



Open Journal of Biodiversity and Ecosystems

Volume 1, 2026





Open Journal of Biodiversity and Ecosystems

Volume 1: 2026

Editorial team:

Editor-in-Chief: Nina Lenger, student

Managing Editor: Pamela McDormand, alumnus

Andres Acosta, student

Graham Ball, student

Laura Hollis, student

Nadia Croeser, alumnus

Dolapo Adejumo, alumnus

Cover image: Davies Ezra Chogawana (2026)

We are a student- and alumni-led Diamond Open Access Journal

This issue is dedicated in loving memory of Finn (Geneva) McDormand (21), daughter of Pamela McDormand, who passed away suddenly in March 2026. Finn shared their mother's love of nature, especially orangutans, sharks, salamanders, frogs and rabbits.



THE UNIVERSITY of EDINBURGH
Library



EDINBURGH
DIAMOND

Published by the [University of Edinburgh](https://www.ed.ac.uk) with support from [Edinburgh Diamond](https://www.ed.ac.uk/diamond).
All material is licensed under a [Creative Commons Attribution 4.0 International \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/)
ISSN: 2977-8433 (Online)

Table of Contents

IV Editorial

Research Articles

- 1 Ecosystem Disruption in Colombia's Páramo: Assessing Anthropogenic Change through a DPSIR Framework
Andres Acosta
- 11 Untangling Wildlife Law and Enforcement in Pakistan: From Crime to Reform
Fiza Adil and Muhammad Razi
- 25 Drivers and Pressures of Wetland Degradation in Malawi: A Narrative Review
Davies Ezra Chogawana, Eleanor S. Devenish-Nelson, and Mphatso Martha Kalembe
- 33 Urban tree cover improves breeding bird abundance across all public cemeteries in one of Europe's largest cities.
Alistair Marjot and Patrick J. C. White

Photo Essay

- 53 Waters of Life: Stories from Elephant Marsh
Davies Ezra Chogawana

Book Review

- 59 Regenesi: Feeding the world without devouring the planet
Graham Ball

Letters

- 64 Large whales fill a vital role in the ocean ecosystem, making their conservation an essential aspect of overall ocean health
Pamela McDormand

Reflection

- 66 Biodiversity, Wildlife and Ecosystem Health Programme: Beginnings, Reflections, Highlights, Future
Sharron Ogle, Ellie Devenish-Nelson and Rob Thomas

Editorial

Communication has always been the foundation of good science. From the time when Charles Darwin wrote letters back and forth with other scientific colleagues of his era, to the present-day rapid exchange of files over the internet. The way scientists share their findings with each other and with the world has been shifting in an increasingly technological world.

In the recent past, science journals were paper-only, and subject to fees for those who wished to publish and payment for those who wished to read. Academic libraries, of course, have subscriptions to the most popular journals, but not all readers are connected to a university. Increasing digitization means digital articles may be downloaded and read in an instant, but many journals still charge for access, and publication fees for researchers remain high in most cases. This may be a challenge for those who may not have the financial means, including students and early career researchers and those from countries in marginalised countries. Socioeconomic status can be a barrier, but that does not mean these ideas are less deserving of dissemination and may also lead to an unfair bias in publication toward those who can afford to pay. Diamond Open Access journals are changing how we access information, with journals that are free to read, and with no charge for publishing your work. Additionally, it can be challenging to get a foot in the door of the world of scientific publication. Student journals can be instrumental in opening that door, allowing new researchers to enter the collective conversation of science. Witnessing the publication process from behind the scenes lends a valuable perspective for students and researchers.

Serving on the editorial board of a student journal is also a great way to learn about the inner workings of the publishing universe, gaining insights into what journal editors are looking for, how the process works, how to review and evaluate submissions, giving and receiving meaningful feedback, and most of all, learning about peer review. Peer review is the foundation of scientific research. I firmly believe that every scientist needs to learn how to review, and they will become a better writer, and a better scientist, for it. Collaborating as a team and communicating with authors is also an incredibly valuable skill that comes with being a part of a project like this. Our editorial board consists of a mix of current students and alumni of the Biodiversity, Wildlife and Ecosystem Health (BWEH) masters programme at the University of Edinburgh, and the journal helps foster relationships between these two groups.

It is my hope that *The Open Journal of Biodiversity and Ecosystems* will also serve as a bridge between learning and doing, between students, alumni, and researchers, between art and science, and between scientific knowledge and its audiences. On a rapidly changing planet, we all need to stay informed on the issues of biodiversity, conservation, ecology, ecosystems, nature, sustainability, and human behaviour, as well as the policies and governance underpinning these valuable concepts. Understanding how ecological systems work, how humans impact them and how we can influence other humans to make changes in their behaviour are all instrumental in building a safe and livable planet for all. With no paywall, open access journals can help more people can gain an understanding of this knowledge and the importance of maintaining the natural systems that support life on our planet.

Our journal will be filled with not only standard journal articles but also science letters, project reports, photography, art, book reviews, and reflective writing. Our aim is for this journal to encompass a wider range of thinking and expression, in line with the interdisciplinarity that is a cornerstone of the BWEH programme. Humans tend to compartmentalize ideas into tidy boxes like science, art, humanities, but more and more we see how these concepts blend together. Art and the keen sense of observation, along with an appreciation of beauty blends gently into studies of the world around us. Meanwhile, in order to bring about the change this planet needs, we need the sociological understanding of how best to bring about shifts in human behaviour. Science is not performed in isolation, but requires collaboration across many disciplines. Open access journals also mean that the general public can find information directly at its source, and enhance their own scientific literacy and critical thinking skills.

In this issue, we will hear from researchers on urban bird diversity in Germany, land use and ecosystem degradation from Malawian wetlands to the Andes mountains, weaknesses in wildlife laws in Pakistan. We also have a book review centering around our food systems and a brief communication on the ecosystem services provided by large whales. We feel particularly honoured to include a reflection of the BWEH programme that has brought us all together, to celebrate the 15th anniversary, which took place in 2025. May you find within these pages, content that is informative, insightful, and thought provoking, that furthers your understanding of the issues our authors and contributors have presented.

Thanks and Acknowledgements

I would like to thank our hardworking, dedicated editorial team, including original founding members who have moved on but contributed during the formative stage, reviewers, our faculty advisors, the entire BWEH program, the staff at Edinburgh Diamond, and the Public Knowledge Project for their journal software and editorial courses, the authors and contributors who have entrusted us with their work, with special thanks for your patience while we paused our journal work during a difficult time for my family.

Pamela McDormand, managing editor, *The Open Journal of Biodiversity and Ecosystems*

We hope you enjoy our inaugural issue of The Open Journal of Biodiversity and Ecosystems. To find out more about making a submission, becoming involved with our editorial board, or to sign up for notification of future issues, please visit our website:

<https://open.journals.ed.ac.uk/index.php/ojbe/index>

Ecosystem Disruption in Colombia's Páramo: Assessing Anthropogenic Change through a DPSIR Framework

Andres Acosta

Deanery of Biomedical Sciences, The University of Edinburgh

Email:

A.Acosta-Calderon@sms.ed.ac.uk

Received: September 2025

Accepted for publication: May 2026

Published: July 2026

Abstract

The Páramo ecosystem is one of the most distinctive high-Andean ecosystems in the world, hosting extraordinary biodiversity and playing a critical role in the provision of ecosystem services. Notably, nearly half of the global extent of páramos lies within Colombia, making them essential not only for national sustainability but also for global climate regulation. These ecosystems sustain millions of people through water provision, regulate regional hydrology, and act as carbon sinks, while supporting exceptionally high levels of endemism. However, they are increasingly threatened by the dual forces of climate change and human activity, including agriculture, mining, and infrastructure development. Understanding the drivers of change and their cascading consequences is therefore essential for informed conservation and governance.

This study applies the Drivers-Pressures-State-Impact-Response (DPSIR) framework to examine the complex socio-ecological dynamics affecting Colombian páramos. The framework allows a structured assessment of how socio-economic and climatic drivers translate into pressures such as land-use conversion to mining and agriculture, and hydrological disruption, which in turn alter the ecological state of these fragile landscapes. Evidence shows that although 86% of Colombia's páramos still retain natural vegetation, their integrity is increasingly compromised by habitat fragmentation, soil degradation, and water imbalance. Projections under climate change scenarios further indicate upslope displacement of species and ecosystems, leading to habitat compression and heightened risks of biodiversity loss. By mid-century, up to half of the páramo extent in key areas such as Chingaza National Park could become climatically unsuitable, with severe implications for water security and carbon storage. The impacts of these changes extend beyond ecological integrity to human well-being, given that páramos supply about 70% of Colombia's freshwater and underpin hydroelectric generation, agriculture, and urban consumption. Loss of regulating services also raises the risk of conflicts over land and water use, particularly in vulnerable rural communities. Responses have emerged at multiple levels. Yet these measures are unevenly enforced and often clash with local livelihood strategies. This analysis highlights the urgent need for integrated, participatory governance that bridges ecological science with socio-cultural realities.

Keywords: Colombian páramo; DPSIR framework; ecosystem services; climate change; biodiversity conservation; land-use change; adaptive governance; socio-ecological system

1. Introduction

Perched atop the Andes mountains, the páramo ecosystem is one of the world's most extraordinary and fragile landscapes. Its ancient vegetation, over four million years old, has birthed an extraordinary array of life with high

Vol. 1, 2026

endemism, sustained by its unique combination of low temperatures, high precipitation, and specialised biota (>3,400 vascular plant species with ~60–90% endemism; and ~30 endemic genera out of 300) (Madriñán *et al.*, 2013; Vargas *et al.*, 2023). Páramos are considered a biodiversity hotspot, the most species-rich ecosystem in the world's

DOI: 10.2218/hvdg7e20

tropical montane regions (Rangel & Orlando, 2018; Sklenář *et al.*, 2014), and the richest alpine vegetation type globally (Hofstede & Llambí, 2020)—within which Colombia hosts nearly ~51% of the world's páramos (Molina *et al.*, 2019; Sarmiento *et al.*, 2013), making it critical to global páramo conservation. Páramos supply 70% of Colombia's water (Burbano-Girón *et al.*, 2020), sustaining human livelihoods for over 8,000 years (Farley & Bremer, 2017). Comparative analyses with other ecosystems and biomes at a global scale further highlight the páramo's singular value, emphasising the urgency of conservation strategies that can strengthen its resilience to both anthropogenic pressures and climatic stressors (Sgrò *et al.*, 2010; Diazgranados *et al.*, 2021). Importantly, páramos provide key ecosystem services, *primarily* water provision, climate regulation via carbon sequestration, and biodiversity maintenance (Buytaert *et al.*, 2006; Buytaert *et al.*, 2011; Farley *et al.*, 2013; Suarez *et al.*, 2022; Vergara & De-Pellegrin, 2025). Given that socio-economic, political, and cultural drivers vary by country (Ostrom, 2011), and Colombia's páramos face distinct pressures, this analysis focuses specifically on the Colombian context.

This paper applies the Drivers-Pressures-State-Impact-Response (DPSIR) framework to critically assess how anthropogenic activities drive environmental change (Kyeré-Boateng & Marek, 2021; Tscherning *et al.*, 2012) in Colombia's páramos, disrupting ecosystem services such as water regulation, carbon sequestration, and biodiversity maintenance.

Figure 1 illustrates the DPSIR framework applied to anthropogenic activities affecting the páramo's ecology and ecosystem services. Drivers (left panel), such as economic growth, population expansion, social changes, political systems, and climate change, drive land-use changes (central-left panel), represented by mining, agriculture, infrastructure development, and industry. These changes create Pressures (e.g., habitat degradation, pollution, resource extraction), which in turn alter the State of the environment by modifying key ecological conditions.

The resulting Impacts (central-right panel) affect ecosystem services, including water provision and regulation, biodiversity, climate regulation and climate resilience. Responses (far right)—legal protection, participatory land-use planning, restoration and monitoring, and payment for ecosystem services (PES)—aim to curb pressures, stabilize state, and secure benefits.

2. Objectives

The purpose of this study is to unravel how Colombia's páramos are being reshaped by both direct anthropogenic pressures—such as agricultural expansion, mining, urbanisation, and land-use change—and the indirect effects of climate change. Using the DPSIR framework as a guiding framework, the research first seeks to identify the drivers of change, from economic expansion and shifting political agendas to global warming and demographic growth. It then examines how these forces translate into direct pressures, such as agricultural intensification, mining, and hydrological disruption, that steadily erode the páramo's ecological fabric.

Beyond cataloguing pressures, the study evaluates the current state of the ecosystem's resilience—reflected in the remarkable proportion of intact vegetation—as well as its vulnerabilities, including habitat fragmentation and declining capacity to regulate water and carbon. The analysis further explores the cascading impacts these transformations have on biodiversity, water security, carbon storage, and the livelihoods of communities who depend on these upland landscapes.

Finally, the research critically reviews responses to address these challenges, ranging from legal protections and participatory land-use planning to payment for ecosystem services schemes and ecological restoration. By integrating these strands, the study aims to propose governance strategies that not only tackle immediate threats but also build long-term resilience, bridging

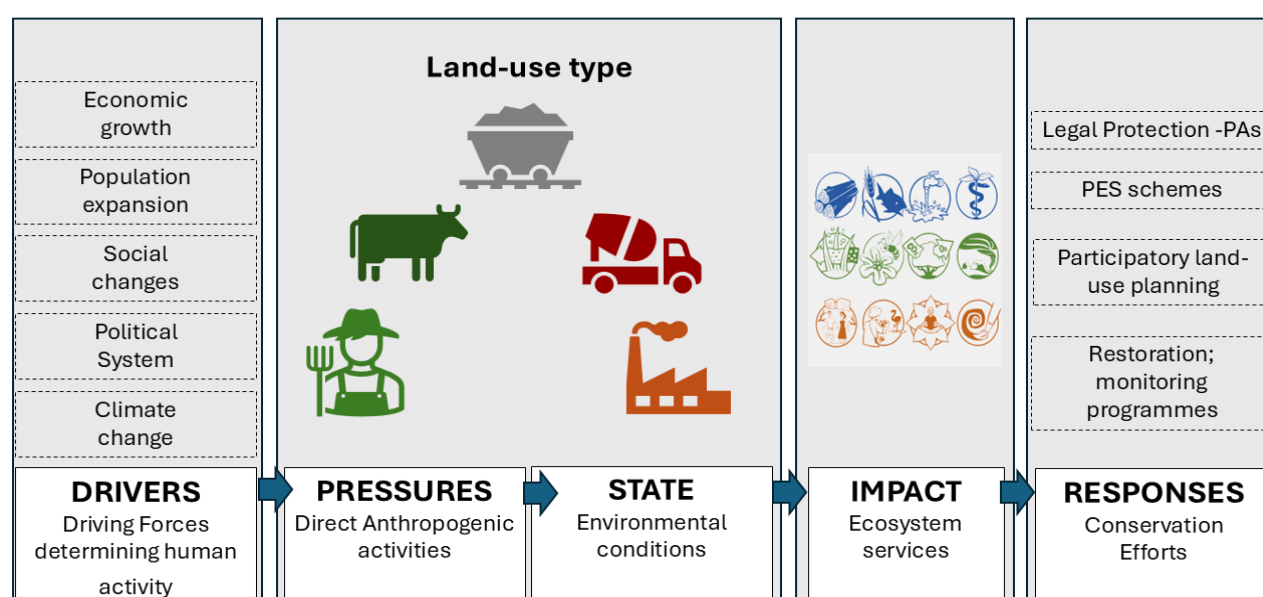


Figure 1. DPSIR framework applied to land-use changes in Colombia's páramo ecosystem. This diagram illustrates the Drivers-Pressures-State-Impact-Responses (DPSIR) model in the context of anthropogenic activities affecting the páramo. Source: Author's own elaboration, adapted from Schirpke *et al.* 2023; Icons for ecosystem services by Jan Sasse designed for TEEB

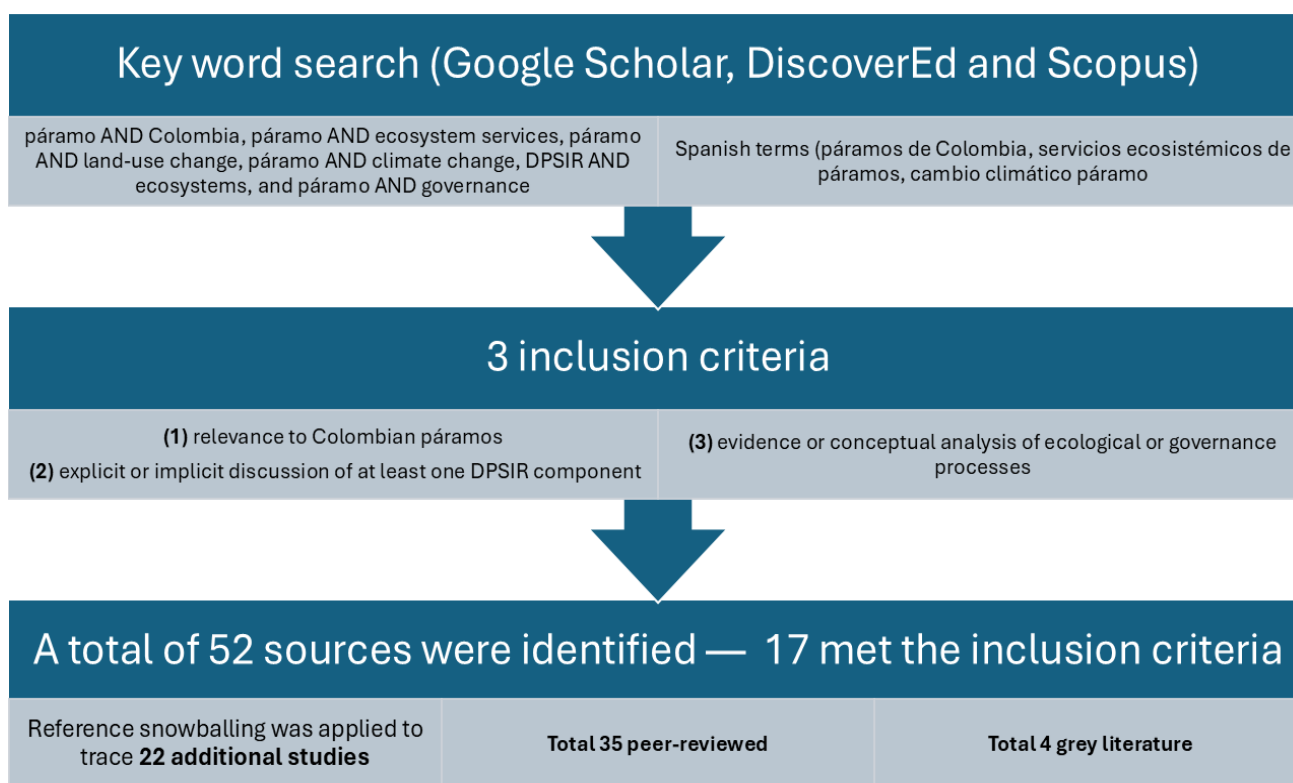


Figure 2. Methodological workflow of the systematic literature review. The process included a keyword search in multiple databases (Google Scholar, DiscoverEd, and Scopus), application of three inclusion criteria, and final selection of sources. From 52 identified publications, 17 met the criteria. Reference snowballing identified 22 additional studies for analysis.

ecological science with the socio-cultural realities of Colombia's high mountain landscapes.

It is important to clarify this study's scope and contribution. Whilst the DPSIR framework facilitates systematic review of existing responses, this analysis does not attempt to comprehensively evaluate whether current conservation strategies are sufficient or to identify detailed opportunities for enhancement across all initiatives. Given the substantial attention Colombian páramos have already received—including major programmes such as the GEF-funded 'Páramos for Life' project—such a comprehensive strategy assessment would constitute separate research. Instead, this study's contribution lies in applying the DPSIR framework to reveal the complex inter-relationships between drivers, pressures, ecosystem states, impacts, and responses at a national scale, providing an integrative diagnostic assessment that can inform prioritisation of future governance attention and research.

3. Materials and Methods

This study applies the Drivers-Pressures-State-Impact-Response (DPSIR) framework to analyse the socio-ecological dynamics of environmental change in Colombia's páramo ecosystems. DPSIR is a widely used conceptual tool (Folkens *et al.*, 2023; Kyere-Boateng & Marek, 2021; Maxim *et al.*, 2009) for linking human activities with ecological outcomes and policy responses (Tscherning *et al.*, 2012), providing a structured way to assess causal relationships between anthropogenic drivers, environmental pressures from human activities, ecosystem condition, resulting impacts, and societal responses (Folkens *et al.*, 2023). It becomes important to note that

establishing causal relationships is not always a straightforward process, given that environmental impacts are usually caused by a variety of drivers and complex dynamics of synergies.

The methodology followed a systematic literature review —Illustrated in Figure 2— using the propositional inventory method (Folkens *et al.*, 2023). This approach systematically extracts and categorises information from the literature according to predefined criteria, ensuring transparency and reproducibility (Folkens *et al.*, 2023). The goal was to generalise patterns of socio-ecological change affecting the páramo through a synthesis of existing empirical and conceptual studies.

A keyword search was conducted across Google Scholar, DiscoverEd and Scopus, between September 2024 and September 2025. Search terms included: páramo AND Colombia, páramo AND ecosystem services, páramo AND land-use change, páramo AND climate change, DPSIR AND ecosystems, and páramo AND governance. Additional synonyms and Spanish terms (páramos de Colombia, servicios ecosistémicos de páramos, cambio climático páramos) were included to capture Latin American scholarship (see Figure 2). To avoid missing relevant material, grey literature (e.g. government reports, NGO assessments, and doctoral theses) was also reviewed, given its importance in Latin American environmental governance contexts.

All publications were screened against *three inclusion criteria*: (1) relevance to Colombian páramos; (2) explicit or implicit discussion of at least one DPSIR component; (3) evidence or conceptual analysis of ecological or

governance processes (see Figure 2). Irrelevant studies, duplicates, or papers only peripherally mentioning páramos were excluded. A total of 52 sources were initially identified, of which 17 met the inclusion criteria. To broaden coverage, reference snowballing was applied (Jalali & Wohlin, 2012), whereby the bibliographies of these core publications were systematically reviewed to identify and include additional relevant studies not captured in the initial database search. This process yielded 22 further sources for analysis—for a total of 39 relevant scientific papers (35 peer-reviewed and 4 grey literature reports).

Each source was categorised according to DPSIR components (Folkens *et al.*, 2023; Kyere-Boateng & Marek; 2021; Maxim *et al.*, 2009). For example, drivers included economic growth, population expansion, climate change, and political agendas; pressures covered agriculture, mining, infrastructure development, and pollution; state captured hydrological, ecological, and land-cover conditions; impacts focused on ecosystem services disruption (e.g. water provision-regulation), biodiversity loss, and carbon balance; and responses encompassed legal frameworks, community initiatives, and market-based mechanisms such as payment for ecosystem services (Galvis *et al.*, 2018; Folkens *et al.*, 2023; Kyere-Boateng & Marek; 2021; Maxim *et al.*, 2009; Tscherning *et al.* 2012).

Climate change is categorised as a driver in this analysis, following established DPSIR applications at national and regional scales (Bruno *et al.*, 2020; Moss *et al.*, 2021) and is consistent with the IPBES global assessment, which ranks climate change as the third most significant driver of biodiversity change globally (IPBES, 2019). Whilst climate change is itself a consequence of global anthropogenic greenhouse gas emissions, at the scale of this study—focused on Colombia's páramo ecosystems—climate change functions as an external forcing factor that drives localised pressures (such as altered precipitation patterns, temperature increases, upslope displacement and glacial retreat) which in turn affect ecosystem state and generate impacts on biodiversity and ecosystem services. This framing is standard in national and regional DPSIR applications where the analytical boundary is drawn at the ecosystem or country level rather than globally.

Coding was performed manually and cross-checked against keyword occurrences to ensure consistency (see Table 1). In this context, coding refers to the systematic classification of textual information into analytical categories (i.e., DPSIR elements), allowing patterns and causal relationships across the literature to be identified, compared, and synthesised in a structured manner.

While the DPSIR framework structured the analysis, qualitative synthesis allowed for critical reflection on cross-scalar interactions (e.g., climate change amplifying socio-economic drivers), trade-offs (e.g., conservation vs. livelihoods), and governance tensions (e.g., conflicts over land rights) (Folkens *et al.*, 2023; Kyere-Boateng & Marek; 2021; Maxim *et al.*, 2009). This approach enabled not only a descriptive mapping of causal pathways but also an interpretative discussion of resilience and policy implications for safeguarding páramo ecosystems.

Table 1. Example of coding method applied to selected sources within the DPSIR framework

Reference	Drivers	Pressures	State	Impacts	Responses
Buytaert <i>et al.</i> (2011)	Climate change; population growth	Land conversion for agriculture and mining; water extraction	Altered hydrology	Declining water regulation; carbon loss	Restoration measures (suggested)
Burbano - Girón <i>et al.</i> (2020)	Policy change; socio-economic development	Agriculture; mining; infrastructure expansion	86% natural vegetation cover	Habitat fragmentation; biodiversity decline	Legal protection (Law 99/1993; Law 1930/2018)
Díazgranados <i>et al.</i> (2021)	Climate Change / Warming	Upslope species migration	Restricted elevational range	Risk to endemic species (<i>Espeletia</i>)	Monitoring recommendations

4. Results and Discussion

4.1 Drivers

Economic growth and population expansion in Colombia, driven by national and international market demands for diverse products—e.g. petroleum and coal exports, agricultural commodities (e.g. coffee, cut flowers, livestock, potatoes), manufactured goods, and services—have intensified land-use pressures on páramos alongside the accelerating impacts of climate change (Llambí *et al.*, 2020; Hofstede & Llambí, 2020). Climate change exacerbates socio-economic drivers by altering temperature and precipitation patterns, destabilising ecosystem function (Buytaert *et al.*, 2011; Cresso *et al.*, 2020; Díazgranados *et al.*, 2021; Hofstede & Llambí, 2020).

Warming in Colombian páramos has reached $+0.7^{\circ}\text{C}$ *warming-rate-per-decade* (Ruiz *et al.*, 2008), and 56% of Colombian páramos expect increased temperatures by 2050 (Ruiz *et al.*, 2008), exacerbating ecosystem service disruption (Buytaert *et al.*, 2011; Díazgranados *et al.*, 2021).

Beyond temperature shifts, climate change threatens páramos' hydrological and carbon-storage functions: increased evapotranspiration, declining soil moisture, and altered precipitation regimes destabilise water regulation, affecting downstream water provision (Buytaert *et al.*, 2011). Warming also accelerates soil organic matter decomposition, potentially shifting the páramo from a carbon-sink to a net-carbon-source, reinforcing global climate feedback loops (Buytaert *et al.*, 2011). Climate change-driven rising temperatures are also expected to cause upslope displacement of páramos, whereby warming forces species and vegetation zones to migrate towards higher, cooler elevations (Buytaert *et al.*, 2011; Cresso *et al.*, 2020; Díazgranados *et al.*, 2021; Tovar *et al.*, 2013).

Projections indicate an upward-shift in the lower boundary (Figure 3) (Tovar *et al.*, 2013). However, unlike most biomes, páramos' upper boundary (~5,000 m; green

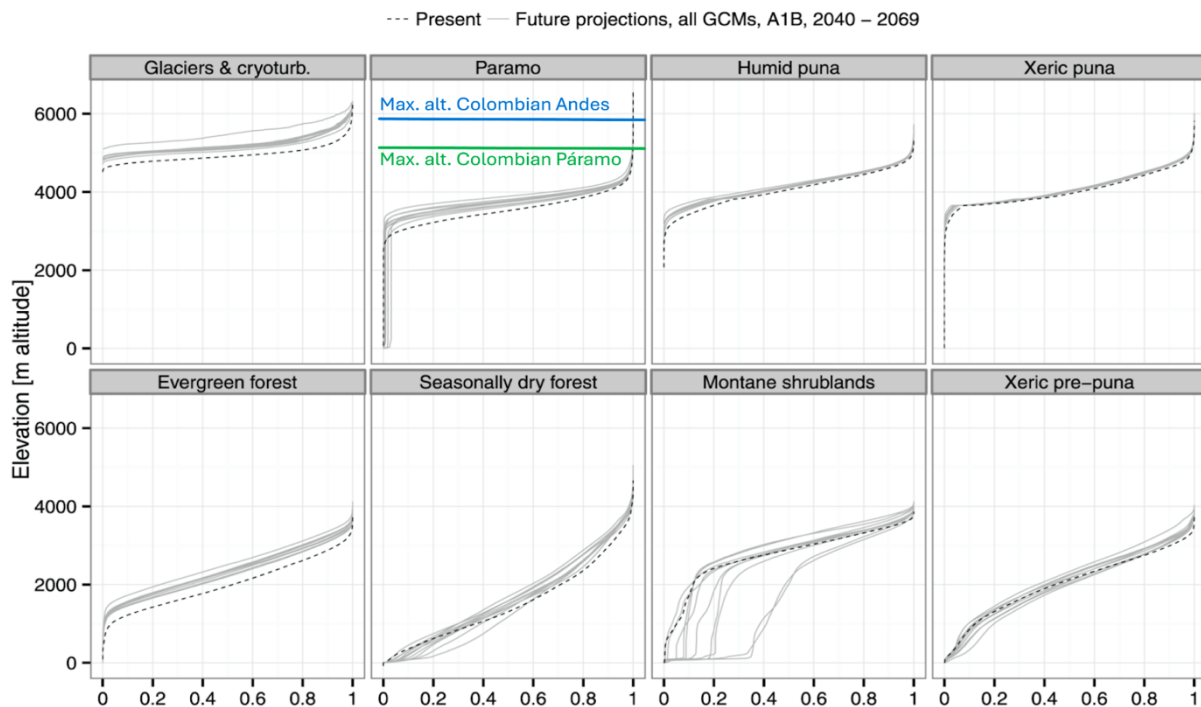


Figure 3. Elevation range shifts under mid-21st century climate projections (2040–2069). Glaciers, páramo, humid puna, and evergreen montane forest display upslope displacement of their lower boundaries, as shown by future projections (grey lines) relative to current distributions (dotted line). Colombian Páramo's upper limit (~5,000 m; green) and the maximum altitude of the Colombian Andes (~5,800 m; blue) are indicated. X-values are scaled 0–1 for comparability across landscapes. Adapted from Tovar *et al.* (2013).

line Figure 3) (Christmann & Oliveras, 2020) remains constrained by the Colombian Andean Mountain range (~5,800 m; blue line Figure 3), increasing the risk of *habitat compression* (Tovar *et al.*, 2013).

As an example, projections for Chingaza National Park—one of Colombia's most important páramos, supplying water to over 10 million people—indicate that by 2041–2060, climate change could render 39–52% of its páramo extent unsuitable during the dry season and 13–34% during the wet season (Cresso *et al.*, 2020). Figure 4 illustrates these projected shifts, comparing historical (1960–1990) and future (2041–2060) conditions under two Representative Concentration Pathways (RCPs), which depict greenhouse gas concentration trajectories: RCP 4.5 reflects a stabilisation pathway, while RCP 8.5 represents a high-emission scenario leading to stronger warming (Cresso *et al.*, 2020). Maps show dry (1, 3, 5) and wet (2, 4, 6) seasons, where green areas represent suitable conditions, dark grey indicates where temperature or precipitation thresholds are exceeded, and the red outline marks the current páramo extent (SIAC) (Cresso *et al.*, 2020).

These challenges are particularly acute for species with slow reproductive cycles—a common trait in this ecosystem—leaving them highly vulnerable to rapid climatic shifts (Diazgranados *et al.*, 2021). Climate change is accelerating upslope habitat migration in tropical mountain systems, yet keystone taxa such as *Espeletia*—already confined to the highest páramo zones—have not much higher ground to retreat to (Diazgranados *et al.*, 2021).

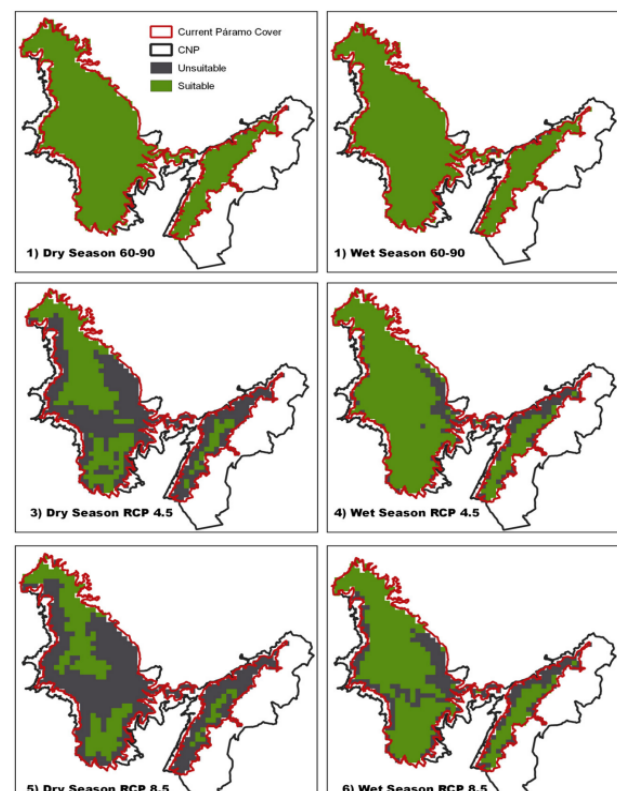


Figure 4. Potential páramo extent in Chingaza National Park under historical (1960–1990) and future (2041–2060) climate conditions. Maps show dry (1, 3, 5) and wet (2, 4, 6) seasons under RCP 4.5 and RCP 8.5 scenarios. Green areas represent suitable conditions; dark grey indicates where temperature (*T*) or precipitation (*P*) thresholds are exceeded. The red outline marks the current páramo extent (SIAC). Adapted from Cresso *et al.* (2020).

Table 2. Summary of the DPSIR Framework Applied to Colombia's Páramo Ecosystem: This table synthesises the key socio-economic drivers, resultant pressures, changes in ecosystem state, their impacts on ecosystem services, and societal responses in Colombia's páramos. It provides a structured overview of how anthropogenic activities influence ecological integrity and ecosystem services provision, supporting the critical analysis in this study. Icons are visual aids for identifying framework categories.

DPSIR Component	Description	Colombia's Páramo Case	Key References
Drivers 	Socio-economic and environmental factors. Policy and governance.	Economic expansion Population growth. Social change Political systems Climate change.	→ Buytaert <i>et al.</i> , 2011 → Cresso <i>et al.</i> , 2020 → Diazgranados <i>et al.</i> , 2021 → Hofstede & Llambí, 2020 → Tovar <i>et al.</i> , 2013
Pressures 	Direct human activities affecting the ecosystem	Land conversion for agriculture and mining Urban expansion Damming Pollution	→ Burbano-Girón <i>et al.</i> , 2020 → Buytaert <i>et al.</i> , 2011 → Leroy & García, 2021 → Vergara & De-Pellegrin, 2025
State 	Current ecological conditions resulting from anthropogenic pressures	Despite 86% <i>natural vegetation</i> cover, habitat loss is increasing Hydrological disruption threat	→ Burbano-Girón <i>et al.</i> , 2020 → Buytaert <i>et al.</i> , 2006, 2011 → Christmann & Oliveras, 2020 → Llambí <i>et al.</i> , 2020
Impact 	Consequences on ecosystem function, structure and ecosystem services (ES)	Declining Water regulation & provision ESs Reduced Carbon sequestration ES Habitat fragmentation/ Connectivity loss Biodiversity loss	→ Buytaert <i>et al.</i> , 2011 → Harden 2006 → Farley & Bremen 2017 → Suarez <i>et al.</i> , 2022
Responses 	Legal, community, and policy measures addressing degradation	→ Protected Areas —Legal protection (Law 99/1993; Law 1930/2018) → Participatory land-use planning → PES schemes → Restoration and monitoring programmes	→ Burbano-Girón <i>et al.</i> , 2020 → Farley & Bremen 2017 → Leroy & Barrasa García, 2021 → Llambí <i>et al.</i> , 2020 → Suarez <i>et al.</i> , 2022

Paleoecological evidence (e.g. pollen records) supports the research done on upslope displacement of páramos, indicating that páramos expanded downslope during glacial periods but contracted and fragmented at higher elevations in warmer interglacial periods (Groot *et al.*, 2011; Hooghiemstra *et al.*, 2006; Madriñán *et al.*, 2013; Vuilleumier, 1987; White 2013). The current anthropogenic warming trend mirrors this pattern, but at an accelerated rate, limiting páramos' ability to adapt (Buytaert *et al.*, 2011; Diazgranados *et al.*, 2021; Cresso *et al.*, 2020; Groot *et al.*, 2011; White 2013).

Beyond climatic factors, socio-political processes shape páramo dynamics. Approximately 45-51% of Colombia's páramos fall under National Protection, while legal indigenous territories and community-led initiatives promote sustainable land-use (Llambí *et al.*, 2020). However, competing land claims, agrarian development policies, and post-conflict interventions—including land restitution and illicit crop management—create a complex governance landscape that varies spatially across Colombia's páramos. These governance challenges are particularly acute in regions affected by armed conflict and the subsequent peace process, where overlapping territorial claims and weak institutional capacity influence how anthropogenic pressures unfold (Burbano-Girón *et al.*, 2020; Llambí *et al.*, 2020; Vergara & De-Pellegrin, 2025). Additionally, a lack of an integrated monitoring system challenges the effective assessment of páramos' land-use changes (Llambí *et al.*, 2020).

4.2 Pressures

Colombia's páramos face escalating pressures from land conversion for agriculture and mining, hydrological modifications, and pollution (Buytaert *et al.*, 2011; Llambí *et al.*, 2020). The pursuit of economic growth and ensuring food security relies on agricultural expansion, particularly potato, blueberry, and livestock farming, which increases environmental pressures. Associated activities drive deforestation, soil degradation, and habitat fragmentation, thereby weakening ecosystem resilience (Buytaert *et al.*, 2006). Although significant areas of agricultural land were re-designated as reserves—especially between 1976 and 1982 (Burbano-Girón *et al.*, 2020)—agriculture and grazing remain dominant land uses. This creates persistent conflicts between national conservation policies and the livelihood needs of rural communities (Leroy & García, 2021).

