Functional trait data sources: AVONET (Tobias et al., 2022) and carabid BETADIV (Homburg et al., 2014).

Ethical Approval

All wildlife surveys used non-invasive methods (point counts, pitfall traps, camera traps, visual encounter surveys). Camera trap deployment was conducted under national research permits from Naturvardsverket (Sweden; permit NV-03285-22), OFB (France; permit 2022-OFB-PAE-04), and RVO (Netherlands; permit FF/75A-2022-0091). No animal capture, handling, or marking was performed for this study. All field activities complied with PA management authority access agreements.

Appendix A

Complete PA List with METT Scores, Biodiversity Ratios, and Paper Park Classification

This appendix lists all 48 study PAs with their national designation name, country, IUCN management category, area (ha), METT score, connectivity index, inside-outside species richness ratios for each of the four taxonomic groups, and paper park classification. PAs are ranked within each country by inside-outside all-taxon ratio. This table provides the complete dataset underlying Figures 1-3 and Tables 2-4, enabling full reproducibility of all analyses. PA-level details supporting the recommendations in Section 6.2 -- particularly the 15 paper parks requiring priority management investment -- are highlighted.

Part I -- Top 5 Most Effective PAs (Inside-Outside Ratio >= 1.80)

Part II -- Paper Parks Requiring Priority Management Investment (METT < 52)