Land-use restrictions aimed at páramos' conservation often overlook local cultural ties to the landscape, exacerbating tensions (Leroy & García, 2021). Legal and illegal gold mining further degrades páramo soils and contaminates water sources with heavy metals (Buytaert *et al.*, 2011; Llambí *et al.*, 2020). Meanwhile, infrastructure development, including roads, urban expansion, dams and artificial reservoirs, disrupts ecosystem function and hydrological balance (Buytaert *et al.*, 2006, 2011; Burbano-Girón *et al.*, 2020).

Despite legal protections, >13–15% of páramos (449,500 ha) have been converted to pastures, crops, and

exotic plantations (Burbano-Girón *et al.*, 2020; Llambí *et al.*, 2020). Additionally, numerous mining concessions for carbon and gold extraction, influenced by fluctuating governing parties, fuel social conflicts (Llambí *et al.*, 2020).

Anthropogenic drivers exert mounting pressures on Colombia's páramos, reducing ecosystem services and causing habitat loss (Table 2).

4.3 State

The intrinsic state of Colombia's páramo, shaped by high specialisation, has evolved over millions of years (Christmann & Oliveras, 2020; Madriñán *et al.*, 2013). While water regulation is widely recognised as a key ecosystem service (Buytaert *et al.*, 2006), biodiversity is often undervalued by local communities (Leroy & García, 2021). Moreover, habitat fragmentation from mining, urban expansion, and agriculture disrupts biodiversity networks, weakening ecosystem resilience (Table 2) (Llambí *et al.*, 2020). Hydrological alterations from extraction and mining contamination disrupt water retention and downstream flow regulation (Buytaert *et al.*, 2006).

As shown in Figure 5, most Colombian páramos retain *natural vegetation*, but significant areas are transformed by

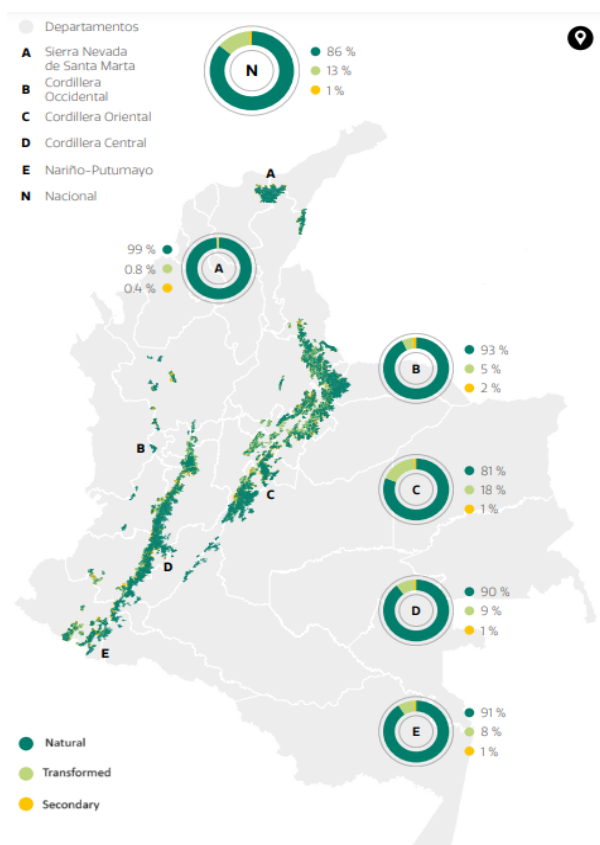


Figure 5. Natural, secondary, and transformed land cover of Colombian páramos. The figure illustrates the current state of land cover, showing areas with natural vegetation (dark green), secondary vegetation (light green), and transformed areas due to human activities such as agriculture and infrastructure (yellow). The extent of transformation reflects the pressures exerted on the ecosystem and its capacity to maintain ecological functions. Figure sourced from Burbano-Girón *et al.* (2020).

Vol. 1, 2026

human activities (Burbano-Girón *et al.*, 2020). These changes undermine key ecosystem services, including water retention, provision, and carbon sequestration: páramo's sponge-like soils and peatlands regulate water flow and store carbon, helping mitigate climate change (Buytaert *et al.*, 2011; Cresso *et al.*, 2020; Diazgranados *et al.*, 2021). However, ongoing land-use changes threaten these functions, reducing resilience (Sgrò *et al.*, 2010).

In a comparative analysis, we see that 86% of Colombia's páramos retain *natural vegetation* at a national level, (Figure 5) (Burbano-Girón *et al.*, 2020), a proportion matched *only* by the least disturbed global biomes (i.e. Tundra, Boreal forests/taiga) (Figure 6). In contrast, montane grasslands and shrublands—where páramos are classified (Olson *et al.*, 2001; Tovar *et al.*, 2013)—have far less intact vegetation globally, highlighting páramos' relative ecological integrity. However, increasing anthropogenic pressures threaten this state (Williams *et al.*, 2020). Recognising their strategic importance, Colombia has legally protected páramos since *Law 99 of 1993*, later reinforced by *Law 1930 of 2018* (Burbano-Girón *et al.*, 2020).

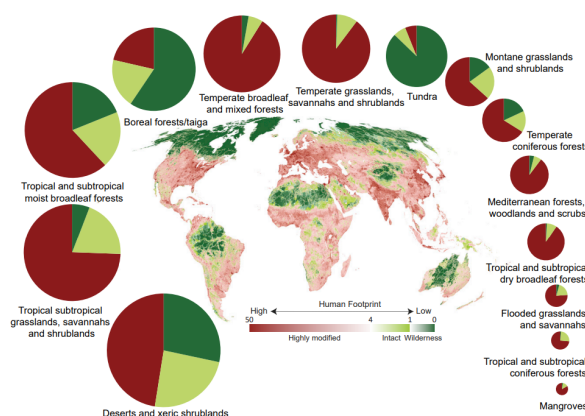


Figure 6. Global Human Footprint Map (2013) showing levels of human modification across biomes. Pie charts indicate wilderness (dark green), intact (light green), and highly modified (red) areas. While tundra and boreal forests remain largely intact, montane grasslands and shrublands—where páramos are classified—show greater modification. Adapted from Williams *et al.* (2020).

4.4 Impact

Grazing and burning of large extensions of Colombia's páramos began in the 1500s with European colonisation (Buytaert *et al.*, 2006; Harden, 2006), severely disrupting biodiversity, ecosystem service provision, and human well-being (Buytaert *et al.*, 2011; Burbano-Girón *et al.*, 2020). The loss of endemic species further weakens ecosystem resilience, making páramos increasingly vulnerable to change (Sgrò *et al.* 2010).

European-introduced livestock exert greater force-per-foot, compacting soils more than native camelids, reducing infiltration and moisture retention, with lasting hydrological impacts (Harden, 2006; White & Maldonado, 1991). Hydrological instability weakens water regulation services, disrupting biodiversity, agriculture, and water security for millions, with reduced availability potentially driving social conflicts, particularly in rural communities

DOI: 10.2218/hvdg7e20

reliant on páramo-fed rivers (Buytaert *et al.*, 2011; Farley & Bremen 2017; Harden 2006).

Climate-induced shifts further jeopardise water regulation—*already* affecting drinking water and hydroelectric resources (Buytaert *et al.*, 2011; Diazgranados *et al.*, 2021)—, while accelerated soil decomposition risks reduced carbon sequestration capability (Cresso *et al.*, 2020; Diazgranados *et al.*, 2021) and shifting páramos from carbon-sinks to net-emitters - amplifying global warming (Buytaert *et al.*, 2011). Unlike above-ground biomass, soil carbon loss is largely irreversible, heightening páramos vulnerability (Buytaert *et al.*, 2011).

The cumulative effects of these impacts (Table 2) endanger ecosystem integrity, socio-economic stability and ecosystem services provision. As shown in Figure 7, 51% of Colombia's páramos benefit from legal protection, while Figure 5 indicates that only 13% are transformed, reflecting *high conservation value* (Burbano-Girón *et al.*, 2020). However, large, unprotected areas remain vulnerable, threatening ecosystem health (Buytaert *et al.*, 2011).

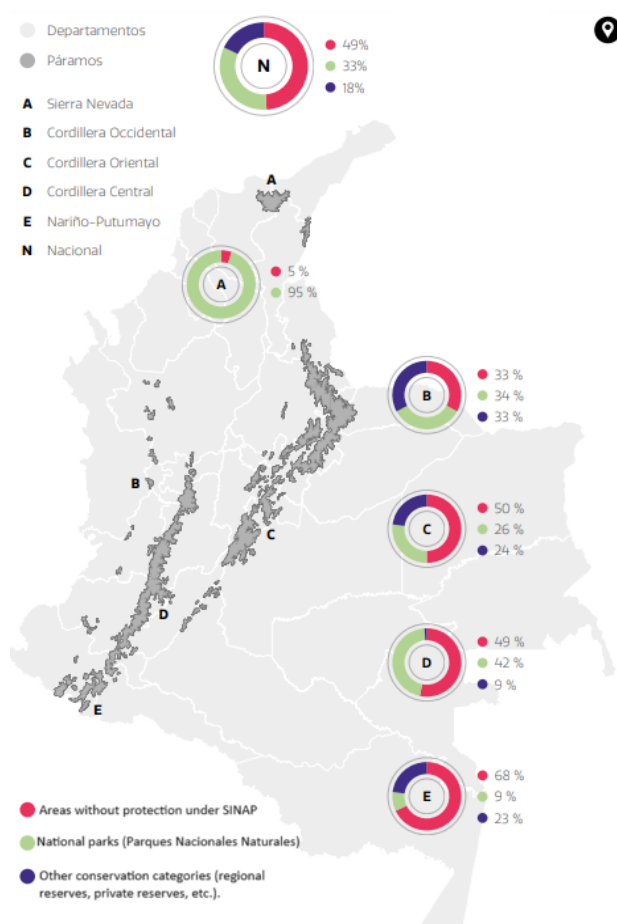


Figure 7. Proportion of conservation areas within Colombian páramos. The figure illustrates the extent of protection under three categories: areas without formal conservation status (fuchsia/pink), national parks (green), and other conservation categories (i.e. regional reserves, private reserves, etc.). (purple). Variability in protection coverage is evident across different páramo complexes, with some regions benefiting from extensive conservation measures while others remain largely unprotected. Data sourced from Burbano-Girón *et al.*, (2020).

4.5 Responses

Colombia's páramos benefit from substantial national and international conservation attention and responses to the degradation of Colombia's páramo ecosystem have emerged across legal, institutional, and community levels. At the national scale, legal frameworks such as Law 99 of 1993 and Law 1930 of 2018 established páramos as strategic ecosystems, prohibiting extractive activities and mandating sustainable land-use alternatives (Burbano-Girón *et al.*, 2020). Notably, 51% of Colombia's páramos are currently under some form of legal protection (Figure 7) and 86% retain natural vegetation cover (Figure 5), reflecting a comparatively high degree of conservation (Burbano-Girón *et al.*, 2020). While these laws signal political recognition of páramos' value, their enforcement remains inconsistent, often clashing with agricultural practices and local livelihoods. Beyond domestic legal frameworks, initiatives such as the GEF-funded 'Páramos for Life' project (implemented through Instituto Alexander von Humboldt), among others, demonstrate significant investment and institutional coordination. These efforts, alongside widespread environmental education programmes and public engagement, reflect the ecosystem's emblematic status within Colombia. The present DPSIR analysis, therefore, builds upon this existing foundation, providing a systematic framework for examining how conservation responses interact with the broader socio-ecological pressures affecting these landscapes.

In order to ensure long-term ecological resilience, effective planning and decision-making for páramo management must also recognise and integrate the participation of local and Indigenous communities, whose leadership and cultural and socio-economic ties to the ecosystem are essential for reconciling conservation goals with livelihood needs (Burbano-Girón *et al.*, 2020).

Participatory land-use planning within Indigenous 'resguardos' (Indigenous reserves) and community-led sustainable agriculture projects illustrate adaptive governance models that balance conservation with socio-cultural needs (Llambí *et al.*, 2020; Leroy & Barrasa Garcia, 2021). Payment for ecosystem services (PES) schemes, including water funds, offer incentivise sustainable management, linking upstream conservation with downstream beneficiaries (Galvis *et al.*, 2018; Farley & Bremer, 2017). Similarly, restoration projects in degraded peatlands and grasslands provide opportunities to recover carbon storage and hydrological regulation functions (Suarez *et al.*, 2022).

At a broader scale, integrated monitoring strategies exist (Burbano-Girón *et al.*, 2020) and emphasise the need to track biodiversity, land-use dynamics, and ecosystem services collectively (Llambí *et al.*, 2020). Strengthening such monitoring would support adaptive management by aligning policy goals with ecological outcomes. Overall, these responses demonstrate that safeguarding páramos requires not only protective legislation but also mechanisms that integrate community knowledge, economic incentives, and long-term ecological monitoring into decision-making.

5. Conclusion — integration of evidence and critical analysis

Applying the DPSIR framework reveals that the erosion of Colombia's páramo resilience is the outcome of tightly coupled socio-economic, political and climatic drivers acting through direct anthropogenic pressures. Economic expansion, food-security goals and demographic change have translated into intensified land-use pressures (notably agriculture and grazing), mining, and infrastructure development; simultaneously, rising temperatures and altered precipitation regimes exacerbate hydrological disruption and biological stress (Buytaert *et al.*, 2011; Llambí *et al.*, 2020). Their combined impact is already producing detectable changes in state—from altered soil moisture and peatland condition to fragmentation of habitat networks—with cascading impacts on water provision, carbon storage and endemic biodiversity (Burbano-Girón *et al.*, 2020; Cresso *et al.*, 2020; Diazgranados *et al.*, 2021).

Comparative analyses further highlight the páramo's singular value among global ecosystems, emphasising the urgency of conservation strategies that can strengthen its resilience to both anthropogenic pressures and climatic stressors (Sgrò *et al.*, 2010; Diazgranados *et al.*, 2021). Although a relatively high proportion of páramo area remains under natural cover and some 51% lies within formal protection instruments (Burbano-Girón *et al.*, 2020), legal protection does not equate to effective conservation on the ground. Enforcement gaps, competing land claims, and livelihood dependencies mean that legal measures (e.g. Law 99/1993; Law 1930/2018) must be complemented by inclusive governance and locally appropriate management to avoid maladaptive outcomes.

On this basis, four interlinked policy and management priorities emerge.

1. **Strengthen cross-scale governance and co-management.** Legal protection should be paired with co-management arrangements that legally recognise and integrate Indigenous and local authorities, thereby aligning conservation goals with livelihood needs and customary land uses (Burbano-Girón *et al.*, 2020; Llambí *et al.*, 2020).
2. **Integrate climate adaptation into land-use planning.** Spatial planning must incorporate climate-driven vulnerability (upslope habitat compression, shifting hydrological regimes) to prioritise protection and restoration of climate refugia and key water-source catchments (Tovar *et al.*, 2013; Cresso *et al.*, 2020).
3. **Scale restoration and ecosystem-service mechanisms.** Restoration of degraded peatlands and expansion of payment-for-ecosystem-service schemes and water funds should be targeted where they yield the greatest co-benefits for carbon storage and downstream water security (Farley & Bremer, 2017; Suarez *et al.*, 2022).
4. **Improve enforcement and adaptive monitoring.** Strengthened enforcement of extractive restrictions must be supported by a national, integrated monitoring framework that tracks ecological and socio-economic indicators (e.g.

vegetation cover, peat depth and carbon stocks, baseflow and water quality, species elevational ranges, and community well-being metrics) and triggers adaptive management responses (Llambí *et al.*, 2020).

Finally, the synthesis identifies *priority research needs* to reduce critical uncertainties and inform policy: **(a)** empirical quantification of páramo soil and peat carbon dynamics under warming and land-use change; **(b)** fine-scale hydrological modelling linking headwater condition to downstream water security; **(c)** spatially explicit vulnerability mapping that combines climatic, ecological and socio-economic layers; and **(d)** social-ecological studies on the effectiveness and equity outcomes of PES and co-management arrangements. Addressing these gaps will require interdisciplinary collaboration and long-term funding commitments.

In summary, safeguarding Colombia's páramos requires integrated, participatory strategies that combine legal protection, locally legitimate governance, targeted restoration, and a rigorous monitoring and research agenda. Aligning scientific evidence with socially responsive policy can strengthen the páramo's unique biodiversity, and therefore, its critical regulating services can be maintained in the face of accelerating anthropogenic and climatic pressures (Buytaert *et al.*, 2011; Williams *et al.*, 2020).

Acknowledgements

I thank Dr Ellie Devenish-Nelson (Co-Director, Programme of Biodiversity, Wildlife and Ecosystem Health; course instructor, Ecosystem Health and Sustainability) for her critical feedback and teachings on the DPSIR framework and its application to this publication. I also thank Dr Flora Rendell-Bhatti for guidance on studying ecosystem resilience, environmental ethics, and governance: essential subjects for developing this publication. The foundational research of the Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Parques Nacionales Naturales de Colombia, and local conservation authorities are foundational for this synthesis. This work was completed thanks to the Biodiversity, Wildlife and Ecosystem Health Programme, teaching staff and tutors at The University of Edinburgh, and builds on the knowledge and stewardship of Indigenous communities, local communities, and conservation practitioners protecting Colombian páramo ecosystems.

Funding

AVI USA provided partial financial sponsorship support for the author's studies in the MSc Biodiversity, Wildlife and Ecosystem Health programme at The University of Edinburgh.

Ethical statement

This study synthesises published literature on Colombian páramo ecosystems within a complex sociopolitical context involving land rights, livelihood dependencies, and conservation governance. All sources are cited according to best practice, and findings are presented to support informed, participatory approaches to páramo management that recognise local and Indigenous knowledge systems

References

- Bruno, M.F., Saponieri, A., Molfetta, M.G. and Damiani, L., (2020). The DPSIR approach for coastal risk assessment under climate change at regional scale: The case of apulian coast (Italy). *Journal of Marine Science and Engineering*, 8(7), p.531. <https://doi.org/10.3390/jmse8070531>
- Burbano-Girón, J., Molina Berbeo, M. A., Gutiérrez Montoya, C & Ochoa-Quintero, J. M. (2020). Estado de conservación de los páramos en Colombia. En: Moreno, L. A., Andrade, G. I., Didier, G & Hernández-Manrique, O.L. (Eds.). Biodiversidad 2020. Estado y tendencias de la biodiversidad continental de Colombia. Bogotá, D. C., Colombia: *Instituto de Investigación de Recursos Biológicos Alexander von Humboldt*. 112p. Available at: <https://reporte.humboldt.org.co/biodiversidad/2020/cap1/101/#seccion2>
- Buytaert, W., Celleri, R., De Bievre, B., Hofstede, R., Cisneros, F., Wyseure, G., & Deckers, J. (2006). Human impact on the hydrology of the Andean paramos. *Earth-Science Reviews*, 79(1-2), 53-72. <https://doi.org/10.1016/j.earscirev.2006.06.002>
- Buytaert, W., Cuesta-Camacho, F., & Tobón, C. (2011). Potential impacts of climate change on the environmental services of humid tropical alpine regions. *Global Ecology and Biogeography*, 20(1), 19-33. <https://doi.org/10.1111/j.1466-8238.2010.00585.x>
- Christmann, T., & Oliveras, I. (2020). Nature of alpine ecosystems in tropical mountains of South America. In *M. I. Goldstein & D. A. DellaSala (Eds.), Encyclopedia of the world's biomes* (pp. 282-291). Elsevier. <https://doi.org/10.1016/B978-0-12-409548-9.12481-9>
- Cresso, M., Clerici, N., Sanchez, A., & Jaramillo, F. (2020). Future climate change renders unsuitable conditions for paramo ecosystems in Colombia. *Sustainability*, 12(20), 8373. <https://doi.org/10.3390/su12208373>
- García et al. (2019). Unveiling dimensions of stability in complex ecological networks. <https://doi.org/10.3390/su12208373>
- Diazgranados, M., Tovar, C., Etherington, T.R., Rodríguez-Zorro, P.A., Castellanos-Castro, C., Rueda, M.G. and Flantua, S.G., (2021). Ecosystem services show variable responses to future climate conditions in the Colombian páramos. *PeerJ*, 9, p.e11370. <https://doi.org/10.7717/peerj.11370>
- Farley, K.A. and Bremer, L.L., (2017). "Water is life": Local perceptions of Páramo grasslands and land management strategies associated with payment for ecosystem services. *Annals of the American Association of Geographers*, 107(2), pp.371-381. <https://www.jstor.org/stable/45387906>
- Farley, K. A., L. L. Bremer, C. P. Harden, and J. Hartsig. (2013). Changes in carbon storage under alternative land uses in páramo grasslands: Implications for payment for ecosystem services. *Conservation Letters* 6:21–27. <https://doi.org/10.1111/j.1755-263X.2012.00267.x>
- Folkens, L., Bachmann, D. and Schneider, P., (2023). Driving forces and socio-economic impacts of low-flow events in Central Europe: A literature review using DPSIR criteria. *Sustainability*, 15(13), p.10692. <https://doi.org/10.3390/su151310692>
- Galvis Hernández, M., Trujillo Becerra, M.M., Sosa Botero, C., Avella Rodríguez, L.C. y J.P Romero Rodríguez. (2018). Estrategias de financiación para la gestión del páramo. En Moreno, L. A, Andrade, G. I. y Gómez, M.F. (Eds.). (2019). Biodiversidad 2018. Estado y tendencias de la biodiversidad continental de Colombia. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt. Bogotá, D. C., Colombia. <https://reporte.humboldt.org.co/biodiversidad/2018/cap4/406/#seccion9>
- Groot, M.H.M., Bogotá, R.G., Lourens, L.J., Hooghiemstra, H., Vriend, M., Berrio, J.C., Tuentler, E., Van der Plicht, J., Van Geel, B., Ziegler, M. and Weber, S.L., (2011). Ultra-high resolution pollen record from the northern Andes reveals rapid shifts in montane climates within the last two glacial cycles. *Climate of the Past*, 7(1), pp.299-316. <https://doi.org/10.5194/cp-7-299-2011>
- Harden, C. P. (2006). Human impacts on headwater fluvial systems in the northern and central Andes. *Geomorphology* 79:249–63. <https://doi.org/10.1016/j.geomorph.2006.06.021>
- Hofstede, R. G. M., & Llambí, L. D. (2020). Plant diversity in páramo—Neotropical high mountain humid grasslands. In *M. I. Goldstein & D. A. DellaSala (Eds.), Encyclopedia of the world's biomes* (pp. 362-372). Elsevier. <https://doi.org/10.1016/B978-0-12-409548-9.12481-9>
- Hooghiemstra, H., Wijninga, V.M. and Cleef, A.M., 2006. The paleobotanical record of Colombia: implications for biogeography and Biodiversity1. *Annals of the Missouri Botanical Garden*, 93(2), pp.297-325. [https://doi.org/10.3417/0026-6493\(2006\)93\[297:TPROCI\]2.0.CO;2](https://doi.org/10.3417/0026-6493(2006)93[297:TPROCI]2.0.CO;2)
- IPBES (2019) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://files.ipbes.net/ipbes-web-prod-public-files/inline/files/ipbes_global_assessment_report_summary_for_policymakers.pdf
- Jalali, S. and Wohlin, C., 2012, September. Systematic literature studies: database searches vs. backward snowballing. In Proceedings of the ACM-IEEE international symposium on Empirical software engineering and measurement (pp. 29-38). <https://doi.org/10.1145/2372251.2372257>
- Kyere-Boateng, R. and Marek, M.V., (2021). Analysis of the social-ecological causes of deforestation and forest degradation in Ghana: Application of the DPSIR framework. *Forests*, 12(4), p.409. <https://doi.org/10.3390/f12040409>
- Leroy, D. and Barrasa Garcia, S., (2021). Which ecosystem services are really integrated into local culture? Farmers' perceptions of the Colombian and Venezuelan páramos. *Human Ecology*, 49(4), pp.385-401. <https://doi.org/10.1007/s10745-021-00251-y>
- Llambí, L.D., Becerra, M.T., Peralvo, M., Avella, A., Baruffol, M. and Díaz, L.J., (2019). Monitoring biodiversity and ecosystem services in Colombia's high andean ecosystems: toward an integrated strategy. *Mountain Research and Development*, 39(3), p.A8. <https://doi.org/10.1659/MRD-JOURNAL-D-19-00020.1>

- Madriñán, S., Cortés, A. J., & Richardson, J. E. (2013). Páramo is the world's fastest evolving and coolest biodiversity hotspot. *Frontiers in Genetics*, 4, 192. <https://doi.org/10.3389/fgene.2013.00192>
- Maxim, L., Spangenberg, J.H. and O'Connor, M., (2009). An analysis of risks for biodiversity under the DPSIR framework. *Ecological economics*, 69(1), pp.12-23. <https://doi.org/10.1016/j.ecolecon.2009.03.017>
- Molina, R.A., Campos, R., Sánchez, H., Giraldo, L. and Atzori, A.S., (2019). Sustainable feedbacks of colombian paramos involving livestock, agricultural activities, and sustainable development goals of the agenda 2030. *Systems*, 7(4), p.52. <https://doi.org/10.3390/systems7040052>
- Moss, E.D., Evans, D.M. and Atkins, J.P., (2021). Investigating the impacts of climate change on ecosystem services in UK agro-ecosystems: An application of the DPSIR framework. *Land Use Policy*, 105, p.105394. https://hull-repository.worktribe.com/preview/3763553/MossEvansAtkins_LUP_Mar2021.pdf
- Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GVN, *et al.* (2001) Terrestrial Ecoregions of the World: A New Map of Life on Earth. *Bioscience* 51: 933–938. [https://doi.org/10.1641/0006-3568\(2001\)051\[0933:TEOTWA\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2)
- Ostrom, E., (2011). The challenges of achieving conservation and development. *The Annual Proceedings of the Wealth and Well-Being of Nations*, 4. <https://ssrn.com/abstract=2176268>
- Rangel, C., Orlando, J. (2018). El páramo colombiano: aspectos macroecológicos y ecológicos. In *Rangel-Ch., J. O. (Ed.), Colombia Biodiversidad Biótica XVI. Patrones de riqueza y diversidad de las plantas con flores en el bioma de páramo* (pp. 83-141). Universidad Nacional de Colombia - Instituto de Ciencias Naturales. Bogotá. Recovered from: <https://repositorio.unal.edu.co/handle/unal/81486>
- Ruiz, D., Moreno, H.A., Gutiérrez, M.E. and Zapata, P.A., (2008). Changing climate and endangered high mountain ecosystems in Colombia. *Science of the total environment*, 398(1-3), pp.122-132. <https://doi.org/10.1016/j.scitotenv.2008.02.038>
- Sarmiento, F. O. (2000). Breaking mountain paradigms: Ecological effects on human impacts in managed tropandean landscapes. *Ambio*, 29(7), 423-431. <https://doi.org/10.1579/0044-7447-29.7.423>
- Sarmiento, C.; Cadena, C.; Sarmiento, M.; Zapata, J. (2013). Aportes a la Conservación Estratégica de los Páramos de Colombia: Actualización de la Cartografía de los Complejos de Páramo a Escala 1:100.000; *Instituto de Investigación de Recursos Biológicos Alexander von Humboldt: Bogotá, Colombia*. https://www.researchgate.net/publication/296706263_Aportes_a_la_conservacion_estrategica_de_los_paramos_de_Colombia_Actualizacion_de_la_cartografia_de_los_complejos_de_paramo_a_escala_1100000
- Schirpke, U., Tasser, E., Borsky, S., Braun, M., Eitzinger, J., Gaube, V., Getzner, M., Glatzel, S., Gschwantner, T., Kirchner, M. and Leitinger, G., (2023). Past and future impacts of land-use changes on ecosystem services in Austria. *Journal of Environmental Management*, 345, p.118728. <https://doi.org/10.1016/j.jenvman.2023.118728>
- Sgrò, Lowe, & Hoffmann. (2010). Building evolutionary resilience for conserving biodiversity under climate change. *Evolutionary Applications*, 4, 326-337. <https://doi.org/10.1111/j.1752-4571.2010.00157.x>
- Sklenář, P., Hedberg, I. and Cleef, A.M. (2014), Island biogeography of tropical alpine floras. *J. Biogeogr.*, 41: 287-297. <https://doi.org/10.1111/jbi.12212>
- Suarez, E., Chimbolema, S., Jaramillo, R., *et al.* (2022). Challenges and opportunities for restoration of high-elevation Andean peatlands in Ecuador. *Mitigation and Adaptation Strategies for Global Change*, 27, 30. <https://doi.org/10.1007/s11027-022-10006-9>
- Tovar, C., Arnillas, C.A., Cuesta, F. and Buytaert, W., (2013). Diverging responses of tropical Andean biomes under future climate conditions. *PloS one*, 8(5), p.e63634. <https://doi.org/10.1371/journal.pone.0063634>
- Tscherning, K., Helming, K., Krippner, B., Sieber, S. and y Paloma, S.G., (2012). Does research applying the DPSIR framework support decision making?. *Land use policy*, 29(1), pp.102-110. <https://doi.org/10.1016/j.landusepol.2011.05.009>
- Vargas, O.M., Madriñán, S. and Simpson, B., (2023). Allopatric speciation is more prevalent than parapatric ecological divergence in a recent high-Andean diversification (*Linochilus*: Asteraceae). *PeerJ*, 11, p.e15479. <https://doi.org/10.7717/peerj.15479>
- Vergara Buitrago, P. and De Pellegrin Llorente, I., (2025). A systematic review of ecosystem services in the Rabanal páramo (Colombia). *Integrated Environmental Assessment and Management*, p.vjae029. <https://doi.org/10.1093/inteam/vjae029>
- Vuilleumier, F. (1987). 13. The Origin of High Andean Birds. In: Eldredge, N. ed. *The Natural History Reader in Evolution*. New York Chichester, West Sussex: Columbia University Press, pp. 108-116. <https://doi.org/10.7312/eldr92092-019>
- White, S. (2013). Grass páramo as hunter-gatherer landscape. *The Holocene* 23:898–915. <https://doi.org/10.1177/0959683612471987>
- White, S. and Maldonado, F., 1991. The use and conservation of natural resources in the Andes of southern Ecuador. *Mountain Research and Development*, pp.37-55. <https://doi.org/10.2307/3673526>
- Williams, B.A., Venter, O., Allan, J.R., Atkinson, S.C., Rehbein, J.A., Ward, M., Di Marco, M., Grantham, H.S., Ervin, J., Goetz, S.J. and Hansen, A.J., (2020). Change in terrestrial human footprint drives continued loss of intact ecosystems. *One Earth*, 3(3), pp.371-382. <https://doi.org/10.1016/j.oneear.2020.08.009>

Untangling Wildlife Law and Enforcement in Pakistan: From Crime to Reform

Fiza Adil¹, Muhammad Razi²

¹ Institute of Zoology, University of the Punjab, Lahore, Pakistan

² District Bar Association, Sialkot, Pakistan

Email:

fizaadil74@gmail.com

Received: July 2025

Accepted for publication: January 2026

Published: July 2026

Abstract

Pakistan's wildlife laws have undergone notable evolution since colonial times, transitioning into a fragmented, provincially governed framework. While the country has enacted several federal and provincial statutes to regulate wildlife conservation, prevent illegal hunting, and control wildlife trade, enforcement remains weak and inconsistent. It is often undermined by legal loopholes, institutional incapacity, and socioeconomic privilege. This review examines key legal provisions governing wildlife protection in Pakistan, identifies enforcement challenges, and evaluates key and recent judicial interventions that have played a corrective role where administrative systems have failed. Drawing from recent precedents and conservation initiatives, the paper highlights critical gaps in legal architecture and compliance with international obligations under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and Convention on Migratory Species (CMS). Furthermore, the review underscores systemic issues such as overlapping species listings, outdated penalty structures, weak protected area management, private wildlife keeping, and the persistence of wildlife-related crimes. Additionally, while the judiciary has intervened in several landmark cases to uphold conservation principles and constitutional protections, these efforts remain reactive rather than preventive. It concludes by emphasising the need for harmonised legal reform, institutional strengthening, and transparent enforcement to secure long-term biodiversity protection in Pakistan.

Keywords: Wildlife crime, law enforcement, Pakistan, legislation, case laws

1. Introduction

The term *wildlife* encompasses all untamed living beings, regardless of size or origin, including animals, birds, insects, plants, fungi, and even microscopic organisms (Bandeira and Fonseca, 2020; Preece and Chamberlain, 1993). Many of these species are overlooked and threatened with extinction due to poor planning and lack of coordination among state agencies. Conservation systems are being undermined by accelerating habitat loss resulting from anthropogenic activities like land-use change and agricultural expansion (Goudie, 2018; Yang *et al.*, 2024; Yuan *et al.*, 2024). Albert Einstein called human indifference toward animals both morally wrong and spiritually damaging. Most world religions, including Islam, clearly prohibit cruelty to animals and only permit their killing for food (Rahman, 2017).

Pakistan hosts rich biodiversity supported by varied ecological habitats and environmental conditions (Khan *et al.*, 2023). It spans three of the world's six biogeographic realms and four major biomes, from arid deserts to alpine forests, each sustaining distinct species shaped by the country's diverse topography and climatic zones (Baig and Ahmed, 2007). Its wildlife includes 198 mammal species, 700 birds, 177 reptiles, 22 amphibians, 198 freshwater fish, and around 5,000 invertebrate species (Pakistan National Report, 2019). Despite low endemism (5% plants, 0% birds, 4% mammals, and 11% fish) Pakistan's biodiversity remains unique and rich (key examples in table 1), shaped by a mix of ecological regions and species origins (Khan *et al.*, 2022). Owing to this richness, Pakistan appears to face heightened exposure to wildlife related crimes (WWF-Pakistan, 2019).

Table 1. Key Species of Pakistan (Source: IUCN Red List via www.iucnredlist.org/).

Species Name	IUCN Status (Global)	Population Trend (Global)	Protected under National Laws/Acts?	CITES Listing	Threats
Indus river dolphin (<i>Platanista minor</i>)	Endangered (EN)	Increasing	Fully protected	Appendix I	Biological resource use, habitat modification, pollution
Balochistan/ Asian black bear (<i>Ursus thibetanus</i>)	Vulnerable (VU)	Decreasing	Fully protected	Appendix I	Habitat loss, direct killing, poaching, trade, bear-baiting
Snow leopard (<i>Panthera uncia</i>)	Vulnerable (VU)	Decreasing	Fully protected	Appendix I	Habitat alteration, hunting, trapping, conflict with local people
Common leopard (<i>Panthera pardus</i>)	Vulnerable (VU)	Decreasing	Fully protected	Appendix I	Habitat fragmentation, illegal poaching and trade, conflict with farmers, trophy hunting
Brown bear (<i>Ursus arctos</i>)	Least Concern (LC)	Stable	Fully protected	Appendix II	Habitat alteration, hunting, bear-baiting, pollution
Indian pangolin (<i>Manis crassicaudata</i>)	Endangered (EN)	Decreasing	Fully protected	Appendix I	Hunting, poaching, illegal trade
Punjab urial (<i>Ovis vignei punjabiensis</i>)	Vulnerable (VU)	Decreasing	Protected (regulated trophy hunting)	Appendix I	Habitat alteration, poaching
Markhor (<i>Capra falconeri</i>)	Near Threatened (NT)	Increasing	Protected (regulated trophy hunting)	Appendix I	Illegal hunting, poaching, habitat loss, diseases
Woolly flying squirrel (<i>Eupetaurus cinereus</i>)	Endangered (EN)	Decreasing	Not mentioned specifically	No CITES legislation found	Habitat loss, trade

Wildlife crime refers to violations of laws protecting wild animals and plants. Such activities inflict harm on individual species and drive populations toward extinction, and are also often interconnected with broader criminal networks (Haq *et al.*, 2023). Some prominent types of wildlife-related crimes in Pakistan are illegal hunting and poaching (Ahmad *et al.*, 2022; Amin *et al.*, 2024), bear-baiting (Ahmad *et al.*, 2025), habitat loss (Business Recorder, 2022; WWF, 2022), poor management of protected areas and wildlife facilities (Ilyas, 2018a; Khan *et al.*, 2022), private keeping of wild animals and cruelty towards them (Usman *et al.*, 2022) etc. These issues can be attributed to inadequate funding, weak law enforcement, and human-wildlife conflict, compounded by socioeconomic conditions, and a general lack of public seriousness toward wildlife-related offences

(Ilyas and Qazilbash, 2021; Khan *et al.*, 2025a; Rashind, 2024).

Each province has its own wildlife laws, while a single federal law governs trade and the implementation of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 1973). However, the core goals of wildlife protection and welfare remain unmet. According to the World Animal Protection Index, which grades countries from A (best) to G (worst), Pakistan received low scores across several categories, including “G” for animals used in farming, “E” for animals in captivity, “D” for the welfare of wild animals, and “F” for government accountability (Koreshi, 2020; World Animal Protection, 2020). While the amendment of the *Sindh Wildlife Protection, Preservation, Conservation*

and Management Act 2020 and several recent court decisions mark positive progress, they remain modest compared to the scale and complexity of wildlife crime in the country. Strengthening enforcement and legal reform will require far more sustained effort to match the pace of these challenges. Since the 18th Amendment, no comprehensive review has pulled together the fragmented pieces of Pakistan's wildlife laws. With illegal trade, habitat loss, and weak enforcement continuing to grow, this study set out to close that gap and take stock of recent legal and institutional changes.

Using a narrative, desk-based approach, the review examines where Pakistan's current wildlife laws and enforcement efforts stand, their strengths, their gaps, and the areas most in need of reform. Sources were drawn from peer-reviewed research, legal databases, case records, and reliable news reports published between 2018 and 2025. Each was chosen for its relevance to wildlife law, governance, enforcement issues, or policy developments.

The review's goal is (i) to assess how well existing laws are working, (ii) to highlight persistent governance and enforcement weaknesses, and (iii) to suggest reforms that can bring national efforts closer in line with global conservation standards and strengthen wildlife protection across the country.

2. Legal Provisions of Wildlife Protection in Pakistan

Pakistan's wildlife protection system has gradually evolved from colonial-era regulations into a fragmented framework shaped by post-devolution governance (Usman *et al.*, 2022). Today, the responsibility for wildlife conservation lies mainly with the provinces, while the federal Ministry of Climate Change oversees policy direction and ensures compliance with international agreements. The key federal legislation, the *Pakistan Trade Control of Wild Fauna and Flora Act 2012*, was introduced to implement CITES and related international obligations (Khan, 2021). At the provincial level, wildlife is managed through separate laws and corresponding rules unique to each region (see table 2). These laws mainly address two areas: habitat protection through the creation of protected areas, and regulation of hunting and commercial exploitation. Species are categorized under different Schedules that define their legal status, ranging from those that may be hunted under special permits, to species allowed for possession or export with certification, and those fully protected under a complete ban on hunting and trade (Khan *et al.*, 2025b; Rashind, 2024).

The *Pakistan Penal Code* defines animals as all non-human living beings and prohibits acts harmful to them. Under Section 289, neglecting the care of an animal in one's possession, if it endangers human life or causes serious harm, can lead to imprisonment for up to six months (Pakistan Penal Code, 1860). While this provision

indirectly safeguards animals, it primarily addresses risks to humans. Similarly, the *Prevention of Cruelty to Animals Act 1890*, introduced by the British during colonial rule, provides the earliest legal basis for animal welfare. It criminalises abuse, including beating, cruel killing, neglect, starvation, and animal fighting. While it also addresses illegal hunting of endangered species, it excludes free-ranging wild animals from protection, and violations remain widespread across Pakistan. Similarly, *The Northern Areas Wildlife Preservation Act 1975* restricts private ownership of wild animals, permitting exceptions only for scientific research or accredited zoological institutions. However, enforcement remains inconsistent, and illegal possession persists (Koreshe, 2020). Collectively, these provisions reflect Pakistan's gradual shift from colonial-era animal welfare concepts to a fragmented framework that still lacks modern wildlife protection standards.

In 2020, the Sindh government introduced a revised wildlife law with stricter penalties, broader species protection (including migratory wildlife), and provisions for First Information Report (FIR) registration and dedicated wildlife police stations. The law also criminalises the online and black-market trade of wild animals and promotes anonymous reporting. These measures led to 411 registered cases and the rescue of 25,000 animals in the same year (*Sindh Wildlife (Protection, Preservation, Conservation and Management) Act, 2020*). While it marks progress, effective implementation remains a challenge.

3. Key Enforcement Issues

3.1 Legal inadequacies and loopholes

Historically, Pakistan's wildlife legislation has imposed relatively lenient penalties for wildlife related offences, reflecting low legal threshold for deterrence. While Sections 289, 377, and 428 of the *Pakistan Penal Code, Act XLV of 1860* criminalizes animal cruelty and negligent behaviour, the prescribed fines remain nominal (typically not exceeding PKR 3,000 i.e. $\approx$ USD 10.70). The *Prevention of Cruelty to Animals Act (PCA Act) 1890* sets an even lower penalty, with maximum fine capped at just Rs. 500 ($\approx$ USD 2). Moreover, penalty provisions are inconsistent across provinces (see table 2).

The categorization of species under provincial wildlife laws remains inconsistent, leading to confusion and enforcement challenges. For example, the *Balochistan Wildlife (Protection, Preservation, Conservation and Management) Act, 2014* lists certain species simultaneously as protected and game animals, which reflects internal contradictions within the legislation. In contrast, the *Sindh Wildlife (Protection, Preservation, Conservation and Management) Act, 2020* represents a more progressive reform, introducing stricter penalties, expanding the list of protected species, and establishing dedicated wildlife police stations. Despite such improvements, most provincial frameworks still fail to criminalize animal cruelty and baiting explicitly, relying instead on the outdated *Prevention of Cruelty to Animals*

Table 2. *Wildlife-related National and Provincial Laws/Acts in Pakistan. (U.S = Under Section)*

Law/Act	Jurisdiction	Scope	Max. Penalties	Implementation Body
Pakistan Trade Control of Wild Fauna and Flora Act (CITES Law) 2012	Extends to All over Pakistan. Regulated under Federal Government.	Fauna & Flora	U.S 3: 1yr to 2yrs imprisonment OR with fine 0.500 million Rupees to 1 million Rupees	Management Authority (Ministry of Climate Change & Environmental Coordination in collaboration with Provincial/ Territorial Wildlife Departments & Pakistan Customs). Triable by: Senior Civil Judge in Islamabad having Special Powers to try offences under this law only on written complaint made by the duly authorised officer + Environmental Protection Tribunal.
Prevention of Cruelty to Animals Act of 1890 (PCA Act)	Extends to whole Pakistan. Regulated under Provincial Government.	Fauna	U.S 4: Fine which extends to 500 Rupees or with 2yrs imprisonment.	Police (Investigating Authority) & Magisterial Court (For Inquiry & Trial) on information and on application is authoritative for the implementation of the Act.
Northern Areas(Gilgit-Baltistan) Wildlife Preservation Act 1975	Extends to the whole of the Northern Areas. Regulated under Provincial Government.	Fauna	U.S 34[1(i)]: Fine which extends to 2000 Rupees or 2yrs Imprisonment or both with the cancellation of any license or permit held under this Act and recovery of shooting fee for the game specified in this Act.	Department: Forest, Wildlife & Environment Department of Government of Gilgit-Baltistan. Investigating Authority: Police/Officer Appointed by Provincial Government Triable by: Magisterial Court (Not less than 1 st Class) /Civil Court (For Inquiry & Trial) to take cognizance only on written application/ complaint from the relevant Authority.
Islamabad Wildlife (Protection, Preservation, Conservation and Management) Ordinance 1979	Extends the Islamabad Capital Territory. Regulated under Federal Government.	Fauna	U.S 26(1): Fine (Rs. 2,000) or imprisonment (max. 1 year).	Department: Islamabad Board of Wildlife Management. Investigating Authority: An Authorised Officer of grade 17 or above in collaboration with nearest Police Station. Triable by: Magistrate of First Class appointed by Federal Government.
Punjab Wildlife (Protection, Preservation, Conservation and Management) (Amendment) Act, 2007	Extends to the whole territory of Punjab. Regulated under Provincial Government.	Fauna	U.S 21(ii): Fine (Rs. 20,000-30,000/-) or imprisonment (1-5 yrs) along with confiscation of the weapon and suspension of license or permit for a period of 5 years.	Department: Punjab Wildlife Management Board. Investigating Authority: An Authorised Officer in collaboration with Police Officials. Triable by: Magistrate of First Class appointed by Provincial Government

Table 2 continued on next page

Table 2. *Wildlife-related National and Provincial Laws/Acts in Pakistan. (U.S = Under Section)*

Law/Act	Jurisdiction	Scope	Max. Penalties	Implementation Body
Baluchistan Wildlife (Protection, Preservation, Conservation and Management) Act, 2014.	Extends to the whole of Baluchistan except Tribal Areas and regulated under Provincial Government.	Fauna	U.S 52 (According to V Schedule): Imprisonment up to 10 years but not less than 5 years and fine which may extend up to Rs. 1,000,000/-.	Department: Baluchistan Council for Conservation of Wildlife. Investigating Authority: Authorised Officer with assistance of Police/Security Agency. Triable by: No Court Inferior than Judicial Magistrate of 1 st Class shall take cognizance on written complaint by the Authorised Officer.
Khyber Pakhtunkhwa Wildlife and Biodiversity (Protection, Preservation, Conservation and Management) Act, 2015	Extending the whole of the Province of the Khyber Pakhtunkhwa & regulated under Provincial Government.	Fauna	U.S 68(1) (According to 4 th Schedule): Fine (Rs. 45,000/-) or imprisonment (3 yrs) along with confiscation of the weapon and suspension of license or permit for a period of two years.	Investigating Authority: Wildlife Force along with KPK Wildlife & Biodiversity Board in collaboration with Nearest Police Station. Triable By: No court inferior than Judicial Magistrate of First Class.
Azad Jammu and Kashmir Wildlife (Protection, Preservation, Conservation and Management) Act, 2014	Extends to whole of the Azad Jammu and Kashmir regulated under AJ&K Government.	Fauna	Fine: Rs. 10,000/- to 30,000/- or with imprisonment of 6 months to 1 yr [U. Sections: 15(2), 16(2), 18(v), 19(2), 21(2), 41(2), 44(7) & 52(2)]	Authoritative Departments: Wildlife and Fisheries Department along with Wildlife Management Advisory Board & Executive Committee with assistance of Police Department. Triable by: No court inferior to a Civil Judge or Judicial Magistrate of First Class & District Magistrate or any Magistrate of the first Class specially empowered in this behalf by the government may try summarily under the Code of Criminal Procedure 1898.
Sindh Wildlife (Protection, Preservation, Conservation and Management) Act, 2020	Extends to the whole of the Province of Sindh & regulated under Provincial Government.	Fauna	U.S 71 & 3 rd Schedule (Sr. No.5): Imprisonment of either description up to 06 years with fine up to rupees Ten lac with value of loss as determined (u/s section 90).	Authorities: Sindh Wildlife Department along with Sindh Council for Conservation of Wildlife & National Management Authority with the assistance of Wildlife Police (with the help of Police Officer, Rangers Officer, Coast Guard, Marine Security Agency and Custom Officer, Forest Officer).

Act 1890, which applies primarily to domesticated or captive animals and leaves wild species insufficiently protected. It also remained unamended until 2018, and even then, revisions were limited to increased penalties for select offences.

These internal contradictions hinder enforcement and conflict with Pakistan's obligations under international agreements such as CITES and the Convention on Migratory Species (CMS) (Ahmed, 2016). Furthermore, there is no policy or structured implementation framework at the national level governing the welfare and

treatment of captive wildlife, whether in zoos or private possession (Shah, 2018).

Between 2020 and 2025, constitutional benches began recognising animals as sentient beings with inherent dignity and rights rooted in Islamic stewardship. Yet, the legal landscape remains fragmented. Each province operates under distinct legislative frameworks, ranging from progressive reforms to antiquated colonial statutes. Without legislative harmonisation, Pakistan risks fostering an unequal landscape (Anjum *et al.*, 2025).

Under wildlife legislation, protected areas in Pakistan are classified into three categories: national parks, wildlife sanctuaries, and game reserves. However, this classification is outdated and does not align with the International Union for Conservation of Nature (IUCN)'s six-category framework (Dudley, 2008), which includes additional types such as strict nature reserves, habitat/species management areas and protected landscapes, that better capture modern conservation priorities. Moreover, provincial wildlife agencies manage protected areas but lack authority in surrounding areas, where development often threatens wildlife conservation (Daran *et al.*, 2023; Khan, 2003; Khan *et al.*, 2022).

Existing laws also fail to reflect current research findings, resulting in outdated or incomplete species listings. As a result, several species of both endemic status and international conservation importance remain unrecognized within provincial and national legislation. A striking example is the woolly flying squirrel (*Eupetaurus cinereus*), an endemic mammal documented in northern Pakistan, which is absent from all national and provincial wildlife protection schedules (Jackson *et al.*, 2022). This omission likely stems from the limited research available on the species, underscoring the critical need for updated evidence-based assessments to guide future legislative reforms.

While Pakistan has numerous wildlife laws in place, they remain fragmented, outdated, and poorly aligned with scientific knowledge and international commitments. The lack of coordination across provinces and the presence of legal ambiguities have created significant loopholes, weakening the overall effectiveness of wildlife protection. These legislative gaps directly weaken enforcement efforts, which already struggle with their own persistent challenges.

3.2 International Obligations and compliance gaps

Pakistan is party to key multilateral environmental agreements, including CITES (1973), the Convention on Biological Diversity (CBD, 1992), and CMS (1979). These treaties require member countries to regulate wildlife trade, protect endangered species, and report on biodiversity conservation (CBD, 1992; CMS, 1979; Government of Pakistan, 2017). Although Pakistan has taken steps like signing a Memorandum of Understanding (MoU) with United Nations Office on Drugs and Crime (UNODC) to counter illegal wildlife trade (Radio Pakistan, 2018), its compliance remains inconsistent. For

example, in 2014, Saudi Prince Fahd bin Sultan violated both Pakistani and international conservation laws by illegally hunting over 2,100 endangered houbara bustards (*Chlamydotis macqueenii*), exceeding permit limits and targeting birds within protected areas. This act breached the CITES and highlighted systemic failures in enforcement and permitting oversight (The Third Pole, 2014). Similarly, the U.S. Fish and Wildlife Service also intercepted a shipment from Pakistan linked to fraudulent documentation in 2018, yet no domestic legal action followed (Shahid, 2021). Such cases reveal that Pakistan's treaty commitments often lack credible enforcement on the ground.

More recently, WWF (World Wide Fund for Nature)-Pakistan, in a letter to the Ministry of Climate Change and Environmental Coordination, opposed the proposed transfer of two snow leopards (*Panthera uncia*) from the Naltar Rescue and Rehabilitation Centre to Moscow Zoo. The organisation warned that it contradicts both national and international conservation commitments and could set a harmful precedent for future transfers of threatened species (WWF-Pakistan, 2025a).

3.3 Weak Institutional Management

Protected areas in Pakistan often lack the staff, resources, and authority needed for effective management. Most agencies are poorly funded, with limited research and training infrastructure or technological tools (Daran *et al.*, 2023; Khan *et al.*, 2022; Razzaq and Ali, 2024). They are only effective when backed by strong management systems and community involvement (Khan and Bhagwat, 2010). In this regard, existing wildlife legislation in Pakistan remains inadequate, as provincial authorities have jurisdiction only within protected areas, not their surroundings, where development often threatens biodiversity. Although local participation is key to long-term conservation success, Pakistan's protected area framework still lacks legal space for community-based or co-managed governance (Baig and Ahmed, 2007; Daran *et al.*, 2023; Hessami *et al.*, 2021). Evidence from further regional and international contexts shows that involving local communities into protected area governance significantly improves conservation outcomes and sustainability (Dutta and Dutta, 2023; Nyaupane *et al.*, 2024; Rahman *et al.*, 2022).

Pakistan's zoos reflect another side of this systemic neglect. Poor infrastructure, untrained staff, and the absence of binding welfare standards have led to repeated animal welfare crises, as demonstrated by the suffering and subsequent death of the Asian elephant (*Elephas maximus*) Noor Jehan (Ilyas, 2023) at Karachi Zoo. This gap is also reflected in the case of Kaavan, the elephant kept under horrific conditions in Islamabad Zoo since 1984. His prolonged suffering, despite public attention and expert concern, reflects the institutional inability to enforce even basic welfare standards. Only after a global campaign and court order by Justice Athar Minallah was Kaavan relocated to Cambodia in 2020 (Saeed, 2024).

Other examples include Suzie and Babloo, two brown bears (*Ursus arctos*) used for dancing in tribal areas and later transferred to Islamabad Zoo, where they continued to suffer from malnutrition and zoonosis due to poor enclosure standards, again requiring judicial intervention to secure their transfer abroad (FOUR PAWS International, 2020). Lahore Zoo has faced repeated incidents compromising animal welfare. International scrutiny prompted broader evaluation of zoo management across Pakistan. Notably, Islamabad Zoo lost 15 rare animals, while Peshawar Zoo reported over 30 animal deaths, including a snow leopard (*Mujtaba*, 2020). In 2020, following the High Court's order to close Islamabad Zoo, two lions (*Panthera leo*) died after caretakers set their enclosure on fire during relocation. Ten more animals, including deer (*family Cervidae*), a blue bull (*Boselaphus tragocamelus*), and an ostrich (*Struthio camelus*), also died due to staff negligence (Rashind, 2024).

3.4 Illegal wildlife trading and hunting

Illegal wildlife trade and hunting remain equally pressing problems. According to the Snow Leopard Trust (2025), only about 3% of reported wildlife crimes reach law enforcement agencies. Despite the existence of multiple regulations, wildlife trafficking persists due to weak enforcement and the exploitation of legal loopholes. Traffickers often misuse licenses issued for breeding or research purposes to smuggle rare species, including lions (*Panthera* spp.), macaws (*family Psittacidae*), and iguanas (*family Iguanidae*), many of which end up in private collections. This illegal trade is further facilitated by fraudulent documentation and porous land routes, particularly through Balochistan, while enforcement responses remain inconsistent across provinces (Salim, 2025). Most existing laws restricting game hunting are not enforced. While some species like falcons and cranes are protected, many other threatened species still lack adequate management measures (Khan *et al.*, 2022).

In 2021, the Wildlife Department Rawalpindi Division arrested 103 individuals for illegal hunting and fined 653 others for various wildlife violations (The Express Tribune, 2022). The maximum penalty for snow leopard poaching is just PKR 45,000 (~\$160), a figure far below the species' black-market value (Snow Leopard Trust, 2025). The Islamabad Wildlife Management Board (IWMB) rescued five endangered turtles: Indian roofed turtle (*Pangshura tecta*), black pond turtle (*Geoclemys hamiltonii*), crown river turtle (*Hardella thurjii*), Indian flap-shelled turtle (*Lissemys punctata*), and Ganges softshell turtle (*Nilssonina gangetica*) that were being illegally sold at a pet shop in Islamabad's F-10 sector and safely released them into the Indus River (Pakistan Observer, 2022). Additionally, an undercover survey of 55 markets in 23 Pakistani cities revealed that the majority of wildlife species and animal products sold were listed under CITES and the IUCN Red List of threatened species (Ilyas, 2018b). The Punjab Wildlife Department recovered a rare snow leopard skin and arrested a suspect during a raid in a private housing society in Lahore,

highlighting ongoing efforts to curb illegal wildlife trade (Mehmood, 2024). Recently, Amin *et al.* (2024) reported the presence of both legal and illegal trade of wildlife and domesticated birds in District Tank, Khyber Pakhtunkhwa, which highlights the ongoing challenges in regulating local wildlife markets.

3.5 Private keeping and bear-baiting

The illegal ownership and exploitation of wild animals by influential individuals remains another serious yet under-addressed enforcement issue in Pakistan. Members of the elite class frequently violate provincial wildlife laws by keeping tigers, lions, leopards, and even crocodiles in private residences, often as a display of social status and prestige (Usman *et al.*, 2022). While Section 12 of the *Punjab Wildlife Act 1974* technically permits the private keeping and breeding of wild animals through the issuance of a "certificate of lawful possession," such allowances are conditional and apply only to species not listed as fully protected under the Act's Second and Third Schedules. In practice, however, broad officer discretion and weak enforcement have turned this provision into a loophole, enabling the proliferation of private menageries and commercial breeding farms under the guise of legality. This disregards ethical and welfare considerations and undermines the fundamental conservation principle that wild animals belong in their natural habitats. A particularly disturbing case involved Kashif Zameer, a businessman and TikToker, who was filmed in 2021 beating a chained lion and allowing it to roam his home. Despite widespread public outrage, no legal action was taken, and the lion remained in his custody (Daily Pakistan, 2021). This was not an isolated incident. According to Punjab Wildlife and Parks Department, a recent crackdown led to the confiscation of 18 illegally kept lions, raids on 38 breeding farms, and arrests of eight individuals involved in violations (The Jerusalem Post, 2025). Alarming, the department reported that 584 lions and tigers are currently being held in private homes and breeding facilities across Punjab.

Similarly troubling is the persistence of bear-baiting, a cruel blood sport that continues despite being outlawed under the *Prevention of Cruelty to Animals Act 1890* and explicitly banned in 2001 (Ahmad *et al.*, 2025; Khan, 2020). The practice remains especially prevalent in Punjab, where nearly all of bears used in such fights are subjected to extreme cruelty, including the removal of claws and breaking of teeth to make them defenceless (Rashind, 2024). Most of these bears are Asiatic black bears (*Ursus thibetanus*), listed as Vulnerable by the IUCN (Garshelis and Steinmetz, 2020). Although Sindh province has made some efforts to curb this practice, enforcement remains inconsistent, and illegal bear-baiting events continue with impunity, often protected by powerful landowners (Khan, 2020). Socio-economic and cultural factors also strongly influence bear baiting in Punjab, along with the lack of alternative livelihoods shaping kalandars' (bear keepers') willingness to give up bears, highlighting the need for targeted awareness and livelihood interventions (Rooney and Millam, 2014).

Post-2020 reports confirm that while wildlife authorities and NGOs have helped limit the practice in some regions, bear-baiting remains widespread in Punjab, where multiple recent rescues of Asiatic black bears revealed severe mutilations, including claw removal, tooth breaking, and forced dog fights (FOUR PAWS International, 2024; The Express Tribune, 2025).

4. Recent Key Legal Precedents:

Despite persistent gaps in legislation and weak enforcement, judiciary has shown a positive trend in playing a corrective role in upholding wildlife protection laws. Recently, at the inaugural 2025 International Conference on Animal and Environmental Rights in Lahore, Pakistan, Supreme Court Justice Ayesha A. Malik emphasised the need for "strict punishment" for perpetrators of animal cruelty, asserting that the protection of animals constitutes a constitutional obligation (Dawn, 2025). The following case laws reflect how courts have intervened to safeguard ecological interests where institutional mechanisms have fallen short.

Province of Sindh v. Lal Khan Chandio (2016 SCMR 48)

The Supreme Court of Pakistan examined the legality of a notification issued by the Sindh Forest and Wildlife Department under Section 40 (1) of the *Sindh Wildlife (Amendment) Act, 1993*, which sought to remove the houbara bustard from the list of protected species and permit its hunting. The Court, comprising Chief Justice Jawwad S. Khawaja, Justice Dost Muhammad Khan, and Justice Qazi Faez Isa, found that the Provincial Government had acted beyond its statutory authority in attempting to alter the conservation status of a species classified by scientific authorities as "vulnerable" and under severe population decline. The Court emphasised the binding nature of Pakistan's international commitments under the CITES and CMS, both of which prohibit the exploitation of the threatened species.

Rejecting arguments based on economic or diplomatic justifications (such as the supposed benefits derived from foreign dignitaries hunting the bird) the Court underscored that legal protections for wildlife are not transactional nor subordinate to political or financial considerations. It declared the impugned notification *ultra vires* the *Sindh Wildlife Protection Ordinance 1972* and held that neither the federation nor the provinces possessed legal authority to permit the hunting of a species listed as threatened or vulnerable. The judgment directed the federal government to align domestic legislation with its international treaty obligations and to ensure that provincial laws are compliant with CITES and CMS frameworks. Beyond its immediate impact on halting Houbara Bustard hunting, this judgment set an important precedent for strengthening judicial oversight of wildlife governance in Pakistan, reinforcing that environmental protection and treaty compliance are constitutional obligations rather than discretionary policy choices.

Prof. Zahid Baig Mirza v. CDA & Others (PLD 2022 Islamabad 398)

In this landmark judgment, Chief Justice Athar Minallah of the Islamabad High Court ruled on multiple disputes concerning illegal land use within the Margalla Hills National Park. The Court held that the *Islamabad Wildlife Ordinance 1979*, being a special law, overrides the jurisdiction of the Capital Development Authority (CDA) in the National Park area. It declared the construction of a golf course and other unauthorised commercial activities by various state-affiliated entities as unlawful, unconstitutional, and violative of the right to life under Article 9.

The Court reaffirmed that no authority, including the armed forces, is above the law and emphasized that national parks are inviolable ecological assets meant exclusively for conservation. Citing the constitutional obligation to protect natural habitats, the Court ordered immediate cessation of unauthorised activities, sealing of the golf course, restoration of encroached land, and strict enforcement against further degradation. The federal government, CDA, and Islamabad Wildlife Management Board were held jointly accountable for the park's protection.

This case sets a critical precedent by establishing that environmental protection is a constitutional duty and that no institution can claim immunity from compliance with conservation laws. It also has since guided subsequent judicial oversight, including the Supreme Court's *Monal Group of Companies v. CDA* (Civil Petition No. 304 of 2022, decided 21 Aug 2024), which reaffirmed the IHC's findings on encroachments and the public-trust doctrine.

Haji Ali Muhammad & Others v. Secretary, Ministry of Foreign Affairs & Others (2025 CLC 922)

In this case, the petitioners (members of local community) challenged the declaration of a community-owned area as a Community Game Reserve under Sections 38 and 39 of the *Balochistan Wildlife (Protection, Preservation, Conservation & Management) Act 2014*, seeking to halt regulated hunting of the Houbara Bustard by Arab dignitaries, under restrictions imposed under Section 16 of the same Act. The petitioners alleged infringement of local rights, including restricted movement, displacement of residents and livestock, and intimidation by foreign hunters and officials.

However, the Balochistan High Court, per Justices Muhammad Ejaz Swati and Nazeer Ahmed Langove, found the petition legally deficient, as the petitioners failed to provide documentary proof of land ownership or demonstrate that they represented the requisite 80% of the local community, as required under the law. The Court held that vague and unsupported factual claims cannot warrant relief under constitutional writ jurisdiction. The judgment upheld statutory hunting restrictions under Section 16, dismissed the petition for lack of evidence, and reinforced the legal obligation to comply with wildlife protection laws.

Although the petition articulated credible socio-economic and livelihood concerns, the judgment illustrates a recurrent procedural problem i.e. legitimate grievances are frequently defeated by evidentiary and standing requirements. Where laws impose high thresholds for community representation and require documentary proof of ownership, marginalised groups, often lacking formal title deeds or organised representation, are disadvantaged. This gap can turn substantive rights into illusory protections. Communities facing genuine harm may be unable to obtain interim relief or substantive remedies because the courts must apply strict proof and jurisdictional rules. Remediating this requires procedural reform (lowering onerous representation thresholds and accepting alternative evidence of communal use), strengthened legal aid for affected communities, and institutionalized consultative mechanisms that document community consent before designations are made.

The Monal Group of Companies v. CDA & Others (2024 SCMR 1563)

In this significant environmental ruling, the Supreme Court, comprising Justices Qazi Faez Isa, Jamal Khan Mandokhail, and Naeem Akhtar Afghan, held that all licenses, allotments, or permissions granted by the Capital Development Authority (CDA) or the Remount, Veterinary & Farms Directorate for the operation of restaurants within the Margalla Hills National Park were in direct violation of the *Islamabad Wildlife (Protection, Preservation, Conservation & Management) Ordinance 1979*. The Court declared such permissions are void and of no legal effect, reinforcing the inviolability of protected areas under statutory conservation mandates.

The petitioners' plea to legalise such commercial operations within the National Park was rejected. The Court directed that all restaurants, except small kiosks licensed by the Islamabad Wildlife Management Board under strict limitations, must vacate the premises within three months. To strengthen the governance of the National Park, the Court further recommended appointing a CDA officer as a member of the Wildlife Board and suggested WWF's involvement in implementing these directives.

By ordering the removal of restaurants, the Court reinforced a key conservation principle i.e. that economic or recreational interests cannot override statutory protection of wildlife habitats. The decision is widely viewed as a positive precedent for conservation, reaffirming the ecological integrity and non-negotiable status of Pakistan's protected areas.

5. Other positive developments

Recently, WWF-Pakistan, in a press release issued on World Wildlife Day 2025, announced the launch of Pakistan's first mobile application to report wildlife crimes and support coordinated action by government and law enforcement agencies (WWF-Pakistan, 2025b). The first Wildlife Crime Scene Investigation (WCSI) training was also held in Chitral, Pakistan, equipping field staff to

tackle illegal wildlife trade (responsible for the poaching of an estimated 8 snow leopards annually) through forensic techniques, legal enforcement, and community engagement (Snow Leopard Trust, 2025). Moreover, in April 2025, IUCN Pakistan, in collaboration with the Punjab Wildlife Department, launched the province's first comprehensive wildlife census to gather data on species distribution, populations, and threats (IUCN, 2025). The project is expected to provide critical insights that could inform evidence-based wildlife policy and legislative reforms in the future. Most importantly, the Punjab government has established wildlife courts to tackle offences like poaching and encroachment, with amended laws now imposing fines up to Rs. 5 million (≈ USD 18,000). A new conservation board has been formed, alongside initiatives worth Rs. 1.73 billion (≈ USD 6.18 million), including a 3D wildlife cinema, ecotourism projects, a Rs. 1.47 billion (≈ USD 5.25 million) wildlife hospital, and Rs. 60 million (≈ USD 0.21 million) youth internship program (Khattak, 2025).

6. Recommendations

After examining the numerous legal and ethical shortcomings that undermine effective wildlife protection, it is essential to propose targeted reforms to address these critical gaps.

- Provincial wildlife laws should be standardised by aligning species schedules, penalties, and enforcement mechanisms with scientific data and international commitments under CITES, CMS, and CBD.
- Existing laws should be amended to explicitly criminalise cruelty against wild species, remove contradictions in species classifications, and incorporate updated species assessments, including endemic and at-risk taxa like the Woolly Flying Squirrel.
- Law enforcement agencies should tailor their strategies based on emerging trends and intelligence gathered from social media platforms (Haq *et al.*, 2023).
- Funding, training, and technological support for provincial wildlife departments should be increased. Government should establish dedicated units for forensic wildlife crime investigation and ensure coordination with police and customs authorities.
- Government should also expand the legal authority of wildlife agencies to include buffer zones around protected areas and embed participatory governance mechanisms.
- Moreover, the *PCA Act 1890* should be strengthened by incorporating species-specific welfare standards (particularly for animals in captivity such as zoos) aligned with the internationally recognized FIVE FREEDOMS of animals i.e. freedom from (1) hunger and thirst, (2) discomfort, (3) pain, injury or disease, (4) fear and distress, and to (5) express normal

behaviour (Farm Animal Welfare Council, 1992; Mäekivi, 2018).

- Strict enforcement and regulation of judicial directives must involve holding violators accountable regardless of their background, timely implementation of rulings, interdepartmental coordination, and stringent monitoring frameworks.
- Finally, promotion of nationwide public awareness campaigns addressing wildlife crime and animal welfare should be encouraged.

Priority reforms include standardising species schedules and improving captive-wildlife welfare, while near-term feasible steps involve boosting funding and training for provincial departments.

Conclusion

While Pakistan's wildlife legislation has gradually progressed with time, the gap between policy and enforcement remains substantial. Legal inconsistencies across provinces, outdated species classifications, minimal penalties, and the lack of a centralized implementation strategy continue to hinder effective protection. Institutional weaknesses further aggravate the issue, with understaffed and under-resourced agencies unable to monitor protected areas or curb illegal trade

effectively. Private keeping of wild animals, illegal hunting by privileged actors, and cruel practices like bear-baiting persist with impunity, reflecting deep-seated enforcement failures.

Nonetheless, judicial pronouncements have begun to play a pivotal role in rectifying administrative shortcomings. Landmark judgments by superior courts have reaffirmed constitutional and international commitments, holding state entities accountable for violations of law. Complementary efforts, such as the establishment of wildlife courts, conservation boards, and cross-border collaboration, signal progress. Yet, these developments must be institutionalised and expanded in line with the proposed reforms, particularly legal harmonisation, strengthened enforcement, and public awareness, to address the scale and urgency of the threats facing Pakistan's biodiversity.

Acknowledgements

The authors gratefully acknowledge **Adv. Muhammad Adil**, a distinguished civil lawyer at the Sialkot Bar Association, for his valuable guidance in interpreting legal aspects and case studies, which enriched the depth of this review.

References

- Ahmad, F., Rehan, M., Bosso, L. and Kabir, M. (2025) 'Asiatic black bear in Pakistan: a comprehensive review and conservation indications', *Mammalian Biology*, pp.1-18. doi: <https://doi.org/10.1007/s42991-025-00479-x>
- Ahmad, S., Nabi, G., Hacker, C.E., Strelnikov, I.I. and Luan, X. (2022) 'Increasing threats to snow leopard survival in Pakistan', *Frontiers in Ecology and Evolution*, 10, p.818798. doi: <https://doi.org/10.3389/fevo.2022.818798>
- Ahmed, O.S. (2016) 'The legal status of hunting houbara bustards by foreign dignitaries', *LUMS LJ*, 3, p.51. Available at: https://web.archive.org/web/20180426085356id_/https://sahsol.lums.edu.pk/sites/default/files/legal_status_of_hunting_houbara_bustards.pdf
- Amin, S., Fareed, M.F., Ullah, I., Rehman, A.U., Farooq, U., Saigra, D.B., Ashfaq, A.B. and Ali, H. (2024) 'Legal and illegal trade of wildlife and domesticated birds in District Tank, Khyber Pakhtunkhwa: A case study of two local markets (Mandies)', *Biologia (Lahore)*, 70(2), pp.61-65. doi: <https://dx.doi.org/10.17582/journal.Biologia/2024/70.2.61.65>
- Anjum, R., Barkat, A. and Jatoti, A.A. (2025) 'Fragmentation To Framework: Harmonizing Animal Protection Laws Across Pakistan', *Research Journal for Social Affairs*, 3(4), pp.117-127. doi: <https://doi.org/10.71317/RJSA.003.04.0266>
- Azad Jammu and Kashmir Wildlife (Protection, Preservation, Conservation and Management) Act 2014. Available at: <https://faolex.fao.org/docs/pdf/pak190113.pdf> (Accessed 22 Oct. 2025).
- Baig, M.B. and Ahmed, M. (2007) 'Biodiversity in Pakistan: status challenges and strategies for its conservation', *International Journal of Biology and Biotechnology*, 4(4), pp.283-292. doi: <https://www.cabidigitallibrary.org/doi/full/10.5555/20083205049>
- Balochistan Wildlife (Protection, Preservation, Conservation and Management) Act 2014. Available at: <https://balochistancode.gob.pk/pdfviewer.aspx?pdffile=5843ea69-ae62-44c5-93e3-5f73f191a024.pdf> (Accessed 22 Oct. 2025).
- Bandeira, V. and Fonseca, C. (2020) 'Wildlife and Sustainable Development', In *Life on Land* (pp. 1-14). Encyclopedia of the UN Sustainable Development Goals. Springer, Cham. doi: https://doi.org/10.1007/978-3-319-95981-8_72
- Business Recorder (2022). *Wildlife populations have seen 69pc decline since 1970*: WWF. [online] Available at: <https://www.brecorder.com/news/40203023> (Accessed 19 Jul. 2025).
- CBD (1992) *Convention on Biological Diversity*. Rio de Janeiro: United Nations. Available at: <https://www.cbd.int/convention/text/> (Accessed: 7 October 2025).

CITES (1973) *Convention on International Trade in Endangered Species of Wild Fauna and Flora*. Washington, DC: United Nations Environment Programme. Available at: <https://cites.org/eng/disc/text.php> (Accessed: 7 October 2025).

CMS (1979) *Convention on the Conservation of Migratory Species of Wild Animals*. Bonn: United Nations Environment Programme. Available at: <https://www.cms.int/en/convention-text> (Accessed: 7 October 2025).

Daily Pakistan (2021). *Kashif Zameer who hosted 'Ertugrul' to Pakistan seen beating pet lion in viral video*. [online]. 12 May. Available at: <https://en.dailypakistan.com.pk/12-May-2021/kashif-zameer-who-hosted-ertugrul-to-pakistan-seen-beating-pet-lion-in-viral-video> (Accessed 9 Jul. 2025).

Daran, D.E., Al Ajlani, R., Zia-ud-Din, M. and Elhajraoui, F.E. (2023) 'Management of biodiversity in Pakistan protected areas and its legal implications', *Journal of Wildlife and Biodiversity*, 7 (supplementary issue), pp.1-13. doi: <https://doi.org/10.5281/zenodo.14273594>

Dawn (2025). *Justice Ayesha A. Malik calls for strict penalties for mistreating animals*. 19 January. Available at: <https://www.dawn.com/news/1886236> (Accessed: 22 Oct. 2025).

Dudley, N. (ed.) (2008) *Guidelines for applying protected area management categories*. IUCN.

Dutta, M. and Dutta, P.K. (2023) 'Community-based conservation in Eastern Himalayan biodiversity hotspot-a case study', *Indian Journal of Traditional Knowledge (IJTK)*, 22(1), pp.220-229. doi: <https://doi.org/10.56042/ijtk.v22i1.33482>

Farm Animal Welfare Council (FAWC). (1992) 'FAWC updates the five freedoms', *Veterinary Record*, 131(18), 357.

FOUR PAWS International (2020). *The End of Marghazar Zoo in Islamabad: Four Paws Relocates Bears Suzie and Bubloo to Jordan*. [online] 17 December. Available at: <https://www.four-paws.org/our-stories/press-releases/december-2020/the-end-of-marghazar-zoo-in-islamabad-four-paws-relocates-bears-suzie-and-bubloo-to-jordan> (Accessed 13 October 2025).

FOUR PAWS International (2024). *FOUR PAWS Rescues Two Baiting Bears Abused for Fighting in Punjab*. [online] Available at: <https://www.four-paws.org/our-stories/press-releases/april-2024/rescue-baiting-bears-punjab> (Accessed 18 Oct. 2025).

Garshelis, D. & Steinmetz, R. (2020) *Ursus thibetanus* (amended version of 2016 assessment). *The IUCN Red List of Threatened Species 2020*: e.T22824A166528664. [online] doi: <https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T22824A166528664.en> (Accessed 13 October 2025).

Goudie, A.S. (2018) *Human impact on the natural environment: Past, present and future*. John Wiley & Sons. ISBN: 978-1-119-40355-5

Government of Pakistan (2017). *Pakistan National Biodiversity Strategy and Action Plan: For Achieving Aichi Biodiversity Targets and Sustainable Development Goals 2017–2030*. [online] Available at: <https://www.cbd.int/doc/world/pk/pk-nbsap-v2-en.pdf> (Accessed 19 Jul. 2025).

'Haji Ali Muhammad & Others v. Secretary, Ministry of Foreign Affairs & Others' [2025] CLC 922

Haq, R.U., Abdulabad, A., Asghar, S. and Szabo, J.K. (2023) 'Clicks and comments: Representation of wildlife crime in Pakistan in social media posts', *Global Ecology and Conservation*, 43, p.e02473. doi: <https://doi.org/10.1016/j.gecco.2023.e02473>

Hessami, M.A., Bowles, E., Popp, J.N. and Ford, A.T. (2021) 'Indigenizing the North American model of wildlife conservation', *Facets*, 6(1), pp.1285-1306. doi: <https://doi.org/10.1139/facets-2020-0088>

Ilyas, A. and Qazilbash, M. (2021). *Apathy towards animal rights in Pakistan: What needs to be done*. [online] SDPI. October. Available at: https://sdpi.org/apathy-towards-animal-rights-in-pakistan-what-needs-to-be-done/publication_detail

Ilyas, F. (2018a). *Zoo animals suffer because of staff shortage, poor sanitation*. [online] Dawn. 22 February. Available at: <https://www.dawn.com/news/1390870/zoo-animals-suffer-because-of-staff-shortage-poor-sanitation> (Accessed 9 Jul. 2025).

Ilyas, F. (2018b). *Illegal trade in wildlife rife across Pakistan, says study*. [online] Dawn. 12 March. Available at: <https://www.dawn.com/news/1394654> (Accessed 11 Jul. 2025).

Ilyas, F. (2023, April 3). *Experts ask govt to take immediate steps for welfare of zoo animals*. Dawn. <https://www.dawn.com/news/1745574> (Accessed 20 Jul. 2025).

Islamabad Wildlife (Protection, Preservation, Conservation and Management) Ordinance 1979. Available at: <https://faolex.fao.org/docs/pdf/pak64392.pdf> (Accessed 20 Oct. 2025).

IUCN (2025). *Launch of the Punjab Wildlife Census Project in Lahore, Pakistan*. Retrieved from <https://iucn.org/story/202504/launch-punjab-wildlife-census-project-lahore-pakistan> (Accessed 18 Oct. 2025).

IUCN Red List (www.iucnredlist.org) (Accessed 11 Jul. 2025).

Jackson, S.M., Li, Q., Wan, T., Li, X.Y., Yu, F.H., Gao, G., He, L.K., Helgen, K.M. and Jiang, X.L. (2022) 'Across the great divide: revision of the genus *Eupetaurus* (Sciuridae: Pteromyini), the woolly flying squirrels of the Himalayan region, with the description of two new species', *Zoological Journal of the Linnean Society*, 194(2), pp.502-526. doi: <https://doi.org/10.1093/zoolinlean/zlab018>

Khan, A.N., Khan, H.A. and Ammar, E.E. (2022) 'A Review: Protected Areas of Pakistan Management and Current Issues', *American Journal of Biological and Environmental Statistics*, 8(4), pp.112-116. doi: <https://doi.org/10.11648/j.ajbes.20220804.13>

Khan, M.S. and Bhagwat, S.A. (2010) 'Protected areas: a resource or constraint for local people?', *Mountain Research and Development*, 30(1), pp.14-24. doi: <https://doi.org/10.1659/MRD-JOURNAL-D-09-00024.1>

Khan, M.S.H. (2021). 'Wildlife Policy in Pakistan', [online] RRA SIA. Available at: <https://rr-asia.woah.org/app/uploads/2021/01/pakistan.pdf> (Accessed 09 Jul. 2025).

Khan, R.S. (2020). *Low-profile sanctuary in Pakistan a ray of hope for baited bears*. [online] Dialogue Earth. 6 October. Available at: <https://dialogue.earth/en/nature/low-profile-sanctuary-in-pakistan-a-ray-of-hope-for-baited-bears/> (Accessed 9 Jul. 2025).

Khan, S.Z., Kamran, M. and Javid, A. (2025b) 'Wildlife laws of Pakistan and Islamic teachings: Critical review: وائلہ لائف سے متعلقہ', *Al-Marjān*, 3(1), pp.417-334. Available at: <https://al-marjan.com.pk/index.php/Journal/article/view/180> (accessed Jun 10, 2026)

Khan, T., Ahmad, S., Mehmood, T., Khan, S.R., Khan, D.U., Khan, S., Ullah, M. and Rahim, E. (2025a) 'Assessing Human-Wildlife Conflict in Lakki Marwat, Pakistan: Economic Impacts and People's Perceptions', *European Journal of Wildlife Research*, 71(4), p.73. doi: <https://doi.org/10.1007/s10344-025-01927-2>

Khan, Z., Siddiqui, S., Zehra, A., Khan, I., Iqbal, M., Aslam, S., Noor, L., Nisar, P., Lateef, T., Khan, S. and Ali, M. (2023) 'Protected areas of Pakistan: Wildlife of some selected national parks – A review', *Canadian Journal of Pure and Applied Sciences*, 17(1), pp.5621–5636. doi: <https://www.researchgate.net/publication/368396269>

Khan, Z.I. (2003) 'Protected areas in Pakistan: Management and issues', *Journal of the National Science Foundation of Sri Lanka*, 31(1-2). Available at: <https://jnsfsl.sljol.info/articles/3036/files/submission/proof/3036-1-10568-1-10-20110510.pdf>

Khattak, A. (2025). *Punjab to set up wildlife courts to protect animals*. [online] ProPakistani. 15 January. Available at: <https://propakistani.pk/2025/01/15/punjab-to-set-up-wildlife-courts-to-protect-animals/> (Accessed 10 Jul. 2025).

Khyber Pakhtunkhwa Wildlife and Biodiversity (Protection, Preservation, Conservation and Management) Act, 2014. Available at: https://kpcode.kp.gov.pk/uploads/THE_KHYBER_PAKHTUNKHWA_ENVIRONMENTAL_PROTECTION_ACT_2014.pdf (Accessed 10 Oct. 2025).

Koreshi, M.H. (2020). *Animal rights in Pakistan: Being kind to every kind*. [online] Courting the Law. Available at: <https://courtingthelaw.com/2020/07/27/commentary/animal-rights-in-pakistan-being-kind-to-every-kind> (Accessed 10 Jul. 2025).

MÄEKIVI, N. (2018) 'Freedom in captivity: managing zoo animals according to the 'five freedoms'', *Biosemiotics*, vol. 11, no. 1, pp. 7-25. doi: <http://dx.doi.org/10.1007/s12304-018-9311-5>.

Mehmood, A. (2024). *Lahore authorities recover snow leopard skin in crackdown against illegal wildlife trade*. [online] The Express Tribune. 30 August. Available at: <https://tribune.com.pk/story/2492178/laure-authorities-recover-snow-leopard-skin-in-crackdown-against-illegal-wildlife-trade> (Accessed 9 Jul. 2025).

'Monal Group of Companies v. CDA' (Civil Petition No. 304 of 2022, decided 21 Aug 2024)

Mujtaba, M. (2020). *With neglect and abuse rampant, Pakistan must permanently shut down its zoos*. [online] Arab News Pakistan. Available at: <https://www.arabnews.pk/node/1763401> (Accessed 19 Jul 2025).

Nyaupane, G.P., Poudel, S. and York, A. (2024) 'Governance of protected areas: an institutional analysis of conservation, community livelihood, and tourism outcomes', In *Protected Areas, Sustainable Tourism and Community Livelihood Linkages* (pp. 191-210). Routledge. doi: <https://doi.org/10.1080/09669582.2020.1858089>

Pakistan National Report (2019). *Pakistan's 6th National Report to the United Nations Convention on Biological Diversity*. Ministry of Climate Change, Government of Pakistan, pp.81. Available at: <https://www.cbd.int/doc/nr/nr-06/pk-nr-06-en.pdf> (Accessed 10 Jul. 2025).

Pakistan Observer, (2022). *IWMB rescues five endangered turtles from F-10*. [online] Pakistan Observer. 3 August. Available at: <https://pakobserver.net/iwmb-rescues-five-endangered-turtles-from-f-10> (Accessed 10 Jul. 2025).

Pakistan Penal Code (Act XLV of 1860). Available at: <https://www.fmu.gov.pk/docs/laws/Pakistan%20Penal%20Code.pdf>

Pakistan Trade Control of Wild Fauna and Flora Act, 2012. Available at: https://www.senate.gov.pk/uploads/documents/1358920143_502.pdf

Preece, R. and Chamberlain, L. (1993) *Animal welfare & human values*. Wilfrid Laurier Univ. Press. ISBN: 0-88920-227-3

Prevention Of Cruelty to Animals Act 1980 (No. XI of 1890). Available at: <https://punjabcode.punjab.gov.pk/uploads/articles/the-prevention-of-cruelty-to-animals-act-1890-pdf.pdf>

‘Prof. Zahid Baig Mirza v. CDA & Others’ PLD [2022] Islamabad 398

‘Province of Sindh v. Lal Khan Chandio’ [2016] SCMR 48

Punjab Wildlife (Protection, Preservation, Conservation and Management) (Amendment) Act, 2007. Available at: [https://fwf.punjab.gov.pk/system/files/THE%20PUNJAB%20WILDLIFE%20\(PROTECTION,%20PRESERVATION,%20CONSERVATION%20AND%20MANAGEMENT\)%20\(AMENDMENT\)%20ACT,%202007.pdf](https://fwf.punjab.gov.pk/system/files/THE%20PUNJAB%20WILDLIFE%20(PROTECTION,%20PRESERVATION,%20CONSERVATION%20AND%20MANAGEMENT)%20(AMENDMENT)%20ACT,%202007.pdf)

Punjab Wildlife (Protection, Preservation, Conservation and Management) Act, 1974. Available at: <https://faolex.fao.org/docs/pdf/pak64336.pdf>

Radio Pakistan (2018). WWF, UNODC sign MoU to curb illegal wildlife trade in Pakistan. [online] 29 March. Available at: <https://radio.gov.pk/29-03-2018/wwf-unodc-sign-mou-to-curb-illegal-wildlife-trade-in-pakistan> (Accessed 9 Jul. 2025).

Rahman, M.K., Masud, M.M., Akhtar, R. and Hossain, M.M. (2022) ‘Impact of community participation on sustainable development of marine protected areas: Assessment of ecotourism development’, *International Journal of Tourism Research*, 24(1), pp.33-43. doi: <https://doi.org/10.1002/jtr.2480>

Rahman, S.A. (2017) ‘Religion and animal welfare—An Islamic perspective’, *Animals*, 7(2), p.11. doi: <https://doi.org/10.3390/ani7020011>

Rashid, R.F. (2024) ‘Wildlife Protection in Pakistan-An Analysis of Legal and Ethical Constraints’, *PLR*, 15, p.25. Available at: <https://heinonline.org/HOL/LandingPage?handle=hein.journals/pakislr15&div=5&id=&page=>

Razaq, U. and Ali, S. (2024). ‘Analyzing the Resource Constraints that the Islamabad Wildlife Management Board Faces in Carrying Out its Tasks within the Existing Legislative Framework’, *The Critical Review of Social Sciences Studies*, 2(2), pp.860-874. doi: <https://doi.org/10.59075/k89yvh35>

Rooney, T.P. and Millam, K.C. (2014) *A quantitative analysis of kalandars and captive bears in Pakistan*. WSPA Asia and Bioresource Research Centre. Available at: <https://corescholar.libraries.wright.edu/biology/208/>

Saeed, A. (2024). ‘A Case for Animal Sentience in Pakistan:" Kaavan" the Elephant's Incredible Story’, *LUMS LJ*, 10, p.151. Available at: <https://sahsol.lums.edu.pk/sites/default/files/2024-05/A%20Case%20for%20Animal%20Sentience%20in%20Pakistan%20%E2%80%9C%20Kaavan%E2%80%9D%20The%20Elephant%E2%80%99s%20Incredible%20Story%20Case%20Commentaries.pdf>

Salim, Y. (2025). *Caged for profit: Pakistan's underground animal trade*. [online] T-Magazine, The Express Tribune. 30 March. Available at: <https://tribune.com.pk/story/2537180/caged-for-profit-pakistans-underground-animal-trade> (Accessed 9 Jul. 2025).

Shah, R. (2018). *Animal legislation*. [online] Dawn. Available at: <https://www.dawn.com/news/1425442> (Accessed 9 Jul. 2025).

Shahid, J. (2021). *Private operators misusing trophy hunting scheme*. [online] Dawn. Available at: <https://www.dawn.com/news/1612363> (Accessed 9 Jul. 2025).

Sindh Wildlife Protection (Amendment) Ordinance, 1993. Available at: https://sindhlaws.gov.pk/setup/publications_SindhCode/PUB-16-000470.pdf

Sindh Wildlife (Protection, Preservation, Conservation and Management) Act, 2020. Available at: <https://www.pas.gov.pk/uploads/acts/Sindh%20Act%20No.XXIII%20of%202020.pdf>

Sindh Wildlife Protection Ordinance, 1972. Available at: https://www.sindhlaws.gov.pk/setup/publications_SindhCode/PUB-15-000210.pdf

Snow Leopard Trust (2025). *Forensics in the Field: Wildlife CSI Training in Pakistan*. [online] 16 April. Available at: <https://snowleopard.org/forensics-in-the-field-wildlife-csi-training-in-pakistan> (Accessed 10 Jul. 2025).

The Express Tribune, (2022). *103 held for illegal hunting in 2021: The Wildlife Department has issued orders to expedite operations against hunters*. [online] 27 January. Available at: <https://tribune.com.pk/story/2340644/103-held-for-illegal-hunting-in-2021> (Accessed 10 Jul. 2025).

The Express Tribune (2025). *Wildlife fights persist in Punjab despite ban*. [online] 12 January. Available at: <https://tribune.com.pk/story/2561936/wildlife-fights-persist-in-punjab-despite-ban> (Accessed 18 Oct. 2025).

The Jerusalem Post (2025). *Pakistan confiscates 18 illegal lions after one escapes, attacks woman and children*. [online] 7 July. Available at: <https://www.jpost.com/international/article-860273> (Accessed 10 Jul. 2025).

'*The Monal Group of Companies v. CDA & Others*' [2024] SCMR 1563

The Northern Areas (Gilgit-Baltistan) Wildlife Protection Act 1975. Available at: <https://faolex.fao.org/docs/pdf/pak166907.pdf>

The Third Pole (2014). *Pakistan violates law to permit Arab royals' illegal safaris*. Earth Journalism Network, 12 May. Available at: <https://earthjournalism.net/stories/pakistan-violates-law-to-permit-arab-royals-illegal-safaris> (Accessed 20 Jul. 2025).

Usman, A., Hassan, M., Rehman, Z.U. and Sial, A.Q. (2022) 'Legal framework in aid of biological diversity and statutory deficiencies in Pakistan', *Brazilian Journal of Biology*, 84, p.e262695. doi: <https://doi.org/10.1590/1519-6984.262695>

World Animal Protection (2020). *Animal Protection Index 2020*. London: World Animal Protection. Available at: <https://api.worldanimalprotection.org/> (Accessed: 7 October 2025).

WWF-Pakistan (2019). *Speakers call for stringent measures to tackle wildlife crime*. [online] Available at: <https://www.wwfpak.org/?354751/Speakers-call-for-stringent-measures-to-tacklewildlife-crime> (Accessed 12 Jul. 2025).

WWF (2022) *Living Planet Report 2022 – Building a nature-positive society*. Almond, R.E.A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (Eds). WWF, Gland, Switzerland.

WWF-Pakistan (2025a). *WWF-Pakistan strongly opposes the move to transfer snow leopards to Moscow*. [online] 17 May. Available at: <https://www.wwfpak.org/?391815/WWF-Pakistan-strongly-opposes-the-move-to-transfer-snow-leopards-to-Moscow> (Accessed 11 Jul. 2025).

WWF-Pakistan (2025b). *WWF-Pakistan launches app to report wildlife crimes*. [online] WWF-Pakistan. 3 March. Available at: <https://www.wwfpak.org/?390817/WWF-Pakistan-launches-app-to-report-wildlife-crimes> (Accessed 10 Jul. 2025).

Yang, L., Xu, H., Pan, S., Chen, W. and Zeng, J. (2024) 'Identifying the impact of global human activities expansion on natural habitats', *Journal of Cleaner Production*, 434, p.140247. doi: <https://doi.org/10.1016/j.jclepro.2023.140247>

Yuan, R., Zhang, N. and Zhang, Q. (2024) 'The impact of habitat loss and fragmentation on biodiversity in global protected areas', *Science of the Total Environment*, 931, p.173004. doi: <https://doi.org/10.1016/j.scitotenv.2024.173004>

Drivers and Pressures of Wetland Degradation in Malawi: A Narrative Review

Davies Ezra Chogawana¹, Eleanor S. Devenish-Nelson², Mphatso Martha Kalembe³

¹ Biodiversity Division, Malawi Environment Protection Authority, Lilongwe, Malawi

² The University of Edinburgh, Edinburgh, United Kingdom

³ Biodiversity Division, Environmental Affairs Department, Lilongwe, Malawi

Email:

chogawana@gmail.com

Received: July 2026

Accepted for publication: May 2026

Published: July 2026

Abstract

Wetlands in Malawi provide vital ecosystem services, yet they face increasing anthropogenic and environmental pressures that have resulted in their degradation. This review synthesised findings to identify and analyse the key drivers and pressures contributing to wetland degradation in Malawi. Three major wetland ecosystems in Malawi – Lake Chilwa, Elephant Marsh and the Kasungu floodplain – were represented, from six studies. The most prominent drivers identified include population growth, poverty, weak governance, hydro power and irrigation development, commercial agriculture, climate change and invasive alien species. These drivers result in direct pressures such as wetland encroachment for agriculture, human settlement, resource overexploitation and altered hydrology. The review highlights the interconnected nature of these drivers and underscores the need for integrated management approaches that address both immediate pressures and their underlying causes. Despite limitations in geographic scope and data availability, the findings offer critical insights for policy and practice aimed at sustaining Malawi's wetland ecosystems. Further research is recommended, particularly in underrepresented regions and in relation to emerging threats such as invasive alien species, climate change and commercial land use expansion.

Keywords: Wetland degradation, wetland conservation, Malawi, Lake Chilwa

1. Introduction: Wetlands in Malawi

Malawi is endowed with diverse natural resources, with approximately 20% of its land covered by water bodies and wetlands (Fig.1) (Chiotha et al., 2018). Major wetlands in the country include Elephant Marsh and Lake Chilwa in the southern region, the Kasungu inland floodplains in the central region and the Vwaza Marshes in the northern region, all of which provide critical ecological services and support local livelihoods (Chiotha et al., 2018; Kosamu et al., 2012; Manda et al., 2023; Wood, 2011).

Two of Malawi's wetlands are designated as Ramsar sites: Elephant Marsh (61,556 ha; Ramsar Site 2308) and the Lake Chilwa wetland (240,000 ha; Ramsar Site 869), both located on community lands (Chiotha et al., 2018). The Vwaza Marsh, in contrast, is the only major wetland under formal protected area management, designated as a Wildlife Reserve (Manda et al., 2023). The other wetlands in Malawi lie in communal areas, with the inland floodplains in central Malawi recognized as highly suitable

for agriculture (Wood, 2011). The distribution of wetlands in Malawi can be seen in Figure 1.

1.1 Drivers and Pressures of Wetland Degradation

Wetland degradation is driven by both direct pressures and underlying drivers. Here, pressures refer to direct, localized actions that degrade wetlands, while drivers are the broader socio-economic, institutional, or environmental forces that give rise to those pressures (Asselen et al., 2013; Dzoga et al., 2020). The consequences of wetland degradation are significant, especially in a country so dependent on the ecosystem services from wetland habitats (Kafumbata et al., 2014). For example, overfishing can diminish dietary protein availability in a country where fish is the primary source of animal protein (Bonaccio et al., 2017; Kosamu et al., 2012). Increased sediment load from unsustainable

agriculture on wetland degrades critical breeding habitats for sensitive bird species such as *Rynchops flavirostris*

(African Skimmer), which depend on sandbanks for nesting (Branch, 2016). Similarly, sediment deposition disrupts fish spawning grounds, threatening aquatic biodiversity and undermining the reproductive success of fish species (Brown et al., 2022; Kosamu, 2014). Moreover, wetlands play a critical role in climate change mitigation and adaptation by protecting communities from flooding through their water attenuation functions and by providing irrigation to support recovery after droughts (Forsythe and Turpie, 2016). Continued wetland degradation and loss, however, reduces the capacity of communities to cope with climate related challenges (Kafumbata et al., 2014). Without wetlands, people lose critical options for adapting during periods of drought, water scarcity and other climate stresses (Wood, 2011.). Collectively, these interlinked processes not only diminish biodiversity but also compromise the ecological resilience of wetlands, threatening their long-term functionality and the ecosystem services they provide.

Understanding the underlying drivers of wetland degradation is therefore a critical step towards establishing the enabling conditions necessary to effectively safeguard these ecosystems from further harm. Globally, wetland degradation is driven by multiple interacting factors such as agricultural expansion, economic development and population growth, which are predominant contributors to wetland loss and degradation (Asselen et al., 2013; Convention on Wetlands et al., 2025; Kundu et al., 2024). Often, a single driver can result in multiple pressures; for instance, population growth leads to both expanded agriculture and increased settlement (Asselen et al., 2013). Conversely, certain pressures may stem from multiple drivers; for example, wetland conversion for agriculture may arise due to population growth, economic demand, or climate change-induced water scarcity (Asselen et al., 2013). In Malawi, reported pressures include agricultural expansion, human settlement, overexploitation of biological resources and water extraction (Manda et al., 2023). These pressures are driven by factors such as population growth, poverty, limited awareness of wetland values and institutional weaknesses (Kosamu et al., 2012). The two Ramsar sites are the most studied wetlands in Malawi as their designation has stimulated scientific interest and research. The other wetlands have only a few papers on them or remain understudied. Therefore, this study provides a synthesis of the available literature, highlighting trends in wetland degradation across these better studied areas, while acknowledging that generalizations to the entire country are limited by gaps in coverage and the small number of existing publications.

1.2 Objective of the Study

To conduct a narrative review on the key drivers and pressures contributing to wetland degradation in Malawi, with the aim of identifying those drivers and pressures that have the greatest impact.

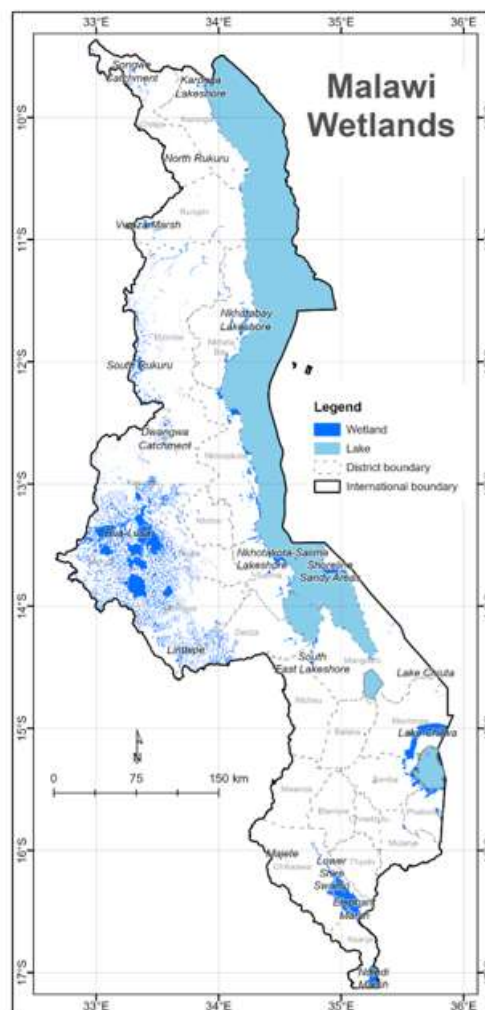


Figure 1: Distribution of Wetlands in Malawi.

2. Methods: Determining Drivers and Pressures

To provide a clear and logical understanding of drivers and pressures, this study defines them as follows: drivers are societal factors that lead to activities contributing to wetland degradation, whereas pressures are the direct activities causing wetland degradation (Dzoga et al., 2020). The Drivers–Pressures–State–Impact–Response (DPSIR) framework was used as a reference point to guide the assessment of drivers and pressures. The framework provides a logical structure by linking underlying societal drivers to direct pressures, and by illustrating the subsequent impacts and responses (Dzoga et al., 2020). To determine the key pressures and drivers of wetland degradation in Malawi, the study employed a narrative literature review. Literature reviews are increasingly being used in scientific research to synthesize existing knowledge and provide a comprehensive understanding of a chosen topic (Pautasso, 2019). There are two types of literature reviews that can be undertaken for a study – systematic and narrative (Pautasso, 2019).

A systematic review is aimed at answering a research question using a pre-defined protocol (Holland and

DeVille, 2021; Ojala et al., 2021; Pullin, 2016). It is guided by a research question which directs the researcher to conduct the relevant search, with facts and results from the reviewed journals synthesized to answer the question (Fatorić and Seekamp, 2017). This method prevents the author's bias towards their own perspective on the question posed by the research (Schmidt, 2005).

A narrative review provides an overview of the current state of knowledge on a subject and synthesizes qualitative evidence from multiple studies in a concise and coherent manner (Holland and DeVille, 2021; Ojala et al., 2021; Pautasso, 2019). Unlike systematic reviews, narrative reviews can utilise published articles that used different methodologies and research questions but include data which answers the objective of the review (Pautasso, 2019). Narrative reviews are used for qualitative data synthesis and can utilise articles which do not include statistical analysis (Holland and DeVille, 2021). The research question is usually broader and not narrowed down as in systematic search (Holland and DeVille, 2021). The narrative review also follows an order of search which starts by defining the search question, identifying the key search words for the topic and conducting a search (Holland and DeVille, 2021; Ojala et al., 2021). The narrative review is criticized for biasness as it does not have a pre-defined protocol (Pullin, 2016). Narrative review accommodates the use of grey literature, which can be subject to biasness from an institutions or projects perspective. Whilst, systematic reviews have been criticized for their narrow inclusion criteria, which may exclude valuable contextual information and evidence from non-peer-reviewed sources, thereby limiting the breadth of perspectives considered on a given topic (Pautasso, 2019). This study examined the drivers and pressures influencing wetland conservation, which provided the context for understanding wetland degradation in Malawi. A narrative review approach was chosen to enable the synthesis of a broad range of literature and to capture the diversity of underlying causes. The scarcity of peer-reviewed studies on wetlands in Malawi necessitated the inclusion of grey literature, which provided context-specific and locally relevant insights that are often absent from academic sources. Employing a narrative review was therefore appropriate, as it allowed for a comprehensive and descriptive analysis of the issue while integrating both scholarly and practice-based evidence (Holland and DeVille, 2021).

A scoping search was done on Web of Science to check availability of peer reviewed journals on wetlands degradation in Malawi, but the search resulted in few articles. Therefore, this narrative review expanded its search to Google Scholar to review other published work on wetlands in Malawi. Grey literature from government agencies, internationally recognised websites like Ramsar and working papers were utilised. Grey literature increases the scope of information as it contains data that might not be published due to its null/negative results, thereby reducing biasness (Pappas and Williams, 2011). Further, grey literature gives more recent data, which is mostly provided by experts from the field, which reduces time lag

in accessing emerging issues (Haddaway and Bayliss, 2015).

The key search terms for the study were; Status of wetlands in Malawi, Wetlands Degradation in Malawi, Utilisation of wetlands in Malawi, Pressures on Wetlands

in Malawi and Access to Wetlands. The articles for review were selected for inclusion by evaluating the titles of the articles that the broader search produced. The articles which did not meet the inclusion criteria of having either Malawi, Pressures, Degradation or Wetland in their title were excluded. The remaining articles were subsequently screened by reviewing their abstracts to assess their relevance to the research question concerning the drivers and pressures influencing wetland degradation in Malawi. Articles that did not address these aspects were excluded from the review. The Final list of articles was then examined in full to determine if they had relevant data. Finally, the data collected from the chosen articles was summarised, explaining in detail the significance of wetlands degradation and underlying drivers and pressure on wetlands.

3. Results

The search managed to retrieve 69 articles. Of the 69 articles retrieved, eleven articles were excluded as they were duplicates. The remaining 58 articles were subjected to preliminary screening based on their titles; 42 articles were excluded using this criterion. Abstracts of the remaining 16 articles were reviewed for relevance to drivers and pressures of wetland loss in Malawi, leading to the exclusion of 10 articles. Of the 69 articles that were retrieved, only 6 articles qualified for detailed review as per the objective of the search. Table 1 summarises the selected studies.

The studies returned by the search only represented three of Malawi's wetlands, located in two regions of Malawi (South and Central). Lake Chilwa, Elephant Marsh and Kasungu floodplains are distributed across 7 of Malawi's 28 districts. Five were peer reviewed articles; one was a commissioned report for Ramsar site preparation.

3.1 Key drivers identified

Findings from the narrative review identified six primary drivers contributing to wetland degradation in Malawi:

3.1.1. Population Growth

Population growth was identified as a driver in all six reviewed articles. Malawi experienced a population increase of 35% between 2008 and 2018, representing an annual growth rate of 2.8% (Government of Malawi, 2018). Rapid population growth has resulted in increased pressure on wetland from unsustainable agricultural practices (Brown et al., 2022; Schuyt, 2005).

3.1.2. Poverty

Poverty was cited in five of the reviewed studies. Over 70% of Malawians live below the poverty line (Xu et al.,

2019) and wetland resources are often overutilised by impoverished people, leading to its degradation (Kosamu et al., 2012).

S/N	Study Title	Location	Author, Publication Year
1	Climate Resilient Livelihoods and Sustainable Natural Resource Management in The Elephant Marsh, Malawi.	Elephant Marsh Wetland	Branch, 2016
2	Conditions for Sustainability of the Elephant Marsh Fishery in Malawi.	Elephant Marsh	Kosamu, 2014
3	Common Pool Resource Management in Lake Chilwa, Malawi: A Wetland Under Pressure.	Lake Chilwa Wetland	Mvula and Haller, 2009
4	Riparian Ecosystems Resilience and Livelihoods Strategies Under Test: Lesson from Lake Chilwa in Malawi and Other Lakes in Africa.	Lake Chilwa Wetland	Kafumbata, Jamu and Chiotha, 2014
5	Economic Consequences of Wetlands Degradation for Local Populations in Africa.	Lake Chilwa Wetland	Schuyt, 2005
6	Enhancing Sustainable Agriculture and Wetlands Interaction in Small Inlands Wetland Systems.	Kasungu inland flood plains	Wood, 2011

3.1.3. Government Policies and Programs

Three studies identified government policies and programs as contributing factors. Policy direction on development activities puts pressure on the extent of utilisation of wetland resources (Wood, 2011).

3.1.4. Hydropower and irrigation development

Water abstraction from upstream sources due to irrigation and hydro power generation was cited in three studies as a major threat. Excessive withdrawal of water is a pressure that impacts the hydrological flows of wetlands, thereby impacting their ecological integrity and negatively affecting species dependent on consistent water flows (Brown et al., 2022; Kafumbata et al., 2014).

3.1.5. Climate change

Climate change was cited in three articles as a driver of wetland degradation by increasing frequency of droughts and dry spells, resulting in drying and water stress of wetlands (Jørstad and Webersik, 2016). Lake Chilwa has been recorded as the wetland most affected by climate change in Malawi (Kafumbata et al., 2014), having experienced substantial fluctuations in water levels associated with droughts, erratic rainfall, and flooding events, resulting in adverse effects on aquatic habitats and the ecosystem services. Areas that rely on wetlands as a means of climate adaptation, like Simulemba in Kasungu, have also suffered due to wetland degradation caused by climate change (Wood, 2011).

3.1.6. Commercial Agriculture

Commercial agriculture was noted in two articles as a driver of wetland degradation. The pressures of agro-chemical and population increase as a result of the establishment of commercial farms poses a threat to wetlands (Brown et al., 2022).

3.1.7. Invasive Alien Species

Invasive alien species were highlighted in one study as a driver on wetland biodiversity loss. These species

outcompete native species in wetlands, which puts pressure on the ecosystems structure, thereby deteriorating habitat quality (Branch, 2016).

4. Discussion

This review sets out to identify and analyse the primary drivers and pressures contributing to wetland degradation in Malawi. The reviewed studies provide a comprehensive understanding of the multiple anthropogenic and environmental pressures acting on wetlands, and the underlying socio-economic and policy drivers. Seven major drivers were identified and are discussed together with the pressures arising from each, in order of significance.

4.1.1. Population growth

The identification of population growth as the most important driver reflects the rapid growth that has significantly increased pressure on Malawi's wetlands (Brown et al., 2022). Rising population has led to the pressure of increased food demand, prompting the expansion of agricultural activities into wetland areas (Schuyt, 2005). Similar trends have been reported in the Kilombero Wetland in Tanzania, where over 50% of the area has been converted to agriculture due to population pressure (Materu et al., 2018). The loss of wetland area compromises the provision of essential ecosystem services (Koko et al., 2020). For example, intensive cultivation within wetlands results in soil erosion and sedimentation (Mvula and Haller, 2009), degrading habitat quality. Increasing sediment loads can have multiple negative impacts, such as altering important migration stopover points for the *Rynchops flavirostris* (African Skimmer), a species sought after by birdwatchers (Branch, 2016), as well as disrupting fish spawning grounds (Kakuru et al., 2013). Such impacts on ecosystem services could

ultimately lead to a reduction in the quality of life for the human populations who depend on these wetlands.

4.1.2. Population growth

With over 70% of Malawians living below the international poverty line of \$1.90 per day (Machira et al., 2023), dependence on wetlands for subsistence is high, resulting in the high importance of poverty as a driver. In their efforts to meet basic needs, impoverished communities often overexploit wetland resources (Kosamu et al., 2012). This means that pressures from unsustainable fishing methods, including the use of gill nets and mosquito nets, have decimated fish populations and inadvertently

harmed non-target species, such as the *Nettapus auritus* (pygmy goose) in the Elephant Marsh (Brown et al., 2022). Overfishing also reduces food availability for predators like the *Haliaeetus vocifer* (fish eagle) and the *Crocodylus niloticus* (Nile crocodile) in the Elephant Marsh (Brown et al., 2022; Kosamu, 2014). Poaching is another pressure arising from extreme poverty; for instance, the *Hippopotamus amphibius* (hippopotamus) population in the Lake Chilwa Wetland has been nearly extirpated due to poaching (Kafumbata et al., 2014; Mvula and Haller, 2009). Similar poverty-driven degradation patterns have been reported in Zimbabwe and Kenya (Mahlatini et al., 2020; Terer et al., 2004) and demonstrate that this is a pervasive regional driver.

4.1.3. Hydropower and Irrigation Development

Malawi faces a pressing need to provide sufficient food and energy for its population. Currently, only about 15% of Malawians are connected to the national electricity grid. To address this energy deficit, the government has been developing hydropower stations, while on the food security front, irrigation has been promoted to increase agricultural productivity. However, both hydropower generation and irrigation development have emerged as major hydrological drivers of wetland degradation. Excessive water withdrawals from upstream areas for irrigation alter natural flow regimes, thereby reducing water availability within wetlands (Brown et al., 2022). This disrupts ecological processes and affects species dependent on water flows (Kafumbata et al., 2014). In the Lake Chilwa Wetland, upstream irrigation activities have reduced inflows, leading to declining fish populations (Kafumbata et al., 2014). Similarly, the Elephant Marsh, which depends on the Shire River for its hydrological regime, faces increasing pressure from upstream water abstractions and flow regulation associated with hydropower and irrigation schemes along the river. Three hydropower stations are currently operational, and construction will soon begin on a fourth. The Shire Valley Transformation Programme is also developing a 43,000-hectare irrigation scheme on the same Shire River (Shire Valley Transformation Program - Phase 1 - 2023). These developments risk further altering the hydrological regime of the wetland and highlight the potential for irrigation and hydro power generation developments to become increasingly important drivers of wetland degradation.

4.1.4. Government Policies and Programmes

Government initiatives, while aimed at addressing food insecurity and poverty, have unintentionally driven wetland degradation. Following the 2000/01 droughts, Malawi promoted irrigation as a strategy to boost food production (Wood, 2011). Wetlands specifically faced the

pressure of being targeted for irrigation development and, in Lake Chilwa alone, 2,000 acres were converted for this purpose (Mvula and Haller, 2009; Schuyt, 2005). Fertilizer subsidy programmes further incentivized winter cropping, primarily conducted in wetlands (Wood, 2011). This intensification of agriculture introduces agrochemicals into wetland ecosystems, harming aquatic fauna (Kosamu, 2014). Current agricultural programmes lack adequate provisions to protect the ecological integrity of wetlands

(Kosamu, 2014). Similar outcomes have been observed in Tanzania and Zimbabwe, where wetlands targeted for agricultural expansion under poverty alleviation programmes experienced degradation (Mahlatini et al., 2020; Materu et al., 2018). Wood et al (2025) discuss the policy tension between conservation and livelihood development in wetlands and call for the need to balance wetland protection and local needs, preventing a strong 'conservationist perspective', which has affected promotion of multiple wetlands uses. This demonstrates that absence of policy direction in wetland use continues to be a driver of wetland degradation.

4.1.5. Climate Change

Climate change has increased the frequency of droughts, floods and dry spells, leading to the drying of wetlands and water stress (Chiotha et al., 2017). This has caused wetland degradation and the loss of critical ecosystem services, undermining nutrient cycling and hydrological regulation, which are essential for agriculture and fishing (Makwinja et al., 2024). Droughts have reduced water volumes or caused complete drying of wetlands; for instance, Lake Chilwa Wetland has dried up on several occasions (Kafumbata et al., 2014). Similarly, high evapotranspiration rates have been reported at Elephant Marsh (Makwinja et al., 2024).

Reduced hydrological flow in wetlands negatively affects crop and fish production, thereby impacting the livelihoods of local communities (Kafumbata et al., 2014). As a coping mechanism to climate induced droughts, communities often cultivate along the edges of wetland basins in search of residual moisture (Branch, 2016). This practice leads to siltation, agro-pollution, sedimentation and loss of wetland marshes, thereby further degrading the wetland and reducing ecosystem services (Makwinja et al., 2024).

Although wetlands are considered an adaptation option in Malawi, (Jørstad and Webersik, 2016) emphasize the need to identify additional adaptation strategies, as wetlands are increasingly threatened by climate change, making them unpredictable and unreliable. Communities that depend on wetlands for climate change adaptation are particularly affected by wetland degradation (Chiotha et al., 2017; Jørstad and Webersik, 2016), highlighting the need for multiple, complementary adaptation options and

recognition that climate change is a driver of wetland degradation.

4.1.6. Commercial Agriculture

Commercial farming operations are emerging as localized but significant drivers of wetland degradation

(Brown et al., 2022). In the Elephant Marsh, the proximity of the Illovo Sugar Plantations poses risks of agrochemical runoff, though direct impacts are yet to be documented (Branch, 2016). Pressures from the use of heavy machinery and land clearance threatens indigenous vegetation and disrupts natural wetland functions (Brown et al., 2022; Mvula and Haller, 2009). Moreover, employment opportunities associated with commercial agriculture attract migrants, leading to local population increases, which in turn place additional pressure on nearby wetlands such as Lake Chilwa and the Elephant Marsh (Branch, 2016).

4.1.7. Invasive Alien Species

While not identified here as a leading driver, the spread of invasive alien species is increasingly recognised as an emerging threat to wetland ecosystems in Malawi (Branch, 2016). In the Elephant Marsh, invasive plants such as *Pistia stratiotes* (Water Lettuce), *Azolla filiculoides* (Waterfern), and *Pontederia crassipes* (Water Hyacinth) have been reported in abundance (Branch, 2016). These species alter habitat structure, reduce water quality, and diminish the availability of suitable habitat for birds like the pygmy goose, as well as for aquatic invertebrates and fish (Branch, 2016). In the Lake Chilwa Wetland, *Prosopis Juliflora* (Mesquite) and *Pontederia crassipes* (Water Hyacinth) obstruct sunlight penetration, inhibiting photosynthesis and reducing biodiversity (Schuyt, 2005).

4. Limitations of the Study

This review is subject to limitations. First, the search returned a small number of peer-reviewed literature on wetlands in Malawi. Secondly the geographic focus of the reviewed studies was biased toward southern Malawi, particularly Lake Chilwa and Elephant Marsh, leaving central and northern wetlands underrepresented. The small sample size means that the relative importance of key drivers (e.g. invasive species) may be underestimated. Further, important but localized pressure may have been overlooked due to geographic biases.

5. Conclusion

The literature review has identified key drivers and pressures of wetland degradation and how these are impacting wetlands values in three major wetlands in Malawi. Wetland degradation in Malawi is driven by a complex interplay of socio-economic, policy and environmental factors. High poverty levels and rapid population growth drive communities to overexploit wetland resources in pursuit of food security and livelihoods. In response to food insecurity, government has developed policies and programs to avert hunger. However, these programs have resulted in unintended negative consequences on wetlands. These human and policy pressures are further compounded by environmental factors such as climate change, which accelerates wetland drying and exacerbates resource loss. Together, these socio-economic, policy and environmental dynamics interact to reinforce the cycle of wetland degradation.

6. Recommendations

Effective wetland conservation in Malawi requires a multi-level response that addresses drivers and direct pressures. This includes development of wetland policy that recognizes the multiple use values of wetlands and the need for its conservation. Farmers in wetland areas should adopt agriculture practices that reduce the need for increasing land areas for production. They should also cultivate high value crops that increase income for rural communities. Alternative livelihoods to agriculture should be promoted in wetland communities and there should be mainstreaming of wetlands issues in public and private sector investment and development programs. Other responses should be to improve governance and enforcement of environmental regulations, integration of wetland protection into broader land-use planning and recognition of wetlands in Strategic Environmental Assessment and Cumulative Assessments. Further research is needed in underrepresented regions and on the impacts of emerging threats such as invasive alien species and climate change.

7. Declaration

The authors declare no competing interests.

References

- Asselen, S.V., Verburg, P.H., Vermaat, J.E., Janse, J.H., 2013. Drivers of Wetland Conversion: a Global Meta-Analysis. *PLoS ONE* 8, e81292. <https://doi.org/10.1371/journal.pone.0081292>
- Bonaccio, M., Ruggiero, E., Di Castelnuovo, A., Costanzo, S., Persichillo, M., De Curtis, A., Cerletti, C., Donati, M.B., De Gaetano, G., Iacoviello, L., Iacoviello, L., Donati, M.B., De Gaetano, G., Vermeylen, J., De Paula Carrasco, I., Giampaoli, S., Spagnuolo, A., Assanelli, D., Centritto, V., Spagnuolo, P., Staniscia, D., Zito, F., Bonanni, A., Cerletti, C., De Curtis, A., Di Castelnuovo, A., Lorenzet, R., Mascioli, A., Olivieri, M., Rotilio, D., Bonaccio, M., Costanzo, S., Gianfagna, F., Giacci, M., Padulo, A., Petrarola,

- D., Magnacca, S., Marracino, F., Spinelli, M., Silvestri, C., dell'Elba, G., Grippi, C., De Lucia, F., Vohnout, B., Zito, F., Persichillo, M., Verna, A., Di Lillo, M., Di Stefano, I., Pampuch, A., Pannichella, A., Vizzarri, A.R., Arcari, A., Barbato, D., Bracone, F.,
- Di Giorgio, C., Panebianco, S., Chiovitti, A., Caccamo, S., Caruso, V., Rago, L., Cugino, D., Ferri, A., Castaldi, C., Mignogna, M., Guszcz, T., Di Giuseppe, R., Barisciano, P., Buonaccorsi, L., Centritto, F., Cutrone, A., Fanelli, F., Santimone, I., Sciarretta, A., Sorella, I., Plescia, E., Molinaro, A., Cavone, C., Galuppo, G., D'Angelo, D., Ramacciato, R., 2017. Fish intake is associated with lower cardiovascular risk in a Mediterranean population: Prospective results from the Moli-sani study. *Nutrition, Metabolism and Cardiovascular Diseases* 27, 865–873. <https://doi.org/10.1016/j.numecd.2017.08.004>
- Branch, W.R., 2016. Climate Resilient Livelihoods and Sustainable Natural Resource Management in The Elephant Marsh, Malawi: Biodiversity of the Elephant Marsh: Herpetofauna. <https://doi.org/10.13140/RG.2.1.3926.6803>
- Brown, C., Joubert, A., Turpie, J., Reinecke, K., Birkhead, A., Forsythe, K., Davies, T., Mgoola, W., Nyirenda, J., Arthur, R., 2022. The Elephant Marsh, Malawi – Part 3: the application of an eco-social model to assess options for managing ecological status. *African Journal of Aquatic Science* 47, 405–420. <https://doi.org/10.2989/16085914.2022.2044750>
- Chiotha, S., Jamu, D., Nagoli, J., Likongwe, P., Chanyenga, T., 2018. Socio-Ecological Resilience to Climate Change in a Fragile Ecosystem: The Case of the Lake Chilwa Basin, Malawi, 1st ed. Routledge. <https://doi.org/10.4324/9781351057103>
- Chiotha, S., Likongwe, P.J., Sagona, W., Mphepo, G.Y., Likoswe, M., Tsirizeni, M.D., Chijere, A., 2017. LAKE CHILWA BASIN CLIMATE CHANGE ADAPTATION PROGRAMME IMPACT: 2010 – 2017.
- Convention on Wetlands, Robertson, H., Fennessy, S., Hilton, G., Job, N., Kumar, R., Simpson, M., Aggestam, F., Aldred, M., Chacón, A., Costanza, R., Davidson, N., Field, C., Finlayson, C.M., Gandra, F., Gillis, L.G., Hernández-Blanco, M., Moritsch, M., Thornton, S., Wood, K., Van 'T Hoff, V., 2025. Global Wetland Outlook 2025: Valuing, conserving, restoring and financing wetlands. Convention on Wetlands. <https://doi.org/10.69556/GWO-2025-eng>
- Development Projects : Shire Valley Transformation Program - Phase 1 - P158805 [WWW Document], n.d. URL <https://projects.worldbank.org/en/projects-operations/project-detail/P158805> (accessed 3.7.24).
- Dzoga, M., Simatele, D.M., Munga, C., Yonge, S., 2020. Application of the DPSIR Framework to Coastal and Marine Fisheries Management in Kenya. *Ocean Sci. J.* 55, 193–201. <https://doi.org/10.1007/s12601-020-0013-y>
- Fatorić, S., Seekamp, E., 2017. Are cultural heritage and resources threatened by climate change? A systematic literature review. *Climatic Change* 142, 227–254. <https://doi.org/10.1007/s10584-017-1929-9>
- Forsythe, K., Turpie, J., 2016. Climate Resilient Livelihoods and Sustainable Natural Resource Management in The Elephant Marsh, Malawi.
- Government of Malawi, 2018. 2018 Population and Housing Census Preliminary Report.
- Haddaway, N.R., Bayliss, H.R., 2015. Shades of grey: Two forms of grey literature important for reviews in conservation. *Biological Conservation* 191, 827–829. <https://doi.org/10.1016/j.biocon.2015.08.018>
- Holland, I., DeVille, N.V., 2021. Measuring Nature Contact: A Narrative Review. *Int. J. Environ. Res. Public Health*.
- Jørstad, H., Webersik, C., 2016. Vulnerability to climate change and adaptation strategies of local communities in Malawi: experiences of women fish-processing groups in the Lake Chilwa Basin. *Earth Syst. Dynam.* 7, 977–989. <https://doi.org/10.5194/esd-7-977-2016>
- Kafumbata, D., Jamu, D., Chiotha, S., 2014. Riparian ecosystem resilience and livelihood strategies under test: lessons from Lake Chilwa in Malawi and other lakes in Africa. *Phil. Trans. R. Soc. B* 369, 20130052. <https://doi.org/10.1098/rstb.2013.0052>
- Kakuru, W., Turyahabwe, N., Mugisha, J., 2013. Total Economic Value of Wetlands Products and Services in Uganda. *The Scientific World Journal* 2013, 1–13. <https://doi.org/10.1155/2013/192656>
- Koko, I.A., Misana, S.B., Kessler, A., Fleskens, L., 2020. Valuing ecosystem services: stakeholders' perceptions and monetary values of ecosystem services in the Kilombero wetland of Tanzania. *Ecosystems and People* 16, 411–426. <https://doi.org/10.1080/26395916.2020.1847198>
- Kosamu, I., 2014. Conditions for Sustainability of the Elephant Marsh Fishery in Malawi. *Sustainability* 6, 4010–4027. <https://doi.org/10.3390/su6074010>
- Kosamu, I., De Groot, W., Kambewa, P., De Snoo, G., 2012. Institutions and Ecosystem-Based Development Potentials of the Elephant Marsh, Malawi. *Sustainability* 4, 3326–3345. <https://doi.org/10.3390/su4123326>

- Kundu, S., Kundu, B., Rana, N.K., Mahato, S., 2024. Wetland degradation and its impacts on livelihoods and sustainable development goals: An overview. *Sustainable Production and Consumption* 48, 419–434. <https://doi.org/10.1016/j.spc.2024.05.024>
- Machira, K., Mgonezulu, W.R., Malata, M., 2023. Understanding poverty dimensions and transitions in Malawi: A panel data approach. *Research in Globalization* 7, 100160. <https://doi.org/10.1016/j.resglo.2023.100160>
- Mahlatini, P., Hove, A., Maguma, L.F., Chemura, A., 2020. Using Direct Use Values for Economic Valuation of Wetland Ecosystem Services: A Case of Songore Wetland, Zimbabwe. *GeoJournal* 85, 41–51. <https://doi.org/10.1007/s10708-018-9947-3>
- Makwinja, R., Curtis, C.J., Tesfamichael, S.G., 2024. Vulnerability of Ecosystem Services and Functions of Elephant Marsh, Malawi, to Land Use and Land Cover Change. *Wetlands* 44, 102. <https://doi.org/10.1007/s13157-024-01860-1>
- Manda, L., Salako, K.V., Kataya, A., Affossogbe, S.A.T., Njera, D., Mgoola, W.O., Assogbadjo, A.E., Sinsin, B., 2023. Co-management brings hope for effective biodiversity conservation and socio-economic development in Vwaza Marsh Wildlife Reserve in Malawi. *Front. Conserv. Sci.* 4, 1124142. <https://doi.org/10.3389/fcsc.2023.1124142>
- Materu, S.F., Urban, B., Heise, S., 2018. A critical review of policies and legislation protecting Tanzanian wetlands. *Ecosyst Health Sustain* 4, 310–320. <https://doi.org/10.1080/20964129.2018.1549510>
- Mvula, P.M., Haller, T., 2009. Common pool resource management in Lake Chilwa, Malawi: a wetland under pressure. *Development Southern Africa* 26, 539–553. <https://doi.org/10.1080/03768350903181332>
- Ojala, M., Cunsolo, A., Ogunbode, C.A., Middleton, J., 2021. Anxiety, Worry, and Grief in a Time of Environmental and Climate Crisis: A Narrative Review. *Annu. Rev. Environ. Resour.* 46, 35–58. <https://doi.org/10.1146/annurev-environ-012220-022716>
- Pappas, C., Williams, I., 2011. Grey Literature: Its Emerging Importance. *Journal of Hospital Librarianship* 11, 228–234. <https://doi.org/10.1080/15323269.2011.587100>
- Pautasso, M., 2019. The Structure and Conduct of a Narrative Literature Review, in: Shoja, M., Arynchyna, A., Loukas, M., D’Antoni, A.V., Buerger, S.M., Karl, M., Tubbs, R.S. (Eds.), *A Guide to the Scientific Career*. Wiley, pp. 299–310. <https://doi.org/10.1002/9781118907283.ch31>
- Pullin, A., 2016. Selecting appropriate methods of knowledge synthesis to inform biodiversity policy. *Biodivers Conserv.*
- Schuyt, K.D., 2005. Economic consequences of wetland degradation for local populations in Africa. *Ecological Economics* 53, 177–190. <https://doi.org/10.1016/j.ecolecon.2004.08.003>
- Terer, T., Ndiritu, G.G., Gichuki, N.N., 2004. Socio-economic values and traditional strategies of managing wetland resources in Lower Tana River, Kenya. *Hydrobiologia* 527, 3–15. <https://doi.org/10.1023/B:HYDR.0000043332.96368.c5>
- Wood, A., 2011. Enhancing sustainable Agriculture-Wetland Interactions in the small inland wetland systems of Malawi.
- Wood, A., Thawe, P., Snell, M., 2025. Analysing wetland enterprise in northern Malawi using a modified community capitals framework: the case of garlic farming. *Journal of Rural Studies* 119, 103780. <https://doi.org/10.1016/j.jrurstud.2025.103780>
- Xu, T., Weng, B., Yan, D., Wang, K., Li, X., Bi, W., Li, M., Cheng, X., Liu, Y., 2019. Wetlands of International Importance: Status, Threats, and Future Protection. *IJERPH* 16, 1818. <https://doi.org/10.3390/ijerph16101818>

Urban tree cover improves breeding bird abundance across all public cemeteries in one of Europe's largest cities

Alistair Marjot¹ and Patrick J. C. White^{1,2}

¹ School of Applied Sciences, Edinburgh Napier University, Edinburgh, UK

² Centre for Conservation & Restoration Science, Edinburgh Napier University, Edinburgh, UK

Email:

alistair.marjot@gmail.com

Received: September 2025

Accepted for publication: February 2026

Published: July 2026

Abstract

Urbanisation can lead to the destruction and fragmentation of natural landscapes, significantly reducing biodiversity and disrupting ecological functions and services. Green spaces within cities, including cemeteries, act as refuges for urban biodiversity and provide vital habitats for various taxonomic groups, such as birds. Understanding how local and landscape factors influence biodiversity in urban cemeteries is essential to inform effective conservation efforts. This study assessed breeding bird abundance, richness, and diversity across all of Munich's public cemeteries during May and June 2022. The influence of local variables (cemetery size and tree cover) and landscape variables (tree cover and road cover within a 1 km radius) was analysed using GIS. Surprisingly, none of these explanatory variables had a strong effect on species richness, species diversity, or taxonomic diversity. This may indicate the need to examine other spatial scales or use different measures of urbanisation. However, bird abundance within fixed-radius point counts in the largest and most densely wooded cemeteries was approximately two-thirds greater than in the smallest and least densely wooded cemeteries, indicating that both area and tree cover are critical for supporting bird populations. These findings highlight trees as key habitat features in urban cemeteries, suggesting that tree conservation and health should be top priorities for urban green space management. This further supports the need to conserve urban trees for the multiple benefits they provide to human residents. Further research into the functional diversity of urban cemetery birds and the influence of cemetery tree age on these avian communities is warranted.

Keywords: Avian ecology, avifauna, tree cover, urban ecology, urban green spaces, urbanisation.

1. Introduction

In highly urbanised landscapes, such as cities, semi-natural habitat patches that have been left relatively undisturbed are of great conservation importance (Löki *et al.*, 2019; Ramírez-Albores *et al.*, 2024). Commonly referred to as urban green spaces, these patches are open or semi-open green areas, containing vegetation and other resources that provide suitable habitat for urban flora and fauna (Curzel *et al.*, 2021). These spaces are also of great importance to humans in terms of their social value as public areas that contribute significantly to mental well-being of urban residents (Botzat *et al.*, 2016). The importance of this ecosystem service became even more apparent during the COVID-19 pandemic (Ugolini *et al.*,

2020). Examples include wooded streets (Curzel *et al.*, 2021), parks (Godoy *et al.*, 2024), allotments (Korányi *et al.*, 2021), urban forests (de Groot *et al.*, 2021), sacred sites such as shrines and temples (Matsumoto *et al.*, 2024), and cemeteries (Villaseñor and Escobar, 2019). Cemeteries can be defined as “burial grounds, especially a large, landscaped park or ground laid out expressly for the deposition or interment of the dead, not being a churchyard attached to a place of worship” (Rugg, 2000, p. 260). Previous research has shown that cemeteries can represent key refuges for biodiversity in heavily urbanised areas (Barrett and Barrett, 2001; Čanádý and Mošanský, 2017; Tryjanowski *et al.*, 2017; Villaseñor and Escobar, 2019). The long-term existence and undisturbed status of many urban cemeteries allow them to support relatively high

biodiversity compared to surrounding urban land use types and therefore to act as biodiversity refuges in heavily urbanised landscapes (Löki *et al.*, 2019).

Recently, urban ecology research has attempted to categorise bird species based on their ability to exploit urban habitats and tolerate urban disturbances, broadly dividing species into one of three categories: urban avoiders, urban adaptors, and urban exploiters (Geschke *et al.*, 2018; Korányi *et al.*, 2021). For example, urban exploiters have generally been shown to have broader dietary niches than urban avoiders, allowing them to better utilise food resources provided by cities (Palacio, 2020). Urban avoiders, in contrast, include many tree-foraging and insectivorous species, which are better adapted to woody habitats (Korányi *et al.*, 2021). This contrasts with urban adaptors and exploiters, which are better adapted to make use of human-based resources, including an improved ability to breed successfully on artificial structures such as buildings (MacGregor-Fors and Schondube, 2011). This makes urban cemeteries, with their mixed habitat-matrix of semi-wooded grassland, heavily interspersed with human-made graveyard-related structures, unusual in their potential to host bird species from across these different urban-exploitation categories.

Species richness is a response variable frequently used to measure biodiversity in urban ecology research (Jiguet *et al.*, 2005). For most taxa, the main factors affecting species richness are habitat size, heterogeneity of the area, degree of isolation from other similar habitat patches, and the productivity and age of the area (MacArthur and Wilson, 1967). Previous studies of bird communities in urban green spaces have mainly focused on determining how bird species richness is affected by certain explanatory variables, including patch-level attributes (local to each site) and landscape attributes. Commonly studied patch-level variables include green space type (de Groot *et al.*, 2021; Korányi *et al.*, 2021; Morelli *et al.*, 2018), site size (Dale, 2018; Leveau, 2021; Oliver *et al.*, 2011), vegetation (tree and shrub) coverage (Callaghan *et al.*, 2018; Morelli *et al.*, 2018; Villaseñor and Escobar, 2019), tree richness (Oropeza-Sánchez *et al.*, 2024), and age of trees (Tryjanowski *et al.*, 2017). Commonly studied landscape variables, on the other hand, include isolation (Dale, 2018), degree of urbanisation around the site (Korányi *et al.*, 2021; Oliver *et al.*, 2011; Villaseñor and Escobar, 2019), and vegetation coverage around the site (Callaghan *et al.*, 2018; Villaseñor and Escobar, 2019).

However, species richness is not the only response variable that has been studied in urban ecology research on bird communities in urban green spaces. For example, abundance is another measure that has been used to investigate how local and landscape drivers affect bird communities in urban environments (Mayorga *et al.*, 2020; Tryjanowski *et al.*, 2017; Villaseñor and Escobar, 2019). Similarly, species diversity (Callaghan *et al.*, 2018;

Tryjanowski *et al.*, 2017) and taxonomic diversity (Curzel *et al.*, 2021; Morelli *et al.*, 2018) are diversity indices that have commonly been used to investigate the influence of size-, local-, and landscape-level habitat factors on bird communities in urban green spaces.

The objective of this study was to broadly quantify the avian diversity of cemeteries within a major urban area and to investigate how this avian diversity relates to environmental characteristics at the patch level (local, within-site variables) and at the landscape level. Specifically, this study assessed how well the abundance, species richness, species diversity, and taxonomic diversity of breeding bird communities within Munich's urban cemeteries can be predicted by local variables (cemetery size and cemetery tree cover) and landscape variables (tree cover and road cover within 1 km of the cemetery). This study aimed to test the hypothesis that these diversity indices are significantly related to the local and landscape variables outlined above, as well as to combinations of, and interactions between, these local and landscape variables.

2. Materials and methods

2.1 Study area

This study was carried out in Munich, Bavaria, Germany (contextual information about the city provided in Supplementary Material 1). In total, the city contains approximately 30–40 public and private cemeteries, varying in size from less than 0.5 ha to approximately 50 ha, with the exception of the 160 ha Waldfriedhof forest cemetery (not included in this study for reasons discussed later). The cemeteries included in this study are typically made up of a matrix of lightly wooded areas and more open, lawned green spaces. They are dominated at ground level by a variety of stone structures (e.g. headstones, statues, and occasionally larger tombs) arranged in a regular pattern across large areas of the cemetery (example photographs provided in Supplementary Material 2).

2.2 Study design

In total, 23 urban cemeteries in the city of Munich were selected for bird surveys in this study (see Figure 1). These cemeteries were identified as being suitable for this study for several reasons. First, all cemeteries surveyed are classed as public cemeteries, meaning they are freely accessible to the public and open at 8:00 a.m. This allowed all surveys to be conducted at a favourable time (consistent with other urban bird studies), as the optimum time for bird surveys is during the 3–4-hour window after sunrise, when birds are most active and vocal, ensuring the highest

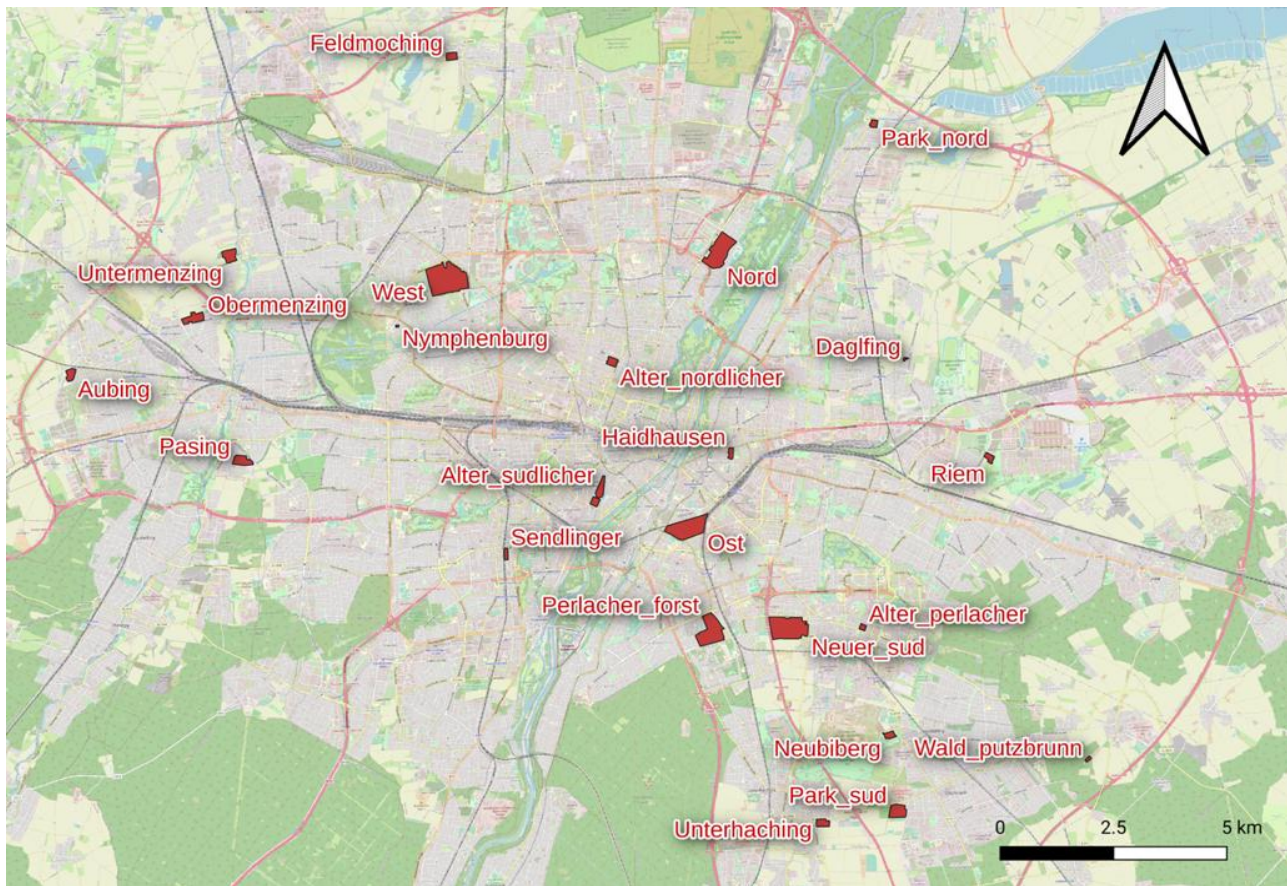


Figure 1. A map showing all 23 Munich cemeteries selected for bird surveys for this study, with these cemeteries being shown in red. Other Munich cemeteries not selected for this study, of which there are very few, are not shown. The outer motorway ring road can be clearly seen, and all cemeteries surveyed are located within this ring road. Map created using QGIS (QGIS Development Team, 2022) and OpenStreetMap (OpenStreetMap contributors, 2022).

detectability (Bibby *et al.*, 2000). Second, all cemeteries surveyed are located within the outer motorway ring road, as beyond this the land use changes markedly and rapidly from an urban landscape (the focus of this study) to an agricultural one. Further study design choices and justifications can be found in Supplementary Material 3.

2.3 Extraction of local and landscape variables using GIS

The area of each cemetery was calculated using Quantum Geographic Information System (QGIS) and the road density within 1 km of each cemetery was calculated using QGIS and the Urban Atlas 2018 map provided by the Copernicus Land Monitoring Service (Copernicus Land Monitoring Service, 2022). Finally, tree cover within the 50 m point count radius, cemetery tree coverage and tree coverage within 1 km of each cemetery were calculated using QGIS and the Street Tree Layer (STL) 2018 map (see Figure 2) provided by the Copernicus Land Monitoring Service. To study the effect of local and landscape variables on the richness and diversity of cemetery birds, cemetery area, 50 m point count radius tree cover and cemetery tree cover were used as local variables and tree and road cover (within a 1 km buffer) were used as landscape variables (Figure 2b). Further justifications for this 1 km buffer can be found in Supplementary Material 4.

Bird species richness and diversity have been shown to be positively related to green space area (Mayorga *et al.*, 2020; Pirzio Biroli *et al.*, 2020), as well as vegetation (tree and shrub) coverage (Callaghan *et al.*, 2018; Morelli *et al.*, 2018; Villaseñor and Escobar, 2019), and therefore this study aimed to find out if these relationships also held true for urban cemeteries. As urbanisation has been frequently shown to reduce bird species richness (Batáry *et al.*, 2018; Clergeau *et al.*, 2006), this study used road cover as a landscape variable, since this provided a measure of the level of urbanisation surrounding each cemetery. However, some studies have not found such an effect (Korányi *et al.*, 2021), so this study aimed to investigate whether the level of urbanisation surrounding cemeteries might affect bird species richness and diversity. Road cover was assumed to provide an accurate measure as the area of the roads was also taken into account (i.e. roads are treated as two-dimensional polygons rather than as simple one-dimensional linear structures) and therefore larger roads, which are likely to be busier, faster, and more noisy, potentially providing a greater disturbance to birds in more highly urbanised areas, were accounted for by using road cover as an explanatory variable.

2.4 Bird surveys and diversity indices

One observation point, located as close to the centre of each cemetery as possible, was assigned per cemetery. This

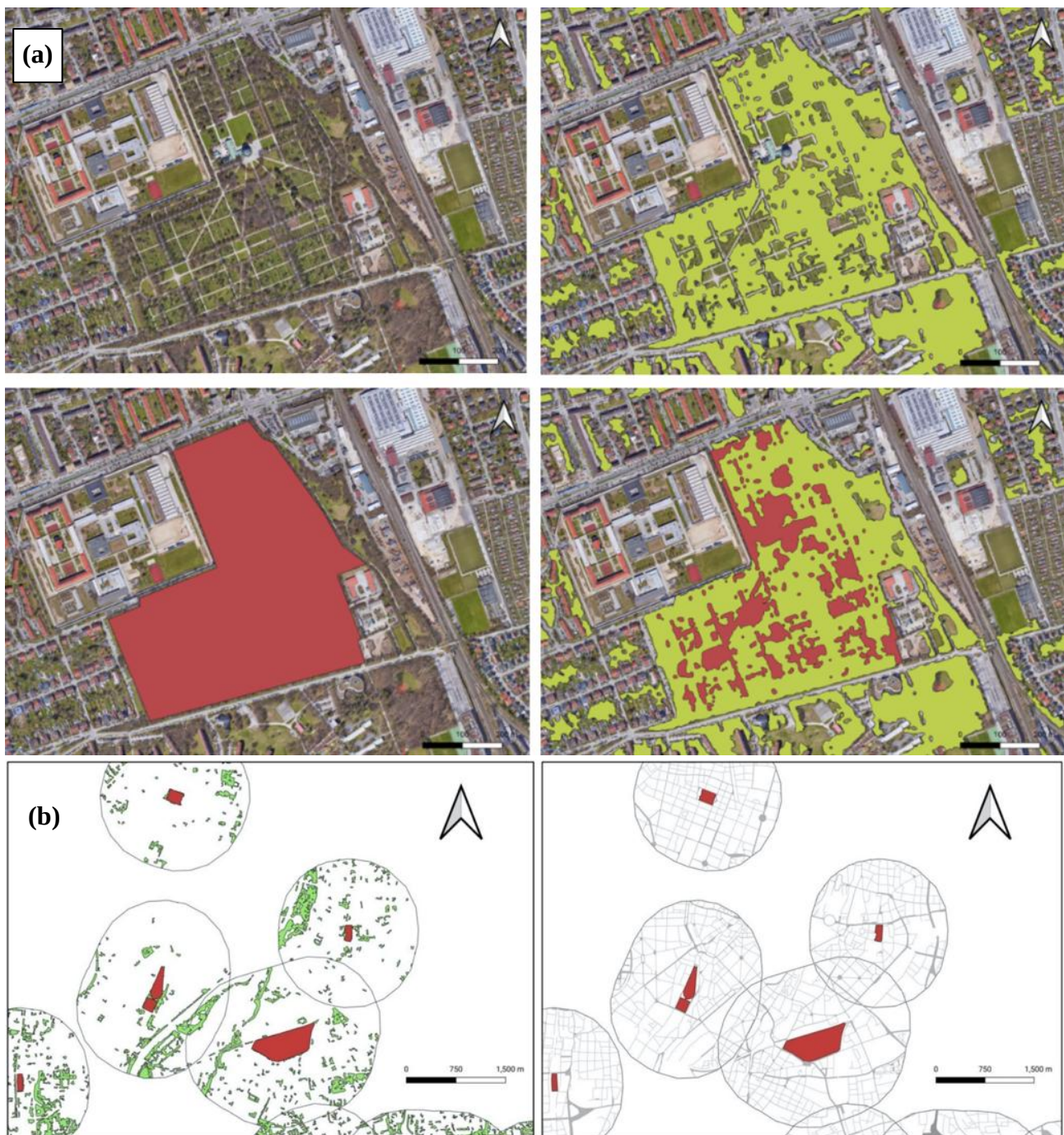


Figure 2. Examples of how local and landscape variables were extracted using GIS, including: **(a)** Street Tree Layer (STL) 2018 map (Copernicus Land Monitoring Service, 2022) being used to calculate within-cemetery tree cover for a Munich urban cemetery (Friedhof am Perlacher Forst)—top left: satellite image of cemetery, top right: STL overlay, bottom left: cemetery polygon (also used to calculate area), bottom right: cemetery polygon with STL overlay (ready for analysis in QGIS). Maps created using QGIS (QGIS Development Team, 2022), and Google Maps (Google, 2022). **(b)** 1 km buffers being used to measure the tree and road cover surrounding each cemetery—left: tree cover within 1 km, calculated using the Street Tree Layer 2018 map (Copernicus Land Monitoring Service, 2022), right: road cover within 1 km, calculated using the Urban Atlas 2018 map (Copernicus Land Monitoring Service, 2022). Maps created using QGIS (QGIS Development Team, 2022).

was done to minimise edge effects of external disturbances, such as traffic, that could negatively affect bird detection. All cemeteries were surveyed twice during the survey period, which was the second half of May (the month of peak breeding activity) and the first half of June. All surveys were conducted between 08:00 and 10:00 on clear windless days (DeGraaf *et al.*, 1991), which helped to ensure birds were not sheltering during surveys, maximising detectability. Two surveys were conducted per cemetery (with the data then being pooled across both

surveys) as a precautionary measure to mitigate the impact of any fluctuations in factors such as the time at which the survey was conducted, the temperature, or any unexpected circumstances or disturbances such as funerals being held (which did occur once) or cemetery grounds-keeping and maintenance taking place (which occurred several times). Fixed-radius point counts were conducted by entering the observation point, waiting for one minute (Korányi *et al.*, 2021), and then recording all birds heard or seen within a 50 m radius for 15 minutes (Jiguet, 2009). Further

information and justifications for 50 m point counts are provided in Supplementary Material 5.

Several diversity indices were then calculated from the pooled data for each cemetery, including observed species richness (S_{obs}), Chao1 estimated species richness (S_{est}) for pooled data, Simpson’s Index of diversity ($1 - D$), and taxonomic diversity (Δ). Total abundance of birds was also calculated for each cemetery. Further information and justifications for chosen diversity indices are provided in Supplementary Material 6.

2.5 Statistical analysis

First, all variables were checked for any pronounced skew by plotting the histograms and judging these by eye.

Cemetery area (measured in hectares) showed strong positive skew with a large number of smaller cemeteries and a small number of much larger cemeteries (see Figure 1). Area was therefore natural log-transformed, which is a common transformation with positively skewed data (West, 2021) after which it showed a more symmetrical distribution. Multicollinearity across the five explanatory variables was then tested, as correlation between explanatory variables can make it difficult to interpret results of the statistical analyses used subsequently; for example, by decreasing the reliability of model parameter estimates (Alin, 2010). VIFs (Variance Inflation Factors) were calculated on the predictor set using the ‘car’ package in R (Fox and Weisberg, 2019). A VIF was calculated for each explanatory variable. Although less conservative

Table 1. Candidate set of *a priori* hypotheses and associated models for predicting the response variables: abundance, Chao1 species richness, Simpson’s diversity, and taxonomic diversity (Δ), from four explanatory variables: cemetery size, cemetery tree cover, 1 km tree cover and 1 km road cover.

Model	Explanatory variables	Hypotheses: Abundance/Chao1 species richness/Simpson’s diversity/taxonomic diversity (Δ) is predicted by...
1	(Null model)	...none of the variables measured
2	Area	...the size of the cemetery
3	Cemetery tree cover	...tree cover within the cemetery
4	1 km tree cover	...tree cover within 1 km of the cemetery
5	1 km road cover	...road cover within 1 km of the cemetery
6	Area + cemetery tree cover	...the size of the cemetery and tree cover within the cemetery
7	Area + 1 km tree cover	...the size of the cemetery and tree cover within 1 km of the cemetery
8	Area + 1 km road cover	...the size of the cemetery and road cover within 1 km of the cemetery
9	Cemetery tree cover + 1 km tree cover	...tree cover within the cemetery and tree cover within 1 km of the cemetery
10	Cemetery tree cover + 1 km road cover	...tree cover within the cemetery and road cover within 1 km of the cemetery
11	1 km tree cover + 1 km road cover	...tree and road cover within 1 km of the cemetery
12	Area * cemetery tree cover	...the interaction between the size of the cemetery and tree cover within the cemetery
13	Area * 1 km tree cover	...the interaction between the size of the cemetery and tree cover within 1 km of the cemetery
14	Area * 1 km road cover	...the interaction between the size of the cemetery and road cover within 1 km of the cemetery
15	Cemetery tree cover * 1 km tree cover	...the interaction between tree cover within the cemetery and tree cover within 1 km of the cemetery
16	Cemetery tree cover * 1 km road cover	...the interaction between tree cover within the cemetery and road cover within 1 km of the cemetery
17	1 km tree cover * 1 km road cover	...the interaction between tree and road cover within 1 km of the cemetery

thresholds may be used, VIF values of > 2.5 are generally considered to indicate “considerable collinearity” (Johnston *et al.*, 2018). Since VIF for a predictor can change depending on which other variables are present in the predictor set, we took a stepwise approach, removing the predictor with the highest VIF that was > 2.5 , where applicable, then recalculating VIFs of remaining variables, and repeating if necessary. When the variable with the highest VIF that exceeded this threshold (50 m tree cover; $VIF = 4.65$) was removed from the global model, all recalculated VIFs were below 2.5. This indicated that multicollinearity between the remaining four explanatory variables could now be assumed to be sufficiently low so as not to bias the interpretation of all subsequent models. Additionally, a correlation matrix for the remaining explanatory variables was produced, with Pearson correlation coefficients for all pairwise combinations of explanatory variables being ≤ 0.50 .

Next, four candidate sets of generalised linear models were created. Apart from using a different response variable each time, these four candidate sets of models contained the same seventeen models (see Table 1 for an example candidate model set). Models were fitted with normal errors and identity-link functions. We tested the

assumption of normality of residuals visually on quantile-quantile plots (White *et al.*, 2019) and the residuals were approximately normally distributed. The four candidate model sets were then used to explore how well each of the four response variables (abundance, species richness, species diversity and taxonomic diversity) could be predicted from the four explanatory variables, as well as from pairwise combinations and first-order interactions between these explanatory variables. For the model comparison approach taken in this study, higher values for the ratio of sample size to number of parameters to be estimated ($N:q$) are typically preferred (Jackson, 2003). For this reason, models containing three- or four-way combinations and second- or third-order interactions between explanatory variables were not included in the candidate sets, as the number of parameter estimates required for such models would be too high relative to the sample size used in this study. Each candidate model set was created based on *a priori* hypotheses (see Table 1). A null (no terms) model was also included in each candidate model set. Using the ‘MuMIn’ package in R (Barton, 2018), all models in each candidate set were ranked according to their small-sample Akaike information criterion (AICc), with inferences then being taken from any models in the confidence set of $AICc \leq 2$ (Anderson and Burnham, 2002;

Johnson and Omland, 2004). We also reported Akaike's weights which represent the relative likelihood of each model given the data (Johnson and Omland, 2004). As we were dealing with spatial data, we checked for spatial autocorrelation of model residuals using the 'ncf' package in R (Bjørnstad, 2022). We plotted spline correlograms with Moran's *I* to see if model residuals showed significant correlation with distance between cemeteries, with cemetery centres plotted as UTM coordinates (zone 32N covering Munich).

The R package 'sjPlot' (Lüdecke, 2021) was used to plot all models in the confidence set of $AICc \leq 2$, as well as to plot marginal effects (i.e., the effects when covariates are

kept constant). Finally, for models in the confidence set containing multiple explanatory variables, the 'tab model' function of the R package 'sjPlot' (Lüdecke, 2021) was used to calculate standardised beta estimates (β) to help compare effect sizes of the explanatory variables within these models. Using the 'MuMIn' package, we also calculated model-averaged parameter estimates and standard errors weighted by each model's Akaike's weight (w_i), as well as relative variable importance, which is the sum of model weights over all models that include each explanatory variable (Barton, 2018).

Table 2. A list of all the bird species observed during this study, along with their total abundance across all surveys, their abundance as a percentage of the total number of birds observed across all surveys, and the proportion of cemeteries in which they were observed. The species in this table have been ranked first by proportion of cemeteries in which observed, then by abundance. Species observed in >90% of cemeteries are shown in bold.

Scientific name	Species name	Total number observed across all cemeteries	As a percentage of all birds observed	Proportion of cemeteries in which observed
<i>Turdus merula</i>	Common blackbird	162	17.3	1.00
<i>Parus major</i>	Great tit	103	11.0	1.00
<i>Sylvia atricapilla</i>	Eurasian blackcap	94	10.1	1.00
<i>Corvus corone</i>	Carrion crow	77	8.2	0.96
<i>Cyanistes caeruleus</i>	Eurasian blue tit	81	8.7	0.91
<i>Phylloscopus collybita</i>	Common chiffchaff	51	5.5	0.91
<i>Fringilla coelebs</i>	Common chaffinch	99	10.6	0.87
<i>Dendrocopos major</i>	Great spotted woodpecker	38	4.1	0.83
<i>Erithacus rubecula</i>	European robin	34	3.6	0.70
<i>Columba palumbus</i>	Common woodpigeon	32	3.4	0.61
<i>Carduelis carduelis</i>	European goldfinch	23	2.5	0.48
<i>Chloris chloris</i>	European greenfinch	18	1.9	0.48
<i>Sitta europaea</i>	Eurasian nuthatch	18	1.9	0.39
<i>Troglodytes troglodytes</i>	Eurasian wren	22	2.4	0.35
<i>Certhia brachydactyla</i>	Short-toed treecreeper	17	1.8	0.35
<i>Turdus pilaris</i>	Fieldfare	7	0.7	0.13
<i>Garrulus glandarius</i>	Eurasian jay	5	0.5	0.13
<i>Picus viridis</i>	European green woodpecker	4	0.4	0.13
<i>Corvus frugilegus</i>	Rook	10	1.1	0.09
<i>Aegithalos caudatus</i>	Long-tailed tit	8	0.9	0.09
<i>Columba livia</i>	Domestic pigeon	7	0.7	0.09
<i>Muscicapa striata</i>	Spotted flycatcher	4	0.4	0.09
<i>Passer domesticus</i>	House sparrow	4	0.4	0.09
<i>Passer montanus</i>	Eurasian tree sparrow	4	0.4	0.09
<i>Periparus ater</i>	Coal tit	3	0.3	0.09
<i>Pica pica</i>	Eurasian magpie	2	0.2	0.09
<i>Pyrrhula pyrrhula</i>	Eurasian bullfinch	2	0.2	0.09
<i>Phoenicurus ochruros</i>	Black redstart	2	0.2	0.04
<i>Emberiza citrinella</i>	Yellowhammer	1	0.1	0.04
<i>Poecile montanus</i>	Willow tit	1	0.1	0.04
<i>Regulus regulus</i>	Goldcrest	1	0.1	0.04
<i>Turdus philomelos</i>	Song thrush	1	0.1	0.04

Variable importance in this context can be interpreted as the probability that a variable will be in the best model (Giam and Olden, 2015).

3. Results

3.1 Results overview

In total, 935 birds from 32 species were observed during the 46 bird surveys (see Table 2). The four most abundant species were the Common blackbird (*Turdus merula*) (162), the Great tit (*Parus major*) (103), the Common chaffinch (*Fringilla coelebs*) (99), and the Eurasian blackcap (*Sylvia atricapilla*) (94), each of which represented over 10% of all individuals observed. The species found in the highest proportion of cemeteries were the Great tit, Eurasian

blackcap, and Common blackbird, which were observed in all cemeteries surveyed (1.00), followed by the Carrion crow (*Corvus corone*) (0.96), Eurasian blue tit (*Cyanistes caeruleus*) (0.91) and Common chiffchaff (*Phylloscopus collybita*) (0.91).

The minimum and maximum values for all explanatory and response variables are shown in Table 3, along with the median and interquartile range (IQR) for each variable. The full results for each of these variables, for each cemetery surveyed, are available in Supplementary Material 7. In terms of the response variables, abundance and estimated species richness were relatively variable, varying by approximately a factor of two between the minimum and maximum values, whereas the values for Simpson's diversity and taxonomic diversity had a much smaller range by comparison.

Table 3. Minimum, maximum, median, and interquartile range values for all variables analysed in this study.

Explanatory variable	Minimum	Maximum	Median	IQR
Area (ha)	0.3	49.6	4.5	6.9
Cemetery tree cover (%)	0.0	91.2	65.9	22.1
1 km tree cover (%)	1.9	32.1	11.2	8.3
1 km road cover (%)	4.8	12.4	8.5	5.0
Response variable				
Total abundance	23	55	41.0	12.5
Estimated species richness (Chao1)	9.0	18.0	14.0	3.0
Simpson's index of diversity (1-D)	0.85	0.92	0.88	0.02
Taxonomic diversity (Δ)	2.61	3.07	2.83	0.17

Table 4. Model comparison results for candidate models predicting bird abundance within fixed-radius point counts from four explanatory variables: cemetery size, cemetery tree cover, 1 km tree cover, and 1 km road cover. k , number of estimated parameters; $\ln(L)$, log-likelihood; AICc, small-sample Akaike's information criterion; Δ AICc, difference between AIC for the given model and the best model; w_i , Akaike's weights. The model in the confidence set (Δ AICc ≤ 2) is shown in bold.

Model	Explanatory variables	k	$\ln(L)$	AICc	Δ AICc	w_i
6	Area + cemetery tree cover	4	-73.6	157.5	-	0.74
12	Area * cemetery tree cover	5	-73.6	160.7	3.2	0.15
2	Area	3	-77.9	163.1	5.6	0.04
8	Area + 1 km road cover	4	-77.2	164.6	7.1	0.02
15	Cemetery tree cover * 1 km tree cover	5	-76.1	165.7	8.2	0.01
7	Area + 1 km tree cover	4	-77.8	165.8	8.4	0.01
3	Cemetery tree cover	3	-79.7	166.6	9.1	0.01
14	Area * 1 km road cover	5	-76.9	167.4	9.9	0.01
10	Cemetery tree cover + 1 km road cover	4	-78.9	168.0	10.5	0.00
5	1 km road cover	3	-80.5	168.2	10.8	0.00
9	Cemetery tree cover + 1 km tree cover	4	-79.1	168.4	11.0	0.00
13	Area * 1 km tree cover	5	-77.8	169.2	11.7	0.00
1	(Null model)	2	-83.0	170.6	13.1	0.00
16	Cemetery tree cover * 1 km road cover	5	-78.6	170.7	13.2	0.00
11	1 km tree cover + 1 km road cover	4	-80.5	171.2	13.7	0.00
4	1 km tree cover	3	-82.7	172.7	15.3	0.00
17	1 km tree cover * 1 km road cover	5	-80.4	174.4	16.9	0.00

3.2 Abundance

When comparing candidate models for predicting abundance from the four explanatory variables (as well as from pairwise combinations of, and first-order interactions between, these variables), only model 6 (abundance is predicted by cemetery size and cemetery tree cover) had a $\Delta\text{AICc} \leq 2$. This model had an Akaike's weight (w_i) of 0.74, with the next best model (model 12: abundance is predicted by the interaction between cemetery size and cemetery tree cover) having a ΔAICc of 3.2 and an Akaike's weight of 0.15 (see Table 4). Model 6 showed no significant spatial autocorrelation of residuals (correlogram in Supplementary Material 8).

For the two variables in the top model (cemetery size and cemetery tree cover), the marginal effects, along with their 95% confidence intervals, are plotted in Figure 3. The overall model predicting abundance from cemetery size and cemetery tree cover had a total explanatory power (conditional R^2) of 55.8% (see Table 5). The abundance of birds is significantly positively related to the logarithm of the area of the cemetery ($p < 0.001$, $\beta = 0.56$). The slope of this relationship is 3.78 (± 1.02 SE). The abundance of birds is also significantly positively related to tree cover within

the cemetery ($p = 0.003$, $\beta = 0.45$). The slope of this relationship is 0.20 (± 0.07 SE). Although the standardised beta estimates (β) were similar for both explanatory variables, the β values show that the standardised effect size for cemetery area was slightly higher than for cemetery tree cover (see Table 5).

3.3 Chao1 species richness, Simpson's diversity, and taxonomic diversity

When comparing candidate models (see Table 1) for predicting the remaining three response variables from the four explanatory variables (as well as from pairwise combinations of, and first-order interactions between, these variables), the results were somewhat more equivocal than those regarding the abundance of birds. For Chao1 estimated species richness, five out of the seventeen models had a $\Delta\text{AICc} \leq 2$ and similar Akaike's weights (Supplementary Material 9). In fact, the null model was the best-supported. For predicting Simpson's diversity, only two models had a $\Delta\text{AICc} \leq 2$. Although the best-supported model was model 2 (species diversity is predicted by cemetery size), this was closely followed by model 1 (the

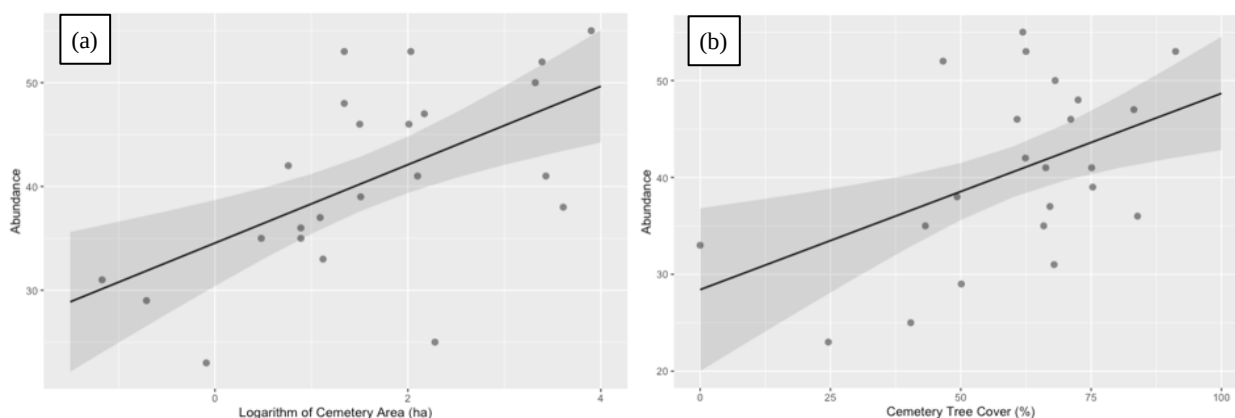


Figure 3. Predicted marginal effects, with 95% confidence regions, for the model shown in bold in Table 4, which includes the effects of: (a) the logarithm of cemetery area, and (b) cemetery tree cover, on the abundance of birds within fixed-radius point counts.

Table 5. Slope estimates, 95% confidence intervals, standardised beta values, and significance (p) values, shown in bold, for the effect of cemetery area and cemetery tree cover on the abundance of birds (the model shown in bold in Table 4).

Predictors	Estimates	std. Beta	CI	standardised CI	p
(Intercept)	22.31	0.00	13.59 – 31.03	-0.29 – 0.29	<0.001
Log cemetery area	3.78	0.56	1.79 – 5.76	0.26 – 0.85	<0.001
Cemetery tree cover	0.20	0.45	0.07 – 0.33	0.16 – 0.74	0.003

N = 23

R^2 0.558

null model), which had a ΔAICc of 0.4, and both models had very similar Akaike's weights (Supplementary Material 10). Similarly, for predicting taxonomic diversity, only two models had a $\Delta\text{AICc} \leq 2$. The best-supported model was model 5 (taxonomic diversity is predicted by road cover within 1 km of the cemetery), again closely followed by model 1 (the null model), which had a ΔAICc

of 0.3. In both cases, the models had very similar Akaike's weights (Supplementary Material 11).

3.4 Model averaging and variable importance

Model-averaged parameter estimates for each of the four model sets for the four bird response variables are in Table 6. For abundance, both area and cemetery tree cover had relative variable importance of > 0.90 , with all others ≤ 0.15 . For the three other response variables, there were

no variables that showed as high relative importance, with area having the highest relative importance for estimated species richness, and Simpson's diversity, and road cover within 1 km for taxonomic diversity, but close to 0.5 in each case, interpreted as approximately 50% probability they would be in the best model.

Table 6. Model-averaged parameter estimates, standard errors (SE), and relative variable importance values across the four response variables. The ':' symbol represents an interaction term between two variables. Parameters are ordered by variable importance, highest to lowest.

Response variable	Parameter	Estimate	SE	Variable importance
Abundance	intercept	23.193	6.520	-
	ln(area)	3.601	2.417	0.97
	cemetery tree cover	0.204	0.098	0.91
	cemetery tree cover : ln(area)	0.022	0.091	0.15
	1 km road cover	0.967	0.948	0.04
	1 km tree cover	0.899	1.104	0.03
	cemetery tree cover : 1 km tree cover	-0.031	0.014	0.01
	1 km road cover : ln(area)	-0.356	0.572	0.01
	1 km tree cover : ln(area)	-0.002	0.146	0.00
	cemetery tree cover : 1 km road cover	-0.025	0.038	0.00
	1 km road cover : 1 km tree cover	-0.028	0.129	0.00
Chao1 species richness	intercept	14.183	2.107	-
	ln (area)	0.564	0.801	0.48
	cemetery tree cover	-0.034	0.041	0.36
	1 km road cover	-0.115	0.427	0.23
	1 km tree cover	-0.024	0.108	0.15
	cemetery tree cover : ln(area)	0.020	0.034	0.03
	1 km road cover : ln(area)	0.037	0.187	0.02
	cemetery tree cover : 1 km road cover	-0.014	0.012	0.01
	1 km tree cover : ln(area)	0.011	0.047	0.01
	cemetery tree cover : 1 km tree cover	-0.001	0.005	0.01
	1 km road cover : 1 km tree cover	0.011	0.039	0.00
Simpson's diversity	intercept	0.882	0.012	-
	ln(area)	0.003	0.006	0.55
	1 km road cover	0.000	0.003	0.21
	1 km tree cover	0.000	0.001	0.19
	cemetery tree cover	0.000	0.000	0.17
	cemetery tree cover : ln(area)	0.000	0.000	0.03
	1 km road cover : ln(area)	0.001	0.001	0.02
	1 km tree cover : ln(area)	0.000	0.000	0.01
	cemetery tree cover : 1 km road cover	0.000	0.000	0.01
	cemetery tree cover : 1 km tree cover	0.000	0.000	0.00
	1 km road cover : 1 km tree cover	0.000	0.000	0.00
Taxonomic diversity	intercept	2.761	0.101	-
	1 km road cover	0.015	0.012	0.48
	ln(area)	0.013	0.034	0.21
	cemetery tree cover	0.000	0.002	0.20
	1 km tree cover	0.000	0.006	0.18
	1 km road cover : 1 km tree cover	0.000	0.002	0.01
	1 km road cover : ln(area)	0.000	0.009	0.01
	cemetery tree cover : 1 km road cover	0.000	0.001	0.01
	cemetery tree cover : ln(area)	-0.001	0.002	0.01
	1 km tree cover : ln(area)	0.000	0.002	0.00
	cemetery tree cover : 1 km tree cover	0.000	0.000	0.00

4. Discussion

4.1 The effect of local and landscape variables on urban cemetery bird communities

In this study, the abundance of birds in urban cemeteries was found to increase with greater levels of within-cemetery tree cover. This is most likely because trees provide suitable habitat for a wide variety of species, including woodland insectivores and tree- and hollow-nesting birds (Ikin *et al.*, 2015). Urban trees are well known for the wider ecosystem benefits they provide to urban residents, including their contribution to mental well-being, their pollution mitigation and air quality enhancement properties (Russo and Cirella, 2024), and their significant cooling effects (Li *et al.*, 2024). This study provides further evidence that urban trees also support other forms of urban biodiversity, providing multiple benefits for both humans and wildlife in densely urbanised areas.

Bird abundance was also found to increase with cemetery size. This finding aligns with established ecological expectations and macroecological theories such as the theory of island biogeography (MacArthur and Wilson, 1967) and the occupancy-abundance relationship (Gaston, 1996). Interestingly, the abundance of birds in urban cemeteries could be best predicted when both cemetery area and cemetery tree cover were considered within the same model. This makes sense, as even a very large cemetery may not be able to support many species if it is predominantly composed of a simple grassland habitat. Likewise, a cemetery with extensive tree cover may still hold a lower abundance of birds if it has a small area.

Contrary to what was hypothesised, species richness, species diversity, and taxonomic diversity of birds were not found to be clearly related to the local variables of cemetery size or cemetery tree cover. In addition, the chosen landscape variables were not found to have a clear effect, with tree and road cover within 1 km of the cemetery having little predictive power for any of these measures of bird diversity. This was somewhat in contrast to what was expected, based on some previous findings (Villaseñor and Escobar, 2019). This may simply be because most cemeteries surveyed in this study were big enough and had sufficient tree coverage to support similarly broad ranges of species. It may also be true that the dispersal distances of most of the birds observed in this study are great enough, and the degree of isolation of cemeteries low enough, to ensure that the bird species inhabiting these cemeteries can easily move between them, resulting in fewer specialised species and therefore more similar levels of diversity between cemeteries. Indeed, Munich is a very green city with high densities of urban green spaces, frequently connected by wooded streets.

This appears to be the first study in which bird surveys have been conducted across all of Munich's public cemeteries. Therefore, as birds are an effective indicator or umbrella group for other types of urban fauna (Branton and Richardson, 2011), this study represents an important initial step in studying and monitoring the biodiversity of this particular urban green space type in southern

Germany's largest city. This study only conducted bird surveys during May and June. Although this survey period was deliberately chosen to try to coincide as much as possible with the breeding season (leading to greater detectability of birds during surveys as birds are highly vocal and active), some research has found a seasonal effect on native birds in urban environments, with abundance and richness of birds being higher in the autumn compared to the summer (Villaseñor and Escobar, 2019). The average temperature and precipitation for Munich in May and June of 2022 was highly similar to the usual climate in Munich for those months. Different patterns of bird diversity might be observed outside the breeding season with a different community composition, with some breeding birds having left Munich and other wintering birds having arrived. As this was a single year study, it may not capture interannual variation in environmental conditions and resource availability that might influence the patterns of bird diversity in relation to cemetery characteristics. The weather was broadly representative of other recent bird breeding seasons in Munich, however. This study used road cover as a measure of the degree of urbanisation surrounding cemeteries. However, this may not be effective, as Munich's streets are generally lined with trees and may therefore be acting as green corridors for birds, rather than as urban barriers (Curzel *et al.*, 2021). Other indicators may more accurately reflect the level of urbanisation surrounding urban green spaces, such as the percentage of impervious surfaces (Korányi *et al.*, 2021).

The cemeteries surveyed here were found to have many features that enable them to act as biodiversity refuges in this very densely populated city. For example, the respectful way in which this green space type is used, with no cycling, jogging, or dogs allowed (based on personal observations of regulations), and the general quietness and calm behaviour of those using the cemeteries, means that disturbances to wildlife are kept to a minimum. The presence of a wide variety of vegetation types, including areas of open grassland, many shrubs, and generally a high level of tree coverage from a range of species, ages and sizes, provides opportunities for a wide range of bird species, from ground-feeders, such as European green woodpeckers (*Picus viridis*), to trunk-foragers, such as the short-toed treecreepers (*Certhia brachydactyla*) commonly heard (but less commonly seen) during this study.

A wide range of bird species were observed during this study, including species from 16 different families. Interestingly, 4 of the 32 species observed during surveys are currently classed as 'Near Threatened' by the German Red List Centre (Rote Liste Zentrum), including the Spotted flycatcher (*Muscicapa striata*), the House sparrow (*Passer domesticus*), the Eurasian tree sparrow (*Passer montanus*), and the Yellowhammer (*Emberiza citrinella*), with all other species observed classed as 'Not Threatened' (Grüneberg *et al.*, 2016). At the very least, therefore, urban cemeteries in Munich appear to be providing suitable habitat for species that may be showing general trends of population decline across Germany, demonstrating the conservation value of urban cemeteries in heavily urbanised landscapes.

4.2 Future research

Increasingly, ecological research, particularly on birds, is looking at the composition of communities from a functional diversity perspective. Functional diversity is a biodiversity metric based on the functional traits of species and provides additional information to the traditional taxonomic diversity approach, making functional diversity another important measure of diversity that can be used to analyse bird communities (Curzel *et al.*, 2021; Morelli *et al.*, 2018; Petchey and Gaston, 2006). Examples of functional trait categories include body mass, foraging technique, diet, nest location, and migration status, amongst many others (Korányi *et al.*, 2021). Functional homogenisation is known to occur alongside the biotic homogenisation caused by urbanisation, and the functional diversity of bird communities in urban habitats has been shown to decrease as the surrounding landscape becomes increasingly urbanised (Croci *et al.*, 2008; Korányi *et al.*, 2021). Future research on bird communities in Munich's urban cemeteries, as well as cemeteries in other urbanised areas, should include functional diversity as a response variable, to determine whether local and landscape variables are having a negative impact on this, even if similar effects are not observed in more standard biodiversity metrics such as species richness or diversity.

The weak predictive power of models for species richness, Simpson's diversity, and taxonomic diversity may imply that there are additional, unmeasured factors that we did not consider. During this study, it was clear that the cemeteries surveyed varied considerably in terms of their age and that the age (and often, therefore, the size) of the trees within them also varied widely as a result. Although some previous research has investigated the effects of fine-scale habitat characteristics, such as tree age, on birds in urban green spaces (Donnelly and Marzluff, 2006; Ferenc *et al.*, 2014; Mörtberg and Wallentinus, 2000), a specific study investigating the effect of the age and size of cemetery trees on their bird communities would be

valuable. This is because the rapid growth of cities means that many new cemeteries are also being created as areas at the urban fringe are developed. Indeed, this was the case with several of the cemeteries surveyed in Munich, which were clearly relatively new and therefore had a markedly different age composition of trees compared to some of the old, or *alter*, cemeteries in the city centre. These more ancient cemeteries clearly contain much older stands of trees and although they are still much visited and partially maintained by groundskeeping staff, they are not in 'active' use for new burials in the same way as the other, less ancient cemeteries are. The effect of such tree and cemetery age-related variables on the taxonomic and functional diversity of birds in urban cemeteries may therefore represent a valuable topic for future research.

4.3 Conclusion

This is the first time an extensive set of bird surveys has been completed across all of Munich's public urban cemeteries. This study aimed to determine if the abundance, richness, and diversity of breeding birds could be predicted by various local and landscape variables, including cemetery area, cemetery tree cover, tree cover within 1 km of the cemetery, and road cover within 1 km of the cemetery. Whilst abundance within a fixed-radius point count was found to be strongly related to cemetery area and cemetery tree cover, the absence of any relationship regarding various indices of diversity is an interesting result. Further research may be needed to explore whether relationships exist at different spatial scales or perhaps in different cities. This study does highlight how tree coverage can increase bird numbers in urban cemeteries, adding to the extensive list of benefits urban trees provide.

Declaration

The authors declare no competing interests.

References

- Alin, A. (2010). Multicollinearity. *Wiley Interdisciplinary Reviews: Computational Statistics*, 2(3), 370–374. <https://doi.org/10.1002/WICS.84>
- Anderson, D. R., and Burnham, K. P. (2002). Avoiding Pitfalls When Using Information-Theoretic Methods. *The Journal of Wildlife Management*, 66(3), 912. <https://doi.org/10.2307/3803155>
- Barrett, G. W., and Barrett, T. L. (2001). Cemeteries as repositories of natural and cultural diversity. *Conservation Biology*, 15(6), 1820–1824. <https://doi.org/10.1046/J.1523-1739.2001.00410.X>
- Bartoń, K. (2022). MuMIn: Multi-Model Inference. R package version 1.47.1. <https://CRAN.R-project.org/package=MuMIn>.
- Batáry, P., Kurucz, K., Suarez-Rubio, M., and Chamberlain, D. E. (2018). Non-linearities in bird responses across urbanization gradients: A meta-analysis. *Global Change Biology*, 24(3), 1046–1054. <https://doi.org/10.1111/GCB.13964>
- Bibby, C., Burgess, N., Hill, D., and Mustoe, S. (2000). *Bird census techniques*. Academic Press.
- Bjørnstad O.N. (2022), ncf: Spatial Covariance Functions. R package version 1.3-2. <https://CRAN.R-project.org/package=ncf>
- Botzat, A., Fischer, L. K., and Kowarik, I. (2016). Unexploited opportunities in understanding liveable and biodiverse cities. A review on urban biodiversity perception and valuation. *Global Environmental Change*, 39, 220–233. <https://doi.org/10.1016/j.gloenvcha.2016.04.008>

- Branton, M., and Richardson, J. S. (2011). Assessing the Value of the Umbrella-Species Concept for Conservation Planning with Meta-Analysis. *Conservation Biology*, 25(1), 9–20. <https://doi.org/10.1111/J.1523-1739.2010.01606.X>
- Callaghan, C. T., Major, R. E., Lyons, M. B., Martin, J. M., and Kingsford, R. T. (2018). The effects of local and landscape habitat attributes on bird diversity in urban greenspaces. *Ecosphere*, 9(7). <https://doi.org/10.1002/ecs2.2347>
- Čanády, A., and Mošanský, L. (2017). Public Cemetery as a biodiversity hotspot for birds and mammals in the urban environment of Kosice city (Slovakia). *New Pub: Lithuanian Nature Research Centre*, 27(3–4), 185–195. <https://doi.org/10.1080/21658005.2017.1366024>
- CDC (Climate Data Centre). DWD. Archived from the original on 14 January 2017. Retrieved 2 May 2016. https://www.dwd.de/DE/klimaumwelt/cdc/cdc_node.html;jsessionid=AB2FD90DB16A31B55E20AD406ED1D066.live21063
- Chao, A., and Chiu, C.-H. (2016). Species Richness: Estimation and Comparison. *Wiley StatsRef: Statistics Reference Online*, 1–26. <https://doi.org/10.1002/9781118445112.STAT03432.PUB2>
- Clergeau, P., Croci, S., Jokimäki, J., Kaisanlahti-Jokimäki, M. L., and Dinetti, M. (2006). Avifauna homogenisation by urbanisation: Analysis at different European latitudes. *Biological Conservation*, 127(3), 336–344. <https://doi.org/10.1016/J.BIOCON.2005.06.035>
- Cornell Lab of Ornithology in partnership with Birds in the Hand, LLC. (2022). *Merlin Bird ID* (Version 2.1.4) [Mobile app]. Apple App Store. <https://apps.apple.com/us/app/merlin-bird-id-by-cornell-lab/id773457673>. Google Play Store. https://play.google.com/store/apps/details?id=com.labs.merlinbirdid.app&hl=en_GB&gl=US&pli=1
- Croci, S., Butet, A., and Clergeau, P. (2008). Does Urbanization Filter Birds on the Basis of Their Biological Traits. *The Condor*, 110(2), 223–240. <https://doi.org/10.1525/cond.2008.8409>
- Curzel, F. E., Bellocq, M. I., and Leveau, L. M. (2021). Local and landscape features of wooded streets influenced bird taxonomic and functional diversity. *Urban Forestry & Urban Greening*, 66. <https://doi.org/10.1016/J.UFUG.2021.127369>
- Dale, S. (2018). Urban bird community composition influenced by size of urban green spaces, presence of native forest, and urbanization. *Urban Ecosystems*, 21, 1–14. <https://doi.org/10.1007/s11252-017-0706-x>
- de Groot, M., Flajšman, K., Mihelič, T., Vilhar, U., Simončič, P., and Verlič, A. (2021). Green space area and type affect bird communities in a South-eastern European city. *Urban Forestry & Urban Greening*, 63. <https://doi.org/10.1016/J.UFUG.2021.127212>
- DeGraaf, R. M., Geis, A. D., and Healy, P. A. (1991). Bird population and habitat surveys in urban areas. *Landscape and Urban Planning*, 21(3), 181–188. [https://doi.org/10.1016/0169-2046\(91\)90017-G](https://doi.org/10.1016/0169-2046(91)90017-G)
- Dombart, T., *Der Englische Garten zu München*. Munich: Hornung, 1972. ISBN 3-87364-023-6
- Donnelly, R., and Marzluff, J. M. (2006). Relative importance of habitat quantity, structure, and spatial pattern to birds in urbanizing environments. *Urban Ecosystems* 2006 9:2, 9(2), 99–117. <https://doi.org/10.1007/S11252-006-7904-2>
- European Union. Copernicus Land Monitoring Service. (2022). European Environment Agency (EEA). <https://land.copernicus.eu/>
- Farah Shafawati, M. T., Md-Nor, S., and Abdullah, S. A. (2016). Implications of patch size and landscape matrix towards native-forest bird species in fragmented forests. *Malaysian Applied Biology Journal*, 45(1), 55–63.
- Ferenc, M., Sedláček, O., and Fuchs, R. (2014). How to improve urban greenspace for woodland birds: Site and local-scale determinants of bird species richness. *Urban Ecosystems*, 17(2), 625–640. <https://doi.org/10.1007/S11252-013-0328-X>
- Fox, J., Weisberg, S. (2019). *An R companion to applied regression*, 3rd edn. Sage, Thousand Oaks.
- Gaston, K. J. (1996). The Multiple Forms of the Interspecific Abundance-Distribution Relationship. *Oikos*, 76(2), 211. <https://doi.org/10.2307/3546192>
- Geschke, A., James, S., Bennett, A. F., and Nimmo, D. G. (2018). Compact cities or sprawling suburbs? Optimising the distribution of people in cities to maximise species diversity. *Journal of Applied Ecology*, 55(5), 2320–2331. <https://doi.org/10.1111/1365-2664.13183>
- Giam, X. and Olden, J. D. (2015) Quantifying variable importance in a multimodel inference framework. *Methods in Ecology and Evolution*, 7(4), 388–397 <https://doi.org/10.1111/2041-210X.12492>
- Godoy, I. N., Gorleri, F. C., Cristaldi, M. A., and Leveau, L. M. (2024). Species Richness and Composition of Forest Birds in Urban Parks and Reserves of Buenos Aires City, Argentina. *Animals*, 14(4), 602. <https://doi.org/10.3390/ANI14040602>
- Google. (2022). [Google Maps of Munich]. Retrieved April 21, 2022, from <https://www.google.com/maps/@48.1309149,11.5862151,25037m/data=!3m1!1e3>

- Grüneberg, C., Bauer, H.-G., Haupt, H., Hüppop, O., Ryslavý, T. and Süßbeck, P. (2016). Rote Liste der Brutvögel Deutschlands. 5. Fassung, 30. November 2015. – *Berichte zum Vogelschutz* 52, 19–67.
- Harrell, Jr, F. (2022). Hmisc: Harrell Miscellaneous. R package version 4.7-1. <https://CRAN.R-project.org/package=Hmisc>
- Ikin, K., le Roux, D. S., Rayner, L., Villaseñor, N. R., Eyles, K., Gibbons, P., Manning, A. D., and Lindenmayer, D. B. (2015). Key lessons for achieving biodiversity-sensitive cities and towns. *Ecological Management & Restoration*, 16(3), 206–214. <https://doi.org/10.1111/EMR.12180>
- Jackson, D. L. (2003). *Revisiting Sample Size and Number of Parameter Estimates: Some Support for the N:q Hypothesis*.
- Jiguet, F. (2009). Method learning caused a first-time observer effect in a newly started breeding bird survey. *Bird Study*, 56(2), 253–258. <https://doi.org/10.1080/00063650902791991>
- Jiguet, F., Renault, O., and Petiau, A. (2005). Estimating species richness with capture-recapture models: choice of model when sampling in heterogeneous conditions. *Bird Study*, 52(2), 180–187. <https://doi.org/10.1080/00063650509461389>
- Johnson, J. B., and Omland, K. S. (2004). Model selection in ecology and evolution. *TRENDS in Ecology and Evolution*, 19(2). <https://doi.org/10.1016/j.tree.2003.10.013>
- Johnston, R., Jones, K., and Manley, D. (2018). Confounding and collinearity in regression analysis: a cautionary tale and an alternative procedure, illustrated by studies of British voting behaviour. *Quality and Quantity*, 52(4), 1957–1976. <https://doi.org/10.1007/S11135-017-0584-6>
- Kociolek, A. v., Clevenger, A. P., st. Clair, C. C., and Proppe, D. S. (2011). Effects of Road Networks on Bird Populations. *Conservation Biology*, 25(2), 241–249. <https://doi.org/10.1111/J.1523-1739.2010.01635.X>
- Korányi, D., Gallé, R., Donkó, B., Chamberlain, D. E., and Batáry, P. (2021). Urbanization does not affect green space bird species richness in a mid-sized city. *Urban Ecosystems*, 24(4), 789–800. <https://doi.org/10.1007/S11252-020-01083-2>
- Kowarik, I., Buchholz, S., von der Lippe, M., and Seitz, B. (2016). Biodiversity functions of urban cemeteries: Evidence from one of the largest Jewish cemeteries in Europe. *Urban Forestry & Urban Greening*, 19, 68–78. <https://doi.org/10.1016/J.UFUG.2016.06.023>
- Landeshauptstadt München, Redaktion. *Landeshauptstadt München – Bevölkerung*. Landeshauptstadt München. Archived from the original on 19 February 2016. Retrieved 12 February 2022. <https://stadt.muenchen.de/infos/statistik-bevoelkerung.html>
- Lee, M. B., Peabotuwage, I., Gu, H., Zhou, W., and Goodale, E. (2019). Factors affecting avian species richness and occupancy in a tropical city in southern China: Importance of human disturbance and open green space. *Basic and Applied Ecology*, 39, 48–56. <https://doi.org/10.1016/J.BAAE.2019.08.003>
- Leveau, L. M. (2021). Big cities with small green areas hold a lower proportion of migrant birds: A global analysis. *Urban Forestry & Urban Greening*, 57. <https://doi.org/10.1016/j.ufug.2020.126953>
- Leveau, L. M., Ruggiero, A., Matthews, T. J., and Isabel Bellocq, M. (2019). A global consistent positive effect of urban green area size on bird richness. *Avian Research*, 10(30). <https://doi.org/10.1186/s40657-019-0168-3>
- Li, H., Zhao, Y., Wang, C., Ürgé-Vorsatz, D., Carmeliet, J., and Bardhan, R. (2024). Cooling efficacy of trees across cities is determined by background climate, urban morphology, and tree trait . *EGUsphere [Preprint]*. <https://doi.org/10.5194/EGUSPHERE-2024-234>
- Lim, H. C., and Sodhi, N. S. (2004). Responses of avian guilds to urbanisation in a tropical city. *Landscape and Urban Planning*, 66(4), 199–215. [https://doi.org/10.1016/S0169-2046\(03\)00111-7](https://doi.org/10.1016/S0169-2046(03)00111-7)
- Löki, V., Deák, B., Lukács, A. B., and Molnár V., A. (2019). Biodiversity potential of burial places – a review on the flora and fauna of cemeteries and churchyards. *Global Ecology and Conservation*, 18. <https://doi.org/10.1016/J.GECCO.2019.E00614>
- Luck, G. W., Davidson, P., Boxall, D., and Smallbone, L. (2011). Relations between Urban Bird and Plant Communities and Human Well-Being and Connection to Nature. *Conservation Biology*, 25(4), 816–826. <https://doi.org/10.1111/J.1523-1739.2011.01685.X>
- Lüdecke, D. (2021). sjPlot: Data Visualization for Statistics in Social Science. R package version 2.8.10. <https://CRAN.R-project.org/package=sjPlot>.
- MacArthur, R. H., and Wilson, E. O. (1967). *The theory of island biogeography*. Princeton University Press.
- MacGregor-Fors, I., and Schondube, J. E. (2011). Gray vs. green urbanization: Relative importance of urban features for urban bird communities. *Basic and Applied Ecology*, 12(4), 372–381. <https://doi.org/10.1016/J.BAAE.2011.04.003>
- Marzluff, J. M. (2008). Island Biogeography for an Urbanizing World How Extinction and Colonization May Determine Biological Diversity in Human-Dominated Landscapes. *Urban Ecology*, 8(2), 157–177. https://doi.org/10.1007/978-0-387-73412-5_23

- Matsumoto, K., Nakajima, K., Ito, M., and Takada, M. B. (2024). Sacred sites provide urban green spaces that maintain bird diversity in the megacity of Tokyo, Japan. *Urban Forestry & Urban Greening*, 101. <https://doi.org/10.1016/J.UFUG.2024.128550>
- Mayorga, I., Bichier, P., and Philpott, S. M. (2020). Local and landscape drivers of bird abundance, species richness, and trait composition in urban agroecosystems. *Urban Ecosystems*, 23(3), 495–505. <https://doi.org/10.1007/s11252-020-00934-2>
- McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, 127(3), 247–260. <https://doi.org/10.1016/J.BIOCON.2005.09.005>
- Morelli, F., Mikula, P., Benedetti, Y., Bussi re, R., and Tryjanowski, P. (2018). Cemeteries support avian diversity likewise urban parks in European cities: Assessing taxonomic, evolutionary and functional diversity. *Urban Forestry & Urban Greening*, 36, 90–99. <https://doi.org/10.1016/J.UFUG.2018.10.011>
- M rtberg, U., and Wallentinus, H. G. (2000). Red-listed forest bird species in an urban environment — assessment of green space corridors. *Landscape and Urban Planning*, 50(4), 215–226. [https://doi.org/10.1016/S0169-2046\(00\)00090-6](https://doi.org/10.1016/S0169-2046(00)00090-6)
- Oksanen, J., Simpson, G., Blanchet, F., Kindt, R., Legendre, P., Minchin, P., O'Hara, R., Solymos, P., Stevens, M., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., De Caceres, M., Durand, S., Evangelista, H., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., Hill, M., Lahti, L., McGlinn, D., Ouellette, M., Ribeiro Cunha, E., Smith, T., Stier, A., Ter Braak, C., Weedon, J. (2022). *vegan: Community Ecology Package*. R package version 2.6-4. <https://CRAN.R-project.org/package=vegan>.
- Oliver, A. J., Hong-Wa, C., Devonshire, J., Olea, K. R., Rivas, G. F., and Gahl, M. K. (2011). Avifauna richness enhanced in large, isolated urban parks. *Landscape and Urban Planning*, 102(4), 215–225. <https://doi.org/10.1016/j.landurbplan.2011.04.007>
- OpenStreetMap contributors. (2022). Planet dump. Retrieved April 21, 2022, from <https://planet.openstreetmap.org/>
- Oropeza-S nchez, M. T., Solano-Zavaleta, I., Cuad n-Hern ndez, W. L., Mart nez-Villegas, J. A., Palomera-Hern ndez, V., and Z niga-Vega, J. J. (2024). Urban green spaces with high connectivity and complex vegetation promote occupancy and richness of birds in a tropical megacity. *Urban Ecosystems* 2024 28:1, 28(1), 1–18. <https://doi.org/10.1007/S11252-024-01612-3>
- Palacio, F. X. (2020). Urban exploiters have broader dietary niches than urban avoiders. *Ibis*, 162(1), 42–49. <https://doi.org/10.1111/IBI.12732>
- Pennington, D. N., Hansel, J., and Blair, R. B. (2008). The conservation value of urban riparian areas for landbirds during spring migration: Land cover, scale, and vegetation effects. *Biological Conservation*, 141(5), 1235–1248. <https://doi.org/10.1016/J.BIOCON.2008.02.021>
- Petchey, O. L., and Gaston, K. J. (2006). Functional diversity: Back to basics and looking forward. *Ecology Letters*, 9(6), 741–758. <https://doi.org/10.1111/J.1461-0248.2006.00924.X>
- Pirzio Biroli, A., van Doren, B. M., and Grabowska-Zhang, A. (2020). Drivers of avian species richness and community structure in urban courtyard gardens. *Journal of Urban Ecology*, 6(1). <https://doi.org/10.1007/s10933-020-00934-2>
- QGIS Development Team. (2022). QGIS Geographic Information System (Version 3.18, Z rich) [Computer software]. Open Source Geospatial Foundation. <http://qgis.org>
- Ram rez-Albores, J. E., S nchez-Gonz lez, L. A., P rez-Su rez, M., Navarro-Sig enza, A. G., and Franco-Maass, S. (2024). Greenspaces as shelters for the conservation of bird diversity in a big city. *Urban Ecosystems*, 27(6), 2047–2059. <https://doi.org/10.1007/s11252-024-01573-7>
- R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- R Studio Team (2022). RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA. <http://www.rstudio.com/>.
- Rugg, J. (2000). Defining the place of burial: what makes a cemetery a cemetery? *Mortality*, 5(3), 259–275.
- Russo, A., and Cirella, G. T. (2024). Urban Ecosystem Services in a Rapidly Urbanizing World: Scaling up Nature's Benefits from Single Trees to Thriving Urban Forests. *Land* 2024, Vol. 13, Page 786, 13(6), 786. <https://doi.org/10.3390/LAND13060786>
- Seto, K. C., G neralp, B., and Hutyr , L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*, 109(40), 16083–16088. <https://doi.org/10.1073/PNAS.1211658109>
- Tryjanowski, P., Morelli, F., Mikula, P., Kri t n, A., Indykiewicz, P., Grzywaczewski, G., Kronenberg, J., and Jerzak, L. (2017). Bird diversity in urban green space: A large-scale analysis of differences between parks and cemeteries in Central Europe. *Urban Forestry & Urban Greening*, 27, 264–271. <https://doi.org/10.1016/j.ufug.2017.08.014>

Ugolini, F., Massetti, L., Calaza-Martínez, P., Cariñanos, P., Dobbs, C., Ostoic, S. K., Marin, A. M., Pearlmutter, D., Saaroni, H., Šaulienė, I., Simoneti, M., Verlič, A., Vuletić, D., and Sanesi, G. (2020). Effects of the COVID-19 pandemic on the use and perceptions of urban green space: An international exploratory study. *Urban Forestry & Urban Greening*, 56, 1618–8667. <https://doi.org/10.1016/J.UFUG.2020.126888>

Villaseñor, N. R., and Escobar, M. A. H. (2019). Cemeteries and biodiversity conservation in cities: how do landscape and patch-level attributes influence bird diversity in urban park cemeteries? *Urban Ecosystems*, 22(6), 1037–1046. <https://doi.org/10.1007/S11252-019-00877-3/TABLES/4>

West, R. M. (2021) Best practice in statistics: The use of log transformation. *Annals of Clinical Biochemistry: International Journal of Laboratory Medicine*, 59(3), 162-165. doi:[10.1177/00045632211050531](https://doi.org/10.1177/00045632211050531)

Whelan, C. J., Wenny, D. G., and Marquis, R. J. (2008). Ecosystem Services Provided by Birds. *Annals of the New York Academy of Sciences*, 1134, 25–60. <https://doi.org/10.1196/annals.1439.003>

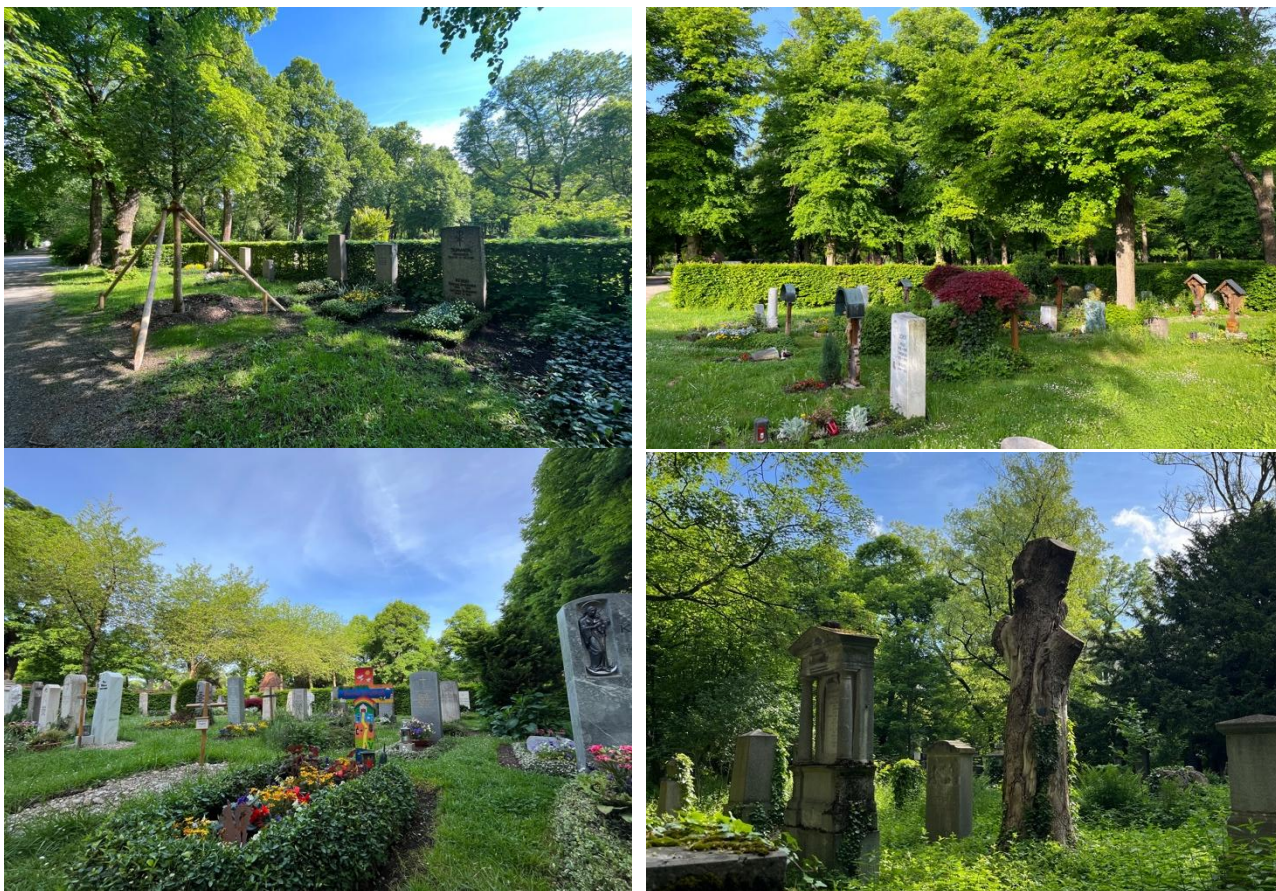
White, P., Redford, P. and Macdonald, J. (2019) That assumption of normality. University of the West of England Quantitative Research Methods Project. <https://uwe-repository.worktribe.com/output/3294821>

5. Supplementary material

5.1 Supplementary material 1. Contextual information about Munich.

Munich is a city with an area of 311 km² and a population of approximately 1.5 million residents (Landeshauptstadt München, 2022). The city is situated at 520 m above sea level in Bavaria, Germany (48°08'15"N 11°34'30"E). The land surrounding the city mainly consists of arable land, grassland, and forest. The climate is temperate with an annual average temperature of 9.7 C and an annual average rainfall of 944 mm (DWD, 2022). Munich is the most densely populated municipality in Germany. Despite this, the city contains one of the world's largest urban public parks: the *Englischer Garten* (the English Garden), which covers an area of 3.7 km², making it larger than Central Park in New York City (Dombart, 1972). In addition to its many parks, the city has numerous other green spaces, including allotments and cemeteries.

5.2 Supplementary Material 2. Examples of the typical matrix of vegetation (trees, shrubs, and grass) and human-made structures in Munich's urban cemeteries – top left: *Perlacher Forst*, top right and bottom left: *Nordfriedhof*, bottom right: *Alter Südfriedhof*.



5.3 Supplementary Material 3. Further study design choices and justifications.

All cemeteries surveyed are located within the outer motorway ring road. This ensured that all cemeteries were close enough that they could be reached by bicycle if possible, or, where necessary, by private vehicle or public transport, and that multiple cemeteries could be surveyed in one morning, maximising the overall sample size (number of cemeteries) that could be obtained for this study, the cemeteries selected are a variety of different sizes, ranging from 0.3 ha to 49.6 ha (see Table 3), representing, approximately, a 100-fold increase in size, which allowed the effect of cemetery area to be properly investigated and used as an explanatory variable in this study. As many suitable cemeteries as possible were surveyed within the data collection time period available for this study (i.e., the largest possible sample size was obtained), which helped to minimise any bias in terms of the locations of the cemeteries relative to the surveyor's residence by ensuring that a large geographical spread across the city was achieved (see Figure 1).

5.4 Supplementary Material 4. Justifications for the 1 km buffer surrounding each cemetery.

Although a somewhat arbitrary choice, the 1 km distance for the buffer surrounding each cemetery (see Figure 2b) was also chosen because similar research has previously used this distance over which to measure road and tree coverage (Farah Shafawati *et al.*, 2016; Villaseñor and Escobar, 2019). In addition, although other research has suggested using buffers of 5 km or even greater (Callaghan *et al.*, 2018), after viewing buffers of different sizes in QGIS, it was decided that a larger buffer size might result in too much overlap, potentially leading to a high degree of similarity in the measurements for tree and road cover between cemeteries (and therefore, potentially, less clear results). Conversely, although other research has used smaller buffers, such as 500 m (Korányi *et al.*, 2021), it was decided that a buffer size smaller than 1 km might not be adequate to detect any effects, due to the large dispersal distances of the surveyed bird species.

5.5 Supplementary Material 5. Further information and justifications for 50 m point count.

Based on the findings of some preliminary surveys used to practice and assess survey techniques for this study, the chosen method, to be used for all bird surveys, was a 50 m fixed-radius point count (Bibby *et al.*, 2000). This was preferred to the transect method as it involved less disturbance to birds (after the settling period), allowed the stationary surveyor to use binoculars effectively, and maximised the effectiveness of the smartphone app used to aid the identification of bird species (the effectiveness of which is greatly reduced by sounds made during a transect survey, such as footsteps on a gravel-covered cemetery path), all of which ensured higher levels of successful detection of bird species during surveys. A 50 m radius was used, as it was decided that accurate visual identification and abundance-scoring over a greater distance (e.g., 75 m or 100 m) could not be guaranteed, and that bird calls and songs, which provided the main method of identification during surveys, could also not be accurately detected or identified at distances greater than 50 m (as well as the fact that greater distances might begin to exaggerate any detection biases resulting from the different sizes and different call and song volumes of different species).

The one-minute settling-down period was used to give time for birds to resume normal behaviour (Chamberlain and Rolando, 2014) and was judged to be sufficiently long, as cemetery birds constantly experience human presence throughout the year anyway and are therefore well-habituated to human presence. To aid and verify bird identifications, the bird sound identification feature of the Merlin Bird ID smartphone application (developed by the Cornell Lab of Ornithology in partnership with Birds in the Hand, LLC) was used during all surveys. This ensured maximum accuracy of identification by aiding the surveyor when multiple bird calls could be heard at once and by allowing the surveyor to listen back to the audio recording after each survey, so that the surveyor could verify that species had been correctly identified from their songs and calls.

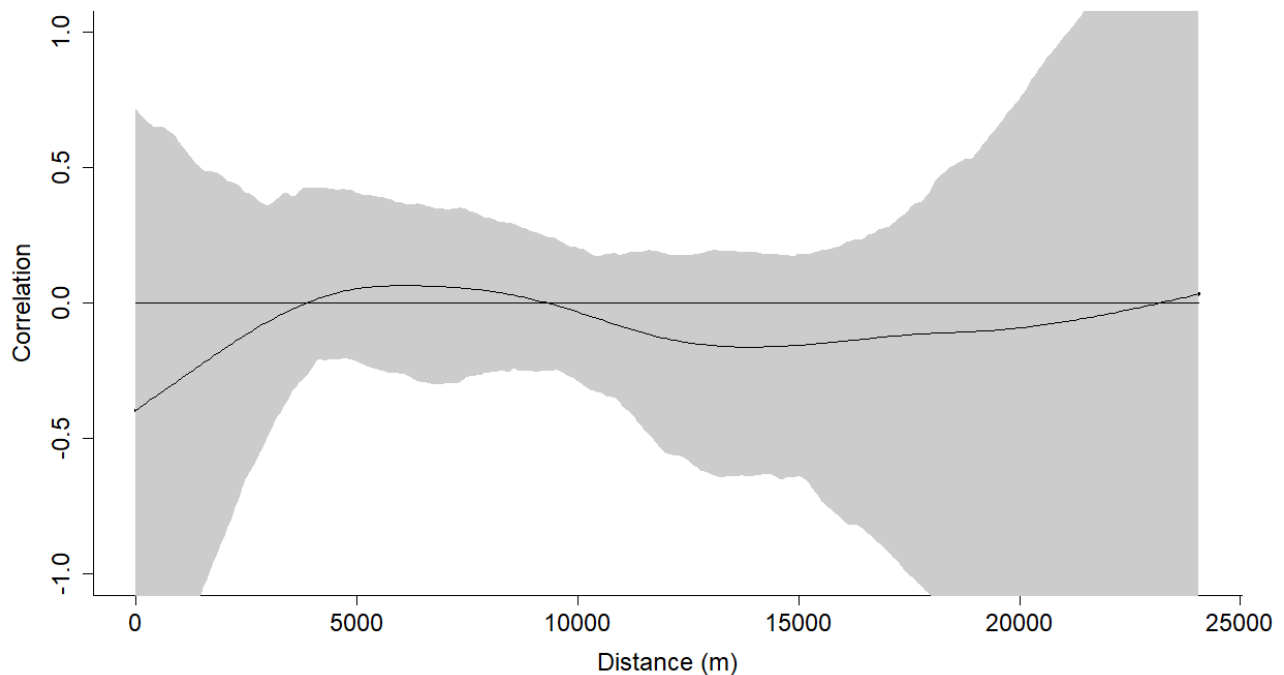
5.6 Supplementary Material 6. Further information and justifications for chosen diversity indices.

The Chao1 species richness estimator used estimates true species richness by also considering an estimate of the species missed by the sampling, based on the relative frequencies of rare species and less rare species in the data (Chao and Chiu, 2016). Alpha (α -) diversity relates to the local diversity of an individual site or habitat, and although species richness is an important element of this, α -diversity also includes a component of species evenness, which indicates how evenly the proportions of each species are distributed across a site (Magurran, 2004). Heterogeneity indices combine both of these elements of α -diversity. In this study, the heterogeneity index calculated for each cemetery was Simpson's Index of diversity ($1 - D$). A potential limitation of this diversity measure is that it treats species equally, only considering relative abundances. Diversity can also be quantified using taxonomic diversity, with the diversity of taxa representing diversity in evolutionary divergence among the taxa (Clarke and Warwick, 1998). Taxonomic diversity was therefore calculated for each site. First, a distance matrix containing pairwise taxonomic path lengths between all observed species was produced. This gave the number of taxonomic levels separating any two species. A measure of taxonomic diversity (Δ) was then calculated for each cemetery by taking the average taxonomic path length between any two individuals randomly selected from the pooled data for a site.

5.7 Supplementary Material 7. Summary statistics for each cemetery, ordered alphabetically.

Cemetery	Area (ha)	Cemetery tree cover (%)	1 km tree cover (%)	1 km road cover (%)	Total abundance	Observed species richness	Estimated species richness (Chao1)	Simpson's index of diversity (1-D)	Taxonomic diversity (Δ)
Alter Nordlicher	3.80	91.2	5.4	11.6	53	10	10.0	0.87	2.92
Alter Perlacher	1.62	65.9	21.1	12.4	35	10	11.5	0.85	2.91
Alter Südlicher	8.77	83.2	8.1	11.3	47	10	10.0	0.87	2.64
Aubing	4.52	75.3	7.9	6.6	39	11	11.0	0.88	2.79
Daglfing	0.49	50.1	9.4	5.1	29	13	14.7	0.89	2.86
Feldmoching	3.80	72.5	7.6	6.5	48	15	15.5	0.90	2.91
Haidhausen	2.43	83.9	9.1	12.0	36	12	12.6	0.88	3.01
Neubiberg	3.06	0.0	14.9	5.1	33	12	17.0	0.88	2.75
Neuer Süd	37.14	49.3	16.7	10.8	38	13	18.0	0.89	2.83
Nord	29.57	46.6	31.5	10.2	52	11	12.0	0.88	2.73
Nymphenburg	0.31	67.9	32.1	7.7	31	10	10.2	0.87	2.76
Obermenzing	8.13	75.1	11.2	8.5	41	12	18.0	0.89	2.75
Ost	30.86	66.3	9.4	11.8	41	14	14.8	0.90	2.95
Park Nord	2.43	43.2	9.5	4.8	35	9	9.0	0.86	2.75
Park Sud	9.81	40.4	11.8	7.1	25	11	12.5	0.88	3.07
Pasing	7.47	71.1	16.6	5.5	46	15	15.8	0.92	2.89
Perlacher Forst	27.60	68.1	19.6	11.4	50	14	14.2	0.89	2.97
Riem	2.97	67.1	10.0	7.7	37	13	13.9	0.87	2.75
Sendlinger	2.14	62.4	17.0	11.8	42	14	14.2	0.91	2.89
Unterhaching	4.49	60.8	6.3	6.5	46	12	14.0	0.87	2.61
Untermenzing	7.58	62.5	11.2	8.6	53	14	14.8	0.89	2.74
Wald Putzbrunn	0.91	24.6	1.9	5.7	23	12	13.7	0.89	2.78
West	49.58	61.9	19.7	11.6	55	14	14.2	0.91	2.96

5.8 Supplementary Material 8. Spline correlogram of model 6 for abundance analysis. Grey shaded areas represent 95% pointwise confidence intervals. The confidence intervals overlap zero across the whole distance range indicating no significant spatial autocorrelation.



5.9 Supplementary Material 9. Model selection, using Akaike's Information Criterion, for predicting species richness (Chao1 estimated species richness) from four explanatory variables: cemetery size, cemetery tree cover, 1 km tree cover, and 1 km road cover.

Model comparison results for candidate models. k , number of estimated parameters; $\ln(L)$, log-likelihood; AIC_c , small-sample Akaike's information criterion; ΔAIC_c , difference between AIC for given model and best model; w_i , Akaike's weights. The models in the confidence set ($\Delta AIC_c \leq 2$) are shown in bold.

Model	Explanatory variables	k	$\ln(L)$	AIC_c	ΔAIC_c	w_i
1	(Null model)	2	-53.3	111.2	-	0.19
2	Area	3	-52.2	111.6	0.4	0.16
6	Area + cemetery tree cover	4	-50.9	112.0	0.8	0.13
3	Cemetery tree cover	3	-52.4	112.0	0.8	0.13
8	Area + 1 km road cover	4	-51.2	112.6	1.4	0.10
5	1 km road cover	3	-53.2	113.6	2.4	0.06
4	1 km tree cover	3	-53.3	113.8	2.6	0.05
7	Area + 1 km tree cover	4	-52.0	114.3	3.1	0.04
9	Cemetery tree cover + 1 km tree cover	4	-52.3	114.8	3.7	0.03
12	Area * cemetery tree cover	5	-50.7	114.9	3.7	0.03
10	Cemetery tree cover + 1 km road cover	4	-52.4	115.0	3.8	0.03
14	Area * 1 km road cover	5	-51.1	115.8	4.6	0.02
16	Cemetery tree cover * 1 km road cover	5	-51.4	116.4	5.2	0.01
11	1 km tree cover + 1 km road cover	4	-53.1	116.5	5.3	0.01
13	Area * 1 km tree cover	5	-52.0	117.5	6.3	0.01
15	Cemetery tree cover * 1 km tree cover	5	-52.3	118.1	6.9	0.01
17	1 km tree cover * 1 km road cover	5	-53.1	119.7	8.5	0.00

5.10 Supplementary Material 10. Model selection, using Akaike's Information Criterion, for predicting species diversity (Simpson's index of diversity) from four explanatory variables: cemetery size, cemetery tree cover, 1 km tree cover, and 1 km road cover.

Model comparison results for candidate models. k , number of estimated parameters; $\ln(L)$, log-likelihood; $AICc$, small-sample Akaike's information criterion; $\Delta AICc$, difference between AIC for given model and best model; w_i , Akaike's weights. The models in the confidence set ($\Delta AICc \leq 2$) are shown in bold.

Model	Explanatory variables	k	$\ln(L)$	$AICc$	$\Delta AICc$	w_i
2	Area	3	63.5	-119.7	-	0.27
1	(Null model)	2	61.9	-119.3	0.4	0.22
8	Area + 1 km road cover	4	63.9	-117.5	2.2	0.09
7	Area + 1 km tree cover	4	63.5	-116.8	2.9	0.06
6	Area + cemetery tree cover	4	63.5	-116.8	2.9	0.06
4	1 km tree cover	3	61.9	-116.6	3.1	0.06
3	Cemetery tree cover	3	61.9	-116.6	3.1	0.06
5	1 km road cover	3	61.9	-116.6	3.1	0.06
12	Area * cemetery tree cover	5	64.5	-115.4	4.3	0.03
14	Area * 1 km road cover	5	64.2	-114.9	4.8	0.02
9	Cemetery tree cover + 1 km tree cover	4	61.9	-113.7	6.0	0.01
10	Cemetery tree cover + 1 km road cover	4	61.9	-113.7	6.0	0.01
11	1 km tree cover + 1 km road cover	4	61.9	-113.7	6.0	0.01
13	Area * 1 km tree cover	5	63.6	-113.6	6.1	0.01
16	Cemetery tree cover * 1 km road cover	5	63.2	-112.8	6.9	0.01
15	Cemetery tree cover * 1 km tree cover	5	62.1	-110.7	9.0	0.00
17	1 km tree cover * 1 km road cover	5	61.9	-110.4	9.3	0.00

5.11 Supplementary Material 11. Model selection, using Akaike's Information Criterion, for predicting taxonomic diversity (Δ) from four explanatory variables: cemetery size, cemetery tree cover, 1 km tree cover, and 1 km road cover.

Model comparison results for candidate models. k , number of estimated parameters; $\ln(L)$, log-likelihood; $AICc$, small-sample Akaike's information criterion; $\Delta AICc$, difference between AIC for given model, and best model; w_i , Akaike's weights. The models in the confidence set ($\Delta AICc \leq 2$) are shown in bold.

Model	Explanatory variables	k	$\ln(L)$	$AICc$	$\Delta AICc$	w_i
5	1 km road cover	3	18.5	-29.8	-	0.26
1	(Null model)	2	17.0	-29.5	0.3	0.22
2	Area	3	17.4	-27.6	2.2	0.09
3	Cemetery tree cover	3	17.3	-27.3	2.5	0.08
11	1 km tree cover + 1 km road cover	4	18.6	-26.9	2.9	0.06
8	Area + 1 km road cover	4	18.5	-26.9	2.9	0.06
10	Cemetery tree cover + 1 km road cover	4	18.5	-26.9	2.9	0.06
4	1 km tree cover	3	17.0	-26.8	3.0	0.06
6	Area + cemetery tree cover	4	17.6	-25.1	4.7	0.02
7	Area + 1 km tree cover	4	17.4	-24.6	5.2	0.02
9	Cemetery tree cover + 1 km tree cover	4	17.3	-24.4	5.4	0.02
17	1 km tree cover * 1 km road cover	5	18.6	-23.6	6.2	0.01
14	Area * 1 km road cover	5	18.5	-23.6	6.2	0.01
16	Cemetery tree cover * 1 km road cover	5	18.5	-23.6	6.2	0.01
12	Area * cemetery tree cover	5	17.7	-21.9	7.8	0.01
13	Area * 1 km tree cover	5	17.4	-21.3	8.5	0.00
15	Cemetery tree cover * 1 km tree cover	5	17.4	-21.3	8.5	0.00

Waters of Life: Stories from Elephant Marsh

A photo essay by Davies Ezra Chogawana

The Elephant Marsh is a large floodplain wetland located in the districts of Chikwawa and Nsanje in southern Malawi, South Eastern part of Africa. Covering an average area of approximately 60,000 ha, the marsh varies considerably in extent due to seasonal fluctuations in rainfall and river discharge. It forms part of the Lower Shire River floodplain ecosystem and is characterized predominantly by rooted swamp vegetation interspersed with grassy margins. The wetland comprises two main zones: the northern section, which consists largely of semi-permanent marshland, and the southern section, which contains numerous islands and areas of floating vegetation.

The marsh supports rich biodiversity, productive fisheries, agricultural activities, and a range of cultural and livelihood values for surrounding communities. In August 2024, during a field mission examining opportunities for Malawi's blue economy, I visited the southern section of the Elephant Marsh to assess its ecological and socioeconomic significance. A boat journey through the marsh's waterways provided an opportunity to observe the dynamic interactions between local communities, economic activities, and the wetland ecosystem

This series of photos illustrates the marsh's beauty and ecological value, from bird life to canoe-based transportation and rice farming. Yet, it also confronts pressing threats: unsustainable fishing, encroaching agriculture, brick burning, and human-wildlife conflict. Together, the images and narrative reflect the complex interplay of society, ecology, and economy. Even though there is ongoing environmental degradation, the Marsh is still a sanctuary and a source of livelihoods.



*Elephant Marsh is one of the few wetlands that have a thriving population of Hippos (*Hippopotamus amphibius*), a potential source of tourism income for the Marsh.*



Bird populations are thriving at Elephant Marsh. The availability of grasses and water provide a quality habitat to over 110 bird species. Ploceus xanthops (African Golden Weaver) bird nest's, such as those pictured, are a common sight, reflecting the marsh's importance as a breeding ground for avian populations.



Rice cultivation at Elephant Marsh is not only for food security but also for income.



The hydrological regime of the wetlands is determined by the Shire River which runs across it. Canoes are the most common mode of transport in the wetlands.



Unsustainable fishing practices, such as this weir fish trap, are a threat to wetland fisheries in Elephant Marsh. A barrier of plastics and reeds prevent fish from passing through to the other side. This creates an enclosure with an unfavourable, warmer micro-environment, prompting fish to move away from the barrier. In attempting to escape, most of the fish (including juveniles) and other aquatic species moving through the waterway are intercepted and funnelled into a trap strategically positioned along the enclosure. This non-selective fishing method captures a large proportion of the fish population and can lead to depletion of fish stocks, and the unintended capture of non-target aquatic species, thereby threatening the ecological sustainability of the wetland ecosystem.



Population growth and increasing demand for farmland are pushing cultivation closer to riverbanks. The picture shows maize farmers cultivating on edges of river bank. This encroachment accelerates soil erosion and sedimentation, degrades fish breeding habitats, and can introduce agrochemicals into waterways, increasing the risk of eutrophication. It also weakens riverbanks, making them more prone to collapse which alters natural water flows.



Unsustainable land uses have emerged, driven by poverty. Here, open redbrick burning has degraded the buffer zone of the marsh. Poverty-driven land use pressures have led to widespread brick making in the marsh's buffer zone. Soil is excavated from wetland areas to mould bricks for building houses, leaving pits that disrupt natural hydrology, while trees are felled for fuelwood to fire the bricks. These practices degrade wetland soils, vegetation, and ecosystem functions.



*The ever-increasing land pressure has forced farmers to rice farmers to cultivate closer to the river banks, in areas which are habitats for the Nile crocodile (*Crocodylus niloticus*), resulting in human wildlife conflict.*



Livestock grazing in Elephant Marsh. Elephant Marsh provides vital grazing land for livestock, supporting one of the main livelihood activities in surrounding communities. With high livestock populations in nearby districts, the marsh serves as an important source of pasture, underpinning local food security and household incomes.



Elephant Marsh provides grass that supports local livelihoods through thatching, broom making, and income generation. Many nearby households rely on marsh grass for roofing their houses, while others harvest and sell it as a source of cash income. When managed sustainably, grass harvesting is a renewable wetland enterprise that supports communities while maintaining the marsh's ecological integrity.



Cruising through Elephant Marsh is both thrilling and therapeutic. A boat journey along the Shire River can take visitors from Elephant Marsh to Ndinde Marsh and onward to Malawi's border with Mozambique. Surrounded by rich biodiversity and cooled by the river breeze, the experience offers a unique and relaxing way to appreciate the beauty of this remarkable wetland landscape.

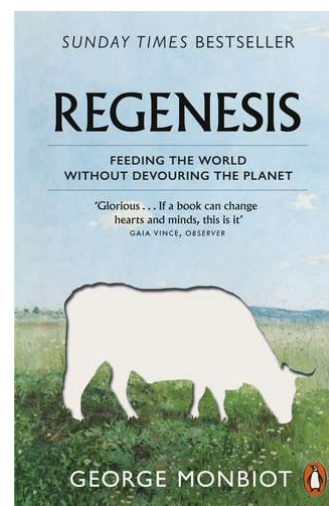
Book review: *Regeneration: Feeding the world without devouring the planet* George Monbiot. 2022. Published by Penguin, ISBN 978-0-14-313596-8

Graham Ball

The University of Edinburgh University, UK.

Email:

grahamball648@gmail.com



Published by Penguin Books (2022). Cover design by Isabelle De Cat. Cover photograph © Bridgeman Images

Keywords: sustainable agriculture, soil ecology, climate mitigation, nature-based solutions, environmental governance, socio-ecological systems, tipping points.

Regeneration: Feeding the world without devouring the planet. By George Monbiot

George Monbiot is a newspaper columnist, investigative journalist and political and environmental activist. He is a tenacious reporter and has long been a fierce defender of environmental protections and human rights. His meticulously researched and accessible writing has won him awards around the world, most recently the 2022 Orwell Prize for Journalism, and his work has received widespread critical acclaim. At the same time, his aggressive and partisan journalistic style (he admits he writes objectively but never impartially) has won him less enviable accolades, including a life sentence *in absentia* in Indonesia and *person non grata* status in other nations.

He studied zoology at Oxford University in England, and although the natural world would later become the focus of some of his most influential works, he began his career in investigative journalism exploring human rights flashpoints around the world. His first three books reported on land expulsions, forced transigrations and other social injustices against indigenous communities across Asia, South America and Africa. Later, he

broadened his focus to include the climate, natural world and politics in the UK and abroad. Heat (2007) explored the climate crisis and its potential solutions, then Feral (2014) looked at issues surrounding agricultural land use in the UK and the value of the rewilding movement.

Regeneration was published in 2022 and was at least partially inspired by the ongoing ecological crisis in the River Wye in Wales, UK. Upset by the rapid decline in the health of the river, in 2021 Monbiot organised what he claimed to be the world's first live-broadcast documentary to find out what was happening to the river and who was responsible. The documentary featured contributions from river health campaigners and local community members from around the UK, all of whom reported sudden declines in river ecosystem health and aesthetic beauty at locations across the country. Perhaps the most alarming aspect of the investigation was the fact that while the health of the UK's rivers is declining, the governmental budgets allocated to their protection have been cut by up to two thirds. Monbiot argues that the local campaigners he invited to talk on the broadcast are actually the only people actively trying to prevent profit-driven agribusinesses from destroying our rivers. *Rivercide*, aired

on July 14th 2021, marked the beginning of Monbiot's relentless investigation into the poorly regulated and environmentally unsound practices of the UK agricultural sector.

Thus, *Regenesi*s was researched and written to find out how and why agriculture has such destructive impacts on nature, why those impacts are neither monitored nor regulated and what changes we must make to continue feeding ourselves without causing further harm. Thankfully, though, the book is far from an exhausting list of bad news and immoral actors. At heart Monbiot is an outdoorsman deeply inspired by nature, and his

admiration for the natural world is the spoonful of sugar that helps this ecoanxiety-inducing medicine go down.

The book begins with a wonderful introduction into the underground world of soil ecology, digging into the dizzying biodiversity and ecological complexity found just beneath our feet. Monbiot's infectious curiosity and the delight with which he learns about a world that is new to him make this subterranean exploration deeply satisfying to read. He includes many captivating facts and anecdotes that are immediately accessible to readers of all backgrounds. If you would be interested to know of the 'tamed evil' that is likely to be residing in your fruit bowl, or to ponder the 'enigma of the oribatids', or discover what made soldiers' wounds shine with a ghostly 'angel's glow' during the American civil war, you will find the answers to these and many more mysteries woven into the book's narrative.

Readers learn that the biodiversity of English soils may rival that of the Amazon rainforest, and that a single gram of soil can contain a billion microbes and a kilometre of fungal hyphae. These are figures that the mind can scarcely comprehend, let alone process in any meaningful way. Monbiot takes the exploration further and gives his readers a glimpse into the complex chemical relationships that have evolved between trees, fungus and bacteria. It is these intricate and finely balanced relationships, invisible yet vital, that underpin terrestrial ecosystems and form the basis of our food production systems. As is clear to anyone with even a passing interest, farming is not a process well-suited to the protection of intricate and finely balanced relationships, even in its most environmentally-considerate forms. Brutal tilling regimes and extensive monocultures have devastated soil health around the world. This is the stark reality that sets the stage for the book's main thesis: how to maintain our vast food output even as the ecological bedrock of the whole endeavour becomes unstable.

*Regenesi*s discusses food production as a global system through the lens of modern systems thinking. It describes our food production and distribution networks in terms of stocks, flows, links, nodes, hysteresis, resilience and redundancy. These are familiar concepts to ecologists and environmental scientists, and the ideas are readily applicable to a discussion of the global food system. The potential for systemwide collapse becomes clear as

Monbiot lists the ways in which the globalization of our food distribution, and the domination of production by a

handful of agribusiness behemoths, has eroded every one of the facets that maintain a resilient system. The global shift towards a homogenous diet, storage of food surpluses by for-profit entities, and just-in-time distribution practices have left the entire system weak and vulnerable. The phenomenon of 'flicker', whereby a struggling system begins to show inconsistencies prior to a catastrophic loss of stability, is especially terrifying when applied to a system that feeds 8.3 billion people.

A common thread that runs through Monbiot's writing, in this book and in others, is his critical examination of our precious received wisdom, which he encourages us to

rethink and often abandon. His arguments are forceful and may occasionally veer towards the strident but are always convincing and firmly scaffolded with supporting evidence. He carefully unpicks many of the entrenched ideas that cloud the issues of climate change, food scarcity and biodiversity loss. It is commonly believed that some of the keys to these crises lie in the obvious failings of the system as it is, illustrated by ideas like:

- We waste a third of food, so just redistribute it.
- Farmers are forced into bad practices by the low cost of supermarket food, so food pricing should reflect the real environmental costs of production.
- If everyone ate naturally grown organic food and embraced modern agroecological approaches we would decimate our ecological footprint.
- If food was grown and distributed locally everyone would be healthier and the food industry would be decarbonized into the bargain.

These views are widespread, and there are almost certainly aspects of truth and great value in each of them. However, Monbiot exposes the hidden misconceptions, misinformation and bad logic, and shows that in the context of the world's growing population and shrinking habitats none offer any real hope. He goes on to explore deeply rooted myths, such as the romantic notion of the farmer as pastoral guardian living at one with nature, and the idea of Grandma's kitchen as a bastion of healthy, environmentally-friendly food preparation. Such idylls, as you can by now guess given the general tone of the book, do not hold up well against critical examination.

*Regenesi*s provides a wonderful education in topics that are not usually known among laypeople. Some of the issues are genuinely intractable, wicked problems that challenge our established society, and for which only society as a whole can realistically be held accountable. For example, as countries gain wealth diets become richer in protein and fats, a correlation known as Bennett's Law. This trend is sure to put increasing pressure on dwindling land resources, but it is a seemingly unshakable

companion of societal development. Rising temperatures and CO₂ levels have a silent but pernicious side effect – our crops are losing valuable nutrition and gaining ‘empty’ calories. We will need to eat more to reach our

recommended daily allowances of B vitamins, calcium, protein and many more of our essential nutrients. Other issues are clearly the products of human failing, be it regulatory weakness, corporate greed, political apathy, or any number of other modern evils. For example, a vast ecological dead zone in the Cambrian Mountains in Wales is the unfortunate result of a major habitat hysteresis, a permanent loss of ecosystem complexity, which is linked to poor policy decisions surrounding sheep farming subsidies. The meaningless Red Tractor logo, awarded to farms that ‘farm with care’ is singled out for particular criticism as a symbol of underfunded and ineffectual government regulation.

The idea that we are cumulatively exposed to carcinogens and forever chemicals because farmland is a cheap way to dispose of ‘night soil’ is particularly repulsive, and I will save the unsavoury details for those who wish to read the book itself. We also learn of the widespread environmental damage caused by some ‘green’ solutions such as biofuel for transport, and alternative production materials such as corn starch and potato. No one, ecologically minded or not, can read about the activities of America’s euphemistically named Wildlife Services and not be horrified. The ‘cyanide landmine’ is every bit as dismaying as it sounds and just one part of a chapter that I wish I could unread.

A great strength of Monbiot’s journalistic style is his determination to weave the views and lived experiences of real people through his discussions of challenging concepts. He visits food banks to learn about the lives of struggling families in the midst of a crushing post-pandemic cost of living crisis. He visits the hardworking people of charity organisations such as Fareshare, who are doing their best to focus help where it is needed. Most important of all, he gets to know the farmers who are trying to shape the future of agriculture by learning how to grow food without destroying their land. One of the book’s central characters is Iain Tolhurst, a farmer who, through his own pioneering Stockfree Organic approach, has coaxed rising yields from seven acres of moderate quality agricultural land without artificial fertilizers, pesticides, manure, or livestock input. The people and their stories are treated with care and they serve to add depth to the overall structure of the narrative. They also provide a welcome contrast to the more challenging, less cheerful content.

The second half of *Regenesi*s is devoted to the potential solutions to the bad news provided in the first. Those who follow current environmental affairs will recognise this well-travelled path, used by so much climate and biodiversity communication in the last fifty years: ‘it’s bad, but it’s not too late!’ There are enough good ideas and novel approaches found here to allow the

reader hope for the future, but I also felt a sense of apprehension. Some solutions, such as replacing annual crops with perennials like the American crop Kernza, encourage cautious optimism. Others, such as replacing meat with bacterially-grown protein products, seem like the last-ditch efforts of a distant, exotic future. Given the

scale of the problem, it is perhaps unsurprising that the solutions are not built upon readily actionable, incremental improvements. They require tough, revolutionary, wholesale changes to our lives. I will not go into details here, and I hope that anyone who has not yet read this book will feel compelled to do so. One thing held in common by the possible solutions outlined in the book is that uptake must be swift and wide-ranging, so the more people that experience this book’s clamorous wake-up call the better.

Although *Regenesi*s was published in 2022, its messages are becoming more relevant with each passing year. We are now seeing the first of the long-feared tipping points as the Amazon begins an irreversible shift

to grassland, and the coral reefs begin their final decline. Florida’s elkhorn and staghorn corals were declared functionally extinct in late 2025, and with the Global Tipping Points Report 2025 we were faced with the grim but inevitable news that warm water corals are now in a state of long-term global deterioration. The loss of the world’s reefs is incalculable, but insignificant compared to the chaos that would ensue if our food systems disintegrated.

In November 2025, the UK held its first ever National Emergency Briefing on the climate and nature crises. Nine experts from academia, industry and healthcare gave impassioned speeches with the same message repeated again and again: climate and biosphere breakdown are no longer adverse future outcomes, they are currently unfolding existential emergencies. Tipping points, nature loss and food security, many of the main themes of *Regenesi*s, were major focal points and received particularly dire warnings. However, even on this stage the state of global soil health went unrepresented. Professor Paul Behrens of Oxford University described the damage that our food system is causing, from climate change to antibacterial resistance, but made no mention of the declining quality of our soil. Perhaps his presentation would have been different had he read *Regenesi*s before writing his script. Regardless, Professor Behrens makes it clear how precariously-positioned our society is becoming, as climate change amplifies the problems inherent in our food distribution systems. As the professor explains, Eighty per cent of food security experts foresee civil unrest in the UK in the next 50 years as a result of food supply crises. It is terrifying indeed to imagine how close we are to societal instability simply because we cannot protect the environment that feeds us.

Following in the footsteps of the book itself, I will end this review on a positive note. The extensive research Monbiot undertook to write the book (he said he read over

5,000 academic papers) gave him a crash course in soil science and an overview of the current problems from his journalist's wide-angled perspective. Much of the book is devoted to a crucial trade-off within the agricultural system – that of high yields and environmental health. Unfortunately, we have never been able to attain the first without sacrificing the second. Introduced above, Iain Tolhurst (known to Monbiot and his readers as Tolly) has

managed through extensive trial and error to harness natural soil system balances and fluctuations and bring the best out of his crops at minimal cost to the natural environment. Our knowledge of soil systems is so poor, however, that Tolly's success has proven impossible to replicate with any real consistency. In the book, Monbiot outlines the problem: that funding tends to be spent on the exploration of soil chemistry, when in fact it is the soil biology, brought to life so vividly within the pages of *Regenesi*, that may hold the key to the yield/damage dilemma. Monbiot explains the need for the world's soils to be mapped to a greater resolution and for the dynamic interplay between crops, bacteria and fungi to be better understood. He mentions, in passing, that we would do well to invest our time and money in an Earth Rover project to help us master our own soils, instead of pouring

countless billions of dollars into each gram of soil analysed from Mars. He makes a sensible point. Since the book was published, Monbiot has in fact put his money (and a considerable lump of Jeff Bezos's) where his mouth is. Along with Professor Tarje Nissen-Meyer, Professor Simon Jeffry, and Katie Bradford, he founded the non-profit Earth Rover Program, which launched on World Soil Day, December 5th 2025. With four million dollars from the Bezos Earth Fund, the program is revolutionizing soil science by using seismology to read

soil content. All a farmer needs to take advantage of the fledgling science of 'soilsmology' is a cheap sensor, a small metal plate and a welder's hammer. The founders hope that future farmers anywhere in the world,

regardless of their financial resources, will have instant access to useable information about the health of their soil. That this promising new technology is in the hands of a non-profit, and especially one founded by George Monbiot and others like him, feels like a victory for sensible climate solutions and a ray of hope for the future.

For anyone involved or even interested in the world of biodiversity and ecology, *Regenesi* is painful but

essential reading. Monbiot thoroughly interrogates the inner workings of our self-made biodiversity crisis, holds corporations and governments accountable, and is realistic about what it will take to solve the problems. While his writing is clearly hardened by anger and frustration at what he sees as a broken system, at the same time it is tempered by a keenly communicated love for living things and the natural world. As he writes on his website, "I love not man the less, but nature the more". Like *Feral* before it, the book occupies a point somewhere near the intersection of conservation efforts, state governance, political will and powerful lobbying from the agricultural industry. The resulting Gordian Knot is a bureaucratic nightmare typical of other environmental and climate issues, with further nature losses as the usual unavoidable outcome. While the final message of the book is ultimately positive, those who already experience any form of ecological grief will find it a gruelling experience. It is a vital and accomplished work of journalism and one that will remain relevant, unfortunately, for many years to come.

References

- Earth Rover Program. Available at: <https://www.earthroverprogram.org/>
- George Monbiot (2025). In *Wikipedia*. https://en.wikipedia.org/wiki/George_Monbiot
- Horton, H. (2025, December 5). 'We can tell farmers the problems': experts say seismic waves can check soil health and boost yields. *The Guardian*. Available at: <https://www.theguardian.com/environment/2025/dec/05/soilsmology-seismic-waves-soil-health-boost-yields>
- Lenton, T. M., Milkoreit, M., Willcock, S., Abrams, J. F., Mc Kay, D. L. A., Buxton, J. E., ... & Wieners, C. (2025). Global tipping points report 2025.
- Monbiot, G. (2007). *Heat: How we can stop the planet burning*. Penguin UK.
- Monbiot, G. (2014). *Feral: Rewilding the land, the sea, and human life*. University of Chicago Press.
- Monbiot, G. (2025, December 5). Over a pint in Oxford, we may have stumbled upon the holy grail of agriculture. *The Guardian*. Available at: <https://www.theguardian.com/commentisfree/2025/dec/05/agriculture-revolution-soil-farming-earth-rover-program?>
- National Emergency Briefing on Climate and Nature (2025). Available at: <https://www.nebriefing.org/>
- The Orwell Prize (2022). 2022 Journalism Prize Winner. Available at: <https://www.orwellfoundation.com/journalist/george-monbiot/>
- Readfern, G. (2025, October 13). Planet's first catastrophic climate tipping point reached, report says, with coral reefs facing 'widespread dieback'. *The Guardian*. Available at: <https://www.theguardian.com/environment/2025/oct/13/coral-reefs-ice-sheets-amazon-rainforest-tipping-point-global-heating-scientists-report>
- Rivercide (2021). *Rivercide*. Available at: <https://rivercide.tv>

Large whales fill a vital role in the ocean ecosystem, making their conservation an essential aspect of overall ocean health

Pamela McDormand <https://orcid.org/0009-0008-1818-7885>

Email:

pamjwm@gmail.com

Keywords: Ecosystem engineering, whales, carbon, nutrient cycling, conservation, primary productivity

Large whales within the ocean ecosystem

There are several ways large whales impact their marine environment: nutrient cycling, supporting primary productivity, physical engineering, carbon sequestration (within their biomass), and habitat creation. They also fill a cultural role and possess intrinsic value, but those discussions are outside the scope of this succinct letter. With so many ways that large whales impact the marine environment, conservation efforts must be strengthened to ensure their survival.

These massive mammals can grow up to 33 m in length, with the blue whale topping out as the largest known animal to ever grace this planet (NOAA). The runners-up include right, bowhead, fin, humpback, sperm, and grey whales, all of them averaging from 30 to 100 tonnes as adults (International Fund for Animal Welfare, 2025). This collection includes whales from multiple taxa, as most are baleen whales, but the sperm whale is a member of the Odontocetes class (International Fund for Animal Welfare, 2025). Their similar size and feeding habits allows them to be grouped together functionally.

Nutrient Cycling and Primary Productivity

These large whales require several tonnes of food per day, in the form of plankton and other marine invertebrates, as well as fish for some (Baumgartner *et al.*, 2007), to support their large body mass. Feeding methods vary with each species, but mostly involve variations on filter feeding upon dense prey patches, many of which are found near the ocean floor (Baumgartner *et al.*, 2007). The subsequent fecal waste these whales produce is rich in nutrients and is typically deposited near the surface (Roman, *et al.*, 2016). This represents an influx of

nutrients ripe for fertilizing the photosynthetic organisms that remain near the surface where sunlight can still penetrate (Roman, *et al.*, 2016). In this way, whales are moving these limiting nutrients to where they are needed, allowing micro- and macro-algae to take up carbon dioxide from the atmosphere adjacent to the water and convert it into sugars through photosynthesis.

Ecosystem Engineering

Additionally, when these whales move through the water column on deep dives to forage on the seafloor, their massive size allows them to act as physical engineers, altering the marine landscape, even creating upwelling zones as they resurface (Roman, *et al.*, 2014). Evidence of mud on the rostrums of some whales indicates they may be digging through the substrate to forage (Hamilton and Kraus, 2019).

Carbon sequestration

As they feed and grow, these large cetaceans hold within their bodies a significant amount of carbon (Smith, 2006). Lipids consist of about 77% carbon and 54% protein (Jelmert and Oppen-Bernsten, 1996). After accounting for dry biomass of 40%, about 10% of their body consists of carbon (Jelmert and Oppen-Bernsten, 1996). While uncertainty lies within any calculations of carbon storage by whales, their large mass and long lifespan may allow them to be considered a carbon sink, especially when coupled with the previously mentioned ability to stimulate carbon dioxide uptake by marine algae (Pearson, *et al.*, 2023). They continue to sequester carbon after they die and sink to the ocean floor (Pearson, *et al.*, 2023).

Whale Falls

Even in death, these whales continue to play a supportive role. When a large whale dies and falls to the seafloor, they create a unique habitat similar to hydrothermal vents (Smith and Baco, 2003). These ‘islands’ or zones of underwater productivity can support a large number of species, many of whom are unique to whale carcasses (Smith and Baco, 2003). Researchers have identified four unique stages of whale decomposition, each with its own complement of community members, such as fish, sharks, crustaceans, worms (especially of the genus *Osedax*), and bacteria that play different roles in breaking down the massive carcasses into nutrients to be recycled by these benthic dwellers (Smith, *et al.*, 2015). Some of these species are also at risk of extinction because of reductions in whale populations, highlighting a potential cascade of ecological impacts (Smith, *et al.*, 2019).

Whale conservation

Many groups worldwide are working to further whale conservation, some who focus on single species, such as

the North Atlantic Right Whale Consortium (NARWC), to more general organizations such as World Wildlife Federation (WWF) and International Fund for Animal Welfare (IFAW). Marine Protected Areas (MPA's) can create an umbrella of protection by minimizing harm for an entire ecosystem and all the components within it, both biotic and abiotic (Marcos *et al.*, 2021). Protecting even just one keystone species can lead to wider ranging protections, as they support ecosystem functions (Bell, 2025). Ecosystem-based management is an ever-growing strategy, considered the best option for protecting our oceans (Roberge and Angelstam, 2024).

Conclusion

Large whales boost primary productivity, cycle nutrients, physically restructure the marine environment, sequester carbon, and create unique habitat. When we protect whales, we support an entire marine community, one that relies on the ecosystem services these whales provide.

References

- Baumgartner, M., Mayo, C., and Kenney, R. (2007) ‘Enormous Carnivores, Microscopic Food, and a Restaurant That’s Hard to Find’ In: (Kraus, S. and Rolland, R. eds.) *The Urban Whale: North Atlantic Right Whales at the Crossroads*. United States of America: Harvard University Press, pp. 138-171 Also available at: https://www.whoi.edu/cms/files/Urban_Whale_Chapter5_59401.pdf
- Bell, J. (2025) ‘The ripple effect: How protecting one species can safeguard an entire ecosystem’ International Fund for Animal Welfare. Available at: <https://www.ifaw.org/au/journal/ripple-effect-protecting-one-species-safeguard-entire-ecosystem>
- Hamilton, P. and Kraus, S. (2019) ‘Frequent encounters with the seafloor increase right whales’ risk of entanglement in fishing groundlines’ *Endangered Species Research*, 39:235-246 DOI:10.3354/esr00963
- IFAW.org (2025) <https://www.ifaw.org/ca-en/journal/types-of-whales> November 20, 2025
- Jelmert, A. and Oppen-Berntsen, D. (1996) ‘Whaling and Deep-Sea Biodiversity’ *Conservation Biology*, 10(2):653-654 DOI:10.1046/j.1523-1739.1996.10020653.x
- Marcos, C., Diaz, D., Fietz, K., *et al.*, (2021) ‘Reviewing the Ecosystem Services, Societal Goods, and Benefits of Marine Protected Areas’ *Frontiers in Marine Science* 8:613819 DOI: 10.3389/fmars.2021.613819
- NARWC.org North Atlantic Right Whale Consortium
- NOAA (no date) <https://www.fisheries.noaa.gov/species/blue-whale>
- Roberge, J. and Angelstam, P. (2004) ‘Usefulness of the Umbrella Species Concept as a Conservation Tool’ *Conservation Biology* 18(1):76-85 DOI:10.1111/j.1523-1739.2004.00450.x
- Roman, J., Nevins, J., Altabet, M., *et al.*, (2016) ‘Endangered Right Whales Enhance Primary Productivity in the Bay of Fundy’ *PLoS ONE*, 11(6):e0156553 <https://doi.org/10.1371/journal.pone.0156553>
- Roman, J., Estes, J., Morissette, L. *et al.*, (2014) ‘Whales are marine ecosystem engineers’ *Frontiers in Ecology*, 12(7):377-385 <https://doi.org/10.1890/130220>

Smith, C., and Baco, A. (2003) 'Ecology of Whale Falls at the Deep-Sea Floor' *Oceanography and Marine Biology: An Annual Review*, 41:311-354 Available at:

<https://www.soest.hawaii.edu/oceanography/faculty/csmith/Files/Smith%20and%20Baco%202003.pdf>

Smith, C. (2006) 'Bigger Is Better: The Role of Whales as Detritus in Marine Ecosystems' in Estes, J., Demaster, D., Doak, D., et al., (eds.) *Whales, Whaling and Ocean Ecosystems*, United States: University of California

<https://doi.org/10.1525/california/9780520248847.003.0022>

Smith, C., Glover, A., Treude, T., et al., (2015) 'Whale-Fall Ecosystems: Recent Insights into Ecology, Paleoecology, and Evolution' *Annual Review of Marine Science*, 7:571-96 DOI:[10.1146/annurev-marine-010213-135144](https://doi.org/10.1146/annurev-marine-010213-135144)

Smith, C., Roman, J., and Nation, J. (2019) 'A metapopulation model for whale-fall specialists: The largest whales are essential to prevent species extinction' *Journal of Marine Research*, 77 (Supp.): 283-302 DOI:[10.1357/002224019828474250](https://doi.org/10.1357/002224019828474250)

World Wildlife Fund (WWF) (2024) 'Meet the Biggest Animal in the World' Available at:

<https://www.worldwildlife.org/stories/meet-the-biggest-animal-in-the-world>

Biodiversity, Wildlife and Ecosystem Health Programme: Beginnings, Reflections, Highlights, Future

Ellie Devenish-Nelson¹, Sharron Ogle, and Rob Thomas¹

¹ College of Medicine and Veterinary Medicine, University of Edinburgh

Email:

Ellie.Devenish@ed.ac.uk

Received: February 2026

Accepted for publication: March 2026

Published: July 2026

Keywords: Interdisciplinary, Online distance learning, postgraduate

Programme history, purpose and evolution

The Biodiversity, Wildlife and Ecosystem Health (BEWH) programme emerged from an initiative that came out of the College of Medicine and Veterinary Medicine in collaboration with Royal Zoological Society of Scotland, under the auspices of the University's Global Health Academy, that brought together the disciplines of human health, animal health and ecosystem health. Work began on putting the programme together in late 2009 with the first student intake in September the following year. At this stage the programme was run almost single-handedly by then Programme Director Dr Sharron Ogle with support from part-time academic staff and administration staff. In 2010, for the first intake, we had 99 notes of interest in our programme, an impressive number considering it was a new programme. From those 99 interested, half were from Europe, a quarter from sub-Saharan Africa, and the rest were North, South America, and Asia combined. We made 49 offers and ended up with 20 students on programme.

Over the subsequent two years of the three-year part-time programme, new student cohorts were added until in 2013 we had students registered across the whole MSc portfolio. We have been supported by the administrative team of the Biomedical Teaching Organisation for many years, who have been invaluable in the running of the programme. The teaching team was meanwhile expanded and has continued to grow to accommodate new and additional elective courses on an increasingly diverse yet highly relevant range of subjects. The number of students at any one time also gradually grew to around 180, especially around and since the Covid-19 pandemic when there was an increased demand for online programmes. Over the past 15 years we have also hosted five, week-long Summer Schools in Scotland, which have been a real

highlight for both students and staff, blending academic and social activities and creating an even stronger sense of community (Fig. 1).



Figure 1. Students and Staff during the BEWH Summer School 2019 in Edinburgh. Credit: staff member

Since the programme's launch in 2010, it has consistently attracted strong student cohorts. This sustained demand has enabled us to build and retain a dedicated teaching team (Fig. 2) with the breadth of expertise needed across disciplines. Having a dedicated teaching team that is focused just on one programme is fairly unique in academia. The stability of this team brings several benefits: continuity in student-staff relationships that foster community and inclusivity; robust internal quality assurance in curriculum development; resilience across individual courses; and consistent calibration of marking and feedback practices. The strength of our pedagogy, teaching, and student support is reflected in our

repeated recognition in teaching and staff awards, including shortlisted for the CMVM Staff Team Excellence Award and multiple nominations and shortlistings for the Edinburgh University Student Association (EUSA) Teaching Awards over the years.

The Programme's scope is perhaps more relevant and indeed urgent today than it was in 2009 and we have ensured that all our teaching and learning material covers 'real-world' challenges. The programme encourages and applies a holistic, interdisciplinary approach that navigates conflicting interests around, for example, biodiversity loss, climate justice, food security and the central role of ecosystem services. The interdisciplinarity of global challenges and the responses to them is perhaps the principle educational purpose of the Programme, and a realisation that without ecosystem health there is no human health.

Reflections from Dr Sharron Ogle on the programme origins

"15 years is mad. When we started, it was literally just me, and a few colleagues, also working in the online learning sphere at Edinburgh. I suspect maybe 400 or 500 students have come through (PGCert, PGDip, MSc or PPD routes) and over 300 have graduated out of the programme with a master's degree. If you'd said 15 years ago that was how it was going to turn out, I definitely wouldn't have thought that was possible. When, let's be honest, we were kind of making it up a little bit as we went along."



Figure 2. BWEH teaching, support and administrative team in 2024. Credit: Linh Trinh.

Programme ethos

At the core of the programme is a belief that every student arrives with valuable and relevant knowledge worth sharing. We build on that foundation by creating space for students to learn from one another, supported by thoughtful guidance, engaging materials, and feedback that speaks directly to their growth, reinforcing a culture of co-creation, self-directed learning and a vibrant curriculum. Over time, this approach does more than strengthen academic skills. It helps students find their voice, gain confidence in expressing it, and develop the kind of critical thinking that shapes how they engage with the world. Many

alumni describe realising—sometimes only in hindsight—how naturally they now navigate complexity or are confident in expressing their own voice. The impact is reflected in our community too: in the past four years, three graduates of the Biodiversity, Wildlife and Ecosystem Health MSc have been invited to deliver the Student Oration at their Winter Graduation Ceremonies.

Our cohort is intentionally diverse, drawing applicants from a wide range of professional and cultural backgrounds. This reflects our belief that addressing biodiversity loss and ecosystem health requires insight from every sector and society. Many students join us as established professionals, bringing perspectives that enrich discussions and spark student-led learning. In turn, the programme equips them to deepen their existing careers, transition into more environmentally focused roles, or strengthen their ability to teach and communicate about global challenges.

"I'm so happy I took the leap and signed up for this course. It has been a challenging 3 years, but I learned so much and am proud of the work I've completed and that I had such wonderful guidance. I love how the BWEH team is progressive and accommodating of all backgrounds, levels, and skillsets. They really embrace diversity." (Postgraduate Taught Experience Survey Response, University of Edinburgh 2025)

Shifting focus and complexity

In the early years, the programme was largely centred on biodiversity and the protection of individual species. Over time, this focus broadened into a more comprehensive ecosystem-based approach. In recent years, however, both biodiversity and ecosystem considerations have, to some extent, been overshadowed by the growing prominence of climate discourse. While climate change is undeniably critical, its dominance has sometimes displaced other essential priorities. The biodiversity agenda, in particular, has been compressed and marginalised. The challenges facing conservation today feel markedly more complex than they once were. This is partly because the issues themselves have evolved, but also because our collective awareness has deepened. The traditional model—where conservationists from the Global North would enter the Global South and prescribe solutions—has increasingly been recognised as inadequate and, in many cases, counterproductive.

Reflecting on the past fifteen years, the field appears to have undergone successive layers of change—each new priority added atop the last—creating a sense of cumulative complexity that continues to shape contemporary conservation practice. Addressing these challenges requires not only scientific and technical expertise but also the engagement of communicators, journalists, educators, entrepreneurs and many others who are willing to participate in difficult, nuanced conversations. The evolution of the field mirrors broader societal shifts, underscoring the need for inclusive, reflective, and context sensitive approaches to conservation. The curriculum mirrors the complexity of the issues students care about. It takes a holistic, interdisciplinary approach, guiding them

through the tensions surrounding biodiversity loss, climate justice, food security, and the role of ecosystem services. A key attribute of the programme has always been the emphasis given to reflective practice. This facilitates both critical thinking and more recently, the concept of positionality. This latter approach responds to and embraces the different individual, collective, socio-economic and cultural perspectives that underpin global challenges acknowledging the potential biases that may influence discourse at a local and international level. Students consistently tell us that this blend of perspectives—combined with the diversity of their peers—is one of the most valuable aspects of their experience, shaping both their understanding and their sense of purpose (Fig. 3).



Figure 3. Word cloud generated by alumni and current students during an online event to celebrate the programme's 15th anniversary.

Changing curriculum and alumni contributions

We didn't use video conferencing when we started in 2010 as everything was very much text-based and very low-tech, to accommodate connectivity issues and time zones differences in our globally distributed student cohort. Over the years, we have introduced many more audio-visual resources as well as live sessions and online 1-to-1 meetings. However, our core content remains rooted in our low-tech and asynchronous beginnings, because we know that pedagogically all the bells and whistles don't necessarily lead to better academic performance and, nothing we do can overcome the issue of time zones. Imagine that during our 15th Anniversary event in October 2025, it was the first time Sharron had seen the faces of some of the very first cohort of students!

When we started, we had two compulsory courses, and only eight elective courses. We did a lot of course sharing in the early days, because we'd just started. Now we have three compulsory (PGCert) courses and offer 27 electives. Some of those are still drawn from other programmes, but most are delivered from within our programme. This suite of elective courses allows students to shape their own portfolio of specialist areas to enable an even more 'bespoke' profile to their (PGDip) programme.

Some of our elective courses have really been developed in response to our students and alumni. Our programme integrates alumni widely as guest tutors, to fill gaps in teaching team subject knowledge, share practitioner experiences and increase representation, and greatly improves the student's overall learning experience (Devenish-Nelson and Ogle, 2022; Devenish-Nelson and

Sinclair, 2025). Our engagement of alumni as guest tutors reinforces both the value of our growing community of practice and provides beneficial networking opportunities for current students. For example, the Conservation Psychology course was developed by an alumnus who did a psychology project in her third year. More recently, the Conservation Finance course was co-created with three of our alumni with expertise in this area. By drawing on the professional experience of our alumni we are able to create highly topical and diverse elective courses to strengthen our interdisciplinary portfolio.

Reflections from Dr Sharron Ogle on engaging alumni in teaching

"We've gone, well, great, let's harness that and make something out of it. I think we've always been a programme that's been really open that way. One of the strengths, and one of the sources of pride over the years, is being able to incorporate the vast experience of our students and alumni."

While the traditional ‘dissertation’ style final year (Written Reflective Element) remains the standard route to Masters, since 2022 we have offered an alternative route built around a combined 30 credit project (Applied Interdisciplinary Research) that has a practical application, supplemented by a further 30 credits from the second-year elective offering. This alternative route was developed in part due to feedback from students who are already advanced in their careers and did not require a traditional dissertation, but rather an opportunity to apply their learnings to develop a resource with real-world application. So far, the uptake of this route has been high, and we’ve seen some amazing resources created that have subsequently been implemented (e.g. pollinator action plans, education materials, policy briefs). Both of the routes to Masters are led by the individual, empowering them to identify and define a project that is pertinent to their specific interests.

Intangible value of Summer School

Summer School has been an integral part of our curriculum from the inaugural one in 2015 (Fig. 4) and subsequently being held every two years (pandemics and funding allowing). As online distance learners, our student cohort miss out on the face-to-face aspect of being an MSc student. Although we work hard to build community and we know that students can feel part of a community without ever meeting each other or the programme team in person (Ogle 2018), we also know that there is a tangible impact of attending a Summer School on student's feeling of community, that filters into their remaining time on the programme and in their support network after graduating. Summer schools provide a vital opportunity for students to develop relationships between year groups and between staff and students, as well as offering a chance to exchange ideas and knowledge. Bringing these groups together physically is a motivating space where barriers are broken down through sharing of people's ideas, values and lived experiences.



Figure 4. Students participate in the first BWEH Summer School in Edinburgh and the Highlands in 2015. Credit: Rob Thomas

Alumni impact

A significant outcome of the programme's 15 years of operation has been the emergent global network of over 400 alumni forming a community of practice across sectors, cultures and international boundaries (with over 130 members in our alumni LinkedIn group). The capacity to understand and examine the underlying science and to translate this into accessible and meaningful language and action is a critical purpose of this programme. It empowers our graduates (Fig. 5) to be at the forefront of the democratisation of environmental decision-making, enabling bottom-up and top-down responses to global challenges (BWEH 2025). A recent survey (BWEH 2023) of our alumni demonstrated significant programme satisfaction (96%), with most alumni feeling part of a community and valuing the diversity of our student cohort (Fig. 6). Our metrics indicated notable transformations in alumni transitioning into professions or leadership roles within the environmental sector. The perceived impacts reported by our alumni were overwhelmingly positive for conservation and individual capacity. We hear so many wonderful stories of local, national, and international impacts our alumni are having in the conservation and wider world - too many to mention here!



Figure 5. Students and staff celebrating at the 2024 graduation ceremony. Credit: Christina Philippou

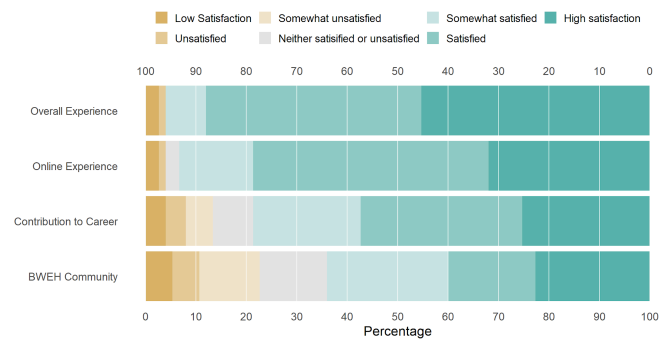


Figure 6. Results of a 2023 survey showing alumni satisfaction for elements of the BWEH programme (BWEH 2023).

That the Open Journal of Biodiversity and Ecosystems has been set up and is run by students and alumni of our programme is further testament to the motivation, innovation and capacity of our students. The journal's interdisciplinary focus is a true reflection of our programme's ethos and principal educational purpose, and we are excited to support and follow the journal as it grows. Further, the hugely successful BWEH 15th Anniversary Event (Fig. 7) was also organised by alumni, showcasing their dedication to the programme. It was an incredible event that was full of joyful reconnections and celebrations of our community.



Figure 7. Screenshot of some of the participants at our BWEH 15th Anniversary Event in October 2025.

Diversity and Representation matters

Thinking about the future, a significant gap that remains in our student cohort is the limited representation of voices from the Global South, which is of central importance to global conservation practice. We know that the impact of our programme is particularly high for our Global South alumni. We believe that meaningful representation is essential for learning, for improving decision-making, and for ensuring that conservation approaches reflect the realities experienced by those most affected. The conservation field is in constant motion, continually adapting to shifting global dynamics, and the ability to keep pace depends on the inclusion of diverse viewpoints. This ongoing evolution mirrors broader societal changes and reinforces the need to move beyond outdated models. However, financial barriers continue to restrict participation from the Global South, and although initiatives such as the Commonwealth Scholarship Programme have expanded access, challenges persist. In 2026-27, we are excited to be welcoming our first intake of MasterCard Foundation Scholars and hope that this is the

start of greater access to online education for African students.

Reflection and Continuity

We have a deep sense of gratitude for all those who have participated in the programme, as well as for the staff who have supported it throughout its development. Each cohort brings together an exceptional group of highly motivated and intellectually curious individuals, and it is this combination of dedicated participants and committed staff that contributes to the programme's success. One of the most rewarding aspects for us is the ability to witness the impact of this collective effort—seeing how the knowledge, dialogue, and experiences cultivated here translate into meaningful contributions through the work of our graduates. It is a privilege to occupy this intermediary space, guiding participants through course choices, facilitating important conversations, and supporting them as they navigate their academic and professional journeys. The hope is always that they will emerge from the programme equipped to achieve something truly significant.

Reflections from Dr Sharron Ogle on coming full circle

"It's really nice to be in this middle space where we can help navigate people through course choices, through conversations... and then hopefully to go out the other end and do something really special. Seeing this happening now gives me a really nice sense of coming full circle. Starting with very little, and a massive leap of faith with the first few groups of students and now coming to this point."

Shaping the Future

As we reflect on our 15th Anniversary, we are also facing big changes to the programme. Dr Sharron Ogle stepped down as Programme Director to go on to new adventures in early 2026, when Rob Thomas and Dr Ellie Devenish-Nelson took over as co-Directors. It is difficult to fully articulate the work and dedication that Sharron has invested, since its inception, in the programme, the student community and the teaching team (Fig. 8), but we endeavour to continue the success and the recognition that

the programme has enjoyed as a result of her inspirational leadership. Rob and Ellie look forward to leading the programme and our amazing team for this next phase and will do our very best to fill the big shoes that Sharron has left behind. As we move forward with (for now) a slightly smaller team, we will inevitably have to make some changes to the shape and content of some of the programme, although we do envisage some exciting opportunities for our future students. However, it is non-negotiable to us that we maintain the quality of teaching and learning as well as the overall student experience that is so important to us and our student body.

Sharron's final thoughts on leaving the programme: staff, students, impact, and pride

"I'm going to be leaving the programme, and I've felt really positive about that. I'm very grateful for those that have made it happen. I feel quite overwhelmed, actually, by just the amazingness of everybody. I couldn't have done it myself. I know things are just going to go from strength to strength. The team that are in place now are really amazing, and I'm really happy to hand that over. It's moments like this [15th Anniversary event] that you just, for me, recognise what has happened over the last 15 years. Now it just feels like such a professional space that I don't think I could have made myself. With all these amazing professional people who now are with us, it feels proper. There's been such buy-in and commitment from people to learn and talk to each other. You can't ask for more than that. I feel immense pride."

Acknowledgements

We wholeheartedly thank all the students who have passed through the BWEH programme, without whom this programme would not be the success that it has become and from whom we have learnt so much. We thank all the current and past teaching, support and administrative staff, who have been instrumental in ensuring we have developed a high-quality learning environment. Thanks to Nadia Croeser for summarising Sharron's comments during the BWEH 15th Anniversary Event.

References

- BWEH (2026) BWEH inspiring change: Alumni testimonials from the MSc Biodiversity, Wildlife and Ecosystem Health <https://storymaps.arcgis.com/stories/8fa581899cb3489883519d05f2ff77d0>
- BWEH (2023) BWEH Alumni Survey Results <https://sway.cloud.microsoft/nhnCJkI39cv7iFAW?ref=Link>
- Devenish-Nelson, E. and J. Sinclair, 2025. [Co-benefits of alumni as tutors: evidence and top tips](#), Teaching Matters Blog, University of Edinburgh
- Devenish-Nelson, E. and Ogle, S. 2022. [Bringing in alumni as guest tutors to teach and inspire students](#), THE Blog, Times Higher Education.
- Ogle, S. 2017. [Building community online](#), Teaching Matters Blog, University of Edinburgh
- University of Edinburgh (2025) Postgraduate Taught Experience Survey (PTES) 2025. Unpublished raw data. University of Edinburgh.